Rapid Assessment Procedure for Seismic Evaluation of Existing Buildings: A Case Study for CUET Campus

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Abstract

Bangladesh is located in a seismically moderate zone in the world seismic map. The presence of existing fault lines around this region are capable of producing damaging earthquakes in future. No large earthquake has been recorded in these faults for many years, which indicates a huge strength gathered underground that could cause serious earthquakes around the country. Frequently occurring and recent small-size earthquakes make us aware about the future risk. The Chittagong division is quite vulnerable to earthquakes as per the seismic zonation map of Bangladesh National Building Code (BNBC). One of the leading engineering universities of the country, Chittagong University of Engineering & Technology (CUET), has a campus located about 27 km away from the heart of the Chittagong city centre. This study aims to prepare a seismic vulnerability map based on Rapid Screening Procedure (RSP) at CUET campus. Structural information database was prepared and presented in Geographic Information System (GIS). The outcome of this study showed that most of these buildings are in good condition.

Keywords: *Assessment, Rapid Screening Procedure, Performance, Vulnerability.*

Introduction

Bangladesh is located in a seismically moderate region in the world seismic map prepared by Global Seismic Hazard Assessment Programme (GSHAP, 1992). An earthquake of even moderate size can produce massive destruction in major urban areas of the country, especially in Dhaka, Sylhet and Chittagong. There exist a few faults in this region that can cause strong earthquakes in the country. One of them is the Dauki fault at the area bordering Sylhet and the other one is Sitakunda-Taknaf fault at Chittagong. A recent study by Comprehensive Disaster Management Programme (CDMP) proposed five earthquake fault scenarios with a maximum possible earthquake (Mw) (as shown in Figure 1) with a value of Mw 8.0 and 8.5. No large earthquake has occurred in these faults for many years, which means a huge strength is gathered underground that could cause serious earthquakes in Bangladesh and its sourrounding region. Moreover, recent small size earthquakes in India, Pakistan and Myanmar make us aware about the future risks in this region.

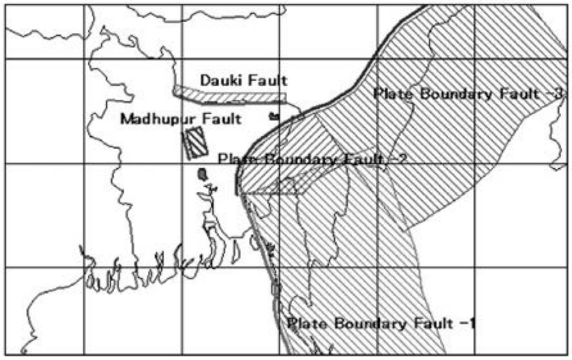


Figure 1: Earthquake Fault Model in Bangladesh (CDMP, 2009).

Chittagong University of Engineering & Technology (CUET) is one of the leading technical institutions in the country, located about 27 km off the Chittagong city centre. This region has a seismic coefficient of 0.15g in the seismic zoning map of Bangladesh National Building Code (BNBC, 1993). This map was based on Peak Ground Acceleration (PGA) considering a return period of 200 years. Recently House Building Research Institute (HBRI) completed a project to upgrade the existing BNBC code. Draft seismic design provisions of the building code have been submitted in December 2010 where the concept of Maximum Credible Earthquake (MCE) has been introduced correspond to a return period of 2475 means 2% probability of exceedance in 50 years. In this new seismic map, CUET falls in zone number 3 with a coefficient of 0.28 g (Al-Hussaini et al., 2012).

The campus area is situated in the hilly region near the side of the Chittagong-Kaptai road. It has been felt necessary to prepare a structural database of existing buildings at CUET campus. This study was undertaken by the Institute of Earthquake Engineering Research (IEER) to assess the seismic safety of existing structures by applying two-level based seismic vulnerability assessment technique. In the first level, Rapid Screening Procedure was applied by visualising the structural vulnerability parameters. In the second level, some of the reinforced concrete buildings were assessed by checking their structural integrity.

Methodology

It is neither feasible nor possible to assess all the buildings in detail level. RSP is generally applied before going in for a structural detail level of investigation. Simple risk assessment procedures are applied based on the structure's level of importance in terms of building use. Two major types of structures are present at CUET. One type is Reinforced Concrete (RC) frame structures with masonry infill and another is Unreinforced Masonry Buildings (URM) with flexible or rigid diaphragm. For an RC building, Turkish simple screening procedure (Ozcebe et al., 2006) was followed where the procedure contains two levels of assessment. The first level is called Walkdown Evaluation which does not require any analysis, and its goal is to determine the priority levels of buildings that require immediate intervention (Ozcebe et al., 2006). The second level is called Preliminary assessment when more in-depth evaluation of building stocks is required. In this stage, analysis requires data on the dimensions of the structural and non-structural elements in the most critical storey. For URM buildings, Rapid Visual Screening (FEMA 154) was applied.

Turkish Method (Ozcebe et al., 2006)

Tier 1 Assessment

A street survey procedure based on simple structural and geotechnical parameters that can be observed easily from the sidewalk. The time required for an observer for collecting the data of one building from the sidewalk is expected to be about 20 minutes. The parameters that are selected for representing building vulnerability in this study are the following:

1. The number of storeys above ground (1 to 7)
2. Presence of a soft storey (Yes or No)
3. Presence of heavy overhangs, such as balconies with concrete parapets (Yes or No)
4. Apparent building quality (Good, Moderate or Poor)
5. Presence of short columns (Yes or No)
6. Pounding between adjacent buildings (Yes or No)
7. Local soil conditions (Stiff or Soft)
8. Topographic effects (Yes or No)

The intensity of ground motion at a particular site predominantly depends on the distance to the causative fault and local soil conditions. The intensity zones are expressed accordingly, in terms of the associated Peak Ground Velocity (PGV) ranges.

Zone I	:	60<PGV<80 cm/s
Zone II	:	40<PGV<60 cm/s
Zone III	:	20<PGV<40 cm/s

The selected buildings were mainly low-rise buildings with one to five storeys above ground. According to the proposed seismic map of BNBC code, for CUET campus the peak ground acceleration is around 0.25 g, considering site effects it can be taken as more than 0.35 g. Corresponding PGV can be taken as between 60 cm/s to 70 cm/s (Wu et al., 2003). Hence, for calculating performance score, Zone I (60<PGV<80) was considered.

Table 1: Base Scores and Vulnerability Scores for Concrete Buildings

Number of Storeys	Base Scores (BS)			Vulnerability Scores (VS)					
	Zone I	Zone II	Zone III	Soft Storey	Heavy Overhang	Apparent Quality	Short Column	Pounding Effect	Topo. Effects
1 or 2	100	130	150	0	-5	-5	-5	0	0
3	90	120	140	-15	-10	-10	-5	-2	0
4	75	100	120	-20	-10	-10	-5	-3	-2
5	65	85	100	-25	-15	-15	-5	-3	-2
6 or 7	60	80	90	-30	-15	-15	-5	-3	-2

The vulnerability parameters of a building are obtained from Walkdown surveys and its location is determined, the seismic performances score (PS) can be calculated by using Eqn. 2.1:

$$PS = (BS) - \sum (VSM) \times (VS) \qquad (2.1)$$

Where BS is the Base Score defined in Table 1, $\sum$(VSM) is the Summation of Vulnerability Score Multiple and VS is Vulnerability Scores.

Tier 2 Assessment

The following parameters were chosen as the basic estimation parameters in the preliminary assessment level.

No. of storeys (n): this is the total number of individual floor systems above the ground level defined by “n.”

(1) Minimum normalised lateral stiffness index (mnlstfi)

This index represents the lateral rigidity of the ground storey, which is usually the most critical storey. It is calculated by considering the columns and the structural walls at the ground storey. The mnlstfi parameter shall be computed based on the following relationship:

$$mnlstfi = \min (I_x, I_y) \qquad (2.2)$$

where,

$$I_{nx} = \frac{\sum (I_{col})_x + \sum (I_{sw})_x}{\sum A_f} \times 1000 \quad , \quad I_{ny} = \frac{\sum (I_{col})_y + \sum (I_{sw})_y}{\sum A_f} \times 1000 \qquad (2.3)$$

where $\sum(I_{col})_x$ and $\sum (I_{col})_y$ are the summation of the moment of inertias of all columns about their censorial x and y axes, respectively. $\sum (I_{sw})_x$ and $\sum (I_{sw})_y$ are the summation of the moment of inertias of all structural walls about their censorial x and y axes, respectively. I_{nx} and I_{ny} are the total normalised moment of inertia of all members about the x and y axes, respectively. $\sum A_f$ is the total floor area above ground level.

(2) Minimum normalised lateral strength index (mnlsi)
It indicates the base shear capacity of the critical storey. In the calculation of this index, unreinforced masonry filler walls are assumed to carry 10 per cent of shear force that can be carried by a structural wall having the same cross-sectional area (Sozen, 1997). As in mnlstfi calculation, the vertical reinforced members with a cross-sectional aspect ratio of 7 or more are classified as structural walls. The mnlsi parameter shall be calculated by using the following equation:

$$mnlsi = \min(A_{nx}, A_{ny}) \quad (2.4)$$

where

$$A_{nx} = \frac{\sum(A_{col})_x + \sum(A_{sw})_x + 0.1\sum(A_{mw})_x}{\sum A_f} \times 1000 \quad (2.5)$$

For each column with a cross-sectional area denoted by A_{col}:

$$(A_{col})_x = K_x.A_{col} \; (A_{col})_y = K_y.A_{col} \quad (2.6)$$

where k_x=1/2 for square and circular columns; k_x=2/3 for rectangular columns with b_x>b_y; k_x=1/3 for rectangular columns with b_x<b_y; and k_y=1-k_x

For each shear wall with cross-sectional area denoted by A_{sw}:

$$(A_{sw})_x = K_x.A_{sw} \; (A_{sw})_x = K_x.A_{sw} \quad (2.7)$$

where k_x=1 for structural walls in the direction of x-axis; k_x=0 for structural walls in the direction of y-axis; and k_y =1-k_x

For each unreinforced masonry filler wall with no window or door opening and having a cross-sectional area denoted by A_{mw}:

$$(A_{mw})_x = K_x \,.A_{mw}(A_{mw})_x = K_x \,.A_{mw} \quad (2.8)$$

where k_x=1.0 for masonry walls in the direction of x-axis; k_x=0 for masonry walls in the direction of y-axis; and k_y=1-k_x

(3) Normalised redundancy score (nrs)
Redundancy is the indication of the degree of the continuity of multiple frame lines which distribute lateral forces throughout the structural system. The normalised redundancy ratio (nrr) of a frame structure is calculated by using the following expression:

$$nrr = \frac{A_{tr}(nf_x - 1)(nf_y - 1)}{A_{gf}} \tag{2.9}$$

where A_{tr} = the tributary area for a typical column. (A_{tr} shall be taken as 25m^2 if nf_x and nf_y are both greater than and equal to 3. In all other cases, A_{tr} shall be taken as 12.5m^2); nf_x = the number of continuous frame lines in the critical storey (usually the ground storey) in x directions; nf_y = the number of continuous frame lines in the critical storey (usually the ground storey) in y directions; A_{gf} = the area of the ground storey, i.e., the footprint area of the building. Depending on the value of nrr computed from Eqn. 2.9, the following discrete values are assigned to the normalised redundancy score (nrs):

nrs = 1 for $0 < nrr \leq 0.5$

nrs = 2 for $0.5 < nrr \leq 1.0$

nrs = 3 for $1.0 > nrr$

(4) Soft storey index (ssi)

On the ground storey, there are usually fewer partition walls than in the upper storeys. This situation is one of the main reasons for the soft storey formations. Since the effects of masonry walls are included in the calculation of mnlsi, soft storey index is defined as the ratio of the height of the first storey (i.e., the ground storey), H_1, to the height of the second storey, H_2.

$$ssi = \frac{H_1}{H_2} \tag{2.10}$$

(5) Overhang ratio (or)

In a typical floor plan, the area beyond the outermost frame lines on all sides is defined as the overhang area. The summation of the overhang area of each storey, $A_{overhang}$, divided by the area of the ground storey, A_{gf}, is defined as the overhang ratio.

$$or = A_{Overhang}/A_{gf} \tag{2.11}$$

(6) Performance Classification

The Damage Index (DI) or the damage score corresponding to the life safety performance classification (LSPC) shall be computed from the discriminate function given in Eqn. 2.12.

$$DI_{LS} = 0.620n - 0.246mnlstfi - 0.182mnlsi - 0.699nrs + 3.269ssi + 2.728or - 4.905 \tag{2.12}$$

In the case of immediate occupancy performance classification (IOPC), the damage index can be computed based on the following Eqn. 2.13:

$$DI_{IO} = 0.808n - 0.334mnlstfi - 0.107mnlsi - 0.687nrs + 0.508ssi + 3.884or - 2.868 \quad (2.13)$$

In the proposed classification methodology, buildings are evaluated according to both performance levels. The steps to be followed are listed below. The Cut-off Value (CV) for each performance classification can be calculated using Eqn. 2.14. The LS_{CVR} and IO_{CVR} values shall be obtained from Table 2, based on the number of storeys above the ground level. The Cut-off Modifier Coefficient (CMC) values are adjustment factors, which introduce the spatial variation of the ground motion in the evaluation process. These values shall be taken from Table 3, based on the building location relative to the fault and the soil type at the site.

$$CV_{LS} = LS_{CVR} + |LS_{CVR}| \times (CMC-1),$$
$$CV_{IO} = IO_{CVR} + |IO_{CVR}| \times (CMC-1) \quad (2.14)$$

Table 2: Variation of LS_{CVR} and IO_{CVR} values with number of storeys

N	LS_{CVR}	IO_{CVR}
3 or Less	0.383	-0.425
4	0.430	-0.609
5	0.495	-0.001
6	1.265	0.889
7	1.791	1.551

Table 3: Variation of CMC values with soil type and distance to fault

Soil Type	Shear Wave Velocity (m/s)	Distance to Fault (km)				
		0-4	5-8	9-15	16-25	>26
B	>760	0.778	0.824	0.928	1.128	1.538
C	360-760	0.864	1.000	1.240	1.642	2.414
D	180-360	0.970	1.180	1.530	2.099	3.177
E	<180	1.082	1.360	1.810	2.534	3.900

(3) By comparing the CV values with associated DI value, calculate performance grouping of the building for LSPC and IOPC as follows:

If $DI_{LS} > CV_{LS}$ take $PG_{LS}=1$
If $DI_{LS} < CV_{LS}$ take $PG_{LS}=0$
If $DI_{IO} > CV_{LS}$ take $PG_{IO}=1$
If $DI_{IO} < CV_{LS}$ take $PG_{IO}=0$

To decide the probable expected performance level of the building the damage scores obtained from equations 2.12 and 2.13 should be compared with the storey dependent cut-off values obtained from equation 2.14. In each case, the building under evaluation is assigned an indicator variable of "0" or "1." The indicator variable "0" corresponds to "none, light or moderate damage" in the case of LSPC and "none or light damage" in the case of IOPC. Similarly, the indicator variable "1" corresponds to "severe damage or collapse" in the case of LSPC and "moderate or severe damage or collapse" in the case of IOPC. In the final stage, the building is rated in the "low risk group" if both indicator values are zero or in the "high risk group" when both indicator values are equal to unity. In all other cases buildings are classified as cases "requiring further study." Further investigations have indicated that these buildings generally lie in the moderate risk group.

Rapid Visual Screening

Rapid visual screening (RVS) of buildings for potential seismic hazards, originated in 1988 with the publication of the Federal Emergency Management Agency (FEMA) 154 Report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* (FEMA, 1988). RVS provides a procedure to identify, record and rank buildings that are potentially seismically hazardous. This screening methodology is encapsulated in a one-page form, which combines a description of a building, its layout and occupancy, and a rapid structural evaluation related to its seismic hazard. The RVS has been developed for a broad audience, including building officials and inspectors, and government agency and private-sector building owners, to identify, inventory, and rank buildings that are potentially seismically hazardous. Field screening of individual buildings consists of verifying and updating building identification information, walking around the building and sketching a plan and elevation view on the survey forms, determining occupancy class, number of occupants, collecting information of soil type, identifying potential nonstructural falling hazards, lateral-load-resisting system seismic performance attribute score modifiers (e.g., number of storeys, design date) and determining the final score by adjusting the basic structural hazard score with the score modifiers. The final score is the deciding factor as to whether further evaluation is required or not. A photograph of the building is required to justify the buildings properly. Table 4 represents the seismic regions classification depending on acceleration response. According to FEMA 154 RVS procedure the vulnerability parameters are described below:

(1) Number of Storeys: The number of storeys is a good indicator of the height of a building. This parameter is a good measure to identify the amount of damage it may sustain. On soft soils, a tall building may experience considerably stronger and longer duration shaking than a shorter building of the same type. If the building has 4 to 7 storeys, it is considered a mid-rise building. On the other hand, a building having 8 or more storeys is considered a high-rise building.

(2) Pre Code: This score modifier applies for buildings in high and moderate seismicity regions and is applicable if the building being screened was designed and constructed

prior to the initial adoption and enforcement of seismic codes applicable for that building type.

(3) Benchmark: This modifier is applicable if the building being screened was designed and constructed after significantly improved seismic codes applicable for that building type were adopted and enforced by the local jurisdiction. The year in which such improvements were adopted is termed the "benchmark" year.

(4) Year Built: Building age is tied directly to design and construction practices. Therefore, age can be a factor in determining building type and thus can affect the final scores. This information is not typically available at the site and thus should be included in pre-field data collection. If information on "year built" is not available, a rough estimate of age will be made on the basis of architectural style and building use.

(5) Plan Irregularity: This parameter includes buildings with re-entrant corners, where damage is likely to occur; buildings with good lateral-load resistance in one direction but not in the other; and buildings with major stiffness eccentricities in the lateral force-resisting system, which may cause twisting around a vertical axis. Buildings with re-entrant corners include those with long wings that are E, L, T, U, or + shaped.

(6) Vertical Irregularity: This includes buildings with setbacks, hillside buildings, and buildings with soft storeys. If the building is irregularly shaped in elevation, or if some walls are not vertical, then the modifier is applied.

(7) Soil Type: Soil type has a major influence on amplitude and duration of shaking, and thus structural damage. Generally, the deeper the soils at a site, the more damaging the earthquake motion will be. The six soil types considered in the RVS procedure are hard rock (type A), average rock (type B), dense soil (type C), stiff soil (type D), soft soil (type E), and poor soil (type F). If there is no basis for classifying the soil type, a soil type E should be assumed.

(8) Note: g = acceleration due to gravity.

Table 4: Regions of Seismicity with corresponding spectral acceleration response (FEMA 154)

Region of Seismicity	Spectral Acceleration Response, SA in horizontal direction (short-period, or 0.2 sec.)	Spectral Acceleration Response, SA in horizontal direction (long-period or 1.0 sec.)
Low	Less than 0.167 g	Less than 0.067 g
Moderate	Greater than or equal to 0.167 g but less than 0.500 g	Greater than or equal to 0.067 g but less than 0.200 g
High	Greater than or equal to 0.500 g	Greater than or equal to 0.200 g

The Final Structural Score, S, is determined for a given building by adding (or subtracting) the Score Modifiers for that building to the Basic Structural Hazard Score for the building. The result is documented in the section of the form entitled Final Score (see Figure 2). Based on this information, and the "cut-off" score selected during the pre-planning process, the screener then decides if a detailed evaluation is required for the building and circles "YES" or "NO" in the lower right-hand box (see Figure 2). FEMA 154 has three seismic zones where Chittagong region falls into moderate seismic zones for short-period structures with spectral acceleration less than 1.0 sec. As most of the buildings are less than 5 storeys, the study area falls in moderate seismic zone for RVS application. Soil type was considered as D in the FEMA 154 handbook considering expert opinion. Figure 2 shows an example of score modifiers for performance score calculation. Fundamentally, the final S score is an estimate of the probability (or chance) that the building will collapse if ground motions occur that equal or exceed the maximum considered earthquake ground motions. These estimates of the score are based on limited observed and analytical data, and the probability of collapse is therefore approximate. A final score of S = 2 implies there is a chance of 1 in 10^2, or 1 in 100, that the building will collapse if such ground motions occur.

OCCUPANCY			SOIL	TYPE						FALLING HAZARDS			
Assembly Commercial Emer. Services	Govt Historic Industrial	Office Residential School	Number of Persons 0 – 10 11 – 100 101-1000 1000+	A Hard Rock	B Avg. Rock	C Dense Soil	D Stiff Soil	E Soft Soil	F Poor Soil	☐ Unreinforced Chimneys	☐ Parapets	☐ Cladding	☐ Other:

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

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	5.2	4.8	3.6	3.6	3.8	3.6	3.6	3.0	3.6	3.2	3.2	3.2	3.6	3.4	3.4
Mid Rise (4 to 7 stories)	N/A	N/A	+0.4	+0.4	N/A	+0.4	+0.4	+0.2	+0.4	+0.2	N/A	+0.4	+0.4	+0.4	-0.4
High Rise (>7 stories)	N/A	N/A	+1.4	+1.4	N/A	+1.4	+0.8	+0.5	+0.8	+0.4	N/A	+0.6	N/A	+0.6	N/A
Vertical Irregularity	-3.5	-3.0	-2.0	-2.0	N/A	-2.0	-2.0	-2.0	-2.0	-2.0	N/A	-1.5	-2.0	-1.5	-1.5
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-0.2	-0.4	-0.4	-0.4	-0.4	-0.2	-1.0	-0.4	-1.0	-0.2	-0.4	-0.4	-0.4	-0.4
Post-Benchmark	+1.6	+1.6	+1.4	+1.4	N/A	+1.2	N/A	+1.2	+1.6	N/A	+1.8	N/A	2.0	+1.8	N/A
Soil Type C	-0.2	-0.8	-0.6	-0.8	-0.6	-0.8	-0.8	-0.6	-0.8	-0.6	-0.6	-0.6	-0.8	-0.6	-0.4
Soil Type D	-0.6	-1.2	-1.0	-1.2	-1.0	-1.2	-1.2	-1.0	-1.2	-1.0	-1.0	-1.2	-1.2	-1.2	-0.8
Soil Type E	-1.2	-1.8	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6
FINAL SCORE *S*															

COMMENTS	Detailed Evaluation Required
	YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know
BR = Braced frame
FD = Flexible diaphragm
LM = Light metal
MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm
SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Figure 2: Basic score modifiers for final score calculation (moderate seismicity zone).

Analysis and Results

A total of 61 existing buildings were considered for this study. There were a few buildings under construction which were not taken into consideration for the purpose of this study. Among the surveyed buildings, 56 per cent are RC structures, 38 per cent buildings are masonry with rigid diaphragm and the rest of the buildings are masonry with flexible diaphragm (see Figure 3). All these buildings are less than 6 storeys high. Figure 4 represents the number of existing buildings according to their storey numbers. The pie chart reflects that about 92 per cent of the buildings are less than 4 storeys high. Figure 5 shows the number of existing Masonry and RC buildings for different number of storeys. It has been found that most of the masonry structures are single-storeyed buildings.

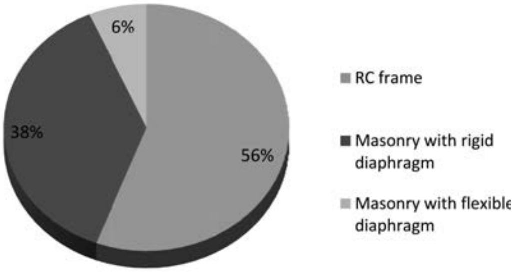


Figure 3: Building Types at CUET campus area.

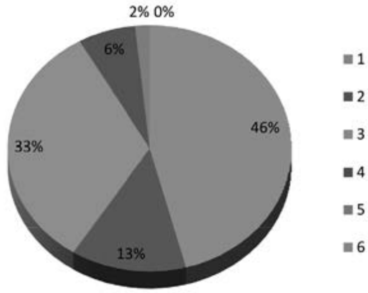


Figure 4: Buildings exist according to number of storeys.

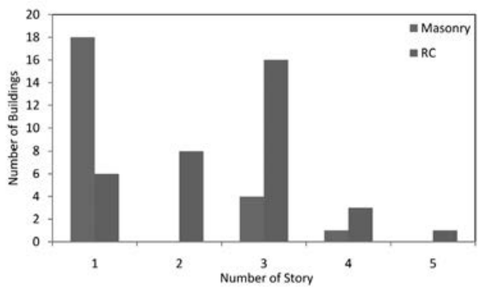


Figure 5: Number of RC and Masonry buildings according to number of storeys.

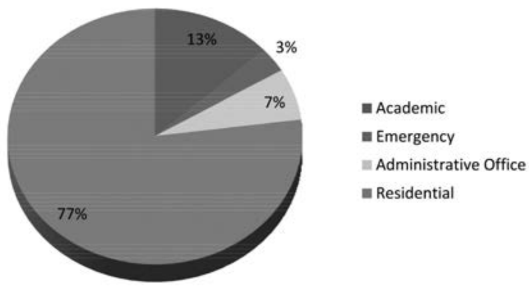


Figure 6: Occupancy class of the buildings.

Total buildings are classified into four categories based on their purpose of use. Figure 6 presents existing categories of building use in percentages. The majority of the buildings are used for residential purposes. Only 13 per cent of the buildings are used for academic purposes, 7 per cent buildings are administrative and 3 per cent are for emergency centres. Figure 7 shows the relationship between building occupancy class and their structural types. This relationship reflects that emergency centres and educational buildings are made by RC structures. From visible inspection, about 26 per cent buildings are found apparently in good condition, 69 per cent in moderate and the rest 5 per cent are poor (see Figure 8). Figures 9 and 10 are present relationships of building visible physical status with their building uses and structural types, respectively. From the engineering

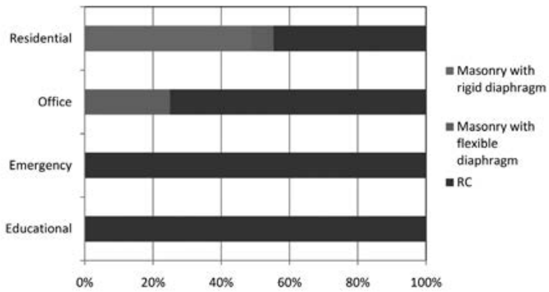


Figure 7: Relationships between Building Uses and Structural Types for CUET.

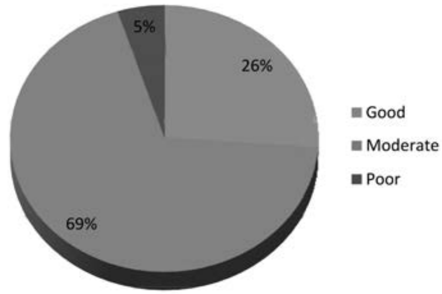


Figure 8: Building Apparent Quality.

judgment it was found that one of the emergency centres looks poor; all the other educational buildings are in moderate situation. The masonry buildings constructed with flexible diaphragm need to improve their physical state.

First stage assessment was basically Walkdown procedure consisting of Turkish level 1 and RVS. Turkish level 1 survey method was used for 34 RC structures. CUET is geographically situated in the hilly regions so that topographic effects are considered for the study. Figure 11 shows the information about existing vulnerability parameters for the RC buildings, however, soft storey parameters also checked for both types of building classes. There is no soft storey presence in the existing buildings at CUET. Only one building has heavy overhang cantilever floor area. Pounding effect exists for two structures.

In the level 1 survey, Performance Score (PS) calculated for each RC building. Figure 12 shows the calculated

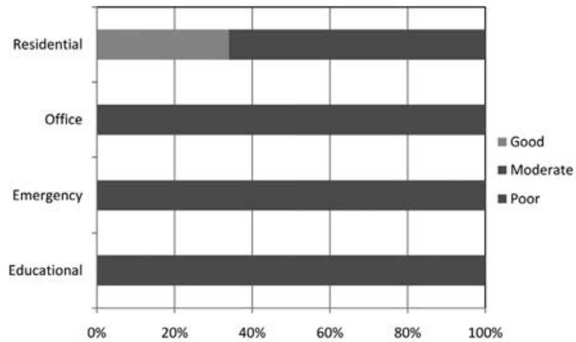


Figure 9: Relationships between Building Uses and Apparent Quality for CUET.

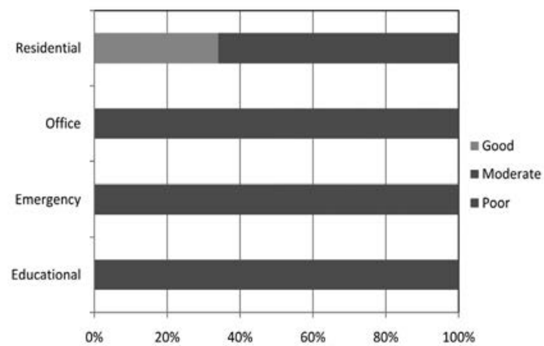


Figure 10: Relationships between Structural Types and Apparent Quality for CUET.

PS where blue and green lines are showing a margin for the performance classes. The building having a score above 75 is classified as low risk building. Buildings having a score below 50 are considered as high risk buildings. Scores ranging from 50 to 75 remarked as moderate risk class. Table 5 represents level 1 performance score variations with different number of storeys.

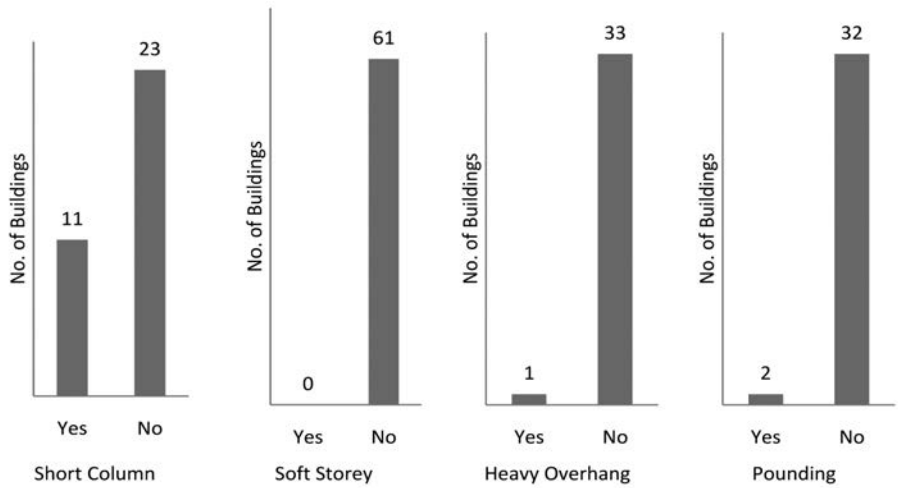


Figure 11: Existing Vulnerability Parameters

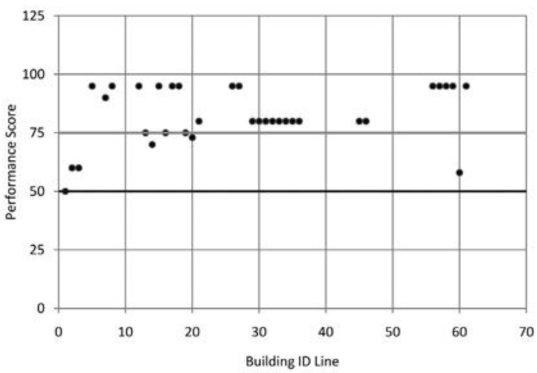


Figure 12: Performance Scores obtained from Walkdown survey.

The mean value of PS parameter is 87.56 with a standard deviation value of 12.55 for existing RC buildings. A normal distribution plot for the PS shows in the figure 13. For the Masonry buildings, FEMA 154 RVS method was considered in this study where a score greater than 1.0 can be considered as low risk as there was no specified classification prescribed. It has been observed that each of these masonry buildings has the same probability of collapse equal to 25 per cent. This is because of the similarity in type and configuration amongst the buildings.

Table 5: PS variations in the level 1 assessment

Number of Storeys	Performance Score (PS)			Total
	50	51-75	> 75	
1	0	0	6	6
2	0	0	8	8
3	0	5	11	16
4	0	3	0	3
5	1	0	0	1
Total	1	8	25	34

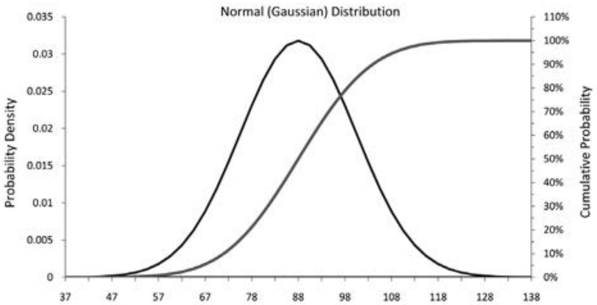


Figure 13: Normal distribution of PS.

In the Second level Turkish assessment, eight buildings were analysed based on building importance level in terms of building use. Academic and administrative buildings were preferred in this stage. Survey Identification number was assigned for each building as shown in Figure 15 (a). Two buildings (identity numbers 1 and 16) were assumed to be separated in two segments from their foundation. So, each of these two buildings is considered as a separate structure. Table 6 represents the summary of calculation values in level 2 assessment as per section 2.1.2. These building integrity values were checked after taking detailed structural floor sketches and preliminary assessment calculation steps prescribed in the methodology chapter. Figure 14 shows a typical ground floor sketch during the level 2 survey. All of the buildings (except 5 storeyed student hall) are low risk class. The hall building falls into moderate risk group. The survey results are represented in the Geographic Information System (GIS) maps (see Figure 15 and Figure 16). As the nearest Chittagong-Tripura fold belt was about 50 km away, so CMC value considered for the distance to fault was >26 km for the calculation of CV values. Table 6 shows that CV_{LS} and CV_{IO} are about 1.2 and 0.5, respectively, depending on the local soil conditions and building height. Redundancy of the building number C-15 is very low, rest of the buildings have good redundancy ratio for which value of nrs is equal to 3. It was found that only a single building contains heavy overhang.

Table 6: Summary of assessment results in level 2 of Turkish Assessment

ID No.	n	mnlstfi	mnlsi	nrs	ssi	or	DI_{LS}	DI_{IO}	CV_{LS}	CV_{IO}
C-1a	5	0.051	0.96	3	1.00	0.30	-0.0084	0.6551	1.5726	0.0012
C-1b	4	0.015	1.16	3	1.00	0.00	-1.4674	-1.3179	1.3661	0.7167
C-05	1	0.159	6.21	3	0.00	0.00	-4.481	-3.882	1.21	0.5100
C-08	2	0.028	6.64	3	1.00	0.00	-3.7076	-3.5244	1.2167	0.5002
C-13	3	0.044	2.73	3	0.89	0.00	-2.7218	-2.3568	1.2167	0.5002
C-15	2	0.008	1.73	1	0.86	0.00	-1.8387	-1.6853	1.2167	0.5002
C-16a	3	0.098	3.10	3	1.00	0.00	-2.4606	-2.361	1.2167	0.5002
C-16b	3	0.109	3.50	3	1.00	0.00	-2.5359	-2.4075	1.2167	0.5002
C-18	2	0.045	3.14	3	1.00	0.00	-3.0751	-3.1556	1.2168	0.5002
C-20	3	0.017	2.76	3	1.00	0.00	-2.3785	-2.2973	1.2168	0.5002

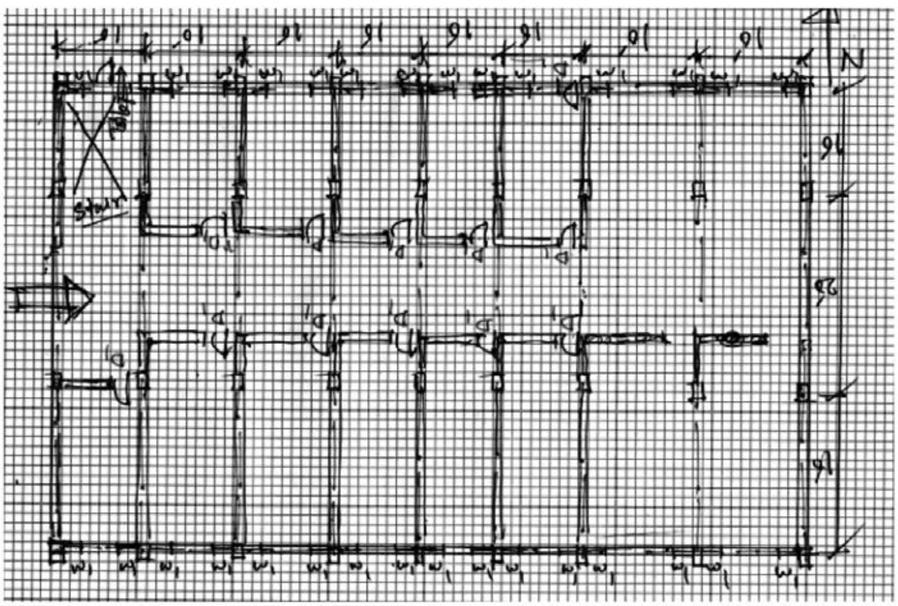
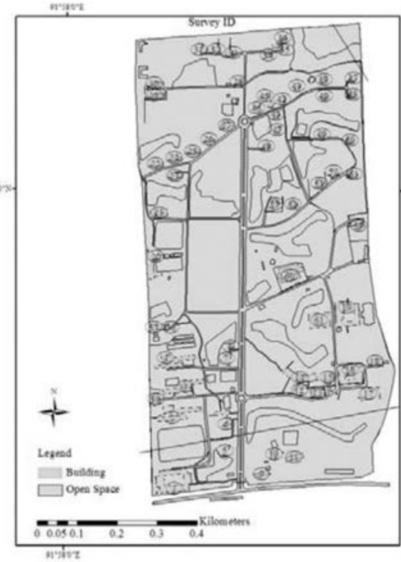
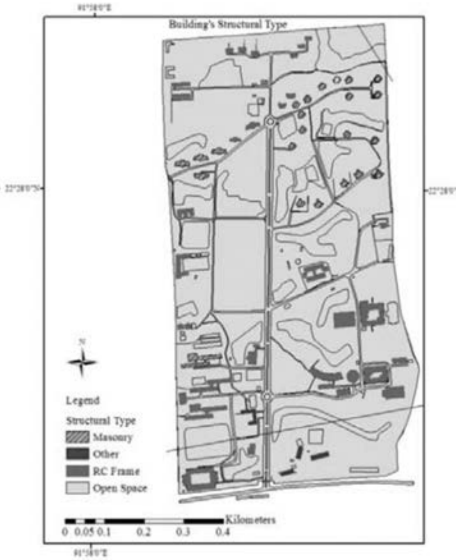


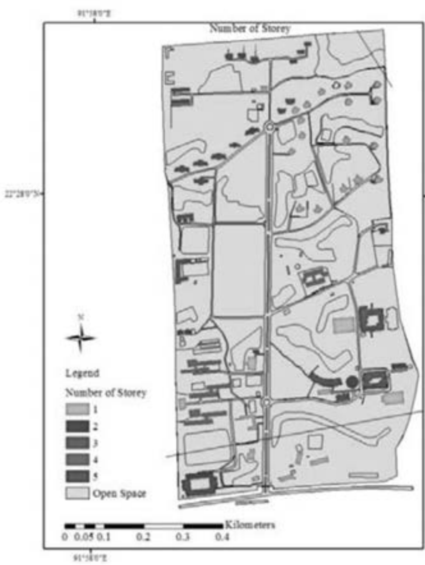
Figure 14: A ground floor sketch of a building.



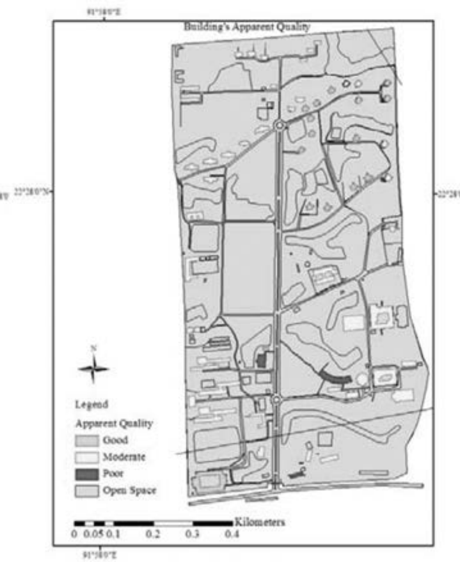
(a) Building Survey Identification Number



(b) Structural Types of the buildings

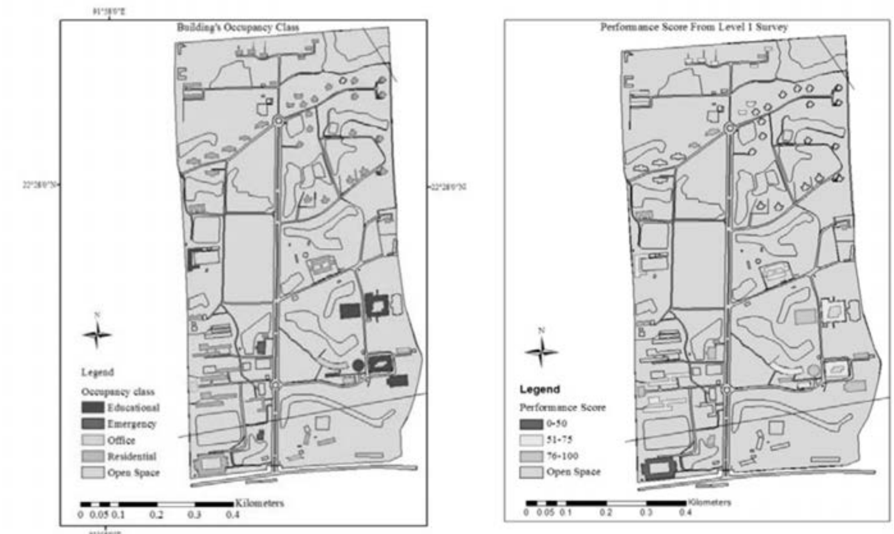


(c) Building's Number of storeys



(d) Apparent Quality of the Building

Figure 15: Structural Types, Building's Storey Numbers and Apparent Physical Quality.



(c) Building's Number of storeys (d) Apparent Quality of the Building

Figure 16: Occupancy types and Performance Scores.

Conclusion

This study presents a seismic vulnerability assessment technique on a small scale for the CUET campus area. RVS and Turkish methods are reliable procedures to mark a conclusion before starting any detail structural assessment. The RSP is the decisive indicator as to whether further detailed structural assessment will take place or not. Turkish method is reasonably acceptable because the structural pattern is very similar with other Bangladeshi buildings. From the study a rapid screening database was prepared which will be very useful before starting any future work at CUET. The Walkdown survey yielded the complete inventory of building stock in CUET campus. At the end of this survey it has been obtained that CUET campus contains mainly two structural types of buildings. Most of the buildings obtained good performance scores from level 1 assessment. Among the surveyed buildings, only 2 per cent of the buildings fall into the category, highly vulnerable to earthquake. RVS results are very similar for all masonry buildings. This is because all buildings of these type are constructed following a unique pattern in their elevation and plan shape. Masonry buildings need to be calculated in detail for more reliable risk identification. It was observed that building performance score decreases with increase in number of storeys. This study contains basic structural vulnerability information which will be useful for the policymaker to undertake future risk assessment and planning. Also, it is suggested that detailed analysis is required to be performed for the buildings having low performance in the level 1 and level 2 analyses.

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