論文 Moment Redistribution in Prestressed Concrete Continuous Beams with External Tendons

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ABSTRACT: Externally prestressed concrete beams are being constructed widely considering the advantages of the method. The use of continuous spans could be an added benefit such as better riding qualities and efficient use of materials. However, the ultimate behavior of such beams is greatly affected by moment redistribution phenomena that occurs due to yielding at critical sections. This paper describes the experimental investigation conducted to examine the moment redistribution in two spans continuous beams with monolithic and epoxy-jointed precast segmental types, with and without confinement reinforcement at the compressive zones of the critical sections.
KEYWORDS: confinement reinforcement, continuous beam, external tendons, moment redistribution, precast segments, prestressed concrete

1. INTRODUCTION

The development of external prestressing has been one of the major trends in construction over the past decade. External prestressing may be defined as prestress introduced by tendons placed outside the structure over the greater part of their length. This type of prestressing could be applied to both new structures and those being strengthened. Previous studies by Matupayont [1] Alkhari [2] have shown that the main difference in behavior between the external and internal unbonded prestress lies in the deflected shape of the beam and tendon. The use of external prestressing is gaining popularity because of its simplicity and cost-effectiveness. Moreover, a significant number of segmental concrete box girder bridges with external tendons have already been constructed. Substantial economical and construction time savings have been indicated for this type of construction. Together with the above merits, the use of continuous span structures could result in an efficient use of materials and better convenience about service conditions.

In externally prestressed continuous beams, the presence of secondary moments due to prestressing, the formation of plastic hinges and the redistribution of moments after yielding are some inherent structural behavior that had to be clearly understood. To obtain an insight of the moment redistribution behavior of such beams, an experimental program was conducted with monolithic and precast segmental specimens having two spans. The results of the investigation are presented in this paper, with emphasis on the influence of confinement reinforcement on load-displacement characteristics and moment redistribution.

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2. EXPERIMENTAL PROGRAM

2.1 TEST SPECIMENS

To study the moment redistribution pattern, four specimens of two spans continuous beams with equal span length of 4.05 m were cast. The beams were T-section throughout the length except at the deviators, mid-support and the end blocks. One beam was monolithically cast and the rests were with precast segments with epoxied joints. Fig. 1 shows the layout of the test specimens. The main variable in the experimental program was the provision of confinement reinforcement at the compression zone of concrete, at critical locations. This was provided with the view of improving ductility, as shown in the previous study. The monolithic beam, specimen No. 1 (Mono), was provided with confinement reinforcement at the mid-support and mid-span sections. In precast beams, specimen No. 2 (Seg-NC) was not provided with confinement, while specimen No. 3 (Seg-SC) was confined only at mid-support location and specimen No. 4 (Seg-AC) was confined as same as Specimen No. 1. The confinement was provided with D10 at 50 mm pitch, in the form of a looped stirrup. At mid-span section, it was located in the top flange whereas at mid support section it was placed at the bottom of the web. The test variables and the materials used are given in Table 1. The precast segments were 300 mm in length and they were provided with shear keys and match cast to have a good fit at the joints. These were later epoxied and joined by prestressing.

Table 1: Test variables and materials

Specimen No.	Span length L (m)	Distance between deviators Sd (m)	Nominal Concrete Strength fc' (MPa)	Tendon type	Design tendon force (kN)	Reinforcement		
						longitudinal	confinement	
							mid-span	mid-support
1. Mono (monolithic beam)	4.05	1.80	39.25	SWPR7A 2-12.4 mm	177.0	top: 2-D13, 2-D 6 bottom: 2-D13	yes	yes
2. Seg-NC (precast segment)							no	no
3. Seg-SC (precast segment)							no	yes
4. Seg-AC (precast segment)							yes	yes

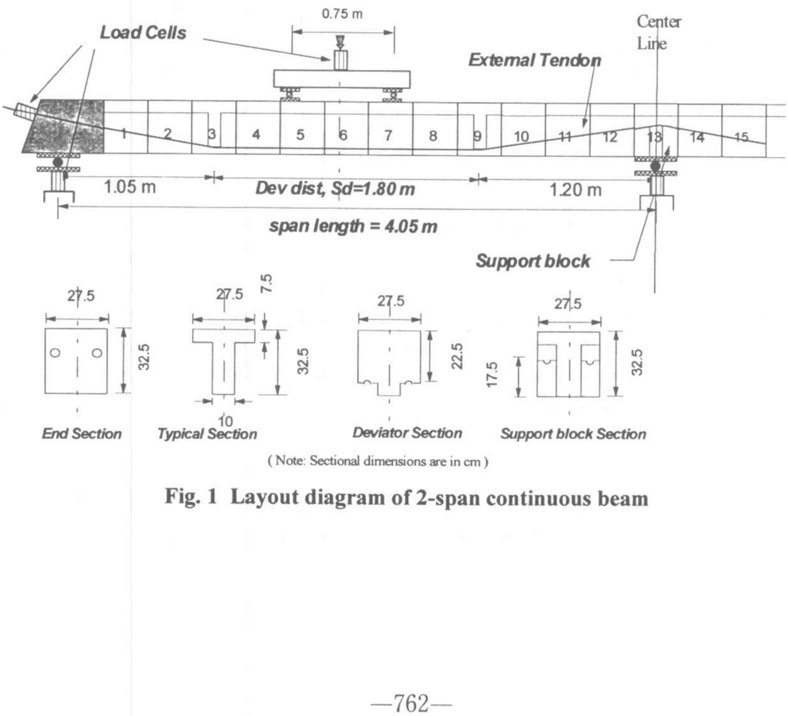


Fig. 1 Layout diagram of 2-span continuous beam

2.2 INSTRUMENTATION

Electrical resistance strain gauges were attached to all the reinforcements (main, stirrups and confinement) at critical locations, before concreting. Strain gauges were also attached to the concrete surface of the cast specimen along the depth of the beam, at desired points. To measure the strain and the loss of prestress along the length of the beam, strain gauges were attached to the steel tendons at various locations. In the monolithic beam, strain gauges in the form of π-gauges were attached at locations where critical cracks were expected. In the case segmental beams, these gauges were mounted at critical joints where joint opening was envisaged. These locations were mainly the mid-support and the mid-spans. Load cells were placed at the anchorage ends of the external cables to measure the cable force. They were also set below the beam at each support to obtain the support reactions. To measure the applied load, the load cells were put below the loading jacks. Displacement transducers were placed at the center of loading span, at the loading points and at the deviator points in each span, to measure the displacement of the beam as well as to monitor the change in tendon eccentricity.

2.3 EXTERNAL PRESTRESSING

For external prestressing, two steel tendons of type SWPR7A with 12.4 mm diameter were used for each specimen. The specimens were subjected to a design prestress of approximately 177 kN (18.0 tonf) which was the maximum allowable value without allowing cracking. This force corresponds to approximately 55% of the tensile strength of the tendons. To reduce friction at the deviators, teflon sheets were inserted between the tendons and deviators. In the monolithic beam, the prestress was applied after lifting the beam over the supports, since the main reinforcement provided were sufficient to resist the moments due to self weight of the beam. However, in the case of segmental beams, the joints were epoxied about a week before the testing and a prestress force of 29 kN (3.0 tonf) was applied to fix the segments together. This force was found to be sufficient to resist the moments due to self weight. After hardening of epoxy, the beam was placed on the supports and further prestressed up to 177 kN. It was necessary to clamp the mid-support to prevent from uplifting during the prestressing, since it was expected to lift from the support when the prestressing was more than about 100 kN. This was achieved by applying a clamping force at the mid-support before prestressing. A clamping force of at least 5.9 kN (0.6 tonf) was necessary to prevent the uplifting.

2.4 LOADING

Symmetrical two-point loading was applied at a distance 0.75 m apart in each span, as shown in Fig. 1. To ensure equal applying loads in each span, the system was arranged in such a way that the applied pressure was the same on each jack. After loading up to 39 kN (4.0 tonf), the claming force at the mid-support was released, since the applied load was sufficient to resist the beam from uplifting. Measurements were taken approximately at 1.0 kN intervals until the specimen yields. After yielding of the specimen, observations were recorded approximately at the increments of 1.0 mm of mid-span displacement. In the case of monolithic specimen, the beam was considered to be failed when the tendon strain reached 8000 microns, which was the yielding strain of the cable. For the precast beams, when crushing of concrete occurred in the compressive zone at both the mid-support and mid-span, the specimen was considered to be failed.

3. TEST RESULTS AND DISCUSSION

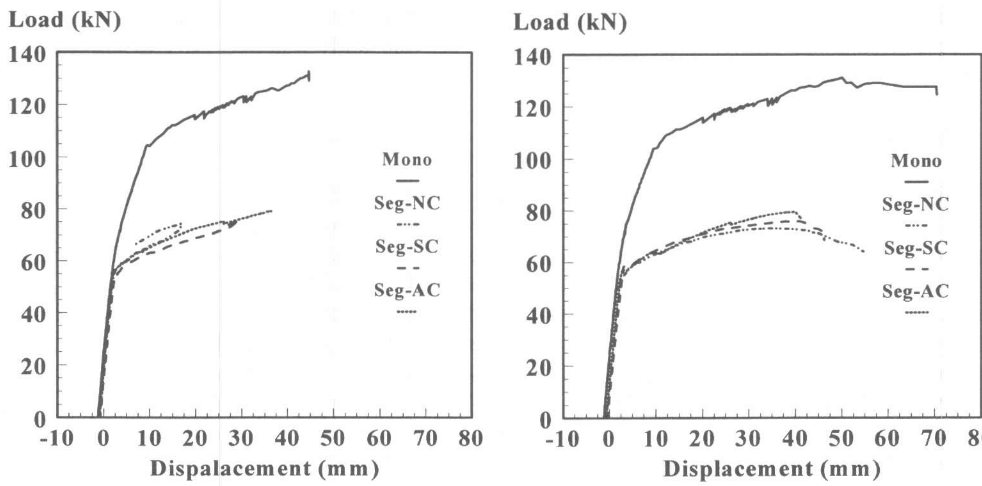
The test results are summarized together with the other parameters in Table 2.

Table 2: Experimental results

Specimen No.	Concrete Strength (MPa)	Applied prestress (kN)	Load at yielding (kN)	Ultimate load (kN)		Max.Deflection (mm)		Ultimate tendon force (kN)	Failure mode
				left	right	left	right		
1. Mono	38.8	177.9	60.8	132.6	131.1	44.7	70.5	270.1	yielding of cable (near mid of right span)
2. Seg-NC	41.3	178.7	53.0	74.4	73.1	16.8	54.7	232.5	crushing of concrete (mid-support and mid of right span)
3. Seg-SC	39.5	177.5	54.9	75.8	76.0	29.4	46.2	240.9	crushing of concrete (mid-support and mid of right span)
4. Seg-AC	36.5	176.4	56.9	79.3	79.6	36.4	41.2	244.0	crushing of concrete (mid support and mid of right span)

3.1 LOAD-DISPLACEMENT CHARACTERISTICS

The observed load-displacement behavior for the left and right spans is given in Fig. 2(a) and 2(b) respectively. It could be seen that the right span had a larger deflection than the left in all specimens. However the ultimate loads on both spans were almost the same. The monolithic beam had a higher load carrying capacity and a larger deflection compared to the segmental beams. In the precast beams, the specimens with confinement reinforcement showed a higher load carrying capacity. Specimens No. 3 and No. 4 had 3.0% and 7.7% higher strength than specimen No.2 that had no confinement. In the same specimens, although the maximum deflection on the right span decreased with the number of critical locations confined, it could be seen that the average displacement of both spans in fact increased. Compared to specimen No.2, No.3 and No.4 showed 5.8% and 8.7% higher average displacement. Table 3 gives the summary of these results. Corresponding increase in the ultimate tendon force also confirms this, since tendon force increases proportionally with the overall deflection. It should be also noted that the concrete strength of the specimens was not the same and the specimens with confinement reinforcement had a lower strength. These observations support the previous findings that the strength and ductility of the beam could be improved by providing confinement reinforcement at the critical sections in the concrete compression zone [3] .



(a) Left Span

(b) Right Span

Fig. 2 Comparison of load-displacement characteristics

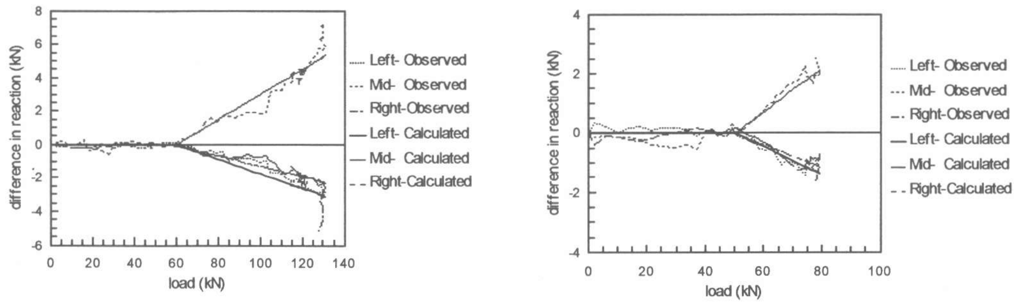
3.2 MOMENT REDISTRIBUTION

In continuous span beams, redistribution of moments is expected after the specimen begins to yield. If the beam behaves elastically, the load-displacement characteristics and the variation of support reactions with load have to show a linear behavior. As such, redistribution of moment is expected to take place from the yielded section to the un-yielded sections. This will result in change of support reaction in non-linear behavior. To study these phenomena, the support reactions were measured. From the variation of load with observed support reactions, the redistribution of moments was calculated. Fig. 3 (a) and (b) compares the observed variation of difference in support reactions and the expected reaction due to elastic behavior with loading for specimens No.1 and No.4. It could be observed that there is a clear change in support reactions, once the specimen yields. In all the specimens, the mid-support reaction showed an increasing value compared to the calculated elastic behavior, while the end supports reactions showed a decreasing value. A curve fitting was done to smoothen the irregularities. From the average predicted curve, the change in support reaction for the ultimate load was computed and hence, the elastic and plastic moments were obtained. The observed moment redistribution is summarized in Table 3. It could be seen that the mid support section had a positive redistribution while the mid span sections showed a negative value. Specimen No.2 showed the largest redistribution, while the monolithic beam also showed considerable value, in both mid-support and mid-spans locations. A clear correlation between the moment redistribution and the influence of confinement could not be observed. This may be attributed to the observation that the yielding at mid-support and mid-spans occurred at very close intervals, thus, not showing a significant redistribution. It is proposed further research should be conducted to study these phenomena.

Table 3: Summary of load-displacement and moment redistribution

Specimen No.	Average maximum load		Average maximum displacement		Observed ultimate moments (M_p) (kNm)*1			Moment redistribution (%) [$1-M_p/M_e$]		
	(kN)	(%)*2	(mm)	(%)*2	mid of left span	center support	mid of right span	mid of left span	center support	mid of right span
1. Mono	131.8	178.8	57.6	161.3	68.5 (73.3)	-108.1 (-97.1)	66.5 (70.0)	-6.7	11.3	-5.1
2. Seg-NC	73.7	100.0	35.7	100.0	38.49 (41.1)	-54.3 (-44.8)	37.8 (41.6)	-6.3	21.0	-9.2
3. Seg-SC	75.9	103.0	37.8	105.8	40.9 (41.9)	-50.3 (-46.7)	41.9 (44.4)	-2.5	7.9	-5.8
4. Seg-AC	79.4	107.7	38.8	108.7	41.7 (43.9)	-62.8 (-58.3)	41.3 (43.0)	-5.0	7.8	-4.2

*1 figures in ( ) are the corresponding elastic moments (M_e) assuming elastic behavior
*2 Seg-NC (segmental beam with no confinement) is taken as the reference



(a) Specimen No. 1 **(b) Specimen No. 4**

Fig. 3 Variation of support reactions with load and comparison with elastic behavior

4. CONCLUSIONS

The experimental investigation of moment redistribution in two spans continuous beams were carried out using monolithic and precast segmental beams. The effect of confinement reinforcement at critical locations on the behavior of the beams was also observed. The following conclusions could be drawn from the above study.

- Comparing the monolithic beam and precast segmental beam, the monolithic beam has a higher load carrying capacity and ductility than the segmental beam.
- The strength and ductility of precast segmental beams could be increased further by providing confinement reinforcement in the compression zone of the critical sections.
- The monolithic beam and the precast beam without any confinement reinforcement showed larger moment redistribution. The mid-support location showed a positive redistribution, while the mid-span sections showed negative redistribution.
- It is proposed that further study should be conducted to obtain a relationship between the moment redistribution and confinement. It would be beneficial to study the behavior of precast segmental beams with external prestressing with un-symmetrical loading.

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