# SEISMIC PERFORMANCE ASSESSMENT OF REINFORCED CONCRETE BUILDINGS WITH MASONRY INFILL WALLS IN EL SALVADOR

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**ABSTRACT**

In this study, two buildings of 3-story with reinforced masonry walls are evaluated, which belong to school typologies, following the methodology proposed by the JBDPA standard and proposing a methodology to estimate the strength of the masonry infills. The increase of the constructions of buildings with concrete frames with reinforced masonry walls has become very popular, and it is important to understand the behavior of the infill walls. It should be noted that the JBDPA does not include provisions to assess buildings of concrete frames with reinforced masonry infill walls. Therefore, this study proposes a methodology to consider the reinforced masonry infill walls. A comparative analysis is done to consider only the bare frame and frame with reinforced infill walls. An approach of how to estimate the strength of reinforced masonry infill walls is proposed.

**Keywords:** Reinforced Masonry Infill, Seismic Protection Index, Seismic Evaluation.

## 1. INTRODUCTION

The need for a method of seismic evaluation of the buildings of El Salvador is becoming increasingly necessary, due to the damage caused by previous earthquakes, which left important economic losses, and at the same time, human losses. Although there have been field surveys of visual inspections of buildings damaged by past earthquakes, these remain only in the stage of rapid inspection. There is no methodology to follow in the national code to rehabilitate these structures; damages were reported for the 1986 and 2001 earthquakes due to many factors such as the lack of the control of illegal constructions, that do not follow any national code or standard and the lack of engineering criteria, which leads to non-earthquake-resistant buildings. In the same way, old buildings which are still in use, suffered damage due to past earthquakes and not much attention was given to them, although their designs followed the oldest version of the national codes which were not reinforced so that they can comply with the current code.

## 2. DESCRIPTION OF THE ANALYZED BUILDINGS

Two buildings of three levels were chosen. The walls are of reinforced masonry infill walls with a thickness of 150 mm in all floor levels, with a Compressive Strength of Masonry of 7.83 Mpa with walls that has openings. The compressive strength of Concrete is 20.6 Mpa, and the yield strength of the reinforcing bars of the columns and walls is 412.00 MPA. This building was examined with the Japanese seismic capacity evaluation to evaluate numerically and through Stera 3D to check the validity of the calculation.

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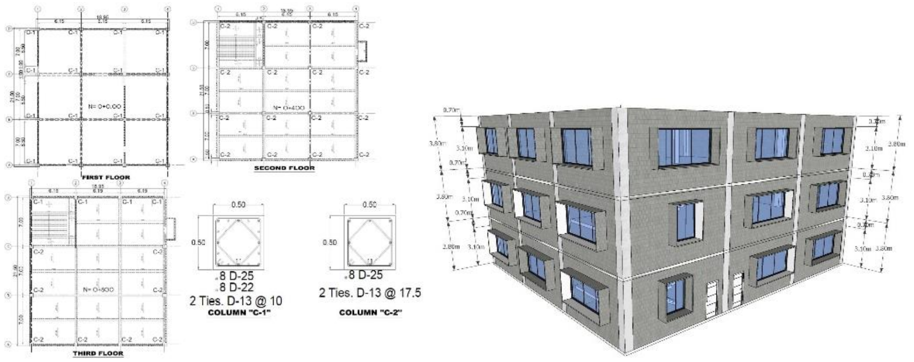

Figure 1. Target Building 1.

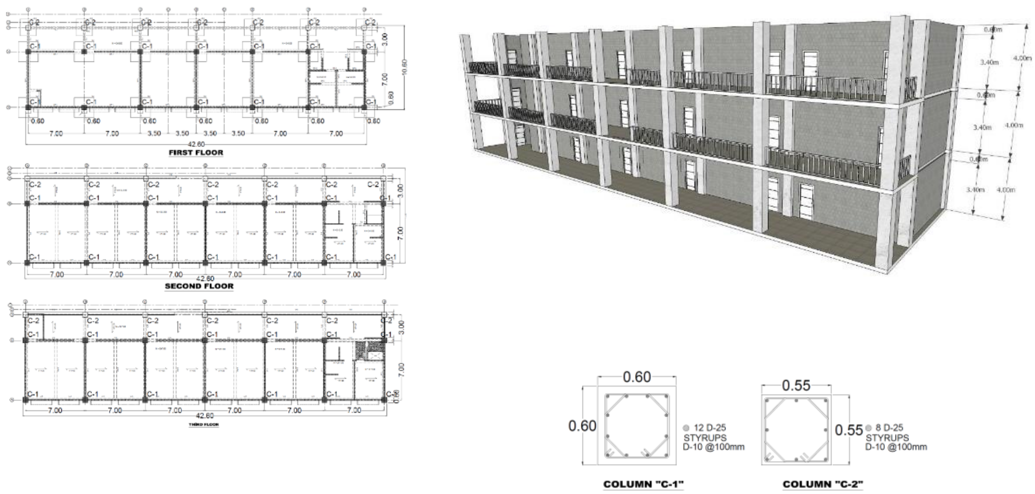

Figure 2. Target Building 2.

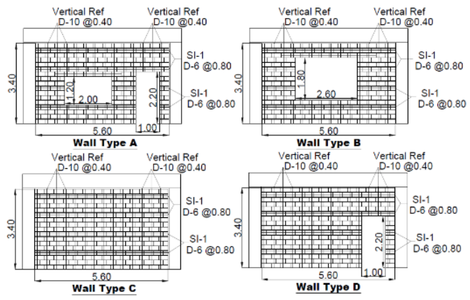


Figure 3. Details of Infill Masonry Walls for Building 1 and 2.

## 3. THEORY AND METHODOLOGY

### 3.1. Proposed methodology for seismic evaluation of low-rise RC buildings with reinforced masonry walls

Two levels of seismic evaluation are proposed for a two school buildings; based on the philosophy of the Japanese standard and considering the effect of the reinforced masonry infill walls. A first level screening is made considering only the geometrical properties of the vertical members and the second level of seismic evaluation is performed considering the reinforcement of the vertical members. The seismic judgment is done by comparing the seismic index of the structure, Is, and the seismic demand index which is proposed based on the seismicity of El Salvador.

### *3.1.1. Basic principles of seismic evaluation methods*

The evaluation of the seismic performance of the Japanese standard involves the strength and deformability of the structure, as it is well known that buildings resistant to earthquakes are not only a function of the lateral force but also that of deformation.

In a structural evaluation, it is necessary to know the structural details of the building of interest with which the strength and capacity of deformation can be calculated. What remains to be found is the intensity of the external disturbance.

$$I_s = E_0 S_D T \tag{1}$$

where $S_D$ is the irregularity index based on the engineering judgment of the plan irregularity and unbalance distribution of stiffness, and the value of $T$ is the time index where the effects of aging, cracking and deflection are considered in this term.

In the Japanese Standard, the value of Is must be higher than the seismic demand index, Iso, of the JBDA Standard which is expressed according to Eq. (2).

$$I_{so} = E_s C_G C_I \tag{2}$$

where $E_s$ is the basic demand protection index, 0.8 for the first level procedure and 0.6 for the second level procedure, $C_G$ is the correction factor for geology and $C_I$ is the importance factor.

Since $S_D$ and T are considered as one, thus the basic seismic index $E_0$ becomes identical to the seismic index $I_s$, and for the evaluation of the safety this value can be compared with a protection index, expressed as a product of ground peak acceleration and the response magnification factor in the form of linear response spectrum (Hiroyuki 1981).

### *3.1.2. First Level Screening*

In the analysis of the building in the first level screening evaluation, the first level screening of the Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (JBDPA) is taken as a guide for the strength and ductility index of concrete columns, and for the strength of masonry infill the Technical Standard for Reinforced Masonry of El Salvador is used. The ductility index in this study is conservatively taken as 1.0. The strength capacity of the building for the masonry infill walls is given by the following equation:

$$c_w = \frac{2 \cdot \tau_c . \sum A_c + \alpha . \tau_{\inf} . \sum A_{if}}{W} \tag{3}$$

where $\tau_{\inf}$ is the average shear strength of masonry infill walls, $\tau_{\inf} = 0.4\sqrt{f'm}$, α is the opening reduction factor of infill wall, ΣAif is the total area of the infill walls, and W is the total weight of the building.

### *3.1.3. Second Level Screening*

In order to include the infill walls in the seismic evaluation for the second level screening, Matsumura equation is suggested for the maximum strength of the infill panel and reaching a drift of 1/250 with a F = 1.0, that at this drift is assumed that reach the Life Safety limit state, at larger values of inter-story drift, the infill wall loses the ability to withstand more forces. The calculations of the strength of the columns and concrete wall is based on the JBDPA Standard. The model proposed by Hossein and Kabeyasawa (2004) is the one used in this research, which is the one adopted by Stera 3D, which proposes a simple model based on the diagonal strut, which is represented as a horizontal spring, which considers the effect of the openings. At the same time Al-Chaar, considers the model of the infill walls as a strut model, but taking into consideration that the openings change the properties of the wall. This is reflected in the fact that the reduction factor modifies the width of the diagonal strut, which was considered in this investigation.

$$\mathrm{V_n} = \left[ k_u k_p \left( \frac{0.76}{h/d + 0.7} + 0.012 \right) \sqrt{F_m^{'}} + 0.18\gamma\delta\sqrt{p_h f_{yh} f_m^{'}} + 0.2\sigma_0 \right] 0.875td \tag{4}$$

where $K_u = 0.64$, $K_p$: $1.16\,\rho_v^{0.3}$ is the coefficient of the effect of flexural reinforcement ratio $\rho_v \frac{a_v}{t*d}\%$, is the vertical reinforcement ratio, $a_v$ is the area of the vertical reinforcement, $t$ is the thickness of the wall, $d$ is the total length of the wall - t/2, $h$ is the height of the wall, $F'_m$ is the compressive strength of masonry, $\gamma = 0.6$, $\delta = 1$, $\rho_h$, is the lateral reinforcement ratio, $f_{yh}$, Yield strength of the horizontal reinforcement and $\sigma_n$ is the axial force.

### 3.2. Seismic protection index

PSHA studies that have been carried out to date in the country have been investigated. A well-known study in this field is the work carried out by researchers Benito et al. (2009), which was based on an initiative carried out throughout the Central American countries and determine the seismic hazard on rock conditions. A uniform hazard spectrum and several seismic hazard curves have been proposed by these researchers for the city of San Salvador in rock conditions, highlighting three hazard levels of 500, 1000 and 2475 years of return period. To be consistent with the methodology of PSHA Benito et al. (2009) for El Salvador, an approximation of the relationship between the PGA with the return periods will be made. This approximation is based on plotting in log-log scale the values coming from the seismic hazard curves of PGA, thus obtaining a power law linear function, which allows predicting return periods for lower peak ground motions values.

The above, with the aim of covering most of the possible, the spectrum of the existing variability in the seismic records, and subjecting the targets buildings to more recurrent acceleration values and observing their performance in respect to the exceedance of their performance levels. Next, the graph obtained from the PEM seismic hazard curve of the PSHA study by Benito et al. (2009), assuming a constant site amplification value of 20% for this intensity measure (PGA).

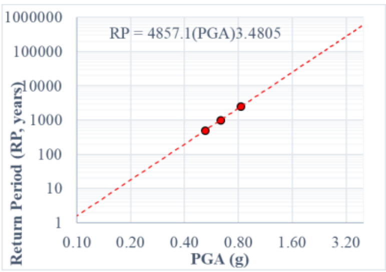


Figure 4. Approximation of the seismic hazard levels from the result of PSHA of Benito et al. (2009).

Table 1. Basic Seismic Protection Index. Upper values for flexural failure type building, lower values for Shear failure type building.

| | | Period of the Ground | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PGA ag/g | No. Storeys n | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0.40 | 1 | 0.60 | 0.90 | 1.10 | 1.30 | 1.30 | 1.3 | 1.30 | 1.30 | 1.30 |
| | | 0.70 | 1.00 | 1.20 | 1.30 | 1.30 | 1.3 | 1.30 | 1.30 | 1.30 |
| | 2 | 0.50 | 0.80 | 1.00 | 1.10 | 1.20 | 1.3 | 1.30 | 1.30 | 1.30 |
| | | 0.60 | 0.90 | 1.00 | 1.20 | 1.30 | 1.3 | 1.30 | 1.30 | 1.30 |
| | 3 | 0.50 | 0.70 | 0.90 | 1.00 | 1.10 | 1.3 | 1.30 | 1.30 | 1.30 |
| | | 0.60 | 0.80 | 1.00 | 1.10 | 1.20 | 1.3 | 1.30 | 1.30 | 1.30 |
| | 4 | 0.50 | 0.70 | 0.80 | 1.00 | 1.10 | 1.2 | 1.30 | 1.30 | 1.30 |
| | | 0.50 | 0.70 | 0.90 | 1.10 | 1.20 | 1.3 | 1.30 | 1.30 | 1.30 |
| | 5 | 0.50 | 0.70 | 0.80 | 0.90 | 1.00 | 1.2 | 1.20 | 1.30 | 1.30 |
| | | 0.50 | 0.70 | 0.90 | 1.00 | 1.10 | 1.3 | 1.30 | 1.30 | 1.30 |
| | 6 | 0.40 | 0.60 | 0.80 | 0.90 | 1.00 | 1.1 | 1.20 | 1.30 | 1.30 |
| | | 0.50 | 0.70 | 0.90 | 1.00 | 1.10 | 1.2 | 1.30 | 1.30 | 1.30 |

## 4. RESULTS AND DISCUSSION

### 4.1. First level screening

As a first part of the evaluation, reinforced concrete walls were analyzed as a proposal for the retrofit. In the following tables show a summary of the strength values provided by each of the vertical elements, including concrete walls.


Figure 5. Comparison of bare frame and frame with Reinforced masonry wall in the First Level Screening, building 1.

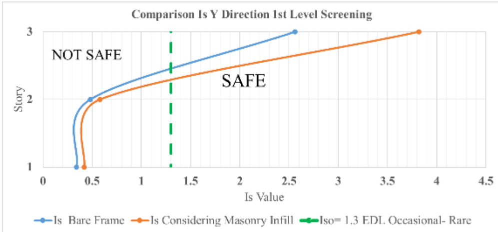


Figure 6. Comparison of bare frame and frame with Reinforced masonry wall in the First Level Screening, building 2.

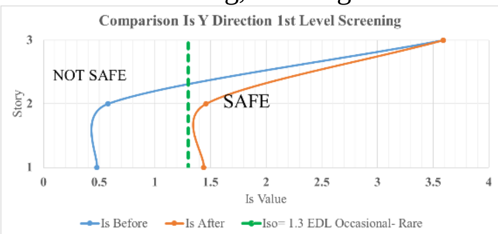


Figure 7. Retrofit with infill wall in Building 1.

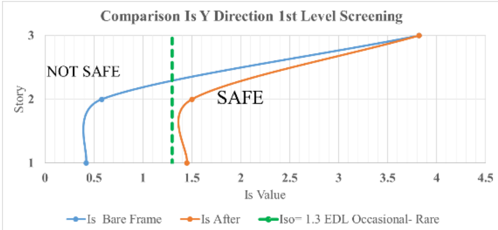


Figure 8. Retrofit with infill wall in Building 2.

It can be seen that when considering the reinforced masonry infill walls, which are part of the elements that are capable of resisting lateral forces, the performance of the structure grows significantly in strength, as many authors have described it in other investigations with different types of masonry. It should be noted that for strength analysis in this study the strength of reinforced masonry was taken from the National Masonry code of El Salvador, which is a value that depends on the Compressive Strength of Masonry.

From Figure 7 and Figure 8, it can be highlighted that by increasing structural elements with greater capacity to resist lateral forces such as concrete walls, it reaches a higher level of safety, and the structure is safe considering the seismic demand index proposed.

### 4.2. Second level screening

The level of calculation of the vertical elements is more detailed in this stage, considering that the beams are strong enough not to fail. Therefore, the calculation of the strength of the columns and the type of failure is made, then the strength of the masonry walls was calculated using the proposed equation of Matsumura.

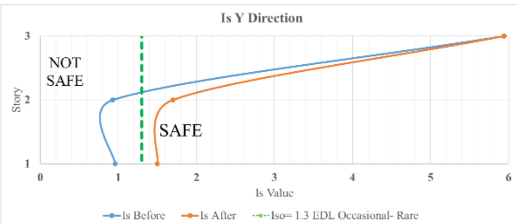


Figure 9. Retrofit with infill wall in Building 1.

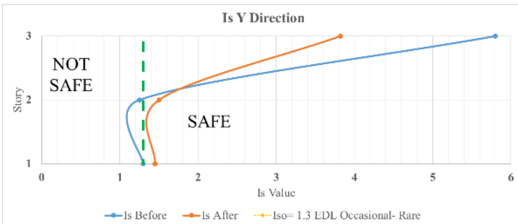


Figure 10. Retrofit with infill wall in Building 2.

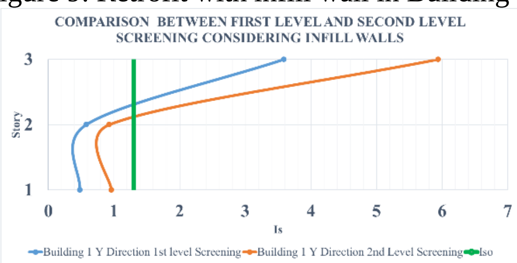


Figure 11. Comparison of 1$^{st}$ and 2$^{nd}$ level screening in Building 1.

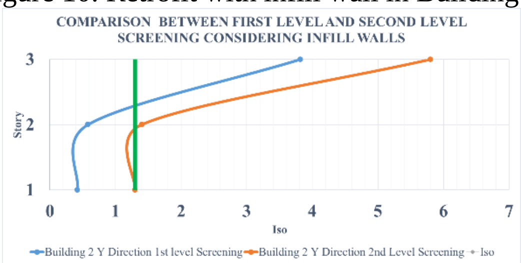


Figure 12. Comparison of 1$^{st}$ and 2$^{nd}$ level screening in Building 2.

When performing the seismic evaluation by the second level screening it can be seen in Figures 11 and Figure 12 that more strength can be perceived because this method is more detailed and considers the contribution to the strength provided by the reinforcement of the infill wall.

## 5. CONCLUSIONS

When observing the results obtained from the analysis of the seismic capacity of the target buildings, it is noted that when considering the infill walls in the evaluation process, the capacity of the building is improved as we increase the capacity to withstand lateral forces. The method to choose for the evaluation of the building should be the most appropriate, either the first level screening or second level screening depending on the type of project that is targeted.

The Seismic Protection index (Iso) is cross-related with the characteristic period of the soil and the Peak ground acceleration which a specific site could have or experience, respectively. For specific sites with long period characteristics (such as Tg = 0.6 sec) the value of the Iso is increased. Thus the structure located on the site will need a higher capacity requirement. The above is also influenced by the hazard level to be considered in the design. As for less recurrent scenarios, PGA values are higher.

In order to take care of the integrity of the infill masonry walls, this study focuses on the vulnerability of these type of elements, so for the calculation of the seismic index of the structure focuses on the evaluation given by the equation that defines strength dominant, since these elements represent a potential danger for people inside the building.

The reinforced masonry infill walls contribute to the improvement of the structures to be able to resist large lateral forces since these provide lateral stiffness. The behavior of the interaction between the frame and the wall is complicated, but many authors model it as a diagonal strut. It should be noted that the modeling of the infill walls should continue to be investigated, given that there are different types of infill walls, which could present different types of behavior.

## ACKNOWLEDGMENTS

I would like to express my greatest gratitude to my supervisor Dr. Shunsuke Sugano for all the valuable help he has given me during my research process, for respecting my suggestions and ideas and for the direction and rigor that he has facilitated. At the same time to Dr. Tatsuya Azuhata, Mr. Inukai Mizuo and Dr. Haruhiko Suwada for all their advice and encouragement that they gave me at every moment during this process.

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