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Experimental Study on Composite Beams Prestressed with Wire Cables

Essais sur des poutres mixtes précontraintes par câbles

Experimentelle Untersuchung von durch Drahtseile vorgespannten Verbundträgern

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1. Introduction

The idea of prestressing a steel bridge with wire ropes originated with F. DISCHINGER, but several points were left for further study before the method could be applied under practical engineering conditions to a continuous composite girder, and consequently the following experimental study was carried out on actual model beams.

The model beams are shown in Fig. 1. Beam C was formed as a composite beam after prestressing of the steel beam, for comparison of its bearing capa-

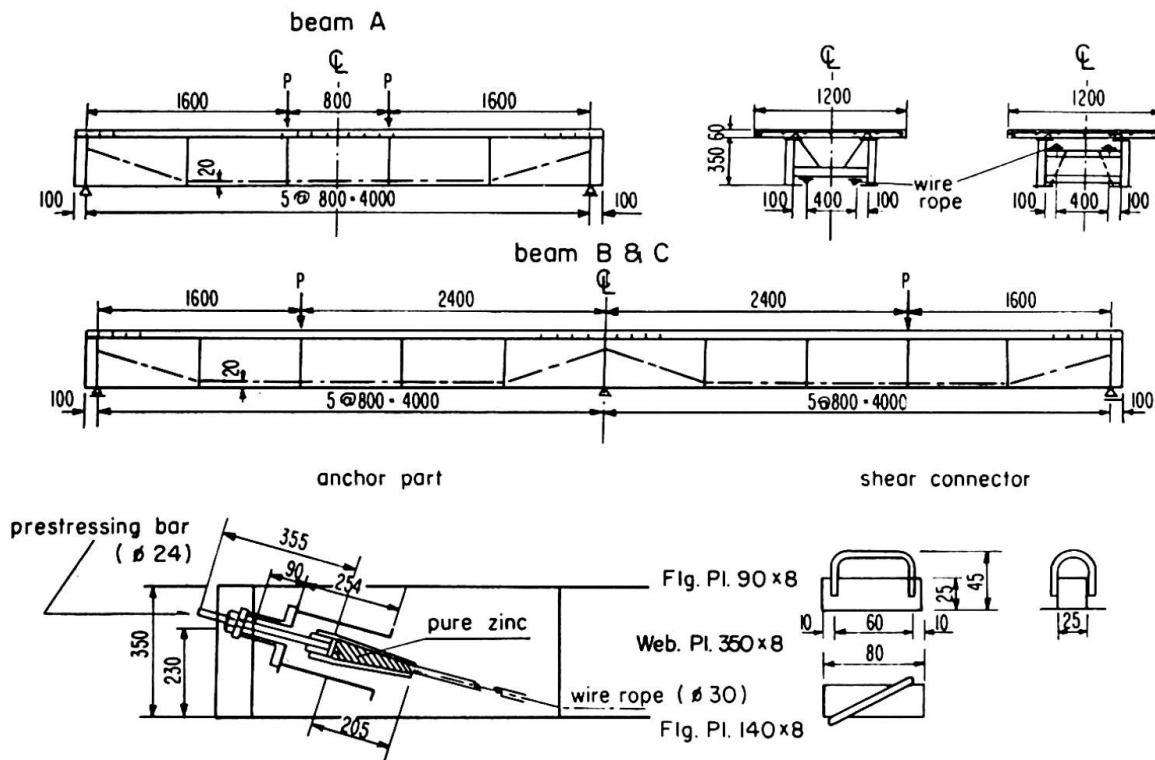


Fig. 1. General view of model beams.

city with that of beam B which was prestressed after the composite girder had been made. After prestressing each of the beams A , B and C and after slackening beam B , concrete was placed on each beam. About four weeks after the placing of the concrete, a prestressing test for beam B was made and subsequently the breaking test for each beam was conducted.

2. Materials and Instruments Used for the Experiment

The compressive strength and the tensile strength of the concrete were $\sigma_{28} = 337 \text{ kg/cm}^2$ and 29.1 kg/cm^2 , respectively, and the yield stress of the steel employed ($t = 8 \text{ mm}$) was 25.9 kg/mm^2 , its ultimate strength 42.7 kg/mm^2 and its elongation 25.0% . The Young's modulus of the locked coil rope ($\varnothing 30 \text{ mm}$) was 16200 kg/mm^2 , its ultimate strength 141 kg/mm^2 and its elongation 2.9% .

In order to apply a tensile force to the wire cable, two high-tensile steel bars ($\varnothing 24$) screwed into a socket were pulled, at one end, by means of two Simplex jacks, anchored with nuts.

For the purpose of applying the load, jacks were used between a loading device and the experimental beams. The loading positions are shown in Fig. 1.

The strain was measured with electric resistance wire strain gauges and the deflection was measured with dial gauges and scales. In addition, an oscillograph was used to check the tensile force by measuring the number of oscillations of the wire rope.

3. Results of the Measurements and Their Consideration

3.1. Prestressing of Each Beam (Steel Beam)

Lubricant was coated on the saddle, on the bend and on the contact surface of the wire cable, but as the friction appeared to remain considerable, prestressing was applied repeatedly, namely $18 \text{ t} \rightarrow 12 \text{ t} \rightarrow 17 \text{ t} \rightarrow 13 \text{ t} \rightarrow 16 \text{ t} \rightarrow 14 \text{ t} \rightarrow 15 \text{ t}$, by means of two sets of jacks at one end of the beam A ; and the nuts were anchored in such a way that the other end of the wire rope was experimentally confirmed to be tensioned at about 15 tons. As regards beams B and C , the experiment was repeated at one end, and after anchoring one end, prestressing was applied at the other end by a similar method. The tensile force of the rope was obtained by taking a mean value of the four gauges symmetrically positioned around the steel bars at the anchored end. The steel beams after applying the prestress are shown in photographs 1 and 2. As the sway bracings of the experimental beam were weak and a slight effect of torsion was observed, reinforcement was applied.

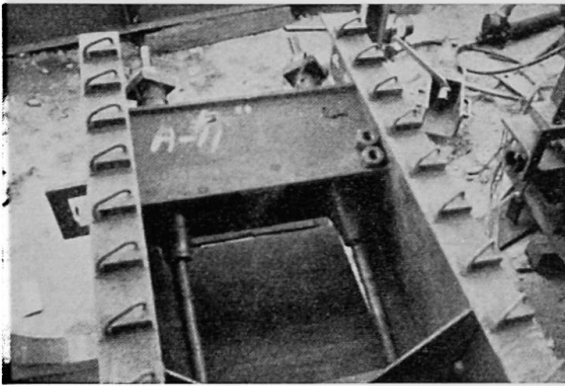


Photo 1.

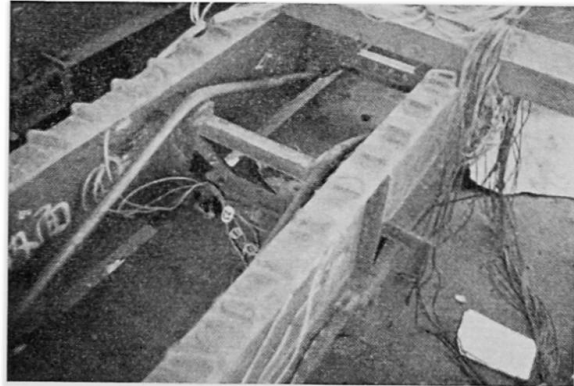


Photo 2.

3.2. Breaking Test of Beam A

The increase in the tensile force of the wire rope due to loading (P) is represented by $X_1 = 0.4781 P$, and its measured result as well as the deflection curve are given in Figs. 2 and 3. The ratio of the measured value of the breaking load $2P = 47.5 \text{ t}$ to the calculated value was 1.09.

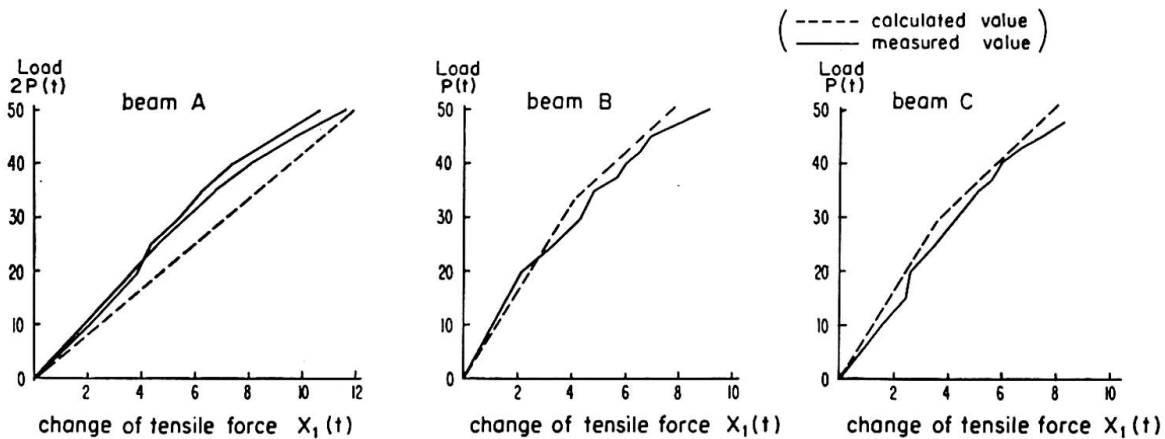


Fig. 2. Change of tensile force of prestressing bars by loading.

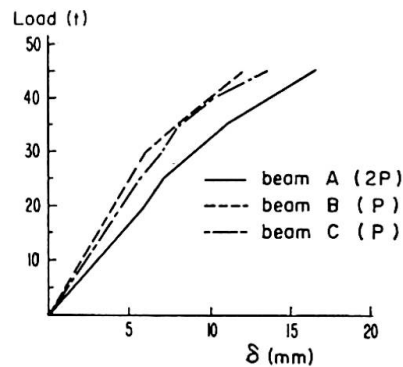


Fig. 3. Load deflection curve.

3.3. Prestressing Test of Beam B (Composite Beam)

Fig. 4 shows the calculated value of the moment due to prestressing. In this case, torsion resulting from the prestressing was not observed. The strain in the concrete slab on the middle support is uneven in the cross section representing shear lag, but the ratio of the mean measured value — 73.0 kg/cm² to the calculated value — 69.0 kg/cm² was 1.06 (assuming $E_c = 3 \times 10^5$ kg/cm²). The stress ratio of the steel beam by span moment being 1.16.

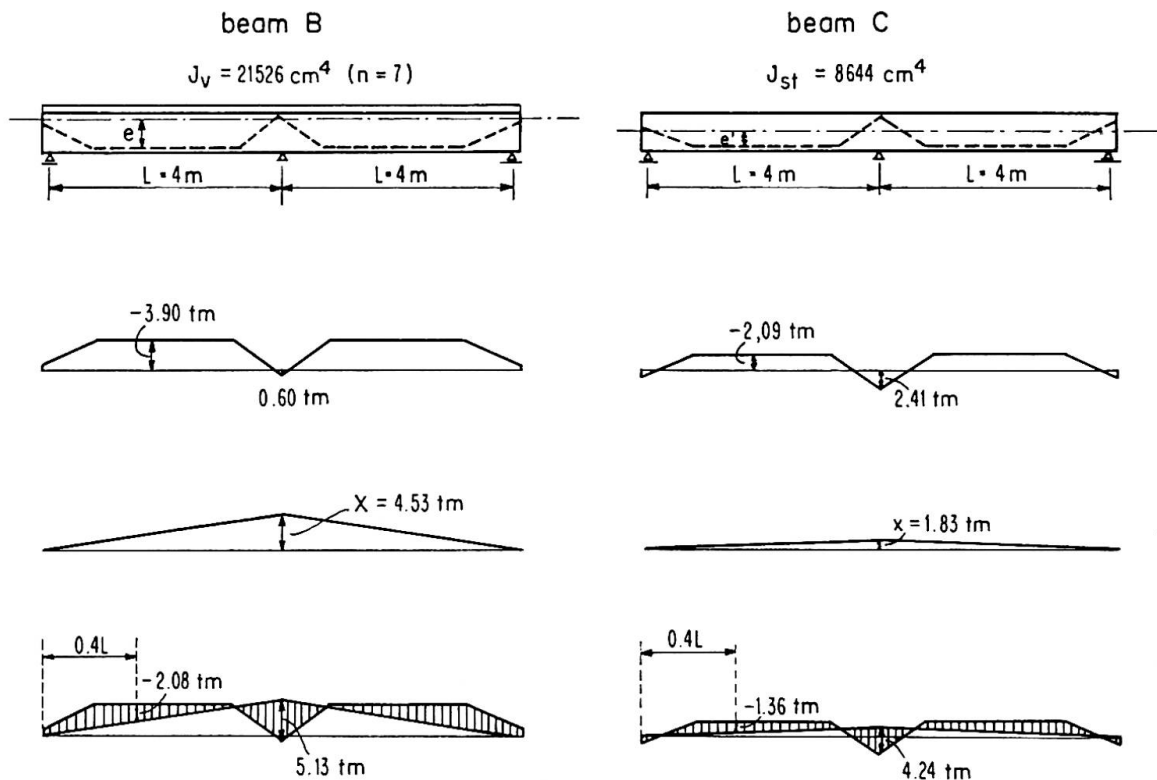


Fig. 4. Moment diagram by prestressing.

3.4. Breaking Test of Beams B and C

From the elastic equations

$$\begin{aligned} X_1 \delta_{11} + X_2 \delta_{12} &= \delta_{10}, \\ X_1 \delta_{21} + X_2 \delta_{22} &= \delta_{20}, \end{aligned}$$

the increase in the tensile force of the wire cable and the reaction of the central support due to loading (P) are obtained as follows,

$$X_1 = 0.1077 P, \quad X_2 = 1.1196 P.$$

The measured value and the load deflection curve are shown in Fig. 2 and 3. The relationship between the square root of the tensile force and the number of oscillations was studied in order to obtain a reasonably proportional relation-

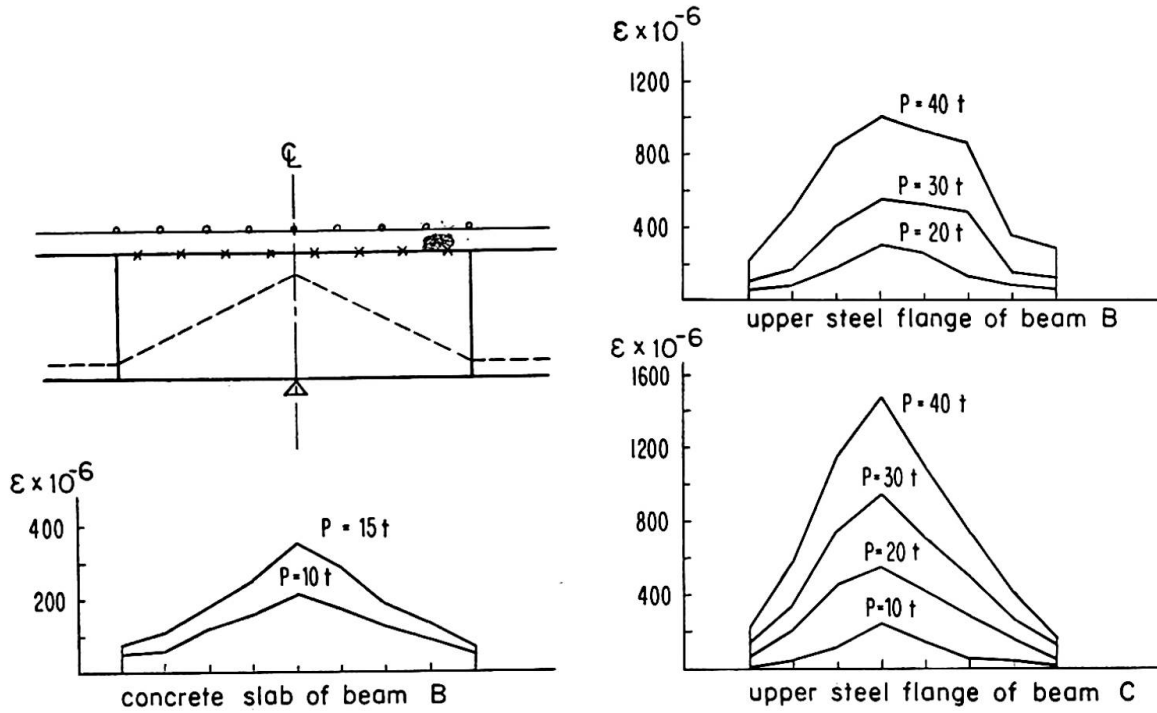


Fig. 5. Strain distribution at the middle support.

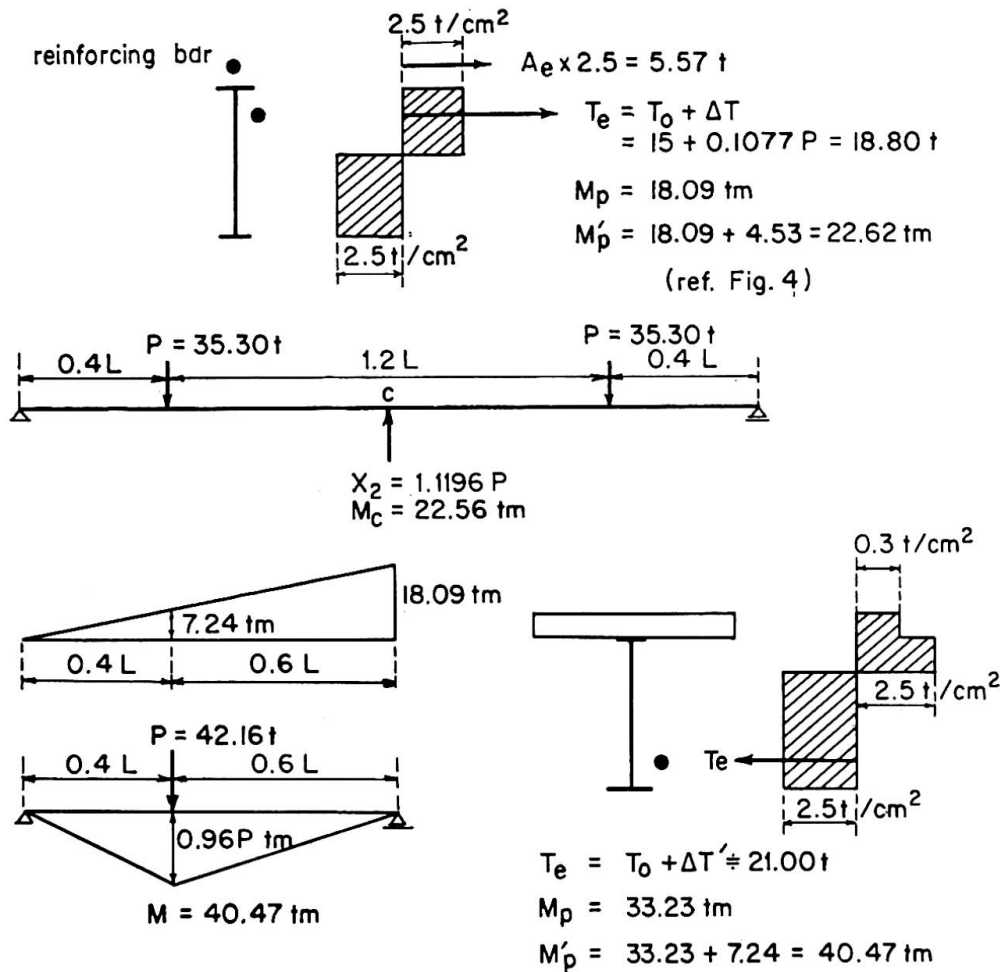


Fig. 6. Calculation of plastic moment.

ship. The distributions of the strain at the central support of the upper fibre of the concrete slab and of the upper flange of the steel beams *B* and *C* are shown in Fig. 5.

As the load is gradually increased, the concrete causes cracks in the central support and subsequently yielding takes place in the section at the central support and at the $0.4L$ position. The measured values and the calculated values are shown in Table 1. The loads which create the hinges on the support as well as at the $0.4L$ position of beam *B* are calculated as shown in Fig. 6.

Table 1

Beam	Value	Crack load P	Loads which create hinges	
			on the support	at the $0.4L$ position
B	meas.	17.5 ton	47.50 ton	47.50 ton
	cal.	15.5 ton	35.30 ton	42.16 ton
	ratio	1.13	1.35	1.13
C	meas.	4.0 ton	45.00 ton	47.50 ton
	cal.	3.4 ton	31.03 ton	42.12 ton
	ratio	1.18	1.45	1.13

The loads which create hinges on the support and at the $0.4L$ position are equal for beam *B*, and approximately equal for beam *C*.

Some of the reasons for the difference between the measured values and the calculated values of a load such as to create plastic hinges on the central support are considered to be as follows:

1. After the crack was produced in the concrete, the strain in the upper flange of the steel beam was a little slow to appear, because of the existence of the concrete.
2. As the cracks spread, the moment of inertia of the central support decreases so that the moment shifts.
3. It is assumed that the elastic equation is applicable until the plastic hinge is created.

In conclusion, although there was a slight difference between the loads that caused cracks in beam *B* and in beam *C*, their bearing capacities were approximately equal.

Summary

In loading tests carried out on prestressed composite beams, within the elastic limits, the measured values and the calculated values were found to be approximately equal.

In this experiment, beam *B*, which was prestressed after the composite beam had been formed, and beam *C* of which only the steel beam was prestressed, showed different crack loads, but their bearing capacities were nearly equal.

It may, therefore, be considered that in cases where this method is adopted, only the prestress necessary for the concrete at the section of the support, should be given after construction of the composite girder, and the remaining tensile force of the wire cable should be used for the stress improvement of the steel beam.

Résumé

Des essais de charge exécutés dans le domaine élastique sur des poutres mixtes précontraintes confirment les prévisions de la théorie.

Lors de ces essais, la poutre *B*, précontrainte après le bétonnage, et la poutre *C* dont seule la partie métallique était précontrainte ont naturellement montré des charges de fissuration différentes, mais leurs résistances à la rupture étaient pratiquement égales.

Si l'on veut adopter ce procédé, il faudra donc n'appliquer à la section mixte que la précontrainte exigée par le béton au droit des appuis et utiliser le reste de l'effort du câble pour améliorer l'état de contrainte de la poutre métallique.

Zusammenfassung

Bei ausgeführten Belastungsversuchen mit vorgespannten Verbundträgern innerhalb des elastischen Bereiches waren die gemessenen Werte und die berechneten Werte annähernd gleich.

Bei diesen Versuchen zeigten der Träger *B*, der nach dem Verbund vorgespannt wurde, und der Träger *C*, dessen Stahlträger allein vorgespannt wurde, verschiedene Rißbelastungen, wobei jedoch ihre Tragfähigkeit annähernd gleich war.

Bei Anwendung dieses Vorspannverfahrens soll nur jene Vorspannung, die für den Beton am Stützquerschnitt des Trägers nötig ist, nach dem Verbund aufgebracht werden und die Rest-Zugkraft der Drahtseile für die Spannungsverbesserung im Stahlträger benutzt werden.

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