A FUZZY BASED APPROACH FOR IMPROVING SEISMIC SAFETY OF MASONRY BUILDING IN KERALA CONTEXT

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ABSTRACT

Seismic safety of the building is one of the most relevant issues in the present social scenario. Sixty percent of the building presently constructed around Kerala falls under the category of masonry buildings. Masonry buildings are most vulnerable type of buildings if seismic safety aspect is not properly considered. The surveys conducted at different places at Kerala where seismic activities were repeated in the past indicated that even after much laws and other related measures, the common man is reluctant to aspect this issue as a prime one in building planning. So a fuzzy logic module is formulated to understand the seismic risk of such buildings with respect to its building configuration. The same is compared with the building plans surveyed already and correlating these results with actual field level results.

Key words: Masonry, Seismic Risk index, Fuzzy, Membership functions, wall density

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1. INTRODUCTION
Masonry buildings formed the bulk of the residential housing units across the world. Further, these type of buildings also represents a large number of public service utilities like hospitals, police stations, old public schools, etc. Another important set of buildings under this segment is the ancient or historical type where a large number of masonry structures were constructed either in bricks or stones. Considering Kerala context earthquakes were continuously experienced at these regions from 1991 also the zone shift from zone II to zone III in IS 1893, revision has changed the design perspective of building towards earthquake. Earlier buildings including non-engineered masonry buildings are failed to accept its significance. In spite of its poor performance against seismic forces, even in the regions that have a high probability of earthquake this method of the construction is preferred the most. The vulnerability of masonry units against earthquakes was the prime reason for large-scale death and causalities reported from the affected regions. The low rise Un-Reinforced Masonry (URM) structures are often characterized by relatively stiff and brittle structural behaviour under loads that are mostly in-plane or out of plane in action. The URM walls also exhibit significant variation in the stiffness characteristics with in-plane walls often having very high stiffness when compared to the out of plane ones. In the absence of large compressive forces, the out of plane walls tend to be brittle and highly vulnerable (Lonhoff, 2017). Also, the type of roofs too play a significant role in deciding the overall stiffness of a small sized unreinforced masonry building.

Fuzzy Logic can be used as a powerful tool for modelling uncertainties and gives meaningful solutions for a complex problem. There are many uncertainties in earthquake forces and masonry structures, considering these facts many of the researchers used fuzzy logic as a tool for solving seismic related problems. In the year 2004, a trial was made by Kanti et al. (2004) to develop an algorithm based on fuzzy logic for assessment of critical damages to RCC structures considering many related parameters. To achieve most economic sections for RCC structures using Eurocode, ACI code and Hongkong code, Kamgar et al. (2018) published a paper on the usage of a fuzzy interference system which efficiently compares different design options. Sen and Ekinci (2016) introduced a fuzzy module applied to Buildings to evaluate geological factors affecting earthquake and further extended the work to mark these features using GIS application. A fuzzy application was introduced by Ayala (2017) for assessing the seismic vulnerability of masonry buildings for the uncertainty in the attribution of a typology to a class. Ottonelli et al.(2018) tried to model the vulnerability in seismic risk assessment for different parameters as Fragility curves. A proposal from Elenas et al. (2013) suggested for damage assessment of buildings using Fuzzy application. This is a paper which has given importance to the general seismic scenario prevailing all over the world. Some improvements on rapid visual screening techniques using fuzzy tools were proposed to predict the damages that can happen during an Earthquake with the help of Fuzzy theory (Sen 2010). Shao et al.(2014) proposed a fuzzy algorithm to apply on earthquake damage rate estimation of buildings. Pinar et al.(2018) proposed a novel Fuzzy based assessment strategy for seismic damage assessment on the Exsit Buildings.

A research study carried out by the authors at two seismically affected areas of Kerala at Kottayam and Thrissur district reinforced the need of law enforcement in local self-government bodies at seismic prone regions towards the planning of masonry buildings (Rajendran, 2009). The study enforces the intervention using Fuzzy based approach and thus indicate the importance of this work.

The logical sequence of the work is detailed in fig1. There are many parameters on which earthquake safety of a building depends. They are soil characterisation, Geometrical Irregularities, structural wall densities, age & location, workmanship, etc. A survey was
conducted at 150 buildings of Varavoor Panchayath of Thrissur District and 100 buildings of Theekoy Panchayath of Kottayam District to assess the features of seismic resistant features of buildings and damages observed during Earthquakes. The survey was on masonry buildings of different occupancies constructed at different periods. The method used was RVS (Rapid Visual Screening) (Moseley et al. 1989) and physical damages were also observed. These were the basis of data for this research work.

Figure 1 Flowchart used to find the structural risk index

The parameters considered for finding structural risk index of a building are

- Wall density- Ratio of transverse area of wall in each principal direction to the total floor area of the building (Tomazevic, 1999).
- Horizontal / plan irregularity- Asymmetry in the building plan
- Vertical irregularity- Asymmetry in the vertical load path of building
- Material quality – construction material quality
- Workmanship – Quality of workers
- Year of construction
- Maintenance & Repair
- Type of masonry construction – Un reinforced/ Reinforced/ Confined masonry
- Site seismic hazard – Seismic zone of the building as per IS 1893
- Site condition –Soil profile in the site.
- Building class – Purpose of the building constructed
- Economic importance

2. FUZZY LOGIC

Fuzzy logic is one of the important classifications in artificial intelligence. Here the computer is trained to think like a human by removing the barriers which differentiate human brain to a
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computer. Fuzzy set theory is the mathematical background of fuzzy logic where the procedure for capturing human thinking is done.

The theory of fuzzy sets is basically a theory of graded concepts, in which everything is a matter of degree or to put if figuratively everything has elasticity. The underlying power of fuzzy sets is that it uses linguistic variables to represent imprecise concepts rather than quantitative variables. The block diagram of the fuzzy system architecture is given in figure 2.

- Fuzzification Module – The inputs of this programs are in terms of numbers. The basic function of a fuzzification module is to convert these numbers into fuzzy sets. It splits the input signal into sub-steps.

![Figure 2: Fuzzy logic architecture](image)

- Knowledge Base – It stores IF-THEN rules provided by experts.
- Inference Engine – These are creating a reasoning process, which is similar to human by making fuzzy inference on the inputs and IF-THEN rules.
- Defuzzification Module – This module is the reverse of the fuzzification module discussed earlier in which the fuzzy sets received as output is converted into values and thus making the program ready for providing an output answer.

3. IMPLEMENTATION OF OUR WORK USING FUZZY LOGIC

The fuzzy synthetic evaluation (FSE) system is used to provide a single outcome/output (e.g., building damageability) by aggregating multiple inputs (e.g., building type, year of construction, site seismic hazard, etc…). There are four steps involved in this FSE.

- Step 1: Identify, collect and quantify input variables essential for the evaluation
- Step 2: Establish membership functions for fuzzification of input variables
- Step 3: Establish rule-based knowledge and inference implication method
- Step 4: De-fuzzification to a single crisp output

The three main components of FSE are,

- Membership functions for the fuzzification of values
- Rule-based inference engine to combine parameters
- De-fuzzification method to convert fuzzified values into a single crisp output.

4. MEMBERSHIP FUNCTIONS

The membership function embodies all fuzziness for a particular fuzzy set and it describes the essence of a fuzzy property or operation. The core of membership function for some fuzzy set
A is defined as that region of the universe that is characterized by complete and full membership in the set A. The triangular (TFN) and trapezoidal (TPFN) membership functions are commonly used in engineering applications as these two define the coordinates and interval of each membership function in a set (Amid. 2014). Figure 3 represents the fuzzy set of membership functions established for determining the degrees of membership value for a level of vertical irregularity (VI). It contains five triangular membership functions to represent the vertical irregularity parameter as expressed below.

<table>
<thead>
<tr>
<th>TFN</th>
<th>Triangular Fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>TFN(0,0,0.25);</td>
</tr>
<tr>
<td>Low</td>
<td>TFN(0.0,0.25,0.5)</td>
</tr>
<tr>
<td>Medium</td>
<td>TFN(0.25,0.5,0.75)</td>
</tr>
<tr>
<td>High</td>
<td>TFN(0.5,0.75,1.0)</td>
</tr>
<tr>
<td>Very High</td>
<td>TFN(0.75,1.0,1.0)</td>
</tr>
</tbody>
</table>

The linguistic description is converted into a transformation value between 0 and 1 using the fuzzy system. Suppose the engineer evaluates very high VI in the building and this very high VI transforms into 0.9 on the x-axis of the figure. The intersecting membership functions deliver the resultant degrees of membership of the assessment. The very high vertical irregularity has a 40% degree membership in high and a 60% degree membership in very high as defined by the membership functions of the parameter.

![Figure 3 Vertical irregularity fuzzy set of the membership function](http://www.iaeme.com/IJCIET/index.asp)

**5. RULE-BASED KNOWLEDGE**

The next step is to give intelligence to the system using FRB (fuzzy rule-based expressions), which provides the fuzzy output sets. The example of FRB is, if building vulnerability is low and seismicity is low, building damageability is low. The rule-based knowledge introduces non-linearity in the overall system where the rules are evaluated in parallel meaning the sequence of rules is insignificant. If we have a system of two independent inputs defined as X1 and X2 and a single output denoted as Y for a collection of N number of linguistic IF-THEN expressions, the Mamdani inference engine is represented as below (Tesfamariam, 2008):

Ri: IF X1 is Ai1 AND X2 is Ai2 THEN Y IS B for i=1,2,…K

Where:
- $R_i$ represents the $i^{th}$ rule
- $X_1$ and $X_2$ are the input variables (antecedents)
- $K$ is the total number of rules
- $A_{i1}$ and $A_{i2}$ are the input membership fuzzy sets
- $Y$ is the output variable (consequent)
- $B$ is the output membership fuzzy set
The combinations of rules require an aggregation operator in order to provide a single fuzzy output value. In the Mamdani system type, the most common aggregation operators are minimum and maximum operators where two sets of fuzzy values (X1 and X2) result into a single fuzzy value (Y).

5.1. De-fuzzification
After aggregating all the membership values of an output, we have to apply de-fuzzification as the final step in the fuzzy evaluation process. A single, crisp output is generated by the de-fuzzification, which involves the evaluation of the fuzzy values that result from the membership functions and rule-base. The centre of the area is the most common de-fuzzification method and is expressed as,

Area of centroid:

\[ \text{Centroid} = \frac{\sum C_{ix} A_i}{\sum A_i} \]  

(1)

Where:

- \( C_{ix} \) Represents the centroid of a shape along X-axis
- \( A_i \) The area of the shape

For example, if the graph of the resultant membership function is as follows, (fig 4).

\[ \text{Centroid} = \frac{\sum C_{ix} A_i}{\sum A_i} = 0.56 \]

6. VALIDATION AND COMPARISON OF THE PROGRAM

![Figure 4 De-fuzzification](image_url)

![Figure 5 Plan of the building (symmetrical)](image_url)
As an initial stage, the data of about 250 buildings were taken and analysed using RVS technique. The discussion on symmetrical building plan and unsymmetrical building plan are as follows fig 5 represents the plan of a symmetrical building and fig 6 represents the plan of an unsymmetrical building.

- Wall density - 0.3
- Horizontal/plan irregularity - 0.1
- Vertical irregularity - 0.3
- Material quality - 0.3
- Workmanship - 0.3
- Year of construction - 0.1
- Maintenance & Repair – 0.3
- Type of masonry construction – Un reinforced (0.7)
- Site seismic hazard – 0.5
- Site condition – 0.5
- Building class – 0.3
- Economic importance – 0.1

Structural risk index of the above building is 0.1 (Very low)

Figure 6 Plan of the building (Unsymmetrical)

- Wall density - 0.5
- Horizontal/plan irregularity - 0.9
- Vertical irregularity - 0.3
- Material quality - 0.3
- Workmanship – 0.3
- Year of construction -0.3
- Maintenance & Repair – 0.5
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- Type of masonry construction – Un reinforced (0.7)
- Site seismic hazard – 0.5
- Site condition – 0.5
- Building class – 0.7
- Economic importance – 0.7

Structural risk index of the above building is 0.7 (High)

The above results indicate the following:

- The buildings with stable values in Rapid visual screening technique of masonry buildings conducted in the survey receives safe Seismic risk values as output by the program which clearly demonstrates the adaptability of the programs.
- The already existing buildings as well as newly proposed buildings can be equally tested using this program.
- The risk variables of the configuration can be given as stepwise output so that the user and engineer are well aware of the risk.
- This program can be extended to give building plan as input and to calculate necessary data for the fuzzy modules from this plan itself as far as possible.

7. CONCLUSIONS

The two building cited in results are existing at Varavur panchayath in Thrissur District and both these buildings are constructed between 1995-2000 in the first building visible crack are not present while for the second building visible cracks are present, which clearly support the output of the program.

As a nutshell, this program can be treated as a yardstick in earthquake safety of buildings in the rural region. This will be helpful to all the stakeholders for enhancing seismic safety. Further, the program can be linked with some drawing algorithm so that improvements proposed for a given plan can be provided as suggestions to the user.

REFERENCES


