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SEISMIC VULNERABILITY ASSESSMENT USING HIGH RESOLUTION SATELLITE DATA AND FIELD STUDIES

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ABSTRACT

Economic factors such as decrease in economic opportunities in rural areas and consequent migration to the urban areas is one of the major reasons for the growth of a city. Urbanization not only changes the entire landscape of a city but also brings in many socio-economic and lifestyle changes. Most recent constructions in the urban areas consist of poorly designed and constructed buildings. Such unplanned and haphazard growth will choke the city and will be potentially dangerous for a natural event like earthquake. Seismic vulnerability assessment of buildings in urban areas is an essential component of a comprehensive earthquake disaster management policy. Detailed seismic vulnerability evaluation is technically complex and expensive procedure because of field survey. Simpler procedures can help to rapidly evaluate the vulnerability of different types of buildings, so that the more complex evaluation procedures can be limited to the most critical things.

Rapid Visual Screening (RVS) is a classical method of preliminary vulnerability studies, which requires minimum input to classify the vulnerability level. In order to assess vulnerability of buildings in rapid manner, in this study an attempt has been made to use satellite data. Part of Vijayanagar, Bangalore has been selected as study area and high resolution satellite data (with spatial resolution of 60cm) was used. The required vulnerability parameters of Falling Hazards, Occupancy, Location/Co-ordinates, No. of storey, Vertical Irregularity and Horizontal Irregularity have been derived using Satellite data. Vulnerability score has been arrived and buildings have been classified according to RVS chart. Field survey has been carried out by visual inspection and vulnerability score of the buildings are arrived at and the buildings are classified according to RVS chart. Vulnerability scores are compared for about 150 buildings in the study area. It is found that more than 80% vulnerability scores obtained from satellite data match with vulnerability scores obtained from field studies.

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INTRODUCTION

Earthquake - a natural disaster that lasts a few milliseconds to a few minutes and can cause immense destruction resulting in loss of life, property, and infrastructure. Often, the damage is due to improper construction methodologies and lack of awareness to take preventive measures to minimize the impact of an earthquake. We can neither predict nor control the occurrence and level of the earthquake accurately. Hence it is important for us to have a clear understanding on the three phases - pre, during and post seismic occurrence.

An Earthquake was not considered as a major disaster in India until the late 1950's since the Deccan Plateau was considered to be a stable and safe zone. However, the major earthquakes at Lathur, Koyna, Bhuj with their resulting devastation forced them to think seriously about earthquake as a major disaster. Earlier India was divided into seven zones based on earthquake occurrence and frequently revised soon after major earthquake in the country, currently four seismic zones. The zonation in India also is not appropriate as the country was divided into four zones with four zonation factors (hazard factor) only. Many recent studies have highlighted that macro level zonation factor (peak ground acceleration) map given in Indian code is lesser or higher than that of the micro level seismic hazard studies (Anbazhagan et al., 2009, Menon et al., 2010). According to current seismic zonation, more than 95% major cities are located in high seismic zones. Many cities lack detailed seismic characterization, poor geotechnical data and detailed site and induced effect assessment. Economic factors such as decrease in economic opportunities in rural areas and consequent migration to the urban areas is one of the major reasons for the growth of a city. Urbanization not only changes the entire landscape of a city but also brings in many socio-economic and lifestyle changes. Most recent constructions in the urban areas consist of poorly designed and constructed buildings. Such unplanned and haphazard growth will choke the city and will be potentially dangerous for natural event like earthquake. Indian has poor seismic disaster management due to lack of modernism and poor or closed ground data resources. Seismic vulnerability assessment of buildings in urban areas is an essential component of a comprehensive earthquake disaster management policy.

Spatial information - images and maps, forms the foundation and basis for most of the planning and implementation of developmental activities; infrastructure development; disaster management support; environmental monitoring; natural resources management; business geographic and many other activities. Even common citizens require maps and spatial information for their localized decision-making. Though abundant data is available, not much of it is properly organized and analyzed, which has resulted in limited outcome and wastage of available resources. These are becoming a hindrance in utilizing resource information in the most productive and timely manner. Advanced technologies of satellite remote sensing, Global Positioning System (GPS), Information Technology (IT) and Geographic Information Systems (GIS) have the capability to generate and integrate data from various resources (spatial and non-spatial). In this study an attempt has been made to carry out seismic vulnerability assessment of building using modern remote sensing data with GIS. The traditional manual survey of the areas and buildings for their assessment of the vulnerability of buildings due to earthquakes is almost impossible as it is very time consuming and tedious. Also the manpower and the costs involved are huge. This is where the technology of remote sensing can be used in conjunction with the conventional field surveys to assess the vulnerability of buildings.

STUDY AREA

Seismic vulnerability needs detailed knowledge about seismic hazard, ground parameter and building stacks. Building stack can be obtained from modern satellite data, but first two parameters should

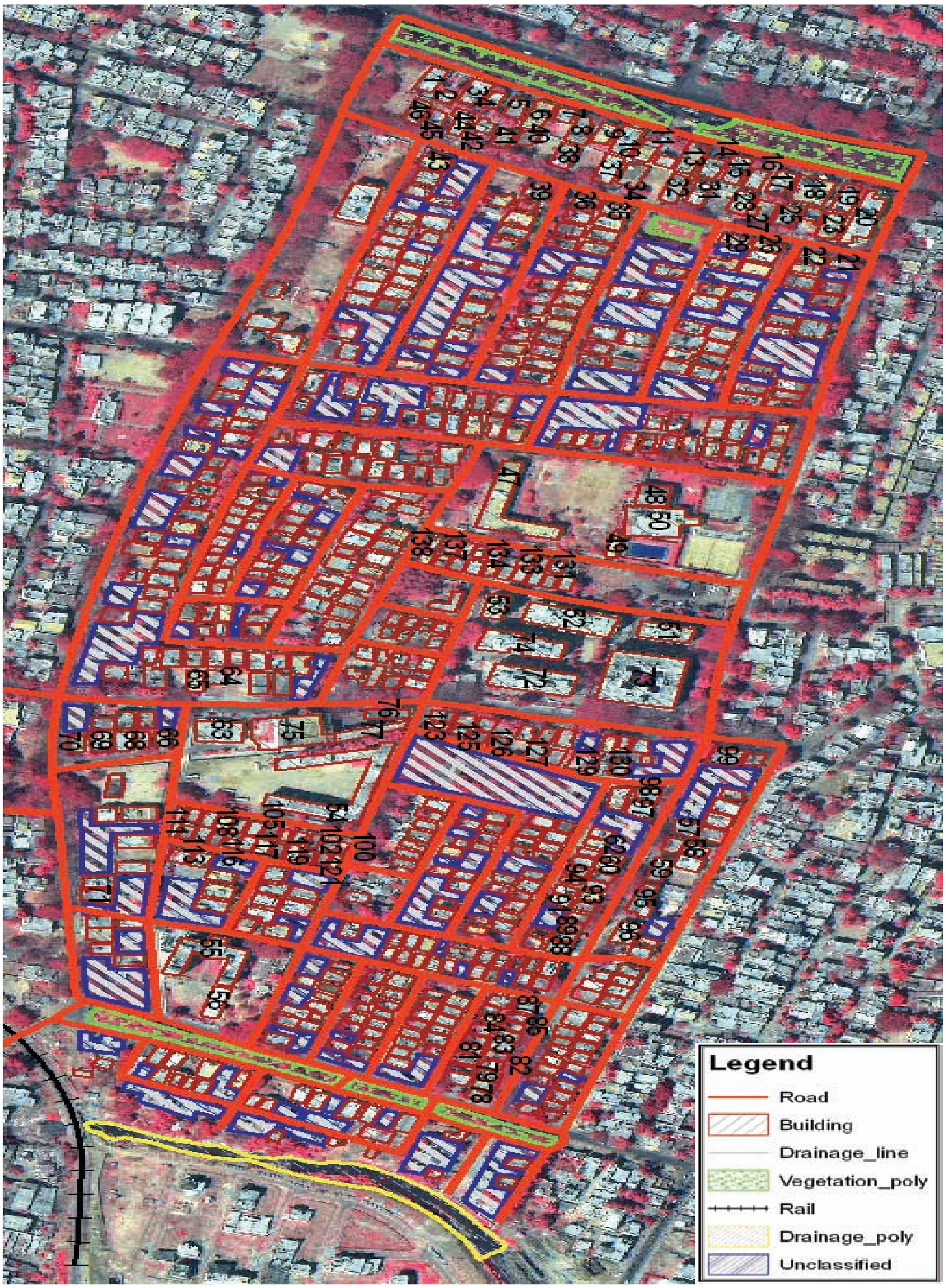

Fig. 1: Study area marked in the satellite image with ground features

be available readily. Peninsular India (PI) once believed to be a stable continent, has experienced many earthquakes indicating that it has become a moderately active region. In particular, Latur earthquake on 30th September 1993 (M 6.3), Jabalpur earthquake on 22nd May 1997 (M 6.0) and Bhuj earthquake on 26th January 2001 (M 7.9) have influenced the need for detailed study of earthquakes and their effects on Indian cities in PI. Part of Bangalore has been selected as study area, where the detailed seismic hazard analysis, site characterization and microzonation parameter are available. Bangalore city covering an area of 220 sq. km, at an altitude of 910 m above MSL, is densely populated and is economically and industrially important for India. It is one of the fastest growing cities in Asia and the fifth largest in India. It is situated at a latitude of 12^o 58' north and longitude of 77^o 36' East. Bangalore, located in the south-western part of India, has an uneven landscape in the south and relatively more level plateau towards the north. Bangalore's rapid growth and very high population density has put pressure on its infrastructure and dilution in standards of building / infrastructure construction. Present constructions include mud buildings to RCC framed structures and steel construction, improper and low quality construction practice and irregular and heavy traffic conditions. The buildings range from a single storey building to high rise buildings of more than 20 floors. Many buildings also have basements. Vijaynagar south western part of Bangalore city has been selected location for this study. This area is designated as high seismic hazard index by Anbazhagan et al (2010), also thickly populated and bustling locality. The locality encompasses all types of buildings and has a moderate to high hazard index value. The various types of rock found in the area include granites, gneisses and magmatites. The soil types are red laterite and red, fine loamy and clayey soils (Anbazhagan and Sitharam 2008). Figure 1 shows the study area marked in satellite image and marked features in the ground.

MATERIALS AND METHODS

The present study involves the collection of satellite data, interpretation of satellite data, creation of the geo-database and collection of field information based on the vulnerability criteria. In order to achieve this, the high resolution satellite data was procured. The Quick-bird satellite data - having a spatial resolution of 61 cm panchromatic and 2.5 m multi-spectral bundled data - was obtained. These bundled data were merged using image processing software. While supplying the Quick-bird satellite data, the standard geometric and radiometric corrections were applied in order to get the precise measurements. DGPS was used and the data has been geo-rectified. Then this geo-referenced data was used for visual interpretation of the Land Use and Land Cover (LULC) features with special emphasis on built-up areas. The interpretation technique and methodology can be described as On-Screen Visual Interpretation carried out using the interpretation keys such as tone/colour, shape, size, texture, shadow, location, association and shadow. The classification systems adopted in the present study are the identification of feature layers such as Buildings, Roads, Drainage (polygon), Vegetation (polygons), Railway Lines and Unclassified. The maps generated from the above procedure were also field verified at few locations for validation and for the unknown features. Then the correlation of the field data with the data interpreted from the image was done using the software Arc GIS, version 9.2. Features identified are further used to image interpretation and for the seismic vulnerability study.

An *interpretation key* guides the interpreter to evaluate the information presented on the image in an organized and consistent manner. The interpretation keys used in visual interpretation technique are Tone or Colour, Size, Shape, Texture, Pattern, Location, Association and Shadow. The application of image interpretation keys with paramters revalt for seismim vulnerability is defined below.

- ✓ Tone or Colour: Variations in colour due to reflectance characteristics. This allows us to classify the Different types of roofs the buildings possess and Aides in differentiating the new buildings to the old buildings.
- ✓ Size: Spatial dimension of the object-Determines the type of building
- ✓ Shape: Physical form of the object and is a function of scale- Determines the type of building and irregularities of the building
- ✓ Texture: Repetition of basic pattern. Occurs due to the tonal repetitions in a group of objects-Aids in classification of buildings and areas and Different types of roofs the buildings possess
- ✓ Pattern: Spatial arrangements of surface features- Aids in classification of areas such as residential, commercial, industrial etc.,
- ✓ Location: Geographic site and location of objects provide clue for identification and their genesis.
- ✓ Association: Situation of the object with respect to the neighbouring features.
  - Buildings along the main roads will have mostly a mixed or commercial development when compared to the cross roads.
  - Buildings associated with playgrounds will mostly be schools/colleges
- ✓ Shadow: formed due to the sun illumination angle, size and shape of the object or sensor viewing angle.
  - This formed the most important factor for the determination of the height of the buildings, i.e. number of stories in the building. Initially one or two prominent buildings were visited and their number of stories was practically seen and then this was correlated to the height of the shadow the buildings had. Since the image was taken at the same time and date the sun elevation angle will be the same for the entire scene. Thus the same principle was extended to all the other buildings and then the height of the buildings was arrived at.

RAPID VISUAL STUDIES (RVS)

A procedure for Rapid Visual Screening (RVS) was proposed in the USA in 1988, which was further modified in 2002 to incorporate the latest technological advancements and the lessons learnt from previous earthquakes. Even though this procedure was developed for the typical constructions in the US, it has been widely used in many other countries with suitable modifications. The RVS method is followed without any structural calculations and this method uses a scoring system that makes use of the building type and its attributes. This procedure facilitates to identify, inventory and rank buildings that are potentially and seismically hazardous. This procedure can be implemented relatively quickly and inexpensively to develop a list of potentially hazardous buildings without the high cost of a detailed seismic analysis of individual buildings. The screening is based on the numerical seismic hazard and vulnerability score. This procedure is being incorporated in a GIS platform. Depending on the buildings, this method can be adopted for both rural and urban areas. After the analysis if a building receives high scores, it is considered to have adequate seismic resistance and similarly if a building receives low scores, it is considered to be more prone to earthquake damages and thus should be referred to a professional who has experience and is trained in seismic design for the strengthening of the building. The data collection form for the RVS procedure is completed for each building screened by the detailed instructions and guidelines for its execution. The parameters of the data collection form vary with the presence of the building with respect to its Seismic Zone. This particular Rapid Visual Screening of Potential Seismic Vulnerability is based on FEMA-154, ATC-

21 and is adopted by the National Disaster Management Authority (NDMA), Government of India. RVS requires simple data of building; these are usually collected from field survey. Mandatory data required for RVS is listed below:

- ❖ Location of Structure
- ❖ Occupancy
  - o Building Type
  - o Maximum number of persons (0-10, 11-100, 100-1000 and 5000)
- ❖ Soil Type
  - o Type I - Hard Soil
  - o Type II - Medium Soil
  - o Type III - Soft Soil
- ❖ Falling Hazards
- ❖ Building Type
  - o No. of Stories (Mid rise 4-7 and High Rise>7)
  - o Vertical Irregularity
  - o Horizontal Irregularity
- ❖ Code detailing Type

From the above parameters, it can be observed parameters RVS is approximated and any high resolution image with Geospatial detail will provide these details except soil type and seismic zone. Most of time soil type and seismic zone factor may not vary building to building. These details can be easily obtained from published maps and data, particular for the city where microzonation maps are ready available. For Bangalore these details are published by Anbazhagan et al (2010). So an attempt has been made to identify the other parameters using high resolution satellite image. Table 1 show parameters required for RVS, Interpretation Key in stile image and features identified for analysis. The different characteristic has been identified from the images, which are future used to arrive Vulnerability score of the building (Ravi Sinha and Alok Goyal, 2007). The final score obtained from the RVS method is taken as the base for interpolation and also the corresponding damage assessment is represented on the map in the form of different colour coding. Figure 2 shows RVS score obtained by desk study using satellite data The red colour indicates the final score by the RVS method to be in between the region 0.70 – 2.0 indicating High Probability of Grade 3

Table 1: RVS parameters, interpretation characteristics of image and features identified

RVS Parameter	Interpretation key	Features identified
Occupancy	Size, Shape, Shadow, Pattern, Association	Residential, Commercial, Recreational, School/ College, Government
Falling Hazards	Shadow, Shape, Size	Chimneys, Towers, Water Tanks
Building Type	Shape, Tone, Size, Pattern, Texture, Shadow,	C1, URM3, S1
No. of Stories	Shadow	Low Rise, Mid Rise, High Rise
Vertical Irregularity	Shape, Tone, Size, Pattern, Texture, Shadow	If there is any presence of vertical irregularity which can be recognized from the image.
Horizontal Irregularity	Shape, Tone, Size, Pattern, Texture, Shadow	If there is any presence of horizontal irregularity which can be mostly recognized on the image.
Soil Type	Tone, Texture, Association. Also from published data.	Hard / Medium / Soft Soil

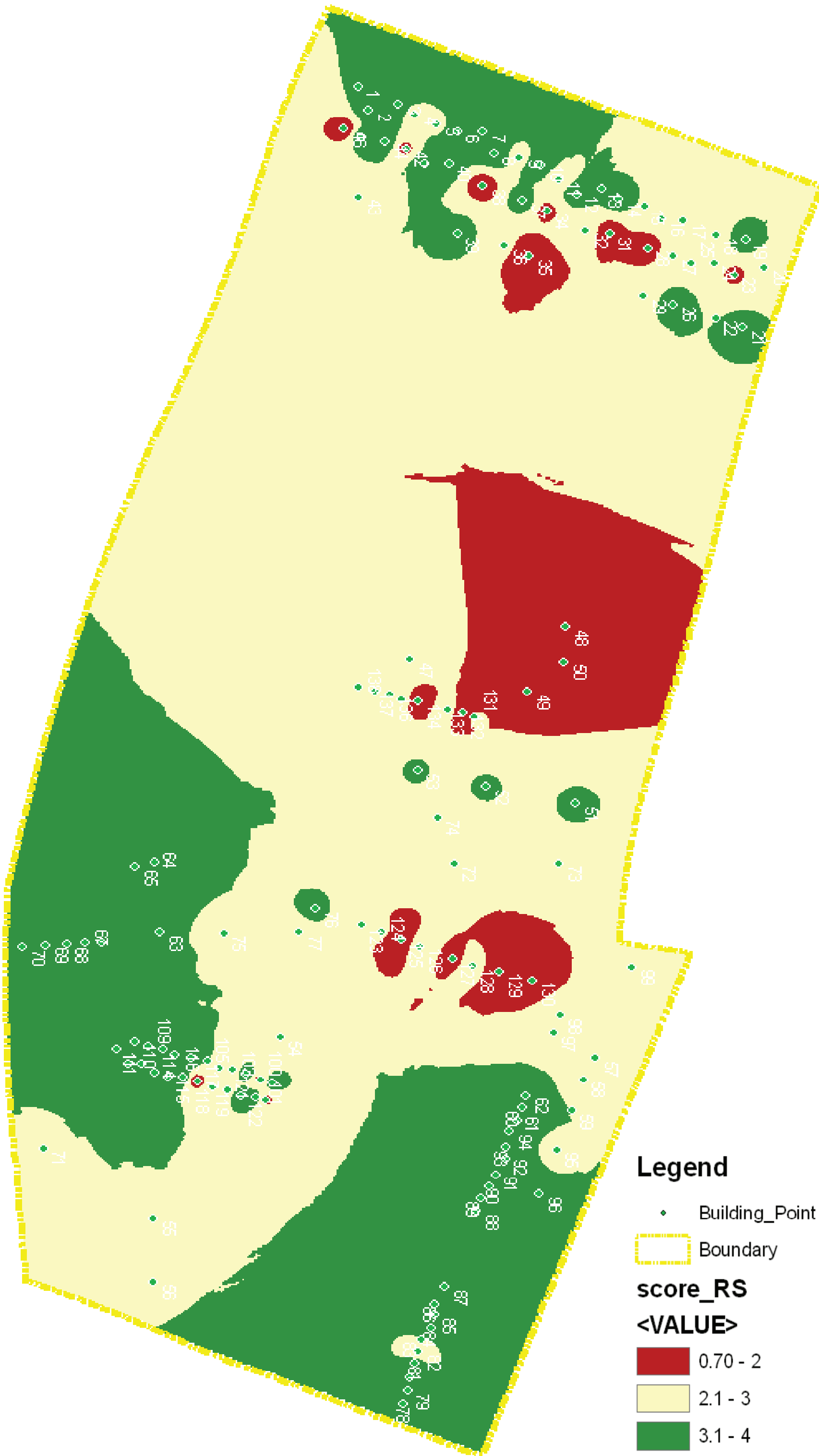

Fig. 2: RVS Score by desk study using high resolution satellite data

damage to Very High Probability of Grade 2 damage, cream colour indicates the final score by the RVS method to be in between the region 2.0 – 3.0 indicating High Probability of Grade 2 damage to Very High Probability of Grade 1 damage and green colour indicate the final score by the RVS method to be in between the region > 3.0 indicating High Probability of Grade 3 damage to Very High Probability of Grade 2 damage.

FIELD SURVEYS

Seismic vulnerability of building using satellite image is pilot study in India, it is mandatory to verify RVS score for the same building using conventional field survey. The registered image of the project site with the latitude and longitude values are prepared on a map and a copy of this is taken to the field survey as a reference. Along with this the copies of the data collection forms are also taken (one for each building). A hand held GPS was also taken to the field for checking of the image registration with the latitude and longitude values of the GPS. Once the individual survey started, firstly its GPS location was checked with map carried. Then a photograph of the building was taken for the reference. Just by seeing the building, we can decide the Current Visual Condition, Occupancy, if the Building is on Stilts / Open Ground Floor, any Falling Hazards, No of Stories and make a note of it. Figure 3 and Table 2 gives comparison of typical building in the study area. RVS score for each building has been arrived and mapped for study area.

Table 5.4: Comparison of remote sensing and field study for typical building

Parameters	Remote Sensing	Field Study
Occupancy	Residential	Residential
No of People	0-10	0-10
Photograph	Yes	Yes
Current Visual Condition	----	Excellent
Falling Hazards	No	No
Total Stories	2	2
Bldg Type	URM3	URM3
Rise of Bldg	Low Rise	Low Rise
Modifiers for Rise	0.0	0.0
Vertical Irregularity	Yes	Yes
Mod – Vertical Irregularity	-1.5	-1.5
Horizontal Irregularity	Yes	Yes
Mod – Horizontal Irregularity	-0.8	-0.8
Code Detailing	Not Known	Not Known
Soil Type	Type III	Type III

RESULT AND DISCUSSION

The results obtained from both the methods are compared in this section. The assessment of accuracy of the data obtained from the Remote Sensing (RS) when compared to the conventional field surveys is calculated. Overall RVS score based on the remote sensing data is matches with 80% of RVS score based on the field study. Some of the important characteristics of parameters are discussed below.

Fig. 3: Typical building observation by field visit photo (left) and satellite image (right)

- Location of Structure is accurately assessed on both the methods
- Occupancy
  - *Building Type*- Assessment of building using by RS was stared with typical image texture. It is difficult to differentiate building type very clearly only RS but also in field studies. Building types listed in Rapid Visual Screening in Ravi Sinha and Alok Goyal, (2007) for field studies are drive from FEMA 154. Federal Emergency Management Agency (FEMA) 154 is presented guideline for Rapid Visual Screening of Buildings for Potential Seismic Hazards, which is typically designed for buildings in USA. This has been slightly modified by Ravi Sinha and Alok Goyal, (2007) for Indian building types. But Indian building types are not accommodated in Ravi Sinha and Alok Goyal, (2007) chart. Indian buildings construction styles are different; it is not possible to accurately assess the same. This shows that whatever possible assessment of building type in field study can be also assessed using RS data.
  - *Maximum number of persons (0-10, 11-100, 100-1000 and 5000)* - This parameter is easily evaluated based on roof area and building type in RS, which matches with more than 80% results from field study.
- Soil Type - this parameter can not be easily identified using field or RS studies, because most of Builds near by area is covered by paved roads or concrete. In this study these details are collected from Anbazhagan et al (2010).
- Falling Hazards- This parameter is easily assessed in RS data because the shadow in the image is with known angle of satellite and sun. Parameter assessed using RS matches well with Field study
- Building Type
  - No. of Stories (Mid rise 4-7 and High Rise>7) - Parameter assessed using RS data considering shadow matches well with Field study
  - Vertical Irregularity – About more than 70% of results from RS data considering shadow is matches with Field study
  - Horizontal Irregularity - About more than 90% of results from RS data considering shadow matches with Field study

- Code detailing Type - This parameter is very difficult to assess in RS as well as Field study as owners of buildings may not be willing to share this information and there no data base from Government office

CONCLUSIONS

The seismic vulnerability assessment of buildings is presently carried out by conventional methods by field surveys, which is labor and cost oriented and also time consuming. Therefore, an attempt is made in this study to utilize the technique of remote sensing in the assessment of seismic vulnerability of buildings. This study shows that RVS score based on the remote sensing data matches with 80% of RVS score based on the field study. Remote sensing based technique is cost effective and less time consuming, it can be easily used for RVS. This study was carried out for part of Bangalore, this may be extended for large area and assessed advantage and limitation in border way.

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