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EFFECT OF PARTIAL PRESTRESSING ON SHORT-TERM DEFLECTION FOR SIMPLY SUPPORTED POST-TENSION CONCRETE BEAMS

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ملخص البحث

أصبح من الشائع استخدام الكمرات مسبقة الإجهاد جزئيا" وخصوصا مع الزيادة المتلاحقة في تكنولوجيا البناء والحاجه لكمرات ذات مسافات طويلة بقطاعات صغيرة مقارنة بالخرسانة المسلحه النمطية وحيث أن التحكم في التشكل الناتج عن أحمال التشغيل من أهم عناصر التصميم لهذه الكمرات فيقدم هذا البحث دراسة لتقدير التشكل اللحظي للكمرات الخرسانية بسيطة الارتكاز و مسبقة الإجهاد جزئيا والمعرضه لعزوم إنحناء وذلك من خلال عرض الطرق الحسابية بالأبحاث والأكواد المختلفة بالاضافة إلي تسليط الضوء على نتائج الاختبارات السابقة. كما تم عمل برنامج للاختبار المعملي مكون من تسعة كمرات خرسانية مع الأخذ في الاعتبار أن يكون الحد الأقصي للعزوم ثابت علي كل الكمرات مع دراسة تغيير كل من نسب حديد التسليح إلي حديد سبق الاجهاد وسمك الغطاء الخرساني وعمق حديد سبق الاجهاد ونسبة حديد التسليح ناحية الضغط. وعلاوة على ذلك تم إنشاء نموذج للكمرات السابقة باستخدام برنامج ANSYS لدراسة مدي توافق النتائج مع الاختبار المعملي واعتمادا" علي هذا النموذج تم الحصول علي نتائج أكثر بتغيير المعاملات السابقة للكمرة. بناء" علي ماسبق تقدم هذه الدراسة اقتراح طريقة لحساب عزم القصور الذاتي الفعال مع الأخذ في الاعتبار تأثير الاجهاد الجزئي.

ABSTRACT

It is a common to use partially prestressed beams especially with rapid development in construction technology and the demand of using long span beams with slender cross-section comparing with traditional reinforced concrete beams. Whereas control of deflection is the most important factor in design of partially prestressed beams, this paper presents a study for assessment of short-term deflection for partially prestressed simply supported concrete beams that are subjected to bending moment. This study is based on formulas stated in different researches and codes. In addition, a program for laboratory tests was created using nine concrete beams, considering a constant moment capacity with variables which are ratios between reinforcement and prestressing steel, concrete cover, eccentricity of prestressing steel and different ratios of compression reinforcement. Moreover, analytical models have been conducted for the previous beams using ANSYS software to conform the results; accordingly more results are obtained for different cases of previous beams variables by using this analytical model. Based on the mentioned studies, a formula has been proposed for the calculation of effective moment of inertia considering effect of partial prestressing.

KEYWORDS: Effective inertia (I_e); Partial Prestressing; Partial prestressing ratio (PPR); Reinforcing index (w); Short-term deflection.

1. INTRODUCTION

Deflection depends mainly on the effective moment of inertia (I_{eff}) which reflects cracking level of element; many formulas have been addressed to estimate (I_{eff}) for partially prestressed concrete beams; the first concept of effective moment of inertia for cracked section was stated by Branson (1977) $I_{eff} = I_{cr} + \left|\frac{M_{cr}}{M}\right| \{I_g - I_{cr}\}$ Eq. 1, further that Naaman (1982) developed this equation considering effect of decompression moment as $I_{eff} = I_{cr} + \left|\frac{M_{cr} - M_{dec}}{M - M_{dec}}\right| \{I_g - I_{cr}\}$ Eq. 2 [1], [6]. Branson equation was applied in ACI 318-M14 [2], ECP 203-2020 [5] and PCI design handbook [3], while Eurocode 2 [4] states another strategy in computing deflection through computing deflection in two extreme cases uncracked and fully cracked sections, then considering the final deflection is a function in these two extreme cases which depend on the ratio $(M_{cr}/M)^2$. In 1989, Ali S. Alemeh and Muhamed H. Harajli [10] proposed a formula for $I_{eff} = \frac{I_{cr}}{M_{cr}/ \quad I_{cr}}$. It is based on an idealization of load-deflection curve.

This paper presents results of load-deflection behavior for experimental test of nine beams with four variables; partial prestressing ratio (0.86, 0.71, 0.41 and 0.29), depth of prestressing steel (380mm, 390mm and 420mm), compression reinforcement ratio (0.12%, 0.4% and 0.8%) and concrete cover (25mm and 50mm). In addition, a comparison was created with analytical method of ACI 318-M14 [2]; also a finite element model was created using ANSYS to simulate each beam. Additional cases were studied based on that model for PPR (0.95, 0.8, 0.6 and 0.5), depth of prestressing steel (350mm and 300mm), compression reinforcement ratio (1% and 1.25%) and concrete cover 70mm. Moreover, six additional results of previously tested beams by Namman and M.H. Harajli [7] have been stated. A proposed formula for effective moment of inertia has been compared with other formulas and results of tests. It has been found that the proposed formula is close to actual behavior especially at high value of partially prestressing ratio.

2. Experimental Work and Results

2.1. Beams Properties and Variables

The experimental program is composed of nine simply supported partially prestressed concrete beams considering a constant ultimate resistance in flexure. Beams dimensions were 300mm width, 450mm overall depth and 4680mm clear span; the 28-days cube compressive strength was 38.5 Mpa. All non-prestressed reinforcement had yield strength of 489 Mpa and ultimate strength of 630 Mpa. On the other hand, prestressing steel were 15.24mm and 12.7mm, and the yield/ultimate strength were 1765/1940 Mpa and 1840/1980 Mpa respectively. The stirrups for all beams were 10mm diameter bars every 200mm at mid-span and 100 at beam ends with a volumetric percentage of 0.40% at mid-span and 0.80% at beam ends. End plate has been erected at each beam ends to enhance distribution of anchor stress on concrete section. In addition, spiral ties 12mm diameter bar with 50mm pitch for a 500mm distance was fixed at ends to resist thrust force. Fig.1 illustrates detailed dimensions of all beams. The profile of prestressing steel is trapezoidal erected inside a corrugated polyethylene duct 25mm diameter with two tubes for grouting

at distance 600mm from beam ends.

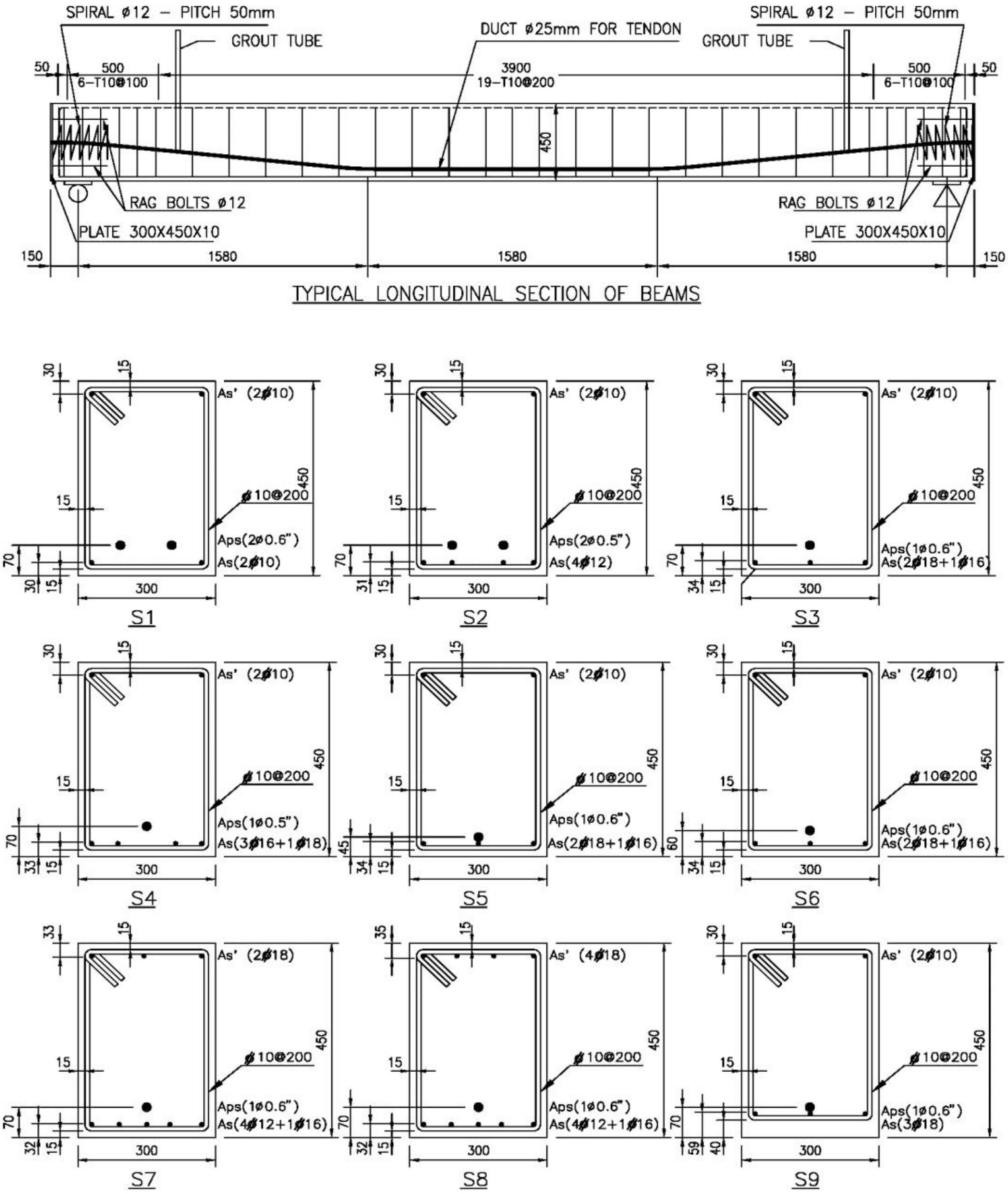


Figure 1: Tested beams details and sections

Variables are partial prestressing ratio PPR $(PPR = \frac{M_{ult.\,of\,pres.steel}}{M_{ult.of\,pres.steel+Rft}})$, depth of prestressing steel, compression reinforcement ratio and concrete cover; as shown in Table 1. Four beams had different PPR which the most important variable of this study, whereas PPR equal 0.86, 0.61, 0.41 and 0.29 assigned for beams S1, S2, S3 and S4 respectively, while remaining beams have PPR close to partial prestressing ratio of beam S3; all eccentricities of prestressed steel were 155mm except for S5 and S6 were 180mm and 165mm respectively; compression reinforcement was 157mm^2 for all beams except for S7 and S8 were 508mm^2 and 1016mm^2 respectively. Cover of reinforcement was 50mm for S9 while it was 25mm for all other beams.

Table 1: Beams variables

BEAM	A_{PS} mm^2	A_S mm^2	A_S' mm^2	d_p mm	d mm	d' mm	cover mm	Partial Prestressing ratio PPR
S1	280 (2Ø0.6")	157 (2T10)	157 (2T10)	380	420	30	25	0.86
S2	197.4 (2Ø0.5")	452 (4T12)	157 (2T10)	380	419	30	25	0.61
S3	140 (1Ø0.6")	709 (1T16+2T18)	157 (2T10)	380	416	30	25	0.41
S4	98.7 (1Ø0.5")	857 (3T16+1T18)	157 (2T10)	380	417	30	25	0.29
S5	140 (1Ø0.6")	709 (3T18)	157 (2T10)	405	416	30	25	0.41
S6	140 (1Ø0.6")	709 (1T16+2T18)	157 (2T10)	390	416	30	25	0.41
S7	140 (1Ø0.6")	653 (4T12+1T16)	508 (2T18)	380	418	34	25	0.43
S8	140 (1Ø0.6")	653 (4T12+1T16)	1016 (4T18)	380	418	34	25	0.43
S9	140 (1Ø0.6")	762 (3T18)	157 (2T10)	380	391	30	50	0.38

2.2. Prestressing Losses

Prestressing force was applied from both ends in five steps consecutively, start by 25% from 1st end then 50% from 2nd end, 75% from 1st end, 100% from 2nd end and last 100% from 1st end. Losses due to friction and seating of anchors are 20.5% for S2 and S4; while losses are 24.5% for other beams as shown in Fig 2 and Fig 3. S1 and S2 had additional losses due to elastic shortening of concrete 1.5% (20.3 Mpa) and 1% (15.2 Mpa) respectively. In addition, long term losses are also calculated (based on guidelines of reference [8] and [9]) due to the duration between prestressing and loading time, and it had a minimal effect about 1% because of short duration with a maximum one month. Table 2 shows summary of losses for each beam.

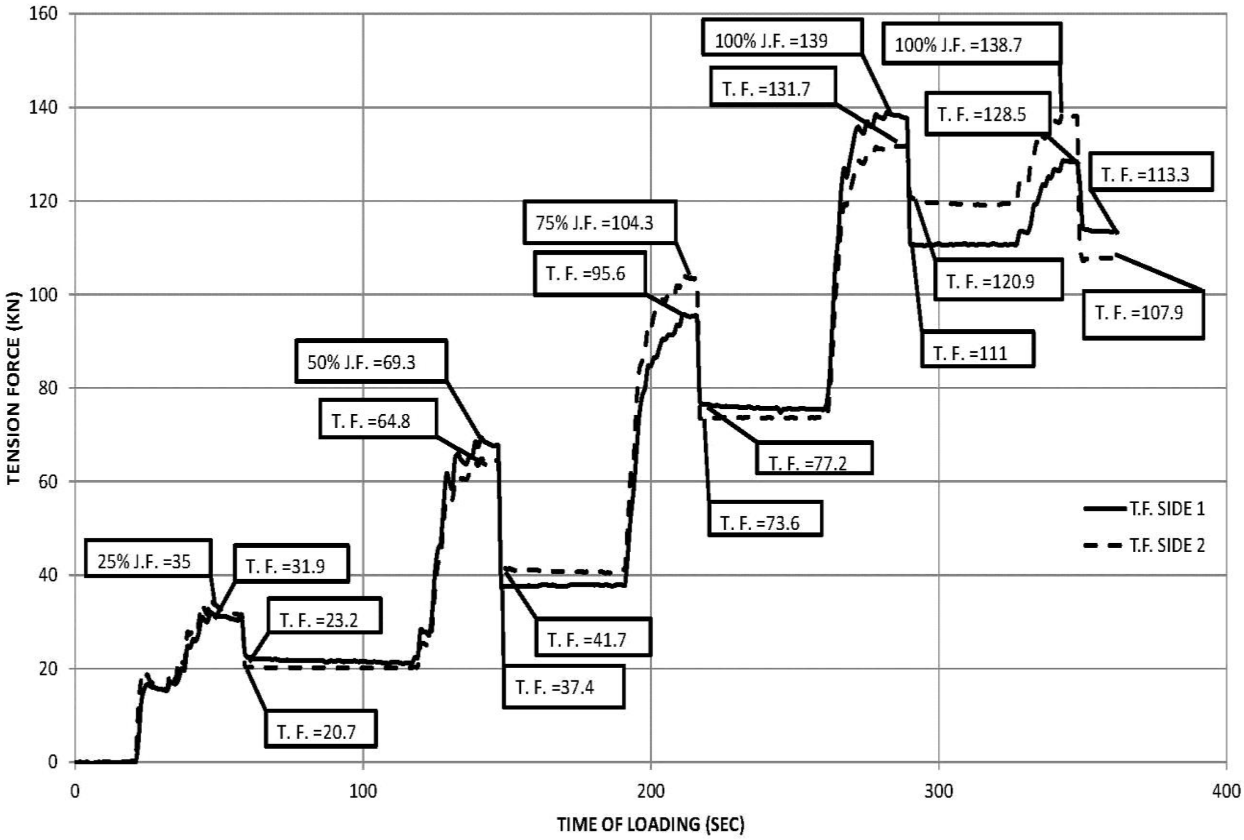


Figure 2: Losses at transfer stage in Group 1- tendon 0.5”

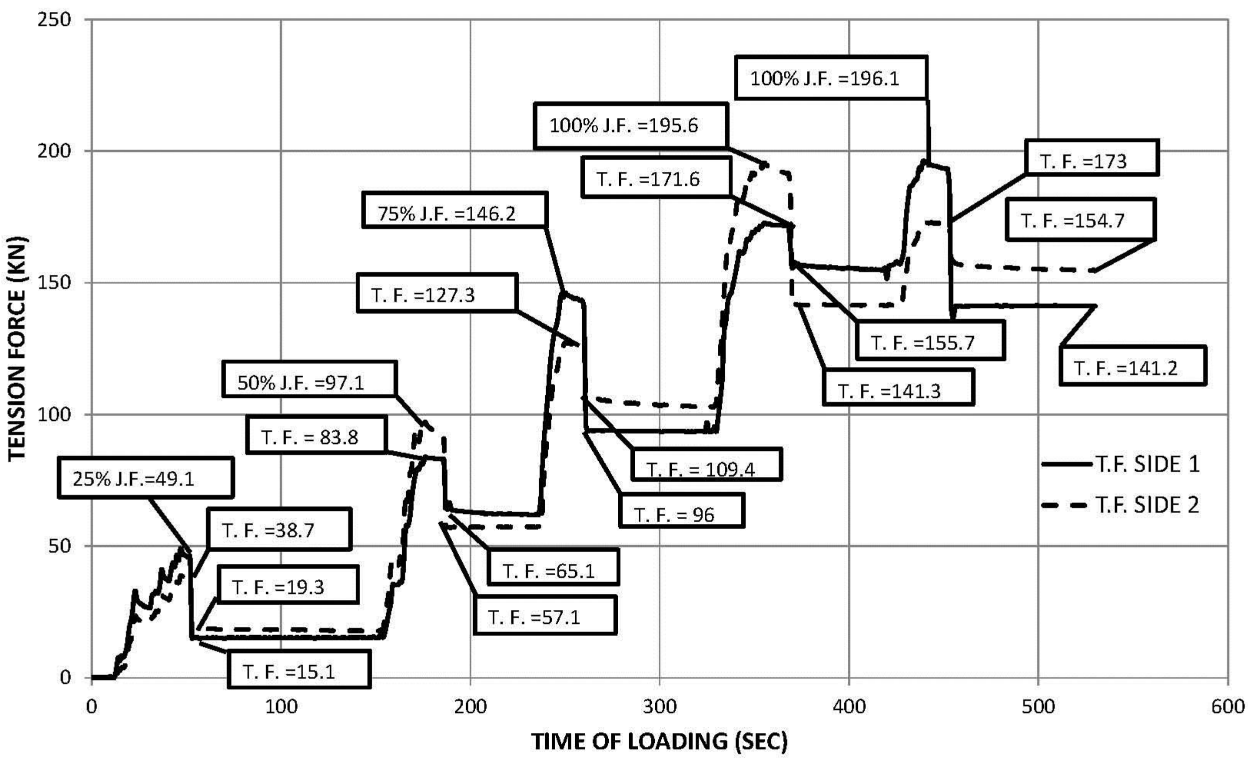


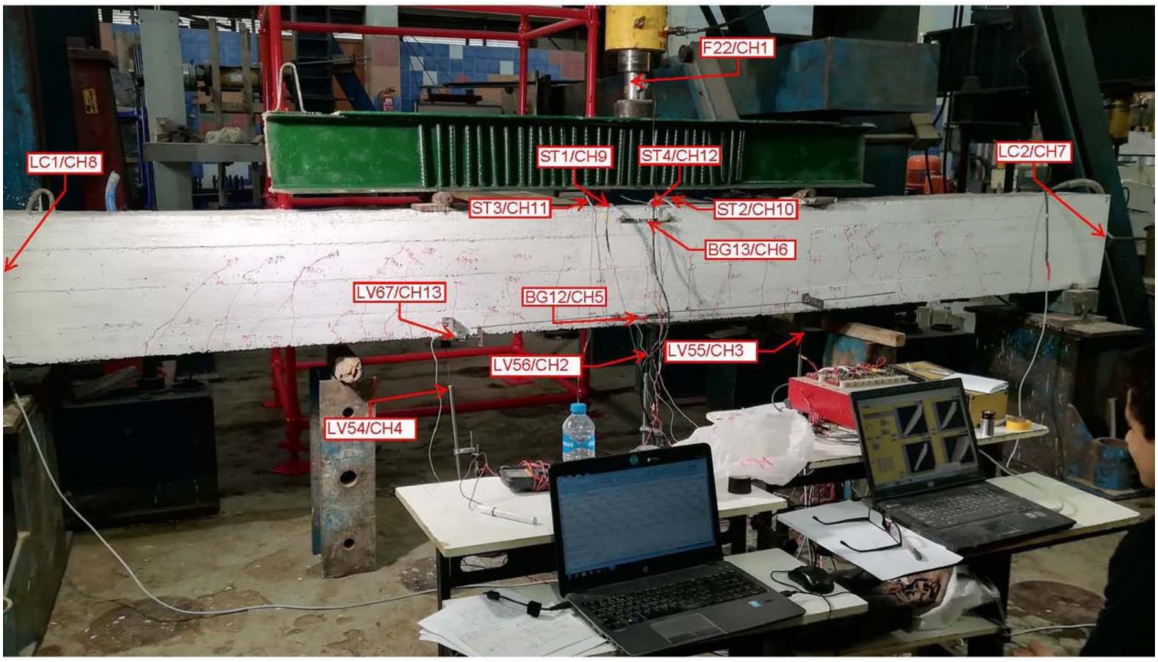
Figure 3: Losses at transfer stage in Group-2 tendon 0.6”

Table 2: Beams Losses

BEAM	Transfer Losses (Mpa)			Long Term Losses (Mpa)			Total Losses (Mpa)	Total Losses (%)
	Friction	Seating	Elastic shortening	Concrete Shrinkage	Concrete Creep	Steel relaxation		
S1	168.2	173.9	20.3	1.8	5.5	2.8	372.5	26.6
S2	88.7	197.6	15.2	4.2	4.1	4	313.8	22.3
S3	168.2	173.9	0	8.1	2.9	3.3	356.4	25.5
S4	88.7	197.6	0	2.3	2	3.6	294.2	20.9
S5	168.2	173.9	0	5.3	3.1	2.9	353.4	25.3
S6	168.2	173.9	0	1.5	2.7	2.5	348.8	24.9
S7	168.2	173.9	0	0.8	2.7	2.4	348	24.9
S8	168.2	173.9	0	1.9	2.7	2.8	349.5	25.0
S9	168.2	173.9	0	3	3	2.7	350.8	25.1

2.3. Test Setup

Fig. 4 shows the test set-up where beams were simply supported on hinged and roller supports at 150mm from both beam ends.



ST1 : BOTTOM STRAIN GAUGE (FRONT SIDE)
ST3 : TOP STRAIN GAUGE (FRONT SIDE)
BG12: BOTTOM BI GAUGE
LV54: VERTICAL LVDT UNDER LEFT LOAD
LV56:VERTICAL LVDT UNDER RIGHT LOAD
LC1: LOAD CELL AT LEFT END
F22: APPLIED FORCE
ST2: BOTTOM STRAIN GAUGE (BACK SIDE)
ST4 : TOP STRAIN GAUGE (BACK SIDE)
BG13: TOP BI GAUGE
LV55: VERTICAL LVDT UNDER MIDDLE OF BEAM
LV67: HORIZONTAL LVDT BETWEEN LEFT AND RIGHT LOADS
LC2: LOAD CELL AT RIGHT END

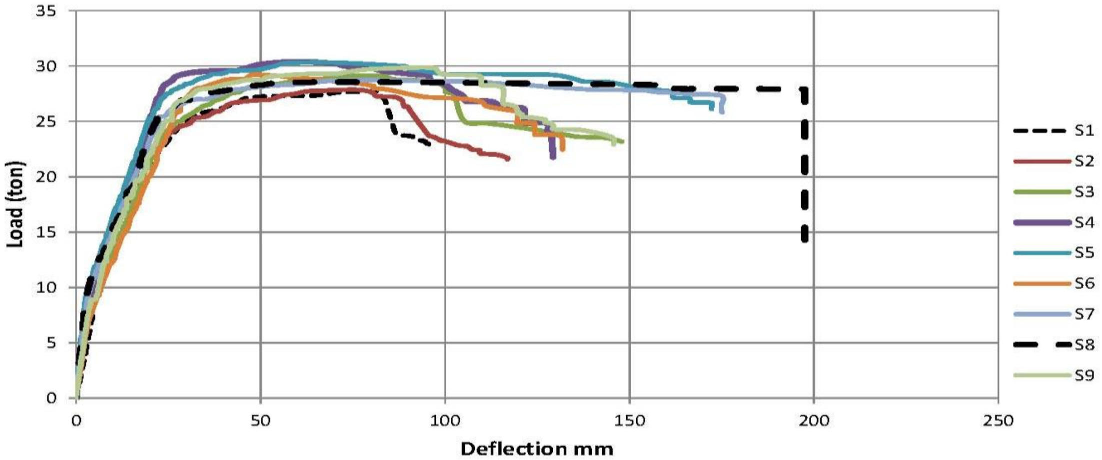
Figure 4: Test set-up

Fig. 4 shows the test set-up where beams were simply supported on hinged and roller supports at 150mm from both beam ends. The beams have been tested under loads till flexure failure. A hydraulic machine of capacity 500 KN has been used on top of stiffened steel I beam that transfer loads to two points on top of concrete beam spaced 1580mm at middle third of clear span. Stroke control system has been used to control deflection increment during applying load where increment starts with 0.5mm till reaching deflection 4mm, then increments increase gradually to be 1mm, 1.5mm, 2mm and 3mm till achieving deflection 10mm, 20mm, 45mm and 60mmm respectively; and finally increment is 5mm till failure. Strain at top and bottom reinforcement was measured using four electric strain gauges fixed with top and bottom reinforcement.

In addition, horizontal linear variable differential transducers were (LVDT) erected on one side of beam and 40mm above bottom level. On the other hand, vertical deflection was measured at middle of beam and under the two concentrated loads by using three linear variable differential transducers (LVDT). All data from previous instrumentations and from load cell under hydraulic machine have been collected through a data acquisition system and software “Lab view”.

2.4. Test Results

The Nine beams were tested till failure, and a comparison between beams ductility is shown in Fig. 5 and it has been found that beam S1 had lower ductility due to high value of its PPR, while beam S8 had the higher ductility (around twice ductility of S1) resulting from lower PPR and maximum compression reinforcement comparing with other tested beams. Failures of all tested beams were ductile failures as shown in Fig. 6. A comparison was developed between deflection from laboratory test results and calculation based on moment-curvature curve (refer to Fig. 7) which indicates acceptable results. In addition, a comparison between actual and estimated cracking-load, yield-load and ultimate load were presented in Table 3; it is clear that calculation for yield-load and ultimate load are very close to actual values with maximum difference ranging between 0% and 13%; while cracking-load indicates less accuracy with maximum difference of 15%.



Beam	S1	S2	S3	S4	S5	S6	S7	S8	S9
Ductility	3.6	4.3	5.5	4.8	6.4	4.9	6.5	7.3	5.4

Figure 5: Load-deflection and ductility comparison between tested beams

Figure 6: Failure modes (ductile) for tested beams

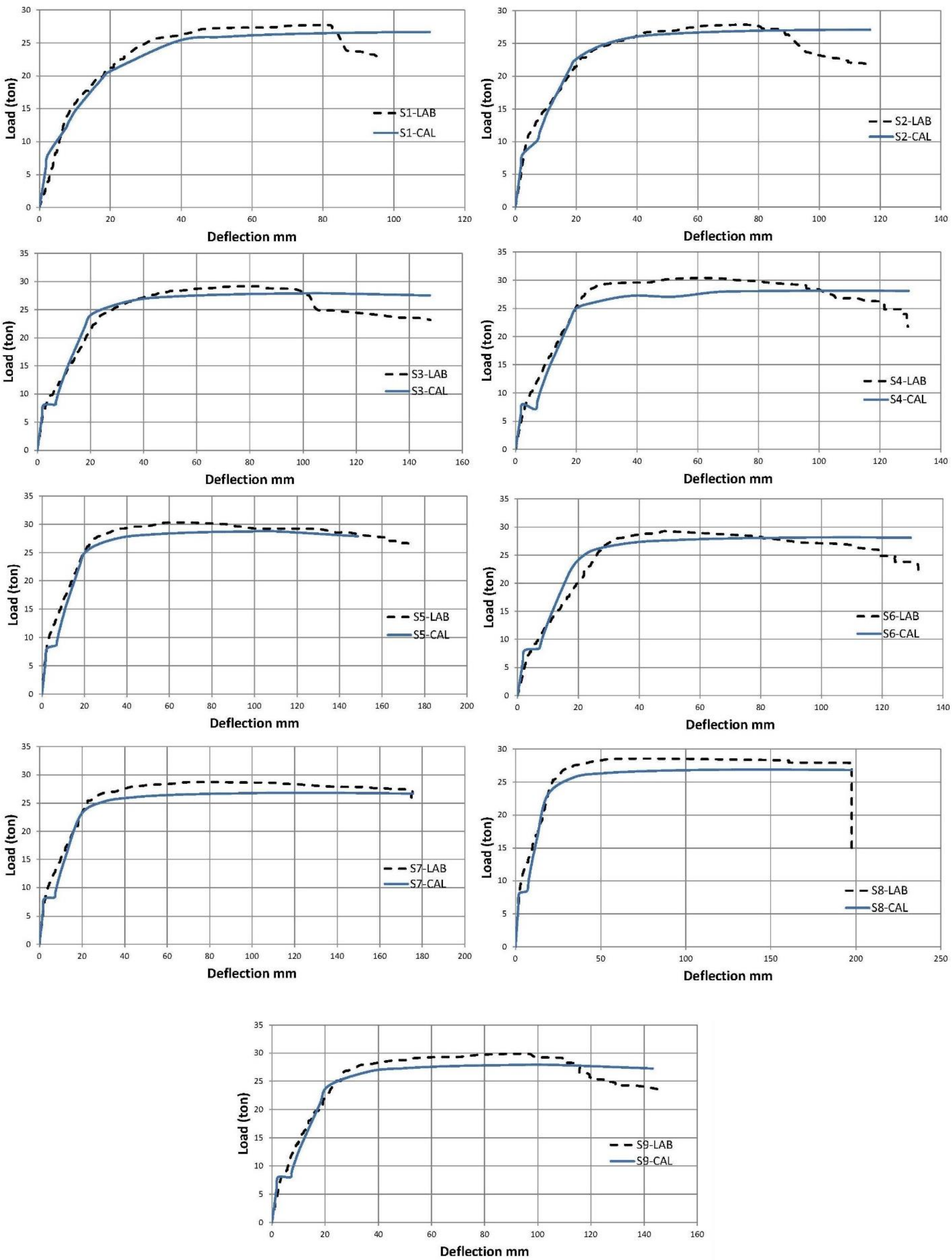


Figure 7: Load-deflection comparison between Lab. results and analytical study

Table 3: Comparison between actual-loads and estimated-loads

Beam	Cracking load (ton)			Yield load (ton)			Ultimate load (ton)		
	Test	Cal.	Test/Cal	Test	Cal.	Test/Cal	Test	Cal.	Test/Cal
S1	12.70	12.13	1.05	22.4	20.49	1.09	27.72	26.65	1.04
S2	11.40	10.12	1.13	23.38	22.39	1.04	27.87	27.09	1.03
S3	8.30	8.09	1.03	22.10	23.94	0.92	29.14	27.89	1.04
S4	6.90	7.09	0.97	23.13	24.96	0.93	30.39	28.16	1.08
S5	9.80	8.59	1.14	26.17	24.84	1.05	30.30	28.76	1.05
S6	8.80	8.30	1.06	25.00	24.96	1.00	29.25	28.16	1.04
S7	9.50	8.23	1.15	22.10	22.89	0.97	28.74	26.82	1.07
S8	9.60	8.45	1.14	25.97	23.02	1.13	28.53	26.89	1.06
S9	8.60	8.00	1.08	23.97	24.23	0.99	29.84	27.90	1.07

Fig. 8 shows the effect of PPR on deflection of the tested beams. It can be classified in two stages; fist stage starts with initial crack till maximum service load and second stage till failure. At first stage, beams with high PPR (S1 and S2) had the lower deflection at same level of loading but deflection difference between all PPR ratios is around 20%. On the other hand, the second stage does not affect design in most cases whereas load is more than limit of maximum service load; this stage shows that lowest PPR of 0.29 (S4) had the minimum deflection with a major difference in deflection of 55% compared to other PPR ratios. Also, beam S3 and S4 had ductility more than beams S1 and S2 as shown in Fig. 8.

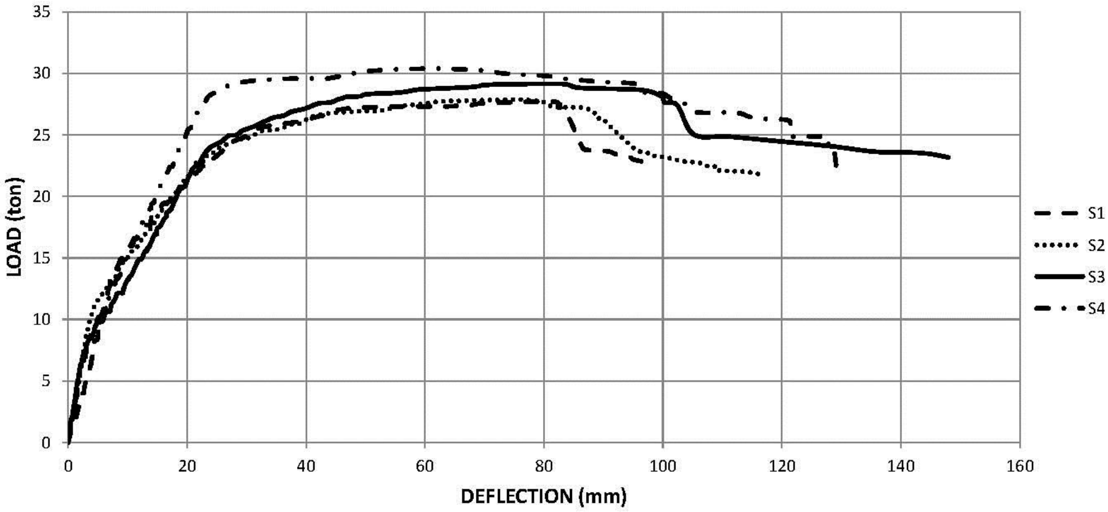


Figure 8: Comparison of tested beams with variable PPR

Also, increasing depth of prestressing by 7% enhances deflection at service load level by 25% and increases ductility as well by 6% as shown in Fig. 9.

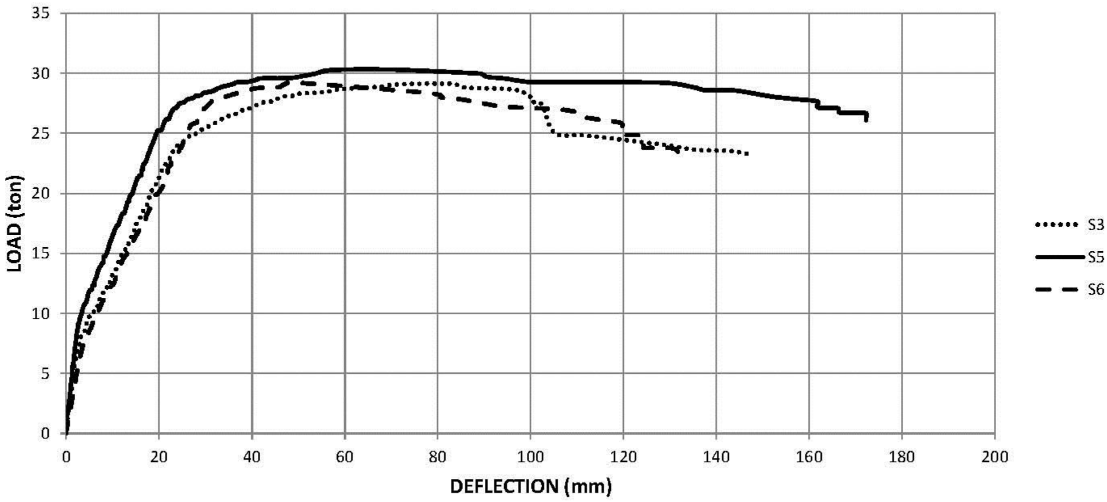


Figure 9: Comparison of tested beams with variable dp

Fig. 10 shows minor effect for compression reinforcement where increasing As' from 0.116% to 0.753% caused only enhancement in deflection by 12%, but ductility has been increased by 40%. Also, effect of concrete cover is minimal as shown in Fig. 11, taking into consideration that this study is based on constant moment capacities for all tested beams.

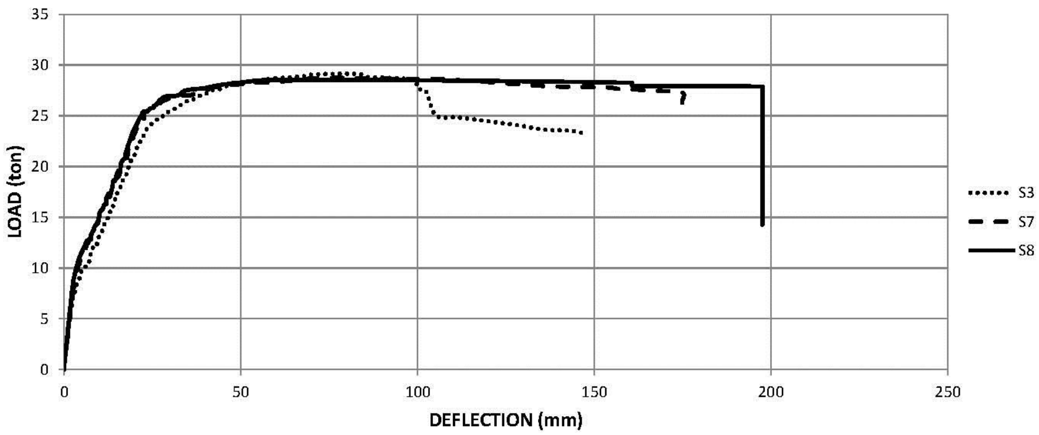


Figure 10: Comparison of tested beams with variable As'

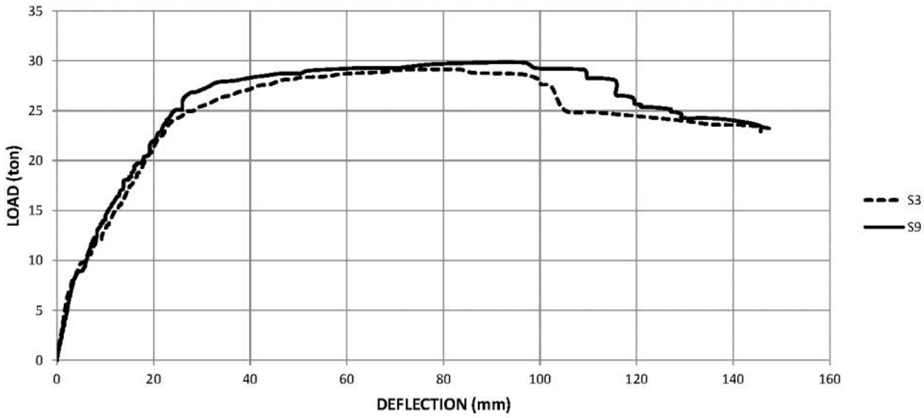


Figure 11: Comparison of tested beams with variable concrete cover

3. Analytical Model and Previous tests by A.E. Namman and M.H. Harajli [7]

3.1. Analytical Model

A 3D-model has been performed using ANSYS software to simulate the experimental test and obtaining more results of the studied variables based on this model. Concrete was modeled using Solid 65 material solver, steel and tendons were modeled using Link 180 material solver, mesh was chosen to be boxes (solid parts and link members) with max dimension of 50 mm, which was found as suitable as reducing mesh to 25mm resulting in less than 2% with solving time of 6 multiples. Boundary limits were chosen to simulate the experiment, with mid-span axis of symmetry (solving half model). Loads are assigned on a steel plate with dimension 300*100*20 mm resting on the concrete, with bottom support of line restricted to move down but allowed to rotate (hinged support).

3.1.1. Comparison between experimental tests and analytical model

Additional results have been obtained using the models including additional PPR of 0.95, 0.70, 0.50 and 0.20, and prestressing depth of 250, 300 and 350, and compression reinforcement of 1% and 1.25%. Results of additional variables are shown in Fig. 12. Also, deflection results from the analytical models were verified with corresponding results of experimental tests, refer to Fig. 13. It is clear that PPR is the most effective variable while As' and depth of prestressing have minimal effect at service load level.

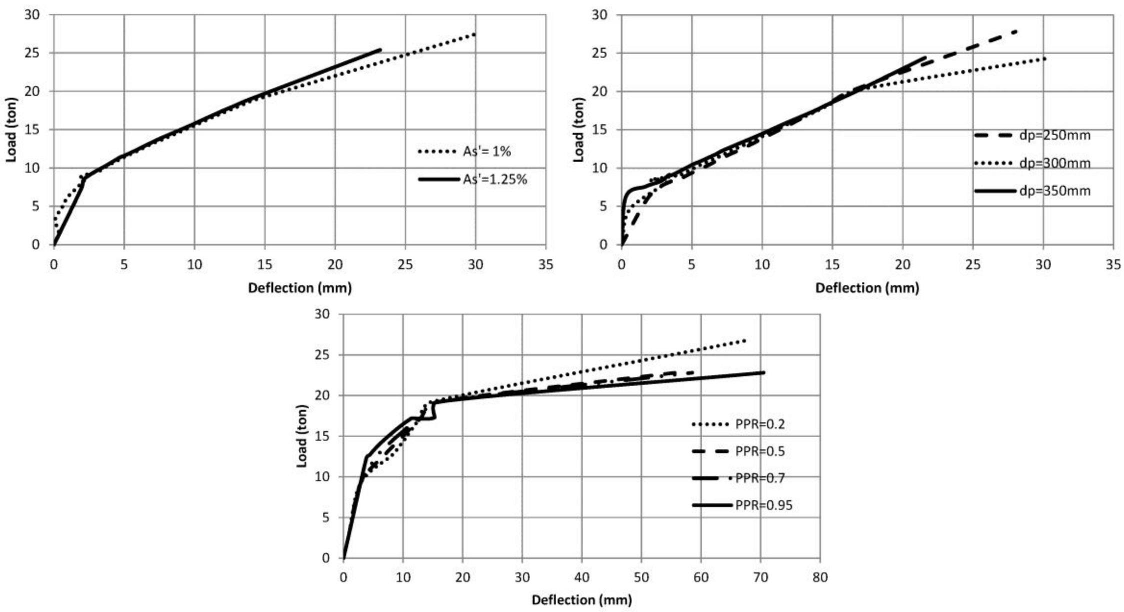


Figure 12: Load-deflection results for additional variable using ANSYS

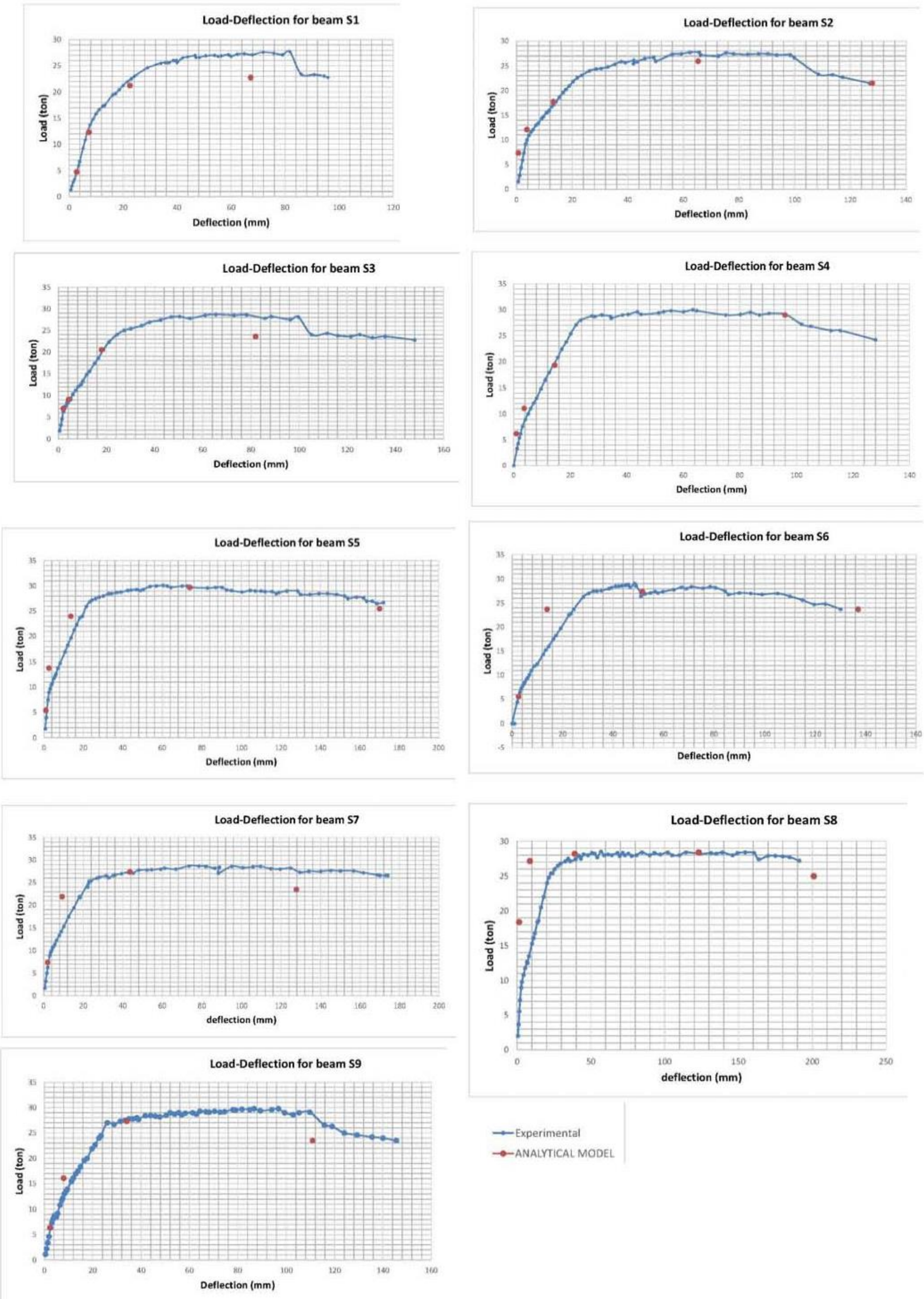


Figure 13: Load-deflection comparison of analytical and experimental results.

3.2. Results of previous tests by A.E. Namman and M.H. Harajli [7]

In 1984, Harajli and Naaman studied the effect of fatigue resistance of partially prestressing concrete beams by testing twelve sets of beams. Each set consisted of two identical beams; first beam subjected to cyclic load, and the second beam subjected to static load. The main variables for the twelve sets were the partial prestressing ratio (PPR) which varied as 0.0, 0.33, 0.67 and 1.0; and the reinforcing index (ω̃) which varied between ω̃max, [illegible] ω̃max and [illegible] ω̃max. Each set consisted of two beams; first subjected to static load till the ultimate load while the second subjected to cyclic load between 40% and 60% from the maximum static load. Fig. 14 show beams properties. This study highlights results of the partial prestressed beams only which is indicated as PP1-S1, PP1-S2, PP1-S3, PP2-S1, PP2-S2 AND PP2-S3; results were compared with proposed formula, refer to Table 4.

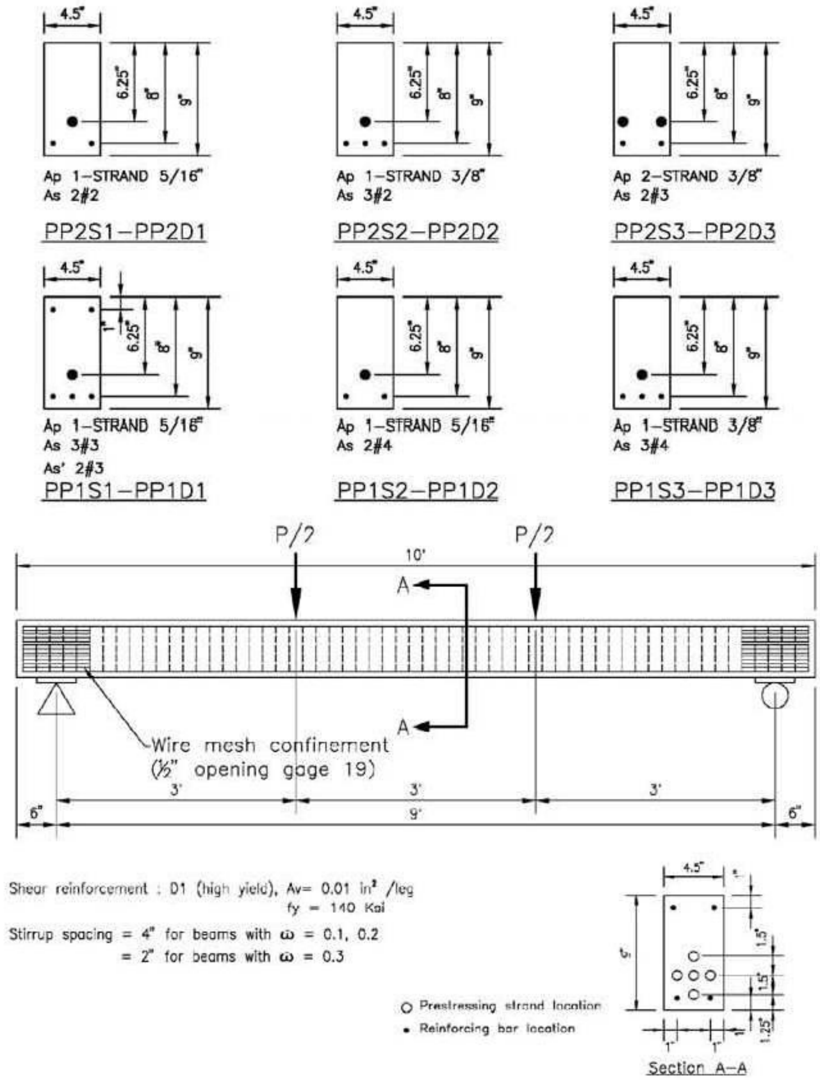


Figure 14: Beams details of test conducted by A.E. Namman and M.H. Harajli

4. Proposed formula for effective inertia and discussion

Reference to results of experimental tests, previous experimental test by A.E. Namman and M.H. Harajli [7] and Analytical model, a formula was proposed (Eq. 3) that is based on Branson equation (Eq. 1) and Namman equation (Eq. 2), and reflecting PPR different levels. $I_{eff} = I_{cr} + \{|\frac{M_{cr}}{M}| - |\frac{M_{dec}}{M}|\}\{I_g - I_{cr}\}$ Eq. 3

Table 4: Comparison of deflection using proposed formula and other methods

BEAM S1						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.7	7.8	7.8	5.3	7.9	6.1	6.7
15.8	10.3	15	8.3	13.8	9.8	10.3
16.6	11.5	17.8	9.6	16.0	11.3	11.8
17.2	13.2	19.9	10.7	17.6	12.4	13.0

BEAM S2						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.3	7.8	9.5	6.4	8.7	6.6	7.2
15.7	11.22	14.6	9.8	12.8	9.5	10.8
16.7	12.67	16.6	11.4	14.4	10.7	12.4
18.7	15.65	20.2	14.5	17.6	13.2	15.6

BEAM S3						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
11.8	8.6	7.9	6.1	7.4	5.7	6.4
15.8	13.3	13.6	11.1	12.3	9.5	11.4
17.3	15.2	15.5	13.0	14.1	11.0	13.3
18.6	16.6	17	14.7	15.6	12.3	15

BEAM S4						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
11.8	7.1	8	6.7	7.5	5.9	6.8
13.14	8.2	9.6	8.2	9.0	7.0	8.3
17.72	12.59	14.7	13.3	13.7	11.0	13.4
19.1	14	16.1	14.8	15.1	12.2	14.9

BEAM S5						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
12.3	6.04	8.1	6.2	7.4	5.8	6.5
14.6	8.35	11.5	9.0	10.3	7.9	9.3
18.2	12.25	16.1	13.5	14.5	11.4	13.8
19.3	13.57	17.4	14.8	15.7	12.4	15.2

BEAM S6						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
11	7.8	6.4	5.0	6.1	4.8	5.3
16.6	15.25	14.4	11.9	13.0	10.1	12.2
18.3	17.6	16.5	14.0	15.0	11.8	14.3
19.4	19.1	17.8	15.4	16.2	12.8	15.7

BEAM S7						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
12.2	6.5	8.4	6.4	7.9	6.0	6.7
13.2	7.85	9.9	7.6	9.2	7.0	8
15.1	10.2	12.8	10.1	11.7	8.9	10.4
19.2	15.2	18.1	15.5	16.6	13.0	15.8

BEAM S8						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.1	7.5	9.2	7.0	8.7	6.6	7.3
15.8	11	13.1	10.4	12.0	9.2	10.8
16.8	12.1	14.5	11.7	13.2	10.2	12.1
18.8	14.6	17	14.3	15.6	12.1	14.6

BEAM S9						
	Deflection (mm)					
Actual load at Lab. (Ton)	Actual	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13	8.4	10.3	7.9	9.5	7.3	8.3
15.1	11	13.5	10.8	12.3	9.4	11.2
17.4	14	16.7	13.9	15.2	11.8	14.3
20.4	18	20.4	18.0	18.8	15.0	18.3

ANSYS BEAM PPR=0.2						
	Deflection (mm)					
LOAD (Ton)	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.7	9.3	10.2	9.4	9.8	7.8	9.5
15.8	11.4	12.3	11.5	11.7	9.5	11.6
16.6	12.2	13	12.3	12.4	10.2	12.3
17.2	12.8	13.7	13.0	13.1	10.8	13.0

ANSYS BEAM PPR=0.5						
	Deflection (mm)					
LOAD (Ton)	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.7	8.2	10.8	8.0	9.8	7.4	8.5
15.8	11.0	14.1	10.8	12.6	9.6	11.3
16.6	12.1	15.2	11.8	13.6	10.4	12.4
17.2	13.0	16.2	12.8	14.5	11.1	13.3

ANSYS BEAM PPR=0.7						
	Deflection (mm)					
LOAD (Ton)	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.7	7.1	9.7	6.4	8.9	6.7	7.4
15.8	10.3	14.8	9.3	12.9	9.5	10.6
16.6	11.5	16.6	10.5	14.3	10.5	11.9
17.2	12.6	18.1	11.7	15.5	11.4	13.0

ANSYS BEAM PPR=0.95						
	Deflection (mm)					
LOAD (Ton)	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
13.7	5.6	4.7	4.3	4.7	4.4	5.8
15.8	8.8	11.8	6.9	11.5	8.4	9.1
16.6	10.2	15.2	8.1	14.3	10.1	10.6
17.2	11.4	17.3	8.8	15.9	11.2	11.6

ANSYS BEAM dp=250						
	Deflection (mm)					
LOAD (Ton)	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
11.8	7.7	8.6	7.8	8.4	6.6	7.9
15.8	12.1	12.9	12.2	12.4	10.1	12.2
17.3	13.6	14.4	13.7	13.8	11.4	13.8
18.6	14.9	15.7	15.1	15.1	12.5	15.1

Cont. Table 4: Comparison of deflection using proposed formula and other methods

ANSYS BEAM dp=300							ANSYS BEAM dp=350						
LOAD (Ton)	Deflection (mm)						LOAD (Ton)	Deflection (mm)					
	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula		ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
11.8	7.3	8.6	7.3	8.2	6.4	7.4	11.8	6.7	8.3	6.6	7.8	6.0	6.8
15.8	11.9	13.4	12.0	12.6	10.0	12.1	15.8	11.6	13.6	11.6	12.5	9.8	11.8
17.3	13.7	15	13.7	14.1	11.4	13.8	17.3	13.5	15.4	13.4	14.2	11.2	13.7
18.6	15.1	16.4	15.2	15.5	12.6	15.3	18.6	15.0	17	15.0	15.7	12.5	15.2
ANSYS BEAM As'=0.01							ANSYS BEAM As'=0.0125						
LOAD (Ton)	Deflection (mm)						LOAD (Ton)	Deflection (mm)					
	ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula		ANSYS	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
12.2	5.9	7.5	5.7	7.2	5.5	6.0	12.2	5.7	7.2	5.5	7.0	5.3	5.8
13.2	6.9	9	6.9	8.5	6.4	7.2	13.2	6.7	8.7	6.6	8.3	6.3	6.9
15.1	9.7	11.8	9.2	10.9	8.2	9.5	15.1	9.4	11.5	8.9	10.6	8.1	9.2
19.2	14.1	17.1	14.4	15.7	12.2	14.7	19.2	13.7	16.8	14.0	15.4	12.0	14.4
PP1-S1 [7]							PP1-S2 [7]						
LOAD (Ton)	Deflection (mm)						LOAD (Ton)	Deflection (mm)					
	ACTUAL	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula		ACTUAL	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
3.89	8.5	10.9	9.7	10.0	8.0	9.8	5.00	11.0	13.2	12.6	12.5	10.6	12.7
4.45	10.3	12.7	11.7	11.9	9.7	11.8	5.56	12.9	14.7	14.2	14.1	12.1	14.3
5.00	12.2	14.5	13.6	13.7	11.3	13.7	5.84	13.7	15.5	15.1	14.9	12.8	15.1
5.84	15.2	17.2	16.5	16.4	13.8	16.5	6.31	16.8	16.8	16.4	16.2	14.1	16.4
PP1-S3 [7]							PP2-S1 [7]						
LOAD (Ton)	Deflection (mm)						LOAD (Ton)	Deflection (mm)					
	ACTUAL	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula		ACTUAL	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
7.35	15.6	14.6	14.3	14.1	12.5	14.4	1.78	2.5	2.8	2.3	3.8	2.8	2.5
7.84	17.1	15.6	15.4	15.1	13.5	15.4	2.00	3.6	4.6	3.4	6.2	4.3	3.6
8.33	18.6	16.6	16.4	16.1	14.4	16.4	2.22	4.7	6.8	4.7	8.4	5.8	5.0
8.82	20.3	17.6	17.4	17.1	15.4	17.1	2.45	6.1	9.1	6.1	10.5	7.3	6.5
PP2-S2 [7]							PP2-S3 [7]						
LOAD (Ton)	Deflection (mm)						LOAD (Ton)	Deflection (mm)					
	ACTUAL	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula		ACTUAL	Namman	ACI	EURO	A.S.Alameh & M.H.Harajli	Proposed formula
2.78	5.6	9.7	6.4	8.7	6.4	7.0	5.56	11.7	18.6	15.1	16.1	12.6	16.0
3.34	8.2	14.1	9.9	12.4	9.2	10.6	6.12	13.8	20.7	17.4	18.3	14.5	18.3
3.89	11.5	17.9	13.6	15.9	12.0	14.3	6.67	16.2	22.8	19.9	20.5	16.5	20.6
4.17	14.4	19.6	15.4	17.6	13.4	16.2	7.23	18.7	24.8	22.2	22.6	18.4	22.9

It has been noted that with high values of PPR, Eq. 1 gives higher value of effective inertia while Eq. 2 results lower value of effective inertia. Also, for lower value of PPR the Branson equation gives results close to the actual behavior. Table 4 presents a comparison between results of deflection within service loads range for the nine tested beams or ANSYS additional deflection results versus proposed formula and other different formulas.

5. Conclusion

Based on results of tested beams, analytical model and results of previous tests, the following conclusions can be deduced:

d. Proposed formula gives acceptable results especially with level of PPR more than 0.50 and is very close to Branson equation for lower values.

e. PPR is the most effective factor for deflection control as an example, increasing PPR from 0.41 to 0.86 caused decreasing in deflection by 18.5%.
f. The presented equation by Branson (recommended by ACI, ECP and PCI) gives the most accurate deflection values for PPR less than 0.50.
g. Increasing depth of prestressing, compression reinforcement and concrete cover have minor effect on deflection, taking into consideration that this study is based on constant moment capacities for all tested beams.
h. Prestressing level is inversely proportionate with ductility, and engineering judgment is required to benefit from enhancement in control of deflection and the required ductility level.
i. Further studies are recommended for studying the effect of above mentioned variables with high strength concrete.

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