Auckland City Council selected the dramatic design submitted by a team of Hyder Consulting, Denton Corker Marshall and Kenneth Grubb Associates as winner of an international design competition for the Te Wero Bridge.

The paper outlines the design principles underpinning the competition entry and illustrates how the unique combination of materials, geometry and counterweights lead to an extremely efficient solution. The paper will also report on development of the scheme since selection as the competition winner.
**Introduction**

Bridge projects such as Te Wero provide opportunities to create instantly recognisable symbols of particular cities, and great bridges are elegant and distinctive enough to evoke wonder and create an attraction in their own right. A key objective for the Te Wero project is to exploit modern technologies and techniques to reflect Auckland’s passion for innovation.

This paper considers the function and visual aspects of the project, its form and image, together with consideration of materials, design and construction issues that led to the final bridge design.

**The Challenge**

The project’s aspiration was to create an iconic object, a breathtaking symbol for Auckland embodied in a unique and distinctive structure. Iconic status demands differentiation and in the case of opening bridges this can be provided by the built form, operation and scale. Our Te Wero design responded to this challenge with a solution targeted specifically at the Viaduct Basin’s unique history and environment.

**Visual Analysis of Context**

The experience of the bridge within its surroundings was considered fundamental to the success of the project. The site is in the centre of a large operating harbour. In addition to a variety of buildings and quayside machinery, the immediate surroundings are populated with operating watercraft of many types, including large yachts. The context of quayside activities, buildings and tall masts is therefore varied and visually active.

Visual Analysis of Bridge Type

The width and span of the bridge are not exceptional, and could easily be satisfied by any number of conventional forms including raised, retracting and swing bridges. However, while these options were explored, none of these provide a significant visual marker when viewed from a distance.

Bascule bridges in their default closed position also offer no presence to the approaching observer and have only a modest profile when viewed from the side. Paired bascules, splitting the span and therefore the length of their leaves in half, have a relatively low and diluted presence even in the elevated position. A half span bascule on this site would have individual leaves of only 20m long (high) but more than 13m wide. It was therefore considered that these stumpy proportions fundamentally compromised any elegant outcome; this analysis suggesting that the...
appropriate bridge type for achieving the prominence and high profile indicated in the brief would have a permanent visual presence and an optimised scale.

**Innovation and Design Quality**

Our design is based on a cable-supported structure, unique in geometry and articulation with no resemblance to other landmark bridges. A vertical tower or mast, aerodynamic in profile and subtly inclined, rises above the surrounding assembly of yachts to clearly mark the crossing point, provide an orientation reference for harbour users and act as a visual focus along the east-west axis. At 60m high, the mast is at an appropriate scale for both its broad context and the project aspirations.

While fulfilling architectural and urban design objectives, the mast also provides structural support for the opening bridge elements. Two cables stretch from high up the mast down to the bridge deck. The cable supported leaves allow for a single span rather than two half spans, thus providing maximised height and presence in the elevated position. The single span also provides for elongated and more graceful proportions for the leaves.

![Proposed bridge – dynamic sculptural composition](image)

**Split Leaves**

The elegant proportions are further enhanced by splitting the deck longitudinally into two separate components. The south leaf, longer and broader than the north, carries the two road lanes. The north leaf combines the two 3m wide pedestrian / cycle paths into a single route of at least 6m width. As well as separating the pedestrian and vehicular traffic combining the pathways creates a more generous civic scale route and transforms the crossing into an opportunity to linger and experience rather than merely pass through.

**Form**

The three primary elements – mast and angled leaves – are composed from similar wing-like profiles. The leaves are straight along the internal edge but have a gentle curve on the outer edge and on the underside. This aerodynamic silhouette suggests the modern sails of contemporary racing yachts, but interpreted in a sculptured and architectural form. In many ways the form is more sculpture than bridge. This is accentuated by the downplaying of prosaic bridge paraphernalia such as handrails. All surfaces of the bridge – deck, soffit and mast - are formed from the same material.
(aluminium) and finished with similar surface coatings in order to give the impression of pure metallic objects rising from the harbour.

Contrasting with the conventional appearance of opening bridges which are usually symmetrical and static, each of the elements is slightly different in length, width and angle, creating a dynamic, asymmetric composition.

The structural design of the opening leaves of the bridge exploits the aerofoil shape to create a torsionally stiff hollow monocoque structure that is extremely efficient. The lines of structural support are expressed by the winch cables leading up to the mast and giving a clear visual indication of the means of operation.

*Bridge Leaves in Closed Position*

*Leaves Commencing Ascent*

**Bridge Motion as Attraction**
As the bridge opens, the two leaves separate further apart coming to rest in a V configuration with the decks angled obliquely to the mast and each other. The twisting motion is facilitated by angling and tilting the trunnion axes for the leaves. This simple device means the motion of the leaves becomes an attraction in its own right, transforming the routine operation into elegant choreography. Viewed from different locations around the harbour and city, infinite combinations of juxtapositions are possible as the bridge leaves move towards the mast.

**Bridge Motion Development**
Simple physical models during the concept development highlighted the attraction of the bridge motion even at that stage, intriguing and delighting those that saw it in operation. Subsequent studies have developed the unique motion and refined the relationship of the trunnion axes.

The distinctive movement causes each bridge leaf to rotate, tilt and twist as it is raised and lowered. This is achieved through the simple method of moving the axes for both bridge leaves relative to the bridge. Each axis is skewed on plan relative to the bridge centreline and each axis is also inclined down from the horizontal. The location of the axes of rotation has been determined to get the desired open position of the bridge leaves.
Reflect European and Pacific Cultural Traditions
Another key influence on the design was a desire to reflect cultural traditions of New Zealand through suggestion and reference. The form of the mast for instance suggests similarities with either a modern high aspect ratio sail or a traditional Maori Taurapa depending on one's viewpoint, both physically and culturally. Links can also be made between the paired leaves of the elevated bridge and Maori twin hulled ships.

Lighting
In the evening, the sculptural qualities of the bridge design will be enhanced through subtle yet effective lighting. A gentle wash of light will spill along the surfaces of all of the elements, including the elevated soffits of the leaves. Necessarily brighter at the base the falloff will deliberately run into darkness before the tips, suggesting the blades continue up into the night sky. On special occasions images will be laser projected onto the mast.

Bridge Approaches Urban Design
Consistent with the design objective of maintaining the bridge as a pure sculptural form, the immediate ground plane is kept as restrained and simple as possible. This sets off the bridge form, much like a plinth serves a sculpture.

Our approach also acknowledges that the actual functions on the adjacent open spaces are yet to be confirmed. They will in any case need to be flexible, in order to accommodate car parking, temporary markets and public events. A clear, hard landscaped surface with as little superfluous treatment and maximum level open space is suggested.

In addition to the gently ramped pedestrian and vehicular approaches a series of shallow terraces and wide public steps run along desire lines between the bridge and the pedestrian route over the heritage bridge. This fully integrates the open space on the north side of Te Wero Island with the bridge. The terracing, oriented as it is to the
outer harbour entrance, provides an ideal location for crowds to view yachts entering the harbour during special events.

Operational Requirements

Our arrangement segregates the pedestrians from the highway and potential future transport modes (such as light rail or guided bus-way) thereby increasing user safety and general ambience of the area.

The structural design allows for both the segregated configuration and the shared arrangement; this gives maximum flexibility for maintenance and future operation. The bridge location and arrangement also provides the desired navigation clearances whilst preserving optimal vessel paths and berthing facilities.

The opening mechanism is effected by winch cables, using a classical drawbridge principle to give a visually simple and obvious method of activation. The opening leaves are counterbalanced by tail-weights innovatively positioned to ensure that the cables remain in tension even when the bridge is opened on a windy day. When conditions are calm, and there is little wind, this arrangement of tail-weight results in the cable tension remaining at a similar level throughout the opening cycle. Energy demand is minimised by use of a balance weight in the mast. This weight stores potential energy and reduces the necessary drive torque and power to very low levels.

A control room is located within the mast, affording the operator excellent views of the bridge and harbour. The bifurcated bridge leaves allow the operator to see that there are no boats or other obstructions to lowering the bridge.
Buildability

The Viaduct harbour is a well used busy harbour with frequent commercial, tourist and private vessel movements. The construction therefore needs to minimise any disruption to the harbour. To reflect these constraints, the caisson, mast and operating machinery will all be erected and commissioned ahead of the installation of the opening leaves. The leaves will therefore be operable very soon after installation, thus minimising any disruption to the main navigation channel. Construction of the fixed spans can be delayed until the opening leaves are operational, thus offering an alternative path for the brief period that the leaves are being installed and commissioned.

Discussions with the Auckland boat building industry have identified a strong potential for the construction of the main aluminium leaves to be undertaken locally; reducing overall cost and increasing the benefits to the local economy from the bridge project.
Materials selection
Our design includes strong and innovative use of materials which are associated with Auckland’s past and present. Extensive use of aluminium used locally for yacht building underpins this theme. The selection of materials allows a low structural weight and adds to its special qualities. The form of the structure reflects the nautical theme by emulating a series of sails, that when raised depict converging yachts heeled and at close quarters.

The four main materials used in our design are aluminium alloy for the opening bridge leaves and also for the cladding to the mast; steel shot for the counterweights; steel sections for the mast framework; and conventional concrete for the foundations, substructures and fixed bridges.

Steel, aluminium and composites were considered for the main opening bridge. Aluminium alloy has been chosen for the opening leaves of the bridge for a number of reasons. The low structural weight has significant benefits in reducing the size and weight of the associated counterweights, foundations and mechanical equipment. The ability to form an efficient monocoque from special extrusions lends itself to a cost effective fabrication with a clean uncluttered appearance. The excellent corrosion resistance of alloys in a marine environment will give a low maintenance long life structure. Many of these benefits of aluminium alloys are also available from structural composites. Aluminium does, however, have a track record for use in highway bridges over many years, whereas this would be a significant step forward in application for composites.

The material used for the counterweights is decided on the basis of cost, volume and ease of installation. Steel, lead and concrete were considered. Lead has the smallest volume but at a significant cost penalty, concrete has a larger volume than desirable for our chosen caisson and bridge geometry, and steel is therefore preferred. Steel shot or small pieces are likely to be most easily transported and installed.

The mast can be fabricated from concrete, steel or aluminium. Flexibility and ease of fixing the mechanical items, control room and stairs within the chosen geometry tend to favour steelwork.
For consistency of appearance with the leaves and also to give a durable low maintenance outer skin, aluminium alloy has been chosen for the cladding. In general the substructures have been designed using standard concrete materials, which are readily available and familiar to general and marine contractors.

**Aluminium extrusion design**

The main deck leaves are designed as aluminium monocoques formed from purpose designed extrusions. This gives an extremely efficient light-weight structure that is easily fabricated to give a robust, distortion free entity. The deck extrusions have been designed along the lines of similar extrusions developed by different extruders in the USA and a number of European countries.

Extensive fatigue testing and many years of successful service on highway bridges confirm their suitability. Through the development of the design we have been in extensive discussion with several extruders to confirm the suitability of our proposed details, developed to accommodate the varying width of bridge deck by having corner extrusions that can be cut to suit and shaped before welding to established deck panel configurations. The quantities of aluminium involved mean that it is economic to commission dies for new extrusions rather than adopt methods involving more fabrication and standard sections or plates.

The extrusions will all incorporate suitable weld preparation faces such that the amount of work on the base material prior to fabrication is minimal. Welding can be carried out using conventional gas shielded process or friction stir welding. The
choice of process will influence the edge details adopted. It is therefore appropriate to involve the fabricator at an early date so that details can be developed to give greatest efficiencies.

Principle of Operation
Each bridge leaf is lifted by the action of a wire rope connected to the leaf, and then passing over a pulley in the mast and to a winch located in the plant room below the base of the mast. The opening leaves are counterbalanced by tail-weights positioned at an angle to the leaf, arranged to ensure that the lifting cables remain in tension even when the bridge is opened on a windy day.

Energy demand is minimised by use of a balance weight in the mast. This weight stores potential energy and reduces the necessary drive torque and power to very low levels.

Each leaf is operated by a separate winch and can be raised independently of the other. Each winch is hydraulically driven via two hydraulic motors. This provides a level of redundancy with the ability to operate the leaf via either motor. The system is rated to operate the bridge with wind gusting to forty knots from any direction.

Bridge Tail Counterweight
Each opening leaf is counterbalanced by a tail-weight positioned at an angle to the leaf. This arrangement results in the tail-weight passing its’ low point before the leaf has reached its’ upper position, thereby counteracting the reduction in torque from the
leaf as it nears vertical. This will ensure that the lifting cables remain in tension for all wind directions, even when the bridge is opened on a windy day.

**Lifting Cable and Tower Pulley**

Each bridge leaf is lifted by the action of a single wire rope connected to the inside edge of the leaf, and then passing over a pulley on the mast and down to a winch located in the caisson plant room below the base of the tower. The cable alignment varies in 3-D as the bridge leaf moves sideways considerably as it is raised. In order to accommodate this movement, the pulley in the tower will be free to swivel about a vertical axis, in this way the pulley will always be aligned with the cable.

The 3-D lifting rope geometry results in variations between direction of the rope pull and the direction of movement of the bridge deck. This, in combination with the tail-weight geometry, delivers a benefit in that the resulting tension is more consistent across the cycle.

**Tower Balance Weight**

Energy demand is minimised by use of balance weights travelling up and down within the mast.

These weights store potential energy, falling when the bridge leaves are being raised, and rising when the bridge leaves are being lowered. In the concept design, this weight has been sized so that the net energy requirement for raising or lowering the bridge is zero.

This arrangement reduces the necessary winch drive torque and power to very low levels. The weights travel up and down within rectangular shafts within the mast and will be fitted with proprietary failsafe mechanisms.

**Emergency Operation**

The arrangement of tail-weight and bridge leaf is designed to ensure that each leaf remains nose heavy in all normal operating conditions. The balance weight, however, reduces the torque on the winch drums to very low levels, and it will therefore be possible to lower or raise the bridge at slow speeds using a small hydraulic power pack or even with a hand pump.