Innovating an effective installation method for precast reinforced concrete elements

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Abstract. This article proposes a prefabricated modular design in which springs and hinges have been used to assist the column's passive installation (energy efficient In this technique, the roof panel and column were joined by a pivot hinge in the factory, enabling the pieces to be hoisted by the crane as a single unit for installation on the worksite. Also, there is a spring installed at a specified distance in the roof panel to assist in pushing the column and fastening it. This method helps to speed up the process of installing elements on the worksite, by reducing the number of times that the crane is used to lift elements throughout the installation process because instead of lifting one element each time, it lifts the two elements together at the same time. It is an efficient approach to reduce effort, time, and cost. In addition, the effect of the spring's position in the panel on the amount of force required to push the column vertically was estimated in this study. The results demonstrate that the farther the spring distance from the pivot hinge, the less thrust force is required to elevate the column. Concerning the hinge that connects the roof panel to the column. The shear and crashing stresses that may be subjected to the hinge throughout the process of vertically installing the column were estimated to be within allowable limits.

Keywords: Prefabricated modular buildings, passive assembly, columns connection, energy efficiency, installation, spring, pivot hinge.

1. Introduction

Prefabricated modular building is the technology of the future. Prefabrication and passive assembly technology can be used to integrate various materials, components, and structural technologies to improve structural performance and building industrialization. It allows fast construction of prefabricated structures by using high-tech systems while considering climate and natural variables.

Passive systems' installation represents assembly mechanisms, accessories, and precision control elements that require zero energy consumption such as hinges, fastening elements, compressed springs, energy-efficient mechanisms, which can effectively contribute to accelerating the process of installing building elements such as columns [1].

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The need for low-cost housing in developing countries like Iraq, which is experiencing exceptional and extreme conditions due to war and political instability, demands the use of a high-tech system. For example, in Iraq, there is an urgent need to create structures for a variety of purposes in a short period of time in order to stay up with the advancement in the area of construction in industrialized nations. Despite the fact that the monolithic building approach has been widely used in building construction in Iraq until now, which one of its major disadvantages is the lengthy construction durations. This also contradicts the increase in population, which had reached over 40 million people in Iraq at present, as shown by fig. 1 [2].

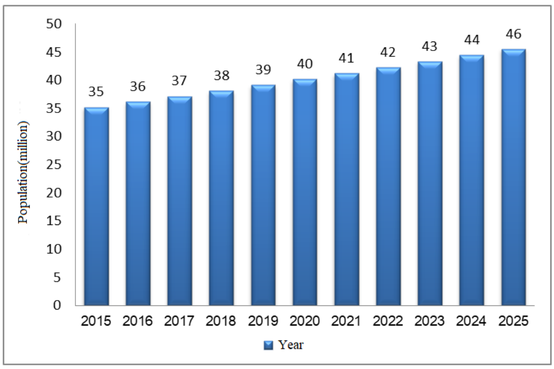

Fig.1. Increase in the population in Iraq

Currently, the effective implementation of the advantages of prefabricated buildings is complicated due to the insufficiency of clarification of the problems of using modular structures in different construction conditions. However, leading scientists contributed to development of a high-speed installation technique that involves creating the solutions by a sequential evaluation of the labor and energy balance components of the installation process.

Badin G.M., Sychev S.A. developed scientific and practical foundations for high-tech installation of prefabricated transformable buildings in the harsh conditions of small and medium-sized cities in Russia.

This development contributed by reducing installation time by 25% compared to a building made of volumetric blocks and the transport volume of one module with folded elements fixed on it is reduced by 3.02 times compared to the construction volume, which reduces transport costs for delivery of modules of prefabricated buildings by 50% [3].

Several researchers, such as Sunkuk Kim, Won-Kee Hong, J. D. Nzabonimpa, and Jisoon Kim, proposed approaches and methods for speeding up the erection of prefabricated elements, which contributed to simplify the building process, reduce construction time, and costs [4, 5] .The study aims to describe the technology of passive assembly of prefabricated elements by using compressed assembly springs and pivot hinges that are used to speed up the installation of prefabrication elements and to choose the appropriate position for these assembly mechanisms and ensures its reliability.

2. Methods of Technological Design and Calculation of Forces Influencing on The Lifting force

The proposed method can be applied to the KUB 2.5 system. In this system, the traditional technique involves fabricating columns and panels individually at the factory and transporting them in stacks by truck to the worksite, where they are then erected one by one in the framework via cranes. The idea of the suggested method is that prefabricated

elements such as the column and roof panel are manufactured at the factory, fastened together and transported as a whole part. Installation of the column in the design position is carried out by turning on the pivot hinge. The mounting console (hinge) serves to temporarily support the adjacent module during the installation period. Flat roof panels are prefabricated in two modifications with dimensions (2980x2980x 160mm, 2980x5980x160 mm) is shown in fig. 2. Column with height 3000 mm and section 400 x 400 mm, to increase the installation speed, a spring is installed in the panel at a specified distance from the end, which helps to push the column and fix it vertically. The iron locks are installed on both sides of the column and panel, which prevents the spring from pushing the columns during transportation to the worksite until it is edited during the installation of column process. A second lock has been put on the adjacent roof to assist support the column's vertical position and prevents it from bouncing during installation (fig. 3, 4).
The required thrust forces given by the spring according to its position on the roof panel have been calculated to choose the suitable position of the spring to lift the column from the transport position to the design position. Also, the shear stresses at the contact point (hinge) between column and panel have been determined due to that shear stresses are one of the most significant factors that can cause a failure in the hinge [6, 7].

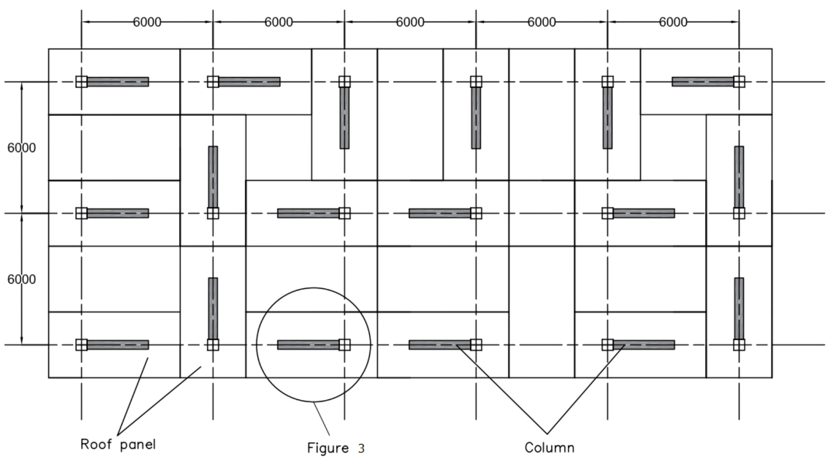

Fig.2. Roof plan of the building showing the distribution of the columns to the panel

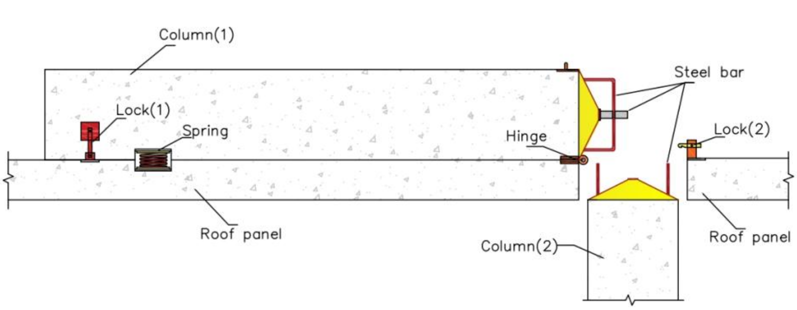

Fig.3. Details of components and assemblies for proposed prefabricated model (roof panel with column)

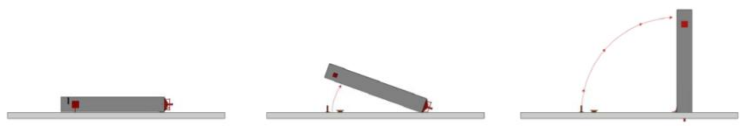

Fig.4. Installation process stages of passive assembly for proposed prefabricated element

This solution helps to speed up the installation process of the elements on the work site by reducing the number of times the crane is used to lift the elements during installation, because instead of lifting each element separately, it lifts two elements together, and this reduces time and thus reduces costs (fig.5).

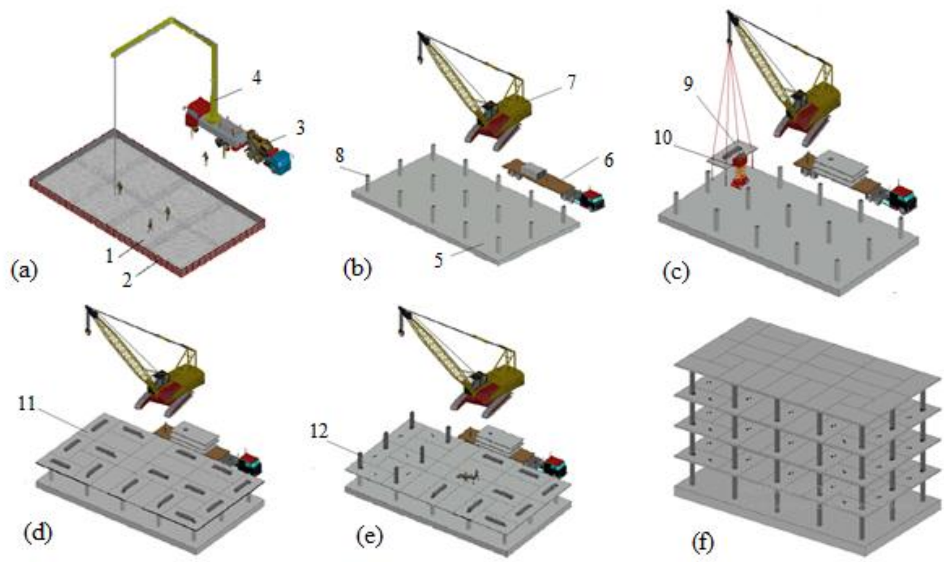

Fig.5. Scheme of building installation: a—Installation of the foundation: (1−metal formwork; 2−reinforcement; 3−concrete mixer truck; 4−concrete pump); b—Installation of columns in the indicated place above the foundation: (5−foundation; 6−cargo transportation; 7−crawler crane 8−columns); c – Raise the assembled elements and install them on the columns of the first floor: (9 – assembled elements; 10 – Scissor lift); d – installation of a passive assembly for prefabricated elements on the 1st floor (11 – passive prefabricated elements); e – passive prefabricated elements in the design position: (12 – column in a vertical position); e – Completed building.

3. Results and Discussion

According to the drawing (Fig. 6), it is necessary to determine all external loads pressing on the column represented by the weight of the column and the reactions of the forces resulting from its weight that makes the column in equilibrium case. In point (F) there is a pivot hinged support, which usually generates two reactive forces (Fx, Fy) and static loads (W1, W2, W3) for three different sections of the column (Sec.1(400*400mm), Sec.2(400*200mm), Sec.3(600*400mm)) [8]. To determine the weight in three columns with different cross-sections, use Eq. (1):

$$w = V * \gamma_c \tag{1}$$

When:
(γ_C): Density of concrete = 2430 Кg / M^3 for type concrete B30 (M400) [9].
(V) : Column volume
$w1 = 0.48 * 2430 = 1166.4Kg$
$w2 = 0.24 * 2430 = 583.2\ Kg$
$w3 = 0.72 * 2430 = 1749.6Kg$
Equilibrium equations can be applied to determine the amount of reacting force (FA, FB, FC, FD and FE).

$$\sum FY = 0 \tag{2}$$
$$\sum FX = 0 \tag{3}$$
$$\sum MF = 0 \tag{4}$$

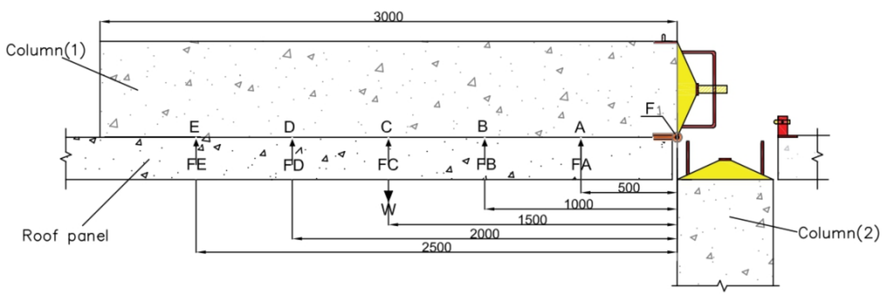

Fig.6. Illustration of the external forces pressing on the column

Reacting force was determined at different distances (500, 1000, 1500, 2000, 2500) mm consecutively in (A, B, C, D, E) from the pivot hinge and for each section of the column (Sec.1, Sec.2, Sec.3) [10], as shown in tab.1

Table 1. Support reaction force (Kg)

Column cross- sections	FA	FB	FC	FD	FE
(Sec.1)	3499.2	1749.6	1166.4	874.8	699.84
(Sec2)	1749.6	874.8	583.2	437.4	349.92
(Sec.3)	5248.8	2624.4	1749.6	1312.2	1049.76

According to the law of conservation of energy, when an object moves by force, a force works as a result of the movement. Gravity pulls the objects which move vertically. If the height of the object changes by amount, then the work with the object is performed due to the force of gravity [11]. Calculations are carried out in two steps:

1- Calculation of the thrust force applied to the column by the spring. Fig.7

- The law of conservation of energy (Energy at point A = Energy at point B)

$$k_1 + u_1 = k_2 + u_2 \tag{5}$$
$$\frac{1}{2}m * v^2 = mgh \tag{6}$$

- Newton's second law

$$f = ma \tag{7}$$

When:
(k_1): Initial kinetic energy

(u_1): Initial potential energy
(k_2): Final kinetic energy
(u_2): Finite potential energy
(v): Body speed
(m): Body weight
(g): Acceleration due to gravity
(h): Difference in elevation
(f): The force necessary to lift the column
(a): Body acceleration

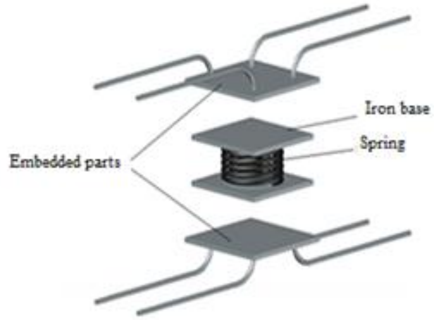

Fig. 7. Spring assembly details

From the law of conservation of energy and Newton's second law that applied above, the thrust force required for the installation of the column vertically was found (see fig.8).

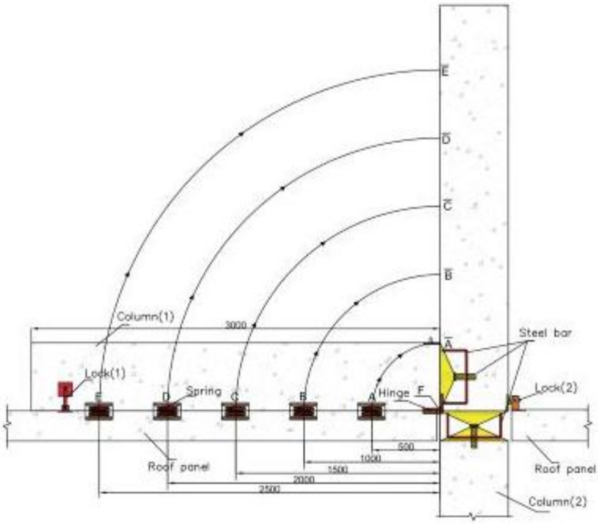

Fig.8. The mechanism of converting the column from the installation position to the design position
According to the location of the spring relates to the hinge and for three cross-sections of the columns (Sec.1, 2, 3) as shown in table (2):

Table 2. The thrust force f necessary to raise the columns in a vertical position (n)

Spring location	A	B	C	D	E
Distance from the pivot hinge	0.5	1	1.5	2	2.5
Force f (Kn), column Sec.1 (dim.400×400 mm)	21.84	10.92	7.28	5.46	4.37
Force f (Kn), column Sec.2 (dim.400×200 mm)	10.91	5.46	3.64	2.73	2.18
Force f (Kn), column Sec.3 (dim.400×600 mm)	32.73	16.37	10.90	8.186	6.54

It was obtained from table (1) that the thrust force required by the spring to raise the column and set it vertically decreases as the spring's position is farther from the hinge, according to the figure 9 , that clarified the relationship between the thrust force and the distance from the joint.

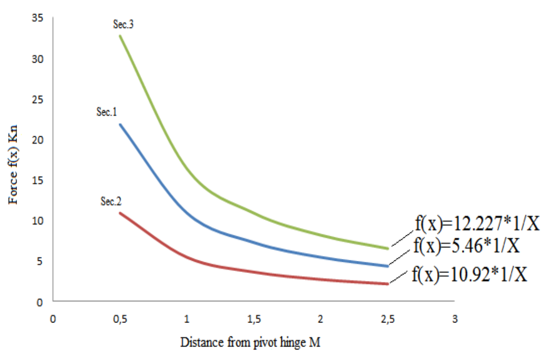

Fig.9. The relationship between the thrust forces required to lift columns and the distance from the pivot hinge for three section columns

In table 3, the necessary spring specifications were designed and selected, where the spring could provide the minimum required thrust force at point E to raise the column from the installation position to the vertical design position according to OST 108.764.01-80 [12].

Table 3. Specifications of spring

Specifications of spring	Table 1	Table 2	Table 3
The minimum thrust force f KN	4.37	2.18	6.54
Spring force at working deformation P2 KN	5.24	2.37	5.24
Springs for working deformation F2 mm	70	70	70
Spring free height, H0 mm	166	151	166
Total number of turns	6	6.5	6
Number of working turns	4	4.5	4
Total weight of spring Kg	3.68	1.92	3.68

2-Calculations for shear and crushing stresses in the Hinges

Pivot Hinge (see fig. 10) was utilized to assist join the panel with the column during manufacturing in the factory, so that they would be as one unit. The hinge is designed from Carbon Steel with dimensions suitable for the amount of loads that will be exposed to it during the installation of the column vertically so that it does not lead to breakage or separation in the hinge. The shear and crushing stresses that might occur during the vertical installation of the column is one of the most significant factors that can cause a failure in the hinge. Therefore, these stresses at the contact point were calculated [13].

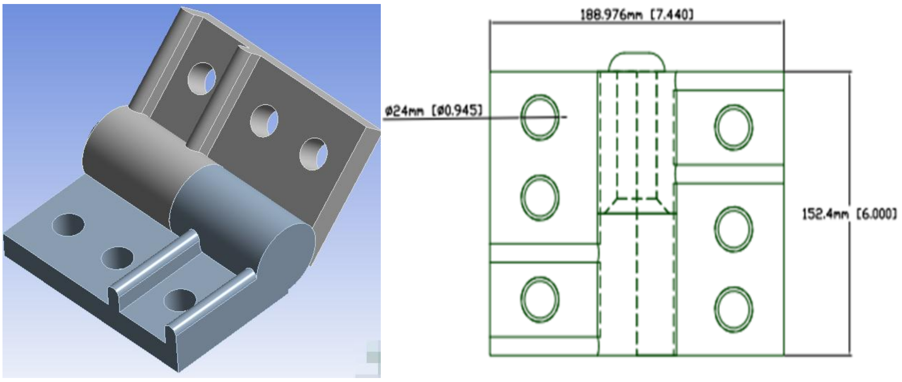

Fig.10. Details of the pivot hinge

By using Eq. (8), check the shear strength of the pin as shown in the Fig.11 [14, 15].

$$\tau_{pIN}=\frac{F}{A} \leq [\tau] \qquad (8)$$

$F = 11430$ N - vertical loads.

$$A = (\pi d^2/4) * n \qquad (9)$$

When:

A = Cut area

n =2 is the number of cut planes.

d = 16 mm Pin diameter.

Yield point = 250 MPA.

Allowable shear stress $[\tau]$= (0.2-0.3)σ_T =0.2σ_T=50MPA , $[\sigma_{cr}]$=130MPA.

$\tau_p = \frac{11430}{791.32} = 14.44\ \mathrm{M}PA < 50$ MPA the shear strength of the PIN is ensured.

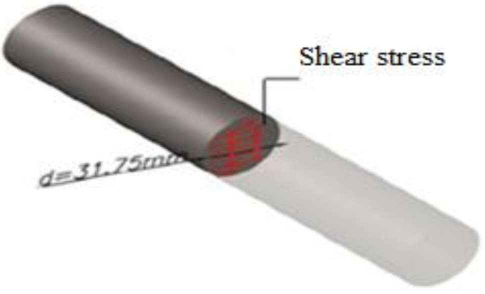

Fig.11. Shear stress affecting on the pin

By using Eq. (10), checking crushing strength. (See fig. 12)

$$\sigma_{cr}=\frac{F}{A_{cr}} \leq [\sigma_{cr}] \quad (10)$$

$\sigma_{cr}=\frac{11430}{3175}=3.6\ MPA < 130\ MPA$ - PIN crushing strength is ensured.
$A_{cr} = d * t_{min} - areaofcrushing$
$t_{min} = 100mm$ Minimum thickness of parts crumpled in one direction

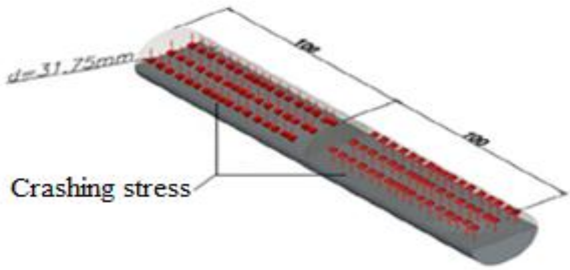

Fig.12. Crushing stress affecting on the pin

4. Conclusion

The time necessary to transport and install the elements will be significantly reduced, which will lead to the reduction of economic costs by 50%. When carrying out the necessary calculations and studying the stability and reliability of assembly mechanisms, it was found that the minimum required thrust forces (4.37, 2.18, 6.54) KN at point E for three cross-section columns (400*400 ,200*400, 400*600) consecutively, that spring could provide the rais of column from the installation position to the vertical design position. There also have been identified the shear stresses τ_{pIN}=14.44 MPA at the contact point (hinge) between panel and column which is less than allowable shear force τ <50 MPA according to the standards. To increase the reliability of hinge, PIN crushing strength was ensured, the crushing stress σ_{cr}=3.6 MPA<130 MPA within acceptable limits to design the pin for each section of column.

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