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A COMPARATIVE PROGNOSTIC DAMAGE SCENARIO OF NON-ENGINEERED MASONRY AND TRADITIONAL ASSAM TYPE HOUSING IN GUWAHATI URBAN CENTRE

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ABSTRACT

The extent of damage to buildings and the resultant loss of life due to most of the earthquakes are attributed largely to vulnerable building typology and their construction practices. These various construction practices often have characteristics that address the prevalent local conditions of weather and other environmental and natural hazards and have evolved based on technology transferred from one generation to the next by word of mouth or through some documentations by practicing masons and end-users. The "Assam type housing" is one such as traditional housing, which has been known for its earthquake-safe construction, using timber as a basic framing material. This traditional housing has been replaced in large numbers by the modified "Assam type looking" masonry housing and this modified housing in masonry has become the conventional building typology in Assam, and different parts of northeast India. The present work attempted to examine the seismic vulnerability of the Guwahati urban centre due to the unscientific transformation of building typology from traditional housing, constructed in timber to more vulnerable housing in unconfined or partially confined masonry constructions. A prognostic damage scenario for the traditional housing in comparison to the conventional housing in unconfined / partially confined and confined masonry buildings have been developed. The damage probability values for various building typologies were adopted and the damage ratios, which represent the ratio of repair or reconstruction cost to the replacement cost for the various typologies of buildings, were used to estimate the economic loss in each municipal ward of the city. The objective of the work is to develop a simplified prognostic damage scenario with first-order approximations of building typology based damage grades for various earthquake intensities as given by Arya and Agarwal [3]. The estimated economic losses based on the prognostic damage scenarios indicate that the estimated losses, which are directly related to the structural damage, have increased many folds due to the transformation from earthquake-safe traditional housing to more vulnerable housings in unconfined or partially confined masonry constructions.

KEYWORDS: Assam Type Housing, Masonry, Builing Typology, Vulnerabilty, Damage, Economic Loss

INTRODUCTION

The detailed assessment of damage following various past earthquakes viz. the 2001 Bhuj earthquake, the 2011 Sikkim earthquake, the 2015 Nepal earthquake, and the 2016 Manipur have shown that both non-engineered and engineered buildings had suffered extensive structural damage as given by Sinha *et al.* [21]. It is also observed that even the non-engineered constructions sometimes possess the required resistance to earthquake ground motions. The traditional "Assam type housing" in the

North-Eastern states and the "Dhajji-Diwari buildings" in Kashmir, which are non-engineered constructions, have performed very well during past earthquakes.

It has been observed that there is an unscientific shift from less vulnerable traditional construction practices, in timbers to more vulnerable construction practices in partially confined or unconfined masonry houses in suburban and rural areas due to various socio-economic reasons [19]. The traditional construction practices were developed with the knowledge of local conditions and local materials viz. timber, bamboo, 'ikra' - a kind of local reed, throughout time-tested experience [14]. However, due to various socio-economic conditions, such traditional practice is systematically replaced with more vulnerable materials and constructions. The state of Assam, along with the entire north-eastern region of India falls in the seismic Zone V as per the seismic hazard map of India. The region has seen a definite shift from earthquake-safe traditional practices to more vulnerable unconfined or partially confined masonry buildings. The traditional construction practice was promoted by the governments before and after independence. The Assam Public Works Department (APWD) had the specifications for such buildings in their standard and schedules, encouraging this construction practice in the past. It has been a matter of concern that, with the emphasis on vertical expansion in the urban centres, this earthquake-safe traditional construction practice has lost its applicability in the urban housing sector. Unfortunately, in suburban and rural areas too, this traditional construction practice is being replaced by more vulnerable non-engineered masonry constructions. Nevertheless, in suburban areas, where adequate spaces are available for planning, the traditional "Assam type housing" still provides a better alternative for earthquake-safe housing.

It is important to estimate the expected performance of the traditional housing for a given earthquake scenario and to understand the risk involved due to an unscientific shift from the traditional housing practice to more vulnerable construction practices as mentioned above. The assessment of seismic risk presents the consequences of an earthquake in terms of the expected damage and loss for a given hazard level. The vulnerability information of any building largely depends on the structural systems of the buildings resisting gravity and lateral loads, the type of construction practices adopted in the given area, and the information about the performance of similar buildings in past earthquakes. The expected earthquake damage scenario is thus primarily can be given as a prognostic damage scenario of different building typologies or taxonomy existing in a given area or a region [5, 6, 13, 15, and 16].

An attempt has been made in this current work to develop a prognostic damage scenario for traditional housing and other conventional housing practices. The objective of the work is to develop a simplified prognostic damage scenario with first-order approximations of building typology based damage grades for various earthquake intensities and the damage probability value for each building typology was adopted as given by Arya and Agarwal [3]. The damage ratios, which represent the ratio of repair or reconstruction cost to the replacement cost of a given building as given for various typology of buildings in the Guwahati city as given by Pathak and Lang [16] and Pathak *et al.* [18] were used to estimate the economic loss for each ward of the city to correlate the prognostic damage to economic losses in various municipal wards of the Guwahati city. The result of this work along with an estimation of economic losses will complement more sophisticated damage assessment in future by providing a general occupancy pattern of human exposure in urban, rural, residential or non-residential dwellings by its construction types [13] and will help to prioritize future disaster mitigation effort in the city municipal areas.

COMPARATIVE PROGNOSTIC DAMAGE SCENARIO

The work on prognostic damage scenarios of a given urban area starts with an understanding of the existing building types in the given area. It is also important to understand the distribution of the building types within the study area to develop the prognostic damage scenario.

1. Delineation of Study Area

The study area or the Guwahati urban centre, adopted here is the current Guwahati city development area as per the Comprehensive Master Plan 2025 published by Guwahati Metropolitan Development Authority GMDA [10]. The Comprehensive Master Plan 2025 includes the Guwahati Municipal Corporation (GMC) area, the additional area towards the western part of the city, part of the eastern extension of the city, and the newly formed wards in the North Guwahati area. The GMC area was originally subdivided into 60 municipal wards and was merged into 31 wards in the year 2013 as shown in Figure 1 [17]. These wards do not show any typical cluster of building typology, which made it necessary to collect data on a large scale by carrying out a building stock inventory survey.

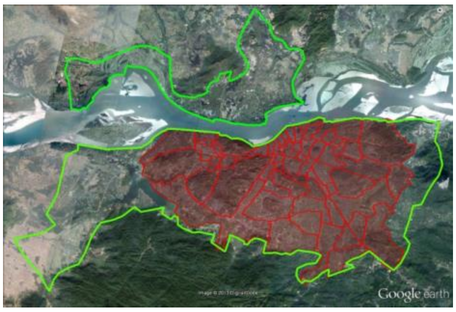


Fig. 1 Overview map indicating the considered study area, the 2025 Guwahati Master Plan area (green line) as well as the municipal wards of Guwahati (red-shaded and outlined areas), (Source: Pathak & Lang 2013 [17])

2. Building Inventory Database

A walk-down survey of more than 15000 individual buildings was conducted to create a representative building stock inventory from each ward containing a large number of samples from each municipal ward. The identification of the total amount of individual buildings in each ward was also made using available satellite imagery (e.g. Google Earth^{TM} images). Based on the survey results, a building typology distribution has been identified for each ward, which is then extrapolated to the total number of buildings in the respective wards. The extrapolation is based on estimated/counted numbers of individual buildings in each ward. The database in this study was thus enhanced to a total no. of 1,17,493 individual buildings from counted nos. of 15, 534 buildings from walk-down surveys in the field. A Linear extrapolation has been done to estimate the distribution of the buildings according to their typology distribution in each municipal ward. Based on these typology distributions as well as the estimated number of buildings in each ward, the building-wise inventory for the entire study area was generated [18]. An inventory database should include geo-referenced information on each building's geographical location (here at ward level), structural information to identify the typology, as well as socio-economic information (occupancy, value, replacement, and repair costs of buildings.). The latter type of information is primarily required to compute economic loss estimates, which represent a consequence that is directly caused by the respective structural and non-structural damage. Table 1 presents the overview and description of typical inventory data collected during the walk down survey with their breakup in various occupancy types. The inventory model contained a large number of samples which could be reliably extrapolated to derive a picture of the distribution of the total number of buildings in each ward.

Figure 2 illustrates the distribution of the existing buildings in Guwahati city according to their occupancy. It is observed that Guwahati is mainly dominated by buildings for residential use, followed by buildings for commercial use and others.

Table 1: Distribution of occupancy types for the investigated buildings*

Occupancy type	**Walk-down field survey**		**Linear Interpolation**	
	Parental share	**No. of buildings**	**Parental share**	**No. of buildings**
Residential	81.434 %	12,650	73.12 %	85,910
Commercial	15.173 %	2,357	21.64 %	25,430
Industrial	1.319 %	205	2.05 %	2,410
Educational	1.577 %	245	2.36 %	2,778
Health	0.193 %	30	0.30 %	356
Religious	0.302 %	47	0.52 %	609
Sum	**100 %**	**15,534**	**100 %**	**117,493**

(*Report no.15–014, EQRisk Project Kjeller (Norway) – Guwahati (India) September 2015 [18])

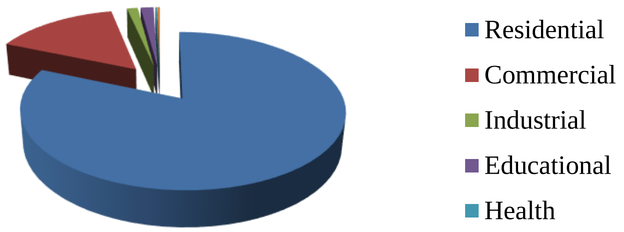


Fig. 2 Distribution of occupancy types for the investigated buildings (Source: Pathak *et al.* 2015 [18])

3. Non-Engineered Building Typology Classification

A building classification scheme was developed for the Guwahati city by Pathak and Lang [17] which resulted from various inventory surveys in Guwahati conducted by Assam Engineering College under the EQRisk Project of NORSAR Kjeller (Norway) and Assam Engineering College Guwahati [17,18].

The classification is provided based on:

- Available wall materials (i.e., Wattle and daub - reed/bamboo mesh with mud/mortar, clay brick, stone, concrete, etc.)
- Available roof and floor system types (i.e. rigid, flexible, heavy, etc.)
- Available building typologies, regarding lateral load-resisting system and material

The majority of houses in the revenue villages around the Guwahati city are of the traditional "Assam type housing" typology as given by Kaushik and Babu [14]. Even though the traditional building typology is more prevalent in rural areas, a significant percentage of this type of housing can also be found in the urban centre and suburbs of Guwahati city. However, in the last two decades, a decrease in the number of these traditional houses has been observed, especially in urban areas. Figure 3 to Figure 6 illustrates the traditional "Assam type housings" in an urban residential area. There has been a legal ban on the felling of trees, which has reduced the supply of timber as a building material. This situation has encouraged masonry constructions for smaller houses and RC (Reinforced Concrete) framed constructions for larger or multi-storied houses. Figure 5 shows the timber truss used in the roofing of typical Assam type buildings built during 1950–60 by the Assam Public Works Department (APWD). Figure 6 illustrates the two-way slope of the roofing system, which provides efficient bracing action at the post plate level against the out-of-plane failure of the walls. These traditional constructions were demolished to replace with multi-storied RC framed constructions.

Fig. 3 Assam type houses around the city of Guwahati with typical timber framing

Fig. 4 Assam type house (left) partly replaced with masonry house (right)

Fig. 5 Assam type house with timber roof trusses

Fig. 6 Assam type house with a two-way sloped roof / hipped roof

Fig. 7 Partially Unconfined masonry houses with lightweight roofing

Fig. 8 Confined masonry building with gable end not braced against out-of-plane failure

Figure 7 and Figure 8 have shown some of the unconfined and confined masonry construction for residential buildings in municipal areas of the Guwahati city, which may be termed as the "Conventional Construction" now, considering their popularity. The description of available building typologies in the Guwahati city is summarized by Pathak and Lang [17] as given in Table 3 along with the mapping to taxonomy given by various sources globally. It may be mentioned here that, for all analysis and presentation, the current work has adopted the PAGER (Prompt Assessment of Global Earthquakes for Response) classification, as given by Jaiswal and Wald [13].

Table 2: Building typology classes representing the traditional constructions and conventional masonry constructions observed in Guwahati city (Source: Pathak and Lang [17])

Building typologies	Illustration
Load-Bearing Timber Frame	
IK – Ikra / W5 Wattle and daub (bamboo mesh with mud) • sloping roofs with light CI sheets supported by trusses made of timber • primarily single story	 
Load-Bearing Masonry Wall	
UMW11L / UFB4 Unreinforced burnt clay brick masonry in cement mortar sloping roofs with light CI sheets supported by timber trusses • bands at tie and lintel levels • Mostly temporary construction for retail shops etc. • mainly single story	 
CMW11L / RM3 Confined brick masonry in cement mortar using burnt clay bricks • sloping roofs with light CI sheets supported by timber trusses • confined burnt clay brick masonry with bands at tie levels, lintel levels, and post plate levels	 

4. Building Typology Distribution in Various Wards of the Guwahati Urban Centre

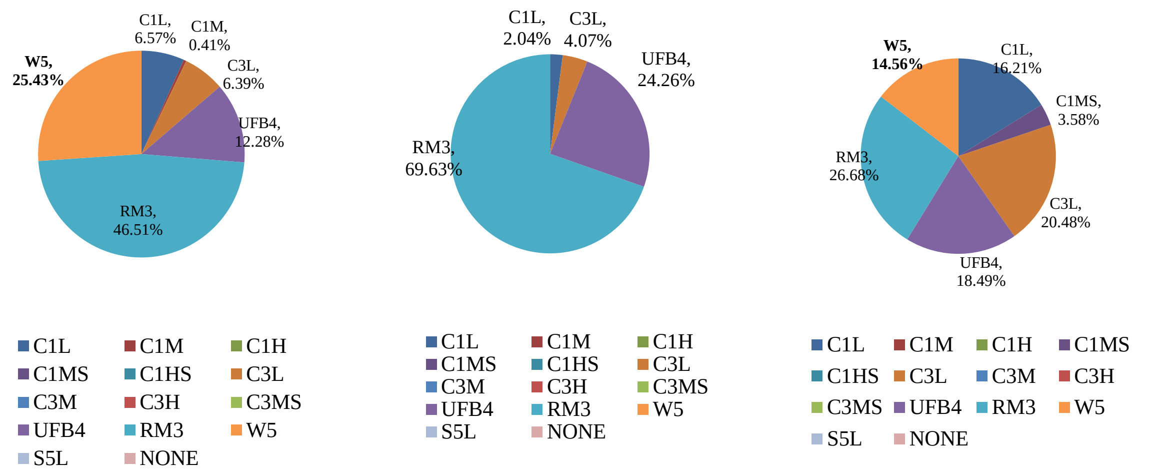
It has been observed that certain parts of the urban centre viz. North Guwahati area, a suburban settlement is still dominated by the traditional "Assam type housing" or typology W5 with an estimated 25.4 % of buildings in W5 typology as shown in Figure 9(a). The Western and Eastern extension of city municipal areas is witnessing the replacement of the traditional construction practices with more vulnerable unconfined masonry housing (UFB4) or confined masonry (RM3) typology as can be seen in Figure 9(b) and (c). It may also be observed that the percentage of building typology W5 is still on the higher side in wards 1 and 2, which are the old municipal area toward the western part of the city covering old residential areas of Jalukbari including Gauhati University campus as given in Figure 10(a) and (b). Similarly, ward numbers 8, 9, 38, and 53 show the presence of W5 typology in a considerable percentage in the urban centre. These areas are some of the earlier settlements in the city, where the traditional housing practices were adopted for the construction of residential houses and public buildings.

Table 3: Building Typology Classes observed in Guwahati Urban centre mapped to global taxonomy of various sources (Reproduced from Pathak *et al.* [18])

Guwahati Building Taxonomy								PAGER[1)]	GEM Taxonomy Shorthand Form[2)]	HAZUS[3)]	Risk-UE[4)]	PSI[5)]	EMS[6)]	WHE-EERI[7)]
Classification		Lateral Load-Resisting System		Roof	Floor	STR-ID EQRisk[8)]	Number of stories							
		System Type	Material	System/ Material	System/Material									
Wood	Load-Bearing Timber Frame	Ikra (Assam-type, wattle, and daub)	Large timber frames with wattle-and-daub infills, cement plaster	Timber or steel truss, CI sheet	Timber or steel truss, CI sheet	IK	1 (2)	**W5**	W+WWD/LWAL/RWO+RWO5/-/-/H:1,2/	–	–	AE2	E	30
Masonry	Unreinforced Masonry	Load-Bearing Wall	masonry wall made of rectangular fired clay bricks, with cement mortar	Timber or steel truss, CI sheet	Timber or steel truss, CI sheet	UMW11L	1	**UFB4**	MUR+CLBRS+MOC/LWAL/-/FW99/ H:1/	–	M3.3	BB1	C	–
	Confined Masonry	Load-Bearing Wall	Masonry wall made of rectangular fired clay bricks, in cement mortar with reinforced concrete confinements	Timber or steel truss, CI sheet,	Timber or steel truss, CI sheet,	CMW11L	1-2 (3)	**RM3**	MCF+MUN99/LWAL/H:1,3/	–	M4	BB2	D	10
Reinforced Concrete	Frame System (Beams and Columns)	Nonductile moment-resisting frame	RC moment frame with unreinforced masonry infills made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCF11L	1--3	**C3L**	CR+CIP/LFINF+ND/-/-/H:1,3/	C3L-PC		DC2	C	16
						RCF11M	4--6	**C3M**	CR+CIP/LFINF+ND/-/-/H:4,6/	C3M-PC		DC2	C	
		Nonductile moment resisting frame with Open ground floor	RC moment frame with unreinforced masonry infills made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCF12L	1--3	**C3L**	CR+CIP/LFINF+ND/-/-/H:1,3/	–		DC2	C	16
						RCF12M	4--6	**C3M**	CR+CIP/LFINF+ND/-/-/H:4,6/	–		DC2	C	
		Ductile moment-resisting frame	RC frames, with unreinforced masonry, infill made of rectangular fired bricks	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RC slabs, (for low-rise: timber/steel trusses, CI sheets)	RCF21L	1--3	**C1L**	CR+CIP/LFM+DU/-/-/H:1,3/	C3L-MC	RC31L	DC1	D – E	–
						RCF21M	4--6	**C1M**	CR+CIP/LFM+DU/-/-/H:4,6/	C3M-MC	RC31M	DC1	D – E	–
						RCF21H	7+	**C1H**	CR+CIP/LFM+DU/-/-/H:7+/	C3H-MC	RC31H	DC1	D – E	–

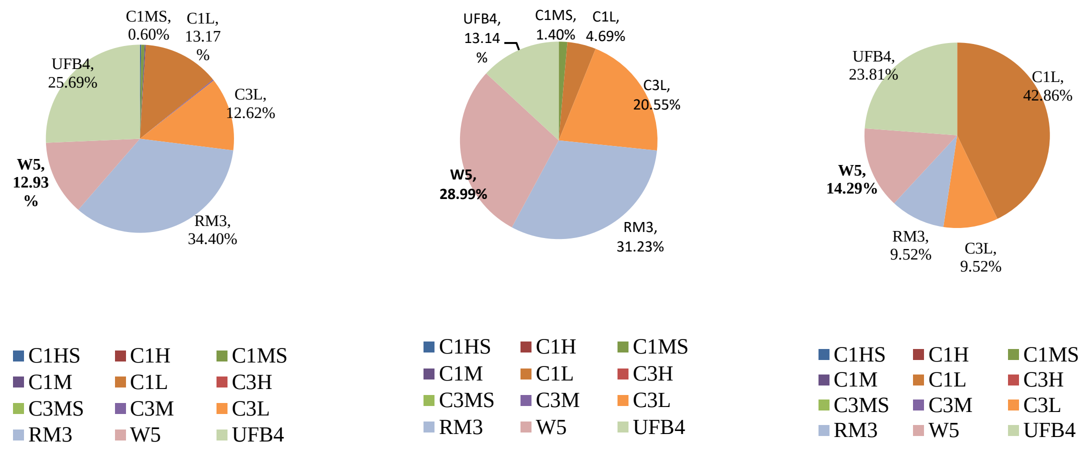
Steel	Light Metal Frame	Steel metal frames	Steel light frames	Steel trusses with CI sheets	Steel trusses with CI sheets	SLF11	1 (2)	**S3**	S+SL/LFM/H:1,2	S3	S1L	DS1	E	–
	Moment Resisting Frame	Moment Resisting Frame	Steel frame with unreinforced masonry infills made of rectangular fired bricks	Steel trusses with CI sheets	Steel trusses with CI sheets	SF11L	1 (2)	**S5L**	S/LFINF/-/-/H:1,2/	S5L	S3L	DS3	E	23

1)Jaiswal and Wald [13]; 2)Brzev *et al.* [5]; D'Ayala *et al.* [6]; 3)ASCE [1.2]; FEMA [8] 4)Lungu *et al.* [15]; Milutinovic and Trendafiloski [16]; 5)Spence *et al.* [22]; 6)Grünthal, ed. [11]; 7) EERI [7]; 8) Pathak *et al.* [18]



(a) Percentage of Building Typology in North Guwahati (b) Percentage of Building Typology in Eastern Guwahati (c) Percentage of Building Typology in Western Guwahati

Fig. 9 Percentage of building typology in various areas of the Guwahati urban centre



(a) Percentage of Building Typology in Ward 1 (b) Percentage of Building Typology in Ward 2 (c) Percentage of Building Typology in Ward 8

Fig. 10 Percentage of building typology in various areas of the Guwahati urban centre

DEVELOPMENT OF PROGNOSTIC DAMAGE SCENARIO

It is important to estimate the probable levels of damages to various building typologies for a given earthquake intensity, to develop a prognostic damage scenario. It has been observed that a majority component of the non-engineered building stock in Guwahati is comprised of W5, RM3, and UFB4 typology as per PAGER classification as presented in Table 2. The vulnerability assessment of these typologies is to be carried out employing suitable methods viz. the expert opinion methods and the empirical methods. The development of vulnerability information for the traditional housing and masonry buildings through the analytical methods is still a topic of research and a reliable procedure is yet not available. The current work has attempted to develop a prognostic damage scenario of the traditional "Assam type housing" (represented by typology W5) and the confined/unconfined masonry housing (represented by typology RM3 and UBF4). The objective is also to understand the consequence of unscientific transformation from the traditional housing to more vulnerable masonry housing through economic losses associated.

1. Definition of Damage states

One of the earliest damage scales were defined by Whitman *et al.* [23] and ATC-13 [4] methodology. Whitman *et al.* [23] first proposed the use of Damage Probability Matrix (DPM) for probabilistic estimation of building damage due to an earthquake. The DPMs are based on a concept that buildings with similar structural typology will have the same probability of a given damage state for given earthquake intensity. The various damage states considered here are namely four different damage states-slight, moderate, extensive, and complete. Arya and Agarwal [3] developed a procedure for probable damage assessment of various building typologies. Under the procedure developed, the damageability grading system is proposed by identifying the (1) the primary structural lateral load resisting system, and (2) building attributes that modify the seismic performance expected for this lateral load-resisting system along with non-structural components. The damage probability is based on code-based seismic intensity, building type, and damageability grade as observed in past earthquakes and covered in MSK / European macro-intensity scale. The study area here is in Zone V of very high seismic hazard is likely to experience MSK Intensity IX or greater [12].

Table 4: Grades of damageability of masonry buildings by Arya and Agarwal [3]

	Classification of damage to masonry buildings
Grade 1	**Negligible to Slight damage (no structural damage, slight non-structural damage)** Structural: Hairline cracks in very few walls Non-structural: Fall of small pieces of plaster only. Fall of loose stones from the upper part of buildings in very few cases.
Grade 2	**Moderate damage (slight structural damage, moderate non-structural damage)** Structural: Cracks in many walls; Thin cracks in R.C.* slab and A.C.* sheets. Non-structural: Fall of fairly large pieces of plaster; Partial collapse of smoke chimneys on the roof; Damage to parapets Chajjas; Roof tiles disturbed in about 10 % of the area; Minor damage in understructure of the sloping roof.
Grade 3	**Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Structural: Large and extensive cracks in most walls; Widespread cracking of columns and piers. Non-structural: Roof tiles detach; Chimneys fracture at the roof lines; Failure of individual non-structural elements (partition, gable walls, etc.).
Grade 4	**Very heavy damage (heavy structural damage, very heavy non-structural damage)** Structural: Serious failure of walls; Gaps in walls; Inner walls collapse; Partial structural failures of roofs and floors.
Grade 5	**Destruction (very heavy structural damage)** Total or near-total collapse of the building
R.C. - Reinforced Concrete A.C.* - Asbestos Cement*	

The vulnerability class of a building type is derived based on the average expected seismic performance for that building type. All building types available in India, have been divided into type A to type F based on the European Macroseismic Scale (EMS-98) recommendations [3] with type A having the highest seismic vulnerability and type F with the lowest vulnerability. It is, therefore, possible to have a damageability range for each building type considering the different factors affecting its likely performance. Therefore, there are some variations in building type, defined as A, B, B+, etc. The building vulnerability is generally highest with the use of local materials without engineering inputs and lowest with the use of engineered materials and skills. However, the traditional building typology, the "Assam type housing" (W5) is found to be one of the lowest vulnerability and much lower than even engineered buildings. Therefore, it is required to recast of the typology based vulnerability classification for Assam in general and Guwahati in particular. The likely damages to buildings have been categorized in different Grades depending on the seismic impact on the strength of the building. The five grades of damageability from damage grade G1 to G5 are specified in MSK and European Intensity Scale as given in Table 4 [3].

2. Relationship of Seismic Intensity, Building Typology & Damage Grades

Giovinazzi and Lagomarsino [9] developed a macroseismic method for vulnerability assessment of buildings, where the DPMs are evaluated for six vulnerability classes considered by the European Macroseismic Scale – 98 (EMS98). Table 5 guides the likely performance of the building in the event of design-level earthquake intensity postulated in a given seismic zone. This information is used to decide if there is a necessity for further evaluation of the building using higher-level procedures. It can also be used to identify the need for retrofitting and to recommend simple retrofitting techniques for ordinary buildings where more detailed evaluation is not feasible.

The Indicative quantities ***Few***, ***Many***, and ***Most*** as defined in European Intensity Scales are as follows:

Few: Less than (15 + -5) %; Many: Between (15 + -5) to (55 + -5) %;

Most: Between (55 + -5) to 100 %

As per the MSK Intensity scale, the average values of these terms may be taken as follows:

Few: 5 – 15 %; Many: 50 %; Most: 75 % [3]

Table 5 is generally based on MSK descriptions. Indian earthquake code [12] defines three soil types hard/stiff, medium & soft. No effect of these is seen in the design spectra of short period buildings, T < 0.4 seconds, covering all the traditional or masonry buildings. Hence the effect may be considered as not so significant [3].

Table 5: Damageability grades of masonry buildings by Arya and Agarwal [3]

	Type of Building	**Zone II MSK VI or Less**	**Zone III MSK VII**	**Zone IV MSK VIII**	**Zone V MSK IX or More**
MASONRY BUILDING	**A**	Many of grade 1 Few of grade 2 (rest no damage)	Many of grade 3 Few of grade 4 (rest of grade 2 or 1)	Most of grade 4 Few of grade 5 (rest of grade 3, 2)	Many of grade 5 (rest of grade 4, 3)
	B & B$^+$	Many of grade 1 Few of grade 2 (rest no damage)	Many of grade 2 Few of grade 3 (rest of grade 1)	Most of grade 3 Few of grade 4 (rest of grade 2)	Many of grade 4 Few of grade 5 (rest of grade 3)
	C & C$^+$	Few of grade 1 (rest no damage)	Many of grade 1 Few of grade 2 (rest of grade 1)	Most of grade 2 Few of grade 3 (rest of grade 1)	Many of grade 3 Few of grade 4 (rest of grade 2)
	D		Few of grade 1	Few of grade 2	Many of grade 2 Few of grade 3 (rest of grade 1)

Table 6: Correlated damage levels given by Arya and Agarwal [3] and the current work

Arya and Agarwal [3]	**Present Work**
G1: Negligible to slight damage (no structural damage, slight non-structural damage) **G2**: Moderate damage (Slight structural damage, moderate non-structural damage)	Slight damage
G3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Moderate damage
G4: Very heavy damage (heavy structural damage, very heavy non-structural damage)	Extensive damage
G5: Destruction (very heavy structural damage)	Complete damage

The present work has defined the damage states in four levels - namely Slight, Moderate, Extensive, and Complete. These damage levels are mainly attributed to the damage of different structural components of the various building types. Moreover, the building typology W5 is not covered by the classification given by Arya and Agarwal [3]. The building typology B, B+, and C may be correlated to typology UBF4 and the typology C+, D may be correlated to typology RM3. The damage levels considered in this work may be correlated to the damage levels given by Arya and Agarwal [3] as given in Table 6.

3. Definition of Damage States

The definition of the damage states - Slight, Moderate & Extensive of various building typology is presented here for the types Ikra (W5), Unreinforced/Unconfined masonry bearing walls (UFB4), Reinforced masonry bearing walls (RM3) respectively in Tables 7.1, 7.2 and 7.3.

Table 7.1: Damage states for building typology - Ikra (W5)

Damage states	Description
Slight Structural Damage	Hairline cracks in few walls; small plaster or gypsum-board / reed-mortar panels' cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys.
Moderate Structural Damage	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across wall panels exhibited by small cracks in wall panels; large cracks in brick chimneys; the toppling of tall masonry chimneys.

Table 7.2: Damage states for building typology - Unreinforced Masonry Bearing Walls (UFB4)

Damage states	Description
Slight Structural Damage	Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with a large proportion of openings; movements of lintels; cracks at the base of parapets, fall of small pieces of plasters only.
Moderate Structural Damage	Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry part may fall from walls or parapets.
Extensive Structural Damage	Large diagonal cracks across In-plane brick wall panels or large cracks at timber, plywood joints; the permanent lateral movement of floors and roof; the toppling of most brick chimneys; cracks in foundations; splitting of window sill plates and slippage of structure over foundations; the partial collapse of the split level structure or other "soft-story" configurations; small foundations cracks.

Table 7.3: Damage states for building typology - Reinforced Masonry Bearing Walls (RM3)

Damage states	Description
Slight Structural Damage	Diagonal hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with a large proportion of openings fall of small pieces of plasters only.
Moderate Structural Damage	Cracks in many walls, Most wall surfaces exhibit diagonal cracks; some of the In-plane (masonry shear walls) have exceeded their yield capacities indicated by larger cracks. Cracks in some RC beams and some RC columns.
Extensive Structural Damage	Serious failures of walls, Large diagonal cracks across In-plane brick wall panels or large cracks at plywood joints; cracks in most RC beams and many RC columns and permanent lateral movement of floors and roof; the toppling of most brick chimneys; cracks in foundations; splitting of window sill plates and slippage of structure over foundations; the partial collapse of the split-level structure or other "soft-story" configurations; small foundations cracks.

In general, repair values for the lower damage states (slight, moderate, in some cases extensive) are a fraction of the replacement value (i.e. damage state-complete). The repair and replacement values may be provided in Indian Currency, INR (representing the costs required to repair or replace every square meter (1 m^2) of the respective building typology. The value may incorporate the values of non-structural components and contents as well as the costs required to, e.g., demolish a severely damaged building, and to remove the debris. It should also be considered that the relative replacement (construction) costs (i.e. costs per m^2) may differ with height. The structural reconstruction cost as compiled by Pathak *et al.* [18] is presented in Table 8.

Table 8: Structural reconstruction costs (excluding costs for non-structural components, demolition, and debris removal) for the different building typology classes in [Rs/m^2]

Typology class PAGER	Average story number, N	Average structural construction cost [Rs/m^2]		Reference [20]
		Residential	Non-Residential	
UBF4	1.25	3,024	3,024	Schedule of Rates for P.W.D. Buildings
RM3	1.5	10,080	10,080	Schedule of Rates for P.W.D. Buildings
W5	1	5,040	5,040	Estimated from rate analysis

The economic model for the building stock of Guwahati is based on actual construction cost estimates provided by the Schedule of Rates for P.W.D. Buildings (Civil Works) 2013–2014 [20] for different categories of buildings given separately for engineered and non-engineered typologies. Based on the plinth area rates for residential and institutional construction provided by the Schedule of Rates for P.W.D. Buildings 2013–2014 [20], reconstruction values for the various construction typologies can be assigned. Table 9 summarizes the Damage Ratios DR_i for damage states (i) for the evaluation of reconstruction values for various typologies [18].

Table 9: Damage ratios DR_i for damage states (i) and cost estimates for demolition and debris removal Pathak *et al.* [18]

Typology class	Damage ratios DR_i for damage state i				Demolition	Debris removal	Comment
	slight	moderate	extensive	complete			
W5	0.05	0.15	1.00	1.00	–	–	replaced by RM3 [1)]
RM3	0.12	0.45	1.05	1.005	4.5 %	0.5 %	
UBF4	0.15	0.50	1.08	1.00	8 %	–	replaced by RM3 [1)]
[1)]In the case of extensive or complete damage, these typologies will be substituted by confined masonry (RM3). Hence, replacement values for damage states extensive and complete are based on those provided for RM3.							

To estimate the final replacement and repair values for the various building typologies namely W5, RM3, and UBF4, the damage ratios - DR_i, which is dependent on damage state i as well as costs for the partial demolishment (especially for damage state extensive) and debris removal (for damage states extensive and complete) are decided. The ratios (DR_i) for damage states - slight, moderate, and extensive have been partly taken from various references [8]. The finally derived matrices for repair and replacement costs are provided in Table 9. These values establish the basis for calculating the economic losses for various building typologies corresponding to their damage states and their geographic distribution over the various municipal wards in the city.

Figure 11 to Figure 13 shows a typical distribution of the building typology W5, UBF4, and RM3 in various municipal wards of the city, with their respective damage probability based on the damage probability values given by Arya and Agarwal [3]. The traditional "Assam type housing" typology (W5) will experience slight to moderate damage, the Unconfined / partially confined masonry buildings are likely to suffer moderate to complete damage, and the Confined masonry buildings are likely to suffer slight to extensive damage corresponding to MSK Intensity IX or more.

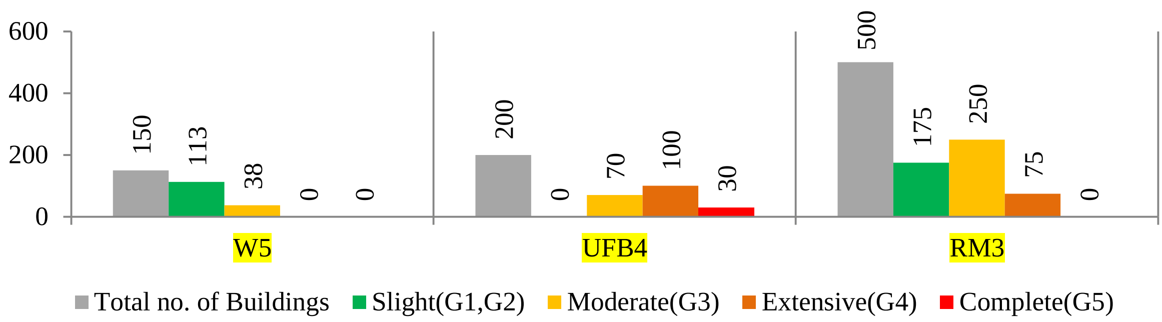


Fig. 11 Number of Buildings in RM3, W5, & UFB4 typology and damageability (WARD 20)

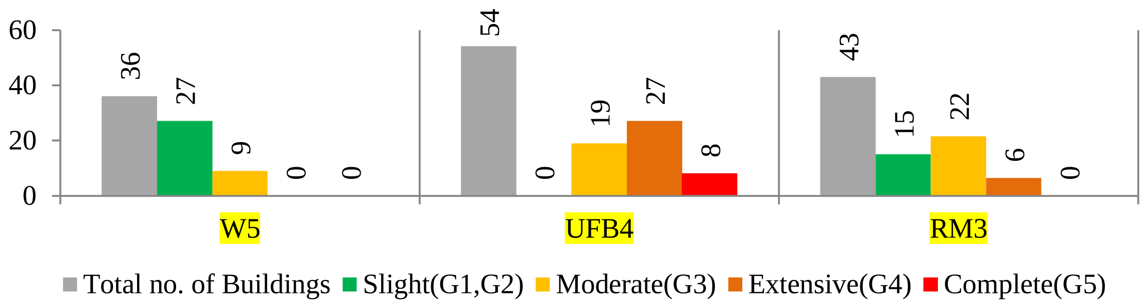


Fig. 12 Number of buildings in RM3, W5, & UFB4 typology and damageability (WARD 21)

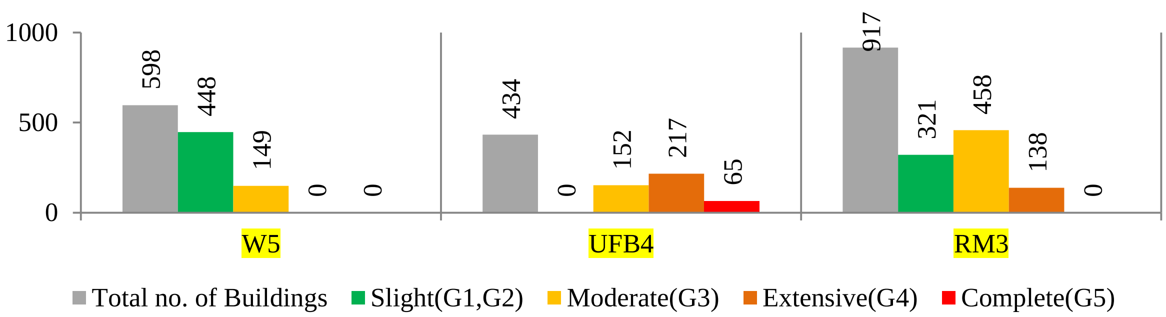


Fig. 13 Number of Buildings in RM3, W5, & UFB4 typology and damageability (WARD 25)

4. Ward Wise Probable Damage Scenario in a GIS platform

The current work represented the probable damage with their damage states in the GIS (Geographic Information System) platform for each typology i.e. W5, UFB4, and RM3. The damage scenario has been given for each ward of the Guwahati city. The prognostic damage scenario in a GIS platform will help the stakeholders' viz. policymakers, various departments involved in disaster risk management to prioritize disaster risk reduction programs. The information provided in the GIS platform provides necessary assistance as a decision support tool for risk reduction initiatives namely disaster response, retrofitting, and reconstruction. Figure 14 to Figure 16 represents a typical distribution of the damage probability of building typology W5, UBF4, and RM3 in various wards of the city, based on the damage probability values given by Arya and Agarwal [3].

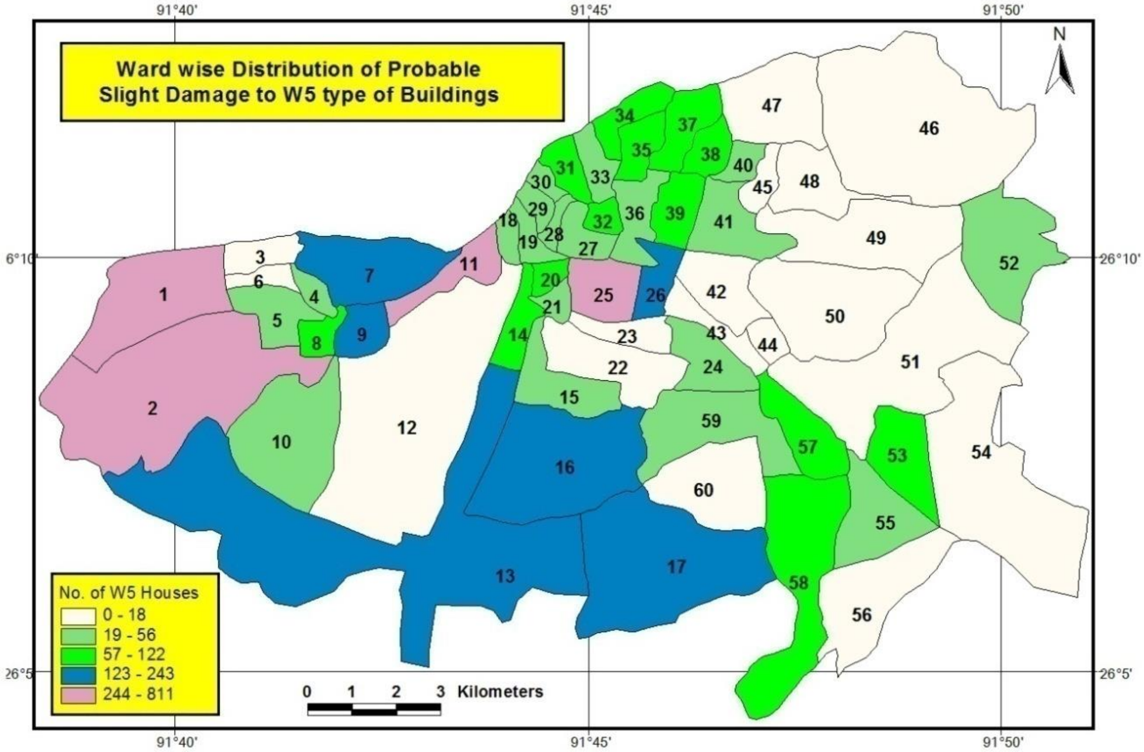


Fig. 14 Ward wise distribution of Probable Slight damage to W5 Type of buildings

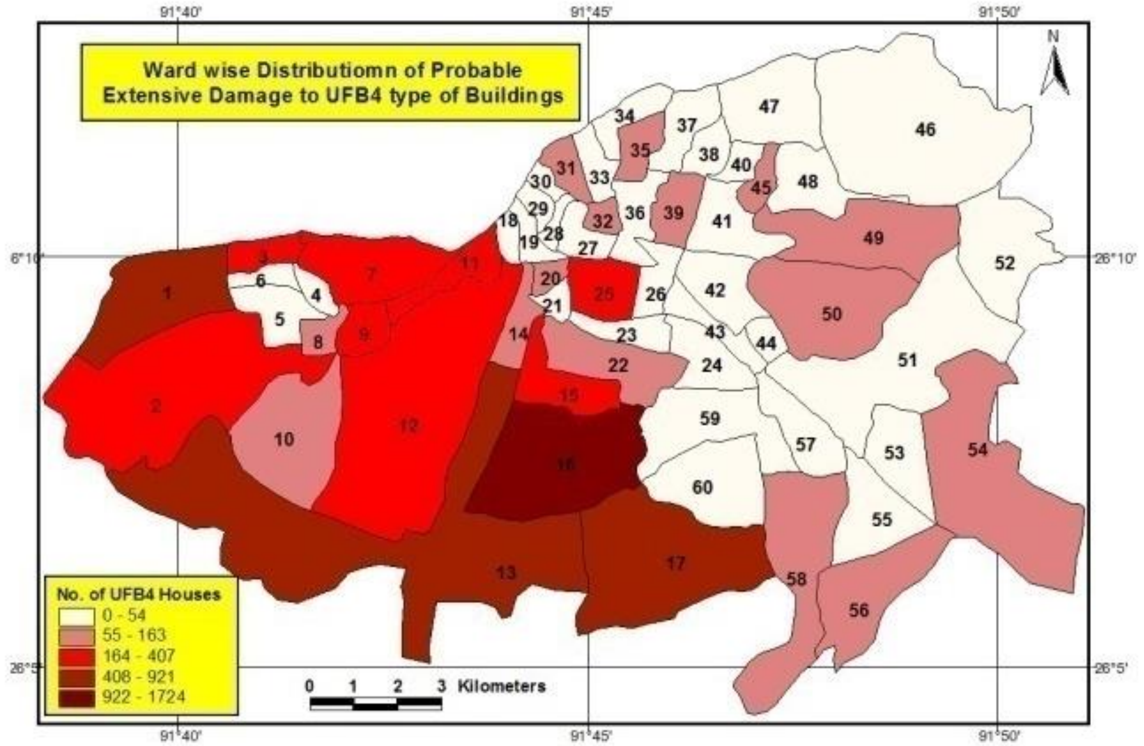


Fig. 15 Ward wise distribution of Probable Extensive damage to UFB4 Type of buildings

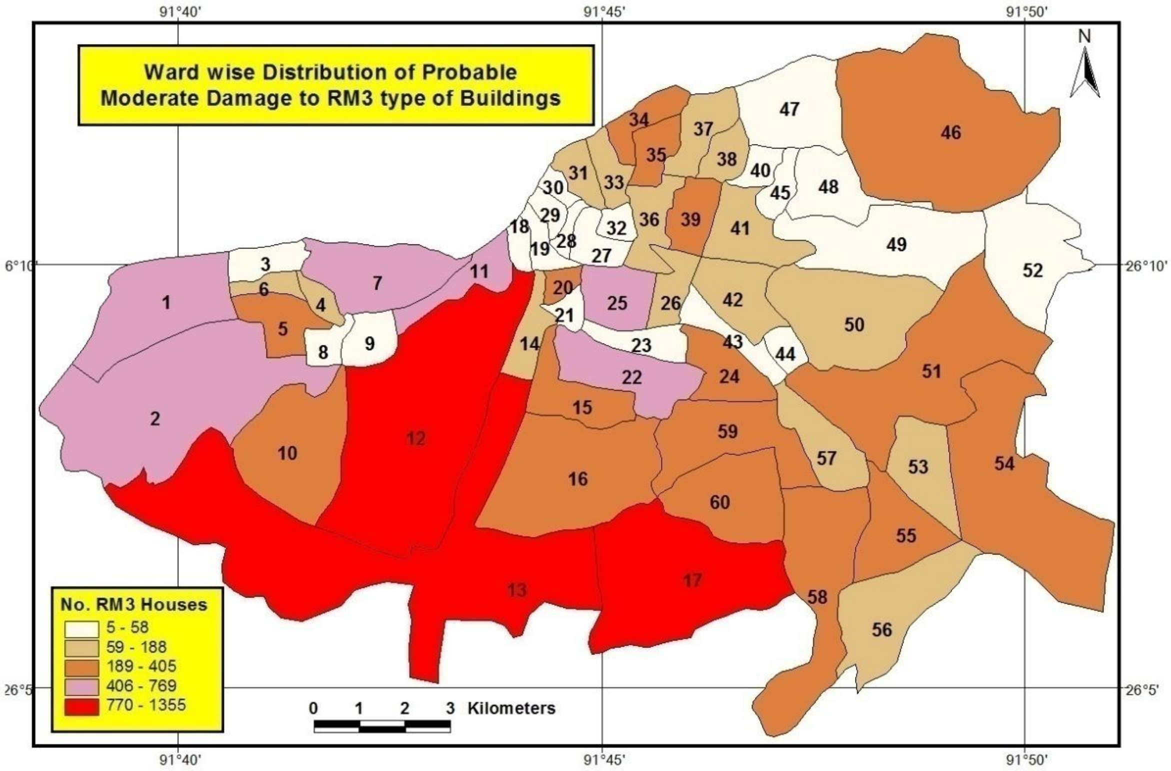


Fig. 16 Ward wise distribution of Probable Moderate damage to RM3 Type of buildings

The current work also attempted to estimate the economic loss related to the replacement cost for each type of typology and their damage states evaluated for each ward of the Guwahati city. Table 10.1 presents the typical economic loss regarding various damage states for the traditional "Assam type housing" represented by typology W5, distributed over various wards of the city.

Table 10.1: Typical ward wise estimated economic loss for various damage states of the traditional "Assam type housing" (typology W5) of Guwahati master plan area.

Ward No.	No. of Buildings with Slight Damage (G1, G2)	Economic Loss (INR) for Slight Damage	No. of buildings with Moderate Damage (G3)	Economic Loss (INR) for Moderate Damage
1	382	11551680.00	127	11521440.00
2	811	24524640.00	270	24494400.00
3	15	453600.00	5	453600.00
4	21	635040.00	7	635040.00
5	53	1602720.00	18	1632960.00
6	13	393120.00	4	362880.00
7	163	4929120.00	54	4898880.00
8	91	2751840.00	30	2721600.00

Table 10.2 presents the typical economic loss regarding various damage states for Unconfined/partially confined masonry buildings represented by typology UBF4, distributed over various wards of the city for moderate to complete damage states.

Table 10.3 presents the typical economic loss regarding various damage states for Confined masonry buildings represented by typology RM3, distributed over various wards of the city for slight to extensive damage. The economic losses estimated are corresponding to MSK Intensity IX.

Table 10.2: Typical ward wise estimated economic loss for various damage states of unconfined / partially confined masonry buildings (typology UBF4) in the Guwahati master plan area.

Ward No.	No. of buildings with Moderate Damage (G3)	Economic Loss (INR) for Moderate Damage	No. of buildings with Extensive Damage (G4)	Economic Loss (INR) for Extensive Damage	No. of buildings with Complete Damage (G5)	Economic Loss (INR) for Complete Damage
1	354	10704960.00	505	32985792.00	152	9192960.00
2	172	5201280.00	245	16003008.00	74	4475520.00
3	145	4384800.00	207	13520908.80	62	3749760.00
4	30	907200.00	42	2743372.80	13	786240.00
5	29	876960.00	42	2743372.80	12	725760.00
6	25	756000.00	36	2351462.40	11	665280.00
7	168	5080320.00	240	15676416.00	72	4354560.00
8	71	2147040.00	101	6597158.40	30	1814400.00

Table 10.3: Typical ward wise estimated economic loss for various damage states of confined masonry buildings (typology RM3) in the Guwahati master plan area.

Ward No.	No. of buildings with Slight Damage (G1, G2)	Economic Loss (INR) for Slight Damage	No. of buildings with Moderate Damage (G3)	Economic Loss (INR) for Moderate Damage	No. of buildings with Extensive Damage (G3)	Economic Loss (INR) for Extensive Damage
1	474	86002560.00	677	460630800.00	203	322282800.00
2	408	74027520.00	582	395992800.00	175	277830000.00
3	29	5261760.00	41	27896400.00	12	19051200.00
4	93	16873920.00	133	90493200.00	40	63504000.00
5	179	32477760.00	255	173502000.00	77	122245200.00
6	119	21591360.00	170	115668000.00	51	80967600.00
7	373	67677120.00	533	362653200.00	160	254016000.00
8	28	5080320.00	40	27216000.00	12	19051200.00

CONCLUDING REMARKS

1. An attempt was made in this work to develop a prognostic damage scenario for the traditional "Assam type housing" in comparison to the conventional housing in unconfined / partially confined and confined masonry in and around Guwahati Urban centre.
2. In this work, a simplified prognostic damage scenario was developed with first-order approximations of building typology based damage grades for various earthquake intensities as given by Arya and Agarwal [3].
3. The various damages were considered namely slight, moderate, extensive, and complete considering the various damage probability values for each building typology as given by Arya and Agarwal [3]. The damage ratios, which represent the ratio of repair/reconstruction cost to the replacement cost of a given building as given for various typology of buildings in the Guwahati city were used to estimate the economic loss for each ward of the city for various damage scenarios.
4. It is estimated that a total of about 6300 nos. buildings of the traditional "Assam type housing" typology (W5) will suffer slight damage, whereas about 2000 nos. will suffer moderate damage. The reconstruction cost for such damages is presented.

5. The nos. of Unconfined / partially confined masonry buildings (UBF4) masonry likely to suffer moderate damage are about 6100 and the reconstruction cost estimated to restore the same buildings to confined masonry (RM3) is presented.
6. The nos. of UBF4 typology buildings experiencing extensive and complete damage are about 9000 and 2200 respectively. About 16000 of RM3 typology buildings will suffer moderate damage and about 5000 of them are likely to suffer extensive damage for the same intensity. The estimated economic losses moderate and extensive damage to RM3 typology buildings is also presented.
7. The estimated economic losses based on the prognostic damage scenarios indicate that the estimated losses, which are directly related to the structural damage, have increased many folds due to the transformation from earthquake-safe traditional housing in timber constructions to more vulnerable housing in unconfined or partially confined masonry constructions.
8. The result of this work along with the estimation of economic losses will complement more sophisticated damage assessment in the future by providing a general occupancy pattern of human exposure and related vulnerability in urban, suburban areas, for both residential or non-residential dwellings by its construction types. It will help to prioritize future disaster mitigation efforts in the city municipal areas of Guwahati.
9. It is also found that, in suburban areas, where adequate spaces are available for planning, the traditional "Assam type housing" still provides a better alternative for earthquake-safe housing.

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REFERENCES

1. American Society of Civil Engineers ASCE (2000). "FEMA-356: Pre-Standard and Commentary for the Seismic Rehabilitation of Buildings", *Federal Emergency Management Agency, Washington, DC.*
2. American Society of Civil Engineers ASCE (2006). "Seismic Rehabilitation of Existing Buildings", *ASCE Standard ASCE/SEI 41-06, Southpointe, Canonsburg, PA.*
3. Arya, A.S. and Agarwal, A. (2007). "Rapid Visual Screening of Masonry Buildings Prepared under the GoI-UNDP Disaster Risk Management Programme", *National Disaster Management Division (NDMA) Ministry of Home Affairs, New Delhi, India*.
4. ATC-13 (1985). "Earthquake Damage Evaluation Data for California", *Applied Technology Council, Redwood City, California, USA.*
5. Brzev, S., Scawthorn, C., Charleson, A.W. and Jaiswal, K. (2012). "GEM Basic Building Taxonomy", *The Report Produced in the Context of the GEM Ontology and Taxonomy Global Component Project, pp. 45*.
6. D'Ayala, D., Meslem, A., Vamvatsikos, D., Porter, K. and Rossetto, T. (2015). "Guidelines for Analytical Vulnerability Assessment – Low/Mid-Rise, Vulnerability, and Loss Modelling", *GEM Technical Report. DOI 10.13117/GEM.VULN-MOD.TR2014.12*.
7. EERI (2000). "World Housing Encyclopedia", *www.world-housing.net.*
8. FEMA (2003). "HAZUS-MH MR4 Technical Manual", *Federal Emergency Management Agency Washington, D.C.*
9. Giovinazzi, S. and Lagomarsino, S. (2004). "A Macroseismic Method for the Vulnerability Assessment of Buildings", *Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, Canada, Paper No. 896*.
10. GMDA (2009). "Master Plan for Guwahati Metropolitan Region – 2025", *Guwahati Metropolitan Development Authority*.
11. Grünthal, G., ed. (1998). "European Macroseismic Scale 1998 (EMS–98)", *Cahiers du Centre Européen de Géodynamiqueet de Séismologie, Luxembourg, Vol. 15*.

12. IS:1893 (2002, 2016). "Criteria for Earthquake Resistant Design of Structures (Part-1)", *Bureau of Indian Standards, New Delhi*.
13. Jaiswal, K.S. and Wald, D.J. (2008). "Creating a Global Building Inventory for Earthquake Loss Assessment and Risk Management", *U.S. Geological Survey Open-file report 2008–1160.*
14. Kaushik, H. and Babu, K.S.R. (2009). "Assam-Type House, WHE Report #154", *World Housing Encyclopedia, www.world-housing.net*.
15. Lungu, D., Aldea, A., Arion, A., Vacareanu, R., Petrescu, F. and Cornea, T. (2001). "RISK-UE – An Advanced Approach to Earthquake Risk Scenarios with Applications to Different European Towns", *WP1 Report: European Distinctive Features, Inventory Database, and Typology*.
16. Milutinovic, Z.V. and Trendafiloski, G.S. (2003). "RISK-UE, an Advanced Approach to Earthquake Risk Scenarios with Applications to Different European Towns", *Report to WP4: Vulnerability of Current Buildings, pp. 109*.
17. Pathak, J. and Lang, D. (2013). "Building Classification Scheme and Vulnerability Model for the City of Guwahati, Assam", *Report No. 13–012, Kjeller (Norway) – Guwahati, India*.
18. Pathak, J., Lang D., Abdelghani, M., Bharali, R., Deka, B., Pathak, S. and Ahmed, I.J. (2015). "Building Classification Scheme and Vulnerability Model for the City of Guwahati, Assam", *Report No. 15–014, Kjeller (Norway) – Guwahati, India*.
19. Patwari, N.N. (2017). "Seismic Vulnerability Assessment and Prognostic Damage Scenario of Conventional and Traditional Housing Around Urban Centres of Assam", *Ph.D. thesis, Gauhati University, Department of Civil Engineering, Assam Engineering College, Guwahati, Assam, India*.
20. PWD (2013-2014). "Schedule of Rates for P.W.D. Buildings - Civil Works (2013-2014)" *Assam Public Works Department (Assam PWD). Govt. of Assam.*
21. Sinha, R., Aditya, K.S.P. and Gupta, A. (2008). "GIS-Based Urban Seismic Risk assessment Using RiskIITB", *ISET Journal of Earthquake Technology, Paper No. 497, Vol. 45, No. 3-4, pp. 41-63*.
22. Spence, R.J.S., Coburn, A.W., Sakai, S. and Pomonis, A. (1991). "A Parameterless Scale of Seismic Intensity for Use in Seismic Risk Analysis and Vulnerability Assessment, in Earthquake Blast and Impact: Measurement and Effects of Vibration", *The Society for Earthquake & Civil Engineering Dynamics, eds, Elsevier Applied Science, Amsterdam, Netherlands, pp. 19-28*.
23. Whitman, R.V., Reed, J.W. and Hong, S.T. (1973). "Earthquake Damage Probability Matrices", *Proceedings of the Fifth World Conference on Earthquake Engineering, Rome, Italy, Vol. 2, pp. 531-2540.*