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Prestressed Concrete Box Girders

Poutres en béton précontraint à section en forme de caisson

Vorgespannte Betonkastenträger

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Introduction

The behaviour, in the post-cracking phase, of reinforced or prestressed concrete box girders subjected to eccentric loads is complex due to the anisotropy and non-linearity of the concrete, the non-linearity of the steel, and, not least, to the change of structural topology due to the initiation and propagation of cracks.

Experimental investigations of reinforced or prestressed concrete beams have been mostly restricted to the determination of crack widths and crack spacing, and to the establishment of empirical relations for the assessment of the ultimate load carrying capacity. Recently Ngo and Scordelis (1) have reported an elastic finite element analysis of reinforced concrete members in which the cracks must be prelocated on the basis of prior knowledge. A linear spring linkage was introduced to represent the bond between steel and concrete. Nilson (2) extended this approach by taking into account the non-linearity of the materials and by simulating the deterioration of bond by using non-linear springs. This approach, however, only allows development of cracks along predefined element boundaries and requires the preparation of new input data after each crack initiation. It does not consider directly the redistribution of stresses due to the energy released by cracking, nor does it consider box girders.

An automatic incremental iterative finite element procedure for the complete analysis of post-tensioned box girders (3) has been developed which takes account of many of the above problems. The three dimensional character of the girders is synthesised and structural actions such as shear lag, load diffusion, and distortion of the box are automatically included in the analysis. The effect of diaphragms of given shear and warping stiffness placed anywhere in the structure can be investigated. To prove the program, a series of twelve post-tensioned simply supported, but torsionally restrained, single cell box girders were tested to destruction under various midspan bending moment/torsion moment ratios (4). The strain distribution, first cracking load, crack pattern, deflection characteristics, and collapse load were compared with those predicted by the analysis.

Analytical Procedure

The flanges and webs of the box are represented, in the usual way, by finite elements lying in the appropriate planes and interconnected at their nodes. Rectangular and triangular membrane elements are used to idealise the concrete, and bar elements are used for the longitudinal, transverse, and shear reinforcement. The steel elements are connected to the adjacent concrete elements at the common nodes. Although the flexural stiffness of the elements forming the structure is neglected, the distortional stiffness of the box is simulated in the assembly of the structural stiffness, as explained later.

The structure is first analysed as an ordinary reinforced concrete one, the prestress being applied as external forces. The contribution of the prestressing steel to the overall stiffness is neglected since, at this stage, the steel is unbonded. For the subsequent application of external loads, the prestressing steel is assumed to be bonded to the concrete and the prestressing steel element stiffnesses are included in the overall structural stiffness matrix.

The external loads are applied in small steps, the element stiffnesses for each load increment being deduced from the state of strain at the end of the previous load step, and from the predicted strain increment for the current load step. The superposition of strains to obtain the total strain is carried out along fixed although arbitary axes.

Material Properties

At the engineering level, concrete in its hardened state can be considered as having no directional dependence as regard its mechanical and physical properties. However, different strain levels are attained in the principal directions of an element after each increment of load. As a consequence, the instantaneous "elastic" constants in the two principal directions differ. The concrete is, therefore, treated as an isotropic material with the principal directions of elasticity coinciding with the principal directions of stress. In the absence of any quantitative evidence, it is assumed that the stress-strain relationship for concrete in a biaxial state of stress is the same in the two principal directions, and is identical to the one for uni-axial state of stress (5).

The stress-strain relationship for prestressing steel was obtained experimentally, and a third degree polynomial fitted to the results by linear regression analysis. For all other reinforcement, a single bi-linear law based on experimental results was adopted.

Diaphragms and Distortional Rigidity

The shear stiffness of a diaphragm is simulated by considering it to be an ordinary plane stress rectangular element connected at its nodes to the four corners of the box. Since the flexural stiffness of the elements is not included in the analysis, the warping restraint provided by the diaphragm is calculated on the basis of a square plate subjected to four self equilibriating corner loads. For the case of rectangular diaphragms, an equivalent square plate is adopted.

The distortional rigidity of the box is simulated by introducing imaginary diaphragms of appropriate shear stiffness at each mesh line.

Structural Stiffness

The stiffness of the structure is redefined at the beginning of each load increment to take into account the non-linearity of the materials and the partial loss of stiffness of newly cracked elements.

Once the principal tensile stress in a concrete element exceeds the allowable tensile stress, a crack is assumed normal to its direction and passing through the centroid. The inclination of the crack remains fixed thereafter. The element after cracking cannot sustain stresses normal to the direction of the crack. For an element with two nodes common with a prestressing steel element, the loss of stiffness due to cracking is made gradual to correspond to the increasing deterioration of bond with load.

The forces released by cracking are redistributed using the stiffness of the elements corresponding to the tangent moduli of elasticity at the time of cracking. Normally, after the first redistribution of the release forces, a search is made for further cracking and the new release forces are applied with the next load increment. However, an option is retained in the program such that it is possible to carry on redistributing release forces until no further cracking takes place, or until less than a given number of elements crack.

The box girder is assumed to fail due to the deterioration of the structural stiffness matrix caused either by high compression in the concrete or by excessive cracking, or by "local" yielding of the steel. If the analysis fails by one of these causes, the load increment is reduced and a reanalysis carried out.

Comparison of Analytical and Test Results

The analytical results obtained for the girders of the previously mentioned test program were compared with the experimental results (6). The girders had spans of 4.57 m and 2.74 m and had various span/depth ratios. The mid-span bending moment/torsion moment ratios investigated were 0, 1.0, 1.5, 2.0 and ∞. For the data reported here, the dimensions and reinforcement of the girders were as in fig. 1, the mid-span bending moment/torsion moment ratio for girder B6 was 1.0 and that for girder B7 was 2.0.

The analytical history of loading for girder B7 is given in table 1. The second load increment was made three times the size of the first load increment. The analysis failed at a downward web load of 60.0 kN plus the release forces due to 41 elements cracking. The failure was due to excessive steel strain. The downward web load was then reduced to 50.0 kN, and the release forces due to 41 elements that had previously cracked, but which had been carried forward to load stage V, were applied. This caused a further 30 elements to crack, and when the release forces corresponding to these were applied, the analysis again failed due to excessive steel strain. The downward web load was reduced to 45.0 kN and further iterations carried out with release forces due to cracking. The girder was subsequently analysed at smaller load increments in order to establish the first cracking load, and the deflection characteristics, more accurately.

Fig. 2 shows the analytical and experimental results obtained for the deflection at the point of application of the downward web load at mid-span for girders B6 and B7. It can be seen that reasonable agreement was obtained throughout the whole of the load history.

The first visual cracks in the test on girder B6 were recorded at a downward web load of 27.9 kN. In the analysis 2 elements cracked at 25.0 kN and a further 7 elements cracked at 30 kN.

The first visual cracks in the test on girder B7 were recorded at a downward web load of 21.9 kN. In the analysis 4 elements cracked at 20.0 kN and a further 26 cracked at 25.0 kN.

The 'safe' theoretical values for the downward web collapse load were 50.0 kN for girder B6 and 45.0 kN for girder B7. The corresponding collapse loads were 50.8 kN and 46.8 kN.

The predicted crack pattern for girder B7 is shown in the left hand half and the experimental crack pattern is shown in the right hand half of fig. 3. In the analytical crack pattern, the longitudinal cracks due to transverse bending are shown to extend for the full length of the beam. These cracks were not computed by the program and are only intended to show the expected position of the transverse bending cracks. It should be pointed out that the analytical crack pattern is only a reasonable representation of the cracks occurring in individual elements.

Conclusions

Comparison of analytical and experimental results shows that the method is capable of predicting deflections, crack patterns, first cracking loads and collapse loads with reasonable accuracy.

References

1) NGO, D., and SCORDELIS, A. C., Finite element analysis of reinforced concrete beams. Journal of American Concrete Institute, 1967, 64 (March) 152 - 163.

2) NILSON, A. H., Finite element analysis of reinforced concrete. Ph.D. thesis, University of California, Berkeley, May 1967.

3) TRIKHA, D. N., An analytical and experimental investigation of post-tensioned single cell box girders. Ph.D. thesis, University of London, October, 1971.

4) TRIKHA, D. N., and EDWARDS, A. D., An experimental study of post-tensioned single cell box girders. Paper submitted to Journal of American Concrete Institute.

5) DESAYI, P., and KRISHNAN, S., Equation for the stress-strain curve of concrete. Journal of American Concrete Institute, 1964, 61 (March) 345 - 350.

6) TRIKHA, D. N., and EDWARDS, A. D., Analysis of concrete box girders before and after cracking. Paper submitted to Institution of Civil Engineers.

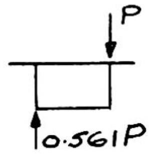
Load Stage	Increase in downward web load kN	Total downward web load P(kN) + (no. of cracked elements loading structure)	Distributed cracked elements. 1st iteration	Carried over cracked elements	Remarks
I	-	-	-	-	Prestress only
II	10.0	10.0	0	0	
III	30.0	40.0	104	67	
IV	10.0	50.0 + (67)	65	41	
V	10.0	60.0 + (41)			Steel strain > 0.015
IV(a)					
(i)	0.0	50.0 + (41)	-	30	
(ii)	0.0	50.0 + (30)	-	-	Steel strain > 0.015
IV(b)					
(i)	5.0	45.0 + (67)	-	56	
(ii)	0.0	45.0 + (56)	-	42	
(iii)	0.0	45.0 + (42)	-	31	
(iv)	0.0	45.0 + (31)	-	10	Time lapse

Table 1

History of loading (analysis) for Beam 7

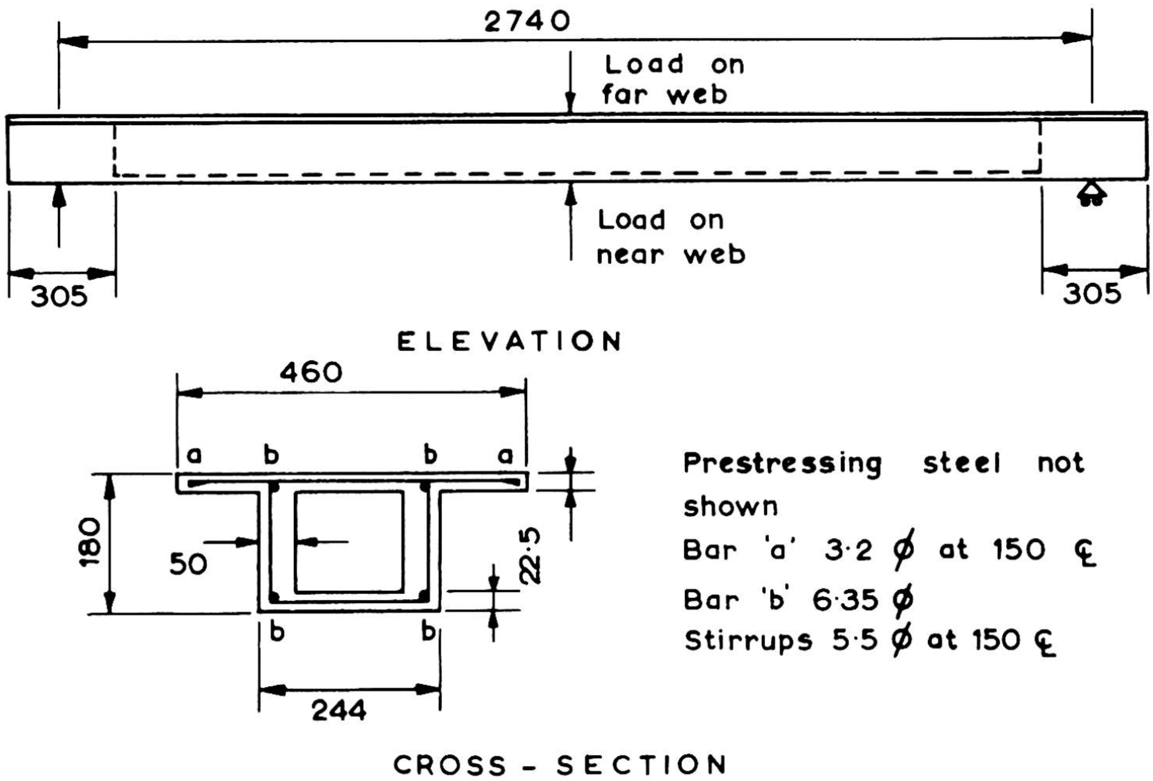


Fig. 1 Girder dimensions and reinforcement

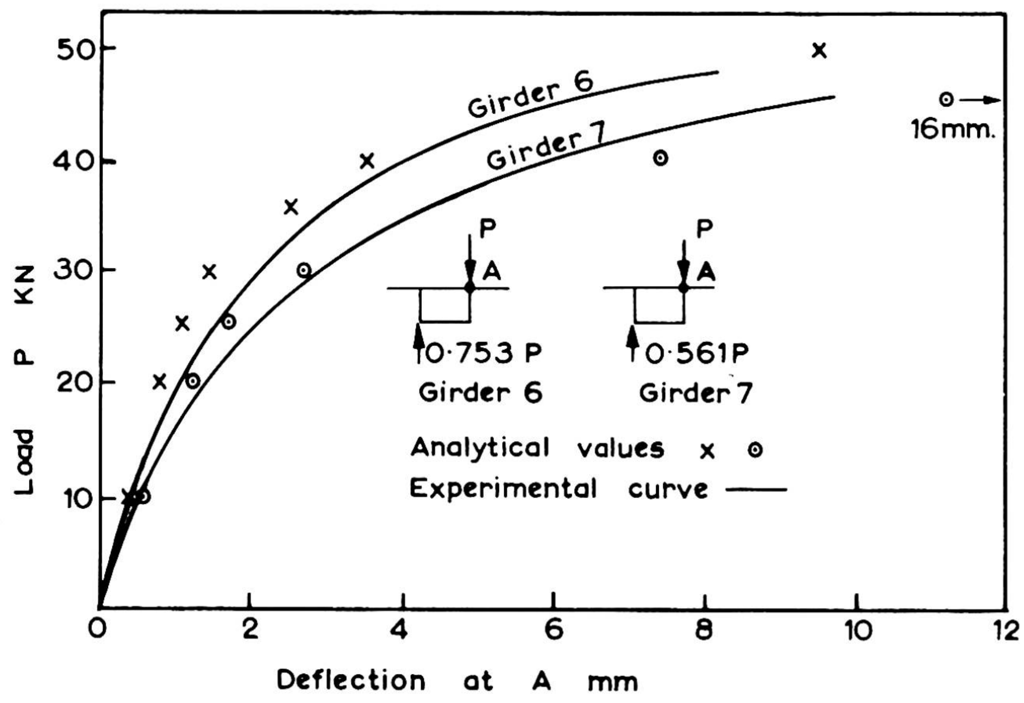


Fig. 2 Vertical deflection

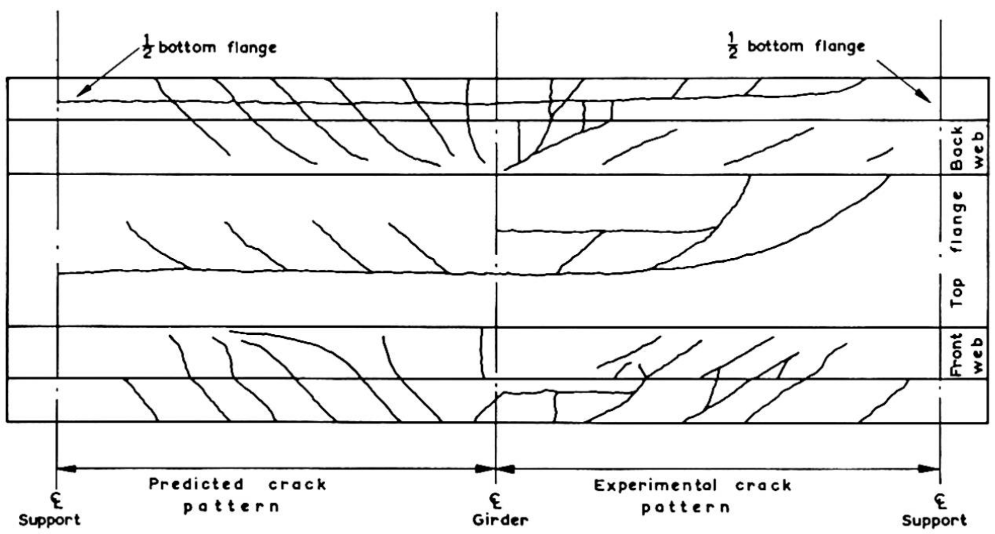


Fig. 3 Predicted and experimental crack patterns Girder B6

SUMMARY

An automatic incremental iterative finite element procedure for the analysis of post-tensioned box girders subject to combined bending and torsion in the uncracked and post-cracking range is reported. The results of the analysis of two post-tensioned single cell box girders, each subjected to a different midspan bending moment/torsion moment ratio, are given, and compared with the experimental results obtained from the corresponding concrete model tests.

RESUME

Ce travail présente une méthode progressive d'analyse itérative automatique, basée sur les éléments finis, pour l'étude de poutres en caisson précontraintes soumises à la flexion et à la torsion dans le domaine non-fissuré et le domaine fissuré. On nous donne ici les résultats de l'analyse de deux poutres en caisson "post-tendues", soumises toutes deux, au milieu de la portée, à différents rapports moment de flexion/moment de torsion. Ces résultats théoriques sont comparés ensuite avec les résultats obtenus lors de tests sur des modèles correspondants en béton précontraint.

ZUSAMMENFASSUNG

In diesem Beitrag wird ein Verfahren zur Berechnung von nachgespannten Kastenträgern unter kombinierter Biegung und Torsion im ungerissenen und gerissenen Zustand vorgestellt. Das iterative und automatisch wachsende Verfahren beruht auf endlichen Elementen. Die Rechenergebnisse von zwei nachgespannten, einzelligen Kastenträgern, von denen jeder in der Mitte durch ein anderes Verhältnis Biegemoment zu Torsionsmoment belastet ist, werden aufgezeigt und mit verschiedenen experimentellen Ergebnissen verglichen, die aus den entsprechenden Modellversuchen gewonnen werden.

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