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THE UNIT LOAD METHOD - SOME RECENT APPLICATIONS

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ABSTRACT

The Unit Load Method has originally been proposed as a procedure to optimise the tensioning process for the stay-cables in cable-stayed bridges and has been implemented in a well-established bridge-design software package for this purpose. The implementation of this method takes into account all relevant effects for the design of cable stayed bridges including construction sequence, second order theory, large displacements, cable sag and time-dependent effects such as creep and shrinkage or cable relaxation.

The underlying ideas of this method can also be applied to other optimisation problems in structural engineering. This paper gives an overview about the wide range of possible applications for which this method can be used and finishes with examples from practical experiences with the Unit Load Method.

KEYWORDS

Structure optimisation, unit load method, cable stayed bridge, concrete arch bridge, incrementally launched bridge

INTRODUCTION

Cable-stayed bridges with multiple stays are highly redundant structures. The stiffness of the load-bearing elements – the pylon, the deck and the cable stays – governs to a large degree the distribution of forces within the structure. The slenderness of the bridge girders in modern cable-stayed bridges has made it imperative for the bending moments to remain within tight limits throughout the construction process. Moreover, it is also very important to achieve a desired optimal moment distribution in the finished structure under dead load. The requirement to achieve a given moment distribution in the main girder and the pylon has led to the practice of adjusting the tension of the stay cables during the individual construction stages. However, adjusting the tension force in the stay-cables is expensive and tensioning strategies must be optimised not only for structural but also for financial reasons. Due to the high redundancy of the structural systems tensioning one single cable also affects the forces in all other cables, the pylon and the bridge deck. Time-dependent processes such as creep and shrinkage also play an important role where parts of the bridge are made of concrete. Moreover, different construction techniques call for different tensioning strategies and impose different boundary conditions onto the structural system. For example, where temporary supports are being used, a constellation could occur where the deck is lifted off its temporary supports during the tensioning process.

Recently a method called the Unit Load Method has been presented for cable-stayed bridges (Janjic et al. 2002) which allows the definition of a desired moment distribution in the final structure under dead-load and then computes the tensioning strategy which will achieve exactly that distribution taking into account construction methods, changes in the structural system (for example due to the individual construction stages), time-dependent effects such as creep and shrinkage or relaxation of pre-stressing tendons and also geometrically non-linear behaviour.

This method is in fact a general algorithm to achieve a desired distribution of section forces in any structure by adjusting certain constraints of the system. Such constraints include, for example, a change in boundary condition (jacking of a support condition), tensioning of cables (e.g. stay cables or pre-stressing tendons) or application of loads. A short summary of this method in combination with three examples demonstrating some of the many possible applications of this method is given in this paper.

THE UNIT LOAD METHOD

In the following the underlying idea of the Unit Load Method will be explained using a simple example (Bruer et al. 1999). Consider a cable-stayed bridge with a structural system as shown in Figure 1a. The desired moment distribution for this example (M^A, M^B, M^C … M^I) is given in 9 points (A, B, C … I) along the main girder as outlined in Figure 1b. The constraints which will be used in this example to achieve this distribution are tensioning of 8 cables (X_1 to X_8) and jacking of the support (X_9) as shown in Figure 1a.

The structure is analysed for a unit load case for each constraint and the results are stored, specifically the results for the bending moments in the points for which the desired bending distribution is given. The system is also analysed for loading with the specified dead-load. With these results a system of linear equations can be established with one equation for each point A to I in Figure 1:

$$M^A = M_P^A + M_{T_1}^A \cdot X_1 + M_{T_2}^A \cdot X_2 + \ldots + M_{T_9}^A \cdot X_9$$

$$M^B = M_P^B + M_{T_1}^B \cdot X_1 + M_{T_2}^B \cdot X_2 + \ldots + M_{T_9}^B \cdot X_9$$

:

:

$$M^I = M_P^I + M_{T_1}^I \cdot X_1 + M_{T_2}^I \cdot X_2 + \ldots + M_{T_9}^I \cdot X_9$$

or, more compact

$$M^K = M_P^K + \sum_{m=1}^{n} M_{T_m}^K \cdot X_m \qquad (1)$$

in which M_L^K is the moment in point K (in the current example $K = A \ldots I$) caused by action L. $L = T_m$ signifies each single unit loading case with m ranging from 1 to n (with $n = 9$ for the current example) and X_m is the unknown multiplication factor for the unit load causing the particular unit load cases. The lower index $L = P$ signifies the load case of dead-load on to the final system. This system of equations can be directly solved for the unknown factors X_m which in turn give the exact values for the forces to be applied at the chosen "degrees of freedom" in order to achieve the desired moment distribution. It should also be noted that the equation system as laid out in Equation 1 is non-symmetric and may contain zero-pivots which must be considered when solving for X_m.

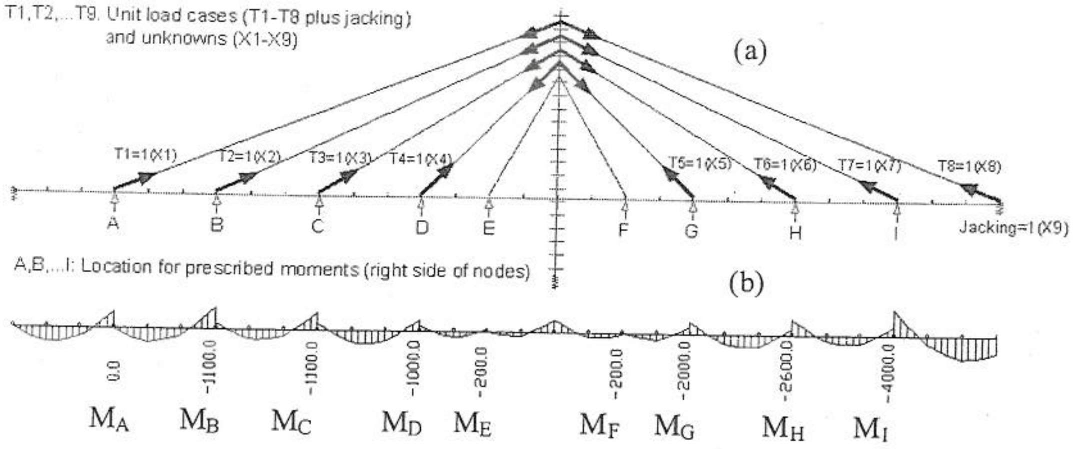

Figure 1. Unit loading cases and desired moment distribution.

This example gives the simplest application of the Unit Load Method. The underlying assumptions include linear-elastic structural behaviour, no time-dependent material properties, and tensioning of the cables on the final system. The equation system in Eqn. 1 is linear only under these assumptions. In order to apply the system in practical design situations, it has been expanded to include these effects (Janjic et al. 2002).

IMPLEMENTATION

The Unit Load Method as described above has been generalised and incorporated into the computer program *RM2000* (TDV, 2001) and has been used successfully in the analysis and design of numerous bridges in many countries. The software is centred around an object-orientated data base. Various pre- and post-processing tools support the input into the system and the processing of results from the system. Most importantly, all functionality is provided to exactly define the planned construction schedule including all changes in the structural system and the exact time frame for all actions to enable an automatic computation of time-dependent effects relevant for the structural behaviour of the structure. A powerful solver module is provided to analyse the structural data and generate results which are again stored into the central data base. Various interface functions allow the import and export of data from the data base for use with other computer programs such as spread sheet software or CAD-packages. The graphic user interface follows the common conventions of modern interactive computer programs.

CABLE-STAYED BRIDGE – VERIGE BRIDGE / MONTENEGRO

The Verige Bridge in Montenegro (Pircher, 2001) is a cable stayed bridge which is currently being designed by Gradis/Maribor of Slovenia using the Unit Load Method as implemented in the *RM2000* software (TDV, 2001). The three cable-stayed main spans (130m, 450m and 130m) are connected on one side to an approach viaduct and on the other side to a support structure on the main land and are supported by two diamond-shaped pylons of 168m height (Figure 2). The cross-section of the superstructure consists of three cells which are separated from each other by vertical webs. The width of the superstructure is 22.9m, the height is 2.8m and the girder is made entirely from pre-stressed concrete. The pylon and the superstructure are to be connected monolythically. The bridge is to be erected segmentally and the exact tension of the stay-cable was determined in such a way that no sub-sequent adjustments were necessary and the desired moment-diagram in the bridge girder was achieved (Figure 4). Stress limits during the construction stages (Figure 3) were also kept within the given limits. The bridge will be located in a seismically extremely active region and to complicate matters, a fault line is situated between the two pylons.

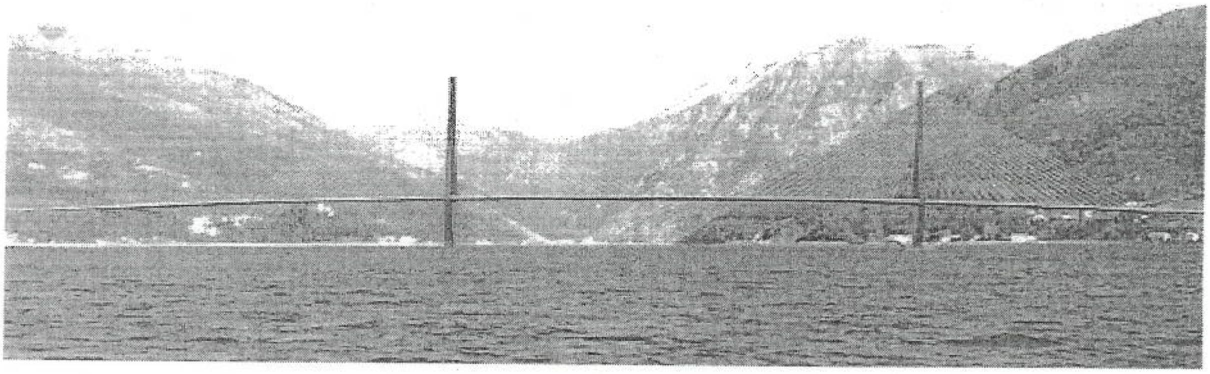

Figure 2. Artists impression of the Verige Bridge.

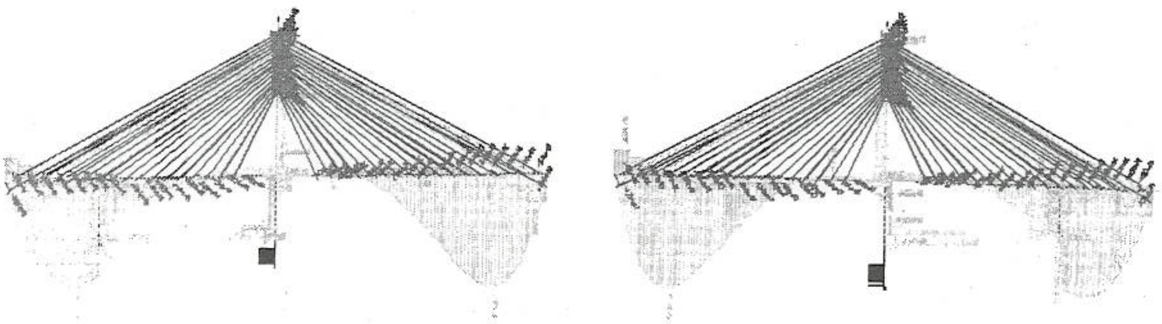

Figure 3. Bending moments, normal and shear forces during construction of the Verige Bridge.

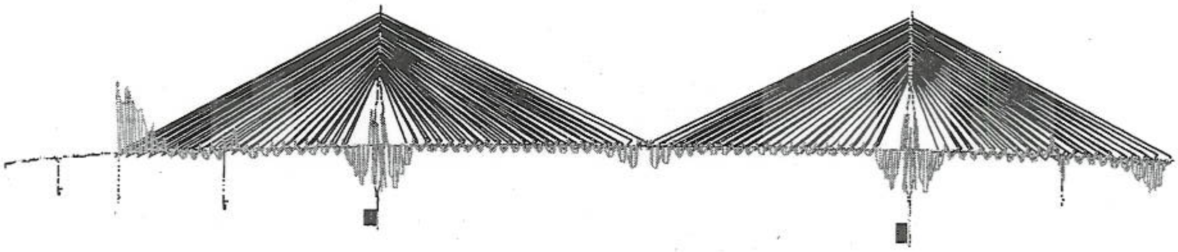

Figure 4. Optimised bending moments upon completion.

ARCH-BRIDGE – PITZ VALLEY / AUSTRIA

During the construction of a large concrete arch (169m span) for a bridge in the Pitz-Valley in Austria (Kargel & Geisler 1983) a novel technique to erect the concrete arch was pioneered. Rather than using large scaffolds to support the arch during construction, the arch was built segmentally and supported by temporary stay-cables. The exact position, the number and the tension forces in the stay-cables had to be adjusted in such a way that the bending moments in the arch remained within tight limits. After closure of the arch, the stay cables were removed and the bridge deck and connecting columns added. A preliminary version of the Unit Load Method was employed to determine an optimal tensioning regime for the stay-cables. Due to this optimisation the stay cables were only tensioned once. Costly and time-consuming adjustments in these tension forces could be avoided.

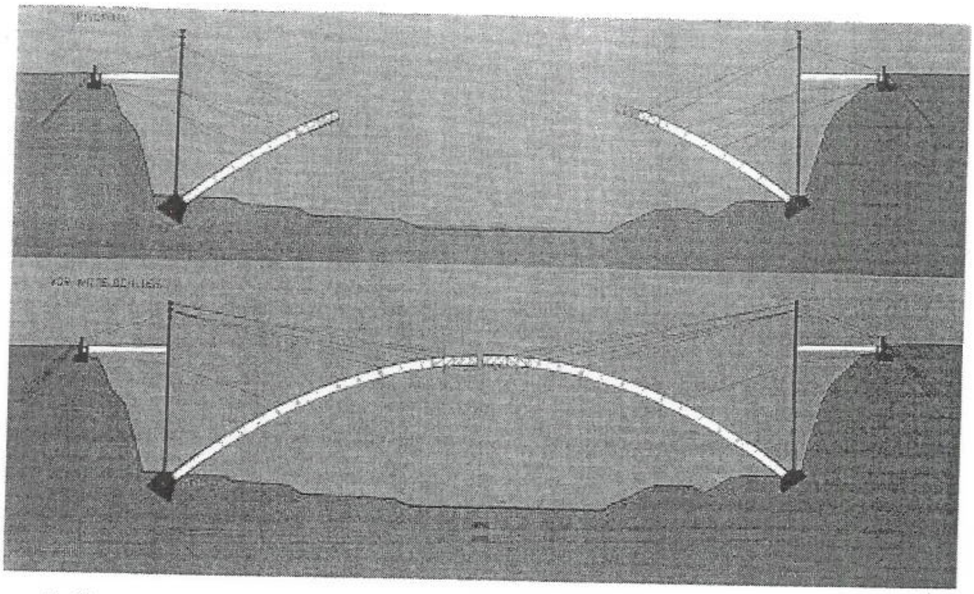

Figure 5. Construction of the arch for the Pitz-Valley Bridge (Kargel & Geisler 1983).

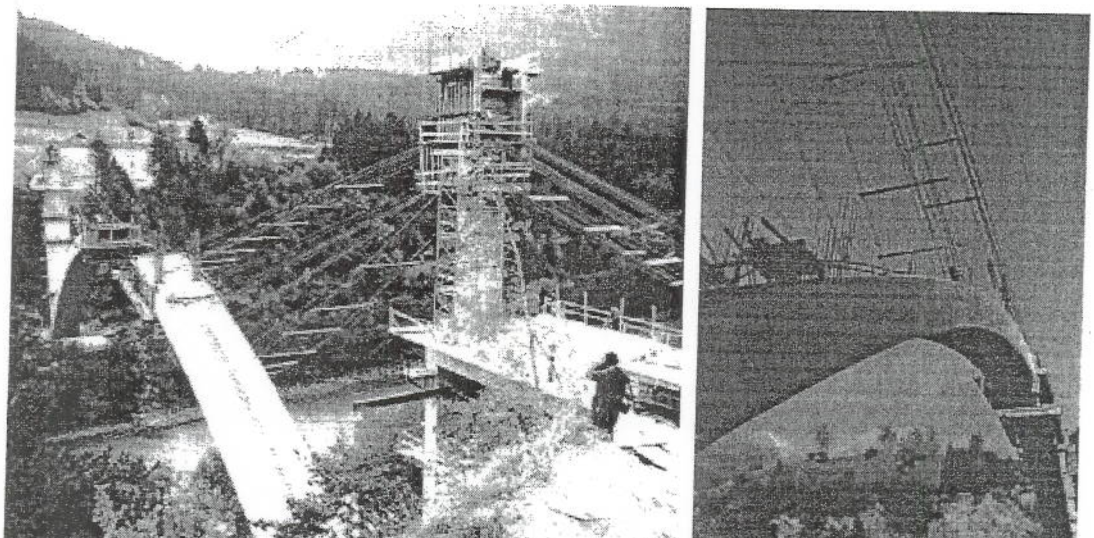

Figure 6. Arch of the Pitz-Valley Bridge during construction (Kargel & Geisler 1983).

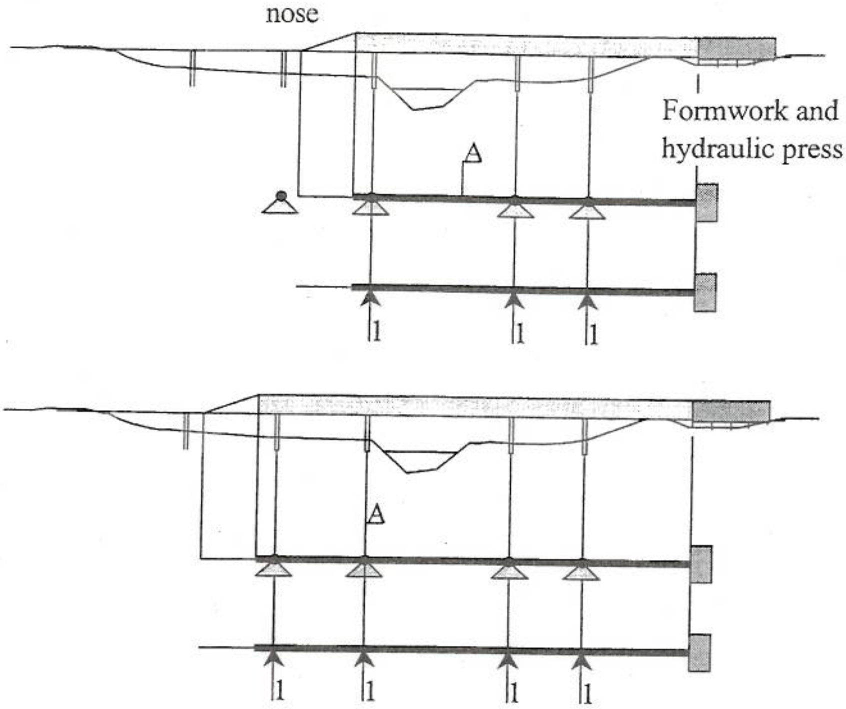

Figure 7. Schematic view of launching procedure.

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