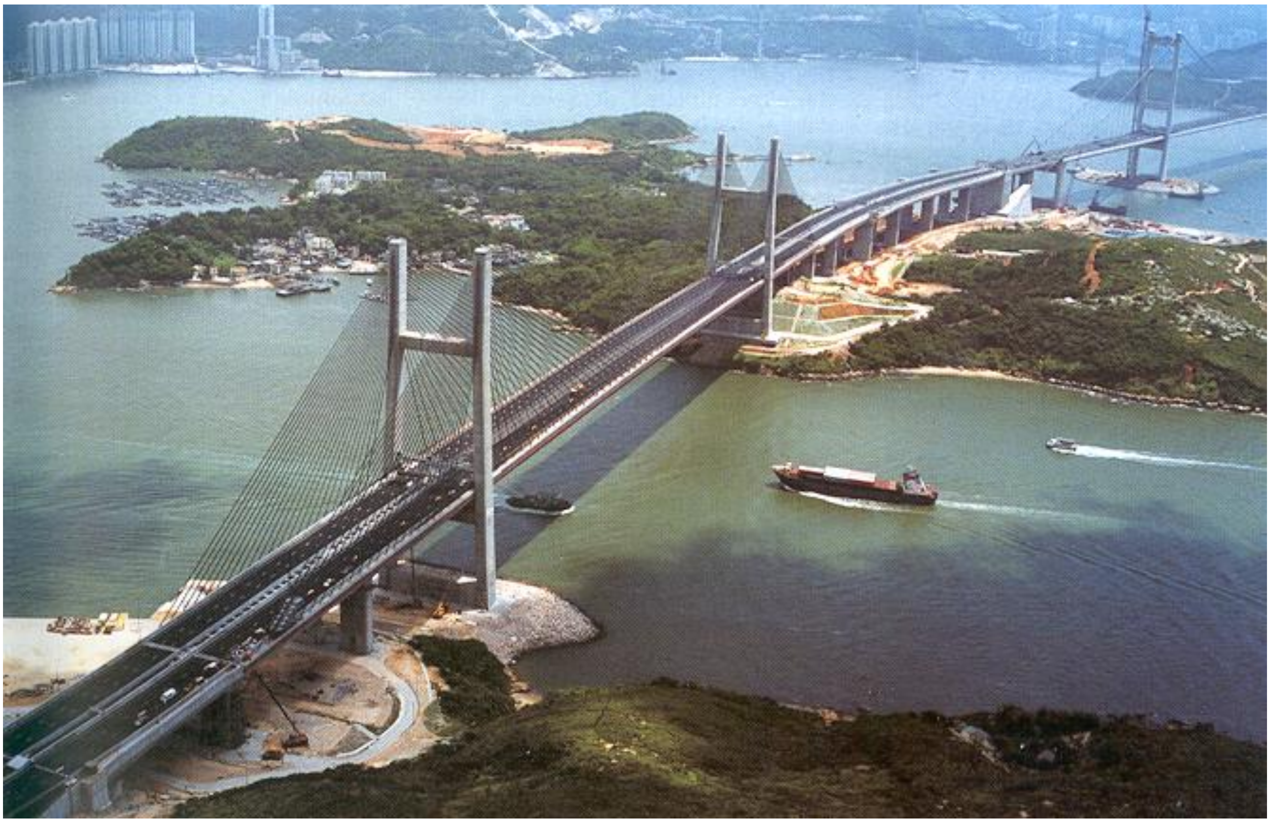


Kap Shui Mun bridge (foreground) and Ma Wan viaduct was probably more technically and contractually challenging than the Tsing Ma (extreme right), and further complicated by a change of designer part way through construction

An extraordinary chapter

Involving a change of designer part-way through, and the amalgamation of bridging and tunnelling techniques, Hong Kong's Kap Shui Mun and Ma Wan project provides lessons for all

by Robin Sham, technical director, Maunsell

THE KAP SHUI MUN BRIDGE and Ma Wan viaducts are among the most spectacular achievements in the Lantau Link, and are pivotal connections between the new airport at Chek Lap Kok and Kowloon and Hong Kong Island.

The design and construction of the bridges has proved to be an extraordinary chapter in the history of bridge engineering. The design harnesses technologies from different disciplines, including long span bridges, tunnelling, and railway works, to create a two-level, combined rail-road bridge with enclosed lower carriageways. What is also remarkable about the project is that it witnessed a change of designers while construction was advancing at an inexorable pace.

In order to fully understand the almost impossible tasks involved, one has to appreciate the intricate history of the project.

In November 1992, the Kumagai-Maeda-Yokogawa-Hitachi Joint Venture (JV) was awarded a contract to design and construct the Kap Shui Mun bridge and Ma Wan viaducts. Site possession was gained in August 1993.

Just over two years later, in late September 1995, the JV consulted Maunsell Consultants Asia Limited in Hong Kong on the possible appointment of a replacement designer to take over the detailed design, and the design responsibility, for the project. Staff in London were alerted to the events in the east and within 48 hours a specialist bridge engineer was arriving in Hong Kong: the same engineer had previously been closely involved in a tender design for the crossing which came second in the 1992 competition.

The subsequent events were of frantic mobilisation and negotiation on several continents, as Maunsell assembled a new design team. Intense cooperation with the JV, and the Hong Kong Highways Department's confidence and determination to proceed, helped iron out many of the inevitable problems.

A strong design team was established on the Lantau site, with full capacity for drawing production, to integrate design with construction. As a result, design development and the resolution of problems encountered during construction were expedited, which was vital given the very high speed of construction. Concurrently, specialist design teams were set up in the UK and sub-consultants were appointed worldwide. The global operation was driven from Lantau, with each team performing complementary roles. Maunsell was formally appointed designer on 15 October 1995.

Key dates

The project had to meet six critical key dates (kd):

kd1 Lantau approaches - release of works area to an adjacent contractor
kd2 Lantau substation for China Light and Power
kd3 Release of the railway envelope to the airport railway operator
kd4 Access to Lantau substation and the utilities envelope to other contractors
kd5 Access across the bridge and viaduct to authorised contractors
kd6 Substantial completion

Of all key dates, failure to meet key dates 3 and 4 would incur very substantial liquidated damages, of around US$170,000 per day. Key date 3 effectively called for completion of the works sufficient to permit the passage of trains. Most of the bridge furniture had to be fitted by key dates 3 and 4. All efforts were therefore directed at meeting key date 3: this became as much a challenge as a threat.

The experience acquired in the project should be documented for the benefit of future projects and as testimony to the achievements of all concerned.

Cable-stayed bridge

The Kap Shui Mun bridge is a cable-stayed structure with a span configuration of 80m, 80m, 430m, 80m and 80m (a total of 750m). 387m of the main span is of steel-concrete composite construction, and the remaining 363m is of prestressed concrete box girder construction. The two-level structure carries the expressway at the top deck and the airport railway in the central region of the lower deck. Emergency carriageways for use under typhoon conditions are provided on either side of the lower deck. The bridge is in a dramatic setting, crossing the turbulent waters of the Kap Shui Mun channel.

The H-shaped towers were designed for structural simplicity and aerodynamic efficiency, and constructed with a self-climbing formork system.

The side spans consist of twin concrete box girders which are linked transversely at the level of the bottom flanges by a beam and slab construction that forms the trackbed to the airport railway. They were designed for incremental launching using a nose formed by three special segments in steel-concrete composite construction. On the Lantau Island, launching was achieved by pulling the girders with strand jacks over the permanent supports and five temporary piers. On Ma Wan, a hydraulic lift-and-push system was utilised to launch the girders over the permanent supports and three temporary piers.

The 387m central part of the main span is of relatively porous construction which has much significance in terms of ventilation. The stay cables were installed and stressed to loads which were adjusted as close to the time of stressing as practicable to allow for environmental and loading conditions which prevailed. Segment erection was achieved in a 2-week cycle for each cantilever, and it alternated between the two cantilevers in consecutive weeks.

Ma Wan viaducts

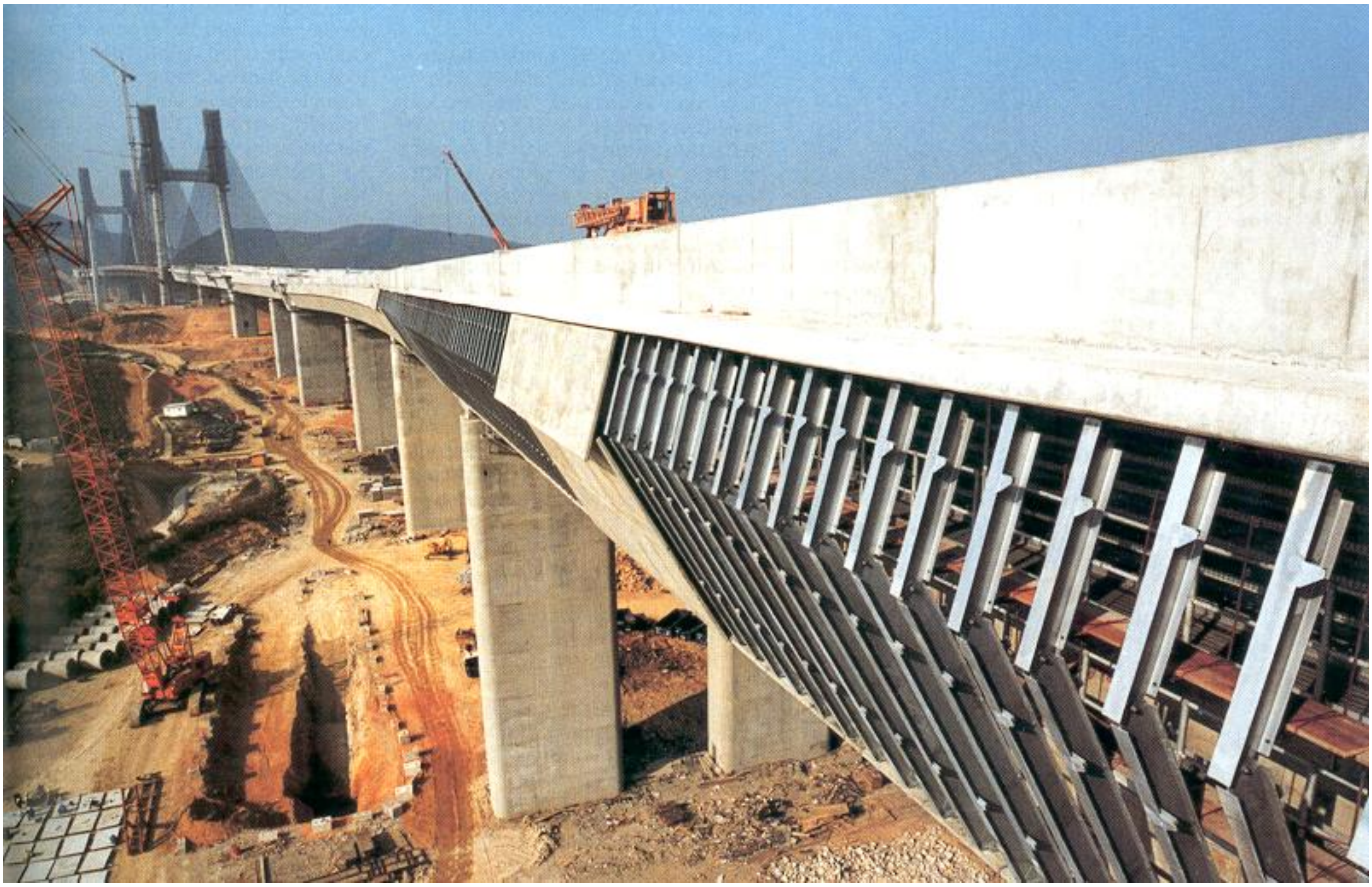
The 502m-long viaducts which carry the airport railway and expressway at high level across the Ma Wan Island, are a breathtaking structure in their own right. Consisting of six spans, this post-tensioned concrete twin box structure was cast in-situ while supported on 35m high birdcage falsework.

As is the case with the adjacent cable-stayed bridge, the viaducts are a two-level structure. Unlike the sea crossing, however, traffic noise restrictions on the Ma Wan Island required the soffit of the viaducts, including that in the central railway envelope, to be devoid of openings. The enclosed lower carriageways are therefore mechanically ventilated with jet fans.

The viaducts widen to provide merging and diverging expressway lanes to connect with future slip roads. When constructed, these slip roads will coil round and under the viaducts to service a forthcoming major redevelopment of Ma Wan.

Hollow piers with large diameter caisson foundations support the viaduct structure. These piers are heavily reinforced to resist in particular the potentially large shear forces resulting from earthquake loading.

The Lantau side, showing main span assembly yard and load-out dock. These are probably the stiffest structures ever launched; note temporary props between larger-section permanent piers



Fascia panels on Ma Wan viaduct provide consistent profile throughout the Lantau Link; voids become utilities corridors

The structures are fitted out with a large quantity of bridge furniture, including access walkways and ladders, inspection platforms, sign gantries, parapets and cable ladders, virtually all of which were designed on site in the heat of the tight programme to meet key dates 3 and 4. Because construction could not be held up while the design of these items was still ongoing, many thousands of chemical anchors had to be post-drilled into the structure for installation of bridge furniture. The designer was involved in an extensive site operation to check the location and detailing of these fixings and avoid conflict with prestressing tendons and reinforcing bars.

A novel feature of the viaducts is the use of precast concrete fascia panels to form an external skin enclosing utilities corridors on either side. The concrete panels are fixed to steel universal column section ribs which are themselves suspended from the main structure. The geometry is varying and complex - the external profile must be compatible with the bridges at either end yet allow sufficient room for the utilities cables and access walkways. The end result is of an exceedingly high functional and architectural merit.

Trackwork

With heavy liquidated damages imposed on key date 3, trackwork design was besieged by pressures from all fronts. The trackwork consists of precast, post-tensioned concrete trackslabs mounted on resilient bearings installed on transverse beams, and are restrained laterally through resilient bearings fixed to concrete corbels cast into the bridge superstructure. The design constitutes a non-ballasted 'floating' system which isolates the trackform from the main bridge structure, thereby minimising the generation of noise and vibration.

During the design development, the acoustic analysis was extended to investigate structure-borne vibrations and the resulting noise levels. Prior to construction, the design was subjected to extensive testing by British Rail Research. The test programme involved the construction of two trial trackwork installations, a running trial, bearing tests, fatigue load tests and computational dynamic analysis for calibration with the results of the running trial and for performance prediction.

Trackwork Re-profiling

A major accomplishment on this project was the application of the Wriggle technique in the trackwork re-profiling. The Wriggle technique originates from tunnel engineering and involves the determination of track alignments in three dimensions to fit through the surveyed tunnel. The technique was successfully used to fit a rail profile (vertical) and alignment (horizontal) through the as-constructed railway envelope in the lower deck. The alignment had to take account of the as-constructed shape of the railway envelope and the need to install railway furniture and emergency exit walkways. In all cases the minimum structure gauge must be maintained.

Unlike tunnels, a bridge is subject to transient as well as long-term movement. in particular the cable-stayed main span is susceptible to considerable movement between different survey operations carried out at different times of day. Due to the very tight programme of work, the survey of the approach spans trackwork setting-out data for the existing spans without the benefit of any survey results on spans which were yet to be built. The deflection predictions, on which the Wriggle exercise partly relied, were incrementally calibrated and adjusted, when it became possible to survey newly constructed spans.

As the bridge was completed, further permanent loads were added while transient construction loads were moved and removed. To compensate for these changing conditions, careful recording of transient loads was undertaken during the survey process and analyses of the bridge were carried out to predict deflections from the time of survey to the time of opening of the railway and to time infinity. Techniques were also devised to minimise the effects of temperature changes on the main span during the survey. By surveying a number of reference points that could be completed while conditions remained reasonably constant, and by carrying out this survey a number of times in different conditions, a mean position for the reference points was established for the main span. From these reference points the railway envelope was then surveyed.

From the survey a three-dimensional model of the railway envelope was developed. This model was then amended by the predicted deflections from the time of survey to time infinity. In places where temporary props were removed, measurements of actual deflections were collected which enabled calibration of the prediction model. The analysis of the deflections of the bridge defined an envelope within which it was predicted the bridge would take its final shape. The mean shape of the envelope was then used to modify the surveyed railway envelope model to which a compliant profile and alignment had to be fitted.

The objective of the Wriggle exercise was to produce a smooth track alignment that provided the necessary clearances at pinch points and maintained minimum curvature requirements. Once established, this alignment was modified to the worst extremities of the deflection envelope and checked against the railway design criteria. The resulting profile on the approach spans was very similar to the design profile. The main span profile, as might be expected on a cable-supported span, no longer took the form of straights joined by a single parabolic curve but a continually varying series of cubic parabolae.

The output from this exercise had to be in a form that was practical to use for setting out. Track level and horizontal position was determined by providing the trackwork subcontractor with simple 'block up' and 'off-set' dimensions from each reference point set in the cross beams at trackslab supports.

The logistics of the work associated with the railway envelope survey and track re-profiling was complicated by construction activities and the tremendous pressures from the construction programme. Despite these constraints the work enabled on-site adjustments during construction to achieve compliance and was critical to the successful completion of the railway work.

Railway envelope within Ma Wan required use of Wriggle technique -more commonly used in tunnelling – to maintain track alignment and profile

Mechanical ventilation

The enclosed lower carriageways of Kap Shui Mun bridge and Ma Wan viaducts are ventilated by a unique combination of both natural and forced ventilation, the design of which has drawn on three-dimensional computational fluid dynamics simulation. This technique studies the fundamental field variables of pressure, temperature and air velocities at the centres of a large number of cellular volumes which are multiply-linked to each other.

The main cable-stayed span of Kap Shui Mun bridge, with its permeable construction, was shown in the design study to be self-ventilating. The enclosed lower carriageways of the rest of the concrete spans and viaducts, which effectively divide the crossing into four separate ventilation zones, are ventilated by means of 44 jet fans distributed throughout the length of the structures. These jet fans are located, in pairs, above the traffic envelope. They are fully reversible and can be controlled automatically or locally at the motor control centres. The jet fans operate together to achieve the required longitudinal air velocity to control both the pollution levels with the carriageways and in the event of a fire, achieve the longitudinal air velocity to control the spread of smoke and hot gases.