# SIESMIC EVALUATION AND REHABILITATION OF RC STRUCTURE IN DOMINICAN REPUBLIC

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**ABSTRACT**

The Dominican Republic is a country with high seismicity that has been affected by earthquake for years. It has been highly vulnerable to earthquakes because of population growth, changes in demography and economic patterns, and other changes in social dynamics. These factors have led to uncontrolled settlements in disaster-prone areas, and the most devastated area is the northern coast because the area has more active faults than other areas. Since most of the existing structures in the country do not comply with the seismic standards or they were designed before the first seismic code, the seismic evaluation and the building rehabilitation of reinforced concrete are important. Therefore the seismic assessment is a way to reduce the risks in case of earthquakes.

**Keywords:** Seismic code, Seismic Evaluation, Rehabilitation, Stera 3D.

## 1. INTRODUCTION

The Dominican Republic is located in the eastern part of Españiola Island in the Caribbean Sea, and it is the second largest island of the Greater Antilles. It occupies a total land of 48,730 km². Its geography is varied; the seismic tectonic framework covers a wide area on its surface and many epicenters are located around the Dominican Republic. A present study shows that earthquakes occurred in the country were produced by the faults which are considered to have been not active at this time. Due to many previous factors the towns are vulnerable, and it is required to assess the seismic performance for existing structures to determine their decisive weakness ties to seismic demand established by the seismic code. In addition, reinforced concrete structure is one of the most common types in cities; therefore there is a necessity to study their seismic vulnerability. In addition, buildings designed and built without earthquake resistant guidelines should not be overlooked and need careful consideration for the proper performance during the occurrence of earthquakes.

## 2. PURPOSE AND SCOPE

The purpose of this study is to describe the behavior of existing reinforced concrete buildings by the evaluation using standard methods to determine design seismic vulnerability of structures in order to adapt various structural rehabilitation methods which are conducted in Japan, to the Dominican Republic.

The scope is to evaluate all the existing structures designed without any seismic codes, and review ability of the structure to withstand moderate and strong earthquakes as much as possible, using vulnerability studies to determine the ability of structures. As many buildings are characterized by deficiencies of the joints, the columns do not have enough shear strength against earthquakes.

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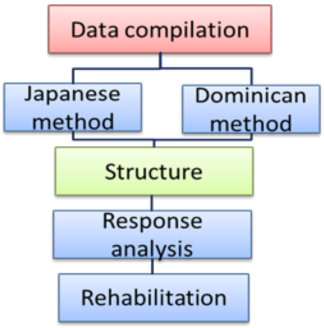


Figure 1. Flow chart of methodology.

## 3. METHODOLOGY

The evaluation used in this study is determined by means of different conditions of the structure, which organizes a quantitative process that allows us to estimate the seismic vulnerability of buildings using equations and the method of evaluation. The parameters can give the conditions and the degree of vulnerability based on the most relevant feature of the used model.
Chronological process used for this case is shown in Figure 1.

## 4. STRUCTURAL EVALUATION GUIDE IN JAPAN

The standard for the seismic evaluation of existing reinforced concrete buildings in Japan is conducted by guideline assessment which has three levels of evaluation area, and for this study we apply only the first and second levels. The seismic performance of buildings is characterized by seismic index of structure (*Is)* as shown in Eq. (1) and the seismic safety of the buildings shall be judged based on the standard for judgment on seismic safety (*Is<sub></sub>*$_O$*)* as show in Eq. (2).

$$I_s = E_0 \cdot S_D \cdot T \quad (1)$$

$$Is_0 = E_s \cdot Z \cdot G \cdot U \quad (2)$$

Where:
$E_0$ :Basic seismic index of structure, $S_D$ :Irregularity index, $T$ : Times index
$E_S$ : Seismic demand index of structure, $Z$ : Zone index, $G$ :Ground index, $U$ :Usage index

The hospital has a main building as shown in Figure 2, and it has the following conditions: the space of the reinforcement bars is considered to be 300 mm in vertical and horizontal direction, and the diameters of reinforced bars 9.50 mm and 12.7mm. The number of layer of the reinforcement is double; the yield strength of the steel is 420 N/mm². The thicknesses of wall on the first and second floors are 250mm, and the third floor is 200 mm and the fourth floor is 150mm. Compressive strength of the concrete is 28 N/mm².

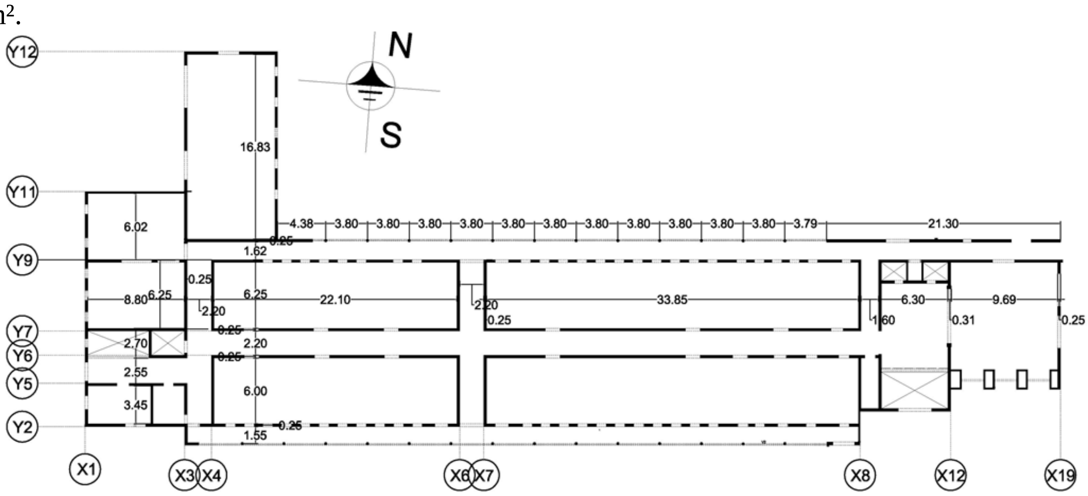


Figure 2. Main building of hospital.

### 4.1 WRC First level screening procedure

The first screening procedure is calculated by seismic index of structure in each direction of the longitudinal and the transverse of the structure.

The seismic index of structure is calculated by Eq. (1). In this method, the evaluation results are different; because the transverse axial force of the walls is considered, it is necessary to realize rehabilitation in the first and second floors in transverse (Y) direction as shown in Table 1, because the building does not comply with the requirements for establishment or basic seismic index demand ($Is_0$).

Table 1. Seismic index *Is* of structure.

| Direction | floor | ∑(twj*Awj) | Cw=∑(twj*Awj)/∑ W*βc | $E_0$=1/Ai*Cw*F (N/mm²) | SD | T | Is=$E_0$*SD*T | $Is_0$ | Evaluation |
|---|---|---|---|---|---|---|---|---|---|
| X | 4 | 4.90E+07 | 2.89 | 1.81 | 1 | 1 | 1.81 | 0.8 | OK |
| | 3 | 6.00E+07 | 1.80 | 1.28 | 1 | 1 | 1.28 | | OK |
| | 2 | 6.65E+07 | 1.33 | 1.11 | 1 | 1 | 1.11 | | OK |
| | 1 | 7.67E+07 | 1.15 | 1.15 | 1 | 1 | 1.15 | | OK |
| Y | 4 | 3.16E+07 | 1.58 | 0.99 | 1 | 1 | 0.99 | | OK |
| | 3 | 3.85E+07 | 1.15 | 0.82 | 1 | 1 | 0.82 | | OK |
| | 2 | 4.36E+07 | 0.87 | 0.73 | 1 | 1 | 0.73 | | NG |
| | 1 | 4.17E+07 | 0.62 | 0.62 | 1 | 1 | 0.62 | | NG |

### 4.1 WRC Second level screening procedure

For this 2nd screening procedure the seismic index of structure is calculated by Eq. (1). At this level of evaluation the structure shows damage in the first and second floors that is given in following Table 2.

Table 2. Seismic index *Is* of structure.

| Direction | Floor | ∑Qu (N) | ∑Wi (N) | group $C_1$ ((∑Qu)/(∑W)) | $E_0$=1/Ai*√($C_1$*$F_1$)² | SD | T | Is=$E_0$*SD*T | $Is_0$ | Calculated | Demand Ctu*SD | Evaluation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | 4 | 8.98E+07 | 1.91E+07 | 4.71 | 4.42 | 1 | 1 | 4.42 | 0.60 | 4.71 | 0.30 | OK |
| | 3 | 1.04E+08 | 3.65E+07 | 2.85 | 3.06 | 1 | 1 | 3.06 | | 3.42 | | OK |
| | 2 | 1.19E+08 | 5.45E+07 | 2.19 | 2.63 | 1 | 1 | 2.63 | | 3.06 | | OK |
| | 1 | 1.36E+08 | 7.30E+07 | 1.86 | 1.86 | 1 | 1 | 1.86 | | 2.98 | | OK |
| Y | 4 | 1.74E+07 | 1.91E+07 | 0.91 | 0.85 | 1 | 1 | 0.85 | 0.60 | 0.91 | 0.30 | OK |
| | 3 | 2.11E+07 | 3.65E+07 | 0.58 | 0.87 | 1 | 1 | 0.87 | | 0.69 | | OK |
| | 2 | 2.45E+07 | 5.45E+07 | 0.45 | 0.56 | 1 | 1 | 0.56 | | 0.63 | | NG |
| | 1 | 2.77E+07 | 7.30E+07 | 0.38 | 0.57 | 1 | 1 | 0.57 | | 0.61 | | NG |

## 5. STRUCTURAL EVALUATION GUIDE IN DOMINICAN REPUBLIC

The Detail Evaluation is used on the condition that the Seismic Design Code is accomplished. Static analysis of progressive push (Pushover) can be applied in the Dynamic method, which was used for this process. This assessment requires the capacity and establishment of the structure to the maximum horizontal force generated for design force, through the application for increasing the lateral force, and total maximal strength should be equal to or less than to the base shear given by Eq.(3).

The result of the evaluation is shown in Table 3. The result indicates that the structure has damages only on the first floor.

$$V = Cb * W \qquad W = \sum_{I=1}^{N} Wi \tag{3}$$

Table 3. Shear base of existing structure

| Existing | Direction | Type of structure | T (s) | Cb | V (KN) |
|---|---|---|---|---|---|
| Structure | **X** | Special reinforced concrete walls | 0.146 | 0.207 | 13821 |
| | **Y** | | 0.235 | 0.281 | 18808 |

**5.1 Comparison method between Japan and Dominican Republic**

The method used in Japan is more detail because it has values to classify the failure and to determine the percentage of damage in each structural element to obtain the level of behavior of the structure. While in the Dominican Republic, the method used is only parameters that applied to determine the behavior of its structures. The procedure to evaluate structures in Japan is stricter, due to that it demands a high percentage of performance in the elements that integrate the structure.

## 5. ANALYSIS RESPONSE SPRECTRAL OF STRUCTURE

In the static and dynamic analyses by the program Stera 3D, the results indicate that on the first and second floors, the structural elements can have severe damage, due to flexural yielding at wall base and the elements resistance loses capacity with relation to the imposed demand. In this case, they do not transmit loads axial to the elements without losing its elastic range. For the reinforcement of this structure we will use shear wall to increase the strength of the walls and the performance of the building. This type of shear wall is a method with easy application that technology and is especially economical, therefore this method would be very feasible in the Dominican Republic.

According to the previous calculations the building only needs rehabilitation on the first and second floors in the transverse direction (Y). But for better structural behavior, the rehabilitation is realized in the whole floors in the mentioned direction to increase, the quantity of structural walls which have following conditions: thickness of 250mm, compressive strength of concrete is 28N/mm², yield strength of reinforcement is 420 N/mm², diameter of horizontal and vertical reinforcement bars is 9.52, reinforced spacing to 200mm. On the first floor eight walls are placed, and on the second and third three walls, and the fourth floor one wall is placed.

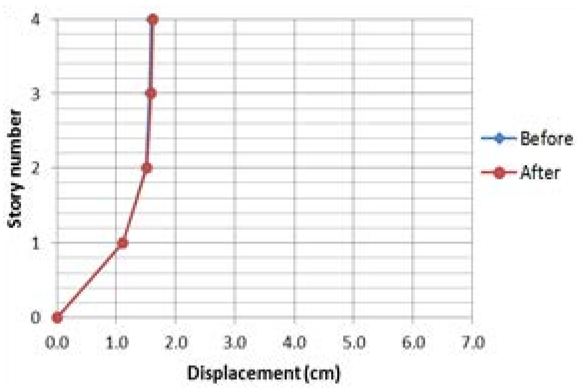

Figure 3. Displacement in longitudinal X.

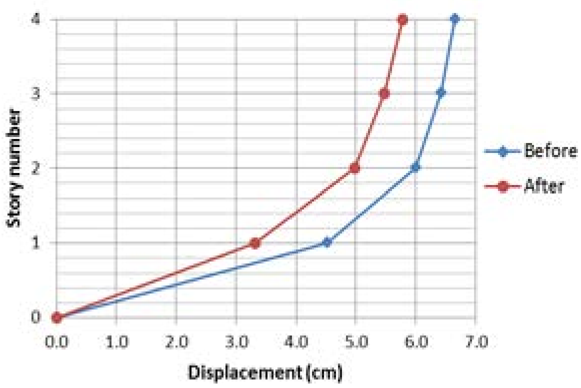

Figure 4. Displacement in transverse Y.

The performance of the building before and after rehabilitation is different with respect to the displacement as shown in Figure 3 and 4. In transverse walls, the rehabilitation for the diminished displacement is realized, but in longitudinal walls, rehabilitation do not make the displacement increase, as this must be for the force that the transverse walls in the longitudinal walls.

## 6. GUIDELINE OF REHABILITATION EXISTEN REINFORCED BUILDING

The rehabilitation in the program Stera 3D is realized, and returns to compare the results of the program with the new results of the theoretical calculations to determine the index of demand which are needed in order that the building has a good behavior by this way in case those earthquakes occur.

### 6.1 WRC First level screening procedure

Table 4. Comparison of seismic index

| | | BEFORE | AFTER REHABILITATION | | |
|---|---|---|---|---|---|
| Direction | floor | Is=$E_o$*SD*T | Is=$E_o$*SD*T | $Is_o$ | Evaluation |
| X | 4 | 1.81 | 1.84 | 0.8 | OK |
| | 3 | 1.28 | 1.32 | | OK |
| | 2 | 1.11 | 1.14 | | OK |
| | 1 | 1.15 | 1.20 | | OK |
| Y | 4 | 0.99 | 1.01 | | OK |
| | 3 | 0.82 | 0.97 | | OK |
| | 2 | 0.73 | 0.84 | | OK |
| | 1 | 0.62 | 0.83 | | OK |

The resistance of the structure was evaluated based on the force of the floors upon the tension realized in every structural element; with the purpose of finding weak connections and of identifying its behavior which affects the answers of the structural system of the building. As shown in Figure 5 and 6, for the first level procedure the performance of the building after retrofitting the seismic demand index is correct.

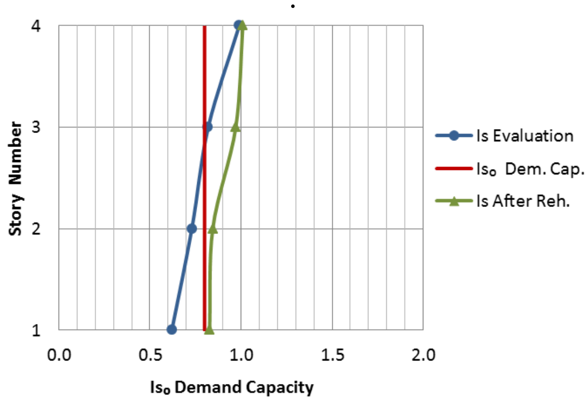


Figure 5. Demand capacity of building in Y direction.

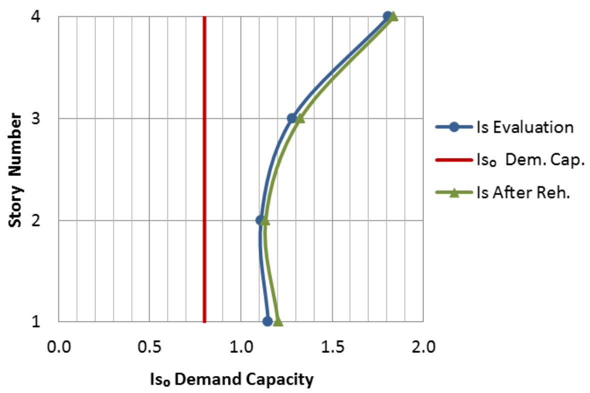


Figure 6. Demand capacity of building in X direction.

### 6.2 WRC Second level screening procedure

Table 5. Comparison of seismic index

| | | BEFORE | | AFTER REHABILITATION | | | | |
|---|---|---|---|---|---|---|---|---|
| Direction | Floor | Is=$E_o$*SD*T | Calculated Ctu*SD | Is=$E_o$*SD*T | $Is_o$ | Calculated Ctu*SD | Demand Ctu*SD | Evaluation |
| X | 4 | 4.42 | 4.71 | 4.52 | 0.60 | 4.83 | 0.30 | OK |
| | 3 | 3.06 | 3.42 | 3.08 | | 3.45 | | OK |
| | 2 | 2.63 | 3.06 | 3.85 | | 4.49 | | OK |
| | 1 | 1.86 | 2.98 | 2.71 | | 4.34 | | OK |
| Y | 4 | 0.85 | 0.91 | 0.91 | | 0.97 | | OK |
| | 3 | 0.87 | 0.69 | 0.93 | | 0.75 | | OK |
| | 2 | 0.56 | 0.63 | 0.93 | | 1.04 | | OK |
| | 1 | 0.57 | 0.61 | 1.04 | | 1.11 | | OK |

The rehabilitation of transverse walls on all stories was performed, and the behavior of the building after retrofitting satisfied seismic demand index, which is correct for the second level procedure.

## 7. CONCLUSION

The aim of this study is to learn the methods of seismic evaluation in Japan. To verify the performance of the structure is to compare the result with the response of the program Stera 3D. Then the methods is used to compare with the one used in the Dominican Republic to determine which conditions are needed for the seismic evaluations to realize in the country. Since the visual evaluation is simply of high quality, then evaluation by the comparison would have to be done by the detailed evaluation that uses the seismic code. The methods used in Japan are a Model of well-structured and well-ordered evaluation by which good quantitative results are obtained.

It is necessary to evaluate the seismic vulnerability in the Dominican Republic to maintain control on the conditions of the buildings. In addition there are a lot of structures in the country but many of them are made of reinforced concrete and designed without any seismic codes. For this reason it is important to determine and to improve the seismic capacity of all these existent buildings that might be of high risk in case of earthquakes.

## 8. RECOMMENDATION

The main goal of the evaluation is to determine the response of the building during the earthquake. It is very important that the buildings have a sufficient capacity deformation to withstand seismic demand properly without deteriorating its strength.

i. Designing structure elements (column) with greater capacity than beams, stirrups suggested well distributed, adequate additional steel, so they can support maximum loads and deformations avoid total collapse of the structure.
ii. It is necessary to evaluate all structures in the country that are designed before the first seismic code and perform rehabilitation.
iii. All structural projects should be designed by taking into account country’s current seismic code and all previous constructions should be checked in accordance with the code.
iv. Developing more rigorous seismic assessment model with more detailed values.


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