Poole Harbour Bridge: Innovation in Cable Stayed Bridge Design

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Summary

1. This competition winning design for a multi-span cable stayed bridge was described by the judges as "world class" and has attracted considerable international interest. The bridge contains a number of innovative features, most notably the longitudinal stays connecting the tops of the pylons together and back to the abutments, and these are described in this paper. Environmental factors were paramount, and the design is a sensitive and elegant response to these factors.

Introduction

2. In 1995, the United Kingdom Highways Agency launched an international open design competition for the Poole Harbour Crossing. The need for a crossing had been established many years previously, and the competition was welcomed as part of the Agency's commitment to procuring better quality design in their new bridges and structures. The competition attracted 99 entries, and was won by an international team led by Flint & Neill Partnership which included the Danish architects Dissing+Weitling, engineers Rambøll and Terence O'Rourke who are landscape architects, ecologists and planners based in Bournemouth near to the site.

The Site

3. The shallow waters and extensive mudflats of Poole Harbour are of exceptional nature conservation value, and the scenery and local attractions draw many thousands of tourists each year. This is a highly sensitive Site of Special Scientific Interest with bird and marine life habitats of international significance, and there are many environmental constraints which affect this scheme. However, at the bridge site itself, where it crosses Holes Bay, these factors are less significant than elsewhere in Poole Harbour, and the Environmental Impact Assessments undertaken to date have shown a very positive outcome for the bridge proposal.

4. This low lying estuary, with wide open horizons, requires the bridge to be as transparent as possible to prevent excessive blockage of views. Equally, its alignment with the approach roads enables it to be seen from a distance by approaching motorists, so the visual quality and impact is

of primary importance. These factors led to the desire for maximum slenderness and delicacy in the finished design, and influenced many of the engineering solutions adopted.

5. Water depth is shallow, with peripheral mud flats at low tide and reed beds extending about 180m from the south west shore. This prevents the use of large floating lifting gear, which strongly influences the choice of construction method and thus the design itself. Furthermore, the sediments are known to be contaminated due to earlier industrial activity, so construction methods must be devised to avoid the release of contaminated mud into the water.

6. Careful treatment of the abutments and approaches is necessary, and shoreline footpaths at both ends provide opportunities for landscape and amenity enhancement. At the north east abutment, the plan geometry of the widening roadway and the required roadway level leads to the need for an additional structure, the Triangular Bridge, in place of an embankment at the shoreline, so as to enhance transparency and prevent blockage of the open views across the bay.

Overall Design Concept

7. The bridge is 700m long overall, but the brief called for a clearance of 19m over a navigation channel only 20m wide. Multiple short span solutions were rejected as too intrusive and disruptive, and a long span would have required heavy and dominant pylon or arch structures which are inappropriate in this setting. The most economic span length, which also met the environmental and aesthetic constraints, was found to lie in the 100 - 150m range. Several options were considered with spans in this range, and the final design adopts multiple 142m cable-stayed spans, with A-shaped pylons up to 50m high. (Figure 1)

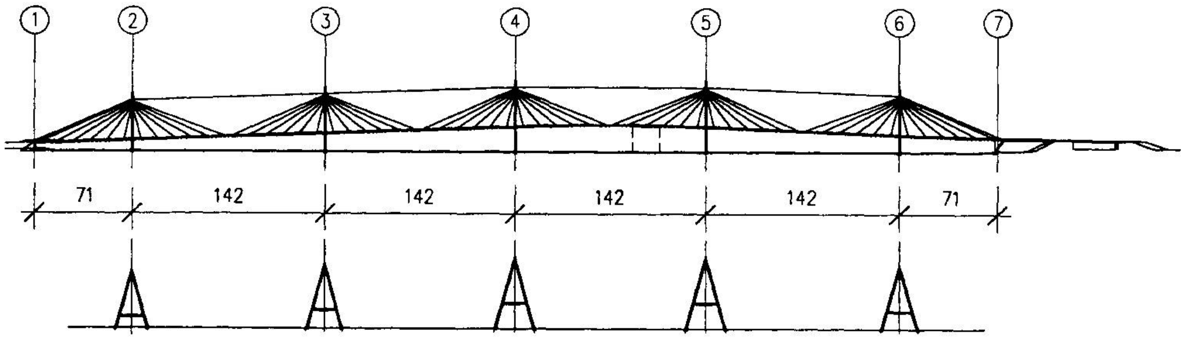

Fig. 1: General Arrangement - Elevation

8. The bridge evokes the imagery of the masts of boats scattered around the bay, with a strong rhythm creating a harmony with the environment, and the cathedral-like driver's eye view along the bridge deck adds excitement to the experience of the crossing, framing the landscape in a memorable way. This is a design with a strong and attractive visual statement, a clear identity and characteristic image, as can clearly be seen in the colour photomontage views.

The Novel Stay System

9. The slenderness of the pylons and deck was maximised in order to achieve the desired transparency and delicacy, and it was this that led to the evolution of the novel stay system.

In multi-span cable stayed bridges, the peak effects arise from patch loading in any one span. The deflection of that span pulls the pylon tops inwards and the adjacent spans lift up because they are not tied down to the ground, unlike a conventional cable-stayed bridge. There is a concentration of curvature in the middle of the adjacent spans and this gives rise to high deck bending moments. (Figure 2) The problem also arises in cross-wind aerodynamic behaviour where vibration modes involve alternate spans moving up and down, concentrating effects again at the midspan positions.

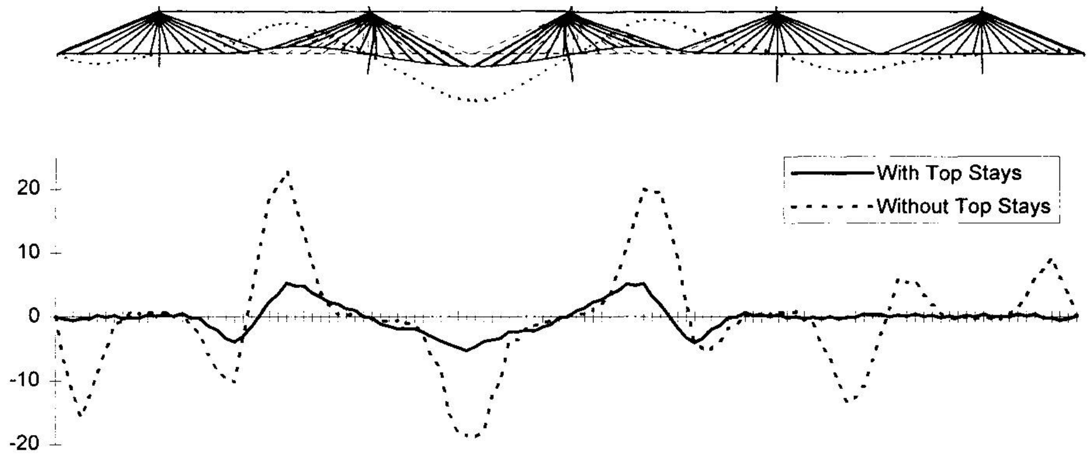

Fig 2: Displacements and Bending Moments (MNm) for live load in Span 3-4.

10. There are various ways of controlling this problem, as proposed by Tang [1], one of which is to tie the tops of the pylons together as adopted here. Other possibilities include crossing over the stays at midspan or tying the tops of each pylon to the base of the adjacent pylons. On the Ting Kau Bridge in Hong Kong, a 4-span cable stayed bridge, the top of the central pylon is tied to the deck at the adjacent tower positions, as described by Bergermann & Schlaich [2]. Both at Ting Kau and in the solutions suggested by Tang, the longitudinal forces arising from these extra stabilising stays are transmitted into the deck as axial compression. At Poole, however, the top stays are anchored back to the abutments, providing in effect a direct tie to stabilise each pylon head, thus adding considerable stiffness to the system and avoiding the extra deck compression.

11. The simple longitudinal tie between the pylon tops is also the best solution from a detailing point of view, since the other options all involve crossing over the stays making the deck edge details clumsy and more complicated. The pylons are not designed with fixed bases, but as a result of anchoring the top stays to the abutments and not the deck, they can all be erected early to permit deck erection to commence at all 5 pylons concurrently.

Articulation

12. The deck is fixed longitudinally to the central pylon only, being free to expand towards each end. Normally this would concentrate all longitudinal forces at this point, but in this case the stay system distributes a significant proportion directly to the abutments. There are no vertical bearings at the pylons, the deck being suspended throughout on the stays to prevent the peak bending effects that otherwise occur at bearing positions. Lateral restraint is provided to the deck at each abutment and each pylon.

Deck Design

13. The high strength Grade 40 reinforced concrete deck comprises two edge beams, carried by the stays at 12.6m centres, with transverse ribs at 3.15m centres supporting a 220mm deck slab. The sloping sides are kept as shallow as possible to enhance the slender appearance, and the edge detail is maintained throughout the length of the bridge without deviation at the pylons. This gives a clean, unified appearance, and facilitates construction. Stay anchorages are contained in pockets within the depth of the edge girder to avoid unsightly protrusions on the soffit. (Figure 3)

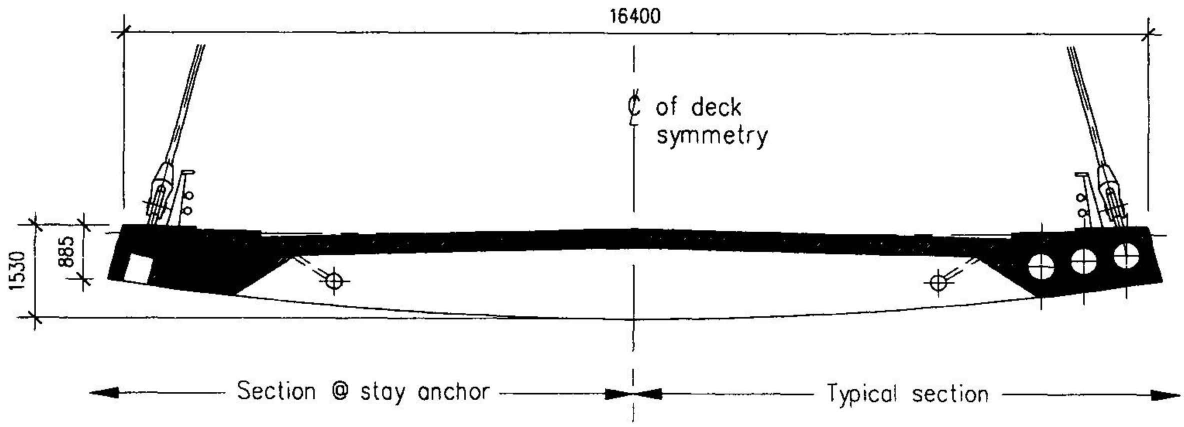

Fig. 3: Typical Deck Cross Section.

Pylon and Stay Design

14. The pylons are simple A-frames with 1.2m diameter high yield steel tubular legs whose wall thickness varies from 35mm to 50mm. A slender tie between the legs is concealed within the depth of the deck girder and supports the lateral bearings. The relative proportions of the A-frames vs. the span evolved through careful consideration of the required roadway width and the pylon heights necessary for an efficient stay system.

15. The stays are galvanised steel wire spiral strands between 85mm and 120mm in diameter, socketed at both ends, and anchored to a lug on the pylon and a cast steel threaded anchor at deck level. Pre-fabricated stays achieve greater slenderness than site-assembled strand bundles, as a result of both their smaller diameter and their less bulky anchorages, and if properly detailed and constructed they also provide the greatest confidence in long term performance. The twin top longitudinal stays have screwed tensioning devices incorporated into the socket anchorage at the pylon head. Individual strand replacement is possible throughout, including the top stays, and the whole system is designed to facilitate future maintenance and achieve a long service life.

Foundations

16. All foundations use open tube steel piles driven into the marine deposits, and the ten individual pylon leg foundations each have three 1.5m diameter raking piles, varying in length from about 20 to 25m. The concrete pile caps use pre-cast ring segments as permanent cofferdams within which the piles are driven and the in-situ connection is constructed. This system ensures that any release of disturbed mud from each work site into the bay is minimised.

Dynamic Behaviour

17. Although the deck is relatively heavy (25 tons/m), it is also relatively stiff due to the stay system and the modest span length, and the A-frame cross section arrangement ensures a high torsional stiffness. As a result, the first vertical bending and torsional modes are well separated, with predicted natural frequencies of 0.3 Hz and 0.7 Hz respectively. Wind tunnel tests have not yet been performed, but significant aerodynamic instability is not anticipated. The twin top stays have a relatively high dead load tension in order to achieve the desired stiffness, and studies have indicated that wind-induced vibration of these is unlikely as a result. They are separated by about 20 diameters so interference and wake buffeting effects are minimal.

Abutments

18. At the north east end, the link to the abutment is provided by the reinforced concrete Triangular Bridge, which has a ribbed soffit to mirror that of the main bridge and is integral with the abutment walls so as to avoid bearings and minimise maintenance requirements. An inverted tripod pier supports the ends of the Triangular Bridge and the main bridge each side of the expansion joint. At the south west end, the bridge terminates in a simple concrete abutment which retains the end of the approach embankment.

19. At the expansion joints, a novel flexible leaf plate design is proposed in place of traditional rockers. These long flat plates bend to accommodate thermal movements while still carrying the imposed vertical loads, thus avoiding rotating pins and minimising maintenance.

Construction

20. Because of insufficient water depth for floating cranes, it envisaged that a temporary jetty will be constructed alongside the bridge extending out from each bank, with a gap of 100m at the navigation channel. The pylons will be assembled on vacant land immediately adjacent to the site and floated or carried into position for lifting by mobile cranes on the jetty. Once all are erected, initially using temporary stays and then finally secured with the top longitudinal stays, deck erection can proceed by conventional balanced cantilever construction. After evaluating the options for pre-casting, it was decided that constructing the deck in-situ in 12.6m bays on travelling formwork was the most economic and avoided the problems associated with joints in pre-cast construction. Temporary stays from the pylons are used to support the end of the travelling form, and the balanced cantilevers are stabilised using temporary props off the jetty. On completion, the jetty will be removed and its temporary piles withdrawn.

Maintenance

21. The design was developed from the outset with minimum maintenance requirements in mind. It is partly for this reason, for example, that a concrete deck was adopted throughout in order to avoid the need for regular painting and the long term problems associated with welded steelwork in fatigue-prone areas. The number of bearings and expansion joints, which are usually high maintenance items, have been minimised, and the north east approach bridges have integral abutments. Innovative maintenance free flexible leaf bearings are used at the expansion joints, so the only moving parts are the sliding PTFE lateral buffers.

22. The steel pylons will require periodic painting, but the use of clean tubular sections with smooth paint surfaces is intentionally maintenance friendly. There are no stiffeners, bolted joints or external corners where dirt and water can collect, and this extends the life of the paint treatment and facilitates effective re-painting considerably.

23. High level access up to about 30m above deck level can be by mobile hydraulic lift, which could be used during off peak periods, without the need for a bridge closure. Excessive pylon heights have been avoided in order to facilitate such maintenance.

Conclusion and System Developments

24. The Poole Harbour Bridge design has developed with a strong emphasis on visual quality, and a desire for slenderness arising from the site characteristics has led to an innovative cable stay system which will be the first of its kind in the world. The modest span length is ideal for such an innovation, but there is no fundamental reason why these ideas cannot be further developed and extended to much longer spans for potential application to very long crossings. The span limit for this particular system arises when the axial stiffness of the top stays becomes too low to provide sufficient restraint to the pylon heads. Aerodynamic effects also become more significant with greater span and would need to be carefully evaluated. The possibility of adopting unequal spans in order to spoil coherent vibration of all spans over the entire length should be examined.

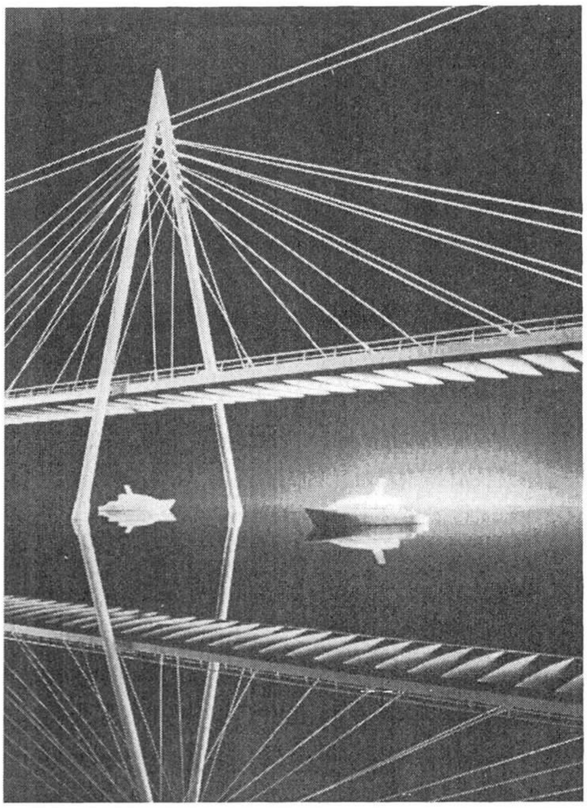

Fig.4: View of 1:100 Physical Model

Acknowledgements

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References

1 Man-Chung **Tang**: Multispan Cable Stayed Bridges. *Bridges into the 21st Century, Hong Kong, October 1995, and also the 15th IABSE Congress, Copenhagen, June 1996.*

2 R. **Bergermann** & M. **Schlaich**: Variety in Cable Stayed Bridge Design (the conceptual design of the Ting Kau bridge). *IASS Symposium on the Conceptual Design of Structures, Stuttgart, October 1996.*