A New Twist

N.W. Dekker

Have you ever seen a bridge that looks like a Slinky™? Since its completion, the Moretele Gardens Bridge in Pretoria, South Africa, has become a landmark as a result of its pleasing and unusual spiral shape.

The pedestrian bridge connects two residential areas over a busy highway, and provides access to schools and other social and educational facilities. The local community required a bridge with a protective canopy, so designers considered creative solutions. They analyzed ways of using a circular canopy as a structural shape that also would support the bridge's walkway and the pedestrians. The challenge was to convert the circular shape into a discrete structural system–and the only way to create the spiral was using structural steel.

DESIGN

If a spiral is subjected to shear forces and bending moments, two principal modes of deformation become readily apparent: an accordion effect and a racking effect. Basic structural mechanics would dictate that flexural resistance could only be generated by material placed sufficiently far apart from the axis of bending. Four stringers placed at the upper and lower extremes of the spiral instinctively satisfy this requirement.

Diagonals commonly are required to transfer shear over the length of the truss. In this case the segments of the spiral perform this function, transmitting shear forces, axial forces and bending moments. The four stringers placed in pairs at the top and the bottom effectively inhibit both principal deformation effects. A variable pitch, where the pitch is reduced progressively near the supports, would provide a more optimized structural solution, but would have complicated the fabrication process. A compromise solution using a constant pitch/diameter ratio of 0.5 provided a sufficiently efficient system.

The unusual geometric shape of the helix symbolizes linear movement along the axis. The right-handed rule in vector algebra illustrates this relationship between circular and linear geometry. On this structure, the linear movement is that of pedestrians through the bridge.

TESTING AND MODELING

In this type of structure, the actual load-deformation characteristics of the welded joints connecting the spiral segments to the four stringers can

Curved, round HSS segments were welded to the stringers in the shop to form half-shells (the sides of the bridge). To create a complete spiral, more curved, round HSS segments were welded between the left and right half-shells.

affect the overall stiffness of the frame. In order to model the structure accurately for the purpose of analysis, a full-size joint was tested in the structural laboratories of the University of Pretoria.

These tests indicated that, although the joint showed an initially soft response, the load-deformation relationship at working loads approached that of a fully rigid joint. The initial soft response of the joint required an increase in the pre-camber of the two main spans and the analytical model was softened slightly to simulate the actual joint behavior.

The structure was modeled and analyzed using a three-dimensional space-frame analysis program with non-linear and buckling-analysis capabilities. In order to account for the initial soft response of the welded, unstiffened joints, the flexural stiffness of the members was reduced slightly.

A buckling analysis of the main span indicated failure of the top chords by lateral buckling. While elastic buckling analyses do not reflect the actual buckling resistance of a structure, high values of the buckling load factor indicate that the actual strength of the structure is limited by the strength of the material. The members therefore were sized on the basis of a Von Mises interaction equation.

A dynamic modal analysis showed that the lowest mode of vibration corresponds to a natural frequency of 3.6 Hz. However, the permissible accelerations according to BS 5400 part 3 Appendix C were not exceeded.

In practice, the bridge has a comfortable feel in terms of dynamic response. Small oscillations can be induced but the damping is better than expected from what essentially is a light steel bridge.

Given the high shear forces and bending moments induced in the stringers over the first 4 m (13′) from the support, the first 6 m (20′) of the stringers consisted of 219 mm by 10 mm circular HSS (8.6″ dia. by 0.4″ thick). The remaining members all consisted of 219 mm by 6 mm circular HSS (8.6″ dia. by 0.25″ thick). Hot-rolled wide-flange beams were used to support the 140 mm-thick (5.5″) concrete walkway.

The final mass of steelwork over the full 76 m (250′) length amounted to 38 T (42 tons). The cost premium paid for this unusual system was less than 15% of the originally proposed superstructure alone. Significantly greater premiums often are paid for cosmetic steel work used as decorations to more mundane structural systems.

FABRICATION AND CONSTRUCTION

The superstructure was fabricated off site. The helical main span and end spans were assembled in the steel fabricator's workshops and transported to site after painting. The reinforced-concrete walkways through the helix and the pre-cast concrete balustrades were constructed after the spans were placed in position on the substructure.

The actual fabrication process was well planned and therefore turned out to be relatively simple. Four spiral segments were cut from round HSS sections rolled to a full revolution of 4 m (13′) diameter. Half-shells were fabricated by welding the side segments of the spiral elements to two of the stringers.

The top and bottom portions of the spiral were inserted to complete the shape. Comprehensive non-destructive testing was then carried out on all the welded joints. The main spans were erected quickly and easily on a Sunday morning, with a minimum of disruption to traffic and to the delight of a large number of spectators. The ease of erection provided testimony to the outstanding tolerances achieved in the fabrication.

The clean appearance of the bridge was maintained in the choice of the shape of the sub-structure and the manner in which the bearings were integrated into the design. Since completion, the following awards have recognized the unique nature of this structure:

- Regional award of the South African Institution of Civil Engineers
- Commendation in the aesthetics category of the Fulton awards.
- "Innovative Design" and "Tubular Structures" categories winner of the 2003 South African Institute of Steel Construction Steel Awards.
- Tubular structures award by the Association of Steel Pipes and Tubes.

N.W. Dekker, Pr. Eng., Ph.D., is a professor in the Department of Civil Engineering, University of Pretoria, South Africa.

CLIENT

Tshwane Metropolitan Council,
Metsweding Metropolitan Council,
South African National Roads Agency

STRUCTURAL ENGINEERS

Dekker & Gelderblom, Pretoria, South Africa and RTBA Design Services, Pretoria, South Africa

CONSULTING ENGINEERS AND PROJECT MANAGERS

LTE Consulting, Midrand, South Africa
Boksan Projects, Olifantsfontein, South Africa

MAIN CONTRACTOR

Stefanutti & Bressan, Isando, South Africa

ENGINEERING SOFTWARE

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