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MODERN REPAIRING TECHNIQUES OF RC BUILDINGS DAMAGED DUE TO EARTHQUAKE DISASTER –A REVIEW

[a] ***Muhammad Abrar***

a: Department of Civil Engineering, University of South Asia Lahore, abrar19125@gmail.com

Abstract- Earthquake is the natural hazard which is caused by movement of tectonic plates underneath the earth and has severe impact like collapse of buildings, bridges and roads. Due to these characteristics it has a great influence on economy, social life of humans of a country as natural hazard. Reinforced concrete (RC) buildings get damaged by the high intensity earthquakes along with the loss of life of occupants. The purpose of the study is the impact of earthquake on human life, damages due to earthquake and its influence towards economy. The aim of this paper is to study the modern techniques that are being used to repair and strengthen earthquake damaged RC buildings. The state of the art literature is reviewed and it has been observed that retrofitting is widely used in strengthening and repairing of RC building. This paper focuses on the damages of RC buildings due to earthquake in Pakistan and different types of retrofitting for repairing and strength enhancing. Since there are limited techniques present to rehabilitate the earthquake damaged RC building so there is a need of experimental work to find out new ways of repairing.

Keywords- Earthquake, Fiber reinforced polymer (FRP), Repairing techniques, Retrofitting.

1 Introduction

An earthquake is a hazard which may become disaster when there is a vulnerable society present in risk area. It is a phenomenon of large intensity with limited time duration, causes loss of lives and economical damage along with disruption of social life. If earthquake becomes disaster it exceeds the local capacity and resources so sometimes external aid is needed to cope this disaster. Earthquake may cause the damages of roads, collapse of buildings and bridges. During the earthquake in Pakistan in 2005 about 400,000 buildings were collapsed or damaged. About 79,000 injured, 90,000 died and more than 3.5 million were homeless. Govt. reported that more than 19,000 children died under school buildings collapse [1]. Due to the damage of these structures and hospitals the emergency treatment centers were established in timber houses. As earthquake damaged this huge amount of structures so social life of humans was highly affected. To accommodate these earthquake affected homeless people, there was a need of vast re-construction for fully damaged buildings, rehabilitation and repair of partially damaged building to make them suitable for living.

The most of the damages in RC buildings occurs due to short columns, large and heavy overhangs, defects due to workmanship, discontinuity of beams, and lack of control [2]. Seismic hazard assessment is important factor to take part to the efforts towards increasing the resilience of cities [3]. Different types of data bases are present that records damages due to worldwide hazards. It has been observed that the ratio of loss has been considerably increase after 1970. There are many factors that are responsible for this change in trend of loss in terms of damages of buildings, economy and loss of human life. Urbanization is the important factor with growing population. Due to this factor the vulnerability against hazard has considerably increased. Hence population in danger zone areas related to earthquake has considerably increased. The damages due to earthquake has to be compensated by means of repairing of damaged buildings and reconstruction.

Reconstruction cost is much higher than repairing that's why repairing is often accomplished to strengthen the earthquake partially damaged structures [4]. Retrofitting is most popular technique for repairing and strengthening [5] [6].

The purpose of this paper is to provide a comprehensive overview to the damages due to earthquake. Damages due to earthquake in Pakistan during earthquake of 2005 are mainly focused. The loss of life, number of homeless people, damages of houses and impact of these factors is on overall economy and rehabilitation costs is studied. Damages due to earthquake, failure pattern and methods to repairing and strengthening of RC structures are discussed.

2 Earthquake Disaster impacts in Pakistan

Earthquake is a natural phenomenon caused by ground motion due to movement of tectonic plates underneath of earth [7]. It has some triggering point from which it generates and spread to a vast area in short time. An earthquake was recoded on 8th of October 2005 in Pakistan. It was the strongest earthquake of the history of Pakistan. The main center of this earthquake was northern area of Muzafarabad district with depth 26 km and had magnitude of 7.6. High seismic activity was noticed in terms of aftershocks after main event of earthquake. About 12,909 aftershocks were recorded by Pakistan meteorological department and 59 aftershocks had magnitude of 5.0 or greater than this value [1] [8]. The most affected areas due to earthquake in Khyber Pakhtunkhwa were Abbottabad, Shangla, Kohistan, Mansehra, and Batagram. Some areas of AJK were also affected i.e. Poonch, Bagh and Muzaffarabad.

2.1 Socio-economic loss due to earthquake

There were about 5.1 million people affected due to earthquake in 2005. People of Pakistan experienced many earthquakes which are present on record. A number of people died and huge economy loss was noticed during study of literature. As a result of this inflation also increased in Pakistan. A number of people became homeless and it was a big challenge to provide new home to those affected persons. Table 1 provides comprehensive data of causalities due to earthquake excluding tsunami, number of homeless people and total number of affected people in a year along with damages in US dollar (USD) from 1935 to 2019. Impact of damage on consumer price index (CPI) is also given [9]. Asian development and World Bank published a report in which they claim that 787,583 houses were affected. 203,579 housed were completely collapse down during 2005 earthquake.

Total economic loss of Pakistan was calculated as $5 billion. Table 2 shows the economic loss in terms of restoration of livelihood, re-construction cost, relief package, death/injury compensation and percentage of total loss. It was noticed that there was huge loss of lives during earthquake of 2005 as compared to other earthquake of Pakistan. The number of yearly deaths from 1980 to 2014 due to earthquake are present in Fig 1. The causalities during earthquake in 2005 are nearly 39,000. The ratio of deaths registered is quite low [10]. On the other hand EM-DAT system recorded 73,338 deaths. It is clear from this two databases that the values of recorded causalities are different by different disaster data base resources. This can be due to lack of database management or due to unreliable data gathering means and missing data cards.

Table 1-Total loss due to earthquake in Pakistan [9]

Year	Total Deaths	Injured	Homeless	Total Affected	Total Damages ('000 US$)	CPI
1935	60000	25000		25000		5.37
1945	4000				25000	7.06
1972	100			5000		16.36
1974	4700	15000	5200	50200	3255	19.29
1981	250	2000		2000	5000	35.57
1981	6	12		237		35.57
1983	24	543		543	3000	38.96
1984	4	12		12		40.63
1985	5	38		12038	2000	42.07

1986				750		42.87
1990	11	250		250		51.11
1990	11	40		40	1000	51.11
1990		6		6		51.11
1991	300	574	29465	204794	10000	53.27
1992	4					54.88
1992	36	100	2000	2100		54.88
1997	50	100	10000	10100		62.79
1998	1	11	600	611		63.76
2001	12	100		914292	500	69.26
2002	17	65	4000	15065		70.36
2002	19	40		140782		70.36
2002	3					70.36
2004	24	63	2320	13148		73.88
2005	73338	128309	5000000	5128309	5200000	76.39
2008	166	320		75320	10000	84.22
2011	2			1000		87.98
2013	41	175		15175		91.12
2013	399	599		185749	100000	91.12
2013	22	50		50		91.12
2015	280	1745	133900	502590		92.71
2015	3	85		85		92.71
2016	6	42		142		93.88
1909	231					3.52
1955	12					10.47
2019	39	746		130398	17000	100.00

Table 2- Loss of economy due to earthquake of 2005 in Pakistan [1]

Category	**US $ M**	**Percentage of total**
Death and injury compensation	205	3.9
Relief	1,092	21.0
Restoration of livelihoods	97	1.9
Early recovery	301	5.8
Short-term reconstruction	450	8.7
Long-term reconstruction	3,053	58.7
Reconstruction	3,503	66.4
Total	5,198	100.0

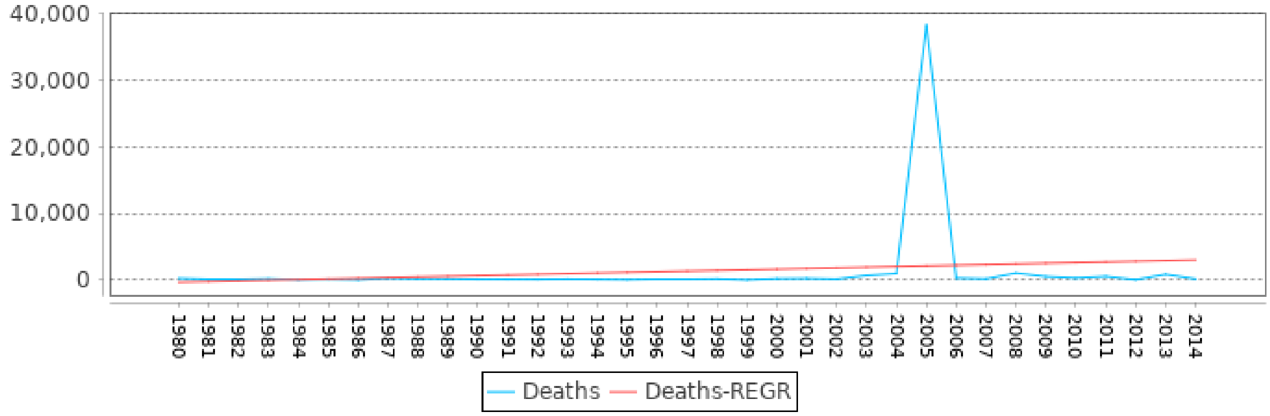

Figure 1: Number of people died due to earthquake from 1980 to 2014 [10]

3 Properties of earthquake damaged RC buildings

Earthquake causes partially damage or total collapse of RC buildings. It has been observed that while designing, building code of earthquake safety provisions is not followed properly that may cause severe damage to RC buildings. Due to this fact a large number of buildings collapsed in Pakistan under earthquake loading. Figure 2 shows the number of houses damaged due to earthquake from 1980 to 2014. Usually cracks are present on the surface of columns, beams and other components of RC structures. The nature, depth and opening of cracks can be observed so that it may be concluded, either cracks are present in concrete cover or they are at full depth. [11] Conducted a series of experiments to understand the failure pattern of Elliptical hollow section (EHS) beams and columns under seismic loading. This study revealed that it was local buckling failure in EHS columns and under combined cyclic and compression bending. There was a diverse failure in case of concrete filled columns including local buckling. Energy dissipation performance and ductility can be enhanced by applying concrete in fill or by improving compactness of steel section.

Columns are the compressive members of RC structure. RC columns must have sufficient ductility and rigidity in earthquake resistance design framework. Under seismic load, columns cannot fulfil the displacement demand hence expected performance cannot be achieved. The phenomenon mostly occurs in case of short columns where stiffness is quite high due to shorter in length than other floor columns [12]. The seismic motion cause lateral load effect whereas short columns try to compensate it by stiffness. Hence short columns do not show the desired ductile behavior. In this scenario, to increase ductility, shear reinforcement is increased [13]. Figure 3 shows the short column shear failure in RC building structure [1]. The failure of beam and column joint can be happened due to insufficient length of development (see figure 4). The development of full strength happens when length of embedment is sufficient.

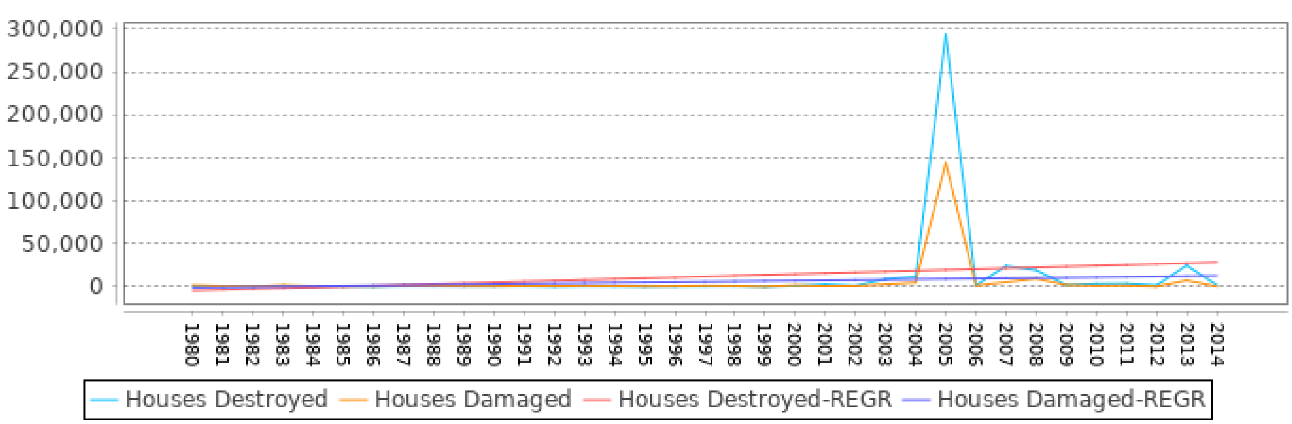

Figure 2: Houses destroyed due to earthquake during 1980 to 2014 [10]

Figure 3: Shear failure in RC short column [1]

Figure 4: Anchorage failure [1]

4 Modern repairing techniques

Earthquake damaged structures needs a repairing and strengthening for rehabilitation and reuse. For post-earthquake re-construction structure stiffness, site selection, beams columns joints and integrity of structures load transformation pattern is analyzed [14]. Fiber reinforced polymers (FRP) and its derivative wraps are most widely used materials in strengthening and repairing of RC buildings. External jacketing technique is also use to enhance the strength of columns. Steel jacketing is the most commonly used against gravity and seismic loads [15]. Due to increase of displacement demand, low flexural stiffness weakens the jacketing effectiveness. To overcome this flaw external collars are applied. For enhancing the performance of short columns external collars are found successful. An investigation was carried out to compare the performance of carbon fiber reinforced polymers (CRFP) wrapped columns and externally collar column to reference columns with no external strengthening. Results indicates that shear cracks are limited due to both strengthening techniques. These columns are more ductile than the reference column and energy absorption is higher than reference columns. If aspect ratio is same the increase in cross-section increased the strength [13].

Since shear failure and diagonal rupture is the failure pattern in short columns under seismic loads. Carbon fiber-reinforced polymer sheets and glass fiber-reinforced polymer bars as diagonal, transverse hybrid techniques are used to enhance strength [16]. Studies indicated that the wrapping of short columns by FRP prevents the buckling. Moreover it leads to a hinge on top and bottom of the column. The wrapping changes the failure from shear to flexure failure [17]. The performance of short columns is considerably increased because energy dissipation is increases to 800% and ductility up to 125% by use of corner strip-batten full wrapping technique [18]. In another study, Polyvinyl chloride tube (PVCT) with high-strength concrete (HC) was used to check the seismic behavior of short columns. HC-PVCT short columns strength degradation was slower and ductility was increased significantly as compared to HC short columns [19].

4.1 Retrofitting technique of strengthening RC buildings

Retrofitting is most widely used to strengthen and repair damaged structures [20]. Buckling-restrained-braces (BRBs) is an efficient technique of retrofitting to enhance strength of RC building present in high seismic zone areas. An experimental study was carried out to check the effectiveness of BRBs. The RC building seismic performance was observed before and after retrofitting with BRBs under incremental dynamic analyses and non-linear static analyses. The model with BRBs retrofitting found more effective under seismic ground motion [21]. Selection of suitable retrofitting rely upon the structural considerations, economy and usage of that particular structure [22]. The available and required shear resistance is calculated by multi-degree-of-freedom. Hence the difference of available and required is fulfilled by steel bracing as additional elements (retrofitting).The retrofit interventions are made to mitigate main structural deficiencies to meet current building code requirement. These building code requirements confined the damage to non-structural elements and provide and way to non-ductile failure mechanism. By increasing the ground motion intensities, retrofit alternatives are evaluated. Mean annual frequency and expected yearly loss of collapse is quantified by risk based decision variables. The retrofit alternatives were then evaluated through increasing ground shaking intensities to quantify risk-based decision variables, such as the expected annual loss and mean annual frequency of collapse. Cost-benefit analysis is also done to check economic feasibility [23].

5 Conclusion

By conducting this study following conclusions can be drawn:

- There was local buckling failure in EHS columns under combined cyclic and compression bending whereas there was a diverse failure in case of concrete filled members including local buckling.
- The bending section governed the failure mode and abrupt failure of concrete section having no buckling failure was noticed.
- Suitable retrofitting depends upon the type of building, failure and economy. Cost-benefit analysis is done to check economic feasibility.
- HC-PVCT short columns strength degradation was slower and ductility was increased significantly as compared to HC short columns.

The conclusion illustrate that columns fail in buckling failure when undergo seismic loading. Failure patterns are different for different type of failure, hence retrofitting is applied according to need of RC buildings. FRP and steel braces retrofitting is most suitable for most of the RC buildings.

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