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# Seismic Vulnerability Assessment of RC Buildings of Nagpur (North-East) using Rapid Visual Screening

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***Abstract: Earthquake phenomenon as a natural hazard is causing high levels of damages to the structures around the world. The damages and losses caused by recent earthquakes have increased. The damage and loss caused by recent earthquakes has increased. Most of the existing buildings in Nagpur (India) are designed to withstand gravity loads only without the provision of earthquakes. It is therefore necessary to study the vulnerability of reinforced concrete structures to avoid high risk. The north-east region of the city is surveyed through rapid visual screening methodology using two different screening forms. Two different forms are selected to choose better form for Indian context. The damage grade is assigned to the buildings from 1 to 5 as per the European Macroseismic Scale-1998 for both the methodology independently. According to the grading systems buildings are identified for the further detailed evaluation.***
***Keywords: Seismic vulnerability, Rapid visual screening, Existing buildings, Earthquake.***

## I. INTRODUCTION

World has experienced numerous destructive earthquakes in the history resulting numeral of fatality and severe property damage [11]. Numerous of engineered and non-engineered buildings have damaged as well as collapsed via the Bhuj earthquake (India) [9]. The urban areas of a country have experienced a rapid growth in population through the previous few decades due to migration of people from rural areas to the urban areas for the reason of earning [11]. In present’s scenario, most of the existing buildings all around the globe are not designed to withstand against any strong ground shaking. Although, the data required for the vulnerability assessment of each building during the earthquake are not available which results in the more damage and life loss [8]. The Indian subcontinent is quite frequently observing earthquakes of varying magnitudes. Few earthquakes occur of low to moderate at an interval of 2-3 years [14].

Nagpur comes in Zone II as per Indian zoning map that is acknowledged as safest zone as it is low seismicity region [4]. Although the town hasn’t witnessed any seismic activity of magnitude 4 on Ritcher scale since 1938. Geological Survey of India has noted predominant features of neo-tectonic activity in vicinity (200 plus Km) of Nagpur that can trigger low to moderate earthquakes in the area. Narmada and Gwaligarh faults both are 200km distance from the city as per GSI and their effect cannot be neglected [23].

## II. METHODOLOGY

The methodology of the paper comprises of three major stages which are presented in flow chart below:

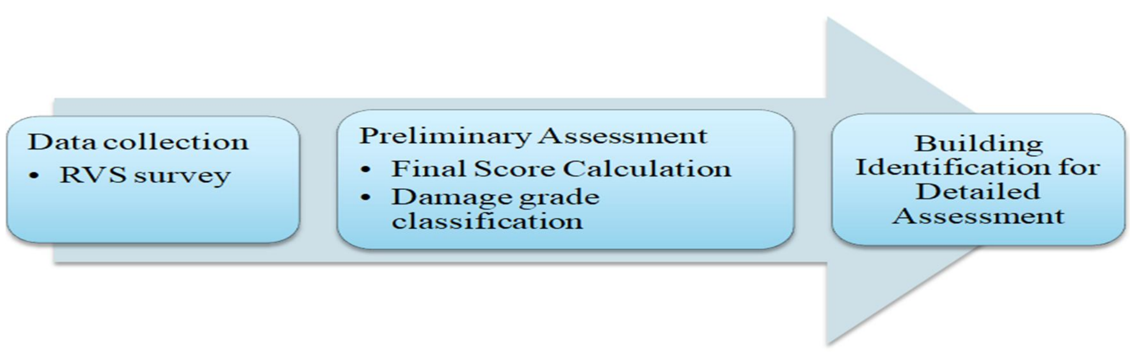


Fig. 1: Vulnerability Assessment Flow Chart

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Steps of methodology are as follows:

1) Selection of area of region of the city for Rapid Visual Screening.
2) Selection of two RVS forms proposed by Ningthaujam and Nanda [1] and FEMA.
3) Conduction of the RVS survey for the selected area by the two forms.
4) Calculation of Final Score using survey data by both the forms.
5) Categorization of damage grade of RC buildings as per final scores.
6) Comparison between the two RVS forms.
7) Identification of buildings requiring detailed seismic investigation.

### A. Rapid Visual Screening

The earthquake capacity of a building is estimated by means of seismic vulnerability procedures [1]. There are numerous methods that have been established to calculate the earthquake vulnerability of building [8]. Detailed seismic assessment is a precisely difficult and costly process and it is able to be conducted on a limited quantity of buildings [3,8]. Hence it is essential to employ simple procedures that can help to calculate the vulnerability outline of different types of buildings rapidly, so that the complex assessment procedures can be restricted to the critical buildings only [9].

Rapid visual screening (RVS) is such a method which is inexpensive procedure for recognizing the structures that are highly vulnerable that need to be evaluated in depth for suitable structure mitigation action [3,15].

The RVS is a score assigning procedure including determination of seismically risky structures by evaluating structural insufficiency [6]. This is generally conducted by walk around survey on site for individual building in the region selected [9]. A plenty of guidelines are offered by Federal Emergency Management Agency (FEMA) in United States for seismic hazard estimation and rehabilitation of buildings [7].

RVS procedure allows prioritizing the building to be additionally examined so that scientific and other resources can be more precisely employed [10].

The examination, data gathering and conclusion process usually conducted at the site and requires around half an hour depending upon the size of building [3].

The methodology is proposed on the basis of some key factors that influence the risk of seismic hazards for any structure which can be seismicity, soil conditions, type of structure, irregularities of the structure etc [9]. Vulnerability of structures can also be suggested by an expert who is working in this field [6].

### B. Seismic Vulnerability Assessment

The vulnerability of existing buildings is measured by calculating RVS scores employing numerical seismic hazard [9]. Once the building is recognized as seismically unsafe, such buildings shall be further evaluated by an experienced professional in seismic evaluation and design [15].

The five damage grades of EMS-98 are used to classify the level of vulnerability of the buildings surveyed. Final score of 2 is taken as cut off for the assessment below which further evaluation is recommended [2,3,7,8,9,10,15].

### C. Building Parameters

Various researches have proven that different building parameters affect the different damages of the building at the time of a strong ground shaking [1,15].

Major parameters affecting the performance of the building that are being used to calculate the score during the survey using the forms, are seismicity of the region, type of structure, plan and vertical irregularities, age of the buildings, type of soil etc.

### D. Damage Grading System

The procedure makes use of a damageability grading scheme as per European macroseismic scale 1998 (EMS-98) that necessitates the assessor to (1) recognize the primary lateral load-resisting system, and (2) recognize building characteristics that can adapt the seismic response predictable incorporating non-structural components [20]. Grade 2 is taken as cut off above which the buildings need to be further re-evaluated.

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Table 1: Damage grading system as per EMS-98 [20].

| Grade | Damage Effects |
|---|---|
| Grade 1 (Slight) | No damage to minor damage (Minor Non structural damage)<br>Fine cracks can be seen in plaster on structural members as well as in partition walls. |
| Grade 2 (Moderate) | Moderate damage (Minor structural damage, Reasonable Non structural damage)<br>Cracking occurs over structural frame members and structural walls and fall of plaster/mortar can be seen. |
| Grade 3 (heavy) | Significant to high damage (Reasonable structural damage, Major Non structural damage)<br>Large cracking over partition walls and cracking of beam column joint as well as spalling of concrete cover can be seen. |
| Grade 4 (Very heavy) | Extremely high damage (Large structural damage, extremely large Non structural damage)<br>Large cracking over frame elements, concrete failure in compression, rebar fracture, failure of bond, some column failure etc. |
| Grade 5 (Collapse) | Devastation (extremely heavy structural damage)<br>Failure Ground storey parts resulting collapse of the structure. |

*E. Selected Region for RVS*


Fig. 2: Map showing the selected vicinity

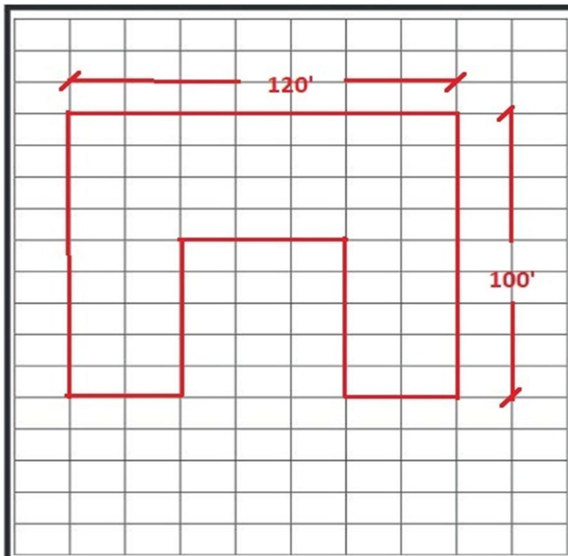
The north-east region of the city has been chosen for the assessment as the mild tremors were felt by the residence on 12$^{th}$ May 2015 when an earthquake of 7.4 magnitude hit Nepal [24]. The selected region mainly comprises of some parts of ward number 3 and ward number 22 of the city. As per the census 2011, ward number 3 has 5409 households with 26809 of population whereas ward number 22 has 3133 households with 18153 of population [25]. The selected vicinity has around 2200 households. A set of 44 (2%) buildings is randomly surveyed for RVS within the selected area using two methodologies comprises of RVS proposed by Ningthoujam and Nanda [1] for Indian context and FEMA 154 originated in USA. The orange dots in the figure 2 represents the location of the building assessed using the screening forms. Each building is assessed twice for the differentiation between both the methodologies. Based on the score calculation of both the methods, damage grades are assigned to the buildings as per the guidelines of the methodologies. The score computation formula of the methods is presented below:

Table 2: Final Score Calculations

| Score Calculation (Ningthoujam and Nanda [1]) | Score Calculation (FEMA) |
|---|---|
| S = BS + Σ (VS*VSM) | S = BV + Σ BVM |
| BS - Basic Score | BV - Basic Value |
| VS - Vulnerability Score | BVM - Basic Value Modifier |
| VSM- Vulnerability Score Modifier | |

### *F. Case Study*

An educational building of G+1 is taken for the case study from the surveyed buildings. Scores are calculated based on the two methodologies as presented in Fig: 1 and Fig: 2. As per Ningthoujam and Nanda [1], the building will face grade 4 damage and need further detailed evaluation, whereas the school building will face grade 2 damage as per FEMA and need not further re-evaluation for the seismic event.




Building Name Azad Nagar Urdu High School
Address Farooque Nagar Teka Nagpur
Other Identifiers ---
GPS Co-ordinates (If available) ---
No. Stories 2 Year Built 1992
Total Floor Area (sq. Ft. /sq. m) 12000 sq.ft
Seismic zone II
Surveyor Shamshad Ali Date 15/12/2019

| OCCUPANCY | | SOIL TYPE | Age of the building: |
|---|---|---|---|
| Commercial Residential Educational ✓ | Occupancy number 400 | Type I Hard, Type II Medium, Type III Soft | Age of building (In years) 27 |

**BASIC SCORE, MODIFIERS, AND FINAL SCORE, S**

| | Seismic zone | | Zone II | Zone III | Zone IV | Zone V |
|---|---|---|---|---|---|---|
| | Basic scores | | 1.00 | 1.70 | 2.00 | 2.70 |
| Basic score modifier | Substantial overhang | | +0.41 | +0.41 | +0.41 | +0.41 |
| | Age of building : Increment per year | 27x | +0.02 | +0.02 | +0.02 | +0.02 |
| | Poor construction quality | | +2.20 | +2.20 | +2.20 | +2.20 |
| | Moderate construction quality | | +1.10 | +1.10 | +1.10 | +1.10 |
| | Poor Maintenance condition | | +1.30 | +1.30 | +1.30 | +1.30 |
| | Moderate Maintenance condition | | +0.65 | +0.65 | +0.65 | +0.65 |
| | Type of soil: | | | | | |
| | Soil type-I | | -4.86 | -4.86 | -4.86 | -4.86 |
| | Soil type-II | | -2.43 | -2.43 | -2.43 | -2.43 |
| | Soil type-III | | 0.00 | 0.00 | 0.00 | 0.00 |
| | Number of stories: Increment per storey | 2x | +0.10 | +0.10 | +0.10 | +0.10 |

FINAL SCORE, S= 2.39

| Final score | S<1 | 1≤S<1.5 | 1.5≤S<2 | 2≤S<2.65 | 2.65<S |
|---|---|---|---|---|---|
| Assigned damage grade | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Grade 5 |

**RECOMMENDED ACTION FOR DIFFERENT DAMAGE GRADE:**

Grade 1/2: Seismically safe but non-structural damage can be harmful to occupants so repairing work is recommended for the building

Grade 3/4/5: Seismically not safe as structural damage will occur so further re-evaluation and retrofitting is recommended for the building

**Recommended action to be taken for the existing building:**

Further re-evaluation is recommended.

Fig. 3: RVS proposed by Ningthoujam and Nanda [1]

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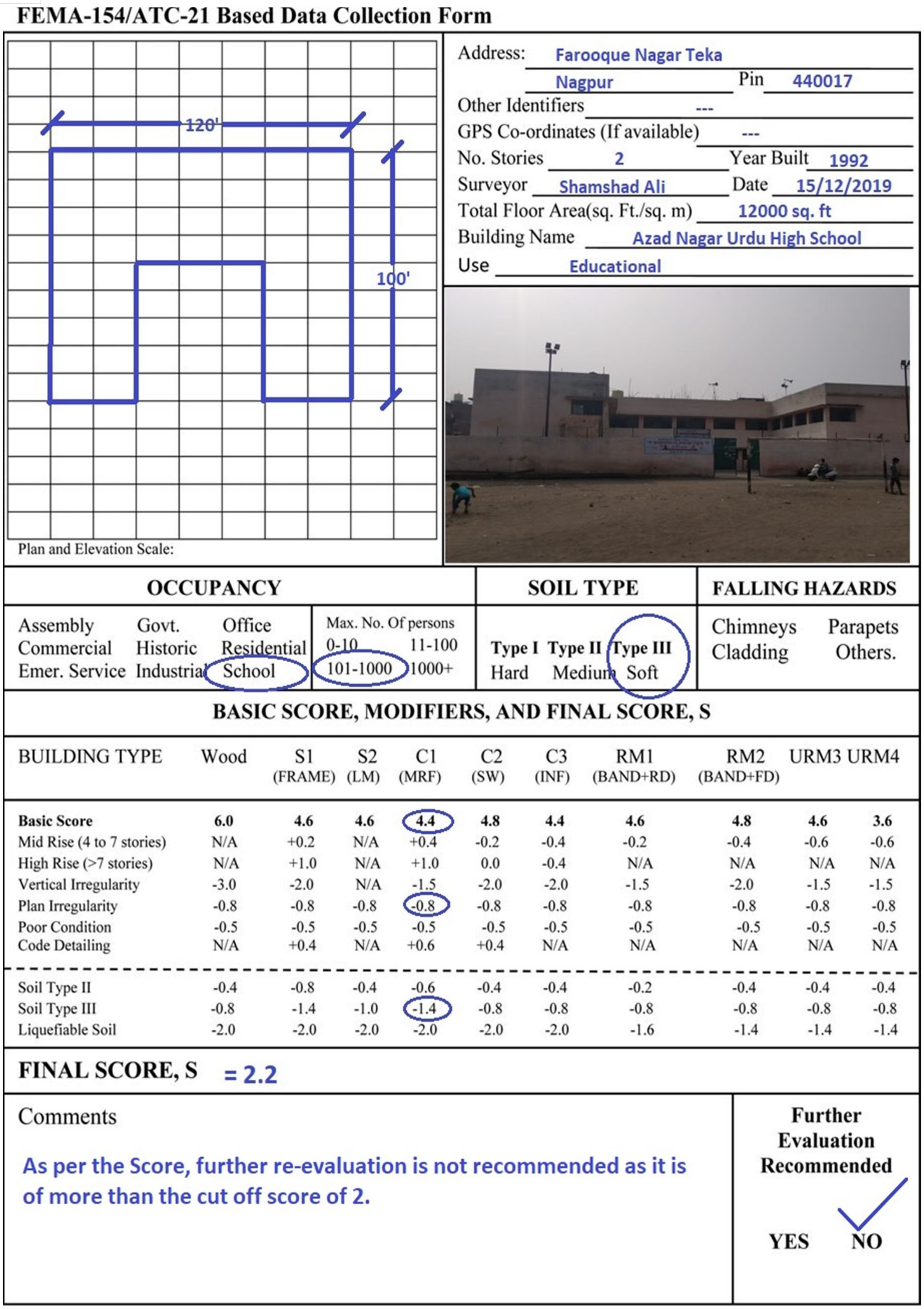

**FEMA-154/ATC-21 Based Data Collection Form**



Address: Farooque Nagar Teka
Nagpur Pin 440017
Other Identifiers ---
GPS Co-ordinates (If available) ---
No. Stories 2 Year Built 1992
Surveyor Shamshad Ali Date 15/12/2019
Total Floor Area(sq. Ft./sq. m) 12000 sq. ft
Building Name Azad Nagar Urdu High School
Use Educational

| OCCUPANCY | | | | SOIL TYPE | FALLING HAZARDS |
|---|---|---|---|---|---|
| Assembly<br>Commercial<br>Emer. Service | Govt.<br>Historic<br>Industrial | Office<br>Residential<br>School | Max. No. Of persons<br>0-10 11-100<br>101-1000 1000+ | Type I Type II Type III<br>Hard Medium Soft | Chimneys Parapets<br>Cladding Others. |

**BASIC SCORE, MODIFIERS, AND FINAL SCORE, S**

| BUILDING TYPE | Wood | S1 (FRAME) | S2 (LM) | C1 (MRF) | C2 (SW) | C3 (INF) | RM1 (BAND+RD) | RM2 (BAND+FD) | URM3 | URM4 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Basic Score** | **6.0** | **4.6** | **4.6** | **4.4** | **4.8** | **4.4** | **4.6** | **4.8** | **4.6** | **3.6** |
| Mid Rise (4 to 7 stories) | N/A | +0.2 | N/A | +0.4 | -0.2 | -0.4 | -0.2 | -0.4 | -0.6 | -0.6 |
| High Rise (>7 stories) | N/A | +1.0 | N/A | +1.0 | 0.0 | -0.4 | N/A | N/A | N/A | N/A |
| Vertical Irregularity | -3.0 | -2.0 | N/A | -1.5 | -2.0 | -2.0 | -1.5 | -2.0 | -1.5 | -1.5 |
| Plan Irregularity | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 |
| Poor Condition | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 |
| Code Detailing | N/A | +0.4 | N/A | +0.6 | +0.4 | N/A | N/A | N/A | N/A | N/A |
| Soil Type II | -0.4 | -0.8 | -0.4 | -0.6 | -0.4 | -0.4 | -0.2 | -0.4 | -0.4 | -0.4 |
| Soil Type III | -0.8 | -1.4 | -1.0 | -1.4 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 | -0.8 |
| Liquefiable Soil | -2.0 | -2.0 | -2.0 | -2.0 | -2.0 | -2.0 | -1.6 | -1.4 | -1.4 | -1.4 |

**FINAL SCORE, S** = 2.2

Comments

As per the Score, further re-evaluation is not recommended as it is of more than the cut off score of 2.

**Further Evaluation Recommended**

**YES** **NO** ✓

Fig. 4: RVS sheet by FEMA [9]

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## III. RESULTS

The interpretation of the survey data has been represented in the form of bar charts. Figure 5 represents the variation in the occupancy type within the sample surveyed. 87% of the buildings are residential, 10% are commercial and 5% are the educational buildings. The vertical axis shows the % of damage calculated by both the methodologies that needs details evaluation (above grade 2). Forms proposed by Ningthaujam and Nanda shows high level of damage whereas FEMA shows only few residential buildings of getting damage.

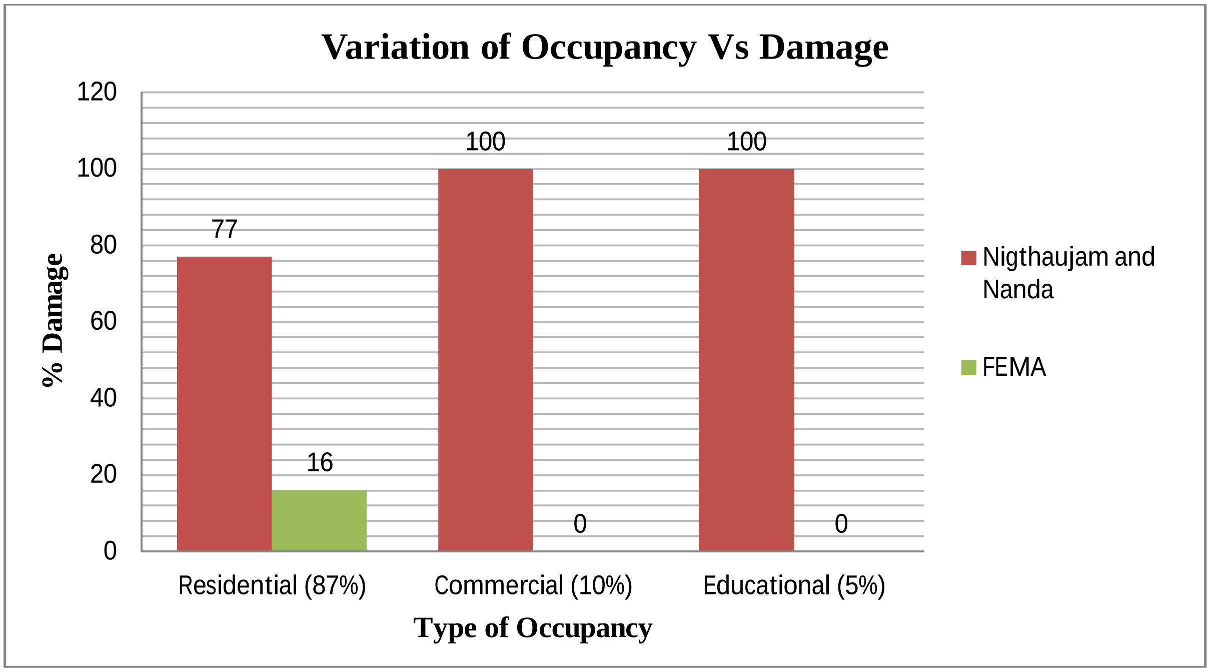


Fig. 5: Distribution of types of occupancy

Figure 6 represents the distribution of the storeys of the buildings surveyed. Maximum storey of the building is 4 within the vicinity and most of the buildings are of 2-3 storeys. Ningthaujam and Nanda, FEMA indicates the number of buildings getting the grade above 2 that emphasizes the heavy damage. Here also more damage prediction is made by the first form whereas FEMA shows very less damage of the buildings.

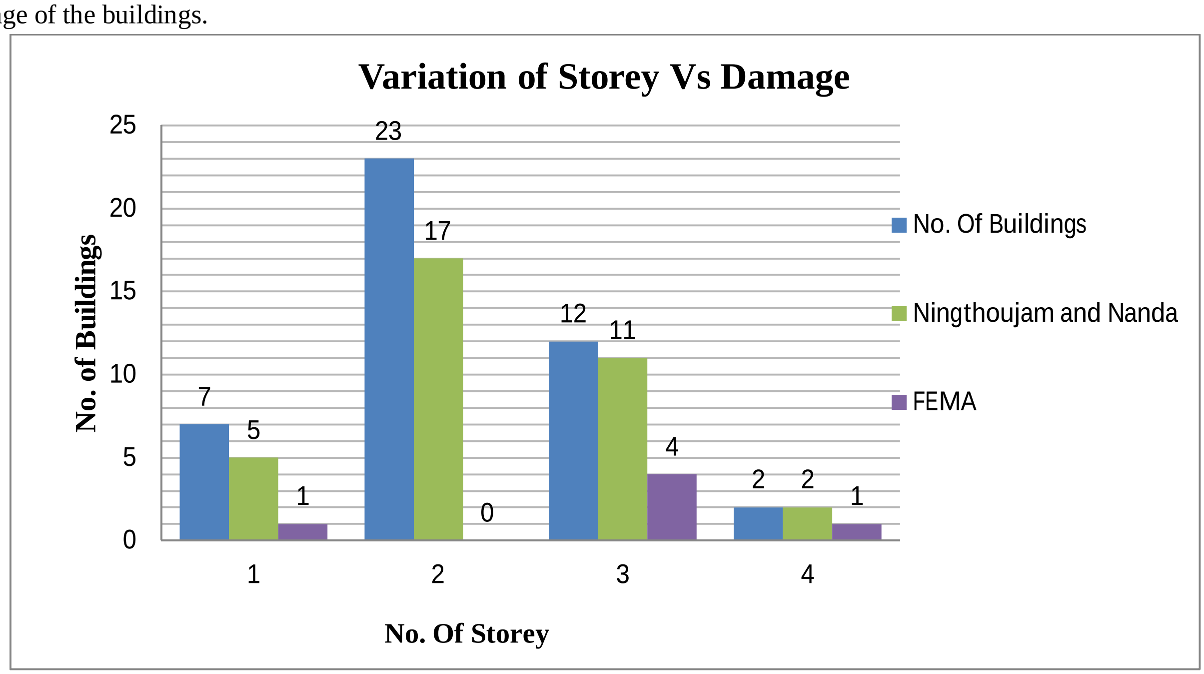


Fig. 6: Distribution of Storey of the buildings

Variation in the age of the RC buildings surveyed is represented in figure 7. In the selected region, most of the buildings are of 10 to 20 years and few of more than 20 years. In this chart, Ningthaujam and Nanda and FEMA indicate the number of buildings that require more detailed assessment as per the score calculated by the RVS forms. It can be seen that with increase of age of the buildings, damage also increases in the first case because the first form uses the age of building to calculate the RVS score, on the other hand FEMA recommended form doesn't contain the age in the calculation of score.

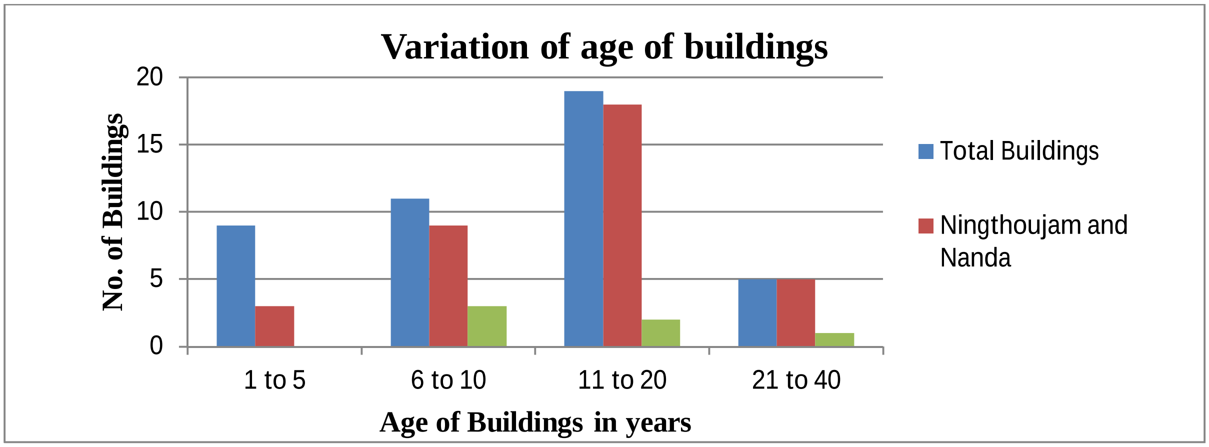


Fig. 7: Distribution of age of the buildings

The detailed comparison of all the grades calculated by the two methodologies within the selected area is represented in figure 8. It can be noted that only 21% (sum of grade 1 and grade 2) of buildings lie between slight to moderate damage calculated by Ningthaujam and Nanda whereas 86% of the buildings lie in the same range by FEMA. Ningthaujam and Nanda suggested screening form shows higher % of buildings fall under grade 4 and grade 5. FEMA recommended screening form illustrates only 14% of grade 3 damage of the buildings of none of grade 4 and grade 5.

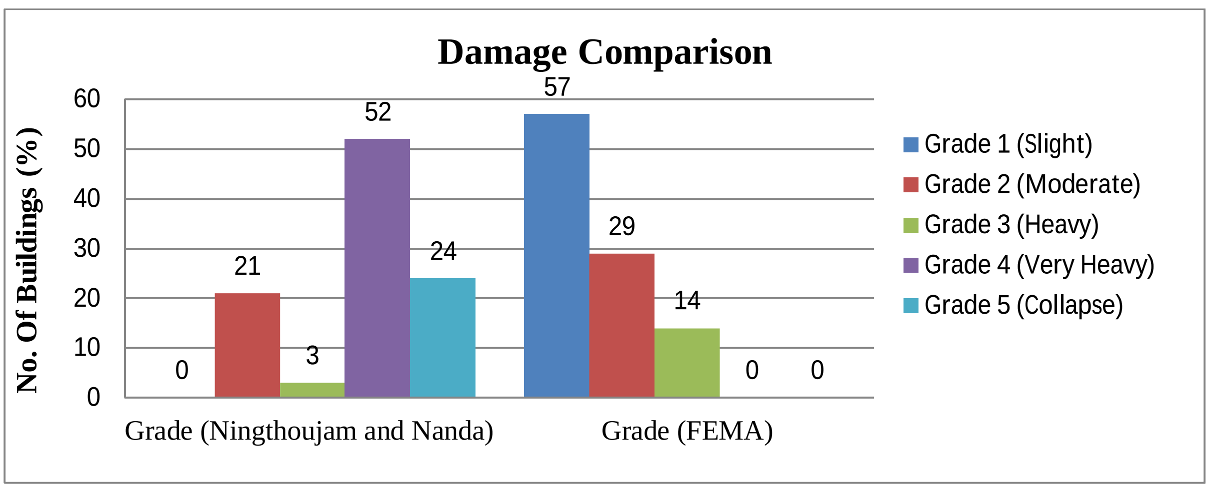


Fig. 8: Damage assigned by the two forms

## IV. CONCLUSION & DISCUSSION

On the basis of the survey data and preliminary assessment, we concluded as follows:

*A.* 79% of the total building surveyed needs further more detailed evaluation as per Ningthoujam and Nanda [1] and recommended for suitable retrofitting measures.

*B.* The methodology proposed by the Ningthoujam and Nanda [1] was performed on zone V, the basic value and basic value modifiers are provided for other zones for soft soil condition that needs to be modified for rest of the zones to verify its accuracy for other zones. This screening form uses the age of building and number of storey to calculate the score that's why increase in both the parameters result in higher value of damage grade.

*C.* Only 14% of the total buildings need more detailed evaluation as per FEMA code of screening. As this screening form uses the plan and vertical irregularity for estimating the score, most of the buildings surveyed within the vicinity likely to get less damage.

*D.* About 24% of damage grade of the total screened buildings is matched by both the methodologies. For comparing the accuracy of the screening forms, the detailed software evaluation shall be conducted and an expert suggestion will also be helpful in this regard.

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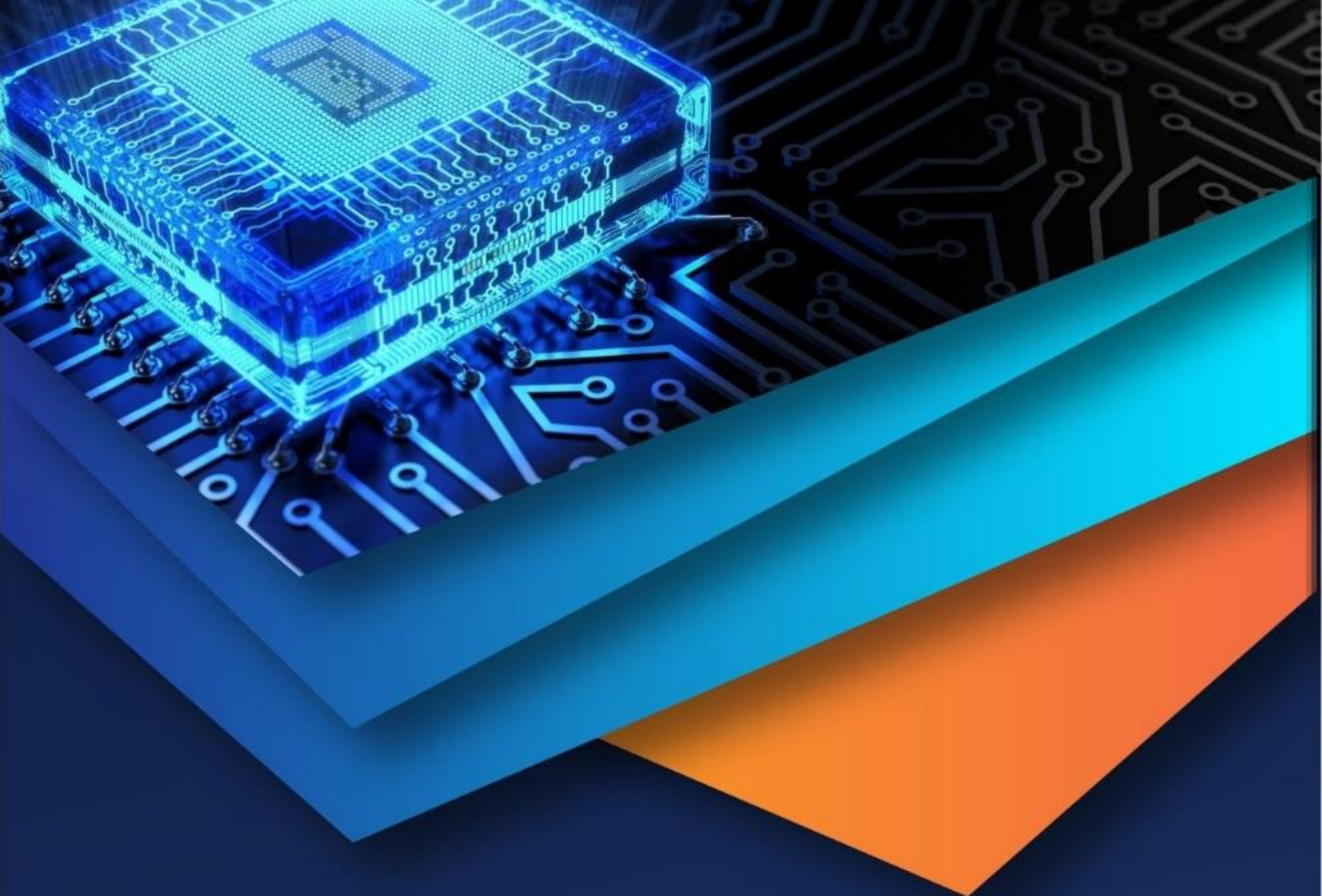

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