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# Design of Girder and Cables for Train Loads

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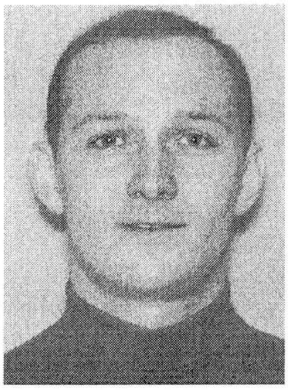

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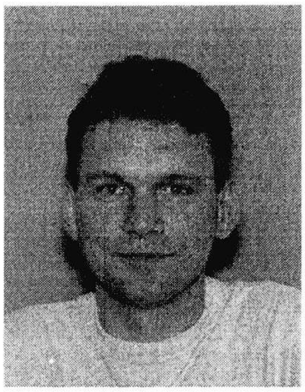
Mr. Lars Hauge born 1962, received his civil engineering degree from the Technical University of Denmark, year 1986. Has through his work with some of the world's largest bridges obtained considerable expertise in design of cable stayed and suspension bridges.



## Abstract

### The Cable Stayed Bridge of the Öresund Link

The High Bridge of the Öresund Link is a Cable Stayed Bridge with a Main Span of 490 m and two side spans of 160m and 141m respectively. The Pylons, with two single towers each, are constructed in reinforced concrete and the Bridge girder is a two level composite girder. The two level composite girder comprises a main carrying steel truss and a upper roadway deck slab in concrete.

The Cable Stays are arranged as a harp system with 10 Cable Stays in each cable fan. The Cable Stay inclination with horizontal is 30° Deg, and the distance between the anchorages on the Girder are 20 m. For anchorage of the Cable Stays in the Pylon, a cast-in steel box has been designed. See Figure 1.

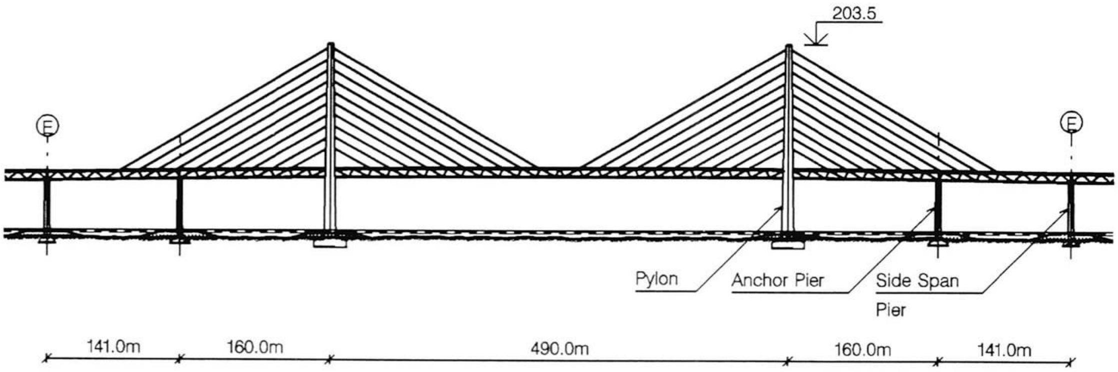



*Figure 1 : Öresund Link, Cable Stayed Bridge. Side view.*

The structural design was based on the Eurocodes with an associated Project Application Document and a Design Requirement document. The Design Requirement document supplemented and took precedence over the other two documents, with specific loads and other requirements covering topics which are not considered in the Eurocodes.

During detailed design computer models was established in order to perform the general verification of the Bridge, but also to perform the rather complex analyses related to the Train loads such as :

- Comfort analyses
- Dynamic Actions
- Fatigue analyses

Other complex effects with considerable design impact, but without connection to the Train loads, such as shrinkage and creep effects, shear lag and cable stay rupture, was also analysed.

**Comfort Analysis**

The vertical accelerations within a passenger coach was evaluated for a train with a speed of 200 km/hour, in order to verify that the comfort criteria's was fulfilled. A maximum vertical acceleration of 0,5 m/sec$^2$ (peak value), was found during passage of an expansion joint. Compared to the max. acceptable vertical peak acceleration of 2,0 m/sec$^2$, the girder is found to be well within the acceptable limits. Figure 2 gives body accelerations for one of the analysed passenger trains crossing the bridge.

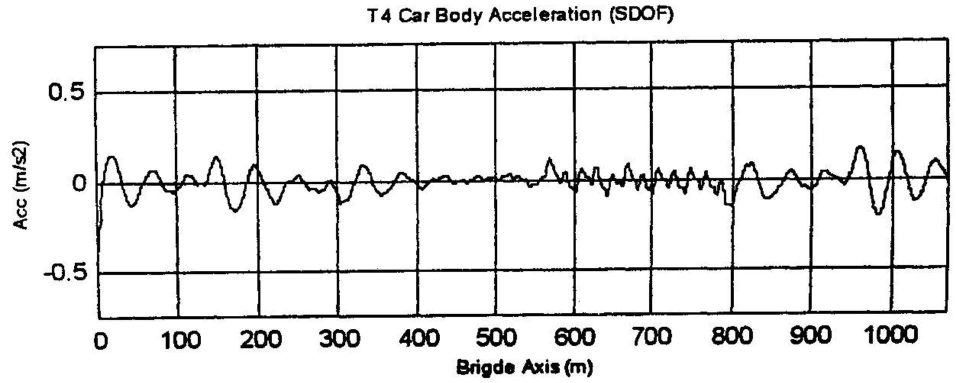



*Figure 2 : Acceleration results for a passenger train crossing*

**Dynamic Actions**

Dynamic effects from crossing of a train, was included in the design of both Girder and Cables, by introduction of a dynamic load factor. Analyses was carried out in order to determine the dynamic load factor of the global actions. The general result of the analyses, was a dynamic load factor depending on both the type of bridge element analysed, but also the element position in the bridge.

The dynamic load factors for crossing of a UIC train, was found to be in the range of 1.02 to 1.05 for the Girder, and 1.01 to 1.06 for the cable stays considering tension and 1.30 for detensioning.

Dynamic load factors was determined separately for "fatigue" trains. Here the global dynamic load factors was found to be in the range of 1.02 to 1.40 for the girder structure, and 1.02 to 1.30 in the cable stays considering tension and 1.02 to 3.60 for detensioning.

**Fatigue Analysis**

The Railway Tracks are supported on the lower bridge deck, a closed steel box with orthotropic deck panels, supported by transverse bulkheads with maximum 3,00 m spacing. General stress and plate buckling analyses has been performed for the steel panels and transverse bulkheads, but the major work has been related to the fatigue verification. Combination of fatigue contributions from both wind, roadway traffic and trains was made, with however the fatigue contribution from the trains as dominating. In order to perform the rather detailed fatigue verification, based on a great number of stress information's, a special computer programme was developed.

# An Innovative Technique for Fitting Trackwork Alignments Through the Railway Envelope of a Cable-stayed Bridge

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Robin Sham, born 1954, received his BSc in 1978 (Birmingham) and PhD (Structural Engineering) in 1989 (Imperial College). He is Technical Director responsible for Bridges & Special Structures and was Designer's Project Manager for the successful Kap Shui Mun Bridge & Ma Wan Viaduct Project in Hong Kong, opened in 1997.

## Abstract

The Kap Shui Mun Bridge and Ma Wan Viaducts are 2-level structures which carry the expressway on 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 railway.

The innovative design concept aims at making possible what effectively is a tunnel in the air, to be constructed at an extraordinary rate, on time and within budget.

The cable-stayed structure has a main-span of 430m and a total length of 750m. Structural efficiency is enhanced by double steel-concrete composite action in the main span in that both the top and bottom flanges of the steel superstructure are formed in concrete.

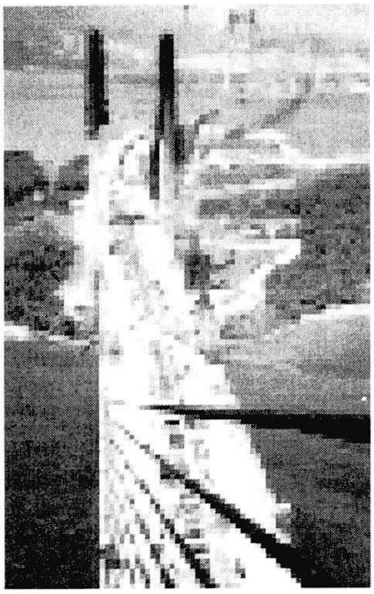

*Fig 1 - Kap Shui Mun Bridge & Ma Wan Viaduct*

The trackwork for the airport railway is contained in the central region of the lower deck of these bridges. The trackform design consists of precast, post-tensioned concrete trackslabs mounted on resilient bearings which are installed on transverse beams. The trackslabs are also restrained laterally through resilient bearings fixed to concrete corbels which are positioned on either side of the trackslab and cast into the bridge superstructure. The design constitutes a non-ballasted 'floating' trackslab system which isolates the trackform from the main bridge structure thereby minimising the generation of noise and vibration.

In order to meet an exceptionally tight programme, trackwork construction had to be concurrent with bridge construction. However, trackwork construction within the partially completed bridge superstructures would only be possible if design techniques could be developed to control the setting out of the trackwork under the most unusual conditions which existed.

With full co-operation from the contractor, Maunsell's Wriggle technique was applied to the trackwork reprofiling. 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 track profile must satisfy the railway design criteria in terms of gradient and curvature. The alignment had to take account of the as-constructed shape of the railway furniture and emergency exit walkways. In all cases the minimum structure gauge must be maintained.

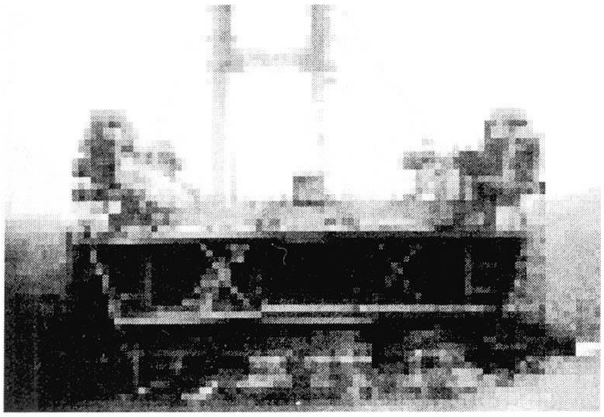

*Fig 2 - A Cross-section of the Main Span*

Unlike a tunnel, a long-span crossing 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 had to be carried out when temporary propping and falsework were still in place and the main span closure was yet to be completed. Similarly, as the construction of Ma Wan Viaducts progressed, the Wriggle exercise had to produce 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.

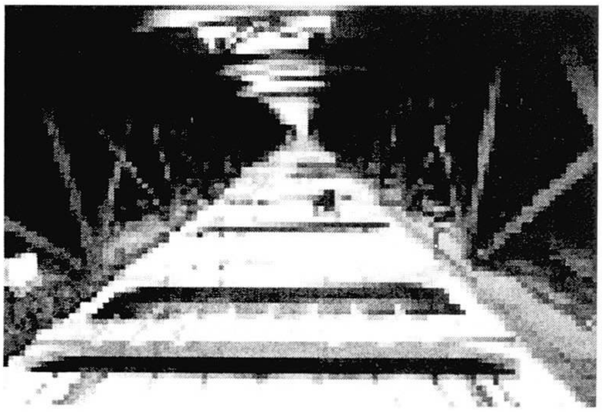

*Fig 3 - Railway Envelope*

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. The output from this exercise had to be supplied to the trackwork subcontractor at a staggering rate and in a form that was simple, accurate, and practical to use for setting out.

The logistics of the work associated with the railway envelope survey and track reprofiling were complicated by construction activities and the intense 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.

# Comfort Criteria for High Speed Trains on the Øresund Bridge

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Anders Thomsen received his degree from the Technical University of Denmark in 1994. He has worked as design engineer for the ASO Group on the Øresund Bridge design for 3 years and joined ISC in 1998.

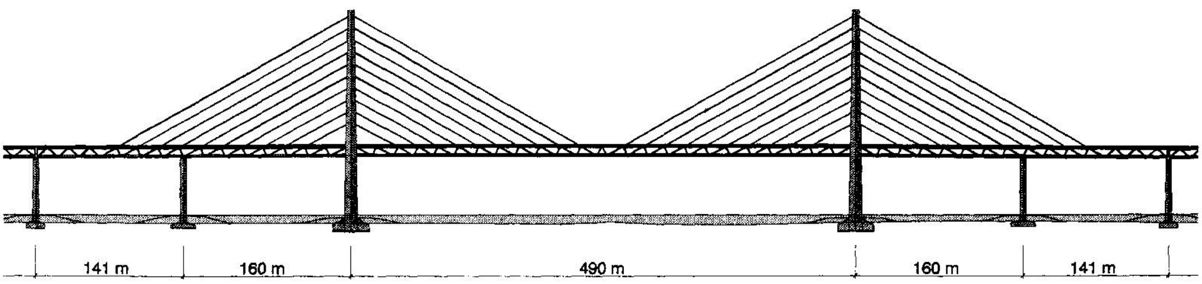
## Abstract

The comfort criteria for the Øresund Bridge are based on the ORE reports, which specify rules for limitation of:

- vertical accelerations
- torsional deformations
- deformations at expansion joints

The Danish and Swedish Railway Authorities had furthermore specified that the wheel pressure shall be at least 75% of the static wheel pressure for all train types:

During the pre-tender phase ASO Group carried out a comprehensive study of the effects of these requirements on the design of the two-level bridge.




*The 490m main span is the longest cable-stayed span in the world carrying both road and rail*

Four types of passenger trains were specified to travel at a design speed of 200 km/hour, they were:

- the Swedish X 2000 train
- the Danish IC 3 train
- the Danish IR 4 train
- the Euro City train

Furthermore a heavy freight train travelling at 120 km/hour was investigated. Due to poor spring characteristics of the wagons in this train it was found that the wheel relief requirement mentioned above could not be fulfilled, when an empty wagon of this train passed an expansion joint. It was finally decided to waive this requirement as being unrealistic.

The analyses aimed at simplifying the requirements for the number of investigations to be carried out by the Contractor's designer in the detailed design. This would be possible if it was demonstrated that some of the trains would always experience smaller accelerations than other trains, or if the requirements for vertical accelerations were more onerous than the requirements for deformations at expansion joints or vice versa. It was, however, found that no such simplification could be made.

# Nonlinear Dynamic Analysis of Cable-Stayed Bridges Excited by Moving Vehicles

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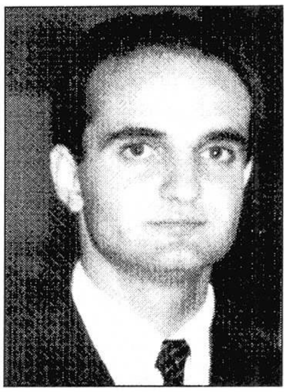

Raid Karoumi, born 1964, received his M.Sc. degree in Civil Engineering in 1990 and his Dr. Techn. degree in 1999 from the Royal Institute of Technology in Stockholm. Between 1990 and 1993 he worked as a consultant and was involved in a variety of special projects.

## Abstract

The dynamic response of bridges subjected to moving vehicles is complicated. This is because the dynamic effects induced by moving vehicles on the bridge are greatly influenced by the interaction between the vehicles and the bridge structure. Although several long span cable-stayed bridges are being build or proposed for future bridges, little is known about their dynamic behavior under the action of moving vehicles. As cable-stayed bridges are getting longer, lighter, and more slender, accurate procedures need to be developed that can lead to a thorough understanding and a realistic prediction of the structural response due to traffic loading. It is well known that large deflections and vibrations caused by dynamic tire forces of heavy vehicles can lead to bridge deterioration and eventually increasing maintenance costs and decreasing service life of the bridge structure.

In this paper, a method for modeling and analysis of the nonlinear dynamic response of cable-stayed bridges excited by moving vehicles is presented. The bridge structure is discretized utilizing the nonlinear finite element method and the dynamic response is evaluated using a combined Newton-Newmark algorithm. A beam element, which includes geometrically nonlinear effects and is derived using a consistent mass formulation, is adopted for modeling the girder and the pylons. Whereas, a two-node catenary cable element derived using exact analytical expressions for the elastic catenary, is adopted for modeling the cables. All sources of geometric nonlinearity and other important factors that significantly influence the dynamic response, such as bridge damping and bridge-vehicle interaction, are considered.

The vehicle model used in this study is a so-called suspension model that includes both primary and secondary vehicle suspension systems. As the vehicle equation of motion is coupled to the bridge equation of motion through the interaction force existing at the contact point of the two systems, an iterative procedure is adopted to solve these two sets of equations.

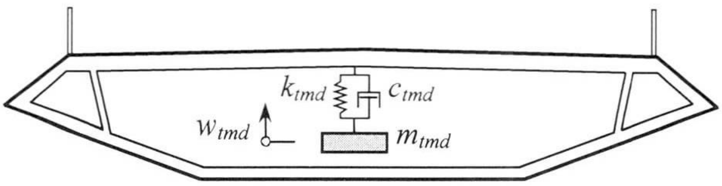


*Figure 1: Cross section of bridge girder with a tuned mass damper, TMD*

As energy dissipation in cable-stayed bridges is very low and may often not be enough on its own to suppress vibrations, the efficiency of a so-called tuned mass damper on controlling traffic-induced vibrations, is investigated. A tuned mass damper is a vibration absorber tuned to a particular mode of the bridge and consists of a mass, a viscous damper and a linear spring, see Figure 1.

A simple cable-stayed bridge model is analyzed to highlight the dynamic effects and to show the influence of vehicle speed, bridge damping, and a tuned mass damper on the bridge dynamic response.

# Deformability of Long-Span Cable-Stayed Bridges for Railways

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## Abstract

Cable-stayed bridges have been of great interest in recent years, particularly with respect to the fan-shaped scheme as a valid and alternative solution to suspension bridges for long spans.

Troitsky (1) and Gimsing (2) have reviewed the problems and advantages of cable-stayed bridge solutions and reported on the latest and most interesting projects.

For long-span bridges one of the most important problems is related to the deformability under live loads. In the case of bridges carrying both road and railway traffic, and for spans greater than 1000 m, this aspect can seriously influence the design and the feasibility of the structure.
In this work an analysis of the static and dynamic behaviour of the bridge is developed, modeling the train passage as a dynamical action or an equivalent static load.

Como *et al.* (3) analyzed the static behaviour of long span stayed-cable bridges showing the prevailing truss behaviour of the bridge. Bruno and Grimaldi (4) investigated the nonlinear static behaviour of cable-stayed bridges using both a continuous and a discrete model of the bridge, and showed the strong influence of nonlinearities for long spans. Moreover, the dynamic behaviour of cable-stayed bridges has been investigated by Bruno (5) analyzed the effects of moving loads, and by Bruno, Maceri and Leonardi (6) who analyzed aerodynamic instability problems.

In the above studies fan-shaped cable-stayed bridges were studied using both a continuous and a discrete model of the bridge, and the dominant truss behaviour of the bridge was found. In particular, the influence of the dynamic properties and geometric nonlinearities of towers are included in the analysis.

In this paper the continuous model proposed in the previous works is employed to develop static and dynamic analyses. In addition a discrete model is also applied to give some useful comparisons between analytical and numerical results.

The aim of the paper is to give same results and conclusions related the main geometric and mechanical parameters able to influence or control the bridge deformability.

In particular, the geometric aspect ratio L/H between the main span length and the tower height, the loads ratio p/g between live and dead loads, the relative flexural stiffness between girder and stays, are taken into account.

Obtained results show the strong influence of the rail load on the midspan deflection and on the girder slopes. As well known these last quantities in many cases represent the main parameter which have to be considered in deformability control.