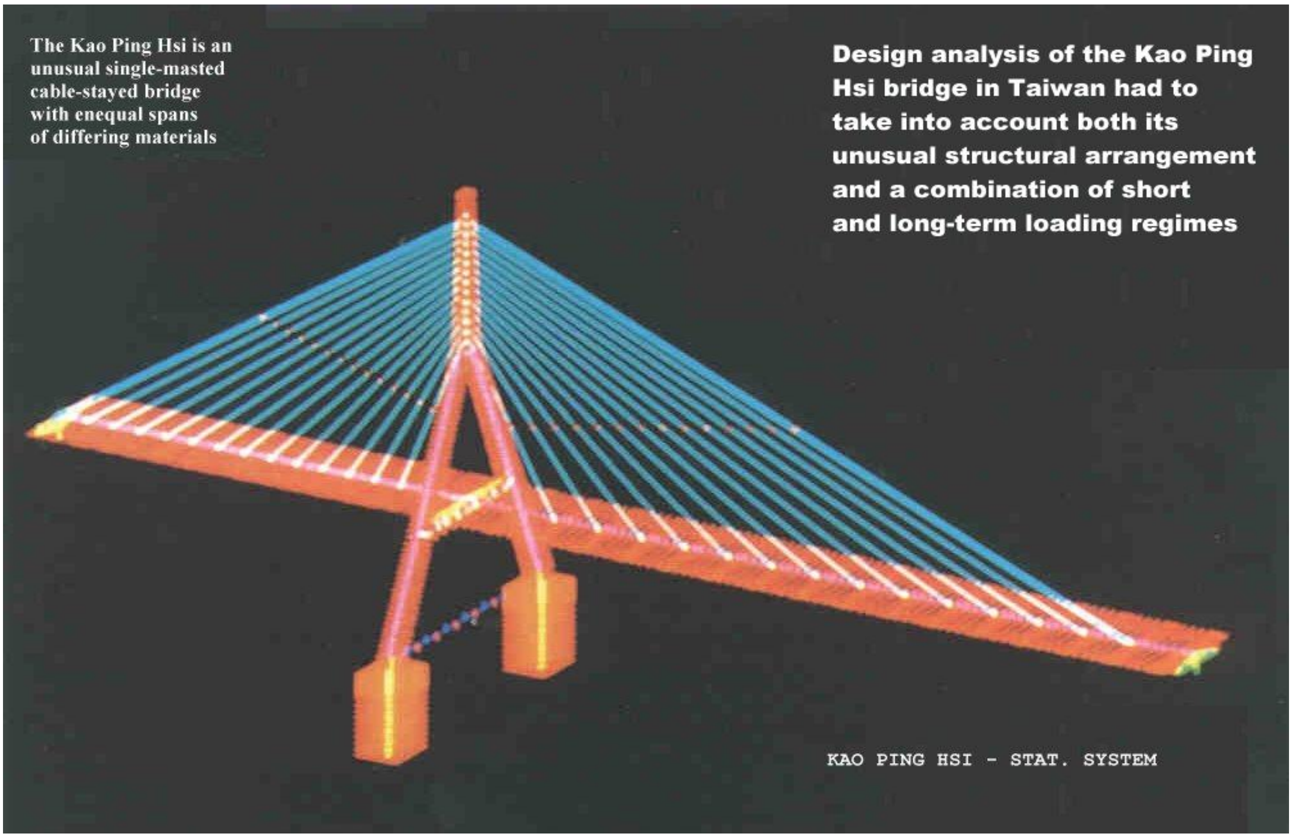

RM with a view

PHE KAO Ping Hsi bridge in Taiwan is an unusual cable-stayed structure, with a single 183.5m-high pylon and two unequal spans of 183.3 and 330m. The shorter span is a prestressed concrete box girder, while the longer span is a multicell steel box girder. 28 pairs of stays support the 34.4m-wide deck, which will carry traffic on the island's Second Freeway between Taipei and Kaohsiung. The unusual structural arrangement and a very tight final design period combined to make the structural analysis of the bridge an interesting challenge.

The consultant for the project is Taiwanese firm 3F, which is using RM Spaceframe software from Austrian company TDV for the structural analysis. Since its foundation in 1970, TDV has been developing a program library for structural, geomechanical and infrastructure design. Between 1970 and 1985, motorway construction over Austria's difficult landscape spurred the company to develop a software system for bridge engineering. This was used for many of Austria's motorway bridges.

The most important elements of the package are program systems for the statical calculation of two- and three-dimensional frame structures. The modular program supports all standard structural analysis tasks and offers various additional modules for tackling project-specific problems (eg theory of stability, dynamics, and suspension cables). In addition to the frame structure program, other problems of bridge design have been specifically considered. For pre-stressed concrete structures, the program computes the distribution of tensioning forces, the cable geometry, the load types, and the pre-stressing as well as creep and shrinkage. Different construction stages are considered and relevant design code checks required by national standards (eg normal stress, ultimate load, principle stress and shear capacity) are included.

In Taiwan, the construction sequence meant that the deck has become a composite structure. First, the shorter concrete section is erected span by span on seven temporary piers. The central prestressed box is erected first, with the cantilever slabs following in a later construction stage. The change of the structural system between construction and finished stages means that creep and shrinkage must be considered. These will cause forces to be redistributed between the box section and the cantilever slab.

Whereas internal prestressing is used in the final stage, external pre-stressing is used temporarily during construction while the bridge is supported by temporary steel piers. RM Spaceframe was used to simulate this delicate procedure and to carry out all the design code checks. The final position of the temporary piers was only decided seven months before construction began, restricting the time available for the final structural analysis to two and a half months. TDV regards this tight timeframe as an illustration of the software's high performance.

The lower part of the pylon is erected at the same time as the first deck sections. Construction of the upper part is synchronised with the cantilevering of the longer steel span and the application of the stay cables. Forty-two construction stages for the pylon had to be simulated in detail to obtain complete information about the pre-camber requirements during construction.

The 22m steel deck segments are pre-assembled near the pylon and lifted by a hanging carrier to the front end of the cantilever. Here, a derrick crane is used to connect the new segment to the girder. The derrick crane is then advanced to the end of the segment it has just erected, the stay cables are tensioned and the next segment is erected. Apart from calculating pre-camber values for each step of the construction sequence, RM Spaceframe was also used to consider the transition from the assembly of the last segment to the final stage. This included assembling the final segment, assuming that both the hanging carrier and the derrick are in the front end position; removing the derrick, hanging carrier, temporary steel towers and temporary prestressing of the PC deck; applying additional permanent loads; prestressing the diaphragms of the PC deck; and creep and shrinkage.

One of the problems facing designers of cable-stayed bridges is working out a tensioning sequence for the cable stays. Even though the actual construction sequence and the schedule differed from the assumptions made in the tender design, it was possible to compensate for this by adopting a one-step tensioning strategy. This should ensure that no permanent structural changes will be required. The challenge was to find a sequence which guarantees similar internal forces to those given by the preliminary design. For the Kao Ping His bridge it was more sophisticated than a straightforward set of linear equations, because it is a hybrid structure and creep and shrinkage must be considered. RM Spaceframe processed the iterative equation and verified that a one stage stressing sequence is possible. A check of all intermediate stages showed no sign of compressive cable forces, excessive uplift forces at the support or unacceptable stress levels.

The tensioning strategy is closely related with the creep and shrinkage behaviour. For the effects of creep and shrinkage on the PC girder, pylon anchorage zones, steel deck and stay cables to be evaluated, time dependent simulations based on the construction process were conducted. Any changes to the construction process needed to be evaluated, to see if they require a recalculation.

Designing a cable-stayed bridge economically requires that the bending stiffness of the bridge deck is used to achieve an efficient distribution of the load on the stay cables. This was achieved by imposing an appropriate pre-deformed shape on the whole bridge deck, which was included in the pre-camber calculation.

The final result of the analysis is in three parts. First was the camber diagrams, which showed the pre-camber for the whole structure and the actual position of all segments in each individual construction stage. The second part was the fabrication shapes. The detailed geometry of all segments was worked out, taking into account and compensating for all deformations arising between the assembly of the segment and the final stage. The final part was the stress-free prefabrication shape, composed by the fabrication shape of the single segments.

RM Spaceframe software was used to solve all the structural problems arising during the construction of the Kao Ping Hsi bridge. Using a consistent data structure, the complete analysis can be carried out in as little as two and a half months. The package also provided easily generated graphical representations of results.

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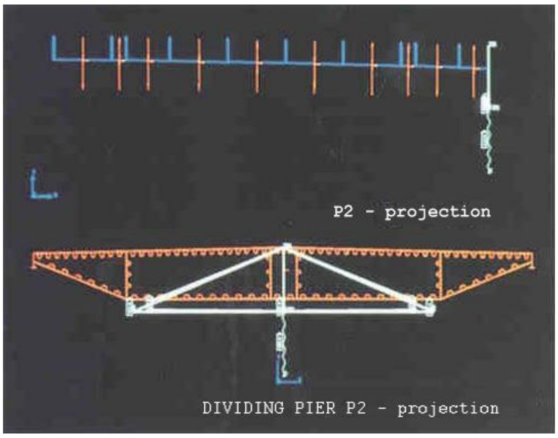
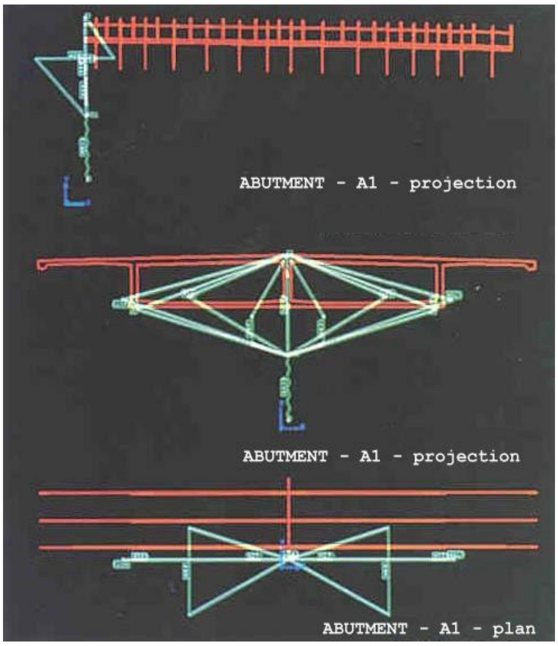
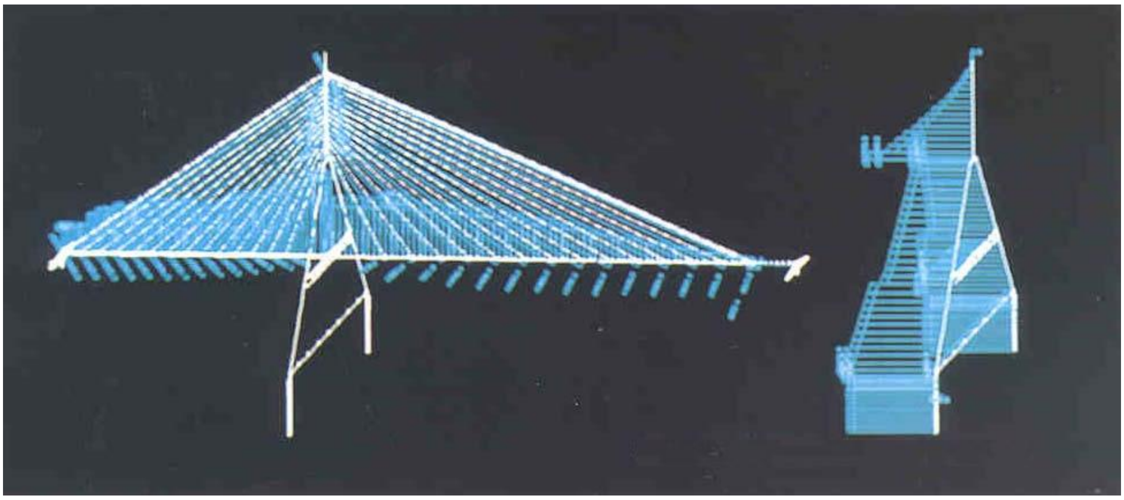


Section through steel deck



Section through the concrete deck (in red) at the abutment



Output showing max/min normal forces according to Aashto procedures