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BEHAVIOUR AND DESIGN OF PRECAST CIRCULAR COLUMN-BASE POCKET CONNECTIONS WITH SMOOTH AND ROUGH INTERFACE FOR R.C. BRIDGES

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الملخص

هذة الدراسة تقدم نتائج اختبارات معملية لاستهداف دراسة نوعين من وصلات الجيب بين أعمدة ذات قطاع دائرى و قواعد ذات الاسطح البينية الناعمة و الخشنة معرضه لأحمال رأسية و أفقية حتى الإنهيار، الأحمال الواقعة على الوصلة تنتقل لوصلة الجيب بالإرتكاز و الخشونة من غير وجود اى وصلات حديد. برنامج الإختبار يتضمن إختبار نوعين من وصلات الجيب (وصلات الجيب الخارجية و وصلات الجيب الداخلية جزئيا) ذات اسطح بينية (السطح بين العمود و الجيب) ناعمة و خشنة (ثلاث عينات ذات اسطح ناعمة وثلاثة ذات اسطح خشنة) و عينة واحدة من عمود بقاعدة بدون وصلة جيب بإستخدام خرسانة مسلحة ذات مقاومة عادية تحت تأثير حمل رأسي وأفقي متصاعد تدريجيا من الصفر حتى حمل الإنهيار و تحديد كلاً من (حمل التشريخ، سلوك العينة، دوران الوصلة، المقاومة المرنة و النهائية). من الأهداف الاساسية لهذا البحث هو لتحديد مدى تأثير تغير الارتفاع الكلى للوصلة وارتفاع الوصلة الخارجى على سلوك الوصلة سواء ذات أسطح بينية ناعمة او خشنة بإستخدام نتائج الإختبارات المعملية.

ABSTRACT

This research investigates the behavior and design of two types of pocket connections between circular precast column and foundation with smooth and rough interface under vertical and horizontal simultaneous loads from zero load up to failure, applied loads can transfer by bearing and friction without reinforcement splice. The experimental program included the testing of two types of specimens of socket connections (partially embedded - external) with smooth and rough interface (three specimens with smooth surface and three with rough surface) and one control (monolithic) specimen using normal strength concrete under simultaneous vertical and horizontal loads up to failure from different points of view (opening load, deformational behavior, joint rotation, ductility and ultimate capacity). One of the main objectives of this research is to evaluate the effect of the variation of embedded depth, external stiffener depth on the behavior of the introduced connection with smooth and rough interface using the experimental results.

Keywords: Socket connections, precast concrete, shear key, experimental research, smooth interfaces, rough interfaces, struts and ties.

INTRODUCTION

The main difference between precast and a cast-in-place structure is the existence of connections between the elements in which they are made at the site. In other words, it can be said that the behavior of a structural system of precast concrete is directly related to the knowledge of the behavior of its connections, which are responsible, among others, for the redistribution of the efforts of the structure.

This research investigates the behavior and design of two types of pocket connections between circular precast column and foundation with smooth and rough interface under vertical and horizontal simultaneous loads from zero load up to failure, applied loads can transfer by bearing and friction without reinforcement splice.

The pocket connections can be classified into three main categories according to the location of the pocket with respect to the footing as follows; (a) the Pocket Embedded connection in which the pocket is located totally inside the footing depth; (b) the External Pocket connection in which the pocket is located totally above the footing depth as a reinforced concrete pedestal walls forming the pocket are made above the footing; (c) the Pocket Partially Embedded connection in which a portion of the pocket is located inside the footing depth and the other portion is located above the footing.

A Comparison is then done between the results of the experimental behavior of two types of pocket connections between circular precast column and foundation with smooth and rough interface and proposed STM for specimens.

A behavior model for the pocket base connection was presented by Leonhardt and Mönnig. All the main existing design models, like Willert and Kesser, Osanai et al., Bruggeling & Huyghe and Canha design models are derived from this behavior model.

The main known experimental investigations are: (a) the experimental research presented by Osanai et al. on pocket connections subjected to vertical and horizontal loads with large eccentricities and this investigation didn't include pedestal walls; (b) the experimental investigation made by Canha on pocket connections subjected to vertical loads acting on the top of the column with large eccentricities and this investigation include pedestal walls.

This study is motivated by the fact that there are very few experimental results addressing the behavior of the pocket base connections of circular configuration and they address only the externally embedded and the fully embedded pocket connections, although the existing models result in quite different amounts of reinforcements.

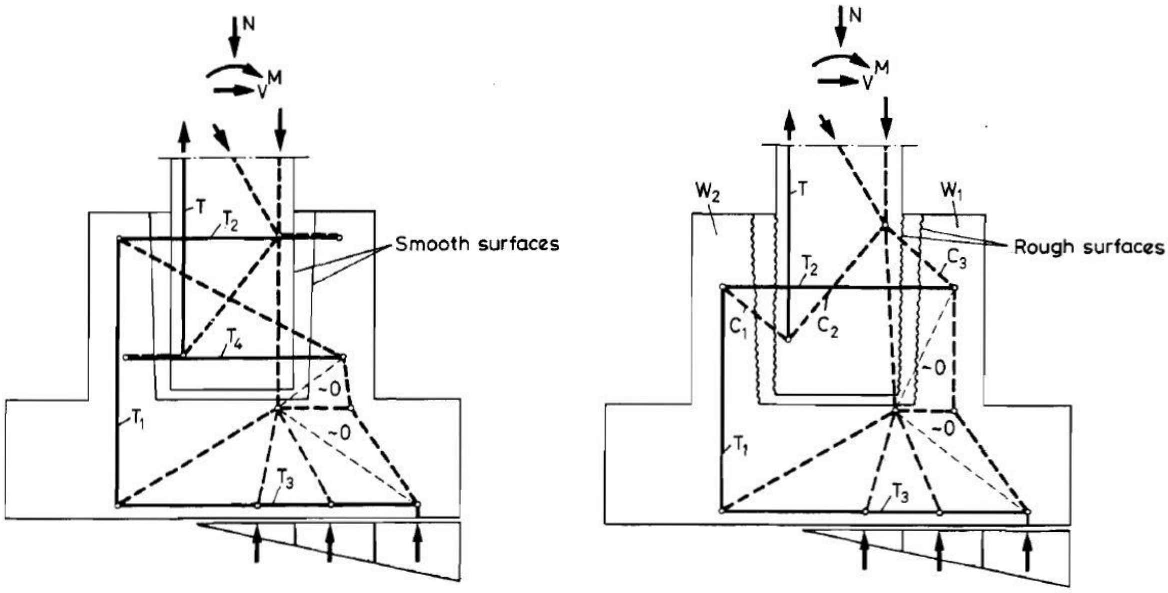
This paper presents an experimental investigation on two types of pocket base connections with smooth and rough surface interface subjected to loads with medium eccentricities and pedestal walls are emphasized.

BEHAVIOR MODEL

This work is based on behavior model by Schlaich & Schäfer who proposed strut and tie model for external pocket connection with smooth and rough surface interface with square configuration as shown in Figures 1 and 2.

For smooth pocket connection, there is two horizontal ties (T_2 &T_4) at top and bottom of pocket should be covered by horizontal reinforcement at these locations, the vertical tie (T_1) is at pocket wall and represented the vertical reinforcement at pocket, the straining actions of column moves to pocket with strut (C_3) at pocket corners with an angle 45°.

For rough pocket connection, there is only one horizontal tie at middle of the pocket height (T_2) that results from the inclined compression strut from column to pocket (C_3), the inclination of strut (C_3) is due to the transfer of column straining action to pocket with the shear keys that forms the rough surface.



Smooth surface pocket connection

Rough surface pocket connection

Figure 1 Strut and tie model for smooth and rough surface pocket connection (Schlaich & Schäfer, 1991)

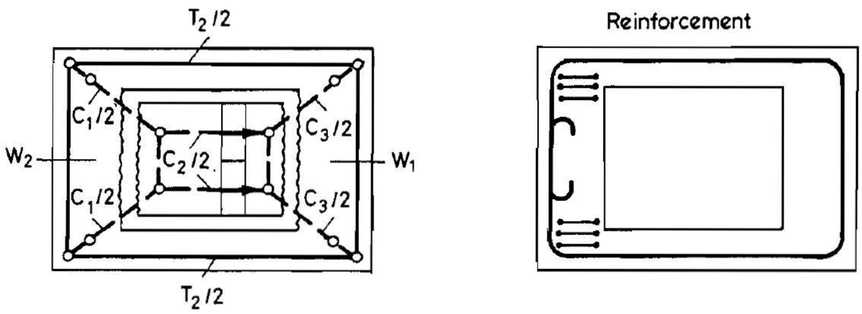


Figure 2 Strut and tie model for walls in horizontal projection and its corresponding reinforcement (Schlaich & Schäfer, 1991)

EXPERIMENTAL INVESTIGATION

The experimental program is designed to evaluate the behavior of pocket connections with smooth and rough surface interface tested under vertical and horizontal simultaneous loads from zero load up to failure. It consists of a total of seven specimens divided as follows; one control specimen which is a CIP ordinary connection made between a column and a footing with column diameter of 30 cm and six pocket connections as follows:

1- Three specimens were with a smooth surface (one externally embedded and two partially embedded specimens).

2- Three specimens were with a rough surface (one externally embedded and two partially embedded specimens), the configuration of the shear keys that made the rough surface of column and pocket shown in Figure 3 which was like what stated by CANHA 2004.
The geometry of all pocket connection specimens is shown at Figure 4 and Table 1.

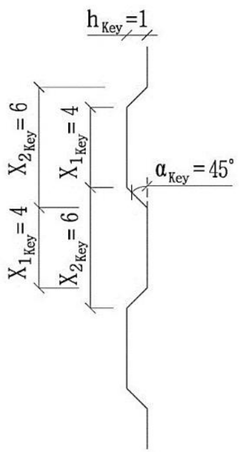
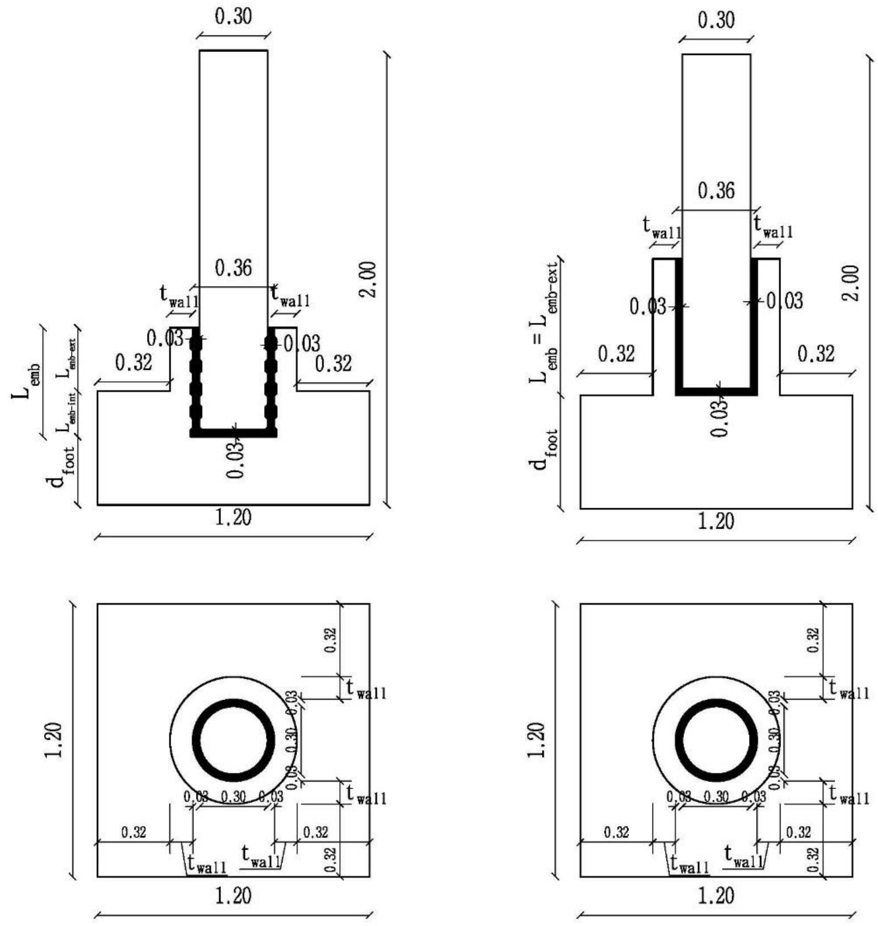


Figure 3 Shear keys configuration of the rough specimens

Table 1 Summary of the geometric characteristics of the tested specimens

Specimen Label	Pocket Type	Surface Condition	e (m)	L_{emb} (m)	$L_{emb-ext}$ (m)	$L_{emb-int}$ (m)	d_{foot} (m)	t_{wall} (m)	Shear Keys		
									α_{Key}	$X1_{Key}$ (cm)	$X2_{Key}$ (cm)
Control	-------	-------	0.225	-------	-------	-------	0.5	-------	-------	-------	-------
S-X-60	External	Smooth	0.225	0.6	0.6	-------	0.5	0.1	-------	-------	-------
S-PE-60	Partialy-embedded	Smooth	0.225	0.6	0.4	0.2	0.3	0.1	-------	-------	-------
S-PE-40	Partialy-embedded	Smooth	0.225	0.4	0.2	0.2	0.3	0.1	-------	-------	-------
R-X-48	External	Rough	0.225	0.48	0.48	-------	0.5	0.1	45°	4	6
R-PE-48	Partialy-embedded	Rough	0.225	0.48	0.28	0.2	0.3	0.1	45°	4	6
R-PE-32	Partialy-embedded	Rough	0.225	0.32	0.12	0.2	0.3	0.1	45°	4	6



(a) Partially embedded **(b) Externally embedded specimen**

Figure 4 Dimensions of pocket connection specimens (dimensions in meter)

Figures 5, 6 and 7 present all specimen's pocket reinforcement in elevation and plan. Figure 8 shows the test set-up where the vertical load is applied at the beginning of the test and then after reaching its maximum value of 320 kN the horizontal load is applied at the top of the column until failure.

Three specimens were with a smooth surface between column and the pocket, one externally pocket with embedded length equals twice column length (Lemb=2h). the other two specimens are partially embedded, one with embedded depth equals twice column length (Lemb=2h) and the other one with embedded depth equals 1.33 times column length (Lemb=1.33h).

The other three specimens were with a rough surface between column and the pocket, the configuration of the shear keys that made the rough surface of column and pocket shown in Figure 4.3 which was like what stated by CANHA 2004, the embedded length for externally and partially embedded pocket was taken 0.8 from the corresponding smooth specimens, one externally pocket with embedded length equals 1.6 times column length (Lemb=1.6h). the other two specimens are partially embedded, one with embedded depth equals 1.6 times column length (Lemb=1.6h) and the other one with embedded depth equals 1.067 times column length (Lemb=1.067h).

We try a smaller value for embedded depth of the pocket than stated in Leonhardt and Mönnig (1977) and NBR-9062/85(1985) as the eccentricity is different and we introduce a new type of pocket connections which is partially embedded which expected to have a better fixation than externally embedded.

All columns were designed with a flexural capacity greater than that of the pocket walls by 30% in order to ensure pocket rapture.

For vertical reinforcement of pocket at all specimens, we took the same number of reinforcements of all specimens which is the minimum value needed for vertical reinforcement at smooth and rough specimens which is 4 bars with 8mm diameter.

For horizontal reinforcement at smooth specimens, we get upper and lower stirrups corresponding to ties (T_2 &T_3) and the in-between stirrups then we put only two stirrups at top of pocket and only one stirrup at level of top of footing as expected at this region the confinement stress is low and distribute the remaining stirrups in between.

For horizontal reinforcement at rough specimens, we get middle stirrups corresponding to tie (T_2) and the distributed stirrups among pocket then we put all stirrups among the pocket with equal distances without any concentration of stirrups either at top or bottom of pocket.

For horizontal reinforcement at partially embedded specimens for smooth and rough interfaces, we put only two stirrups with 8 mm diameter at the embedded part of pocket (20cm) as there isn't any expected stress at this embedded region.

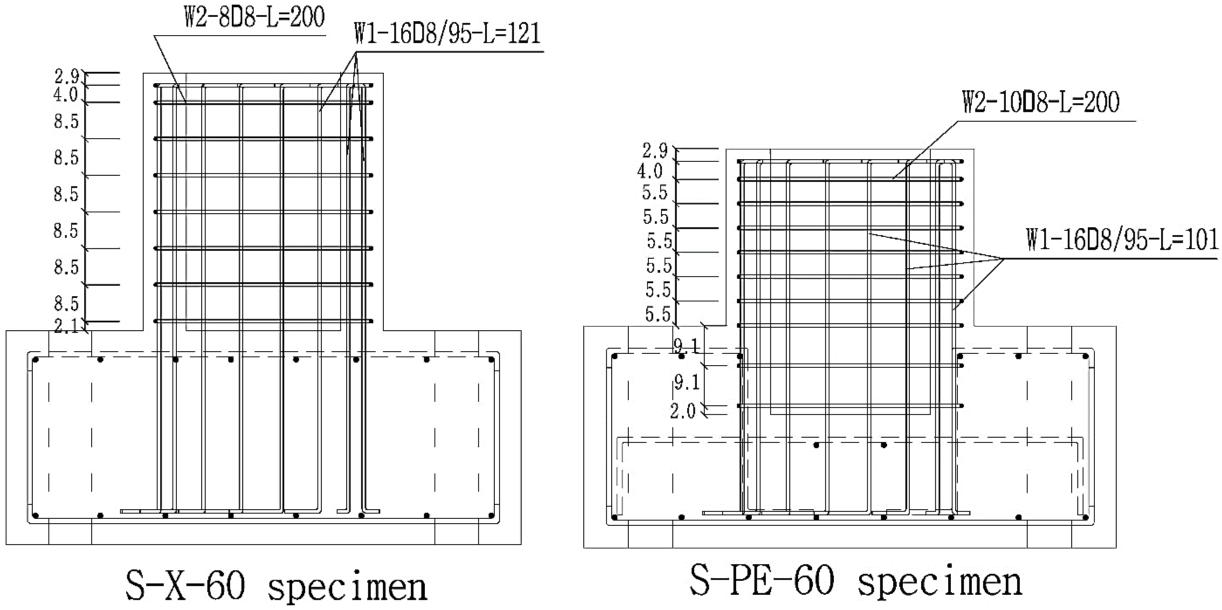


Figure 5 Reinforcement details of pocket of specimens (S-X-60 , S-PE-60) at elevation

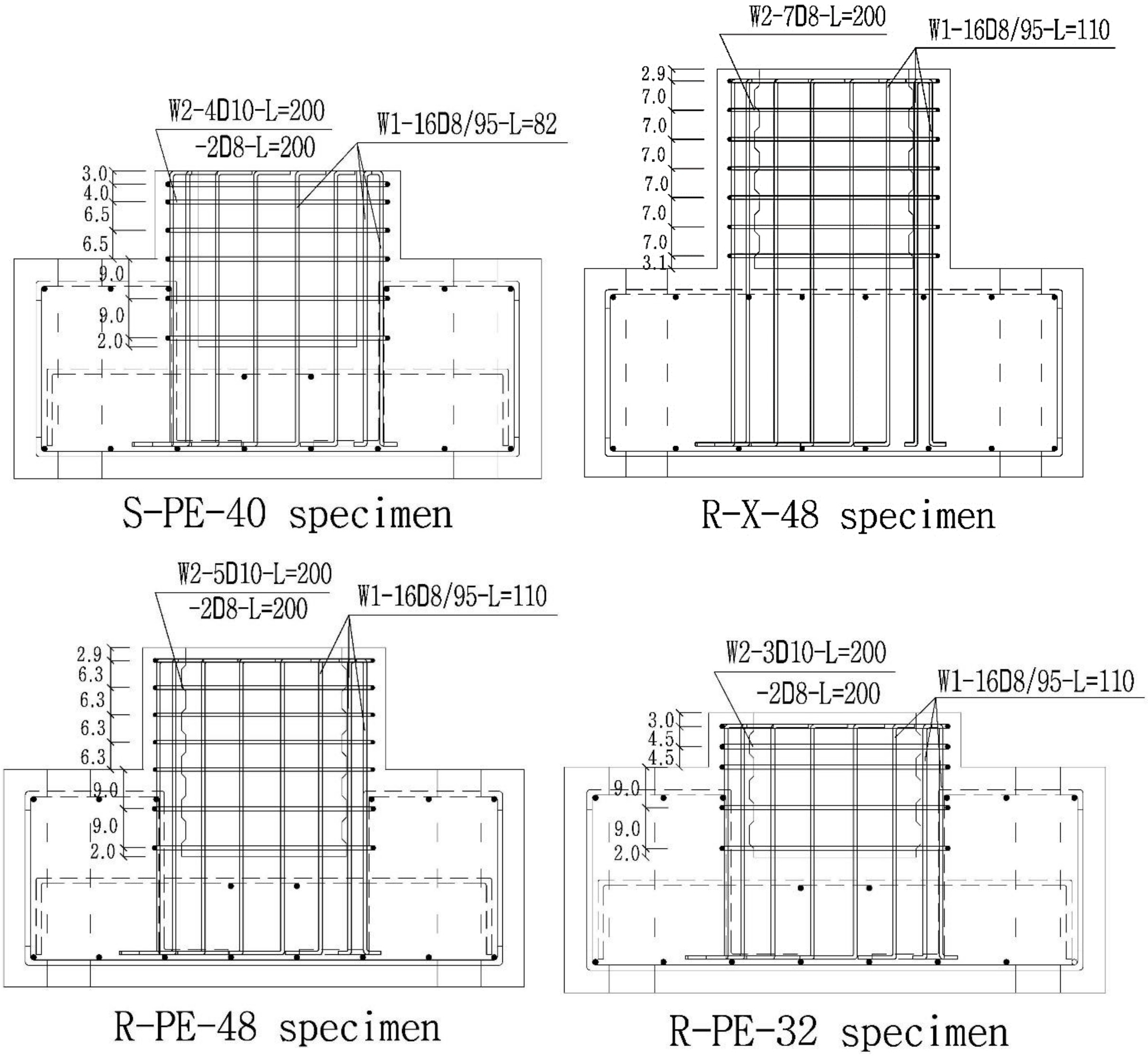


Figure 6 Reinforcement details of pocket of specimens (S-PE-40 , R-X-48 , R-PE-48 , R-PE-32) at elevation

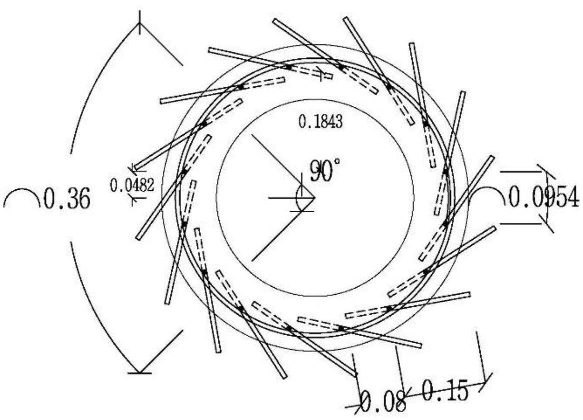


Figure 7 Reinforcement details of pocket at plan

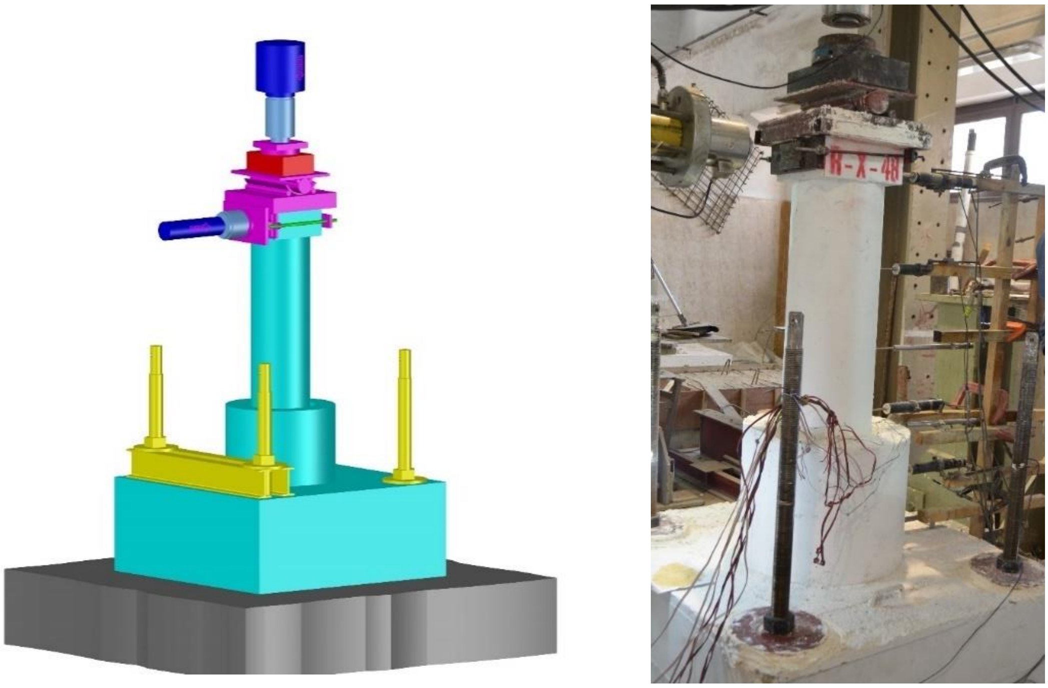


Figure 8 The test scheme of the specimen

EXPERIMENTAL RESULTS

1) Load-displacement

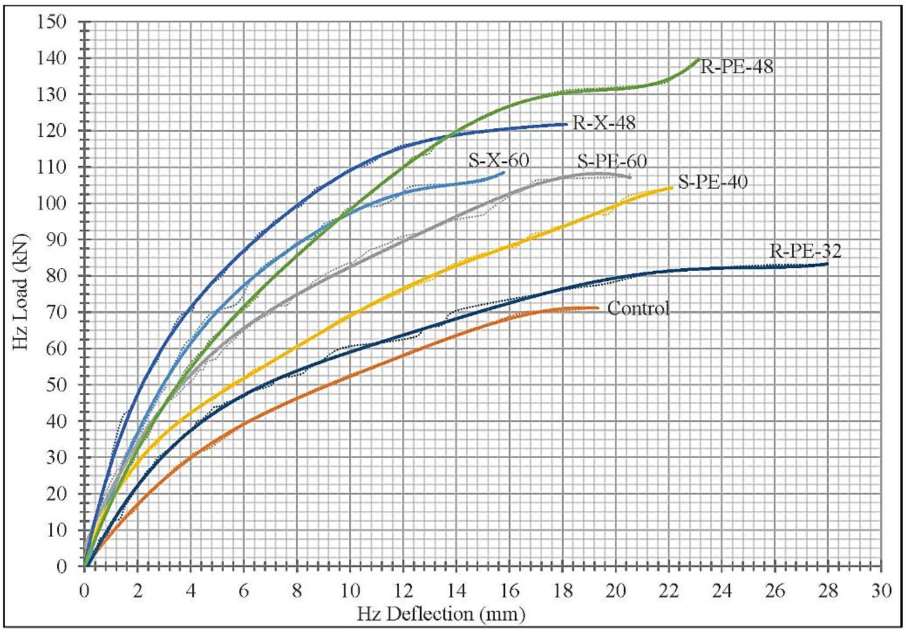


Figure 9 Load-displacement curve for all specimens

Figure 9 shows the load-displacement curve among all specimens till maximum horizontal load sustained by specimens, the following observation are concluded:

1. For specimens with embedded length equals 48cm with rough surface (external and semi embedded), they have larger load capacity than other tested connection as embedded length is enough for fixation and contact region between column and pocket is better,

2. Specimen R-PE-32 showed the lowest load capacity as it has embedded length not enough for column fixation and it has the lowest stiffness and largest ductility as column clear height is the highest,

3. For the same surface pocket connections, as clear height of column increased, it showed more deformation of column at maximum load and decrease specimen stiffness,

4. For smooth pocket connections, they are almost having the same load capacity, but S-X-60 specimen failed due to pocket failure at its vertical reinforcement and column concrete crushing while S-PE-60 and S-PE-40 specimens, they failed due to yielding of reinforcement and crushing of concrete at column,

5. For R-X-48 and R-PE-48 specimens, though at R-PE-48 specimen, clear height of column is larger, but it showed more load capacity. That is due to working of pocket stirrups after load 124kN though vertical column reinforcement has yielded and column concrete reached maximum strain.

6. For R-PE-32 specimen, it has the nearest stiffness and load capacity to control specimen as the nearest clear height to control specimen but with more deformation than control one as column reinforcement is more than control one.

2) Load-strain (POC VL RFT)

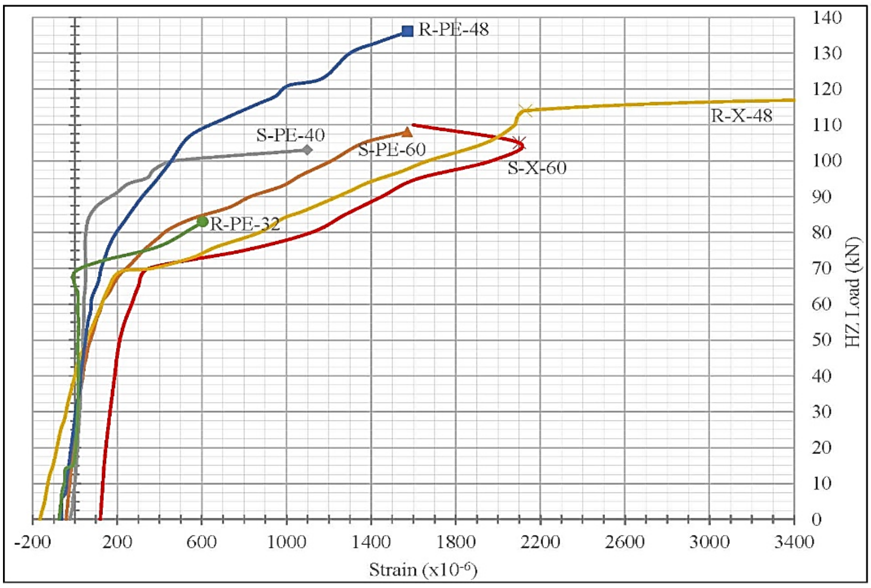


Figure 10 Load – strain curve (pocket vertical reinforcement) for all specimens

Figure 10 shows the load-strain curve for pocket vertical reinforcement among all pocket connections, the following observation are concluded:

1. As external height of pocket increased as the pocket depend on cantilever action in its behavior, so it depends mainly on vertical reinforcement (cantilever behavior) than stirrups (confinement behavior), also whenever external height decreases as pocket stiffness increases then it will depend mainly on confinement behavior than cantilever one,

2. For S-PE-60 and R-PE-48 specimens, although vertical reinforcement strain was almost the same but load capacity for rough specimen is more than smooth one, that is

due to the rough specimen depend on stirrups near the maximum load which increased the capacity of connection and also the presence of shear keys between column and pocket which improved strength of connection and load transfer between column and pocket,

3. The rate of strain gain for all specimens increased after the appearance of first horizontal crack at pocket.

3) Load-strain (POC HZ RFT)

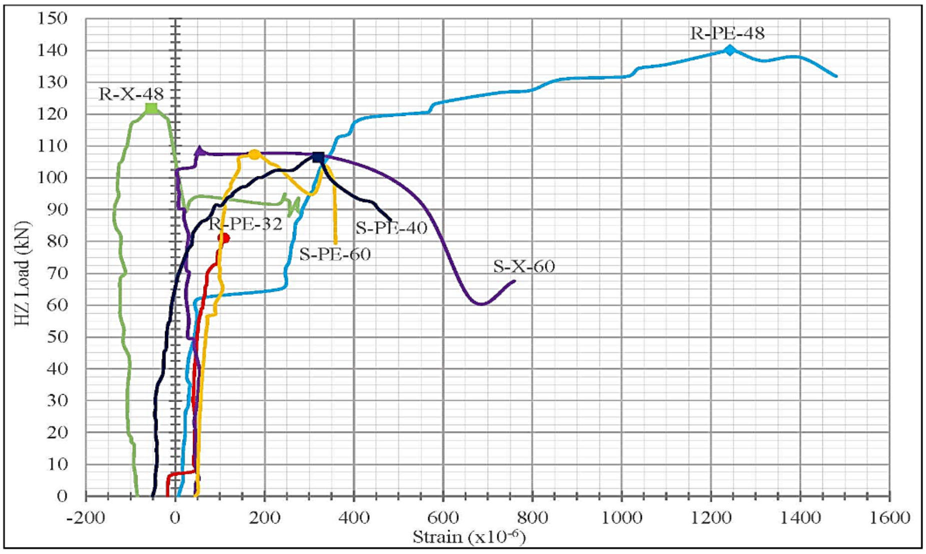


Figure 11 Load – strain curve (pocket horizontal reinforcement) for upper stirrup (strain 3) for all specimens

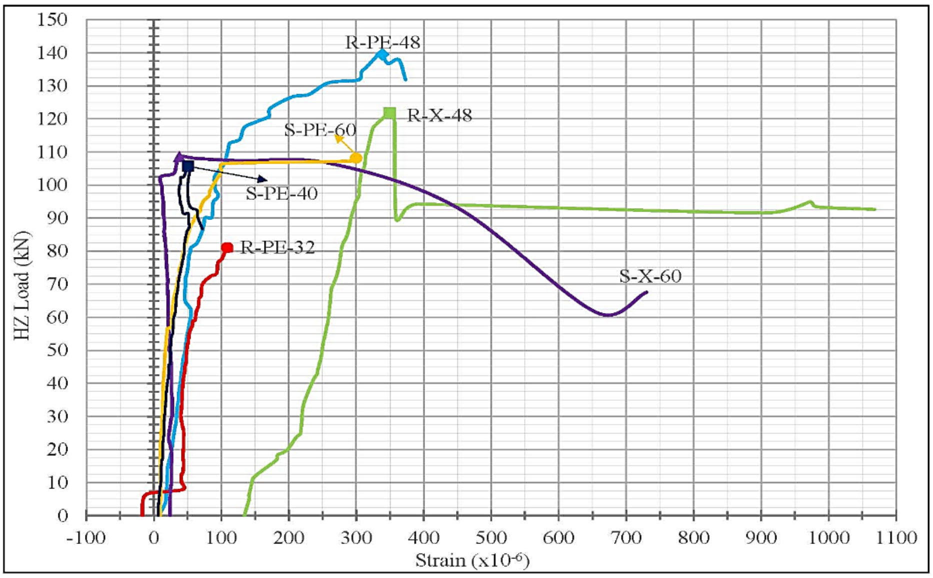


Figure 12 Load – strain curve (pocket horizontal reinforcement) for middle stirrup (strain 4) for all specimens

Figures 11 and 12 show the load-strain curve for pocket horizontal reinforcement for upper and middle stirrup respectively among all pocket connections, the following observation are concluded:

1. For smooth surface pockets, the effect of upper stirrups increased as external height of pocket decreases, so stiffness of pocket increases so it depends more on confinement behavior. At post peak part, at S-X-60 specimen, the horizontal stirrups either top or middle stirrups increased much more other partially embedded stirrups as the vertical reinforcement of this specimen yielded before maximum load reached then it depends on horizontal confinement till maximum horizontal displacement reached,

2. For R-PE-32 specimen, either vertical or horizontal reinforcement didn't work enough during loading as the embedded length is not enough to transfer load from column to pocket,

3. For rough surface specimens, the external one (R-X-48) didn't depend on upper stirrups as the vertical cantilever action is the dominate and its stiffness is low but middle stirrups worked more than upper one due to transfer of load from column to pocket by shear keys, while the partially embedded one, the horizontal stirrups specially the upper one have a great influence on behavior of pocket and at load transfer from column to pocket due to the external height of pocket is less than the external pocket specimen and its middle stirrups worked mostly like S-X-60 specimen due to the same reason.

4) Load-strain (COL VL RFT)

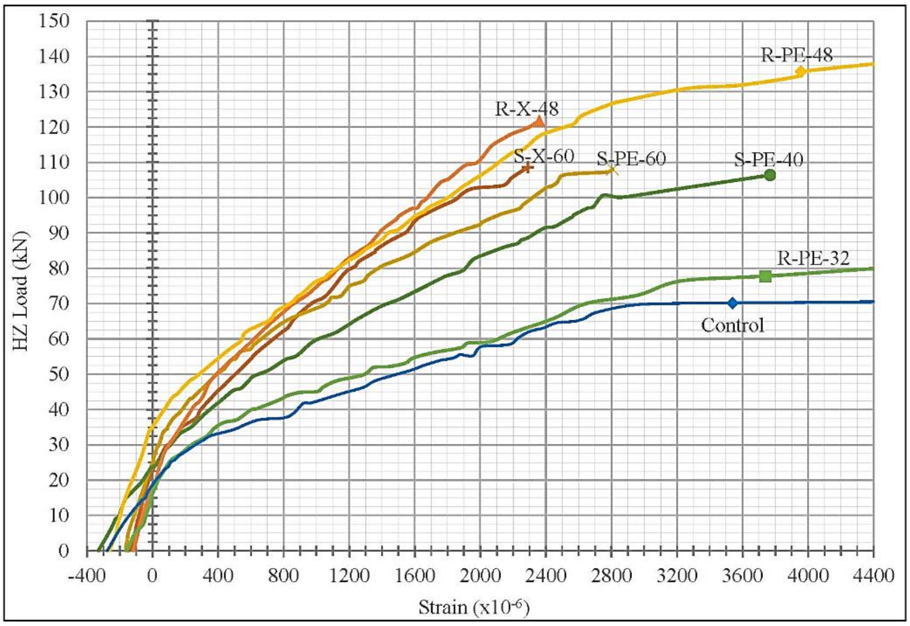


Figure 13 Load – strain curve (column vertical reinforcement at top of pocket) for strain 6 for all specimens

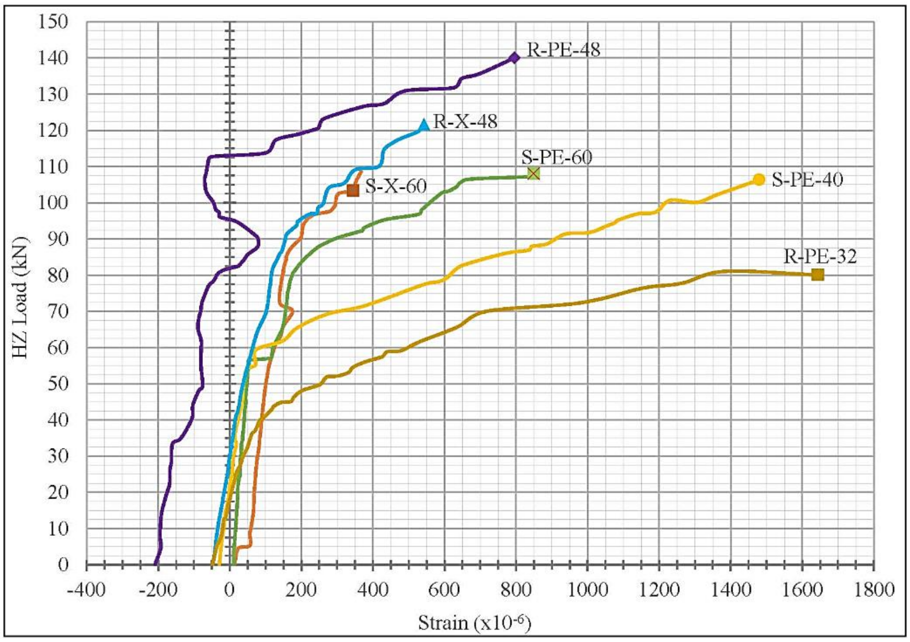


Figure 14 Load – strain curve (column vertical reinforcement at 15cm pocket base) for strain 5 for all specimens

Figures 13 and 14 show the load-strain curve for column vertical reinforcement at top of pocket and at 15cm from pocket base respectively among all specimens, the following observation are concluded:

1. For the specimens with the same total embedded length (external and partially embedded), the external pocket has less rigidity than partially embedded one, so the pocket deformed with column at external more than partially embedded one then stresses in embedded column reinforcement in external was less than partially embedded,

2. For the specimens with the same total embedded length (external and partially embedded), the partially embedded specimens yielded at load almost equals the load of external ones that was due to the clear height of column in partially embedded was larger than of external specimens,

3. For R-PE-32 specimen, column reinforcement almost reached yield stress at the same load as control specimen that is due to the convergence of column clear height also the stress at reinforcement inside pocket was high as the embedded length no enough for column fixation,

4. For S-X-60 and R-X-48 specimens, although the clear height of column of S-X-60 is less than R-X-48 and maximum load at S-X-60 is less than R-X-48 but the stress in column reinforcement was almost equal that was due to the pocket rigidity of S-X-60 is less than R-X-48 so the deformations happened to S-X-60’s pocket is much more what happened to R-X-48’s pocket,

5. For S-PE-60 and R-PE-60 specimens, although the clear height of rough one was larger than the smooth one, but it yielded at load more than the smooth one due to the contribution of horizontal reinforcement which increase connection stiffness and made it resist more load.

5) Load-strain (COL and POC concrete)

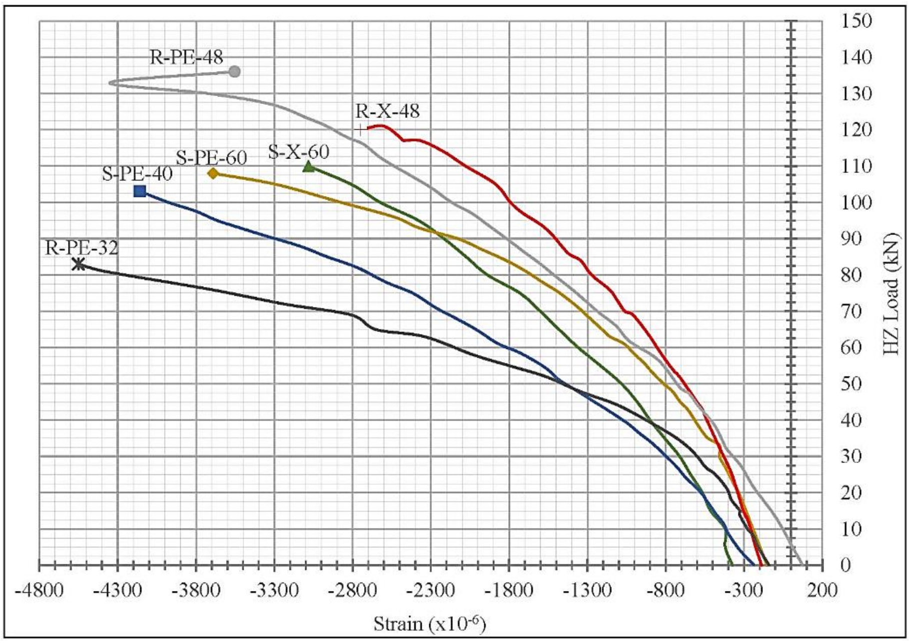


Figure 15 Load – strain curve (concrete at column) for all specimens

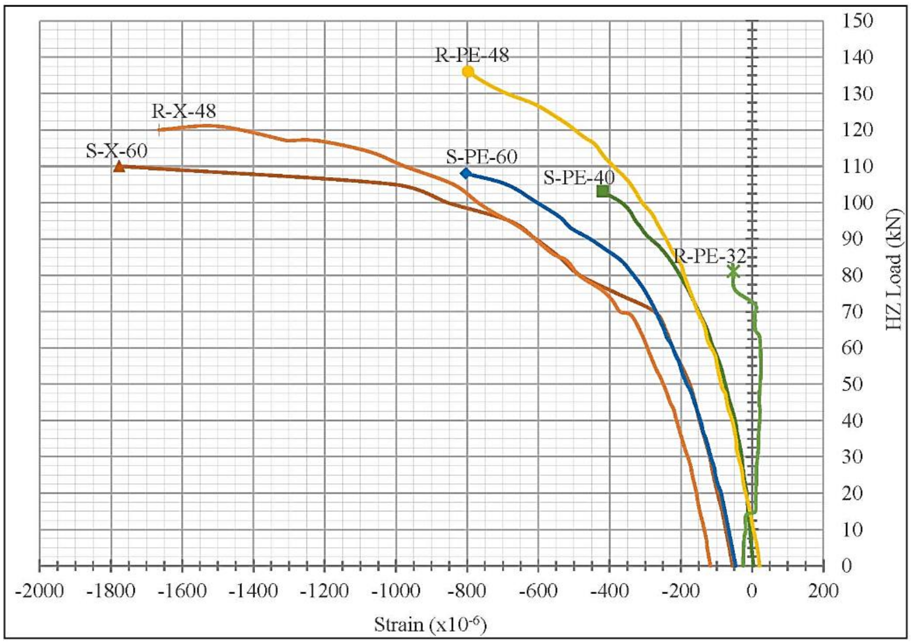


Figure 16 Load – strain curve (concrete at pocket) for all specimens

Figures 15 and 16 show the load-strain curve for concrete strain at column and pocket respectively among all specimens, the following observation are concluded:

1. For all specimens, as pocket height increases as compressive strains at end of pocket increases,

2. For R-PE-48 and S-PE-60, they almost had the same compressive strain at bottom of pocket and had the same tensile strain at pocket vertical reinforcement but load

capacity of R-PE-48 is more than S-PE-60 which was due to shear keys at connection and horizontal stirrups contribution at rough surface one.

CONCULSIONS

Based on experimental results of the seven specimens investigated in this research, some observations and conclusions were drawn. The main conclusions drawn from this study are summarized as follows:

(1) All pocket connection specimens, horizontal load capacity or moment capacity considering obtained fixation point exceeds tested control specimen, worth meaning that partially embedded specimens capacity controlled by column failure and pocket connection column exceeds in reinforcement percentage than control specimen column.

(2) According to maximum curvature of column and pocket, rough specimens showed lower curvature than smooth specimens which means that roughness between column and pocket make the column with pocket behave like monolithic column with bigger cross section at bottom.

(3) For all specimens except R-P-32 specimen, height of fixation point from pocket base increases for partially embedded specimens than external pocket specimens at the same total pocket height, and also all specimens showed good fixation of pocket to column (this is obvious according to horizontal load capacity and height of fixation point from pocket base) except R-X-32 specimen which showed fixation point place at very low height and connection failure happened at lowest capacity compared to remaining pocket connections.

(4) Partially embedded specimens showed better flexural capacity than external pocket specimens with the same total pocket height and, they are more economic than external pocket connections.

(5) For external pocket connections whether with smooth or rough surface interface, vertical bending behavior is the major behavior specimen failure while for partially embedded specimen's horizontal confinement action took place much more than external ones.

(6) According to vertical reinforcement tensile strain at pocket connection column. At the embedded part of column, the tensile strain at vertical reinforcement showed more values at embedded pocket connections than external ones with same embedded lengths which ensure the more fixation of partially embedded connections than external ones.

(7) For R-PE-32 specimen, total pocket height was not enough to make good fixation for column than other embedded lengths of the rest specimens.

(8) Rough specimens showed more monolithic behavior of pocket with column than smooth specimens as calculated moment at top of every pocket indicated that compressive strain of column at top of pocket should be more at rough specimens than smooth ones, but the opposite result was happened.

(9) As pocket provides more fixation to column as confinement behavior of top horizontal reinforcement of pocket began to appear at pocket overall behavior.

(10)The main vertical reinforcement at pocket walls at tension side is more critical at external pocket specimen than partially embedded ones as the failure was governed by yielding of this reinforcement.

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