NUMIRICAL MODELING OF CIRCULAR POCKET CONNECTIONS WITH ROUGH AND SMOOTH SURFACE INTERFACE USING FINITE ELEMENT METHOD

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Abstract—Although pocket connections are used since the 1950's, there are only a few researches addressing the behavior and design of this connection, especially for circular columns. Generally, there are two types of pocket connections, internally and externally embedded connection. These configurations limit the use of such connections in the case of bridges, where big moments need to be transferred to the footing. Hence, an extensive experimental program was conducted at Ain shams University-Cairo, to study the behavior of pocket connections. A new pocket configuration with partially embedment is introduced in these studies. This paper presents the finite element modeling results of the experimentally tested circular pocket connections. It also describes the calibrated modeling parameters of the contact element in case of smooth and rough interface surfaces.

A comparison is conducted between the experimental and the nonlinear FE results. The FE models captured with reasonable accuracy the failure modes and deflection profiles of the experimental tested specimens.

INDEX TERMS— Pocket connection; Precast column; foundation; Nonlinear finite element models.

1. INTRODUCTION

Pocket connection between precast column and the base is constructed by embedding the column into a prepared cavity in the base, which is called pocket. The cavity is with greater dimension than that of the column. The gap between the column and base is then filled with cast in place concrete (grout).

The interface surface between column and grout and that between grout and base may be smooth or rough, using shear keys enhance the force transfer mechanism. So the required embedded length of the column inside the pocket for connections with rough surface interface is lower than that with smooth ones.

There are three types of pocket connections depending on the location of the pocket with respect to the foundation: externally, partially, and internally embedded as shown in Figure 3-1.

2. PREVIOUS ANALYTICAL STUDIES

Leonhardt proposed an analytical model for rough and smooth surfaces that is widely used in the design of rectangular pocket connections in which friction forces are neglected, so it is considered to be a conservative model [1]. Willert proposed an analytical model for the connection in which friction forces are mobilized [2].

Based on an experimental work for rectangular connections with smooth and rough interface surfaces, two design models were proposed by Canha. The model for smooth surface interface considers the influence of friction forces generated between the column and pocket in addition to the eccentricity of the column base reaction on the foundation as shown in Figure 3-3. The design model for connections with rough surface interface is based on bending theory, which is shown in Figure 3-2 [3], [4].

3. PREVIOUS NUMERICAL STUDIES

Ebeling conducted numerical modeling for connections with smooth surface interface tested by Canha. He recommends using Coulomb's friction model in defining the contact elements between the surface interfaces. The definition of the contact element depends on two main parameters; FKN: Normal contact stiffness and μ: coefficient of friction. Ebeling recommends using 1 value for FKN and 0.70 for coefficient of friction [5].

Farouk performed experimental and numerical investigation for square connections with rough surface

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interface. Using FKN=0.1, and μ=0.70 for rough square specimens was recommended [6].

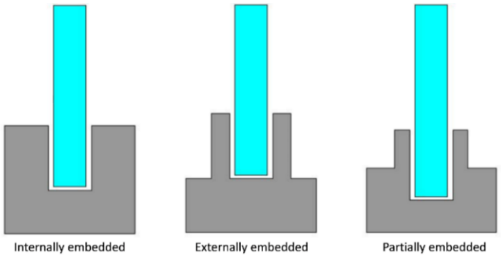

Figure 3-1 Different types of pocket connections according to location of the pocket with respect to the foundation

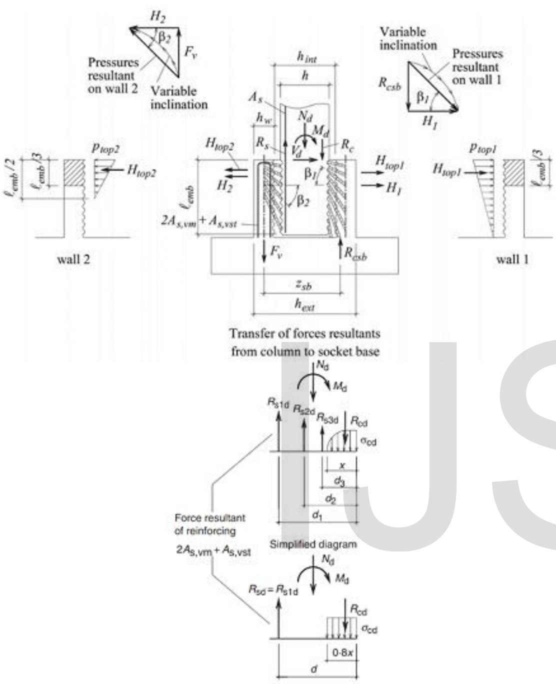

Figure 3-2 Proposed design model for connections with rough surface interface [4]

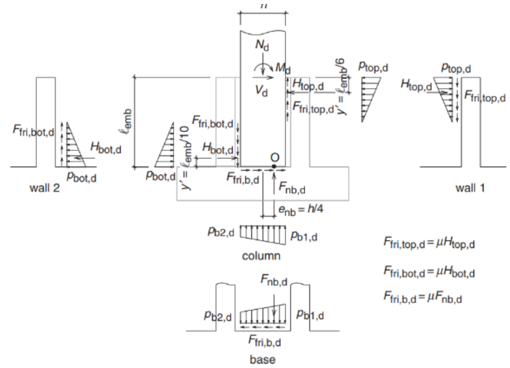

Figure 3-3 Design model for connections with smooth surface interface [3]

The objective of the present study is to determine modeling parameters for circular connections with rough and smooth surface interface using three-dimensional finite element analysis. For this purpose different tested specimens are modeled using ANSYS program [7].

4. Experimental Database

The database used in this study is gathered from experimental research conducted at Ain Shams University, by Mashaal [8].

Table 4-1, and Table 4-2 show the dimensions and steel details for the tested connections, respectively.

The specimens consist of two groups: three specimens with rough surface interface and three specimens with smooth surface interface. Each group includes two partially embedded and one externally embedded specimens. The specimens are loaded by a vertical force of 420 kN, then horizontal force is applied and increased gradually till failure. The eccentricity (e/t) values for the specimens range from 0.66 to 1.10 at failure loads.

Figure 4-1 shows test setup for the specimens tested.

Table 4-1 Circular specimens geometric characteristics summary

Specimen	Interface Surface	Type	Embedded Length (mm)	Column Diameter "h"(mm)	Wall Thickness (mm)	Grout Thickness (mm)
R-PE-32	Rough	Partially Embedded	320 (200 inside base)	Diameter 300	100	30
R-PE-48	Rough	Partially Embedded	480 (200 inside base)	Diameter 300	100	30
R-X-48	Rough	Externally Embedded	480	Diameter 300	100	30
S-PE-60	Smooth	Partially Embedded	600 (200 inside base)	Diameter 300	100	30
S-PE-40	Smooth	Partially Embedded	400 (200 inside base)	Diameter 300	100	30

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S-X-60	Smooth	Externally Embedded	600	Diameter 300	100	30

Table 4-2 Circular specimens reinforcement characteristics summary

Specimen	Column RFT.	Pocket RFT.		Foundation RFT.
		HZ.	VL.	
R-PE-32	12D16	16D8	3D10+ 2D8	8D12 Top & Bottom
R-PE-48	12D16	16D8	5D10+ 2D8	8D12 Top & Bottom
R-X-48	12D16	16D8	7D8	8D12 Top & Bottom
S-PE-60	12D16	16D8	10D8	8D12 Top & Bottom
S-PE-40	12D16	16D8	4D10+ 2D8	8D12 Top & Bottom
S-X-60	12D16	16D8	8D8	8D12 Top & Bottom

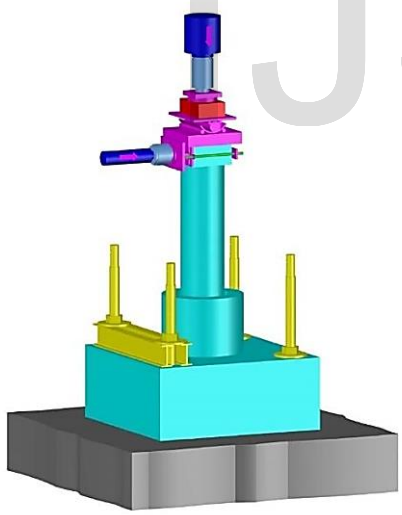

Figure 4-1 Test setup of the specimens

5. Finite Element Analysis

5.1 Finite element modeling

Three-dimensional nonlinear FE models were developed using ANSYS software package.

In this part, the used materials and elements definitions for concrete, contact, and steel are described.

Solid65 is used to model concrete behavior, in which linear and multilinear proprieties are defined. Link180 truss element is used for steel discrete modeling [7].

CONTA174, and TARGE170 are used for contact element simulation between column, grout, and base surfaces [7].

Concrete stress strain curve is computed using Krishnan equations[10].

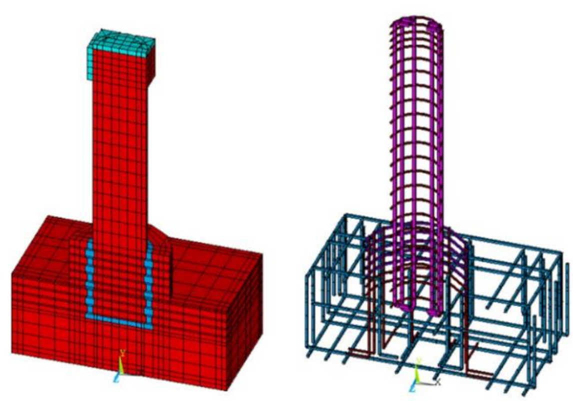

Figure 5-1 Concrete meshing and Steel Elements for tested specimen R-PE-48

Since the model is symmetric about X, so half of the model is developed with displacement constrains equals zero in z direction. Boundary condition and loads are shown in Figure

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5-2 . All specimens are loaded with vertical load 420 kN then the horizontal load is applied and increased gradually till failure.

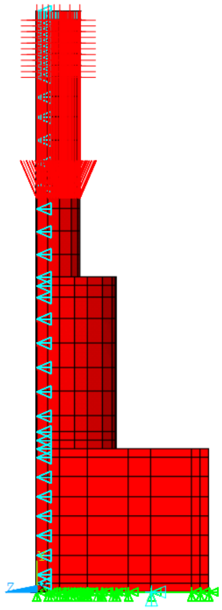

Figure 5-2 Side view for specimen showing loads & boundary conditions

5.2 Sensitivity study

Sensitivity study is performed to get contact element modeling parameters that best simulate the tested specimens behavior. The main parameters used in the sensitivity study for contact element definition between column, pocket, and base interface surfaces are FKN (Normal contact stiffness) and μ (friction coefficient between different contact surfaces).

For FKN (0.1, 0.5, 1, and 10) values are studied. For μ (0.3, 0.5, 0.7, and 1) values are studied.

Effect of these parameters on concrete crushing load, steel yielding load, and load displacement relation of the specimens are studied.

5.2.1 Specimens with rough interface surface

Table 5-1 shows effect of FKN variation on Δ (horizontal displacement) at 5 different load levels for specimens with rough surface interface compared to experimental results. Using 1 and 10 for FKN give closest results to the experiment.

Table 5-1 Normal Contact Stiffness effect on load displacement relation of connections with rough surface interface

Model	FKN	Mean Percentage Difference	Mean	Standard deviation
R-PE-32	0.1	14%	31%	11%
R-PE-48		44%		
R-X-48		36%		
R-PE-32		17%		
R-PE-48	0.5	15%	16%	1%
R-X-48		15%		
R-PE-32		5%		
R-PE-48	1	7%	8%	2%
R-X-48		11%		
R-PE-32		6%		
R-PE-48	10	0%	4%	3%
R-X-48		7%		

Table 5-2 shows effect of FKN variation on reinforcement yielding load of the specimens compared to the experiment. Using value 1 for FKN gives best results compared to the experiment.

Table 5-2 Normal Contact Stiffness effect on reinforcement yielding load for connections with rough surface interface

Model	FKN	P_{yield} Model. (KN)	P_{yield} Exp. (KN)	$P_{Model.}$ / $P_{Exp.}$	Mean Percentage Difference	Standard deviation
R-PE-32		-	76	-		
R-PE-48	0.1	114.8	126	91%	2%	16%
R-X-48		125	110	114%		
R-PE-32		80.8	76	106%		
R-PE-48	0.5	115	126	91%	0%	6%
R-X-48		113.2	110	103%		
R-PE-32		80.6	76	106%		
R-PE-48	1	116	126	92%	-1%	5%
R-X-48		109.2	110	99%		
R-PE-32		-	76	-		
R-PE-48	10	114.6	126	91%	2%	15%
R-X-48		123.4	110	112%		

Table 5-3 shows effect of FKN variation on concrete crushing load of the specimens. Using 1 for FKN gives best results compared to the experiment.

Table 5-3 Normal Contact Stiffness effect on concrete crushing load of connections with rough surface interface

Model	FKN	P_{crush} Model (KN)	P_{crush} Exp. (KN)	P_{Model} / $P_{Exp.}$	Mean Percentage Difference	Standard deviation
R-PE-32	0.1	87.6	80	110%	3%	4%

R-PE-48		127.2	131	97%		
R-X-48		-	-	-		
R-PE-32		92	80	115%		
R-PE-48	0.5	131.2	131	100%	8%	10%
R-X-48		-	-	-		
R-PE-32		93.6	80	117%		
R-PE-48	1	132.2	131	101%	9%	11%
R-X-48		-	-	-		
R-PE-32		-	80	-		
R-PE-48	10	129.6	131	99%	-1%	4%
R-X-48		-	-	-		

From all above results, it was found that using 1.00 gives closest results to the experiment.

Table 5-4 shows coefficient of friction variation effect on Δ (horizontal displacement) at 5 different load levels for specimens with rough surface interface compared to experimental results Using 0.70 and 1.00 for μ give closest results to the experiment.

Table 5-4 Friction coefficient effect on Load displacement relation for connections with rough surface interface

Model	μ	Mean Percentage Difference	Mean Percentage Difference	Standard deviation
R-PE-32		12%		
R-PE-48	0.3	19%	4%	13%
R-X-48		22%		
R-PE-32		9%		
R-PE-48	0.5	15%	3%	10%
R-X-48		16%		
R-PE-32		7%		
R-PE-48	0.7	11%	2%	7%
R-X-48		13%		
R-PE-32		5%		
R-PE-48	1	8%	1%	5%
R-X-48		9%		

Table 5-5 shows coefficient of friction variation effect on reinforcement yielding load of specimens with rough surface interface compared to experimental results. Using 0.70 value gives closest results to the experiment.

Table 5-5 Friction coefficient effect on reinforcement yielding load for connections with rough surface interface

Model	μ	P_{yield} Model. (KN)	P_{yield} Exp. (KN)	P_{Model} / $P_{Exp.}$	Mean Percentage Difference	Standard deviation
R-PE-32	0.3	80.2	76	106%	-3%	5%
R-PE-48		114.2	126	91%		
R-X-48		105.6	110	96%		
R-PE-32		81.4	76	107%		
R-PE-48	0.5	114.8	126	91%	-2%	6%
R-X-48		105.6	110	96%		
R-PE-32		80.2	76	106%		
R-PE-48	0.7	115.6	126	92%	0%	5%
R-X-48		112.8	110	103%		
R-PE-32		80.6	76	106%		
R-PE-48	1	116	126	92%	-1%	5%
R-X-48		109.2	110	99%		

Table 5-6 shows coefficient of friction variation effect on concrete crushing load of specimens with rough surface interface compared to experimental results. Using 0.70 gives closest results to the experiment.

Table 5-6 Friction coefficient effect on concrete crushing load for connections with rough surface interface

Model	μ	P_{crush} Model (KN)	P_{crush} Exp. (KN)	P_{model} /$P_{Exp.}$	Mean Percentage Difference	Standard deviation
R-PE-32		94.6	80	118%		
R-PE-48	0.3	132.2	131	101%	10%	12%
R-X-48		127.2	120	-		
R-PE-32		94.6	80	118%		
R-PE-48	0.5	133.2	131	102%	10%	12%
R-X-48		-	120	-		
R-PE-32		92	80	115%		
R-PE-48	0.7	132.2	131	101%	7%	5%
R-X-48		127.2	120	106%		
R-PE-32		93.6	80	117%		
R-PE-48	1	132.2	131	101%	9%	11%
R-X-48		-	120	-		

From all above results, it was found that using 0.70 gives closest results to the experiment.

5.2.2 Specimens with smooth interface surface

Table 5-7 shows effect of FKN variation on Δ (horizontal displacements) at 5 different load levels for specimens with smooth surface interface compared to experimental results. Using 1 and 10 for FKN give closest results to the experiment.

Table 5-7 Normal Contact Stiffness effect on Load displacement relation for connections with smooth surface interface

Model	FKN	Mean Percentage Difference	Mean Percentage Difference	Standard deviation
S-PE-40		24%		
S-PE-60	0.1	25%	24%	0%
S-X-60		24%		
S-PE-40	0.5	9%	12%	2%

S-PE-60		12%		
S-X-60		16%		
S-PE-40		7%		
S-PE-60	1	10%	10%	2%
S-X-60		13%		
S-PE-40		3%		
S-PE-60	10	6%	7%	3%
S-X-60		12%		

Table 5-8 shows effect of FKN variation on reinforcement yielding load of the specimens compared to the experiment. Using 1 for FKN gives best results compared to the experiment.

Table 5-8 Normal Contact Stiffness effect on reinforcement yielding load for connections with smooth surface interface

Model	FKN	P_{yield} Model (KN)	P_{yield} Exp. (KN)	$P_{Model}/P_{Exp.}$	Mean Percentage Difference	Standard deviation
S-PE-40		115.4	100	115%		
S-PE-60	0.1	134.8	108	125%	9%	14%
S-X-60		84	96	88%		
S-PE-40		115	100	115%		
S-PE-60	0.5	-	108	-	-3%	25%
S-X-60		76.6	96	80%		
S-PE-40		114.8	100	115%		
S-PE-60	1	139.2	108	129%	8%	18%
S-X-60		86	109	79%		
S-PE-40		113.8	100	114%		
S-PE-60	10	137.4	108	127%	10%	14%
S-X-60		86.4	98	88%		

Table 5-9 shows effect of FKN variation on concrete crushing load of the specimens. Using 0.50 for FKN have a convergence problem with R-PE-32.

Table 5-9 Normal Contact Stiffness effect on load crushing for connections with smooth surface interface

Model	FKN	P_{crush} Model (KN)	P_{crush} Exp. (KN)	$P_{Model}/P_{Exp.}$	Mean Percentage Difference	Standard deviation
S-PE-40		103.2	92	112%		
S-PE-60	0.1	129.4	101	128%	20%	11%
S-X-60		-	-	-		
S-PE-40		100.4	92	109%		
S-PE-60	0.5	127.4	101	126%	18%	12%
S-X-60		-	-	-		
S-PE-40		102	92	111%		
S-PE-60	1	137.6	101	136%	24%	18%
S-X-60		-	-	-		
S-PE-40		104.2	92	113%		
S-PE-60	10	138	101	137%	25%	17%
S-X-60		-	-	-		

From all above results, it was found that using 1.00 for FKN gives closest results to the experiment.

Table 5-10 shows coefficient of friction variation effect on Δ (horizontal displacements) at 5 different load levels for specimens with smooth surface interface compared to experimental results. Using 1 for FKN gives closest results to the experiment.

Table 5-10 Friction coefficient effect on Load displacement relation of connections with smooth surface interface

Model	μ	Mean Percentage Difference	Mean Percentage Difference	Standard deviation
S-PE-40		12%		
S-PE-60	0.3	19%	18%	4%
S-X-60		22%		
S-PE-40		9%		
S-PE-60	0.5	15%	13%	3%
S-X-60		16%		
S-PE-40		7%		
S-PE-60	0.7	11%	10%	2%
S-X-60		13%		
S-PE-40		5%		
S-PE-60	1	8%	7%	1%
S-X-60		9%		

Table 5-11 shows coefficient of friction variation effect on reinforcement yielding load of specimens with smooth surface interface compared to experimental results. Using 0.70 for μ gives closest results to the experiment.

Table 5-11 Friction coefficient effect on reinforcement yielding load of connections with smooth surface interface

Model	μ	P_{yield} Model (KN)	P_{yield} Exp. (KN)	$P_{Model}/P_{Exp.}$	Mean Percentage Difference	Standard deviation
S-PE-40		112.8	100	113%		
S-PE-60	0.3	128	108	119%	1%	18%
S-X-60		68.6	96	71%		

S-PE-40		113.6	100	114%		
S-PE-60	0.5	128.8	108	119%	2%	18%
S-X-60		69.2	96	72%		
S-PE-40		114.2	100	114%		
S-PE-60	0.7	134.8	108	125%	0%	24%
S-X-60		67.6	109	62%		
S-PE-40		114.5	100	115%		
S-PE-60	1	139.2	108	129%	4%	22%
S-X-60		68	98	69%		

Table 5-12 shows effect of μ factor variation on concrete crushing load of the specimens.

Table 5-12 Friction coefficient effect on concrete crushing load for connections with smooth surface interface

Model	μ	P_{crush} Model (KN)	P_{crush} Exp. (KN)	P_{Model} / $P_{Exp.}$	Mean Percentage Difference	Standard deviation
S-PE-40		116.2	92	126%		
S-PE-60	0.3	128.8	101	128%	27%	1%
S-X-60		-	-	-		
S-PE-40		108.6	92	118%		
S-PE-60	0.5	131.4	101	130%	24%	9%
S-X-60		-	-	-		
S-PE-40		104	92	113%		
S-PE-60	0.7	140	101	139%	26%	18%
S-X-60		-	-	-		
S-PE-40		102	92	111%		
S-PE-60	1	137.6	101	136%	24%	18%
S-X-60		-	-	-		

From all above results, it was found that using 0.50 for μ gives closest results to the experiment.

5.2.3 Summary of sensitivity study

Table 5-13, and Table 5-14 show selected contact element parameters for circular connections with rough and smooth surface interfaces. Selected parameters for other factors are also introduced.

Table 5-13 Validated Parameters for Rough circular specimens.

Parameter	Used Value
FKN	1.00
Friction Coefficient (μ)	0.70
τ max	10
Open Shear Transfer Coefficient	0.50
Closed Shear Transfer Coefficient	0.70
Convergence Criteria	Force
Convergence Tolerance	0.05

Table 5-14 Validated Parameters for Smooth circular specimens

Parameter	Used Value
FKN	1.00
Friction Coefficient (μ)	0.50
τ max	10
Open Shear Transfer Coefficient	0.50
Closed Shear Transfer Coefficient	0.50
Convergence Criteria	Force
Convergence Tolerance	0.05

5.3 Load deflection behavior

To ensure the accuracy of obtained modeling parameters, this section present a comparison of load displacement curves of FE models and experiments.

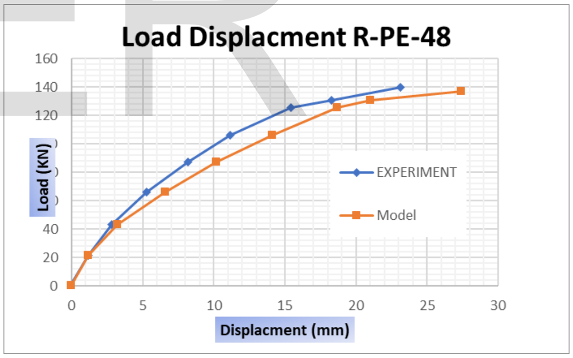

Figure 5-3 Load displacement curve for R-PE-48 specimen.

Figure 5-3 shows load displacement curve for R-PE-48 model compared to experimental results. Failure load and displacement of the model was at 136.8 KN and 27.4 mm which compares well with experimental results 139.6KN and 23.12 mm with a deviation 2 and 18% respectively.

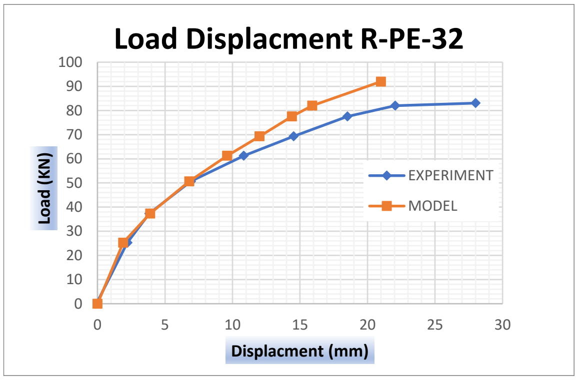

Figure 5-4 Load displacement curve for R-PE-32 specimen

Figure 5-4 shows load displacement curve for R-PE-32 model compared to experimental results. Failure load and displacement of the model was at 101 KN and 29 mm which compares well with experimental results 83 KN and 28 mm with a deviation 21% and 3.5% respectively.

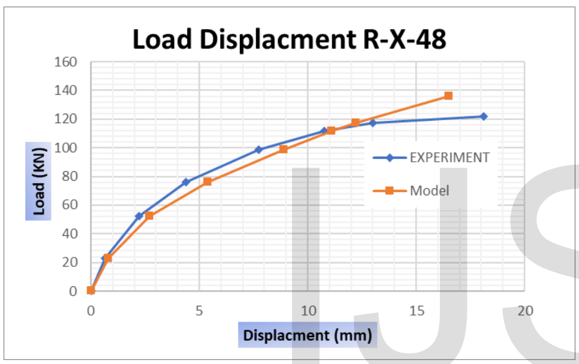

Figure 5-5 Load displacement curve for R-X-48 specimen

Figure 5-5 shows load displacement curve for R-X-48 model compared to experimental results. Failure load and displacement of the model was at 128.3 KN and 15.1 mm which compares well with experimental results 121.8KN and 18.1 mm with a deviation 5 and 16% respectively.

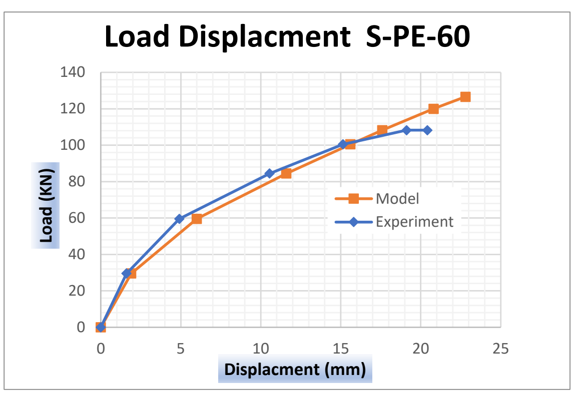

Figure 5-6 Load displacement curve for S-PE-60 specimen

Figure 5-6 shows load displacement curve for S-PE-60 model compared to experimental results. Failure load and displacement of the model was at 126.6 KN and 22.8 mm which compares well with experimental results 108 KN and 20.4 mm with a deviation 17% and 12% respectively.

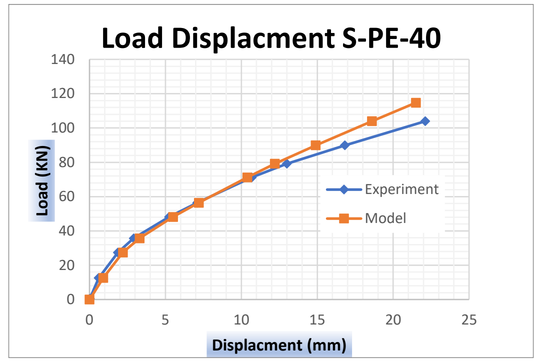

Figure 5-7 Load displacement curve for S-PE-40 specimen

Figure 5-7 shows load displacement curve for S-PE-40 model compared to experimental results. Failure load and displacement of the model was at 116 KN and 21.6 mm which compares well with experimental results 104KN and 22.1 mm with a deviation 12 % and 2% respectively.

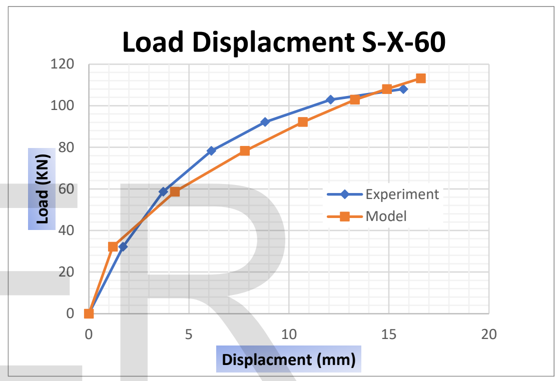

Figure 5-8 Load displacement curve for S-X-60 specimen

Figure 5-8 shows load displacement curve for S-PE-40 model compared to experimental results. Failure load and displacement of the model was at 113 KN and 16.6 mm which compares well with experimental results 104KN and 15.7 mm with a deviation 9 % and 6% respectively.

From the previous results shown Figure 5-3 to Figure 5-8, there is good agreement between the numerical results and the experimental results.

6. Summary and Conclusions

1- Obtained contact element modeling parameters for smooth and rough surface interface are valid for externally and partially embedded pocket connections.
2- Coulomb's friction model simulates the experimental contact behavior of pocket connection closely.
3- For circular pocket connections with rough and smooth surface interface, using 0.70 and 0.50 value for μ (friction coefficient) gives the closest results to tested specimens, respectively.

4- For circular pocket connections, using 1.00 value for FKN (normal contact stiffness) for smooth and rough surfaces gives the closest results to tested specimens.

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