Seismic Vulnerability Assessment of major construction pattern of the of Srinagar city

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ABSTRACT

The estimation of the seismic risk of settled regions is connected to the level of earthquake hazard, structure susceptibility and degree of exposure to seismicity. Development of vulnerability studies in populated areas can be accomplished pointing to classify building vulnerabilities and mitigate the seismic risk; therefore, a complete identification and inspection survey of the old building stock of Srinagar city has been carried out. The key objective of this paper is to discuss the vulnerability assessment, by presenting a proposed method, which determines the level of vulnerability, then assessing physical damage and its relationship to seismic intensity. We used different seismic hazard exposures on the vulnerability components like demography, land use/land cover (LU/LC), building density, building age, building structure, building material, structural vulnerability and overall seismic pattern. The study indicates that although the lack of present earthquake resistant measures in all these building these buildings have survived the odds of time. Although with age, the strength of these buildings has decreased because of the decaying of construction material. The need of the hour is to renovate these older buildings.

Keywords: Srinagar city, seismic risk, older buildings, vulnerability assessment, seismic intensity

I INTRODUCTION

Earthquakes are a major threat to humanity, eradicating thousands of lives every year in different parts of the world with huge loss to civil infrastructure. National Geophysical Data Centre (http://www.ngdc.noaa.gov) data estimates more than 1.9 million deaths during the last 100 years from earthquakes an average of 17, 000 persons were killed every year. Seismic vulnerability in India is well evidenced by numerous past earthquake-related catastrophes viz. 1993 Latur earthquake of Mw 6.2 (11,000 deaths, USD 280 million–1.3 billion economic loss), 1997 Jabalpur earthquake of Mw 5.8 (38–56 deaths, USD 37–143 million economic loss), 1999 Chamoli earthquake of Mw 6.8 (103 deaths), 2001 Bhuj earthquake of Mw 7.7 (227 000 deaths, USD 4600 million economic loss), 2005 Kashmir earthquake of Mw 7.6 (86,000 deaths, USD 2.3 billion economic loss) and 2011 Sikkim earthquake of Mw 6.9 (111 deaths, USD 22.3 billion economic loss). As per Seismotectonic Atlas of India and its Environs [7], more than 60 percent of its area lies in high hazard zones due to the presence of major active faults in its plate boundaries and continental interiors, which produced large earthquakes in the past and have potential to generate major earthquakes in future as well. [15] [3] predicted around 150 000 and 200 000 fatalities and very high economic loss due to future great Himalayan earthquakes. [16] suggested the maximum expected loss due to earthquakes in India to be around USD 350–650 million for the next 50 years at 10% probability of exceedance.

Kashmir Basin is located on the NW portion of the active continent-continent collision of Indian and Eurasian plates. Flanked on all sides by mountain ranges (Greater Himalayan Range on the North, Pir Panjal Range on the South), the Kashmir Valley has been for millennia both blessed and cursed by its geography and geology. As the Indian plate continues to push northward, stresses continue to build on massive faults along the Himalayan arc. Fraction of these stresses let loose along a relatively small fault segment in the fall of 2005 (7.6Mw, Kashmir Earthquake) in Muzaffarabad, Kashmir, killing more than 86,000 people, reducing houses, even entire mountainsides, to rubble. Many moderate and large earthquakes have shaken the Kashmir Valley itself in historic times. Most noteworthy were the events of 1505, 1555, 1885 and 2005.

Srinagar, summer Capital of Jammu and Kashmir lies close to the Active plate boundary between Indian-Eurasian plates and within the reach of active seismogenic structures. The city is one of the most densely populated region in the State as well as in Himalayan region and as a major business and industrial hub; it supports vital commercial and transportation infrastructures. The city is positioned at the fringe of seismic zones IV and V as per the seismic zonation map of India (IS 1893-2002). Resting on a sedimentary stratum of 1.3 km thickness above the basement it is highly susceptible to earthquake catastrophes. The city was affected by near and far sources like the Indus Kohistan seismic zone in the Kohistan zone, Hazara-Kashmir Seismic zone, Kashmir Seismic zone, Jammu seismic zone, Kangra Seismic zone, Chamba seismic zone, and the NW Himalayan extent. Due to such sensitive geological and seismotectonic setup, it is apparent that earthquake catastrophes may happen anytime in the near future and might cause huge human and economic loss unless preventive measures are not immediately taken towards disaster mitigation and management. Thus the vulnerability analysis of the city of Srinagar as undertaken in the present study involves multi-criteria risk evaluation through thematic integration of contributing vulnerability components viz. demography, LU/LC, building density, building age, building structure, building material, structural vulnerability and overall seismic pattern.

The city of Srinagar:

The Srinagar City, the second largest urban city in Jammu and Kashmir (Area 1,979 Sq. Km), 34° 5' 1.1616" N and 74° 47' 50.53" E, has developed primarily on the banks of the River Jhelum, with an area of 294 Km^2 (114 sq. mi.), at an elevation of 1,585 meter (5,200 ft.). The population of Srinagar was 122618 in 1901; 1,027,670 in 2001 and 1,236,829 in 2011 (Census 2011). Due to enormous population, it has encroached the back swamp and marshy land and has resulted in rapid but skewed urbanization. The built-up area of the City has increased by 173 percent from 1911 to 1971 at the decadal rate of 28 percent. However, this rate steepened from 1971 to 2011 at the decadal rate of 33.25 percent [12]. The city is divided into 68 municipality wards. More than 60% of the city has built-up areas with residential buildings, congested business hubs, hospitals and schools, etc.,

IJARSE
ISSN: 2319-8354

some of which are very ancient and in dilapidated form with unplanned construction adhering to non-seismic safety standards.

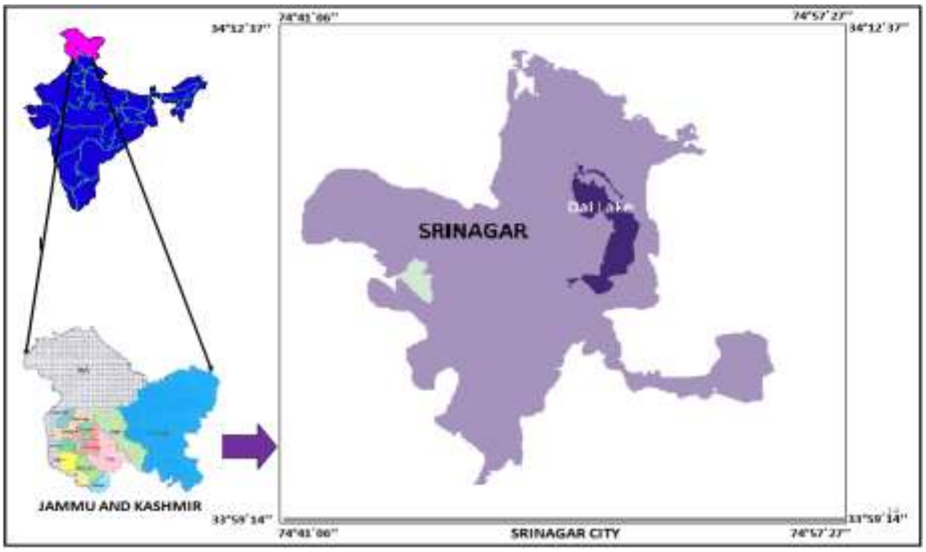

Fig.1: Shows the location map of the Srinagar City.

Demographic setup:

Table 1 shows the population growth of Srinagar city since 1901 to 2011. The population of Srinagar city during the last century (1901-2011) has grown remarkably. In 1901, the population was 122618 and increased from 1225837 in 2011, representing approximately tenfold upsurge equivalent to 900 % growth, with addition of 1103219 individuals. Decadal growth from 1901-1961slowed down from 22.46% in 1931 to 15.71% in 1961, attributing to political unrest and partition of the subcontinent which led to a mass migration of people. The decadal growth improved since 1961 onwards and reached its peak in 2001 when it touched 64.32 %. The Srinagar city achieved the metropolitan status in the year 2008 due to its dynamic trend in the population growth during last century. The rapid change in the demographic dimension of the city enormously effected the socio-economic structure of the city and led to unscientific, unplanned and vulnerable construction pattern.

Year	Population	Decadal Growth Rate	Area Km^2	Density Per Km^2
1901	122618	N.A	12.8	9579
1911	126344	3.04	12.85	9832
1921	141735	12.18	14.48	9788
1931	173573	22.46	17.6	9862
1941	207787	19.71	17.6	11806
1951	246522	18.64	29.52	8351
1961	285257	15.71	41.44	6884
1971	403413	34.31	82.88	4867
1981	606002	40.13	208.9 1	2912
1991	194902	N.A	N.A	N.A
2001	995806	64.32	278.1	3581
2011	1225837	23.13	416.3	4407

Table 1: Srinagar City- Population Growth, Source: Census of India, 1901-2011, Srinagar Municipal Corporation. NA (Not Available).

International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No.04, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

Land use/land cover (LULC):

The massive burden of the population has wielded massive impact on the existing land use/ land cover of Srinagar city. Since, Srinagar is summer capital of the state and represent largest commercial hub of the valley and huge number of people settled in and around the city, which eventually caused rapid LULC changes. LISS-IV and PAN 2010 (NRSC Data Centre, ISRO) have been utilised in the present study and data was classified based on the maximum likelihood method from 1971-2010. In 1971, the overall built up area of the city was 2556.50 ha and increased to 6626.03 ha in 2011 and non-built up area considerably reduced from 20890.00 ha in 1971 to 16820.47 ha in 2011. The enlargement of the built-up area absorbed substantial fraction of forest, agricultural land as well as water bodies and marshy areas. Area under agricultural in 1980 was 144.08 Km^2 and reduced to 109.49 Km^2 in 2010 with nearly 34.59 Km^2 of loss in three decades. Area under forest cover in 1980 was 3.46 Km^2, which reduced to 1.53 Km^2 in 2010, loss of 1.93 Km^2. Total area under barren land in 1980 was 5.39 Km^2, which reduced to 4.80 Km^2 in 2010, loss of 5.9 Km^2. The total area under water bodies in 1980 was 21.45 Km^2, which reduced to 18.95 Km^2 in 2010 with loss of 2.50 Km^2 in three decades.

Building density:

The construction materials of structures is one of the most significant feature in assessing vulnerability to seismic hazard. The building density map was generated with the help of poor spectral and spatial resolution imageries (Landsat TM) through visual interpretation techniques using image elements such as tone, texture, shape, size, shadow, pattern, association and location. In 2011, the total number of residential buildings in city was 182829 (Census 2011). The housing density calculated was classified into four categories, and vulnerability values were assigned on the basis of housing density into Low (Housing density < 500)), Moderate (Housing density 500 - 1000), High (Housing density 1000 - 2000 Very High (Housing density > 2000) (Fig 2).

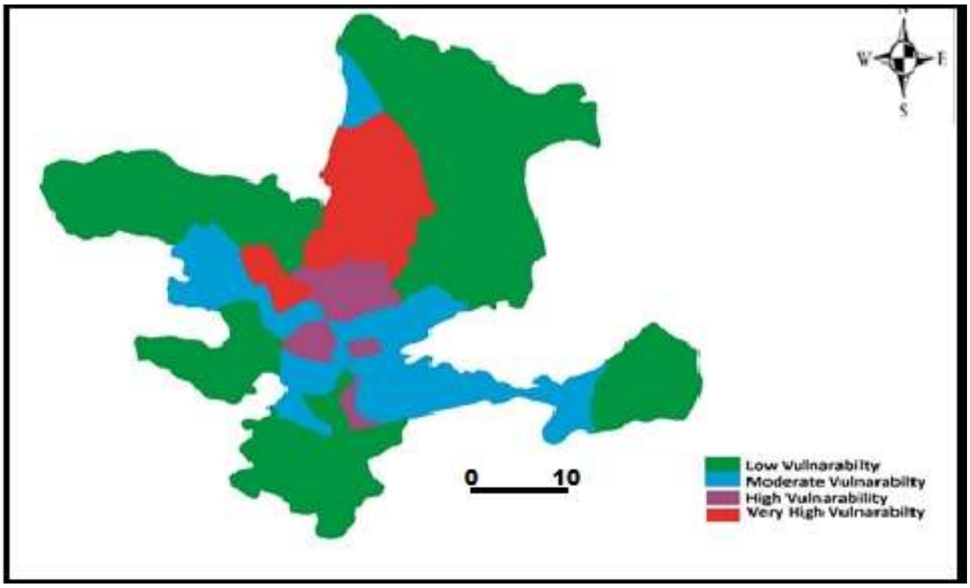

Fig.2: Shows the Vulnerability of Srinagar city based on density of buildings.

Building Age:

Age of the buildings determines the level of vulnerability of buildings. Older the building higher is the vulnerability [14]. Under strong seismic excitations, older buildings are more vulnerable to severe damage or total collapse. Based on age, the building of Srinagar city were grouped into three vulnerable classes: High (age >70 years), moderate (age <50 years) and low (age <10 years) (Fig.3). The central part of the city including Downtown area has buildings which have even age more than 150 years. Most of these buildings are built of with stone, bricks, wood and mud used as cementing material. These buildings possess higher vulnerability as the building material has almost decayed with age.

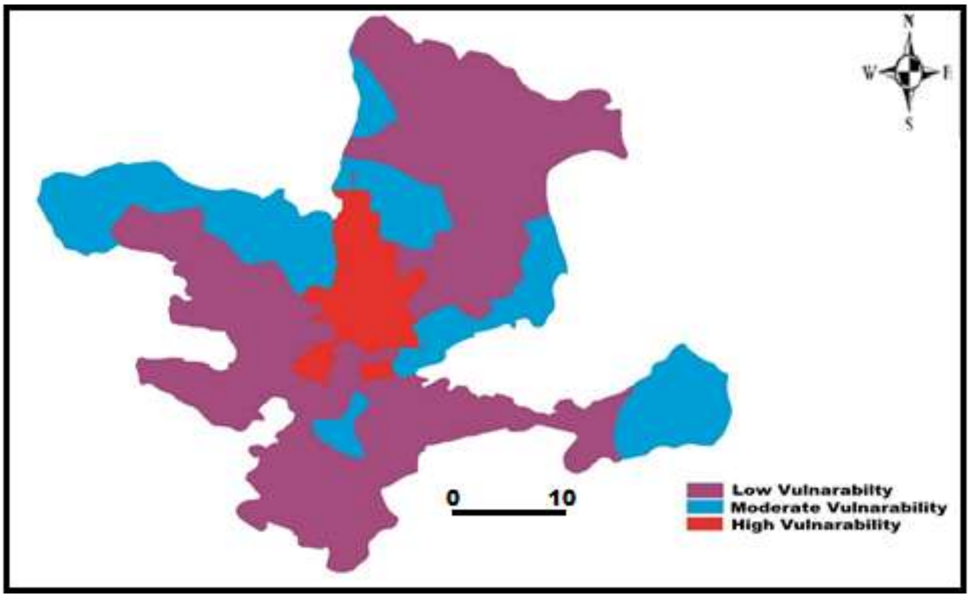

Fig.3: Shows the Vulnerability of Srinagar city based on age of buildings.

Building structure:

The city of Srinagar has a number of timber structures in the form of houses, shrines and bridges. These structures have had great past and have survived the ravages of time, these are good examples of unique artisanship and techniques. The use of timber has been in the form of structural members comprising the beams and columns. Their dimension are quite large and without any joint. The members like columns are lotus shaped with corbelling, carvings and standing on stone bases. They not only provide structural stability but also adore the space to enclose. Moreover, they with the beams increase strength of the structures. Often these points are covered with brackets (iron braces) (Fig.4). These are also good examples of architectural edifices. Brackets have been also used at the eves of building to supports the roof and ornate the facade. With beams and columns adding to the structure, timber also finds usage in the foundations and near ground floor level finish comprising wooden flooring.

Fig.4: Shows the iron braces placed on corners, which increase the seismic resistance of buildings.

Building material:

Most of the conventional buildings in Srinagar were constructed on two basic construction systems: Taq and Dhajji-Dewari. The first system, built of load bearing masonry piers and infill walls with wood runners at each floor level, used to bind the walls together with the floors and the second system built of a braced timber frame with masonry infill [8]. Both allow for a superior ductility, permit controlled lateral displacement during seismic loading. Although, with time the construction pattern and material changed with houses mainly made with bricks and concrete. According to building material, the city is divided into four vulnerable categories based on the strength of the building material: Sun-dried mud brick and Wood buildings (Very High Vulnerability), Brick and Wood buildings (High Vulnerability), Brick and Iron buildings (Moderate Vulnerability) and Concrete buildings (Low Vulnerability). The older buildings in the downtown area were constructed using sun-dried bricks and mud as cementing material. The foundation was made of stones and wooden logs were used as beams and columns, which unknowingly acted as seismic resistant structures. In some structures iron braces at corners were used to support the structure and make it earthquake resistant structure.

Structural vulnerability of older buildings:

Indicators selected for assessing the structural vulnerability of Srinagar city

- Plan irregularity
- Age of residential buildings
- Height/Number of storey of residential buildings
- Construction material of residential
- Soil condition
- Slope and ground condition

The overall vulnerability was calculated as the weighed sum of six parameters after [1] [6] used in the formulation of the seismic vulnerability index of sixteen buildings in Srinagar city (Table 2). These parameters are related to 5 classes of growing vulnerability classes: A, B, C, D and E (Table 1a, b) based on the Value of “ah” $ah = a_0 I \beta$

ah = design seismic coefficient for the building

a_0 = basic seismic coefficient for the Seismic zone in which the building is located (IS 1893:2002 Part I)

I = Importance factor applicable to building (IS 1893:2002 Part I)

β = soil foundation factor (IS 1893:2002 Part I)

IJARSE
ISSN: 2319-8354

Category	Value
A	2
B	2.5
C	3
D	3.5
E	4

Category	Range of ah
A	0.04 to <0.05
B	0.05 to 0.06
C	>0.06 to < 0.08
D	0.08 to < 0.12
E	>0.12

Table 2a, b: -a) Table for building categories for Basic Structural Hazard (BSH) b) Earthquake Resisting Features.

SPECIFICATIONS		**BM**	**HB**	**RR**	**DM**	**DS-1**	**DS-2**	**WM**	**SH**	**IHS**	**OBH**	**IM**	**MM**	**SPC**	**KM**	**AN**	**LDMS**
HIGH RISE	**Up to 2 story**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Between 3-7 storey	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	More than 7 storey	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
QUALITY Of CONSTRUCTION	**Good**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Medium	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
	Low	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
VERTICAL IRREGULARITY	**Steps in elevation, inclined walls, discontinuities in Load path, buildi**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

	ngs on high terrains																
	Without Vertical irregularity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOFT STOREY	**Open on all sides building tall ground floor, building on Stilts**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
	Without Soft Storey	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLAN IRREGULARITY	**“L,U, E, T” or other irregular Building Shape**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
	Without Plan Irregularity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POUNDING	**Floor level of Adjacent building not aligned**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

	&<10 mm of Separation per storey																
	Without Pounding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FALLING HAZARDS	**Chimneys, Parapets, Cladding, Excessive, Cantileverage, Overhead tank**	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
	Without Falling Hazard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOIL CONDITIONS	**Buildings founded on Rocks**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Buildings Founded on Medium Soil	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
	Buildings Founded on Soft/Sandy	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.3	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6

	Soil																
GROUND CONDITIONS & SLOPE AMBIENCE	**Buildings in Hill Slopes /Tank Bunds /Reservoir Rims with Slope >10^0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gentle Slope	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	Moderate	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	Steep	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
EARTHQUAKE RESISTANCE MEASURES ADOPTED	**Yes**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	No	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL MODIFIERS Performance Modification Factor (PMF)		-0.9	-1.5	-1.8	-0.7	+0.7	-0.25	-2.1	-2.6	-0.3	-3.1	-0.85	-1.85	-1.1	-0.85	-1.45	-1.65
FINAL SCORE Basic Structural Hazard (BSH)		3	3.5	2.45	4	3	2.25	3	3.45	4.0	3.5	2.45	2.55	2.5	2.65	2.45	1.85
S (Structural score)		2.1	2	0.65	3.3	3.7	2	0.9	0.85	3.7	0.4	1.6	0.7	1.4	1.8	1.0	0.2

IJARSE
ISSN: 2319-8354

Table 3: Shows the seismic vulnerability index of buildings in Srinagar city { Baba Manzil, Saidakadal (BM), Heritage building, Srinagar (HB), Rattan Rani Hospital, Srinagar (RR), Darial Manzil, Nowhatta Srinagar (DM), Dukan-e-Sangeen, Fatehkadal Srinagar (DS-1), Dukaan-e-Sangeen, Fatehkadal Srinagar (DS-2), Wakeel Manzil, Bohrikadal Srinagar (WM), Shah Heritage, Bohrikadal Srinagar (SH), Islamia High School, Rajourikadal Srinagar (IHS) and Old bridge Habakadal (OBH) Inayat Manzil Dukan-I_Sangeen, Fatehkadal (IM), Mather-I-Maharban, Daulat Abad (MM), Sri Pratap College, M. A. Road (SPC), Khanday Manzil, Safa Kadal (KM), Anand Niwas, Barbar Shah (AN) and Lal Ded Memorial School, Ganpatyar, Budyar (LDMS)}.

Overall seismic pattern:

As the Indian subcontinent continues to push northward, stresses continue to build on massive faults along the Himalayan arc. Crustal adjustments occur in form of recurrent seismicity. The rate of convergence between the Indian and Eurasian plate has a direct impact on the seismicity in Kashmir Himalayan region. These stresses let loose along a relatively small fault segment in the fall of 2005. More than 80,000 people died when the magnitude 7.6 Mw Kashmir quake hit this region reducing houses, even entire mountainsides, to rubble. Many moderate and large earthquakes have rocked the Kashmir Himalaya in historic times [13] [9] [11] [3] [5] [2]. NEIC data suggest the earth earthquakes are frequent in this region (Fig 4). With a few exceptions, existing earthquake resistant building codes are not applied uniformly to new [4]. Choosing a level of seismic hazard or risk for engineering design is highly convoluted in this region. A good seismic design should be based on rigorous study (geological, geotechnical) of this area. With mandatory earthquake resistance on all new construction, cities on the Indian subcontinent can evolve toward safety with minimal effort. In many cases this evolution will require no more than the enforcement of existing laws like IS 1893-2002.

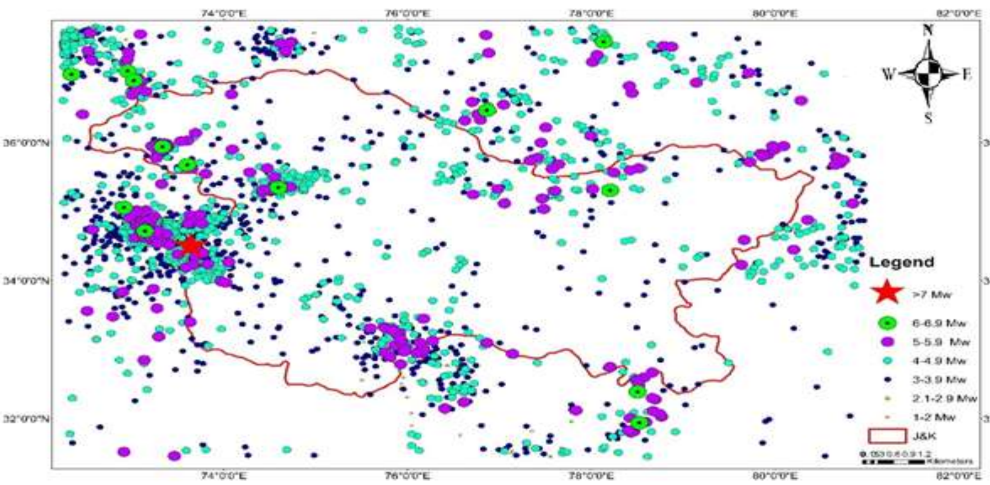

Fig 4: Shows major and minor earthquakes since 1972-2016 in Kashmir Himalaya (source: NEIC, IRIS, IMD).

II DISCUSSION AND CONCLUSION

Comparing with the great advances made in methodology for engineering all around the globe, there is still a long way to go to catch up with modern engineering technologies in Kashmir Valley. The method of building construction plays a vital role in reducing the loss of life and property. The loss however cannot be reduced to zero but can be mitigated when proper steps are taken at right time. The construction of earthquake resistant building is one of the best steps one can take to ensure the safety. Buildings such as those found in Srinagar, if encountered in developed places, would probably be condemned immediately as unsafe. Although the lack of modern industrial-level precision in old buildings of Srinagar city, they have acted as earthquake resistant since past century while the area being rocked by earthquakes regularly. The probability of a mega earthquake in Kashmir Himalaya in future will prove a real test to all types of construction in the city. The traditional pattern of construction is safer than the present form of unplanned construction. The traditional pattern of construction might be well suited for earthquakes in such seismotectonic setup but due to enormous growth in population upto 1225837; sophisticated traditional buildings have paved way to a ramshackle hodgepodge of weak and stiff built structures, with little resistance to earthquake ground motions. The newly built construction are stiff and with most structures designed without taking into consideration the level of seismic hazard imposed in the area. The progress of modernization and industrialization threatens to result in the eventual demolition of these old traditional buildings [8]. The victimisation of urban sprawl has also played major role leading to higher vulnerability of structures. An alarming increase in the construction of civil infrastructure encroaching the water bodies and even flood plains of Jhelum. These flood plains consist of highly liquefiable material, which can cause higher damage to concrete structures. A proper strategy need to be formulated to minimise the damage and if the current form of construction patterns continue the expected damage will increase further. An expectancy of a mega earthquake in this part of Himalaya in near future really leads the future of the city in bleak. Most recent advances in the field of seismic hazard assessment should be incorporated in the construction of new structures in the Kashmir Valley to minimise the loss otherwise be prepared for higher damage and mortality.

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