Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (39) No. (3) july, 2017

Behavior and Design of Precast Column/Base Pocket Connections with Smooth Surface Interface

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الملخص

هذة الدراسة تقدم نتائج اختبارات معملية لاستهداف دراسة ثلاثة أنواع من وصلات الجيب ذات الاسطح البينية الناعمة معرضه لاحمال رأسية و أفقية و الأنواع هي (وصلات الجيب الخارجية، وصلات الجيب الداخلية، و وصلات الجيب الداخلية جزئيا) و تم عمل محاكاة نظرية لوصلات الجيب الخارجية باستخدام نموذج الضاغط و الشداد و تم تقديم توصيات و مساعدات تصميم و تم التأكد من مقربة نتائجة للعينات التي تم اختبارها في البحث بجانب عينات اخري موجودة في الدراسات السابقة أخيرا، تم التوصل الى بعض الاستنتاجات و التوصيات للأبحاث اللاحقة. ومن ثم تم التوصل الى النتائج التالية: (أ) بإعتبار ان وصلات الجيب الداخلية تمثل حالة التثبيت الكلى للعمود حيث ان الإنهيار حدث فى العمود و لم يحدث شئ فى وصلة الجيب او القاعدة الخرسانية, و بذلك فإن وصلة الجيب الداخلية جزئيا تمثل (75% الى 90%) من حالة التثبيت الكامل معتمدا على نسبة طول الوصلة الكلى, أما بالنسبة الى وصلات الجيب الخارجية فهى تمثل نسبة 50% من حالة التثبيت الكامل. (ب) يعتبر طول الوصلة المساوى ل 1.33 من البعد الكبر للعمود هو طول كافى لتمثيل وصلة العمود بالقاعدة المصبوبين فى الموقع و ذلك فى حالة استخدام وصلات الجيب الداخلية و الداخلية جزئياً. (ج) تعتبر وصلات الجيب الداخلية جزئياً هى الحاله الاكثر توفيرا لإعطاء أقصى مقاومة لعزوم الانحناء. (د) تعتبر وصلة الجيب الداخلية كلياً هى أفضل وصلة لتمثيل الوصلات الإعتيادية المصبوبة بالموقع وذلك بسبب عدم حدوث الانهيار فى الوصلة او فى القاعدة الخرسانية.

ABSTRACT

This paper presents a theoretical and experimental study of the pocket connections of precast concrete structures. The Experimental investigation included six specimens subjected to vertical and horizontal loads applied at the top of the column with medium eccentricities. Two of the specimens were externally embedded, another two specimens were partially embedded and the final two specimens were fully embedded specimens. The experimental results indicated the need to revalue the previous design models for this connection. A Strut and Tie design model is proposed for the design of the externally embedded specimens and was adjusted to the experimental results obtained in the present experimental study and the experimental results obtained from Canha[4] experimented specimens subjected to loads with large eccentricities. Based on the present experimental results, the following conclusions can be drawn: (a) the proposed Strut and Tie design model for smooth surface interfaces provides the closest predictions of the experimental results; (b) the proposed Strut and Tie design model is suitable to represent connections subjected to medium and large eccentricities ($0.3 \le e/t \le 5$); (c) the partially embedded pocket connections are the most economic type of the pocket connections to give big flexural capacity; (d) the fully embedded pocket connections are the closest type to represent a monolithic connection where no failure happened in the pocket itself.

Keywords: precast column base, pocket foundation, smooth interfaces, struts and ties.

INTRODUCTION

The precast column-base pocket connection used in precast concrete structures is built by embedding a column portion into a cavity in the foundation and the space between the cavity and the column is filled with cast-in-place concrete.

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 behavior model for the pocket base connection is presented by Leonhardt and Monnig[1]. All the main existing design models, like Willert and Kesser[2], Osanai et al.[3] and Canha[4] design models are derived from this behavior model. This study is motivated by the fact that there are very few experimental results addressing the behavior of the pocket base connections and they address only the externally embedded and the fully embedded pocket connections, although the existing models result in quite different amounts of reinforcements.

The main known experimental investigations are: (a) the experimental research presented by Osanai et al.[3] 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 and Jaguaribe[5] on pocket connections subjected to vertical loads acting on the top of the column with large eccentricities and this investigation include pedestal walls.

This paper presents an experimental investigation on three types of pocket base connections with smooth surface interface subjected to loads with medium eccentricities and pedestal walls are emphasized. Then a Strut and Tie design model for the externally embedded specimens is proposed according to the existing experimental results.

BEHAVIOR MODEL AND DESIGN MODELS

Figure 1 shows the behavior model of the pocket base connections presented by Leonhardt and Monnig. This model accounts for two compression resultants H_{top} and $H_{bot.}$ The resultant of the top pressure H_{top} applied on wall 1 is transferred to the longitudinal walls 3 and 4 as half of this resultant ($H_{top}/2$) acting on each wall which requires a main horizontal reinforcement ($A_{s,hm}$) at the top region of the walls 3 and 4, Then walls 3 and 4 transefer the force to the foundation with a tension force in the corners (F_{vm}), which requires a main vertical reinforcement ($A_{s,vm}$) and a compression force (R_{cs}) in the concrete strut. While The bottom pressure is transferred directly to the foundation due to the large rigidity of the compression side of the pocket. This model leads to conservative results as it doesn't account for friction forces generated at H_{top} and $H_{bot.}$

All the existing design models are computational models derived from the equilibrium equations of the forces generated inside the pocket. The main design models are based on this behavior model. Leonhardt and Monnig[1] also present a design model in which all friction forces are neglected. The other design models differ between each other in the consideration and positioning of friction forces.

The Willert and Kesser[2], Osanai et al.[3] and Canha[4] design models accounts for all the three friction forces ($F_{fri,top}$, $F_{fri,bot}$ and $F_{fri,b}$) generated from the compression resultants H_{top}, H_{bot} and by the reaction F_{nb} on the foundation base. However, the Willert and Kesser[2] model doesn't take into account the displacement e_{nb} of F_{nb}.

Canha[5] proposed two design models based on the behavior of the base of the precast column in the pocket foundations with smooth surface interfaces. And proposed recommendations to be used for pocket connections subjected to loads with small eccentricities.

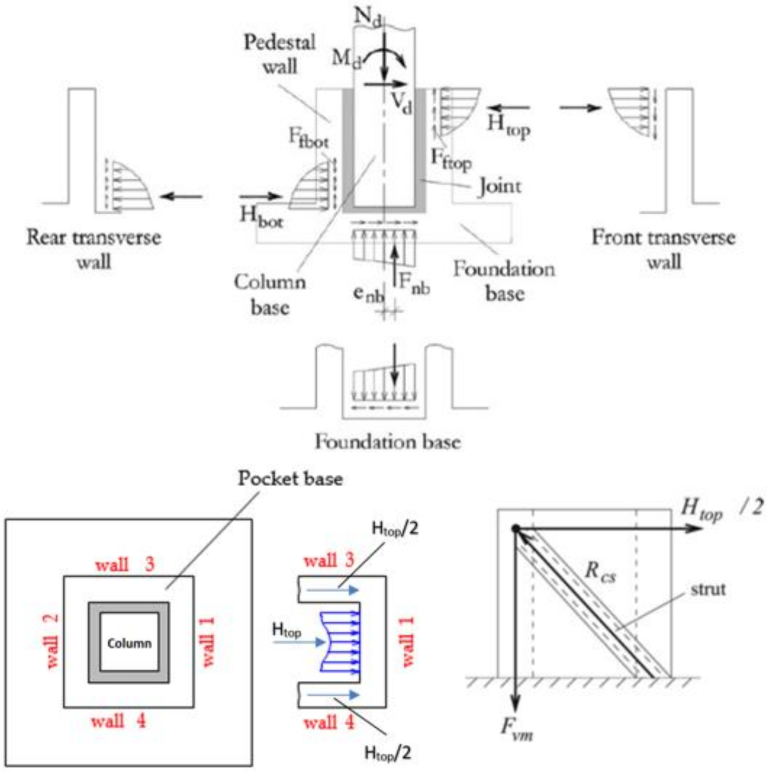

Figure 1: force flow in pocket base connections - LEONHARDT & MÖNNIG (1977)

- adapted from EL DEBS (2000)

EXPERIMENTAL INVESTIGATION

The experimental program is designed to evaluate the behavior of pocket connections with smooth 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 pilot specimen which is a CIP ordinary connection made between a column and a footing and three quarter scale different types of pocket connections (externally embedded, partially embedded and internally embedded) in which every type contains two different embedded length specimens as shown in Table 1.

The specimens' geometry was determined from the column cross section of 300 mm X 300 mm and were shown in figures 3, 4 & 5 for Group A, B and C, respectively.

Table 1: Test Specimens Groups

Group Name	No. of Specimens	Specimen ID	Embedded length (mm)
Pilot	1	S1	-----
Group (A) Externally embedded	2	SS-E1	400
		SS-E2	600
Group (B) Partially embedded	2	SS-P1	400
		SS-P2	600
Group (C) Internally embedded	2	SS-I1	400
		SS-I2	600

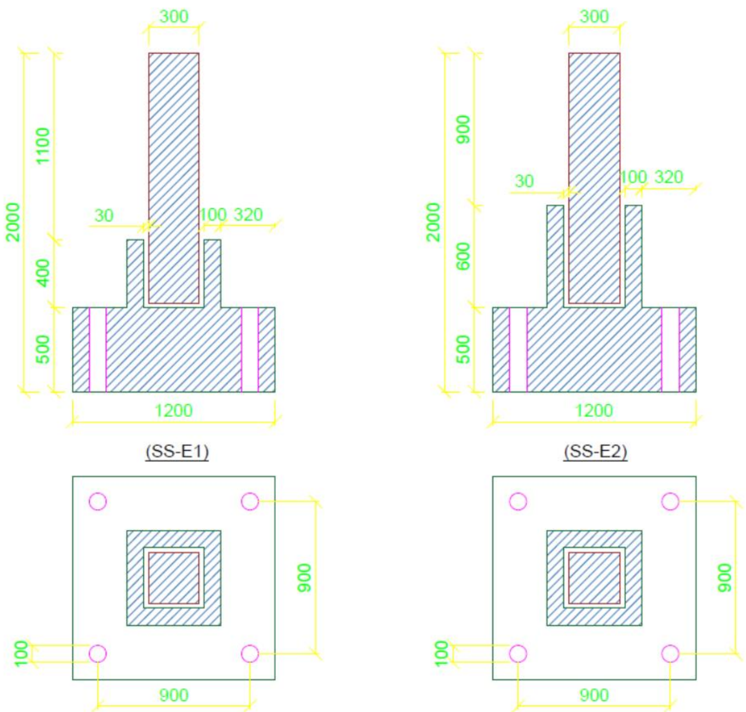

Figure 2: Externally embedded pocket connection specimen concrete dimensions

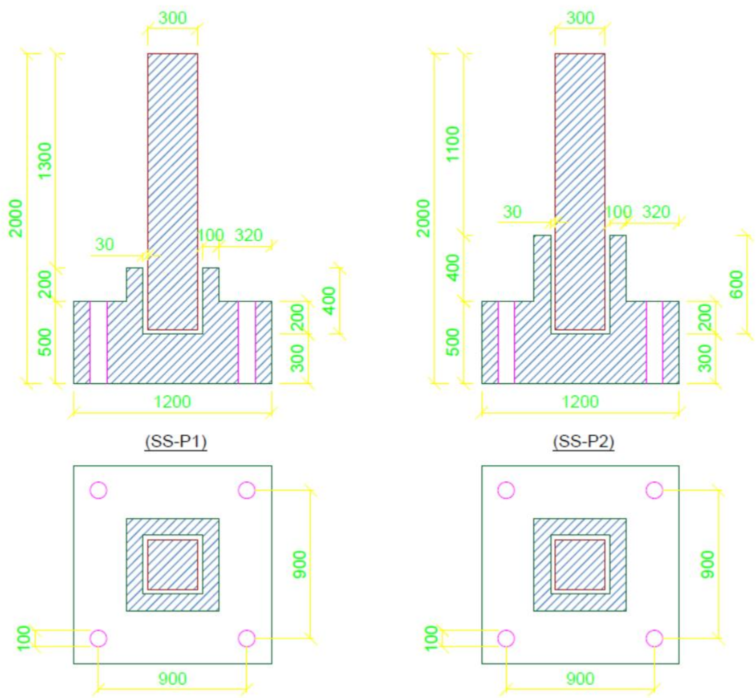

Figure 3: Partially embedded pocket connection specimen concrete dimensions

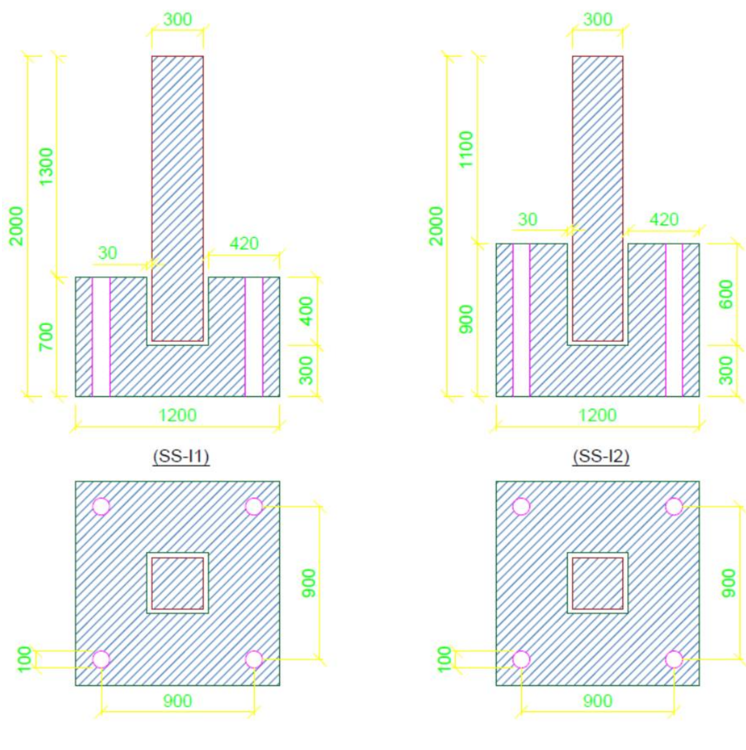

Figure 4: Internally embedded pocket connection specimen concrete dimensions

Figure 5 presents the reinforcement nomenclature and table 2 presents the experimental program characteristics and the reinforcement of each specimen. Figure 6 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 650 kN the horizontal load is applied at the top of the column until failure.

The embedded length values of 2t and 1.33t (where t is the bigger cross sectional dimension of the column) were used to determine the behavior of the pocket connections and their flexural capacity when changing the embedded length. It is worth noting that the recommended value for the smooth surface pocket connection is 2t so another value of 1.33t is proposed to determine the possibility of using reduced embedded length when dealing with pocket connections subjected to small or medium eccentricities.

All columns were designed with a flexural capacity greater than that of the pocket walls by 50% in order to ensure pocket rapture. The pedestal walls of the external pocket specimens were designed according and then the same reinforcement values were used in the semi embedded and fully embedded specimens.

The concrete cubic compressive strength was 44 Mpa determined according to ECP 203-2007, while the yield stress and strain was determined according to Egyptian Standard No: 262/2009. For the cast in place grouting used to fill the gap between the precast column and the pocket cavity, a grout with compressive strength greater than that of the pocket was used to ensure pocket rupture without a local failure happening in the grouting itself.

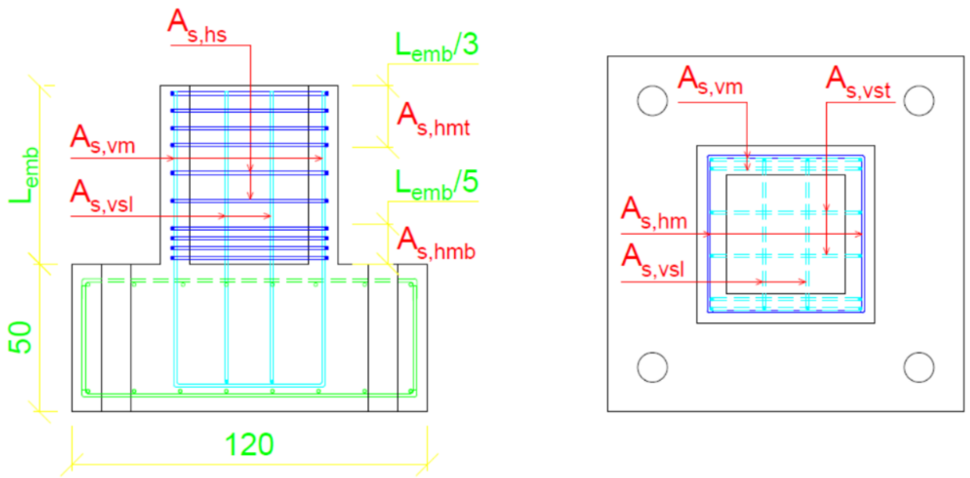

Figure 5: Reinforcement of pocket base

Specimen	Interface	L_{emb} (mm)	$A_{s,hmt}$, $A_{s,hmb}$ (mm^2)	$A_{s,hs}$ (mm^2)	$A_{s,mv}$ (mm^2)	$A_{s,vsl}$, $A_{s,vst}$ (mm^2)
SS-E1	Smooth	400	3Φ10=235.5	2Φ10=157	2Φ10 =157	2Φ10 =157
SS-P1						
SS-I1						
SS-E2		600	4Φ8=201.2	2Φ8=100.6		
SS-P2						
SS-I2						

Table 2: Test Specimens Groups

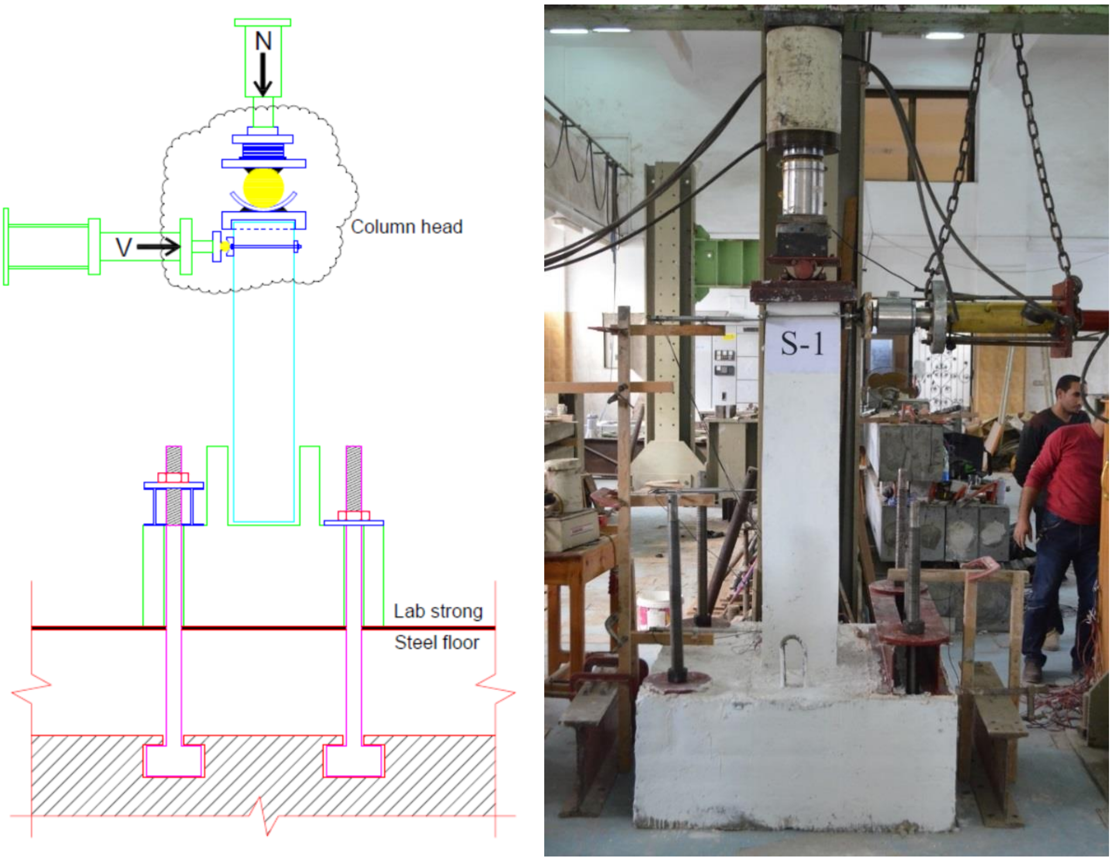

Figure 6: Test set-up

Table 3: Experimental results of the Specimens

Specimen	Fcu (MPa)	Fy (MPa)		N_{exp} (kN)	F_{exp} (kN)	Resulting Moment (kN.m)	Yield strain reached			
		Φ8	Φ10				$A_{s,vm}$	$A_{s,vst}$	$A_{s,hmt}$	$A_{s,hmb}$
SS-E1	44	335	505	650	115	118.5	yes	yes	No	No
SS-E2					150	123	yes	yes	No	No
SS-P1					180	221.65	No	No	No	No
SS-P2					172	177.2	No	No	yes	No
SS-I1					202	248.5	No	No	No	No
SS-I2					233	240	No	No	No	No

The main experimental results are presented in table 3. For Group (A) specimens' failure mode, the failure happened in the pocket itself by the yielding of the vertical reinforcement in the pocket. For Group (B) specimens' failure mode, the failure happened in the column before the failure of the socket itself in the (SS-P1) specimen while for the (SS-P2) specimen the failure happened in the horizontal reinforcement of the pocket before the failure of the column. For Group (C) specimens' failure mode, the failure happened in the column itself and nothing happened to the footing.

the fully embedded pocket connections, Group C specimens, are the closest type to represent a monolithic connection where no failure happened in the pocket itself and it happened in the column as the connection was very rigid and the strains of the pocket reinforcement were very small.

it is worth noting that despite the embedded length of SS-P1 is less than that of SS-p2, the capacity of the SS-P2 specimen was less than the capacity of the SS-P1. The reason for that is that the horizontal reinforcement in the SS-P1 is greater than that used in SS-P2, besides, the horizontal reinforcement in SS-P2 is more critical than the vertical reinforcement which is opposite to what happened in SS-P1 specimen and this returns to the increased cantilever length of the SS-P2 walls above the footing.

Despite the failure happened in Group C specimens in the column itself and the two columns have the same flexural capacity, the capacity of SS-I2 is greater than that in SS-I1 and this returns to the increased cantilever length of SS-I1 column above the footing than the SS-I2.

The vertical reinforcement in Group A specimens is more critical than the horizontal reinforcement while the opposite happens in Group B specimens and this is because, in Group A specimens, the back-bottom pressure of the column is acting on the pocket walls which results in overturning of the pocket and results in big stresses in the vertical reinforcement while in Group B specimens, the back-bottom pressure of the column is acting on the footing itself so no overturning happened in the pocket and the column is concentrating its pressure on the front transverse wall only which results in a big strain in the upper horizontal reinforcement.

ADJUSTED MODEL

From the experimental results, a Strut and Tie design model is proposed for the externally embedded pocket base connections which takes into account the tension stresses appeared on the rear transverse wall as shown in figure 7 which results from the back-bottom pressure of the column and that's why the strains monitored on the bottom horizontal reinforcement were very small if compared to the top horizontal reinforcement.

Figure 7: Vertical crack appeared on the rear transverse wall

The Strut and Tie design model is shown in figure 8 and is based on some assumptions based on Leonhardt and Monnig[1] and Canha[4] which assumes that the front-top pressure of the column acts at distance ($L_{emb}/6$) from the top of the pocket and the bottom-back pressure of the column acts at distance ($L_{emb}/10$) from the bottom of the pocket which is slightly decreased because of the high rigidity of the pocket in its compression side. The bearing pressure of the column on the base can be assumed to be acting at an eccentricity ($e_{nb} = t/4$) which is the point of application of the force F_{nb} on the footing.

The bottom pressure is assumed to be distributed into two compression Struts C2 and C3 the first compression strut C2 is acting horizontally and is responsible for the bottom horizontal reinforcement tension force while the second strut C3 is acting from the base of the column on the top of the rear transverse pocket wall and is responsible for the horizontal tension stresses and the vertical crack appeared at the top of the rear transverse wall and can be used for better simulation of the overturning of the pocket walls as a whole and the increase in the vertical reinforcement tension force and the decrease of the horizontal reinforcement tension force.

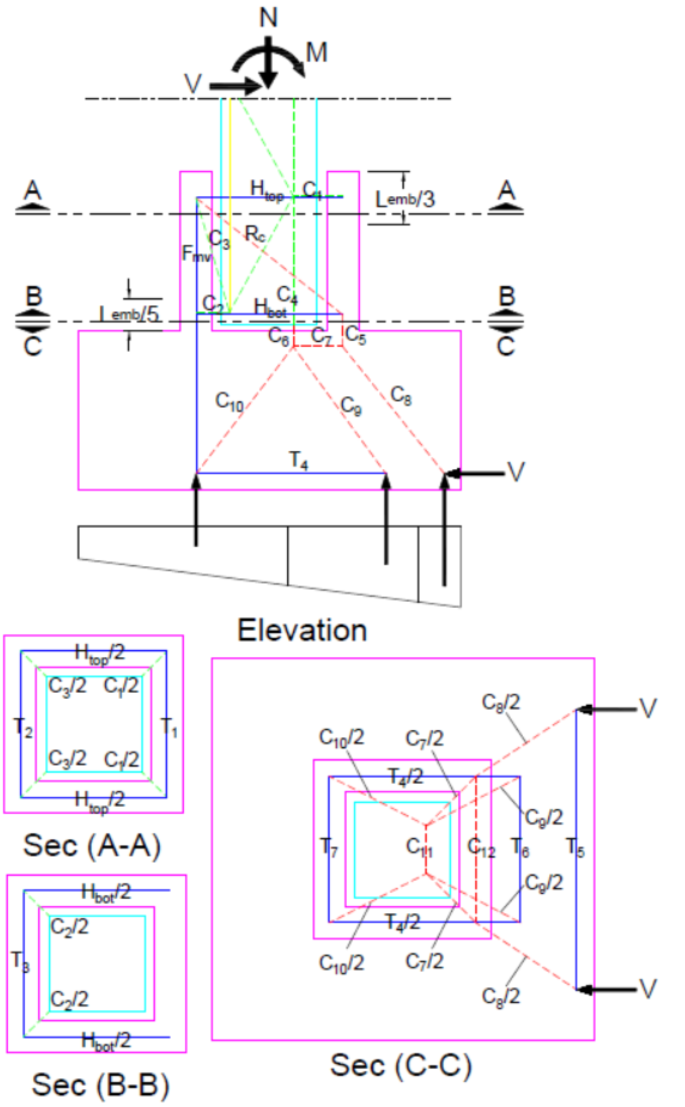

Figure 8: Proposed Strut and Tie design model for Externally Embedded specimens

COMPARISON OF THEORITICAL AND EXPERIMENTAL RESULTS

The values of the Strut and Tie design model beside the values obtained from the previous design models are compared to the experimental results and presented in table 4. It should be pointed out that the experimented externally embedded pocket connections by Canha[4] is presented in the comparison and were used in the verification of the model.

The capacity of the specimens was determined by the Strut and Tie model by assuming that the failure will happen in the vertical reinforcement as the Strut and Tie model considers the vertical reinforcement as the critical reinforcement and the top horizontal reinforcement is used only as a confinement for the pocket walls.

For SS-E1 and SS-E2, the maximum horizontal force acting on the top of the column is determined according to the corresponding normal force used in the test which is (650 kN), while for Canha's specimens SI-2, SI-3 and SI-4, the maximum bending moments acting on the top of the column are determined according to the corresponding normal force used in the test which are 203 kN, 336 kN and 275 kN respectively.

From Table 4, it is shown that the proposed Strut and Tie design model is the best model to represent the externally embedded specimens with maximum deviations from the experimental by 30% and these deviations decreases with the decrease of the embedded length. Although Canha model for big eccentricity is more closer to her experimental program but in SI-4, she overestimates the capacity of the specimen by 15%, also her design model results in a big tensile stresses on the horizontal reinforcement than the vertical reinforcement and that’s why the failure, according to her model, happened in the horizontal reinforcement which is not consistent with experimented failure mode and that’s why the proposed Strut and Tie model is the closest among the existing models to estimate the pocket capacity with its actual failure mode.

Table 4: Comparison between experimental results and design models

Points of Comparison	Specimen									
	SS-E1 (L_{emb}/t =1.33)		SS-E2 (L_{emb}/t =2)		SI-2 (L_{emb}/t =2)		SI-3 (L_{emb}/t =2)		SI-4 (L_{emb}/t =1.6)	
	Horizontal Load (kN.m)	(%) of the experimental	Horizontal Load (kN.m)	(%) of the experimental	Bending moment (kN.m)	(%) of the experimental	Bending moment (kN.m)	(%) of the experimental	Bending moment (kN.m)	(%) of the experimental
Experimental	115	100	150	100	376	100	403	100	330	100
1] Proposed Strut and Tie Model	94.5^{v}	82	103^{v}	69	275.4^{v}	73	291.6^{v}	72	259.2^{v}	79
2] Canha big eccentricity 2007[4]	89.3^{h}	78	74.7^{h}	50	303^{h}	80	310^{h}	77	378^{h}	115
3] Canha small eccentricity 2011[5]	54.4^{h}	47	47^{h}	31	----	---	----	---	----	---

- **(^{v}) means that the failure happened in the vertical reinforcement.**
- (^{h}) means that the failure happened in the horizontal reinforcement.

CONCLUSIONS

Based on the test results of the six specimens tested in this research and the data stated by other researchers in the literature review, some observations and conclusions were made as follow:

1- The Partially Embedded pocket connections are the most economic type of the pocket connections to give big flexural capacity.

2- The fully embedded pocket connections are the closest type to represent a monolithic connection where no failure happened in the pocket itself.

3- From the experimental results, tension stresses appeared on the rear transverse wall which may be resulting from the back-bottom pressure of the column and that's why the strains monitored on the bottom horizontal reinforcement were very small if compared to the top horizontal reinforcement.

4- The main vertical reinforcement in the tension side of the pocket walls is more critical in the externally embedded specimens than the partially embedded specimens.

5- The main horizontal reinforcement in the upper one third of the pocket walls is more critical in the partially embedded specimens than the externally embedded specimens.

6- The behavior of the pocket walls in the externally embedded specimens seems to be monolithic as if the pocket is a part of the column until the vertical reinforcement reaches its yield strain then the horizontal reinforcement starts to sustain the loads.

7- The Proposed Strut and Tie design model is suitable to represent externally embedded pocket connections subjected to medium and large eccentricities ($0.3 \leq e/t \leq 5$).

8- The Proposed Strut and Tie design model for smooth surface interfaces provides the closest predictions of the experimental results.

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