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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 damaged. 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 analytical 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.

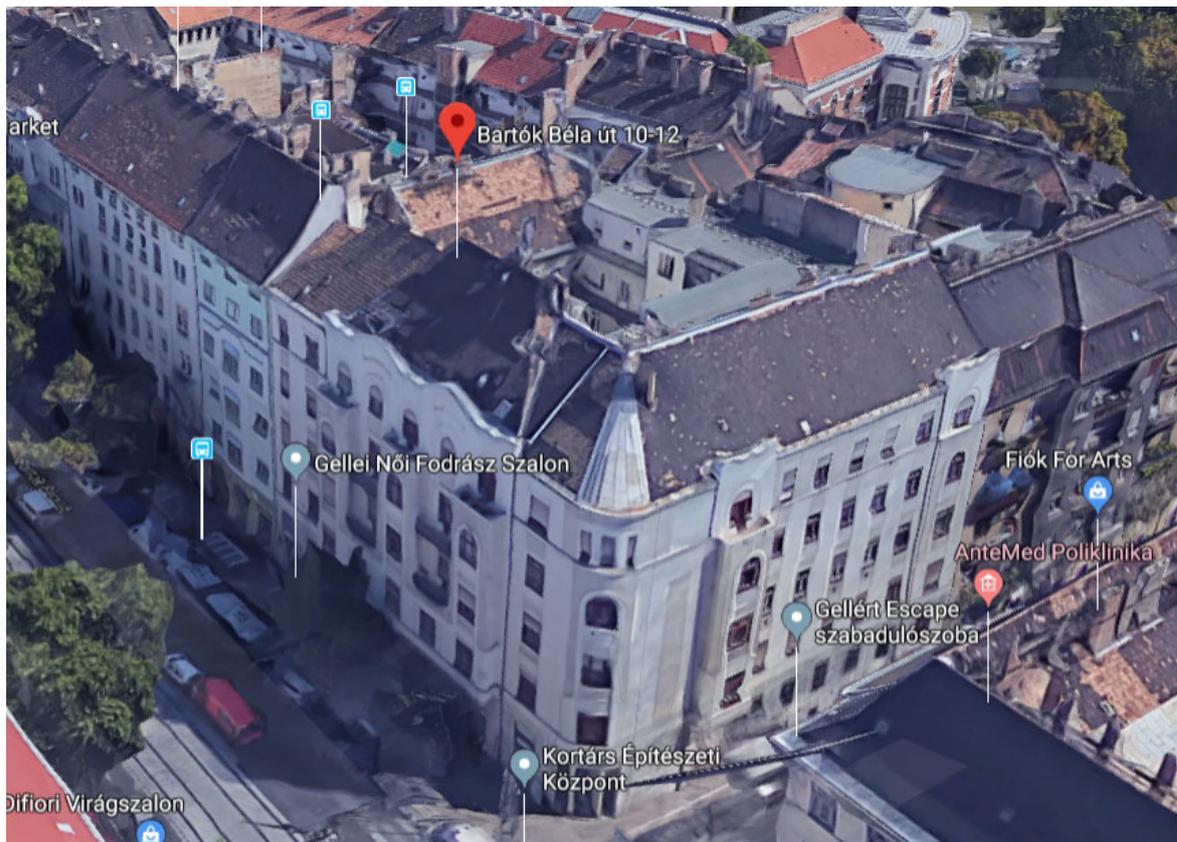


Figure 1. Existing building photo from google map

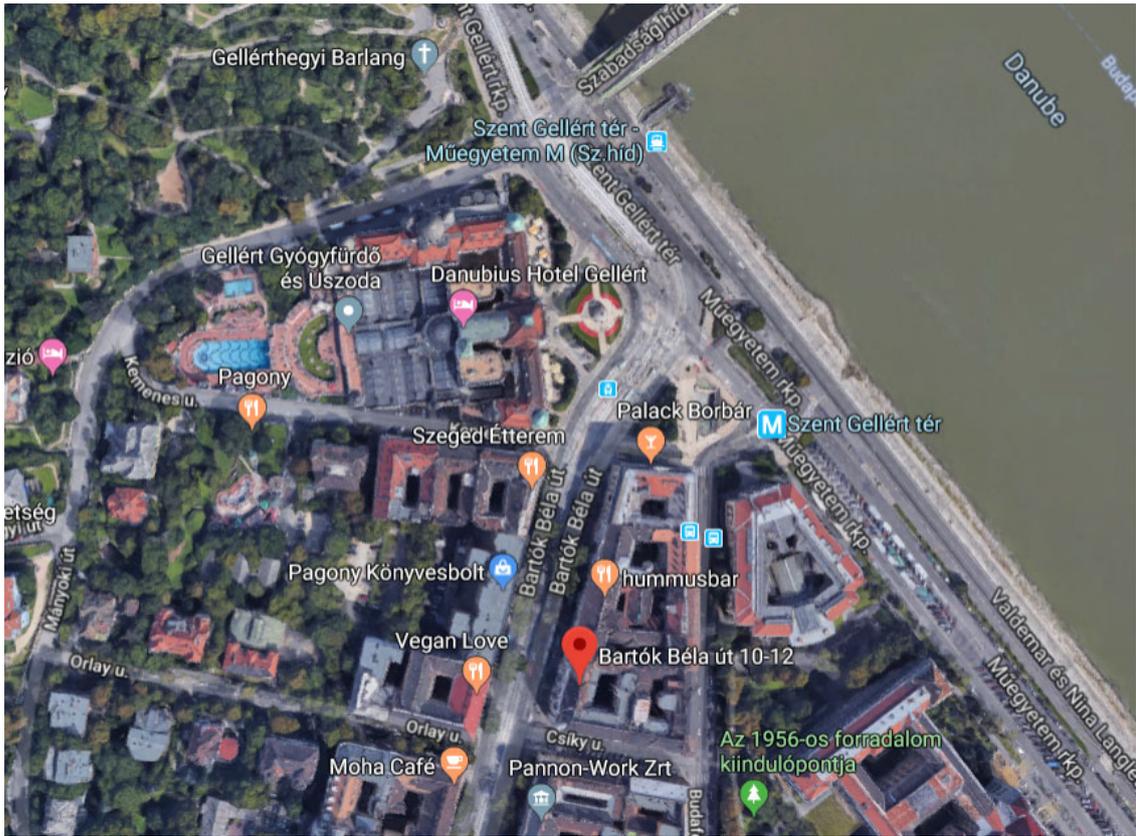


Figure 2. Existing building location from google map

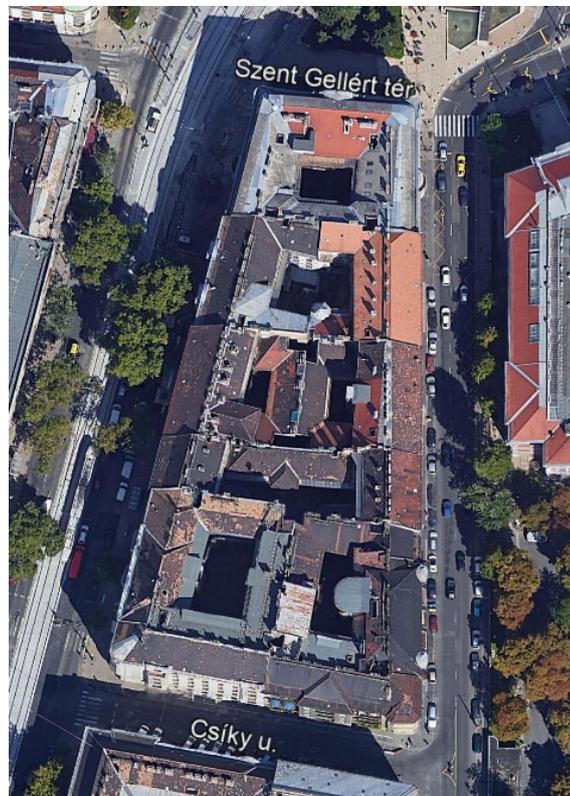


Figure 3. Selected structure top view with adjacent buildings

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 cracks 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 **Level 1**
MODERATE Seismicity

FEMA P-154 Data Collection Form

Address: _____ Zip: _____

Other Identifiers: _____

Building Name: _____

Use: _____

Latitude: _____ Longitude: _____

City: _____ State: _____

Screening(s): _____ Date/Time: _____

No. Stories: Above Grade: _____ Below Grade: _____ Year Built: 1st 2nd 3rd

Total Floor Area (sq. ft.): _____ Code Year: _____

Additional: None Yes (Years) Built: _____

Occupancy: Assembly Commercial Hotel Services Historic Shelter Industrial Office School Government University Warehouse Residential, 1-2 units

Soil Type: A B C D E F G H I J K L M N O P Q R S T U V W X Y Z Other

Geologic Hazards: Liquefaction: Yes/No/DK/Less/Less/No/DK/Less/No/DK Surf. Rupt.: Yes/No/DK

Adjacency: Pounding Falling Hazards from Taller Adjacent Building

Irregularities: Vertical (Substructure) Plan (Type) Other

Exterior Falling Hazards: Unsecured Chimneys Heavy Cladding or Heavy Veneer Parapets Appendages Other

COMMENTS: _____

SKETCH: Additional sketches or comments on separate page

FEMA BUILDING TYPE	Do Not Know	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20
Basic Score	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Severe Vertical Irregularity, V_v	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Plan Irregularity, P_v	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Pre-Code	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Post-Benchmark	1.4	2.0	2.6	3.2	3.8	4.4	5.0	5.6	6.2	6.8	7.4	8.0	8.6	9.2	9.8	10.4	11.0	11.6	12.2	12.8	13.4
Soil Type 0-3 (storey)	0.7	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6	10.2	10.8	11.4	12.0	12.6
Soil Type 4-3 (storey)	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8	-1.9	-2.0	-2.1	-2.2	-2.3	-2.4	-2.5	-2.6	-2.7	-2.8	-2.9	-3.0	-3.1	-3.2
Soil Type 4-3 (storey)	-1.2	-1.3	-1.4	-1.5	-1.6	-1.7	-1.8	-1.9	-2.0	-2.1	-2.2	-2.3	-2.4	-2.5	-2.6	-2.7	-2.8	-2.9	-3.0	-3.1	-3.2
Minimum Score, S_{L1}	1.6	1.2	0.9	0.6	0.3	0.0	-0.3	-0.6	-0.9	-1.2	-1.5	-1.8	-2.1	-2.4	-2.7	-3.0	-3.3	-3.6	-3.9	-4.2	-4.5

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{L2}$

EXTENT OF REVIEW: Exterior: Partial All Sides Aerial Interior: None Visible Entered

Drawings Reviewed: Yes No

Geologic Hazards Source: _____

Contact Person: _____

LEVEL 2 SCREENING PERFORMED? Yes, Final Level 2 Score, S_{L2} No

Nonstructural Hazards? Yes No

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data; DK = Don't Know

Legend: W1 = Non-pierced retaining wall; W2 = Pierced retaining wall; W3 = Shear wall; W4 = Shear wall; W5 = Shear wall; W6 = Shear wall; W7 = Shear wall; W8 = Shear wall; W9 = Shear wall; W10 = Shear wall; W11 = Shear wall; W12 = Shear wall; W13 = Shear wall; W14 = Shear wall; W15 = Shear wall; W16 = Shear wall; W17 = Shear wall; W18 = Shear wall; W19 = Shear wall; W20 = Shear wall

Rapid Visual Screening of Buildings for Potential Seismic Hazards **Level 2 (Optional)**
MODERATE Seismicity

FEMA P-154 Data Collection Form

Optional Level 2 data collection to be performed by a civil or structural engineering professional, architect, or graduate student with background in seismic evaluation or design of buildings

Big Name: _____ Final Level 1 Score: $S_{L1} =$ _____ (Do not consider S_{L2})

Screeners: _____ Level 1 Irregularity Modifiers: Vertical Irregularity, $V_v =$ _____ Plan Irregularity, $P_v =$ _____

Date/Time: _____ ADJUSTED BASELINE SCORE: $S = (S_{L1} - V_v - P_v) =$ _____

STRUCTURAL MODIFIER(S) TO ADD TO ADJUSTED BASELINE SCORE

Topic	Statement (If statement is true, circle the "Yes" modifier; otherwise cross out the modifier)	Yes	Subtotal
Vertical Irregularity, V_v	Stairing: <input type="checkbox"/> W1 building: There is at least a full story grade change from one side of the building to the other. <input type="checkbox"/> Non-W1 building: There is at least a full story grade change from one side of the building to the other.	-0.4	-0.4
Weak	W1 building: There is an unbraced cripple wall in the crawl space. <input type="checkbox"/> Non-W1 building: There is an unbraced cripple wall in the crawl space.	-0.7	-0.7
Soft Story	W1 building: There is a garage opening without a steel moment frame, and there is less than 8 ft of wall on the same line for multiple occupied floors above, use 16 ft wall minimum. <input type="checkbox"/> Non-W1 building: There is a garage opening without a steel moment frame, and there is less than 8 ft of wall on the same line for multiple occupied floors above, use 16 ft wall minimum.	-1.4	-1.4
Soft Story	W1A building: There are openings at the ground story (such as for parking) over at least 50% of the length of the building. <input type="checkbox"/> Non-W1 building: There are openings at the ground story (such as for parking) over at least 50% of the length of the building.	-1.4	-1.4
Non-W1 Building	Length of lateral system at any story is less than 50% of that at story above or height of any story is more than 2.0 times the height of the story above. <input type="checkbox"/> W1 building: Length of lateral system at any story is less than 50% of that at story above or height of any story is more than 2.0 times the height of the story above.	-1.1	-1.1
Non-W1 Building	Length of lateral system at any story is between 50% and 75% of that at story above or height of any story is between 1.3 and 2.0 times the height of the story above. <input type="checkbox"/> W1 building: Length of lateral system at any story is between 50% and 75% of that at story above or height of any story is between 1.3 and 2.0 times the height of the story above.	-0.6	-0.6
Seaback	Vertical elements of the lateral system at an upper story are outboard of those at lower stories. <input type="checkbox"/> Non-W1 building: Vertical elements of the lateral system at an upper story are outboard of those at lower stories.	-1.2	-1.2
Short Column	There is an in-plane offset of the lateral elements that is greater than the length of the elements. <input type="checkbox"/> Non-W1 building: There is an in-plane offset of the lateral elements that is greater than the length of the elements.	-0.4	-0.4
Pier	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35, C36, C37, C38, C39, C40, C41, C42, C43, C44, C45, C46, C47, C48, C49, C50, C51, C52, C53, C54, C55, C56, C57, C58, C59, C60, C61, C62, C63, C64, C65, C66, C67, C68, C69, C70, C71, C72, C73, C74, C75, C76, C77, C78, C79, C80, C81, C82, C83, C84, C85, C86, C87, C88, C89, C90, C91, C92, C93, C94, C95, C96, C97, C98, C99, C100, C101, C102, C103, C104, C105, C106, C107, C108, C109, C110, C111, C112, C113, C114, C115, C116, C117, C118, C119, C120, C121, C122, C123, C124, C125, C126, C127, C128, C129, C130, C131, C132, C133, C134, C135, C136, C137, C138, C139, C140, C141, C142, C143, C144, C145, C146, C147, C148, C149, C150, C151, C152, C153, C154, C155, C156, C157, C158, C159, C160, C161, C162, C163, C164, C165, C166, C167, C168, C169, C170, C171, C172, C173, C174, C175, C176, C177, C178, C179, C180, C181, C182, C183, C184, 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C683, C684, C685, C686, C687, C688, C689, C690, C691, C692, C693, C694, C695, C696, C697, C698, C699, C700, C701, C702, C703, C704, C705, C706, C707, C708, C709, C710, C711, C712, C713, C714, C715, C716, C717, C718, C719, C720, C721, C722, C723, C724, C725, C726, C727, C728, C729, C730, C731, C732, C733, C734, C735, C736, C737, C738, C739, C740, C741, C742, C743, C744, C745, C746, C747, C748, C749, C750, C751, C752, C753, C754, C755, C756, C757, C758, C759, C760, C761, C762, C763, C764, C765, C766, C767, C768, C769, C770, C771, C772, C773, C774, C775, C776, C777, C778, C779, C780, C781, C782, C783, C784, C785, C786, C787, C788, C789, C790, C791, C792, C793, C794, C795, C796, C797, C798, C799, C800, C801, C802, C803, C804, C805, C806, C807, C808, C809, C810, C811, C812, C813, C814, C815, C816, C817, C818, C819, C820, C821, C822, C823, C824, C825, C826, C827, C828, C829, C830, C831, C832, C833, C834, C835, C836, C837, C838, C839, C840, C841, C842, C843, C844, C845, C846, C847, C848, C849, C850, C851, C852, C853, C854, C855, C856, C857, C858, C859, C860, C861, C862, C863, C864, C865, C866, C867, C868, C869, C870, C871, C872, C873, C874, C875, C876, C877, C878, C879, C880, C881, C882, C883, C884, C885, C886, C887, C888, C889, C890, C891, C892, C893, C894, C895, C896, C897, C898, C899, C900, C901, C902, C903, C904, C905, C906, C907, C908, C909, C910, C911, C912, C913, C914, C915, C916, C917, C918, C919, C920, C921, C922, C923, C924, C925, C926, C927, C928, C929, C930, C931, C932, C933, C934, C935, C936, C937, C938, C939, C940, C941, C942, C943, C944, C945, C946, C947, C948, C949, C950, C951, C952, C953, C954, C955, C956, C957, C958, C959, C960, C961, C962, C963, C964, C965, C966, C967, C968, C969, C970, C971, C972, C973, C974, C975, C976, C977, C978, C979, C980, C981, C982, C983, C984, C985, C986, C987, C988, C989, C990, C991, C992, C993, C994, C995, C996, C997, C998, C999, C1000, C1001, C1002, C1003, C1004, C1005, C1006, C1007, C1008, C1009, C1010, C1011, C1012, C1013, C1014, C1015, C1016, C1017, C1018, C1019, C1020, C1021, C1022, C1023, C1024, C1025, C1026, C1027, C1028, C1029, C1030, C1031, C1032, C1033, C1034, C1035, C1036, C1037, C1038, C1039, C1040, C1041, C1042, C1043, C1044, C1045, C1046, C1047, C1048, C1049, C1050, C1051, C1052, C1053, C1054, C1055, C1056, C1057, C1058, C1059, C1060, C1061, C1062, C1063, C1064, C1065, C1066, C1067, C1068, C1069, C1070, C1071, C1072, C1073, C1074, C1075, C1076, C1077, C1078, C1079, C1080, C1081, C1082, C1083, C1084, C1085, C1086, C1087, C1088, C1089, C1090, C1091, C1092, C1093, C1094, C1095, C1096, C1097, C1098, C1099, C1100, C1101, C1102, C1103, C1104, C1105, C1106, C1107, C1108, C1109, C1110, C1111, C1112, C1113, C1114, C1115, C1116, C1117, C1118, C1119, C1120, C1121, C1122, C1123, C1124, C1125, C1126, C1127, C1128, C1129, C1130, C1131, C1132, C1133, C1134, C1135, C1136, C1137, C1138, C1139, C1140, C1141, C1142, C1143, C1144, C1145, C1146, C1147, C1148, C1149, C1150, C1151, C1152, C1153, C1154, C1155, C1156, C1157, C1158, C1159, C1160, C1161, C1162, C1163, C1164, C1165, C1166, C1167, C1168, C1169, C1170, C1171, C1172, C1173, C1174, C1175, C1176, C1177, C1178, C1179, C1180, C1181, C1182, C1183, C1184, C1185, C1186, C1187, C1188, C1189, C1190, C1191, C1192, C1193, C1194, C1195, C1196, C1197, C1198, C1199, C1200, C1201, C1202, C1203, C1204, C1205, C1206, C1207, C1208, C1209, C1210, C1211, C1212, C1213, C1214, C1215, C1216, C1217, C1218, C1219, C1220, C1221, C1222, C1223, C1224, C1225, C1226, C1227, C1228, C1229, C1230, C1231, C1232, C1233, C1234, C1235, C1236, C1237, C1238, C1239, C1240, C1241, C1242, C1243, C1244, C1245, C1246, C1247, C1248, C1249, C1250, C1251, C1252, C1253, C1254, C1255, C1256, C1257, C1258, C1259, C1260, C1261, C1262, C1263, C1264, C1265, C1266, C1267, C1268, C1269, C1270, C1271, C1272, C1273, C1274, C1275, C1276, C1277, C1278, C1279, C1280, C1281, C1282, C1283, C1284, C1285, C1286, C1287, C1288, C1289, C1290, C1291, C1292, C1293, C1294, C1295, C1296, C1297, C1298, C1299, C1300, C1301, C1302, C1303, C1304, C1305, C1306, C1307, C1308, C1309, C1310, C1311, C1312, C1313, C1314, C1315, C1316, C1317, C1318, C1319, C1320, C1321, C1322, C1323, C1324, C1325, C1326, C1327, C1328, C1329, C1330, C1331, C1332, C1333, C1334, C1335, C1336, C1337, C1338, C1339, C1340, C1341, C1342, C1343, C1344, C1345, C1346, C1347, C1348, C1349, C1350, C1351, C1352, C1353, C1354, C1355, C1356, C1357, C1358, C1359, C1360, C1361, C1362, C1363, C1364, C1365, C1366, C1367, C1368, C1369, C1370, C1371, C1372, C1373, C1374, C1375, C1376, C1377, C1378, C1379, C1380, C1381, C1382, C1383, C1384, C1385, C1386, C1387, C1388, C1389, C1390, C1391, C1392, C1393, C1394, C1395, C1396, C1397, C1398, C1399, C1400, C1401, C1402, C1403, C1404, C1405, C1406, C1407, C1408, C1409, C1410, C1411, C1412, C1413, C1414, C1415, C1416, C1417, C1418, C1419, C1420, C1421, C1422, C1423, C1424, C1425, C1426, C1427, C1428, C1429, C1430, C1431, C1432, C1433, C1434, C1435, C1436, C1437, C1438, C1439, C1440, C1441, C1442, C1443, C1444, C1445, C1446, C1447, C1448, C1449, C1450, C1451, C1452, C1453, C1454, C1455, C1456, C1457, C1458, C1459, C1460, C1461, C1462, C1463, C1464, C1465, C1466, C1467, C1468, C1469, C1470, C1471, C1472, C1473, C1474, C1475, C1476, C1477, C1478, C1479, C1480, C1481, C1482, C1483, C1484, C1485, C1486, C1487, C1488, C1489, C1490, C		

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: Urban <input type="checkbox"/> Rural <input type="checkbox"/> No. of occupants in the building: Day _____ Night _____ Number of stories in the building: _____ GPS Co-ordinates: Latitude: _____ Longitude: _____
Side picture of building 	

Type of Use of the Building:

Residential			
Private Dwelling <input type="checkbox"/>	Flat <input type="checkbox"/>	Dormitories <input type="checkbox"/>	Hotels <input type="checkbox"/>
Educational			
Aganwadi <input type="checkbox"/>	School <input type="checkbox"/>	College <input type="checkbox"/>	
Institutional			
Hospital <input type="checkbox"/>	Community Health Center <input type="checkbox"/>	Old age Homes <input type="checkbox"/>	Orphanage <input type="checkbox"/>

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Assembly

Cinema Hall <input type="checkbox"/>	Town Hall <input type="checkbox"/>	Marriage Hall <input type="checkbox"/>
Community Hall <input type="checkbox"/>	Restaurant <input type="checkbox"/>	Court Complex <input type="checkbox"/>

Important Government Buildings

D.C Office <input type="checkbox"/>	D.C Resident <input type="checkbox"/>	Tourism Office <input type="checkbox"/>
P.W.D Offices <input type="checkbox"/>	HPSEB Offices <input type="checkbox"/>	HPIPH Offices <input type="checkbox"/>

Emergency Buildings

Police Station <input type="checkbox"/>	Fire Station <input type="checkbox"/>
---	---------------------------------------

Service Buildings

Telecommunication <input type="checkbox"/>	Electric Sub Stations <input type="checkbox"/>	Water Pump Stations <input type="checkbox"/>
--	--	--

Commercial

Shop <input type="checkbox"/>	Super Market <input type="checkbox"/>	Vegetable Market <input type="checkbox"/>
-------------------------------	---------------------------------------	---

Cowshed

2. Exposure to Hazard Types

Geological	Hydro-meteorological	Others
Earthquake <input type="checkbox"/>	Riverine Flood <input type="checkbox"/>	Cloud Burst <input type="checkbox"/>
Landslide <input type="checkbox"/>	Wind Storm <input type="checkbox"/>	Hail Storm <input type="checkbox"/>
	Avalanche <input type="checkbox"/>	Flash Flood <input type="checkbox"/>
	Maximum height of the snow deposition: _____	
		Fire <input type="checkbox"/>
		Forest Fire <input type="checkbox"/>
		Lightning <input type="checkbox"/>

3. Site Characterization

Site Morphology:

Flat <input type="checkbox"/>	Crest <input type="checkbox"/>	Downward Slope <input type="checkbox"/>	Trough <input type="checkbox"/>
-------------------------------	--------------------------------	---	---------------------------------

Soil:

Soil Type			Soil Nature		
Hard <input type="checkbox"/>	Medium <input type="checkbox"/>	Soft <input type="checkbox"/>	Expansive <input type="checkbox"/>	Non Expansive <input type="checkbox"/>	Unknown <input type="checkbox"/>

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Parameters for Liquefaction potential of soil

Depth of the water table (in ft): _____	Whether the soil is sandy? Yes <input type="checkbox"/> No <input type="checkbox"/>
---	---

4. Basic Details about Building

Building Code Compliance:

Engineered Building <input type="checkbox"/>	Non-engineered Building <input type="checkbox"/>
--	--

Type of Construction:

RC Frame <input type="checkbox"/>	Brick Masonry <input type="checkbox"/>	Stone Masonry <input type="checkbox"/>	Rammed Earth <input type="checkbox"/>	Hybrid <input type="checkbox"/>
-----------------------------------	--	--	---------------------------------------	---------------------------------

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 <input type="checkbox"/>	Flat to mild (0-15°) <input type="checkbox"/>
	Medium (15°-30°) <input type="checkbox"/>
NO <input type="checkbox"/>	Steep (>30°) <input type="checkbox"/>

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Age, area and cost of the building:

Age of construction _____	Average built-up area (ft ²) _____	Cost of construction (in `) _____
---------------------------	--	-----------------------------------

Foundation:

Type of Foundation	Isolated <input type="checkbox"/>	Combined <input type="checkbox"/>	Raft <input type="checkbox"/>	Pile <input type="checkbox"/>	Spread <input type="checkbox"/>	Mat <input type="checkbox"/>
Depth of Foundation (ft)	_____					

Floor Details:

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

Wall Details:

Wall Material	Concrete <input type="checkbox"/>	Burnt Brick <input type="checkbox"/>	Unburnt Brick <input type="checkbox"/>	Dressed Stone <input type="checkbox"/>	Undressed Stone <input type="checkbox"/>	Wood <input type="checkbox"/>	Mud <input type="checkbox"/>	Grass/Bamboo <input type="checkbox"/>	Plastic/Polythene <input type="checkbox"/>
For stone masonry, size of the stone > 300 mm YES <input type="checkbox"/> NO <input type="checkbox"/>									
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)

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

Roof Details:

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

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	<input type="checkbox"/>					
Column	<input type="checkbox"/>					
Wall	<input type="checkbox"/>					

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

Type of Building Distress:

WALL:

 Corner crack in wall <input type="checkbox"/>	 Settlement crack <input type="checkbox"/>	 Bulging <input type="checkbox"/>
 Wall overturning <input type="checkbox"/>	 Partial wall collapse <input type="checkbox"/>	 Vertical cracks in full depth of the wall <input type="checkbox"/>
 Wythe separation <input type="checkbox"/>	 Diagonal cracks near opening (door & window) <input type="checkbox"/>	 Vertical cracks above door/window <input type="checkbox"/>

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ROOF:

 Roof sag <input type="checkbox"/>	 Roof collapse <input type="checkbox"/>
---	--

COLUMN:

 Shear cracks in column <input type="checkbox"/>	 Column sway <input type="checkbox"/>
---	--

BEAM:

 Shear cracks in beam <input type="checkbox"/>	 Horizontal cracks in beam <input type="checkbox"/>	 Tensile cracks in beam <input type="checkbox"/>
---	--	---

OTHER DEFICIENT PARAMETERS:

Water seepage	Corrosion	Quality of construction	Quality of concreting	Maintenance
YES <input type="checkbox"/>	YES <input type="checkbox"/>	Poor <input type="checkbox"/>	Poor <input type="checkbox"/>	Undertaken <input type="checkbox"/>
NO <input type="checkbox"/>	NO <input type="checkbox"/>	Moderate <input type="checkbox"/>	Moderate <input type="checkbox"/>	Not Undertaken <input type="checkbox"/>
	If YES, severity of corrosion	Good <input type="checkbox"/>	Good <input type="checkbox"/>	
	Minor <input type="checkbox"/>			
	Acute <input type="checkbox"/>			

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6. Vulnerability factors for specific hazard types:

Earthquake:

SHAPE OF THE BUILDING:

 Rectangular <input type="checkbox"/>	 Circular <input type="checkbox"/>	 L-Shape <input type="checkbox"/>	 T-Shape <input type="checkbox"/>
 U-Shape <input type="checkbox"/>	 H-Shape <input type="checkbox"/>	 Plus Shape <input type="checkbox"/>	None of the above <input type="checkbox"/>

VERTICAL IRREGULARITIES:

Presence of setbacks	YES <input type="checkbox"/>	NO <input type="checkbox"/>
Presence of step back	YES <input type="checkbox"/>	NO <input type="checkbox"/>

STRUCTURAL IRREGULARITIES:

Presence of different storey height	Presence of soft storey	Presence of short column	Presence of reentrant corners	Presence of heavy overhangs
YES <input type="checkbox"/>	YES <input type="checkbox"/>	YES <input type="checkbox"/>	YES <input type="checkbox"/>	YES <input type="checkbox"/>
NO <input type="checkbox"/>	NO <input type="checkbox"/>	NO <input type="checkbox"/>	NO <input type="checkbox"/>	NO <input type="checkbox"/>

PRESENCE OF HORIZONTAL BAND (MASONRY CONSTRUCTION):

Horizontal band at plinth level	YES <input type="checkbox"/>	NO <input type="checkbox"/>	Can't be identified <input type="checkbox"/>
Horizontal band at lintel level	YES <input type="checkbox"/>	NO <input type="checkbox"/>	Can't be identified <input type="checkbox"/>
Horizontal band at sill level	YES <input type="checkbox"/>	NO <input type="checkbox"/>	Can't be identified <input type="checkbox"/>
Horizontal band at roof level	YES <input type="checkbox"/>	NO <input type="checkbox"/>	Can't be identified <input type="checkbox"/>

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-Shape
 U-Shape
 H-Shape
 Puls Shape
 None of the above

Irregularities:
 Vertical (type/severity): _____
 Plan (type): _____
 Floor plans

3. Construction Technology

Prefabricated <input type="checkbox"/> Traditional <input type="checkbox"/> Reinforcement <input type="checkbox"/> Refurbishment / Restoration <input type="checkbox"/> New technologies <input type="checkbox"/>	
---	--

2

4. Information about building and building elements

Foundation

Type of Foundation	Isolated <input type="checkbox"/>	Combined <input type="checkbox"/>	Raft <input type="checkbox"/>	Pile <input type="checkbox"/>	Spread <input type="checkbox"/>
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										
1 st 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		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																											
1 st level																											
2 nd level																											
3 rd level																											
4 th level																											
5 th 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  <input type="checkbox"/>	Concrete <input type="checkbox"/>	Steel <input type="checkbox"/>
Open Gable  <input type="checkbox"/>	Metal <input type="checkbox"/>	Wood <input type="checkbox"/>
Box Gable  <input type="checkbox"/>	Stone/Slate <input type="checkbox"/>	If truss is anchored to the beam <input type="checkbox"/>
Shed roof  <input type="checkbox"/>	Wood <input type="checkbox"/>	If truss is anchored to the wall <input type="checkbox"/>
Hip roof  <input type="checkbox"/>	Burnt brick <input type="checkbox"/>	
Other <input type="checkbox"/>	Tile <input type="checkbox"/>	

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

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

Level / Type, number and size of the opening	Door		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
1 st level	14	13							1	13														11		2	1
2 nd level	13	15							1	12														12		2	1
3 rd level	12	16							1	11														13		2	1
4 th level	13	15							1	12														12		2	1
5 th level	4	9	2						2															1		4	4

Distance (m)

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		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			
1 st level	23	4	3						13		1	6											4				
2 nd level	19	5	3						12		4												3			2	
3 rd level	20	6	3						13		4												4			2	
4 th level	20	6	3						13		4												4			2	
5 th level	8		2						2		2	2															

Distance (m)

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	<input checked="" type="checkbox"/>			
Connected	<input checked="" type="checkbox"/>			
Enclosed				

Roof Details

Roof Type	Material	Presence of truss
Flat 	Concrete <input type="checkbox"/>	Steel <input type="checkbox"/>
Open Gable 	Metal <input type="checkbox"/>	Wood <input type="checkbox"/>
Box Gable 	Stone/Slate <input type="checkbox"/>	If truss is anchored To the beam <input type="checkbox"/>
Shed roof 	Wood <input type="checkbox"/>	If truss is anchored To the wall <input type="checkbox"/>
Hip roof 	Burnt brick <input type="checkbox"/>	
Other <input type="checkbox"/>	Tile <input type="checkbox"/>	

5. Condition assessment

Present condition

New Moderately Poor

Detailed description: None of the significant crack was appeared.

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

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

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				

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	$9 \cdot 10^{-6}$	$4 \cdot 10^{-6}$	$11.9 \cdot 10^{-6}$	$1.3 \cdot 10^{-5}$	$8 \cdot 10^{-6}$

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).

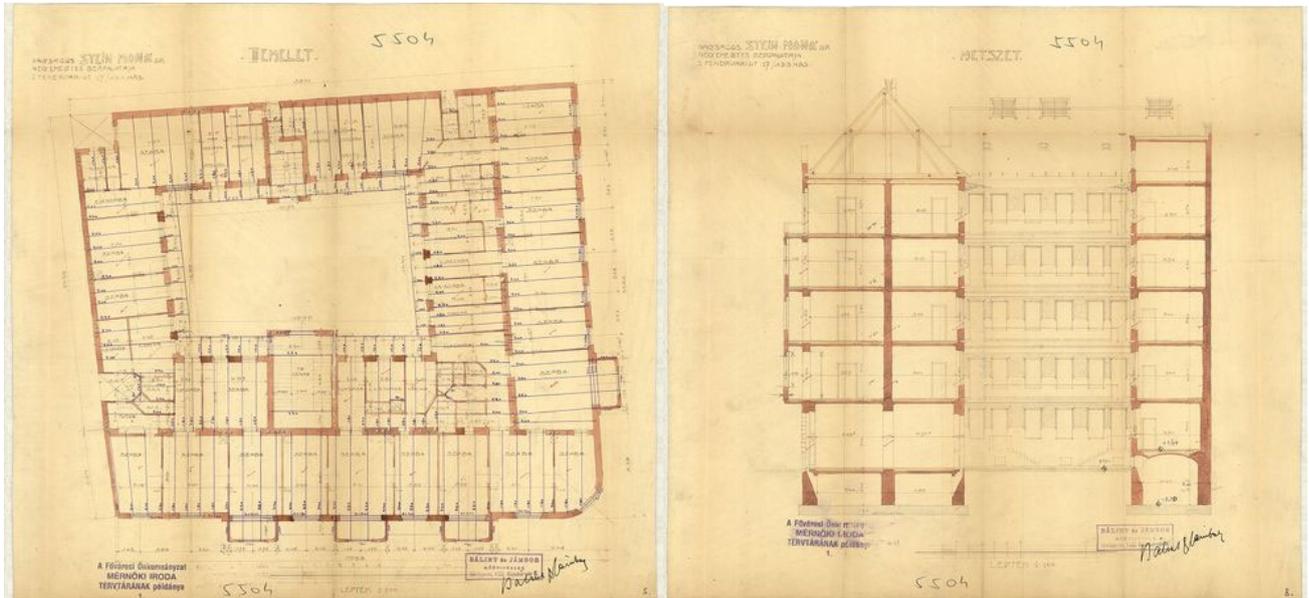


Figure 17. a) Samples of the typical plan and b) vertical plan (old drawings)

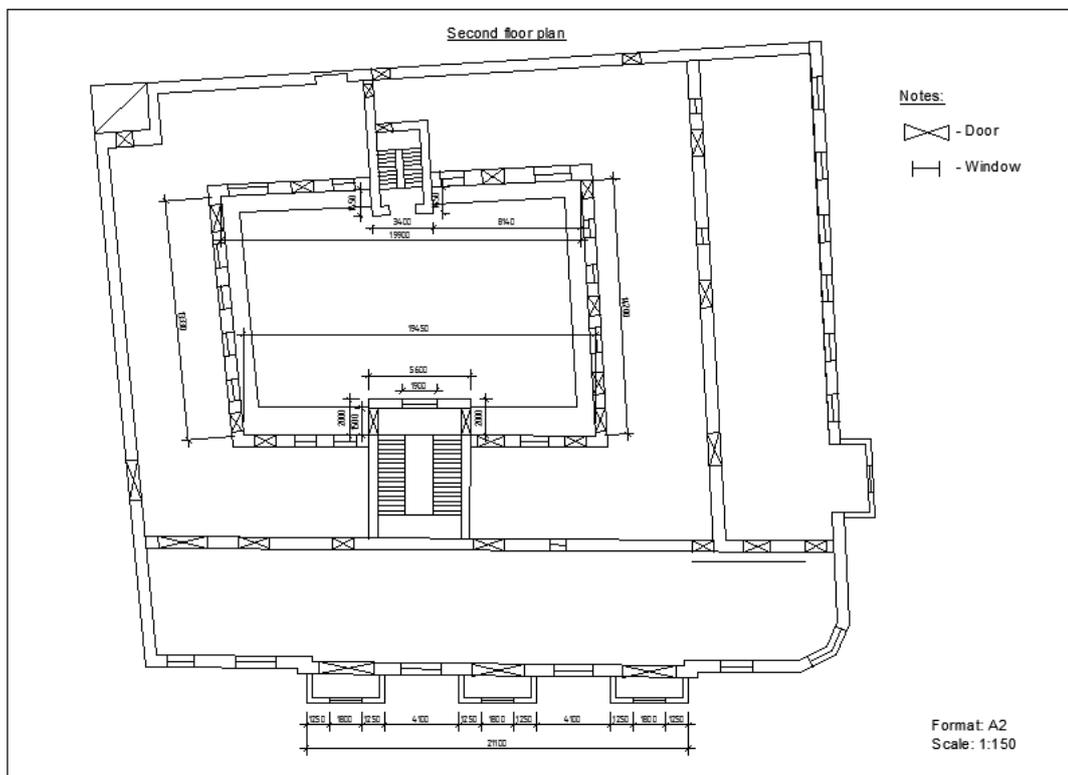


Figure 18. Sample of the walls and openings plan of typical floor (new drawing)

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 (m²)	Volume (m³)	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 1st and 2nd 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)

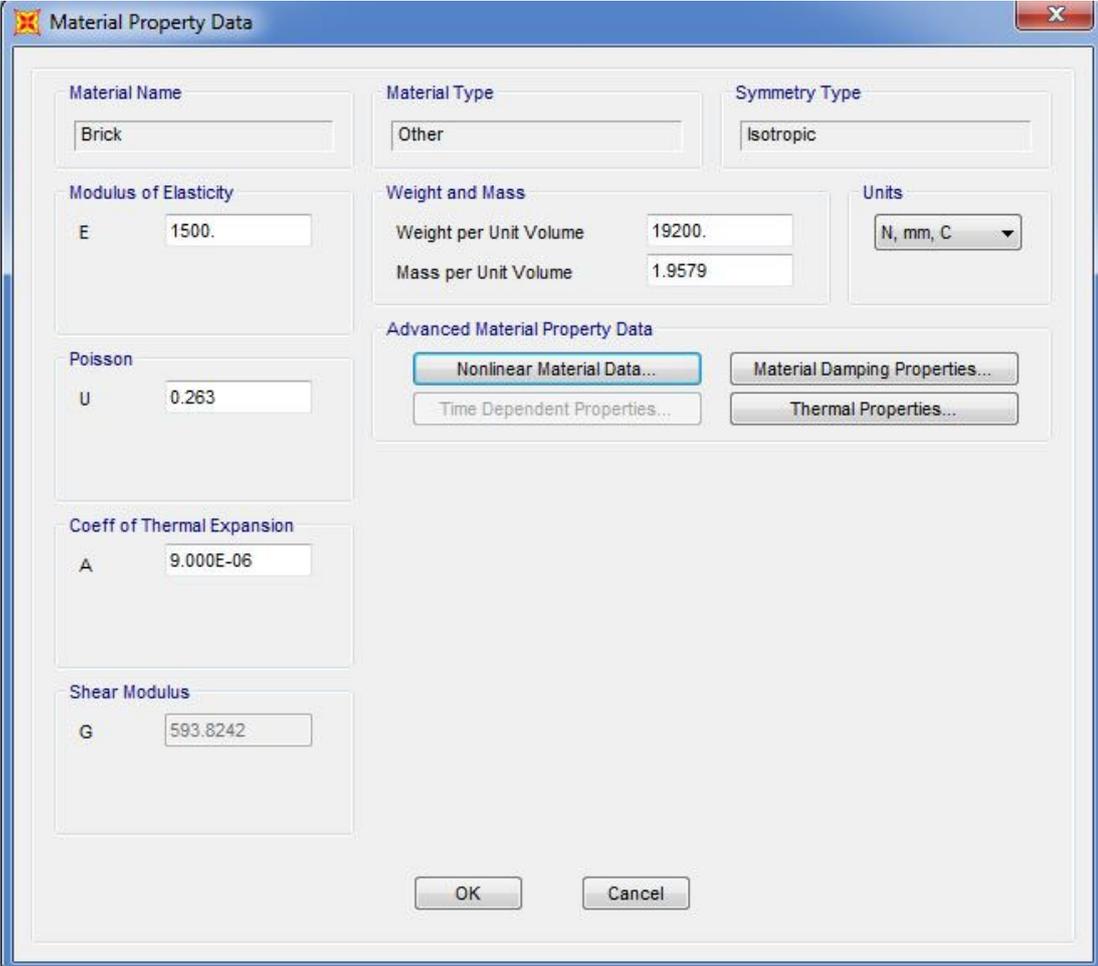


Figure 19. Material property data

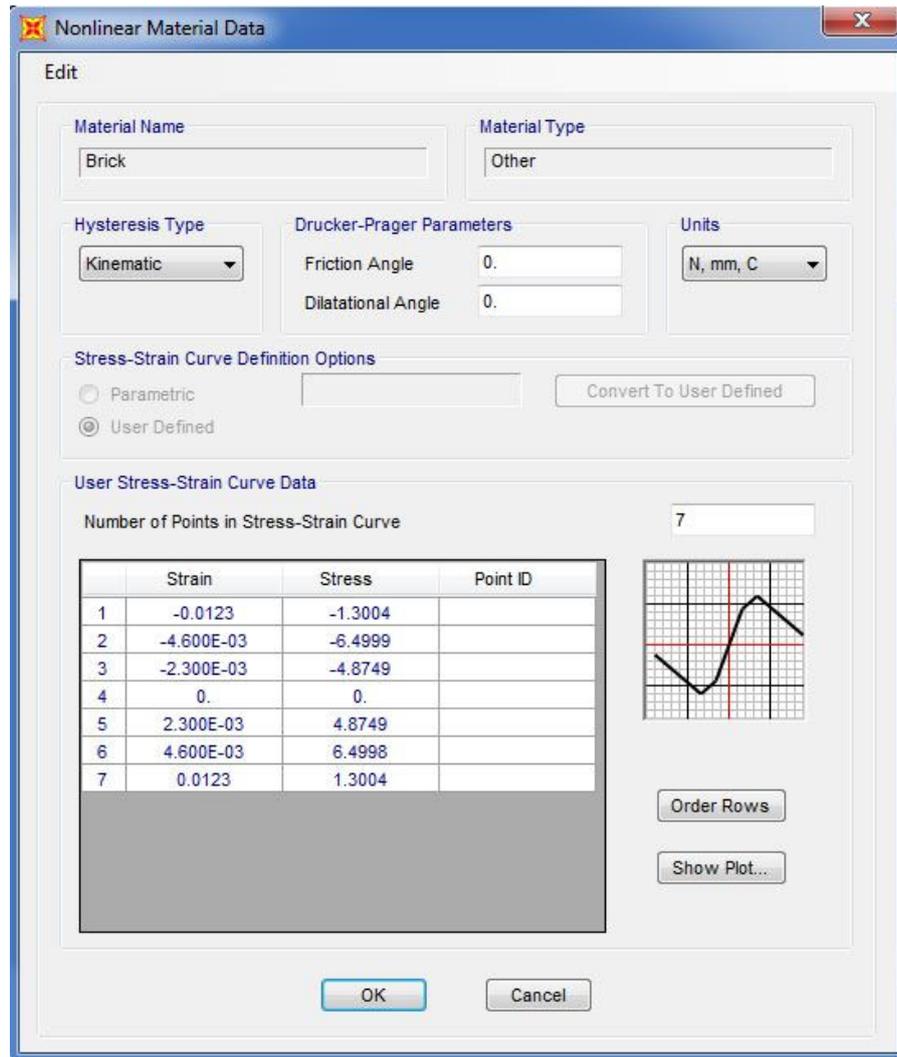


Figure 20. Nonlinear material data

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

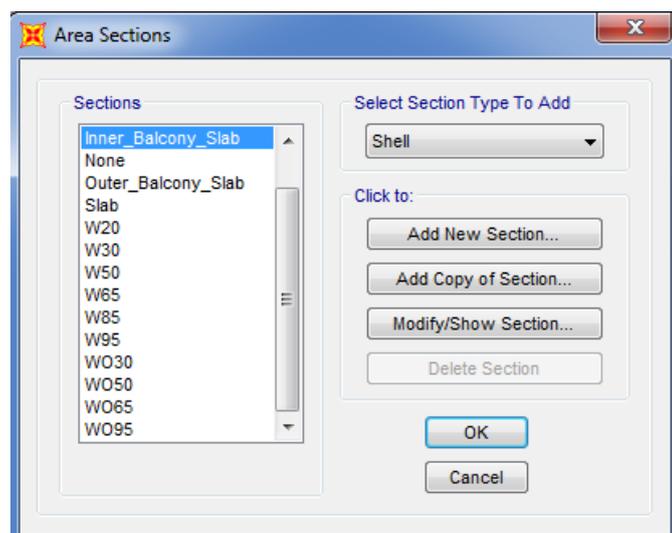


Figure 21. List of the wall sections

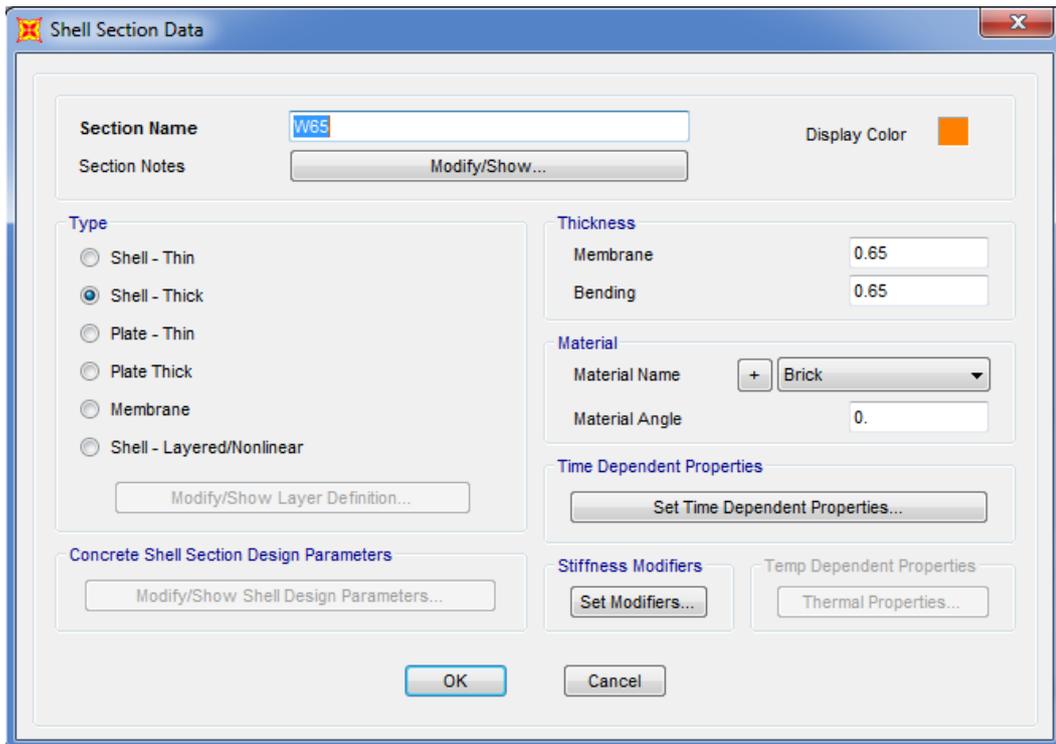


Figure 22. Shell section data for the wall with thickness 65 cm

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

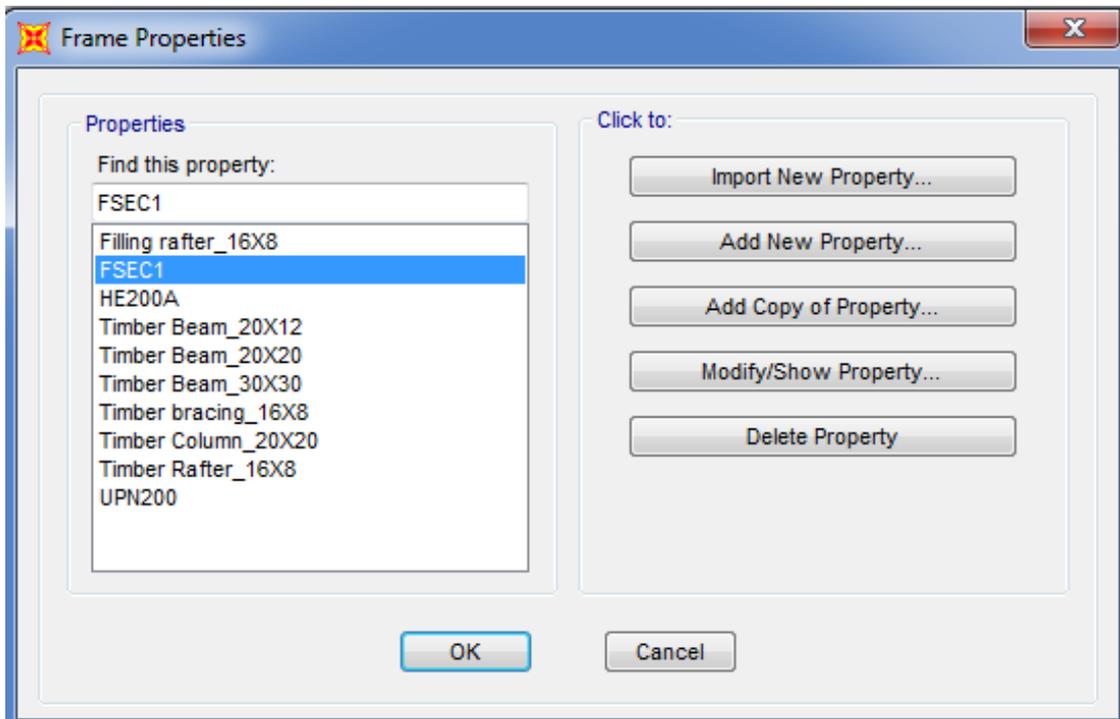


Figure 23. Frame properties

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.

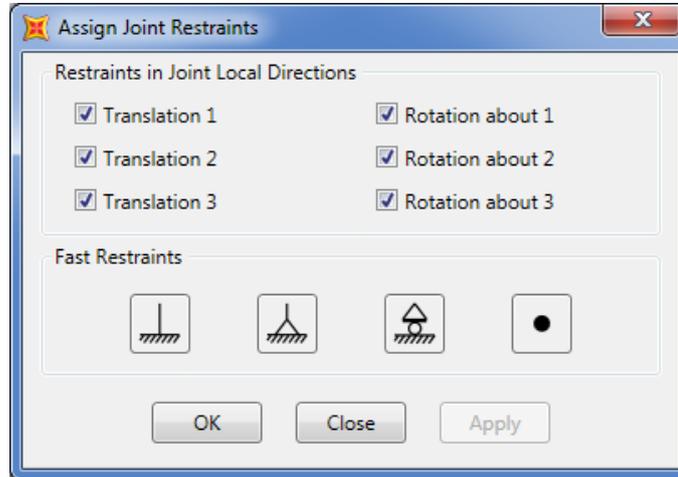


Figure 24. Joint restraints

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

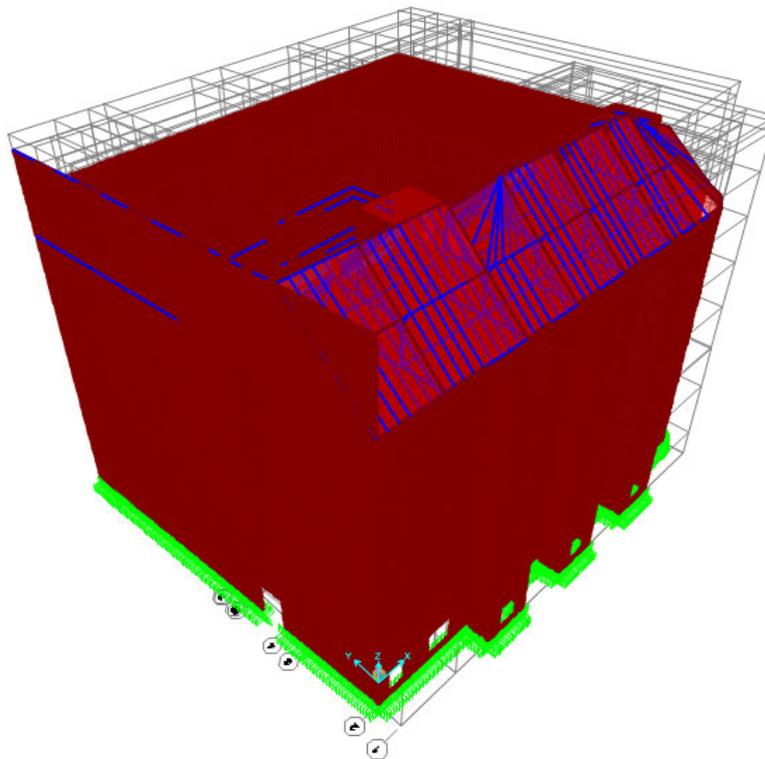


Figure 25. 3D model of the building

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.

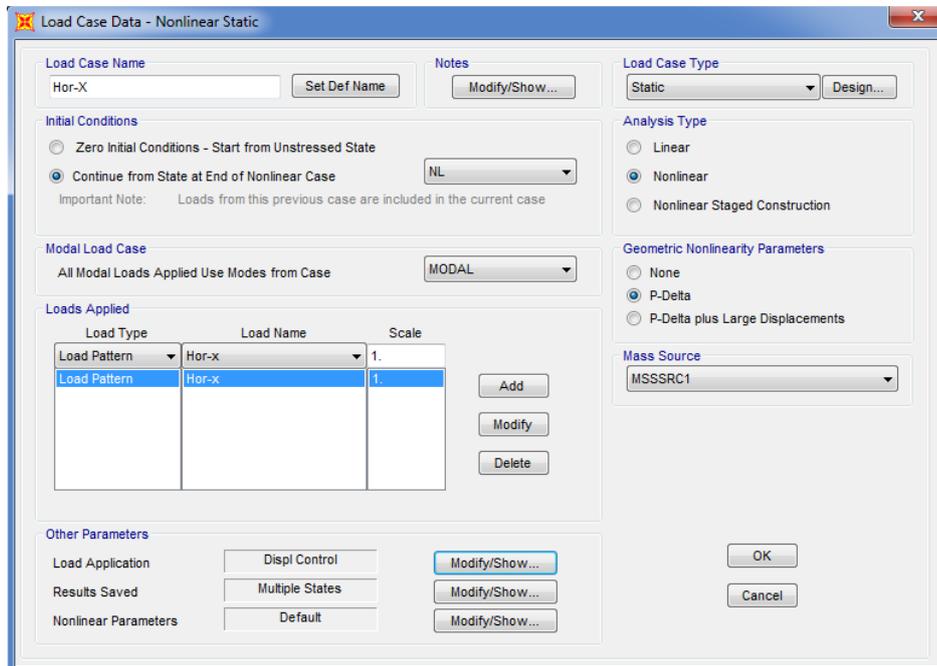


Figure 26. Horizontal load case modified for nonlinear static analysis

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

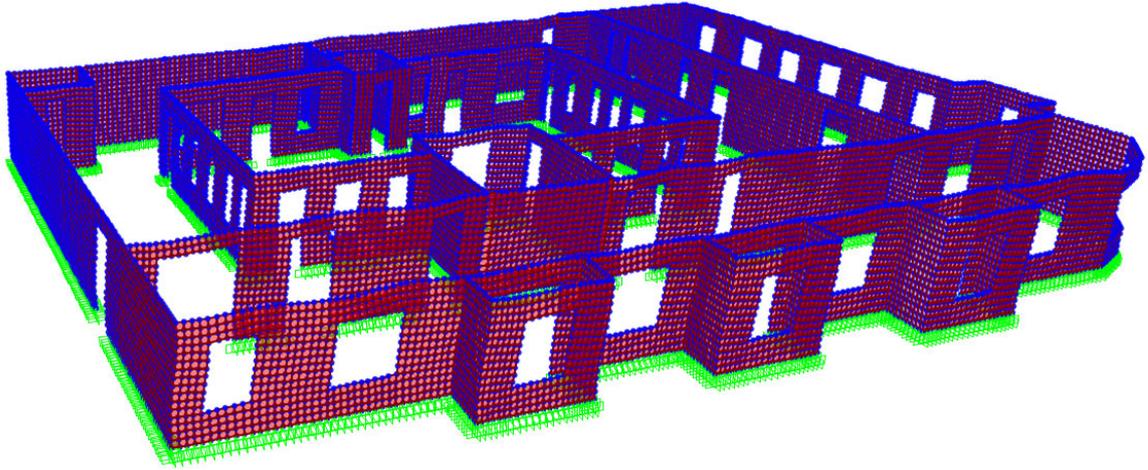


Figure 27. Deformed shape of the single floor walls

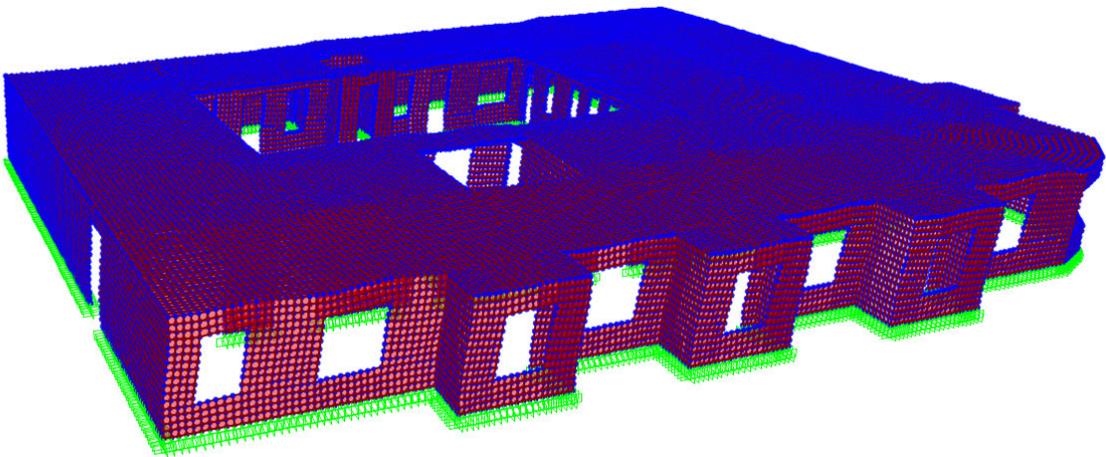


Figure 28. Deformed shape of the single floor walls and slab

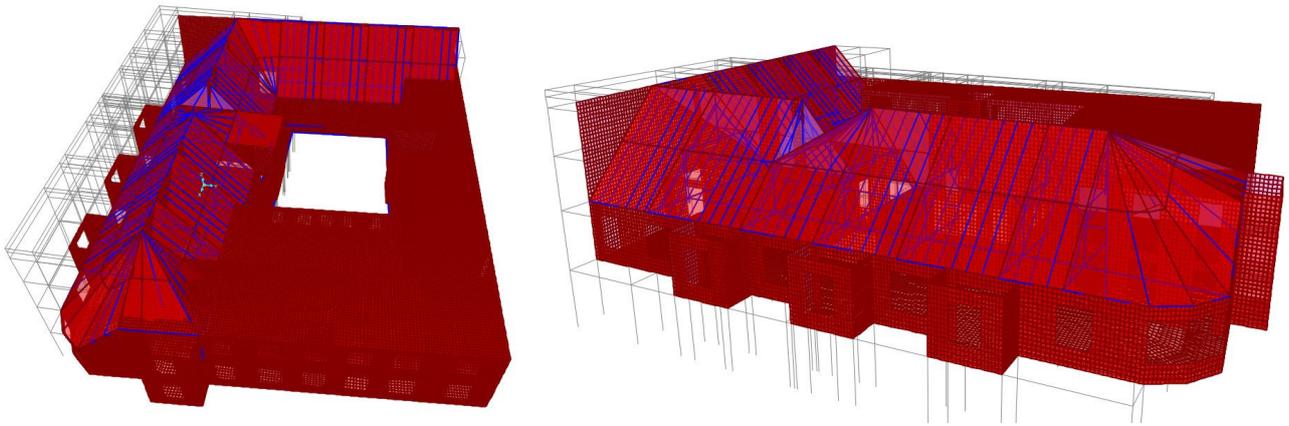


Figure 29.a,b 3D model for last floor and loft construction

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]:

$$\text{Fragility} = P[\text{LS}|\text{IM} = y] \quad (1)$$

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)

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

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

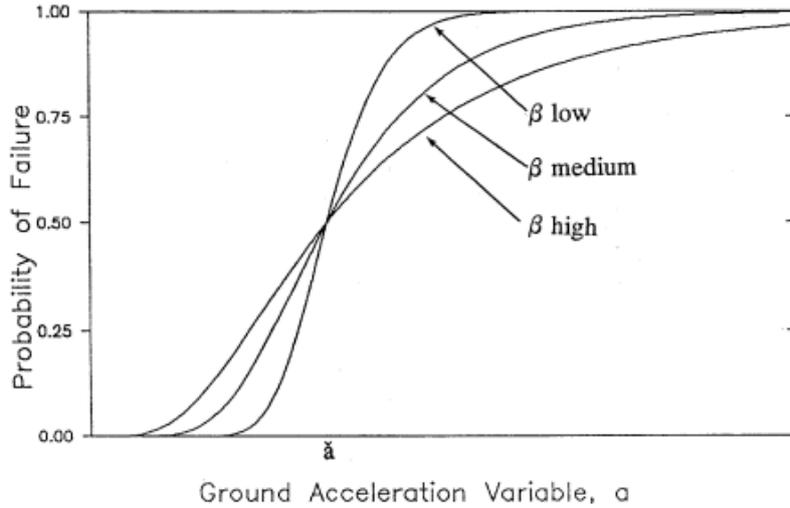


Figure 30. Fragility curve based on the lognormal distribution [11]

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 independent and lognormal.

Fuzzy Random (FR) Method - damage quantification is naturally fuzzy, its probability is the expectation of the membership function μ_E 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]:

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

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

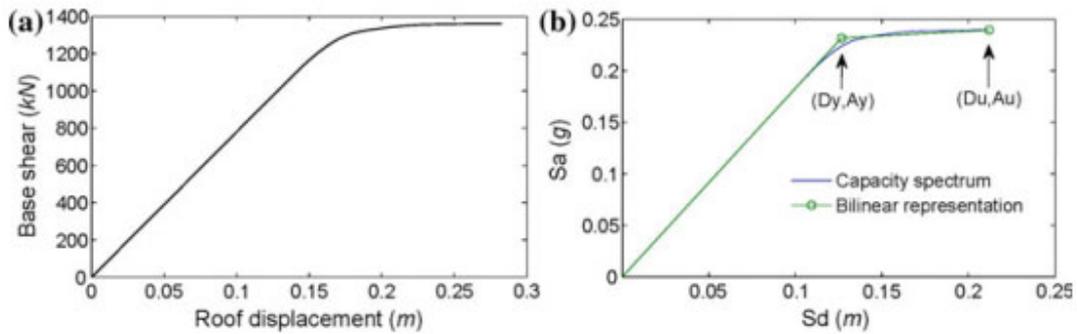


Figure 31. Capacity curve (a) and capacity spectrum (b) obtained from the deterministic APA [12]

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 [?].

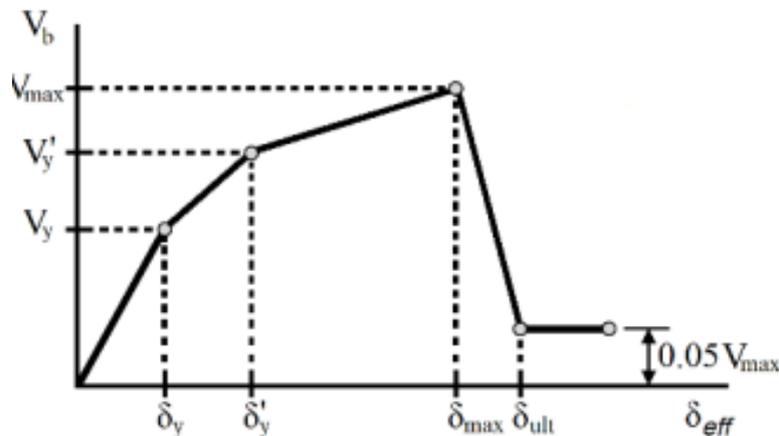


Figure 32. Idealizations of the F - δ backbone curve for masonry walls.

8.3 Definition of IDA (Incremental Dynamic Analysis) curve

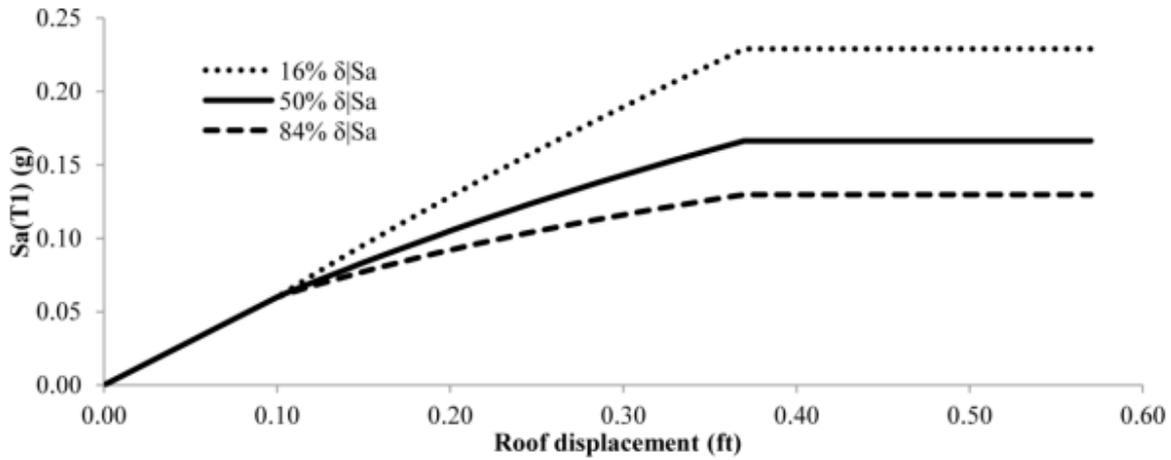
IDA (Incremental Dynamic Analysis) STUDY is a dynamic analysis study of a given structural model parameterized by the scale factor of the given ground motion time history.

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.

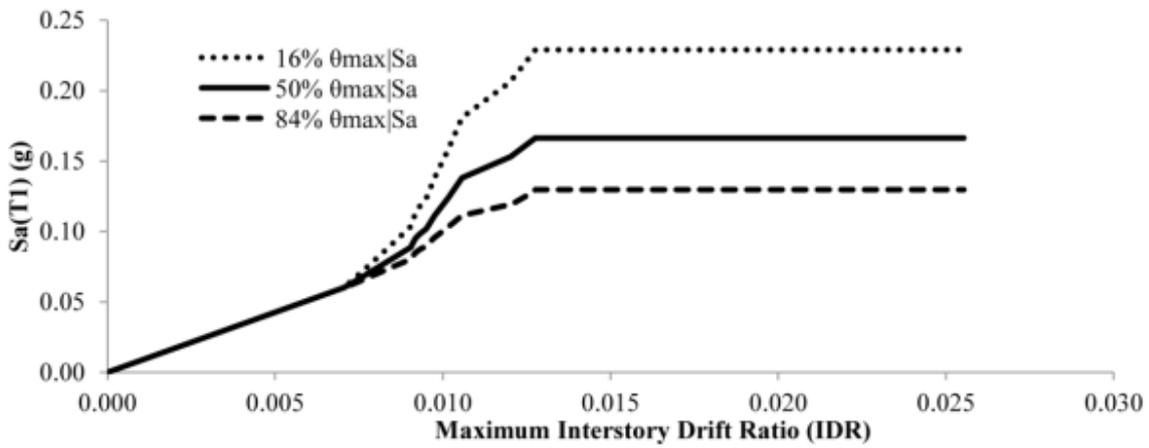
An IDA CURVE SET is a collection of IDA curves of the same structural model under different accelerograms that are all parameterized on the same IMs and DM [13].

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].



(a) Sa(T1)(g) vs Roof displacement



(b) Sa(T1)(g) vs Maximum Interstorey Drift Ratio

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).

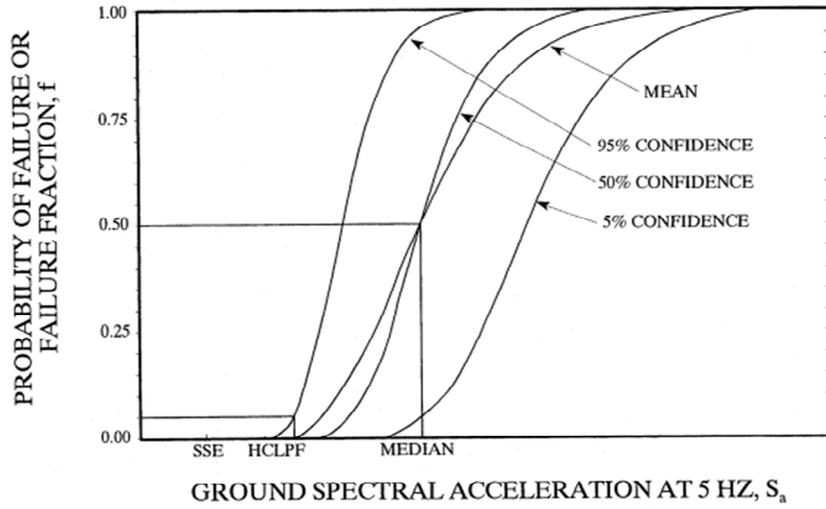


Figure 34. Illustration of fragility curves [11]

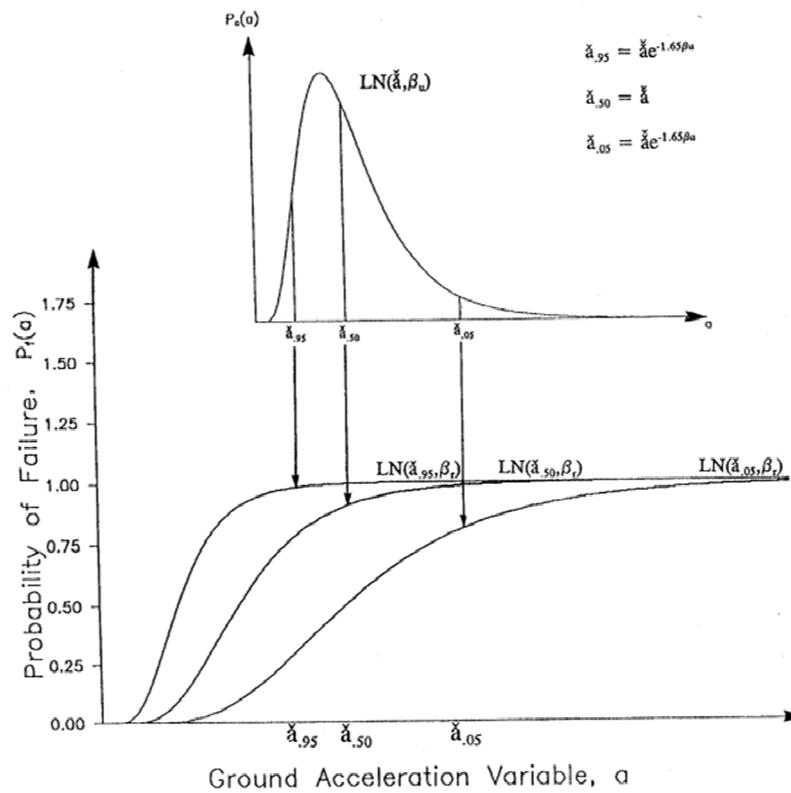


Figure 35. Family of fragility curves at 95%, 50% and 5% confidence levels [11]

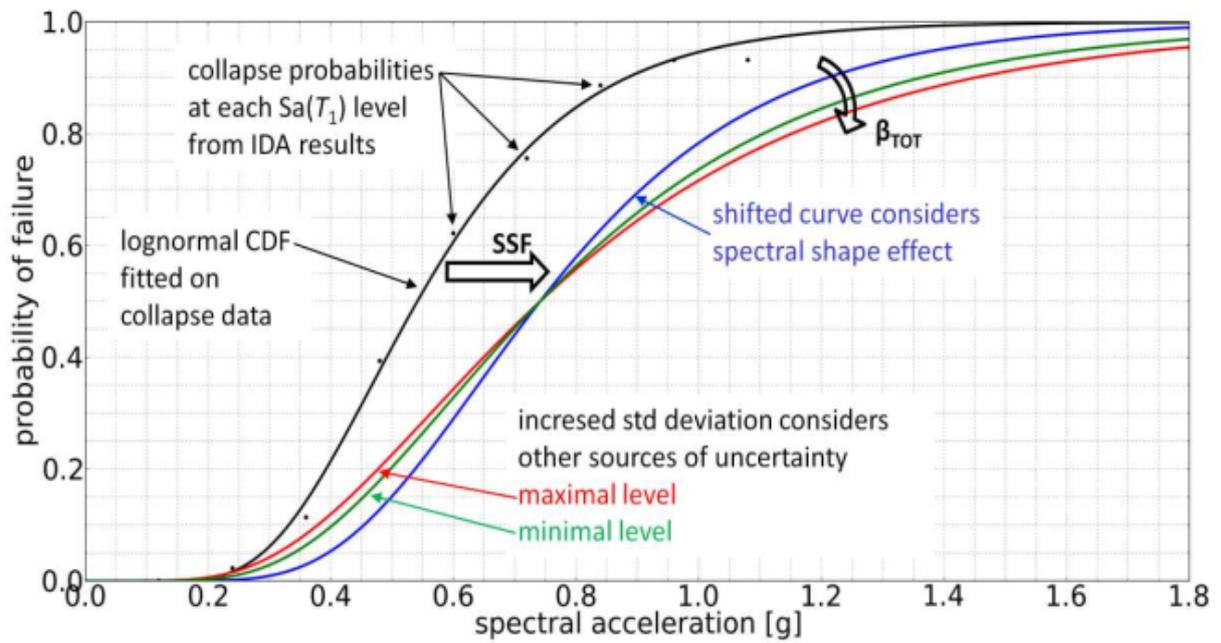


Figure 36. Fragility curve, conditional probability of failure [15]

Steps for hazard curve are given in Fig. 37.

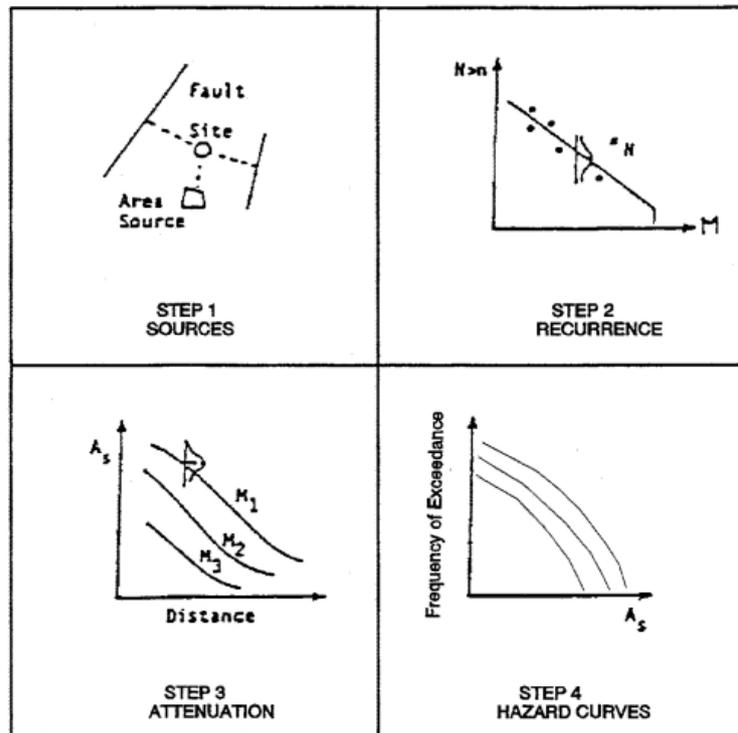


Figure 37. Seismic hazard analysis steps [11]

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].

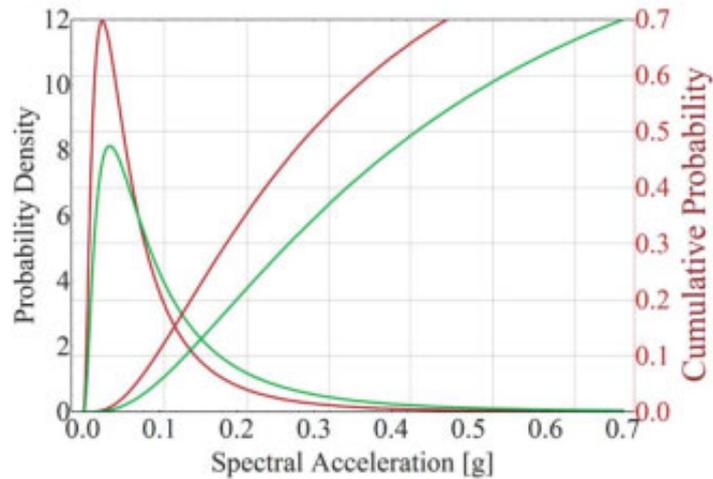


Figure 38. Hazard curve, PDF and CDF for two sites (Kosovo (green) and Italy (red; PGA = 0.2 g) [15]

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

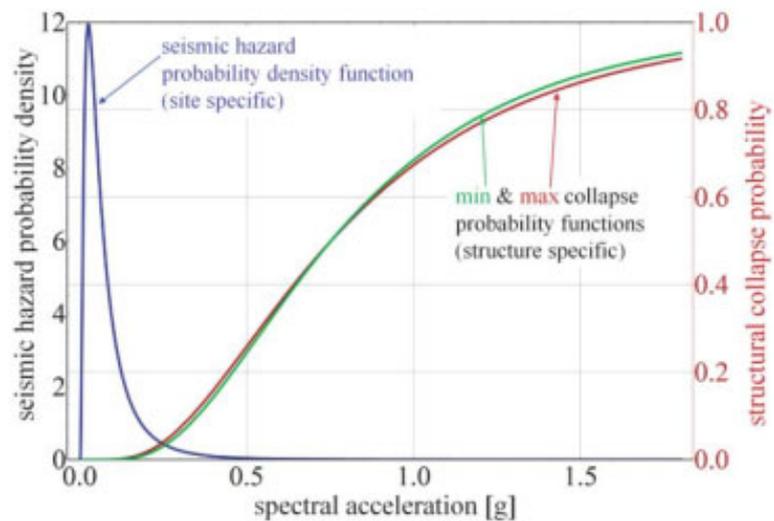


Figure 39. Fragility and hazard curves [15]

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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