Computer-aided design and analysis of multiple Tee-beam bridges

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SYNOPSIS

Bridge girders consisting of multiple parallel pre-stressed Tee-beams are often analysed as grillage systems. Such grillage systems can be categorised and the analysis of such systems can be automated to a high degree exploiting common features of such multiple Tee-beams. A study has been undertaken to define these features and to form the basis for a computer method for the analysis and the design checks of multiple Tee-beam bridges. Application examples given in this paper illustrate this method and its application in a computer program.

1 INTRODUCTION

Multiple Tee-beams are often chosen as structural systems for bridge girders. Reasons for this choice over other possible systems are manyfold (1). Multiple Tee-beams allow for savings in material in comparison with hollow boxes, and thus also reduce the self-weight which is advantageous in unstable soil conditions. Tee-beams are easier to cast than other cross-section forms and the formwork is simpler to assemble. The girder height is generally rather small which is often an important argument in urban areas. Changes in width of the roadway can be implemented simply by changing the number of Tee-beams (Figure 1). The option of using pre-cast members is often advantageous when overpasses must be erected over roadways under traffic conditions. A survey by the IABSE organisation in 1979 found that 71% of multiple Tee-beams are in fact double-Tee-beams. Typical examples for multiple Tee-beams have span lengths of 20m to 35m and a section-depth-to-span ratio of no less than 1/20.

Figure 1. KS7 Selzthal (Austria) – Transition from double Tee to quadruple Tee-beam.

Multiple Tee-beams are generally rather easy to erect but pose unique challenges for the structural analysis and the design. An ongoing research project at the Centre for Construction Technology and Research (CCTR) at the University of Western Sydney deals with the computer modelling, the analysis and the computer-supported design of such structures. This paper will report on some of the findings.

2 SOME MODELLING ISSUES

General

A structural computer model of a multiple Tee-beam bridge must reflect the true response of the planned structure under the expected loading situations given by the respective design codes. Numerous analytical and numerical approaches exist with which this goal can be achieved to a satisfactory level of precision. Most commonly used computer models nowadays consist of beam elements or finite elements (2). Literally all relevant design codes base their checking rules on beam theory which oftentimes makes the use of numerical methods other than beam theory cumbersome. Finite element models may give more accurate results for certain structural details but such models do not provide the specific information needed to perform design code checks (3). It is for this reason that this paper will be limited to reflections regarding grillage models of multiple Tee-beam bridges (4) consisting of series of longitudinal beams representing the Tee-beams connected laterally by cross-beams representing the roadway slab (Figure 2). Much useful information on this topic can be found in Hambly (5).

An adequate model for a multiple Tee-beam bridge must reflect the following structural properties:

- *Response of the structure under vertical loading*. The longitudinal elements under purely vertical loading each have a certain stiffness and interact with each other via the roadway slab modelled by cross-beams. The decision of how the deck is split and how the cross-beams are connected to the longitudinal system is important. Among other issues it is important to note that the centre of gravity for each member often differs from the centre of gravity of the complete bridge deck. Effective width considerations of the bridge deck elements must be implemented.
- *Response under horizontal loading*. The shear centre and the centre of gravity are typically not aligned for horizontal loading. The horizontal loading must therefore be applied at the correct level to create the correct effects in the deck. Effective widths considerations for horizontal loading usual differ from the considerations for vertical loading.
- *Torsion*. Transmission of loading from one longitudinal beam to the next is done via bending of the cross-beams which in turn leads to torsional loading of the longitudinal beams. Since the torsional stiffness of open cross sections such as Tee-beams is rather small this issues must be addressed carefully. Cross-members located at the supports and piers commonly compensate for torsional effects.

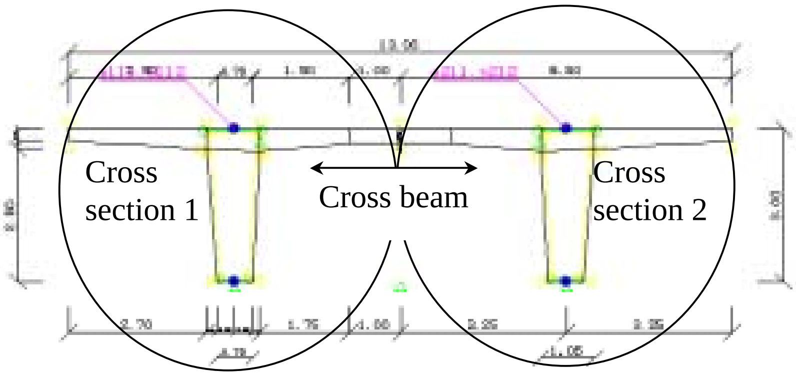

Figure 2. Cross-section of a double-Tee-beam.

Geometry of the Structural System

Bridge structures have a three-dimensional geometry and the structural system for a computer analysis must reflect this. Simplifications into two-dimensional models often neglect important effects and are therefore not appropriate. Modern software tools for bridge engineers should provide the means to define a detailed 3-D representation of a given bridge structure. In order to model the exact geometry of a multiple Tee-beam bridge attention must be paid to a number of important details. The plan view and the elevation of such bridges are governed by the specific geometric requirements of the road allignement (Figure 3). These requirements also have repercussions on the geometry of the cross-section along the bridge. The cross-fall of the road slab leads to inclined top slabs and Tee-beams with different height levels. Skew ends are often found in such bridges and attention must be paid to model these support conditions correctly. These geometrical requirements often have significant structural effects and should all be considered in an appropriate structural model. The exact modelling of the geometry of off-ramps and road widenings also poses challenges to the geometry pre-processor of any bridge design software.

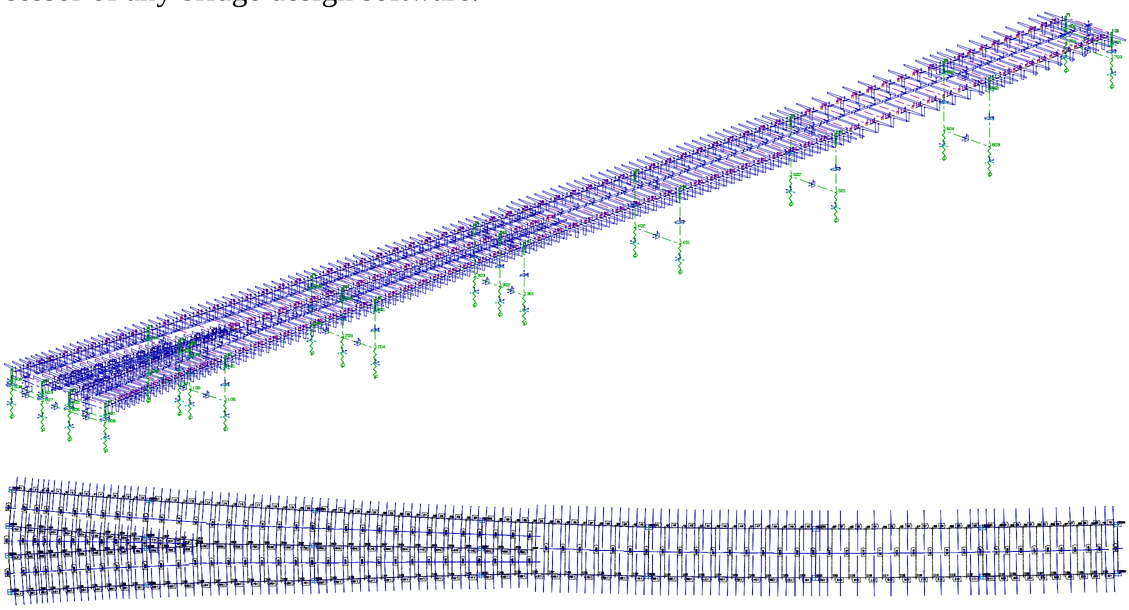

Figure 3.Axonometric and plan view of KS7 Selzthal (Austria).

Time Axis

In the construction of multiple Tee-beam bridges a number of construction stages are involved during erection. Especially when composite systems are involved it is important to model all stages of the structure during construction precisely. Composite systems for such structures include concrete-steel but also concrete-concrete composite cross-section where onsite-concrete slabs are poured on top of pre-cast beams. Time-dependent effects are important factors in concrete structures and must be considered adequately. Bridge design software supporting the design of such bridges must have the facilities to define the time schedule precisely, handle composite cross-sections and give correct results for all occurring time-dependent effects.

Pre-Stressing & Post-Tensioning

In a concrete Tee-beam the centre of gravity is often close to the top of the cross-section. The eccentricity of pre-stressing or post-tensioning tendons is therefore less above the supports than it is in mid-span leading to high secondary moments. These high secondary moments often compensate large portions of the primary effects leaving the designer only the axial compressive forces to work with. Often internal grouted tendons are deemed sufficient by the bridge designers but in some regions a combination of internal and external pre-stressing tendons is used. Bridge design software should have all necessary functionality to support the bridge engineer in finding the most efficient pre-stressing scheme for each individual girder.

Roadway Slab

The roadway slab represented by the cross-beams requires a few considerations. The connection of the cross-beams with the longitudinal Tee-beams governs the introduction of torsional moments into the Tee-beams (Figure 4). Oftentimes a rough model for this slab is sufficient in order to represent the global structural behaviour of the slab-beam system. If a more detailed approach is desired then two approaches are common: either the slab can be modelled in greater detail or the response of the rough overall model is used as boundary conditions for a separate model for the transversal analysis of the roadway slab. Bridge design software should be flexible enough to handle all these design approaches.

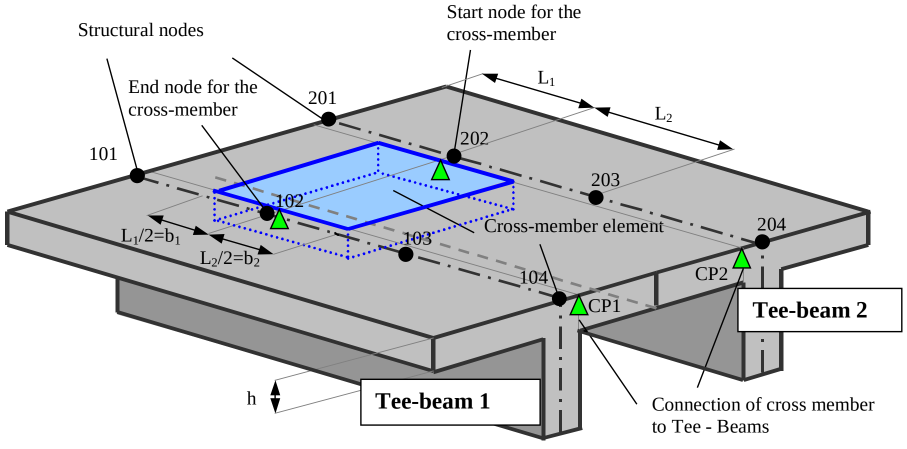

Figure 4. Definition of cross-members representing the roadway slab.

Multi-Span Pre-Cast Tee-Beams

A common way of assembling multi-span Tee-beam bridges is to use simply supported pre-cast Tee-beams supported between piers at first which are subsequently connected by cast onsite concrete slabs. The casting sequence of the concrete slabs is often geared towards reducing the locked-in stresses in the final composite system. Shear connectors between pre-cast beams and concrete slab ensure that forces are transmitted fully between the slab and the pre-cast components. In Australia, the Super-Tee system is an example for this method. More often than not such structures are rather un-spectacular bridge structures for which the design follows proven standard procedures. However, when attempts are made to increase the efficiency of such structures many details must be taken into account during the structural analysis correctly. Computer programs supporting the bridge designer must have the capability to support the analysis of these effects.

- The change in structural system at the piers where the pre-cast beams are simply supported at first and made continuous by the concrete slab at a later time.
- Differential creep and shrinkage in the individual parts of the concrete-concrete cross-section.
- Change in cross-section properties including the shift in the centre of gravity due to the addition of the concrete slab.
- Removal of temporary props where these are used for the initial stage.

Design Aids

Automated design checks for SLS checks and ULS checks should be available and the section capacity should be provided by the software. Individual load combinations with different intensity factors for different combinations must be prepared and managed by the software package supporting the design of bridges in general. ULS checks require that equilibrium of cross-section capacity and external loads of all components around the centre of gravity of the relevant cross section must be achieved. The design of various details such as the shear connectors between individual cross-section parts in composite sections are also important. Bridge design software must give feedback for all these design issues and support the engineer in making economical and technically sound decisions.

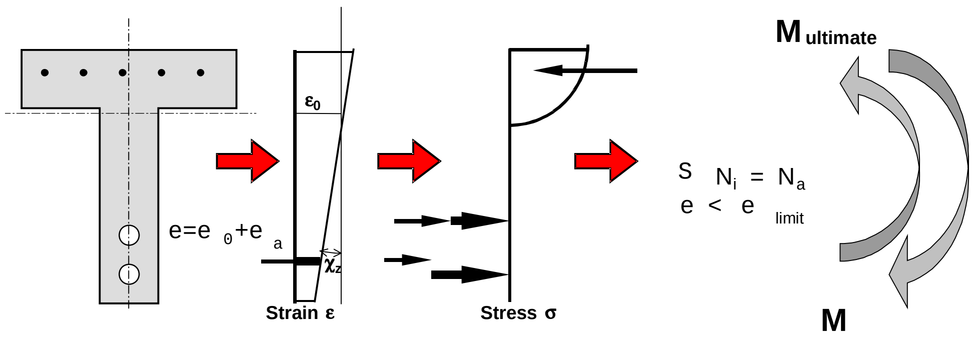

Figure 5. ULS check for a Tee-beam.

3 IMPLEMENTATION

The design and analysis functions for multiple Tee-beam bridges as described in the previous sections have been implemented into a proven bridge design package called *RM2000* (6). The software is centred around an object-orientated data base. A specific bridge-orientated pre-processor supports the input of the exact geometry of multiple Tee-beam bridges. The construction schedule can be defined to simulate the evolution of the structure during erection and to include all information to automatically consider time-dependent effects. Cross-section properties are computed automatically for all stages and updated according to the construction stage. Interactive functions support the definition of the tendon layout in three dimensions and gives immediate feedback on the stress distribution in the tendons as soon as stressing actions are defined. Load combinations are prepared according to the respective requirements and automated design check procedures use these combination results.

4 APPLICATION EXAMPLE: *MUUGA BRIDGE*, ESTONIA

A nine-span double Tee-beam bridge was designed recently for a highway project near Tallinn, Estonia. The design height of the bridge girder was limited to 1.7m and the span arrangement was set to 25m+7x35m+25m. The bridge had to be designed for three traffic lanes which resulted in a girder width of 10.8m and a width of the traffic area of 9.0m. The decision for the double-Tee-beam as the structural system for the bridge girder was governed by the rather extreme slenderness required by the design brief. The bridge allignemet was to be straight in plan view but curved in elevation. Design was to be performed according to Eurocode EC2. The structural system of this bridge is shown in Figure 6.

For the construction stages the individual Tee-beams were pre-stressed internally (Figure 7). For the final stage additional external post-tensioning was introduced (Figure 8). Cross-beams made from steel provided lateral support for the two Tee-beams and also served as deviators for the external post-tensioning. Two of the eight piers are skew by three metres in both directions complicating the geometry of the bridge girder.

The design of this bridge was supported by the software package *RM2000* (6) which included the functionality described above. The saving in time and effort in comparison with a less integrated approach were considerable.

5 CONCLUSIONS

The design of bridges consisting of multiple Tee-beam girders requires much attention to specific details. Computer software supporting the bridge design engineer should be able to give the required structural feedback on these specific details. Pre-processing tools should be available to enable the exact structural description of the three-dimensional bridge geometry, analysis tools should be available to simulate the structural response of such a structure and automated design check procedures should be available to support the optimisation of the bridge according to individual design codes. This paper describes the requirements of such a bridge design software and reports on the implementation of these requirements into an existing bridge design package. An application example illustrates the points raised in this paper.

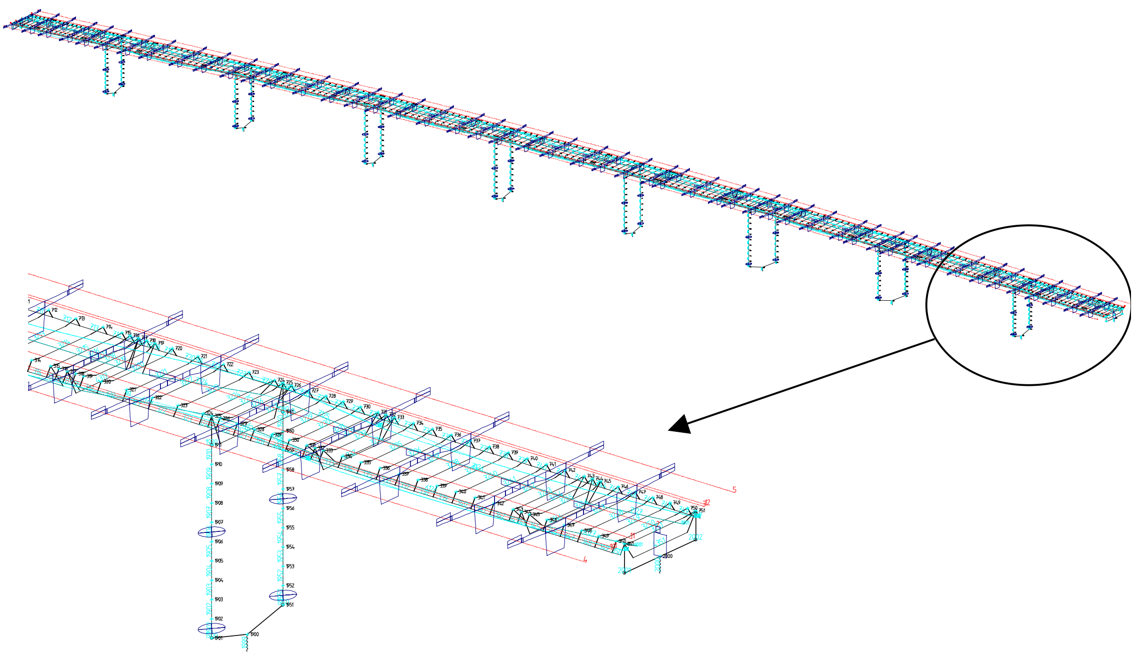

Figure 6. Structural system of the Muuga Bridge.

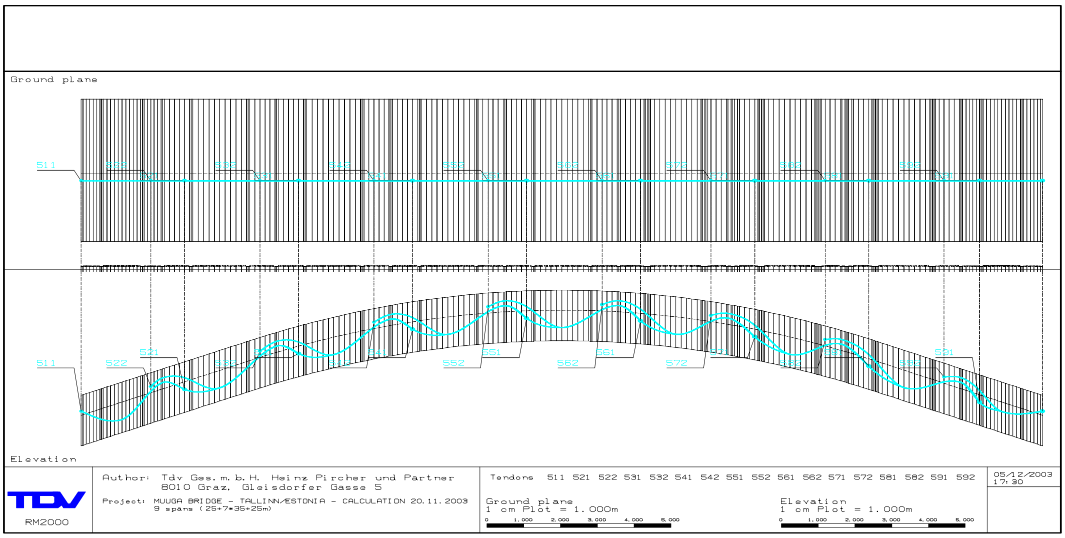

Figure 7. Layout of the internal tendons.

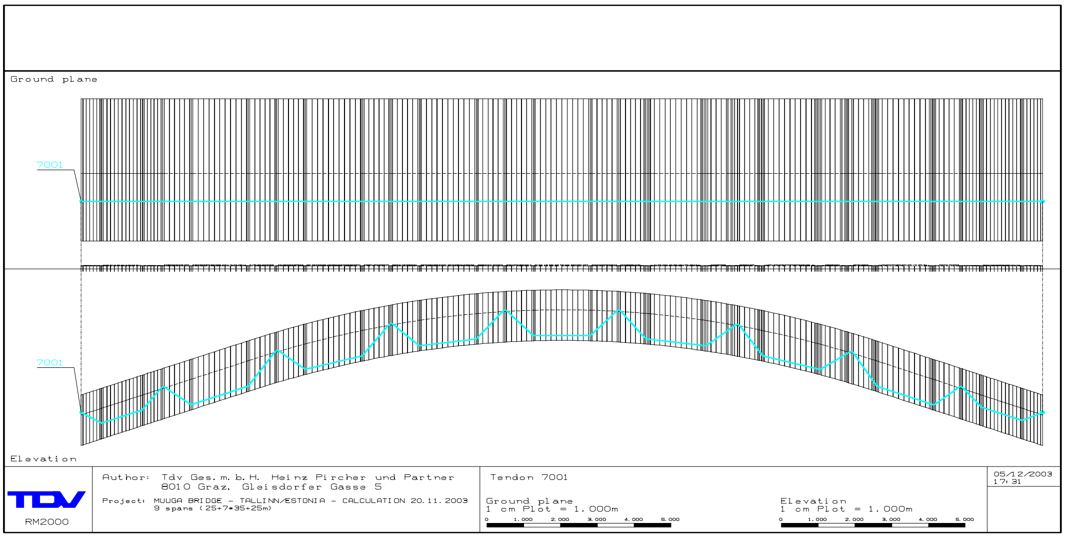

Figure 8. Layout of the external tendons.

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