SEISMIC SAFETY IMPROVEMENT OF HOUSING SECTOR IN THE HISTORICAL CENTER OF THE CITY OF SANTA TECLA IN EL SALVADOR

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ABSTRACT

In earthquake-prone countries like El Salvador, with cities destroyed multiple times by earthquakes, it is now a priority to channel through urban planning proper measures to mitigate and prevent future damage from seismic events, and ensure the safety of population. Tecla is one of the riskiest cities in El Salvador in terms of seismic risk. With the goal of concluding feasible measures for Santa Tecla to increase its seismic safety, an urban seismic risk analysis was performed to understand the current situation and, based on them and the analysis of similar Japanese cases on disaster management, propose realistic measures to increase seismic safety of the city. Additionally, under the assumption that houses are the most damaged structures due to earthquakes, a seismic evaluation and retrofitting analysis and proposal is done to a typical housing models inside Santa Tecla in order to increase their capacity.

Keywords: Urban Planning, Earthquake Disaster Mitigation, Housing, Confined Masonry.

1. INTRODUCTION

El Salvador is located in a high seismic zone, and earthquakes have caused large damages in the past. The Metropolitan Area of San Salvador (AMSS from now onward) is the most representative urban area of El Salvador, consisting of 14 cities from two departments, including the capital city (San Salvador). However, it has been largely damaged by earthquakes in the past. One of the main causes of this is the exponential and uncontrolled urbanization process the cities have had, outside of proper regulations to ensure their safety and disaster mitigation. San Salvador and Santa Tecla are cities highlighted as high seismic risk prone zones due to their characteristics and urban configuration. Santa Tecla has been greatly damaged in the past due to earthquakes, and multiple infrastructures, specially houses and public buildings, have presented considerable damage. This study aims to analyze urban seismic risk of Santa Tecla first, to develop measures to increase its seismic safety, and then to analyze the current performance of the housing sector in the city and propose ways to enhance it.

2. URBAN PLANNING FOR EARTHQUAKE DISASTER MITIGATION AND RECOVERY IN SANTA TECLA

2.1. Urban Seismic Risk Assessment for Santa Tecla

In order to understand and analyze the seismic risk present in Santa Tecla, four aspects of the urban configuration of Santa Tecla will be taken into consideration to develop an integrated seismic risk assessment to Santa Tecla: Natural Hazard, Built Environment, Community Awareness and Local

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Authorities Preparedness. The current status of each area is a described in the following sections.

Natural Hazard:
Regarding Natural Hazard in Santa Tecla in relation with seismic activity, we can mention three main aspects:

a) The local fault system, which is the main reason behind the high seismicity of the area.
b) The volcanic and mountainous surroundings, that have been the scenario of multiple landslides triggered by seismic motion.
c) Insufficient and unreliable information about geological characteristics of Santa Tecla, which is settled over a considerable layer of soft, white soil that affects the performance and soil-structure interaction of the area.

Built Environment:
To have a general understanding of the situation of the built environment in Santa Tecla, the performance of three types of buildings is generally described below:

a) **Public Buildings:** Public buildings have been greatly affected by past seismic events in Santa Tecla. Most of the public facilities in Santa Tecla are very old buildings, with constructive systems such as adobe and bahareque, and lacking seismic and structural design. Main public buildings, such as the City Hall and the local Public Hospital, were severely damaged by the January 13, 2001 El Salvador Earthquake, and had to be completely demolished and rebuilt.
b) **Housing:** Old housing dwellings in Santa Tecla, particularly in the Historical Center, are masonry buildings with lacking seismic design, big construction areas and usually one or two stories. Adobe and bahareque houses have been greatly damaged in past earthquakes, and most of them have been demolished or abandoned ever since 2001. Common seen damage includes short column, torsion, vibration, overweight, low quality of materials, yielding and shear failure of walls.
c) **Social Infrastructure:** Regarding social infrastructure, most damaged elements due to landslides are highways and roads, whose rehabilitation takes a considerable amount of time. Lacking amount of shelters and evacuation sites according to the total population of the city were found, as additional locations had to be appointed as emergency shelters in past seismic events. Additionally, no official evacuation routes have been assigned.

Community Awareness:
As for community awareness and preparedness in Santa Tecla, there is a lot of space to improve. Currently, the community knowledge of Seismic Risk Mitigation and Recovery and Disaster Management in general, is very weak and not much work is done in terms of educating the community and increasing their preparedness in case of emergency. Some of the points to improve on are: Seismic Damage and Rehabilitation, Evacuation Drills (there are no evacuation drills performed in Santa Tecla), Side effects of seismic activity, Basic knowledge on First Aids and emergency procedures, Community Development and Organization, Dissemination of DM information, disaster protocols, and such.

Local Government:
Currently, the Local Government possesses a Disaster Mitigation Plan. Considerable efforts have been made to improve the knowledge on seismic risk; additionally, there have been efforts to work on landslide risk and flood areas. Most of the established protocols are inclined to after-disaster action. Mitigation and Preparedness is still an area to improve. Other areas to improve are Disaster Preparedness and knowledge, Seismic Damage and Rehabilitation, Evacuation Drills, Urban Fire, First Aids, Community Development and Organization disaster protocols, and such.

2.2. Study of Similar Japanese Cases in Urban Disaster Mitigation

Four Japanese similar cases in Urban Disaster Mitigation were studied in order to understand what kind of measures could be applied to Santa Tecla to mitigate seismic risk. The studied cases were: Arakawa

District, Negishi District, Kyojima District and the City of Yokohama. The similarities and respective applicable measures to the Santa Tecla case are summarized in the following Table.

Table 1. General similarities and applicable measures between related Japanese Disaster Mitigation Study Cases and Santa Tecla.

Similarities	Applicable Measures
- Densely populated area - Existence of non-engineering housing - Houses prone to damage /largely damaged houses in the past - Lack of disaster mitigation social infrastructure - Lack of established evacuation routes and sites - Lack of involvement by the community in decision-making processes and project development - Weak awareness and knowledge of the community about disaster mitigation measures and readiness	- Improvement of housing sector by implementing projects with necessary conditions to ensure people's safety - Area readjustment by developing of housing projects under current design standards - Development of disaster mitigation infrastructure, such as evacuation sites and parks - Establishment of new and improvement of existent evacuation routes in case of emergency - Training program for the community in terms of disaster mitigation measures and strategies - Improvement of community organization and implementation of participative processes for project development and maintenance (sustainability) - Promotion of social economy

2.3. Proposed measures to enhance Urban Seismic Safety in Santa Tecla through Urban Planning

Based on the comprehensive analysis of the urban seismic risk in Santa Tecla, and taking into consideration the lessons of the four related Japanese cases, the following list of measures is proposed in order to enhance seismic safety in Santa Tecla. The possible measures were evaluated in terms of applicability and adaptability regarding the seismic risk situation in Santa Tecla to make the proposal feasible.

a) Promote and increase the participation of community in Disaster Management Planning (DMP) and project execution.
b) Increase the dissemination of DMP knowledge and training for both authorities and communities.
c) Application of a disaster management and preparedness permanent program that includes activities such as evacuation drills, seminars, visits to schools and such.
d) Identify new possible shelters and evacuation sites, with a determined coverage zone in order to ensure they can give proper aid in case of emergency.
e) Identify ideal evacuation routes, with proper signaling and needed maintenance work.
f) Study and promotion of seismic evaluation and retrofit for houses, for both technical and non-technical users, to decrease the possible damage due to seismic motion.
g) Analysis of possible settlements to be relocated.

3. ENHACING OF HOUSING SEISMIC SAFETY IN SANTA TECLA

3.1. Target Building

To have a general understanding of the current performance of houses inside Santa Tecla, first a typical housing model should be selected for analysis. According to Kattan et al. (2016), most damage due to seismic events is located in the Historical Center of Santa Tecla, where houses have the following basic characteristics: Wide construction area, mainly one storied, common materials: Confined masonry, internally reinforced masonry, adobe and bahareque. For this study, we have selected two typical models of confined masonry houses, depicted in the following Figure.

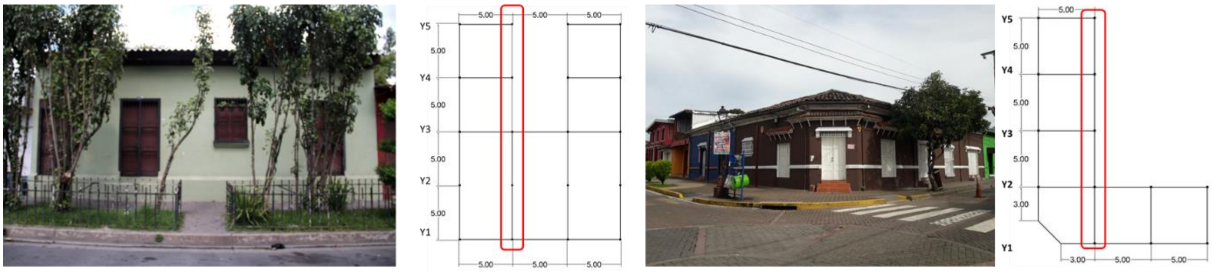

Figure 1. Typical Housing Models to be studied with their general measures.

3.2. Seismic Evaluation for Target Housing Models Following the JBDPA Guideline

The Japan Building Disaster Prevention Association (JBDPA) proposed seismic evaluation methodology is based on the calculation of the Seismic Index of Structure I_S, which can be calculated by Eq. (1) for both transversal and longitudinal directions. I_S is compared with I_{SO}, Seismic Demand Index of Structure (2), which should be equal to or larger than 0.6 or 0.7 in case of school buildings.

$$I_S = E_0 \cdot S_D \cdot T \tag{1}$$
$$I_{SO} = E_S \cdot Z \cdot G \cdot U \tag{2}$$
$$I_S \geq I_{SO} \tag{3}$$

Where E_0 is the Basic Seismic Index of the Structure, S_D is the Irregularity Index and T is the Time Index. For Eq. (2), E_S is the Basic Seismic Demand Index, reduced by the Importance Index (U). Before proceeding to calculate Seismic Index of Structure of the houses, first the Seismic Demand Index of Structure must be calculated, which is given by Eq. (2). For the First Level Screening, it will be assumed that the Zone Index (Z) and Soil Index (G) are equal to 1.0. For the First Level Screening, E_s is equal to 0.8. The Importance Factor is given by the usage of the building and its occupancy level in case of emergency. In this case, a house, the Importance Factor is equal to 1.0. With these values, I_{so} can be calculated as follows:

$$I_{so} = \ 0.80 \times 1.00 = 0.80$$

Then, the Basic Seismic Index of Structure is calculated for both houses, which will be the larger value obtained from the following equations.

Table 2. Calculation of the Basic Seismic Index of Structure for both housing models.

Block House (U Shape)	**Corner House (L Shape)**
$E_0 = \frac{n+1}{n+i}(C_W + \alpha_1 C_C) \cdot F_W = (1)(0.528 + 0.7 \times 0.053)(1) = 0.565$	$E_0 = \frac{n+1}{n+i}(C_W + \alpha_1 C_C) \cdot F_W = (1)(0.892 + 0.7 \times 0.09)(1) = 0.955$
$E_0 = \frac{n+1}{n+i}(C_{CS} + \alpha_2 C_W + \alpha_3 C_C) \cdot F_{SC} = (1)(0 + 0.7 \cdot 0.528 + 0.5 \cdot 0.053)(0.8) = 0.317$	$E_0 = \frac{n+1}{n+i}(C_{CS} + \alpha_2 C_W + \alpha_3 C_C) \cdot F_{SC} = (1)(0 + 0.7 \cdot 0.892 + 0.5 \cdot 0.09)(0.8) = 0.535$
$\rightarrow E_0 = 0.565$	$\rightarrow E_0 = 0.955$

Assuming the value of 0.8 as Time Index (T) and the values of Irregularity Index (Sd) of 0.9 and 0.85 for the Block House and Corner House, respectively. With these values, the Seismic Index of

Structure I_S can be calculated as:

Table 3. Evaluation of Seismic Index of Structure for both housing models.

Block House (U Shape)	Corner House (L Shape)
$I_S = E_0 \cdot S_D \cdot T = 0.565 \cdot 0.9 \cdot 0.8 = 0.407 < 0.8$	$I_S = E_0 \cdot S_D \cdot T = 0.955 \cdot 0.85 \cdot 0.8 = 0.649 < 0.8$

Under the First Level of Screening of the JBDPA Guideline for Seismic Evaluation, both the Block House and the Corner House Model are **not safe** against seismic event and should be further evaluated and retrofitted.

3.3. Possible Retrofitting Techniques

Several methods for reinforcing and retrofitting masonry buildings have been studied in order to enhance performance capacity of them, especially for houses. Architectural Institute of Japan (AIJ) proposes a series of diverse retrofitting techniques tested in different developing countries that, when applied, can contribute in increasing deformation capacity and strength. The possible effects after retrofitting are shown in Figure 2.

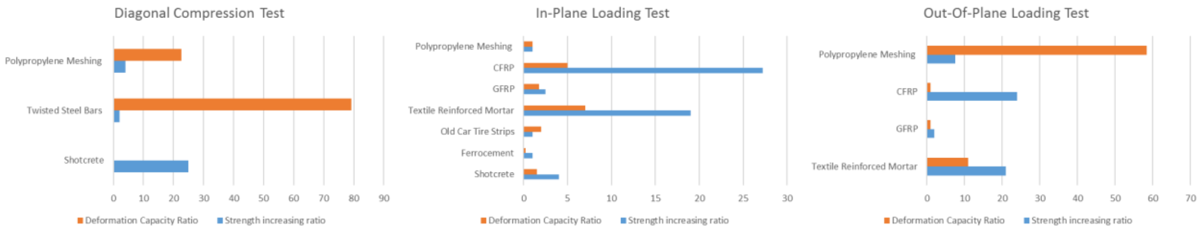

Figure 2. Comparison in obtained results from diagonal compression tests, in-plane loading tests and out-of-plane loading test.

Based on the possible effects of the retrofitting and the feasibility of application in the particular case of Santa Tecla, the following techniques are recommended.

Table 4. Proposed Retrofitting Techniques for Santa Tecla.

Technique	Description
Shotcrete	Cast concrete layer and mesh of steel rods on existing wall
Ferro cement	Galvanized steel mesh and mortar layer on existing wall
Steel wire mesh reinforcement	Reinforcement of 2 horizontal and vertical mesh strips; The vertical strips are placed at the intersections of the walls, the center of long walls and loose corners
Bamboo reinforcement	Bamboo pieces placed as buttress, crowning beams

5. CONCLUSIONS

After the Urban Seismic Risk Assessment, the study of the Japanese Similar Cases, and the Seismic Evaluation and Retrofitting Analysis of typical housing models inside Santa Tecla, the following can be concluded:

a) The importance and necessity of developing a comprehensive methodology to understand and assess urban seismic risk integrating the different aspects of vulnerability and exposure. For cities in developing countries, like Santa Tecla, it is not only needed to deepen the technical research and planning in terms of Disaster Mitigation and Recovery, but also to assess the socio-economical vulnerability of seismic risk if the aim is to formulate feasible and realistic measures to mitigate and enhance seismic safety in the area.

b) One of the most important acquired lessons from the Japanese study cases is the importance of working with the community, increasing their awareness, knowledge and preparedness on disaster mitigation and their involvement in local planning.
c) Current seismic evaluation methodology in El Salvador needs to be improved and strengthen, especially in terms of monitoring evaluated cases, and researches and studies on the behavior of masonry structures should be further developed to improve processes such as seismic evaluation and retrofitting, especially in terms of houses.
d) Further investigation should be done regarding reinforcement and rehabilitation of existent buildings in El Salvador, especially in terms of possible retrofitting techniques to apply, and in the case of private property, such as houses, motivation and support strategies should also be studied in parallel to technical research if the aim is to get people to reinforce their houses.
e) People should be able to understand and develop their own evaluation and retrofitting of their houses, if needed, and the government should be able to offer guidance and support to every resident and owner to improve the status of their houses. Both technical and socio-economic strategies should be considered and applied in order to improve seismic safety of houses.

6. RECOMMENDATION

a) Promotion of holistic and comprehensive urban seismic risk assessment methodologies, which includes key aspects to understand the current seismic vulnerability in urban areas. This suggests the intervention of different experts and the consideration of additional aspects such as socio-economic vulnerability.
b) In the particular case of Santa Tecla, further studies on the geological characteristics of the area should be considered to understand accurately the site effects on the structures.
c) Developing of a proper Seismic Evaluation Methodology for Masonry Structures
d) Include a section regarding the upgrading and enhancement of existent buildings on any updates on the Salvador Seismic Design Code. Seismic Evaluation and Retrofitting concepts should be introduced and updated, simultaneously promoting more research and studies on the subject.

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