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Systematic Review for Behavior of Post-Tensioned Concrete Members with Different Tendon Bonding Conditions

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ABSTRACT

The prestressed members of a post-tensioned cable are classified as either bonded or unbonded according to the tendon bonding conditions. Trials and research that interested in a discrepancy between bonded and unbonded of different kinds of prestressed concrete members were rarely reported. This investigation aims to carry out a statistical comparison between the behaviours of bonded and unbonded post-tensioned prestressed members based on Meta-Analysis. To perform this, previous experimental studies on post-tensioned concrete members are reinvestigated, and statistical analysis is conducted using Meta-Analysis based on the standardized mean difference. The findings of the prior tests trials and current synthesized statistical analysis are implemented for better understanding the action of concrete members that include both bonded and unbonded post-tensioned prestressed reinforcements. The summary total effect size is recorded as -0.09 standard deviation with -0.805 to 0.757 confident interval and the p-value is 0.821. From the statistical point of view, the result is not statistically significant and no evidence indicates to reject the null hypothesis. So, there is not any function between the flexural strength and the conditions of different tendon bonding of post-tensioned prestressed concrete members. There is a lack of experimental information and investigations about the difference between bonded and un-bonded post-tensioning prestressed members. That means additional experimental work is needed to fulfil this lack.

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1. Introduction

The durability decay due to steel corrosion that occurs due to the influence of a tension zone crack in concrete is considered as a first disadvantage of using ordinary reinforced concrete members. While the crack control at the level of service loadings is considered as the main advantage in the concrete prestressed members. Hence, large structural applications are adopting prestressed concrete as a fundamental system because of the entire use of compressive concrete strength at a post-service level and via proper design by controlling cracking, corrosion, and deflection at the serviceability level. Commonly, prestressed concrete can be made in two systems namely pre-tensioned or post-tensioned. The latter can be constructed either as concrete with unbonded post-tensioned or concrete with bonded post-tensioned. Nowadays, prestressing in general and post-tensioning, in particular, is an adult technology. It furnishes economic, efficient, and wise structural solutions for a diverse and wide range of applications. Moreover, another classification of the prestressed concrete system that assumed the prestressed concrete is either fully or partially prestressing which is controlled by the design concept. The allowable tension stresses are the key to this classification. In fully prestressed concrete, at full-service load, the tensile stresses in concrete members must be either eliminated or be within allowable values that resist by concrete tensile strength only. On the other hand, if the tension stresses and cracking under full-service loads is allowed then the prestressed concrete is classified as partially prestressing [1–3].

Despite many decades, the design procedures for prestressed concrete have been developed and coded, there is still a lack of full understanding of the structural design of post-tensioned concrete members, especially for complex structural failure mechanisms. Moreover, previous trials of the discrepancy between bonded and unbonded for a variety of concrete members are seldom reported. Only little experimental studies are compared the behaviour of post-tensioned concrete members with bonded and unbonded prestressing. A series of post-tensioned concrete beams were tested by [4] in 1971 and they have examined the difference between the bonded and bonded prestressing in terms of ultimate moment strength. In 1981 Cooke et al. [5] investigated the flexural strength of the one-way concrete slabs with a post-tensioned system with two types of tendon bonding conditions. In 2012 Hussien et al. [6] tested nine normal and high strength concrete beams with bonded and unbonded prestressing systems. Till 2012, no experimental trial was found in the literature that can be used as a comparison tool between both the two systems namely bonded and unbonded tendon in two-way concrete [7]. Furthermore, most of the existing experimental trials in the literature on concrete slab-column connections with the post-tensioned system were performed with only unbonded prestressing slabs [8]. Only one connection test trial was found in the literature with a bonded post-tensioned slab conducted in 2004 by [9]. Fortunately, in 2017, Oukaili and Khattab [10] recorded experimentally the cracking load of ten prestressed concrete beams with the bonded and unbonded prestressing mechanism.

These important experimental data are carefully statistically re-examined in this systematic review to build proposed statistical modelling by using Meta-Analysis to study the problem in depth. To better understand the unclear picture resulting from the lack of scarce experimental trials and due to the absence of direct experimental comparisons in the aforementioned experimental trials, a systematic statistical review is conducted. One of the main aims of this study is to capture more accurate and reliable conclusions for the behaviour of unbonded prestressing post-tensioned members as compared with bonded prestressed post-tensioned members. With the help of the using synthesize statistical techniques based on Meta-Analysis, past experimental trials are strictly collected and reproduced in such a statistical method that convert the experimental data to more combined meaningful information.

2. Methodology

The search strategy was implemented based on boolean combinations of suitable, and concise keywords. The number of experimental trials that were screened and included in this paper is based on defined inclusion and exclusion criteria. The inclusion criteria adopted in this systematic review covers all experimental trials that include the comparative investigation of the concrete members with post-tensioned in two different mechanisms either bonded or unbonded prestressing systems on an identical scale. Trials have been written in the English language. Trials must combine clear and complete experimental data that can convert them to information using statistics. Hence, only trial programs that have been used coincide specimens in all design details except for different tendon bonding are included in this study. Analytical and numerical trials are assumed as part of the exclusion criteria. Trials with fire, corrosion, and fatigue are also excluded. Trials with either external bonding techniques or fibre prestressed concrete members are further excluded [11,12]. The data in each trial for unbonded prestressing tendon type is named as a control group on one side while the bonded type data is titled as a treated group on another side for the equivalent trial.

The statistical simulation for the extract data from the chosen experimental trials is carried out based on Meta-Analysis. The effect size is calculated based on the control group and the treated group's standardized means difference (d) for each trial as in the following equation.

$$\boldsymbol{d} = \frac{\bar{X}_1 - \bar{X}_2}{S_{within}} \tag{1}$$

In the numerator, $\bar{\boldsymbol{X}}_1$ and $\bar{\boldsymbol{X}}_2$ the sample means in the two groups. In the denominator $\boldsymbol{S}_{within}$ the within-groups standard deviation pooled across groups,

$$\boldsymbol{S}_{within} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}} \tag{2}$$

The variance of $\boldsymbol{d}$ is given approximately by

$$\boldsymbol{V}_d = \frac{n_1 + n_2}{n_1 n_2} + \frac{d^2}{2(n_1 + n_2)} \tag{3}$$

The standard error of $\boldsymbol{d}$ is the square root of $\boldsymbol{V}_d$,

$$\boldsymbol{SE}_d = \sqrt{\boldsymbol{V}_d} \tag{4}$$

The pooled standard deviation was used to express the average standard deviation for control and treated data. Each trial weight was found based on the inverse of average variance[13]. The weight assigned to each study in a fixed-effect meta-analysis is given as:

$$W_i = \frac{1}{V_{Y_i}} \tag{5}$$

where $\boldsymbol{V_{Y_i}}$ is the within-study variance for study ($\boldsymbol{i}$). Furthermore, the confidence interval for each trial was calculated and used to show the importance of that trial. The total weight of all the chosen trials was used to find the summary effect size variance. As a result, the summary effect size variance was used to define both the summery effective size and its confident interval [14]. The effect size for each trial and the summary with their confident interval were drawn in a forest plot. The weighted mean (***M***) is then computed as:

$$\boldsymbol{M} = \frac{\sum_{i=1}^{k} \boldsymbol{W_i Y_i}}{\sum_{i=1}^{k} \boldsymbol{W_i}} \tag{6}$$

Where $\boldsymbol{k}$ is the number of studies. So $\boldsymbol{M}$ is the sum of the products $\boldsymbol{W_i Y_i}$ (effect size multiplied by weight) divided by the sum of the weights. The variance of the summary effect is estimated as the reciprocal of the sum of the weights, or

$$\boldsymbol{V_M} = \frac{\boldsymbol{1}}{\sum_{i=1}^{k} \boldsymbol{W_i}} \tag{7}$$

3. Trials structures

Even this study is mainly concerned with the experimental trials as mentioned in the inclusion and exclusion strategic criteria, a general review for the main numerical studies of various bonding conditions of tendon profile is conducted to support the message of this study. Numerical analyses based on the so-called finite element technique of concrete prestressed members were carried out since old times. Modelling of bonding mechanism between the tendons profile and the adjacent concrete is considered the main key for simulating various kinds of prestressing systems. The principle of strain compatibility may be applied directly to simulate the tendons in pre-tensioned concrete members and bonded post-tensioned concrete members. The methodology of initial strain or equivalent temperature in tendons before applying the service loads is used to solve the pre-tensioned prestressing systems [15–18]. On the contrary, the numerical simulation of an unbonded post-tensioned concrete member requires a special formulation [18–22]. Most of the numerical attempts considering the numerical modelling of unbonded prestressing type are limited to beam members only. Little numerical trials are concerned with two or three-dimensional unbonded post-tensioned concrete members [23–26].

Unfortunately, experimental trial programs on bonded post-tensioned members are scarce. From these entire experimental trials, only four programs [4–6,10] were thoroughly examined and used further in the statistical analysis due to rich information contents that can be compared statistically. They included the identical geometry, properties and design details except for the tendon-bonding type. In the remaining of this section, the chosen prior four experimental trials are reviewed thoroughly.

The first trial in 1971 by Mattock et al. [4] tested bonded versus unbonded post-tensioned ten beams. Seven of them are supported by external hinges and the rest three are supported by continuous supports. Each span was 8.53m in length. The program classified those beams into four groups. In the first group, three beams of two-span continuous T-beam symbol as (CB1, CU1, and CU2) were considered. Three simply supported T-beams were considered in the second group which are named (TB1, TU1, and TU2). While, the third group consists of three simply supported rectangular beams titled (RB1, RU1, and RU2). Finally, the fourth group includes one simply supported T-Beam named (TU3) which was identical to TU1 or TU2 except in the amount of bottom mild steel and additional single 9.5 mm non-prestressed seven-wire strand which was worked as extra reinforcement. In specimens CB1, TB1, and RB1, the post-tensioned tendons are bonded type and surrounded by corrugated steel ducts. These three bonded specimens are parallel to CU1, TU1, and RU1 having unbonded post-tensioned tendons respectively. All the unbonded tendon specimens used plastic sheathes for tendon profiles. Tendons geometry and properties, mild steel position with its quantity, and properties, concrete properties, boundary and loading position with its type and rate for all specimens are found in the designated reference and as shown in Fig.1. According to the findings, as shown in Table 1, it has concluded, for the simply supported bonded post-tensioned beams, the ultimate strengths are greater by up to 20% than those of the unbonded matched specimens. It is known based on ACI 318 the strengths of both identical bonded and unbonded post-tensioned concrete beams have been yielded similar values. Mattock et al. [4] interpreted this large difference because of the presence of steel ducts that are neglected in the ACI code.

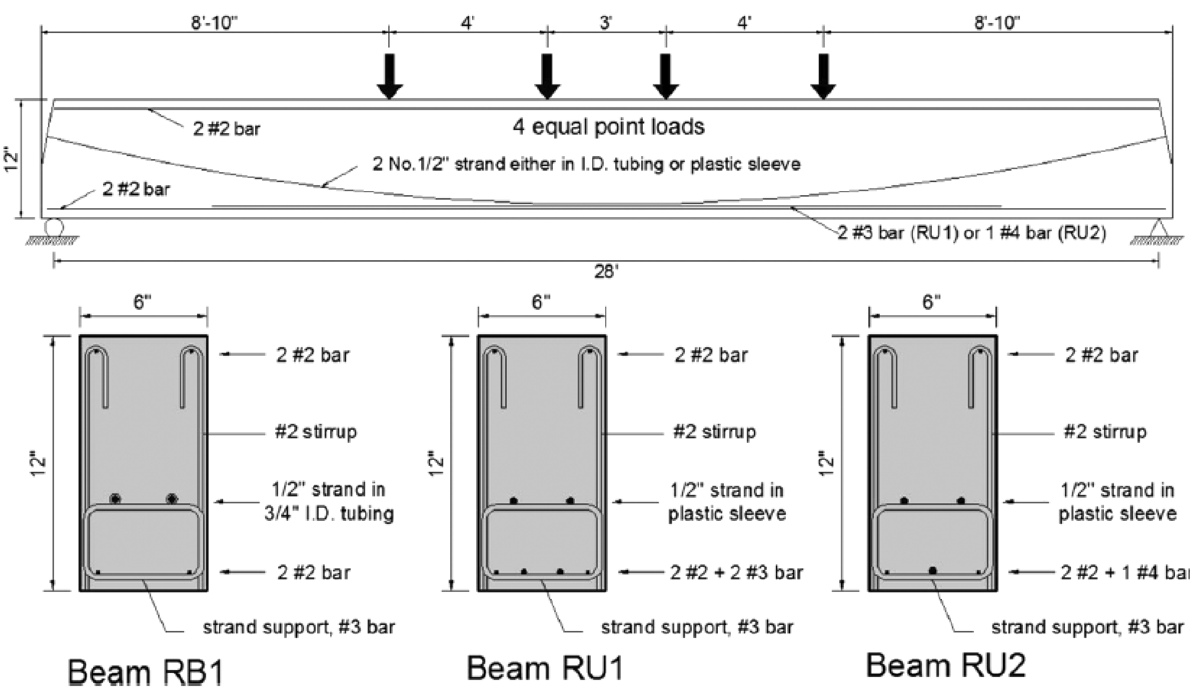

Fig. 1. Post-Tensioned beams conducted by Mattock et al. [4].

Table 1
Ultimate moment strength for beams examined by Mattock et al. [4].

Specimen	fse_exp, Ksi	fps_ACI, Ksi	fps_exp, Ksi	Mn_ACI, in.-Kip	Mn_exp, in.-Kip
"RB1"	188.2	247.0	"NA"	668	827
"RU1"	183.1	200.9	208.1	657	707
"RU2"	186.6	204.4	205.2	652	689
"TB1"	182.9	264.2	"NA"	8359	973
"TU1"	182.6	242.6	260.3	989	1105
"TU2"	181.6	241.3	253.5	825	905
"CB1"	"NA"	264.2	"NA"	835	812
"CU1"	192.8	252.5	"NA"	890	1014
"CU2"	193.5	250.1	"NA"	850	843

Notes: fse_exp is measured effective tendon experimentally stress; fps_exp is tendon nominal stress experimentally measured by using load cell at the end of the tendon; fps_ACI is nominal tendon stress according to ACI; NA is not available.

The second trial in 2012 by Hussien et al. [6] tested nine 4.4 m reinforced concrete beams. Some of these beams are provided with only non-prestressed reinforcement and others with prestressed tendons. The depths of these beams are 340 mm and their widths are 160 mm. The properties and geometry of materials used in this study are found in designated reference as shown in Fig.2. Three kinds of compressive concrete strengths namely 43, 72, and 97 MPa were investigated. Two types of tendon bonding conditions with three kinds of prestressing indexes 0%, 70%, and 100% were also carried out as seen in Table 2. The program of nine specimens has classified those beams into three groups. The first group consists of two non-prestressed beams named "B1" and "B4" reinforced with bars of 6ø10mm diameter as shown in Fig.2a. The grade of concrete is 72 and 97 MPa respectively. The second group includes two bonded fully prestressed post-tensioned concrete beams with only one 15.4 mm strand as drawn in Fig.2b. The grade of concrete adopted in this group is 72 and 97 MPa, respectively. The final group consists of five partially prestressed post-tensioned concrete beams named "B2", "B5", "B7", "B8", and "B9". Those beams have only one 12- mm strand with 2ø10mm diameter non-prestressed bars, as recorded in Fig.2c. The grade of concrete of "B7" is 43 MPa, and the grade of concrete is 72 MPa used for both "B2" and "B8". While both specimens "B5" and "B9" have a grade of concrete equal to 97 MPa. The bonded prestressing strands system is used for specimens B2 and B5. While, the unbonded prestressing strands system is adopted by specimens "B7", "B8", and "B9". Based on the test results as shown in Table 3, regarding the effect of grouting in comparing the "B2" and "B5" specimens of bonded tendons system with "B8" and "B9" of unbonded tendons system respectively, it was concluded that no significant differences in terms of both cracking and ultimate loads between two types of tendon bonding conditions. It was noticed a significant difference in the maximum deflection between the two types of systems.

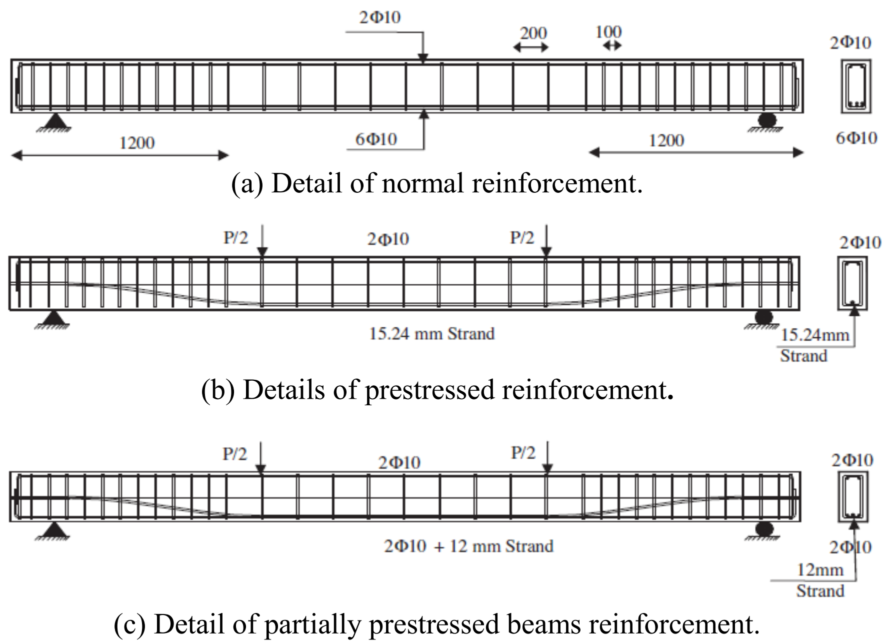

Fig.2. Detail of beams reinforcement tested by Hussien et al. [6].

Table 2
Specimens Program for beam Tested by Hussien et al. [6].

Name of Specimens	Concrete Grade MPa	Normal Bar	Area of Strand (mm)	Index of Prestressing
"B1" Bonded	72.0	6ø10	-	0.00
"B2" Bonded	75.0	2ø10	099.0	0.70
"B3" Bonded	76.0	-	140.0	1.00
"B4" Bonded	95.0	6ø10	-	0.00
"B5" Bonded	97.0	2ø10	099.0	0.70
"B6" Bonded	94.0	-	140.0	1.00
"B7" Unbonded	43.0	2ø10	099.0	0.70
"B8" Unbinded	72.0	2ø10	099.0	0.70
"B9" Unbonded	95.0	2ø10	099.0	0.70

Note: Where legend of the beams was as follows: Beam number-compressive strength- fully (F) or partially (P) or without prestressing (N)-bonded (B) or unbonded(U).

Table 3
Experimental results for beams tested by Hussien et al. [6].

Beams	Cracking stage		Yield stage		Ultimate stage	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
"B1"	33.0	2.54	103.0	16.80	152.0	140.7
"B2"	64.0	3.15	079.0	19.05	148.0	121.8
"B3"	70.0	3.57	083.0	19.88	135.0	63.2
"B4"	39.0	2.81	105.0	18.90	157.0	138.0
"B5'	67.0	3.56	081.0	19.80	153.0	112.0
"B6"	74.0	4.09	088.0	20.70	145.0	76.0
"B7"	47.0	4.07	115.0	29.20	141.0	76.0
"B8"	63.0	3.54	113.0	25.40	148.0	66.0
"B9"	65.0	3.60	121.0	24.80	155.0	53.0

The third trial in 1981 by Cooke et al. [5] studied bonded versus unbonded post-tensioned twelve simply supported one-way slabs under two-point external loads. The twelve slabs are classified in general as nine unbonded tendon post-tensioned prestressing systems and three bonded tendon post-tensioned prestressing systems. The program in detail is classified the twelve slabs into four groups. The first group consists of three slabs designated as (Slab 1, Slab 2, and Slab 3) and prestressed with unbonded tendons with a span length of 4.6 m. The second group is included three slabs entitled (Slab 4, Slab 5, and Slab 6) that are consist of unbonded profile tendons of span length of 3.4 m. The Third Group consists of three slabs named (Slab 7, Slab 8, and Slab 9) that are prestressed with also unbonded tendons with a span length of 2.2m only. The final group is included three bonded post-tensioned slabs designated as (Slab B4, Slab B5, and Slab B6) where are identical to (Slab 4, Slab 5, and Slab 6) respectively. The only difference was in the tendons bonding to the concrete. All slabs thickness is kept to 180 mm. In each group, the first two slabs have the same span length with three straight tendons of 12.7 mm diameter, whereas the third slab in each group has three straight tendons of 15.9 mm diameter. All tendons are placed at an eccentricity of 121 mm. The non-prestressed reinforcement isn't provided in all specimens. Slabs named 4, 5, 6, B4, B5, and B6 are used for further discussion in this study, they are exposed to line loads at two different points located 1.1 m from each support as shown in Fig.3 with the detailed geometry and cross-sectional dimensions. According to the test results, the ultimate strength of the one-way slabs with bonded and unbonded post-tensioned strands is found to be quite similar, as shown in Table 4. Knowing that the two specimens are identical in all aspects except in the tendon-bonding boundary condition. This conclusion is not applied to Slab 6 and Slab B6 because these slabs have low prestressing steel ratios (out-of-the-ordinary standard application). This lower ratio resulted in lower flexural strength in these slabs. It is found also, Slabs 6 and B6 have been responded as a function to first cracking. Based on the above two reasons, Slabs 6 and B6 are considered out of this study. Flexural strength of Slab 4 was recorded 2.6% higher than the corresponding strength in Slab B4. While a higher moment strength of 2.8% was recorded in Slab B5 compared to Slab 5 (Table 4).

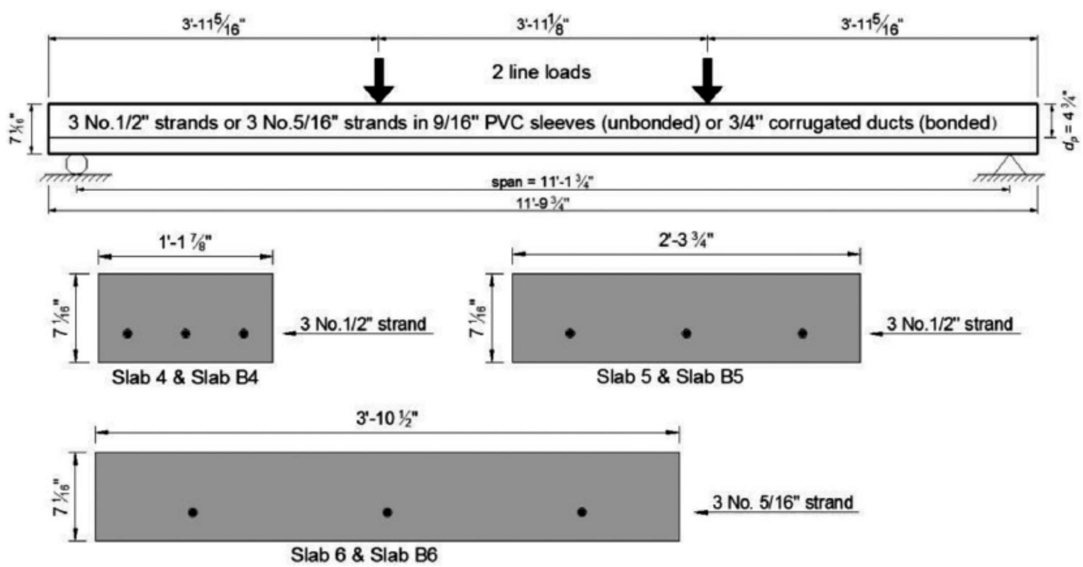

Fig. 3. Slabs conducted by Cooke et al. [5].

Table 4
Beams experimental results conducted by Cooke et al. [5].

Specimen	fse_exp, Ksi	fps_ACI, Ksi	fps_exp, Ksi	Mn_ACI, in.-Kip	Mn_exp, in.-Kip
“Slab 1”	169.0	185.7	196.0	318.6	344.2
“Slab 2”	166.0	189.3	198.0	356.4	334.9
“Slab 3”	174.0	234.0	212.0	194.4	132.5
“Slab 4”	169.0	186.6	200.0	327.6	396.2
“Slab 5”	167.0	192.2	209.0	346.8	385.1
“Slab 6”	177.0	234.7	228.0	195.6	170.3
“Slab 7”	169.0	185.8	206.0	320.4	379.4
“Slab 8”	169.0	192.6	216.0	362.4	403.5
“Slab 9”	175.0	234.7	233.0	195.6	213.3
“Slab B4”	174.0	256.1	“NA”	363.4	359.6
“Slab B5”	169.0	256.1	“NA”	436.7	396.0
“Slab B6”	180.0	256.1	“NA”	210.1	191.5

The final, fourth study in 2017 by Oukaili and Khattab [10] tested ten concrete beams with the full scale of overall dimensions (200×300×3300) mm. These beams are divided into four groups. Two fully reinforced concrete beams (FR) represent the first group. In both second and third groups, three partial prestressed concrete beams (PP) for each one with bonded and unbonded prestressing system type respectively. In the final group (fourth), additional two fully prestressed specimens with bonded mechanism (FP) are tested. The compressive strength of concrete based on the cylinder at 28 days is 40 MPa for all specimens. The yield and ultimate strength of a deformed non-prestressed steel bar that was used for both flexure and shear are 570 MPa and 650 MPa respectively. Tendons geometry and properties, mild steel position with its quantity, and properties, boundary and loading position with its type and rate for all specimens are found in the designated reference and as shown in Fig.4. The tested beams are examined with different partial prestressing ratios (PPR) under four points system. The deflection Δ_{cr} and load at cracking Pcr were recorded as shown in Table 5. For comparison purposes, only groups 1 and 2 are included within the scope of this study. According to the test results, as shown in Table 5, regarding the effect of different bonding conditions in comparing the "group 2" specimens of unbonded tendons system with “group 3" of bonded tendons system respectively, it was concluded that no significant differences in terms of both cracking loading and cracking deflection at mid-span between two types of tendon bonding conditions.

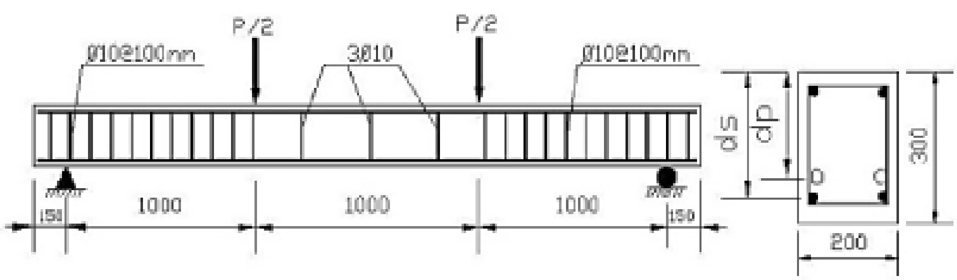

Fig. 4. Detail of beams reinforcement tested by Oukaili and Khattab [10].

Table 5
Experimental results for beams tested by Oukaili and Khattab (10).

Group	Beam	PPR	Pcr (kN)	Δ_{cr} (mm)
1	FR-UN	0.000	20.0	1.10
	FR-MAX	0.000	22.0	1.70
2	PP-U-TC	0.743	67.0	3.00
	PP-U-TR	0.409	68.0	3.00
	PP-U-CC	0.339	72.0	2.88
3	PP-B-TC	0.771	70.0	3.33
	PP-B-TR	0.529	67.0	2.50
	PP-B-CC	0.358	73.0	2.25
4	FP-B-TC	1.000	70.0	3.12
	FP-B-CC	1.000	90.0	4.24

4. Statistical analysis results and discussion

The statistical techniques based on Meta-Analysis for concrete post-tensioned members including both bonded and unbonded are illustrated in this section, which includes the effect size and the weight of each trail, assumptions used in the statistical modelling, and the summary effect size and their confidence interval.

In the first trials [4] that studied bonded versus unbonded post-tensioned concrete beams, the uncontrolled group mean and the standard deviation depended on six (n_1=6) records of beams RU1, RU2, TU1, TU1, CU1, and CU2. While the treated group is used three (n_2=3) records of beams RB1, TB1, and CB1 as shown in Table 6. Note that specimen TU3 is excluded from statistical analysis due to match missing in bottom non-prestressing reinforcement with other beams. While in the second trial [6] that tested post-tensioned concrete beams that include both bonded and unbonded tendons, the uncontrolled group mean and the standard deviation depended on two (n_1=2) records of beams B8 and B9. While the treated group used four (n_2=4) records of beams B2, B3, B5, and B6 as shown in Table 6. Noting that both specimens B3 and B4 are excluded from statistical analysis due to the nature of beams with non-prestressing exist. Besides, B7 was also dismissed from this model due to the match missing in ultimate compressive strength with other beams. In the fourth trial [10] that studied bonded versus unbonded post-tensioned concrete beams, the uncontrolled group mean and the standard deviation depended on three (n_1=3) records of beams PP-U-TC, PP-U-TR, and PP-U-CC. While the treated group is used also three (n_2=3) records of beams PP-B-TC, PP-B-TR, and PP-B-CC as shown in Table 6. Noting that specimens FR-UN, FR-MAX, FB-B-TC, and FP-B-CC are excluded from statistical analysis due to matching problems. The final trial [5] tested bonded and unbonded post-tensioned one–way slabs. The uncontrolled group mean and the standard deviation depends on three (n_1=3) records of slabs Slab 4, Slab 5, and Slab 6. While the treated group is used three (n_2=3) records of slabs Slab B4, Slab B5, and Slab B5 as shown in Table 6. Noting other specimens is excluded from this statistical analysis due to match missing purpose. The Meta-Analysis algorithm is applied to convert these data to more meaningful information in terms of effect size and confident interval for each trial and for the total grand summary as shown in Table 7. The latter information is converted to a fast readable graph which is named a forest plot as shown in Fig. 5.

From Tables 6 and 7, the effect size and the p-value of the first trial [4] are -0.04 and 0.955 respectively. The lower and the upper bounds of the confident interval is range from -1.430 to 1.342. These values are plotted in the first row of the forest plot as shown in Fig.5. From a statistical point of view, the result is not statistically significant. In the second trial [6], the effect size and the p-value are -0.38 and 0.688 respectively. The lower and the upper bounds of the confidence interval is range from -1.986 to 1.236. Even there is a small change in the values of effect size and the p-value as compared with the first trial, not enough evidence to reject the null hypotheses (H_o: The two tendon bonding conditions are equivalent in terms of member capacity). These values are plotted in the second row of the forest plot as shown in Fig.5. The effect size and the p-value of the third trial [5] are -0.01 and 0.991 respectively. The confidence interval is ranged from -1.610 to 1.590. The third trial is approximate to follow the same trend as the first trial. The third trial results are plotted in the third row of the forest plot as shown in Fig.5. The effect size and the p-value in the fourth trial [10] are 0.28 and 0.733 respectively. The confidence interval is ranged from –1.325 to 1.891. These values are plotted in the fourth row of the forest plot as shown in Fig.5. Even though the effect size is a positive value, the result is inconclusive from the statistical point of view. The summary effect size and the p-value for the synthesized tails are -0.09 and 0.821 respectively. The summary results are plotted in the last row of the forest plot as shown in Fig.5. Based on the results of the summary effect size and p-value, the null hypothesis can't be rejected.

Table 6
Basic Data.

#	Study	Member Type	Control (Unbonded)			Treated (Bonded)			p-value
			Mean	SD	n_1	Mean	SD	n_2	
1	Mattock et al.,[4] 1971	Beam	877.17	165.49	6	870.67	88.94	3	0.955
2	Hussien et al.,[6] 2012	Beam	151.50	4.95	2	148.33	7.74	6	0.688
3	Cooke et al.,[5] 1981	Slab	317.20	127.34	3	315.70	109.09	3	0.990
4	Oukaili and Khattab,[10] 2017	Beam	69	2.64	3	70	3.00	3	0.733

Table 7
Basic Information.

#	Study	Effective Size	Confident Interval		Weight %
			LL	UL	
1	Mattock et al.,[4] 1971	-0.04	-1.430	1.342	32%
2	Hussien et al.,[6] 2012	-0.38	-1.986	1.236	21%
3	Cooke et al.,[5] 1981	-0.01	-1.610	1.590	24%
4	Oukaili and Khattab,[10] 2017	0.28	-1.325	1.891	24%
Summary		**-0.09**	**-0.805**	**0.757**	**100%**

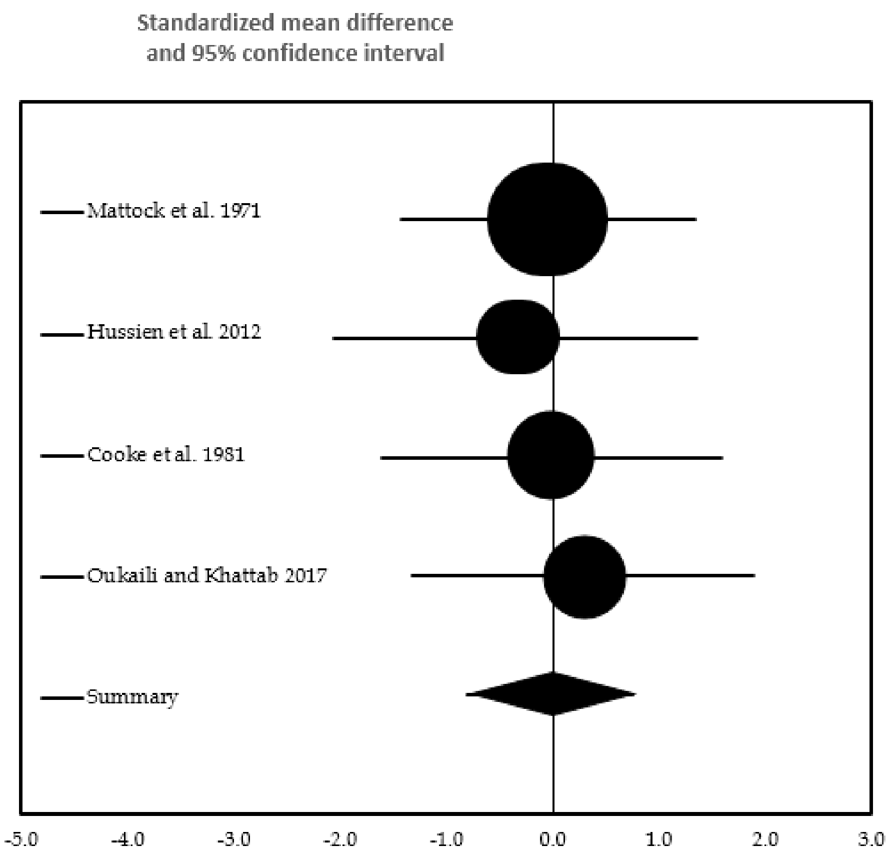

Fig. 5. Effect of different tendon bonding conditions.

5. Conclusions

The present systematic review throughout the statistical model builds using Meta-Analysis has been conducted to better understand the influence of different bonding conditions for the tendon profile on the flexural behaviour of concrete members prestressed with post-tensioned reinforcement. Applicability of the proposed method has been limited on effective size, weight, confidence intervals, and the p-value of prior four experimental completed programs studies.

Based on the discussion of the results obtained by statistical simulation, no significant differences are found in terms of the influence of different bonding conditions of tendon profile on the capacity of concrete post-tensioned members. In other words, the summary results in terms of the net effect size were -0.09 times the standard deviation with a p-value equal to 0.821. So, not enough evidence exists to reject the null hypotheses (H_o: The two tendon bonding conditions are equivalent in terms of member flexural capacity). More experimental investigations are required to settle this problem.

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Conflict of interest

The authors assure that there is no dispute or any conflict of interest. This research has not been published before. It is not under consideration for publication elsewhere.

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