Computer Aided Design of Prestressed Concrete and Composite Bridges using Novel TDV Software

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SYNOPSIS

This contribution addresses the importance of modern software tools for the design of bridge structures and the stability and serviceability checking process.

Due to the complexity of modern bridge structures and the continuously rising demands for quality and safety, traditional proceeding with splitting the different tasks of the design and erection phase of bridges into small portions performed by different design teams, is not suitable anymore.

Supporting the design and proof checking process by using highly sophisticated software systems is in fact the only way to avoid the pinchers of rising computational requirements and lessening human resources. These integrated software tools perform design and checking tasks from the very beginning to the last detailed design check.

By means of the TDV bridge analysis package RM2006 it is shown, how such software tools can considerably enhance and ease the design work for complex bridge structures by supporting design tasks, complex static and dynamic analysis tasks and detailed proof checking tasks in closed sequence.

1. INTRODUCTION

1.1 The bridge design process

The bridge design process in the narrower sense usually starts when basic boundary conditions have already been fixed. I.e. the conceptual formulation based on the requirements of the operational capacity (e.g. width of the carriage-way, maximum incline) and of the terrain to be bridged (alignment within the total road or railway project, total length, etc) has already been established.

1.2 Basic decisions

Based on the conceptual formulation, the load bearing system has to be evaluated in more detail, fixing basic parameters such as the material to be used (steel or concrete), the number of spans and piers, the fundamental shape of the super-structure (often given by existent falsework), and – last but not least – by the construction method (span by span, free cantilevering etc) often determined by the availability of the appropriate construction equipment. Sometimes, these anticipated constraints are evaluated by comparing different preliminary drafts. These comparisons are often based on architectonic requests, but major bridges also require extensive feasibility studies for finding an optimal solution comprising aesthetics and economics.

1.3 Actual design process

The actual design process starts at this point, and it contains the **preliminary design** works for getting sufficiently accurate bidding documents and contract specifications. In the next step, the **detailed design** work for optimising structural details and for officially and in detail proof checking the stability and durability of the structure is performed. Finally – in the erection process – concomitant **erection control** analyses for calibrating the design assumptions are done if required.

Performing all these tasks on the same mathematical model considerably facilitates the total design process, provided the design tool, like **RM2006** [1], consistently allows solving all related problems, and permits starting with a rough model and continuously refining it as required in the design process.

2. MATHEMATICAL MODEL

2.1 General

The mathematical model of a structure consists of «**General Properties**» describing physical parameters like the material behaviour, of the «**Geometric Model**», describing the alignment of the structure in space as well as the cross-section geometry, and the «**Time Model**», describing the construction sequence and the structural behaviour during life-time.

In RM2006, the geometric model is created with the interactive graphic geometric preprocessor GP, whereas the time domain (definition of schedule data) is handled in the GUI of the analysis package RM. GP creates the model in terms of general entities and allows generating either simple models based on beam theory or complex models with 2 or 3 dimensional finite elements [2].

2.2 Creating the Geometric Model

The geometric pre-processor GP allows for easily defining the structural model of any bridge structure. Complicated geometric conditions can easily be considered by defining “axes” in plan and elevation view, with using all geometric elements (straight, circular, parabolic, spiral, etc) commonly known in road construction. The first step is therefore to define the appropriate superstructure axis as a section of the road or rail project. The superstructure itself is later related to this axis.

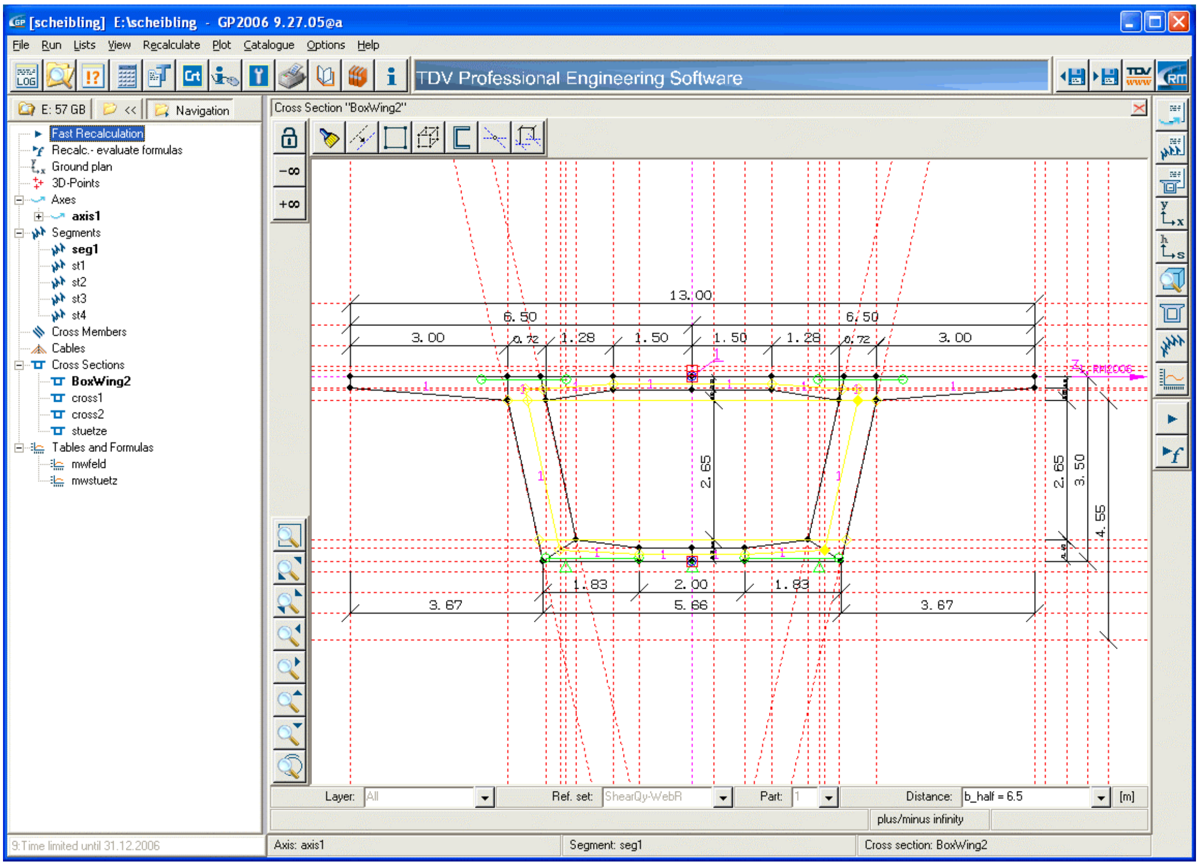


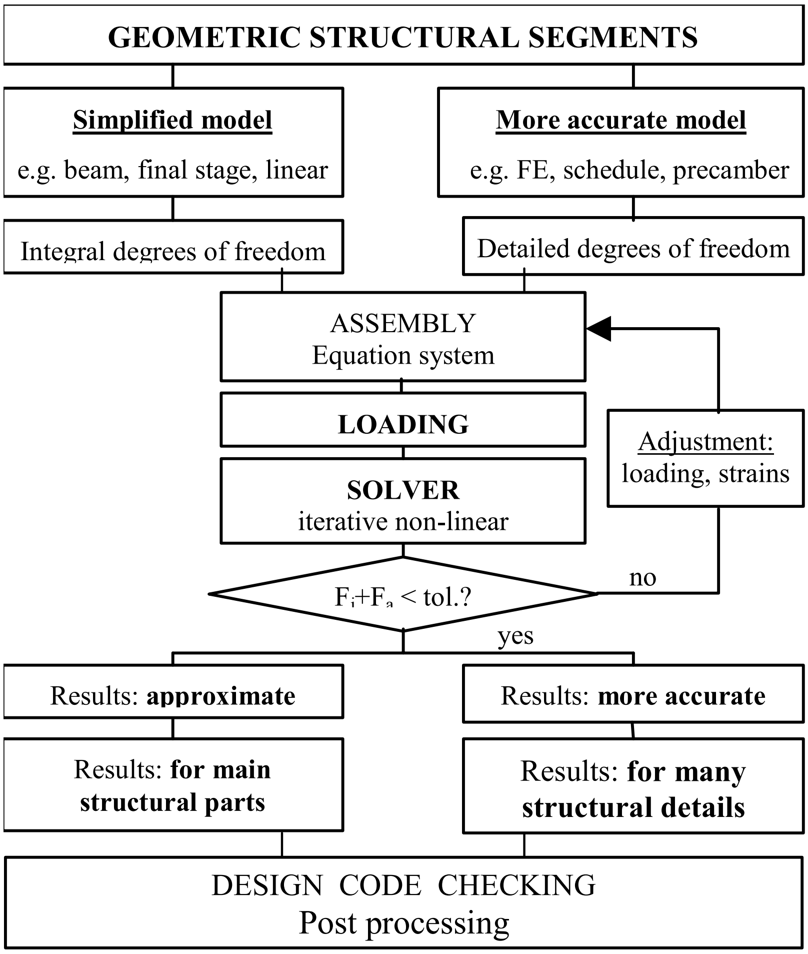
Figure 1: Interactive graphic construction of cross-sections

The second step is the definition of the relevant cross-sections. Extensive graphic input facilities allow for efficiently constructing any type of bridge cross-section on the screen. A range of similar cross-sections can be easily created by appropriately using “variables” for the decisive geometric parameters. These variables are functions of the “station”, i.e. the position on the previously defined bridge axis. Therefore, once the constitutive relations between the stations and the variable parameters have been specified, the correct cross-sections will be automatically allocated.

The third step – allocating the cross-sections to the axis – creates so-called “segments”. These segments relate the physical model to the structural model (elements, nodes) and contain the subdivision information and the relevant cross-section data for the subdivision points. Node coordinates, node numbers and element numbers of the structural elements are automatically created from these data, but the user can govern the numbering scheme by defining start numbers and appropriate increments.

2.2 Construction Schedule

Once the geometric model has been established, the model data are passed to the central analysis unit. The GUI of this program allows for defining the schedule data with any required fineness. This includes the definition of all impacts (loadings) occurring during construction and operation time. Different schedule variants can be defined, from assuming one total loading case acting on the final structure for performing a rough preliminary analysis, up to a very detailed approach, considering all different intermediate states occurring in the construction stages.



The time domain is considered from the very beginning by establishing a global time axis mirroring the time from the construction start during erection time and operation time to infinity. The different structural parts are activated and the loading is applied at the respective points in time corresponding to the construction process on site. The time dependent effects occurring in the intervals (creep and shrinkage) are fully considered on the correct structural system.

However, the “Schedule” is not only a reflection of the construction process on site, but a global framework [3] defining the scheduled behaviour of the structure as well as the required investigations, optimisations and proof checks for any intermediate state during construction, and for the final stage after completion and at infinity. Variations of the schedule – e.g. in order to find the most economic proceeding or to adapt it to unforeseen events like time delays – can be easily performed by modifying or adding “schedule actions” at the appropriate point in time.

3. PRELIMINARY DESIGN

The preliminary design works aim at getting sufficiently accurate bidding documents and contract specifications with a minimum effort. Therefore, these works are often done separately by using a simple program giving very fast approximate results. However, there is a big disadvantage, that any data prepared for this preliminary analysis cannot easily be used later for the detailed design analyses.

Using a consistent tool in any case increases the initial effort, because basic parameters allowing for a later sophisticated analysis have to be considered at the very first beginning. But in general, this slightly higher initial effort is fully compensated by the advantages gained in the detailed design phase. Additionally, the quality of the preliminary design is higher, because – with respect to saving time in the final design – a better mathematical model is already used in this phase.

However, in order to capitalise on these advantages, the software package must allow for very efficiently refining the mathematical model if required. This applies to the geometric model, for instance for later consideration of concrete haunches in the cross-section. But it mainly concerns the construction schedule, where allowable simplifications in the preliminary design are evident. Last but not least it also applies to calculation methods and global options, like considering or not considering precamber.

4. DETAILED DESIGN

The main task of the detailed design works is optimising structural details, dimensioning structural parameters like the required reinforcement, and in detail proof-checking the stability and durability of all structural parts – during construction and later in the operating stage. Therefore it is clear, that the used program must be able to perform all analysis tasks, which may arise in working on bridges of any type.
The RM program not only allows full non-linear mechanical analyses for all types of bridge structures (static and dynamic), but also contains special design check modules for proof-checking stability and serviceability in accordance with most national design codes worldwide. These checking functions include sophisticated checks for pre-stressed and reinforced concrete (fibre stress check, ultimate load check, shear capacity check, robustness check etc) as well as stability and failure checks for structures being at buckling risk.

The reinforcement design functions are included in these checking modules; they determine the required additional reinforcement if needed. This applies to the longitudinal reinforcement (bending, robustness) as well as to the shear reinforcement due to shear force and/or torsion.

With respect to accurately considering the structural behaviour in the time domain, it is worth while mentioning, that the program uses a consistent approach for properly taking into account all creep and shrinkage effects as well as steel relaxation. The respective constitutive relations as postulated by many design codes or institutes like CEB-FIP are provided in the standard database of the program.

Accurately considering traffic loading requires sophisticated superposition and load case exclusion functions as provided in RM. The evaluation of the traffic loading is based on “Lanes”, specified in the geometric model, and fictitious “Load trains” moving along the lanes. Influence lines are calculated for the different lanes, and for every relevant result value the load train is placed in the critical position.

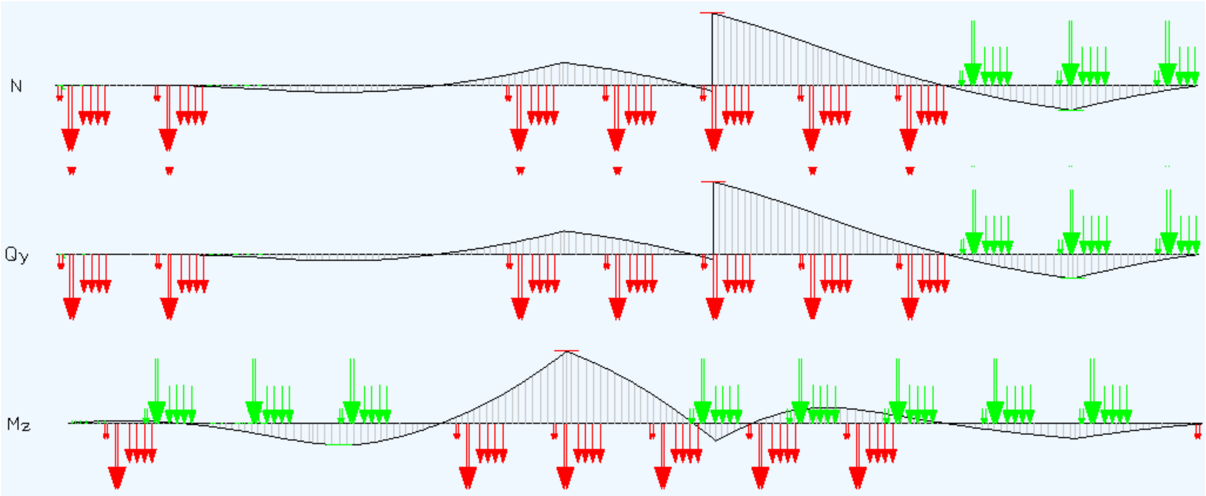


Figure 2: Influence lines and relevant traffic loading in accordance with Indian code

Evaluating the respective result values with the concurrent force components and superimposing the results of the different lanes gives the envelope of the worst stressing state.

5. DYNAMIC BEHAVIOUR

In the detailed design process, static analyses are often not sufficient for assuring safety, serviceability and durability of the structure. There are 3 areas of interest, where dynamic analyses are required: the earthquake response of the structure (if the bridge is located in a seismically active area), the effects of dynamic traffic loading (e.g. for high speed railway projects), and wind-induced vibrations (for cable stayed and suspended long-span bridges).

5.1. Earthquake Analysis

Performing dynamic earthquake analyses by evaluating response spectra has meanwhile become state-of-the-art for structures built in seismically sensitive areas. Working with static dummy loads is only allowed for minor buildings. Superimposing the relevant natural modes of the structure after factorising them with the appropriate participation factors gives the maximum amplitudes of the stressing state.

5.2. Rolling Stock Analysis

A time history approach is required for investigating the dynamic impact of vehicles passing a bridge [4].

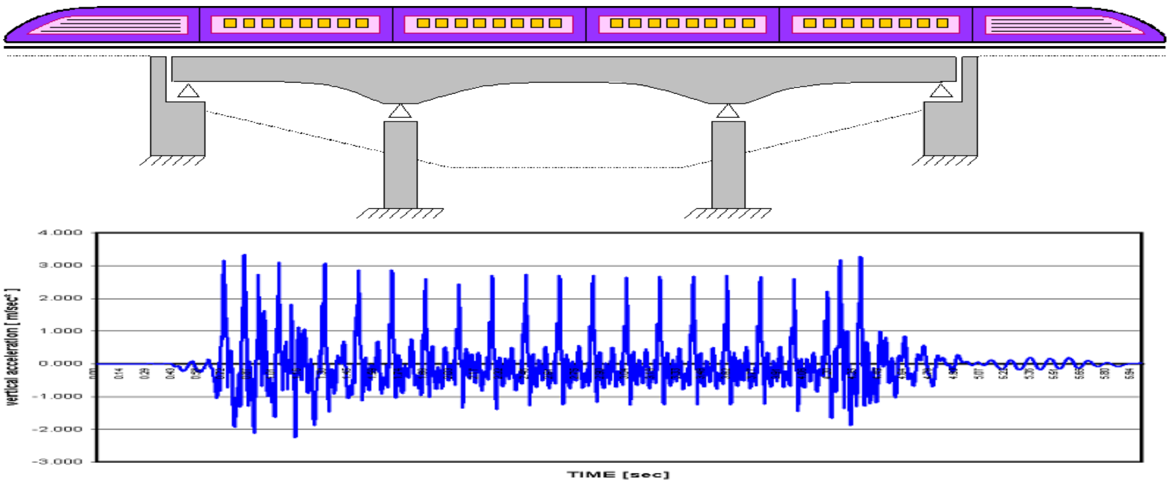


Figure 3: Vertical acceleration time history at mid-span due to a passing train

In order to consistently analysing the behaviour, moving masses and time dependent loading must be considered. The demand for these analyses arose due to the high-speed railway systems currently being established in many countries. RM contains a very efficient module for performing such complex rolling stock analyses.

5.3. Dynamic Wind Analysis

The wind related functions of RM match nearly all needs for the design of long-span bridges. Arbitrary complicated wind profiles with varying wind speed and turbulence intensity are easily defined. Together with the cross-section related shape factor diagrams defining the dependency of the drag- lift- and moment coefficients on the attack angle of the wind impact, these wind profiles allow a comprehensive wind buffeting analysis taking into account the varying along-wind and lateral forces of gusty wind events.

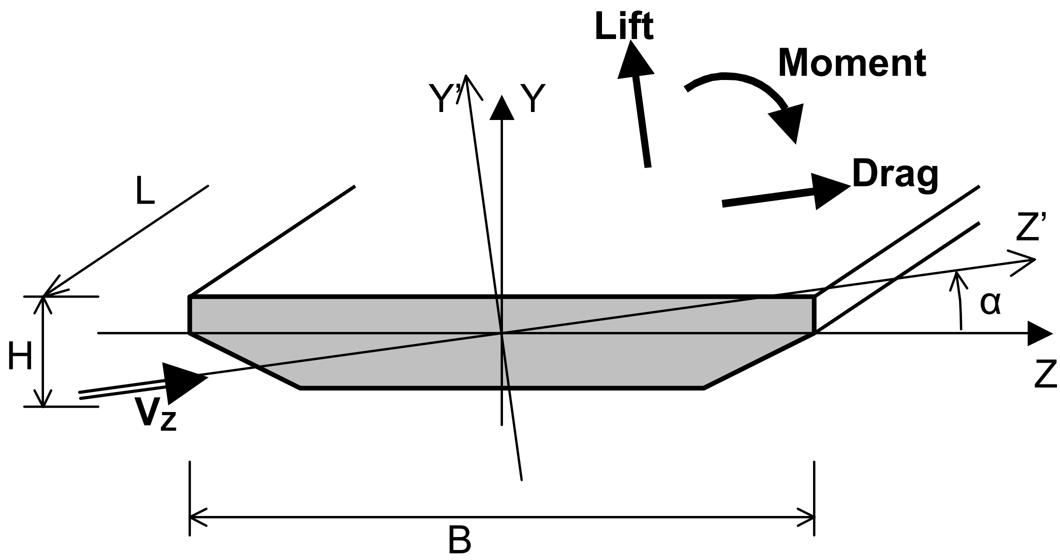


Figure 4: Wind forces acting on the bridge section

The structural wind buffeting calculation is performed in the modal space and in the frequency domain. It includes aerodynamic damping and stiffness effects due to structural movement caused by the wind flow. All computations are based on the tangential stiffness of the structure at a given point in time – the structure under permanent loading and mean wind – allowing for including all prior non-linear effects.

6. OPTIMISATION

Optimisation procedures (e.g. for evaluating the required stay cable stressing sequence in order to achieve a given maximum stress state in the superstructure or for optimisation of tensioning of temporary stays etc) are another great help in the design process. The algorithm implemented in **RM** models in detail every construction stage. The tensioning of each single cable is considered at first as a unit load case taking into account the current structural system and then influencing all previously applied unit load cases.

All other loadings (e.g.: self weight of the new segment, moving the traveller etc.) related to the individual erection procedure are also calculated step by step. All displacements and internal forces are accumulated and divided into one „constant“ (self weight etc.) and several „variable“ components. Each „variable“ component is related to one tensioning unit loading case and optimised in additional constraint module. Further details are given in [5].

7. PRE-CAMBER, ERECTION CONTROL

Another outstanding functionality of RM is the erection control facility. TDV’s erection control module allows not only predicting and monitoring the bridge erection process but also solves forward and backward problems in the bridge design process. RM is able to run structural analyses in different calculation modes controlled by the user.

In the design practise, the engineer chooses the target geometry and a force/stress distribution in the service state. In the erection control mode with automatic kink correction, RM fits the structure into the target position and constrains the chosen force/stress distribution by calculating segment fabrication shapes, stress free lengths of the cables, section shop-forms and a pre-camber line for each stage. The program gives information if force action on site is necessary by assembling the new segments. This allows determining any necessary equipment and possible construction problem already in the early design stage.

This analysis results in design values of fabrication shapes and stress-free cable lengths. These values form the basis for establishing the formwork on site or for producing the individual pre-cast segments. However, despite accurate fabrication, deviations from the target shape may arise in the erection process. RM is now capable to determine the required corrections in the erection control mode. Any deviation from the predicted pre-camber line is input as a loading, and the program supports the engineer to fix the future changes in the erection steps by using the inbuilt optimisation tool.

8. SUMMARY

The use of specialized software tools considerably enhances the bridge design project due to allowing for using one basic geometric model for all required design tasks. Specialised programs like **RM2006** contain a consistent framework allowing for starting with a rough model for preliminary design and continuously refining it in accordance with the actual needs in the design process.

Recent developments even allow for proceeding beyond the traditional design phase, to erection control and erection monitoring tasks. Based on the model used for the design, any deviations in the erection phase can be controlled and eventually necessary adaptations of the erection schedule or method can be easily designed.

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