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Analysis of Dismantled Bridge Girders

Analyse des poutres de ponts démontés

Analyse von demontierten Brückenträgern

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SUMMARY

Post-tensioned prestressed bridge girders subjected to a heavy long-term service were experimentally tested and numerically analysed. A nonlinear method based on the finite element beam layered model and a three-dimensional nonlinear brick elements of a commercial package were used to verify the experimental results. Load-deflection curve, detailed examination of crack propagation, influence of environment, bearing capacity and the influence of bonded and partially bonded tendons were among the most important factors.

RÉSUMÉ

Des poutres précontraintes de ponts soumises à de lourdes charges de longue durée ont été soumises à des essais et analysées numériquement. Une méthode non-linéaire par éléments finis et un modèle tridimensionnel ont été utilisés pour une comparaison avec les résultats d'essai. Les facteurs les plus importants étaient la dépendance entre charge et flèche, l'examen détaillé du développement des fissures, l'influence du milieu, la force portante limite et l'influence des câbles partiellement et complètement injectés.

ZUSAMMENFASSUNG

Die mit nachträglichem Verbund vorgespannten und sich im Betrieb unter langfristigen und schweren Lasten befindenden Brückenträger wurden experimentell geprüft und numerisch analysiert. Die nichtlineare Methode, die auf dem Stab-Schnitt-Modell und auf den nichtlinearen dreidimensionalen Elementen von Computer-Programmen beruht, wurde zur Überprüfung von experimentellen Ergebnissen verwendet. Die Belastungs-Durchbiegungs-Kurve, die Detailuntersuchung der Rissentwicklung, der Umgebungsfaktor, die Grenztragfähigkeit und der Einfluss von injektierten und teilweise injektierten Kabeln gehörten zu den wichtigsten untersuchten Faktoren.

1. INTRODUCTION

Experimental testing of dismantled structures can bring valuable information about their behavior under specific conditions. Present study describes the experimental testing and following numerical modeling of two girders of a dismantled road overbridge near Lipnik and two girders of a road bridge near Vsestary, Czech Republic. These testing provided us with a unique chance for detailed investigation, evaluation of structural performance and verification of loading capacity of prestressed concrete girders after a long service life. An advanced numerical analyses using nonlinear FEM technique respecting real behavior of girders were carried out.

2. EXPERIMENTAL TESTING

2.1 Lipnik overbridge

2.1.1 General description

Lipnik overbridge was built as a temporary one. For 20 years it was subjected to heavy loading and aggressive environment being above a railway. It was necessary to dismantle the overbridge mainly due to damages of supports and bridge accessories. Two selected girders were tested and numerically analyzed. Girders were slightly damaged during dismantling.

2.1.2 Materials

The quality of concrete was very high, up to 10 per cent higher than the design required with the strength in a range from 62 to 71 MPa. Real dimensions of the girders were carefully measured and compared to design parameters. Surface degradation of concrete by chlorides was not deep due to the high quality of concrete and did not influence the bearing capacity of the girders. The worst chloride damages were found in anchor regions but the strength of prestressing cables was not decreased. Material properties like strength of concrete in tension and compression and stress-strain diagram of prestressing steel were examined. Nine pieces of 50mm diameter cylinders were used for material tests of concrete of each girder. Prestressing steel properties were determined from 42 test specimens for girder L1 and 45 test specimens for girder L2.

2.1.3 Load tests

Girders were gradually loaded and unloaded respecting the load increment corresponding to 20 per cent of the design load. The girders L1 and L2 collapsed due to crushing of concrete at the load level of 260 per cent. The first visible cracks were identified in the cross-section of rusted stirrup applying the load level of 120 per cent. Other cracks were found at the load level of 140 per cent. The girders were cut in two cross-sections after the tests had been finished to investigate the location of prestressing cables. Some cables were found to be fully bonded, some of them partially bonded and some of them unboded, eventually rusted. These tests were prepared and supervised by the second author, and more details can be found in [1].

2.2. Vsestary bridge

Vsestary bridge was built of 19m span girders in 1969. A poor design and the details workmanship caused water leaking into the structure. Some of the edge girders were damaged by frozen water and lengthwise cracks were detected especially in the bottom slab. The bridge was partially dismantled and two girders were selected for experimental testing. Material tests, measurements of dimensions and the way of loading were similar to the previously described testing. The first girder (V1) was loaded up to 262 per cent of the design load when the loading was stopped due to large deflections but the girder did not collapse. Girder V1 represented moderately damaged girders of the bridge. Girder V2 suddenly collapsed at the level of 217 per cent of the design load due to the crushing of concrete. This girder was highly deteriorated by leaking water and chlorides and partially damaged during dismantling. The first author had a chance to participate the testing and collected all necessary information.

3. NUMERICAL ANALYSIS

All four girders were numerically tested using alternative methods based on the nonlinear finite elements procedures. Real dimensions of the girders taking into account local damages, measured locations of prestressing cables and results of material tests were used as an input data.

3.1 Beam layered model

A beam FEM layered model similar to [2], that has been successfully used and verified for several analyses of reinforced and prestressed girders ([3]) were also adopted here .

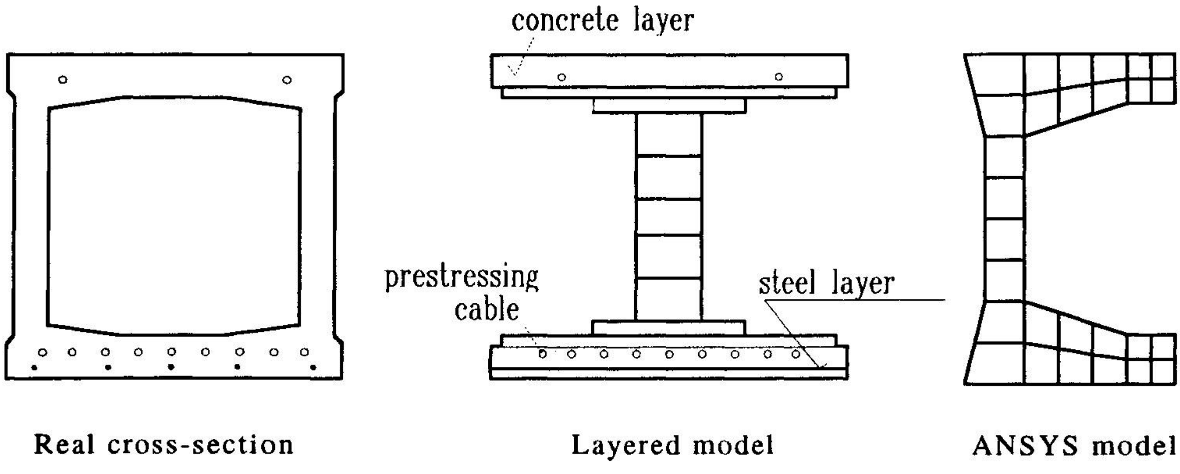

Fig. 1 - Modeling of cross-section

3.1.1 General description

The model respects nonlinear behavior of materials, time dependent volume changes like creep and shrinkage, a history of loading and prestressing and partially bonded/unbonded cables. Time-dependent analyses with estimated values of loads and creep parameters were performed to calculate the level of stress in prestressing cables at the beginning of load tests. Real cross-section of girder L1 and corresponding layered and ANSYS models are shown in Fig. 1. Fig. 2 demonstrates girder L1 with its prestressing cables.

3.1.2 Simulation of load tests

A combination of incremental method and Newton-Raphson iteration technique was used to perform the solution. Load increments in the numerical analysis corresponded to the load increments of the test, usually 20 per cent of the design load. Equivalent load was applied as concentrated forces at the same location like the forces of load test.

3.1.3 Numerical simulation

A full Newton-Raphson method with the change of a stiffness matrix after each iteration was found to be the most suitable method because of quite fast convergence requiring up to 15 iterations per load step. Beam models are simple from numerical point of view. A full nonlinear analysis was completed within a few minutes on PC 486 computer.

3.2 Nonlinear brick model

A commercial finite element method package ANSYS [4] was also used to confirm numerical results. 3D nonlinear reinforced concrete brick element SOLID65 was adopted to discretize the girders and model the properties of concrete. Offset nodes beam element BEAM44 was used for prestressing cables. The same level of load increments and the full Newton-Raphson iteration technique were applied here. FEM discretization of girder V1 using 2842 brick elements and 2504 beam elements is shown in Fig. 3. 3D analyses offer very sophisticated results but are quite complex from numerical point of view. The results were available on the same computer like beam analysis in 67 hours. One should consider whether improved results worth such increasing of computation time. ANSYS models were developed as a part of [5].

3.3 Parametric studies

3.3.1 Time-dependent analysis

Several parametric studies have been carried out for a better understanding of the behavior of the girders. The most important study was related to the calculations of the level of prestressing before tests started. Various values of creep parameters and loads were considered in these analyses to obtain an estimation of stress in prestressing cables at the beginning of load tests.

3.3.2 Real cracks modeling

The propagation of cracks were carefully investigated during the load tests. The location of cracks were monitored for all load increments. This enables us to carry out the analysis respecting real cracks regions. For this parametric study the layered beam model was used Cracked layers were not determined by calculation but were directly input as pre-defined data for all load increments. This study helped us to assess the accuracy of the method.

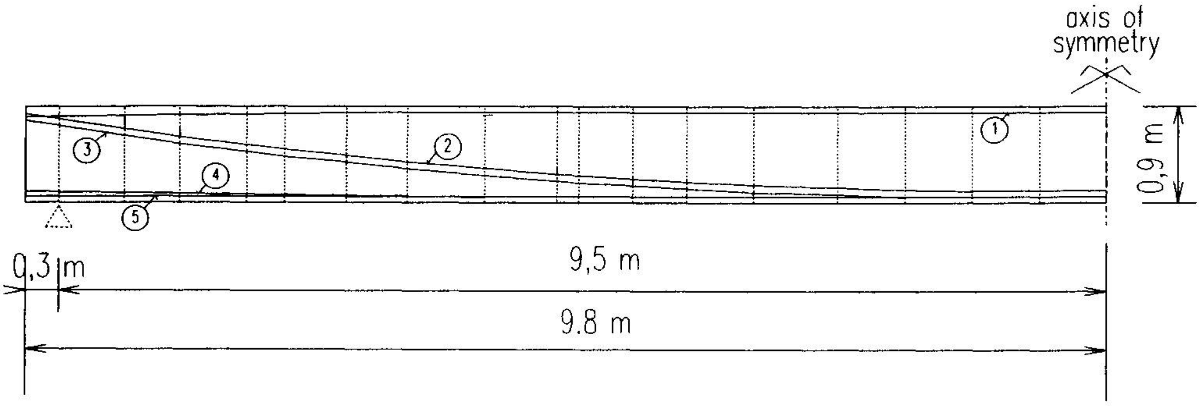

Fig. 2 - Girder L1 - Layered Model

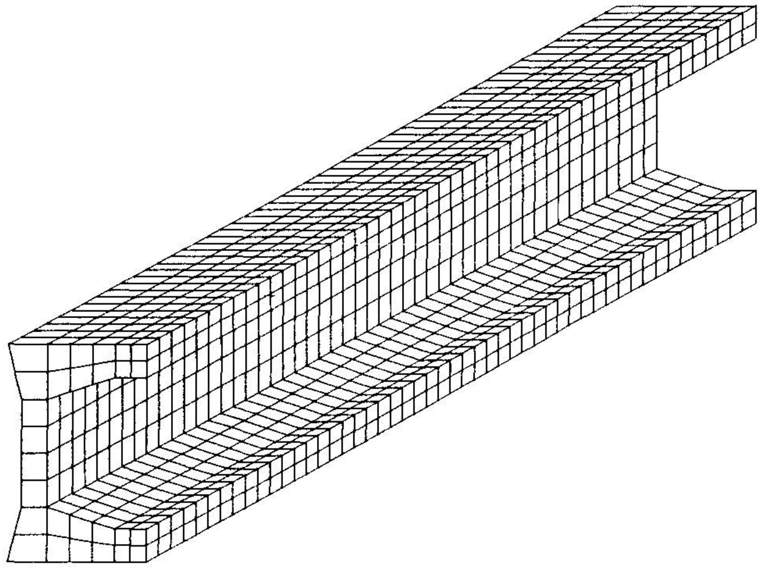

Fig. 3 - ANSYS model

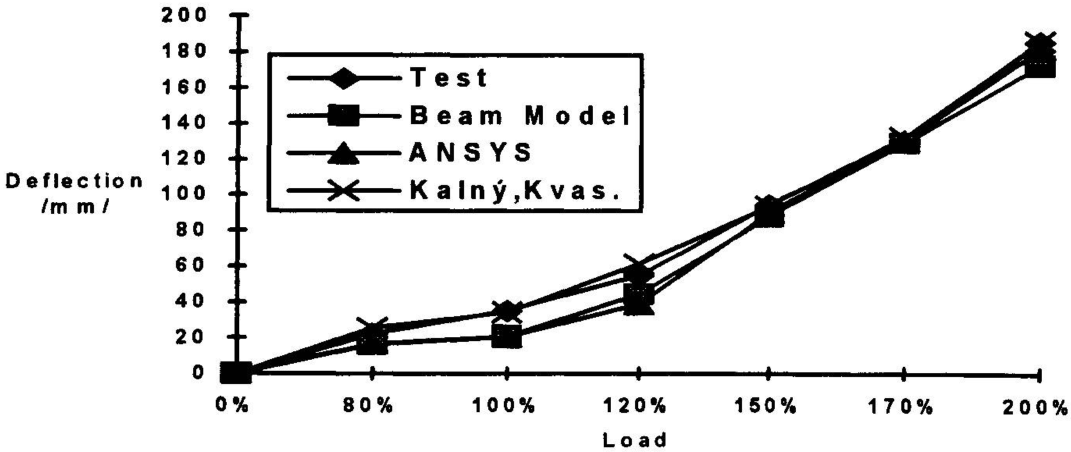

Fig.4 Load-deflection Curve for Girder V2

3.3.3 Bonded and unbonded cables analyses

Girder L1 was analyzed considering the prestressing cables fully bonded, unbonded and partially bonded as described during experimental investigation. The bonded cables were included in the stiffness matrix and perfect connection with concrete was assumed. The unbonded cables were not included to the stiffness matrix and their strain was dependent on the deformation of the girder and the value of friction parameter. A special procedure was developed to model the behavior of partially bonded cables.

4. RESULTS

Load-deflection curves for girder V2 are shown in Fig.4. Girders V1 and V2 were analyzed also by Kalný and Kvasnička [6] using nonlinear 2D plane strain elements for concrete and beam elements for prestressing cables. Girders L1 and L2 satisfied ultimate load requirements as confirmed by experimental tests as well as numerical analyses. Deterioration of anchor regions was not acceptable for further serviceability of the girders.

5. CONCLUSIONS

Experimental as well as numerical analysis confirmed expected general assumptions. Numerical results were in a good agreement with experimental results and the influence of the most important factors investigated showed an assumed behavior. It was confirmed that numerical models suitable and verified for the analysis of prestressed girders can also be adopted in the process of evaluation of dismantled structures after a long service life in case of taking into account the above factors. These numerical models can, under certain circumstances, replace or reduce expensive experimental load tests.

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