Buitengragt Structural Steel Pedestrian Bridge

BUITENGRAGT STRUCTURAL STEEL PEDESTRIAN BRIDGE

JOINT WINNER – Technical Excellence category
Submitted by the SAICE Western Cape Branch

KEY PLAYERS

Client City of Cape Town
Professional Team Arcus Gibb Engineers; Vela VKE Consulting Engineers; GAPP Architects; COA Architects; Jan Ford Landscape Architects
Main Contractor Vusela Construction
Major Subcontractor ADM Engineering

INTRODUCTION

The unique Buitengragt pedestrian bridge was sculpted from its circumstances. Out of the technical challenges of the site, the project team created a unique, but simple and aesthetically pleasing structure that blends beautifully into the busy backdrop of the Cape Town city centre.

The bridge was necessitated by the 2010 FIFA World Cup to accommodate the expected increase in pedestrians who would have to cross the five lanes of the continuously busy Buitengragt roadway. Today the bridge is a positive legacy of greatly improved pedestrian linkages in the city.

The position of the structure presented a number of challenges to the design team. Partly founded on top of a buried parking garage and partly on land reclaimed from the sea, the foundation design required some innovative ideas. The fact that the bridge had to fit into a narrow corridor between two of the city's main hotels also influenced the design outcomes. The need to limit the noise impact was a further constraint.

A structural steel asymmetric box girder was not an obvious choice of structural form. It did, however, offer a number of specific benefits. Firstly the use of structural steel significantly reduced the dead weight of the bridge, which had to be 4 m wide. This was important,

1 Buitengragt pedestrian bridge in Cape Town – side view of upstand beam
2 Main span being lifted into position
3 Built-in piers and lift shaft

considering the founding conditions. The use of an up-stand beam was necessary to keep the level of the walking surface as low as possible. In so doing the length of the bridge was limited to fit the available space. Because it would be necessary for pedestrians to access the structure along its length, a closed box section with an up-stand beam on one side was developed. The lift shafts (for disabled access) and additional access staircases were then able to connect directly onto the open side of the bridge deck.

In its final form the steel structure is 101 m long with six spans – 17,7 m; 17,7 m; 27 m; 14 m; 14 m; and 11 m. The lengths of the first two spans were set by the spacing of columns in the underground parking garage.

DESIGN DEVELOPMENT

Foundations

Resting on the roof of a buried parking garage, the foundations for the first two spans of the bridge are unique. The structural steel piers are connected to large hollow concrete boxes that displace the existing fill material. In the end, no additional loading was applied to the existing roof structure. The boxes were also packed tightly with polystyrene blocks to ensure that they never fill with water.

Deck section

The preliminary deck design took its direction from a sensitivity analysis of the serviceability performance of the structure. The design also varied the plate thicknesses of the deck sections along its length to reduce costs. Using a concrete slab between the deck cantilevers in lieu of steel plate also resulted in significant savings.

Bridge articulation and pier dimensions

In deciding upon the fixity of the bridge, different ways of providing the necessary transverse rotational restraint to the box girder were reviewed. In the end, a built-in pier was preferred because of the simplicity of the connection detail. This, however, introduced technical challenges, as the pier was also subject to forced longitudinal displacements due to thermal expansion and contraction of the continuous deck section. The simplest means of reducing the bending stresses was to limit the width of the pier section to 200 mm. In fact, the stress range in the pier is purely a function of the modulus of elasticity of the material and the width of the pier. In the case of forced displacements, an increase in pier stiffness does not reduce the induced stresses, as it attracts additional load effects.

Longitudinally the bridge is fixed at its northern lift shaft. Behind its architectural cladding the lift structure is braced internally to subtly provide a rigid point that anchors the bridge. From this stable point the continuous deck section expands and contracts in response to temperature ranges.

Transversely, the piers are set out at an angle to the vertical. This generates relieving moments in the section that allows

it to taper geometrically towards its base. The end result is unique and aesthetically pleasing, and in harmony with the asymmetric deck section.

DETAILED DESIGN

Piers

The piers for the bridge are fabricated steel sections with internal stiffeners to prevent localised plate buckling under the applied compressive stresses. Five of the six piers were fabricated using Grade S355JR steel. However, the first pier was constructed using a high-strength steel, Domex 550. The use of high-strength steel is appropriate when a higher tensile strength is required. In short columns it will also increase the axial capacity of the section. In the case of intermediate and long columns the benefit of high-tensile steel is lost as the section becomes susceptible to buckling.

Deck section

In a steel box girder bridge the effects of shear lag and buckling of unsupported plate sections in compression must be accounted for. For the hogging and sagging regions of the bridge the effective deck sections were developed taking account of the reduced effective area of any compression flanges. These sections were then used to check the serviceability stresses in the plates.

The compressive buckling resistance of the web plates was another important design consideration. Using a plate model, the stresses in the webs were calculated and verified using hand calculations. In this instance the 10 mm transverse diaphragms, provided at approximately 2 m centres, help restrain the web panels against local buckling. These diaphragms also prevent the distortion of the box girder under the applied torsional stresses.

DYNAMICS

Dynamic load cases were analysed because the bridge would be a heavily trafficked structure, and first vertical mode of vibration is in a frequency range susceptible to excitation from pedestrian loading (see Table 1). The calculated vertical and lateral accelerations were well within acceptable comfort levels.

FABRICATION AND CONSTRUCTION

The bridge deck section consists of over 3 500 individual plates. The dimensions of these plates were calculated numerically and then checked graphically using a 3-D CAD model. This approach gave the design team certainty about the geometric detailing of the bridge, which was essential when it came to checking the contractor's fabrication drawings.

Plate distortion on the box section during the welding process was a major fabrication issue, especially on the thicker plates, and required internal bracing to maintain the section geometry for accurate matching of the segments. The fabricator had to develop welding procedures and sequences that minimised heat build-up and distortion. Over the twelve months of construction, the fabrication process had to be continually managed and monitored.

MANAGERIAL ASPECTS

The conceptual design of the bridge was subjected to a rigorous reviewing process. Monthly technical meetings, attended by all the relevant stakeholders, were scheduled with the client to present the design development. The final design of the bridge was therefore a product of close consultation with architects, town planners, heritage consultants, landscapers and security services.

Table 1 Natural frequency of structure from analysis model

Mode	Frequency (Hz)	Mode Shape
1	2,36	Lateral and vertical
2	3,20	Lateral and vertical
3	3,42	Longitudinal and vertical
4	3,71	Vertical
5	4,40	Vertical

4 Protruding fins wrap around upstand beam
5 Northern access at median

The bridge is unconventional in that it incorporates items such as lift shafts, architectural lighting, glazing and CCTV. The successful integration of these items into the design and during construction required careful coordination on a technical and architectural level. A review and approval process was therefore put in place so that each member of the professional team could be informed about the design development of the various components on the bridge.

Building a bridge next to the city's two busiest hotels also meant that all construction activities had to be continually monitored to reduce dust and noise pollution.

A key factor in managing a highly technical project is the quality of the construction monitoring services. A specialist resident engineer (RE) managed one assistant RE at the site and one at the fabrication yard. Specialist welding inspectors were also employed. Rigorous quality management procedures were put in place to ensure that no steps were missed. A proactive approach was fundamental to ensure that the contractor catered for the risks adequately and had contingency plans in place.

CONCLUSIONS

The bridge was constructed on budget and completed in time for the start of the 2010 FIFA World Cup. An important factor in meeting the deadline was the involvement of members of the Southern African Institute of Steel Construction, who were invited by the professional team to provide the contractor with independent expertise in programming and resourcing.

The Buitengragt pedestrian bridge is an attractive new Cape Town icon, and has already become part of many pedestrians' daily route. □

What the judges had to say

One should not be fooled by the simplicity of this bridge. Technically speaking this is excellence in engineering design of the highest order. It is a unique structural steel bridge of which the form was dictated by various constraints, such as an existing underground garage on the south side which determined where columns could go, a five-lane road to cross which determined where other columns could go, the founding material that was all reclaimed sea front so a light steel bridge was the way to go, the infamous incomplete freeway coming from Sea Point which may one day be completed and would then require clearance from the new bridge, its partially restricted location between two busy hotels, and the requirement of access for disabled persons. The net result: a shallow bridge where the available height controls the spans related to the overall length of the bridge, and with lifts for disabled persons. The challenges relating to the on-site welding were exceptionally well handled. The bridge is described by the designers as being the most successful bridge they have built if pedestrian usage is the basis of assessment.

Source: http://www.saice.org.za/downloads/monthly_publications/2011/2011-Civil-Engineering-december/#/0