The Vegas *High Roller*

Location
Las Vegas, Nevada, USA

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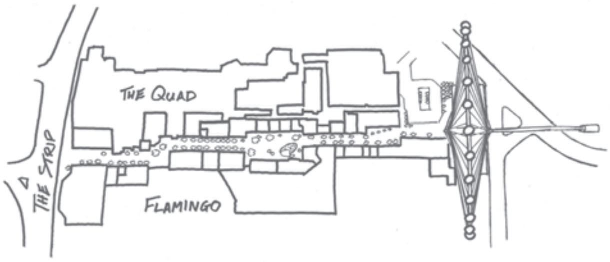

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1. Sketch plan of the LINQ development (see previous pages).

2. The Hettema Group's concept for the cabin experience.

Setting the scene

The *High Roller* in Las Vegas, Nevada, is now the world's tallest observation wheel. It opened to the public on 31 March 2014, concluding five years of design and construction in which Arup was involved throughout, from the early concept stage to completion. The project drew upon the expertise of numerous Arup staff from around the world, demonstrating the value of the firm's global networks, and many of the design challenges also required close collaboration with contractors, fabricators, suppliers and other consultants.

Without the willing participation of all these parties, the *High Roller* would not be the technical success that it is.

The *High Roller* is the anchor attraction of Caesars Entertainment's new LINQ development at the heart of the Vegas Strip (Las Vegas Boulevard). The LINQ comprises a high quality retail, dining and entertainment area, replacing an under-used alley extending east from the Strip (pp2–3 and Fig 1), previously occupied by an old casino and multistory car park. The LINQ connects directly with several adjacent casinos owned by Caesars.

Caesars initially engaged The Hettema Group (THG), an attraction design consultancy, to develop ideas for an iconic feature. Historically, Las Vegas developers intent on creating landmarks have opted for replicas of famous structures such as the Eiffel Tower, but Caesars and Hettema decided on a large and distinctive observation wheel.

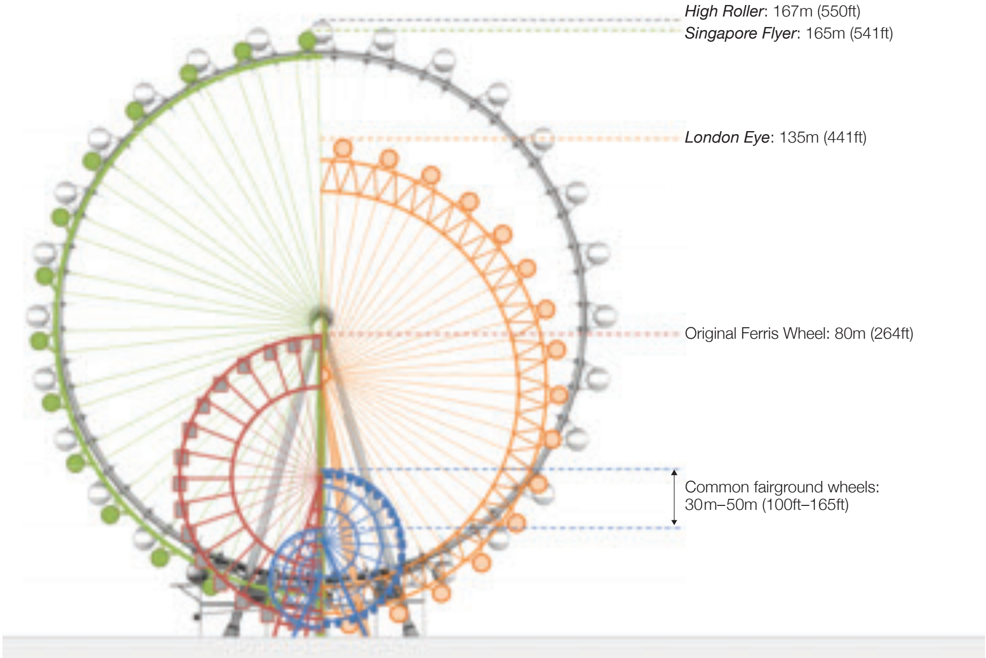
Arup was engaged in June 2009, on the basis of its involvement with two previous record-breaking giant wheels, the *London Eye* and *Singapore Flyer*[1], to start the process of engineering the creative vision into a buildable reality.

The first stage was to develop alternative structural concepts in keeping with the desired aesthetic of the wheel (Fig 2) and the significant footprint constraints of the proposed site, but Arup's role developed progressively as the project proceeded, and almost every aspect of the completed wheel was designed by, or heavily influenced by input from, Arup.

A brief history of observation wheels

Images of small observation wheels can be found in documents dating back centuries, but it was George Ferris's wheel, built for the 1893 Chicago World Fair, that really brought such rides to a wide public. The original Ferris Wheel was an 80m (262ft) tall engineering marvel enjoyed by hundreds of thousands of passengers, and other similar wheels quickly followed, in London (1895, 94m/308ft), Blackpool (1896, 61m/200ft), Vienna (1897, 65m/213ft) and Paris (1900, 100m/328ft), all inspired by Ferris's landmark design. These wheels had railcar-like cabins hung from the rim, using gravity to stabilise them. They would pause as each cabin passed the loading area to allow passengers on and off.

With the exception of Vienna's *Wiener Riesenrad*, all these giants of the late 19th century have now perished. During the 20th century, smaller Ferris wheels continued to proliferate around the world as staples of fairgrounds and amusement parks, typically ranging from 30m–50m (100ft–165ft) in height (Fig 3).



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3. Size comparison of observation wheels through history.

4. *The London Eye*.

5. Comparison between standoff and structural systems of the *London Eye, Singapore Flyer* and *High Roller.*

In the late 1980s and 1990s Japan embraced observation wheels and constructed the *Cosmo Clock 21* (Yokohama, 1989, 113m/370ft), the *Tempozan Ferris Wheel* (Osaka, 1997, 113m/370ft) and the *Daikanransha* (Odaiba, 1999, 115m/377ft). Up to this time, such wheels typically used heavy truss structures, or radial compression struts with tensioned circumferential elements. These were ideal for fairgrounds, being simple to fabricate and easy to erect, but this form limited the maximum size that could be economically achieved.

The year 2000 saw the realisation of a real technical leap forward with the opening of the 135m (443ft) *London Eye*, designed by Marks Barfield Architects and originally engineered by Arup (Fig 4).

Its structure is exactly like that of a colossal bicycle wheel, with tensioned spokes holding a rim in compression (interestingly, the same system used in the first flurry of wheels, including Ferris's own), and enabling it to be much larger than any previous wheel.

The rim of the *Eye* comprises a fully braced tri-chord steel truss, and the cables are arranged to provide lateral stability as well as carry the weight of the wheel. Arguably even more importantly, the *Eye*'s cabins are positioned outside the rim and do not rely simply on gravity to stay level. Instead, they are captured in two slewing bearings and are rotated by an active stability system.

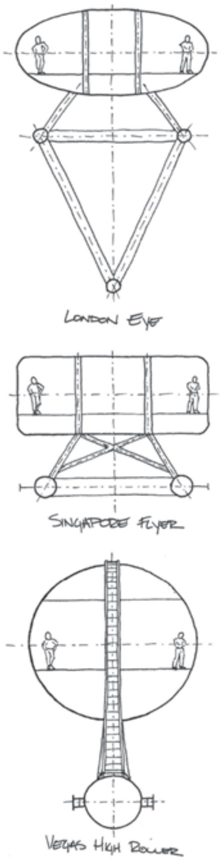
While this innovation certainly adds complexity, it gives passengers a more "stable" ride and a much more open view, particularly at the apex.

The completion in 2006 of China's *Star of Nanchang*, designed and built by Nanchang Star Entertainment Ltd, set a new height record of 160m (525ft), using the traditional compression strut system together with gravity-stabilised cabins. Just two years later the Arup-engineered *Singapore Flyer* opened with an official height of 165m (541ft). The *Flyer* has a similar structural system to the *Eye*, but with a two-chord ladder truss instead of the *Eye*'s tri-chord, stabilised in its weak axis by the cables.

Developing the reference design

Caesars Entertainment's vision for its new wheel had aspirations of lightness, freedom and an unforgettable passenger experience in every respect — to achieve something magical. Thus motivated, the Arup/Hettema design attempted to push the boundaries to make the most of a 360˚ panorama of Las Vegas and its spectacular surrounding desert environment.

This led to the development of a narrow, single tube rim supporting 32 large spherical cabins (changed to 28 as built), each with a single slewing ring, standing further out from the rim than is the case on either the *London Eye* or the *Singapore Flyer* (Fig 5). This minimises visual obstruction and maximises the panoramic views and sensation of free flying as it revolves.



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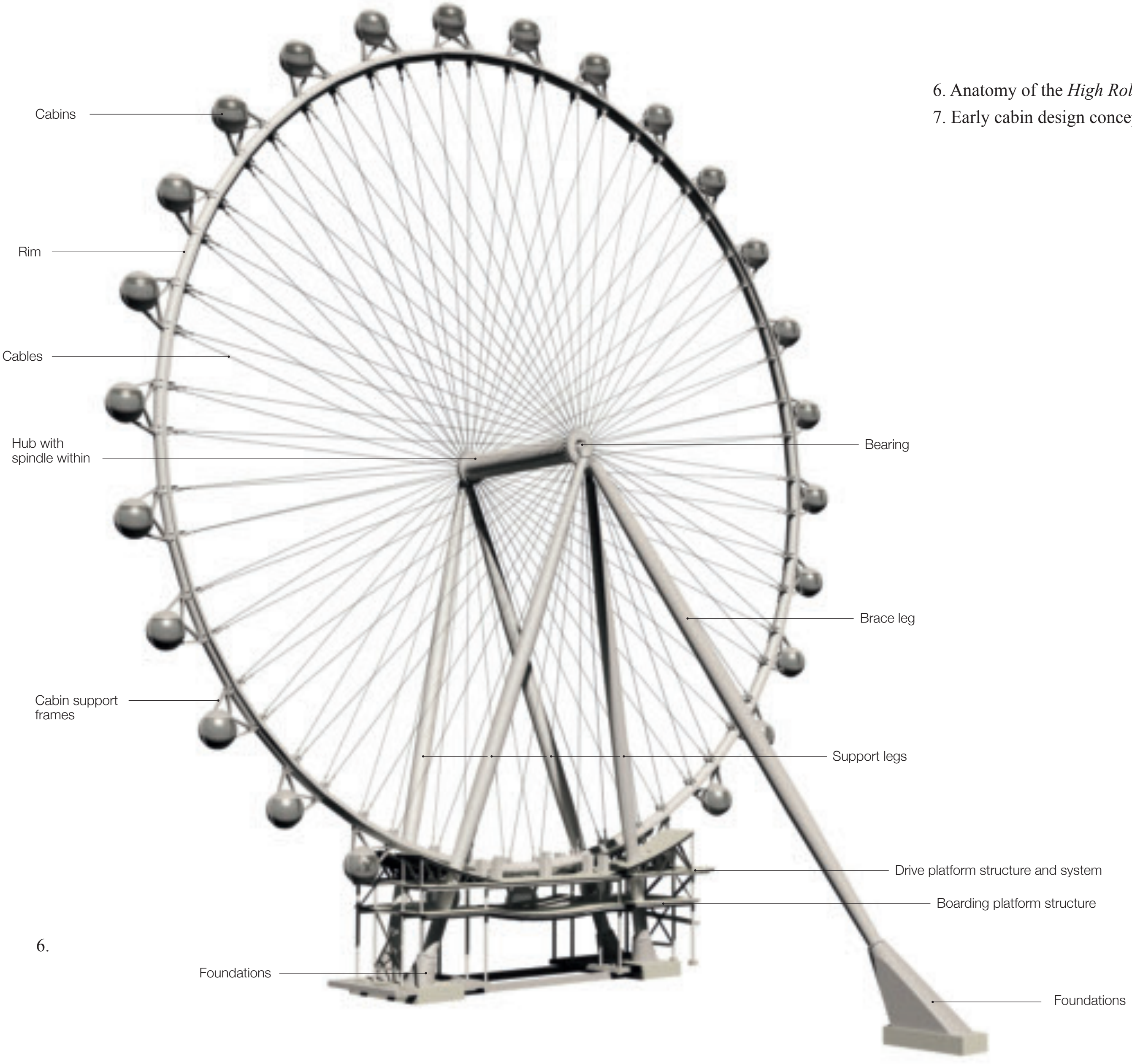

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6. Anatomy of the *High Roller*.

7. Early cabin design concept.

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When initial concepts for the *High Roller* (Figs 6–7) had been selected by the client, Arup was commissioned to develop a detailed reference design, in collaboration with THG, to enable the client to take this unconventional project to the construction market with a high degree of definition. The reference design was fully multidisciplinary, and its scope included:

- structural design of the wheel, supporting structure, and passenger loading building
- wind engineering and occupant comfort assessment under wind-induced motions
- geotechnical engineering and foundation design
- the mechanisation, including the drive and control systems
- cabin design, including structure, façade/glazing, HVAC, doors, controls, communications, and stabilisation systems
- utility and emergency (back-up) electrical power distribution for all systems including attraction lighting
- fire and evacuation engineering, including development of emergency response planning, means of access and escape, emergency power definition, and back-up safety systems
- acoustic and noise consulting
- preliminary FMEA (failure modes and effects analysis) documentation for permitting.

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8. Each *High Roller* cabin hangs from a V-shaped support frame.

9. The support structure under construction, showing the canting inwards of the main legs, and the brace leg angling outwards from the spindle.

Reference structural design

Design basis

The design of most aspects of the *High Roller* followed a performance-based approach. While existing codes of practice and design specifications offer solid methodologies for buildings or bridges, they are not fully applicable to unusual structures such as giant observation wheels.

One primary code used for the project covers the design of amusement rides[2], and this was selectively supplemented with portions of other codes, and bespoke methodologies developed by Arup. Where appropriate and feasible, the results of these analyses were verified with physical testing.

Support structure

The site constraints were a major driver in developing the form of the wheel support structure. The site is bounded to the west by a raised monorail, to the east by a road, and to the north by a road and an underground storm culvert. This left only a narrow footprint for the wheel to sit on with some additional space to the east — in a parking lot on the other side of the road — if needed for some lateral stability structure.

The four main steel tubular legs supporting the hub which carries the weight of the wheel are inclined to form two A-frames in the north-south direction, which also provide lateral stability in that direction.

However, both frames have to be canted inwards (from a maximum separation at the hub) so that their foundation plinths at the north and south extremes of the site fit within the site's restricted width.
A single tubular steel brace leg, from the east end of the spindle over the road to a concrete plinth in the parking lot, provides out-of-plane stability (Fig 9).

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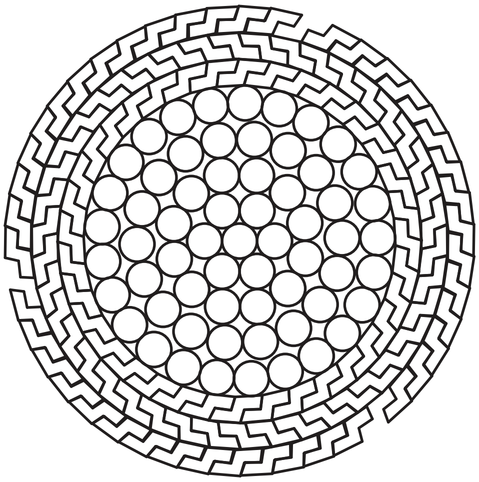

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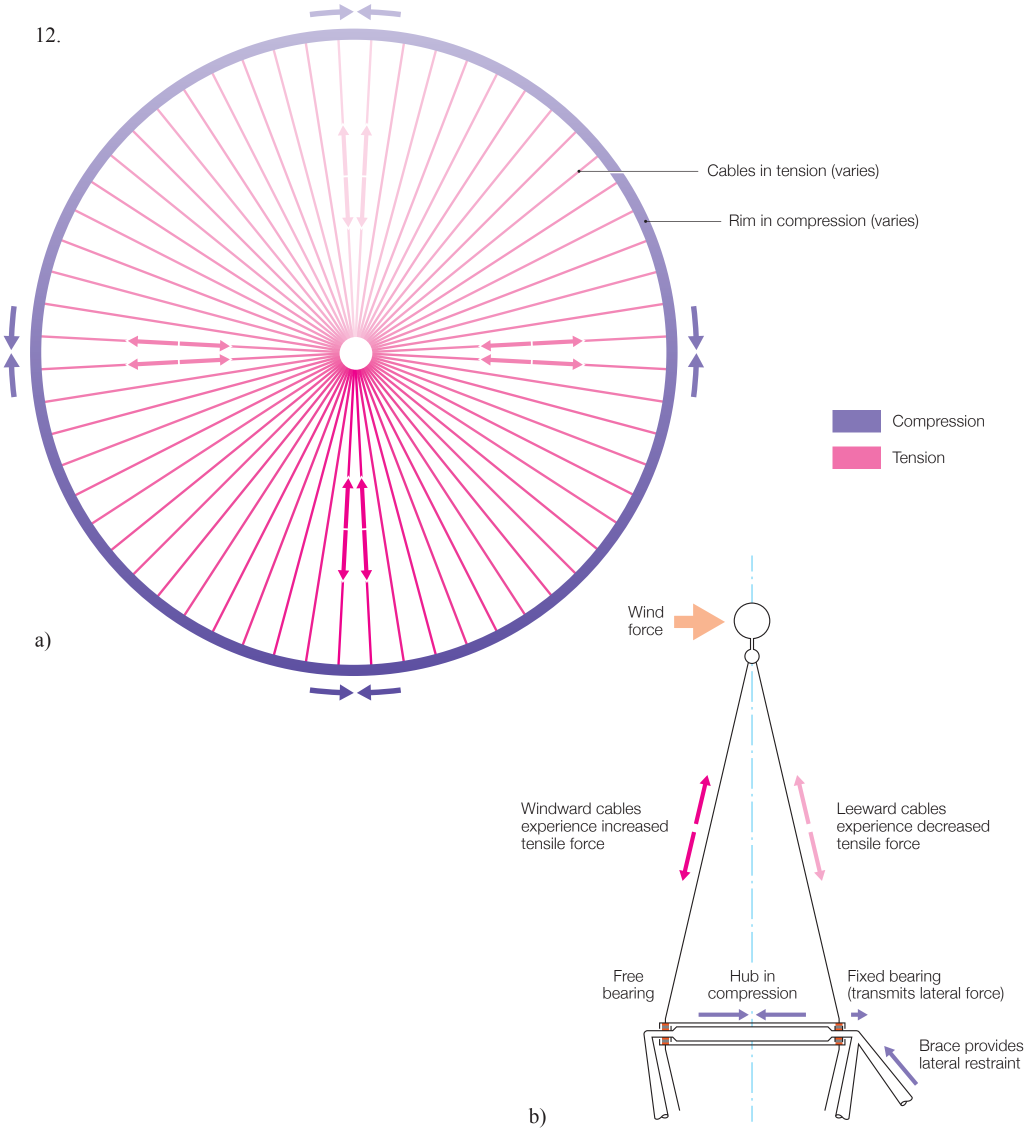


Rotating wheel

The structure rotating about the fixed spindle is essentially an oversized 128-spoke bicycle wheel. The spokes comprise 75mm (3in) diameter locked coil cables (Fig 10), because they provide the best stiffness–to–diameter ratio. This compactness reduces both the visual impact and the wind loading; an added benefit is that the interlocking "Z"s that form the outer layers of the cables offer better weatherproofing than spiral strand cables (Fig 11). To protect against vortex shedding, one Z-strand is removed from each cable, creating a helical groove up its length, similar to the helical strakes often seen on tall chimneys. Locked coil cables were also used on the *Eye* and the *Flyer*.

The cables are an essential part of the wheel structure, providing all the support for the rim and cabins. Though all the cables are set to the same length initially, gravity loading results in those at the bottom of the wheel carrying a higher tension than those at the top. Similarly, the overturning moment of the wheel caused by lateral wind loads is resisted by an increase in tension in half of the cables and a decrease in the other half (Fig 12).

10. Cables.

11. Cross-section of the 75mm (3in) diameter cable.

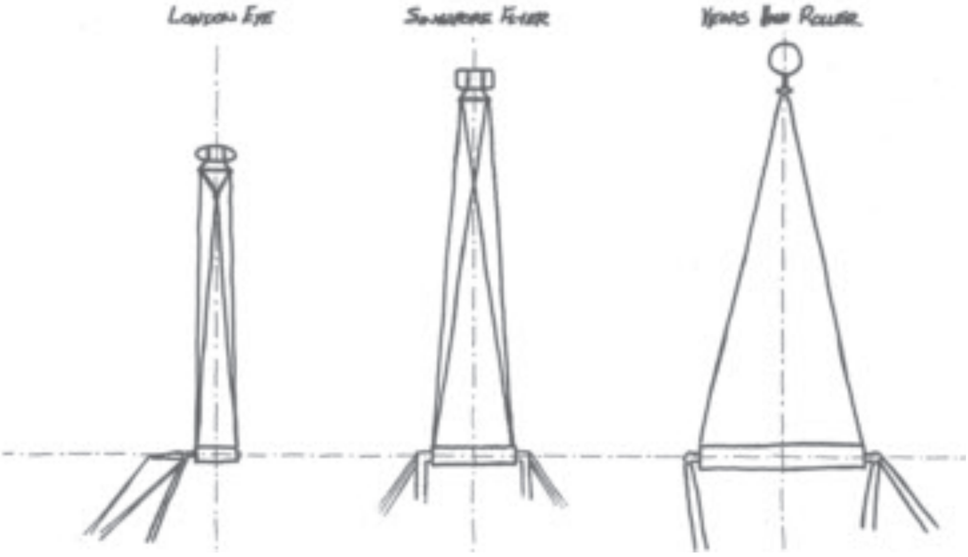
12. The forces on tension wheels: a) gravity; b) wind.

13. Comparison of hub lengths and cable angles on the *London Eye*, *Singapore Flyer* and *High Roller*.

14. The hub.

The choice of a single minimum diameter steel tube for the rim required the cables to provide more lateral stability to it than the wider "truss" designs for Arup's previous wheels. The *High Roller*'s single 2m (6ft 7in) diameter tube rim, constructed of 56 straight segments, is relatively flexible compared with the *London Eye*'s 8m (26ft) wide tri-chord truss, so the necessary stability was achieved by aligning the cables with greater inclination in the lateral direction, necessitating a longer hub.

The hub on the *Eye* is just 8m (26ft) long, partly limited by the flexibility in its cantilevered spindle. The *Flyer* took advantage of having support for its spindle at both ends and increased the hub length to 16m (52ft), while the *High Roller*'s hub is almost twice this at 30m (98ft) (Figs 13–14).



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Fatigue

Observation wheels like the *High Roller* are not just structures, but machines. Additional considerations arising from a wheel's rotation include the need for drives and bearings, the importance of fatigue in the design process, and wear and maintenance. Fatigue is a deterioration of structural capacity due to the growth of cracks in materials subjected to many reversals of loading.

Static resistance of the weight of the *High Roller* requires the tension in the cables at the bottom of the wheel to be far greater than that in the top cables. Correspondingly, the compression in the rim varies from high at the bottom to low at the top.

As the wheel rotates, each structural element moves from a bottom position to a top position, and therefore passes through these zones of high tension/high compression and low tension/low compression — one stress cycle per revolution. The stress cycles can induce fatigue damage in the cables, their attachment points to the rim and the hub, every hole and bracket on the rim, and every weld.

During the intended operational life of the wheel, all the elements in the rotating part of the structure will experience over 650 000 cycles of primary load fluctuation due to rotation, so in the reference design fatigue was considered for all of the rotating steelwork. Members were sized and details were developed to minimise fatigue susceptibility. Load reversals due to rotation do not arise in the stationary parts (the spindle, the legs, and the brace leg).

Cable fatigue

Design against cable fatigue is one of the more challenging problems for observation wheels. Not only does the tension in a cable vary during each wheel rotation, but the cables are subject to cyclic bi-directional bending due to the need to support their self-weight in the varying orientations.
In the plane of the wheel it is evident that the cables will experience maximum sag at the three o'clock and nine o'clock orientations, and no sag when they at the top or bottom.

However, the cables are also inclined out of the plane of the wheel, so when at the top the cables sag inwards; at the bottom they sag outwards. At the three o'clock position, the cables sag clockwise; at nine o'clock the sag is counter-clockwise.

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This bi-directional bending action is particular to giant observation wheels. The literature on cable fatigue is based primarily on research for bridge applications, dealing almost exclusively with axial load fluctuations only.

The Arup team therefore "deconstructed" the axial fatigue guidance and developed an analytical model for axial + bending fatigue in cables. The key to achieving long fatigue life is minimising detrimental bending effects (imposed moments and curvatures at the ends), and the following design measures were adopted for the cable ends:

- low-friction spherical plane bearings to reduce the moments at the cable ends at the hub and rim (Figs 15–16)
- extra-long clevises (U-shaped fasteners) between the cable end and the bearing to minimise the moment at the cable end itself.

Because of the uncertainty around cable fatigue, particularly due to bending, Arup commissioned physical testing to validate the assumptions in its analysis. This was done at Bochum University in Germany and showed that the selected bearing friction met the specification, and that the fatigue performance was in line with the predictions.

The Bochum tests also gave information about long-term elongation of the cables during repeated cycling, which enabled Arup to predict the loss of tension in the cables during the first few years. Just like a bicycle wheel, the *High Roller* needs its spokes re-tensioning.

15. Cable connections to the hub.
16. Cable connections to the rim.

Structural steel fatigue

Fatigue damage is caused by the propagation of a crack from an initiation point such as an inclusion in the parent steel, or a stress riser generated by a geometric discontinuity and/or a weld. Once a crack has started to form, the rate of propagation is affected by the toughness of the material.

The weld details on the rotating portion of the wheel were selected for their fatigue performance. All welds were detailed as complete joint penetration (CJP) welds, which typically experience much lower levels of fatigue damage than partial joint penetration (PJP) or fillet welds.

The weld procedures were specified to conform to AASHTO (American Association of State Highway and Transportation Officials) procedures for fracture-critical elements, which demand a higher level of inspection and better post-weld heat treatment, among several additional requirements. To control the rate of crack propagation should fatigue damage start, Arup's specification called for ASTM *A709*[3] Grade 50 steel, a bridge steel tougher than those used for buildings.

Tougher steel with verified through-thickness properties was also necessary to permit welding of cruciform connections without tearing the centreline of the plate.

17. Rendering of the hub and spindle.

18. The spindle has one fixed and one floating bearing.

19. Rendering of the fixed end of the hub and spindle.

20. Hub end forgings, in which the bearings are located.

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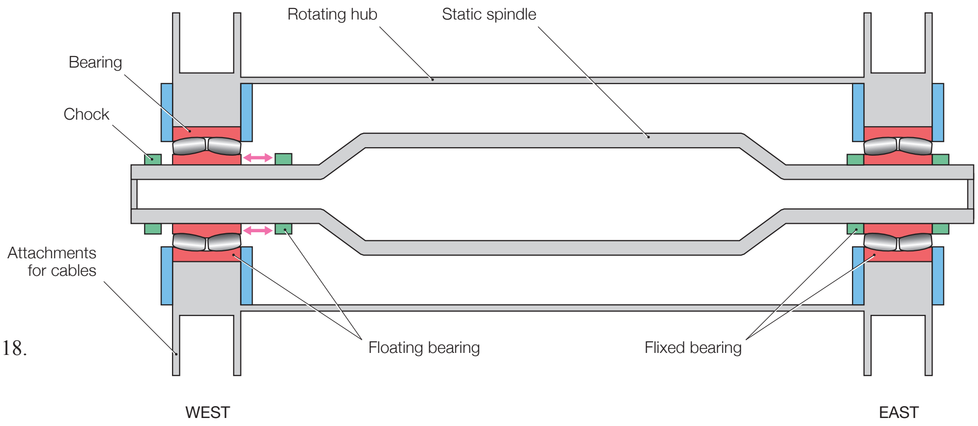

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Hub/bearings/spindle

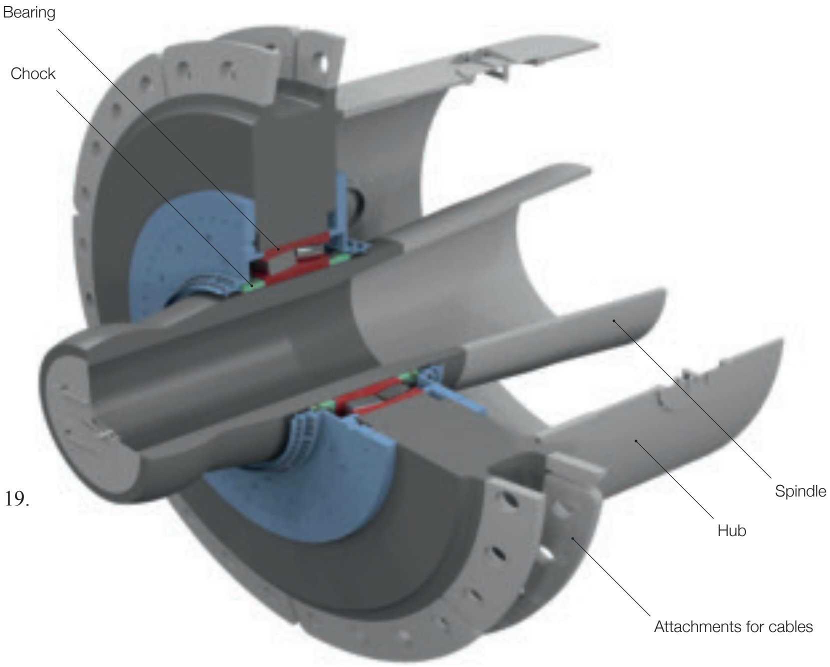
General arrangement

The rotating portion of the wheel interfaces with the static support structure by means of a hub rotating on a fixed spindle via two bearings, one at each end. To best suit this particular application, the design team chose spherical roller bearings, with the following main requirements:

- capable of carrying large radial and axial loads to cope with the wheel's huge weight and the significant wind loads that it attracts
- able to accommodate misalignment of their inner and outer rings without experiencing pinching on the rollers; as loading conditions on the wheel vary, the hub and spindle undergo different amounts of bending, resulting in angular misalignment between the hub and the spindle at the bearing locations.

Thermal loading on the structure can lead to differential expansion of the hub relative to the spindle. The bearings must be able to transfer axial loads, but they also have to be arranged so as to prevent build-up of large internal forces. These dual requirements led to the east bearing being axially fixed to both the hub and the spindle, allowing it to transfer axial loads, but with the west bearing left free to slide on the spindle (Figs 17–19).

The bearings themselves were supplied by SKF based on a performance specification developed by Arup. Each bearing weighs around nine tonnes and is designed to survive the wheel's full 50-year life without having to be replaced.



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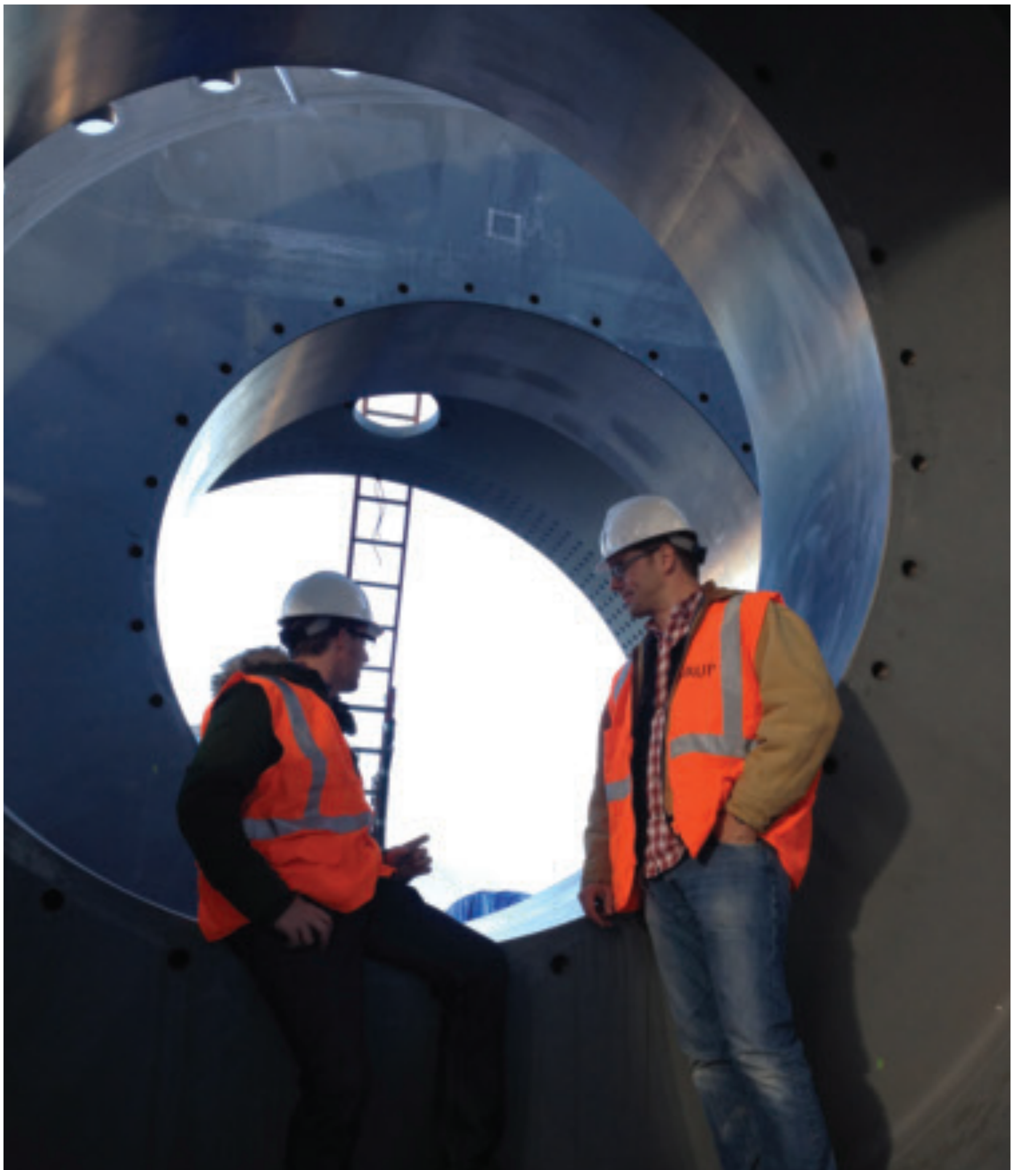


Each bearing is tightly located in the hub using a tapered collar sitting around its outsides. At the interface between the bearings and the spindle there is a clearance fit, and a ring of chocks on either side of the bearings. For the fixed east bearing, the chocks are located firmly against the bearing's inner ring; at the west bearing, they are set back to allow axial movement.

The hub supporting structure

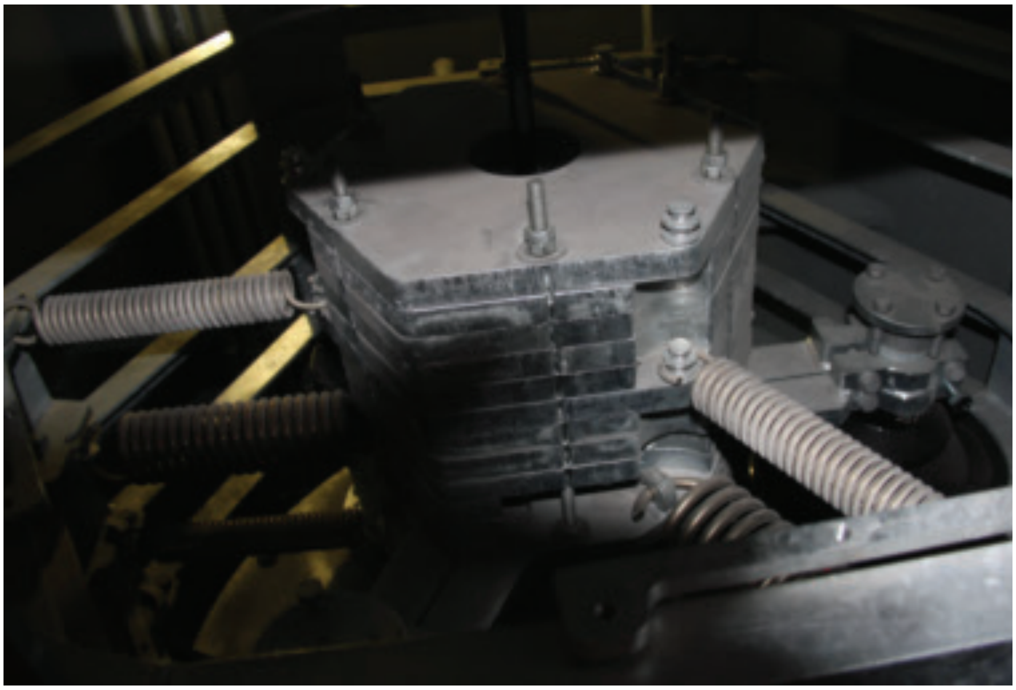
For the bearings to survive the 50-year design life, the structural housings must provide uniform and very stiff support. Any hard spots or excessive flexibility in the structure around the bearings would transfer a disproportionate share of the overall load into individual rollers as they pass. The hub and spindle were therefore specified as thick forged rings, manufactured by Japan Steel Works (JSW) (Fig 20).

While the bearings are designed to last the full life of the wheel, provision has been made for them to be replaced if premature degradation does occur for any reason. This is a major task, and would involve building a truss between the support legs below the hub. This would allow the hub, supporting the weight of the rest of the wheel, to be jacked up from this truss, relieving the load on the spindle.

The top of the legs would then be removed, and the end of the spindle extracted from the hub, taking the bearing with it. This is certainly a challenging process that should never have to be executed, but allowing for it was essential to guarantee the *High Roller* meeting its design life.

Achieving adequate bearing life also depends on keeping the grease needed for lubrication and sealing free from wind-blown sand and other contaminants. Each bearing is protected by steel cover plates bolted to the hub, minimising the gap to the spindle, and triple-layered rubber seals close the gap between the static spindle and the rotating parts.

Pressurising the cavities between the layers of seals with grease ensures a constant outward movement of grease and prevents the ingress of any contamination, whether particulate or fluid. Grease is also pumped into the bearing itself, entering between the two rows of rollers and moving outward, thereby flushing out any contamination.



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Wind

Although wind-induced motion is common to many tall structures, the *High Roller*'s light weight and low natural frequencies make it particularly susceptible to this type of dynamic response, both globally and locally in individual elements.

The aeroelastic stability of the cables was checked for vulnerability to vibrations from vortex shedding, galloping, flutter and rain-induced vibration, and in the design, allowance was made for Stockbridge dampers (small dumbbell-shaped tuned mass dampers) to be included on the cables if the vibrations were larger in practice than expected. These, however, have not as yet been required. The tubular members forming the support legs and the brace leg were predicted to be susceptible to vortex shedding excitation, and tuned mass dampers were incorporated in them (Fig 21) to control the potential response.

The team used a combination of analysis and wind tunnel testing to predict the dynamic wind response of the wheel as a whole. Site-specific desktop studies estimated the wind climate for the wheel, based on local airport wind records. The drag characteristics of the rim and cabins were initially estimated from code coefficients, and were then checked for several orientations relative to the wind direction by means of wind tunnel tests (Fig 22).

Static wind loads with a selection of patch loading scenarios to consider non-uniform gust distributions were used for the strength design of the wheel, but more sophisticated approaches were required to predict the wind-induced motions that passengers might experience.

Though there are now recognised vibration acceptance criteria for many types of structure, nothing existed specifically for giant observation wheels. Acceptability of vibration is a matter of perception, and the context is crucial. Arup developed bespoke criteria based on an amalgamation of the available guidance and previous experience.

The dynamic response of the wheel under service winds was predicted with spectral analysis, using purpose-written spreadsheets to account for gust correlation across the unique spatial distribution of the wheel elements. It was found that perceptible motions in the cabins would be generated over 10 natural modes of the wheel with frequencies between 0.4Hz–2.5Hz.

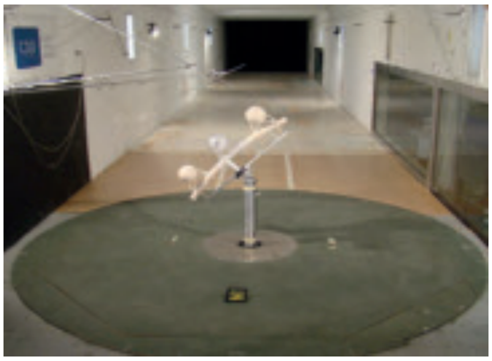
Unfortunately, all wind motion acceptance criteria are expressed on the assumption that a single frequency dominates in each direction (as is invariably the case for tall buildings where the problem is most usually encountered). There was therefore no clear way to establish whether or not a given multi-frequency response would prove acceptable or not.

For this reason, it was decided to set up a physical demonstration so that the client and design team could experience the predicted motions under various wind conditions on a motion platform. A series of time history wind response analyses were performed to develop simulated motion histories to apply to the test platform.

Arup's wind team in London produced sets of wind force time histories based on incident wind spectra to apply simultaneously to multiple loading points on the wheel, accounting for spatial correlation of wind gusts of different sizes. The response analyses were performed for different wind speeds using the design team's LS-DYNA model of the entire wheel, and for cases with and without supplemental damping.

The general consensus from the physical test was that a level of supplemental damping was needed to provide acceptable comfort in a one-year wind — the agreed target return period for continuation of normal operation.

The necessary level of damping could be provided by incorporating viscous dampers in the lateral guidance units at the drive platforms, although provision was also made in the steelwork to add tuned mass dampers at each cabin support in future if deemed necessary.



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21. Tuned mass damper in one of the support legs.

22. Wind tunnel test.

23. Platform structure.

24. At the boarding platform.

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The platforms

Passengers approach the *High Roller* through the wheel building where the tickets are sold and pre-show entertainment flashes information about the ride to come.
The wheel building connects to a four-storey platform structure that straddles the wheel, from which passengers can enter and exit the cabins (Fig 23). The platform is curved to match the arc of the rim, and the cabins move by at 0.25m (10in)/sec — slow enough for boarding while the wheel is in motion (Fig 24). It takes about 1.5 minutes for a group of up to 40 passengers to exit the wheel to the east and a new group to enter from the west.

The positions of the platform edges have to allow for variation in the positions of cabins as they enter the platform zone. Variations arise from movements of the rim of the wheel due to wind loading, thermal expansion, and contraction under the extreme temperature range of the Nevada desert and differential solar heating causing the whole wheel to lean slightly one way or the other.

There is also potential differential settlement between the platform foundations and the wheel foundations, and finally, despite stringent erection tolerances, the as-built geometry of the platform and wheel will not be perfect. All these factors had to be taken into account and controlled so that the required gap would be small enough for passengers to comfortably step into the cabins, but large enough to accommodate potential movements and construction tolerances.

In operation the cabins can move laterally under wind and thermal loading, but viscous dampers eliminate any sudden jerks as passengers enter and exit. The mechanisms that drive and control the wheel are designed to track along the rim and move laterally and radially to match its movements.
To minimise the effect of construction tolerance, the platform edges were installed after the wheel was finally “trued”, so that they positioned to the as-built rim geometry.

Finally, the edge of each cabin was fine-tuned to match the finished platform.
Under extreme events, such as earthquakes or winds exceeding the design return period, the lateral restraints will lock off to limit excessive rim movements and thereby prevent damage to any of the sensitive mechanisms or cabins.

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The cabins

The *High Roller* carries 28 cabins each accommodating up to 40 passengers. By comparison, the 32 cabins of the *London Eye* and the 28 of the *Singapore Flyer* each accommodate up to 25 and 28 passengers respectively. Each cabin is a complex entity in its own right, somewhere between a building and an automobile in terms of design considerations.

As well as having to provide an entertaining and pleasant experience with excellent day and night views and the sense of being "on top of the world", they had to be engineered to function in what is essentially a desert environment.

The original THG concepts were based on the almost ellipsoidal *London Eye* capsule design, but the Arup team, through its early involvement, was able to suggest a simple yet elegant alternative – a spherical cabin – which was quickly adopted. The basic structure is formed around two hemispherical steel frames connected to the slewing bearing that sits within a structural steel ring mounted to the wheel rim (Figs 25–26).

Glazing

Developing a viable glazing system was a key factor in the reference design, and achieving both the highest visual quality and the highest solar/thermal performance of the glazing was essential to the design's success.

The type of glass and chosen solar control significantly impacted the thermal performance and the size of the heating, ventilation and air-conditioning (HVAC) system. Steps were taken at concept stage to reduce the cooling requirements by minimising the extent of overhead glazing, but the amount of glass necessary for panoramic views required further steps to reduce the cooling loads.

The glazing also needed to satisfy other safety issues associated with extreme summer temperatures in excess of 40°C (104˚F) — such extreme heat could easily make surfaces in the cabin too hot to touch (the solar gain on single-glazed units in the Las Vegas sun can cause surface temperatures to rise beyond 70°C/158˚F).

It was quickly established that double glazing was needed to handle the temperature extremes, but the challenges of differential thermal expansion of the two glass panels and the air gap remained. Expansion and contraction of the air would generate varying pressures within the double glazing, and Arup's façades team determined that this could lead to cracking at the supports.

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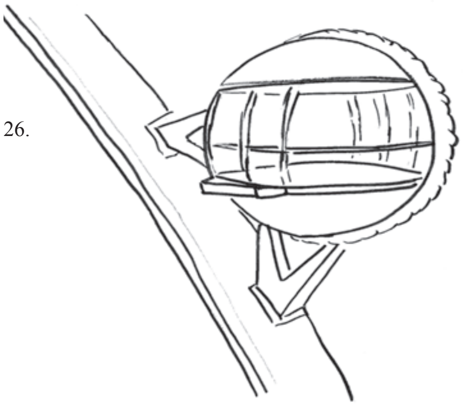

A vent in the double glazed cavity was therefore included in each panel, accommodating the expansion and keeping stresses in the glass at acceptable levels. The air gap also included a desiccant, to avoid problematic condensation.

At the temperatures that can occur in Las Vegas, re-radiation into the cabin also becomes problematic, so it was essential that most of the glazing be insulated. The design team considered deployable external shading, but the sun's intensity at low altitudes made this unviable.

The outer glass layer has a simple absorptive coating, selected for its balance of optical qualities, but again this had a side-effect of causing the outer layer to heat up, so this needed to be dealt with, as described above. The coating is non-reflective, providing clear views from the cabins and enabling higher quality photos through the glass. It also has low transmissivity to reduce the amount of solar heat entering the cabins.

In the reference design the main space of the cabins — that portion accessible to the passengers — is fully glazed using large laminated double glazed units (Fig 27). Eight glazed units per cabin are used, each doubly curved to follow the spherical form. The doors are single glazed, to reduce the weight on the door mechanism.

Cabin HVAC

Even after optimisation of the glazing system, a large HVAC system (around 25kW of cooling) is still required in each cabin, housed in the belly below the passenger floor (Fig 28). Cooled air is passed to the top of the cabins through ducting close to the structural ring, and released around the perimeter of the ceiling. This allows cool air to flow down the glass, preventing it from getting uncomfortably hot to touch.

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This air, now slightly warmed, is then extracted downwards through vents under the seats and used to cool the HVAC and electrical equipment beneath. Finally the air is reintroduced to the cooler and circulated back into the cabin at the top. Fresh air enters the system through intakes, as well as from deliberate leakage from the outside environment into the belly.

The passenger space is kept slightly pressurised relative to the outside environment, so that at any locations where air can pass in or out, there is cool air flowing out rather than hot air flowing in.

Electrical power is supplied to the rim at platform level using several collector shoes sliding on conductor rails (busbars) on the moving rim. Since the cabins rotate relative to the rim, a similar system is required to transfer the power into the cabins. The transistor box in each cabin generates a significant heat load, which contributes to the required size of the HVAC system.

Each cabin has an uninterrupted power supply in the form of a high capacity lithium battery with over six hours' running time, so that life-critical systems can continue to operate if the main power supply fails.

Stability and safety

The orientation of each cabin is controlled with an active rack-and-pinion stability system. This is backed up by a battery-powered secondary stability system also installed under the floor, which provides continuity of function if the primary system fails. The cabins are stable (will not overturn) in fully passive mode even if all power fails, though achievement of precise orientation would be compromised.

Many other features are included to maintain a safe passenger environment, and developing these formed a large part of the FMEA for the cabin systems undertaken throughout the development.

If the HVAC fails, a fan provides continued ventilation; though not particularly comfortable, this gives adequate cooling in an emergency situation. The interior finishes of the cabins were selected to minimise combustibility and reduce the risk of fire, compliant with *NFPA 130*[4]. Further safety features are discussed later in this article.

25. One of the 28 *High Roller* cabins.
26. Cabin concept sketch.
27. Close-up of cabin glazing.
28. One cabin being assembled, showing the internal arrangement.

29.

Mechanisation/electrical/communications
Arup's reference package included an engineered design of all these systems, together with performance specifications for a design–supply–install–commission contract. Five main systems comprise the mechanisation: the primary drive, the backup drive, the lateral restraint (and damping), the electrical distribution, and the communications distribution.

All of these cross the interface between the rotating structure and the static structure, and must accommodate differential movements between the two due to the rotation itself, the faceted form of the rim, thermal and wind loads, and fabrication tolerances.

Primary drive

The primary drive system is based on those for the *Eye* and the *Flyer*, using individually-driven truck tyres to grip the rim and rotate the wheel (Fig 29). Electrically controlled actuators provide the contact force between the tyres and the drive rail, a welded steel box on the side of the main rim tube.

Each tyre is driven by a hydraulic motor with a small gearbox, which fits neatly within the drive unit arms (Fig 30). Hydraulic motors were selected for their compactness and good torque profile at low speeds. Electric motors could have been used, as on the *Flyer*, and they have some advantages, but the substantial gearing needed adds weight and takes up space.

The four tyres and motors on each drive unit are mounted on the top bar of a four-bar linkage which leans against the rim, supported by a nylon roller running on the side of the drive rail and held in contact by its own weight. A hydraulic cylinder across the diagonal of the four-bar linkage is used to retract the drive units for maintenance.

Backup drive

Though the primary system has 100% redundancy, an independent backup drive system can rotate the wheel should primary drive fail totally. The backup has its own diesel-powered hydraulic power units and three clamps that engage with the drive rail in a similar manner to a disc brake.

The clamping blocks can be extended and retracted along the rim to haul it round. In a storm, the backup drive system can be used as a "hand brake" to prevent rotation of the wheel.

30.

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Lateral restraint and damping

The rim passes between two pairs of lateral guidance units at the drive platform level. Load-balanced nylon rollers apply a force to the side of the drive rail, which is controlled by hydraulic cylinders. These cylinders can operate in different modes, fully locking off lateral movements of the rim (during a storm, for instance), or providing damping during normal operation (Fig 31).

29. Layout of the mechanisation systems on the drive platform.

30. Drive unit engaged on the rim.

31. Lateral restraint.

32.

Electrical distribution

Supplying power to the cabins and the wheel lights requires electrical distribution right round the rim, via a busbar system. Collector shoes at the drive platform engage with five continuous conductive rails around the rim. The electrical distribution system has 100% redundancy of the shoes and, if a break were to occur in the conductive rails, power can travel in either direction around the rim, ensuring that all cabins continue to have power.

Communications distribution

The transfer of communications signals from the rotating wheel to the static structure occurs at the hub and spindle (Fig 32). Communications cables span (supported by messenger cables) from the rim to the hub, where the signal is transferred across the rotating-static interface using “leaky coaxes” (coaxial cables with gaps in the outer conductor to allow the signal to leak into or out of the cable along its entire length). These are housed in the hub, which protects them from weather and contamination, as well as malicious interference.

Safety

Since the wheel can hold over 1000 passengers at any one time, and there is no direct emergency escape route from the cabins, incorporation of safety features was a major design driver from the beginning. From an overall structural perspective, the structure has minimal redundancy, and with multiple non-redundant elements.

The design was approached by using a FMEA, standard practice in the design of many mechanical engineering projects from commercial airplanes to rollercoasters. This enabled the team to identify potential failure points and their consequences, and design of mitigation measures including increased resiliency of elements, incorporating additional redundancy, and development of emergency response plans. A comprehensive list of natural hazards, accidental incidents and system malfunctions or failures was assembled, and a mitigation or response strategy was developed. Satisfactory solutions to every eventuality were required as a condition of licensing the wheel for operation.

Safety design features

The following were incorporated:

Drive mechanism: The primary drive system has 100% redundancy, ie the capacity to rotate the wheel with just half the drive units operational. Each set is powered through separate electrical circuits and, in the event of utility power loss, there is an emergency power supply. The primary drive can also rotate the wheel at double speed and in reverse to allow emergency evacuation of a particular cabin if required.

Drive backup: In the event that all power fails there is a separate backup drive, incorporating a "sloth-like" system (Fig 33). This is not incorporated in either the *London Eye* or *Singapore Flyer*.

Cabin stability: The cabins have to rotate relative to the rim as the wheel operates so that the floor remains horizontal (otherwise the glazed walls quickly become the floor). In the *High Roller* stability is maintained by a doubly-redundant active system in each cabin. A gravity mode still exists as a final system for maintaining an upright cabin (Fig 34).

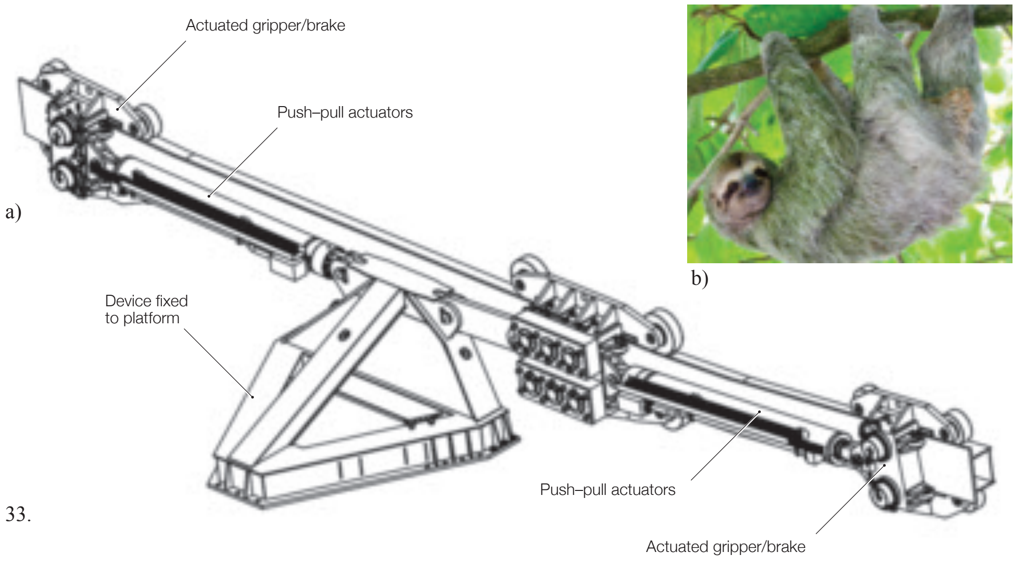
Other cabin features: Each cabin is equipped with water and other emergency supplies, as well as having communications back to the control office. Smoke detectors and cameras allow the control staff to monitor activities in the cabins.

Fire: The cabins contain minimal flammable materials, and emergency ventilation will operate should smoke extraction be required.

Lightning protection: While lightning storms are uncommon in Las Vegas, a direct strike on the wheel may cause both electrical and mechanical damage. For this reason, a special lightning conductor slip ring was incorporated to prevent a lightning strike crossing through the main bearing, damage to which could prevent rotation of the wheel.

Evacuation: In the extremely unlikely event of the wheel being unable to rotate — failure of either all drive systems or the main bearings — there is an evacuation plan, involving a combination of high reach equipment and rope rescue. For cabins near the top, rescue staff from the local Clark County Fire Department Heavy Rescue team worked with Arup to develop methods of access via ropes, ladders and other features. Some modifications were necessary to the rim design to make this possible (Fig 35).

Earthquake: Las Vegas is in a region of moderate seismicity. The wheel is designed to remain operational after a major earthquake (allowing evacuation while rescue services are busy elsewhere), so the structure was designed to be fully elastic during the 2475-year return period seismic event. As a precaution, "fuse" details were included in anchor bolts at the bases of the legs to allow a ductile mechanism to form in the case of even more extreme loads (Fig 36).



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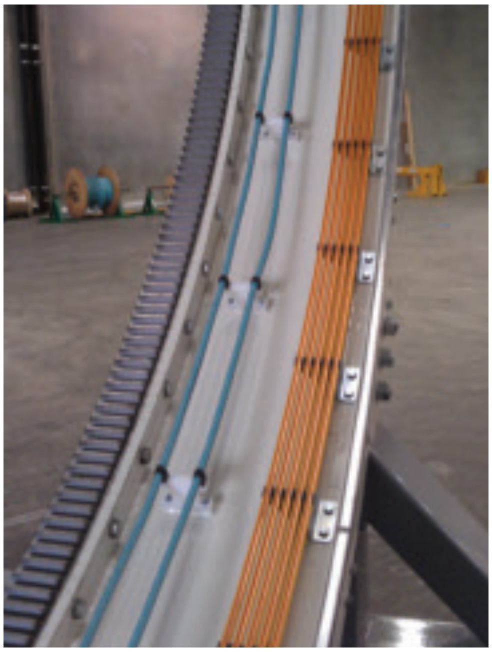

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35.

32. The hub contains and protects the communications distribution system.

33. The "sloth-like" backup drive system.

34. Cabin ring showing stability system and electrical distribution.

35. Cabin access ladder.

36. Tightening anchor bolts in the support legs.

37.

38.

37. Brace leg plinth.

38. Shear key, before installation.

Foundations and geotechnical design

The wheel is supported by three main foundations — for the north legs, the south legs, and for the brace leg. Each steel leg attaches to a giant concrete plinth via an assembly of embedded anchor rods. The two north plinths sit on a common pile cap, as do the two south plinths. The brace leg lands on a plinth with its own pile cap (Fig 37).

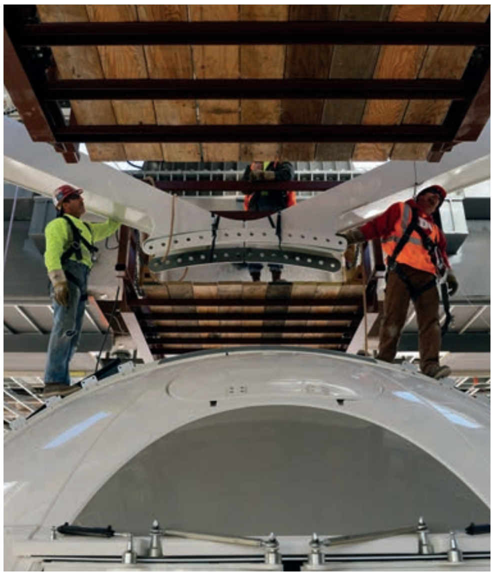
The connection between the legs (including the brace leg) and the plinths comprises a shear key (Fig 38) to locate the steel relative to the concrete, a stiffened base plate, and an array of unbonded anchor rods that connect to a plate embedded within the plinth.
The heavily reinforced, cast-in-situ concrete plinths transfer the loads from the support legs into the pile cap. Each plinth was poured monolithically; special concrete mix design and means of placement were adopted for the very hot weather pours necessary in Las Vegas.

The 2.4m (8ft) thick pile caps are connected by grade beams and supported by 0.9m (3ft) diameter drilled shafts that extend 10.7m–13.7m (35ft–45ft) deep. Each pair of main support legs is supported by an 18-pile group, while the brace leg is supported by an eight-pile group.

The piles pass through several layers of alluvial deposits and caliche, a hard calcareous deposit commonly formed near major washes in the Las Vegas Valley.
Over geological time, carbonate minerals were transported from the surrounding mountains and dissolved into the groundwater, and their precipitation in the arid Valley climate resulted in a cemented soil mass. Because of its erratic deposition, caliche varies greatly in its thickness, hardness, cementation and lateral continuity.

The ground investigation focused on identifying the variability in caliche thickness, stiffness and persistence, as well as the strength and stiffness properties of the softer alluvial layers underlying the support leg foundations. In situ P– and S–wave suspension velocity logging[5] and pressuremeter testing was used to supplement preliminary borings and refine understanding of the subsurface stratigraphy.

Arup's pile design was confirmed by high-strain dynamic load tests on two production shafts. Both achieved total shaft capacities of over 8800kN (2000 kips), more than four times the design service load.



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Procurement and construction

Introduction and contractual setup

There is no "standard" procurement process for giant observation wheels, and one of Arup's earliest roles was to advise the client on the options. Following the precedents of the *London Eye* and the *Singapore Flyer*, the original proposal was that Arup would develop a reference design for the *High Roller* that would be released for a complete design–build contract.

Towards completion of the reference design Arup assisted the client in testing the market for potential design–build contractors but, despite concerted attempts, it became apparent that there would be no takers for a single turnkey contract, and that the project would have to be let as a series of contracts managed and co-ordinated by the client.

The main contractor selected for the wheel itself — American Bridge Company (AB) — submitted a bid that was limited to the supply and erection of the main wheel steel and its ancillaries. AB's proposal excluded responsibility for the Construction Documents (CD) design phase, and for any aspect of the foundations, boarding platform, drive equipment, and cabins.

Construction of the foundations and platforms was let to Richardson Builders; the cabins and their V-shaped support frames were developed as design–build items by Leitner-Poma of America (LPOA), and were lifted onto the wheel (Fig 39) by AB. The mechanisation systems were let as a design-build contract to Schwager Davis Inc.

Extended Arup role

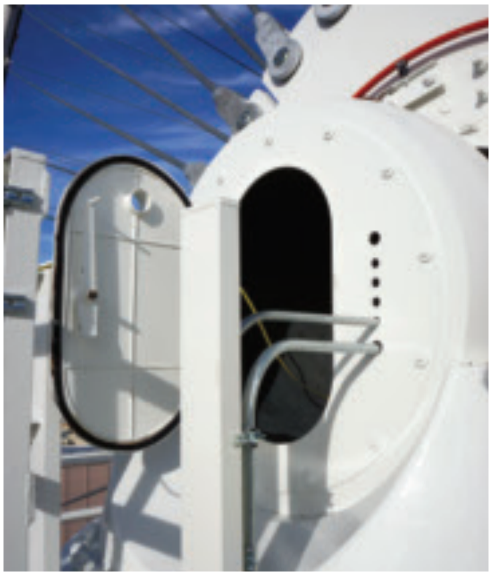
In the absence of a full design–build contractor the client asked Arup to develop the reference design of the wheel, the structure, the platforms and the foundations to the CD stage and take on the construction administration throughout. This extended the firm's role for multidisciplinary services that included structural, geotechnical, fire, electrical, and plumbing engineering, and blast resiliency.

Arup also took the main role in design co-ordination, working with the client's small project management team, because the *High Roller* was a project in which there was no architect leading the design team as with a conventional building project. THG was involved through the reference design, but did not take on a co-ordination role. Local entertainment architecture specialists Klai Juba Wald developed the architectural components of the platform design, but again without any overall co-ordination role.

A further consequence was that Arup had to consider the minutiae of access requirements and design in detail the related components. Access through the wheel includes ladders up every leg to the hub and spindle.

Doors in each end of the spindle (Fig 40) allow east–west movement without climbing down 70m and then back up again. There is access, through an opening in the floor of the spindle, to the inside of the hub. Here, a complex of ladders and platforms allows maintenance staff to inspect the bearings, collect grease rejected by the bearings, and exit through external hatches to stand on the hub for cable inspection.

Arup's role co-ordinating the interfaces between the various contractors included building (in *Navisworks*) an integrated model of all the wheel systems that was used for clash detection and to aid communication. This incorporated 3-D model data from the design–build cabin and mechanisation contractors, the architects and other sub-consultants, and included all drive equipment, the connection of the cabins to the main wheel structure, the power to the cabins, the lighting equipment, and cabin communication — every bolt, bracket and piece of conduit on the project.



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The decision to go down this route was a wise one. Many elements of the wheel, being fabricated by different companies, had to fit together with fine tolerances, and field alterations — welding, drilling, cutting — were particularly undesirable because of the implications for fatigue performance.

The success of this approach can be measured, in part, by the number of requests for information (RFIs) Arup received related to attachments to the rim — just four. On site, (almost) everything simply fitted perfectly together.

This was the first time Arup had taken responsibility for this level of design and construction of a wheel, and so this was a great opportunity to help fully deliver one of these rare projects.

39. Cabin being installed by American Bridge.

40. Spindle end door.

Structural design for Construction Documents phase

The CD design of the wheel structure was a major co-ordination challenge in incorporating the fabrication and erection methods and schedule of the AB contract. Fabrication was undertaken in Shanghai by AB's subcontractor ZPMC (Shanghai Zhenhua Heavy Industry Co Ltd).

Many aspects of the design finally executed involved balancing multiple requirements for structural integrity and performance with the constraints associated with the way that AB wished to fabricate and erect, the capabilities of fabricators and requirements of manufacturers, the lift capacities of the cranes, etc.

For example, the design of the hub, spindle and bearings was strongly driven by requirements associated with the bearings supplied by SKF. To mobilise their full capacity, the bearings had to be housed within smooth supporting structures with a 73µm (0.0029in) tolerance and hardened surfaces. The ends of the hub could not be manufactured to these requirements by ZPMC, and ultimately JSW was engaged to produce forged end pieces machined to this tolerance (limited only by the accuracy of its measuring tools) and provide the hardened surface.

JSW also managed to develop a weld procedure that gave acceptable performance for the welds between the forgings and the structural steel, which had to meet the fracture critical toughness requirements. The hub/spindle assembly needed to be designed with two fully bolted splices so that AB could lift it in three pieces, each at the full capacity of the largest crane in Nevada.

Arup as engineer needed these components to transmit the structural loads and was ultimately responsible for ensuring that the design balanced everyone's requirements. This was done in very close collaboration with the other three companies, including developing an installation method that was validated with dynamic finite element analyses (conducted by Arup and SKF) to simulate the insertion of the tapered collars that capture the bearings.

On site, installing each bearing took just a couple of hours and the whole complex process went precisely to plan (Fig 41). This was a huge testament to the success of this collaborative process.

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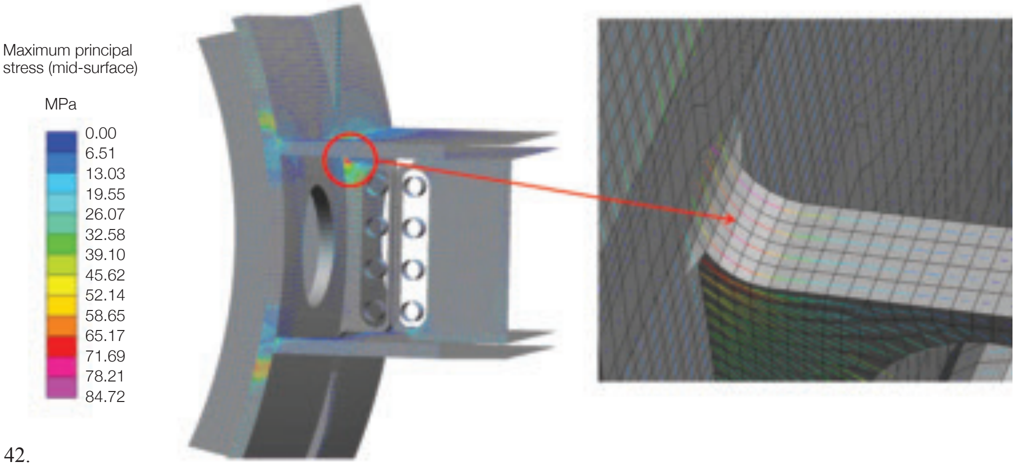

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Fatigue

As already noted, for the structural steel in the rotating part of the wheel, fatigue considerations affected every aspect of the design. All details were optimised to avoid fatigue; every hole and attachment to the rim was explicitly drawn, so that it could be fabricated in the shop to avoid on-site alterations. All components welded to the rim were aligned with the direction of the cycling stress, and profiled to reduce stress risers. Every penetration was assessed in relation to the surrounding geometry to ensure that the increase in stress that it generated would be acceptable. This level of thoroughness, while seeming, perhaps, excessive at the time, meant that only four alterations were required on site.

The team conducted fatigue analysis by various means depending on the complexity of the specific location. A finite element analysis using a relatively coarse shell mesh was used to determine the overall stress patterns. For simple connections, eg in-line brackets and holes, these stresses were used directly with the appropriate code fatigue classifications to determine the expected life.

For more complex geometries, such as the cable connection to the hub, a fine shell mesh was used to better assess the geometric flow of stress. The hotspot fatigue assessment method was used to calculate the expected life, based on extrapolated surface stresses, following the methodology in *BS7608*[6]. In a few locations, where the standard hotspot method was inappropriate due to the complex geometry, a very fine solid finite element mesh was built and a special assessment methodology developed to ensure appropriate application of the fatigue calculation theory (Fig 42).

41. Tapered collar being lifted into place, to fit around the bearing.

42. Solid mesh finite element fatigue analysis.

Welding

Particular challenges were presented by several details of the drive rail, which is attached all around the rim. These derived from the high cycling stresses, the complex geometries required to carry the longitudinal compression loads in the rim, and the radial compression loads from the drive system combined with the limited access for forming the required welds. While Arup's original geometry was technically possible to produce, the steel fabricator requested some detail changes to suit the proposed sequence of assembly.

Arup and AB went through an iterative process to converge on the final design: Arup would present an option to AB; AB responded with concerns; engineer and contractor discussed possible alternatives; Arup analysed the new design option, made adjustments as necessary, and presented the results to AB. Over weeks, this collaboration arrived at a solution that accommodated the contractor's assembly sequence and also met all the design requirements, most notably fatigue performance.

Owner's Engineer role

For those parts of the design for which Arup was not directly responsible — eg the drive systems and cabins — the firm took on the Owner's Engineer role, providing general reviews of progress and monitoring through detailed design and testing.

Construction

Two contractors

Two general contractors handled the project as a whole: AB for the wheel structure, and Richardson for the LINQ development, the foundations, and the platform. These scopes of work created several important interfaces between them, a critical one being at the concrete plinths of the foundations (Fig 43). As already described, the support legs connect to an anchor bolt assembly that is cast into the massive concrete supports — and the anchor bolt and shear key assembly was fabricated by AB and installed by Richardson. The foundation assembly required very tight geometrical tolerances because it set the position for the support legs, later installed by AB.

There were also many important interfaces between the platform structure and the wheel that required close co-ordination of contractors and fabricators. The platforms were built first, due to schedule constraints on fabricating the steel for the wheel. Several temporary "leave outs" were incorporated into the platforms so the support legs could be lowered carefully through the four-storey structure. After AB completed the wheel, Richardson connected the platforms to the legs and cast the slab edge to match the arc swept by the cabins.

Erection of the wheel

The erection process AB selected was similar to that for the *Singapore Flyer*. The support leg structure was constructed first, and then the hub and spindle were erected. Then the rim was assembled introducing each new element at the base and then rotating it to make space for the next section (Fig 44).

After Richardson completed construction of the foundations, it proceeded to the platforms, incorporating the leave-outs for the main legs of the wheel. Once Richardson handed over the site, AB needled the bottom third of the legs through the leave-outs and attached them to the plinths. Temporary trusses supported the legs as they were completed and capped off with the section known for obvious reasons as the "pants" (Fig 45).


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43. Interface between the plinths and the legs.

44. The rim half-assembled, showing temporary struts.

45. The legs completed by the "pants" being lowered into place.

The hub and spindle were split into three parts: two ends and a middle tube. The hub ends, bearings and spindle ends were assembled on the ground and then lifted into place, the west assembly first. Since the crane did not have the capacity to place the assembly directly into its final position, it was deposited on a sled on the temporary truss and jacked into place. The centrepiece of the hub followed, and then the spindle centre, which was loaded into the hub horizontally. Finally the east end assembly was brought in and attached to complete the central structure.

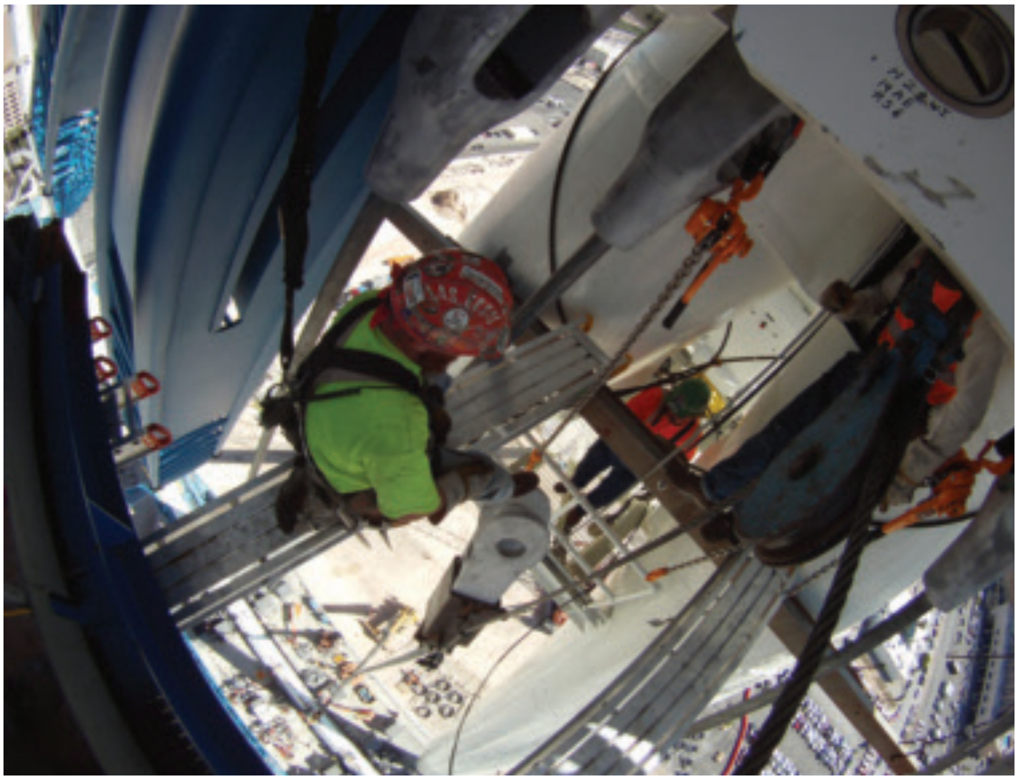
Chain falls from the hub were used to lift the rim sections into place at the six o'clock position (Fig 46). These were supported by temporary trusses from the hub and rotated to make space for the next rim element. As the partial rim was lifted round, the gravity loads were resisted by tie-back cables to temporary foundations to the north. On completion of the rim, the temporary trusses were removed and the cables added and tensioned.

Cable tensioning

Tensioning the cables is a lot less straightforward than it might seem. Even though they all have the same nominal pre-tension, in practice each carries a different load at any given time. Tension in the cables was also used to true the wheel, straightening out some of the fabrication tolerances to hit the extremely demanding ±30mm (1.2in) in any direction.

Having a rim that runs straight and true helps to minimise the gap that passengers must step across at the platforms, and allows the drive system to accurately track along the wheel. The cable tension was specified with a ±10% tolerance to allow for this truing. AB initially set the cable tensions based on length, tightening each clevis by a defined amount from a known slack position (Fig 47).

Once all the cables were set and the wheel trimmed, the final tensions had to be confirmed. This was all done at the six o'clock position, for consistency and ease of access. AB's method for determining the cable tension involved placing accelerometers on the cable, and then "plucking" it like a giant guitar string — done by one person shaking the cable by hand —and measuring the frequency.



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46. American Bridge workers lifting a cable to the hub.

47. The cables were tensioned with hydraulic jacks, and then the clevises rotated by hand.

Progressing the cabins

Detailed design and development

The LPOA design–build contract progressed with several changes to the reference design to accommodate specific requirements. The main proposal was to use a conventional roller slewing bearing solution for the single mounting ring. Arup's reference design had avoided this because of the long lead times to procure large-diameter bearings and the stringent deflection criteria this type of bearing needs for support housings. LPOA proposed a bearing sourced from China, and further analysis by LPOA demonstrated the bearing raceway deflections could be accommodated in the bearing support structure.

The design was also complicated by the cabins' large external diameter and transportation issues. Arup's reference scheme was to transport the cabin halves and assemble them in a clean facility on (or very close to) the site. Introducing the smaller slewing bearing made this more difficult, but the issue was resolved by LPOA moving the whole assembly activity to Las Vegas, foregoing its initial plan to manufacture and assemble at its home base in Grand Junction, Colorado, and transport completed cabin halves to Las Vegas by road.

Another change from the reference design was in the HVAC system. The detailed design changed this to two self-contained units that could be easily removed for maintenance. This came at the expense of additional weight and less effective filter systems, but overall provided a much easier-to-maintain design solution.

The design of the V-frames connecting cabins to wheel rim also varied slightly from the reference design. These were developed to include the power and control signal conduits running inside the welded box section with the electrical connections accessible via waterproof access panels on the inside faces of the V-frames.

Prototype testing

The performance specification required prototype tests to be undertaken prior to starting production of the 28 cabins, and this was done in two phases during the early spring and summer of 2013.
The construction of the prototype cabins was used to determine assembly procedures and develop the assembly fixtures that would be used for the cabins assembled in Las Vegas. The full range of development and acceptance tests for the stability systems and doors included rollover tests and detailed testing of the control systems for compliance with performance specifications, as well as the formal failure modes and effects analysis design approach used for the project (Fig 48).

Cabin and V-frame production

Following completion of the prototype tests, cabin assembly began at the Las Vegas location leased by LPOA, a large industrial unit that provided a secure, clean facility. It was also relatively close to the site (although transportation changed to a longer, more circuitous route to reduce difficulties). During this time additional testing of the HVAC units, waterproofing tests and several pre-determined factory acceptance tests on the bearings and control systems were completed at the facility (Fig 49).
The V-frames were subcontracted by LPOA to a fabricator in Kingman, Arizona, and these were delivered directly to site.


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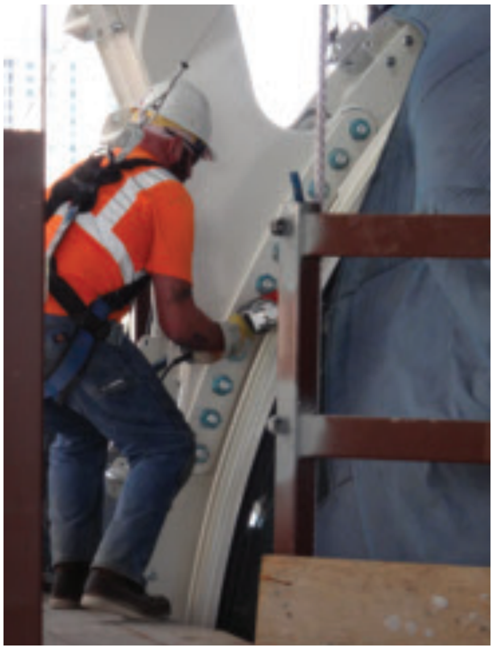
Cabin installation

The V-frames and cabins were installed in November and December 2013, attached in batches at an initial rate of one per day (Fig 50). First, the V-frames were attached to the wheel rim in a platform fixture moved into position under the rim, and then lifted using chain falls attached to the hub (the same as used to install the rim segments). Then the cabins were loaded onto the V-frames using a different set of temporary platforms rolled in to surround the cabins. This system proved much faster than originally planned, and the rates achieved for other large wheels.

Commissioning

The cabins were commissioned during January and February 2014, following operational readiness tests to verify the integrated ride control system (IRCS). This brought together inputs from all 28 cabin control systems with the main drive for the wheel into a single integrated system in the control room. During this time the licensing permit was obtained from Clark County. This required a full set of submissions to the local authority for review, including 25 000 O&M manual pages.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48. Cabin prototype testing.
49. Cabin assembly, Las Vegas.
50. V-frame installation.
51. Uninterrupted views of Las Vegas and beyond (overleaf).

“Vegas demands audacity and over-the-top. The *High Roller* is so much more elegant and beautiful than any other wheel. The creative intent was to have it appear to be lightweight, without a lot of structure...

The team is the most important thing. We needed people who were not intimidated by the large scale, not afraid of being part of something special that everyone is going to recognise.”

Greg Miller, Senior Vice President of development for Caesars Entertainment.

“It’s rare to be part of something this great.
At the same time it can be extraordinarily challenging.”

David Codiga, Executive Project Director.

“What could be more thrilling for an ‘experience designer’ than to design something that, perhaps from the moment it opens, will be an icon on the Las Vegas Strip, and a permanent fixture on one of the most famous skylines in the world? That’s a designer’s dream... One of the truly beautiful things about the *High Roller* is that spherical, pearl-shaped cabin on the outside of a tubular ring.”

Phil Hettema, THG.

“As a long-time resident of Las Vegas I could not be more proud of this project. The architecture team worked very closely with the engineers from Arup, and to see our vision come to life in such a gorgeous way is incredibly exciting. From the entry point, through to the interior design of the cabins, each and every detail has been beautifully realised.”

John Kasperowicz, THG.

“Even from afar, the *High Roller* is a delight, adding a playful ring of color to the Vegas skyline.”

Jorge Labrador, writing in the “Spotlight” section of *Las Vegas magazine*.

Conclusion

At an event hosted by Caesars Entertainment in the wheel building a couple of weeks after the opening on 31 March, 2014, an adjudicator from Guinness World Records officially announced that the *High Roller* is the world's largest observation wheel, and presented Caesars with the certificate.

Though its size is notable, the *High Roller*'s true value lies in its significance for Las Vegas and what it may represent for the future. Caesars' LINQ development has converted an under-used alley into a pleasant, pedestrian-friendly street of al fresco dining and artisan shops, with the *High Roller* towering at its end. Such a graceful attraction — clean, crisp, lit to delight, and arcing effortlessly over the city — is in marked contrast to the themed hotels and flashy cocktail bars elsewhere.

To enjoy their 30 minutes of encapsulated wonder, passengers are ushered into the discreetly air-conditioned cabins, quite comfortable despite the open doors on both sides for disembarkation and boarding.

Such a level of comfort was not easily achieved. The glazing is doubly curved, double laminated for strength, and double glazed for thermal comfort. Cool air from the HVAC equipment tucked away in the belly flows up through ducts and cascades down the inside of the glass, which would otherwise be too hot to touch. The coating on the glazing was selected for its near-perfect balance of optical qualities, sun protection, glare reduction, and minimal reflections at night.

As the cabin glides up, the ride feels smooth and stable, a testament to the damping system that reduces wind-induced vibrations, and the precisely controlled drive system. This feeling of security is no illusion; the drive system has 100% redundancy, as well as a completely independent backup system. In fact, the FMEA all but guarantees that the wheel will keep turning no matter what, but… if it cannot be rotated for some reason, Clark County Heavy Rescue will put its evacuation plan into action.

At the top, uninterrupted views stretch in every direction: the Eiffel Tower and Bellagio fountains; the glittering lights of the Strip; the vastness of the desert, and magnificent mountains east and west. A few other cabins and faint shadows of passengers behind the tinted glass can be seen, but the structure almost vanishes, thanks to Arup's unique structural system. The cabin extends far beyond the single tube rim, unobtrusive in its slenderness, and being held by just one bearing maximises the amount of viewing space and the feeling of lightness.

At the end of the journey the cabin lines up to the dauntingly narrow tunnel into the boarding platforms. The cabin in front squeezes precisely through with a hand's-width clearance on each side, yours follows, the doors open, and you disembark…

Even before it opened, Las Vegas was abuzz with chatter about the *High Roller*. Taxi drivers, concierges, bar tenders and guests could see it as a testament to a great city rising, excited for what it represents. Now, with the wheel already an iconic element on the Vegas skyline, reviews have been resoundingly positive. For locals, it signifies a revitalisation and a bright new future. For visitors, it is a fresh take on the uniquely Vegas experience.

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Project credits

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Control system design: *Heywood Engineering*
Main contractor: *American Bridge Company*
Foundations contractor: *WA Richardson Builders LLC*
Cabins design–build contractor: *Leitner-Poma of America Inc (LPOA)* Mechanisation design–build contractor: *Schwager Davis Inc* Platform contractor: *SME Steel Contractors Inc* Mechanisation contractor: *Japan Steel Works Ltd* Main bearing supplier: *SKF*
Platform architect: *Klai Juba Wald Architects Ltd*
Wheel lighting: *4Wall Entertainment* Wind tunnel testing: *Cermak Peterka Petersen (CPP)*.

Image credits

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