Load-bearing reserves of existing bridges

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Summary

The Extended Technical Bending Theory (*ETB*) enables to calculate the state of strain of reinforced and pre-stressed concrete cross-sections stressed by any combination of the stress resultants M_y, M_z, T, V_z, V_y and N. When using the *ETB,* no additional models are required to determine the shear-bearing capacity of these cross-sections. In some specific cases, the more realistic results obtained using the *ETB* identify additional load bearing reserves in existing bridges. Some current examples for the application of the *ETB* will be presented.

Keywords: extended technical bending theory; cross-section dimensioning; shear-bearing capacity; load-bearing reserves; maintenance of bridges; concrete bridges.

1. Introduction

For verifications of the cross-sections, there are normally two main combinations of stress resultants which have to be analysed: bending moments and/or normal force ($M+N$) and shear forces and/or torsional moment ($V+T$). The Technical Bending Theory (*TB*) can only deliver the corresponding state of strain for the combination $M+N$. For the determination of the shear-bearing capacity several different models have been developed. The compatibility criteria of these models should be fulfilled in the ultimate limit state (*ULS*) by empirical equations for the inclination of the compression struts. For this reason, truss models can only deliver the approximate stresses and strains in serviceability limit state (*SLS*). Also the interaction of the combinations $M+N$ and $V+T$ on each other is only considered in *ULS* by the inner lever arm z, the inclination θ and the shift rule. At the moment there are no interaction rules for the calculation in *SLS*.

2. The Extended Technical Bending Theory

A solution for this problem is the Extended Technical Bending Theory [1, 2]. This theory makes it possible to calculate the state of strain of thick-walled cross-sections stressed by any combination of the six stress resultants, even for non-linear materials like reinforced concrete. The *ETB* delivers the strains orientated at the coordinates x and z (ε_x, ε_z and γ), the principal strains and stresses (ε_1 and ε_2, σ_1 and σ_2) with their orientation (φ and θ) and the reinforcement stresses (σ_{sl} and σ_{sw}). Additionally the curvature u can be displayed, because the cross-sections are no longer assumed to stay plane. Because the *ETB* fulfils the equilibrium criteria as well as the compatibility criteria, it describes any load level. By defining stress limits in *SLS* and strain limits in *ULS* the *ETB* enables to base all verifications for reinforced and pre-stressed concrete cross-sections on one single theory.

To integrate the shear forces and the torsional moment into the strain calculation, it is necessary to consider the transverse strain ε_t and the shearing strain γ. This integration means that other models for the calculation of the shear-bearing capacity are no longer required. The resulting state of strain can only be determined by iteration. Therefore the cross-section is divided into single panels and panel elements. For the solution of the correlations at the element level, it is assumed that the principal stresses and the principal strains are coaxial.

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3. Verification of the ETB

To verify the *ETB* and the necessary simplifying assumptions, several documented tests were recalculated using the *ETB*. The comparison of the failure loads and the failure reasons demonstrates convincing conformance between test results and calculations. For example test TA4 documented in [3]: the test failure load was 468 kN*;* the failure load according to the currant German standard is 274 kN (41.5 % difference), the failure load according to the *ETB* is 443 kN (5.3 % difference). Furthermore two large-scale tests were performed to compare the stresses in the reinforcement over the whole load range. The convincing results were published in [2].

4. Applications of the ETB

4.1 Example 1: DB AG railway crossing bridge near Stelle (Lower Saxony)

This bridge was built in 1976 and consists of 12 single-span pre-stressed concrete superstructures. The transverse beams at the ends are also pre-stressed and transfer the loads to reinforced concrete columns with shallow foundations. There is no visible damage to the superstructures and transverse end beams. According to *DB AB guideline 805* assessments of the structural safety of this bridge have been done at different accuracy levels. Approximate calculations according to level 2 deliver β_{UIC} values of 0.55 and 0.57 – controlled by the shear capacity of the transverse end beams. Exact calculations according to level 3 using a structural model with maximum accuracy deliver β_{UIC} values of 0.72 and 0.82 – once again controlled by the shear strain in the transverse end beams. So by agreement with *DB AG* the *ETB* was used for subsequent calculations. The comparable load coefficients according to level 3 using the *ETB* result in values of β_{UIC} = 1.2 and 1.5. The safety of the structure is therefore proven.

4.2 Example 2: Two-span road bridge near Viernheim (Hesse)

In the case of a two-span road bridge near Viernheim a decision was to be made on whether the bridge should be repaired or replaced by a new bridge. One special characteristic of this bridge was that there were only very small amounts of shear reinforcement. Recalculations according to German standards showed that shear forces could only be partly absorbed by the existing reinforcements. When the same bridge was recalculated using the *ETB*, the required safety reserves could be proven for bridge category 30/30 in all areas. But for load model 1, the required safety reserves could not be achieved in all areas, even using the *ETB*. The minimum safety reserve was 1.08, which is smaller than the value required. Because the decision on whether to repair the bridge or to demolish and replace it was influenced not only by considerations of structural safety but also by financial considerations and by the overall state of preservation of the bridge, the road construction authorities decided to demolish the bridge and replace it.

5. Conclusion

These examples demonstrate that the *ETB* is particularly suitable for calculations involving existing reinforced and pre-stressed concrete structures with varying cross-sections. Using the *ETB*, load-bearing reserves can be utilized which could not be identified using traditional methods.

6. References

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