ANALYSIS OF PC BEAM WITH CORRUGATED STEEL WEB USING ACCORDION LINK ELEMENT

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1. RESEARCH OBJECTIVE

This research aims at developing a simple 2-D analysis model for simulating the accordion effect of corrugated steel web, which leads to a practical design method for concrete-steel hybrid PC girders.

2. 2D ANALYSIS MODEL OF CORRUGATED STEEL WEB

2.1 Formulation of accordion link stiffness. Let us examine a trapezoidal portion of the corrugated web cut out at the center of two inclined plates as shown in **Fig. 1a**. When the elastic trapezoidal strip of a unit depth is subjected to two opposite forces P at its ends A and B (**Fig. 1b**), the relative displacement of A and B in the direction of P is obtained as

$$\Delta = \left(\frac{1}{k_N} + \frac{1}{k_M} \right) P \qquad (1)$$

where $k_N = E_s\, t/(b+2s\cos^2\theta)$, $k_M = E_s\, t^3/12\, s^2 \sin^2\theta\, (b+2s/3)$, and E_s is Young's modulus of steel web. P/k_N and P/k_M indicate the relative displacements due to axial force and bending, respectively. The relative displacement Δ in **Eq. (1)** is exactly obtained from the 1-D bar-spring model **(Fig. 1c)**, in which inclined legs of the original trapezoid are replaced by horizontal strips with a reduced length $s\cos\theta$ as well as an equivalent thickness $t' = t/\cos\theta$ and a spring of stiffness k_M is inserted in series. In the 2-D FEM analysis, each trapezoidal portion of the corrugated web is replaced by the equivalent bar-spring model of **Fig. 1c**, in which a 2-D zero-size link element **(Fig. 2)** is used in place of the spring: the vertical spring of each link element is given a very large stiffness k_v to fully transmit vertical shear force Q; the stiffness k_h of the horizontal spring is given the value k_M multiplied by a vertical mesh size.

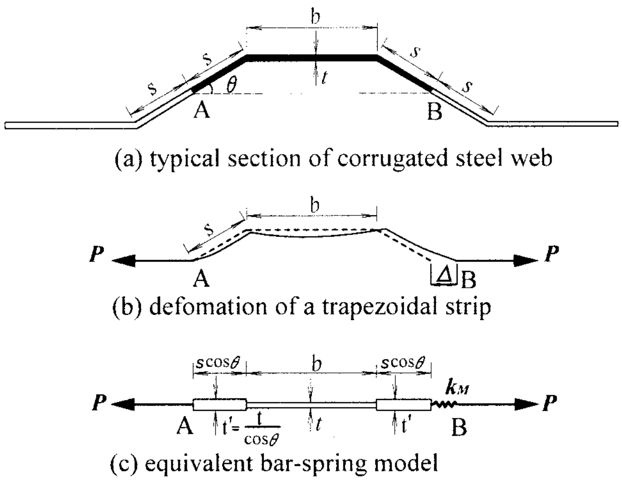

Fig. 1 Simplified model of corrugated steel web

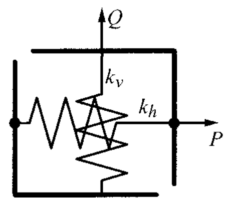

Fig. 2 2-D link element

2.2 Reduced shear stiffness. Almost uniform shear stress, τ, is developed in both longitudinal and inclined panels of the corrugated web under a vertical shear force[1)]. Since the inclined panel is modified to a longitudinal panel of an equivalent thickness $t' = t/\cos\theta$ in the proposed model, its calculated shear stress is reduced to $\tau\cos\theta$. A modified shear modulus, G', must be introduced in order to obtain an equal strain energy between the original corrugated web and the proposed 2-D model. With this definition, we find the reduced shear modulus of $G' = G\cos^2\theta$ for the modified panel with an equivalent thickness t'.

3. ANALYSIS OF PC BEAMS

To illustrate the effectives of the proposed method, 2-D FEM analyses of two PC beam specimens with corrugated web are performed. The dimensions and boundary conditions of Specimen 1[2)] are shown in **Fig.3**. More detailed dimensions and material properties of the Specimens 1 and 2[3)] are given in **Table 1**.

Key words: corrugated web, accordion effect, hybrid structure, prestressed concrete, finite element analysis
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3.1 Strain distribution induced by prestressing. 1300 MPa stress was introduced in each of four tendons (1S21.8) located in concrete flanges of the Specimen 1. In **Fig.4** the distribution of normal strain at midspan, obtained by the proposed 2-D model, is compared with the measured values. The numerical results for beams with concrete and flat steel web are also plotted. Normal strain in the corrugated steel web decreases rapidly to zero over its central portion.

3.2 Cross-sectional distribution of axial strains under a vertical load. In **Fig. 5** the experimental distribution of axial strains across the midspan cross-section in Specimen 1, for the loading condition of P1=100kN and P2=0, is compared with those from two analysis models, namely the beams either with corrugated web or with flat web. The strain distributions in the corrugated web show good agreement between the numerical and experimental results which represent the apparent accordion effect, whereas the strain is linearly distributed in the flat web as expected.

3.3 Load-deflection curve. **Fig. 6** compares the numerical load-deflection response of Specimen 2 under a vertical load at midspan with the corresponding experimental result. Although the numerically predicted failure load agrees well with the experimental value, the analysis model cannot simulate the shear buckling of the corrugated web which was witnessed during the test.

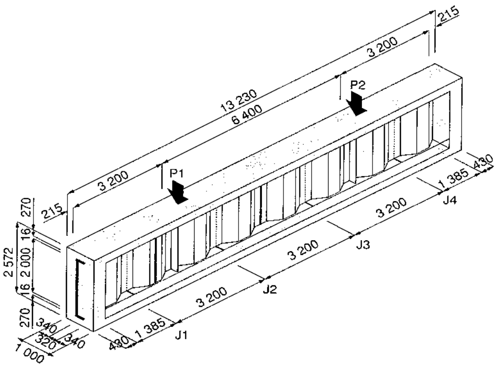

Fig. 3 Test Specimen 1[2] (in mm)

Table 1 Dimensions and material properties

Dimensions (cm)	Specimen 1 [2]	Specimen 2 [3]
span	1280	420
beam depth	257.2	173.2
concrete flange	27x100	25x80
steel flange	1.6x32	1.6x25
steel web	0.9x200	0.32x120
wave hight	22	6
panel length	43	10
material properties		
concrete strength (MPa)	37.9	58
concrete Young's modulus(GPa)	23.8	39.2
steel yield strength(MPa)		
flange	352	297
web	352	403
reinforcement	294	343
tendon	1570	911

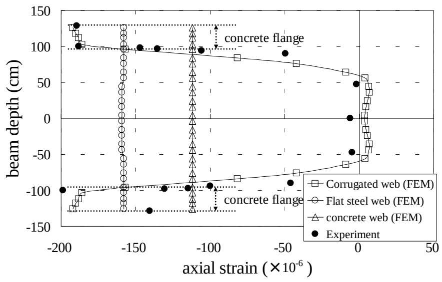

Fig. 4 Distribution of axial strain by prestressing

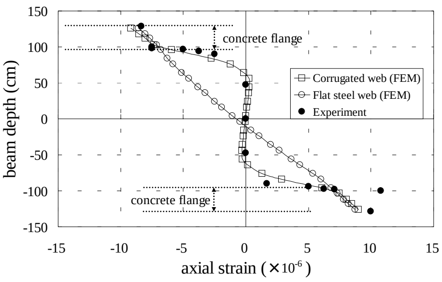

Fig. 5 Distribution of axial strain under a vertical load

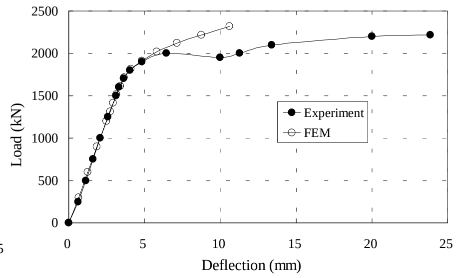

Fig. 6 Load-deflection curve

4. CONCLUDING REMARKS

The proposed 2-D modeling was successful in representing the 3-D accordion effect of corrugated steel web on the strains induced by prestressing, deflection curve and strain distribution under vertical loading. The use of corrugated steel web has a strong effect on the distribution of axial strain over the web due to its accordion effect.

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