Seismic Behaviour of RC Building Located in Erbil, Iraq and Strengthening by Using Steel Frame Sections Precast Bolt-Connected Steel-Plate Reinforced Concrete

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Abstract. This paper present outside strengthening with precast substructures, is a relatively new retrofitting approach that has recently attracted the attention of researchers. Outside strengthening with precast substructure, in contrast to member-level strengthening technologies (e.g., FRP strengthening, enlarging member section areas, and replacing rebars), is a structure-system reinforcement method that integrates the substructure and the original structure, improves overall seismic performance, and changes the deformation mode of the entire structure. The seismic capability of the exterior strengthening with precast bolt-connected steel-plate reinforced concrete is critically evaluated in this paper (PBSPC) Case studies are used to demonstrate the working principles, numerical methodologies, and design approaches. The simulation results were similar with prior studies, demonstrating that the numerical model was effective. The use of building steel representations reduces construction time, increases efficiency, and lowers costs. The goal of this technology is to lower the seismic displacement demand of nonductile. Current RC structures have steel frames connecting to the building floors. These frameworks run parallel to the structure of the building. Ganjan Life City, a building in Erbil, Iraq, is being used as a case study. The ISC 2017 and ASCE 7-10 earthquake codes were used to evaluate the building's seismic performance before and after the reinforcement. The analysis' findings suggest that the recommended technique is correct.

1. Introduction

The seismic load measurement is an essential part of the structure designing process, and it is considered a significant step before assuming any structural design. Building design according to seismic code requirements offers capabilities to withstand earthquakes without collapsing. During earthquakes, the structural sections of the building must be able to withstand lateral loads and thus comply appropriately while increasing loads while maintaining life protection. Horizontal forces do not conform to the definition of vertical forces in facilities, so structural engineers must design for both horizontal and vertical forces in their calculations. As a result, existing structures are strengthened using seismic strengthening techniques. Seismic strengthening methods have a variety of advantages when it comes to protecting buildings from earthquakes. Stiffness, ductility, user-friendliness, improved energy dissipation capability, and reduced seismic risk are all advantages of these specific techniques.

In November 2017, a 7.3 magnitude earthquake rocked the Iraq-Iran border, killing approximately 530 people and wounding hundreds more in Iran alone. As seen in fig. (1) 9 persons were killed and 550 were injured in Iraq's northern area. An earthquake, according to the United Nations, is the most misleading natural disaster. Tornadoes, monsoons, and blizzards all have seasons that may be predicted and tracked weeks ahead of time. Earthquakes, on the other hand, hit without warning. New reports, suggest that we should prepare for an increase in quakes in the coming year, and the cause is an unexpected the Earth's rotation has slowed slightly. It's a real issue that most
Buildings are designed to withstand gravity loads only, rather than considering seismic design, particularly since the area has undergone increased seismic activity in recent years. As a result, seismic strengthening of these existing structures is a major concern, and their seismic integrity is a challenge that requires not only economic and technical considerations but also a critical aspect of life preservation. For the period 1900-1988, an earthquake catalogue was produced for Iraq, which includes 1031 recorded events with magnitudes ranging from 3.7 to 7.4 on the Richter scale. For the period 820-2018, Table (1) summarized some historical earthquake events in Iraq. (Al-busoda, et al.2019).

| Event No. | Year | Magnitude (Richter scale) | Remarks |
|-----------|------|---------------------------|---------|
| 1         | 820  | –                         | Moderate damages in houses of Bagdad city were caused. |
| 2         | 881  | –                         | Most of Bagdad houses were damaged. |
| 3         | 893  | –                         | Roof and damages were severe. |
| 4         | 957  | –                         | Earthquake hit Bagdad. |
| 5         | 979  | –                         | Damages were severe in almost all houses. |
| 6         | 1038 | –                         | Almost all houses in Bagdad were damaged. |
| 7         | 1072 | –                         | Severe earthquake hit Bagdad with 600 house rehmained during the same day. |
| 8         | 1117 | –                         | Earthquake hit Bagdad. |
| 9         | 1133 | –                         | Severe earthquake hit Bagdad; damages in houses were recorded. |
| 10        | 1203 | –                         | Earthquake hit Minal. |
| 11        | 1252 | –                         | Severe earthquake hit Baghdad with collapse on almost all city buildings. |
| 12        | 1648 | –                         | Earthquake hit Baghdad, Minal and area west of Iraq. |
| 13        | 1689 | –                         | Earthquake in Baghdad damaged houses. |
| 14        | 1702 | –                         | Severe earthquake hit Baghdad; total collapse of several buildings. |
| 15        | 1864 | –                         | Three earthquakes hit Bagdad the same day with severe damages on all buildings. |
| 16        | 1917 | –                         | Earthquake hit Bagdad. |
| 17        | 1946 | –                         | Severe earthquake hit Baghdad. |
| 18        | 1990 | 0.9 to 6.7                | Earthquakes hit Heliolys city northwest of Bagdad, and caused severe damages. |
| 19        | 1907 | 6.1                       | Earthquakes hit 100 km south of Heliolys city, southeast of Bagdad. |
| 20        | 2013 | 3.6 and 5.8               | Two Earthquakes hit 00 km south of Heliolys city, northwest of Bagdad. |
| 21        | 2017 | 7.3                       | Series of earthquakes with maximum magnitudes of 7.3 hit 30 km south of Heliolys city, northeast of Bagdad, Iraq. |
| 22        | 2018 | 4.0 to 4.5                | Series of earthquakes with magnitude of 4.0–4.5 hit northeast of Bagdad, Iraq. |

Table 1. Some historical earthquakes

Figure 1. Damages for different structures in northern of Iraq due to Halabjah earthquake, 2017.
2. Related Work

The Strengthening Technique can be described as the process of enhancing existing structures to make them more resistant to seismic loads. Various seismic strengthening methods are available, depending on the conditions and types of structures. Adding new RC shear walls, column jacketing with steel, RC, or carbon fibers, steel bracing, and seismic isolation and dampers are only a few examples of strengthening. To use these methods, the entire building or a portion of it must be evacuated for several months, which means that whether the building is a school or a warehouse, during the strengthening construction, it will lose its function for several months. Steel frames were designed for the strengthening project to withstand the majority of seismic forces and to meet the life safety (LS) limit state. These frames are attached to the outside and directly connected to the RC structural system.

X.Y. Cao, D.C. Feng, G. Wu. (2019) studied Frame-braces composed of precast bolt-connected steel-plate reinforced concrete are shown as a new approach for strengthening existing frames using external substructures (PBSPC) as shown below in fig.(2). The fundamentals of operation, numerical data methodologies and design techniques, as well as case examples, are all covered. The simulation results were as follows:

The numerical model's effectiveness is shown by the fact that it agrees with the findings of previous studies. During the technique, a $\eta$ coefficient was introduced that takes into consideration the design purpose and procedure. Influences from the precast concrete were taken into account. The suggested numerical model and design approach were utilized to carry out a functional engineering retrofitting project in which the structure was subjected to both the design basis earthquake (DBE) and the maximum considered earthquake (MCE). According to the evaluations, the structural demands were clearly lowered within the thresholds, and the inner force was relocated from the existing building to the exterior substructure after strengthening. The incremental dynamic analysis (IDA) and fragility curves were created to show that the new upgrading form has a larger structural capacity and a lower risk of structural damage.

![Typical external sub-structure forms](image)

**Figure 2.** Typical external sub-structure forms

Y. Zhang, Y. Zhuge. (2019): The author earlier presented a prefabricated self-centring steel frame (PSCF) structural structure. Experiments on PSCF connections, plane frames, and overall structures, as well as numerical simulations, were carried out. The PSCF avoids onsite aerial tension of steel strands while attaining identical seismic and self-centring effects as the self-centring steel frame (SCF).
Traditional floor systems, on the other hand, might make it difficult for PSCF and SCF to self-centre. This work established a spatial PSCF with a new type of floor system based on this research to allow frame expansion, and pseudo-dynamic and quasi-static tests were performed in its favour. The results of the tests revealed that the proposed new floor system was capable of permitting frame expansion while still being dependable. Meanwhile, the spatial PSCF with the new floor system has high self-centring capabilities, a dependable gap-opening mechanism, outstanding seismic efficiency, and sufficient redundancy to endure many aftershocks, as shown in figure 3 below.

Figure 3. Details of PSCF

A structure that is subjected to earthquake loads must meet two requirements, namely the strength and stability checks. The accumulation of story drift defines the stability check for a multi-story building. As the range of seismic repair applications grows, new strengthening technologies develop, such as external substructure upgrading approaches, which have been investigated in Japan. Since the 1970s, structural system-level strengthening has been possible (Nakano T, Inai E, Akita T, Ozaki J, Komoto T, Kakiyama T, et al.). The lateral loading test of an external frame specimen was conducted as part of a study on the seismic retrofitting approach of existing reinforced concrete buildings using external frames (part 11). The diagonal elements of both the framed steel brace and the parallel cable-stayed steel rod increase the lateral rigidity of the exterior substructure.
3. Working Principal

Precast elements such as beams, columns, and braces make up the precast bolt-connected steel-plate reinforced concrete (PBSPC) frame-brace substructure shown in this study. All of the components are prefabricated and delivered to the job site for assembly. High-strength friction bolts and steel plates protruding from the component ends link one precast member to the next. To preserve the inner steel plate and shape the integrated structure, the connecting connections are then filled with cast-in-place concrete. Over and above the current RCF's direct connection, the PBSPC frame-brace has its own set of benefits. On the one hand, because the outside beam and column may be compared, it simultaneously strengthens the existing beam and column. The inner portions have been increased in size. The exterior substructure, on the other hand, allows for the use of a harness, which prevents damage to the present RCF's joints by requiring a substantial force to be delivered. The additional brace was transferred to the joint zones. During an earthquake, the steel frame substructure works with the current RCF to improve overall efficiency by changing force-transfer mechanisms and delivering structural-system modifications. The prefabrication process and assembly technologies maintain component correctness while reducing the time required to strengthen them. The precast brace greatly improves the overall structure's lateral stiffness and bearing capability, as well as playing a crucial part in the form improvement, as shown in fig 5.

![Figure 4](image-url) Shows the parallel steel.

![Figure 5](image-url) Shows the strengthening steel frame.
4. Proposed Methodology

4.1. Material Properties and Building Structural System

The case study in this paper is an eighteen-story residential building under construction in Erbil, Iraq, as seen in figs. 6 and 7. The foundation consists of 54 piles in 15.20 cm length and 20 cm width underground and a raft of 1.20 m and the basement are shear walls the dimension of the building is 25 X 36 m and the story height is 3m. The building's structural structure has a slab thickness of 16 cm.

![Fig 6. Shows the structural set of the building.](image1)

In centimetres, the columns' cross-sectional diameters are 40*60, 50*60, 50*80, 55*100, 60*60, 60*70, and 50*50 and beams in centimetres 25*50, 25*60, 30*50, 30*60, 35*60, 40*60. The yield strength of the reinforcement steel is 420MPa and Fc is 35 Mpa.

![Fig 7. Shows the modeling in etabs](image2)

4.2. Hazard of an Earthquake
The geotechnical soil parameters at the construction site were determined via soil boring and laboratory testing. These testing revealed that the soil type is D. The spatial distribution of seismic hazard was determined using a deterministic seismic hazard assessment based on soil parameters. The “Maximum” rupture (in terms of magnitude and total rupture length) that would occur at the location as a result of a deterministic earthquake, between a Mw = 6-7.5 (comparable to the earthquake in Halabja in 2017). A hypothetical event is the "Most Credible Earthquake (MCE)." Figure 5 depicts the findings of a 5% damped elastic response that were gathered and plotted.

Zina A. Abdul Jaleel, Bahman O. Taha (2019), The Zagros and Taurus Mountains provide Erbil with a unique perspective. In the past, a moderate earthquake with a magnitude of 5.5 occurred near Erbil city. Erbil has seen an uptick in seismic activity in recent years. The seismic characteristics of Erbil city, with emphasis on geology and tectonic environment, seismicity, and a previous hazard assessment. Erbil is protected by Quaternary (fluvial sediments) geology, with soil dynamic properties known as soil site Class D.

![Fig 8. Shows design response spectrum](image)

### 4.3. Project to Assess and Strengthen Seismic Performance

To forecast the building's seismic performance before and after the reinforcement, ETABS V18 software was used to produce a finite element model. As shown in Fig 5, the structures were first modeled to represent the structure's initial state. Beams and columns were modeled with frame modeling, while floor slabs were modeled with shell components. The reinforcement steel utilized in the analysis had a yield strength of 420 MPa, whereas the concrete had a compressive strength of 35 MPa. To include the reinforcing details of each structural element in the model, the reinforcement numbers, diameters, and stirrup spacing for each structural member were taken. The non-strengthened building's seismic performance points in the X and Y axes were established. The top displacements of the No reinforced building were calculated to be 0.137m and 0.176m in the X and Y directions, respectively. To withstand the bulk of seismic forces and meet the life safety (LS) limit state, steel frames of various sizes were used for the strengthening.
Fig 9 shows the lateral load to the building.

Fig 10 shows the overturning due to Ex and Ey seismic forces.

Fig 11 shows story drift

Fig 12 shows Base-top displacement pushover-curves for the non-strengthened structure cases X & Y direction behavior.

At a performance point, the top displacements of the unstrengthening building in the X and Y directions were calculated to be 0.138m and 0.10m, respectively. Based on these findings, a strengthening project
is chosen. The strengthening project uses braced steel frames to withstand the majority of seismic forces while also assuring life safety. These frames are attached to the outer floor beams and run parallel to the RC structural system (i.e., they are connected to the building from outside). The torsion effects that could occur during an earthquake due to the existing shear wall were balanced by placing these frames in a symmetrical pattern, as shown in Fig. 4. The diagonal bracing was made of 300 IPE steel pipes that were joined to the structure building with 400 IPE steel pipes. A finite element model of the strengthened structure was built using Etabs v18 software, as shown in Fig. 5, as seen in Fig. 13. Nonlinear analysis was performed on pushovers in the same way as non-strengthened nonlinear analysis was done. The structural and pushover curves of the modified structure were determined. The ASCE 7-10 & ISC 2017 approach was used to test the upgraded structure's seismic performance, and the findings were given. The stronger structure's global drift is half that of the non-strengthened scenario at any particular performance point.

![Fig 13. Shows the strengthening of the building by steel frame in one direction](image)

5. Conclusion

In this paper we describe the affected of shear location, The addition and location of a shear wall affects the centre of mass and rigidity. It can be assumed that there are no asymmetric models. Because of the centre of mass and the centre of gravity, there is no torsion effect. The structure's success with a shear wall is preferable to that without one. Since the centre of mass and rigidity become one kind of closer. Because the shear wall increases the rigidity of the building and sustains lateral forces, displacement is usually reduced. Superior performance and lower displacement in both the x and y directions are noticed when analysis is carried out utilizing response spectrum analysis, as well as better performances with respect to displacement. When experimental experiments or simulations to analyse the behaviour of a system under various conditions are costly or difficult to handle, finite element software, such as ETABS, is a very useful tool for simulating large scale infrastructures (e.g., high rise buildings). The story overturning moment varies inversely with story height, according to the multi-storey building's review. The displacement of stories increased with story height up to the ninth story, where it reached its maximum value, and then began to decrease. Mode shapes are created using dynamic analysis. A simplified variant of modal analysis that is useful for structural design has been characterized as response spectrum modal analysis. The technology enables smooth design spectra to be used in the
evaluation and construction of structures. Although it has been proposed that the process be adapted to modern design requirements.

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