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Case Study

Seismic Sustainability Assessment of Lavasan City

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ABSTRACT: Earthquake is a natural and inevitable phenomenon which can cause huge losses of life and economy. Due to locating on seismic belt and its seismic condition, Iran country, is very sensitive to earthquake. The aim of this study was seismic sustainability of Lavasan city, to evaluate the seismic vulnerability of buildings based on the HAZUS method and geographical information system (GIS). Some information such as type of structures, number and size of floors, population of each regions, soil types and etc were gathered and used the risk analysis software SELENA for calculating. In this method the response curve gained from soil type based on IBC-2006 standard and damping effect for all kinds of structures with the methods listed is calculated in Fema-440. This output includes infrastructure damaged by the type of structure, probable loss of life and damage to property, inflicted by the design based on Iranian Code of Practicefor Seismic Resistant Design of Buildings. The old area of Lavasan city, including areas 6, 9, 10, 11 and 12, shows the highest ratio of damages.

Keywords: Seismic Sustainability, Damage, Risk, Hazus, Lavasan

RUNNING TITLE: Seismic Sustainability Assessment

INTRODUCTION

Iranian plateau is located between the continental convergence of the Arabian and Eurasian plates in the central part of the Alpine–Himalayan seismic belt and the seismicity of this area is very high. The occurrence of devastating earthquakes has imposed notable damages to the buildings and lifelines, and, unfortunately, has caused huge loss of human life. Lavasan is an affluent town in Shemiranat County, Tehran Province, Iran. At the 2011 census, its population was 28,558, in 7,645 families. Lavasan, located northeast of Tehran and north of Latian Dam Lake, which is the crossing point of the North Tehran Fault with about 75 km long, is facing many constructions, constructions that have endangered the lives and capital of the people of that region. In addition, in the northern slopes of Lavasan, the active and seismic fault Mosha with about 200 km long is located, which has a history of high seismicity. The two dangerous faults north of Tehran and Mosha near this area, in the south of Lavasan Bozorg region, converge and form a tectonic node, which is one of the most active zones with high seismic potential (Berberian et al. 1983).

Vulnerability assessment and modeling behavior of buildings with regard to earthquakes have turned into a major concept in hazards studies that have identified the effective factors in earthquake hazard assessment and applied various methods in developing a seismic hazard map.

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Research Procedure

The earthquake loss estimation tool SELENA (Molina, et al. 2010), which is described herein, provides local, state and regional officials with a state-of-the-art decision support tool for estimating possible losses from future earthquakes. This forecasting capability enables users to anticipate the consequences of future earthquakes and to develop plans and strategies for reducing risk. GIS-based software can be utilized at multiple levels of resolution to graphically show loss results and to prepare response strategies (Molina, et al. 2012). This software does not calculate casualties of nonstructural components. This software requires text input files which are consist of soil type information, capacity and fragility curves, probability of collapse of structures, renovation economic losses based on damage type, population information and etc. Generally, 53 different input files are required for probabilistic analysis. Standard response spectrum, based on International Building Code (IBC, 2006), is used for soil classification. This spectrum requires acceleration in periods 0.3 and 1 second. Classification of soil based on shear velocity of soil is also acceptable. Capacity curve is an exact simple mean for prediction of nonlinear displacement response of structure for damage identification. This curve represents actual displacement of a given structure using several spectrums. The used curve in this study has three control points which are design, yielding and ultimate capacity (HAZUS, 2003). Design capacity represents the nominal strength required based on current seismic code provisions. Yield capacity represents the actual lateral strength of the building considering redundancies in design, conservatism requirements of code and actual strength (rather than nominal) of materials. Due to the lack of studies providing required information from structural point of view in our country, and the existence of similarity between structural codes of Iran and that of United States, HAZUS-MH structures coefficients are used (HAZUS, 2003). These parameters are based on moderate code design level levels in concrete and steel and low code design level for masonry structures. (Optimized building damage module that uses seven combinations of design levels and building quality).

Fig 1: District of Lavasan city

Data Preparation and Analysis

Construction materials of structures

There are different classifications for the materials used in the construction of buildings. One of the most important is the ranking done in Standard 2800 (BHRC, 2015) for earthquake -proof structures. In this regulation, structures are divided into three categories according to the materials used for construction; these are steel, concrete and masonry buildings (brick and cement block or stone) as well as sun-dried mud. The results of the research by experts in laboratory experiments and observations from previous earthquakes indicate that mud brick buildings are vulnerable structures which totally collapse the most during an earthquake with a magnitude greater than 6 (Mahdizadeh, 2011). Area of existing buildings of Lavasan Shown in Table 1. (Lavasan Municipality, 2016)

Tab 1: Area of existing buildings (m2)

District		Structural Type		
		Masonry	Steel	Concrete
1	AhmadAbad	47177	89898	82618
2	Astalak	9690	85759	98678
3	Basti	7379	78044	31647
4	Tok Mazraeh	59531	44689	38710
5	Teymur Abad	8285	3275	3060
6	Jaij	150379	110833	107816
7	Sabu-ye Bozorg	18585	12441	4549

8	Sabu-ye Koochak	31026	17704	32162
9	Shurkab	229260	215672	133984
10	Galandovak	128953	111450	85551
11	Naran	233814	371793	264770
12	Najar-Kola	289100	408119	236320

Age of construction

The optimal lifetime of structures in Iran is usually 30 yr. The longer a building's lifetime is, the greater is its vulnerability. Furthermore, according to Standard 2800, the amount of structural damage shows a step-linear function in an earthquake because the quality and the type of construction materials changed at each period during various editions of the regulations. Thus, the structures can be divided into three groups according to their vulnerability: Building age with younger than 10 yr, between 10–30 yr, and 30–50 yr.

Structure damage

Steel Moment Frame (S1):

Slight Structural Damage: Minor deformations in connections or hairline cracks in few welds.

Moderate Structural Damage: Some steel members have yielded exhibiting observable permanent rotations at connections; few welded connections may exhibit major cracks through welds or few bolted connections may exhibit broken bolts or enlarged bolt holes.

Extensive Structural Damage: Most steel members have exceeded their yield capacity, resulting in significant permanent lateral deformation of the structure. Some of the structural members or connections may have exceeded their ultimate capacity exhibited by major permanent member rotations at connections, buckled flanges and failed connections. Partial collapse of portions of structure is possible due to failed critical elements and/or connections. Complete Structural Damage: Significant portion of the structural elements have exceeded their ultimate capacities or some critical structural elements or connections have failed resulting in dangerous permanent lateral displacement, partial collapse or collapse of the building. Approximately 8%(low-rise), 5%(mid-rise) or 3%(high-rise) of the total area of S1 buildings with Complete damage is expected to be collapsed.

Steel Braced Frame (S2):

Slight Structural Damage: Few steel braces have yielded which may be indicated by minor stretching and/or buckling of slender brace members; minor cracks in welded connections; minor deformations in bolted brace connections.

Moderate Structural Damage: Some steel braces have yielded exhibiting observable stretching and/or buckling of braces; few braces, other members or connections have indications of reaching their ultimate capacity exhibited by buckled braces, cracked welds, or failed bolted connections.

Extensive Structural Damage: Most steel brace and other members have exceeded their yield capacity, resulting in significant permanent lateral deformation of the structure. Some structural members or connections have exceeded their ultimate capacity exhibited by buckled or broken braces, flange buckling, broken welds, or failed bolted connections Anchor bolts at columns may be stretched. Partial collapse of portions of structure is possible due to failure of critical elements or connections.

Complete Structural Damage: Most the structural elements have reached their ultimate capacities or some critical members or connections have failed resulting in dangerous permanent lateral deflection, partial collapse or collapse of the building. Approximately 8%(low-rise), 5%(mid-rise) or 3%(high-rise) of the total area of S2 buildings with Complete damage is expected to be collapsed.

Steel Frame with Cast-In-Place Concrete Shear Walls (S4):

This is a "composite" structural system where primary lateral-force-resisting system is the concrete shear walls. Hence, slight, Moderate and Extensive damage states are likely to be determined by the shear walls while the collapse damage state would be determined by the failure of the structural frame.

Slight Structural Damage: Diagonal hairline cracks on most concrete shear wall surfaces; minor concrete spalling at few locations.

Moderate Structural Damage: Most shear wall surfaces exhibit diagonal cracks; some of the shear walls have exceeded their yield capacities exhibited by larger diagonal cracks and concrete spalling at wall ends.

Extensive Structural Damage: Most concrete shear walls have exceeded their yield capacities; few walls have reached or exceeded their ultimate capacity exhibited by large through-the wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement. Partial collapse may occur due to failed connections of steel framing to concrete walls. Some damage may be observed in steel frame connections.

Complete Structural Damage: Structure may be in danger of collapse or collapse due to total failure of shear walls and loss of stability of the steel frames. Approximately 8%(low-rise), 5%(mid-rise) or 3%(high-rise) of the total area of S4 buildings with Complete damage is expected to be collapsed.

Reinforced Concrete Moment Resisting Frames (C1):

Slight Structural Damage: Flexural or shear type hairline cracks in some beams and columns near joints or within joints.

Moderate Structural Damage: Most beams and columns exhibit hairline cracks. In ductile frames some of the frame elements have reached yield capacity indicated by larger flexural cracks and some concrete spalling. Nonductile frames may exhibit larger shear cracks and spalling.

Extensive Structural Damage: Some of the frame elements have reached their ultimate, spalled concrete and buckled main reinforcement; nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns which may result in partial collapse.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. Approximately 13%(low-rise), 10%(mid-rise) or 5%(high-rise) of the total area of C1 buildings with Complete damage is expected to be collapsed.

Concrete Shear Walls (C2):

Slight Structural Damage: Diagonal hairline cracks on most concrete shear wall surfaces; minor concrete spalling at few locations.

Moderate Structural Damage: Most shear wall surfaces exhibit diagonal cracks; some shear walls have exceeded yield capacity indicated by larger diagonal cracks and concrete spalling at wall ends.

Extensive Structural Damage: Most concrete shear walls have exceeded their yield capacities; some walls have exceeded their ultimate capacities indicated by large, through-the-wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement or rotation of narrow walls with inadequate foundations. Partial collapse may occur due to failure of nonductile columns not designed to resist lateral loads.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to failure of most of the shear walls and failure of some critical beams or columns. Approximately 13%(low-rise), 10%(mid-rise) or 5%(high-rise) of the total area of C2 buildings with Complete damage is expected to be collapsed.

Unreinforced Masonry Bearing Walls (URM):

Slight Structural Damage: Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets.

Moderate Structural Damage: Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets.

Extensive Structural Damage: In buildings with relatively large area of wall openings most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams or trusses may have moved relative to their supports.

Complete Structural Damage: Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls. Approximately 15% of the total area of URM buildings with complete damage is expected to be collapsed.

Economic loss

SELENA can also estimate the total amount of economic losses (in any input currency) due to structural damage in any geographical region. Economic loss for building renovation (and for reconstruction, in the case of complete damage) is computed based on the following equation (Molina, et al. 2012):

$$L_{eco} = C_r \sum_{i=1}^{N_{OT}} \sum_{j=1}^{N_{BT}} \sum_{k=1}^{N_{DS}} A_{i,j} P_{j,k} C_{i,j,k}$$

Where NOT is the number of occupation types, NBT presents the number of building types and NDS is the number of damage states. In this equation, Cr , is regional cost multiplier (currently is set to 1.0, but can have different values for each geographical region in order to take into account the geographic cost variations); Aij is the area of building type j with type i occupancy (in m2); Pjk , is the damage probability of a structural damage type k (slight, moderate, extensive or complete) in the building type j and Cijk , is the cost of renovation or reconstruction (per m2) for structural damage k in building type j with i occupancy.

Damage Functions Specification

Building damage functions are in the form of semi logarithmic fragility curves which relate the probability of reaching or exceeding a building damage state for a given PESH (Potential earth science hazards) demand parameter (e.g., displacement response spectrum). Figure 2 provides an example of fragility curve for four damage states used in this methodology.

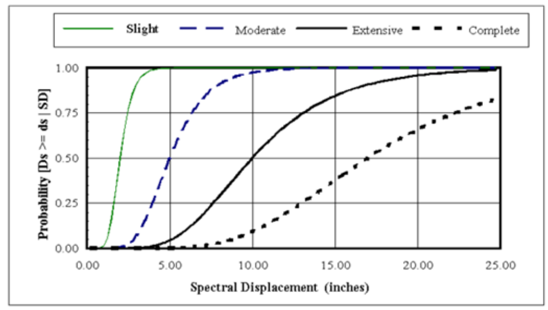


Fig 2: Fragility Curves for Slight, Moderate, Extensive and Complete Damage (IBC, 2006)

Each fragility curve is defined by a mean value of the PESH demand parameter (i.e., either spectral displacement, PGD, spectral acceleration, PGA) corresponding to the damage state threshold and its variability. For example, the spectral displacement, Sd, which defines the threshold of a particular damage state (ds) is assumed to be defined as follow (HAZUS, 2003):

$$S_d = S_{d,ds} \times \varepsilon_d$$

Where Sd ds, is the mean value of spectral displacement for damage state, ds, and εd is a lognormal random variable with unit median and logarithmic standard deviation.

Probabilistic Analysis

The probabilistic analysis procedure denotes the use of spectral ordinates which are taken from probabilistic seismic maps. In addition to the acceleration values (PGA,SaT) for each geographical region, the geographical coordinates of the centroid have to be provided. Probabilistic seismic maps are generally developed for rock conditions such that soil amplification is not included in the spectral ordinates (Molina, et al. 2012). Output files of this software are consisting of mean damage ratio (MDR), economic losses, damaged building area, number of human losses and damage probabilities. Because of high volume data, ArcGis software is implemented in order to show results.

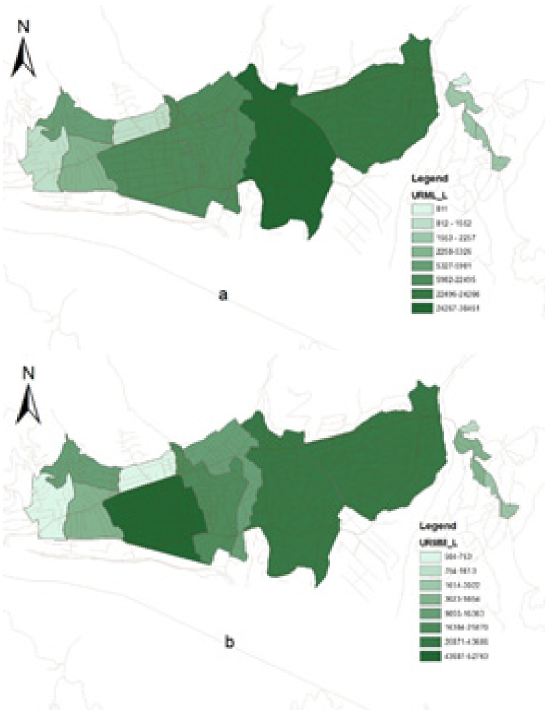
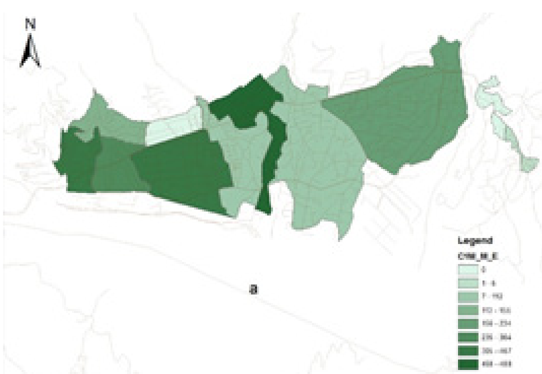


Fig 3: Area of masonry buildings with extensive damage in different areas of Lavasan city(m2), a: 1 story, b: more than 1 story



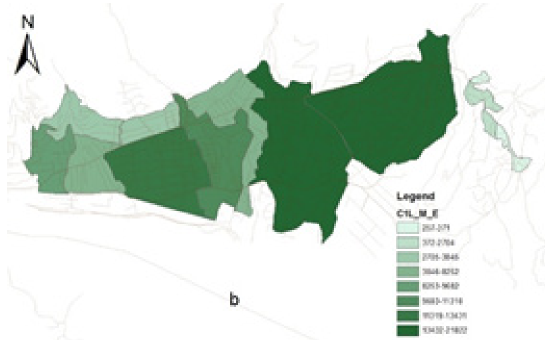


Fig 4: Area of Concrete Moment Frame buildings with extensive damage in different areas of Lavasan city(m2), a: 4 to 8 story, b: 1 to 3 story

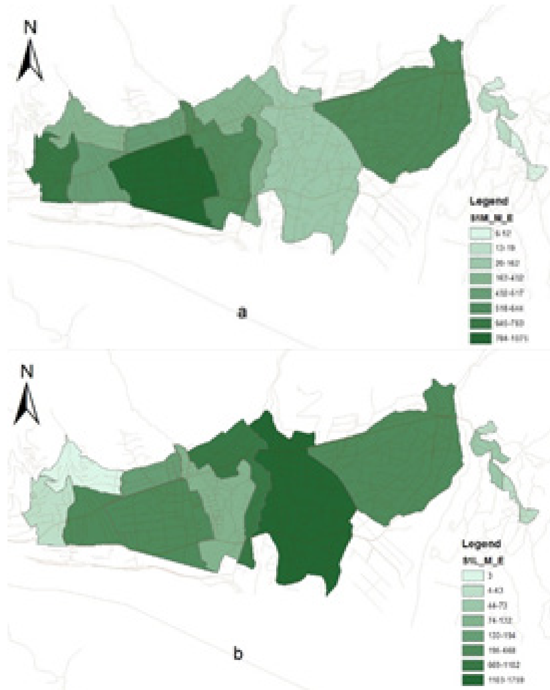
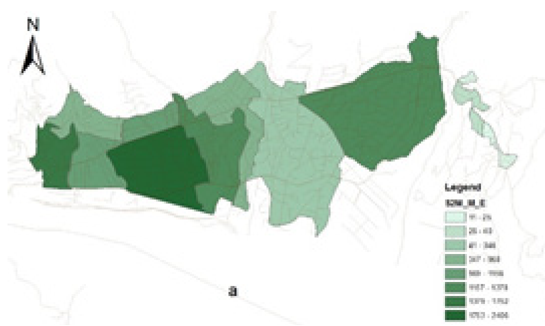


Fig 5: Area of Steel Moment Frame buildings with extensive damage in different areas of Lavasan city(m2), a: 4 to 8 story, b: 1 to 3 story



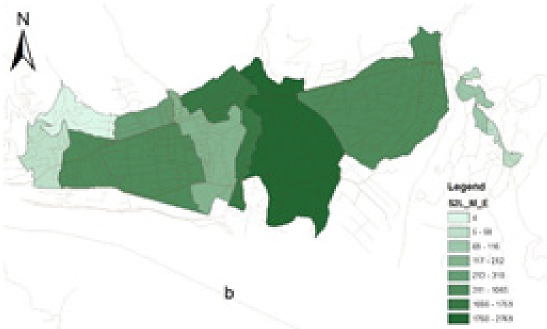


Fig 6: Area of Steel Braced Frame buildings with extensive damage in different areas of Lavasan city(m2), a: 4 to 8 story, b: 1 to 3 story

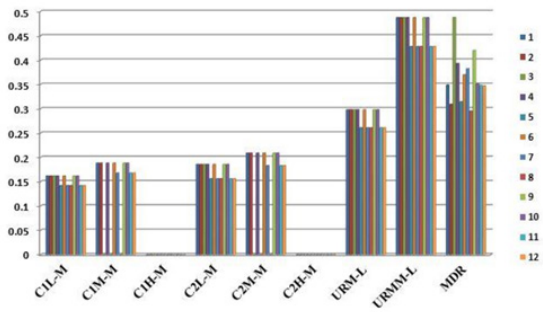


Fig 7: Mean damage ratio computed for concrete and masonry structures

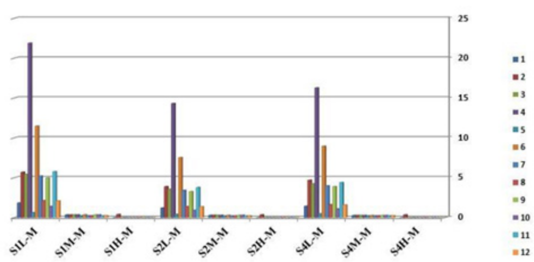


Fig 8: Mean damage ratio computed for steel structures

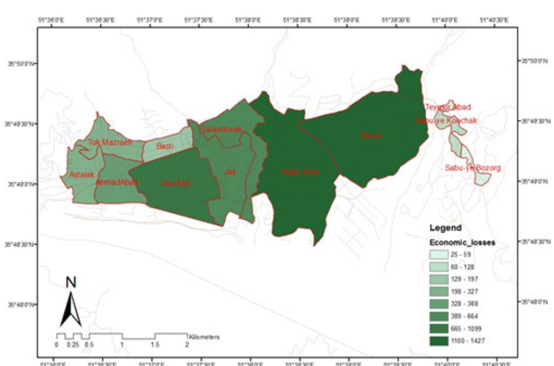


Fig 8: The amount of economic losses caused by earthquakes in different areas (10^9 Rials)

In every seismic risk assessment, majority of casualties belong to Masonry buildings. Regarding the history, the city of Lavasan has lots of these structures. Although, all masonry buildings in the city are supposed to be rehabilitated or substituted with RC and steel structures, in the current situation we need to know which of regions are in the top priority. The old area of Lavasan city, including areas 6, 9, 10, 11 and 12, shows the highest ratio of damages. In contrast, areas 1, 2, 3, 4, 7 and 8 have a lower damage ratio due to newer structures according to the standards. Areas 6 and 9 have a high damage ratio due to the large number of settlements. Soil type is also one of the influential factors in the amount of damage, which in terms of this effect in the design of structures can reduce the damage.

APPENDIX

S1L Steel Moment Frame, low

S1M Steel Moment Frame, mid

S1H Steel Moment Frame, high

S2L Steel Braced Frame, low

S2M Steel Braced Frame, mid

S2H Steel Braced Frame, high

S4L Steel Frame with Cast-in Place Concrete Shear Walls, low- rise

S4M Steel Frame with Cast-in Place Concrete Shear Walls, mid - rise

S4H Steel Frame with Cast-in Place Concrete Shear Walls, high - rise

C1L Concrete Moment Frame, low rise

C1M Concrete Moment

C1H Concrete Moment Frame, high rise

C2L Concrete Shear Walls, low rise

C2M Concrete Shear Walls, mid rise

C2H Concrete Shear Walls, high rise

URML Unreinforced masonry bearing walls, low rise

URMM Unreinforced masonry bearing walls, mid rise

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