BAYESIAN NETWORKS FOR SEISMIC PERFORMANCE ASSESSMENT OF CONFINED MASONRY SCHOOL SYSTEMS

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Abstract

School infrastructure is an important asset of any country that requires special attention to ensure safety of vulnerable population of young children. Specific features of school buildings often increase their vulnerability towards seismic hazards [1]. Well-built confined masonry (CM) buildings are a cost-effective and seismically resilient alternative to ordinary masonry [2] and costlier reinforced concrete buildings [3]. Variations of this typology is observed in India in the form of partially confined masonry (PCM) buildings due to lack of awareness of good CM construction practices and buildings standards before 2016. The notion of better seismic performance of CM typology becomes questionable in such cases. This paper discusses numerical analysis of such PCM school buildings and proposes a Bayesian Networks (BN) approach for analysing the seismic performance of schools at a system level. Application of BN in Engineering problems associated with extreme events is an emerging field of research, as they are suitable for modelling probabilistic interdependencies between variables in complex systems [4]. The approach is illustrated through a case-study of school buildings in Guwahati, India. Inputs for the BN, i.e. capacity and fragility curves for individual PCM buildings, are prepared by numerical analysis using applied element method [5], followed by N2 method [6]. With a simple network connecting hazard (earthquake hazard curve) and inventory variables (fragility curves and corresponding functionality losses), probabilities of final system functionality states with respect to increasing intensity measures are obtained. Analysis for varying building conditions as evidences are carried out, to study the corresponding change in the system states. The methodology shows promise as a tool for performance assessment of complex systems and its applicability as a tool for decision-making in the face of hazards needs to be further explored. This paper is part of an ongoing project examining the potential of extension of this methodology for analysing multi-hazard vulnerability of masonry school building systems.

Keywords: Bayesian networks; Seismic performance; Confined masonry; School infrastructure.

1. Introduction

Assessment of performance of built environment is an integral part of risk assessment against natural hazards. Performance and safety assessment of schools is of utmost importance for various reasons. Numerous cases of disproportionately high damage to schools have proven the significance of ensuring safer school buildings. Damage data of some of the past earthquakes as reported by a project on school earthquake safety initiative by United Nations Centre for Regional Development [7] gives the magnitude of the problem with respect to seismic hazard. The report highlighted collapse of school buildings that caused casualties in events such as Spitak earthquake of 1988, Chi-Chi earthquake of 1999, Wenchuan earthquake of 2008 and Kashmir earthquake of 2005. In India, more than 15000 school buildings were damaged in 2001 Bhuj earthquake of which 1884 buildings collapsed with over 1000 casualties [8,9]. It has been observed from past events that school children are one of the most vulnerable population in earthquakes [7,9]. Common physical characteristics of school buildings are found to make them vulnerable to damage and collapse[1]. Clearly, there is increasing need for devising techniques for assessing their performance which can then assist necessary interventions to ensure safe schooling facilities.

Seismic performance or vulnerability assessment studies generally involve three levels of approach [10]. First, a Rapid Visual Screening is performed through visual observation of the building stock using questionnaires. A second level of assessment is carried out for selected buildings requiring limited engineering information from observation, drawings and on-site measurements. A detailed vulnerability analysis is then performed on chosen buildings based on previous levels of assessment or importance, using detailed computer analysis. Most detailed vulnerability assessments involve complete load-deflection characteristics of the building by dynamic/ time-history analysis. It is important to consider various sources of uncertainty and inter-relations between components involved in a system, while considering vulnerability at a system level.

This paper addresses a school compound as a system, and proposes a methodology based on Bayesian Networks to assess the system functionality performance rather than vulnerability, which is expressed in terms of loss. Bayesian Networks (BN) is an approach for modelling complex systems with uncertainties, in order to obtain exact probabilities of failure of a system [11]. BN based approaches to handle complex problems is a growing field of research [12,13,14,15]. This provides an intuitive visualization of the problem in the form of a directed acyclic graph or network and it is possible to reduce the complexity and interdependency between variables by logically forming the network. Its application in Civil Engineering problems involving extreme loading scenarios is yet to be thoroughly explored [15]. There is immense potential in this tool because of its capability to update system probabilities with input of additional information in system variables. This can be brought to better use, especially at the vulnerability reduction endeavours after natural hazards where data is scarce and real-time updating of probabilities is necessary.

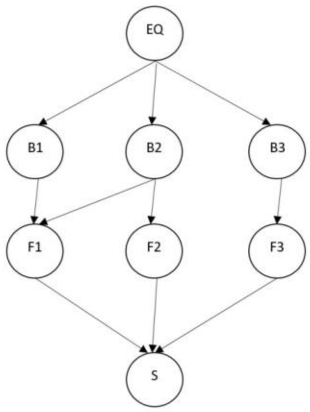
This paper presents the application of BN for the seismic performance assessment of school systems, based on a sample of school buildings at a selected case-study location. Guwahati city in the north-east of India is situated in the most severe seismic hazard zone in India, i.e. zone V according to Indian Standard 1893 (2002) [16]. The region has witnessed several earthquakes in the past, including two great quakes (Ms> 8) in 1897 and 1950 [17,18] and over 20 large earthquakes (7 <Ms<8) [19]. Additionally, the city is affected by annual floods, making it a suitable choice for a multi-hazard vulnerability study in the future. A desk study of school databases of Guwahati city [9] was conducted, followed by a field visit to the location, in order to identify predominant typologies and characteristics of school buildings in the city. It was found that around 75% of the buildings are masonry construction, of which more than 60% are partially confined. Partially confined masonry (PCM) being the predominant typology in the building stock, is chosen for the detailed analysis.

Remaining of this paper is organized as follows: A generic methodology for application of BN for performance assessment problem is presented in Section 2. Inputs to the proposed network are explained and presented for the specific case study in Section 3. Application of BN is then illustrated in Section 4, using the inputs obtained in Section 3. Section 5 concludes the findings of the paper.

2. Methodology

This methodology is illustrated through a sample case. A school compound can have multiple building blocks of different construction typology. These building blocks may have single or multiple functions incorporated, such as class room for teaching, office for administrative works, refectory for providing mid-day meals etc. For proper operation of the school, all these buildings should perform all of their functions.

As mentioned previously, a school compound exposed to a hazard can be considered as a system, from the BN point of view, consisting of different nodes to represent hazard, physical states of building and functionality states of buildings. A simple form of network for a school compound having three buildings can be created as follows (Fig. 1):



EQ: Earthquake hazard

B1/2/3: Buildings in a school system

F1/2/3: Functions of building blocks in the system

S: Overall system performance

Fig. 1 Bayesian Network for a single school compound system

Parent node EQ represents the earthquake hazard, which can be input to the BN as a hazard curve, that gives probability distribution of hazard in terms of intensity measure (IM) such as Peak Ground Acceleration (PGA). Characteristics of this distribution shall depend on the seismicity of the location under study. It is necessary to discretise the probability distribution of hazard, as BN works only on discretised states.

Nodes B1, B2 and B3 represent the physical states of three buildings in a school compound. These can be input as fragility functions for these buildings, as obtained from their analytical seismic fragility analysis presented in Section 3.2. Damage states are identified for each building namely, 1-no damage, 2-slight damage, 3-moderate damage, 4-extensive damage, and 5- complete collapse. Each building has specific fragility functions representing probability of exceedance of each of these damage states for a given value of the hazard intensity measure. From the fragility curves, probability of the building to be in any one of these states can be computed.

As mentioned before, the objective is to consider functionality loss rather than physical damage in the context of a system performance assessment. Nodes F1, F2 and F3 represent utility of the three buildings in the compound, such as F1-Teaching, F2-Administartion and F3-Refectory. Each function can be delivered to a different level, depending on the physical damage state of the building that houses it. This can be categorised as 1- fully functional, 2- partially functional and 3- shut down. The network shows the interlinking of buildings and functions, such as buildings B1 and B2 function as classrooms for teaching, where building B2 also functions as an office for administrative function, and B3 is solely used as refectory for providing mid-day meals.

The end node S represents the state of the system that is the school, which in turn depends on the functionality states of the three buildings. Discrete states can be defined for this node similar to nodes F1, F2 and F3, such as 1-system is intact, 2- system is partially affected and 3- system is shut down.

The steps and data necessary to make operational the BN based methodology for vulnerability assessment of school systems, are:

- Seismic hazard of the locality under consideration;
- Classification of different building blocks in a school compound according to their typology and functions;
- Derivation of fragility curves for the building blocks, after defining physical damage states corresponding to seismic hazard.
- Definition of functionality loss states for each building, corresponding to physical damage states defined above.
- Analysis of the performance of the school system, by determining the performance of individual building blocks in the compound, in terms of functionality loss, and establishing logical relationships between the state of each function and the functional performance of the system.

In the following sections, data requirements for this Bayesian network are explained and generated for the case-study location considered. The simple sample network presented in Fig.1 is then used to illustrate the process of Bayesian Network analysis using these inputs.

3. Inputs to the network

3.1 Hazard curve

Hazard curves give the annual probability of exceedance of IM (such as PGA) at a given location. Indian Standard for earthquake resistant construction- IS 1893 (2002) [16] divides the country into zones of varying hazard intensity. The standard places Guwahati in zone V, which suggests a MSK intensity of IX and above, and expected PGA of 0.18g and 0.36g for Design Basis Earthquake (475 year return period) and Maximum Considered Earthquake (2475 year return period) respectively [20]. Several studies have reported the seismicity of north-eastern region of India including Guwahati. The region is further divided into four subzones and maximum possible earthquakes in these zones are estimated [21,22]. Nath and Thingbaijam (2012) [23] presented hazard maps for India with specific hazard curves for important cities such as Guwahati, which is adopted in the present study. They found that seismic hazard predicted by incorporating local site effects and site-specific GMPEs is higher than the IS 1893 (2002) hazard estimation.

3.2 Seismic fragility curves

Fragility analysis gives a quantitative performance evaluation of different buildings under similar seismic action, in terms of probability of reaching or exceeding a specified damage state or performance level. Analytical fragility assessment of a building stock starts with identifying index buildings in the study sample, followed by numerical analysis to determine the damage states/performance levels. The following sections illustrate each of these steps and the derivation of the fragility curves.

3.2.1 Building typologies

Partially confined masonry (PCM) buildings are found to dominate (about 63%) the school building stock of Guwahati. In order to classify them and identify index buildings, GLOSI [24,25] taxonomy system was applied after necessary modifications. GLOSI system was designed for classification of load bearing masonry school buildings, considering 12 parameters that are relevant in assessing seismic performance. Modifications proposed in this taxonomy to incorporate more granularity to confined masonry typology and particularly to suit the building stock in Guwahati can be found elsewhere [26]. It emerged that all the PCM buildings were built using half-brick thick masonry walls of burnt clay bricks in cement mortar, partially confined by slender RC horizontal and vertical elements. These are single storey buildings with flexible light roofs supported on wooden or steel truss work. The majority, 75% of the PCM blocks, did not have any irregularity, while remaining 25% have plan irregularity. In these buildings, combined area of openings in a wall exceed 10%, hence can be considered as large openings, following EERI guideline 2011 [28]. It is noted that GLOSI uses a different criterion of overall width of opening>50% of wall panel length for designating openings as 'large opening' in unconfined masonry buildings. However as openings reduce seismic resistance of CM walls, a conservative limit as given by [28] is adopted in this study. Horizontal span of wall panels between confining columns exceed 3 m, and hence they are considered as long panels.

Unlike conventional CM buildings, the PCM building in the study do not have the specific features such as toothing or dowel bars at the RC-masonry interfaces, although in some buildings, the correct sequence of construction is followed, i.e. masonry followed by RC [27]. Depending on the sequence of construction and density of confinement, different seismic design levels can be attributed to the PCM buildings as shown in Table 1. A minimum confinement density (MCD) is defined for the purpose of this study based on the spacing criteria of RC elements given by EERI guideline 2011[28] and IS NBC 2016 [29]. Presence of plinth band, lintel band, corner columns and intermediate columns at spacing not exceeding the limits for horizontal and vertical confining elements specified by these guidelines is considered as minimum confinement density. Percentage of buildings in each design level within the study sample are also given.

Table 1 Seismic design levels of buildings in the study sample

Parameter	Attribute	Commentary	% in the sample
Seismic Design Level	Poor Design (PD)	Wrong sequence of construction but has minimum confinement density (MCD)	57
	Low Design (LD)	Correct sequence of construction and MCD	34
	Medium Design (MD)	Correct sequence of construction and high confinement density (additional confinement over and above MCD)	9
	High Design (HD)	Correct sequence of construction and all provisions for CM as specified by [28].	0

The PCM buildings under study belong to PD, LD and MD categories. Three index buildings (IB) are chosen, IB1, IB2 and IB3 with PD, LD and MD seismic design, respectively. Geometric and material properties are considered identical for the three index buildings. Irregularity in plan is not considered.

3.2.2 Numerical modelling and analysis

Extreme Loading for Structures (ELS) [30] - an Applied Element Method (AEM) based software capable of performing advanced non-linear structural analysis - is used to perform the seismic analysis of the three index buildings. The effect of sequence of construction is accounted in the model by the material in the interfaces between RC tie columns and masonry wall panels. Non-linear static pushover analysis is carried out to assess the lateral capacity of IBs. However, instead of applying lateral load at roof level, monotonically increasing ground acceleration is applied, to overcome the difficulty of not having a suitable control node in buildings with flexible roof.

Numerical analysis shows how the failure mechanism of the index buildings is strictly related to the level of seismic design. Specifically two distinct failure mechanisms are observed: local out-of-plane mechanism and global in-plane mechanism. In IB1 and IB2, with poor and low deign levels (indicating inadequate confinement), failure of the portion of walls above lintel by out-of-plane (OOP) is considered as collapse, as this can be life threatening even though the in-plane (IP) walls stand undamaged (Fig. 2). It is noticed that the rotation of OOP walls in IB2 is about the base of the wall due to better connection to RC elements, whereas in IB1, the rotation is about the lintel band, both leading to failure of portion of wall above lintel. The failure occurs for higher ultimate capacity and larger OOP top displacement in IB2 when compared to IB1, which indicate relatively better performance of IB2. For IB3 with medium design level, the confinement is adequate in providing a global behaviour and the damage is mainly concentrated on the IP walls, allowing improved ductility for the whole system without local failure (Fig. 2).

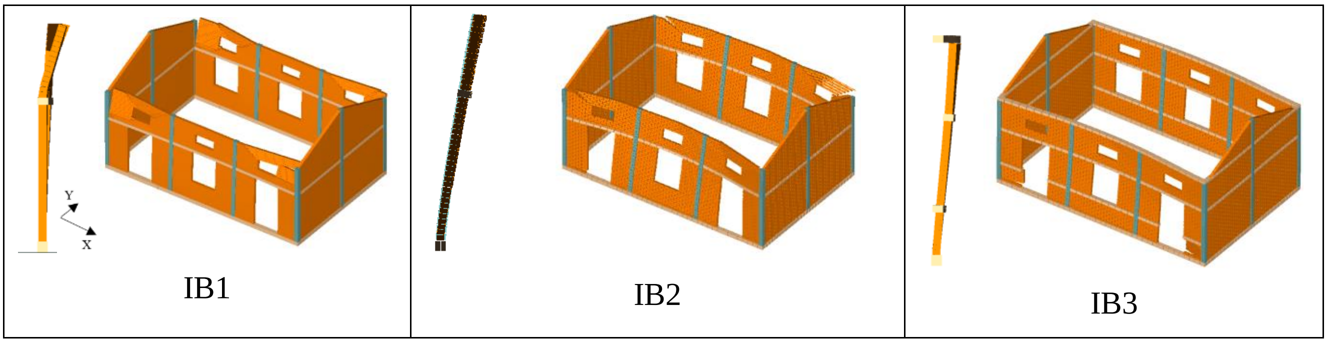
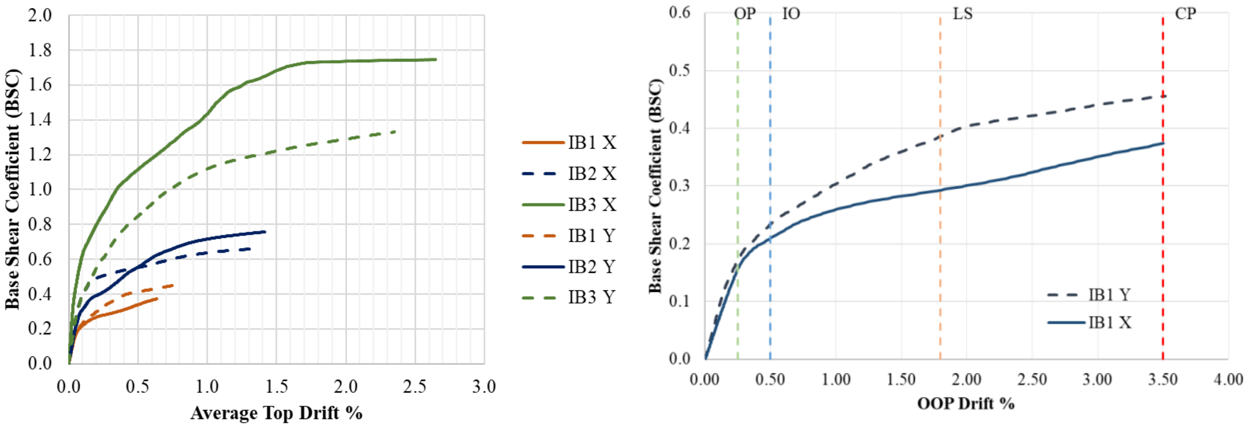


Fig. 2 Failure mechanisms in three index buildings

Capacity curves obtained for these buildings through pushover analysis in the two orthogonal directions are presented in Fig. 3a. Average top drift is calculated with respect to total height of the building for comparison between the three IBs. The base shear coefficient (BSC) represents the lateral capacity as a ratio of mass of the building. IB1 with PD (refer to Table 1) has least ultimate capacity and ductility. IB2 with LD, has almost the double capacity and ductility in both directions. IB3 having MD, shows a much higher ultimate capacity, and global ductility compared to IB2. As mentioned before, for both IB1 and IB2, the OOP failure of the portion of wall above the lintel is identified as constituting the maximum capacity (local failure) whereas in IB3, global displacement is considered to identify failure conditions (global failure). Unlike in IB2 and IB3, the failure occurs due to rotation of portion of wall above lintel in IB1. Hence, the drift is recalculated as ratio of OOP displacement to height of wall above lintel as shown in Fig4b, for further analysis of fragility, as shown in Fig 4b. In IB2 and IB3, OOP drift and global drift are calculated with respect to full height of the walls for the reason observed in Fig 3.



(a) (b)

Fig. 3 a) Capacity curves in two orthogonal directions for the three index buildings: Average top drift vs BSC b) Modified capacity curve for IB1 with OOP drift (upon wall height above lintel) vs BSC

3.2.3 Performance levels and fragility functions

Four structural performance levels namely, operational (OP), immediate occupancy (IO), life safety (LS) and collapse prevention (CP) are considered in this paper which are generally adopted in the context of seismic evaluation of structures [31]. These performance levels are attributed to four damage states, i.e. slight damage state-SDS, moderate damage state-MDS, extensive damage state-EDS and collapse damage state-CDS respectively. Drift limits for different performance levels are defined separately for buildings exhibiting local and global failure mechanisms. According to extensive literature review on OOP local failure of masonry buildings [31,32,33,34,35], collapse displacement limit can be considered as 50% of wall thickness. In the case of IB1 and IB2, with wall thickness of 110 mm, this top displacement is thus 55 mm. Considering the average height of walls above lintel (1500mm), this accounts for a top drift of 3.7%, which is in accordance with findings from other experimental work [34]. Other damage states can be defined as percentage of the collapse limit, as suggested by Doherty et al. (2002) [35]. These values can be used as a base reference for the first two index buildings under this study which has shown local OOP failure mechanism. Along with these reference values, the extent of cracking is considered for fixing performance drift limits for IB1 (as shown in Fig 4b) and IB2 (not shown).

For the global mechanism, there has been considerable research on the in-plane global behaviour of confined masonry, unlike the case of OOP behaviour. Three limit states observed on the capacity curve of CM buildings and their drift values as reported in some of the literature are given in Table 2. These limits are crack limit- $Ø_{cr}$ (point of first significant crack in the walls), maximum attained resistance- $Ø_{Rmax}$ and near collapse- $Ø_u$. These values are used as indicative base reference for damage states and performance levels in the case of IB3, which exhibited a global behaviour. As in the previous case, drift limits are fixed for IB3, taking the extent of damage also into consideration.

Table 2 Drift limits reported in Literature for IP global behaviour of Confined Masonry

Reference	$Ø_{cr}$	$Ø_{Rmax}$	$Ø_u$
Tomazevic and Weiss 2010 [36]	0.27	1.39	2.8
Tomazevic 2007 [37]	0.2-0.4	0.3-0.6	2-4
Chourasia et al. 2016 [2]	0.31	0.83	1.8
Alcocer et al. 2004 [38]	0.15	0.4	-

The capacity curves obtained in the previous section, along with suitable drift limits for performance levels are used for deriving fragility curves using N2 method [5]. Least square error method is applied on performance points obtained in this manner, thus generating fragility curves as a lognormal cumulative distribution. For conducting the N2 method, 22*2 ground motion records as recommended in [31] are used with scaling. Results for the three index buildings for the two directions of loading are presented in Fig. 4.

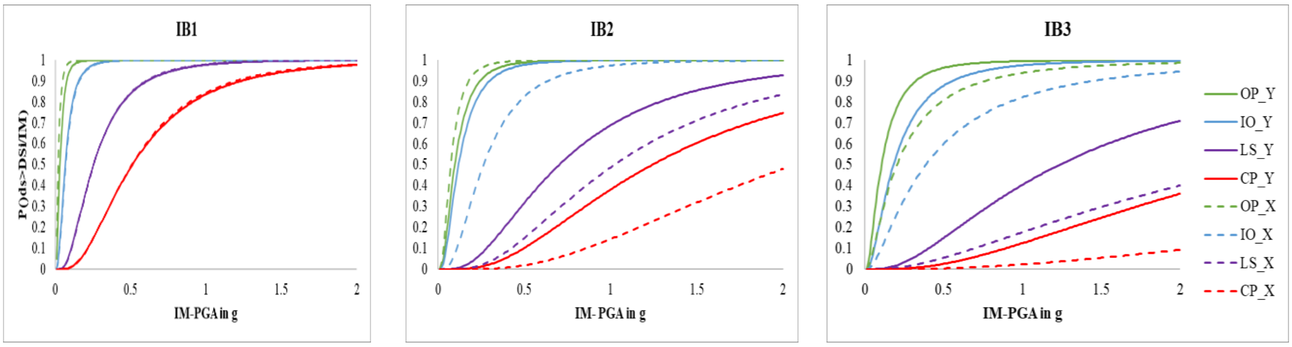


Fig. 4 PGA vs probability of exceedance of four performance levels: Operational (OP), Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP), in two orthogonal directions for the three index buildings.

The fragility curves clearly visualise the improvement in seismic capacity between IB1 to IB3, with increasing levels of the seismic design. In IB1, both orthogonal directions tend to have similar fragility, whereas IB2 and IB3 are clearly more vulnerable in Y direction loading. As anticipated, IB1 with wrong sequence of construction and minimum confinement density is the most vulnerable type of partially confined masonry building among the three considered. IB2 and IB3 with low and medium design levels show significantly improved performance. For a comparison, at PGA level for maximum considered earthquake (0.36g) in the location, probability of exceeding life safety level reduced from 75% in IB1 to 22% in IB2 to less than 9.8% in IB3 under Y direction loading. Similar reduction in exceedance probability of collapse prevention is 30%, 8% and 0.2% in IB1, IB2 and IB3 respectively.

3.3 Conversion of physical to functionality damage

For BN framework aiming for a broader vulnerability assessment, applicable to other natural hazards and combined scenarios in the future, it is more meaningful to assess the system performance in terms of functionality, rather than the physical damage states. As mentioned in the introduction, each building is assigned a function to perform in a school system, and it is important to assess the effect of physical damage of one or more buildings on the overall delivery of the intended function. Probability of a building being in damage state 1 (no damage) is obtained by subtracting fragility function for slight damage from 1. Probability of the building being in any other damage state is derived by subtracting the fragility function of second damage state from the first and so on. Conversion of physical to functional damage states is carried out as shown in Table 3, with reference to the nodes in the BN shown in Fig. 1. Similar conversion is applied when more than one building perform a common function, such as classroom.

Table 3 Conversion of physical damage state/performance level to functionality damage state

Physical damage state/performance level (node Bi)	Functionality state (node Fi)
1(no damage) & 2 (SDS/operational)	1 (fully functional)
3 (MDS/immediate occupancy)	2 (partially functional)
4 (EDS/life safety) & 5 (CDS/collapse prevention)	3 (shut down)

The above conversion to functionality states is in reference to guidelines such as [31] and [39]. For example, immediate occupancy is understood as the state where the structure is safe to occupy, retains its original strength and stiffness, but suffers limited damage and may require repair without shutting down the building.

Similar to functionality of individual buildings, the final system node in the BN is also assigned system functionality states. System functionality states are conditioned on the states of individual functions of the system components, as it logically follows (Table 4). The relations in Table 4 are assumed for illustration purpose, considering the fact that for the uninterrupted functioning of the system, all three functions have to be operating, at least with partial capacity. Hence, if any one of the functions (teaching, administration and refectory) is shut down, the whole school system is assumed to be shut down, in this simulation.

Table 4 Conversion of functionality state to system state

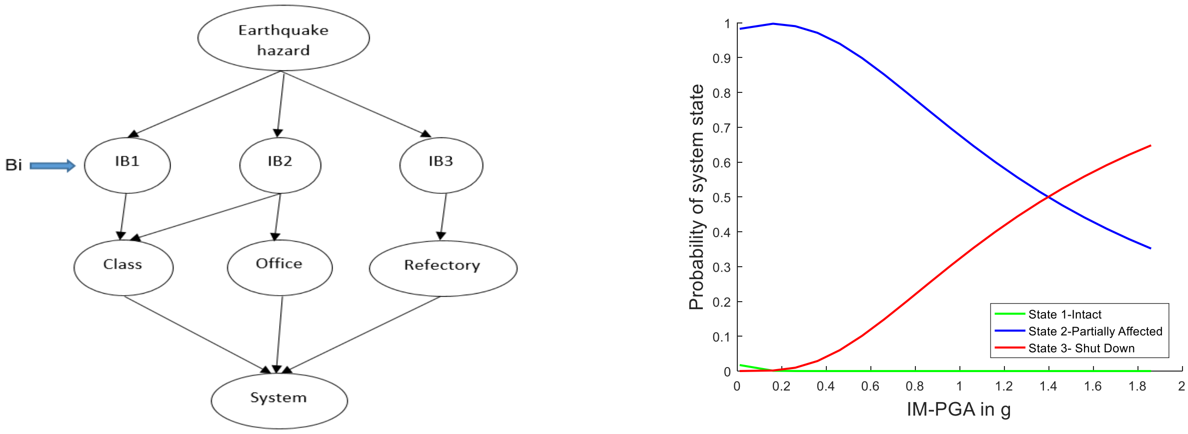
Functionality state (node Fi)	System state (node S)
All F1, F2 & F3 are in state 1	1 (system is intact)
All F1, F2 & F3 are in state 3	3 (system shut down)
All other combinations	2 (system partially affected)

4. Results and discussion

With the inputs explained in the previous section, it is possible to assess the system performance under various scenarios. As it was clear from fragility curves, the index buildings are more vulnerable in the Y direction of loading. Hence, fragility curves in Y are used in the BN as inputs for nodes Bi. Different scenarios considered for the analysis are explained in the following sections.

4.1 Case1: Buildings Bi (B1, B2 and B3) represent IB1, IB2 and IB3 respectively.

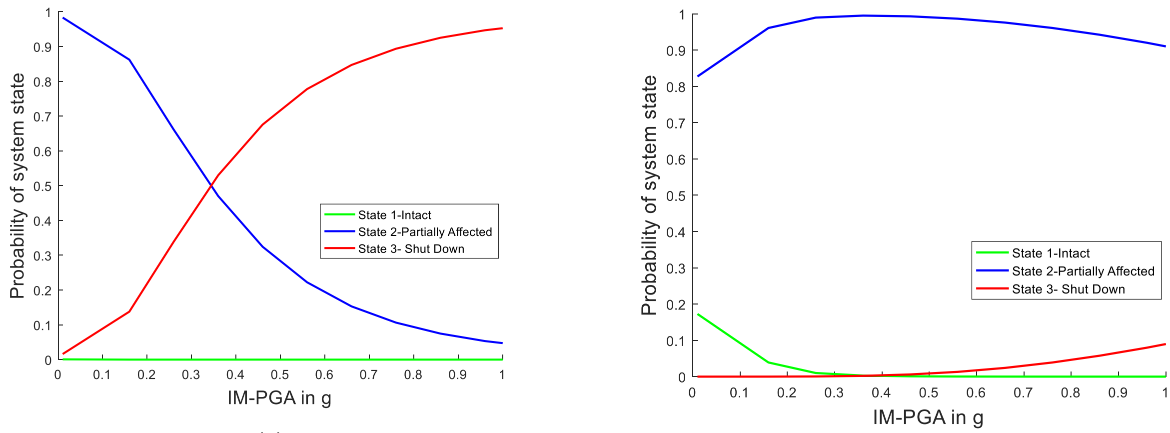
A school system with three building blocks, one each belonging to IB1, IB2 and IB3 typologies is shown in Fig. 5a. It can be understood from Fig. 5b that the system being intact is practically zero beyond very low PGA values of 0.1g, mainly due to the high fragility of IB1. However, since IB2 also function as classroom, this function in the system is fulfilled by IB2, in the absence or failure of IB1, leading to a 70% chance for the system being in partially affected state even at PGA of 1g. With further increase in PGA, the probability of the system going to shut down increases.



(a) (b)

Fig. 5 Case 1- Bi represented by IB1, IB2 and IB3

4.2 Case 2: All Bi representing IB1



(a) (b)

Fig. 6 Case 2 (worst) and 3 (best) combination of building typologies in a school system (PGA up to 1g)

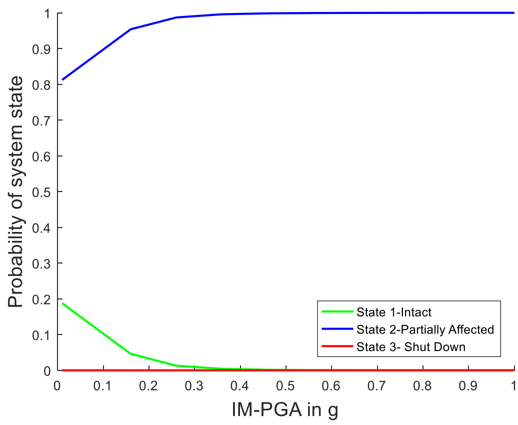
IB1 being the most predominant typology and the most vulnerable, the worst scenario is for all the buildings in a school system to be in this typology. As can be clearly observed from the final system states in Fig. 6a, there is a 50% chance of the system being shut down at as low as 0.36g PGA, which is the PGA corresponding to maximum considered earthquake. The system is most certainly shut down beyond 0.8g.

4.3 Case 3: All Bi representing IB3

If all buildings in a system belong to IB3 or if an intervention is carried out to improve all IB1 buildings to IB3, the improvement can be expected as shown in Fig. 6b. At 0.36g PGA, there is almost 100% chance that the system is only partially affected. Even at very high PGA beyond 0.8g, the system is most likely (90%) to be functioning with partial capacity. This clearly indicates the capability of the BN approach to quantify the benefit of improvements achieved through various retrofit or strengthening actions. Although not illustrated here in detail, the BN gives a platform to compare different strategies for strengthening, hence enabling decision makers to choose the best possible solutions.

4.4 Case 4: Updating system with known information

One of the advantages of using BN for system modelling is that it allows updating of probabilities with known data. For example, in the school system considered in case 1, if it is known that building B1 is operational (slight damage), then the system states modify as shown in Fig. 7a. In this condition, the system is never shut down, as one building is operational, and hence the system is partially functioning.



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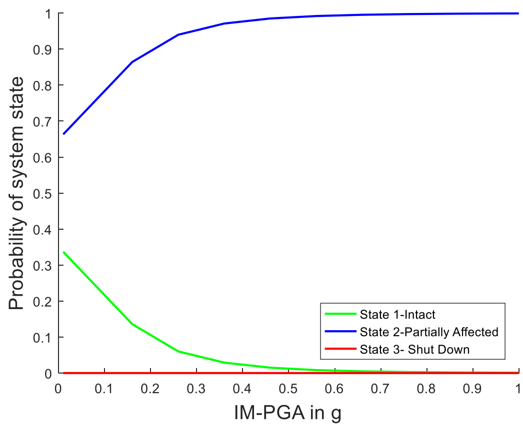


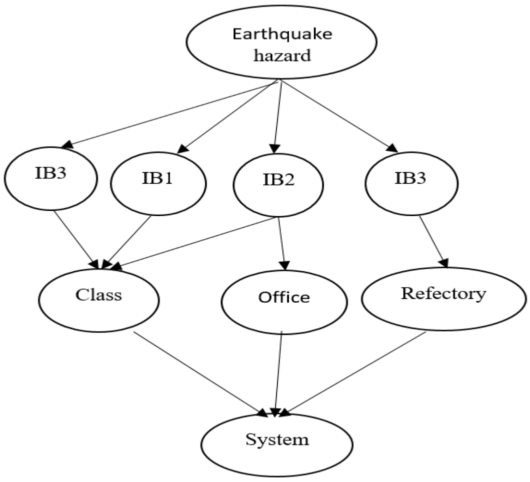
(b)

Fig. 7 Updating system with known information

Considering another fictitious case where all buildings in a school system belong to IB2 typology and function F1 (classroom) is known to be intact. Then the system states probabilities modify as shown in Fig. 7b. As the classroom function is deemed to remain intact, the system has a better chance of being in the intact state at low PGA values.

4.5 Case 5: Expanding BN for larger school systems

In order to represent a school system with 4 building blocks, one block of IB3 type is added to function as a classroom. The original network in Fig. 5a is modified as shown in Fig. 8a. The final system state probabilities of this extended system is shown in Fig. 8b, which shows a better performance compared to the original system in Fig. 5b. If the probabilities of functionality alone (marginal probability of classroom function) is observed, the effect of having more buildings blocks, and under better performing typology can be understood by comparing Fig. 8c (extended system) and Fig. 8d (original system). It can be seen that probability of teaching in classrooms being shut down has reduced from 25% to 5% at 0.36g PGA, and probability of this function being in a partially affected state has improved from 75% to 99%.



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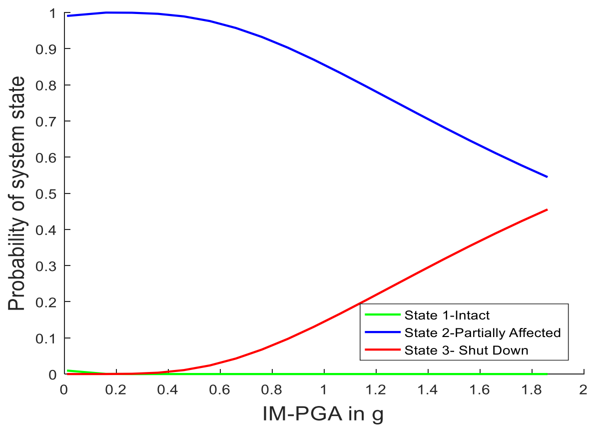

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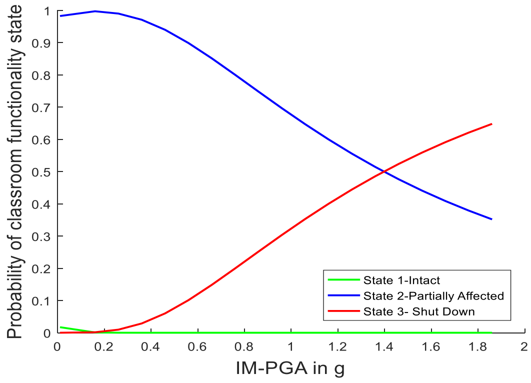

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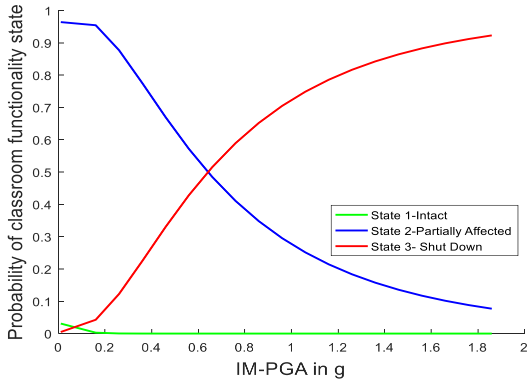

(d)

Fig. 8 a) Expanded BN, b) System states probabilities of extended system, c) marginal probabilities of classroom function in extended BN, d) marginal probability of classroom function in original BN

A variety of other combination of interesting scenarios can be studied using these networks, but for the sake of brevity, the discussion is closed here. It is to be noted that the system states defined in this study can be elaborated further into specific states on a case by case basis and the relations presented in Table 4 shall be modified as required by the specific case of interest.

5. Conclusion

This paper presented the application of Bayesian Network for system modelling and performance assessment under earthquake hazard, with a specific case study of school buildings in Guwahati, India. The objective is to assess the performance of a system having different building blocks as components, in terms of their functionality, rather than physical damage states. A general methodology for BN application in similar studies is presented, followed by an insight into the network inputs, i.e. hazard data, fragility of individual components of the system and functionality definitions. Generation of analytical fragility curves for the index buildings identified is elaborated, as they form the crucial input data in a specific case study. Comparison of seismic fragility of different building typologies, varying in seismic design level is possible by comparing the fragility curves. In the last section, the inputs are used in the BN to have an analysis of system performance in different scenarios. BN analysis enables quantitative comparison between probability of system states under various scenarios. This can assist in interventions to improve system performance by improving structural capacity of the buildings, i.e. modifying low performing typologies to better performing ones.

The BN approach has shown promise in acting as a platform for modelling complex systems, comparative study of different retrofit strategies and updating of system with availability of new data. Although the networks presented represent illustrative simple systems, the approach can be extended to complex system, and further developed to include effects from multiple hazards. Capability of the system to incorporate and propagate uncertainties explicitly in the system is also identified as a next step of study.

6. References

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