PREFACE

In Bhutan, almost all of the rural housing stock is comprised of load bearing structures, predominantly rammed earth structures in Western Bhutan and stone masonry structures in Eastern and Southern Bhutan. These types of houses have proven to be very vulnerable to earthquakes all over the world and the same was experienced in Bhutan with the M6.1 earthquake of 21st September, 2009 in Narang, Mongar and the M6.9 earthquake of 18th September, 2011 in Sikkim which claimed numerous lives and caused severe damages to buildings, particularly our traditional load bearing structures. As Bhutan lies in one of the most seismically active regions in the world, it is imperative that we learn about the vulnerability of our buildings which can then help engineers design interventions to reduce the seismic risk.

This document "Manual for Seismic Retrofitting of Load Bearing Structures" is one important step in quantifying the vulnerability of our load bearing structures to earthquakes. It was developed through collaboration between the Engineering Adaptation and Risk Reduction Division, Department of Engineering Services, the technical core group and its' consultants "ALL Ingegneria" & "AIRES Ingegneria", Italy. The development was supported by the Project "Bhutan: Improving Resilience to Seismic Risk" funded by the Government of Japan, under the Japan Policy and Human Resources Development (PHRD) Technical Assistance Program to Support Disaster Reduction and Recovery, and administered by the World Bank.

The Department of Engineering Services is pleased to bring forth this "Seismic Vulnerability Assessment Guideline for Load Bearing Structures" with the hope that it will benefit all engineers in the field and help assess the seismic vulnerability of load bearing structures. This guideline provides explanation for the widely adopted seismic vulnerability assessment method for load bearing structures, namely CNR-GNDT Italian Method, which has been modified and adapted to the Bhutanese context.

This document like any other technical document will have to be reviewed and updated periodically. If any clarification have to be sought or support in terms of capacity building required, the Department would like to give assurance of its' full support.

We hope that the readers find this manual informative, meaningful and helpful in the field.

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CONTENT

1. INTRODUCTION AND DESCRIPTION OF CNR-GNDT ITALIAN METHOD

With the scope to illustrate in comprehensive way the vulnerability assessment, a brief review of literature on the basic concepts of seismic risk assessment is presented.

According to the United Nations International Strategy for Disaster Reduction (UNISDR), the risk assessment "involves a methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend." [1]

Consequently, a basic equation for determining the absolute risk can be expressed as the relationship between the three components (hazard, vulnerability and exposure) as follows:

RISK = HAZARD • VULNERABILITY • EXPOSURE

For the basic definition of each component, reference can be made to UNISDR terminology. In this case, vulnerability is defined as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard."

Nevertheless, the concepts and definitions of vulnerability are still evolving. From the technical and engineering perspective, vulnerability focuses primarily on the physical aspects and can therefore be defined as "the degree of loss to a given element at risk or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage).[2]

On these premises, seismic vulnerability of the building can be described as the intrinsic characteristic of the building to suffer a certain level of damage when subjected to a seismic event of a given intensity.

The methods developed, in the past years, for seismic vulnerability assessments for loss estimations due to the earthquake occurrence can be classified under different categories.

The CNR-GNDT Italian method which is based on statistical and empirical approach belongs to the category of the score assignment methods. The method has enjoyed remarkable diffusion in Italy, being in use since the last 25 years. The method has been widely used in different countries and thereby providing an extensive validation of the same. The milestone of the method was in the year 1984, thanks to the Italian authors D. Benedetti and V. Petrini. Over time, several authors have characterized the method for different local contexts where it was applied, although the adapted versions remained firmly anchored to the original approach. Similarly, the application proposed here is based on the original approach recognised generally as "GNDT-1994" version.

The result obtained by this method is here called "Normalized Final Score" (S_f) and it makes possible to classify the

[1] See http://www.unisdr.org/we/inform/terminology
[2] UNDRO. Natural disasters and vulnerability analysis: report of Expert Group Meeting. Geneva: Office of the United Nations Disaster Relief Co-ordinator (1979).

buildings of a given area with equal seismic hazard level on a scale of relative seismic vulnerability. This is obtained by assigning a value between 0 and 1 on the basis of the building structural characteristics. These characteristics are quantified as vulnerability parameters and are evaluated considering several assessment elements sorted according to four class scores (A, B, C and D), each one corresponding to an increasing vulnerability category.

Weight factors are assigned to each vulnerability parameter to recognize the degree of importance of the parameter in the seismic resistance of the building. At the end of the procedure, the Normalized Final Score S_f is obtained as the weighted sum of the product of the class score of each vulnerability parameter and its corresponding weight factor. In order to facilitate the comparison between buildings in a sample, the S_f is normalized by dividing by the maximum value that can be obtained from the sum of the products of the weight factors and class scores.

The "Normalized Final Score" (S_f) can be considered as an intermediate step toward the damage estimation of a building hit by a seismic action of specified intensity. In fact, the "complete" and "extensive" formulation of the method permits to establish a direct relation between S_f, the expected damage (expressed on a scale from "0-no damage" to "1-building collapse" and a certain earthquake intensity (generally expressed in terms of ground acceleration).

The achievement of the "complete" and "extensive" formulation requires a successive calibration of the relative scale along with the observation of building damage levels from the data of past earthquakes; the calibration process gives the fragility curves. The knowledge of the fragility curves together with the knowledge of the seismic hazard at each particular site would provide an expected damage which is useful for additional uses (e.g. disaster management planning in the case of earthquake occurrence, definitions of prevention actions for building retrofitting strategies, expected damage scenario for a given earthquake intensity, etc.) other than the relative classification of buildings vulnerabilities. In Annex 2, the procedure to obtain the fragility curves and the calibration of the method based on the damage statistical data of past Italian earthquakes is shown.

In the next sections, input data for filling the form are briefly illustrated and discussed.

As general notes, it is outlined that the form must be completed for each building. Information is generally defined by colouring in the corresponding cells. Squared cells (☐) indicate the possibility of multiple answers - in such cases more than one answer is allowed; round cells (O) indicate the possibility of a single choice. When cells like |__| are present, it is necessary to write numbers (right justified). When underlines are present, it is necessary to write texts (in capital letters and left justified). The dot, in the boxes in which it is present, separates the decimal part of the integer and defines the maximum number of digits that can be carried, and where this is not the case, the numbers are integers.

2. EXPLANATORY NOTES FOR COMPILING FIRST PART OF FORM

The first part of the form is divided into nine sections intended to receive the following information:

Section 1: Administrative data;
Section 2: Building identification;
Section 3: Metrical data;
Section 4: Building use;
Section 5: Building age and interventions;
Section 6: Conditions of finishes and systems;
Section 7: Building typology;
Section 8: Grade and extent of the damage;
Section 9: Comments and sketch.

It is preferable to develop some information during a pre-field planning stage, if possible.

When possible, the survey should be preceded by an interview with local technicians and with the owner of the building, in order to collect general information about the building, such as age of construction, materials, structural typologies, modifications and/or enlargements carried out during the years, instabilities of the foundation soil, etc.

2.1. Section 1: Administrative data

This section collects information in order to identify in an unambiguous way the building and the survey.

- **Building no. :** number given to the building;
- **Form no. :** progressive number given to the survey, within certain territorial boundaries (e.g. dzongkhag, gewog, etc.);
- **Date:** date of the survey;
- **Team:** number given to the team of surveyors
- **Surveyors:** names/initials and signatures of the surveyors

2.2. Section 2: Building identification

This section collects information concerning the identification and location of the building.

- **Building denomination:** effective denomination in case of buildings with a relevant public function. In the case of private buildings, the name the owner;
- **Location description:** identification of the building by street address or other equivalent schemes (e.g. Village/Chiwog/Gewog/Dzongkhag);
- **Latitude/Longitude:** geographic position related approximately to the geometric center of the building;

- **Building position/adjacency:** if the building is not isolated, its position within the aggregate must be indicated (internal, extreme, corner);

2.3. Section 3: Metrical data

This section collects information concerning metrical data of the building.

- **Total no. of storeys:** total number of storeys of the building from the foundation level, including the attic only when practicable;
- **Avg. storey height:** height better approximating the average storey height;
- **Avg. storey area:** area better approximating the average storey area;
- **Max. height eave level:** maximum height from ground level to eave level ;
- **Min. height eave level:** minimum height from ground level to eave level.

2.4. Section 4: Building use

This section collects information concerning the type of use and exposure of the building.

- **Use type:** types of use coexisting in the building. The number of dwelling units has to be indicated in the case of residential use;
- **Utilisation:** approximate percentage of utilisation of the building in spatial and/or temporal terms, according to three levels (<30%, 30%-65% and >65%). Alternatively, it is possible to specify the fact that the building is not used at all, either because, even if functional, there is practically no human presence (not utilised) or because it is under construction, or, finally, because it is abandoned (not utilised);
- **No. occupants:** average number of people usually present in the building;
- **Other designation** information concerning if the building is of historic interest (e.g. subjected to specific code building) or if the building is designed to be used in the event of emergency (shelter);
- **Property:** information concerning the type of property, distinguishing between public or private

2.5. Section 5: Building age and interventions

This section collects information concerning the building age, with indication of the period of construction and eventually of renovation of the building.

- **Year built:** year (or period) of construction of the building. If this information is not available an estimate can be made and squared cells “ Estimated” has to be marked;
- **Code/No Code:** the option indicates if the building was designed or not according to the modern seismic codes;

- **Last significant intervention:** the information indicates the absence or the presence of significant intervention on the building. In case of presence, the type of intervention has to be specified (enlargement, superimposition, restoration, retrofit) with related additional information regarding the construction year (if this information is not available, an estimate can be made and squared cells "☐Estimated" has to be marked). The option "Code/No Code" indicates if the last significant intervention on the building was designed or not according to the modern seismic codes.

2.6. Section 6: Conditions of finishes and systems

This section collects information concerning the conservation state of the finishes and the functional state of the building systems, observed during the survey.

- **Efficient:** systems and/or finishes in good conditions and in line/compliant with proper use;
- **Not Efficient:** systems and/or finishes in bad conditions and not in line/not compliant with proper use.

2.7. Section 7: Building typology

This section collects information concerning the structural and non-structural components of the building.

- **Vertical structures:** type of main vertical structure of the building. Multiple options are allowed in cases of presence of a system combining different significant types of vertical structures. More precise instructions on the vertical bearing system will follow in the paragraph concerning the "Resisting System Quality" in the next chapter;
- **Floor structures:** type of main floor structure of the building. Multiple options are allowed in cases of presence of a system combining different significant types of floor structures;
- **Roof type:** type of bearing structure of the roof;
- **Roofing material:** type of roofing material.

2.8. Section 8: Grade and extent of the damage

This section collects information concerning the damage assessment, useful for the development of fragility curves. The damage assessment includes, in addition to the date of the seismic event, the indication of the grade and extent of the damage, both for structural and non-structural components, in particular: (i) vertical structures, (ii) floor structures and (iii) partition walls.[3] Damage assessment is evaluated and recorded by several matrices describing, for each constructive component, the damage status by its grades and extents. Every row of the matrix contains the damage survey observed at a certain floor level, filled in the following way:

- in column named "H", the Highest grade of the damage (code from A to F in the order of increasing grade of damage)

- in column named "E", the damage Extent, in terms of percentage range corresponding to the most widespread damage (code from 0 to 9 in the order of increasing extent of the damage)
- in column named "G", the Grade of the most widespread damage (code from A to F in the order of increasing grade of damage)
- in column named "N.", the number of floors with the same damage.

Filling out the form will start from the lowest level for proceeding up to the top floor. In case of homogeneous damage (in terms of grade and extent) on contiguous floors it is possible to fill one single row of the matrix by reporting the total number of homogeneous damaged storeys in the last column.

The percentage range is indicated with the number code varying from 0 to 9, as indicated in the following table.

Code	Percentage range	Code	Percentage range
0	< 10%	5	50 - 60%
1	10 - 20%	6	60 - 70%
2	20 - 30%	7	70 - 80%
3	30 - 40%	8	80 - 90%
4	40 - 50%	9	90 - 100%

The grade of the damage is indicated with the letter code varying from A to F, as indicated, hereinafter, for each component.

- **Vertical structures:**

Code	Damage Grade	Description
A	No damage	
B	Slight damage	Cracks up to 1 mm, any type
C	Moderate damage	Crack of type 1, 5, 6 up to 4 mm and of type 2, 3, 7 up to 2 mm Slight damage of type 4, 8, 9
D	Heavy damage	Cracks of type 1, 5, 6 up to 10 mm and of type 2, 3, 7 up to 5 mm Moderate damage of type 4, 8, 9
E	Very heavy Damage	Cracks and damage greater than the grade “D”
F	Collapse	

For the explanation of type of damage and cracks see figure below.

[3] The Italian form also contained the damage survey on the staircases, that in this context it is chosen to neglect, for simplifying

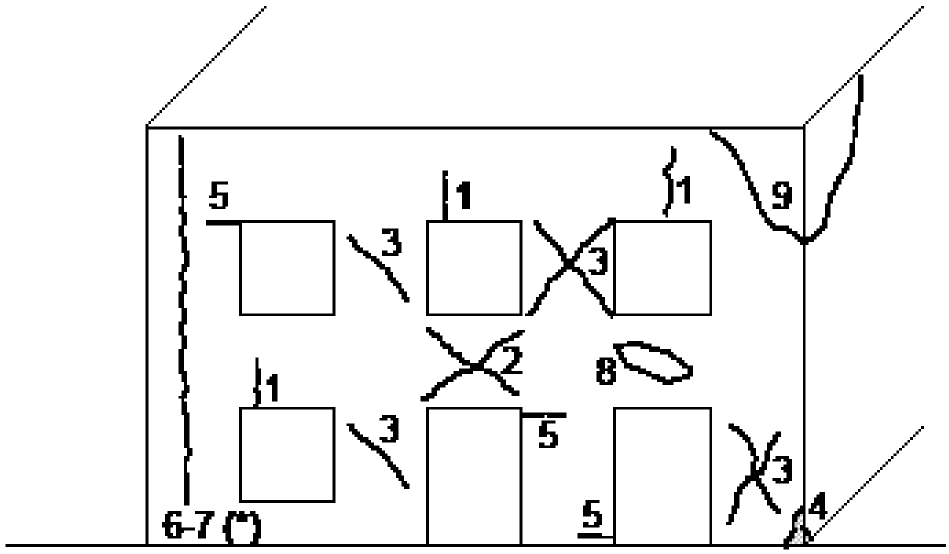


Figure. (*) Vertical corner cracks in one side (type 6) or both sides (type 7) of intersecting walls

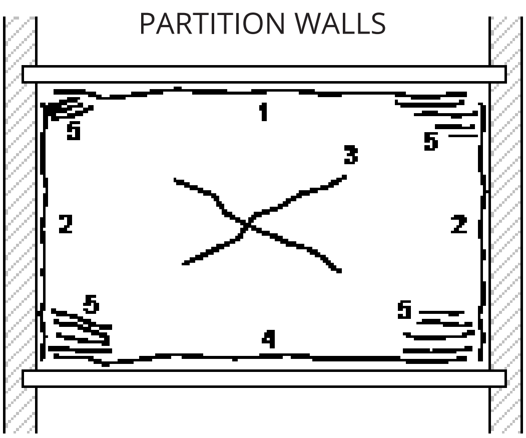
- **Floor structures:**

Code	Damage Grade	Description (the splitted row is roof related):
A	No damage	
B	Slight damage	Hairline cracks (up to 1 mm)
		Fall of some tiles
C	Moderate damage	Extensive cracks (up to 4 mm) Instability in the floor Instability of the joists
		Disconnection of the roofing tiles and / or fall of tiles (<10%) Slight movements of the main beams from their position (<5 mm)
D	Heavy damage	Well-defined gaps between floor structures and vertical structures Relevant cracks, greater than the "C" grade Partial collapse of some joists
		Displacements of the main beams (> 5 mm and <30 mm) Various disconnections in roof tiles and/or fall of a large number of tiles (<20%)
E	Very heavy Damage	Partial collapse of the main beams Large and widespread gaps between the floor structures and the vertical ones Extended collapses of the joists
F	Collapse	

Partition walls:

Code	Damage Grade	Description (Cracks type and width)				
		1	2	3	4	5
A	No damage	-	-	-	-	-
B	Slight damage	≤ 2 mm	≤ 2 mm	≤ 1 mm	-	-
C	Moderate damage	≤ 5 mm	≤ 5 mm	≤ 2 mm	≤ 1 mm	Slight
D	Heavy damage	≤ 10 mm	≤ 10 mm	≤ 5 mm	≤ 1 mm	Moderate
E	Very heavy Damage	> 10 mm	> 10 mm	> 5 mm	> 2 mm	Heavy
F	Collapse	Partial collapse				

For the explanation of the type of damage and crack see figure and description below.



Cracks type: 1, 2 and 4 - Cracks due to the detachment from the contours

Cracks type: 3 - Diagonal cracks in the partition walls

Cracks type 5- Crushing at the corners.

Hereinafter, an example for filling out the form for the "vertical structures" component for a building with three storeys, with different grade and extent of damage is shown.

Floor level	Damage grade	Code	Extent	Code
Ground Floor	Moderate damage	C	21%	2
	Slight damage	B	48%	4
	No damage	A	31%	3
First Floor	Moderate damage	C	25%	2
	Slight damage	B	41%	4
	No damage	A	34%	3
Second Floor	Heavy damage	D	21%	2
	Moderate damage	C	27%	2
	Slight damage	B	31%	3
	No damage	A	21%	2

H	E	G	N.
C	4	B	2
D	3	B	1
Vertical struct.			

The absence of damage it is indicated with the entire code A9A.

2.9. Section 9: Comments and sketch

This section collects any information that the surveyor intends to use to clarify the contents of the other sections of the form, quality of the data or unusual circumstances of any type. Comments must be reported possibly by pointing out the section and the topic they refer to.

The photograph of the building and the plan view indicating the building (possibly extracted by Google Map™) have to be attached in the cells provided for.

If the surveyor needs additional comments or photographs on a separate page, the squared cell (☐) "Additional page" has to be marked.

3. EXPLANATORY NOTES FOR COMPILING SECOND PART OF FORM

The floor level of the building to be taken into account, hereinafter defined as "Test Floor Level", is what can be found in the less favourable conditions in terms of resistance to horizontal forces and is generally the first floor above ground. In cases with strong discontinuity and considerable variations in elevation of the resisting system (where worsening occurs from bottom up), it is necessary to evaluate the worst conditions on the higher floor level (see following figure for explanation)

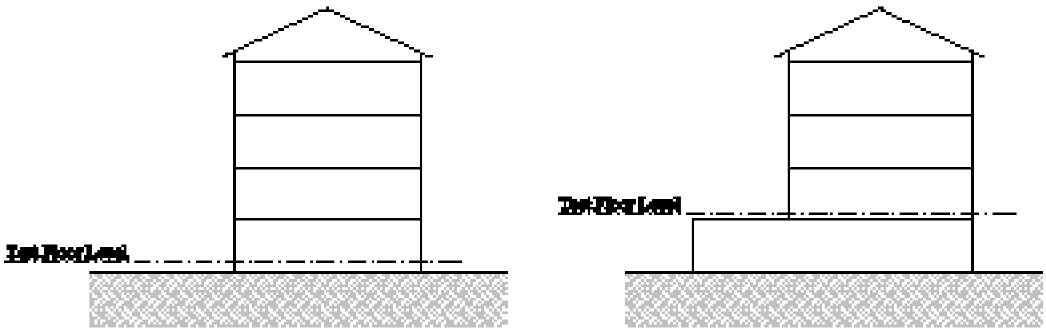


Figure. Test Floor Level in the case of regular building (on left) or building with singularities (on right)

The form is divided into 6 columns to illustrate the following information:

- Vulnerability parameters: list of required parameters, to a maximum of 11;
- Class: classification of the vulnerability parameter in the order of increasing rating class from A (optimal) to D (unfavorable);
- Information quality (IQ): degree of reliability of the input data (H, M, E, N);
- Score: score assigned to the evaluation classes;
- Weight (W): weight factor that is allocated to each vulnerability parameter;
- Assessment elements/Notes: input data and reminders for the determination of the evaluation class.

Column IQ must indicate the letter corresponding to the quality of information (or degree of reliability), defined in the following way:

- H - High quality: direct information (measurements carried out on site, readings taken from reliable charts, visual witnessing information) with a near-certainty degree of reliability;
- M- Medium quality: information that has been mostly deduced (such as those derived from indirect readings from photographs, measurements taken from non-executive documents, non-destructive tests of poor reliability, direct readings of similar situations, oral information from people the surveyor deems trustworthy) with an intermediate degree of confidence between the previous (H) and the next (E).
- E - Estimated: information that has been mainly alleged (measures deduced from reasonable assumptions such as those adopted in standard design practice, oral information other than the above) with a degree of reliability that is slightly above that of a purely random selection.

- N - Not known: with a degree of reliability similar to that of a random choice. In such cases, the surveyor's evaluation is only used as a reference.

Filling out the form can be done in one of the methods described below. The selection is made by the surveyor's coordinator on the basis of their objective and of the significant logistical problems:

- classifying only certain parameters and evaluating only some of the elements while omitting the remainder;
- classifying all parameters and evaluating only some of the elements;
- classifying all parameters and evaluating all elements.

The last option, in the presence of the fragility curves, permits a good estimation of the expected damage.

3.1. Vulnerability parameter: Resisting system type

Regardless of the material and the characteristics of the wall, the parameter represents the degree of "box-like" behaviour of a masonry building. The assessment elements, required for determining the class, are: i) the presence and efficiency of connections between the horizontal structures (floor structures) and the shear walls, ii) the presence and efficiency of connections between intersecting shear walls at the corners as well as at T junctions.

The four classes are defined as follows:

- Class A: Buildings constructed in line/compliant with the seismic code for new constructions.
  Buildings retrofitted in line/compliant with the seismic code for existing constructions.
- Class B: Buildings that, at all levels and on all exposed sides, have connections between the horizontal structures and the shear walls made by bond beams or seismic bands that are capable of efficiently transmitting horizontal shear forces.
- Class C: Buildings that, while not having bond beams or seismic bands at all levels, are constituted by well tied orthogonal walls.
- Class D: Buildings with orthogonal walls that are not effectively tied with each other and that do not have connections between the horizontal structures and the vertical walls

3.2. Vulnerability parameter: Resisting system

The parameter represents the quality of the resisting system by identifying the type of masonry.

The assessment element required to determine the class is the type of masonry. The type is to be indicated on the basis of the type at Test Floor Level.

The four classes are defined in this way:

- Class A: CM - Confined Masonry
- Class B: RM - Reinforced Masonry
- Class C: UMC - Unreinforced masonry with cement mortar (dressed/semi dressed stone masonry, brick, blocks, CSEB etc.)
- Class D: UMM - Unreinforced masonry with mud mortar
  RS - Rubble stone masonry
  AD – Adobe
  RE - Rammed earth

3.3. Vulnerability parameter: Conventional seismic strength

The parameter represents, through a simplified calculation method, an estimate of the “conventional” resistance to the horizontal forces of a masonry building.

This method is based on the following assumptions:

- regularity in the building plan and elevation;
- elevation continuity of masonry piers;
- failure mode of masonry piers due to shear mechanisms by diagonal cracking;
- horizontal structures and vertical structures well connected and in-plane stiffness of horizontal structures to ensure a good box-like behaviour of the building.

If the above assumptions can be verified, this method provides reliable results for “conventional” resistance to the horizontal forces. If the assumptions can not be verified, the reliability of the results obtained in this parameter can be very questionable.

The assessment elements, required for determining the class, are:

- N: number of floors above and including the Test Floor Level;
- A_t: average floor area of the levels included in the calculation;
- A_x A_y: total area of the resistant walls in two orthogonal directions. The length of each resistant wall is measured by including all the total thickness of the orthogonal walls at the intersection. The area of inclined elements of angle β relative to the direction of the force must be multiplied by $\cos^2 \beta$;
- τ_0: shear strength of the masonry present at the Test Floor Level;
- h: average height between floors;
- d_m: average specific weight (density) of the masonry;
- DL: average dead load. This load must include the floor’s dead load and live load (only if it is negligible. E.g. archive, library, etc.).

Once these assessment elements are known, as described above, the C coefficient can be calculated. This coefficient represents the ratio between the ultimate shear strength (at the Test Floor Level and in the less favourable direction) and the building weight above the Test Floor Level.

Details on how to calculate coefficient "C" are shown in the Annex 1.

Categorising a building in one of the four classes is done on the basis of the value $\alpha = C/A_h$ where A_h is the value of the reference seismic load referred to the IS:1893 (Bhutan refers to Indian Code for design of load caused by earthquake).

$$C = \frac{a_0 . \tau_0}{q.N} \sqrt{1 + \frac{q.N}{1.5 . a_0 . \tau_0 (1+\gamma)}} \quad ; \quad A_h = \frac{Z I S_a}{R g}$$

$$\alpha = \frac{C}{A_h}$$

where according IS:1893 :

Z: seismic zone factor;

I : importance factor;

Sa/g: average response acceleration coefficient;

R: lateral load resisting system factor.

The four classes are defined by the following table.

3rd Vulnerability Parameter Conventional Seismic Strength	
Class	**α**
A	α ≥ 1
B	0.6 ≤α< 1.0
C	0.4 ≤ α< 0.6
D	< 0.4

3.4. Vulnerability parameter: Location and soil condition

The parameter assesses the foundations and foundation soil characteristics that affect the overall seismic behaviour of the building. With this parameter, the following can be evaluated: i) the site topography where the building is constructed, ii) the foundation system based on the type of soil and the elevation difference for the foundations.

The assessment elements required for determining the class are:

- slope percentage of the ground: average gradient of the land on which the building stands, measured perpendicularly to the contour lines.
- presence of foundations: the presence or lack of foundations must be specified. Kerbs or thicker sections of masonry that have been sunk into the ground can also be considered as a foundation.

- soil characteristics: this information can be deduced from certifications that may be present and attached to the building design or by analogy with those of neighbouring buildings or by site inspection. The rock option must be selected in the presence of rock outcrops, even where these are covered by deposits of degraded rock. The loose soil option applies to the remaining conditions where it needs to be specified as either loose soil without thrusting (in terms of embankments with the presence retaining walls) or loose soil with thrusting (in terms of absence of retaining walls).
- elevation difference for foundations: this information indicates that the foundations are set at different elevations with the specification of the elevation difference (Δh).

The four classes are defined in the following table:

4th Vulnerability Parameter - Location and soil condition				
Soil Type	**Presence of foundations**	**Slope percentage**	**Elevation difference (Δh)**	**Class**
Rock	Yes	s ≤ 10	-	A
		10 < s ≤ 30	-	B
		30 < s ≤ 50	-	C
		s > 50	-	D
	No	s ≤ 10	-	A
		10 < s ≤ 30	-	B
		30 < s ≤ 50	-	C
		s > 50	-	D
Loose soil without thrusting	Yes	s ≤ 10	Δh = 0	A
		s ≤ 10	0 < Δh ≤ 1	B
		10 < s ≤ 30	Δh ≤ 1	B
		30 < s ≤ 50	Δh ≤ 1	C
		s > 50	-	D
		-	Δh > 1	D
	No	s ≤ 10	Δh = 0	A
		s ≤ 10	0 < Δh ≤ 1	B
		10 < s ≤ 20	Δh ≤ 1	B
		20 < s ≤ 30	Δh ≤ 1	C
		s > 50	-	D
		-	Δh > 1	D
Loose soil without thrusting	Yes	s ≤ 50	Δh ≤ 1	C
		s > 50	-	D
		-	Δh > 1	D
	No	s ≤ 30	Δh ≤ 1	C
		s > 30	-	D
		-	Δh > 1	D

In the case of buildings standing on rock, the elevation difference between the foundation layers is neglected. It should be emphasized that this vulnerability parameter does not represent situations that are characterised by landslides or liquefaction. Possible risks of this type should be evaluated separately and indicated in a sheet of observations.

3.5. Vulnerability parameter: Floor structures

The parameter represents the influence of the floor/horizontal structures as a functioning part of the building's box-like behaviour, which occurs when they are well connected to the vertical walls and when the floor/horizontal structures have high in-plane stiffness.

The assessment elements, required for determining the class, are:

- presence of split-levels;
- presence of rigid or slightly deformable floor/horizontal elements;
- presence of a good connection between the horizontal structures and the resisting masonry walls.

The four classes are defined by the following table.

5th Vulnerability Parameter - Floor structures		
In-plane stiffness and Floor-to wall connection	**Split-levels**	**Class**
Rigid with floor-to-wall connections	No	A
	Yes	B
Slightly deformable with floor-to-wall connections	No	C
	Yes	C
Rigid without floor-to-wall connections	No	D
	Yes	D
Slightly deformable without floor-to-wall connections	No	D
	Yes	D

In the case of assigning a class to a building that presents different types of horizontal structures within the same building, the condition is determined by the worst horizontal element provided this has extended to a non-negligible portion of the floor area.

The percentage of floor structures (with respect to the total of every floor), that has a rigid behaviour in the given plane and are properly connected to the walls, must be specified in the form. This evaluation parameter determines the weighting coefficient to be assigned to this vulnerability parameter.

3.6. Vulnerability parameter: Plan irregularity

The parameter represents the presence of irregularities in the building's plan shape that can influence the seismic behaviour of the building.

The assessment elements required for determining the class are:

- β_1 = a / l x 100, which in the case of rectangular shape is the ratio between the size of the shorter side and the longer side;
- β_2 = b / l x 100, which in the case of plan shapes that deviate from the rectangular shape is the ratio of the

length of the discrepancy and the major side.

In the case where a floor plan presents structures beyond the building's main outline that are within 10% of the main dimensions, the latter area is not considered and the plan configuration is assumed as the basic rectangular shape (see following figure for explanation).

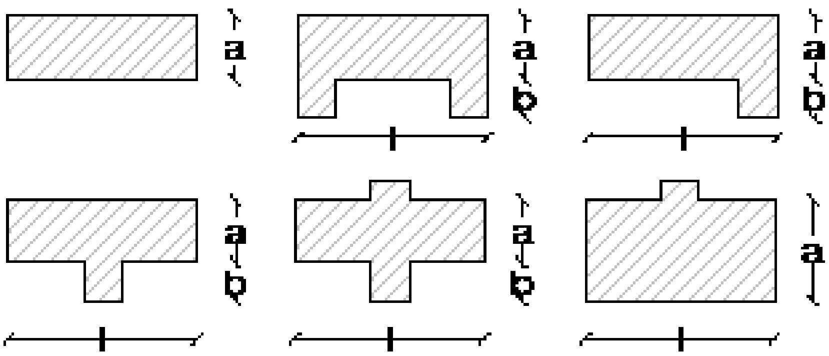


Figure. Plan shape irregularities (examples)

A building is assigned to a given class by considering the worst case in the Test Floor Level. The worst case is determined by parameters β1 and β2 according to the following table.

6th Vulnerability Parameter Plan irregularity		
β_1 = a/l [%]	β_2 = b/l [%]	Class
$\beta_1 \geq 80$	$\beta_2 \leq 10$	A
$60 \leq \beta_1 < 80$	$10 < \beta_2 \leq 20$	B
$40 \leq \beta_1 < 60$	$20 < \beta_2 \leq 30$	C
$\beta_1 < 40$	$\beta_2 > 30$	D

3.7. Vulnerability parameter: Elevation irregularity

The parameter represents the elevation irregularities that influence the seismic behaviour of the building.

The presence of arcade (similarly colonnade) is reported as the percentage ratio between the floor area interested by the arcade and the total floor area (consider the less favourable conditions).

Another element to be considered for this parameter is the presence of towers of significant height and mass with respect the rest of the building (the percentage ratio between the height of the tower T and the building's total height H is shown in the form). The assessment neglects irregularities formed by extensions of moderate size (chimneys, etc.).

The evaluation of mass change takes account of the relationship ± ΔM / M where:

- ΔM is the change in mass between two successive ascending levels (with the + sign if it increases and with the - sign if it decreases);

- M is the mass of the lower floor.

The less favourable case must be assessed.

Percentage changes less than 10% can be taken as zero.

Normally the ratio ± ΔM / M can be replaced by the ratio ± ΔA / A, where A and ΔA are the floor covered area and its variation, respectively.

The guiding principle for the class allocation is always determined by the worse condition.

The four classes are defined in the following table.

7th Vulnerability Parameter Elevation irregularity			
ΔM / M [ΔA / A]	**T/H**	**Δ (*)**	**Class**
ΔA ≤ 10 or zero	T/H ≤ 10 or zero	Δ= 0	A
10 < ΔA ≤ 20	0 < T/H ≤ 10	Δ ≤ 10	B
ΔA > 20	10 < T/H ≤ 40	10 < Δ ≤ 20	C
-	T/H > 40	Δ > 20	D

* Δ = percentage ratio between the floor area interested by the arcade and the total floor area.

If the vertical elements of the building were built using different materials at different levels that lead to changes in classification in the "quality of resisting system" and if these changes result, in the surveyor's view, in significant changes to the stiffness characteristics and/or strength of vertical structures, the following penalties will apply:

- the buildings that would belong, according their geometry, to classes A or B, are placed in class C;
- the buildings that would belong, according their geometry, to geometry class C, they are placed in class D.

3.8. Vulnerability parameter: Maximum distance between walls

The parameter takes into account the presence of transverse load-bearing walls (excluding partition walls) that prevent collapse mechanisms of masonry walls under out-of-plane horizontal action.

The presence of the transverse walls prevents out-of-plane collapse mechanisms when the distance between the given walls is not too great for the constraint to be effective. Effectiveness of the constraint means a strong connection between the longitudinal wall and the transverse wall. The effectiveness of the constrain also depends on the masonry texture and the possible presence of openings near the edge. Therefore, in the case of openings in transverse wall located less than a meter from the edge, the walls are not considered capable of constituting an effective constraint.

The classes are defined according to the less favourable ratio between the distance of transverse load-bearing walls and the thickness of the given wall.

The four classes are defined in the following table.

8th Vulnerability Parameter Maximum distance between walls	
Max ratio l/s	Class
l/s ≤ 15	A
15 < l/s ≤ 18	B
18 < l/s ≤ 25	C
l/s > 25	D

3.9. Vulnerability parameter: Roof

The vulnerability parameter takes into account the roof bearing elements that affect the seismic behaviour of a building. As with the other floor structures, roof bearing elements play an important role in the box-like behaviour of the building. Moreover, if the roofing also exerts lateral forces on its supports, it may cause the collapse of the lower wall.

The assessment parameters required for determining the class are:

- roof structure type: not thrusting, with reduced thrust or thrusting;
- the presence or absence of ceiling bond beam;
- the presence or absence of tie beams or tie rods

The four classes are defined according to the following table.

9th Vulnerability Parameter - Roof			
Classification of the roof structures	Ceiling bond beam	Tie beams / tie rods	Class
Not thrusting	Yes	Yes – No	A
	Yes – No	Yes	A
	No	No	B
Reduced thrust	Yes	Yes - No	B
	Yes - No	Yes	B
	No	No	C
Thrusting structure	Yes	Yes - No	C
	Yes - No	Yes	C
	No	No	D

There are also some assessment elements required to determine the weight factor to be assigned to this vulnerability parameter. They are as follows:

- the roofing dead load DL_r;
- the presence of openings in the support walls evaluated by measuring: i) the length (Ls) of the supporting walls for the roofing and ii) the length (Lr) of roof's perimeter.

Note that the Ls length of the supporting walls should not generally consider the architraves unless they are of a similar stiffness to that of a wall, for example, with a span length/height ratio less than 3-4 (see the following figures for explanation).

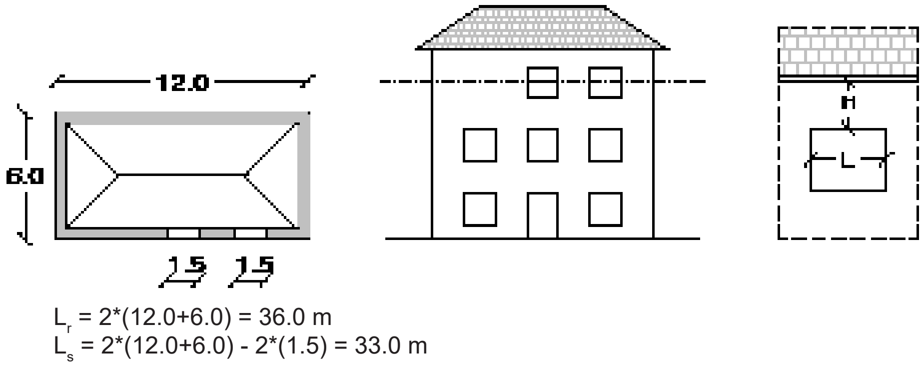


Figure. Examples of lengths of the supporting walls and roof's perimeter

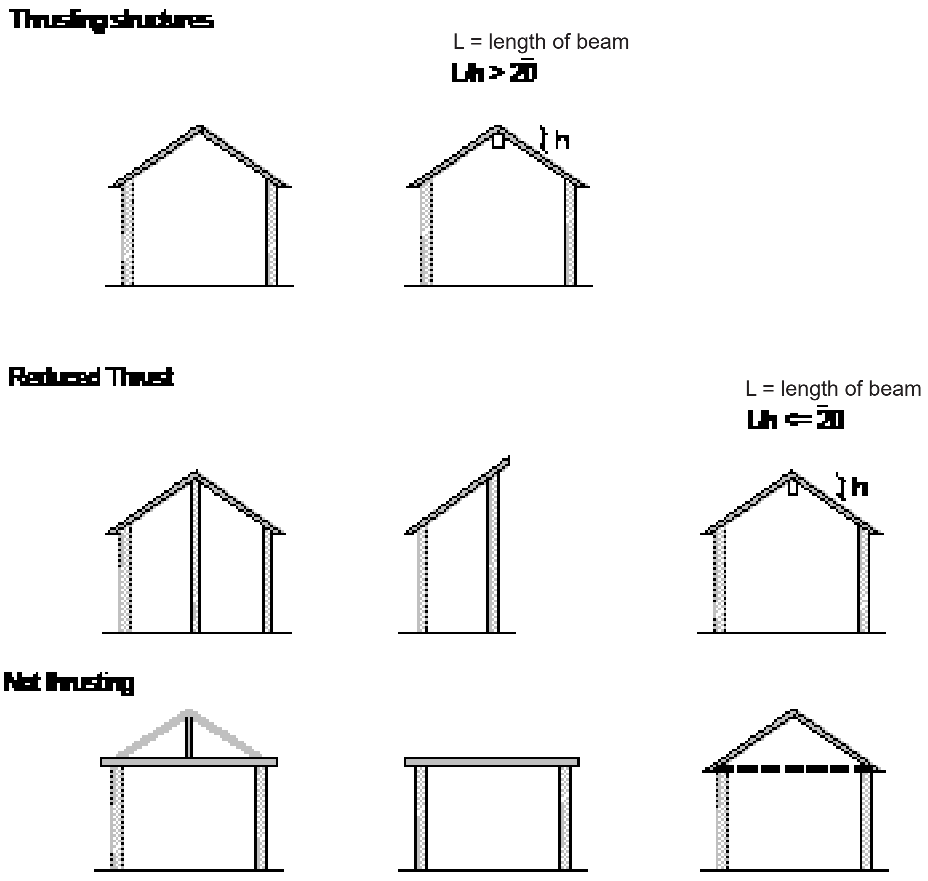


Figure. Examples of roof structure types

3.10. Vulnerability Parameter: Non-structural elements

This parameter takes into account non-bearing elements (chimneys, windows, projections, false ceilings) that, in the event of an earthquake, can fall and cause damage to people or property.

It is a secondary element in assessing vulnerability and therefore it holds no sense to distinguish between the first two classes.

The assessment parameter is determined by how well the non-structural elements are secured to the bearing structure and their size.

The classes are defined as follows:

- Classes A-B: buildings without windows, extensions, projections or false ceilings; buildings with doors that are well-connected to the walls, with small and light chimneys and with well-connected false ceiling;

  buildings with balconies which make up an integral part of the structures;
- Class C: buildings with external frames or small and badly placed signboards on the walls, small and poorly connected false ceilings or large and well-connected false ceilings.
- Class D: buildings with: chimneys or other extensions in the roof that are poorly fastened to the structure, poorly built railings or significantly heavy items that can collapse in event of an earthquake;

  buildings with balconies or other poorly built projections;

  buildings with large and poorly connected false ceilings.

3.11. Vulnerability Parameter: Damage and preservation state

This parameter takes into account the condition of the building and construction materials.

The four classes are defined as follows:

- Class A: walls in good condition with no visible damage;
- Class B: buildings with localised damage caused by earthquakes;
- Class C: buildings that are moderately damaged (cracks width up to 2-3 mm) or has hairline cracks due to the earthquake;

  buildings that do not have damage, but are in poor upkeep to the extent that its structural resistance has been compromised.
- Class D: buildings with out-of-plumb walls and/or serious damage even if just at a local level. buildings characterised by severe deterioration of materials.

  buildings that do not have damage, but are in poor upkeep to the extent that its structural resistance has been compromised.

The Normalized Final Score "Sf" is finally obtained as the weighted sum of the product of the class score of each vulnerability parameter and the corresponding class weight divided by the maximum value that can be obtained by the weighted sum.

The value ranges from 0-1, where 0 represents the least vulnerable buildings and 1 the most vulnerable under a relative scale.

$$S_f = \sum_{i=1}^{11} (Weight * Class\ score)_i \Big/ \sum_{i=1}^{11} (Weight * Maximum\ class\ score)_i$$

The following table provides a summary of scores and weight factors for the different vulnerability parameters.

Vulnerability parameters: class score and weight factors					
Vulnerability Parameters	**Class Score**				**Weight factors**
	A	**B**	**C**	**D**	
1. Resisting system type	0	5	20	45	1.00
2. Resisting system quality	0	5	25	45	0.25
3. Conventional seismic strength	0	5	25	45	1.50
4. Location and soil condition	0	5	25	45	0.75
5. Floor structures	0	5	15	45	var. (0.50 - 1)
6. Plan irregularity	0	5	25	45	0.50
7. Vertical irregularity	0	5	25	45	var. (0.50 - 1)
8. Maximum distance between walls	0	5	25	45	0.25
9. Roof	0	15	25	45	var. (0.50 - 1)
10. Non-structural elements	0	0	25	45	0.25
11. Damage and preservation state	0	5	25	45	1.00

The weight factors take into account the level of importance that the various vulnerability parameters assume for the purposes of the seismic resistance of a structure. Under this point of view, they are condensed in three groups: (i) parameters of primary importance (weighting equal to 1.5); (ii) important parameters (weighting between 0.5 and 1); (iii) secondary parameters (weighting less than 0.5).

For some parameters (no. 5, 7, 9) the weighting varies based on certain assessment elements, as explained below.

<u>Vulnerability Parameter no. 5</u>

In case where there are horizontal elements of various kinds within the same building, the class is assigned based on the lowest score. Here, the weight factor to be given to the assessment parameter is not constant but is defined as:

$w_5 = 0.5/\alpha_0$

Where α_0 is the ratio between the number of floor level with rigid behaviour (class score A or B) and the total number of floor level. Weight factor w_5 is assumed to not exceed 1.

Vulnerability Parameter no. 7

Normally this parameter is assigned a weighting of 1. If the irregularity is caused solely due to the presence of arcades on the ground floor (soft storey), the weighting is reduced to a value of 0.5. This is justified by considering that in this disadvantageous situation the resistant elements are already taken into account for the analysis with their reduced resistant area.

Vulnerability Parameter no. 9

The weighting to be assigned to this element is defined as:

$w_9 = 0.5 + \alpha_1 + \alpha_2$

where:

$\alpha_1 = 0.25$ if the weight of floor is more than or equal to 200 daN /m^2, otherwise $\alpha_1 = 0$;

$\alpha_2 = 0.25$ if the ratio between the roof perimeter L_r and the overall length of the supporting walls L_s is greater than or equal to 2, otherwise $\alpha_2 = 0$.

ANNEX 1

Explanation on the simplified method for the "conventional" resistance

The Annex gives details on how to calculate the coefficient "C" of the third vulnerability parameter "Conventional Seismic Strength". The simplified method considers the building, in its weaker direction, as an equivalent shear wall characterised by a failure mechanism with diagonal cracking (Turnsek-Cacovic model).

The assessment elements are:

- N: number of floors above and including Test Floor Level;
- A_t: average floor area of the levels included in the calculation;
- A_x, A_y: total area of the resistant walls in two orthogonal directions. The length of each resistant wall is measured by including all the total thickness of the orthogonal walls at the intersection. The area of inclined elements of angle β relative to the direction of the force must be multiplied by $\cos^2 \beta$;
- τ_0 : shear strength value of the masonry present at the Test Floor Level;
- h: average height between floors;
- d_m: average specific weight (density) of the masonry;
- DL: average dead load. This load must include the floor's dead load and live load only if this last one is not negligible (archive, library, etc.).

Survey's coordinator establishes a standard database for "conventional" shear strength values, based on experimental tests performed for the different masonry typologies or alternatively extracted from the existing literature.

Once these assessment elements are known, as described above, the coefficient "C" can be calculated. This coefficient represents the ratio between the ultimate shear strength (at the Test Floor Level and in the less favourable direction) and the building weight above the Test Floor Level.

The following parameters are defined as useful for the explanation.

$$a = min(A_x;A_y) \quad ; \quad b = max(A_x;A_y)$$

$$a_0 = \frac{a}{A_t} \quad ; \quad \gamma = \frac{b}{a}$$

$$q = \frac{(A_x+A_y).h.d_m}{A_t} + DL$$

<u>Ultimate shear strength at the Test Floor Level</u>

The ultimate shear strength for each wall is:

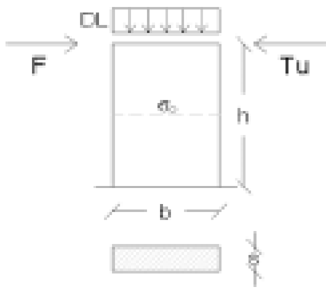
$$T_U = A_{wall} \cdot \tau_0 \cdot \sqrt{1+\frac{\sigma_0}{1.5 \cdot \tau_0}}$$

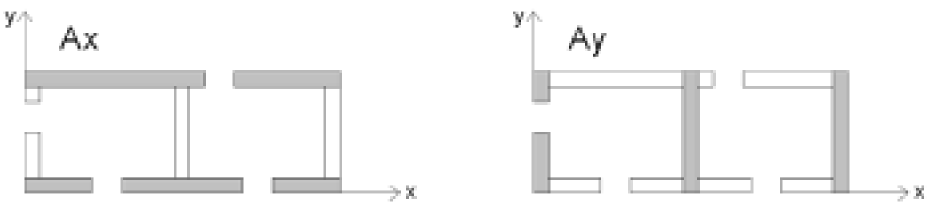
T_U = ultimate shear strength;

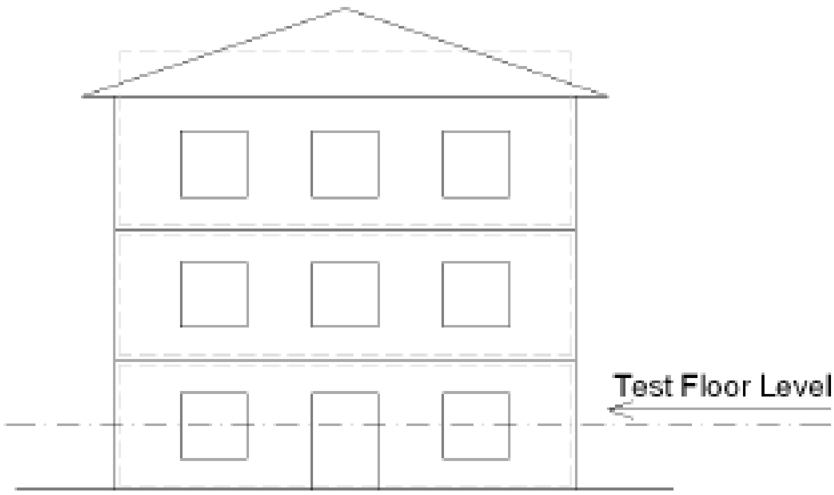
A_{Wall} = total area of the resisting wall;

τ_0 = shear strength of the masonry;

σ_0 = average vertical stress into the wall.







It is possible to assume average values for τ_0 and σ_0 equal for all the floor's walls and so calculate the floor's shear strength in two orthogonal directions X, Y.

For a building with a number of floors "N" the ultimate shear strength of a certain floor is given by:

$$T^*_{U, floor} = min\ (T^X_{U, floor}\ ;\ T^Y_{U, floor})$$

The ultimate shear strength of the building is the minimum of $T^*_{U,floor}$ of the Test Floor Level found in the less favourable conditions in terms of resistance, identified as Test Floor Level (TFL):

$$T^{*}_{U,\,TFL} = min\,(T^{*}_{U,\,floor})$$

$$T^{*}_{U,\,TFL} = \left[min\,(A_{x,TFL}\,;\,A_{y,TFL})\right].\,\tau_0\,.\,\sqrt{1+\frac{\sigma_{0,\,TFL}}{1.5\,.\,\tau_0}} = a.\,\tau_0\,.\,\sqrt{1+\frac{\sigma_{0,\,TFL}}{1.5\,.\,\tau_0}}$$

Assessment of Dead Load of Test Floor Level W_{TFL} and Average Vertical Stress $\sigma_{0,\,TFL}$

Considering "q" as the weight-to-area ratio (see above) and N as the number of floors above and including the Test Floor Level, the average vertical stress into the wall section at Test Floor Level is given as:

$$W_{TFL} = q.N.A_t$$

$$\sigma_{0,\,TFL} = \frac{q.N.A_t}{(A_x+A_y)} = \frac{q\,.\,N}{\left(\frac{A_x}{A_t}+\frac{A_y}{A_t}\right)} = \frac{q\,.\,N}{\frac{a}{A_t}\left(1+\frac{b}{a}\right)} = \frac{q\,.\,N}{a_0\,.\,(1+\gamma)}$$

Assessment of the seismic coefficient "C"

$$C = \frac{T^{*}_{U,\,TFL}}{W_{TFL}} = \frac{a.\,\tau_0\,.\,\sqrt{1+\frac{\sigma_{0,\,TFL}}{1.5\,.\,\tau_0}}}{q.N.A_t} = \frac{a.\,\tau_0}{q.N}\sqrt{1+\frac{q.N}{1.5\,.\,a_0\,.\,\tau_0\,(1+\gamma)}}$$

N.B.

Useful spreadsheet tool comes up with the present guidelines for the calculation of coefficient "C" and more in general for the Normalized Final Scored

ANNEX 2

Explanation on fragility curves

By using the data from past earthquakes, it is possible to obtain the fragility curves which gives the relation between the Normalized Final Score (S_f), the expected damage (d-damage factor) and a certain earthquake intensity (y).

The damage factor ranges between 0 and 1 and is equal the ratio of the repairing cost to the reconstruction cost.

In a chart, where the PGA is on x-axis and the damage factor is on y-axis, the fragility curve can be assumed as a tri-linear curve. The damage factor is in fact not significant until a certain PGA inferior threshold (y_i), after that it increases linearly up until a certain PGA superior threshold (y_c) corresponding to the collapse of the building where it assumes a value of 1.

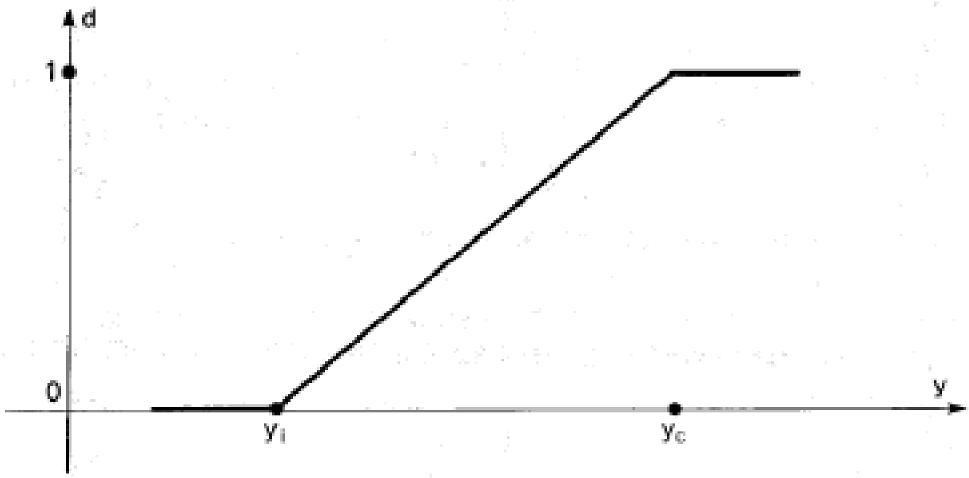


Figure. Tri-linear Fragility curve correlating the damage factor (d) and PGA (y) Gaugenti, Petrini 1993)

The section no. 8 of the first part of the form, with the damage survey, is useful for developing the fragility curves. Damages are evaluated and recorded by matrices that describe the damage status with the various extents and grades of the same, detected for every single floor and for every constructive component (vertical structures, floor structures, partition walls).

The overall damage factor (d) related to the entire building is given by (Angeletti et al.) :

$$d = \sum_{ij} Z_i F_j D_{ij}$$

where:

D_{ij} : partial floor damage index of the i-th constructive component placed on thej-th floor ;

Z_i: weight factors proportional to the economic losses of the i-th component[4];

[4] The Italian authors (V. Petrini et. al) have suggested for Zi the values 0.50, 0.30, 0.15 and 0.05 namely for the following constructive elements: vertical structures, floor structures, staircases and partition walls. Th survey's coordinator has to calibrate the weight factors Zi on the base of the ratio of the cost of the i-th component and the overall cost of the building.

- F_j: weight factors proportional to the ratio between the volume (or the area) of the j-th storey and the overall volume (or the overall area) of the building.

The partial floor damage index Dij is given by:

$$D_{ij} = E.G + \frac{1-E}{3} H$$

where G and H are expressed in terms of numerical value of the six damage grades on the interval 0-1 (namely A=0, B=0.2, C=0.4, D=0.6, E=0.8, F=1) and E is expressed in terms of numerical value of the ten percentage ranges on the interval 0-1 (namely 0.1=0-10%; 0.2=10-20%; 0.3=20-30%; 0.4=30-40%; 0.5=40-50%; 0.6=50-60%; 0.7=60-70%; 0.8=70-80%; 0.9=80-90%; 1=90-100%)

The fragility curves d (y, S_f) relating the expected damage (d) to the Normalized Final Score (S_f) and Peak Ground Acceleration (y), are given by

$$d(y, S_f) = \begin{cases} 0 & per\ y \leq y_i \\ \frac{y-y_1}{y_c-y_i} & per\ y_i < y < y_c \\ 1 & per\ y_c \leq y \end{cases}$$

where y_i is the ground acceleration which causes the first damage and y_c is the ground acceleration which causes the collapse of the building.

$$y_i = \alpha_i \,.\, exp(-\beta_i \,.\, S_f)$$

$$y_c = [\alpha_c + \beta_c \,.\, S_f^{\gamma}]^{-1}$$

y_i and y_c are assumed related to the Normalized Final Score S_f , according by :
The parameters α_i ,β_i , αc , βc and γ are obtained by statistical processing of vulnerability and damage data collected on previous earthquakes.

On this criteria, the authors E. Gaugenti and V. Petrini calibrated the fragility curves for masonry buildings on the base of damage data recorded after the Italian earthquakes in Friuli (1976) and Abruzzo (1984), so to obtain the following parameters and chart.

α_i	β_i	α_c	β_c	γ
0.08	0.0195	1	0.00191	1.8

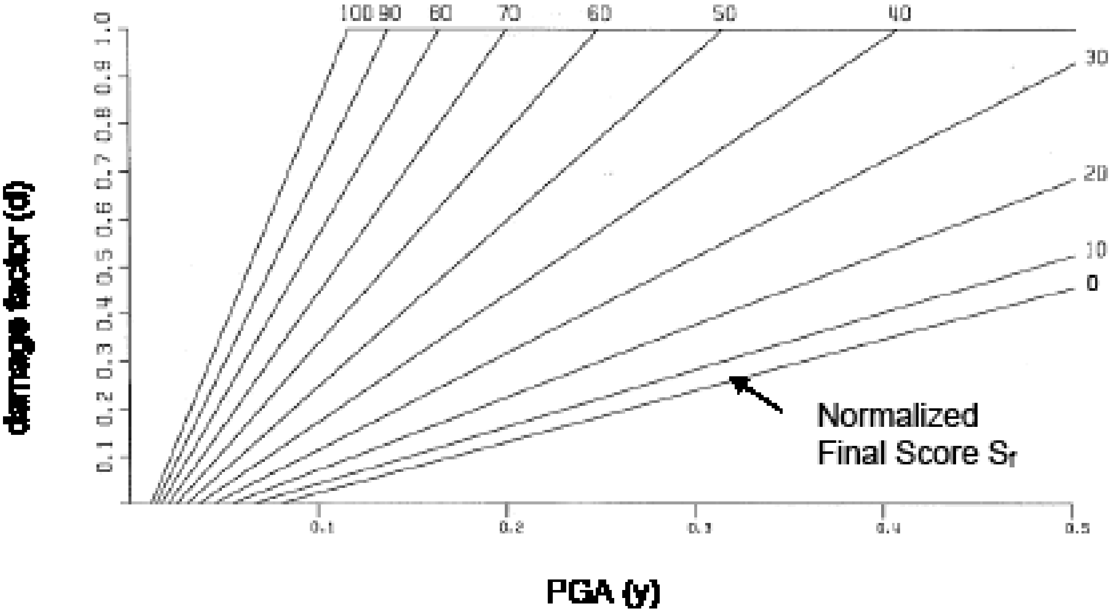


Figure. Fragility curves correlating the damage factor (d) and PGA (y) for different value of Normalized Final Score Sf (Gaugenti, Petrini 1993). Note: Sf is normalized on the range 0-100 .

1st PART - SEISMIC VULNERABILITY ASSESSMENT FORM

Section 1 - Administrative data

Building no: ☐☐☐☐ Form no: ☐☐☐☐ Date (dd/mm/yy): ☐☐☐☐☐☐ Team: ☐☐☐☐ Surveyors: ____________________

Section 2 - Building identification

Building denomination: ____________________ Location description (Address or Village/Chiwog/Gewog/Dzongkhag): ____________________

Latitude: ☐☐☐☐☐☐☐☐ Longitude: ☐☐☐☐☐☐☐☐

Building Position/adjacency: O Isolated O Internal O Extreme O Corner

Section 3 - Metrical data

Total no. of storeys: ☐☐☐☐ Avg. storey height [m]: ☐☐☐☐ Avg. storey area [m²] ☐☐☐☐ Max. height eave level [m]: ☐☐☐☐ Min. height eave level [m]: ☐☐☐☐

Section 4 - Building use

Use type: ☐ Assembly ☐ Commercial ☐ Emergency ☐ Industrial ☐ Office ☐ School ☐ Warehouse ☐ Other: __________ ☐ Residential no. units: ☐☐

Utilisation: O >65% O 30-65% O <30% O Not utilised O Abandoned O Under construction

No. occupants: ☐☐☐☐

Other designations: ☐ Historic ☐ Shelter

Property type: ☐ Public ☐ Private

Section 5 - Building age and interventions

Year built: ☐☐☐☐ ☐ Estimated O code O no code

Last significant intervention: O Nil O Enlargement O Superimposition O Restoration O Retrofit

Year: ☐☐☐☐ ☐ Estimated O code O no code

Section 6 - Conditions of finishes and systems

Exterior finishes:	Exterior frames:	Interior finishes:	Electrical system:	Water system:	Heating system:	Toilet system:	E=Efficient
O E O NE	O E O NE	O E O NE	O E O NE	O E O NE	O E O NE	O E O NE	NE=Not Efficient

Section 7 - Building Typology

Vertical Structures:

☐ RE-Rammed Earth ☐ AD-Adobe ☐ RS-Rubble Stones ☐ CS-Cut Stones ☐ UFB-Unreinforced B.

☐ SDS-Dressed stones ☐ CM-Confined M. ☐ CSEB-Earthen blocks ☐ RM-Reinforced M. ☐ Other __________

Floor Structures: ☐ Wood ☐ Concrete ☐ Steel ☐ Other __________

Roof type: ☐ Wood ☐ Steel ☐ Other __________

Roofing material: ☐ CGI sheet ☐ Wood ☐ shingles ☐ Slates ☐ Bamboo ☐ Other __________

Section 8 - Grade and extent of the damage

Date event (dd/mm/yy): ☐☐☐☐☐☐

H = **H**ighest grade of damage
E = damage **E**xtent (rel.most widespread)
G = **G**rade of the most widespread damage

Damage Grade
A = No damage
B = Slight
C = Moderate
D = Heavy
E = Very heavy
F = Collapse

Damage Extent

0	0-10%	**5**	50-60%
1	10-20%	**6**	60-70%
2	20-30%	**7**	70-80%
3	30-40%	**8**	80-90%
4	40-50%	**9**	90-100%

H	G	E	N.	H	G	E	N.	H	G	E	N.
Vertical Struct.				**Floor Struct.**				**Partition walls**			

Section 9 - Comments and sketch

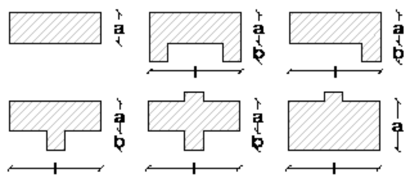
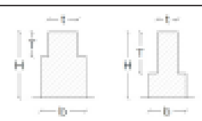
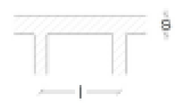
Photograph

Plan view (sketch or Google Map™ picture)

Comments: ____________________

☐ additional pages

2nd PART - SEISMIC VULNERABILITY ASSESSMENT FORM

	Vulnerability parameter	Class	IQ	Score	W	Assessment elements/Notes
1	**Resisting system type**	O A O B O C O D		0 5 20 45	1.00	O In line/compliant with seismic code [Class A] O Connections by bond beams, seismic bands [Class B] O Well tied orthogonal walls [Class C] O Absence of horizontal and vertical connections [Class D]
2	**Resisting system quality**	O A O B O C O D		0 5 25 45	0.25	O CM-Confined Masonry [Class A] O RM-Reinforced Masonry [Class B] O UMC - Unreinforced masonry with cement mortar (dressed/semi dressed stone masonry, brick, blocks, CSEB etc.) [Class C] O UMM - Unreinforced masonry with mud mortar [Class D] O RS - Rubble stone masonry O AD – Adobe [Class D] O RE - Rammed earth [Class D]
3	**Conventional seismic strength**	O A O B O C O D		0 5 25 45	1.50	No. of stories N = |_| Total area [m²] A_t = |_|_|_|_| Resisting wall area [m²] A_x = |_|_| A_y = |_|_| Shear strength [t/m²] τ_0 = |_|.|_| Average storey height[m] h = |_|.|_| Masonry density [t/m³] d_m = |_|.|_|_| Dead load of the floor [t/m²] DL = |_|.|_|_| α = |_|.|_|_| (*see notes*) [Class A] α ≥ 1 | [Class C] 0.4 ≤ α < 0.6 [Class B] 0.6 ≤ α < 1 | [Class D] α < 0.4
4	**Location and soil condition**	O A O B O C O D		0 5 25 45	0.75	Slope % of the ground s = |_|_|% Foundation O yes O no Rock O Loose soil without thrusting O Loose soil with thrusting O Elevation difference for foundations O no O Δh = |_|.|_| *For class type see notes.*
5	**Floor structures**	O A O B O C O D		0 5 15 45	0.50-1.00	Split-levels O yes O no Rigid floor O yes O no Floor-to-wall connections O yes O no % rigid floors (A/B type), walls connected |_|_|% *For class type see notes.*
6	**Plan irregularity**	O A O B O C O D		0 5 25 45	0.50	 β_1= a/l x 100 |_|_| β_2= b/l x 100 |_|_| [Class A] $\beta_1 \geq 80$ $\beta_2 \leq 10$ [Class B] $60 \leq \beta_1 < 80$ $10 < \beta_2 \leq 20$ [Class C] $40 \leq \beta_1 < 60$ $20 < \beta_2 \leq 30$ [Class D] $\beta_1 < 40$ $\beta_2 > 30$
7	**Elevation irregularity**	O A O B O C O D		0 5 25 45	0.50-1.00	 Mass ratio ΔM/M = |_|_|% Height ratio T/H = |_|_|% Surface with arcade: O no O yes Δ = |_|_|_|% *For class type see notes.*
8	**Maximum distance between walls**	O A O B O C O D		0 5 25 45	0.25	 l/s = |_|_| [Class A] l/s ≤ 15 [Class B] 15 < l/s ≤ 18 [Class C] 18 < l/s ≤ 25 [Class D] l/s > 25
9	**Roof**	O A O B O C O D		0 15 25 45	0.50-1.00	Roof structure: O Not thrust. O Reduced thrust O Thrust. Ceiling bond beam O yes O no Tie beams/Tie rods O yes O no Dead load of the roof [t/mq] DL_r = |_|.|_|_| Length of roof support [m] L_s = |_|_| Length of roof perimeter [m] L_r = |_|_| *For class type see notes.*
10	**Non-structural elements**	O A O B O C O D		0 0 25 45	0.25	*For class type see notes.*
11	**Damage and preservation state**	O A O B O C O D		0 5 25 45	1.00	*For class type see notes.*

Building no:	Form no:	Normalized Final Score	S_f = |_|.|_|_|	$S_f = \sum_{i=1}^{11} (Weight * Class\ score)_i \Big/ \sum_{i=1}^{11} (Weight * Maximum\ class\ score)_i$

NOTES AND REMINDERS FOR COMPILING THE FORM

The form must be compiled for an entire building, meaning by “building” a structurally homogeneous unit, generally distinguishable from adjacent buildings for structural typology, different height, age of construction, different storeys height, etc.
Information is generally defined by filling in the corresponding cells. In some sections, squared cells (☐) indicate the possibility of multiple answers: in such cases more than one answer is allowed; round cells (O) indicate the possibility of a single choice. When cells like |__| are present, it is necessary to write numbers (right justified). When underlines are present, it is necessary to write texts (capital letters, left justified). The dot, in the boxes in which it is present, separates the decimal parts of the integer and defines the maximum number of digits that can be carried; where this is not the case the numbers are integers.

The form is subdivided in two parts, for the filling instructions see the guidelines.

Hereinafter, some reminders for the class evaluations

3rd Vulnerability Parameter
Conventional Seismic Strength

$$\alpha = \frac{C}{A}$$

$$C = \frac{a_0 \cdot \tau_0}{q \cdot N}\sqrt{1+\frac{q \cdot N}{1.5 \cdot a_0 \cdot \tau_0 (1+\gamma)}} \quad ; \quad A_h = \frac{ZI\,S_a}{R\,g}$$

$$q = \frac{(A_x + A_y) \cdot h \cdot d_m}{A_t} + DL \qquad a_0 = \frac{a}{A_t} \;;\; \gamma = \frac{b}{a} \qquad a = \min(A_x;A_y) \;;\; b = \max(A_x;A_y)$$

4th Vulnerability Parameter - Location and soil condition

Soil Type	Presence of foundations	Slope percentage	Elevation difference (Δh)	Class
Rock	Yes	s ≤ 10	-	A
		10 < s ≤ 30	-	B
		30 < s ≤ 50	-	C
		s > 50	-	D
	No	s ≤ 10	-	A
		10 < s ≤ 30	-	B
		30 < s ≤ 50	-	C
		s > 50	-	D
Loose soil without thrusting	Yes	s ≤ 10	Δh = 0	A
		s ≤ 10	0 < Δh ≤ 1	B
		10 < s ≤ 30	Δh ≤ 1	B
		30 < s ≤ 50	Δh ≤ 1	C
		s > 50	-	D
		-	Δh > 1	D
	No	s ≤ 10	Δh = 0	A
		s ≤ 10	0 < Δh ≤ 1	B
		10 < s ≤ 20	Δh ≤ 1	B
		20 < s ≤ 30	Δh ≤ 1	C
		s > 50	-	D
		-	Δh > 1	D
Loose soil without thrusting	Yes	s ≤ 50	Δh ≤ 1	C
		s > 50	-	D
		-	Δh > 1	D
	No	s ≤ 30	Δh ≤ 1	C
		s > 30	-	D
		-	Δh > 1	D

5th Vulnerability Parameter - Floor structures

In-plane stiffness and Floor-to wall connection	Split-levels	Class
Rigid with floor-to-wall connections	No	A
	Yes	B
Slightly deformable with floor-to-wall connections	No	C
	Yes	C
Rigid without floor-to-wall connections	No	D
	Yes	D
Slightly deformable without floor-to-wall connections	No	D
	Yes	D

7th Vulnerability Parameter
Elevation irregularity

ΔM / M [ΔA / A]	T/H	Δ (*)	Class
ΔA ≤ 10 or zero	T/H ≤ 10 or zero	Δ= 0	A
10 < ΔA ≤ 20	0 < T/H ≤ 10	Δ ≤ 10	B
ΔA > 20	10 < T/H ≤ 40	10 < Δ ≤ 20	C
-	T/H > 40	Δ > 20	D

*Δ = percentage ratio between the floor area interested by the arcade and total floor area

9th Vulnerability Parameter - Roof

Classification of the roof structures	Ceiling bond beam	Tie beams / tie rods	Class
Not thrusting	Yes	Yes – No	A
	Yes – No	Yes	A
	No	Yes - No	B
Reduced thrust	Yes	Yes - No	B
	Yes - No	Yes	B
	No	No	C
Thrusting structure	Yes	Yes - No	C
	Yes - No	Yes	C
	No	No	D

10th Vulnerability Parameter
Non-structural elements

Classes A-B:	buildings without windows, extensions, projections or false ceilings; buildings with doors that are well-connected to the walls, with small and light chimneys and with well-connected false ceiling;
	buildings with balconies which make up an integral part of the structures;
Class C:	buildings with external frames or small and badly placed signboards on the walls, small and poorly connected false ceilings or large and well-connected false ceilings.
Class D:	buildings with: chimneys or other extensions in the roof that are poorly fastened to the structure, poorly built railings or significantly heavy items that can collapse in event of an earthquake;
	buildings with balconies or other poorly built projections;
	buildings with large and poorly connected false ceilings.

11th Vulnerability Parameter
Damage and preservation state

Class A:	walls in good condition with no visible damage;
Class B:	buildings with localised damage caused by earthquakes;
Class C:	buildings that are moderately damaged (cracks width up to 2-3 mm) or has hairline cracks due to the earthquake;
	buildings that do not have damage, but are in poor upkeep to the extent that its structural resistance has been compromised.
Class D:	buildings with out-of-plumb walls and/or serious damage even if just at a local level. buildings characterised by severe deterioration of materials.
	buildings that do not have damage, but are in poor upkeep to the extent that its structural resistance has been compromised.

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