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REFLECTIONS OF HALABJAH EARTHQUAKE EFFECTS ON THE STRUCTURAL BUILDING DAMAGES IN HALABJAH AND DARBANDIKHAN

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ABSTRACT

Earthquakes hit the earth on daily basis with different intensities. An earthquake of M 7.3 hit Halabjah on 12th of November 2017 and caused structural damages in both Halabjah and Darbandikhan. This paper investigates the reflections of seismic effects on the most structural damages found in the areas presenting a thorough site investigation on the possible reasons behind the building failures and collapses and specifying the probable errors in their constructions and designs. Additionally, some of the most novel techniques of retrofitting are proposed to rehabilitate the damages in the buildings. After the investigation, it is deduced that, most of the structural failures can be attributed to lack of knowledge about lateral loads and not considering them in the design and construction of the buildings in those vicinities. Further, the construction level of the buildings can be considered as unsatisfactory in the affected areas for some serious problems mentioned in detail in the paper. Therefore, most of the buildings needed immediate rehabilitation and some of the most modern methods are proposed in doing so. As a result, it is proved that a proper balance has to be guaranteed between strength, stiffness and ductility in designing buildings to withstand lateral forces from an earthquake.

KEYWORDS: Earthquake effects; Lessons learnt; Structural damages; Halabjah Earthquake

1. INTRODUCTION

Every year, thousands of earthquakes hit the earth with different magnitudes and intensities. Approximately 20 of them are estimated to be of a magnitude of M 7 and above. Kurdistan Region in Iraq is not an exception, on November, 12th , 2017 at 21:18 local time, one of the strongest earthquakes in 2017 hit the area with the magnitude of M 7.3 (Taha & Hasan, 2018). The exact location of the epicenter of the earthquake was located in Iran in the vicinity of Iraq-Iran border. Officially, its name was attributed to Halabjah, a city in Kurdistan region of Iraq, as its epicenter was only 32 km south of it, even though the epicenter of the quake was in Iran, near Ezgeleh at 34.911°N 45.959°E (USGS, 2017a). The tremor caused numerous causalities especially in Iran as estimated that approximately 1,840,000 people lived within 100 km of its epicenter in both Iraq and Iran. The earthquake was recognized worldwide as the deadliest earthquake of 2017, leaving the death toll of more than 400 deaths and more than 7000 injuries (Stein, 2017). Additionally, it caused serious damages to the buildings as more than12000 structural damages were attributed to that earthquake. The most affected areas, in terms of causality and structural damage, were in Sarpol-e Zahab, in Iran, which was 42.35 km away from the epicenter, and Darbandikhan in Iraq which was nearly 40 km away from the

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epicenter. Even though the structural damages and causalities in, Sarpol-el- Zahab was incomparable with Darbadikhan as the rate was extremely higher. Darbandikhan, a city in Kurdistan Region of Iraq, experienced some serious structural damages (Taha & Hasan, 2018). Some of its R.C frame buildings collapsed along with some total collapse of the masonry buildings. On the other side, no serious damage and causalities was reported in Halabjah, even though it was closer to the epicenter and the name of the earthquake attributed to it. Therefore, this paper is a site investigation to the affected areas in Kurdistan region of Iraq trying to interpret the possible engineering reasons behind the structural failures reported in both Halabjah and Darbandikhan. It tries to emphasize the errors and mistakes lead to structural damages or even collapse in some cases based on the principles and philosophy of the earthquake resistance design. In the assessment of the reasons, the authors relied on their engineering judgements on the observed damages by comparing the noted damages with the outcomes of research studies performed on the issues leading to the same type of failure. Therefore, those principles of design and construction that can prevent the noted damages are emphasized in this paper.

1.1 History of Earthquakes in that area:

The epicenter of the earthquake lied about 100 km form the boundary between Arabian and Eurasian plates. The magnitude of the earthquake was M 7.3 and the closest major quakes to that were a pair of M 6.7 and M 6.8 in 1957 and 1958, some 200 km to the southeast of the epicenter's mainshock. Historically, there were no quakes more powerful than a magnitude of 6 within the area of about 100 km to the epicenter of the earthquake in the past 50 years as it can be seen in Figure 1 as it shows the history of the earthquake of a magnitude of M 6 and above. (USGS, 2017a). Moreover, in the Global Earthquake Activity Rate model by (P. Bird et el., 2015) it is expected that only a M 5.5-5.8 would be a typical lifetime magnitude in that area (Bird et al., 2015). Also, the local strain rate was not adequately surveilled and measured by GPS because of the political and military conflicts in that region. Therefore, the occurrence of a quake this strong was a real shock for the area as it was not expected by the scientists. The possible reason behind the quake is the tectonic movement of the Arabia tectonic plate as it is pushed away against Eurasia plate along the Bitlis Suture and Zagros fold belt at a speed of 26 mm/year (Roudbari et al., 2020). The directions of the movement of the tectonic plate in that area are shown in Figure 2. There are two active faults in that area namely Zagros Mountain Front Fault (MFF) which its fault length is 1368 km and High Zagros Fault (HZF) of a length of 1375 km and the epicenter of the earthquake lies in between them. Most of the earthquakes in that area are attributed to the movement of the above two faults. The motion of MFF is considered to be the main cause of the quake. Earlier of that quake, earthquakes of different magnitudes ranging from M 1.9 to M 4.5 hit the area which were considered to be foreshocks of the quake. In addition to 529 earthquakes with magnitudes ranging from M 1.8 to M 4.7 that hit the area after the main quake till 28th of November 2017 which were considered as aftershocks (Alavi et al., 2018).

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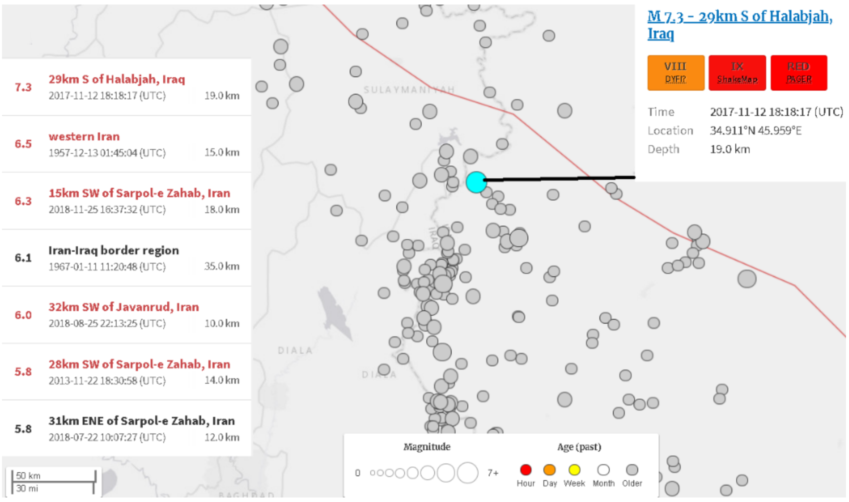

Fig. (1): History of strong earthquake over the past 50 years in 100 km to the epicenter of the Halabjah quake (USGS, 2017b)

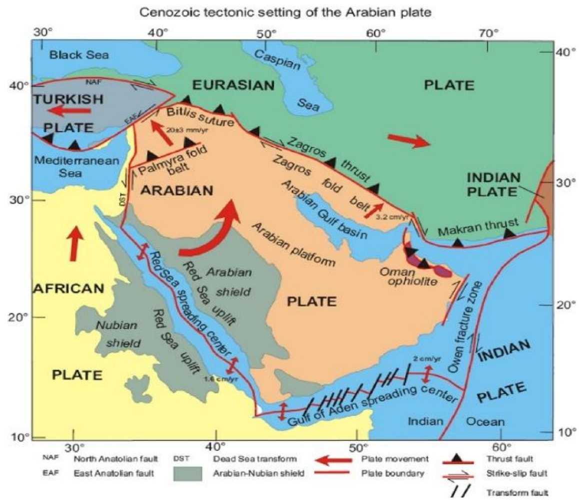

Fig. (2): Fault slips that caused the M 7.3 earthquake (Alavi et al., 2018)

1.2 Earthquake's Impact on Iraq

The tremor was felt all across Iraq, however, only a few areas of it experienced structural damages and collapses. Darbandikhan was the most severely affected city by the quake. It is located in Kurdistan region in north of Iraq in the province of Sulaimania and it is at 55 km southeast of Sulaimania. It is situated at 35.116°N 45.686°E with the average altitude of 520 m above the mean sea level. It was nearly 40 km away from the epicenter of the earthquake as its location is shown with respect to the epicenter of the quake in Figure 3. Figure 3 also shows different levels of intensities felt by the inhabitants in Iraqi cities and towns and as it can be seen in both Halabjah and Darbandikhan the intensity is from 6-7 which caused more damage compared to other areas.

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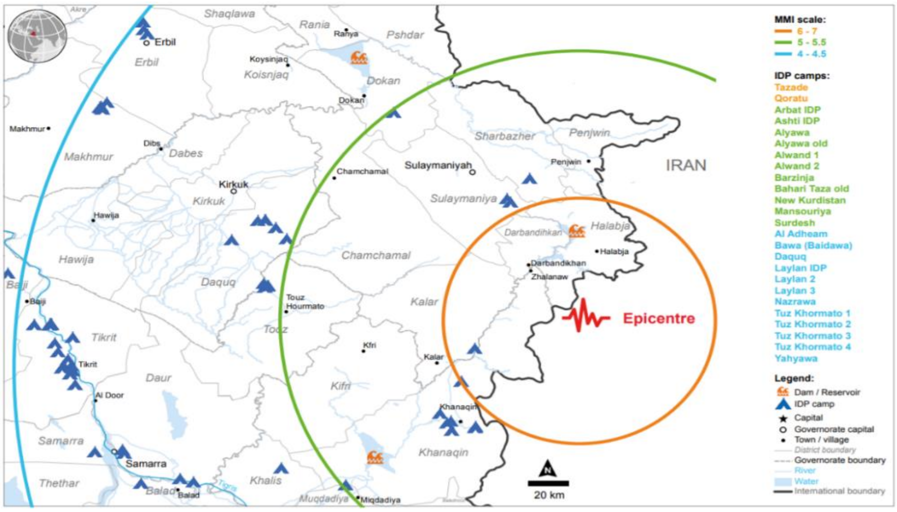

Fig. (3): Location of Darbandikhan with respect to the epicenter of the M 7.3 Earthquake (USGS, 2017a)

Four of the Iraqi causalities and approximately 80 injuries were from Darbandikhan (OCHA, 2017). In terms of structural damages and collapses, several buildings were completely collapsed and numerous buildings are severely damaged causing huge cracks to form in their infill walls and load bearing walls. Holding back the Diyala river, a multi-purpose dam of Darbandikhan was noticeably cracked. Some settlement and landslides noticed on top of the it. It is believed that the cause of these damages in the dam was sliding of the lands that are pushed heavy rocks and rubble onto the dam's spillway (OCHA, 2017).

2. Experimental work and Methodology

The experimental work is carried out in form of site investigations to all the damaged buildings in Kurdistan region of Iraq. The two targeted places are Halabjah and Darbandikhan as most of the reported damage and building collapse took place in Darbandikhan and Halabjah. Therefore, the performed work is in form of visual inspection of the damaged buildings and using engineering judgements in deciding the scientific reasons behind their failure. For this purpose, the authors visited all the areas with damaged structures in both Halabjah and Darbandikhan in a series of trips to investigate the possible causes of structural damages scientifically and propose a suitable solution for retrofitting them if possible. The investigation started by site visiting and taking more than 300 photographs of the damaged buildings and structures in the two cities. The first site investigation visit was carried out to Halabjah on 14th of November, 2017 to all the affected areas and more than two site investigations were carried out to Darbandikhan on 18th of November and 1st of December to collect data and comprehend the possible reasons behind all the damages and the collapses in the buildings and structures. Overall, the authors visited nearly all the damaged buildings in both cities. In Halabjah, nearly 8 buildings are investigated, 6 of which were R.C frame building, one of them was load bearing wall system, and the last one was a school made out of stone. In Darbandikhan, more than 16 buildings are investigated, 8 of which were constructed using R.C frame method and the rest used hybrid system which is combining R.C frame at the ground level and masonry for the rest of the floors. The detailed damage analysis

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is carried out using visual inspections and engineering judgements based on essential principles in earthquake engineering. The cases are discussed individually as some of them had a collection of reasons as possibilities for their damage. Based on the preliminary site investigations it was obvious that in Halabjah, the effects of the earthquake were minor compared to that of Darbandikhan. The following paragraphs of this paper show the detailed analysis and discussion of the causes and reasons behind structural failures and damages.

2.1 Earthquake Impacts on Halabjah

Halabjah is located 14 km away from the Iranian border. It is one of the cities in Kurdistan Region of Iraq which is at 35°11′11″ N 45°58′26″ E. The epicenter of the quake was only 30 km away from Halabjah. During the site investigation visit, no serious damages were observed in buildings in Halabjah, even though, the name of was attributed it based on (USGS, 2017a). The most common types of damage in Halabjah was cracking of infill walls due to the to and fro motion of the buildings during the earthquake. These cracks can be seen in the R.C frame buildings and in partition walls as they transfer the lateral loads from beam-column joints of the upper floor to the one beneath working like a brace that will be exposed to a huge compression force during an earthquake as it can be seen in Figure 4 (c). Also, because those infill walls were made out of concrete blocks, they are weaker than concrete in compression and as a result they develop cracks. These types of cracks are usually diagonal for the reasons mentioned. Examples of the cracks were observed in Halabjah Children Hospital as it can be seen in Figures 4 (a) and (b). The possible solution recommended by ASCE/SEI, (2007) for these walls is repairing of the finishing with blocking the crack using epoxy or strong mortar injection (ASCE/SEI, 2007). The detailed procedure is described by (Dehghani et al., 2015) as it can be done by peeling off the whole cracked finishing surface from both sides and repairing the cracks by filling them with strong mortar then carrying out the finishing on both sides once the mortar dried out. This solution is considered as sufficient, as the main function of infills are to be used as partitions otherwise the whole load is carried by the frame. In fact, they are deliberately built to damage during an earthquake to dissipate some energy based on (Eurocode 8, 2004).

There were some column hinges formed in some of the commercial R.C frame buildings in the area such as that shown in Figure 5 and Figure 6. This type of failure can be explained as the building is not designed to resist earthquake loads and the principle of strong column- weak beam was not followed to prevent collapse. Also, the concrete used for the columns could crumble easily using a little force of a hand so the columns could not resist the shear force on them as the concrete was extremely weak. The authors confirmed that the concrete of the columns could easily come off by using a force as little as a kick as it can be seen in Figure 6. Therefore, due to the oscillation of the building and stiffening the building with masonry walls, the column ends were not free to displace and as a result those hinges were formed. As for retrofitting the columns of this building, some methods are proposed such as using steel caging and PTMS which is post tension metal strap and it is widely proven that it will retrofit the columns easily (Chin et al., 2020; Garcia et al., 2014; Helal, 2012). The method works by tying high tensile strength steel straps around affected areas of the columns using a pneumatic machine for tensioning and then clipping the ends to fix them. Another method is using I section columns next to the existing ones to support them in carrying the gravity loads already on the columns.

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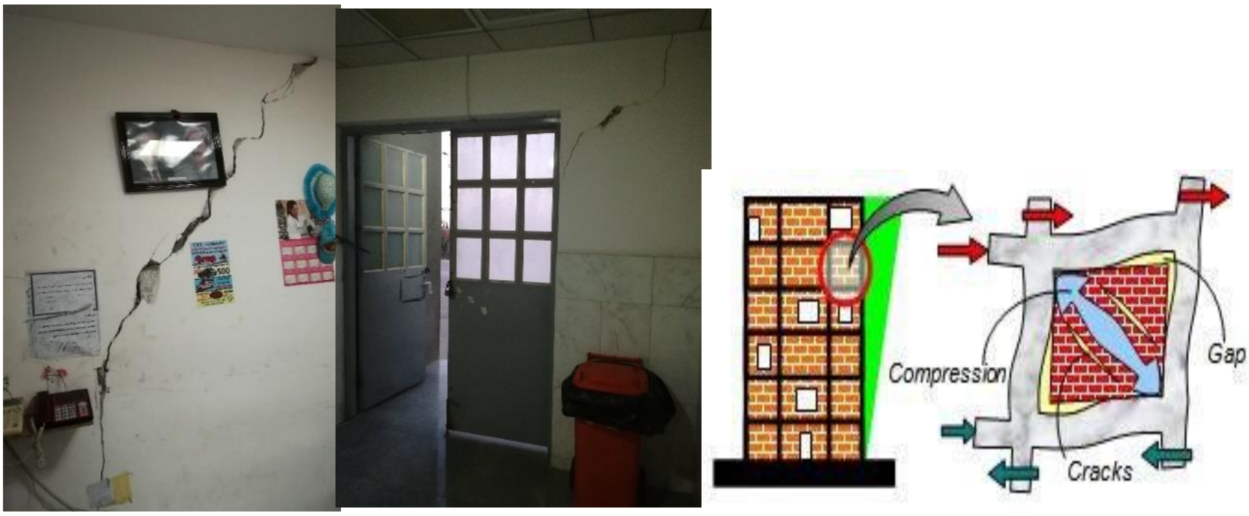

(a) (b) (c)

Fig. (4): (a) and (b)**:** Cracks in infill walls in Children Hospital in Halabjah (c) Illustration of how infill walls work during an earthquake (Murty, 2004c)

Fig. (5): Damage in a column of a 7-story reinforced concrete building in Halabjah

Fig. (6): Easily crushing the concrete by one of the authors as a sign of very weak concrete

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Another common type of damage in both Halabjah was using massive tiles for finishing and Hilan stone for cladding. So, during the earthquake most of the tiles were fallen off because of the vibrations as it is clear in Figure 7 which are the walls of a Hospital in Halabjah. This has led to evacuating the hospital as it caused panic among the staff and patients of the hospital. The irony in this case is that during earthquakes, hospitals must remain fully operational and functional yet they locked down the hospital for hours.

As it can be seen form Figure 7. the status of the concrete block walls was stable as no cracks can be observed in them to point for a failure, therefore, the possible reason for falling the tiling is poor construction and using weak mortar as only the tiles are affected not the walls. Therefore, the solution is to mount new tiles on all the walls again using stronger mortar or change it to gypsum plastering as it is more suitable in terms of construction.

Last type of damage noticed by the authors was in Halabjah Children Hospital and it was the pounding effect happened between the construction joint of the building as it can be seen in Figure 8. This is because the space of the joint was not large enough to house the displacement of the top floor and caused hammering between the two parts of the buildings when they displaced towards each other during the earthquake. The possible solution is to renovate the construction joint and grout the concrete cover of the columns using stronger mortar as the reinforcements were exposed to the air. The columns were in front of the hospital and the load on them was not heavy enough to cause worries but still repairing was needed.

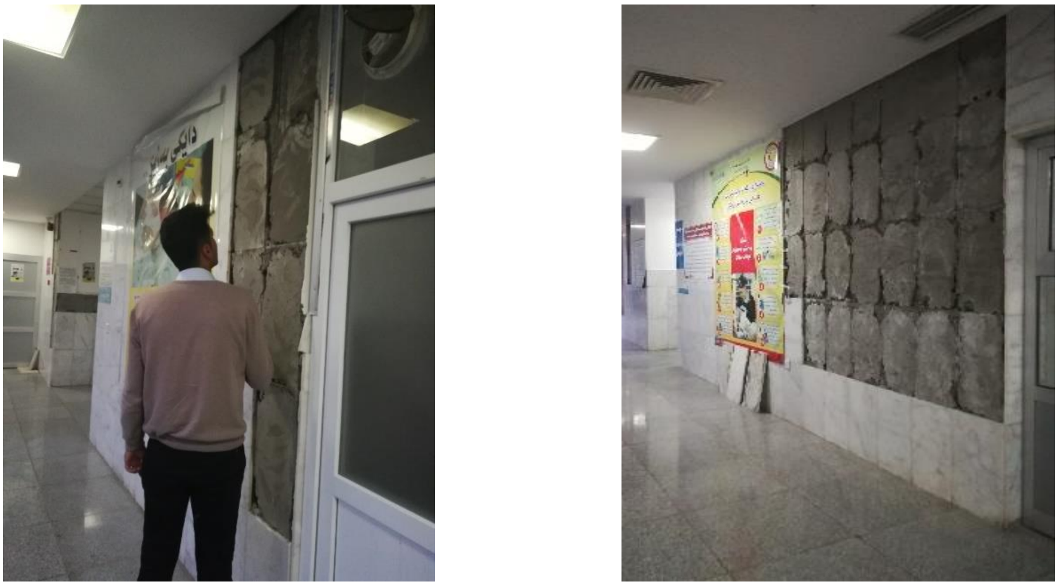

Fig. (7): Falling of heavy tile finishing inside the Children Hospital in Halabjah

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Fig. (8): Pounding effect between two columns in the Children Hospital in Halabjah

2.2 Earthquake Impacts on Darbandikhan

Darbandikhan is a town in Kurdistan region of Iraq located at 35.116°N 45.686°E, where it is the southeast of Sulaimania with a distance of 55 km from it. It was nearly 40 km away from the epicenter of the earthquake yet the damage observed there was more severe than that observed in Halabjah. More than three hybrid buildings (using R.C frame for the ground floor and masonry for the rest of the building floors) were totally collapsed. This is considered as a high rate because hybrid systems used only in the buildings with more than one floor otherwise load bearing wall system is more frequent in the area as the typical type of building as discussed by (Yaseen & Ahmed, 2018) is single storey buildings. The collapsed hybrid buildings of Darbandikhan are shown in Figures 9, 15, and 16.

Numerous factors can contribute in collapsing of these buildings. For instance, in the building shown in Figure 9, which was a two-storey building with a frame base and two masonry floors, apart from using two different systems combined, the mass of the slab and very deep lintels over windows and doors were accumulated in front of building as it can be seen in Figures 10 and 11. This caused it to have more inertia forces during the earthquake and because the upper story was masonry so there was not enough connection between the slab and the supports as to provide the stiffness needed to balance for the inertia forces based on the illustrations in Figure 13. As a consequence, the slab slipped off on the supports and caused the total collapse of the building. Another factor that added to the causes of the total collapse might be the soft storey effects. Because the ground floor was an open area supported only by long columns that was higher than the other floor as it was used as a storage area. Therefore, based on the analogy of the illustrations in Figure 14, it can be concluded that the mass of the first floor of the building was accumulated on top of the ground floor as lumped mass to create an inverted pendulum that caused a huge unbearable drift due to large amount of inertia force that caused the total collapse. Other factors might be irregularities in the plan of the building, as it can be seen from Figure 9, where the left-hand side of the building was longer, which was extending for the whole length of the land of 20 m, wider with a width of nearly 5 and taller, with an estimated height of at least 6 m as it was double spaced used as a parking area as the witnesses reported three buried cars under the rubble of the building, than the right hand side of the building. Because of this, it required a huge slab thickness of an estimate of 25 to 30 cm with very deep lintels with the depth of nearly 80 to

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100 cm all over the front of the building. This shifted the center of mass of the whole building towards the left-hand side and front of the building. Therefore, it was less stiff than the right-hand side so it caused a notable rotation of the whole building. Also, three water tanks can be seen in Figure 9 on the roof top which adds the weight to the roof and can cause drift of the roof by increasing the inertia forces. There are other factors which related to the lack of the details of traverse reinforcement of the columns as it can be seen in Figure 12. Also, the quality of the concrete appears to be not satisfactory enough as it did not resist any shear forces of the columns and a clear cut can be observed in Figure 12 which is a sign of not resisting the column shear forces. From the same figure, it can be seen that the beam sections are larger than that of the columns which is opposite to the principles of designing earthquake resistant buildings where strong column- weak beam has to be applied. Otherwise, the ground floor should have withstood the loads on top like the collapsed building in Figure 15. Looking at Figure 9 a huge crack can be seen in the middle of the slab slicing the slab into two different pieces. This confirms the fact that the building has rotated and the right-hand side of the building pounded to the left-hand side worsening the situation and adding more reasons to the total collapse.

Figure 9. Collapse of a three-story Building using Hybrid system of (R.C Frame- Masonry) (front view)

Fig. (10): Large R.C lintels of depth of more than one meter in front of the house

Fig. (11): the scale of the lintel compared to a 40 cm concrete block

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Fig. (12): Long columns supporting the ground floor (Back of the house)

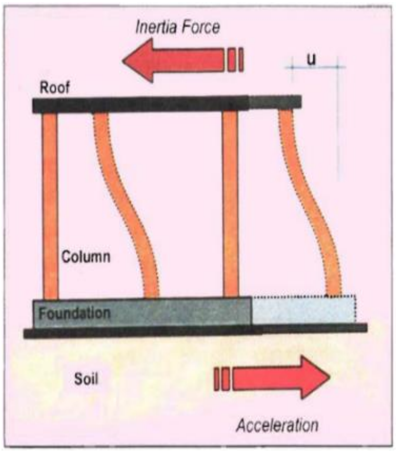

Fig. (13): Basic principles of structural dynamics (Murty, 2004a)

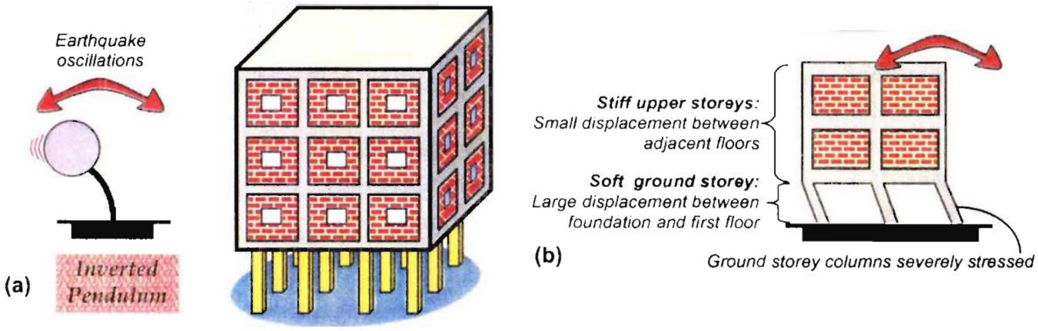

Fig. (14): (a): The principles of soft storey effects as it acts like an inverted pendulum (b) when the ground floor is higher and less stiff, it is considered as a soft storey (Murty, 2004e)

Another building hybrid of a three storey in Darbandikhan, shown in Figure 15, was collapsed due to several reasons apart from using the hybrid system. Most of the above reasons such as strong beam-weak support, asymmetry in plan, and huge slab mass are still true for the failure of this building. Also, Figure 15 (b) shows the side view of the building, and it can be seen that the building was spacious at the first-floor level and there was barely a wall to support all the beam and slab masses. Moreover, it was obvious that the cantilever slab of the first floor in front of the building had a circular long column with an estimated length of 6 m that was used to support the weight of the slab along with those little brittle walls at the end of both sides the of first floor. Because the mass of the building was not distributed evenly as the back of the building had an irregular extra floor, as it can be seen in Figures 15 (a) and 16 (a), adding the mass of the back and shifting the center of mass of the building towards the back and its left hand-side. All in all, having only a long column in front and a huge mass at the back and using the analogy in shown Figure 17, it has caused a rotation of the building, especially the third floor of it, towards its left-hand side and causing the total collapse. The evidence of rotation is clear at the base of the third floor as it can be seen in Figure 16 (a). The crack patterns on the slab, which can be seen in Figure 15 (a), point to the path of the yield line of the slab as it had left with no other supports apart from the long column during the earthquake which can be seen in Figure 16 (b). This happened as, during the earthquake, the slab of the building with

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additional mass of the third floor started rotating towards left so the masonry walls, those helped the long column in carrying the weight, failed and scattered into pieces as they are brittle and the amount of the contact area was not much due to the spacious area. Concrete blocks with no cracks can be seen on the ground which points failure due to rotation. The rotation of the slab had left the column alone in carrying the weight of the slab and from the cracks of the slab it can be concluded that the column was strong enough to cause punching shear and cracks in this pattern in the slab, otherwise, the slab would have just collapse without any cracks of this pattern. Furthermore, a factor that aggravated the situation was not knowing the behavior of the members and not detailing them correctly, for instance, as an obvious shear crack and a shear failure, which is brittle and terminal, can be seen from a short deep beam between what seems like a corridor in the first floor as in Figure 15 (b). From the remainder of the reinforcement of that beam, it can be concluded that it had reinforced as the extension of the other beam and was not treated as a deep beam therefore, it failed in shear breaking the slab into two pieces at that location. A small lintel can be seen behind the shear crack which failed in shear as the left hand-side of it scattered into pieces. These summaries the total causes of failure of this building.

(a) (b)

Fig. (15): (a) Front view of a collapsed three-story hybrid building (b) Side view of the same building

(a) (b)

Fig. (16): (a) Rotation of at the base of the third floor (b) A collapsed circular column

Another collapsed masonry hybrid building was a guest house of the dam shown in Figure 17. From the plan of it, shown in Figure 17 b, it can be concluded that the layout of the plan was not symmetric by using unparalleled walls which provides minimum resistance to lateral loads. Also, the columns in front of the buildings were supporting huge slabs above them without any beams or walls in between to increase their stiffnesses. A beam can be seen hanged on the

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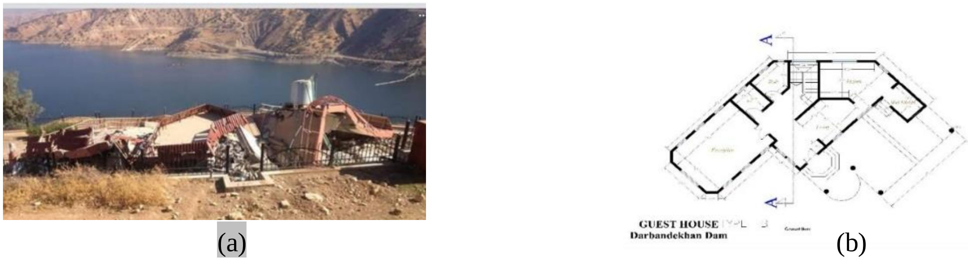
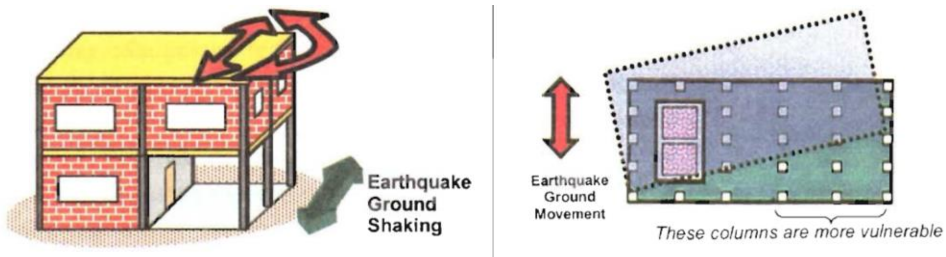
slab between two columns without having any columns or girders to transfer its load. This leads to having a huge inertia forces during an earthquake which leads to rotation of the building as it is illustrated in Figure 18 and led it to fail because of the asymmetry in the plan. This leads to an asymmetry in the stiffness as the first floor of the building was stiffened using masonry walls, however, the ground floor was stiffened using flat slabs supported only by slender columns.



(a) (b)

Fig. (17): (a): Collapse of two-story guest house building using (b): Plan of the building



(a) (b)

Fig. (18): (a)**:** The elevations asymmetry effects (b) Irregular distribution of the stiffness (Murty, 2004b)

A totally collapsed R.C frame observed is shown in Figure 19. The reason of the collapse was an accumulation of short column effects in the basement and soft story mechanism on top of it at the ground floor. The short column theory suggests that for a building floor with different heights of columns, the shorter columns attract more forces as they will be stiffer and as a result, they will either explode or crack diagonally as illustrated in Figure 20. The building shown in Figure 19 had a basement for which the columns of the left- hand side were shortened to make space for windows. As a result, the left-hand side column backed with the ground and did not have a chance to displace freely as the right-hand side did. As evidence, little spaces left for windows can be seen in the basement which proves that there were long columns buried on the left-hand side. Therefore, if the building jerks suddenly from right to left then the columns on the right-hand-side would be free to move while the motion of the columns on the left-hand side is restricted by the ground. As a result, the short columns next to the small widows exploded due to attraction of huge lateral forces as they were stiffer leading to a tilt in the building towards left hand-side, exactly where the small windows were in the basement as it can be seen in Figure 19 (b). The evidence of short column effects can be seen as the whole building collapsed towards left-hand side as in Figure 19 (b). The slab of the penthouse and water tanks can be seen on the left-hand side of the building which appears as if they were thrown this way due to the sudden failure caused by the short column effects in the basement as it can be seen in Figure 19 (b). Adding to the factors, soft storey mechanism might have been another mistake in the collapse of this building, as the first and second storey of the building were stiffer than the ground floor of

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it. So, using the analogy of Figure 14, it can be argued that it has added a reason to the failure. The area moment of inertia of the building added a reason to the failure as the shape was thinner in the direction of the collapse. The aforementioned factors might have contributed in the collapse of this building as having a heavy mass on each floor and having that slim shape which produced less stiffness in the direction of the collapse. The short column effects, was a fatal mistake in this building otherwise, the authors confirm the elements were supplied with enough reinforcements


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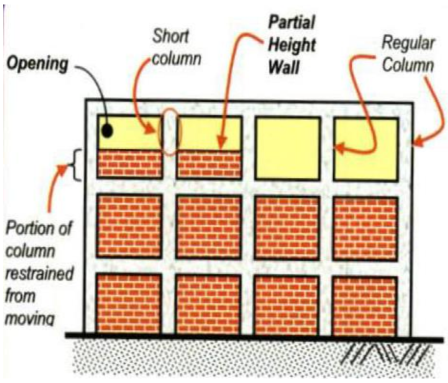
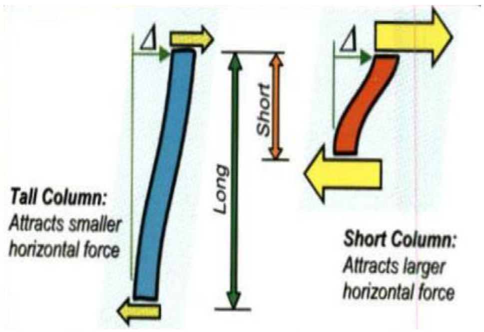
a)

(b)

Fig. (**19 (a)**)**.** The building before collapse. (b) Collapse of Four-story R.C frame Building.



(a)



(b)

Fig. (20 (a)): Typical short column effects. (b): The analogy of short column effects. (Murty, 2004d)

Hinges in upper end columns of Darbandikhan' main bus and taxi station was described as a "strange failure" by the locals. As it can be seen from Figure 21, only the upper part of some of columns were exploded during the earthquake. Several possible reasons contribute in having this kind of failure in the columns. First is that the upper parts of the columns displace more due to more acceleration response per height while only damping and stiffness contribute to counteract that much of displacement. However, in this structure, the shape is an oval which provided minimum resistance as it is irregular, and it has no extra stiffness from walls as they were open spaces so the only members resisting the inertia forces were columns. Yet, that irregularity in the plan makes it vulnerable to earthquake as it has fewer number of columns aligned to provide the stiffness needed to counteract the huge inertia

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forces produced by the mass of the slabs and beams. It also, causes rotations of the slabs and that was leading to sudden explosion of the top parts. Moreover, the lack of the transverse reinforcement close to beams added reasons for not having enough strength in resisting the lateral forces. It can be seen in Figure 21that the spacing of the ties in that sensitive area was more than 40 cm which is not allowed under any circumstances. Pounding effects was another reason, as the station was huge enough to be constructed as one part therefore, it was distributed to more than three parts but with different heights which increases the effects of pounding. From figure 22, it is clear that there is a huge vertical crack between the middle columns in the middle of the photograph which is a clear sign of pounding effects. Also, the height of the floor was more than 4 m to accommodate buses and it has heavy beams and slabs on top. This would be fatal as it acts as an inverted pendulum creating a soft story and leading to such explosions. Lastly, poor quality of the concrete was argued to be another factor in hinging those columns, however, because in some of the columns only the cover of them was spalled therefore, it is believed that the lack of confinement is the main reason not the concrete itself.

The proposed solution was to increase the confinement of the columns. It is recommended to retrofit them using a low cost and fast method of strengthening. First the exploded vicinities have to be filled with a strong concrete where possible otherwise with a strong mortar if it was only the cover spalled. Then, the most suitable method of confinement should be selected in terms price and time of execution. The cheapest and the fastest method in increasing the confinement found in the literature is using PTMS. It is proven by so many researchers in the literature (Chin et al., 2020; Garcia, Hajirasouliha, Guadagnini, Helal, Jemaa, Pilakoutas, Mongabure, Chrysostomou, Kyriakides, Ilki, Budescu, Taranu, Ciupala, et al., 2014; Helal et al., 2016, 2016; Lopez et al., 2012; Ma et al., 2019; Moghaddam et al., 2010). Alternative methods include enlargement of the sections using section enlargement or retrofitting those columns using steel cages. In both cases, the process takes a lot of time and needs extra expenses for the labor works such as reinforcement works, molding and curing.

Fig. (21): Hinging in columns at exterior supports

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Fig. (22): Hinging in columns with an idea on the shape of the station

Another problem in that station and the main hospital of the Darbandikhan was having short column effects causing diagonal cracks in some of the columns as it can be seen in Figure 23. Because having a short column is very dangerous as it would explode straight away due to the large forces attracted by their huge stiffness as is illustrated in Figure 20 (Murty, 2004d). The possible solution is to eliminate having those short columns and distribute the stiffnesses equally. The solution for those exploded areas of the columns is to fill that gap in between the short columns with strong R.C sections like beams to act like shear walls. Also, to extend the beams on top of them onto the slab of the shorter part of the station to a certain length. Knowing that they still have to be confined with some techniques of confinement such as PTMS.

Fig. (23): Short column effects

The rotation effects were clearly visible in a residential building shown in Figure 24. The building was stable at its current state but the twist could have been seen from a distance. The

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main reason of rotation is the center of mass of the building was not aligned with the center of rigidity as described by (Murty, 2004b). This can be observed form the back of the building in Figure 24 (a) that one side (left hand-side) is higher which means heavier than the other side. This caused a rotation in the whole three floors as it is illustrated in Figure 18. The solution for this case is prevention from the design stage and before constructing it, however, the owner of the building started demolition the last floor to reduce the gap between the center of mass and the center of rigidity.


(a)


(b)

Fig. (24): Rotation of a frame building in Darbandikhan (a) Isometric view of the building showing its back(b) Side view of the building

The diagonal cracks in masonry walls were frequent in the general hospital of Darbandikhan as it be seen in Figure 25. The reason for this phenomenon is explained in the previous paragraphs and illustrated in Figure 4 (c). These diagonal cracks along with falling off the finishing tiles and Hilan stone caused panic and fear amongst the staff of the hospital who evacuated the building and caused a lock down of the hospital. Two days after the earthquake and 14^{th} of November the hospital was still closed down while it should have been operational immediately after the earthquake. The only cause of this type of falling was not having a strong bond between the material and the wall during the oscillation of the building during the earthquake. This happened as poor material used in constructed them which is very clear in Figures 26 (a) and (b) where the walls did not even crack while all the finishing materials are peeled off. The possible solution is to repair the area using stronger mortar and using a wire mesh as reinforcement.

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Fig. (25): Diagonal cracks in the infill walls

(a) (b)

Fig. (26) Finishing material state in the Darbandikhan general hospital (a) Falling off of the tiles inside (b) Hilan stone falling outside.

Concrete spalling of the joints in frame buildings was another frequent issue found in some of the R.C buildings in both Darbandikhan and Halabjah. It is frequent when there is an infill wall between the columns and the infill wall is stronger than the concrete of the joint. The philosophy of the design for earthquake recommends having stronger joints than beams and even columns. The main reason for this is the lateral forces are transferred from one floor to the other beneath through the joints and walls as it can be seen in Figure 4 (c). Therefore, the walls have to act like infills not to block the movement of the joints. So, the infills should have cracked not the joints opposite to what it can be seen in Figures 27 (a) and (b). Another reason is not having enough confinement in the joints as it is clear form Figure 27 (b) where the joint has only one tie extended from the column. The solution is to make the joints stronger than the infill wall. This can be done using the same method of PTMS for strengthening the joints by increasing the confinement.

Another frequent damage and sometimes collapse type were found in penthouses which can be seen in Figure 28. The main reason for these failures is thar the response acceleration is higher on the top floor and this causes a huge displacement. More, the penthouse has huge slabs and sometimes even a parapet which adds

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the mass with having a few walls to stand against the inertia forces causing them to fail or collapse. Not having enough connection between the base of the penthouse and the slab its build upon is another factor making it vulnerable to lateral forces. It is proven that with having more axial forces on a member the displacement would be restricted.

(a) (b)

Fig. (27): Concrete spalling in the joints in frame buildings (a) seven-storey residential building in Halabjah (b) Municipality building of Darbandikhan

Fig. (28): Collapse of the penthouse

3. COMPARISON OF TYPES OF DAMAGES BETWEEN HALABJAH AND DARBANDIKHAN.

As it can be seen from Figure 29, the damage in Darbandikhan out weighs the damage in Halabjah as five of the examined buildings totally collapsed while none of the buildings collapsed in Halabjah. Moreover, different earthquake effects can be seen in Darbandikhan starting from cracks in infill walls to short column effects which caused building collapse however, only minor earthquake effects can be observed in the damaged buildings in Halabjah earthquake.

The common type of damage in buildings in Halabjah is crack of infill wall which was observed in 4 buildings. In Darbandikhan, most of the R.C buildings had cracks in their infill walls but only 8 of the 16 investigated buildings were having cracks in their infill walls. Massive tiling was the second most common type of damage and it caused panic during the earthquake. The same panic was observed in Darbandikhan general hospital leading to hospital closure which is not allowed to happen based on the codes of design. Because during the earthquakes hospitals should remain operational and the earthquakes should have minor effects on them.

The main cause for these collapses can be summarized as having stiffness irregularities, short column effects, and soft storey mechanism. Based on the observed collapse, stiffness irregularity was the most frequent type of error leading to rotation, damage and collapse of the

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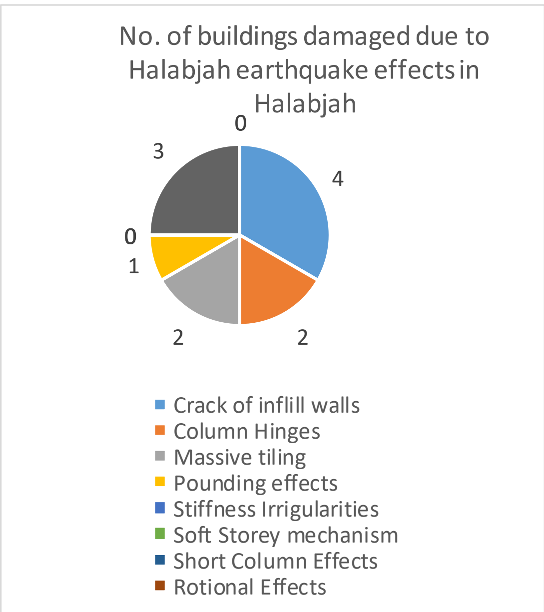
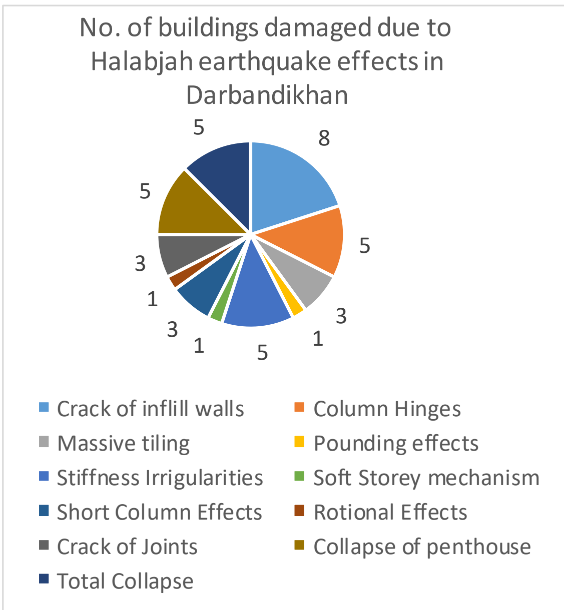
buildings. This is particularly true for the collapsed hybrid buildings. The second most common type of error leading to fatal mistake is short column effects which had noticeable impacts on the buildings such as a total collapse of a four storey building and serious of hinges in both Darbandikhan general park and Darbandikhan general hospital.

4. REMARKS

Finally, it worth mentioning that in this paper only the structural reasons are discussed, otherwise there might be other factors including the soil condition, altitude, location, etc. that might have had inputs in the damages. Also, due to the dangerous state of the collapsed buildings, the authors could not risk their lives looking for other clues that might have helped the research. Additionally, it would have been helpful to get the plan of the buildings however, due to the non-presence of the home owners on the site and evacuation this was not achievable. Moreover, the detail design of the buildings was unknown however two of the collapsed buildings were found on Bing Map which points to their existence before 2013. Therefore, it can be claimed that they were either not designed to resist lateral loads or designed with older code versions. Also, due to not having a national code, the buildings are usually designed based on international codes of design. Therefore, there is a strong the need for having a unified national code for all the designers and site engineers can be understood which can be setup through thorough investigations and data collections on the buildings and areas hit by the earthquakes. As (Issa, 2017) pointed out that there are variety of the design codes used and relied on by the local designers and engineers. Therefore, they should be unified in under a single national code to guide our engineers.



(a)



(b)

Fig. (29): Number of buildings damaged due to Halabjah earthquake effects in both (a) Halabjah and (b) Darbandikhan

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5. CONCLUSION

Structural damages are inevitable during earthquakes and the causes behind building failures vary from one building to another and form a location to another. As it is shown, some of the strong buildings collapsed during Halabjah earthquake while the others survived. Therefore, the earthquakes need to be guided as to where they can damage in a building to release and dissipate their energy. To do so, a satisfying balance should be kept between strength, stiffness and toughness. This can be achieved by knowing and implementing the principles of earthquake design, understanding the behavior of the buildings during earthquakes and avoiding common mistake that leads to the collapse. The following conclusions can be drawn from this paper:

1- Knowing the principles of earthquake resistant buildings outweighs knowing the earthquake design procedures because a four-storey, strongly designed R.C building in Darbandikhan collapsed due to ignoring some of the principles such as avoidance of short column effects.

2- Avoiding stiffness irregularities in the buildings that will be designed to resist earthquake load because most of the collapse observed can be attributed to stiffness irregularities. This is fatal as the building might not have enough stiffness to counteract the inertia forces in all the directions.

3- A strong need in bracing the design principles of hybrid houses which are very common in Kurdistan region of Iraq because some of the totally collapsed building in Darbandikhan were in this category.

4- Using heavy cladding in the hospitals are not preferred as they might fall during an earthquake and they can cause fear and panic leading to a closure of the hospital during an earthquake while they should be functional all the time.

5- Avoidance of having double spaced floor for parking area underneath the buildings as it creates unbalanced stiffness vertically which can cause collapse of the buildings especially those built using hybrid system. This effect is known as soft storey mechanism and it has caused collapse of building during earthquakes in the past.

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