THE EFFECT OF EMBEDDING DEPTH OF H-SECTIONS WITH END-PLATES ON THEIR PULL-OUT BEHAVIOR

H. Khadem [(1)], M. Heristchian [(2)], H. Khadem [(3)]

[(1)] *M.s civil engineering Graduate Student, Islamic Azad University, South Tehran branch, Homayoon.civil.p@gmail.com*
[(2)] *Civil engineering department-Faculty of engineering, Islamic Azad University, heris@azad.ac.ir*
[(3)] *M.s Architecture Graduate, Pratt Institute Brooklyn, New York, Hoomankhadem68@gmail.com*

Abstract

Connections are one of the essential parts of the Steel Structures, due to their decisive role in the overall behavior of the structures. In addition, several studies of earthquakes show that the most structural damages repeatedly happen in areas where connections are located. Column- foundation joint (Link), is the main type of connection in Steel Structures.

Firstly, the importance of Column-foundation joint (Link) connections is due to its main responsibility in transmission of forces of entire structure to the foundation, in which in case of earthquakes, this action can be reversed, as the forces are also transmitted from the foundation to the entire structure. Secondly, Column-foundation joints (Link) are the points of instability in the whole structure during the earthquakes, as well as they affect the entire structure's behavior. The most common method to design and assemble the steel column-foundation joint is using Tie rods. In addition, as an alternative way for this method, part of the column can be directly placed in the foundation as an embedded object (region). Tie rods are weak in reacting to tension, pull-out, bending, and shear forces, because the embedded columns in concrete with end plates show more strength and power against these forces. Therefore, analyzing the pull-out behavior of columns which are embedded inside the foundation is particularly essential.

This paper will discuss the effect of embedding depth of H-Sections with End-plates on their Pull-out behavior. In addition, the numerical models will be generated using Abaqus 6.14-1 finite element software, and the generated analyzation and results will be compared within each other.

Keywords:

Steel H-Sections, Pull-out or Tension force, Embedded Depth, Steel non-linear behavior, Concrete cracking and crushing

1. Introduction

Connections in steel structures are among the most important structural components and have a key role in the overall behavior of structures, yet based on studies of earthquakes they sustained the most structural damages. Moreover, the importance and necessity of studies in the field of loading and seismic loads are quite tangible. Among all types of connections in steel structures, the column-foundation connections are one of the most important connections, in which limited research has been done on it. These connections are important as their first task is to convey all structural forces to foundation, and during the earthquake, it may conversely happen. Secondly, it will be location of overall structural instability and failure especially during the earthquake, and affects the whole structure behavior. According to a report published by Technical council on lifetime Earthquake Engineering (1995)[1] and Northridge Reconnaissance Team (1996)[2], most of baseplate connections that were designed based on previous connections, had no optimal performance on Northridge[3] Earthquake of January 17th in 1994. In addition, after statistical analysis about the failure of steel structures in Kobe[4] earthquake in 1995, large part of structural damages was related to baseplates connections. These studies on the necessity of access to baseplate connections with more ductility emphasized the development of design methods with greater reliability [2]. Among the topics to discuss, tensile behavior of embedded H section steel columns

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[1] Technical council on lifetime Earthquake Engineering (1995)
[2] Northridge Reconnaissance Team (1996)
[3] Northridge California Earthquake of January 17,1994
[4] Hyogo-Ken Nanbu, Kobe, Japan , 1995

with endplate could be the basis for evaluation of tensile behavior of sections buried in concrete that have complex geometries. One of the main reasons for this is the complexity of the intrinsic behavior of these connections, especially under tensile forces (Fig. 1) [1].

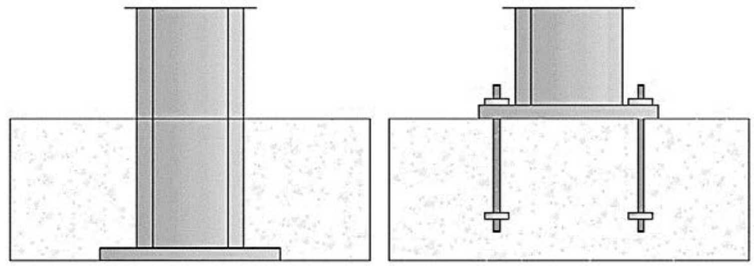


Fig. 1 – Traditional and embedded base plate-foundation connection [1]

Based on post-Kobe research, Hitaka et al. (2003), larger rotational stiffness is expected for embedded column base compare to the conventional baseplate connection. Further, they observed that anchor bolts had fractured or elongated severely in Kobe earthquake, whereas no damage was reported for the embedded column connections [3].

In 2006, three pullout experiments for embedded IPE140 sections were conducted by M.Heristchian and Pour Akbar, as outcomes were given on the bond slip and the related experimental data, and numerical models of the experimental works were studied. Based on the experimental and numerical studies, the following remarks are made [3]:

- For specimen that had identical cross-section within the embedding length, the main resistance source against pullout was the bond stress.
- The specimens that had end plates, bearing strength related to the end plates actually came into effect only after bond slippage occurred.
- Despite of these remarks, more experimental work is required to acquire understanding of the pull out behavior of embedded column bases.

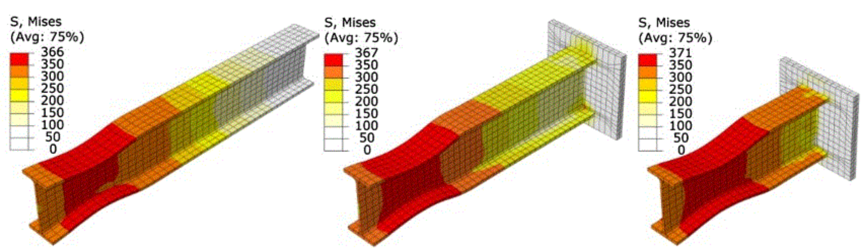


Fig. 2 – Von Mises stress in terms of MPa, models M_1- M_2- M_3, Heristchian et al.[3]

Di Sarno et al. (2007) carried out tests on partially encased composite steel-concrete columns [3]. Pecce and Rossi (2013) have a numerical model for a type of partially encased composite columns in their models [4].Jiho moon at el. (2013) in a study under the title "Evaluation of embedded concrete-filled tube (CFT) column-to-foundation connection" reviewed considered parameters which have already been examined with the expansion of design model and verification based on experimental results that were discussed. Studied parameters included embedded depth, the ratio of diameter to thickness, ratio of rebar cutting, rate of concrete strength at the base, the location of embedding in concrete, and the ratio of Vector Force. Using mentioned parameters, results showed that the mechanism of failure was evaluated, and the results showed increasing in parameters, as well as having direct relationship that can cause brittle fracture of composite embedded columns. Finally, in order to develop the test results and analysis, refined optimal design was used to calculate the embedded depth [5].

Heristchian at el. (2013) in a study called "Ultimate Pull out Strength of embedded plain rebar's" and by using Abaqus finite element modeling software, determined the parameters such as the adhesion between concrete and steel ,the role of friction in the contact area, non-linear behavior of concrete with regard to crack and crush, and non-linear behavior of steel, that were affecting the behavior of the connections. Moreover, the parameters were examined and concluded that results of experiments with analytical models are matching, and could use parameters witch related to contact area between the concrete and steel in other models in the same analysis (Fig.3) [6].

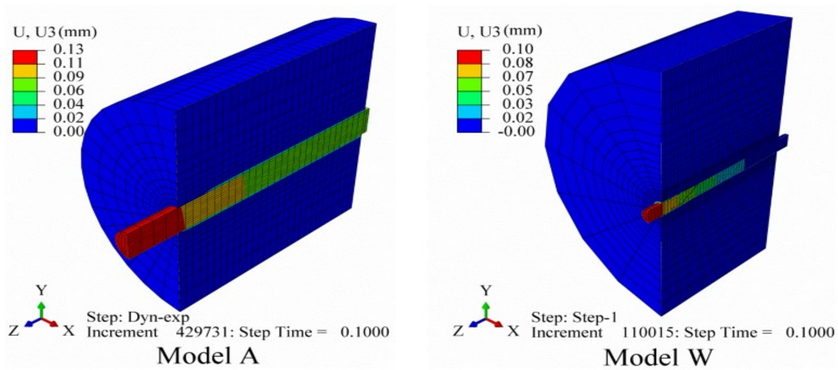


Fig. 3 – Analytical models, Heristchian at el. (2013) [6]

Elsewhere, Heristchian et al. (2014), numerically and experimentally studied the pullout behavior of tapered I and steel box sections embedded in unreinforced concrete (Fig. 4). The test specimens sustained a relatively large portion of the peak load with a large displacement before pullout from the concrete block. Also, the tests show a load plateau between the first and the last peak loads. However, with a higher tapering angle (α), the plateau disappeared and the overall displacement decreased. The numerical models present the effect of boundary conditions, the size of concrete block, the tapering angle, and the coefficient of friction. As shown in Fig. 4, the restraining boundary conditions prevent the concrete block from splitting, which is the most common type of failure in embedded tapered sections, and could double its pullout strength. Under proper confinement, the splitting failure changes into the biconical shape and it could have very large post-failure pullout strength [7].

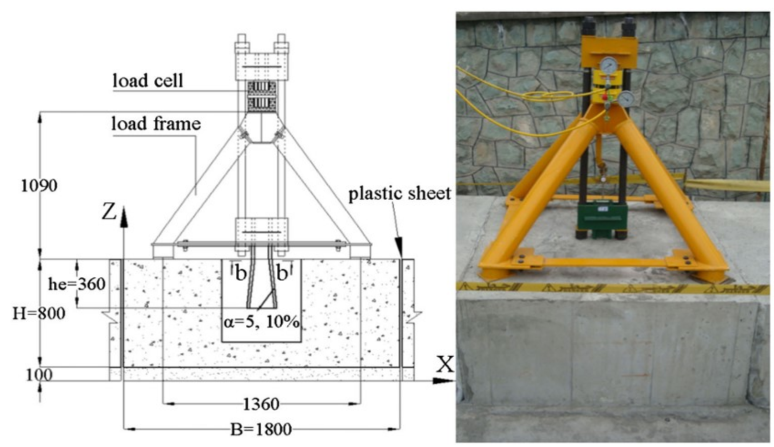


Fig. 4 – The Concrete block, the load frame and a specimen (mm), Heristchian et al. (2014) [7]

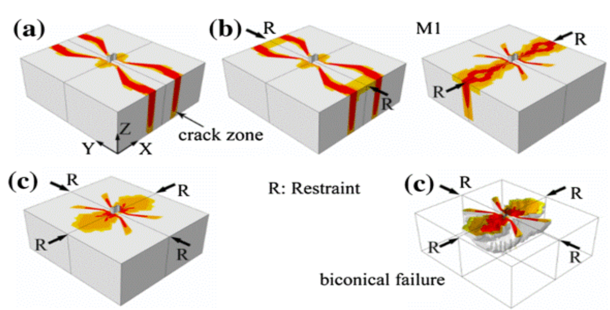


Fig. 5 – Failure mechanism under different boundary conditions, Heristchian et al. (2014) [7]

This study will investigate the effect of embedded depth pullout behavior of "16 analytical H shape steel column" with endplate models which have embedded depth between 100 to 1600 mm.

2. Analytical models

Using an alternative method of embedding H-section columns with an endplate instead of using traditional methods of base plates and anchor bolts to connect the foundation with structure, can be the basis for review and achieve optimum pullout behavior between members. This section will review and introduce specimens modeling procedure and analyzing. Fundamental parameters that affect the behavior of an embedded baseplate connection include the following:

1) Steel column's cross-sectional area 2) H-section embedded depth 3) Concert block dimension 4) Distance of supports (Ochs to Ochs) from each other 5) Distance of supports (Ochs to Ochs) from the edge of concrete block 6) Supports dimensions 7) Dimensions of H-section steel column with endplate 8) Tensile force to achieve 1 cm displacement in steel column(the effective location is top of the steel column's cross-section) 9) Non-linear behavior of steel with material properties 10) Specifications of used concrete block(with crack and crushing parameters). In this paper 16 numerical models were analyzed with finite element software Abaqus 6.14-1.

2.1. Analytical model geometry

Embedded depth is the main variable in this paper, and it is based on the number of specimens defined per 100 mm. To prevent dispersion, specimens were divided in 4 groups of "a", "b", "c", and "d", in which these groups are including variable parameters such as embedded depth, steel column cross-section area(wing and web), endplate dimension, support dimension, support distance from concrete block edge and from each other, and concrete block dimension(Fig. 6)

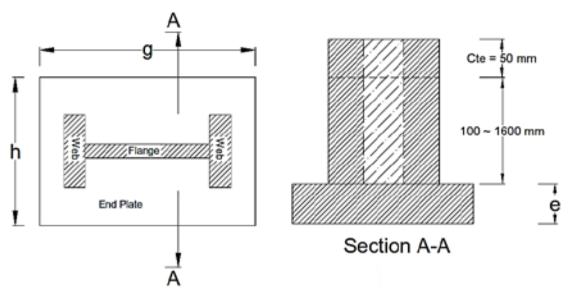


Fig. 6 – Analytical pharametric dimension

Note: In modeling of embedded column with 100 mm embedded depth from group "a", because of endplate protrusion from concrete block, support dimensions were changed.

Figure 7 shows parametric analytical model's plan and section views, and geometric characteristics of all analytical models are given in Table 1.

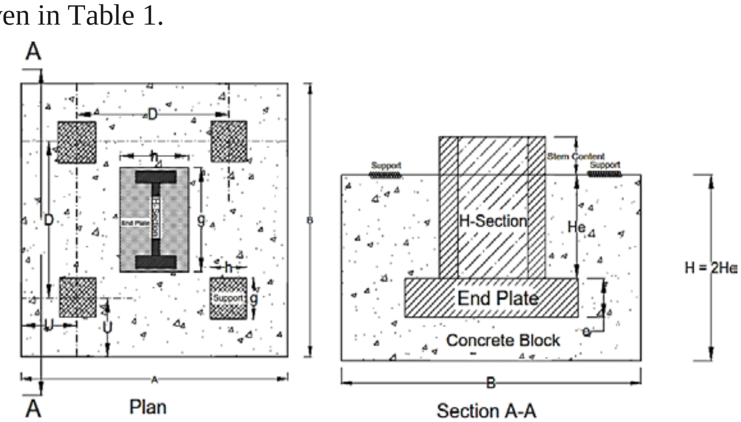


Fig. 7 – parametric analytical model's plan and view

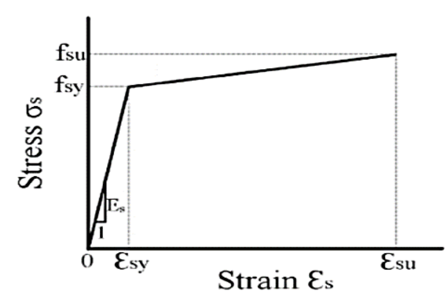
Table 1 – Geometric characteristics of all analytical

Category		a (H-Section Area=50 cm²)				b (H-Section Area=100 cm²)				c (H-Section Area=150 cm²)				d (H-Section Area=250 cm²)			
Parameters / Embedded Depth(he)		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
A=B=7he (The length and width of concrete blocks)		700	1400	2100	2800	3500	4200	4900	5600	6300	7000	7700	8400	9100	9800	10500	11200
H=2he (Concrete block height)		200	400	600	800	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200
D=5he (Supports distance from each other)		500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000
U=he(Supports distance from concrete block)		100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
Supports Dimension (as same as end plates)		220 X 150				300 X 200				400 X 250				500 X 300			
H-Section dimension	Flange Dimension	PL 100 X 12				PL 150 X 15				PL 200 X 20				PL 250 X 24			
	Web Dimension	PL 150 X 6				PL 225 X 8				PL 300 X 12				PL 375 X 12			
	Length	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650
End Plate Dimension	Length &Width	PL 150 X 150	PL 220 X 150			PL 300 X 200				PL 400 X 250				PL 500 X 300			
	Thickness	20				20				24				30			
H-section Outfield from Concrete Block		50															
All of Content are in milimeter																	

2.2. Materials Specifications

To define steel specifications, double-lined diagram is used in modeling, in which related amounts are presented in Table 2.

Table 2 – the mechanical properties of steel



Poisson's Ratio	E_s(Gpa)	ε_{su}	$f_{su}(Mpa)$	$f_{sy}(Mpa)$	Density $(\frac{Kg}{m^3})$	Steel Type	Model No.
0.3	210	0.24	480	235	7850	S 235	He_1
		0.24	480	235		S 235	He_2
		0.24	480	235		S 235	He_3
		0.24	480	235		S 235	He_4
		0.24	480	235		S 235	He_5
		0.21	540	275		S 275	He_6
		0.21	540	275		S 275	He_7
		0.2	600	355		S 355	He_8
		0.2	600	355		S 355	He_9
		0.2	600	355		S 355	He_{10}
		0.2	600	355		S 355	He_{11}
		0.2	600	355		S 355	He_{12}
		0.2	600	355		S 355	He_{13}
		0.2	600	355		S 355	He_{14}
		0.2	600	355		S 355	He_{15}
		0.2	600	355		S 355	He_{16}

To define concrete specifications, "Concrete Damage Plasticity" behavioral model is used. This behavioral model includes features that made concrete one of the most widely and most accurate concrete behavioral models. The model is capable to simulate cracking in tension, crushing in pressure, and it is usable in both implicit and explicit analytical method. For one thing, in finite element analysis of this connection, because of the complexity of materials and contacts, we are forced to use the explicit analysis. In order to define this behavioral model Stress-strain curve of unconfined concrete, uniaxial tension and compression with damage parameters should be imported into the software. Concrete stress-strain is presented based on relationships proposed by Park and Paulay (1975) [8], So that the yielding strain of concrete is shown in Eq. (1), (table3, 4).

$$\varepsilon_{cu} = 0.1f'c \tag{1}$$

Table 3 – Specifications of concrete damage Model [9]

Concrete Damage Plasticity propertice

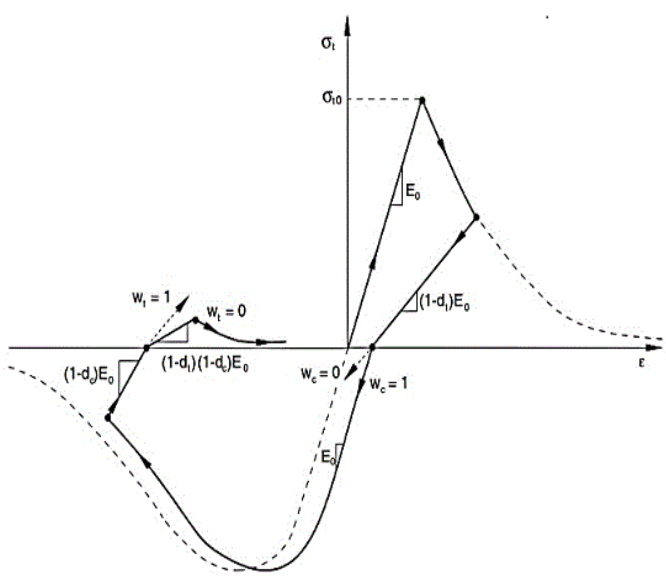


Illustration of the effect of the compression stiffness recovery.

Uniaxial load cycle (tension-compression-tension) assuming default values

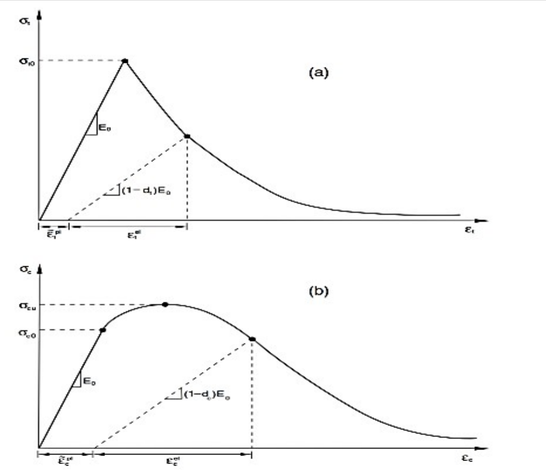
for the stiffness recovery factors: $w_c = 1$ and $w_t = 0$

Dilation Angle($\emptyset$)	15
Flow Potential eccentricity($\in$)	0.1
Viscosity (μ)	0.0
Invariant stress ratio (K_c)	0.6667
Biaxial/Uniaxial compression plastic strain ratio(σ_{b0}/σ_{c0})	1.16

Tension Behavior			
Stress	Cracking strain	Damage	Cracking strain
1.7800E+06	0.0000	0.0000	0.0000
1.457E+06	0.0001	0.3000	0.0001
1.113E+06	0.0003	0.5500	0.0003
9.600E+05	0.0004	0.7000	0.0004
8.000E+05	0.0005	0.8000	0.0005
5.360E+05	0.0008	0.9000	0.0008
3.590E+05	0.0010	0.9300	0.0010
1.610E+05	0.0020	0.9500	0.0020
7.300E+04	0.0030	0.9700	0.0030
4.000E+04	0.0050	0.9900	0.0050
Compression recovery factor ω_c=0.0			

Compression Behavior			
Stress	Inelastic strain	Damage	Inelastic strain
2.4019E+07	0.0000	0.0000	0.0000
2.921E+07	0.0004	0.1299	0.0004
3.171E+07	0.0008	0.2429	0.0008
3.236E+07	0.0012	0.3412	0.0012
3.177E+07	0.0016	0.4267	0.0016
3.038E+07	0.0020	0.5012	0.0020
2.851E+07	0.0024	0.5660	0.0024
2.191E+07	0.0036	0.7140	0.0036
1.490E+07	0.0050	0.8243	0.0050
2.953E+06	0.0100	0.9691	0.0100
Tension recovery factor ω_t=0.0			

Table 4 – the mechanical properties of concrete [9]

Concrete Mechanical Propertice		
	27.6 Gpa	E_c
	0.2	υ
	34 Mpa	f_c'
	2.8 Mpa	f_{ct}
	0.0038	ε_{cu}
	0.08 $^{N}/_{mm}$	G_f
	2400 $^{Kg}/_{m^3}$	Density

Response of concrete to uniaxial loading in tension (a) and compression (b).

2.3. Contact properties between steel and concrete

In order to simulate the suitable behavioral contact area between the steel and concrete, it requires a case that makes it possible to define Adhesion properties, uplift, and slip and friction exist. For this purpose, an embedded behavioral region is used in interaction module, so that the steel columns is embedding in concrete blocks (A similar case happens in reality and formatting operations, and sowing steel column with endplate takes place and finally concrete foundations will be implemented). Moreover, friction coefficient of contact surface is also intended 0.4.

2.4. Analysis type

According to nonlinear behavior of concrete (cracking and crushing), and also the complex performance of contact surfaces, explicit non-linear dynamic analysis is used by considering the geometric non-linear behavior. Quasi-static control behavior of model is presented in the results.

2.5. Boundary conditions

The upper surface of the concrete blocks is z-restrained from four areas. Loading is considered for tensile force (in z direction) on the top of steel column's cross-section to imposing 1 cm displacement (Fig. 8).

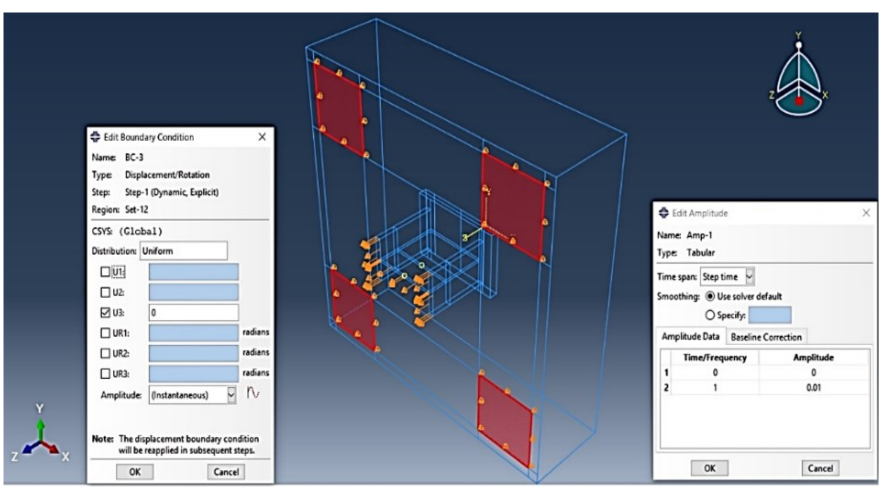


Fig. 8 –Boundary conditions applied

2.6. Finite element Meshing

For finite element meshing, C3D8R element, that is an 8-node linear brick, is used for reduced integration and hourglass control. Also the type of used mesh is Hex-Structured that in structural elements causes meshing more uniform than the other models (Fig. 9).

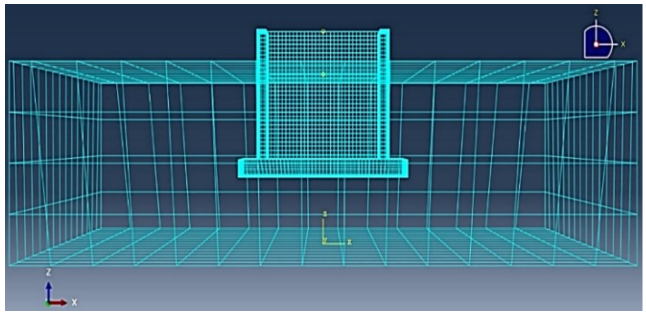


Fig. 9 – Finite element meshing in analytical models

3. Results of analytical models and the effect of basic parameters variables

In general, according to the comparison results of analytical models with each other, as well as pervious research, we can say that there is a possibility of Finite element modeling in these synthetic components with sufficient accuracy by Abaqus software. In Concrete Damage Plasticity behavioral Model, the value of PE Max Principal > 0, Represents evidence of cracking in concrete. For example, Fig.10 shows the cracked concrete areas at the beginning of cracking and when the steel column exudes in analytical models. The main reason for getting out steel columns from concrete is the separation of tapered steel column surrounding concrete (Fig.10).

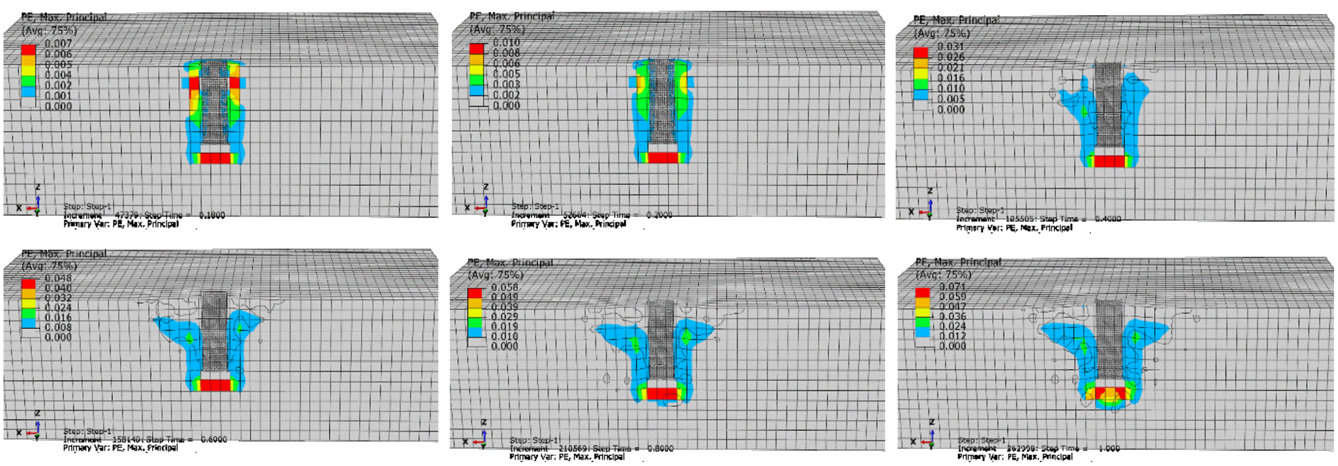


Fig. 10 –cracking progress of concrete block in X-Direction at the time of analysis (t=1s) for the specimen with embedded depth of 700 mm

Note: Due to the abundance and large numbers of graphical results in analytical models, we avoided to display other results, and only mentioned this graphical analytical model results (specimen with embedded depth of 700mm). In acknowledgment part, we review the total results.

As Shown in Fig.11, the steel column stress in Z direction at its maximum value, is less than steel yield stress and the H shape column with an endplate, even though in the upper part tolerates a considerable force, but it is still in elastic zone. Thus, in this analytical model, according to calculations, the conclusion is that steel type S275JR is ok for this analysis Eq. (2). Amount Pu represents the maximum uplift force in terms of KN and amount A is cross-sectional area of steel columns in square millimeters.

$$f_{sy}^{+} = \frac{Load\ (P_u)}{A} = \frac{1759}{6300} = 279.05\ Mpa \qquad 275 \text{ is ok} \qquad (2)$$

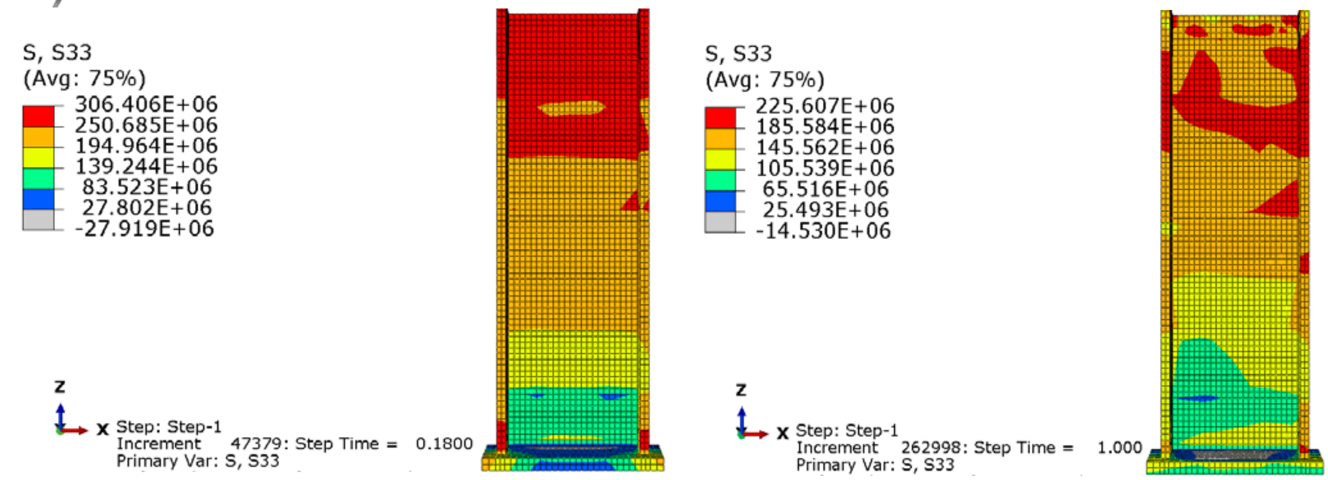


Fig. 11 – steel column stress cantor (in Z direction) of the sample with embedded depth of 700 mm

Fig.12 describes that displacement contour of an analytical model with embedded depth of 700 mm in Z direction at the time of starting to crack, and steel column pulling out from concrete.

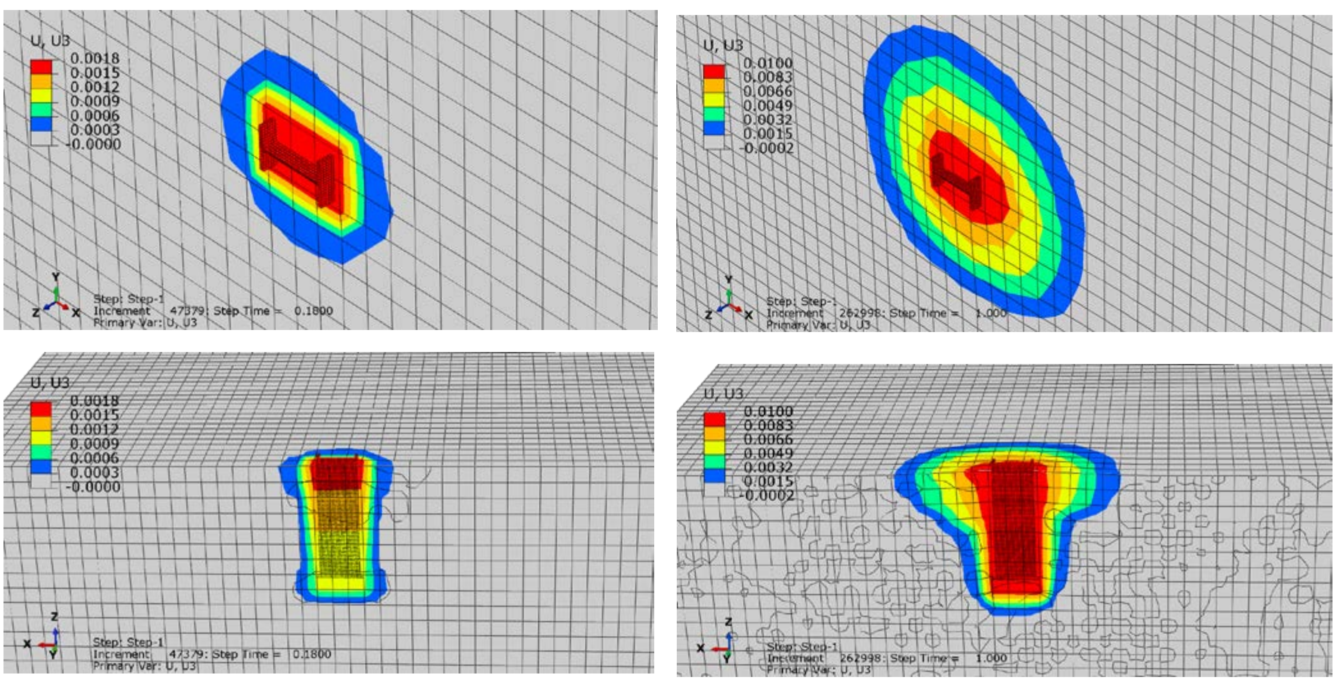


Fig. 12 – steel column displacement Cantor (in Z direction) of the sample with embedded depth of 700 mm

For purpose of static condition and control in analytical model behavior, explicit dynamic analysis usage for analytical modeling with uniform load and comparing kinetic energy with an internal energy is considered. For one thing, in Figure 13, kinetic energy curve and internal energy system is presented in a way that during the analysis, kinetic energy is less than internal energy that means quasi-static behavior of model.

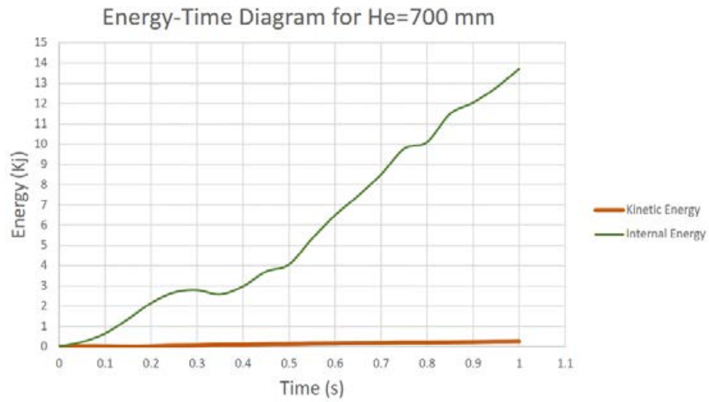


Fig. 13 – Kinetic-Internal energy diagram due to the analytical model with embedded depth of 700 mm

In Fig.14, the amount of input damage to the concrete block and steel column in the beginning of cracking and end of analysis is observed. In the beginning of cracking, damage value is increased due to concrete block cracking progress and path, which eventually took 1 second at the end of analysis in order for steel column to fully come out from concrete block, as the surrounding area of column embedded in concrete block is damaged and destroyed.

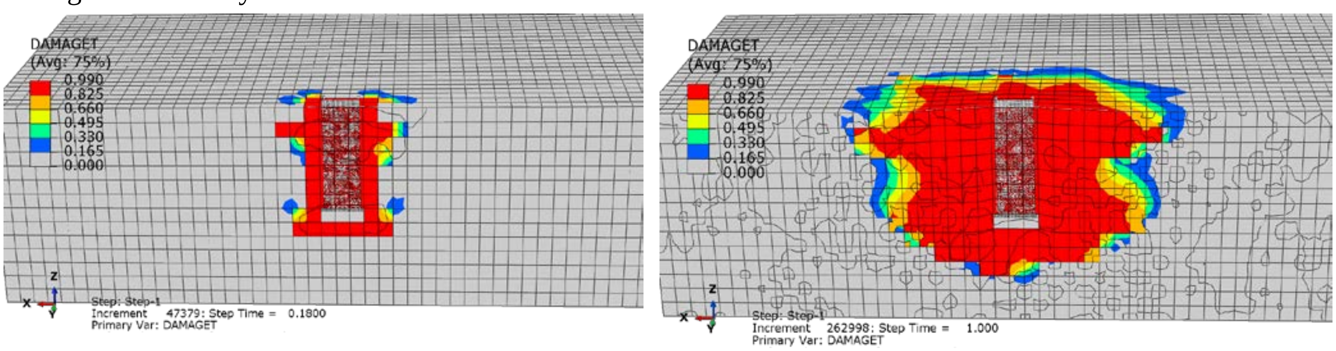


Fig. 14 – Pull out Damage rate cantor due to the analytical model with embedded depth of 700 mm

4. Conclusion

The following results are remarkable regarding H-section column model embedded in concrete:

The results of this 16 analytical models show that with increasing embedded depth in 4 groups divided in regards to steel column's size, the amount of pullout force is also increased. It should be noted that steel columns dimensions in 4 groups of " a", "b", "c", and "d", are different and proportional to the embedded depth of concrete blocks dimensions that have been selected. Physical characteristics of used steel due to pullout force was also obtained, identified, and updated.

In specimens with embedded depth between 100 to 700 mm, by decreasing embedded depth, the tensile force also rises, and force-displacement diagrams are adopted rising upward on trend path. In specimen with embedded depth 800 mm, due to Strength and dimensions of the steel sections used, column hardly get out of concrete block after reaching the necking, in which this reflects the issue that section dimensions toward required tensile load for pulling out the column was small. In specimens with embedded depth of 900 to 1100 mm, as well as specimens with embedded depth of 1300 mm, the tensile load was increasing due to increasing of steel column cross-section and steel strength (at the time of steel column pulling out from concrete block).

In specimens with embedded depth 1200 mm and 1400 to 1600 mm, high embedded depth and steel failure causes steel column failure in contact area with concrete block (beginning of embedded depth) (Fig.15).

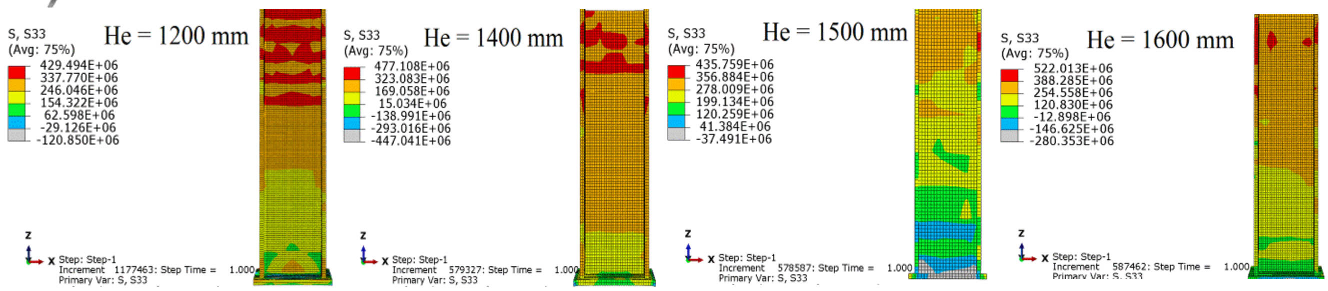


Fig. 15 – steel column stress cantor (in Z direction) of the sample which fractured due to steel failure

As mentioned above and according to Fig. 16, the steel column tensile load is totally increasing and the overall result of the analysis is shown in the chart and table below (Fig.16, 17).

Pu (KN)	He (mm)
190.1	100
331	200
524.1	300
762.7	400
1443.6	500
1734	600
1759	700
2370	800
3860	900
4122.3	1000
4173	1100
4486.5	1200
5442	1300
6135.5	1400
6175	1500
6565.8	1600

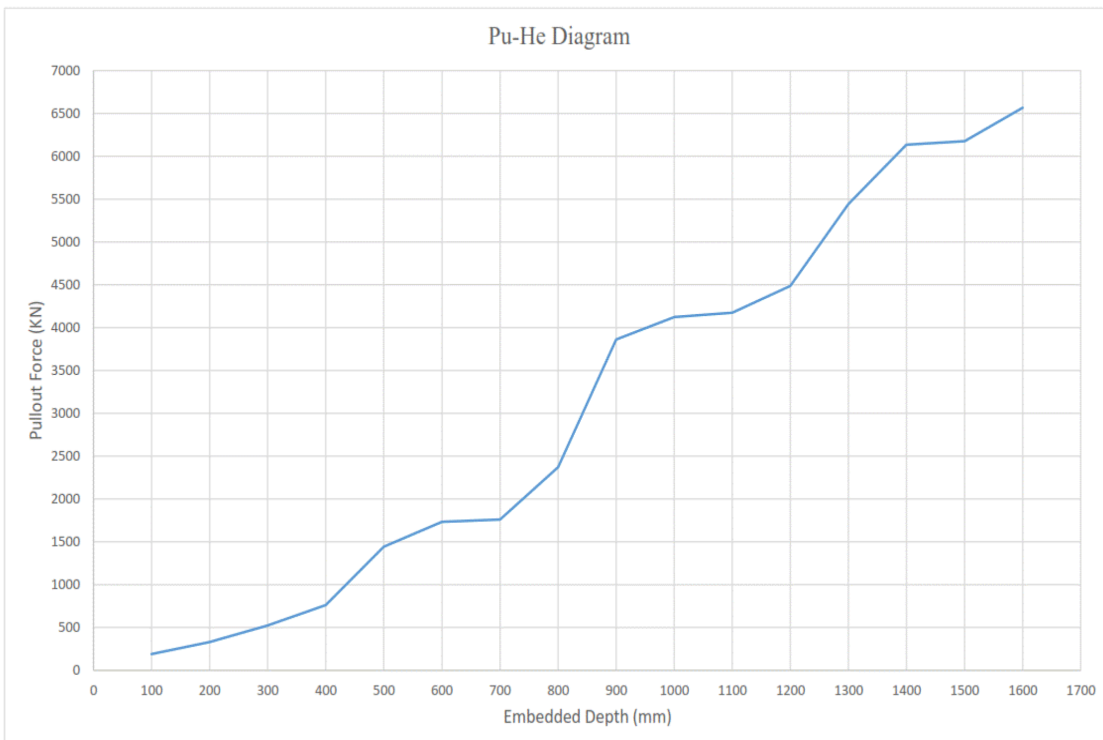


Fig. 16 – Pu-He Diagram of Analytical models

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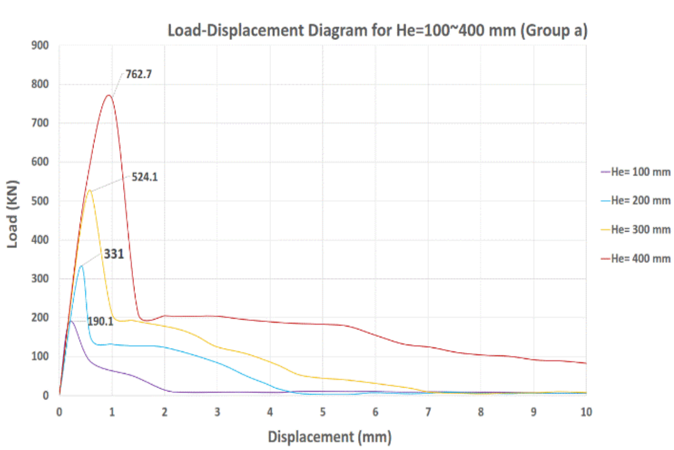

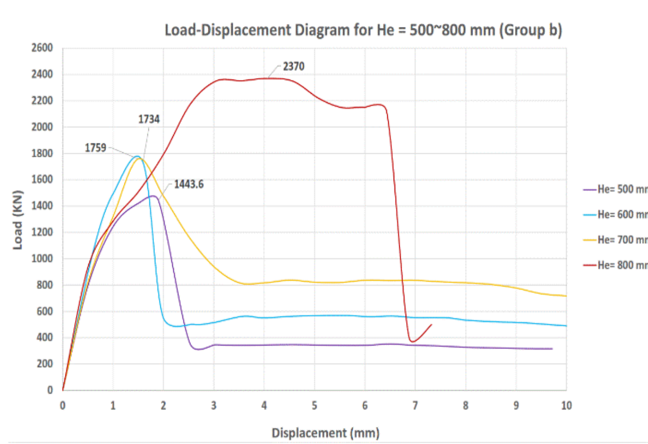

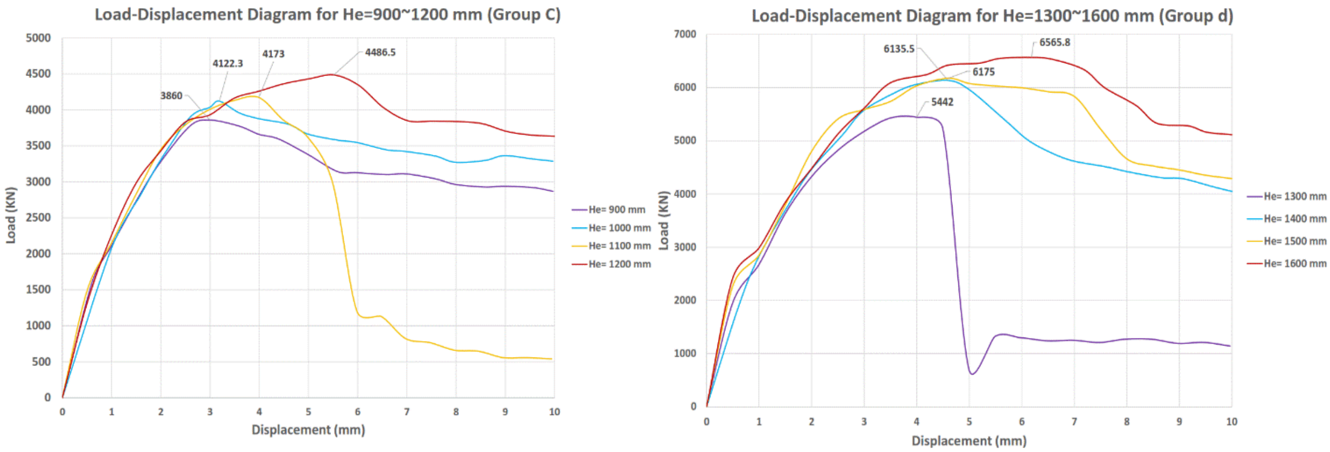

Fig. 17 – Pu-He diagram of analytical model results

Comparison of analytical models shows that the variable items such as embedded depth increase, concrete block dimension increase, steel column dimension increase, and support dimension increase, have been considered in analysis progress, and had a positive effect on H-Section steel column pullout load from unreinforced concrete block and it caused the tensile load to increase.

Analytical results show that with an embedded depth increasing in starting time of cracking and failure in concrete blocks, the process of steel column coming out has also increased.

Comparison of analytical models and verified experimental models show that Assumptions used in analytical models are within good values.

5. References

[1] Prof. Mofid M, Ghaffari A, (2012): Parametric study of simple column-base connections under cyclic loading. *M.Sc.Thesis in Structural engineering - Sharif University of technology 2012/01*, School of civil engineering, Tehran, IRAN.

[2] Grauvilardell J E, Hajjar J F, Lee D, Dexter R J, (2005): ynthesis of Design, testing and Analysis Research on Steel Column Base Plate Connections in High seismic Zones. *Structural Engineering Report No.ST- 04- 02*, University of Minnesota Minneapolis, Minnesota, USA.

[3] Heristchian M, Pourakbar P, Imeni S, Adib Ramezani M, (2014): Ultimate tensile strength of embedded I-sections: a comparison of experimental and numerical results. *International Journal of Advanced Structural Engineering*, **6**, 169-180.

[4] Pecce M, Rossi F, (2013): The non-linear model of embedded steel–concrete composite column bases. *Journal of structural Engineering*, **46**, 247-263.

[5] Jiho moon, Down E, Lehmon and Charles W, Roeder and Hak-Eun lee, (2013): Evaluation of embedded concrete-filled tube (CFT) column-to-foundation connections. *Journal of Engineering Structures*, 22-35.

[6] Herischian M, Adib Ramezani M, Pourakbar P. (2013): Ultimate Pull out Strength of embedded plain rebar's. *journal of Bana* **51**, 24-36, Tehran, IRAN.

[7] Heristchian M, Motamedi M, Pour Akbar P, Fadavi A. (2014): Tensil behaviour of tapered embedded column bases. *Asian Journal of civil engineering*, **15** (4), 485-499.

[8] Park R, Paulay T, (1975): *Reinforced concrete structures*. Wiley, New York.

[9] ABAQUS 6.14 [Computer software], *ANALYSIS USER'S GUIDE-Dassault Systems Simulia Corp*, (2014): **IV**, USA.