Construction of Earthquake Resistant Buildings and Infrastructure Implementing Seismic Design and Building Code in Northern Pakistan 2005 Earthquake Affected Area

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Abstract

In Azad Jammu & Kashmir (AJK) and Khyber-Pakhtunkhwa (Previously NWFP) in the morning of October 08, 2005, there was a major earthquake of 7.6 mw magnitude. Approximately 100,000 people dead, 138,000 seriously injured and around 3.5 million people were displaced. Approximately 400,153 houses, 6,298 schools, 796 health facilities, 6,440 km roads and 50 to 70 % services like communication, power, water, sanitation etc were destroyed and damaged. Due to ground shaking (horizontal and vertical components), most damage to buildings and infrastructure occurred. In this paper, we discussed the building construction found and the reasons and causes for large scale destruction to the buildings and infrastructure. We observed that most of the buildings were built without implementing building code and seismic design. Then we discussed the building code of Pakistan (including seismic provisions), particularly for the earthquake affected area, and its implementation. We also discussed the building code and seismic design for construction in Japan and compared it with the practices in Pakistan. We described the seismic design and how to use seismic design in different kind of building structures to make the building structures more resistant to earthquakes. In this paper, we suggested some solutions for the construction of building structures in Pakistan to make the building structures more resistant to earthquake and to lessen the damage.

Keywords: Earthquake, Building Structures, Infrastructure, Building Code, Seismic design, Pakistan

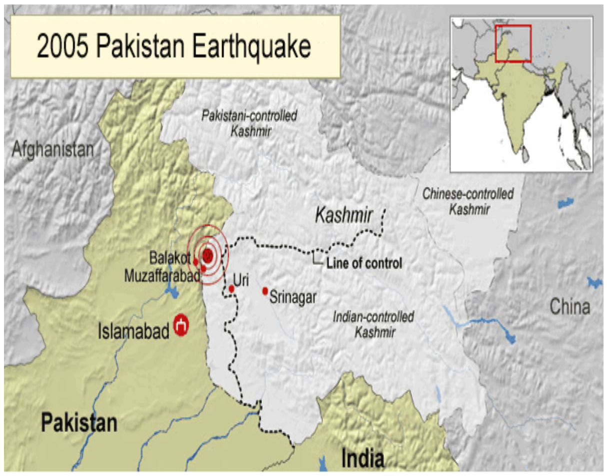
1. *Introduction*

Earthquake is a major natural disaster which caused a lot of destruction in many areas of the world. There was a major earthquake in Quetta (capital of Baluchistan province, Pakistan) causing large scale destruction in 1935. But recently there was another major earthquake in Pakistan having a magnitude of 7.6 mw magnitude striking at 08:50 am Pakistan standard Time (PST, +05 GMT) in the morning of October 08, 2005. Its epicenter was located in the north of Muzaffarabad about 19-20 km and in the east of Balakot tehsil of district Mansehra. Its hypocenter was located at a depth of 16 km below the surface. Its main impact zone was in AJK and Khyber-Pakhtunkhwa province of Pakistan. An area (mostly mountainous and rugged terrain) of about 30,000 sq. km approximately was affected by this earthquake. It damaged about 6,440 km roads. It damaged 50-70 % of services like power, water and sanitation etc. Approximately 400,153 houses, 6,298 schools and 796 health facilities were damaged and destroyed. UN 2006. Approximately 100,000 people were dead, around 138,000 people were seriously injured and 3.5 million people were displaced in this earthquake. ADB & WB, 2005. In the collapses of school buildings, about 19,000 children died. Many highways and important roads were blocked and closed due to damage by earthquake, landslides and rockslides. There is building code with seismic provisions, but it was not well implemented in earthquake affected area. In Japan, the building code and seismic design is well implemented in almost all building structures.

2. *Description of 2005 Pakistan Earthquake*

In This earthquake, the heavily affected areas were Muzaffarabad, Neelum, Bagh, Poonch, Shangla, Abbottabad, Manshehra, Batagram, Balakot, Allai, Beshram and Kohistan. The total estimated cost of damage was around 5.2 billion US dollars including immediate relief, death and injury compensation, emergency medical care, reconstruction and restoration of livelihoods. Beveridge.S. 1975. Ilyas, M, 2005. This earthquake resulted from the seismic activity resulting from the collision of Indian plate and Eurasian plate, because of northwestward motion of Indian plate.

Seeber & Armbuster, 1979. The earthquake occurred within the Hazara-Kashmir syntaxes of the Himalayan fold belt and Indus-Kohistan seismic zone. Balakot-Bage fault was the likely source of earthquake. Hussain 1979. The city of Muzaffarabad suffered intense damage (IX-X on MMI scale) and the city of Balakot was totally destroyed (X on MMI scale), because these cities are within rupture zone. The rupture zone extended in the NW direction damaging the areas of Batagram, Allai and Beshram Qila. Ground deformation was also seen, which was more tectonic. Observational data and reports from the locals suggest a strong vertical component and strong ground shaking. There were also horizontal peak ground accelerations. There were also rockfalls, rockslides and Landslides cutting off the roads and structures on the slope of mountains. Ilyas, M.2005. KMC. COMET, 2006.

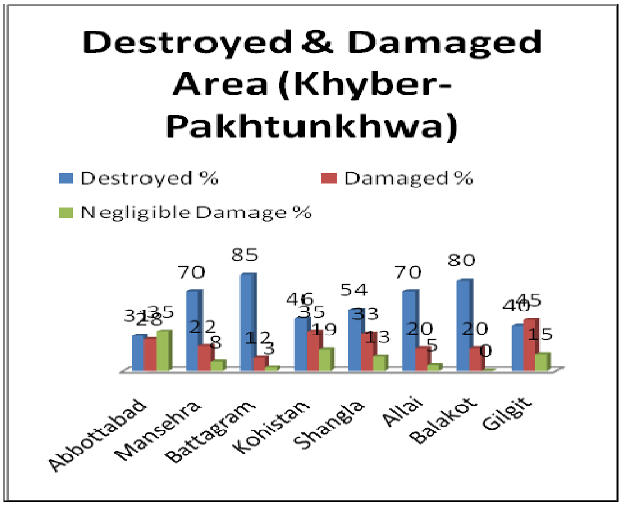


3. *Description of the earthquake affected area*

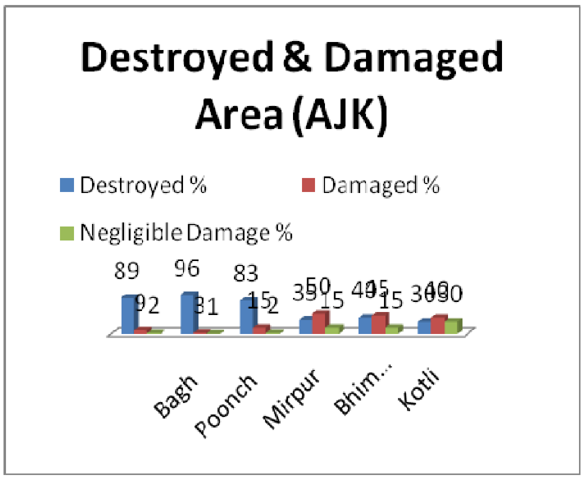
This research was carried out in earthquake affected areas in Azad Jammu & Kashmir (AJK) and the Khyber-Pakhtunkhwa. The state of Azad Jammu & Kashmir (AJK) is the territory of the former state of Jammu and Kashmir, which was liberated by Pakistan and was taken over in October 1947. Kashmir is a disputed territory between Pakistan and India; it is one of the nuclear flash points in the word. The area of AJK is 13,297 sq km and the population is approximately 3.8 million. Durrani, A.J, Elnashai. A.S, Hashash, Y.M.A and Masud, A, 2005. Most households are partly dependent on agriculture, and businesses and Government employment are the major sources of livelihoods. Infrastructure is reasonably well development. AJK is linked to Pakistan and Indian Held Kashmir (IHK) by four major roads. The Metalled roads (as of 2005) nearly 4,760 km, while non-metalled roads nearly 6,116 km. Seeber, L and Armbruster, J.G, 1979. Hussain, A. 2005. Literacy rate of AJK is 60% Khyber- Pakhtunkhwa is a province of Pakistan located in north-western side, bordering Afghanistan and FATA in the west, Gilgit-Baltistan in the north, Islamabad and Punjab in the east and south and Balochistan in the south-western side. The area of Khyber-Pakhtunkhwa is 74,521 sq km and the population is approximately 22 million (estimated in 2008).

4. *Damage to building and infrastructure*

In the 2005 Pakistan Earthquake in AJK and Khyber-Pakhtunkhwa, approximately 400,153 residential building were destroyed and damaged. It is also estimated that 50-70% important official buildings were destroyed and damaged including administration, police, military buildings etc. Due to ground shaking, most damage to building structures occurred. Because of ground failure due to land sliding, rock sliding and subsidence, a large number of building structures located on or near the slopes were destroyed and damaged. COMET, 2005. The most concentration of damaged or destroyed building structures was in Abbottabad, Mansehra, Batagram, Kohistan, Balakot, Allai, Beshram etc in Khyber-Pakhtunkhwa and Muzaffarabad, Bagh, Poonch, Rawlakot, Shangla etc in AJK. In the main event, estimates tell that 60-70% of the building structures were destroyed or badly damaged in Muzaffarabad. In Muzaffarabad, major concentrations of damage were found in the areas of deeper alluvial deposits along the rivers named as Jhelum and Neelum. In Balakot, damage was directly related to fault rupture. Several other towns located along the rupture zone (Bagh to Batagram) several towns also suffered significant damage to their building structures. Collapse of the high rise Margala Towers was due to construction issues in Islamabad which is located over 80 km from the epicenter. EERA & URL 2005.According to the government sources of Pakistan, it is estimated that more than 80% of the total destroyed building structures were located in rural regions. An aerial survey revealed that a large number of buildings destroyed were in the more rural and mountainous areas proximate to the fault rupture. COMET, EERA, URL, 2005.

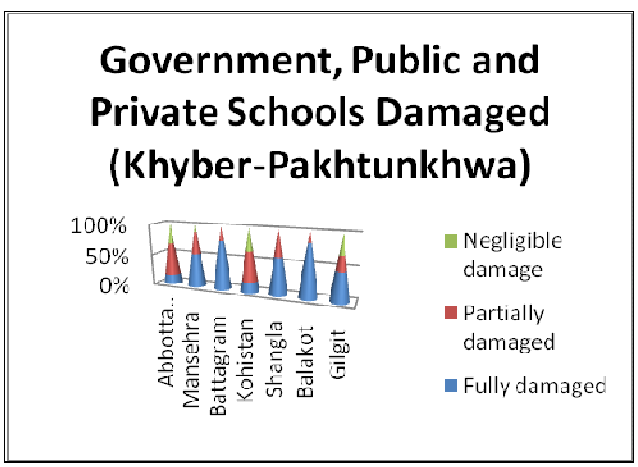


Source: Internal Sources of ERRA, Prime Minister's Secretariat (Public) Islamabad, Pakistan. Preliminary Damage and Need Assessment Report by ADB and World Bank, UNDP, and District Government Pakistan

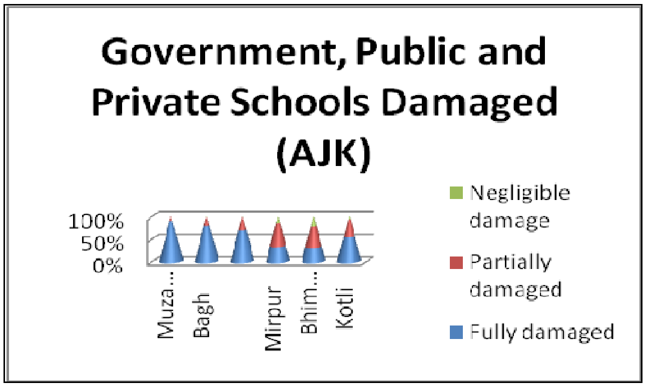


Source: ERRA, Preliminary Damage and Need Assessment Report by ADB and World Bank, UNDP, and District Government AJK Pakistan.

Most of the schools are registered (Government, Public and Private) and some unregistered schools (Mosque school etc). Most of school building collapsed due to non-seismic design, low quality construction, improper design etc. At the time of Earthquake, almost all schools were open and functioning with the classes being held.



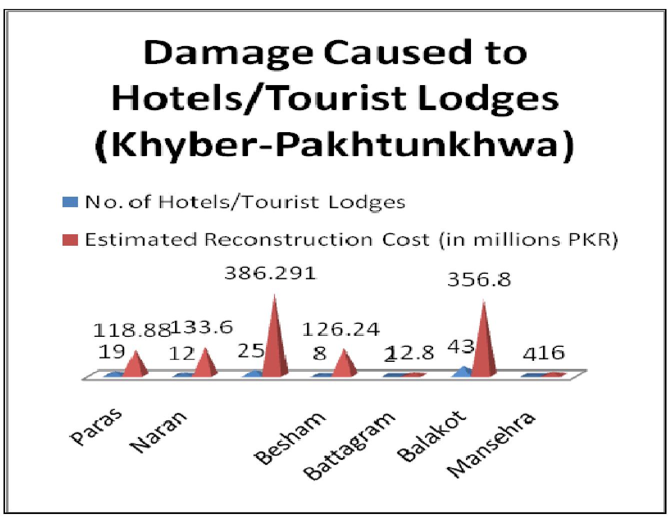
Source: Director Education Pakistan, ERRA, UNDP, URL, WB/ADB Preliminary Survey



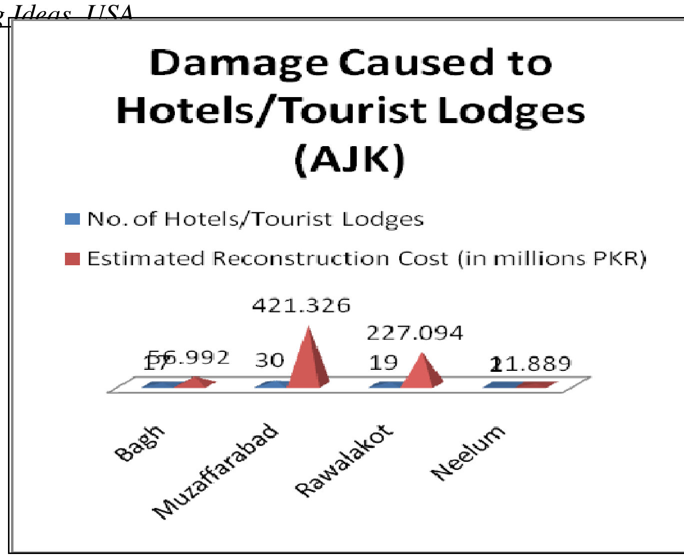
Source: Director Education / Education Statistics Azad Jammu & Kashmir 2004-2005 by EMIS; Azad Kashmir at a Glance 2006, P&D Department Muzaffarabad ERRA, UNDP, URL, WB/ADB Preliminary Survey.

Most of the hospitals in the region also suffered severe damage or collapsed. One main hospital in Muzaffarabad, Combined Military Hospital (CMH) totally collapsed killing or injuring many patients and workers. Ayub medical Complex also faced little damage. There were also many other hospitals like DHQ hospitals and children hospital suffered damage. The major valleys of Jhelum, Neelum, Kaghan and Naran were completed cutted off for land access. Many road closures were due to landslides, rockfalls, slope failures etc. Some major roads were closed such as Karakorum Highway, Kaghan valley road, Neelum valley road etc. There were also many small roads closed and there were also many bridges like reinforced concrete bridges and suspensions bridges collapsed. Most of water supply to Muzaffarabad comes from the river Neelum, which is lifted from 6 intake lines and then treated in clarifiers and sand filters.

This water system was damaged and muzaffarabad was cutted off from water supply. There were also many roof-mounted water tanks which were collapsed. Land telephone services were cutted off due to earthquake and became non-operational. There was also some damage to wireless communication services. Mangla dam and a nearby 30 MW Jhangra hydroelectric power plant supplies electricity to the Muzaffarabad area. The electric power supply to this area was cutted off due to fallen transformers and broken transmission lines. There is no natural gas supply to Muzaffarabad. Mostly heating sources are electricity, LPG and wood from forests. Ilyas, M, 2005. Seeber, L and Armbruster, J.G, 1979. Hussain, A. 2005. Durrani, A.J, Elnashai. A.S, Hashash, Y.M.A and Masud, A, 2005. KMC. COMET, 2005. The majority of tourist spots, hotels and other tourist infrastructure were destroyed by the earthquake.



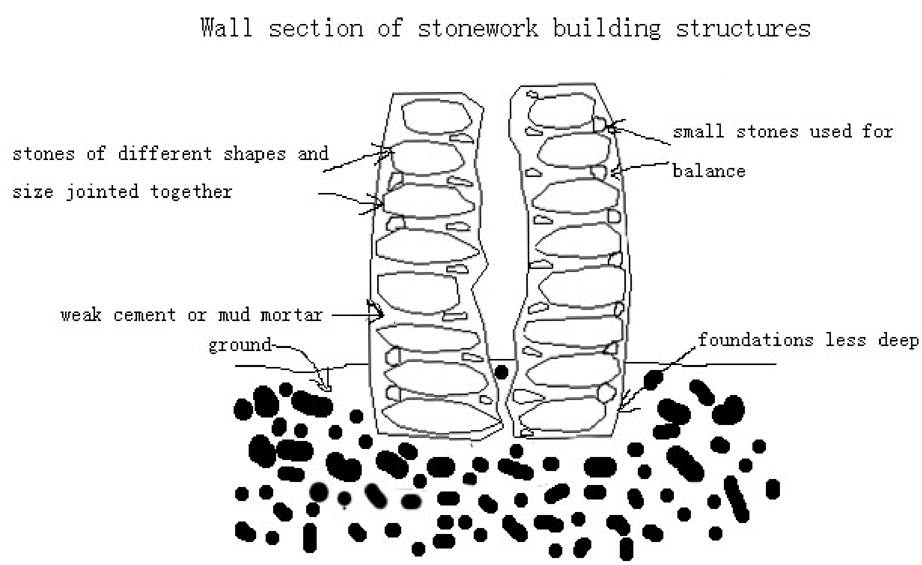
Source: ERRA, , D&SC of ERRA, Ministry of tourism Pakistan (R & S), Khyber-Pakhtunkhwa Pakistan



Source: ERRA, D&SC of ERRA, Ministry of tourism Pakistan (R & S), AJK, Pakistan

5. Building Construction in earthquake affected area

In Pakistan (which is a development country) most of the building structures are made up of unreinforced masonry like concrete blocks, which are not good at resisting to earthquakes. Foundations were contracted mostly of stones or bricks bearing on native soils around 3-4 feet below ground and around 18-24 inches wide. A few steel structure found in most of the wall construction is in lintels (window or door headers). In most cases, it was found that no good ties existed between the walls and the floors and roofs. In the affected area, wall construction of the most buildings, were of non-engineered and non-durable stonework.AJK, 2006. The performance of these buildings in the earthquake was varied and heavily depended on factors like redundancy in structural walls and quality of materials used and construction techniques. In areas of strong ground shaking, most of the stonework wall structures collapsed or intensely damaged. The majority of these structures were constructed of round stones with mud or weak cement mortar. This type of construction had poor block strength and weak mortar. There was absence of seismic detailing which means to construct a building in such a way that the building is less vulnerable to earthquakes or seismic shocks. Generally, the building structures with fired-clay bricks masonry had better performance than other types of wall constructions in the case of earthquakes..FRC, 2006.



Most of the building (some 3-4 stories high), were seen resting completely on non-structural infill walls, where the columns failed below the elevation of first floor. A number of mixed use multistory buildings with open fronts at ground or first level and walled residential or office space in upper stories collapsed or failed. The quality of beams and pillars used in construction of buildings were found non-engineered and low quality material. AJK & FRC, 2006.

A. Shows destruction in Balakot

B. Stonework in Wall Construction

C. Multi-story building with no proper support collapsed

D. Poor Quality Cement and Mud used in Construction

6. The causes of more destruction

In 2005, the destruction of building structures by earthquake was seen a lot due to some reason and causes. These main causes of the more earthquake destruction are as follows.

1. Type of building construction (Brick, stone masonry, mud mortar, RCC frame, wooden frame etc).
2. Non-engineered construction.
3. Low Quality of construction.
4. No use of existing design codes.
5. Absence of art codes and building codes.
6. Use of sand taken from river-side or streams etc.
7. Use of mud taken from mountain slopes and farms.
8. No well trained masons.
9. Some building constructed on mountain slope without proper balance.

7. Seismic Design & earthquake resistant construction

The basis of seismic design is on the application of construction techniques, methods and criteria used for the design and construction of building structures exposed to earthquakes. Lindeburg, Michael R. Baradar, Majid. 2001. The design of structure which blindly follows some seismic code regulation is not likely to assure the survivability from serious damage or collapse. Gotz, Karl-Heinz et al. MCGraw-Hall, 1989. The poor seismic design of building structure may lead to collapse or destruction. In accordance to building codes, building structures are designed in such a way to prevent collapse and to with stand the earthquakes likely to occur at the location of construction. Seismic design provides the building with suitable stiffness, strength, configuration and ductility. Arnold, Christopher, reitherman, Robert, 1982. The basic requirements of seismic design are depending on the structure type, the location of the structure and application of seismic design and criteria. Omori, F. 1900. The stability of ground is also need before the starting the construction. Earthquake resistant construction refers to the implementation of the seismic design and building codes for assuring that the building structures survive through earthquakes.

There are two types of destabilizing actions of earthquake on the building structures: direct (ground shaking, including both horizontal and vertical components) or indirect (landslides, rockslides and soil liquefaction due to earthquake). About 30% population of the world is living or working in adobe structures or earth-made construction. Arnold, Christopher, reitherman, Robert 1982. These structures use bricks made up of mud as basic building material. These structures were widely used in the earthquake affected area of Khyber-Pakhtunkhwa and AJK. These building are very vulnerable to strong earthquakes, but there are some factors used to improve the seismic performance of these buildings: quality of construction, seismic reinforcement and box-type compact layout. Abbas, H. 2005. Al, V.E. 2005. CAPRID. 2006. In Timber frame structures, timber framing is used for complete skeletal framing. If properly engineered it provides seismic survivability and some structural advantages. Gotz, Karl-Heinz et al. MCGraw-Hall. 1989. In the earthquake affected area, the timber is a common building material as there are a lot of forests in the area. In the earthquake affected area, there were some concrete structures. To avoid serious damage or collapse, the concrete frame should have ductile joints and steel reinforcements bars should be used to give strength to the structure. In the high mountainous area with difficult terrain, in the construction of structures, stones are used as basic building material. To make these structures less vulnerable to earthquake, less and light stonework is suggested.

8. Building Code of Pakistan

Pakistan has designated seismic zones ranging from zone 1. The area that suffering in the earthquake was either not designated or was in zoon 2 (UBC Zone 2: low moderate risk). The designation of major cities of Islamabad (Zone 2), Peshawar (Zone 2), Karachi (Zone 2) and Quetta (Zone 4) not agrees with the conditions given in Appendix II of chapter 16 of 1997 UBC. Ilyas, M, 2005. Seeber, L and Armbruster, J.G, 1979. Hussain, A. 2005. Durrani, A.J, Elnashai. A.S, Hashash, Y.M.A and Masud, A, 2005. KMC. COMET, 2005. The major cities of Islamabad, Peshawar and Karachi should also be classified in Zone 4. In urban planning and policy decisions, no priority is given to seismic design. There was negligible code enforcement in the earthquake affected area, except for some high profile projects. Many people constructed and reconstructed without building codes or enforcement. Lindeburg, Michael R. Baradar, Majid, 2001. Gotz, Karl-Heinz et al. MCGraw-Hall, 1989. The basis of the Building code of Pakistan (Seismic provisions 2007) is the definition of the potential earthquake hazard in each part of the country. NESPAK did the major part of seismic zoning and completed peak ground acceleration maps for final draft of building code. The building code, specifically for earthquake affected areas of Pakistan, includes seismic provisions. These seismic provisions contain detailed guidelines, requirements, specifications and procedures for building construction. It also discusses the choice and selection of materials in construction.

There are also recommendations about the design of various type of buildings in different geographical, geological and soil conditions. The quality of building materials is very important in construction of buildings, such as good quality cement, durable bricks etc. Arnold, Christopher, reitherman, Robert 1982. The implementation of building code increases the cost of construction of buildings, but it also makes the buildings more safe and durable.

9. Seismic Design and building code in Japan

Earthquakes are more frequent in Japan. The Niigata 1964 earthquake in Japan caused intense damage to building structures. This damage was limited to the buildings and structures constructed on saturated loose soil deposit. Most destruction was due to ground failure. Approximately 2000 houses were destroyed, but there were only 28 deaths. Also there was Kobe earthquake in 1995 causing loss of human lives and damage to the buildings and infrastructure. BRI, 1996. In the aftermath of this earthquake, to lessen the damage to the building structures and to assure the human safety, new technologies were introduced in the building code and seismic design. Yamanouchi, H and et al, 2000. The seismic design and building code in Japan (revised in 2000) have two main objectives (in response to earthquakes) such as life safety and limiting damage to the buildings. In the revised building code of Japan, seismic provisions were also revised and updated.

This revised and updated building code with seismic provisions was applied for the newly developed building materials, structural elements and systems in construction, upgrading to existing buildings and construction of new buildings structures. These revised seismic provisions in building code leads to the better structural performance of buildings against earthquakes. Hiraishi, H. Midorikawa, M. teshigaware, M.Gojo. W and Okawa.I, 2000. Midorikawa, M. Hiraishi, H. okawa. I, Iiba, M. teshigawara, M.Isoda.H. 2000. Hiraishi, H. and et al. 1999. Miura, K. Koyamada, K. and Iiba, M. 2000. In this building code, two earthquake forces such as maximum earthquake forces and once-in-a-lifetime forces were considered for seismic design of the building structures. In these provisions, ground and soil conditions were taken into account, because different places have different ground and soil conditions. New seismic design procedures were included and particularly the design of earthquake response spectrum. Hiraishi, H. Midorikawa, M. teshigaware, M.Gojo. W and Okawa.I, 2000. Midorikawa, M. Hiraishi, H. okawa. I, Iiba, M. teshigawara, M.Isoda.H. 2000. Hiraishi, H. and et al. 1999. Miura, K. Koyamada, K. and Iiba, M. 2000. The building code with seismic provisions of Japan is more better and effective against damage and casualties due to earthquakes.

10. Comparison (Building codes of Pakistan and Japan)

In Pakistan's building code, at the time of earthquake, there was improper seismic zoning, because the earthquake affected areas were in a moderate risk zone. There are seismic provisions which give detailed guidelines about construction of buildings. It has recommendations about selection of materials for construction and about the design of buildings in different geological and soil conditions. In Japan's building code, the seismic provisions are well revised and updated. It gives directions about proper seismic design of building structures and the construction methods used to make the buildings less vulnerable to earthquakes. It is applied for the newly developed building materials, structural elements and systems in construction, upgrading to existing buildings and construction of new buildings structures. It also discusses the ground and soil conditions and how to construct building at locations with the different condition of ground and soil. In Pakistan, we observed the improper seismic zoning, while in Japan there is proper seismic zoning because earthquakes are frequent in Japan. In Pakistan's building code, there are seismic provisions giving some guidelines about building construction. In Japan's building code, there are seismic provisions containing detailed guidelines for construction and also discussing in detail the seismic design of building structures. In Pakistan, there is negligible building code enforcement except for high profile projects. In Japan, there is well implementation of building code and seismic design in almost all building structures. Japan's building code with seismic provisions is very much better and well updated as compared to Pakistan's building code. There were approximately 6,434 deaths in Kobe earthquake in 1995. Kobe city FIRE bureau, 2006. While there were approximately 100,000 deaths in Pakistan's 2005 earthquake. There was a lot of damage in Pakistan's earthquake, because of negligible implementation of building code and even if it is implemented the seismic provision are not very well updated.

11. Conclusion

This research showed that the many areas of Pakistan are vulnerable to natural disasters like earthquake. Earthquakes are more common in the northern part of Pakistan (Khyber-Pakhtunkhwa and AJK) and western part of Pakistan (particularly Quetta and nearby areas). The earthquake occurred due to collision of north western side of Indian plate with the Eurasian plate in the northern part of Pakistan in the areas of AJK and northern Khyber-Pakhtunkhwa.

The earthquake caused a lot of destruction including human cost and destruction of damage of buildings and infrastructure. A lot of residential and official buildings, schools, health facilities, transportation infrastructures, power and communication infrastructures, water supply and tourism sites faced serious damage; facts and figures about these destruction are described in detail. The destruction was more than expected because of some reasons like the construction techniques used were not good without taking into account the seismic design and provisions. The wall construction was non-engineered and not durable, and there were no good ties of walls with floor and roof. The foundation was not deep and thick to give sufficient support to the structure. The quality of building materials was not up to the standard. There was absence of seismic detailing. In wall construction, the fired-clay bricks perform better than other types of wall constructions. Most multistory buildings were found resting on non-structural infill walls and collapsed easily by ground shaking. The mortar used in walls was mostly mud or low quality cement, making the walls easy to collapse. Some buildings were constructed on mountain slopes without proper balance. Pakistan's seismic zoning ranges from zone 1 to zone 4; the earthquake affected area was in zone 2 which should be in zone 4.

So there was negligible consideration of seismic design in urban planning and construction projects. Most buildings were constructed without the usage of building code and enforcement. The implementation of building code increases the cost of construction, so mostly building code implementation was avoided. The design of buildings and infrastructure should be according to the geographical, geological and soil conditions of the area and the quality of building materials should be up to the standards. The building code should be in accordance with the international standards, with more improvement to the seismic provisions. To lessen the damage and loss of life, the implementation of building code and the use of latest techniques to construct the buildings which are more resistant to disaster like earthquake. A good example to follow is in the case of Japan. Japan's building code including seismic provisions is very well updated and is a worth standard to follow for construction of building structures and other infrastructures. The seismic design is implemented in almost all the building structures in Japan. The seismic design gives the buildings suitable strength, stiffness, ductility and configuration. The basic requirements of seismic design of buildings depend on the type and location of structure and proper application on seismic criteria and design. Around 70% cost of earthquake was related to reconstruction. So in reconstruction, the implementation of building and seismic design is very important and it is also needed to update the code and seismic design according to international standards and the practices in Japan.

12. Recommendations

It is suggested that extensive studies should be carried out in seismology and earthquake resistant construction for developing and updating specifications codes and engineering parameters for the design and construction of several types of structures, for example residential houses, utility buildings and infrastructure like roads, bridges, water and power supply lines. To make the buildings more resistant to earthquakes, the seismic design and building codes should be properly implemented to survive through both direct and indirect actions of earthquake. There are different kind of steps and techniques applied to different kind of structures like improving the quality of material, proper designing and seismic considerations. In construction of buildings and other infrastructure, there are various types of structures and how to make these structures more resistant to earthquakes to avoid collapses and intense damage. In earth-made construction adobe structures, box-type compact layout and seismic reinforcement make the structures less vulnerable to earthquakes. In timber structures, properly engineered skeletal timer framing provides seismic survivability.

In concrete structures, the concrete frame should have ductile joints and steel reinforcement bars should be used to give strength to the structure. In the structures with stone as basic building element, less and light stonework is recommended to lessen the damage in case of earthquakes. It is recommended that the building structures should be properly engineered and should have stability on the ground. Making the structure flexible is also a good choice. The guidelines in the code and by the engineers and architects should be considered in the construction of buildings. It is recommended that the large scale use of stones in building walls should be avoided and other good quality building materials such as bricks, timber and fiber glass should be used. And also good quality of cement should be used. The buildings and other infrastructure should be capable of surviving through the sideways forcers of earthquake. To make the building structure more resistant to earthquake, the building should be like a rigid box and there should be a good binding between foundations, walls, floor and roof. The foundations should be suitably deep to develop a good bond between the building and ground. As we saw in Japan, earthquakes are frequent, but the damage there is less because of the good building code and seismic design of building structures. We should learn from the construction practices in Japan and implement those in construction of buildings and infrastructure in Pakistan. It will make the building structures more resistant to earthquakes and there will be less damage in case of earthquake.

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