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Modelling of earthquake repellent fibre reinforced concrete

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ABSTRACT

Iraq is exposed to significant earthquakes since it is located in the Middle East, in southwestern Asia. Thus, buildings should be designed and constructed to resist seismic forces. This is not always the case. Most of typical fibre reinforced concrete residential buildings in Iraq are designed and constructed to resist gravity loads only without any considerations to earthquake resistance. It is generally assumed by designers that the seismic forces on low and high-rise buildings are low. The building frame structural system and infill walls are assumed to resist such loads. There has been no verification to these assumptions by designers. Several seismic evaluation methodologies exist over around the world including qualitative (empirical) and quantitative (analytical) methodologies. The most suitable seismic evaluation methodology to be used in Iraq is the analytical methodology of pushover analysis since it does not require an observed damage data from previous earthquakes. We have designed two building that could withstand the earthquakes and have been long lasting using the fibre reinforced concrete. The orientation of the long dimension of columns is an important factor in the seismic resistance of both buildings. The direction contains the long dimension of columns have an earthquake resistance larger than the other direction. Buildings having structural walls behave better than other buildings during earthquakes as long as the location of these walls does not form a horizontal irregularities.

Keywords: Earthquake, Modelling, Designing, Fibre reinforced Concrete, Structure, Buildings

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1. Introduction

Earthquakes over the ages killed large number of people and destroyed large number of buildings. Thus, ensuring the safety of people and buildings during earthquakes is a matter of concern. The experience gained from past earthquakes demonstrates that damages are occurred to buildings that do not meet the requirements of seismic resistance design, e.g. buildings designed to resist gravity loads only. Various codes and regulations have been developed all around the world to design new structures to have adequate reinforcement detailing to provide an adequate ductile behavior necessary to resist a targeted earthquake. For existing buildings that were not designed to resist seismic loads, seismic evaluation and rehabilitation guidelines need to be developed to assess the behavior of those buildings in order to propose the required strengthening [1].

Iraq is vulnerable to earthquakes due to its location between the Arabian and African tectonic plates. During the last two millenniums, Iraq exposed to a number of earthquakes that killed thousands of people and

destroyed thousands of buildings. Due to these facts, the need for an evaluation of the seismic resistance of buildings in Iraq is a necessity.
The fibre reinforced concrete building frame (not moment resisting) with masonry infill is the most common type of construction of buildings in Iraq. This system is generally consisted of frame system providing support to vertical loads and a lateral load resisting system such as shear walls, moment frames, etc. In Iraq, this system consists of one-way or two-way ribbed slabs supported on columns which in turn transfer the loads to footings which are supported on the soil. The design and construction practice in Iraq show that most of fibre reinforced concrete buildings having up to 7 stories are designed to resist gravity loads only, without any considerations to seismic resistance design. It is generally assumed by designers that the seismic forces on such buildings are low [2]. The building frame structural system and non-structural elements, e.g. partitions are assumed to resist such loads. These assumptions are seldom verified by designers. Seismic resistance assessment of those buildings is the verification tool for those assumptions.

1.1. Aim of study

The aim of this research is to modeling of a structure that could withstand the seismic risk in existing and new fibre reinforced concrete buildings during earthquakes. This aim is intended to be achieved by accomplishing the following objectives:
1. Investigate the performance and identify the structural deficiencies of the typical fibre reinforced concrete buildings during earthquakes.
2. Determine the contribution of infill walls on the overall strength of the building.
3. Assess the performance of buildings with soft stories.
4. Outline guidelines for designing similar new buildings.
5. Assist in determining strengthening techniques to increase the ability of existing buildings to withstand earthquakes.

1.2. Research scope and limitations

This research is concerned with the evaluation of low-rise fibre reinforced concrete buildings that are designed only for gravity loads in resisting seismic forces in Iraq. Low-rise buildings are buildings with height not exceed 21 meters, i.e. number of stories does not exceed 7 stories. Multi-story buildings are out of the scope of this research (locally referred to as towers). Buildings of normal use, e.g. residential buildings will be considered in this research. Regular fibre reinforced concrete buildings are analyzed in this research. Although, most used vertical and horizontal irregularities in the targeted buildings such as soft story and cantilevers will be evaluated. This research utilized the seismic parameters of IBC 2017 “International Building Code” [3]. Although the buildings of Iraq will be evaluated, the conclusion of the research can be utilized in other locations having similar buildings.

2. Literature review

The literature review includes a review of earthquake phenomenon and the buildings behavior during earthquakes. It also includes a description of the seismic condition of Iraq and the historical records of earthquakes that occurred in Iraq. Furthermore, this research includes a review and discussion about some of the available seismic evaluation methodologies for existing buildings and outlines the findings of recent researches utilizes these methodologies from different parts of the world. It also outlines the findings of the recent researches carried out in the field of seismic evaluation of existing buildings in Iraq [4].

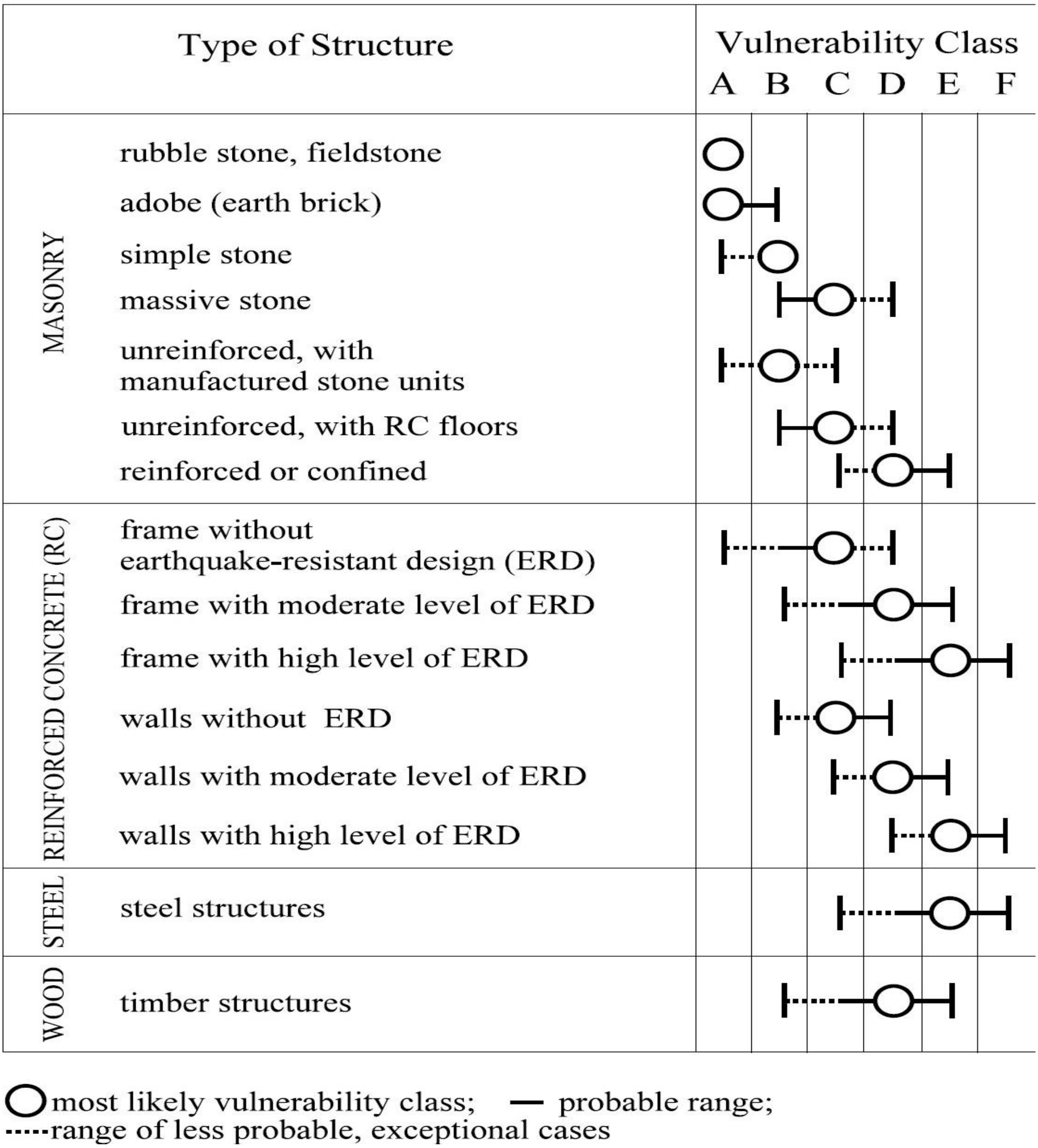


Fig. 1. The definition of the intensity degrees in regard to buildings damage during earthquakes [4]

There is no observed damage data from previous earthquakes for Iraqian buildings to predict effects of future earthquakes. This methodology can be used in Iraq in case of observed damage data for a region of similar characteristics is available.

Analytical methods can be carried out in absence of past earthquake damage records for similar type of buildings [5]. It also used to evaluate a specific building or type of buildings have the same structural characteristics. Based on that facts, analytical methods have been used to evaluate the seismic resistance of Iraqian buildings in the undertaken research.

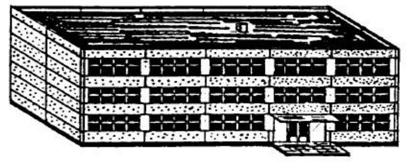
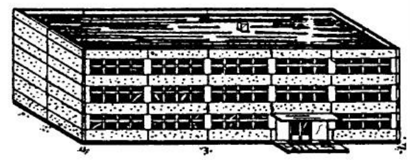
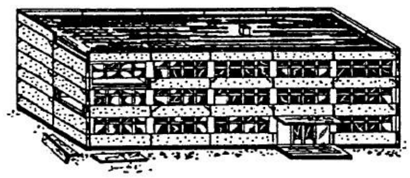
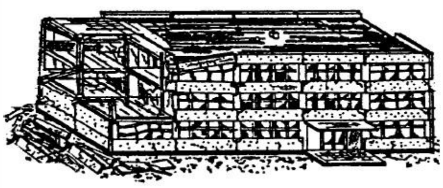
Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Fig. 2. The vulnerability assessment and classification of a structure during earthquakes [5]

2.1. Evaluating seismic performance of existing school buildings in Iraq

The author in research [6] includes a seismic assessment of the existing school buildings in Iraq. The assessment has been carried out based on the EMS-98 scale. The research also includes a seismic evaluation of three samples of the dominant structural systems of school buildings in Iraq by following the guidelines of ASCE 31-03. A comparative study has been carried out on the results obtained from the two approaches.

The results of applying the EMS-98 approach on more than 54 case studies showed that about 60% the school buildings in Iraq is assigned to vulnerability class A and B in which it might expose to full or partial damages (3, 4 and 5 degree of damages as defined by EMS-98) during a specified earthquake scenarios [7-8].
The assessment of schools is out of this research scope. It is recommended to evaluate school buildings by using analytical methods to verify this study results. [8].

2.2. Structural needs of existing buildings in Iraq for earthquake repellent

In this research [Qandil, 2009], a new seismic evaluation method was developed to evaluate the buildings in Iraq in regard to its seismic resistance. The new method has been developed by combining an Israeli method and a Turkish method [9].
The developed approach was applied on thirty three different Iraq buildings which include: residential housing buildings, tower buildings, schools, health clinic and asbestos shelters. It was found that the structural system used on Iraq which is Skelton type is an appropriate system to resist earthquakes of high intensity. The weakness of this system appeared in the case of the presence of soft story. Tower buildings are classified as intermediate and weak in resisting earthquakes, according to the area of shear walls in the building. The fibre reinforced concrete frame system which is used in public buildings is suitable and adequate to resist earthquakes of high intensity. The asbestos buildings are weak and unsuitable in resisting earthquakes forces.
In the undertaken research, the findings of this research will be verified by using analytical methods of analysis.

2.3. Building types

The seismic behavior of buildings during earthquakes depends on their construction materials, structural systems and their use. Accordingly, Iraq buildings can be classified as follows:

2.3.1 Classification according to construction materials

It is known that different materials behave differently during earthquakes based on their engineering properties such as strength and ductility. This leads us to classify Iraq buildings according to their construction materials in order to understand the behavior of each type of buildings during earthquake. Different types of materials are used in the construction of buildings in Iraq. Iraq buildings can be classified according to their construction materials as follows:

2.3.2. Unreinforced masonry buildings in Iraq

This type of buildings is constructed by using an individual blocks bonded to each other by mortar. Sand and rock natural stones and concrete blocks are the most common types of blocks used in the construction of buildings in Iraq. Concrete blocks are commonly used as bearing walls for one story buildings. It also used as an infill walls for fibre reinforced concrete buildings. Concrete blocks buildings can be found mainly in the refugee camps of Iraq as a residential units. Sand and rock natural stones are used in some of old buildings and as cladding in new buildings. The photos in Fig. 3 show deferent types of masonry buildings in Iraq. This type of buildings is seismic vulnerable because it is constructed without following any engineering design principles as well as the brittle behavior of the blocks makes it unfavorable seismic resistant material. Natural stone cladding is considered as a source of danger during earthquakes because it is exposed to fall due to the lack of sufficient attachment to the buildings [10].
The undertaken research is not concerned with the seismic resistance of this type of buildings. Concrete blocks walls which are used as partitions in fibre reinforced concrete buildings designed for gravity loads only are assumed by Iraq designers as a contributor to the seismic resistance of the buildings. This assumption is investigated in this research.

(a) Concrete block building

(b) Sand stone building

Fig. 3. Unreinforced Masonry Buildings [10]

2.3.3. Fibre reinforced concrete buildings in Iraq

Concrete was used in Iraq for thousands of years. Fibre reinforced concrete is the most widely used material for construction of buildings in Iraq. Fibre reinforced concrete consists mainly of two materials: concrete and reinforcing steel bars. Concrete is a brittle material. This fact makes concrete non seismic-resistant material. Concrete is provided by reinforcing steel bars which enhances its ductility which in turn converts it to a seismic- resistant material. Steel reinforcement also resist tensile stresses that concrete cannot resist [11].

Since the vast majority of Iraq buildings are constructed by using fibre reinforced concrete, the need for evaluating the seismic resistance of this type of buildings is an important issue. This reason justifies carrying out the undertaken research. The photo in Fig. 4 shows fibre reinforced concrete buildings in Iraq.

Fig. 4. Fibre reinforced concrete Buildings and structures in Iraq [11]

2.3.4. Steel buildings

Structural steel is used in a special type of structures in Iraq. The use of steel is limited to the construction of warehouses, petrol stations, school sheds, etc. Due to the high ductility of the steel material, these structures behave in a good manner during earthquakes. This type of buildings is not within the scope of the undertaken research [12]. The photo in Fig. 5 shows a steel structure in Iraq.

Fig.4. Steel buildings and structures in Iraq [12]

3. Methodology

Earthquakes cause different kinds and levels of damages on buildings. The level of damage depends on several factors. The main factors are the intensity of the earthquake, type of the buildings in terms of the construction material, structural system, use, and the quality of seismic design of the building. Since these factors are significant in determining the behavior of buildings during earthquakes, a detailed study and investigation on the design and construction practices in Iraq was conducted as part of the undertaken research. Information about the types of buildings, construction materials, and design and construction regulations that exist in Iraq was collected. The collected information is important in determining the type of Iraq buildings to be seismically evaluated in this study. [13].

3.1. Building frame system

Building frame system is the most widely used structural system in the construction of fibre reinforced concrete buildings in Iraq. This system is generally consisted of a space frame skeleton system (non-moment resistance) providing support to vertical loads and in some cases it is provided with a lateral load resisting system such as shear walls and moment resisting frames. The space frame system is consisted of one-way or two-way solid or ribbed slabs supported on columns which in turn transfers the loads to isolated, combined, or raft footings which transfer loads to the soil. Concrete block infill walls are used in this system as internal and external walls. The Photo in Fig. (5) Shows the building frame system.

According to the bylaw of urban planning of the Palestinian National Authority and the [System of Multi-Story Buildings] issued by the Palestinian Authority, fibre reinforced concrete buildings in Iraq can be classified into two major types: low-rise buildings and multi- story buildings. Multi-story buildings are buildings with height exceeds 15 meter measured from the level of the road to the floor level of the last story. The total number of stories shall not be less than 5 stories. In another way, it can be said that the multi-story buildings are the buildings with total height exceeds 21 meters by taking into account the height of the last floor and the mezzanine floor. All other buildings are considered as low-rise buildings.

Fig. 5. Building Frame System using fibre reinforced concrete protected from earthquakes [13]

3.2. Design and contruction practice of fibre reinforced concrete

As a part of the undertaken research, a detailed investigation on the design and construction practice of fibre reinforced concrete buildings in Iraq was carried out in order to collect information required for the seismic resistance evaluation process. Design codes, building characteristics and construction practices that affect the behavior of buildings during earthquakes were also investigated. In order to collect this information, several meetings have been conducted with relevant regulatory bodies such as Ministry of Public Works and Housing, Ministry of Local Government, Iraq Municipality and Association of Engineers. Design requirements and construction regulations of these bodies have been discussed in these meetings. Site visits to several existing buildings have been conducted to collect relevant information. The following points outline the collected information and the main characteristics of fibre reinforced concrete design and construction practice in Iraq:

1. Until now, there is no special building code in Iraq for the structural design of fibre reinforced concrete structures. Also, there is no obligatory law for designing all fibre reinforced concrete buildings to resist lateral loads. Many efforts have been made by the development of a building code for Iraq but these efforts were not successful. Instead of that, they recommended the use of the available building codes but not obligatory. This is adequate since the development of a building code for is not easy and needs a huge efforts.
2. The unique official document in Iraq that contains obligations to the seismic design of fibre reinforced concrete buildings is the “System for Multi-Story Buildings” issued by the Palestinian Authority. This system require the designers to design fibre reinforced concrete building with total height exceeds 21 meters, i.e. multi-story buildings, for seismic and wind loads. This system is adopted by all bodies relevant to the construction of buildings such as ministries, municipalities and Association of Engineers.
3. Other fibre reinforced concrete buildings, i.e. low-rise buildings, are normally designed only for gravity loads without any consideration to seismic design and detailing. Normally, non-seismic design provisions and reinforcement detailing of ACI 318 are used. This makes the behavior of this type of buildings during earthquakes is a matter of concern. So, this research will evaluate the seismic behavior of this type of buildings.

4. Municipalities' regulations allow the owners to add a mezzanine floor and a roof floor to the low-rise buildings without any additional requirements for seismic design. This result in buildings with 7 stories designed and constructed for gravity loads only. This type of buildings is found widely in Iraq which triggered this research.

5. It is generally assumed by designers that the seismic forces act on low-rise buildings are low. Also, the building frame system and non-structural elements, e.g. partitions are assumed to resist such loads. These assumptions are investigated in this research.

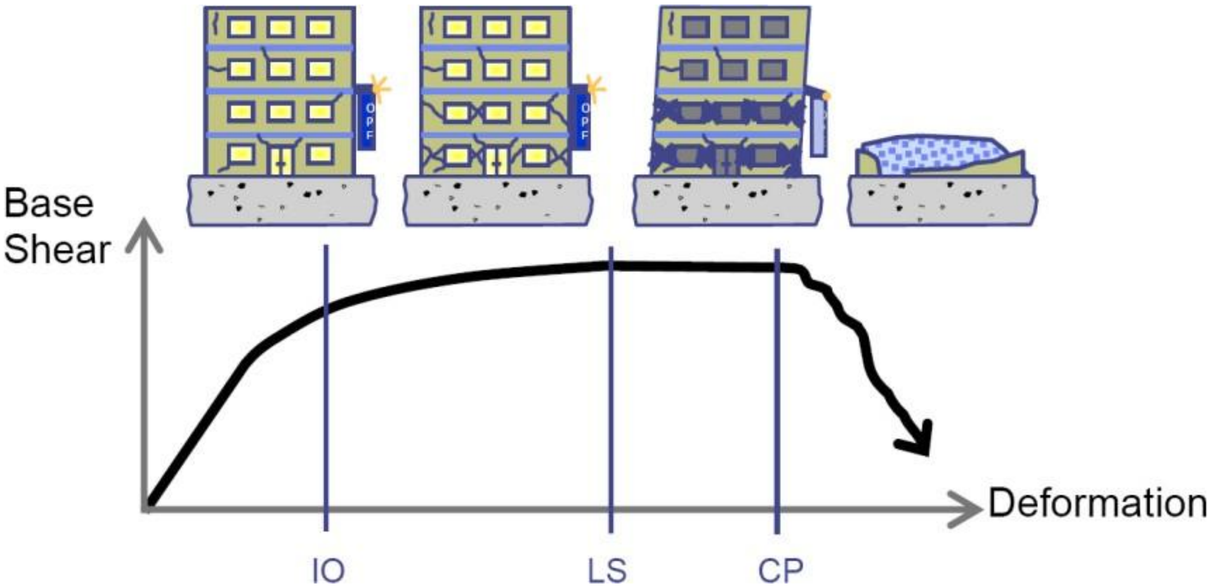


Fig. 6. Performance levels of ordinary building during moderate earthquakes

3.3. Design parameters for resisting earthquakes

This design includes the findings of the detailed investigation which was carried out on the design and construction practices in Iraq with regard to seismic resistance and evaluation. These findings can be summarized as follows:

1) Types of Iraq buildings have been classified according to their construction materials, structural systems and their use. The behavior of each type during earthquake is identified.
2) The type of Iraq buildings that will be seismically evaluated in this research has been identified. This type is the low-rise fibre reinforced concrete buildings designed for gravity loads only. The contribution of infill walls to the overall seismic resistance of the low-rise buildings will be investigated. The influence of the common types of irregularities such as soft story and large cantilevers on the seismic resistance of buildings will be also investigated. The suitable separation distance between adjacent buildings will be determined.
3) Unreinforced masonry building, steel structures, and moment resisting fibre reinforced concrete frame buildings are out of this research scope.
4) Information about the design codes and construction regulations that are used in Iraq has been collected. Latest versions of IBC, ASCE/SEI codes and other codes are considered in this research.
5) Parameters of seismic design that are used in Iraq have been identified. For the seismic design according to UBC 97 code, zone 2A with seismic zone coefficient equal to 0.15 is used for northern part of Iraq and zone 1 with seismic zone coefficient equal to 0.075 is used for southern parts. For the seismic design according to IBC code, values of 0.17 and 0.12 are used for Ss and S1, respectively.
6) Design and construction practices in Iraq buildings that may affect the behavior of buildings during earthquakes either positively or adversely have been outlined. Good practices are concentrating

stirrups over the ends of columns and beams, use of fibre reinforced concrete elevator walls, construction of ground beam, presence of partition walls, and the continuous beam and column reinforcement at the joints. The bad practices are presence of geometrical irregularities, lack of soil tests, and constructing buildings without professional engineering supervision.

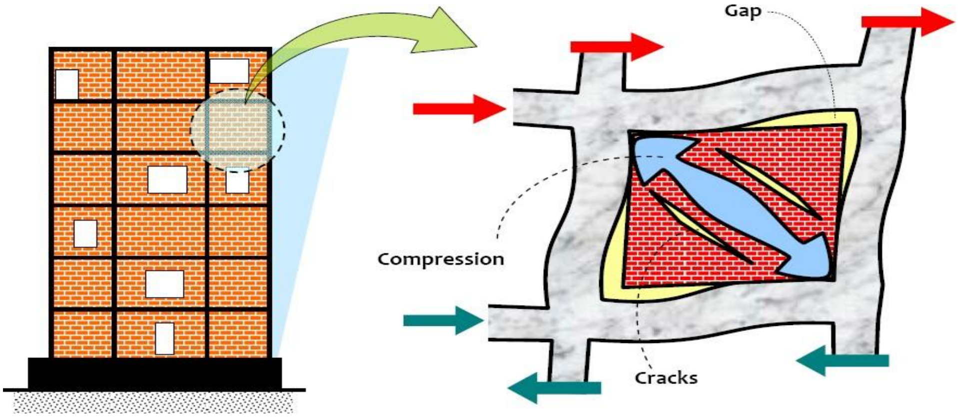


Fig. 6. Deformation of reinforced conctrete frame building with earquake repellent infill walls.

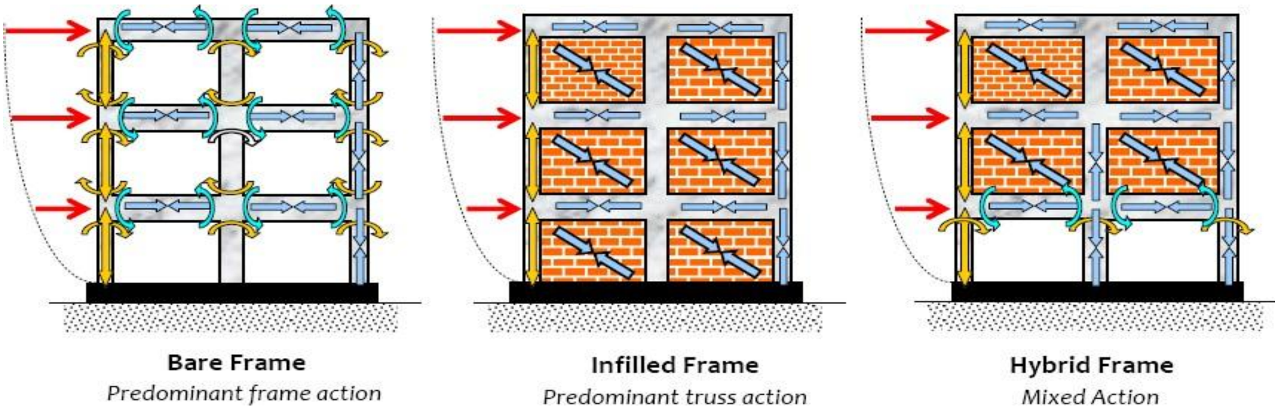


Fig. 7. Lateral force transfer mechanism in reinforced conctrete frame buildings for resisting earthquakes.

3.4. Pushover analysis for fibre reinforced concrete buidings

1. Deformation shape of the structure at any step of pushover analysis. Hinge locations at any step are presented. Hinge colors represent the performance level that the hinge reached based on 356 criteria.
2. Pushover curve in terms of base shear and monitored displacement.
3. Pushover curve intersected with demand curve which show the performance point. Green line represents the pushover curve, blue line represents the demand curve, red lines represent the family of demand spectra of different damping ratios, and gray lines represent the period lines at different values.

4. Results

4.1. Earthquake repellent building design-1

This research was selected carefully to represent the majority of existing residential fibre reinforced concrete buildings of Iraq. The research is divided to two building configurations, i.e. B1 and B2.
Since large number of existing fibre reinforced concrete buildings are regular in plan and elevation, regular buildings were selected as case studies. Although, irregular buildings having vertical and horizontal irregularities such as soft story, cantilevers, and irregular plan were also considered.

Each building configuration is analyzed several times separately as follows:
1. Building frame system with no infill walls in all stories.
2. Building frame system with infill walls in all stories.
3. Building frame system with a soft ground story.
4. One of the three previous cases which perform within the damage performance level with the proposed strengthening.

Table 1. Dimensions and Reinforcement of Building-1 Columns.

Col. No.	Ground+1st Floors		Other Floors	
	Dim. (cm)	**Reinf.**	**Dim. (cm)**	**Reinf.**
C1	20x40	6Φ14	20x40	6Φ14
C2	20x50	8Φ14	20x40	6Φ14
C3	20x70	10Φ14	20x50	8Φ14

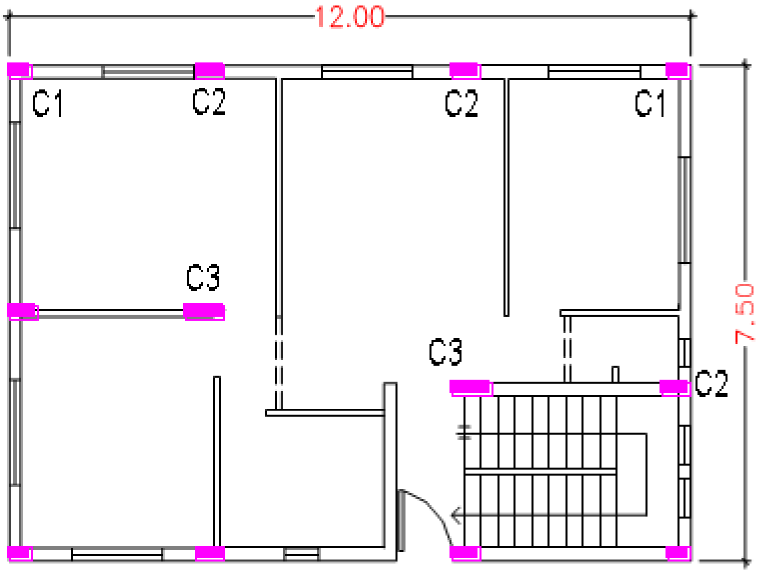


Fig. 8. Floor plan and columns location for earthquake resistent building-1.

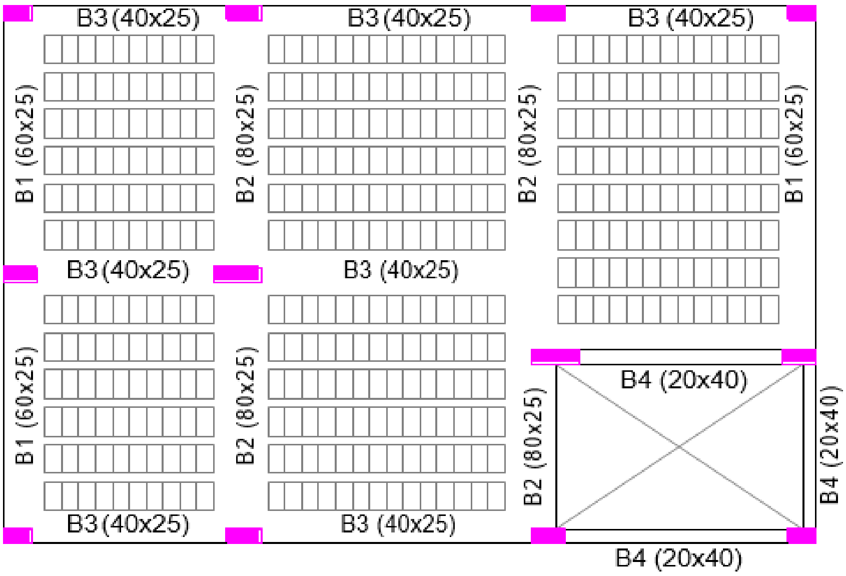


Fig. 9. Beams arrangement and dimensions for earthquake resistent building-1.

4.2. Structural modelling and analysis of design-1

Deformation shape of the structure at any step of pushover analysis is obtained for each direction. Fig.10 and 11 show the deformation shapes for X-direction and Y-direction respectively. The deformation shape for resisting earthquakes also shows the hinge locations at any step of analysis. Hinge colors represent the performance level that the hinge reached.

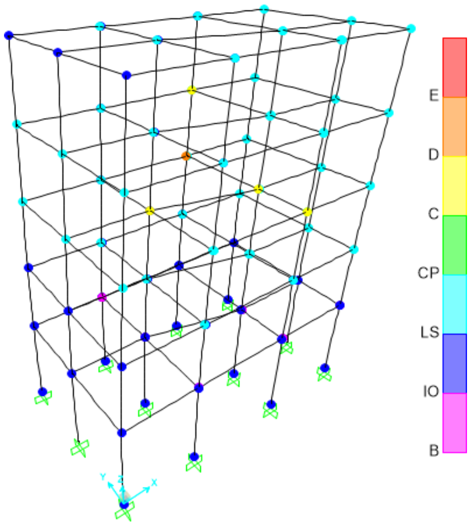


Fig. 10. Design of fibre reinforced concrete building-1 shape in x-direction for resisting earthquakes

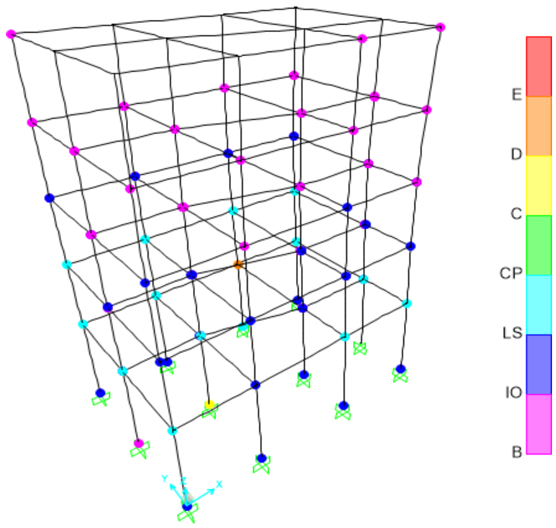


Fig. 11. Design of fibre reinforced concrete building-1 shape in y-direction for resisting earthquakes

4.3. Earthquake Repellent Building Buiding -2

This building is a fibre reinforced concrete building located in Iraq city. The building consists of ground floor, mezzanine floor, 4 typical floors, and roof floor. All floors are of 3m in height (i.e. the building height is 21m). The building dimensions are 20.9m x 14.85m in plan as shown in Fig. 12.

Table 2. Dimensions and reinforcement of building-2 columns

	Ground+1st + Mezzanine Floors		**Other Floors**	
Col. No.	**Dim. (cm)**	**Reinf.**	**Dim. (cm)**	**Reinf.**
C1	20x50	8Φ14	20x40	6Φ14
C2	20x70	10Φ14	20x50	8Φ14
C3	20x80	12Φ14	20x60	8Φ14

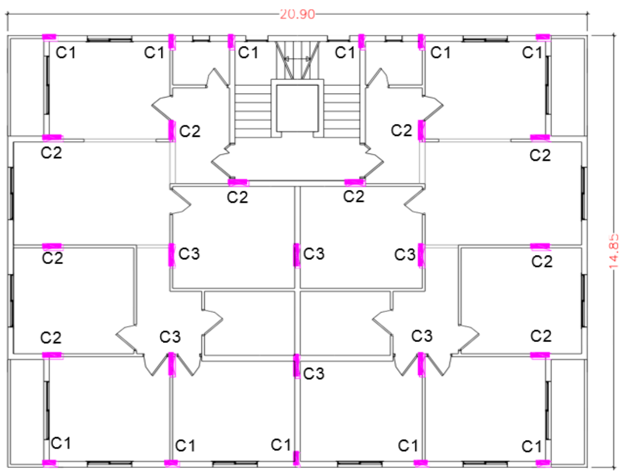


Fig. 12. Floor plan and columns location for earthquake resistent building-2

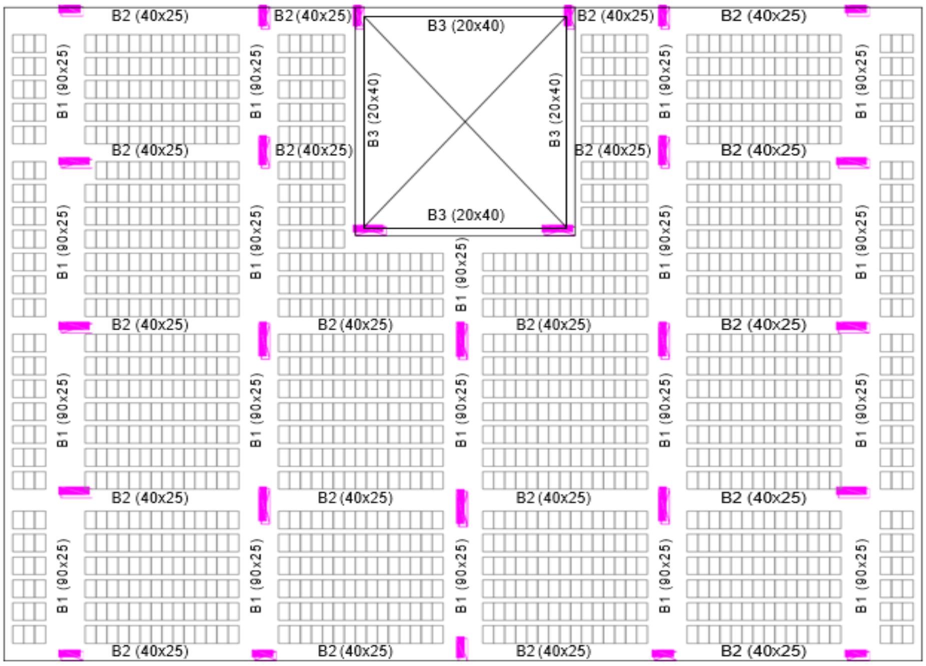


Fig. 13. Beams arrangement and dimensions for earthquake resistent building-2

4.4. Structural modelling and analysis of buiding-2

All modelling, design, and analysis parameters for this building is the same as for building (B1). The targeted displacement is taken as 300mm in each direction.

This building is also analyzed 4 times separately: (1) without infill walls (B2-1), (2) with infill walls in all stories (B2-2), (3) with infill walls and soft ground story (B2-3), and (4) with infill walls, soft ground story, and shear walls in around the elevator (B1-4).

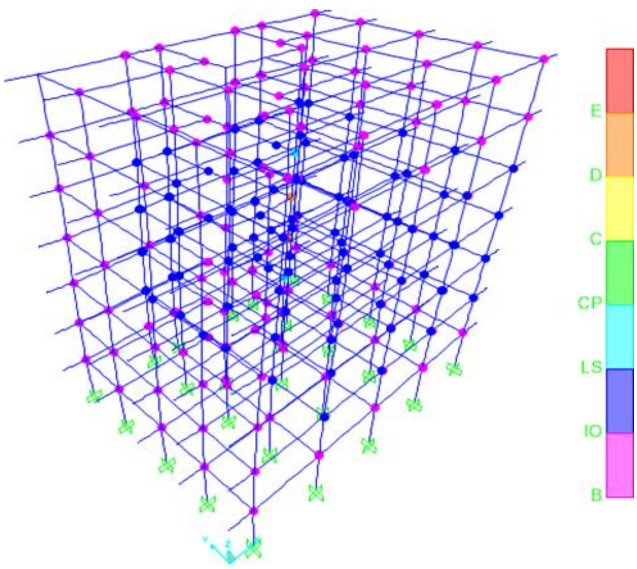


Fig. 14. Design of fibre reinforced concrete building-2 shape in x-direction for resisting earthquakes

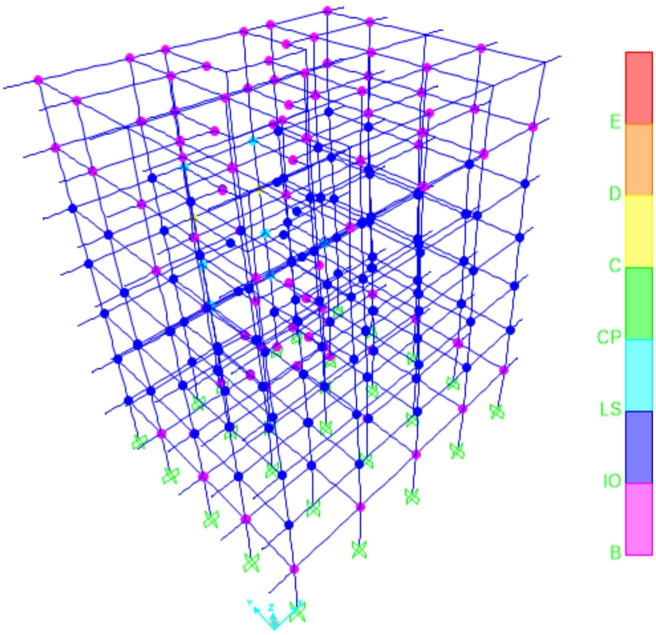


Fig. 15. Design of fibre reinforced concrete building-2 shape in y-direction for resisting earthquakes.

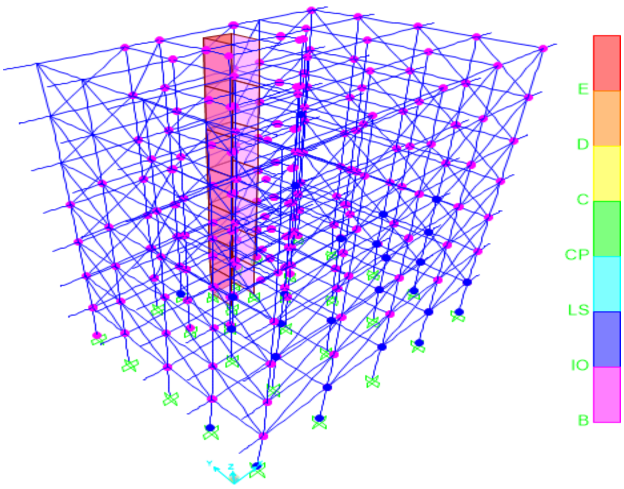


Fig. 16. Design of high-level breaking point in fibre reinforced concrete building-2 shape in x-direction for resisting earthquakes with the magnitude of 8.0 represented by red color

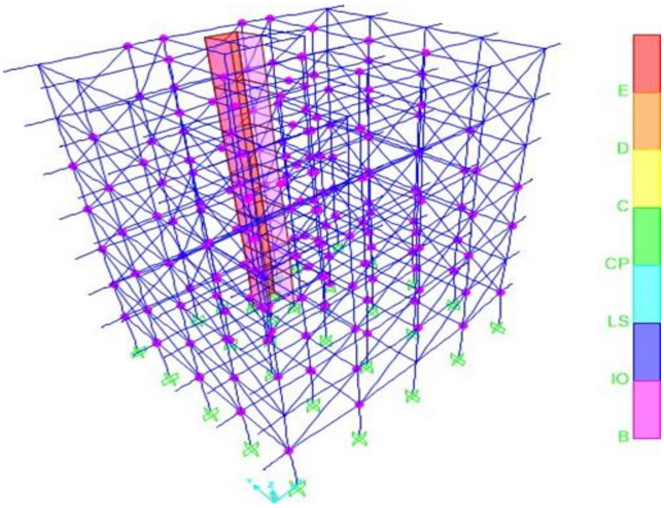


Fig. 17. Design of high-level breaking point in fibre reinforced concrete building-2 shape in y-direction for resisting earthquakes with the magnitude of 8.0 represented by red color

5. Discussion

Based on the results of the earthquake assessment of B1 and B2 building designs and assuming that these designs represent the majority of existing low and high-rise residential fibre reinforced concrete buildings in Iraq, the following conclusions have been drawn:

1) Regular low-rise residential fibre reinforced concrete buildings of Iraq designed for gravity loads only are considered to be seismically safe taking into account the rigidity of the joints between beams and columns only.
2) Buildings have horizontal and vertical irregularities may be exposed to local damages in the ground floor columns during earthquakes which could lead to failures.
3) Presence of infill walls has beneficial effects on the performance of buildings during earthquakes as long as horizontal and vertical irregularities such as soft story do not exists. Infill walls increases the lateral stiffness of buildings and thus enhances its seismic resistance [14].
4) The bad effect of the presence of soft ground stories depends on several factors such as number of stories, building irregularity, etc. Soft stories have no significant adverse effects on regular and symmetric buildings despite the number of stories. Buildings consist of 3 stories or less will not be affected by the presence of soft stories. Soft story decreases the lateral stiffness of irregular buildings significantly and thus reduces the seismic resistance.
5) The orientation of the long dimension of columns is an important factor in the seismic resistance of buildings. The direction contains the long dimension of columns have a seismic resistance larger than the other direction [15].
6) Buildings having structural walls behave better than other buildings during earthquakes as long as the location of these walls does not form horizontal irregularities.

6. Conclusion

The design of building that could resist the earthquakes using fibre reinforced concrete have been taken into considereation and the application of pushover analysis to several low-rise residential reinforced concrete buildings in Iraq. It has been concluded that the pushover analysis is a simple and effective procedure to assess the earthquake resistance of buildings during earthquake. The findings of this research are obtained based on the design of two builidings using fibre reinforced concrete assuming they represent typical residential buildings in Iraq. However, different findings may be obtained if different buildings have been considered, e.g. building with other veridical and horizontal irregularities. In conclusion this research is the first of its kind in assessing the earthquake resistance of typical residential buildings in Iraq. Further research is recommended in the future to assess all types of buildings and determine strengthening techniques for existing buildings. Concerned official authorities in Iraq are encouraged to take actions and draw regulations related to design of low rise buildings to ensure their adequacy to resist seismic forces.

7. Recommendations

Based on the results of the undertaken research, the following recommendations were made for existing buildings, new buildings, concerned authorities, and for future researches.

7.1. Recommendations for existing buildings

Buildings that are venerable to seismic forces such as buildings with soft stories need to be strengthened using proper techniques.

7.2. Recommendations for new buildings

New residential buildings in Iraq are to be designed for earthquake utilization the existing rigidity of the beam column connection, infill walls, and proper orientation of columns to enhance stiffness in the two directions. Special attention should be given to irregularities, if exist.

7.3. Recommendations for concerned public authorities

1. Legal authorities should legislate special bylaws to enforce engineers to design and construct building according to seismic requirements.
2. Plans for rehabilitation and strengthening of existing buildings to resist earthquakes should be developed and enforced.
3. Seismically unsafe building types and practices should be prevented.

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