MŰEGYETEM 1782

Budapest University of Technology and Economics
Faculty of Civil Engineering

Building vulnerability assessment of historic building in Budapest to define the stages of seismic fragility

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Abstract

The city centre of historic cities are densely populated and the inhabitants mostly live in historic buildings. Most of these buildings are made of brick or stone and their structure were designed following the traditional techniques without taking into account the seismic hazards. Accordingly, seismic risk assessment of such masonry structures is an important issue nowadays. This study focuses on the conception of methodology, which implies all the steps for fragility assessment of historic building. City center of Budapest was selected as a typical study area and investigation has been done for one of the historic building.

The research focuses on the building vulnerability assessment of one selected building. The study included in the first step the identification of the building archetype, construction technology and condition of the structure and structural elements. To obtain all these parameters, on site survey was made for the existing building, which also included the measurements of the building geometry and the structural components.

After gathering the information and the new measurements of the building, modifications were made for the old construction plans, which were obtained from archives. The volumes and the weights of the structural elements of the building were calculated.

The extracted data was used to create a numerical model of the building. Linear and non-linear analysis were made for the entire structure to find the capacity curve. According the capacity and fragility curve the seismic hazard was estimated.

Presented methodology is useful tool for the assessment of seismic hazard of historic buildings, not only in Budapest but at other parts of the world, too.

1. Introduction

Buildings are the most important structures when the earthquake occurs. From last 10 years earthquake events, such as the Japan earthquake (2011), the Chile earthquake (2010), the Afghanistan earthquake (2015) and the Nepal earthquake (2015), plenty of buildings were totally collapsed and a lot of them were demaged. Field surveys have shown that the buildings in a poor condition are main cause of human fatalities and property losses. Seismic fragility estimation for existing buildings has become significant issue, especially for last decades, when the frequency of disastrous earthquakes is increased.

Hungary is a country, where the Komárom and the Dunaharaszti earthquakes happened and more than thousand houses were totally collapsed. The buildings in the city centre of historic cities are made by brick masonry. Masonry walls have enough compressive resistance to transmit vertical forces without failure. However, their load bearing capacity against horizontal loads (wind, earthquake) and deformation capacity is low. With the introduction of the new European earthquake standard the design requirements of Eurocode 8 must be fulfilled [1]. Existing building was designed in 1907 year and it is obvious that seismic analyses was not made to estimate seismic fragility and seismic hazard.

Hence, the presented research is relevant and apposite. The case study represents building vulnerability assessment of selected historical (masonry) building in Budapest to estimate seismic fragility.

For shear wall structures, Hwang and Jaw (1990) recommends to show a simplified analythical method. Many researchers use different methodologies to develop fragility curves. These methodologies and the importance of the fragility curve are demonstrated in the research paper [2].

1.1 The aim of the study

- Development of the concepts for building vulnerability assessment according to the site survey.
- Seismic Fragility assessment of historic building due to the building vulnerability estimation.
- The methodology of seismic fragility assessment of historic buildings to be usable for any part of the world. It finally reduces the human fatalities after the natural disasters and will be an economical benefit for the country, too.

1.2 Postulates of the methodology to solve the problem

- Site survey for the existing building; Data collection, required for vulnerability assessment, for experimental and numerical model analysis of historical building;
- Compilation of the building vulnerability assessment sheet according to the site survey.
- Estimation of mechanical properties of the building materials;
- Procure old drawings of the selected building and renew by new measurements;
- Data calculation of the volumes and the weights of the building and its structural elements;
- Design of 3D model and nonlinear static analysis in finite element software Sap2000

- Modeling the methodology of seismic fragility assessment of the existing building;

    Determination of capacity (Force - displacement) curve;

    Definition of IDA (Incremental Dynamic Analysis) curve;

    Representation of seismic fragility and seismic hazard curves.

1.3 Historic value and importance of the structure

Research work was done for brick masonry historic building, located in the heart of the Budapest, on Bartok Bela street 10/12 (Fig. 1,2,3). The front facade of the existing building overlooks the Bartok Bela street, the back facade – Budafoki street, right side facade from Bartok Bela street is located on Csiki street and from left side facade has a border with adjacent building.
The place was perfectly selected. Almost all the Hungarian traditional Buildings , located in the city center are dated in XX century and represents the face of the city. Therefore to protect the historic buildings against the unpredictable earthquake events, has a vital role for the Country.

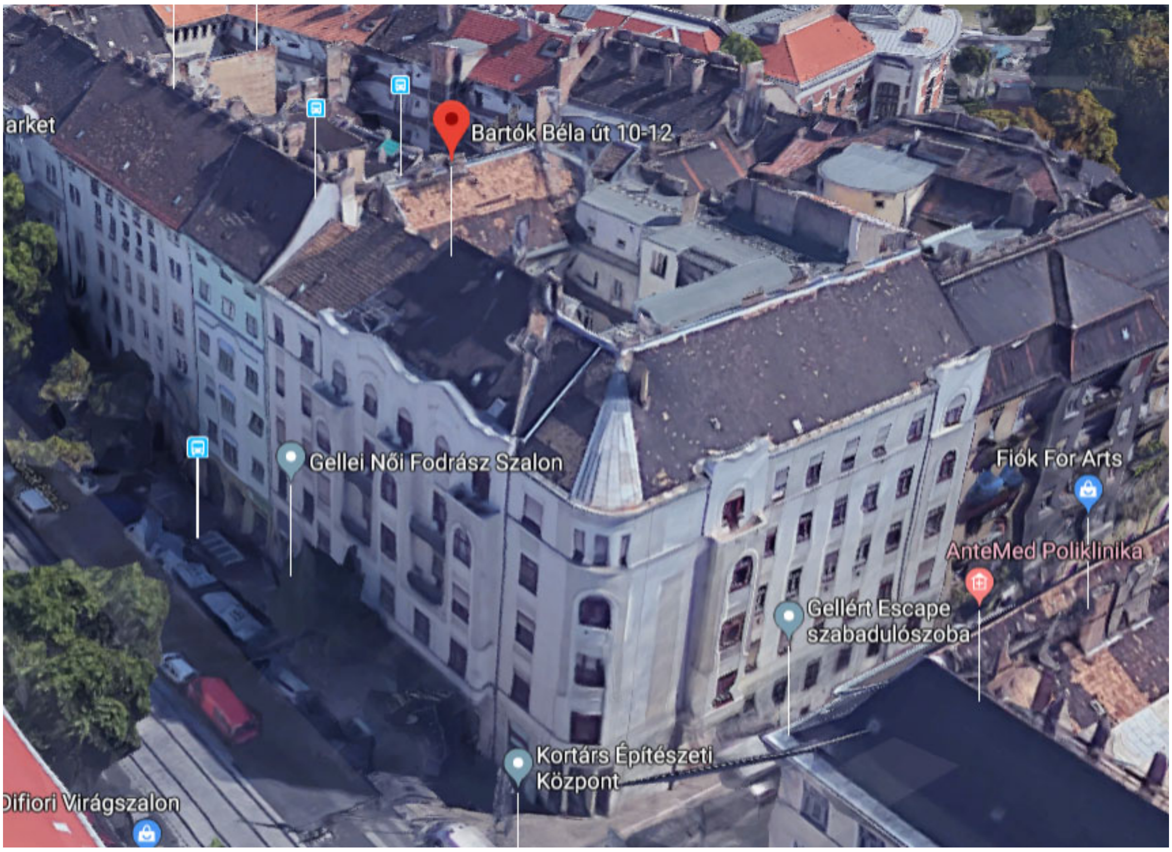


Figure 1. Existing building photo from google map

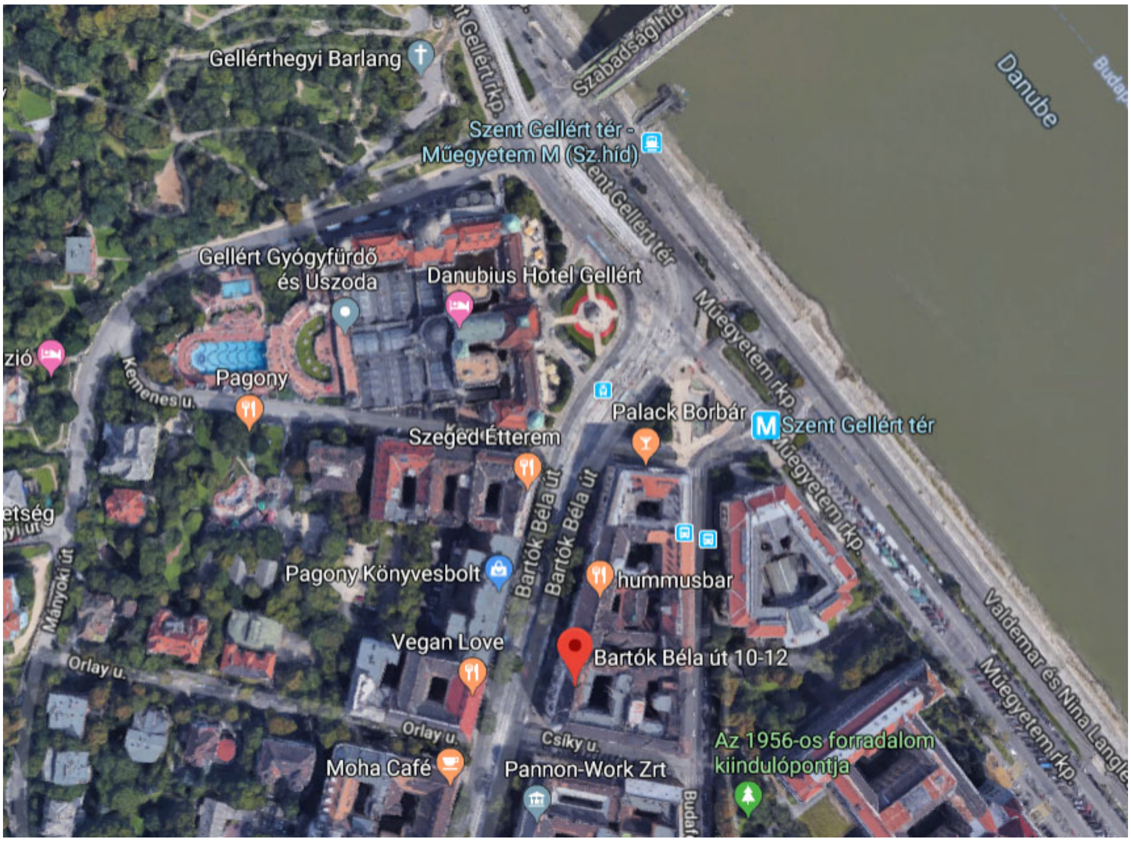


Figure 2. Existing building location from google map

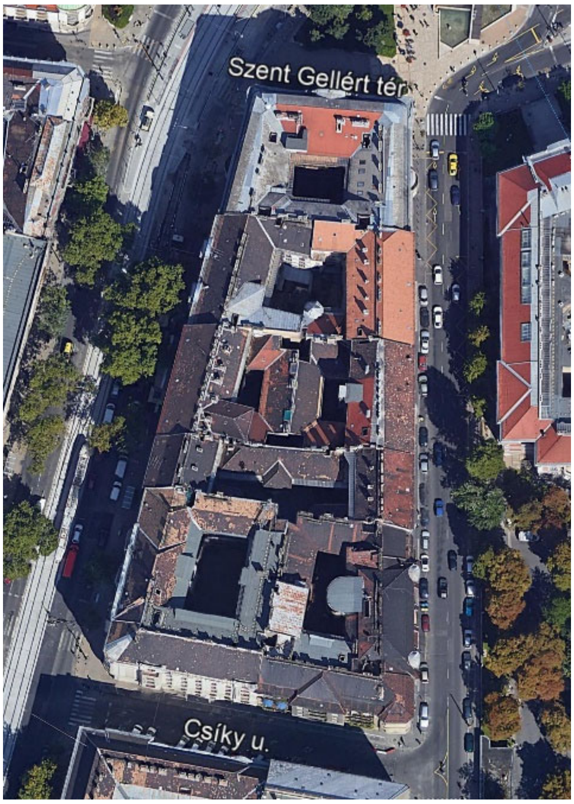


Figure 3. Selected structure top view with adjacent buildings

2. Site Survey

2.1 Steps required to fulfil during the site survey for building vulnerability assessment

- Visual investigation of the building vulnerability;
- Photos have to be taken for both throughout the building and its individual elements; For any special details and damaged structural elements;
- Sketches of the building with it's geometrical measurements, which includes: the height of the storeys, openings; Dimensions of the courtyard, cellar, walls, staircase, balconies, roof; Thickness of the slab, beam and any of significant structural elements;
- Identification of building archetype;
- Define the age, importance and usage of the structure;
- Estimation of construction configuration and construction technology;
- Define the condition of the structure and structural elements;

2.2 Completed work during the site survey

Existing structure is residential building, located in the city center. It was built in 1907. Shape of the structure is rectangular and has vertical irregularity. 5-6 storey building (with additional cellar) is surrounded by courtyard and inner round balconies for each floor (Fig. 4. a,b). Northern and eastern part of the building has 5 storeys, with additional cellar and loft construction (Fig. 5), while the South and western part has 6 storeys with cellar and on the top with flat roof.

Figure 4. a,b Exterior photos of the selected building

Figure 5. loft construction

Site visit had begun by visual check of the cellar and the photos were taken throughout the whole building and its individual structural elements. The major part of the cellar is located under the ground level. Its interior part has 3.5m as total height (Fig. 5). Main load-bearing wall thickness of underground level is 0.95m, meanwhile some of them has 0.5m thickness. The material, used for the wall is brick masonry.

The cellar is represented as corridor system structure (Fig. 6.a) with small, separated rooms from left and right hand side. Brick arches are used as a slab (Fig. 6.b). Inside part of the cellar is dry and there is no water seepage.

There was no possibility to verify the type of the foundation by visual investigation.

Figure 6. a,b   Cellar

The structure has two brick masonry cores with main staircase with elevator (Fig. 7.a,b) and secondary staircase, made by stone. Last floor staircase is not in a good condition and requires more detailed investigation. There is an elevator in the corner of south eastern part.

Figure 7.a,b   Internal Staircase

Ground level is highest level of the building with height of 5.15m, but the floor construction is installed on 1.38 m above from the ground with narrow balconies around the building, surfaced by stone material. The entrances, located on the balcony are connected to the ground by separate, external stone staircases. Some of the upper level balconies have material loss from the bottom part (Fig. 8a,b). Main load bearing brick masonry wall has 0.85m thickness and on the same level 0.5m and 0.4m load bearing and 0.3m secondary walls are represented. Walls around the courtyard have a lot of openings, which is the considerable part for seismic analysis.
The height of the first floor is 4.14m and the above level height - 4.16m. Typical level height is 4m. Only the last storey height is around 3.5m. Wall thicknesses varies from 0.65m to 0.3m.

Figure 8.a,b Material loss, illustrated on the bottom part of the balconies

During the survey, Schmidt hammer was used to check the type of the material of structural elements and in case of concrete segments to define the quality of material.

The crackes discovered in the walls and in the other part of the structural elements are not significantly valuable.
Steel beams with 20cm in height are represented on the edges of the floor and balcony slabs.
The building has seven individual balconies from the front facade from Bartok Bela street, but it could not be available to check.
Due to the Komárom earthquake (1763) it is obvious that the roof part of the buildings are very important and sensitive part during the earthquake event. Houses with displaced roofs and overturned gables are illustrated in the literature [3].
The existing building has two type of the roof construction. From southern side it is an open gable and from western side a shed roof is presented. Major part of the loft construction consists of timber beams, columns and rafters (Fig. 9.a,b,c). Maximum height of the roof is around 6.5-6.7m from the bottom. Some of the walls are continuing until the top of the roof. There are several chimney constructions, too.

Figure 9.a,b,c Loft constructions

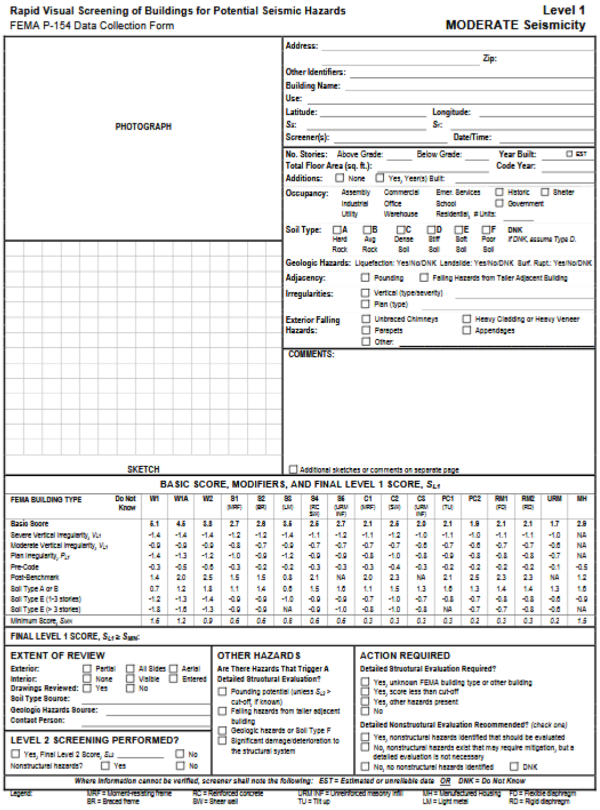
Visual investigation of the loft constructions shows that the materials (Fig. 9.a,b,c) are relatively new, in good condition.

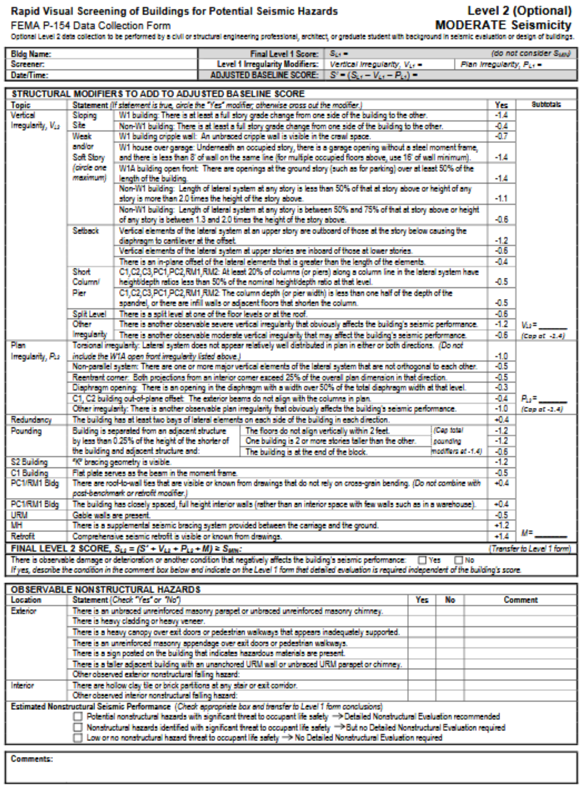
Quality and the condition of the whole building might be rated as moderate.

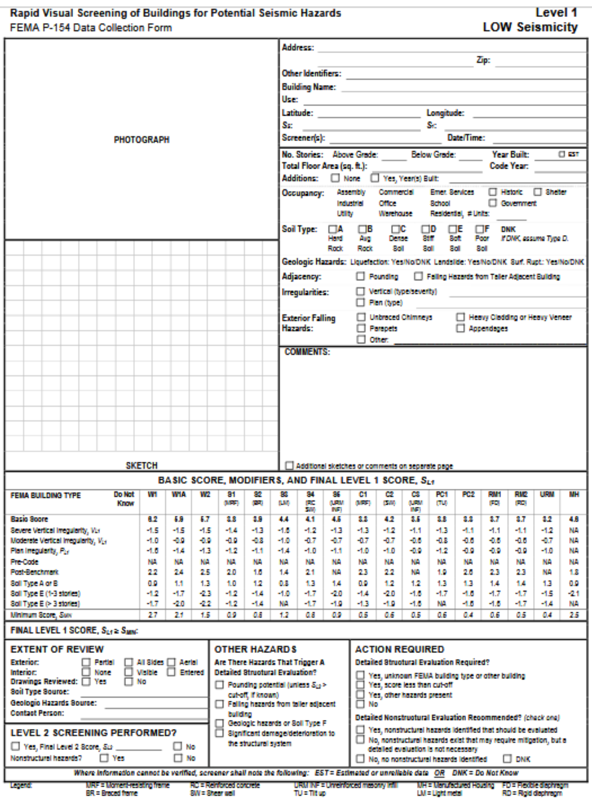
3. Compilation of the building vulnerability assessment sheet

After the searching of Hungarian building vulnerability assessment form, It was revealed that the form does not exist in Hungary. Based on the above mentioned problem for new Hungarian building vulnerability assessment sheet formation, Indian [4] and American [5] forms were selected as a sample. All the items were discussed and modified according to the specifics of Hungarian buildings and its individual characteristics.

To become the process obvious, American (Fig. 10) and Indian forms (Fig. 11 and Fig. 12) are illustrated on this research paper.


Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form
Level 1
MODERATE Seismicity


Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form
Level 2 (Optional)
MODERATE Seismicity


Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form
Level 1
LOW Seismicity

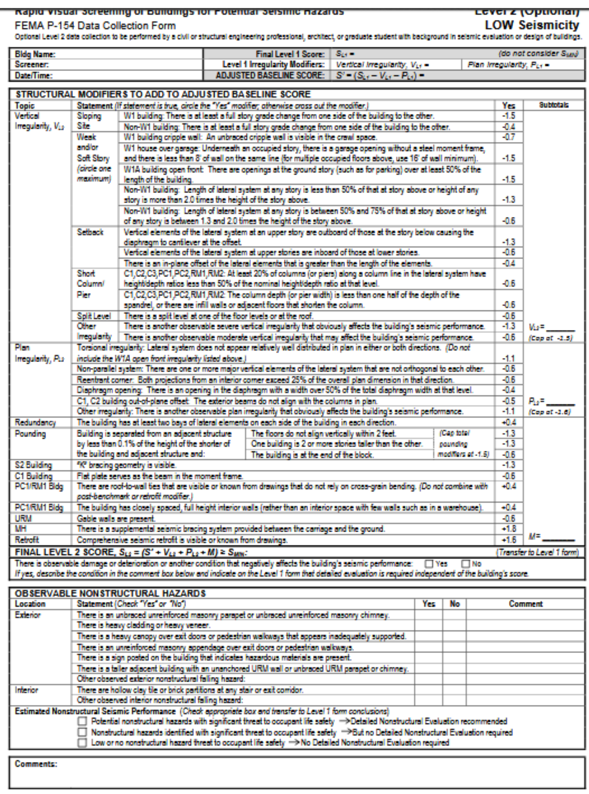
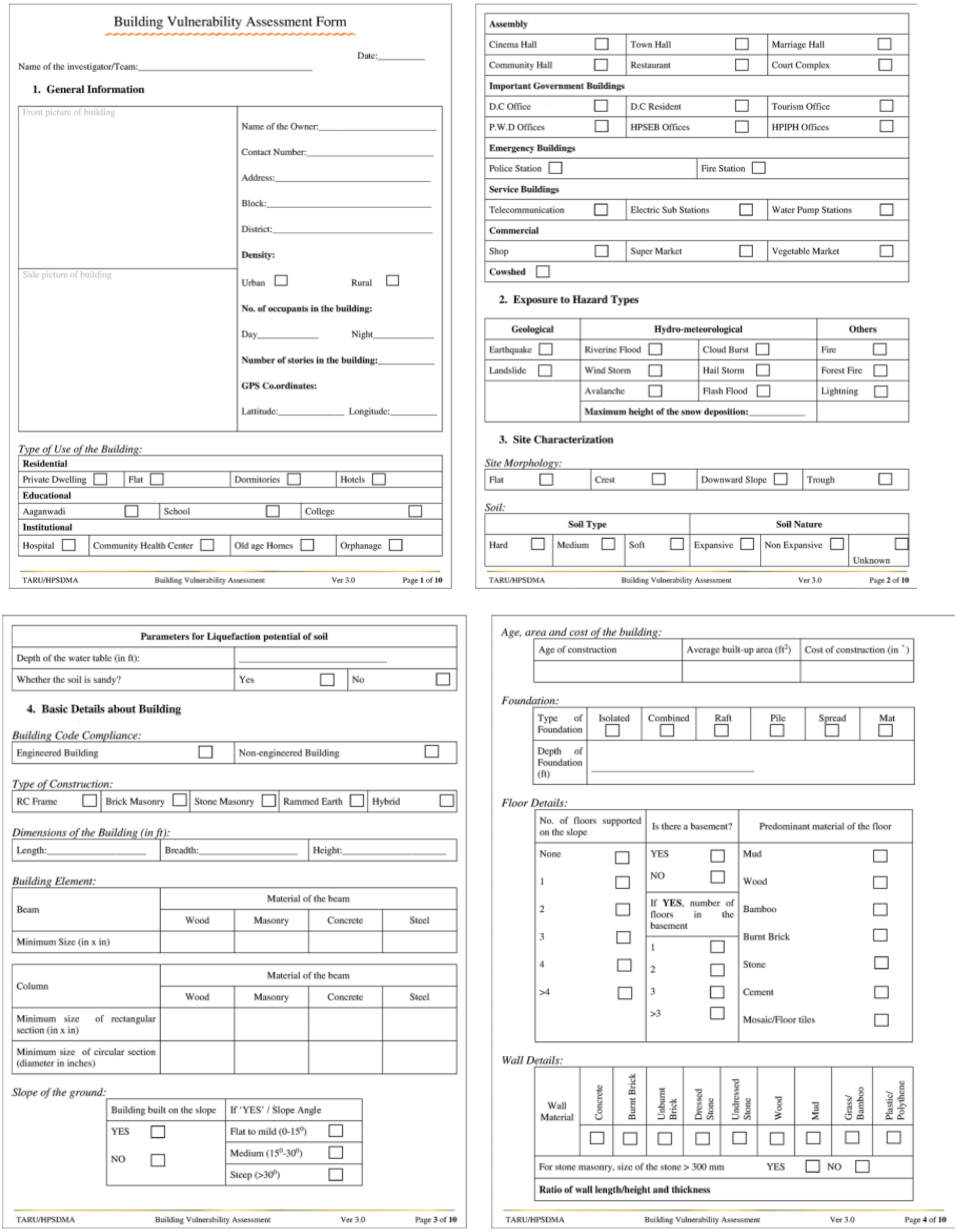

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form
Level 2 (Optional)
LOW Seismicity

Figure 10. Rapid Visual Screening of Buildings for Potential Seismic Hazards Level [5]



Building Vulnerability Assessment Form

Date:________

Name of the investigator/Team:______________________

1. General Information

Front picture of building	Name of the Owner:____
	Contact Number:____
	Address:____
	Block:____
	District:____
	Density:
Side picture of building	Urban ☐ Rural ☐
	No. of occupants in the building:
	Day____ Night____
	Number of stories in the building:____
	GPS Co.ordinates:
	Latitude:____ Longitude:____

Type of Use of the Building:

Residential			
Private Dwelling ☐	Flat ☐	Dormitories ☐	Hotels ☐
Educational			
Aaganwadi ☐	School ☐	College ☐	
Institutional			
Hospital ☐	Community Health Center ☐	Old age Homes ☐	Orphanage ☐

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Assembly		
Cinema Hall ☐	Town Hall ☐	Marriage Hall ☐
Community Hall ☐	Restaurant ☐	Court Complex ☐
Important Government Buildings		
D.C Office ☐	D.C Resident ☐	Tourism Office ☐
P.W.D Offices ☐	HPSEB Offices ☐	HPIPH Offices ☐
Emergency Buildings		
Police Station ☐	Fire Station ☐	
Service Buildings		
Telecommunication ☐	Electric Sub Stations ☐	Water Pump Stations ☐
Commercial		
Shop ☐	Super Market ☐	Vegetable Market ☐
Cowshed ☐		

2. Exposure to Hazard Types

Geological	Hydro-meteorological		Others
Earthquake ☐	Riverine Flood ☐	Cloud Burst ☐	Fire ☐
Landslide ☐	Wind Storm ☐	Hail Storm ☐	Forest Fire ☐
	Avalanche ☐	Flash Flood ☐	Lightning ☐
	Maximum height of the snow deposition:____		

3. Site Characterization

Site Morphology:

Flat ☐	Crest ☐	Downward Slope ☐	Trough ☐

Soil:

Soil Type			Soil Nature		
Hard ☐	Medium ☐	Soft ☐	Expansive ☐	Non Expansive ☐	Unknown ☐

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Parameters for Liquefaction potential of soil			
Depth of the water table (in ft):	____		
Whether the soil is sandy?	Yes ☐	No ☐	

4. Basic Details about Building

Building Code Compliance:

Engineered Building ☐	Non-engineered Building ☐

Type of Construction:

RC Frame ☐	Brick Masonry ☐	Stone Masonry ☐	Rammed Earth ☐	Hybrid ☐

Dimensions of the Building (in ft):

Length:____	Breadth:____	Height:____

Building Element:

Beam	Material of the beam			
	Wood	Masonry	Concrete	Steel
Minimum Size (in x in)				

Column	Material of the beam			
	Wood	Masonry	Concrete	Steel
Minimum size of rectangular section (in x in)				
Minimum size of circular section (diameter in inches)				

Slope of the ground:

Building built on the slope	If 'YES' / Slope Angle
YES ☐	Flat to mild (0-15⁰) ☐
NO ☐	Medium (15⁰-30⁰) ☐
	Steep (>30⁰) ☐

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Age, area and cost of the building:

Age of construction	Average built-up area (ft²)	Cost of construction (in `)

Foundation:

Type of Foundation	Isolated ☐	Combined ☐	Raft ☐	Pile ☐	Spread ☐	Mat ☐
Depth of Foundation (ft)	____					

Floor Details:

No. of floors supported on the slope	Is there a basement?	Predominant material of the floor
None ☐	YES ☐	Mud ☐
1 ☐	NO ☐	Wood ☐
2 ☐	If YES, number of floors in the basement	Bamboo ☐
3 ☐	1 ☐	Burnt Brick ☐
4 ☐	2 ☐	Stone ☐
>4 ☐	3 ☐	Cement ☐
	>3 ☐	Mosaic/Floor tiles ☐

Wall Details:

Wall Material	Concrete	Burnt Brick	Unburnt Brick	Dressed Stone	Undressed Stone	Wood	Mud	Grass/ Bamboo	Plastic/ Polythene
	☐	☐	☐	☐	☐	☐	☐	☐	☐
For stone masonry, size of the stone > 300 mm	YES ☐	NO ☐							
Ratio of wall length/height and thickness									

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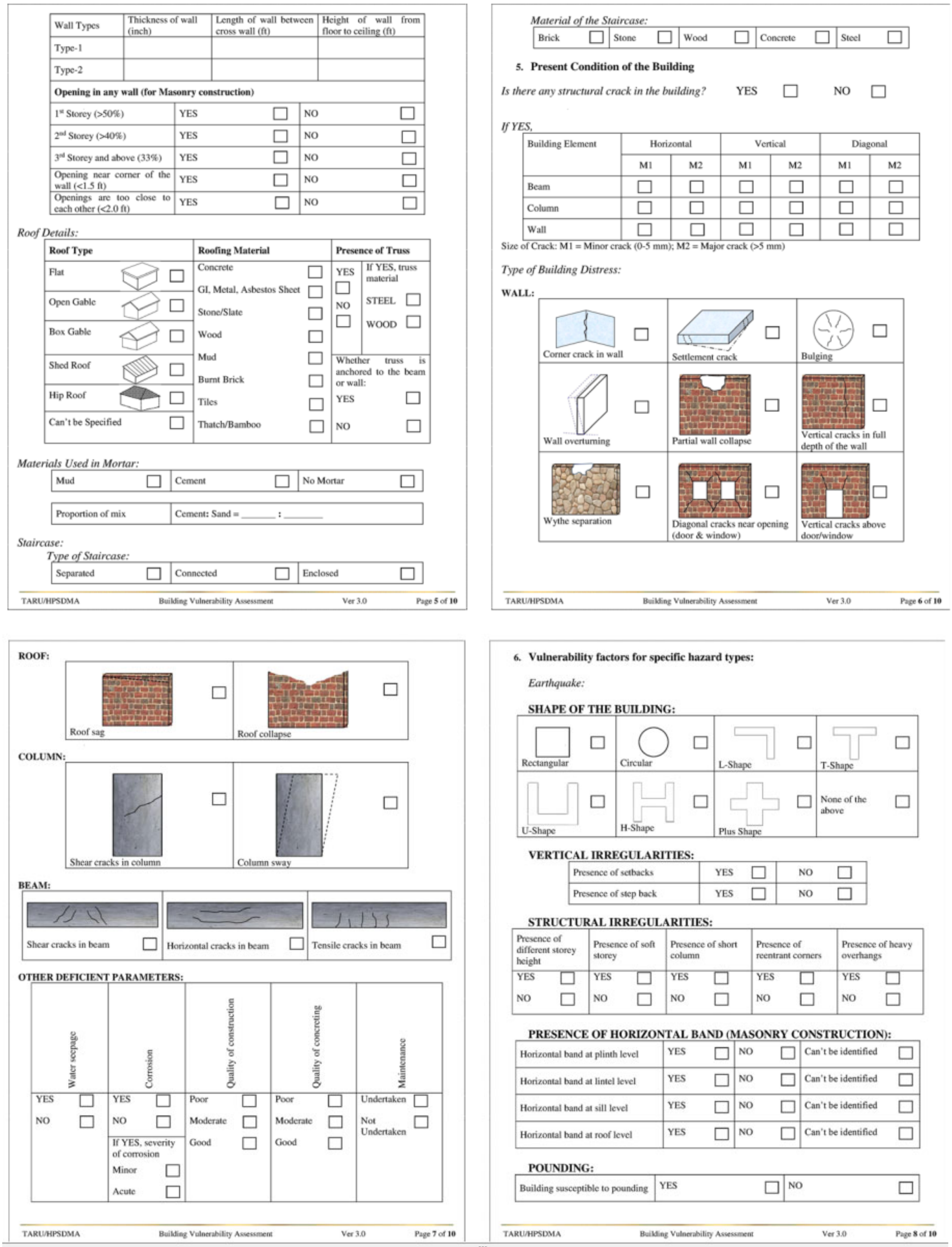
Figure 11. Indian building vulnerability assessment form [4]



Wall Types	Thickness of wall (inch)	Length of wall between cross wall (ft)	Height of wall from floor to ceiling (ft)
Type-1			
Type-2			

Opening in any wall (for Masonry construction)

1st Storey (>50%)	YES	☐	NO	☐
2nd Storey (>40%)	YES	☐	NO	☐
3rd Storey and above (33%)	YES	☐	NO	☐
Opening near corner of the wall (<1.5 ft)	YES	☐	NO	☐
Openings are too close to each other (<2.0 ft)	YES	☐	NO	☐

Roof Details:

Roof Type		Roofing Material		Presence of Truss
Flat	☐	Concrete	☐	YES ☐ / If YES, truss material
Open Gable	☐	GI, Metal, Asbestos Sheet	☐	NO ☐ / STEEL ☐
Box Gable	☐	Stone/Slate	☐	WOOD ☐
Shed Roof	☐	Wood	☐	Whether truss is anchored to the beam or wall:
Hip Roof	☐	Mud	☐	YES ☐
Can't be Specified	☐	Burnt Brick	☐	NO ☐
		Tiles	☐	
		Thatch/Bamboo	☐	

Materials Used in Mortar:

Mud ☐	Cement ☐	No Mortar ☐
Proportion of mix	Cement: Sand = ______ : ______	

Staircase:

Type of Staircase:

Separated ☐	Connected ☐	Enclosed ☐

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Material of the Staircase:

Brick ☐	Stone ☐	Wood ☐	Concrete ☐	Steel ☐

5. Present Condition of the Building

Is there any structural crack in the building? YES ☐ NO ☐

If YES,

Building Element	Horizontal		Vertical		Diagonal	
	M1	M2	M1	M2	M1	M2
Beam	☐	☐	☐	☐	☐	☐
Column	☐	☐	☐	☐	☐	☐
Wall	☐	☐	☐	☐	☐	☐

Size of Crack: M1 = Minor crack (0-5 mm); M2 = Major crack (>5 mm)

Type of Building Distress:

WALL:

Corner crack in wall ☐	Settlement crack ☐	Bulging ☐
Wall overturning ☐	Partial wall collapse ☐	Vertical cracks in full depth of the wall ☐
Wythe separation ☐	Diagonal cracks near opening (door & window) ☐	Vertical cracks above door/window ☐

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ROOF:

Roof sag ☐	Roof collapse ☐

COLUMN:

Shear cracks in column ☐	Column sway ☐

BEAM:

Shear cracks in beam ☐	Horizontal cracks in beam ☐	Tensile cracks in beam ☐

OTHER DEFICIENT PARAMETERS:

Water seepage	Corrosion	Quality of construction	Quality of concreting	Maintenance
YES ☐	YES ☐	Poor ☐	Poor ☐	Undertaken ☐
NO ☐	NO ☐	Moderate ☐	Moderate ☐	Not Undertaken ☐
	If YES, severity of corrosion	Good ☐	Good ☐	
	Minor ☐			
	Acute ☐			

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6. Vulnerability factors for specific hazard types:

Earthquake:

SHAPE OF THE BUILDING:

Rectangular ☐	Circular ☐	L-Shape ☐	T-Shape ☐
U-Shape ☐	H-Shape ☐	Plus Shape ☐	None of the above ☐

VERTICAL IRREGULARITIES:

Presence of setbacks	YES ☐	NO ☐
Presence of step back	YES ☐	NO ☐

STRUCTURAL IRREGULARITIES:

Presence of different storey height	Presence of soft storey	Presence of short column	Presence of reentrant corners	Presence of heavy overhangs
YES ☐	YES ☐	YES ☐	YES ☐	YES ☐
NO ☐	NO ☐	NO ☐	NO ☐	NO ☐

PRESENCE OF HORIZONTAL BAND (MASONRY CONSTRUCTION):

Horizontal band at plinth level	YES ☐	NO ☐	Can't be identified ☐
Horizontal band at lintel level	YES ☐	NO ☐	Can't be identified ☐
Horizontal band at sill level	YES ☐	NO ☐	Can't be identified ☐
Horizontal band at roof level	YES ☐	NO ☐	Can't be identified ☐

POUNDING:

Building susceptible to pounding	YES ☐	NO ☐

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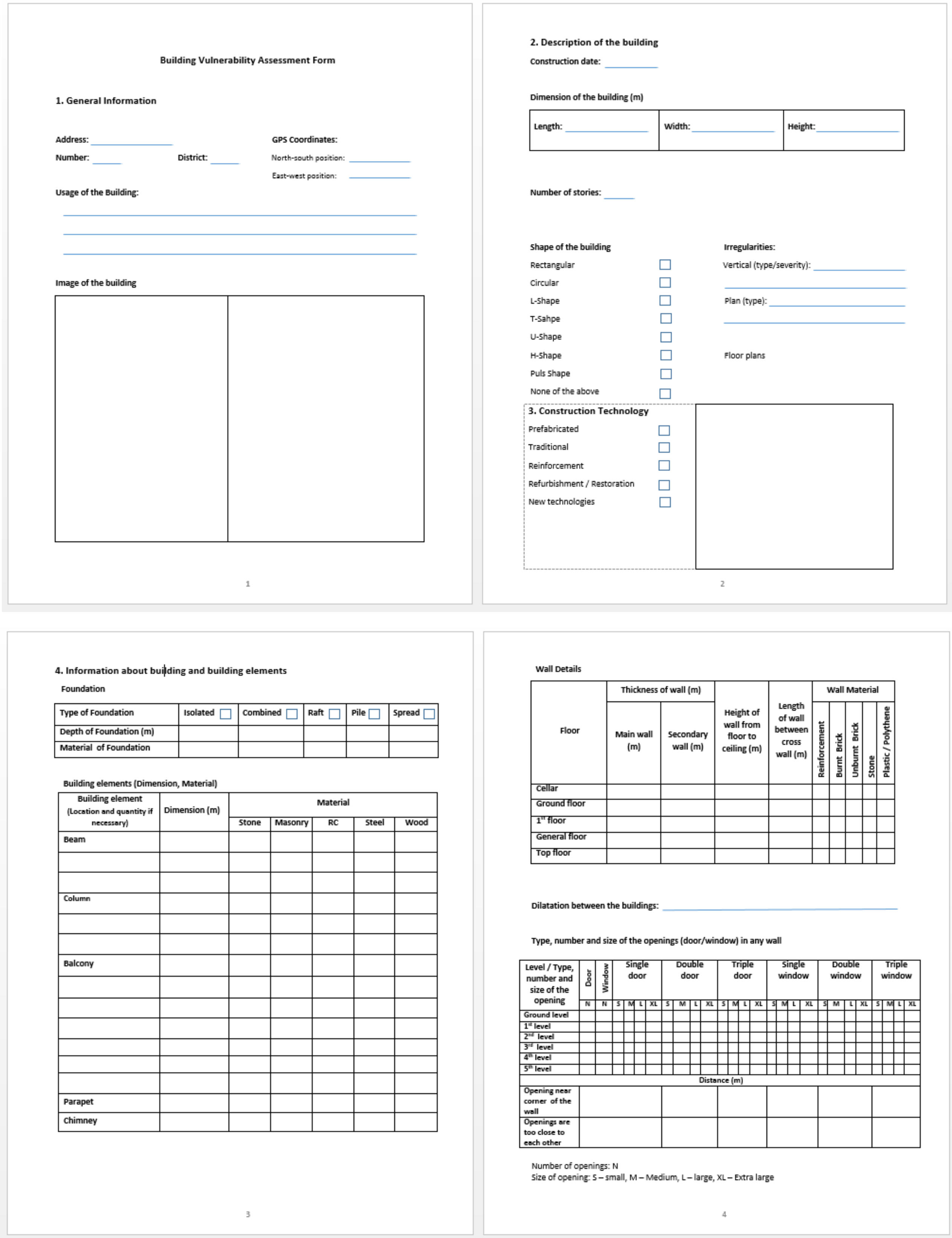
Figure 12. Indian building vulnerability assessment form (continuation) [4]

After the deep discussion and comparison, related to the Building vulnerability assessment form for Hungary, new form was created (Fig.13, Fig.14).



Building Vulnerability Assessment Form

1. General Information

Address: ______ GPS Coordinates:

Number: ______ District: ______ North-south position: ______

East-west position: ______

Usage of the Building:

Image of the building

1

2. Description of the building

Construction date: ______

Dimension of the building (m)

Length:	Width:	Height:

Number of stories: ______

Shape of the building: Rectangular ☐, Circular ☐, L-Shape ☐, T-Sahpe ☐, U-Shape ☐, H-Shape ☐, Puls Shape ☐, None of the above ☐

Irregularities:

Vertical (type/severity): ______

Plan (type): ______

Floor plans

3. Construction Technology: Prefabricated ☐, Traditional ☐, Reinforcement ☐, Refurbishment / Restoration ☐, New technologies ☐

2

4. Information about building and building elements

Foundation

Type of Foundation	Isolated ☐	Combined ☐	Raft ☐	Pile ☐	Spread ☐
Depth of Foundation (m)					
Material of Foundation					

Building elements (Dimension, Material)

Building element (Location and quantity if necessary)	Dimension (m)	Material				
		Stone	Masonry	RC	Steel	Wood
Beam						
Column						
Balcony						
Parapet						
Chimney						

3

Wall Details

Floor	Thickness of wall (m)		Height of wall from floor to ceiling (m)	Length of wall between cross wall (m)	Wall Material				
	Main wall (m)	Secondary wall (m)			Reinforcement	Burnt Brick	Unburnt Brick	Stone	Plastic / Polythene
Cellar									
Ground floor									
1st floor									
General floor									
Top floor									

Dilatation between the buildings: ______

Type, number and size of the openings (door/window) in any wall

Level / Type, number and size of the opening	Door	Window	Single door				Double door				Triple door				Single window				Double window				Triple window			
	N	N	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL
Ground level																										
1st level																										
2nd level																										
3rd level																										
4th level																										
5th level																										
	Distance (m)																									
Opening near corner of the wall																										
Openings are too close to each other																										

Number of openings: N

Size of opening: S – small, M – Medium, L – large, XL – Extra large

4

Figure 13. Building vulnerability assessment form for Hungary

Type and material of staircase

Type / Material	Stone	RC	Steel	Wood
External				
Connected				
Enclosed				

Roof Details

Roof Type		Material		Presence of truss	
Flat	☐	Concrete	☐	Steel	☐
Open Gable	☐	Metal	☐	Wood	☐
Box Gable	☐	Stone/Slate	☐	If truss is anchoured To the beam	☐
Shed roof	☐	Wood	☐	If truss is anchoured To the wall	☐
Hip roof	☐	Burnt brick	☐		
Other	☐	Tile	☐		

5

5. Condition assessment

Present condition

New ☐	Moderately ☐	Poor ☐

Detailed description

Location of Crack	Crack size (mm)	Horizontal			Vertical			Diagonal		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
Beam										
Column										
Wall										
Near openings										
Balcony										
Parapet										
Chimney										

Size of Crack: M1 = Minor crack (0-33%), M2=Moderately crack (33-66%), M3=Major Crack (66-100%)

6

Other deficient parameters

Type / Condition	No evidence	Location	Minor	Major
Water seepage				
Corrosion				
Loss of material				
Quality of concreting				
Bulging or sag of building element				
Overturning of building element				
Collapse of building element				
Other				

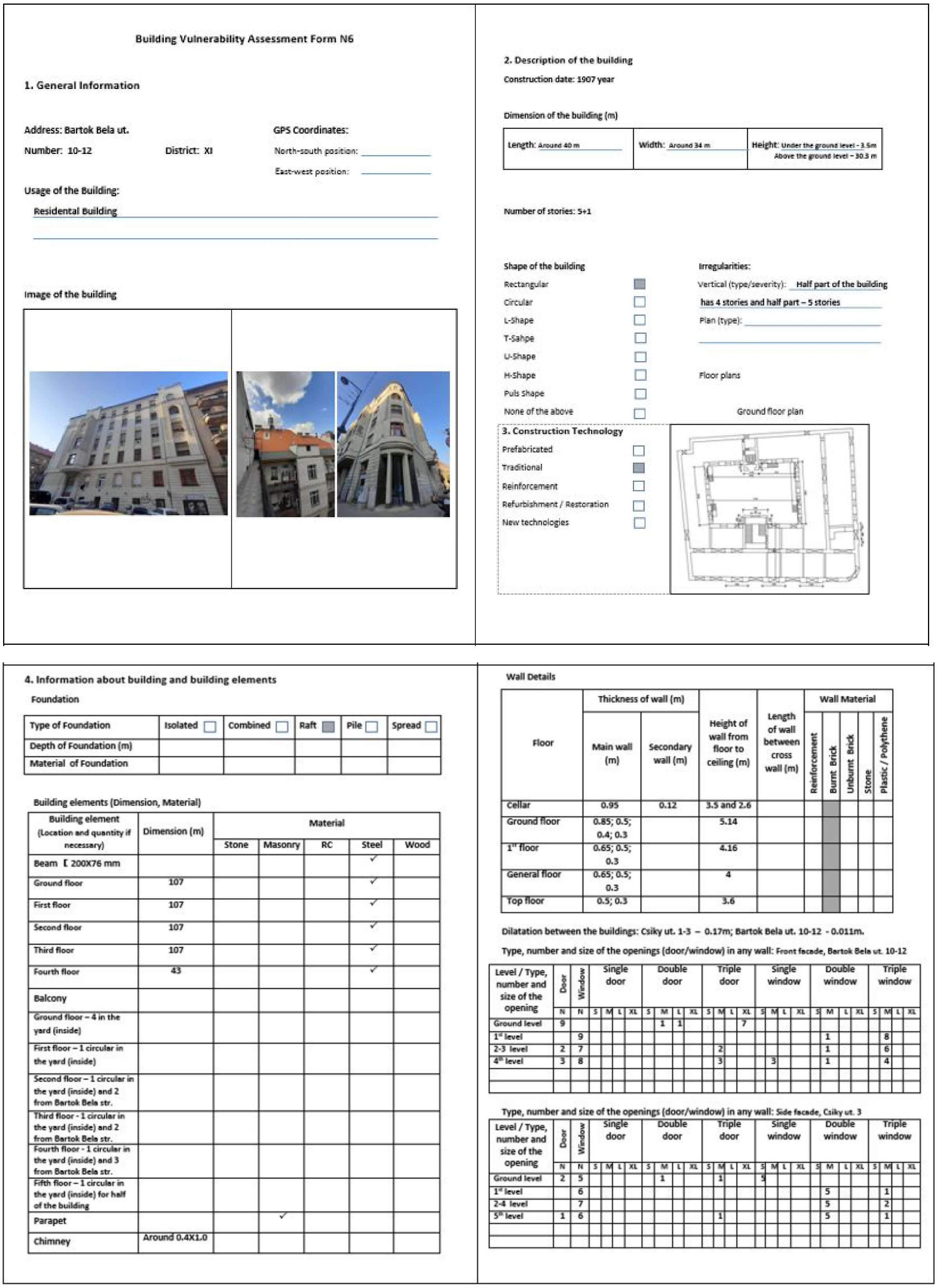
Settlement, Displacement

Name	No evidence	Location	Type	Size (mm)
Settlement				
Displacement				

7

Figure 14. Building vulnerability assessment form for Hungary

Since the required parameters was defined from site survey of the existing structure, the building vulnerability assessment form was filled (Fig. 15, Fig.16).



Building Vulnerability Assessment Form N6

1. General Information

Address: Bartok Bela ut.

Number: 10-12 District: XI

GPS Coordinates:

North-south position: ____________

East-west position: ____________

Usage of the Building:

Residental Building

Image of the building

2. Description of the building

Construction date: 1907 year

Dimension of the building (m)

Length: Around 40 m	Width: Around 34 m	Height: Under the ground level - 3.5m Above the ground level – 30.3 m

Number of stories: 5+1

Shape of the building

- Rectangular ■
- Circular ☐
- L-Shape ☐
- T-Sahpe ☐
- U-Shape ☐
- H-Shape ☐
- Puls Shape ☐
- None of the above ☐

Irregularities:

Vertical (type/severity): Half part of the building has 4 stories and half part – 5 stories

Plan (type): ____________

Floor plans

Ground floor plan

3. Construction Technology

- Prefabricated ☐
- Traditional ■
- Reinforcement ☐
- Refurbishment / Restoration ☐
- New technologies ☐

4. Information about building and building elements

Foundation

Type of Foundation	Isolated ☐	Combined ☐	Raft ■	Pile ☐	Spread ☐
Depth of Foundation (m)					
Material of Foundation					

Building elements (Dimension, Material)

Building element (Location and quantity if necessary)	Dimension (m)	Material				
		Stone	Masonry	RC	Steel	Wood
Beam [200X76 mm					✓	
Ground floor	107				✓	
First floor	107				✓	
Second floor	107				✓	
Third floor	107				✓	
Fourth floor	43				✓	
Balcony						
Ground floor – 4 in the yard (inside)						
First floor – 1 circular in the yard (inside)						
Second floor – 1 circular in the yard (inside) and 2 from Bartok Bela str.						
Third floor - 1 circular in the yard (inside) and 2 from Bartok Bela str.						
Fourth floor - 1 circular in the yard (inside) and 3 from Bartok Bela str.						
Fifth floor – 1 circular in the yard (inside) for half of the building						
Parapet			✓			
Chimney	Around 0.4X1.0					

Wall Details

Floor	Thickness of wall (m)		Height of wall from floor to ceiling (m)	Length of wall between cross wall (m)	Wall Material				
	Main wall (m)	Secondary wall (m)			Reinforcement	Burnt Brick	Unburnt Brick	Stone	Plastic / Polythene
Cellar	0.95	0.12	3.5 and 2.6			■			
Ground floor	0.85; 0.5; 0.4; 0.3		5.14			■			
1st floor	0.65; 0.5; 0.3		4.16			■			
General floor	0.65; 0.5; 0.3		4			■			
Top floor	0.5; 0.3		3.6			■			

Dilatation between the buildings: Csiky ut. 1-3 – 0.17m; Bartok Bela ut. 10-12 - 0.011m.

Type, number and size of the openings (door/window) in any wall: Front facade, Bartok Bela ut. 10-12

Level / Type, number and size of the opening	Door	Window	Single door				Double door				Triple door				Single window				Double window				Triple window			
	N	N	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL
Ground level	9							1	1					7												
1st level		9																		1				8		
2-3 level	2	7										2								1				6		
4th level	3	8										3				3				1				4		

Type, number and size of the openings (door/window) in any wall: Side facade, Csiky ut. 3

Level / Type, number and size of the opening	Door	Window	Single door				Double door				Triple door				Single window				Double window				Triple window			
	N	N	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL
Ground level	2	5						1				1			5											
1st level		6																		5				1		
2-4 level		7																		5				2		
5th level	1	6										1								5				1		

Figure 15. Filled building vulnerability assessment form

Type, number and size of the openings (door/window) in any wall: Cirular facade in the yard

Level / Type, number and size of the opening	Door	Window	Single door				Double door				Triple door				Single window				Double window				Triple window			
	N	N	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL
Ground level	9	17			1			7		1						1				13				2	1	
1st level	14	13					1	13												11				2	1	
2nd level	13	15					1	12												12				2	1	
3rd level	12	16					1	11												13				2	1	
4th level	13	15					1	12												12				2	1	
5th level	4	9	2					2												1				4	4	

Distance (m)

	Door / Window / Single door	Double door	Triple door	Single window	Double window	Triple window
Opening near corner of the wall	Every storey have some openings near corner. Some of them with distance – 0.3 m and others directly in the corner.					
Openings are too close to each other		On the 5th floor, one wall has 2 double doors between the triple windows without any distance.				

Type, number and size of the openings (door/window) in any wall: Openings inside the building

Level / Type, number and size of the opening	Door	Window	Single door				Double door				Triple door				Single window				Double window				Triple window			
	N	N	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL	S	M	L	XL
Ground level	13	4		4				5				2	2			3				1						
1st level	23	4		3				13				1	6							4						
2nd level	19	5		3				12					4							3				2		
3rd level	20	6		3				13					4							4				2		
4th level	20	6		3				13					4							4				2		
5th level	8			2				2				2	2													

Distance (m)

	Door / Window / Single door	Double door	Triple door	Single window	Double window	Triple window
Opening near corner of the wall						
Openings are too close to each other			On the ground floor, one wall has triple door between the windows without any distance.			

Number of openings: N
Size of opening: S – small, M – Medium, L – large, XL – Extra large

Type and material of staircase

Type / Material	Stone	RC	Steel	Wood
External	✓			
Connected	✓			
Enclosed				

Roof Details

Roof Type		Material		Presence of truss	
Flat	☐	Concrete	☐	Steel	☐
Open Gable	■	Metal	☐	Wood	☐
Box Gable	☐	Stone/Slate	☐	If truss is anchoured To the beam	☐
Shed roof	■	Wood	■	If truss is anchoured To the wall	☐
Hip roof	☐	Burnt brick	■		
Other	☐	Tile	■		

5. Condition assessment

Present condition

New ☐	Moderately ■	Poor ☐

Detailed description: None of the significant ckrack was appeared.

Location of Crack	Crack size (mm)	Horizontal			Vertical			Diagonal		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
Beam										
Column										
Wall	allowable									
Near openings	allowable									
Staircase										
Balcony										
Parapet										
Chimney										

Size of Crack: M1 = Minor crack (0-33%), M2=Moderately crack (33-66%), M3=Major Crack (66-100%)

7

Other deficient parameters

Type / Condition	No evidence	Location	Minor	Major
Water seepage				
Corrosion				
Loss of material		On the bottom part of some balcony slabs; On the fifth storey, near the triple window		
Quality of concreting				
Bulging or sag of building element				
Overturning of building element				
Collapse of building element				
Other		Last storey staircase is not in good condition		

Settlement, Displacement

Name	No evidence	Location	Type	Size (mm)
Settlement				
Displacement				

8

Figure 16. Filled building vulnerability assessment form

4. Estimation of mechanical parameters for masonry walls

Mechanical parameters for masonry walls, like Young's modulus (Modulus of elasticity), Poisson ratio, shear modulus and compressive strength have one of the important role. It is essential to know the characteristic of brick masonry walls in order to evaluate the responses of masonry walls for any kind of loading. Individual bricks do possess better compressive capacity as compared to masonry walls. Masonry walls are bound together with either mud mortar, lime mortar or by cement sand mortars of various mixes as per strength requirements. The essential strength properties in engineering are basically the compressive strength and the modulus of elasticity. The American Society for Testing and Materials (ASTM) standard is the most popular for testing bricks and brick masonry for these properties so far [6].

For the presented research paper, separate material characteristic values are illustrated from Hungarian codes and literature (Table 1), but the mechanical parameters for masonry walls was found from studies developed in Department of Structural Engineering, University of Naples Federico II, Naples, Italy [7] (Table 2).

Parameters / Material	brick	wood	steel	reinforced concrete (40-50ys old)	stone
Weight per unit volume	1600-1750	600-700	7000-8000	2300-2400	2650
Modulus of elasticity (MPa)	800-2300	4000	200000	15000-30000	35000-40000
Poisson ratio	0.263	does not have	0,25-0,30	0,15	0,28
Coefficient for thermal expansion	$9*10^{-6}$	$4*10^{-6}$	$11.9 *10^{-6}$	$1.3*10^{-5}$	$8*10^{-6}$

Table 1. Mechanical parameters of material from Hungarian codes and literature

Masonry type	f_m [MPa]		τ_0 [MPa]		E [MPa]		G [MPa]	
	min	max	min	max	min	max	min	max
Old brick masonry with lime mortar	2.40	4.00	0.060	0.092	1200	1800	400	600

Table 2. Mechanical parameters of old masonry wall

5. Modification of the old drawings with new measurements

It is a necessary step to calculate the data of the volumes and the weights of the building and to detect the structural elements of the building.

The old drawings (Fig. 17.a,b) of existing building were procured from Hungarian online archive [8] and were modified by new measurements gathered from the site survey. Several new drawings are illustrated in the research paper (Fig. 18,19,20.a,b).

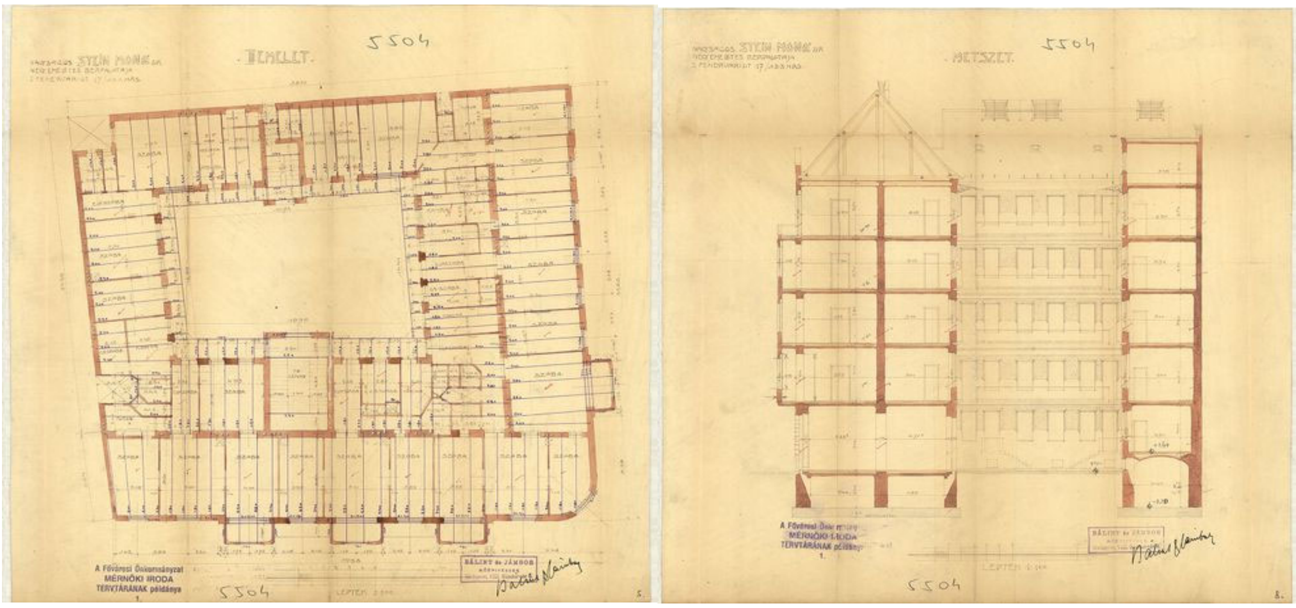


Figure 17. a) Samples of the typical plan and b) vertical plan (old drawings)

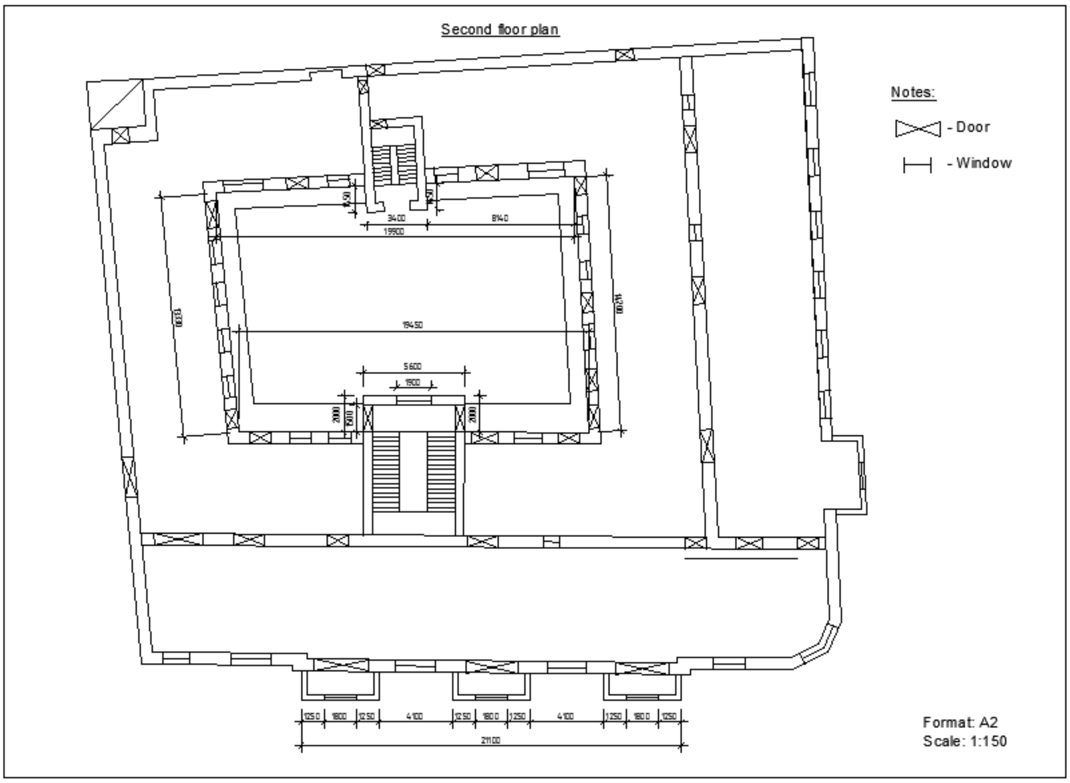


Figure 18. Sample of the walls and openings plan of typical floor (new drawing)

6. Calculated data of the volumes and the weights of the building and its structural elements

After getting the new drawings, the volumes and the weights of each structural elements and finally for the whole building were calculated.

Bartok Bela ut. 10-12						
Structural element	Thickness (m)	Width(m)	Length (m)	Area (m^2)	Volume (m^3)	Weight (ton)
Raft Foundation	0.7			1123.47	786.429	1966.073
Cellar						
Load bearing wall		0.95			826.700	1488.060
Load bearing wall		0.5			17.640	31.752
Non-load bearing wall		0.12			22.610	40.698
Sum (Walls)					**866.950**	**1560.510**
Slab	0.2			1089.22	217.844	217.844
Internal Staircase - STRC-2					1.641	4.2666
Sum (Cellar)					1086.435	1782.621
Ground floor						
Load bearing wall		0.85			876.294	1577.329
Load bearing wall		0.5			87.230	157.014
Non-load bearing wall		0.4			31.440	56.592
Non-load bearing wall		0.3			44.510	80.118
Sum (Walls)					**1039.474**	**1871.053**
Slab	0.2			1101.57	220.314	220.314
Balcony Slab	0.2			59.188	11.838	11.838
Sum (Slabs)					**232.152**	**232.152**
Internal Staircase - STRC-1					4.348	11.305
Internal Staircase - STRC-2					1.946	5.060
External Staircase - STRC-3					2.348	6.105
External Staircase - STRC-4					0.905	2.353
External Staircase - STRC-5					0.786	2.044
External Staircase - STRC-6					0.646	1.680
Sum (Staircases)					**10.979**	**28.545**
Steel Beam (200X76)	0.2	0.076	107			1.969
Sum (Ground floor)					1294.442	2145.557

Table 3. Volumes and weights of structural components of Cellar and ground floor.

First floor						
Load bearing wall		0.65			561.494	1010.689
Load bearing wall		0.5			64.590	116.262
Non-load bearing wall		0.3			29.924	53.863
Sum (Walls)					**656.008**	**1180.814**
Slab	0.2			1089.383	217.877	217.877
Balcony Slab	0.2			59.188	11.838	11.838
Sum (Slabs)					**229.714**	**229.714**
Internal Staircase - STRC-1					4.705	12.233
Internal Staircase - STRC-2					1.897	4.932
Sum (Staircases)					**6.602**	**17.165**
Steel Beam (200X76)	0.2	0.076	107			1.969
Sum (First floor)					892.324	1429.663
Second floor						
Load bearing wall		0.65			528.725	951.705
Load bearing wall		0.5			62.14	111.852
Non-load bearing wall		0.3			26.034	46.8612
Sum (Walls)					**616.899**	**1110.418**
Slab	0.2			1089.383	217.877	217.877
Balcony Slab	0.2			59.188	11.838	11.838
Sum (Slabs)					**229.714**	**229.714**
Internal Staircase - STRC-1					4.685	12.181
Internal Staircase - STRC-2					1.875	4.875
Sum (Staircases)					**6.560**	**17.056**
Steel Beam (200X76)	0.2	0.076	107			1.969
Sum (Second floor)					853.173	1359.157

Table 4. Volumes and weights of structural components of 1^{st} and 2^{nd} floor.

Third floor						
Load bearing wall		0.5			458.275	824.895
Non-load bearing wall		0.3			23.518	42.3324
Sum (Walls)					**481.793**	**867.227**
Slab	0.2			1089.383	217.877	217.877
Balcony Slab	0.2			59.188	11.838	11.838
Sum (Slabs)					**229.714**	**229.714**
Internal Staircase - STRC-1					4.685	12.181
Internal Staircase - STRC-2					1.875	4.875
Sum (Staircases)					**6.560**	**17.056**
Steel Beam (200X76)	0.2	0.076	107			1.969
Sum (Third floor)					718.067	1115.966
Fourth floor						
Load bearing wall		0.5			458.275	824.895
Non-load bearing wall		0.3			23.518	42.3324
Sum (Walls)					**481.793**	**867.227**
Slab	0.2			554.67	110.934	110.934
Balcony Slab	0.2			20.395	4.079	4.079
Loft constr.				519.488		135.067
Chimney constr.						18.4
Sum (Roof)					**115.013**	**268.480**
Internal Staircase - STRC-1					4.685	12.181
Internal Staircase - STRC-2					1.875	4.875
Sum (Staircases)					**6.560**	**17.056**
Steel Beam (200X76)	0.2	0.076	43			0.791
Sum (Fourth floor)					603.366	1153.554
Fifth floor						
Load bearing wall		0.5			230.514	414.9252
Slab	0.2			308.65	61.730	61.730
Loft constr.				253.65		65.949
Sum (Roof)					**61.730**	**127.679**
Sum (Fifth floor)					292.244	542.604
Total Sum					6524.840	11490.928

Table 5. Volumes and weights of structural components of 3rd-4th-5th floor.

Building vulnerability assessment form, new drawings of the existing building, represented data of volumes and weights values of building and building elements, can be used either for experimental or analytical (force-displacement) methods of seismic fragility assessment.

7. Design of 3D model and nonlinear static analysis in finite element software Sap2000

3D model of the existing building was designed in Sap2000. First step was to define material properties (Fig. 19, Fig.20)

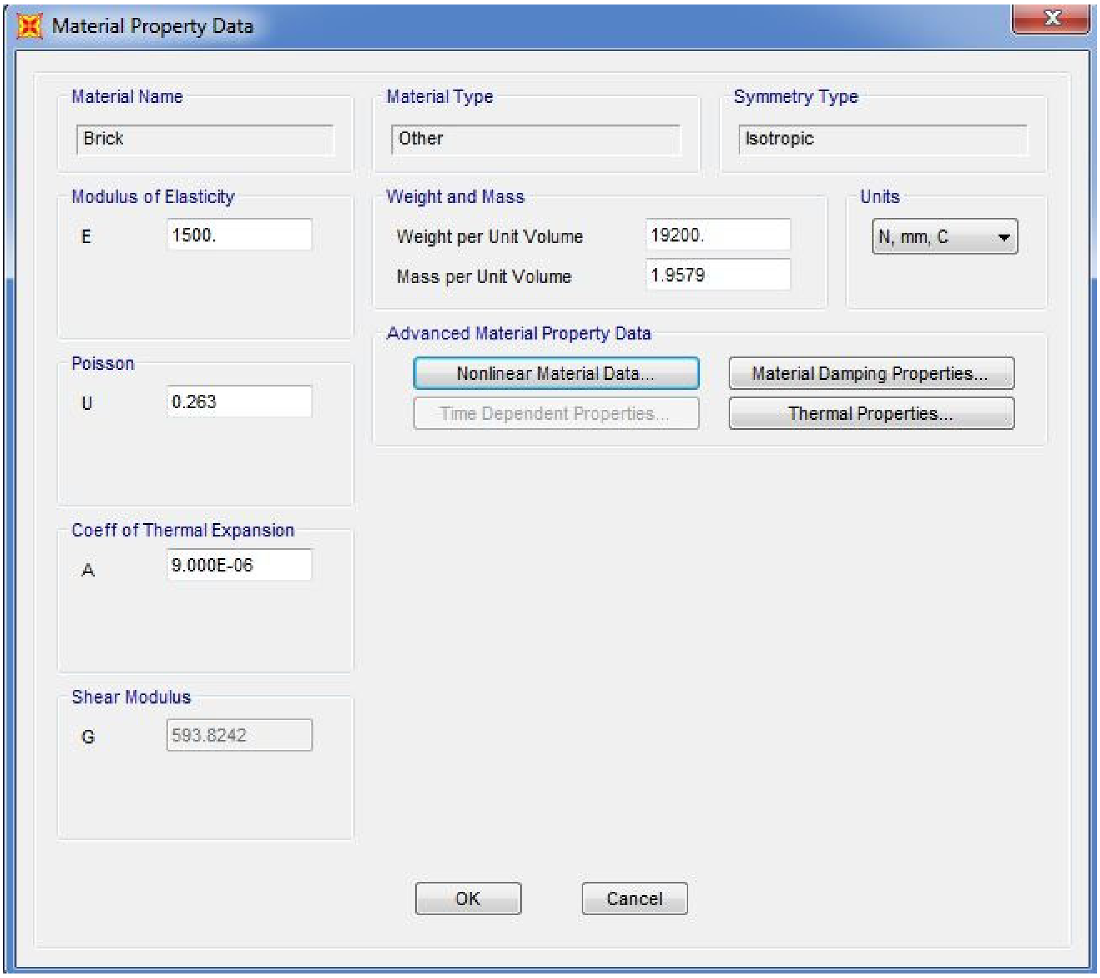


Figure 19. Material property data

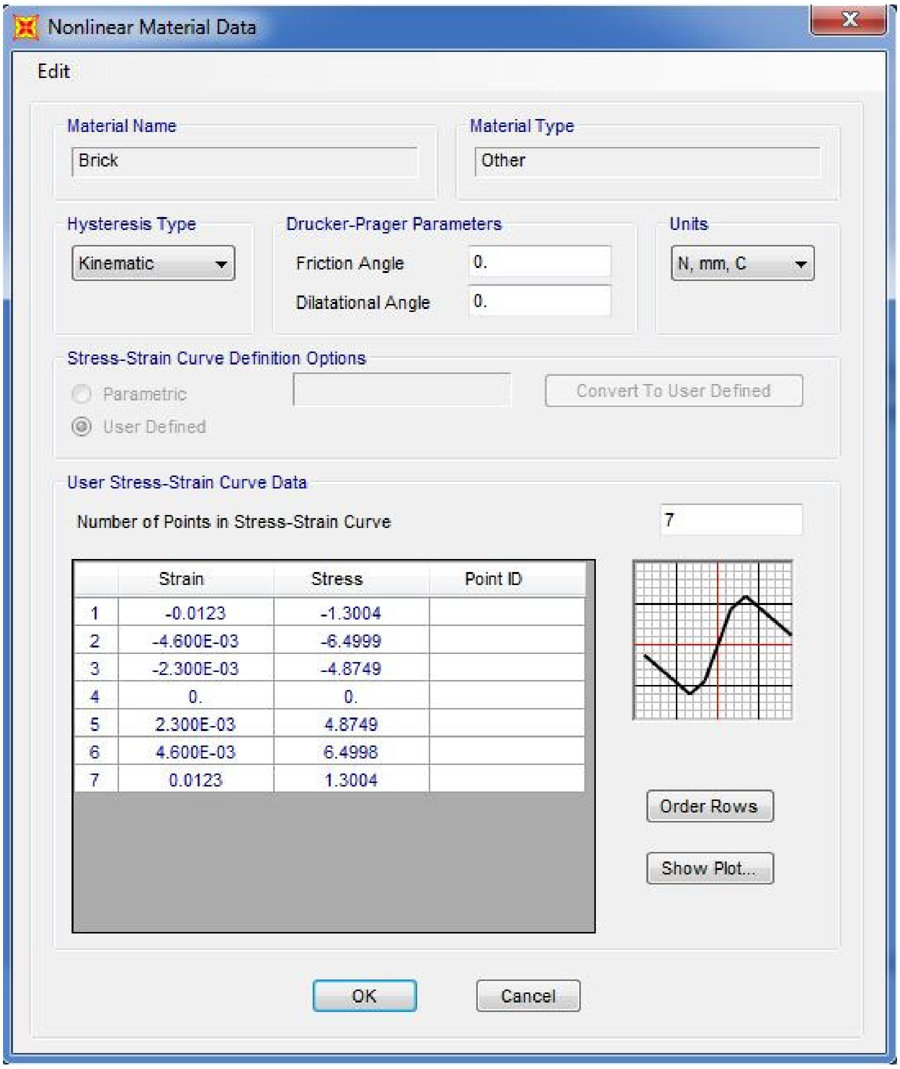


Figure 20. Nonlinear material data

Shell elements were selected for wall sections (Fig. 21, Fig. 22).

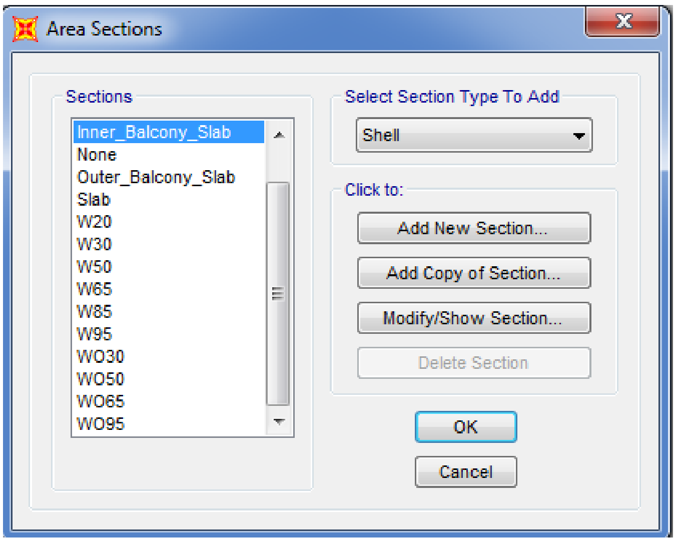


Figure 21. List of the wall sections

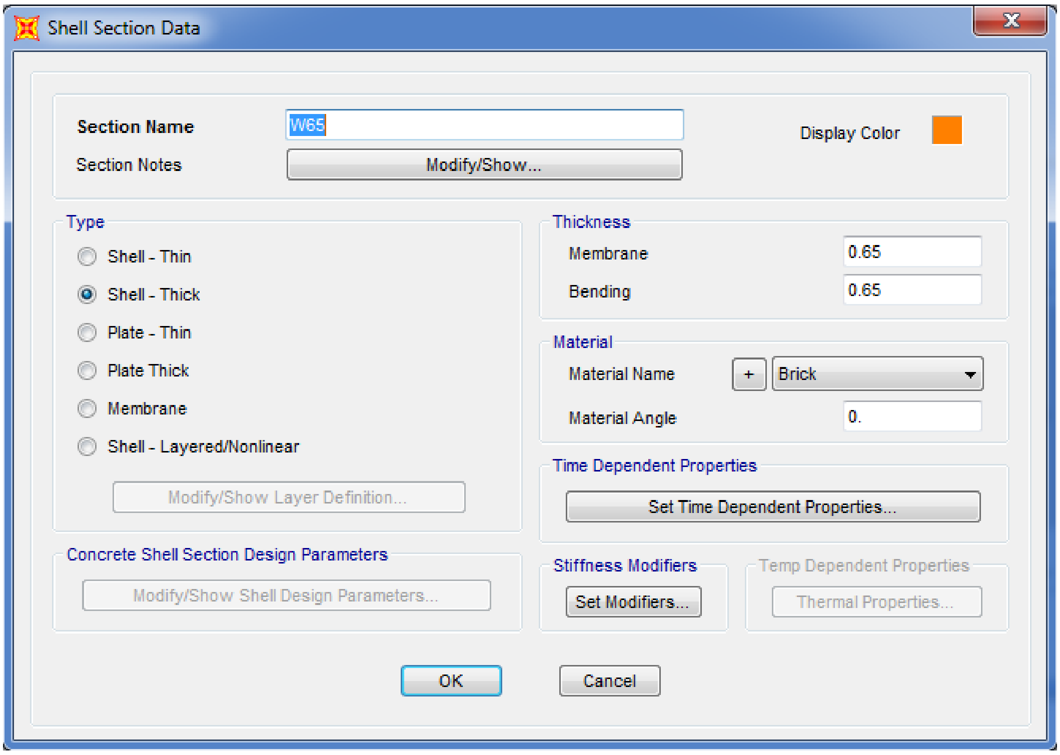


Figure 22. Shell section data for the wall with thickness 65 cm

Steel beams were used on balcony edges, and for loft construction timber frame elements were defined (Fig. 23).

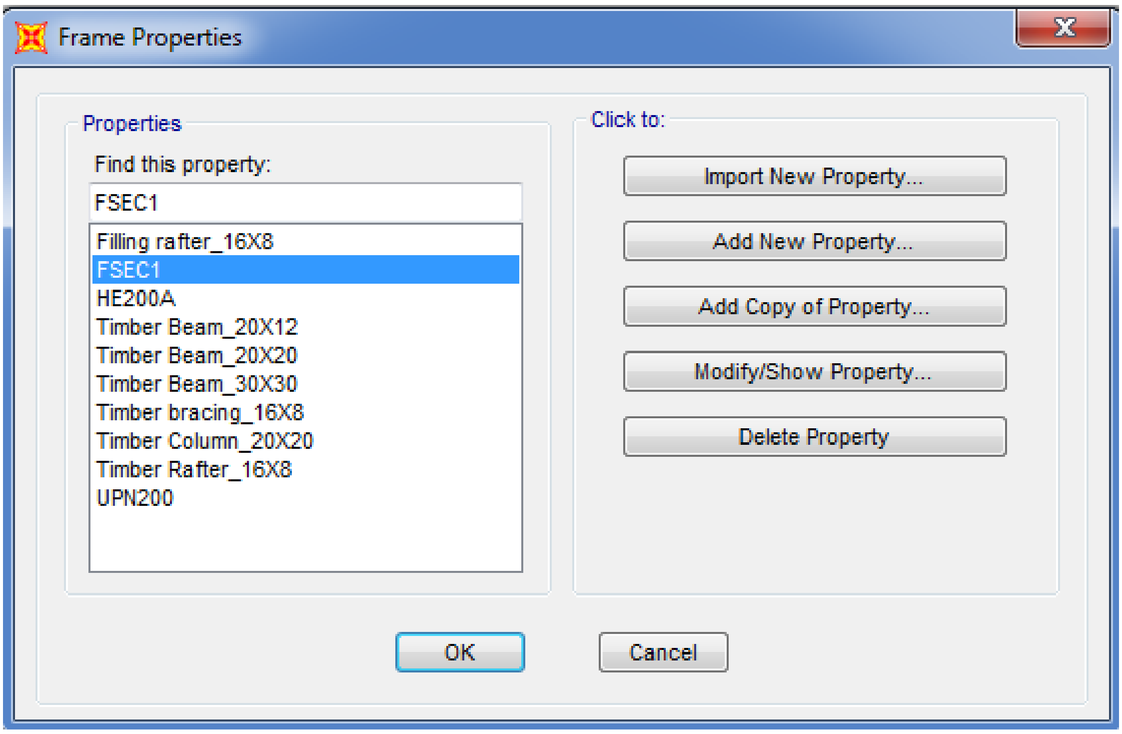


Figure 23. Frame properties

Slab was calculated as a rigid diaphragm.

Shell elements for slab and walls were divided into 0.2 – 0.3m size finite elements. Starting points of the wall finite elements were restrained as it is illustrated on Fig. 24.

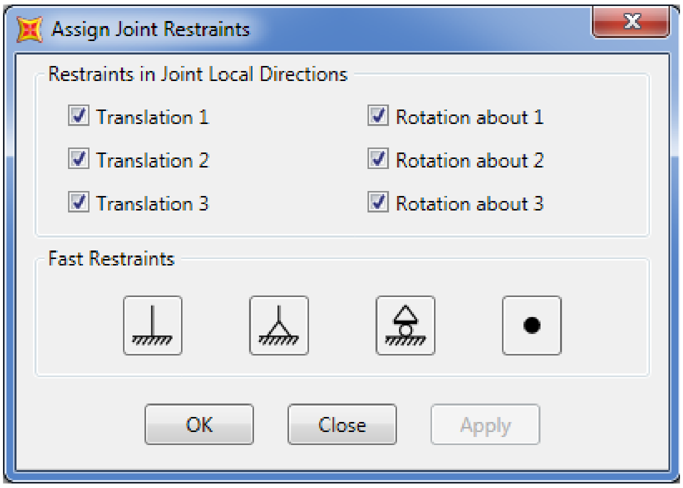


Figure 24. Joint restraints

When the design of the building geometry was completed (Fig. 25), Dead, live and horizontal loads were assigned [9].

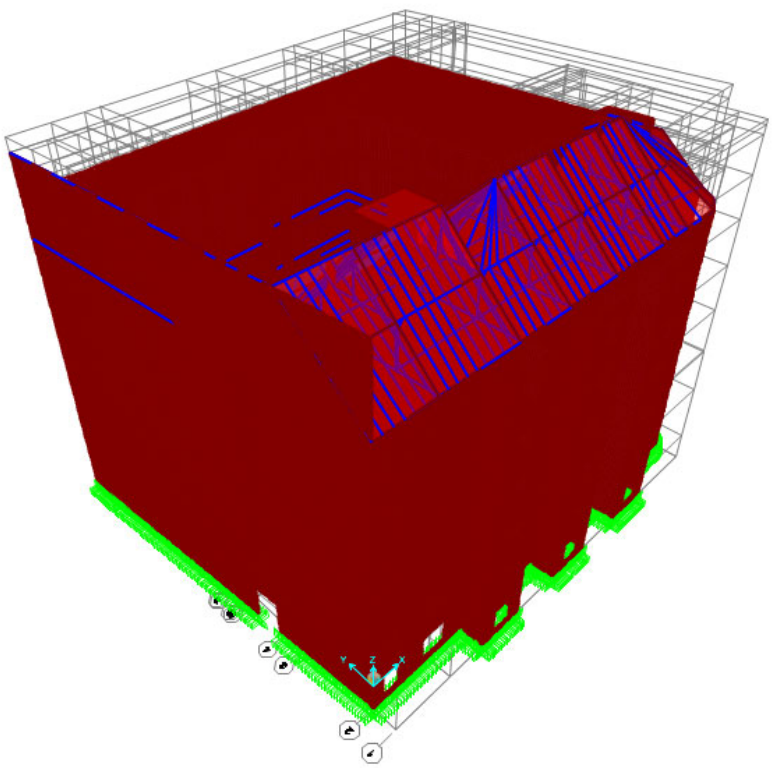


Figure 25. 3D model of the building

Nonlinear static load case was defined for nonlinear static analysis, which combines dead and live loads. Then the horizontal load case was modified for nonlinear static analysis.

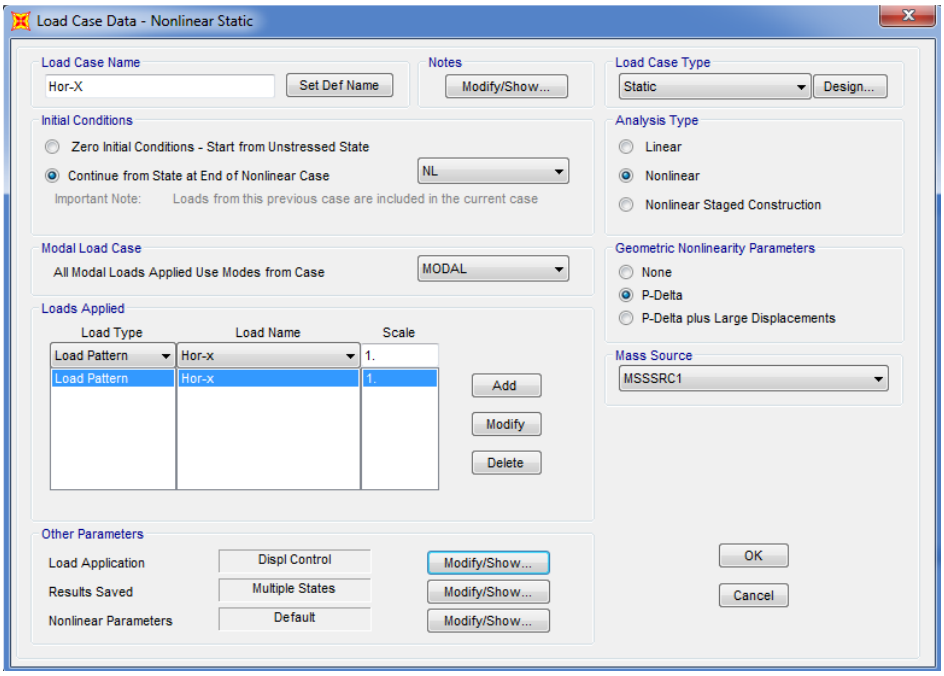


Figure 26. Horizontal load case modified for nonlinear static analysis

To calculate the numerical model of the whole building by nonlinear static pushover analysis requires too much time for masonry building with a large volume. Alternative decision was made to calculate single floor separately and increase the vertical and horizontal loads for each floor (Fig. 27, 28, 29.a,b, Table 6).

Floor number	Dead load KN/m^2	Live load KN/m^2	Assumed Horizontal load KN/m^2
Cellar	104	12	11.6
Ground floor	85	10	9.5
First floor	64	8	7.2
Second floor	49	6	5.5
Third floor	35	4	3.9
Fourth floor	23	2	2.5
Fifth floor	10	-	1

Table 6. Load distribution for each floor of the building

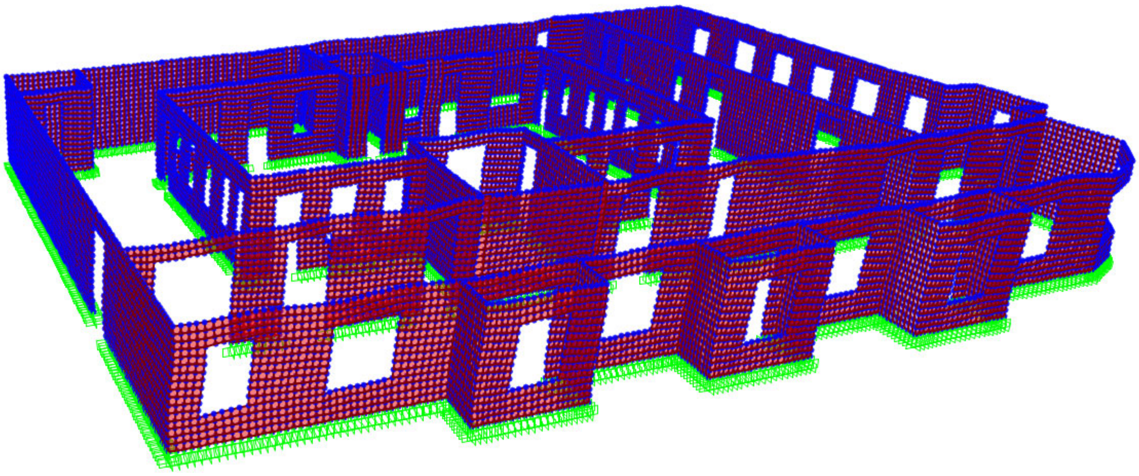


Figure 27. Deformed shape of the single floor walls

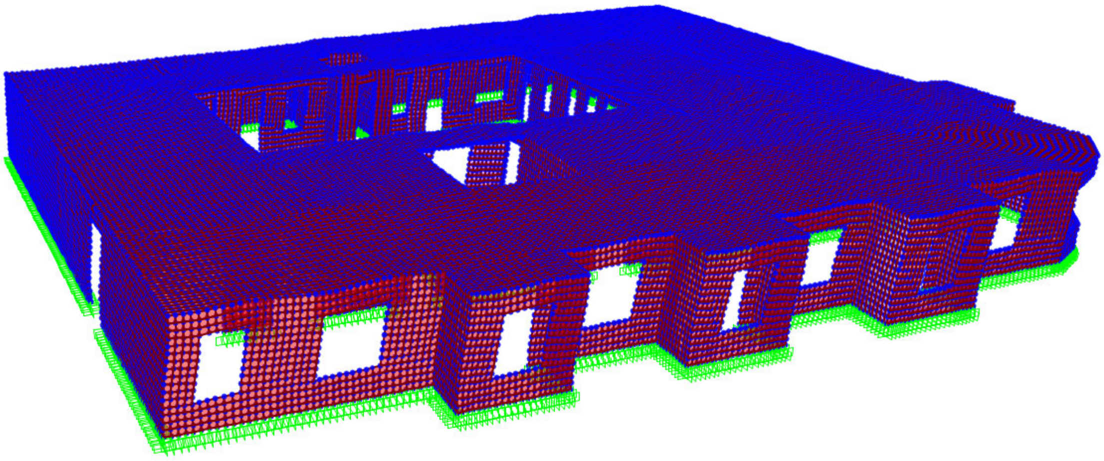


Figure 28. Deformed shape of the single floor walls and slab

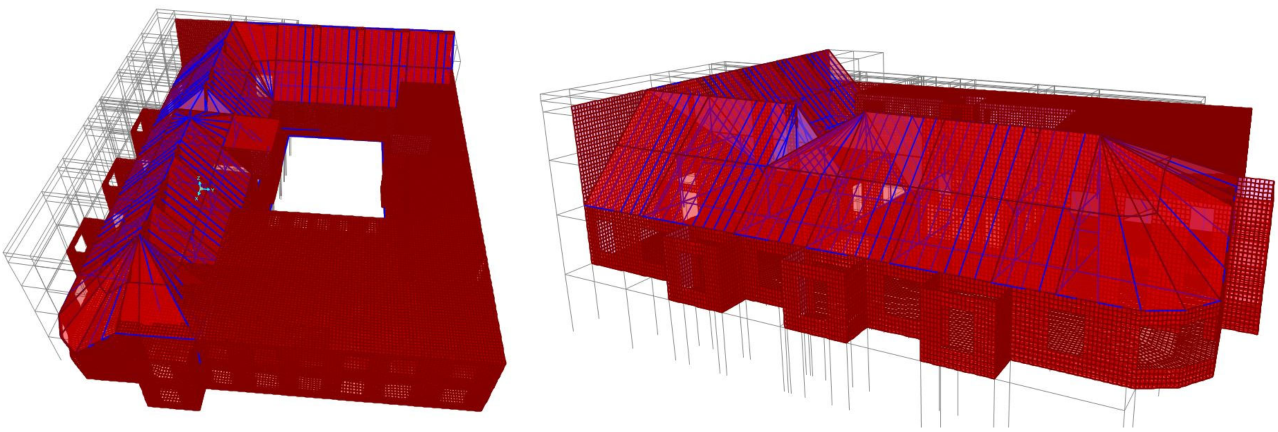


Figure 29.a,b 3D model for last floor and loft construction

Maximum displacements and base shear forces were represented per floor after the nonlinear static calculation (Table 7).

Floor name	Max displacement m	Base shear force KN
Cellar	0.002659	11500.589
Ground floor	0.003842	9439.162
First floor	0.005094	7160.744
Second floor	0.003966	5533.302
Third floor	0.004569	4014.356
Fourth floor	0.003301	2712.403
Fifth floor	0.002051	402.59

Table 7. Maximum displacements and base shear forces for each floor of the building

It is recommended to find maximum displacements and base shear force for whole building by simplified method to estimate the capacity curve.

8. Modeling the Methodology for seismic fragility assessment of the existing building

- Methods of seismic fragility assessment;
- Determination of capacity (Force - displacement) curve;
- Definition of IDA (Incremental Dynamic Analysis) curve;
- Representation of seismic fragility and seismic hazard curves.

8.1 Methods of seismic fragility assessment

Fragility is the probability of exceeding a certain damage state, conditional on the ground motion intensity [10].

There are two main components in the probabilistic seismic risk assessment: 1. information about ground motion hazard on the site and 2. Fragility knowledge with respect to the intensity of the ground motion.

Several methods are established for seismic fragility evaluation in different literature.

The general equation to develop fragility is [2]:

$$\text{Fragility} = P[\text{LS}|\text{IM} = y] \tag{1}$$

where,
LS is the limit state or damage state (DS),
IM is the intensity measure (ground motion), and
Y is the realized condition of ground motion IM.

Relative Frequency (RF) Method - where the capacity is assumed to be deterministic, attaining probability is approximated by the relative frequency.

Lognormal Distribution (LD) Method – Is the most popular method, when capacity is assumed to be deterministic and realizations as some probability distribution function (Fig. 30)

$$P_{ij} = 1 - F_{ij}(C_i) \tag{2}$$

Where F_{ij} is the cumulative probability distribution function [8].

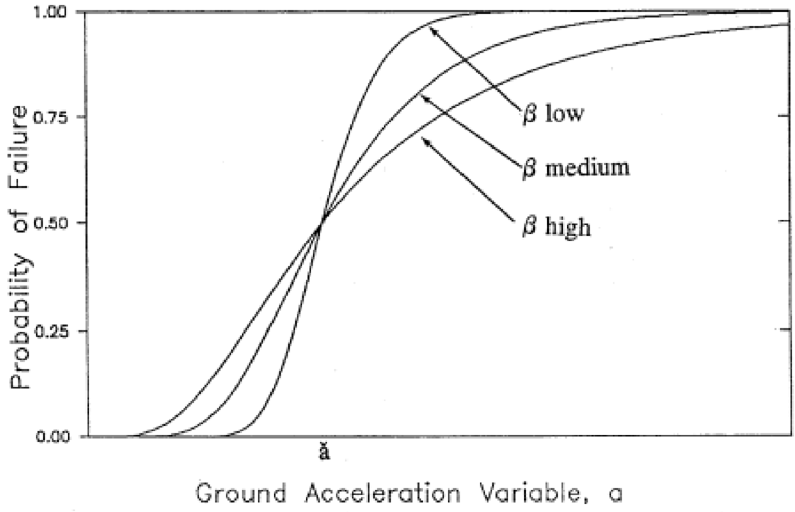


Figure 30. Fragility curve based on the lognormal distribution [11]

Maximum Likelihood (BD) Method - Capacity is assumed to be deterministic and each realization is represented as the result of a multi-outcome Bernoulli-type experiment, which resolves a dichotomy for a number of events. A lognormal distribution function is assumed to illustrate the fragility curves.

First-order Second-moment (FS) Method - demand and capacity are random variables and it is assumed that they are are independent and lognormal.

Fuzzy Random (FR) Method - damage quantification is naturally fuzzy, its probability is the expectation of the membership function µE relevant to this event [10].

For seismic fragility calculation of unreinforced masonry buildings, given formula is required to be used by Frankie et al. (2012) [2]:

$$P(\text{Exceedance}_i|\text{IM}) = \Phi\left[\frac{1}{(\beta_{\text{tot}})_i}\ln\left(\frac{\text{IM}}{\text{LS}_i}\right)\right] \quad (3)$$

where,

$\Phi[\cdot]$ = standardize normal cumulative distribution
$(\beta_{\text{tot}})_i$ = log SD represent total uncertainty
LS_i = threshold value for ith limit state

8.2 Determination of capacity (Force - displacement) curve

To predict the force-displacement (F-δ) relationship for masonry walls, it is accepted to provide either by the analysis of experimental results of masonry wall or numerical analysis of structure.

In case of numerical analysis, Nonlinear static pushover analysis is required to use. The capacity curve expressed by pushover analyses has to be converted into a bilinear curve. Limit- displacement values can be identified (Fig. 31).

For the existing building to use simplified method is more rational, because of the large volume and weight of the building, it is obvious that numerical model calculation takes a lot of time.

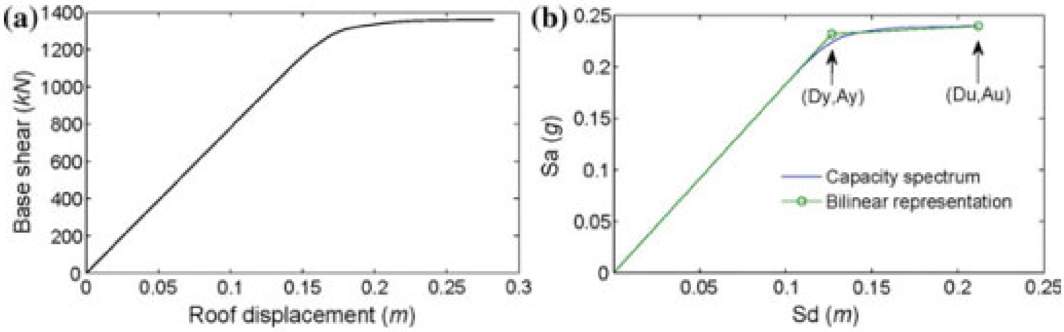


Figure 31. Capacity curve (a) and capacity spectrum (b) obtained from the deterministic APA [12]

To use the illustrated model (Fig. 32) depends on both the description of the damage states on the F-δ curve, the placement of the ultimate point (δ_{ult}, F_{ult}) and the importance of the residual strength of the wall [?].

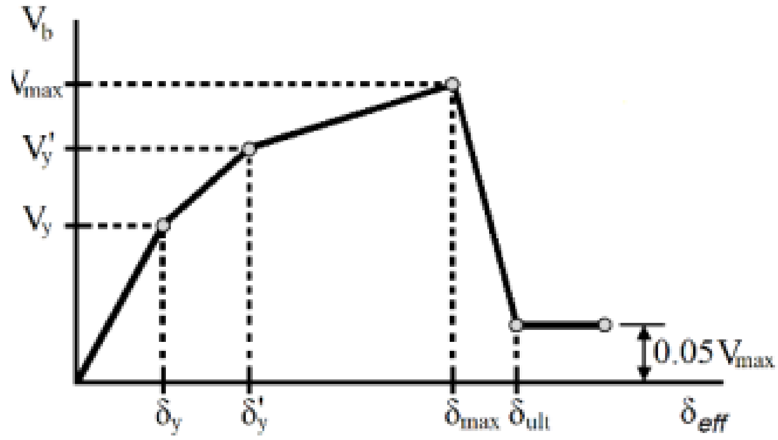


Figure 32. Idealizations of the
F-δ backbone curve for masonry walls.

8.3 Definition of IDA (Incremental Dynamic Analysis) curve

IDA (Incremental Dynamic Analysis) STUDY is a dynamic analysis study of a given structural model parameterized by the scale factor of the given ground motion time history.

An IDA CURVE is a plot of a state variable (DM) recorded in an IDA study versus one or more IMs that characterize the applied scaled accelerogram.

An IDA CURVE SET is a collection of IDA curves of the same structural model under different accelerograms that are all parameterized on the same IMs and DM [13].

The IDA given the structural model and a statistical population of records is no longer deterministic; it is a random line, or a random function DM = f(IM) (for a single, monotonic IM). Then, just as we are able to summarize a suite of records by having, for example, mean, median, and 16%, 84% response spectra, so we can define mean, median and 16%, 84% IDA curves (e.g., Figure 33. a,b) to (marginally) summarize an IDA curve set. Alternatively a parametric model of the median DM given the IM can be fit to all the lines simultaneously [13].

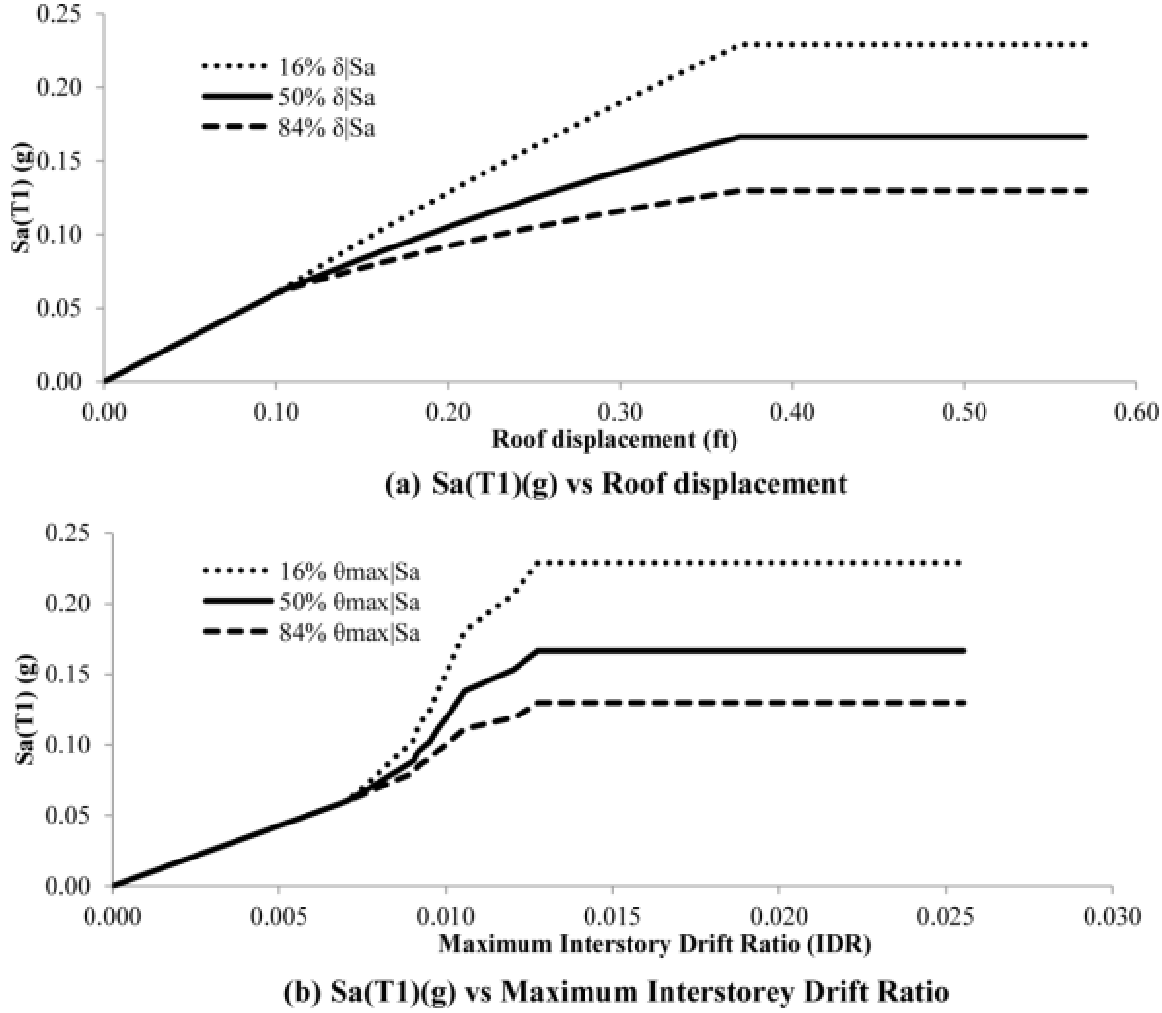


Figure 33. SPO2IDA-predicted IDA fractiles for the equivalent SDoF system (a) Sa(T1)(g) vs Roof displacement, (b) Sa(T1)(g) vs Maximum Interstorey Drift Ratio [14]

The IDA always rises much higher than the SPO in IM terms [13].

8.4 Representation of seismic fragility and seismic hazard curves

The IDA curve estimation give us a direct way to create seismic fragility curve (Fig. 34, 35, 36).

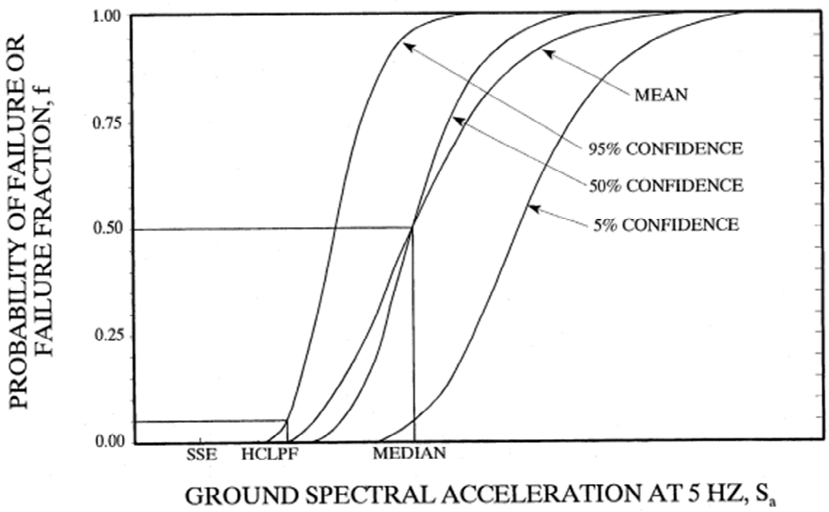


Figure 34. Illustration of fragility curves [11]

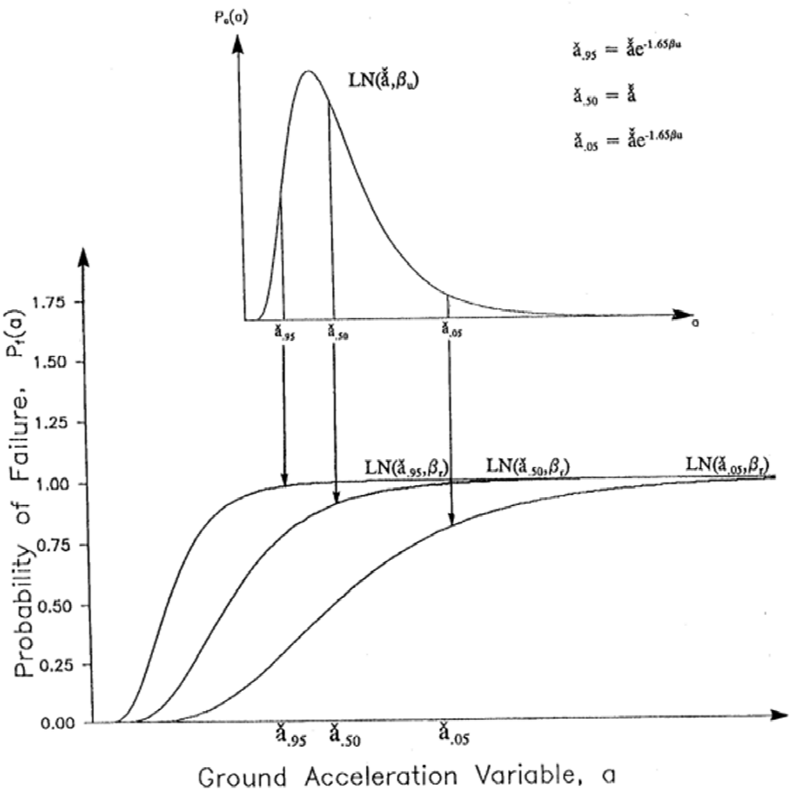


Figure 35. Family of fragility curves at 95%, 50% and 5% confidence levels [11]

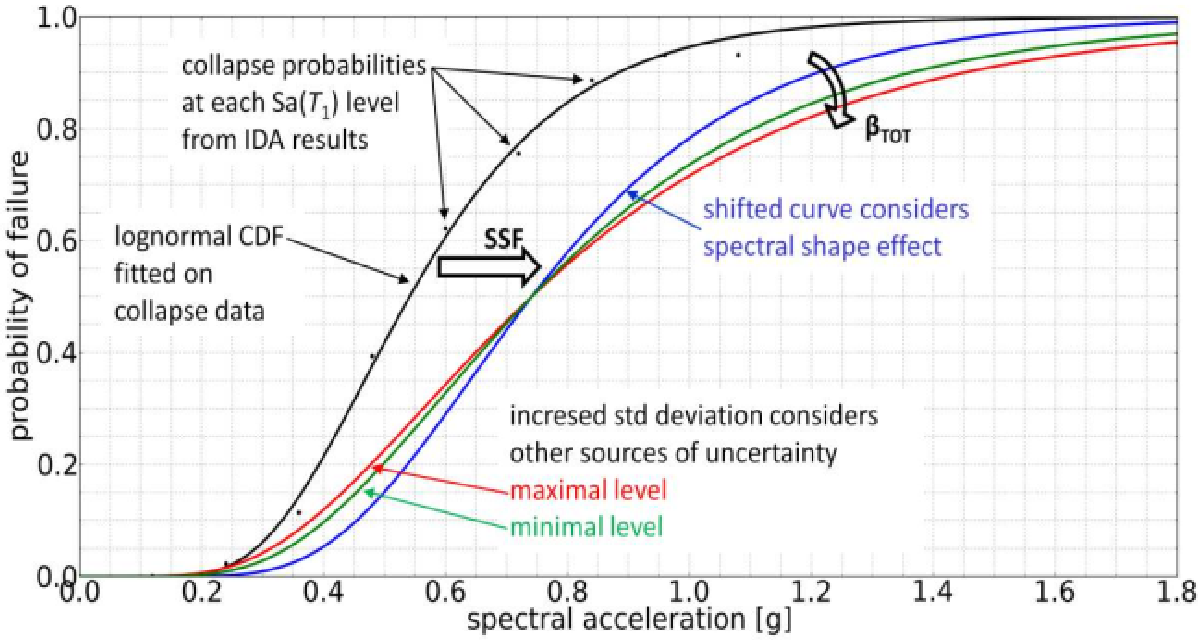


Figure 36. Fragility curve, conditional probability of failure [15]

Steps for hazard curve are given in Fig. 37.

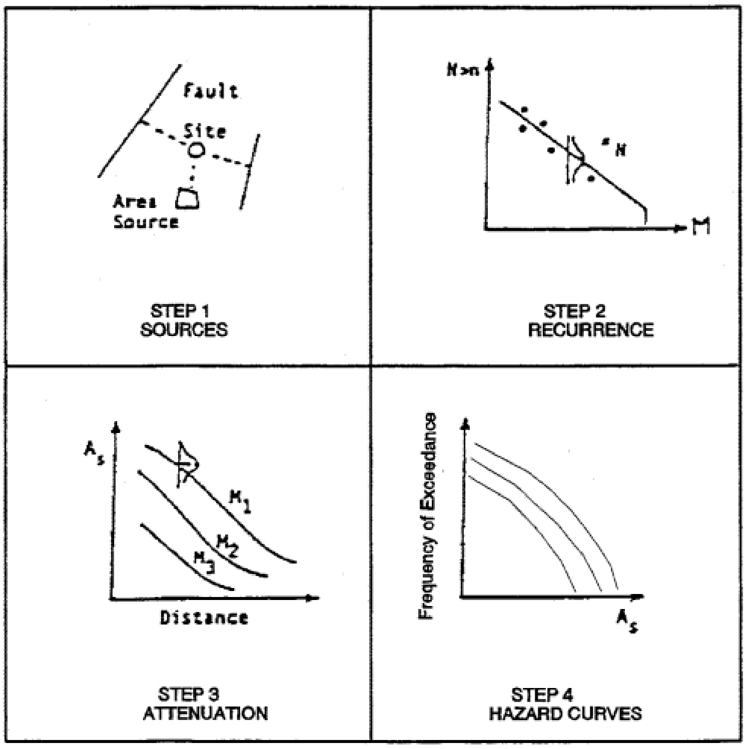


Figure 37. Seismic hazard analysis steps [11]

Hazard curve is given as a probability density as a function of special acceleration (Fig. 38). It reflects the time-dependence and frequency of occurrence of the action, that depends on the location. It is an action-specific feature [15].

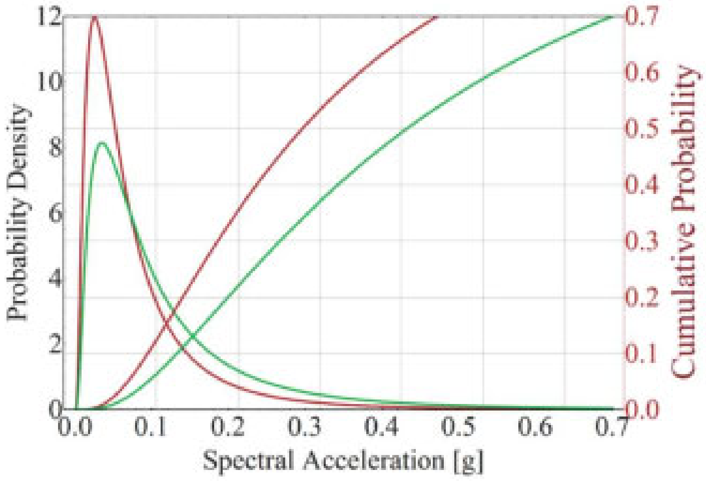


Figure 38. Hazard curve, PDF and CDF for two sites (Kosovo (green) and Italy (red; PGA = 0.2 g) [15]

Finally, we can estimate fragility and hazard curves relationship (Fig. 39)

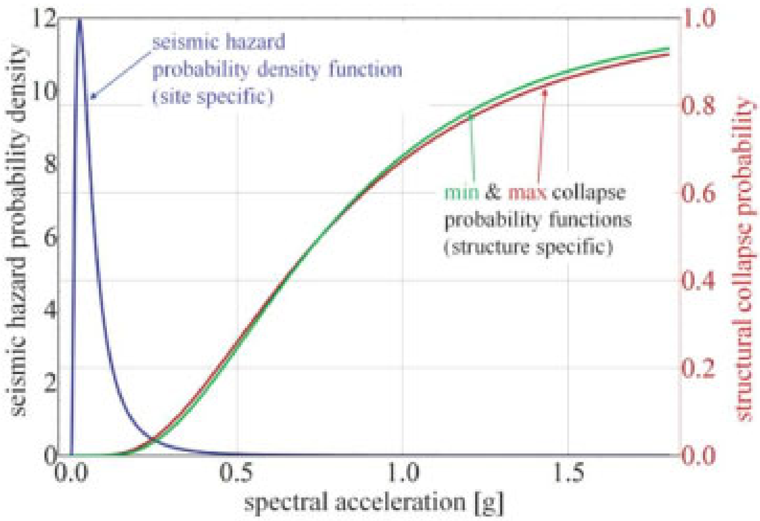


Figure 39. Fragility and hazard curves [15]

Conclusions

The present study focused on the seismic fragility evaluation based on the building vulnerability assessment.

Research paper represents the site survey for Hungarian historic building, gathering the all necessary information of the building for seismic analysis. Indian and American building vulnerability assessment forms are illustrated, which was used to create a new form for Hungary.

Estimation of mechanical parameters of existed material was done according to the relevant literature, collected as from national documents also from foreign laboratory test papers.

All the above mentioned data was used to create the 3D model in finite element software and calculate by Nonlinear static analysis.

Detailed methodological tools are presented, to estimate the capacity (force -displacement) curve and determine the IDA curve, which gives the possibility for seismic fragility and seismic hazard assessment.

The demonstrated methodology will be effective as for pre-earthquake, also for post earthquake seismic hazard assessment of the buildings, which will be a significant benefit for the country.

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