Performance Assessment Indexing of Buildings Through Fuzzy AHP Methodology

Prateek Roshan, Shilpa Pal and Ravindra Kumar

Abstract More than half of the total land area of the Indian subcontinent is prone to earthquakes of moderate to very high intensity. Earthquakes cause damage, and assessment of parameters and factors affecting performance of buildings becomes desirable in order to understand the aspects and phenomenon of the same to make or design better earthquake-resistant buildings. Performance of a building is often expressed in qualitative terms like poor, average, good, better, etc. However, the same can be expressed in quantitative terms too and compared with respect to one another. Analytical hierarchical process (AHP) is a well-known multi-criteria decision-making (MCDM) technique to express qualitative measures in quantitative terms. In order to handle ambiguity of the qualitative assessment by humans, the concept of fuzzy theory was embedded by many researchers to the AHP technique. The current study focuses on the development of performance assessment index (PAI) of buildings using fuzzy AHP technique. The index developed is applied on buildings damaged in 2011 Sikkim earthquake. These buildings are ranked on the basis of the performance score. The advantage of such indexing model is that it can help in anticipating a certain level of performance behaviour, comparing or ranking of the buildings on the basis of performance levels in a the occurrence of a seismic event. In other words, the current study can be used to predict the survivability and performance of a building in case of a likely earthquake. The proposed model for performance evaluation based on fuzzy AHP is simple and hence holds the potential for practical application.

Keywords Damages · Plan irregularity · Lateral load-resisting elements · Analytic hierarchy process (AHP) · Fuzzy logic

P. Roshan (✉)
Department of Civil Engineering, Delhi Technological University, New Delhi, Delhi, India
e-mail: roshan.prateek@yahoo.in

S. Pal
Delhi Technological University, New Delhi, Delhi, India

R. Kumar
Greater Noida Institute of Technology, Greater Noida, Uttar Pradesh, India

S. Ahmed et al. (eds.), *Smart Cities—Opportunities and Challenges*, Lecture Notes in Civil Engineering 58,
https://doi.org/10.1007/978-981-15-2545-2_42

1 Introduction

Every time when an earthquake of substantial magnitude strikes an area, damages of different types and levels are observed in structures. To name a few, configuration of structure, properties of the structural components, ground conditions, quality of construction materials and quality management are some factors that might affect the performance of a structure in a likely earthquake event. Damaged components of the structure can put human lives at risk in various ways. The decision regarding re-habitability of a structure if has been damaged after the seismic event is of a serious concern. The management officials and population become quite concerned and keen to know about occupancy of their buildings.

Observation and knowledge of structural performance of buildings during a seismic activity can undoubtedly help in identifying the strong and weak design aspects, as well as appropriate and desirable material qualities, construction practices and site attributes. Knowledge of such crucial factors, norms and guidelines provides an important step in development of strengthening measures and provisions for various types of buildings. The evaluation is also important in establishing reasonable prevention plans regarding risk assessment, design seismic codes and action plans for risk reduction and for emergency management regarding evacuation plans, repair cost estimate, etc. All these factors would ultimately help in making better and safe earthquake-resistant structures. Ensuring sound, safe and resilient infrastructure and safety of users is indeed a very important milestone in realization of a smart city concept practically achievable.

Performance assessment of a reinforced concrete building is a critical and complex task. So, the decision-making about assessing performance of a building is decomposed into hierarchical models, and subsequently, a fuzzy AHP-based performance assessment index (PAI) model for reinforced concrete buildings has been developed. To handle the ambiguity and uncertainty among the opinions of experts, α-cut method was employed.

A survey questionnaire was developed for the collection of experts' opinion for assigning relative weightage among the different parameters at each level of the proposed model. In total, 21 expert surveys were collected and data was analysed for the generation of PAI. After the development of the model, five sample buildings damaged in Sikkim earthquake 2011 were selected for the application of model.

2 Fuzzy AHP (Analytical Hierarchical Process)

Decision-making regarding how a structure will perform during an earthquake is a complex process [1]. Assessment of the performance of a building in case of a seismic event requires knowledge of its configuration, types and quality of materials used, ground characteristics, efficiency of structural member, and quantitative and qualitative data concerning current state of building and an approach to sum up different types of information into a decision-making process for assessing the likely performance of the entire building.

The analytic hierarchy process (AHP) as presented by Saaty [2] is an effective tool to deal with complex decision-making processes. The human preference approach is uncertain and ambiguous in many situations, and decision-makers might be unable to assign exact numerical values to make comparison judgments [3]. To handle this, the concept of fuzzy theory was embedded by many researchers to the AHP technique. To resolve the imprecision and the ambiguity in assessing the relative importance, fuzzy set theory, introduced by Zadeh [4], has been used and adopted in the current study. This study follows and adopts the concepts of Saaty [2] and Chang et al. [3] to analyse data and reach a consensus among experts. Eigenvector method is used to calculate the (priorities or weights) among elements at the same level of the hierarchical model.

3 Study Area

A M_w 6.9 earthquake struck the adjoining areas of the Nepal–Sikkim border on 18 September 2011 at 18:10 local time, about 68 km north-west of Gangtok and at a focal depth of 19.7 km as reported by United States Geological Survey (USGS) [5]. The earthquake initiated a large number of landslides resulting in significant damage to structures and consequently caused huge infrastructural loss [6]. Sikkim was the most severely affected state of India, followed by West Bengal and Bihar. The maximum seismic intensity was estimated to be around VI+ on the MSK scale. Most multi-storey reinforced concrete buildings were non-engineered and sustained considerable damage due to earthquake shaking, a small number of these collapsed or suffered irreparable structural damages as mentioned in EERI special report [7]. The performance index model is applied on the buildings which were damaged in 2011 Sikkim earthquake [8]. The sample buildings upon which the proposed fuzzy AHP (analytical hierarchical process)-based model is applied are summarized in Table 1.

The information regarding the constructional and architectural features, and the types of seismic damage observed in these buildings during the 2011 Sikkim

Table 1 Buildings for the proposed PAI model application

Seismic event	Studied buildings	Location of buildings in Sikkim
Sikkim 2011	Moonlight School	Chuntang
	Boys' Hostel at SMIT	Gangtok
	House of BDO	Chuntang
	Residential building	Singtam
	Himalchuli Hotel	Gangtok

earthquake are derived from the database of EERI reports [9]. The performance index score for each of the buildings in Table 1 is calculated.

The complex problem of performance assessment of a building can be broken down into a simple, organized and manageable hierarchical format. This hierarchical model follows an analytical and logical sequence and order in which the underlying relationship for each parameter or factor is further subdivided into specific contributing options.

The type of structural force-resisting system used in a building plays a major role in terms of its seismic load-resisting capacity or resiliency. In this study, two types of reinforced concrete buildings are considered, namely shear wall buildings and moment-resisting frames with infill masonry walls.

Shear walls of sufficient rigidity when used in buildings tend to resist seismic forces in a significant manner. It generally behaves as vertical cantilevers and acts as lateral bracing system to the whole structural system while receiving lateral forces from diaphragms and transferring them to the foundation. During seismic excitations of moderate to strong earthquakes, structures with shear wall provisions have tended to perform considerably well [10].

The moment-resistant frames primarily resist lateral forces through the flexural action of columns and beams since they are joined by moment connections. Columns are critical elements since they are responsible for overall strength and stability of a structure. Their strength relative to the connecting beams plays an important role in seismic resistance in controlling sequence of hinge formation among structural members. Ability to deform in-elastically as governed by concrete confinement and shear capacity is critical. The detailing of beam–column connections is also an important factor influencing the seismic performance. Many older frame buildings include masonry infill panels. Unreinforced masonry behaves in a brittle manner and is often regarded as undesirable construction material for seismically active regions; sometimes, they may act as shear walls in controlling deformations, and it may save non-ductile concrete frames until their elastic limit is exceeded. In many cases, non-ductile frames have survived strong earthquakes due to the participation of masonry infill walls, especially when the wall-to-floor area ratio is high.

The seismic-induced inertia load is transferred from the floors to the foundation through the lateral load-resisting system. It advises to avoid discontinuities or changes in this load path so that localized stress concentrations are minimized or avoided. Irregularity in vertical direction also results in abrupt change in strength and stiffness along the height of the building. Vertical and reverse setbacks, variation in column height, soft stories, discontinuity in shear walls, weak columns and strong beams, and any possible modifications introduced to the primary structural system are some of the types of vertical irregularities that needs to be avoided as far as possible to enhance the seismic resiliency [11].

The plan irregularity is an important aspect in determining vulnerability of a building to torsion. It also helps in identifying potential areas of high-stress concentration. A symmetrical plan layout is therefore considered to be a good design practice. Torsion can arise when centre of mass and centre of rigidity do not coincide, and there is asymmetry in strength and stiffness along the periphery of building, presence of re-entrant corners [11].

Seismic design, ductile detailing, quality of construction and materials used determine the resilience of buildings to seismic events as all these are crucial attributes in order to ensure good protection intended in earthquake-resistant design [12]. Inferior material quality and handling errors, lack of proper reinforcement anchorage in beams, columns, joints, improper seismic detailing, etc., are some of poor construction measures.

4 Proposed Performance Assessment Index Model

The flow chart of the current study is shown in Fig. 1.

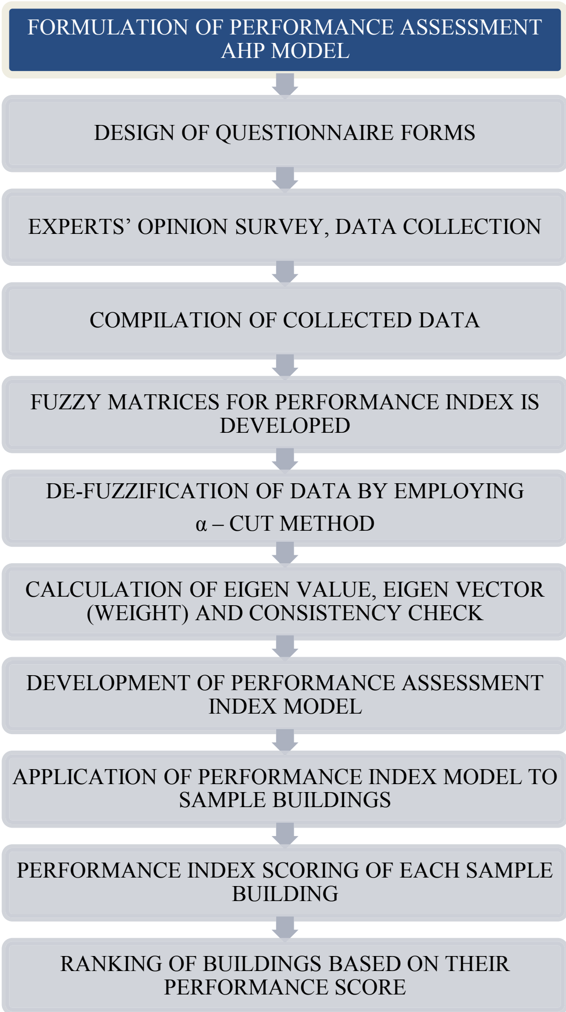
For the performance assessment, three groups of elements were identified, construction quality, configuration of the building and load-resisting system. Construction quality comprises materials used and execution. Materials used are subdivided into concrete and reinforcing steel, and execution includes proper rebar confinement and proper placement of concrete as its sub-divisions. Building configuration comprises features determining overall plan and elevation of the building. Plan of the building was categorized into symmetric plan, non-symmetric plan and plan of a building with re-entrant corners. Building elevation incorporated the effects of soft storey, in-plane discontinuity, setback and mass distribution to the performance of a building. Superstructure and substructure performances are the two sub-elements of load-resisting system. Further, structural system and components of structural members, namely columns, beams and beam–column joints, contribute to overall efficiency and performance score of superstructure. Type of soil and type of footing provided in building accounted for performance score of the substructure element as proposed in this performance assessment hierarchical model.

4.1 Design of Questionnaire and Data Collection

A set of questionnaire was designed to collect experts' opinion on relative importance of attributes in the form of comparison tables for performance assessment model. In the AHP process, the attributes at each hierarchical level are to be compared with each other. Such sample table is shown from Tables 2, 3, 4 and 5 which has a more convenient rectangular format of comparison tables to collect the experts' opinion.

The comparison between criteria '*a*' and '*b*' is on scale from 1 to 9. The selection of any values towards left, i.e. '*a*', gives more weight to it in comparison with '*b*' and vice versa. A value of 9 towards left means criterion '*a*' is extremely important with respect to '*b*', while a value of 7 means that importance of '*a*' is

Fig. 1 Flow chart for formulation of performance assessment AHP model



stronger than '*b*' and so on. The selection of the middlebox, i.e. value 1 by an expert, means that both criteria are equally important. These selected values of the relative importance depend on the mindset of the experts.

Similar tabular matrix questionnaire survey scheme was prepared for all levels of hierarchical structure to generate comparison matrices. These questionnaires were sent to various practising structural and earthquake engineers employed in academics and industries. In all responses from 21, such experts were received which have been designated as *E*1, *E*2, *E*3, …, *E*21, respectively, and the data was compiled.

Table 2 Comparison of the relative preference with respect to: performance assessment index of building

		Extreme		Very strong		Strong		Moderate		Equal		Moderate		Strong		Very strong		Extreme	
S.No.	Criteria 'a'	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria 'b'
		Rating Scale																	
1.	Construction quality																		Building configuration
2.	Construction quality																		Load resisting system
3.	Building configuration																		Load resisting system

Table 3 Comparison of the relative preference with respect to: construction quality of building

		Extreme		Very strong		Strong		Moderate		Equal		Moderate		Strong		Very strong		Extreme	
S.No.	Criteria 'a'	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria 'b'
		Rating Scale																	
1.	Materials used																		Execution

Table 4 Comparison of the relative preference with respect to: materials used

		Extreme		Very strong		Strong		Moderate		Equal		Moderate		Strong		Very strong		Extreme	
S.No.	Criteria 'a'	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria 'b'
		Rating Scale																	
1.	Concrete																		Reinforcing steel

Table 5 Comparison of the relative preference with respect to: reinforcing steel

		Extreme		Very strong		Strong		Moderate		Equal		Moderate		Strong		Very strong		Extreme	
S.No.	Criteria 'a'	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria 'b'
		Rating Scale																	
1.	Ribbed bars																		Smooth bars

4.2 Design of Questionnaire Forms

A set of questionnaire was designed to collect experts' opinion on relative importance of attributes in the form of comparison tables for performance assessment model.

4.3 Data Collection and Compilation

The data of comparison received from different experts was arranged and compiled in tabular formats.

The opinions of experts are demonstrated as a triangle between L and U values representing the lower and upper limits of the membership function, respectively, and the M is the geometric mean of experts' opinion representing the major value of the shape function. Graphically the triangular fuzzy number is

$$a_{ij} = \left(L_{ij}, M_{ij}, U_{ij}\right) \tag{1}$$

where $L_{ij} \leq M_{ij} \leq U_{ij}$.

and $L_{ij}, M_{ij}, U_{ij} \in \left[\frac{1}{9}, 1\right] \cup [1, 9]$.

That is, $\tilde{a}_{ij}$ is an element of fuzzy comparison matrix, where L_{ij}, M_{ij}, U_{ij} are lowest, geometric mean and highest values of the experts' opinions, respectively.

$$L_{ij} = \min\left(B_{ijk}\right), \tag{2}$$

Buckley [13] suggested that the geometric mean of experts' opinion for fuzzy comparison values for each criterion may be calculated as given in Eq. (10)

$$M_{ij} = \sqrt[n]{\prod_{k=1}^{n} B_{ijk}} \quad (3)$$

(k = 1, …, n) and

$$U_{ij} = \max\left(B_{ijk}\right) \quad (4)$$

B_{ijk} represents opinions of expert k for the relative comparison of two criteria i and j (Table 6).

4.4 Data Fuzzification

Fuzzy matrices are prepared from the compiled data of the survey opinion tables prepared using L_{ij}, M_{ij} and U_{ij} values in different levels of comparison tables of performance index model (Table 7).

4.5 Data Defuzzification

The fuzzy matrix is defuzzified by transforming these values into a crisp value considering values of α and λ equal to 0.5, using equation (Table 8)

$$\left(a_{ij}^{\alpha}\right)^{\lambda} = \left(\lambda \cdot L_{ij}^{\alpha} + (1-\lambda)U_{ij}^{\alpha}\right) \quad 0 \le \alpha \le 1, 0 \le \lambda \le 1 \quad (5)$$

The resultant defuzzified single pairwise comparison matrix for Table 2 is expressed in Table 9.

4.6 Calculation of Eigenvalue, Eigenvector and Consistency Check

Principal eigenvalue and eigenvector of this matrix are calculated. The eigenvector represents the weight vector of the attributes. Eigenvalues and eigenvectors of defuzzified matrix are represented as $\lambda_{\max}$ and W, respectively.

Consistency check is also carried for the comparison matrix (Table 10).

The hierarchical model is based on the aforementioned methodology and calculations, and is reflected in Table 11.

Table 6 Experts' opinion for Table 2 of performance assessment index

Criteria '*A*'	Criteria '*B*'	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*E*7	*E*8	*E*9	*E*10	*E*11	*E*12	*E*13	*E*14	*E*15	*E*16	*E*17	*E*18	*E*19	*E*20	*E*21	L_{ij}	M_{ij}	U_{ij}
Construction quality	Building configuration	3	2	5	1	5	2	7	1	1	7	5	3	1/3	5	4	1/3	1	1/5	1	1/2	3	1/5	1.762	7
Construction quality	Load-resisting system	3	3	1/3	1/5	1	1/3	1	1	1/4	5	1	1/4	3	5	3	1/5	1	1/6	1	5	1/3	1/6	0.915	5
Building configuration	Load-resisting system	1/5	1/5	1/7	1/5	1/6	1/4	1/5	2	2	1/5	1/7	1/7	5	1	1/4	5	1	1/5	1	1/4	1/7	1/7	0.409	5

Table 7 Fuzzified matrix for relative preference with respect to: performance assessment of building

Criteria '*a*'/'*b*'	Construction quality	Building configuration	Load-resisting system
Construction quality	1, 1, 1	1/5, 1.762, 7	1/6, 0.915, 5
Building configuration	1/7, 0.568, 5	1, 1, 1	1/7, 0.409, 5
Load-resisting system	1/5, 1.093, 6	1/5, 2.445, 7	1, 1, 1

Table 8 Calculation of L_{ij}^{α}, U_{ij}^{α} and $(a_{ij}^{\alpha})^{\lambda}$ for Table 2 of performance assessment index

α	λ	L_{ij}	M_{ij}	U_{ij}	L_{ij}^{α}	U_{ij}^{α}	$(a_{ij}^{\alpha})^{\lambda}$
0.5	0.5	1/5	1.762	7	0.9810	4.3810	2.6810
0.5	0.5	1/6	0.915	5	0.5408	2.9575	1.7492
0.5	0.5	1/7	0.409	5	0.2759	2.7045	1.4902

Table 9 Defuzzified matrix for relative preference with respect to: performance assessment of building

Criteria '*a*'/'*b*'	Construction quality	Building configuration	Load-resisting system
Construction quality	1.0000	2.6810	1.7492
Building configuration	0.3730	1.0000	1.4902
Load-resisting system	0.5717	0.6711	1.0000

Table 10 Principal eigenvalue, eigenvector and consistency ratio for matrix of performance index

n	Random index	Eigenvalue, λ_{max}	Eigenvectors, W	Consistency index (CI)	Consistency ratio (CR)
3	0.58	3.0766	0.5143, 0.2577, 0.2280	0.0383	0.0660

The maximum performance value is likely to occur when all the performance criteria meet all the favourable constructional and architectural aspects of a building. The corresponding maximum value of performance index is found to be **0.9164,** and calculation of the same has been presented in detail in Table 11.

The performance score calculation is shown for Moonlight School in Table 11.

Table 11 Performance index and performance score of buildings

		MAXIMUM		MOONLIGHT SCHOOL	
S.No	**Particulars**	**Weight**	**Score**	**Weight**	**Index Value**
	TOTAL SCORE		**0.9164**		**0.4009**
A	**Construction Quality**	**0.5143**	**0.9754**	**0.5143**	**0.2354**
A.1	Materials	0.7892	0.9688	0.7892	0.0312
A.1.1	Concrete	0.7259	1.0000	0.7259	0.0000
O1	Good quality	1.0000	1.0000	1.0000	
O2	Poor quality	0.0000		0.0000	1.0000
A.1.2	Reinforcing steel	0.2741	0.8863	0.2741	0.1137
O1	Ribbed bars	0.8863	1.0000	0.8863	
O2	Smooth bars	0.1137		0.1137	1.0000
A.2	Execution	0.2108	1.0000	0.2108	1.0000
A.2.1	Proper rebar confinement	0.7281	1.0000	0.7281	1.0000
O1	Provided	1.0000	1.0000	1.0000	1.0000
O2	Absent	0.0000		0.0000	
A.2.2	Proper placement of concrete	0.2719	1.0000	0.2719	1.0000
O1	Yes	1.0000	1.0000	1.0000	1.0000
O2	No	0.0000		0.0000	
B	**Configuration**	**0.2577**	**0.8251**	**0.2577**	**0.7051**
B.1	Building plan	0.7201	0.7814	0.7201	0.7814
O1	Symmetric	0.7814	1.0000	0.7814	1.0000
O2	Non-symmetric	0.1332		0.1332	
O3	Re-entrant corner	0.0854		0.0854	
B.2	Building elevation	0.2799	0.9374	0.2799	0.5088
B.2.1	Soft-storey	0.0765	1.0000	0.0765	1.0000

Table 12 Total performance index score of buildings

Buildings	Performance index score
Moonlight School	0.4009
Boys' Hostel at SMIT	0.7153
House of BDO	0.5178
Residential building	0.4692
Himalchuli Hotel	0.4596

5 Result and Discussion

Performance assessment index model was decomposed into different units, sub-units, elements and components, a hierarchical model of performance index is developed, and calculations and results are derived based on the aforementioned methodology.

The maximum performance value when the building possesses all the favourable material, design and architectural guidelines anticipated is found to be 0.9164. Performance index score for all the buildings listed in Table 1 was calculated depending upon the performance factors employed in a building. The final performance score of the buildings is given in Table 12.

The obtained weighted score can be normalized and converted to a relative index score at any desired base. The scale has been mapped at the scale of 100 as shown below.

Let WS be the weighted score of any building under consideration and WS_{max} be the maximum possible score in the analysis. The performance index for buildings at the relative scale of 100 can be given a name as 'PI 100' and calculated as

$$PI = \frac{WS\ (\text{Weight score of the considered building})}{WS_{max}(\text{Maximum score out of all buildings})} \times 100 \tag{6}$$

Performance index for buildings at the relative scale of 100 was calculated as shown in Eqs. (7) to (11).

For example, relative performance index (score) of Moonlight School is

$$PI = \frac{WS}{WS_{max}} \times 100 = \frac{0.4009}{0.9164} \times 100 = 43.747 \tag{7}$$

Relative performance index of Boys' Hostel at SMIT is

$$PI = \frac{WS}{WS_{max}} \times 100 = \frac{0.7153}{0.9164} \times 100 = 78.055 \tag{8}$$

Table 13 Ranking of buildings based on relative performance score

Buildings	Relative performance score	Rank
Moonlight School	43.747	5
Residential building	51.200	3
House of BDO	56.504	2
Boys' Hostel at SMIT	78.055	1
Himalchuli Hotel	50.153	4

Relative performance index of House of BDO is

$$\mathrm{PI} = \frac{\mathrm{WS}}{\mathrm{WS_{max}}} \times 100 = \frac{0.5178}{0.9164} \times 100 = 56.504 \tag{9}$$

Relative performance index of Building at Singtam is

$$\mathrm{PI} = \frac{\mathrm{WS}}{\mathrm{WS_{max}}} \times 100 = \frac{0.4692}{0.9164} \times 100 = 51.200 \tag{10}$$

Relative performance index of Himalchuli Hotel is

$$\mathrm{PI} = \frac{\mathrm{WS}}{\mathrm{WS_{max}}} \times 100 = \frac{0.4596}{0.9164} \times 100 = 50.153 \tag{11}$$

Table 13 summarizes ranking of buildings in terms of relative PI (or performance score) obtained for each building.

The performance score and ranking of SMIT Boys' Hostel are highest.

Use of good-quality concrete, proper placement, proper rebar confinement, symmetric building plan, uniform mass distribution, strong column–weak beam design and absence of soft storey, setback, floating/hanging columns, short columns, in-plane discontinuity are the factors that accounted for enhanced performance score of Boys' Hostel at SMIT.

In the 2011 Sikkim earthquake out of these five buildings, SMIT Boys' Hostel has performed better than others [9]. So, the result provided by performance index calculations has been found in accordance with what was observed in reality [6].

6 Plotting of Performance Index Values of Studied Buildings

A graph was plotted for performance index for these five buildings, and the obtained graphs are shown in Figs. 2 and 3.

From Figs. 2 and 3, it is clear that as the performance index of a building increases, the better the building has performed in case of the earthquake.

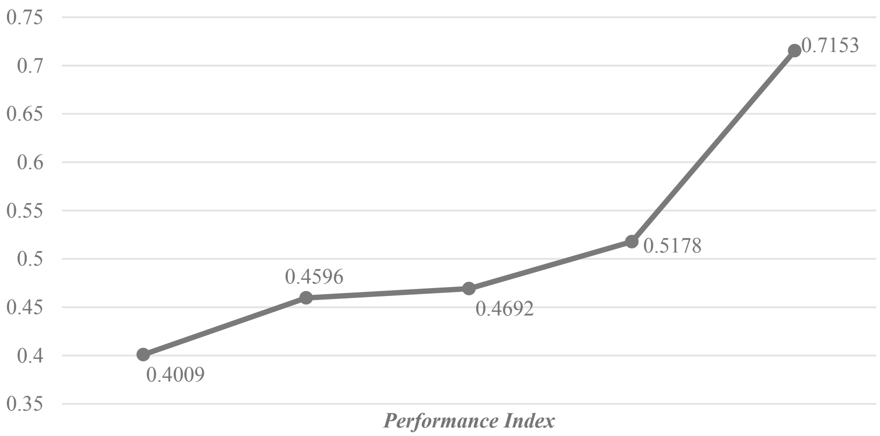


Fig. 2 Performance index score of buildings

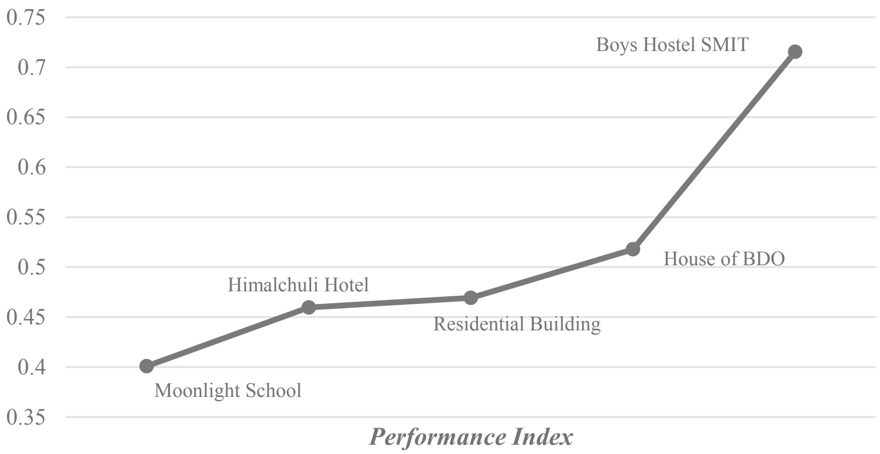


Fig. 3 Buildings in order of their performance index

In other words, it can be concluded that a building with higher performance index has suffered less seismic damage and vice versa.

7 Conclusion

Understanding the structural aspects and parameters affecting the performance of buildings in case of a seismic event is a critical and complex task. So, the decision-making about assessing the same is decomposed into hierarchical models, and subsequently, a performance assessment index (PAI) for reinforced concrete buildings has been developed.

Then, categorizing the factors and parameters contributing to better earthquake-resistant design and their relative importance with respect to each other is determined.

The PAI model is demonstrated through case study of five buildings which were damaged in Sikkim 2011 earthquake to compute their performance score.

These buildings are then ranked on the basis of their performance score. It was found that building with the lowest performance score suffered maximum damage compared to other sample buildings during the earthquake. Also, it is found that building with highest performance score actually survived and performed well compared to other during the seismic event.

The study validates the point that the seismic damage caused to a building is in inverse relation to the performance efficiency and resilience of the building; i.e. the building with high performance score will perform well and suffer less damage in case of a seismic activity.

The presented model is very simple and easy to implement as the value of measurable items or elements for performance assessment index are easily identifiable and quantifiable.

Performance assessment model encapsulates and enlists various provisions to be taken into account to enhance structure's expected behaviour during earthquakes. A proper design and performance-incorporated scheme will ensure risk reduction. As engineers, we strive for greatest authenticity in terms of design, safety and performance of our buildings. In a nutshell, it can be implied that a safe and smart design approach would help make efficient and effective structures, and a subset of smart cities and overall will contribute in better future for the society. The performance index based on fuzzy AHP is simple and hence holds the potential for practical application.

References

1. Carreño ML, Cardona OD, Barbat AH (2007) Neuro-fuzzy assessment of building damage and safety after an earthquake (Chap. VII). In: Intelligent computational paradigms in earthquake engineering. Idea Group Publishing
2. Saaty TL (1980) Analytic hierarchy process. McGraw Hill, N.Y.
3. Chang CW, Wu CR, Lin HL (2009) Applying fuzzy hierarchy multiple attributes to construct an expert decision making process. Exp Syst Appl 36:7363–7368
4. Zadeh L (1965) Fuzzy sets. Inf Control 8:338–353
5. USGS (2011) M 6.9 - Sikkim, India [Online]. Available at: https://earthquake.usgs.gov/earthquakes/eventpage/usp000j88b/executive. United States Geological Survey, Reston, USA. Accessed 18 Sept 2011
6. Rai DC, Mondal G, Singhal V, Parool N, Pradhan T (2012) 2011 Sikkim earthquake: effects on built environment & a perspective on growing seismic risk. 15 WCEE Lisboa 2012

7. EERI (2012) The Mw 6.9 Sikkim-Nepal Border earthquake of September 18, 2011: Learning from Earthquakes, Special Earthquake Report, Earthquake Engineering Research Institute, Oakland, CA
8. Roshan P, Pal S, Kumar R (2018) Seismic damage assessment index of buildings using fuzzy-AHP approach. Int J Tech Innov Mod Eng Sci 4(08)
9. EERI (2013) Online database of concrete buildings damaged in earthquakes [Online]. Available at: http://db.concretecoalition.org/. Earthquake Engineering Research Institute, Oakland, CA. Accessed 4 Nov 2013
10. Saatcioglu M et al (2001) The August 17, 1999, Kocaeli (Turkey) earthquake damage to structures. Can J Civ Eng 30:715–737
11. Arnold C, Reitherman R (1982) Building configuration and seismic design. A Wiley-Interscience Publications, Toronto
12. Mouzzoun M, Moustachi O, Taleb A, Jalal S (2013) Seismic performance assessment of reinforced concrete buildings using pushover analysis, Morocco
13. Buckley JJ (1985) Fuzzy hierarchical analysis. Fuzzy Sets Syst 17:233–247