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Strength Increase under Repeated Loading

Augmentation de résistance sous charges répétées

Festigkeitszunahme unter wiederholter Belastung

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As a part of a research of the low-cyclic loading effects in concrete structures, tests of 4 sets of prestressed pretensioned beams have been performed with the aim to establish the effect of very high overload on the ultimate strength, deformation, crack initiation, propagation and possibly also other parameters.

Each set consisted of 30 nominally identical beams pretensioned by strands 3x Ø 3 mm (steel 140/170 kp/mm^2), the mean strength of concrete was 400 kp/cm^2 (cubes 20x20x20 cm). The sets differed by the amount of reinforcement and by presence or absence of prestressing strands in the compression zone (Fig.1a). The total depth of cross section was varied in each set to ensure zero stresses in extreme fibres of concrete in the unloaded state. The test scheme is shown in Fig.1b.

Ten beams (group I) of each set were subjected to monotonously increasing load up to the failure and the mean strength $\bar{F}_{u1}$ was calculated. The remaining beams were tested in two equal groups II and III. These beams were subjected primarily to the load $F_o = \varkappa . \bar{F}_{u1}$ (with $\varkappa_{II}$ = 0,86 and $\varkappa_{III}$ = 0,92 for group II and III, respectively), then they were unloaded and again reloaded up to the failure load F_{u2} . The loading was controlled by constant deflection increment at the midspan. The loading history is illustrated in Fig.2. A complete record of measured values was obtained during experiment. Following quantities were

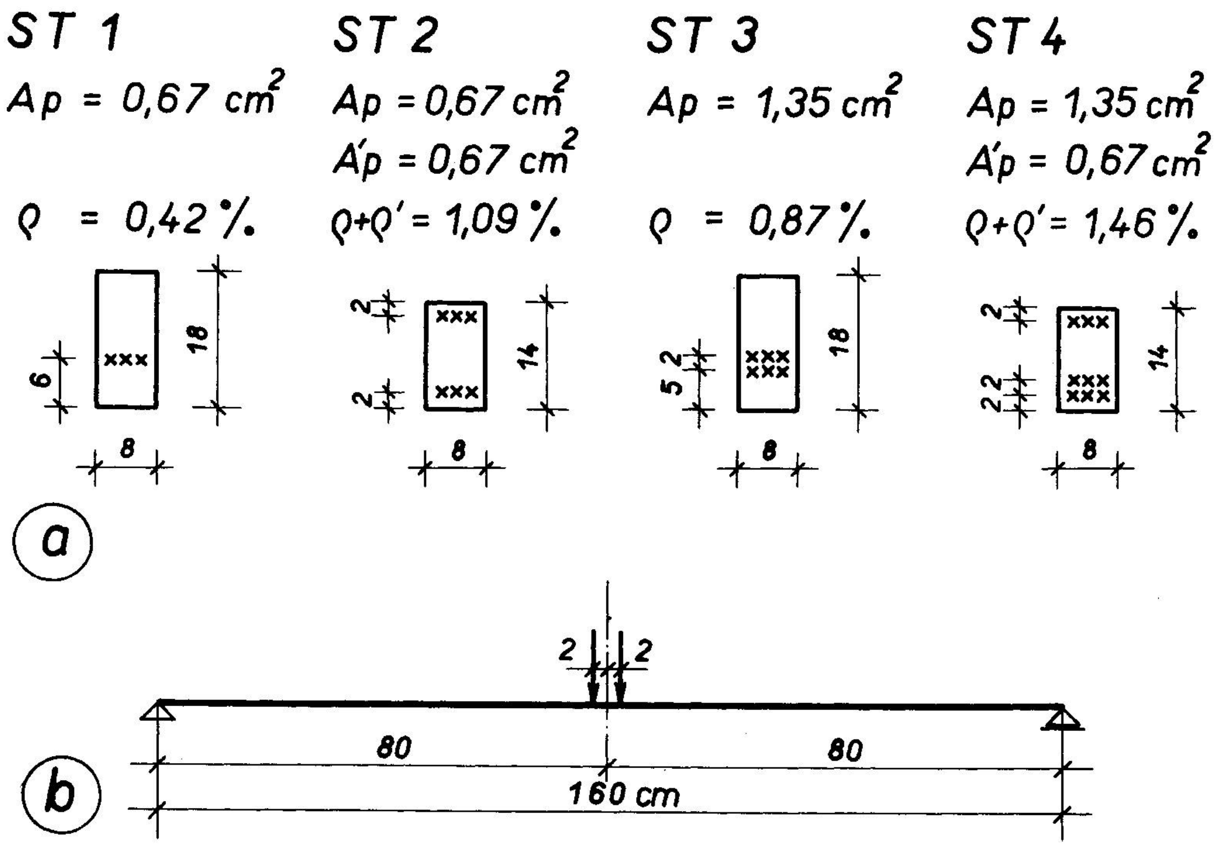

Fig.1. (a) Cross-section of specimens
(b) Test scheme

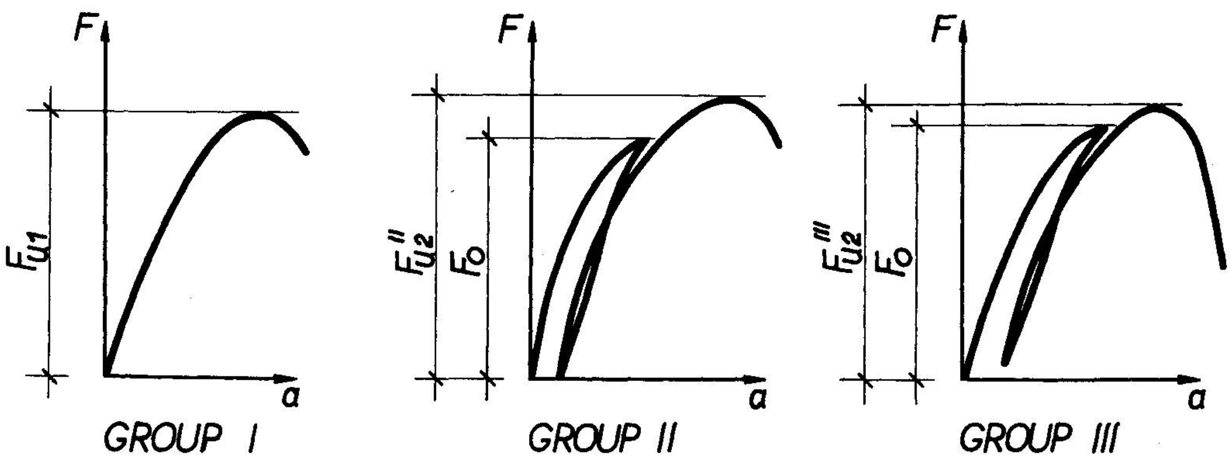

Fig.2. Loading history

measured: load, deflection at midspan, slopes at support sections, bottom fibre strain and compressive and transverse strain of upper fibres. The initiation, propagation and width of cracks were also recorded. Material properties of beams were evaluated before test and also on specimens cut out of beams after failure.

The results show that the load carrying capacity F_{u2} of beams is affected by the initial loading to the value F_o as can be seen from Fig.3. It has been observed in sets ST1, ST3, ST4 (see Fig.3a,c,d) that the initial loading increased the load carrying capacity. Only the ST2 set indicates load carrying capacity decrease (Fig.3b).

The experimental data were statistically processed. The values of statistical parameters of strength for all groups of beams are shown in Tab.1.

SET	ST 1			ST 2			ST 3			ST 4		
GROUP	I	II	III	I	II	III	I	II	III	I	II	III
$\bar{F}_{u1}$ (kp)	2532	-	-	2465	-	-	4303	-	-	3547	-	-
$\varkappa$	0,0	0,86	0,92	0,0	0,86	0,92	0,0	0,86	0,92	0,0	0,86	0,92
$\bar{F}_{u2}$ (kp)	-	2539	2824	-	2319	2431	-	4500	4414	-	3702	3740
$\bar{F}_{u2}/\bar{F}_{u1}$ %	100,0	100,3	111,6	100,0	94,1	98,6	100,0	104,6	102,6	100,0	104,4	105,4
σ	149,8	174,8	142,1	195,7	152,9	194,0	230,2	259,9	199,5	320,9	259,9	202,5
v	0,059	0,069	0,050	0,079	0,066	0,081	0,054	0,058	0,045	0,090	0,070	0,054

Tab.1. Statistical parameters:
$\bar{F}_{u1}$ – mean strength of group I, $\bar{F}_{u2}$ – mean strength of group II and III respectively, $\varkappa$ – $F_o/\bar{F}_{u1}$ (F_o – initial load), σ – standard deviation, v – coefficient of variation

The increase of strength due to the first loading can be clarified by the hypothesis of cyclic strengthening as follows:

Let us consider an element of rectangular cross-section and subjected to bending. Let it be reinforced or prestressed in such a way that under single application of load it would fail by crushing of concrete as soon as the ultimate moment in the cross-section under the load has been attained. Hence, the stress at

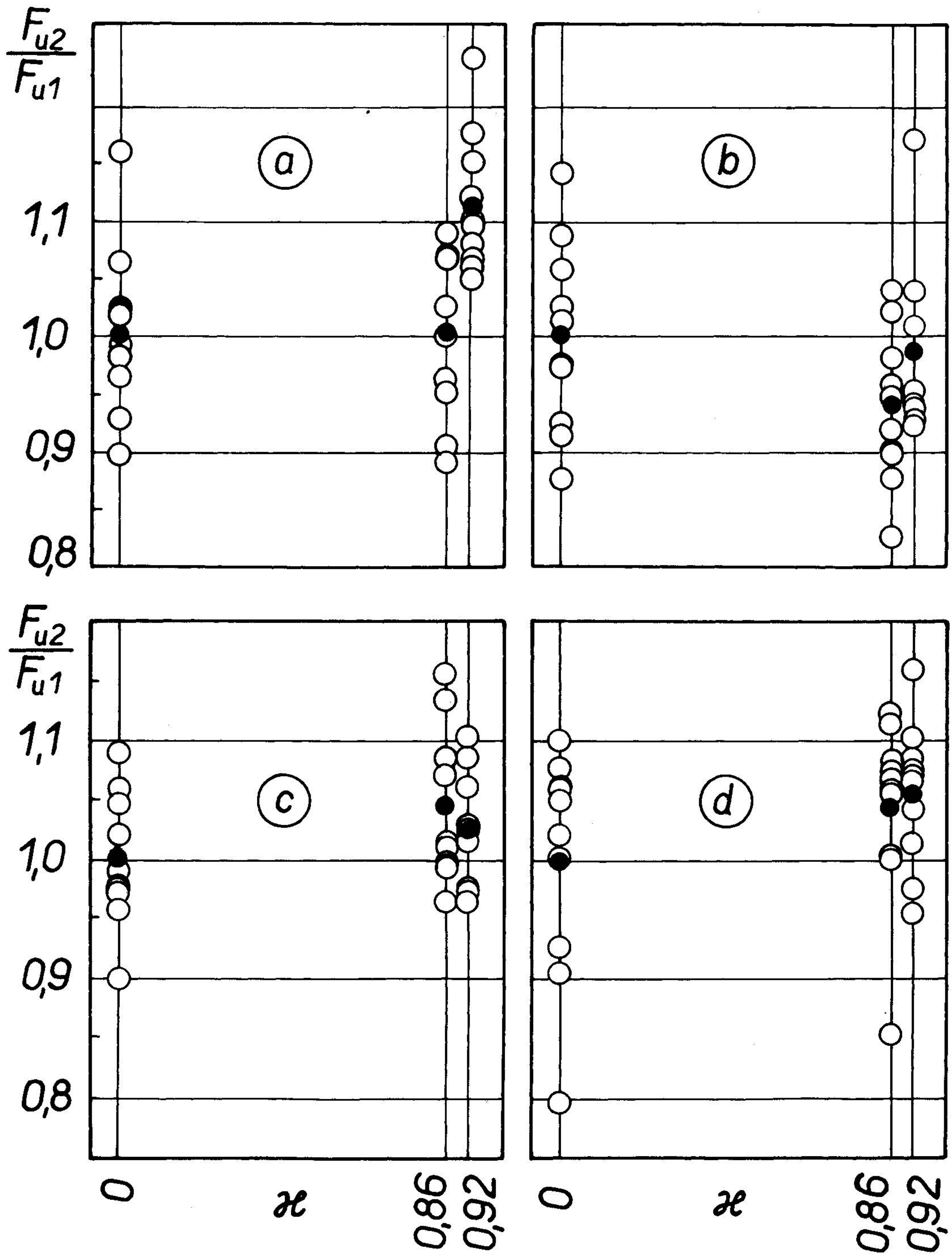

Fig.3. Ultimate strength of specimens
(a) - ST1, (b) - ST2, (c) - ST3, (d) - ST4

failure in the reinforcement is lower than the yield stress or the strength of the reinforcement.

Let this element be loaded by a load $F_o < F_u$ (where F_u is the ultimate strength of the element) in such a way as to produce at least a partial plastic deformation in concrete. Under the load the depth of the compression zone is $x_o > x_u$ (where x_u is the depth due to F_u – see Fig.4). Now, if the element is unloaded, structural changes due to plastic deformation of concrete take place, which may after several repetitions of the load produce partial or total separation of the tension and of the compression zone. Due to this the deformation compatibility of the cross-section will have been substantially reduced and the deformation of the compression concrete is no more geometrically dependent on the deformation of the reinforcement. The element behaves now like a tied arch. The thickness of the concrete part of the arch is x_o .

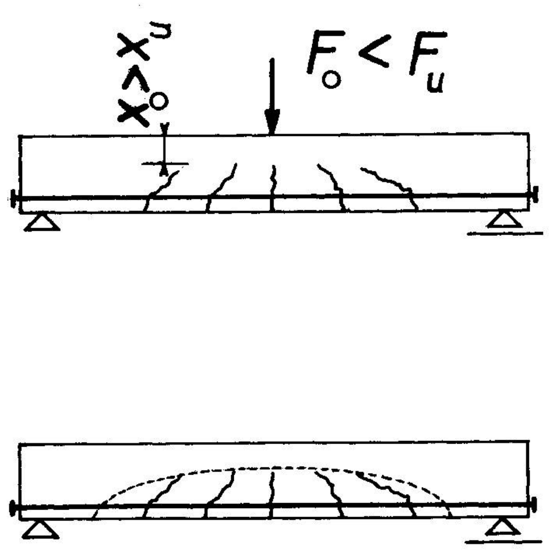

Fig.4. Pattern of failure

The arch behaviour does not change even when the load increases to $F > F_o$, the concrete part of the girder being subjected only to compressive stresses. When the ultimate strength of the element is attained, the force acting in the concrete is

$$C = f_c \, b \, x_o$$

where f_c is the compressive strength of concrete and b the breadth of the cross-section. Owing to the fact that $x_o > x_u$ the force C and consequently also the force T acting in the reinforcement must be higher than at the ultimate strength under single application of load. Hence, after preceding repeated loading the ultimate moment M_{un} is higher than the ultimate moment under a single load application. Assuming the stress in the compression zone as constant, it follows that

$$\frac{M_{un}}{M_u} = \frac{x_0}{x_u}$$

The increase of the ultimate střength of the element has been produced by the change of its structural response.

Obviously, the strength increase can be produced only in elements with compression failure where an increase of the stress in the reinforcement is possible. In elements with tension failure (failing by excessive elongation or by rupture of the reinforcement) the implication of the presented hypothesis would be the reductiva of ultimate strength.

SUMMARY

The effect of overloading on the subsequent load carrying capacity of prestressed concrete beams was experimentally investigated on 120 specimens of four types of cross-section and reinforcement. Statistically processed data indicate that initial load near to the ultimate load increases the subsequent bending strength. A hypothesis of cyclic strengthening is submitted.

RESUME

L'influence de surchargement sur la résistance postérieure de poutres en béton armé a été étudié expérimentalement sur 120 spécimens de 4 types d'armature et de sections différentes. Les résultats traités statistiquement montrent qu'une charge initiale proche de la charge ultime augmente la résistance à la flexion. On propose une hypothèse d'augmentation de résistance cyclique.

ZUSAMMENFASSUNG

Der Einfluss von Ueberbelastung auf die spätere Tragkapazität vorgespannter Betonbalken wurde anhand von 120 Beispielen von vier Querschnittstypen und Bewehrungsarten untersucht. Statistisches Vorgehen bei der Auswertung der Versuchswerte zeigt, dass die anfängliche Last nahe der Traglast den späteren Biegewiderstand erhöht. Eine Hypnothese über zyklische Verstärkung wird angegeben.