PERFORMANCE OF COLUMN-TO-COLUMN MECHANICAL CONNECTION IN PRECAST CONCRETE BUILDING UNDER SEISMIC LOADING

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ABSTRACT

Precast columns in precast concrete structures with floor heights require connections that need confident, reliable, and cost-effective design and implementation methods that can speed up both processes. At the same time, still ensure adequate strength, stiffness, and ductility to the column behavior. Columns specifically have the main role in structures for transmitting vertical and horizontal loads due to seismic effects to the base to fulfill life safety requirements, but the existence of a connection in the column cannot ensure the required. This work aims to study the performance and efficiency of mechanical bolted column connections under the action of seismic loading. In this regard, a column connection used in the precast structure of the new Karbala Provincial Council (KPC) under seismic loading is used as the case study. This building was analyzed and then designed employing special mechanical bolted connections produced by Peikko's products (Column-shoe & Anchor bolts). The analysis gave the exact forces at the connection location and the design using Peikko's column connection performed well under all loading cases including the seismic case. The analysis and design lead to smaller column section selection since it takes into account the interaction of applied loads using special equations.

KEYWORDS

Column Shoe, Column to column connection, Seismic design, bolted connection, Anchor bolts

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1. INTRODUCTION

In seismic-resistance structures with precast concrete (PC) members, the major challenge is to find, reliable economical, applicable, and structurally accepted methods to connect the precast elements in a way so that when subjected to cyclic seismic loads, these connections can provide not only sufficient strength and stiffness but also allow sufficient inelastic deformation capacity and stable hysteresis response of the structure [1]. In framed PC structures columns particularly play a fundamental role in transferring vertical and horizontal loads, to meet the requirement of life safety under seismic loads. Attention should be paid to the connections between precast columns to ensure the integrity of the building, load transfer, and the behavior under different load combinations [2]. The ultimate strength at the joint of precast concrete structures depends on the behavior of the material of joints between segments [3]. The connections between prefabricated elements are typically considered to be the weakest and most critical parts Additionally, in seismic areas, the connections should ensure that the behavior of precast connections is equal to or even better than that of cast-in-place parts [4]. Peikko bolted column connections are considered an excellent solution for such purposes [5]. But was not verified clearly for earthquakes. A Study on an actual building (Karbala Provincial Council) made of precast concrete elements (columns, beams, and hollow core slabs) that are connected by mechanical joints (Column-shoe & Anchor bolts) will be conducted to check the adequacy and performance of these connections in sustaining the imposed loads on the building due to the seismic occurrence. Due to the different types of connections used in the building, a focus will be made here in this work on the column-to-column connections because very limited research work was published on the such connection under seismic effects. There are limited references that deal with the characterization of column-column connections of PC structures [6]. Also, there was limited access to studies that examined column shoe connections due to the privacy of the product's ownership. However, from the experimental data provided and the conclusions gained, it is obvious that this connection system can be used in connecting the parts of the column [7] but needs to check their performance under seismic action. Peikko initiated an extensive experimental research program in 2008 in collaboration with the Politecnico di Milano (Technical University of Milan) to study the performance of Peikko's bolted column-to-foundation connections made with the HPKM column and HPM anchor bolts. The aim was to produce and develop a prefabricated connection that replaces the monolithic connections with the same performance in terms of ductility, energy dissipation capacity, and stiffness [8]. The cyclic loading performance of the Peikko bolted connection for seismic conditions needs to be verified by extensive experimental investigations on full-scale concrete samples of precast and cast-in-place columns. Meanwhile, numerical verification needs to be concluded to check the adequacy of these bolted connections. The performance of the entire connection and its components under monotonic loadings were verified by experimental testing. The initial test with concrete column connections showed that rectangular cross-sections with at least four-column shoes behave rigidly or at least as stiff as in-situ concrete columns with continuous reinforcement under static loading [10]. The tests confirmed that the bolted connection with grout between the precast elements behaves in the same way as the corresponding monolithic reinforced concrete column [11].

2. DISCERPTION OF THE CONNECTION

A typical mechanical bolted column connection consists of column shoes and anchor bolts. The column shoe is placed in the formwork in the precast plant during the production of the column at the bottom end of the upper column and the anchor bolts are cast in the upper end of the lower column in case of column-column connection or cast in-site into the foundation in case of column-foundation connection as shown in Figure (1). The protruding threaded portion of the bolt allows the column shoe base plate to be tightened with a pair of washers and nuts. The tightening of the connection under seismic loading is also ensured by high-strength lock washers. The connection is completed by filling the joint between the columns or the column and the foundation with high-durability, non-shrinking mortar. Once the mortar has reached its design strength, the connection behaves as a reinforced concrete connection. The shear force transmission is done by anchor bolts with lock washers and mechanical locking between mortar and concrete. The design compressive strength of the grout should be at least one class higher than the highest concrete grade of the jointed elements, to avoid the brittle fracture of the concrete at the joint. [8]. Assembling the column shoes on the column requires steel boxes called Recess boxes containing two types (C and M) as shown in figure (2), their cost is low and they can be used multiple times to prevent concrete from filling the shoe hole during casting of the column.

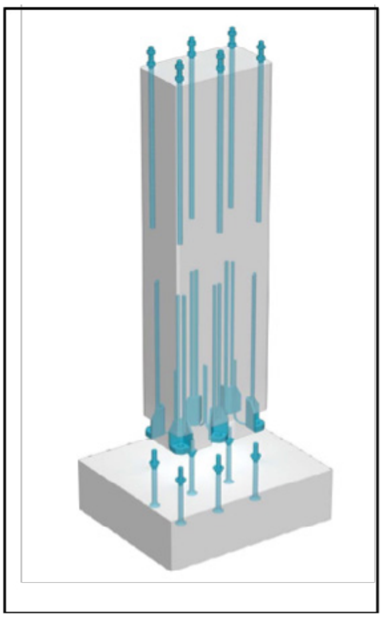

Figure 1. Typical bolted column connection [12]

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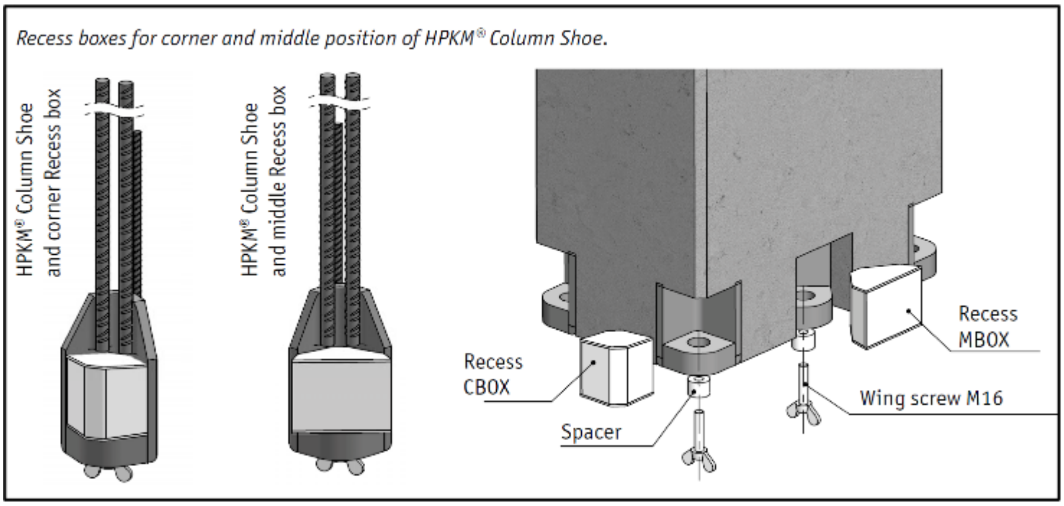

Figure 2. (C and M) types of Recess boxes [12]

3. COMPONENTS OF THE BOLTED CONNECTION (PBC)

3.1. COLUMN SHOES

Column shoes are products used to create moment-bearing connections between precast concrete elements, such as columns, foundations, and walls. The bolted column shoe connection is at least as stiff as a cast-in-place column connection with continuous reinforcement. The loads on the connection are first distributed to the individual column bases. The shear strength of a column shoe is equal to the shear strength of the corresponding anchor bolts [12]. The strength of the column shoe corresponds to the strength of the corresponding anchor bolts. Four or more column shoes can be used in one column cross-section [7]. figure (3) shows Peikko's column shoes that are used here.

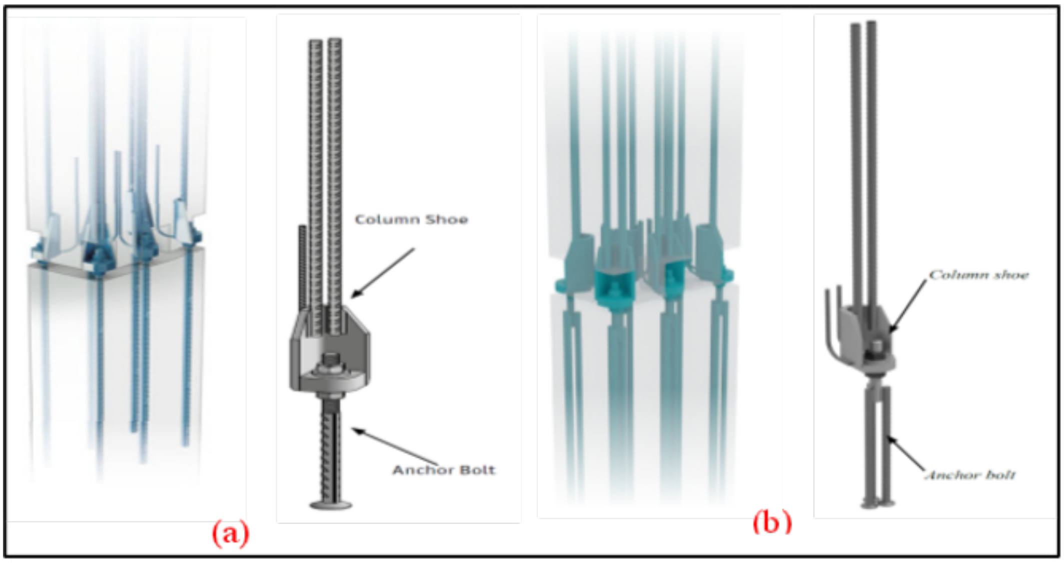

Figure 3. Peikko bolted connection (PBC) for column (a) HPKM column shoe [13], (b) BOLDA column shoe [14]

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3.2. ANCHOR BOLTS

Anchor bolts can provide a solution for most precast connections (e.g., column - foundation, column - column, wall - foundation, wall - wall) as well as fastening of steel columns or even machine fastenings. It's available as L- a type use in shallow structures (e.g., foundations, slabs, beams) due to their relatively short anchor length and P-type for structures with sufficient depth (e.g., pedestals, and columns). if the tensile or shear strength of the anchor bolt steel is insufficient, additional reinforcement may be used to withstand the forces on the anchor bolt and if the concrete cone resistance is exceeded, supplementary reinforcement for the tension load should be provided. reinforcement arrangements can be calculated using the Peikko Designer software following EN 1992-4. With Peikko Designer software it is possible to select the appropriate type and number of anchor bolts to be used in a connection and to check the strength of the connection [13]. During the assembly phase, the forces acting on the anchor bolts are mainly caused by the weight of the column itself and the bending moment and shear force due to the wind load. Since the connection is not grouted, all forces from the column shoe are only absorbed by the anchor bolts. therefore, it must be designed for buckling and bending [12]. The anchor bolts used in column connections are shown in the figure. (4).

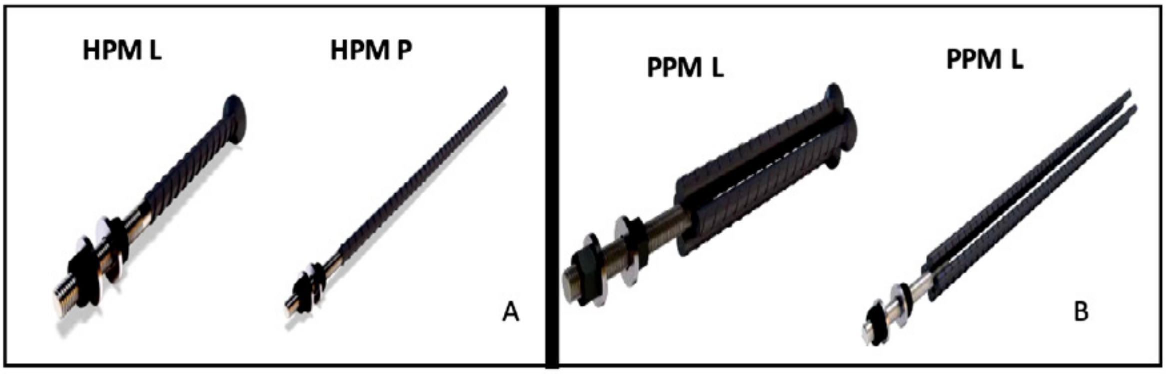

Figure 4. Anchor bolts. A) HPM Rebar Anchor Bolts Type L & type P [15]. B) High Strength Steel Anchor Bolts Type (L & P) [16]

4. MODELING

4.1. MODELING OF THE COLUMNS

Simulation models have the characteristic of being a technique for solving practical problems [17]. The whole structure of the building was divided into seven structures (Blocks) with expansion joints each part was modeled using CSI ETABS Software to analyze the effect of all external forces including seismic forces for the Karbala area according to the Iraqi Seismic Code. These forces were applied to the building and the magnitude of all internal forces acting on the columns at different stations through their total height was obtained. ETABS can give the magnitude of internal forces at

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(0%, 25%,50%,75%, and 100%) of the column's height. This feature could be very useful in the design of the connection since it can help in identifying the magnitude of internal forces corresponding to desired connection location. There are three different column cross-sections in each of the seven blocks (40x40, 60x60, and 70x70 cm) respectively distributed at different positions on the plan (corner, edge, interior). In this work, Block number 7 figure (5) is considered only for these calculations. The seismic details defined in the ETABS model are shown in figure 6

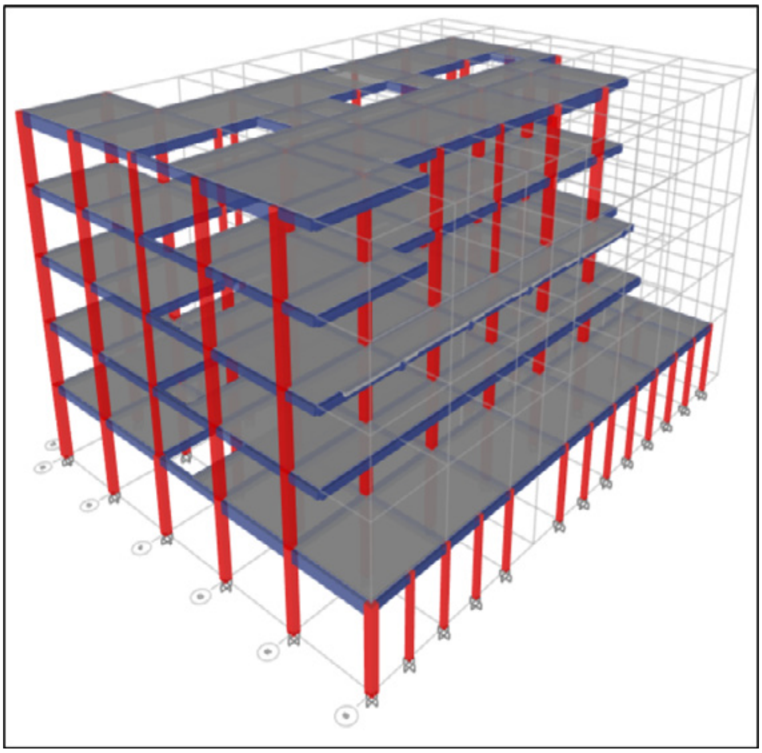

Figure 5. ETABS model of part 7

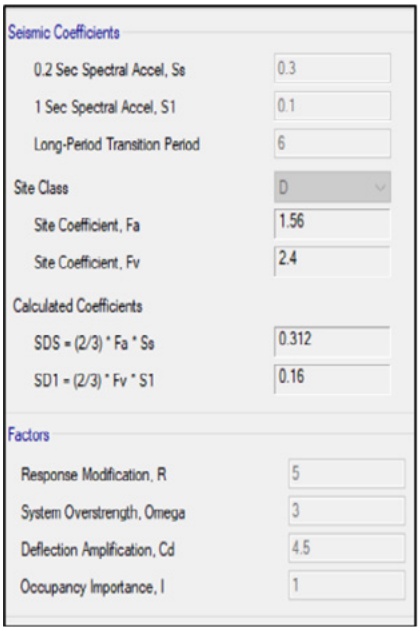

Figure 6. The seismic details defined in the ETABS model

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4.2. SELECTING COLUMN CONNECTIONS USING PEIKKO DESIGNER

For column-to-column connection, HPKM & BOLDA column shoes with HPM & PPM anchor bolts were respectively chosen. The selection of the suitable size of column shoes and anchor bolts to be used for connecting the precast segments was first done manually based on the technical manual provided. The selection of the connection components was verified using Peikko designer software. The software contains a predefined module for different types of column shoes and their corresponding anchor bolts. In the software, there is an implemented design code selection. By selecting the required valid design code, it is possible to check the resistances of each column connection.

5. RESULTS AND DISCUSSION

5.1. RUN ANALYSIS AND GET THE RESULTS IN ETABS

After completing the modeling in ETABS, the analysis process will start to get the magnitude of all internal forces acting on the columns at the selected sections of the columns. After that, the analysis results were filtered, sorted, and rearranged to be used in the next step (Selection of Suitable connection items by Peikko designer). The analysis results used in the selection of the connection components (column shoes + anchor bolts) were selected based on the location of the column i.e., (corner 40x40, edge 40x40, 40x40 interior, 60x60 corner …etc.). For simplicity and to avoid getting a huge number of designed connections for each column cross-section at each location and each story only the greatest values of internal forces on each column cross-section concerning its location due to the application of all types of loads including earthquakes were used to design the connections as shown in figures ((7) - (10)) and Table (1). The manufacturer can use any length of each segment that his factory can produce. The columns were made of three parts only taking into account that each column consists of three individual precast segments to be connected to cover the total height of the building.

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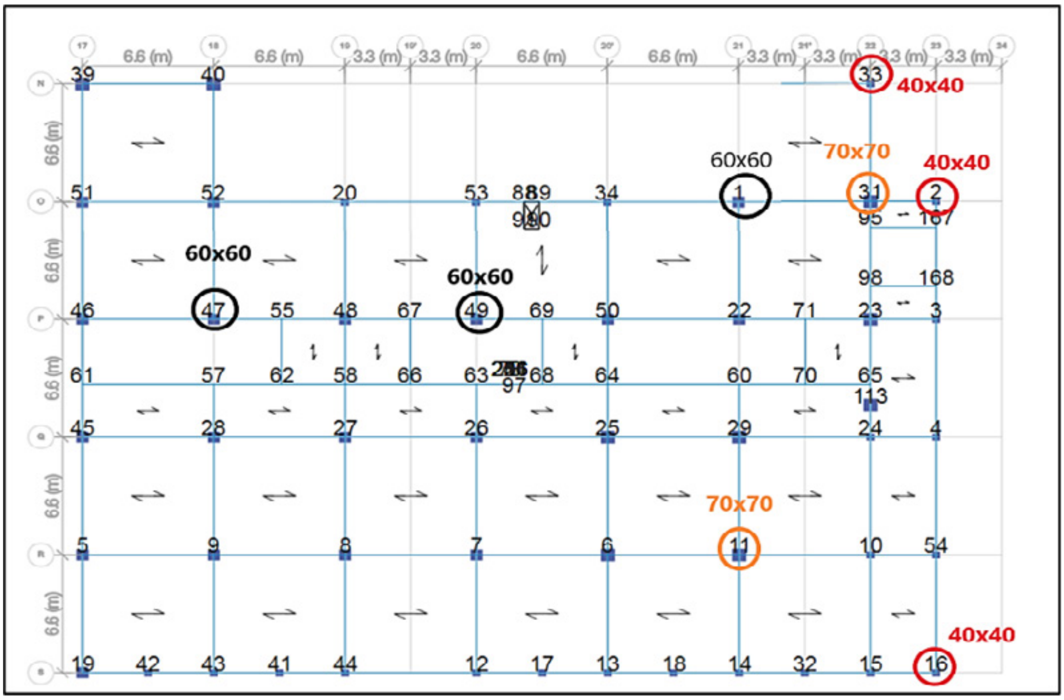

Figure 7. The Column that was subjected to the higher magnitude of internal forces & moments.

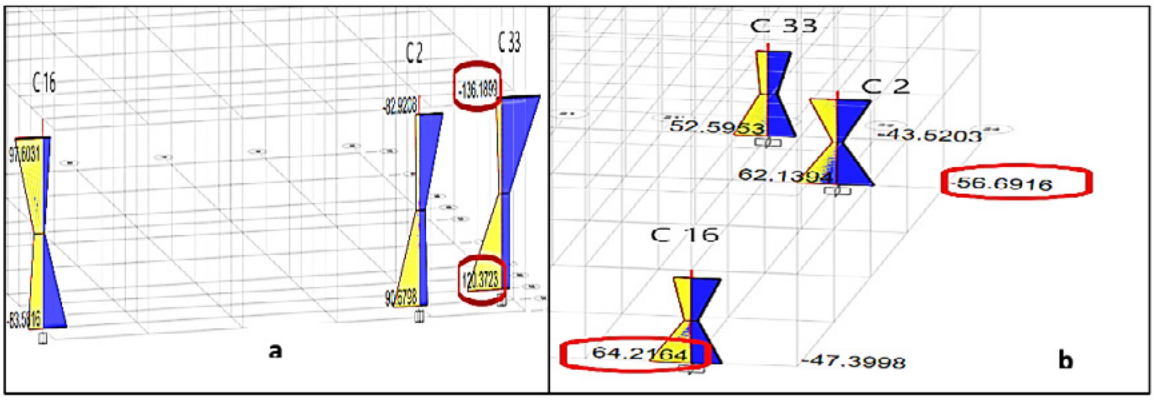

Figure 8. Corner Column 40x40 cm that was subjected to the highest magnitude of internal moments. (a) X-direction, (b) Y-direction.

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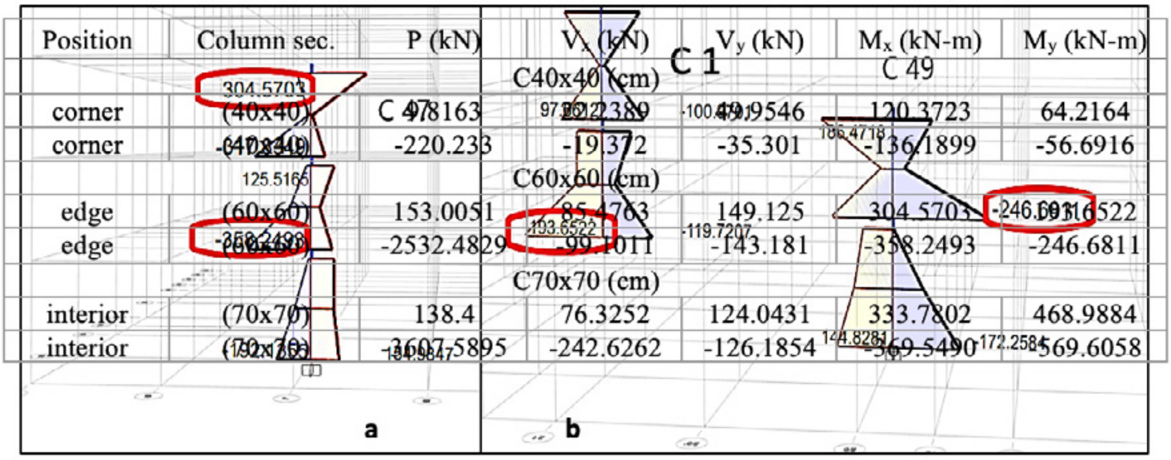

Figure 9. Edge Column 60x60 cm that was subjected to the highest magnitude of internal moments. (a) X-direction, (b) Y-direction.

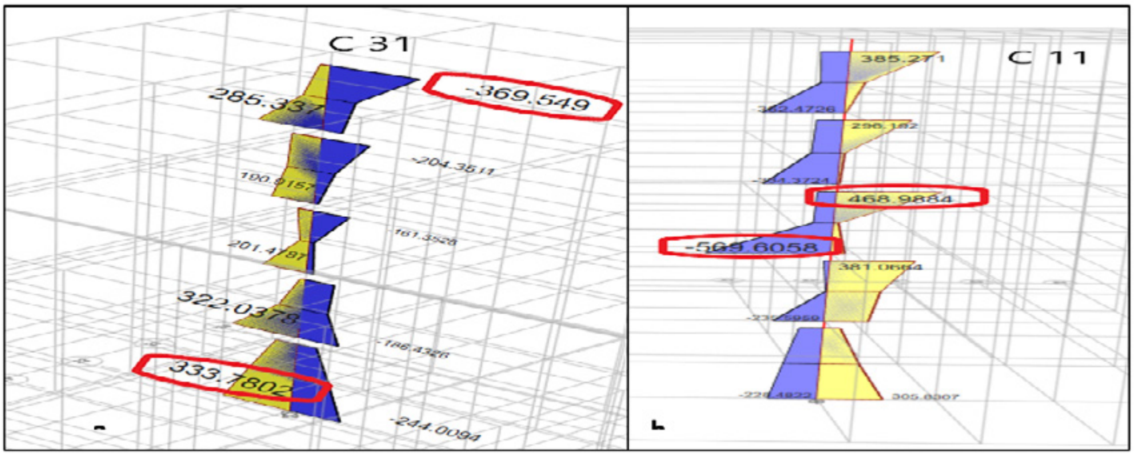

Figure 10. Interior Column 70x70 cm that was subjected to the highest magnitude of internal moments (a) X-direction, (b) Y-direction.

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Table1. Analysis results of the building (Block-7) columns under the effect of all types of loadings including earthquake from ETABS software after filtering, sorting, and rearranging

Position	Column sec.	P (kN)	V_x (kN)	V_y (kN)	M_x (kN-m)	M_y (kN-m)
C40x40 (cm)						
corner	(40x40)	9.8163	22.2389	49.9546	120.3723	64.2164
corner	(40x40)	-220.233	-19.372	-35.301	-136.1899	-56.6916
C60x60 (cm)						
edge	(60x60)	153.0051	85.4763	149.125	304.5703	193.6522
edge	(60x60)	-2532.4829	-99.1011	-143.181	-358.2493	-246.6811
C70x70 (cm)						
interior	(70x70)	138.4	76.3252	124.0431	333.7802	468.9884
interior	(70x70)	-3607.5895	-242.6262	-126.1854	-369.5490	-569.6058

The positive (+ve) values of axial forces (P) refer to tension forces due to seismic effect. However, their values were relatively small due to the weight of the entire building which tends to resist the tension forces. While the negative (-ve) values referred to compression forces due to both gravity load and seismic action. The shear forces sign referred to the direction of forces in the XY plane. While the Moments sign referred to whether the rotation will induce tension or compression forces on the column. The reason why there were (+ve) and (-ve) values were seismic action.

6. DESIGN RESULTS FROM PEIKKO DESIGNER

To Design the column connection (Choosing the right number and size of column shoes and anchor bolts to resist the Seismic loads) the analysis results of Table (1) were used in Peikko designer to check the chosen connection. Design results for one cross-section of each location (corner 40x40, edge 60x60, and interior 70x70) will be presented here. Peikko designer can provide a detailed report for the design process. When no more HPKM Column Shoes can fit in the cross-section to reach the required resistance BOLDA column shoes should be used instead.

6.1. CORNER COLUMN (40X40 CM)

Use 4 (HPKM column shoes - HPM anchor bolts) size 30 with 2 (HPKM column shoes - HPM anchor bolts) size 20 at the middle of the column lower face in the x-direction to satisfy the capacity requirements rather than using 6 (HPKM column shoes - HPM anchor bolts) size 30 for economic reasons and to provide more spacing for concrete as shown in figure (11). The design report indicates that the resistance of the connection was within the safe limits of the selected code provisions. And no failure in both the concrete or steel items (column shoes and anchor bolts). The green dot in the resistance diagram between the moments and the axial forces represents

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the applied load of the column while the dashed line refers to the connection capacity. As shown in figure (12).

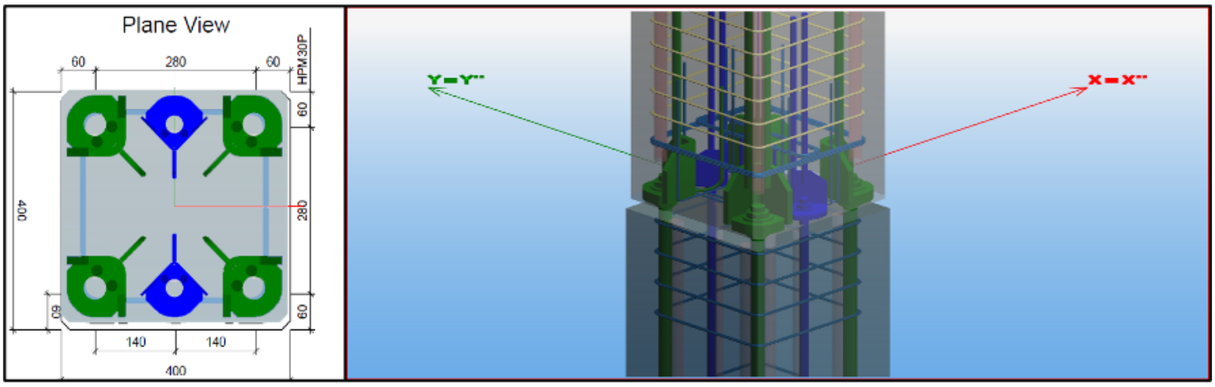

Figure 11. HPKM column shoe & HPM anchor bolts 1st configuration (4 size30 +2 size20)

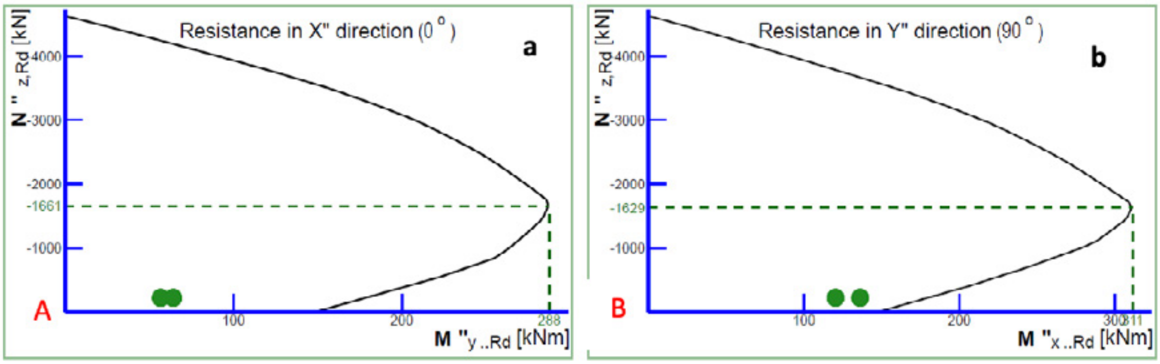

Figure 12. Resistance diagram of the connection, (a)- Resistance in the X direction, (b)- Resistance in the Y direction

6.2. EDGE COLUMN (60X60 CM)

Use 4 (BOLDA column shoe - PPM anchor bolts) size 39 as shown in figure (13). The design report indicates that the resistance of the connection was within the safe limits of the selected code provisions. And no failure in both the concrete or steel items (column shoes and anchor bolts). The green dot in the resistance diagram between the moments and the axial forces represents the applied load of the column while the dashed line refers to the connection capacity. As shown in figure (14).

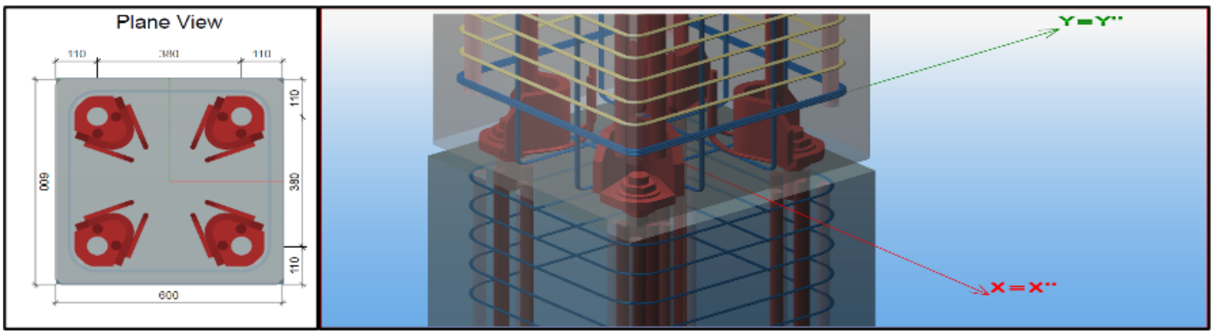

Figure 13. BOLDA column shoe & PPM anchor configuration (4 size39)

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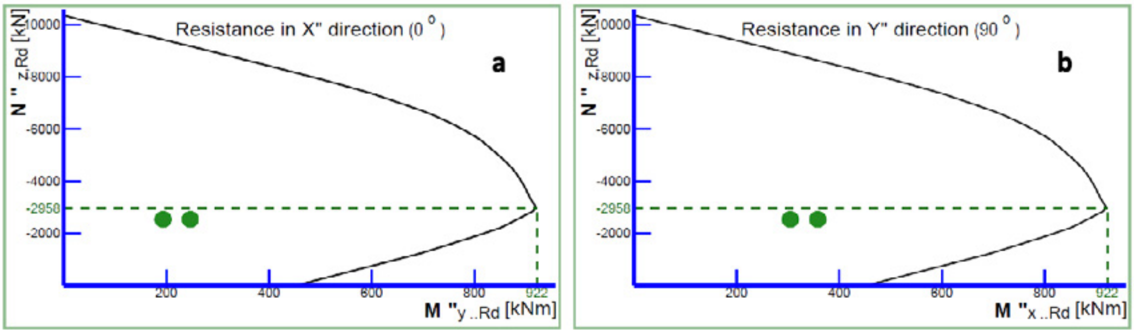

Figure 14. Resistance diagram of the connection. (a)- Resistance in the X direction, (b)- Resistance in the Y direction

6.3. CORNER COLUMN (70X70 CM)

Use 4 (PPM anchor bolts & BOLDA column shoe) size 45 as shown in figure (15). The design report indicates that the resistance of the connection was within the safe limits of the selected code provisions. And no failure in both the concrete or steel items (column shoes and anchor bolts). The green dot in the resistance diagram between the moments and the axial forces represents the applied load of the column while the dashed line refers to the connection capacity. As shown in figure (16).

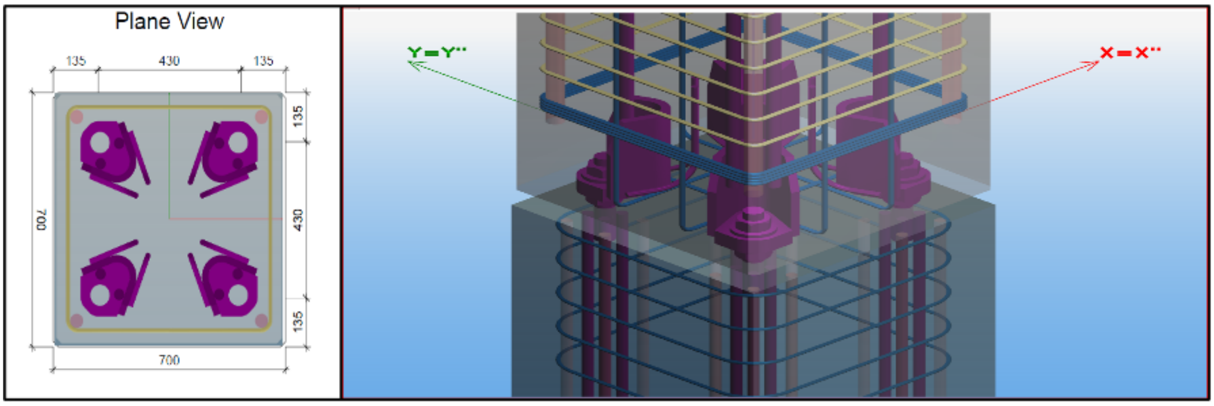

Figure 15. BOLDA column shoe & PPM anchor bolts (4 size45)

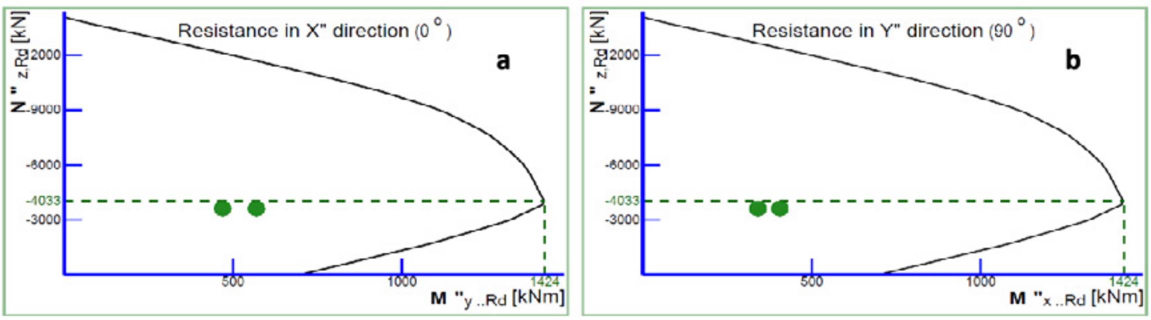

Figure 16. Resistance diagram of 4 - size - 45 configuration. (a)- Resistance in the X direction, (b)- Resistance in the Y direction

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Or we can use 6 (PPM anchor bolts & BOLDA column shoes) size 39 as shown in figure (17). The design report indicates that the resistance of the connection was within the safe limits of the selected code provisions. And no failure in both the concrete or steel items (column shoes and anchor bolts). The green dot in the resistance diagram between the moments and the axial forces represents the applied load of the column while the dashed line refers to the connection capacity. As shown in figure (18). Whichever is more economical.

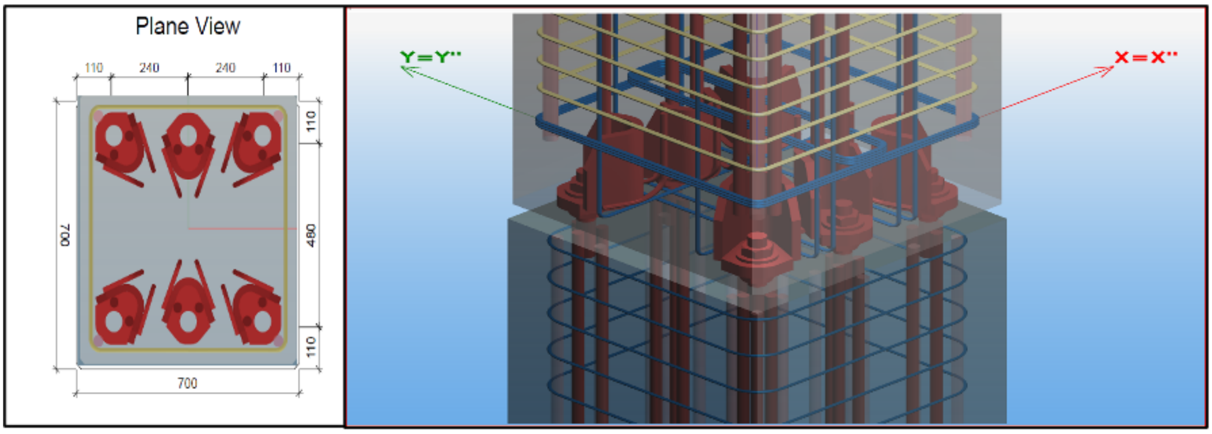

Figure 17. BOLDA column shoe & PPM anchor bolts 2nd configuration (6 size39)

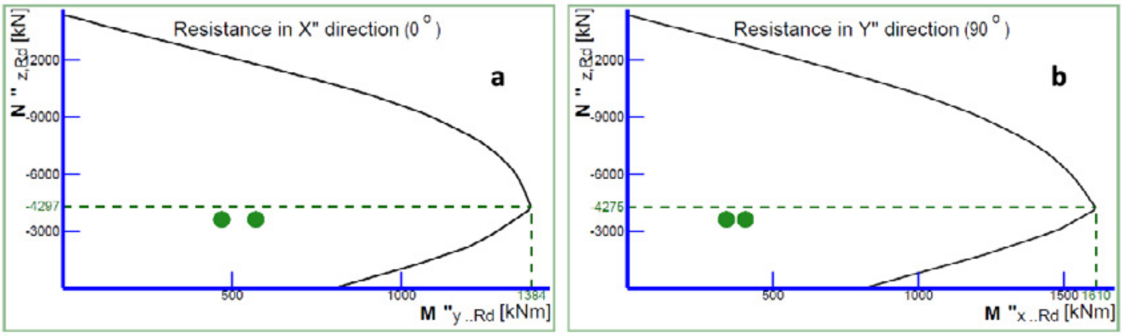

Figure 18. Resistance diagram of the 6 – size 39 configuration. (a)- Resistance in the X direction, (b)- Resistance in the Y direction

6.4. COMPARISON WITH MANUAL SELECTION:

The results from the Peikko designer for precast column-to-column connection were compared with those from a manual selection as follows. The manual selection was done by the capacity tables that the technical manuals of these items contain.

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Table 2. Comparison with Manual Selection

No.	Column cross-section	Manual-selection	Peikko-selection
1	Corner Column 40x40	4 (HPM anchor bolts & HPKM column shoes) size 39	4 (HPM anchor bolts & HPKM column shoes) size 30 with 2 (HPM anchor bolts & HPKM column shoes) size 20 at the
2	Edge Column 60x60	4 (PPM anchor bolts & BOLDA column shoe) size 45	4 (PPM anchor bolts & BOLDA column shoe) size
3	Corner Column 70x70	4 (PPM anchor bolts & BOLDA column shoe) size 52	4 (PPM anchor bolts & BOLDA column shoe) size 45 or 6 (PPM anchor bolts & BOLDA column shoe)

7. CONCLUSIONS

The column shoe connection system seems to have the same advantages as other connection types, but also very fewer disadvantages. The main drawback is that may be considered a relatively expensive solution, especially in certain markets. However, when choosing this solution, one should keep in mind that it saves materials since it ensures a much faster installation process than other solutions and a simple design process. These types of bolted connections (HPKM column shoes with HPM anchor bolts and BOLDS column shoes with PPM anchor bolts) do not require bracing due to the instantaneous mechanical fixing during assembly and a small amount of grouting is required for both types. A great advantage of Column shoes is considered a universal solution for connecting columns. Due to the existence of design tools, it is an easy, fast, and guaranteed way to create a design of this connection. This can lead to shorter duration and less cost in the project design work stage. In addition, it has good performance against seismic or dynamic loads, which gives additional security to the whole structure and was considered a shortage in all precast structures (not fulfilling the seismic requirements). It is necessary to choose a sufficiently strong column shoe and the appropriate anchor bolt in addition to a correct installation process to guarantee the performance of this type of connection system. From all of the above, the following can be concluded:

1. With the grouting mortar the shoe connection behavior is very similar to the behavior of the in-situ concrete column under seismic action.
2. The selection of column shoes and anchor bolts can be easily done with design tools such as Peikko Designer. However, it is very important to pay more attention when seismic, dynamic, or fatigue loads are considered.
3. Most of the stresses are concentrated on the shoe rods. Therefore, when using the column shoe system. this could provide a more economical use for the main reinforcement than a cast-in-place case
4. The column connection items chosen ensured that the principle of the strong column-weak beam is still valid since they provide a strong column connection.

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5. The column connection items chosen can be used in demountable frames because they are removable.
6. More than one size of the same type of column shoe can be used at once in the same cross-section.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.