

論文 Experimental Investigation on the Flexural Behavior of Two Span Continuous Beams with Large Eccentricities

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ABSTRACT: Studies have shown that the ultimate flexural strength of externally prestressed beams is comparatively smaller than the one with bonded beams. One of the possible methods of enhancing the flexural strength of such beams is to place the tendons with large eccentricities. The structural performance can be further improved by making this structure a continuous one. To obtain an insight of the flexural behavior of such beams, an experimental investigation was conducted on two span continuous beams with large eccentricities with various tendon layout. The results of this test are discussed in this paper.

KEYWORDS: continuous beams, external prestressing, flexural strength, large eccentricities, prestressed concrete

1. INTRODUCTION

Researches have shown that the ultimate strength of externally prestressed beams is comparatively lesser than that of similar internal bonded beams [1, 2]. One of the possible methods of enhancing the flexural strength of externally prestressed beams is to place the tendons with large eccentricities. This kind of construction is possible only when external prestressing is used, since the tendons need not be within the concrete section. By this methodology either improvement in strength or reduction in the amount of prestressing can be achieved, leading to economical structures. However, there may be limitations on the amount of effective prestressing which may tend to produce cracks in the top fibers of the beam at the prestressing stage. In a previous investigation, an experimental investigation was carried out on single span beams with large eccentricities to study the influence of effective prestressing on the ultimate flexural strength [3]. The beams tested were typical 'T' shaped flanged beams and the depth of tendon was not significantly large. As such, it was decided to reduce depth of the beam, making it shallow and providing the tendon at a depth considerably below the beam.

The 'Truc de la Fare Bridge' built in France was such kind, consisting of prestressed concrete slab with lateral ribs, supported by means of subtended cables deviated by three steel struts [4]. In this concept, the compressive forces are taken by concrete and tension by external tendon, thus taking advantage of both materials most effectively. The tendon forces are transmitted through intermediate struts connected along the beam. An experimental investigation has been carried out to study the flexural behavior of such single span structures by Hamada, et.al. [5]. It is believed that extending this concept for continuous girders, the structural performance can be improved. To obtain an insight of the flexural behavior of such beams, an experimental study was conducted on two span continuous beams with large eccentricities. The results of this investigation are presented in this paper, with emphasis on the influence of tendon layout on ultimate strength and effective prestressing.

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2. EXPERIMENTAL METHODOLOGY

The test series consists of five two span continuous beams (type A, B and C) whose difference is the layout of external tendon. Specimens A-1, B-1 and C-1 were loaded with symmetrical loading and specimens A-2 and B-2 with unsymmetrical loading. The test variables and materials used are given in Table 1. Specimens type B and C were provided with confinement reinforcement at the compressive zone of concrete at critical locations to improve the ductility of these beams. The beams are 10.4 m long with equal span length of 5.0 m as shown in Fig. 1. The specimens are rectangular shaped having a width and depth of 400 mm and 150 mm respectively. Seven deviators were provided in the form of steel struts at a spacing of 1.25 m. The beams were provided with combined prestressing consisting of pre-tensioned internal bonded tendons and post-tensioned external tendons. The external tendon layout was designed as described below. In specimen type C, the maximum eccentricity of the tendon is 625 mm giving a span to sag ratio of 8. The tendon layout was designed to provide a near parabolic tendon profile. The tendon profile in type A and B was obtained by linear transformation of the tendon profile of type C. The tendon profile of type B is close to a concordant tendon profile, where there is no secondary moments due to prestressing. The eccentricity at the center support was 500 mm, resulting in a mid span eccentricity of 375 mm. In type A, the tendon eccentricity at center support was half the amount of type B at 250 mm, making the eccentricity at mid span as 500 mm.

The amount of internal prestressing was designed to have an effective prestress force of about 200 kN sufficient to resist the self weight of the specimen during handling and before applying the external prestressing. This was provided by 4 nos. of 9.3 mm SWPR7A type pre-tensioned cables. Rectangular stirrups made of 10 mm bars were tied at a spacing of 100 mm along the beam. In specimens type B and C in the loading span and center support region, stirrups were spaced at 50 mm to behave as confinements reinforcements. The design strength of concrete was specified as 50 MPa in 14 days. Steel struts were used as deviators which were fixed to the beam after placing on the supports. For external prestressing 10.8 mm diameter SWPR7B type cable was used with a design value of 25 kN. Teflon sheets were inserted between the tendons and deviators to reduce friction. In specimen A-2, grease was also applied between the sheets and deviators to further minimize the frictional effects. Strain gages were attached to the reinforcements and concrete surface at critical locations. To measure the strain variation in the tendons, gages were fixed at various locations along the length. Load cells were placed at the anchorage ends of the external cable to measure the cable force. They were also set below the beam at each support to obtain the support reactions. The applied load was measured by the load cells put below the jacks. Displacement transducers were placed at the mid span and deviators to measure the vertical deformation of the beam. In symmetrical loading case, two point loading was applied at a distance of 1.25 m in each span as shown in Fig. 1. The loading was stopped when crushing of concrete occurred in the compressive zone at both the midspan and center support. In unsymmetrical loading case, the loading in the right span was set to 50% that of left span. This was the minimum loading necessary to prevent any failure due to reversal of moments in the lightly loaded span.

Table 1. Test variables and materials

No.	Description of specimen	Loading		Tendon eccentricity (mm)		Confinement r/f ^{*1}	Prestressing tendon		Concrete strength (MPa)
		Left span	Right span	Mid span	Center support		Internal	External	
A-1	2 span, symmetrical	100%	100%	500	250	-	1T9.3*4 (4 x 50 kN)	1T10.8*1 (25 kN)	50
A-2	2 span, unsymmetrical	100%	50%			-			
B-1	2 span, symmetrical	100%	100%	375	500	yes			
B-2	2 span, unsymmetrical	100%	50%			yes			
C-1	2 span, symmetrical	100%	100%	625	0	yes	(55% f_{pu})	(20% f_{pu})	

^{*1} volumetric ratio of confinement r/f : 1.85%

stress after prestressing (in MPa): support:- 10.1 (top), -2.8 (bot.), midspan:- -0.6 (top), 8.0 (bot)



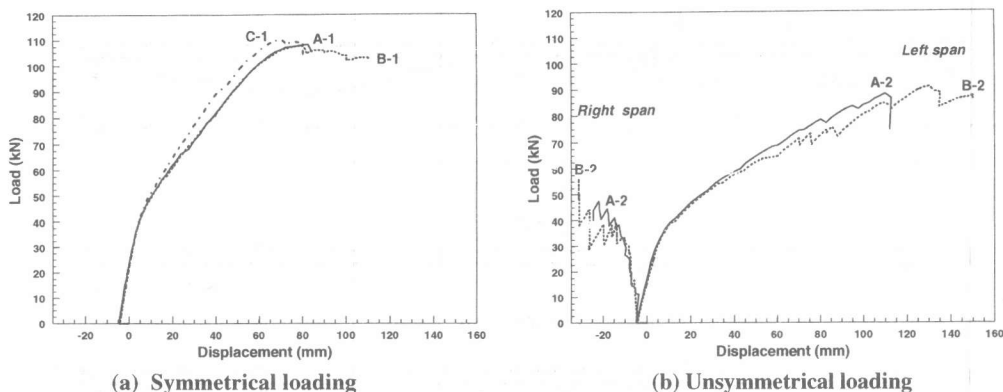


Fig. 2 Load-displacement characteristics

The load displacement characteristics are compared in Fig. 2. The flexural behavior of specimens A-1 and B-1 with symmetrical loading was almost identical up to crushing of concrete. Specimen C-1 also had nearly the same behavior, but with a slightly higher stiffness. This difference can be attributed to the slight adjustment made in the tendon position of C-1 at center support, to avoid sharp bends in the cable. In specimen B-1 that had confinement reinforcement, after spalling of concrete at the mid span region, it was able to sustain the load with further deformation. However, in the other confined specimen C-1, the loading was stopped due to premature crushing of concrete near the center support. Likewise, the unsymmetrically loaded Specimens A-2 and B-2 also showed similar flexural behavior. The confined Specimen B-2 showed a larger displacement than the unconfined one A-2. In unsymmetrical loading, the heavily loaded left span showed a downward deflection while the lightly loaded right span had an upward deformation. From the values of displacement summarized in the Table 2, it can be seen that the ultimate deflections of confined specimens B-1 and B-2 were about 33% higher than that of the unconfined specimens A-1 and A-2.

From the above observation, it can be concluded that in continuous beams with linearly transformed tendon profiles, the flexural behavior is not affected by the tendon layout not only in the linear elastic state, but also in the ultimate limit state. This gives considerable flexibility in designing the tendon layout in beams with large eccentricities, where the tendon eccentricity can be extended below the beam at the midspan or extended above the beam at the support, depending on the clearance available at a particular site.

3.2 STRESS INCREASE IN EXTERNAL TENDONS

Increase in external tendon stress with midspan displacement is given in Fig. 3. There was no yielding of external tendons in specimens with unsymmetrical loading (A-2 and B-2). However, in the specimens with symmetrical loading (A-1, B-1 and C-1) yielding was observed in the external tendons. In Specimen B-2, it was noted that there was a difference of about 10% between the tendon force measured at the left and right ends. This is believed to be created by frictional effects at the deviators due to large angle of deviation, especially at the center support. This difference was reduced to 4% in Specimen A-2, since grease was applied between the deviators and teflon sheets.

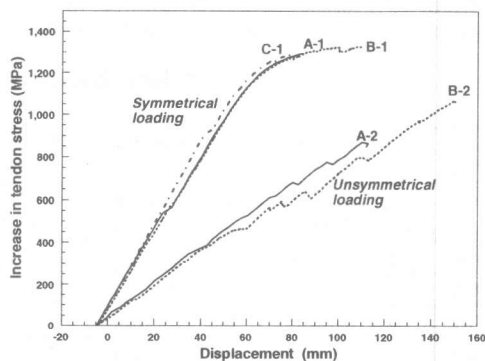


Fig. 3 Increase in tendon stress

The specimens with symmetrical loading had a larger ultimate tendon stress than the specimens with unsymmetrical loading. This can be attributed to the fact that in symmetrical loading case, both spans had a considerable deflection, thus substantially increasing the elongation of the tendon. However, in the unsymmetrical loading, while the left span had a deflection, the right span had an upward deformation, thus having a negative impact on the increase in tendon force. It can be seen that the stress increases in a nearly linear manner up to yielding, following almost the same path for the specimens with symmetrical loading. Similar behavior was observed in the unsymmetrically loaded specimens. As such, it can be inferred that there is a direct relationship between the ultimate tendon force and the midspan displacement. The rate of increase in stress for the symmetrical loading was about 17.5 MPa/mm. The corresponding value for the unsymmetrical loading was 7.5 MPa/mm, nearly half of the value obtained from the symmetrical loading case. It can be concluded that the increase in tendon stress is directly proportional to the midspan deflection. In addition, the rate of change of this stress is influenced by the loading arrangement in each span.

3.3 MOMENT REDISTRIBUTION

In continuous span beams, redistribution of moments is expected after the critical section reaches the yield moment. To verify these phenomena, the support reactions were measured. The variation of support reaction with applied load is illustrated in Fig. 4(a) for the symmetrically loaded specimens. It can be seen that the change in support reaction with load had a nearly bilinear behavior. It was observed that the first plastic hinge was formed in the center support region, since the moment capacity of the center support was lower than that of the midspan section. In unsymmetrical loading case, the first plastic hinge was observed at the left of midspan region. As such, the moments were redistributed towards the center support in these beams. From the support reactions, the ultimate plastic moments (M_p) were calculated at critical sections. The corresponding elastic moments (M_e) were computed assuming a linear behavior. The moment redistribution ratio was calculated from this which is summarized in Table 3. The bending moment profile along the beam was computed from the observed support reactions at various stages of loading. Fig. 4(b) shows the bending moment diagram for Specimens A-1, B-1 and C-1 with symmetrical loading. From Table 3, it can be seen that for symmetrical loading, the observed moment at the midspan was generally higher than the elastic moments, thus having a negative redistribution. On the other hand, the support moments were lower than the calculated elastic moments, leading to a positive redistribution of moments. In unsymmetrical loading the opposite behavior is observed, though the effect was considerably small. The specimen type C showed the largest amount of redistribution while this effect was the least in type B specimens. This is attributed to the difference in the layout of tendon in these specimens. From the above observations it can be inferred that the moment redistribution in continuous beams is influenced by the tendon layout, as well as the loading arrangement in each span.

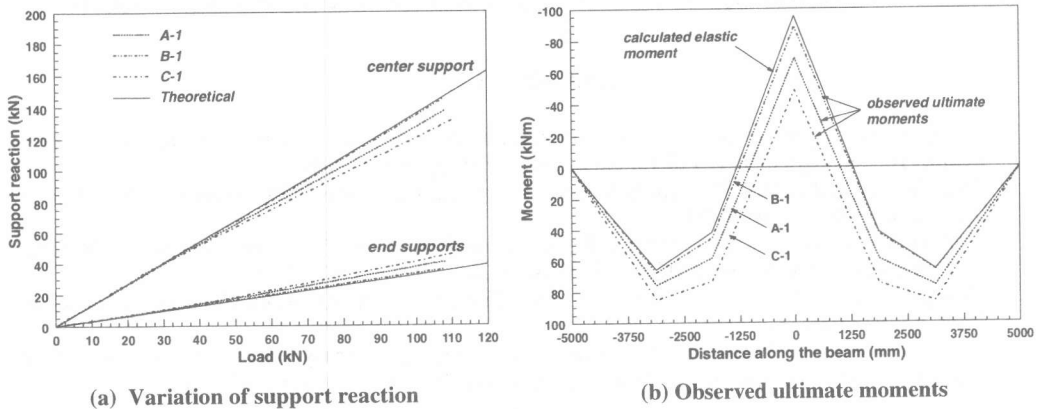


Fig. 4 Effect of moment redistribution

Table 3. Summary of ultimate moments and percentage of moment redistribution

No.	Loading type	Observed plastic moments M_p (kNm)			Calculated elastic moments M_e (kNm)			Moment redistribution [$1 - M_p / M_e$] (%)		
		Left span	Center support	Right span	Left span	Center support	Right span	Left span	Center support	Right span
A-1	Symmetrical	75.8	-68.5	76.2	65.8	-95.2	65.8	-15.2	28.0	-15.7
A-2	Unsymmetrical	60.0	-60.2	-	60.8	-58.1	-	1.3	-3.7	-
B-1	Symmetrical	67.7	-88.5	66.2	65.4	-94.6	65.4	-3.5	6.4	-1.2
B-2	Unsymmetrical	62.4	-60.8	-	62.7	-59.9	-	0.6	-1.6	-
C-1	Symmetrical	85.3	-48.1	86.3	67.0	-96.9	67.0	-27.3	50.4	-28.7

4. CONCLUSIONS

An experimental investigation was conducted with two span continuous beams with large eccentric tendons. The major variable was the tendon layout, based on linearly transformed tendons and the loading pattern on each span. The following conclusions are made from this study.

- The flexural behavior of the beams was not affected by the linear transformation of the tendon layout. The presence of confinement reinforcement did not influence the ultimate strength of these beams.
- The tendon stress increased proportionally to the midspan deformation until yielding of tendon. The rate of increase was influenced by the type of loading arrangement. As such, the ultimate flexural strength of unsymmetrically loaded beams were reduced by about 20%.
- In symmetrical loading case, the midspan sections showed a positive redistribution while the support section showed a negative value. The amount of redistribution was affected by the tendon layout. In the unsymmetrical loading, moment redistribution was not significant.
- It is proposed that further investigation is carried out on the shear behavior of such beams with different type of strut arrangements.

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