Erection Control Analysis - Meeting the Demands of New Construction Techniques

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Summary

New bridge construction techniques such as the pre-cast segmental construction method yield special requirements for the design and proof checking process. In the case of stage-wise erection, an exact calculation of the bridge deformations arising throughout the construction schedule - and therefore the definition of the required pre-camber values and fabrication shapes - was for long time an almost insoluble problem.

An appropriate tool allowing for getting the ability to determine the effects of constraining the structure into a certain pre-defined position at any stage of construction has recently been provided. The respective erection control facility accurately controls the position and the forces in the segments in stage-wise built structures. The presented erection control tool also supports the definition of required compensation measures due to deviations from the scheduled position.

Keywords: Erection Control, geometry control, pre-camber, pre-cast segmental construction

1. Stress-less Geometry – Camber

A common requirement in bridge engineering is that the final bridge shape (after deformations due to permanent loads have occurred) should comply with the theoretical design shape. Therefore, in order to compensate the deformations, the main girders of bridge structures are usually "pre-cambered" during construction. In some cases this deformation compensation process is also applied to other structural parts, such as for instance the pylons of large cable-stayed bridges.

Whenever geometrically linear structural behavior can be assumed, the required camber values - commonly denoted camber-line - can be directly derived from the deflections calculated on the design structural system. An iterative procedure is required if the structural behavior is non-linear.

A new comprehensive approach, which can be used in both linear and non-linear analyses, has therefore been developed. This approach was first presented in [1] and is based on defining the required prefabrication shape as initial strain loading applied on the structural system in addition to the actual external loading. This initial strain loading is modeled with special load types describing element deformations as differential displacements or rotations of the element ends with respect to the connected structural node.

2. Erection and Geometry Control - Principles

The erection geometry can only be seriously controlled using a precise structural analysis that considers all the structural stages occurring during the construction of the bridge as well as the effects from the pre-fabricated shapes (where applicable) of the elements.

The basic principle of classic structural analyses is that elements are connected to the common nodes, representing the degrees of freedoms in terms of displacements and rotations. Difficulties arise if the "face to face" connection is somehow modified in the construction process, or if the segment geometry is deviating from the design state.

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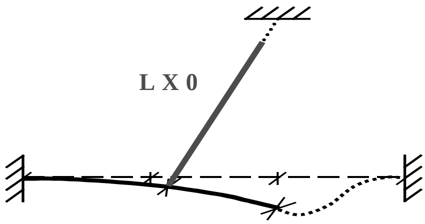
Standard structural analysis codes can obviously not be used anymore after inserting displacement constraints at element faces. Element stiffness properties, including both linear and non-linear geometric terms, have to be transformed accordingly [3], and the local coordinate system of structural elements (defining local forces) is changed.

$$\left\{\delta^{I}_{Elem}\right\} = \left\{\delta^{I-1}_{Elem}\right\} + \left\{\delta^{I-1}_{Node} - \delta^{I-1}_{Elem}\right\} + \left\{\delta^{Kink\_Correction}_{Elem}\right\} \quad (1)$$

One of the most important application fields of the new method is the design process of cable-stayed bridges with optimizing the stay cable tensioning process, as the actual cable forces very much depend on the deformation behavior of the structure during construction. The "real" (stress free) fabrication shape of segments and cables has to be applied to the structure to get sufficiently accurate results. The fabrication shape of cables is purely the stress free length of the cable as shown in Figure 1.



Six input values are needed for defining the stress free fabrication shape of a beam segment as presented in Figure 6. With activating the option “Erection Control”, appropriate changing the structural system is done automatically by the software.

The application of stress free fabrication shapes changes the stiffness matrix and adds additional loading terms. Structural assembling can easily be done using the option "Automatic Kink Correction". This option constrains each reactivated element to the displaced active structure.

3. Pre-cast Segmental – Segment Geometry

Producing bridge segments in a factory under constant and controlled environmental conditions increases the overall quality due to more possibilities for influencing the casting process. Therefore, in the case of pre-cast segmental erection it is essentially important to determine very accurate fabrication shapes because the prefabricated segments must fit together when they are assembled on site and later correction measures on already prefabricated segments are difficult to be performed.

4. Construction Engineering – Compensation Measures

Main application field of the erection control functionality is in construction engineering. When – as it is mostly always the case – different parties using different analysis programs perform design and construction engineering respectively, required pre-camber values are given to the construction engineer in form of Excel tables or construction drawings. The construction engineer has to make sure, that those specifications are meaningful and fit into the intended design shape.

5. Application example – Stonecutters Bridge

The Stonecutters Bridge is a high level cable-stayed bridge, which spans the Rambler Channel in Hong Kong, connecting Nam Wan Kok, Tsing Yi Island and Stonecutters Island. With a main span of 1018 m it will have the second longest cable-stayed span in the world after Sutong Bridge has been completed. The program RM has been used for static analyses and for detailed pre-camber analyses defining the exact shape of the individual segments. It is now regularly used in the construction phase for checking any irregularities occurring during construction.

6. References

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