RESEARCH ARTICLE OPEN ACCESS

Effects Of Earthquakes On Concrete Buildings In Kuwait

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ABSTRACT
Most residential low rise buildings in Kuwait are constructed using reinforced concrete and infill walls. The behaviour of concrete buildings under seismic loading is dependent on ductility and stiffness of concrete buildings which depends on the quality of materials used in construction, the level of technology adopted in design and construction and the workmanship. This paper presents a research done on the effects of earthquakes on concrete buildings in Kuwait. Most buildings are constructed in river valleys where the soil formations are mass deposits of silt and sand, and the sites are characterised by shallow water tables. Weak sites produce higher amplification factors as compared to firm grounds in an event of ground movements.
Design and construction of concrete buildings resistant to earthquakes depends on the risk involved in loss of life and the probability of occurrence of earthquakes in the area. In Kuwait City, tall buildings have been constructed with earthquake resistant features in accordance to local earthquake design code to enable them stand without damage in the event of a minor earthquakes, bear damages without failure in case of major earthquakes and fail completely with warnings in case of extreme earthquakes (PRASAD, 2018).
Al Hamra Tower is the tallest building in Kuwait and currently the 16th tallest building on the planet at 1352 ft. Built with reinforced concrete, Al Hamra Towers is one of the tallest structures built with concrete. Soil conditions on site are composed of sandy silty loose soil subsurface of a depth of approximately 1.4 m and a high water table of approximately 2m below surface level. The rock below is made of sandstone and siltstone. The foundation is composed of a raft and piles system. To resist earthquakes and other lateral loads the structure consists a complex cast in situ reinforced concrete shear wall which transfers lateral loads to the foundation (CLAUS, et al., 2007).

Date Of Submission:02-10-2018 Date Of Acceptance: 13-10-2018

I. INTRODUCTION

When the ground moves in an event of earthquakes buildings tend to remain at rest due to the inertial response as described by Newton's first law of motion. The inertial forces and the stored kinetic energy causes the structure to vibrate. The inertial force generated is dependent on the mass of the building and the magnitude of the earthquake.

Around the world earthquakes occur at many areas where there are complex fault systems. When the rupture occurs, the fault systems release all accumulated strain in stages and at different locations high stresses are formed resulting to successive ruptures until the system becomes stable. These consecutive ruptures cause occurrence of multiple earthquakes which are hard to classify as foreshocks, main shocks or aftershocks (ADEL, 2012).

These repeated earthquakes are responsible for failure of structural systems. Multiple earthquakes cause loss in stiffness and structural strength of the building elements due to loss of strength of material caused by effects of consecutive earthquakes (Chandradhara, 2018). Consecutive earthquakes result to cumulative damage in buildings which reduces their stiffness and strength capacity.

Research on the causes of collapse of reinforced concrete buildings due to seismic activity from historical events has shown that failure in most occasions is as a result of loss of strength and stiffness of the structures due to cumulative damage by previous shocks in multiple earthquakes. Some buildings remained intact during the main shocks but collapsed during the aftershocks (ADEL, 2012).

Seismic damages in reinforced concrete structures have also happened due to plan and development reasons, for example, utilization of inadequately safe cement, the frail reinforcement support of delicate stories and column to beamconnections, construction design resulting to short columns, not looking after shear support and utilization of solid bar feeble segment. Clearly,some of the damages in unreinforced concrete from past earthquakes happened because of the fact that it is not designed to take the seismic loading (Ates, et al., 23June2013).

In occurrence of earthquakes, collision of neighbouring structures happens because of their diverse natural frequencies and additionally, deficient spacing between them. Pounding of adjacent structures in the event of strong earthquakes is not typically considered and more often than not causes very sudden damages despite that seismic action maybe regularly considered in basic design (Ehab, et al., November 2014).

In metropolitan urban areas, structures are frequently close since there is a limited land spaces available and utilization of land shouldbe maximised because of the high population. Hence, for metropolitan urban areas situated in locales of dynamic seismicity, the hammering of adjacent buildings may represent a conceivably major issue. Hammering of adjacent reinforced concrete buildings structures during tremor excitations is one of the reasons for structural damages and collapse of storeys. This lateral impact from the adjacent buildings if not considered in design may cause excessive damages of the struck storey or complete collapse of the whole structure (Ates, et al., 23June2013).

The main causes of seismic failures and damages can be classified into: Design inadequacies (delicate story, deficient horizontal bracing, short columns, strong beam weak column connections, vertical or level inconsistencies, and so forth.) and construction faults (poor workmanship, poor quality control, deficient shear reinforcements in columns, deficient strength of material, short columns.).

II. CONCRETE

Due to its outstanding properties, reinforced concrete is one of the most widely used construction material worldwide.Concrete is a composite material produced by mixing cement, fine aggregates and coarse aggregates with water. Fresh concrete can be shaped to take the desired form unlike other construction materials. However, concrete possess low tensile strength. (World Housing Encyclopedia, 2006)Reinforced concrete is a composite construction material in which reinforcement steels bars are used in concrete to improve the tensile strength of the concrete elements.

Concrete constructions calls for a set level of workmanship, expertise and technology. However, most residential buildings around the world are built without the required assistance from engineers and architects (The Constructor, 2017). These buildings pose death risks to the individuals living among them especially in seismic prone areas.

Concrete is hard material but breaks easily when subjected to tensile stresses due to its low tensile strength. Ductility is necessary for a material to deform without loss in strength or a sudden failure in occurrence of earthquakes. The ductility and tensile strength of concrete elements to withstand seismic forces is achieved by use of steel reinforcements in the concrete elements (Chandradhara, 2018). Structural concrete elements used in building constructions include slabs, beams, columns, shear walls and connections.

The main reason of failure in reinforced concrete structures under seismic loads is failure to consider their ductility in design. Research from previous seismic failures of reinforced concrete design it has been noted that use of poor concrete, weak reinforcement of beam and column joints (Isler, October 12-17, 2008), soft storey and short columns increases the chances of failure in occurrence of earthquakes.

III. SEISMICITY IN KUWAIT

Kuwait is a state located on the Arabian Gulf at the north-western end and on the Arabian Peninsula at the north-eastern part. Due to its closeness to the Zagros belt, its exposed to risk of seismicity and this warrants the need for seismic considerations in the design of structures within Kuwait. The Zagros belt is capable of generating earthquakes of magnitudes up to 7.5 on Richter scale. Kuwait is also prone to local earthquakes of magnitude 5 on the Richter scale usually originating from the southern part of the Minagish oilfields. (SADEK, 2004) An earthquake of magnitude 4.8 took place at Minagish oil field which was felt at Kuwait City causing a lot of terror on 2nd June, 1993. This location experienced again earthquakes of magnitudes 3.9 and 4.2 on September 1997 and 30th December, 1997 respectively (Pascucci, et al., October 12-17, 2008).

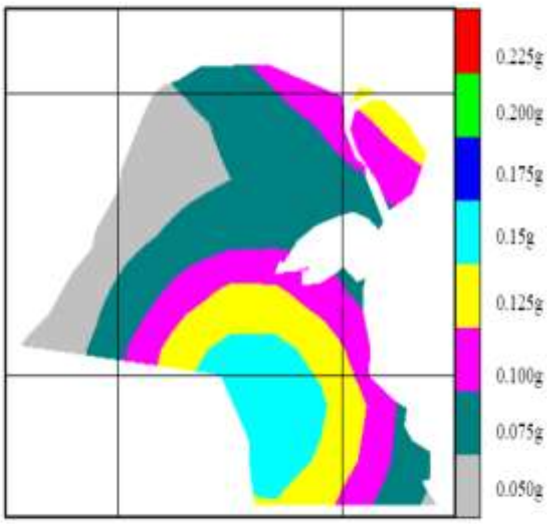

Figure 1 Kuwait seismic hazard map adopted from (SADEK, 2004)

Insufficient and missing data on seismic activity in Kuwait presents a challenge to engineers while performing seismic analysis for various sites in the state of Kuwait. The state of Kuwait is classified as an area of low to moderate seismicity (Pascucci, et al., October 12-17, 2008).

The Arabian Peninsula region is comprised of several tectonic plates, the Red Sea and Dead Sea on its West, the Owen Fracture zone and Gulf of Aden at Southeast and south, Makran and Zagros regions to the northeast and continental Arabian Plate at the centre (Dr. Rabee, April 2015).

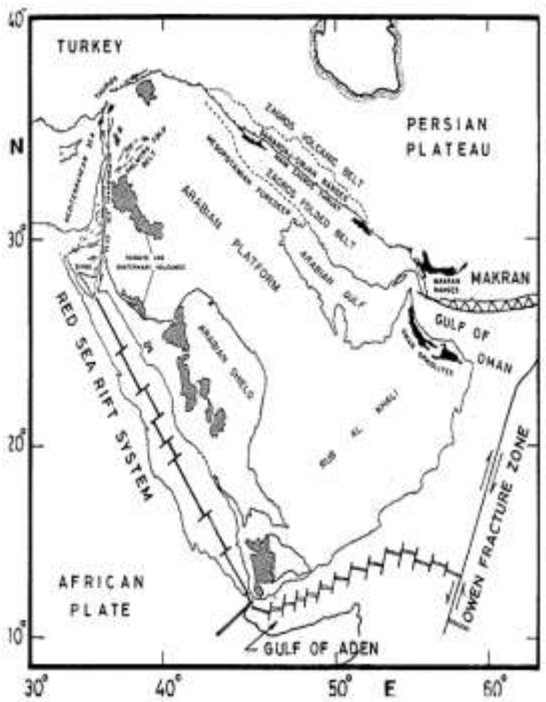

Figure 2 The Arabian Peninsula Tectonic boundaries adopted from (Pascucci, et al., October 12-17, 2008)

Effects of Earthquakes on Concrete Buildings

The response of concrete buildings in occurrence of earthquakes is dependent on various factors such as the building shape, natural frequency of the building, presence of masonry infill wall, presence of short columns, adjacent buildings, soft and weak stories etc. (Girgin & Yılmaz, 2010)

Irregular shape and the layout of concrete buildings has been a major cause of their poor performances in previous earthquakes. It is therefore important for engineers and architects to work as a team from the early project stages to ensure that the building is designed to the simplest and symmetrical shape possible (World Housing Encyclopedia, 2006).

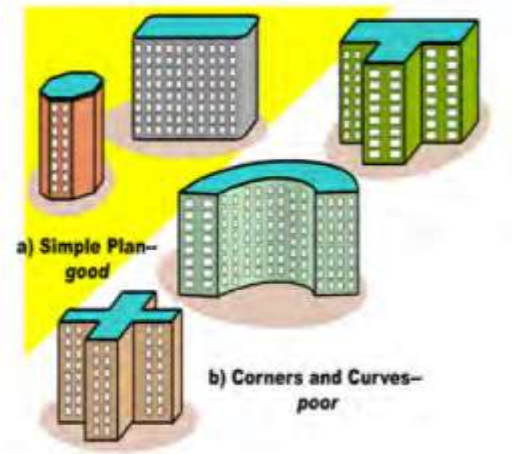

Figure 3 Building shapes affecting seismic failure adopted from (World Housing Encyclopedia, 2006)

Report on past earthquakes have shown that buildings with angular corners on plan have failed terribly as compared to buildings with simple geometrical plans. During ground movements occurring due to earthquakes, the simple plans provided uninterrupted and direct load paths to the building foundations for the forces of inertia.

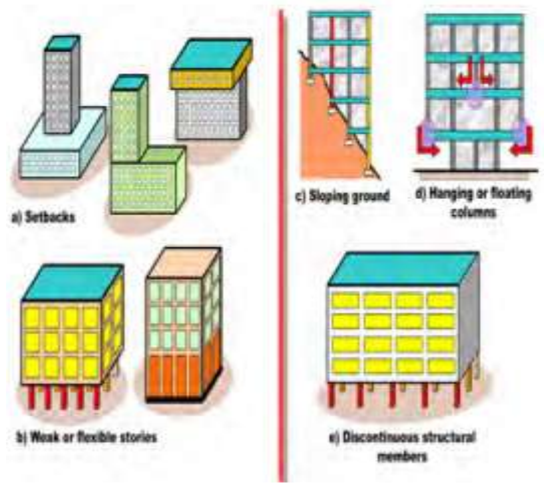

Figure 4 Building load paths adopted from (World Housing Encyclopedia, 2006)

In some instances, irregularity of the structure is avoidedthrough separation of building into simple shape blocks broke by an air gap. This prevents increase in stresses at the sharp corners which causes damage to structural elements. However, the two blocks may strike each other during earthquakes if the separation is insufficient.

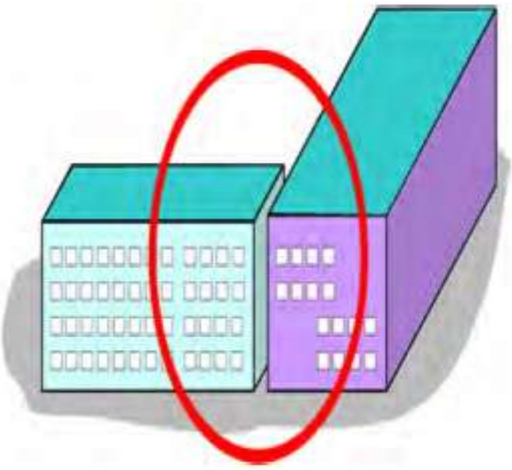

Figure 5 Building separation to avoid sharp corners adopted from (World Housing Encyclopedia, 2006)

Vertical irregularities including uneven number of walls or columns in particular stories within a building shows soft story behaviour and incur damage or total collapse initiated in the weak story (Girgin & Yılmaz, 2010). Concrete buildings built on sloping ground with columns of different heights, these buildings are susceptible to damage or collapse due to failure of the short columns. Failure of these buildings is as a result of sudden change in building seismic resistance at the point of change in structural elements.

Discontinuities in components that are expected to channel tremor loads from the structure to the ground are relevant too. For instance, structures are susceptible to damage or failure if they have columns transferring loads to beams at lower intermediate levels at which point they are discontinued. Concrete buildings with discontinuous reinforced concrete walls are similarly susceptible to damage in occurrence of earthquakes. When the discontinuity of the vertical elements occurs at higher levels, the building faces higher chances of severe damage during earthquakes of higher magnitudes (World Housing Encyclopedia, 2006).

Structures with unpredictable shapes need normality/symmetry in design, which may bring about winding under seismic tremor shaking. For instance, in a propped overhanging building the overhanging segment swings on the comparatively slim pillars under it. It is vital to limit distortion of a concrete buildings during tremors. Torsion causes structural components at a similar floor level to move on a level plane by various extents. Because of torsion, walls and columnson the most affected parts undergo more damage (Girgin & Yılmaz, 2010).

Numerous structures have been seriously influenced by undue torsional impacts amid past tremors. It is best to limit (if not totally prevent) this torsion by insuring that structures have symmetry in design (i.e., consistently conveyed mass and consistently put vertical elements resisting seismic tremor loads symmetrically). seismic tremor opposing casings symmetrically along the outside border of a building; such a format expands building protection from torsion/turning. To improve resistance to torsion seismic resisting frames are placed symmetrically along building exterior perimeter (World Housing Encyclopedia, 2006).

Masonry work is utilized as infill walls in the spaces between columns and beams in both the inside and outside RC outlines. The material of the workmanship infill is the primary variation, ranging from cut common stones (e.g., rock, sandstone or laterite) to man-made blocks and bricks (e.g., hollow concrete blocks, burnt clay bricks and hollo clay tiles).

Figure 6 Masonry infill adopted from (World Housing Encyclopedia, 2006)

Reports from past earthquakes have shown that concrete buildings masonry infill have performed poorly. Masonry infill presents a challenge in design of earthquake resistant buildings and it negatively affects the seismic performance of concrete buildings. To incorporate masonry infill in buildings, it should be carefully designed by a professional engineer to provide bracing to the frame without failing. The infill masonry walls ought to be uniformly distributed within the building to provide a smooth and direct load paths (World Housing Encyclopedia, 2006).

A few columns in reinforced concretebuildings might be significantly shorter as compared to others in the same floor. Short columns happen in structures built on an incline or in structures with mezzanine floors or space sections that are included between two customary floors. In past tremors, reinforced concreteframes withcolumns of differentheights in the same story experienced more damage in the shorter columns than in the taller columns situated on same floor. This is because short columns are stiffer, and require a greaterloading to twist by a similar extent as taller columns that are more elastic. This higherload for the most part brings about a greater damage to short columns (The Constructor, 2017).

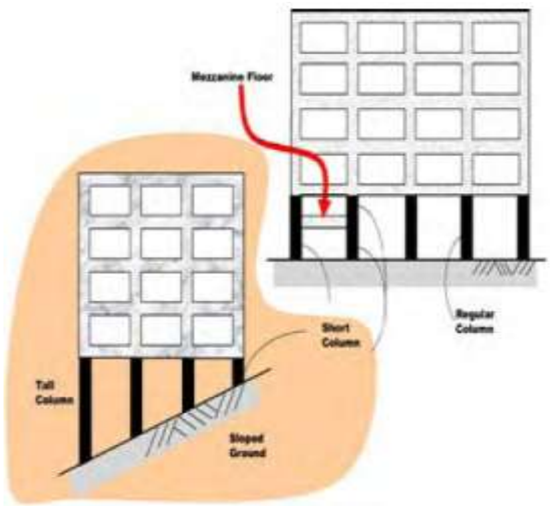

Figure 7 Short columns adopted from (World Housing Encyclopedia, 2006)

There is another uncommon circumstance in structures when the short-section impact happens. Consider a stone work mass of fractional stature with a window above it. The upper part of the section beside the window carries on as a short column because of the nearness of the infill wall, which confines the development of the lower bit of the column. These columns are referred to as captive columns since they are somewhat limited by infill walls. Much of the time, different columns in a similar story are of normal height, as there are no infill walls abutting them. At the point when the floor diaphragm moves on a level plane in occurrence of a seismic tremor, the upper ends of all columns experience a similar relocation. Be that as it may, the solid infill walls confine an equal movement of the lower parts of the captive columns, so the captive columnsdislodge by everything over the short height of the adjoining the window opening. Then again, normal height columns dislodge over the full height. Short columns attract larger seismic forces as compared to normal columns because the effective height over which they can twist is small, this results to short columns sustaining more damage as a result of shear failure(World Housing Encyclopedia, 2006).

When shaking occurs due to seismic activities two building located too close to each other collide in an effect known as pounding. This occurs in buildings of different heights where the roof of the shorter building pounds the mid height of columns of the taller building during strong earthquakes. This may result to collapse or storey damage (Ehab, et al., November 2014).

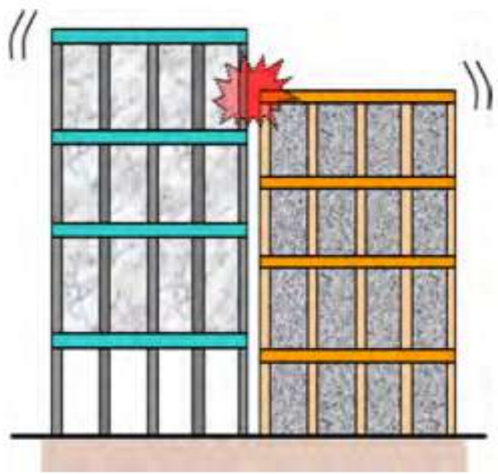

Figure 8 Pounding in adjacent buildings adopted from (World Housing Encyclopedia, 2006)

The most well-known kind of vertical anomaly happens in structures that have an open ground story. An open ground story building has masonry work infill walls and columns in the upper stories however just columns in the ground story. Basically, these structures look as though they are supported by chopsticks! Open ground story structures have reliably indicated poor execution amid past quakes over the world (Girgin & Yılmaz, 2010). In numerous examples, the upper part of an open ground story working (over the ground story level) moves as a solitary inflexible square; this influences the building to behave like an inverted pendulum, with the ground story columns going about as the pendulum pole and whatever is left of the building going about as an unbending pendulum mass. As an outcome, expansive developments happen locally in the ground story alone, consequently actuating extensive damage in the sections amid a seismic tremor. Weak stories can likewise happen in the moderate floors of a building, and cause damage and fall at those levels (World Housing Encyclopedia, 2006).

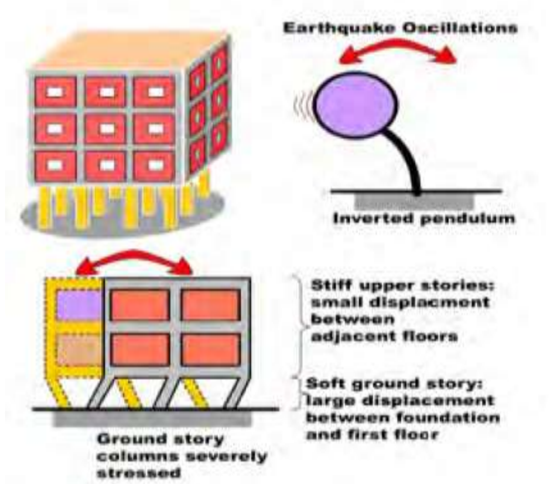

Figure 9 Soft and weak storey adopted from (World Housing Encyclopedia, 2006)

The following two features are characteristic of open ground story buildings:

- Relatively weak ground story as compared to the stories above, i.e., the total horizontal earthquake force (load) resisted at the ground story level is significantly less than the stories above (Girgin & Yılmaz, 2010). Thus, the open ground story is a weak story.
- Comparatively feeble ground story in contrast with the stories above, i.e., the aggregate even quake compel (stack) opposed at the ground story level is altogether not as much as the stories above (Chandradhara, 2018). In this way, the open ground story is a frail story.

In a reinforced concrete frame building subjected to earthquake ground shaking, seismic effects are transferred from beams to columns down to the foundations. Beam-to column connections are also critical in ensuring satisfactory seismic performance of these buildings. The currently accepted approach for the seismic design of reinforced concrete frames is the so-called strong column weakbeam approach (World Housing Encyclopedia, 2006).

In a reinforced concrete building that has experienced seismic ground movements, seismic impacts are transferred from beams to columns and further down to the foundations. Beam to column joints are vital in providing acceptable seismic performance in these concrete structures. The right and acknowledged approach for the seismic design of reinforced concrete structures is known as strong columns and weak beam approach (World Housing Encyclopedia, 2006).

Data collected on past historical earthquakes have shown that concrete buildings designed with weak columns and strong beams experienced damage as compared to concrete buildings design by strong column - weak beams approach (PRASAD, 2018).

These susceptible reinforced concrete buildings have comparatively small column dimensions as compared to beam dimensions as are called strong beam – weak column buildings. From past earthquakes reports failure of small section weak columns has been reported around the world. In case where complete failure doesn't occur the damage on the small weak columns is extensive and not feasible to repair. These buildings are therefore demolished to avoid catastrophic consequences (PRASAD, 2018).

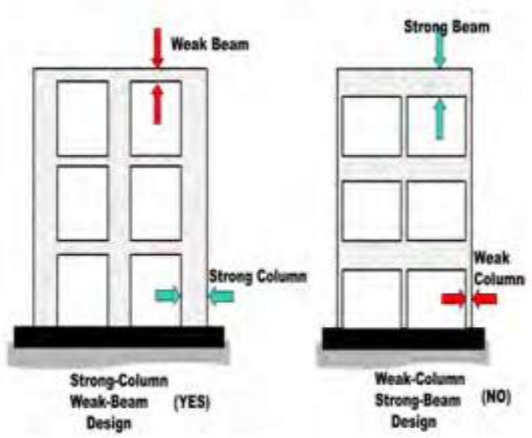

Figure 10 Strong beam - weak column connections adopted from (World Housing Encyclopedia, 2006)

IV. RECOMMENDATIONS IN DESIGN AND CONSTRUCTION OF CONCRETE BUILDINGS

A building designed and constructed to be resistant to earthquakes should withstand minor earthquakes without any structural damage, it should withstand moderate earthquake with minimal structural damage and no failure and in an event of severe earthquakes the building should fail with ample warning (Chandradhara, 2018).

Four main attributes are necessary for a building to perform well in occurrence of earthquakes which include: the form and shape of the building should be simple and regular; the building should possess sufficient lateral strength to withstand the lateral seismic loads, stiffness in plan and elevation and ductility (PRASAD, 2018). Recommendations for design and construction of seismic resistant buildings are listed below:

- Buildings should be constructed in areas with low risk to seismic activities as possible and sites with soft and loose soil formations should be avoided as much as possible.
- To produce earthquake durable designs and constructions and avoid potential sources of danger the building design and construction should be made as simple as possible by avoiding slope at the building foundation level,

avoiding abrupt asymmetric changes in stiffness, avoiding designs and constructions resulting to heavy top levels of the building and long heavy cantilevers and complicated building plans should be separated to produce simple ground plans separated by seismic joints which can be replaced after occurrence of earthquakes.

- Distribution of shear walls and frame elements should be made as symmetrical as possible to increase the capacitance of those elements against torsion vibrations as large as possible. Irregular ground plans should therefore be avoided.
- Long slender buildings should be avoided.
- Ductility should be limited at the lower building parts, this usually happens where the lower floors are left as open as possible for halls to be used as retail spaces, supermarkets, banking, hospitals etc. and therefore the flow of infill walls as in the floors above is interrupted. These practices increase the ductility of the lower floors and therefore increases the chances of failure for the columns.
- Plastic articulations should never be placed in columns, these articulations absorb energy in case of severe earthquakes making the columns weak and susceptible to failure.
- Heavy weights on top parts of building causes the building to act like a reversed pendulum and increases the swing amplitude and vibrations therefore increasing the chances of failure. It should therefore be avoided.
- Redundancy in design and construction of earthquake resistant buildings should be adopted to ensure that failure of one element doesn't result to collapse of the whole structure. When one element fails the loads are transferred to other elements.
- Extensive studies should be carried out to understand the geological formations at the building site. The building should then be designed and constructed to adapt to the conditions underground, ductile buildings should be constructed on soft and loose undergrounds while rigid buildings should be constructed on frim undergrounds.
- Sufficient distances should be provided between buildings to prevent buildings from crushing into each other in an event of earthquakes.

V. CONCLUSION

The effect of earthquakes on concrete buildings in Kuwait is dependent on several factors which include the magnitude of the earthquake, the soil formation at building site, multiple earthquakes, quality of construction materials used in construction, level of technology adopted in construction, workmanship among others.Seismicity decreases the stiffness and ductility of concrete buildings and also results to complete collapse in some cases. Pounding is common in adjacent buildings of different heights where the separation distance between is not sufficient, the shorter building crushes into the taller building leading to collapse.

The effects of soft soils in Kuwait including sandy and silty loose soils plays a major role in amplifying the levels of vibrations due to seismic activities (SADEK, et al., August 1-6, 2004)which have a greater effect on high-rise buildings.

The state of Kuwait faces threat from seismic activities originating locally from the oil mining fields and from the neighbouring tectonic boundaries (Dr. Rabee, April 2015). Therefore, the country should be prepared to face any future threats from severe earthquakes through carrying out elaborate studies on the seismic hazards facing Kuwait, design and construction of earthquake resistant buildings and educating the community on the best behaviour during and after earthquakes.

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Naser S. Almutairi "Effects Of Earthquakes On Concrete Buildings In Kuwait "'International Journal of Engineering Research and Applications (IJERA) , vol. 8, no.10, 2018, pp 34-41