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Structural Characterization Assessment of RC Buildings after Gorkha Earthquake 2015

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ABSTRACT: After the Gorkha Earthquake Nepal 2015, several buildings were damaged and collapsed in Kathmandu valley. In this context, the proposed paper presents an overview of the damage that was observed and the general and detail information collected through Rapid Visual Damage Assessment of 64 numbers of buildings around the Kathmandu valley. The main objective of this research work was to make the database of damaged buildings, to find out the general causes of failure of these buildings, to know the lesson learnt from the Gorkha earthquake 2015 and to recommend for design and construction of RC building in future. The existing status of the buildings are obtained by analysis of collected data in which general information and deficiencies of buildings are ploted out by using statistical tools, then correlation between these parameters is perfomed. The study showed that the selected buildings lie in IX MMI comparing with the seismic hazard map of Kathmandu valley prepared by UNDP.

***Keywords* : Damage assessment, Gorkha Earthquake 2015 ,RC Framed Buildings**

I. INTRODUCTION

Nepal lies in Himalayan region and Himalaya is highly vulnerable to earthquake. Young geology of Nepal is due to Indian Plate converging towards the Eurasian Plate and it still in process, It has experienced great earthquakes in past. The seismic gap in certain region of Nepal reflects the highly seismically active zone [1].

In 1934 earthquake large destruction of only masonry structure occur as RC structure has not been introduced. So, reinforced concrete structure in Nepal has not experience large earthquake yet. The people don't know the behaviour under seismic action and constructing building as they want. This may lead to heavy loss of life, property in the future earthquake. We should always be prepared for forthcoming earthquake so that the destruction may be reduced.

For the last 15 to 20 years there has been a proliferation of reinforced concrete (RC) framed buildings constructed in the urban and semi-urban areas of Nepal. Most of these buildings have been built on the advice of mid-level technicians and masons without any professional structural design input. These buildings have been found to be significantly vulnerable to a level of earthquake shaking that has a reasonable chance of happening in Nepal. Hence, these buildings, even though built with modern materials, could be a major cause of loss of life in future earthquakes.

II. SEISMICITY OF NEPAL

Earthquake are comon events in Nepal. **Error! Reference source not found.** shows the record of past earthquake around the plate boundary in the south Asia. It is evident that Indian plate is sub - ducting into Eurasian plate every year by 3.8 cm to 4.8 cm [2]. This movement of plates is responsible for accumulated strain energy which is released in time to time. In this figure the largest strain energy release on 1950, Asam-Tibet Earthquake is shown.

A. Recent Gorkha Earthquake 2015

Fig B.b shows the location of earthquake epicentre of recent Gorkha earthquake in Nepal map. In the recent, an earthquake of M7.8 occurred in 77 km NW of Kathmandu (in the boarder of Gorkha and Lamjung) at 11:56 on 25 April 2015 with shallow depth of 15 km with maximum Mercalli Intensity of IX, lasting approximately fifty seconds.

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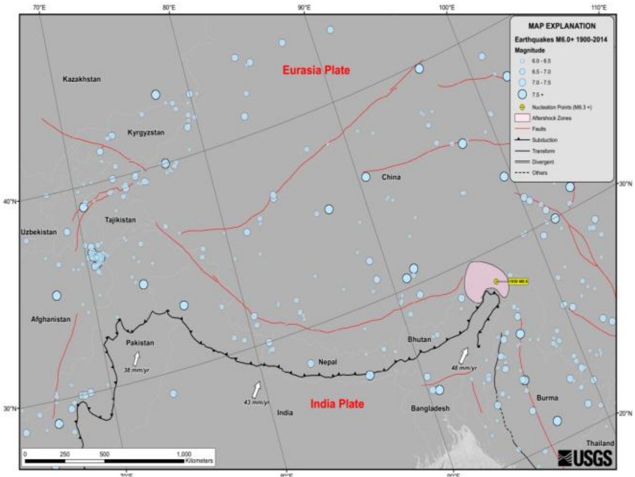

Fig B.a : Earthquake in South Asia
Source:http://mashable.com/2015/05/12/deadly-aftershock-in-nepal

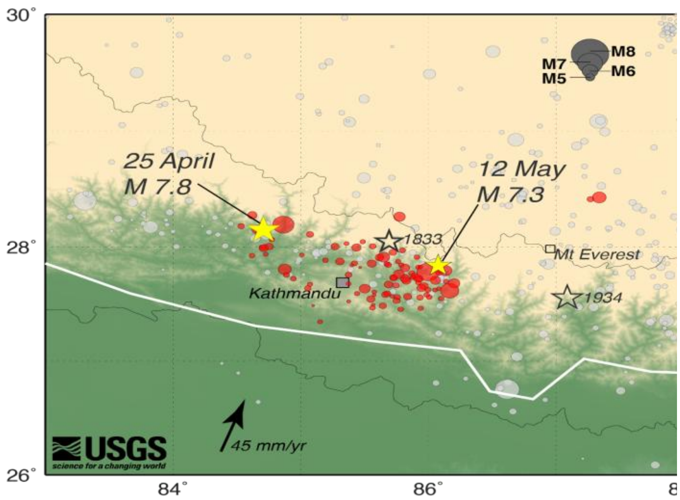

Fig B.b: Map showing more than 100 aftershocks that have occurred since the magnitude 7.8 earthquake in Nepal on April 25, 2015.
Source:http://www.usgs.gov/blogs/features/usgs_top_story/magnitude-7-8-earthquake-in-nepal/

Fig B.b, it shows more than 100 aftershocks that have occurred since the magnitude 7.8 earthquake in Nepal on April 25, 2015 [3]. Nepal faced continued aftershocks throughout the country at the intervals of 15–20 minutes, with one shock reaching a magnitude of 6.7 on 26 April at 12:54:08.

The largest aftershock is a magnitude 7.3 occurred in 18 km south-east of Kodari and epicentre is in boarder of Dolkha and Sindhupalchowk district at 12.51 on 12 May 2015. The 1833 and 1934 represent the most recent large historical earthquakes on this portion of the plate boundary.

It was recorded that officially 8,857 and in total 9018 people dead and 21,952 injured. Ancient monuments were collapsed at UNESCO world heritage sites in the Kathmandu Valley including some at the Bhaktapur Durbar Square, the Kathmandu Durbar Square, the Patan Durbar Square, the Changu Narayan Temple and the Swayabhunath Stupa.

The 7.8-magnitude earthquake completely damaged 1,38,182 houses across Nepal and partially damaged 1,22,694 other homes. Out of them , 10,394 government buildings have collapsed and over 13,000 government buildings were partially damaged, according to Nepal Home Ministry sources.

B. Field Survey

The location of the field survey of damaged buildings due to recent earthquake is choosen as Kathmandu Valley since most affected area was identified to be in this region. During the field visit rapid visual screening was performed. The collected information is tabulated and results are shown in section 3. First of all, general information and sorrounding of selected building was collected from global overview. Then information about elevation and plan was collected measuring interior and exterior wall thickness, floor height and bay width. Number of story and of bays in both direction were noted out. Then after detailed information of structural element such as dimension of section size of beam, column, slab along with reinforcement details were collected. Information about material characteristics of concrete, steel and brick work were also gathered. Photographs of damaged buildings was also taken. Some lacking information were noted out by consulting with the owner and builders, when possible. After that the failure of structural and non-structural elements analysed. Engineering judgement was used to quantify the severity of damage. Finally the possible causes of damage were pointed out.

General information and surroundings of building, information of building in plan and in elevation,structural elements, dimensions, reinforcement and infill walls thickness, material characteristics and damages of building were collected from building damage sites.

There are some criteria for assessing the building which is based on the buildings codes and general fundamental principle of structural engineering. For the tilting of the building the code has specified maximum permissible limit of displacement is 0.04 times total height of building. In case of settlement, 25 mm of settlement is tolerable. For the different criteial of damages study used the FEMA 356[18], ATC 40[19], Eurocode 8: Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings, European Macroseismic Scale 1998[21].

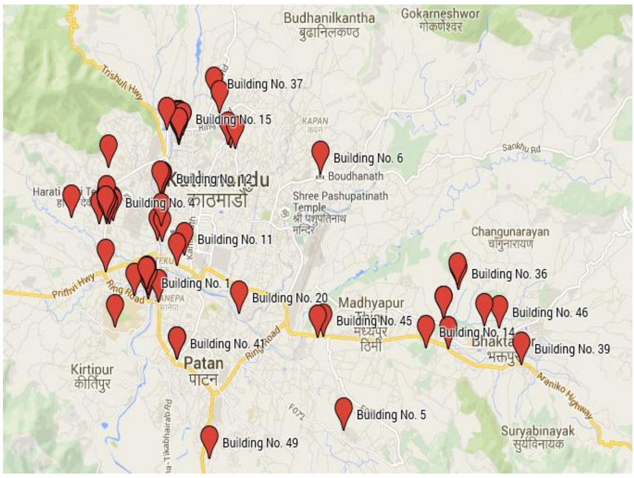

Fig A.a : Location of assessed building in google map

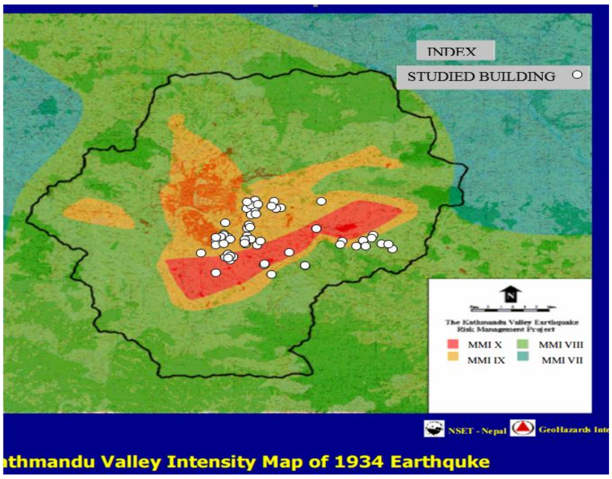

Fig A.b : Kathamandu valley intensity map with damaged building location

Source: UNDP/UNCHS Habitat(intensity map)

III. ANALYSIS OF RESULTS

During the rapid visual damage assessment, obseravations of damaged buildings and possible causes of failures are studied. From the building sites, some of available data were collected. Many moment resisting framed buildings have been surveyed in Kathmandu valley, however in the study, only short listed buildings are listed based on availability of data. The analyses of data have been done based on this data and following results are obtained.

A. General Information and Surroundings

1. Coordinate

The Kathmandu valley is very close to epicenters and soil amplification is predominant here due to thick layer of clay deposit on it. Hence, many damages to the structure have been observed in this earthquake.For the research work the damaged buildings located in Kathmandu valley were surveyed. Fig A.a is the plot of those damaged building in google map. The plot shows that the damaged buildings are scattered all over the three cities, Kathmandu, Lalitpur and Bhaktpur. The probable level of earthquake shaking that the building may face is determined by identifying the location of the building in the seismic hazard map.

For this, the available earthquake intensity distribution map of Kathmandu valley developed by UNDP/UNCHS(Habitat)1994 ,"Seismic Hazard Mapping and Risk Assessment for Nepal" based on the intensity distribution of 1934 earthquake of Nepal. Comparing the location of damaged building of Fig A.a in hazard map of Fig A.b, one can depicts the intensity of IX MMI (Modified Mercalli Intensity) [4].

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2. Positioning and Ground Condition

Fig A.**a** shows the categorization of building according to position among the buildings. The results shows that position of building plays vital role relating to vulnerability as 8% buildings which are located in mid are damaged by earthquake out of 64 studied buildings. Isolated buildings were damaged more which reached 66% whereas 26% buildings which are in corner were found damaged. Mid buildings were damaged lesser due to the support in both direction.

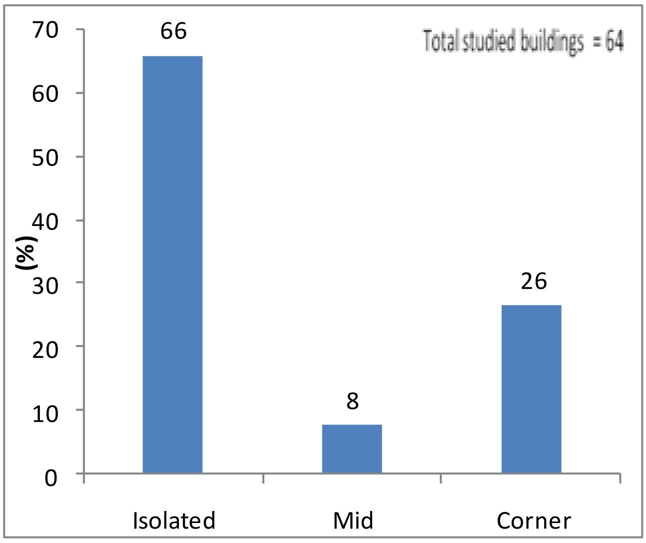

Fig A.a : Position of buildings

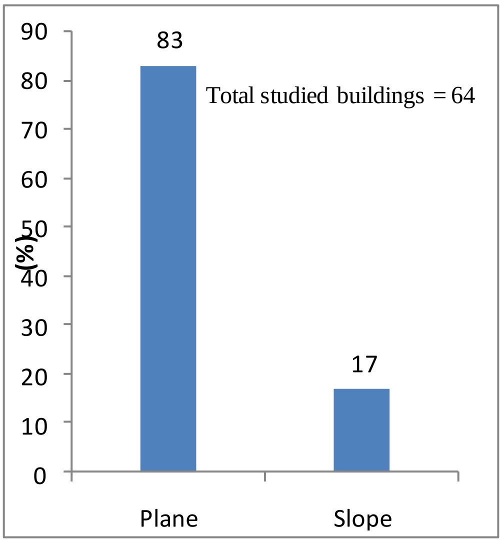

Fig A.b : Classification of buildings according to surrounding terrain

In the geographic terrain building lies in not only in plane but also in sloppy area. So, from the result of graph chart in Fig A.**b**, it is found that out of studied total 64 numbers buildings, 83% were constructed in plane area whereas 17 % in sloppy ground area. Most of the buildings which were constructed in slope area were severely damaged due to unequal settlement of foundations.

3. Number of Stories and Basement

Some information was collected by just looking the building from outside and the results are plotted from available data. Fig A.**c** shows the scatterness of the building in Kathmandu valley according to number of stories. The result indicates that most of the buildings surveyed are four (including three and half) and five stories (including four and half) which occurred damage in earthquake. Two and half and three storied buildings are considered as three storied in chart and they are 14% of buildings among the considered 64 buildings. There are 11 % of buildings of six stories which were damaged by earthquake. There are less numbers of higher storied buildings.

In Kathmandu valley out of total studied 64 buildings, 31 % of buildings are with basement and 69% of buildings are without basement. Basements are being used as vehicle parking and storage purpose.

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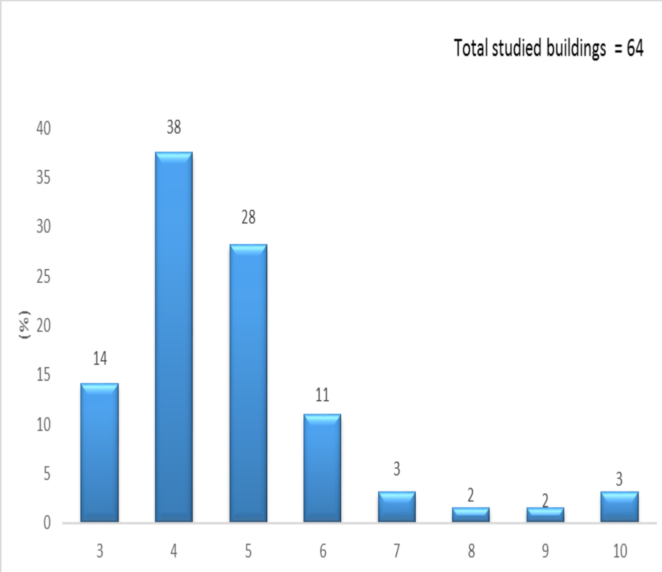

Fig A.c : Damage percentage of buildings in different number of stories

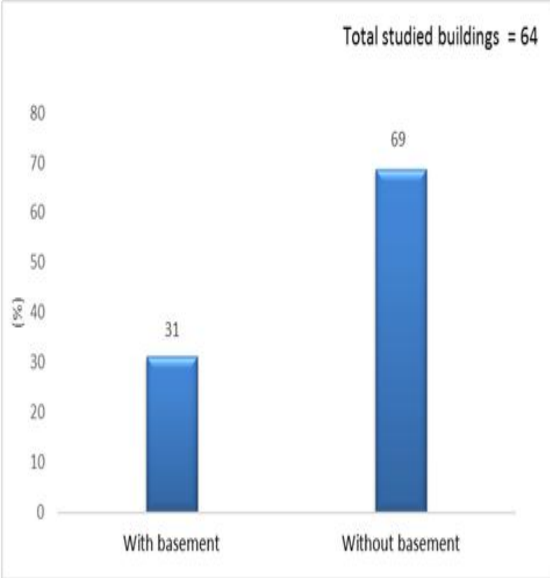

Fig A.d : Status of basemant (building with and without basement)

4) Height with respect to Adjacent Buildings and was Building Structurally Designed

The floor heights of building with respect to adjoining buildings are presented in Fig A.**e**. The result shows that about 58% of buildings are isolated so no compared with others. Out of studied 64 buildings, 30% of buildings are in same level and 12% of buildings have level difference (either higher or smaller).

It is difficult to point out that the building was structurally designed from external outlook. Out of studied 64 buildings, 78% (50 numbers) of buildings are not known whether they were designed or not. They were almost not designed structurally. It is found that only 19% buildings are clearly known that they were structurally designed (see Fig A.**f**). And 3 % were known that they were not structurally designed as per information of building owners.

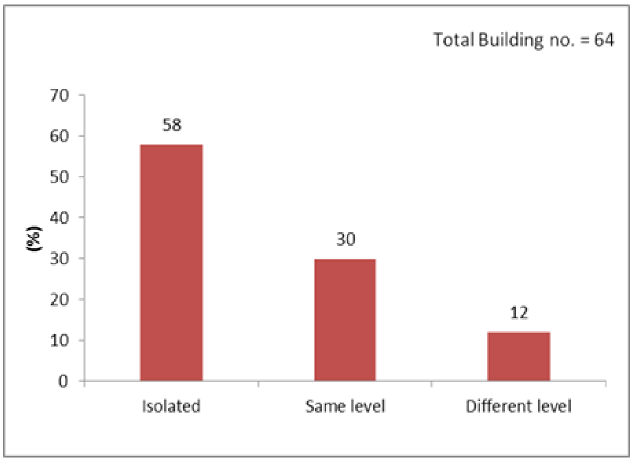

Fig A.e:Height of building with respect to adjoining buildings

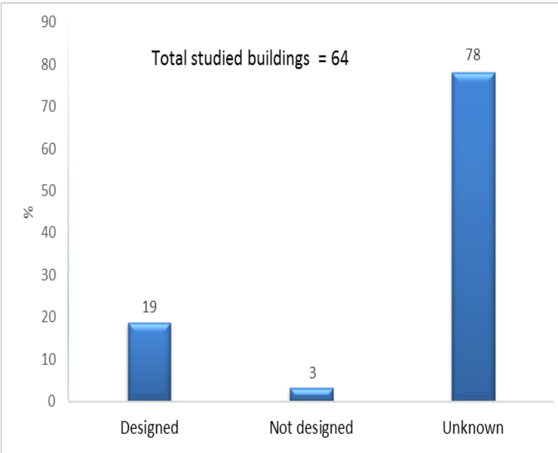

Fig A.f : Structurally designed or not desined building

5)Information in Elevation

Total Height and Regularity in Elevation

In the surveyed building of Kathmandu valley most of the damaged building height lies in between 9 -15 m tall (two and half to five stories) (see Figure 3.2a).This is because of these height buildings are available in city more. The visual inspection of the buildings shows that in the elevation of building seems to be regular. Out of considered 63 buildings 83% buildings have almost regular floor area and mass. This means most of the buildings are almost same floor area in different stories. In this case it is considered that staircase cover floor is not considered in the regularity of floor area and mass.

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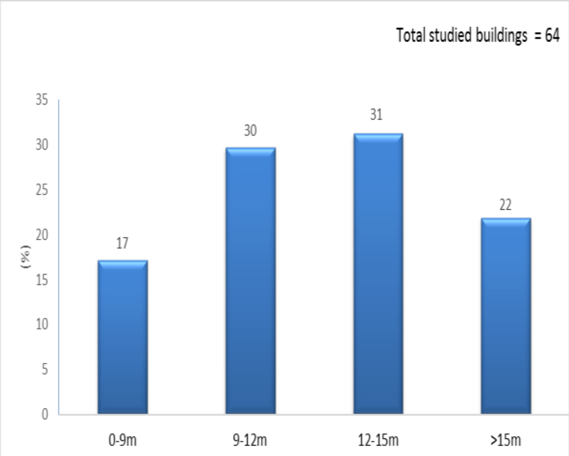

Fig 0.a : Predominant height of building

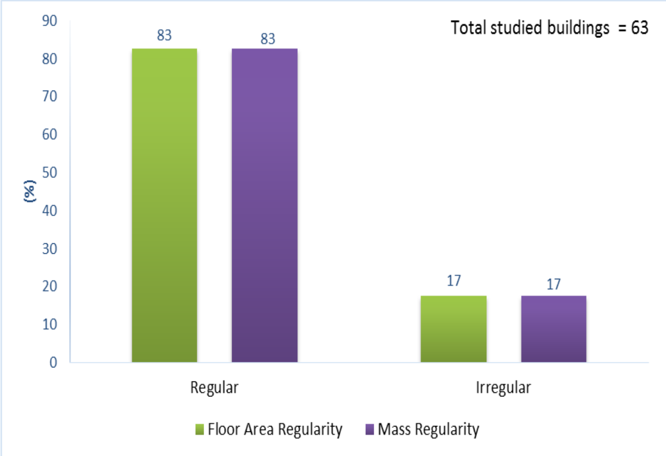

Fig 0.b : Regularity of building in elevation

6)Information in Plan

Regularity of Plan and Number of Bays in both Principle Directions

From the visual inspection, the data were collected to determine the regularity of building plan. In Figure 3.3.a shows that 53% building have almost regular plan (almost rectangular) and 47% building have plan irregularity (other than rectangular)

Fig 0.b shows number of bays in both major direction in the surveyed buildings. In the survey it is considered that along the road is x-direction and perpendicular to road is considered as y-direction. In the one bay building in x directions are used for shopping and residence purpose where land is expensive. The results show that two and three bay buildings are predominant in both directions. These types of bays are used mainly in common buildings. In case of the bay numbers more than four, bays along x – direction(along the road) is more than y – direction in the comparatively cheap land keeping more space in back side and wider along the road for the purpose of shopping .

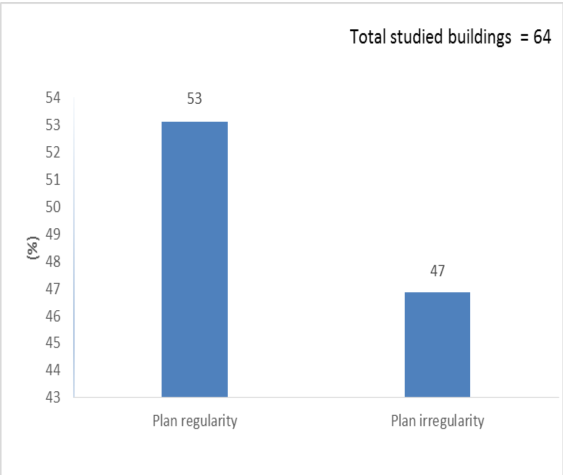

Fig 0.a : Regularity of building in plan

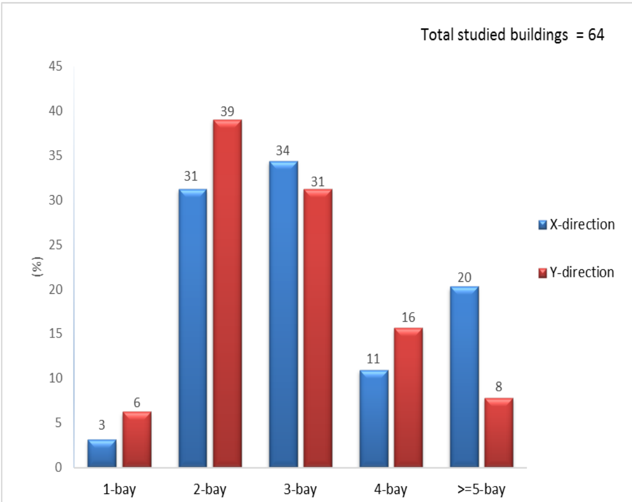

Fig 0.b: Numbers of bays in both direction

7)Equal Span of Bays in Both Major Direction and Regular Distribution of Infill Walls

Fig 0.c shows large portion of surveyed building of 79% and 71% have almost equal span in x - and y - directions respectively. Spans are considered equal if differences of spans are not more than 1.5 m. It shows that drastically differences in span is not in the most of the building which is the positive part from the point of view of structural aspect.

The distribution of infill wall is not regular as shown in Fig 0.d This unequal distribution of infill wall increases unequal distribution of stiffness which cause torsion in the building during earthquake.

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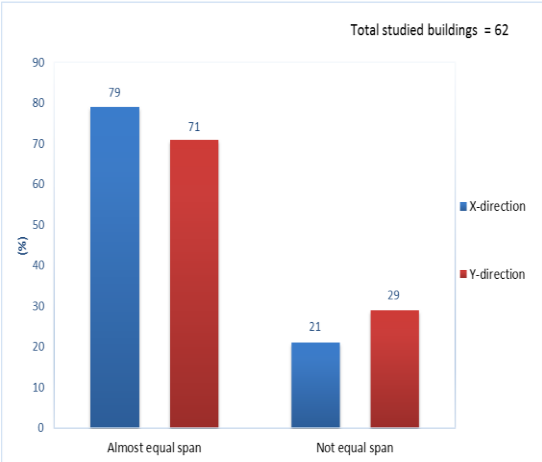

Fig 0.c: Equal span of bays in both direction

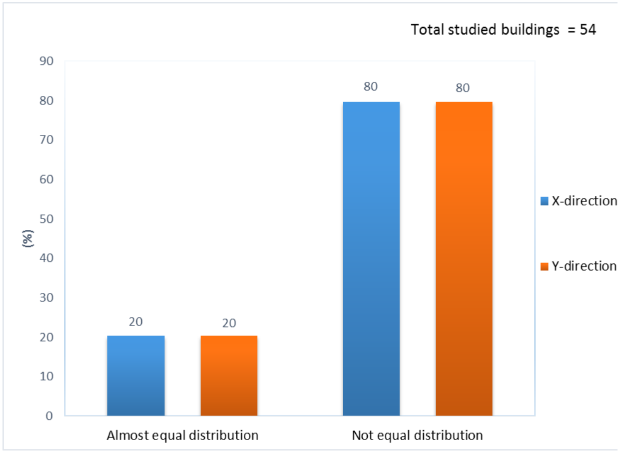

Fig 0.d : Distribution of infill walls

8) Structural Elements, Dimensions, Reinforcement and Infill Walls Thickness

Longitudinal Reinforcement in Column

Longitudinal reinforcement is one of the important parameter that signify the vertical load and bi-axial bending moment capacity of column. Fig 8.a shows 15% buildings have less than 1% reinforcement. The highest numbers of buildings of 39% have longitudinal reinforcement of equal and greater than 1% and less than 1.5% followed by 24% of building have reinforcement of equal and greater than 1.5% and less than 2%. Similarly, about 17% of the buildings have longitudinal reinforcement equal and greater than 2% and less than 2.5%. Only 4% of buildings have reinforcement >4%. There are no buildings found which have reinforcement from 2.5-4%. Actual reinforcements in columns are less than required even though in chart it shows higher value because sizes of columns sections are quit smaller than required otherwise it would be lesser than that.

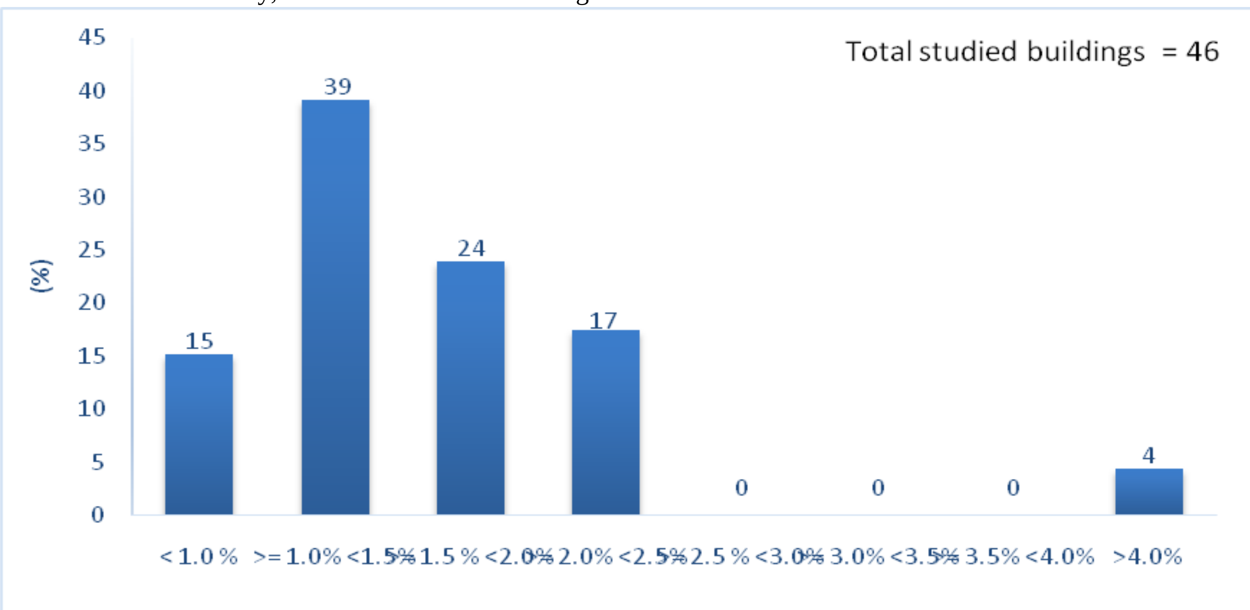

Fig 8.a : Longitudinal reinforcement percentage in columns

9) Shear Reinforcement Spacing in Column

Transverse reinforcement in column are not visible in most of the cases, however most of the building(58% out of considered 45 buildings) have spacing of 150 mm with diameter of 7 and 8 mm at near the support of column (see Fig 8.b) even though in approximate calculation it needs 100 mm center to center but it is seen that only 7% buildings have this amount of reinforcement. Diameter of transverse reinforcement is mainly used of 7 mm diameter and 8 mm diameter. Fig 8.c shows that out of considered 25 buildings, at the mid height 52% building has 150 mm cen-

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ter to center transverse reinforcements. From this two charts, it can be seen that at mid height of column, shear reinforcements are quite good but near the support of columns, they are not enough.

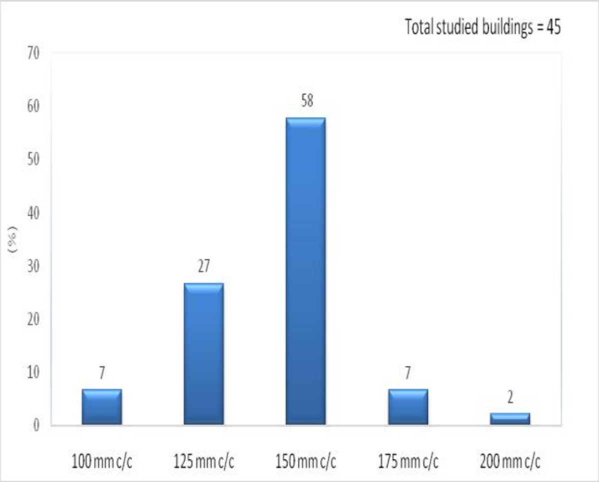

Fig 8.b : Stirrups spacing at support of columns

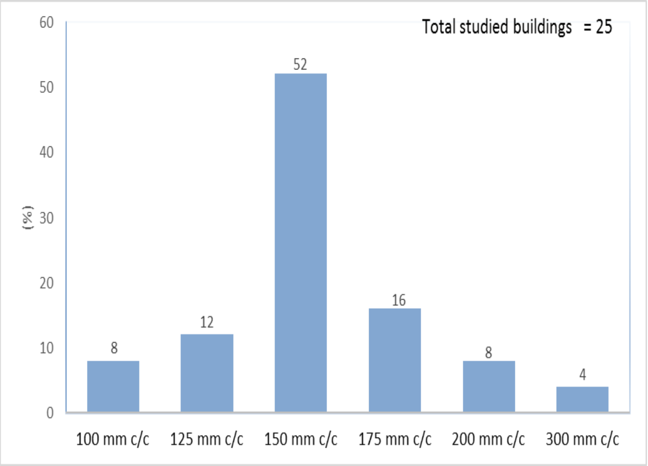

Fig 8.c : Stirrups spacing at mid of columns

10) Material Characteristics

Quality of material also influence the strength of the structural members and consequently to structural system itself. Fig 10.a shows that out of studied 64 numbers of buildings, 61% of buildings have poor quality of concrete. Similarly, Fig 10.b shows that the quality of concrete in vibration shows 52% buildings have poor quality. This is the cause for the crushing of concrete in the column support and joint. The results show that TMT steel were used mostly in the buildings which are more vulnerable in compared to Tor steel used buildings (see Fig 10.c). This might be because TMT have less ductility than Tor steel.

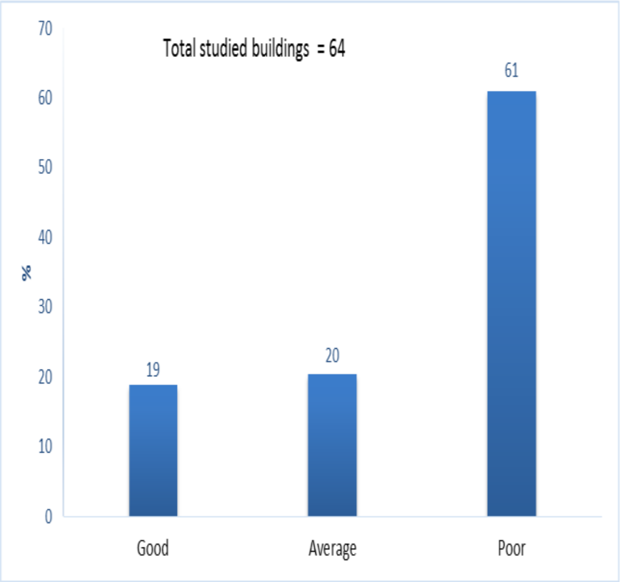

Fig 10.a : Quality of concrete

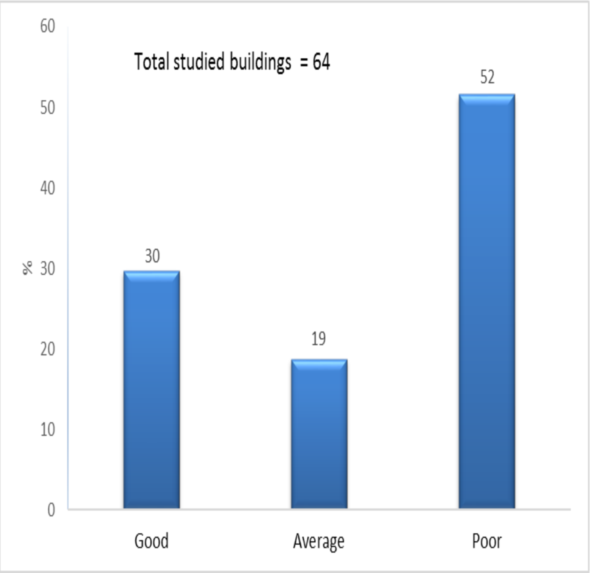

Fig 10.b : Quality of concrete in vibration

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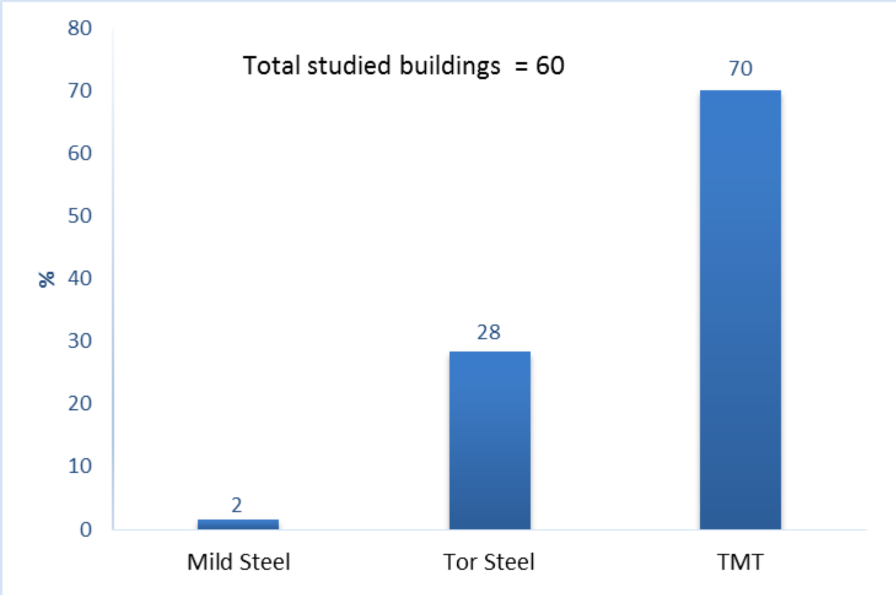

Fig 10.c : Buildings with different types of reinforcements

11) Damages

Damage Grades

Damage of the building can also be classified according to European Micro-seismic Scale (EMS 98). Fig 11.a shows that out of 63 studied buildings the heightest percentage of buildings of 38 % lies in damage grade D5 followed by D4, D2, D3 and D1 respectively.

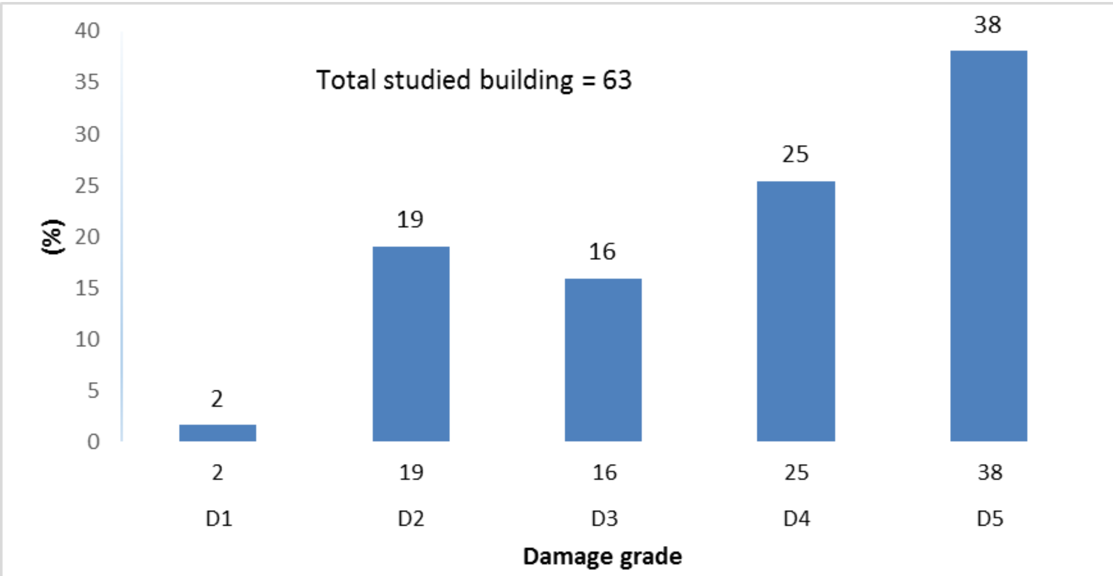

Fig 11.a : Classification of building based on damage grade

12) Soft Story Evidence and Settlement of Building

The analysis of data collected from field survey shows that soft story failure evidence is observed in 41 percent of building. Fully collapse of ground floor, most of the damages of ground floor columns with respect to above stories is considered as a soft story evidence.

Due to very weak soil deposit area, soil amplification, settlement and liquefaction are most probable in this zone. The graph in Fig 11.b shows out of studied 64 buildings, 14% building are settled. It happens due to foundation in weak soil, not enough size of foundations, heavy load in small foundations, unequal level of foundation footings, different soil strata in different footing, high water table and other causes.

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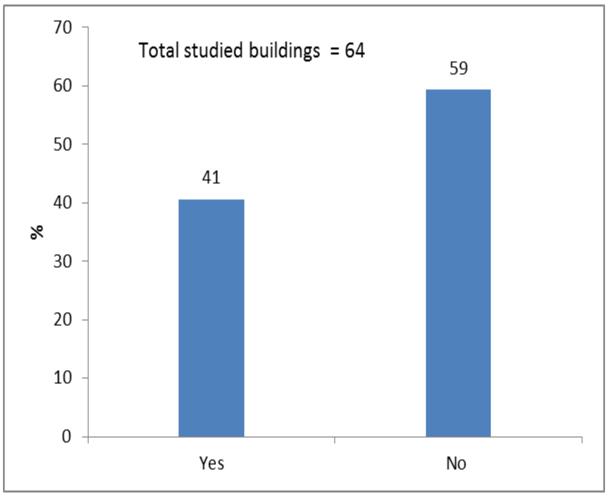

Fig 11.b : Classification of building according to soft story

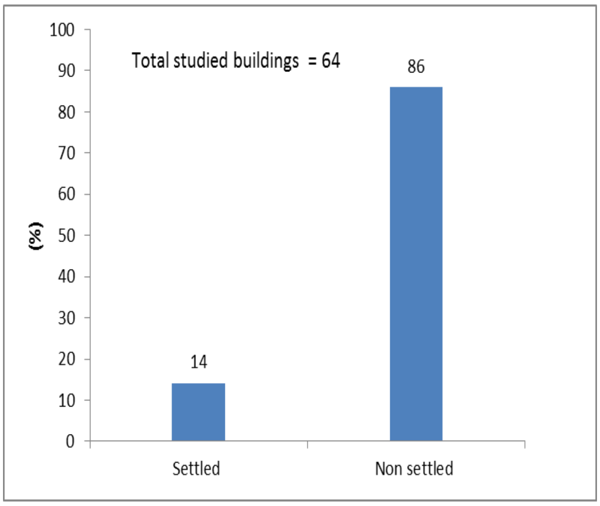

Fig 11.c : Classification of buildings according to settlement

13) Tilting of Building and Damage of Structural Elements

It is believed that Kathmandu valley have high soil deposited of up to about 600 m (source: slide of B. N. Upreti). Tilting of building is observed in some of the building. It is observed that 19% of buildings from the 64 studied buildings seem tilted (see Fig 11.d). It is due to weak soil, very slender building, unequal mass in plan is and in elevation.

Damage of the structural elements such as column, beam, joint, slab-stair and infill are plotted in Fig 11.e. The results show that the most probable damage are observed in column and infill followed by slab-stair and joint. The least damage was observed in beam, this might be because of strong beam weak column mechanism.

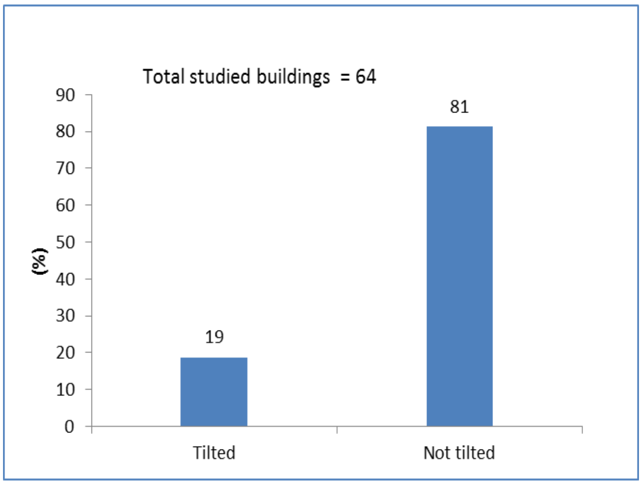

Fig 11.d : Tilting of buildings

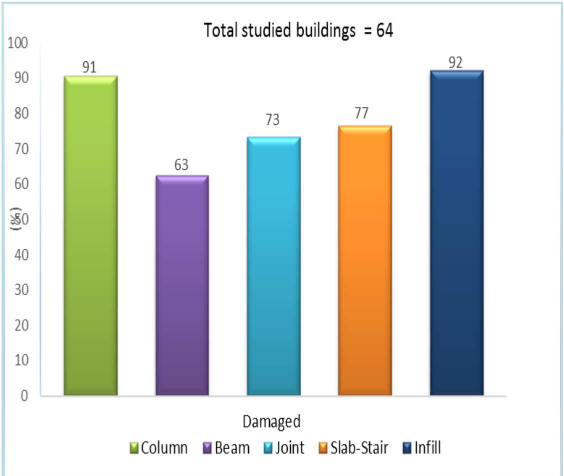

Fig 11.e : Damage of structural elements

IV. CONCLUSION AND RECOMMENDATION

- The surveyed buildings for damage assessment of the buildings lie in IX MMI comparing with the seismic hazard map of Kathmandu valley prepared by UNDP**.** Most of the damaged buildings are found to be isolated of 4 story(including three and half) and 5 storey(including four and half). About 31% of the studied buildings have basement and only 19 percent of the buildings are structurally designed.

- Regarding information in elevation, the predominant height of the buildings are found in the range of 12 – 15 m and 83 percent of the buildings are seen in regular with respect to floor area and mass.

- About 53 percent of the building are almost regular in plan. Most of the buildings have 2-3 bays in with equal span along both major direction. On the contrary, 80 percent of the buildings does not have equal distribution of infill wall.

- Regarding to longitudinal reinforcement in column, the highest 39 percent of the buildings have reinforcement ranges in 1% -1.5%. There is no buildings found which have reinforcement from 2.5-4%. Most of the building have stirrups spacing of 150 mm with diameter of 7 and 8 mm diameter at mid and support of column which

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shows quite deficiency of transverse reinforcement in columns.

- The quality of concrete and concrete vibration are observed to be poor in 61% of surveyed buildings. In case of the steel used in the buildings, 70% have TMT steel and only 28 % have Torsteel.
- The highest percentage of 38 % of the buildings are assessed as Grade 5 and 25% of buildings are assessed as Grade 4. It is seen that 41% of the buildings have soft storey evidence, about 14% of the buildings are damaged due to settlement and 19% buildings are found to be tilted. About 91-92% of the columns and infill walls, about 73% of joints and slab-stair and about 63% of the beams are observed to be damaged.

Due to high seismicity of Kathmandu valley it is recommended to introduce general principle of earthquake resistant elements such as (bands, stitches) in the building. The geometry of the building should be symmetrical from both major direction and there must be equal distribution of infill wall in both direction as far as possible. The flexural and shear reinforcement provided in column is not sufficient, hence capacity design with strong column weak beam principle is recommended. The workmanship of the concrete work is not satisfactory, so it is better to use concrete mixer and vibrator instead of manual mixing and compacting. Regarding the reinforcement, it is better to use Tor steel rather than TMT . It is recommended to avoid soft story evidence, short column in the buildings design and soil test is recommended for any construction to avoid settlement and tilting. To prevent brittle failure, ductile detailing should be followed as per the norms. In addition, enforcement of codes should be strict and built the structure only after proper analysis and design.

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