Paper No. TS-2-3

Seismic Performance Model of an Important Building in Peru - Evaluation of a Hospital Structure -

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ABSTRACT

Nowadays it is very common to find the use of analytical methods in the development of seismic evaluations related to buildings structures. However, knowledge of nonlinear behavior in those structures leads to consider the use of such methods which take into account the capacity of the structure and the demand due to seismic excitation.

The intention of this study is to promote the use of these methods to take into account, in a structural analysis, the concept of *performance* of the structure and *level of structural damage* due to seismic demand.

In this sense, we found interesting to evaluate an important building structure like it is a Hospital. Hospital structures, especially, need to ensure their continued operation (structural and functional) even after the occurrence of a major earthquake. Therefore, the performance of these structures and the level of expected damage that arise due to seismic excitation should be monitored with special emphasis.

INTRODUCTION

In the usual practice is common to talk about *structural analysis* which makes use of the dynamic properties of structures, to obtain the response later (the modes obtained in the dynamic analysis) depending on the reduced elastic spectra. These reductions of the elastic response are due to the knowledge of nonlinear behavior of structures and they have proved to give very approximate results. However, many times we find that this reduction factor of the elastic force is very general. Sometimes we find structures that do not necessarily correspond to a clear classification to adopt any of the values of reduction found in our codes. This and some other disadvantages lead us to seek alternative methods.

For this reason we are going to apply another kind of process in the evaluation of a Hospital Structure. A nonlinear method known as ***Capacity Spectrum Method*** (CSM) is going to be used to determine the *Structure Performance* under seismic Demand. This method is well explained in the report of ATC-40. CSM uses the intersection of the Capacity Spectrum curve and a reduced Demand Spectrum to estimate maximum displacement at the top of the building.

In recent years, many hospitals in Latin America and the Caribbean stopped functioning as a result of earthquakes. But, with the proper acquaintance, about the response (performance) of the structure to a seismic excitation, we can make decisions to ensure its function even after the earthquake.

One of the main objectives of this study is to extend conclusions about the necessity of reinforcing this particular structure by the application of the CSM. Once the Performance Point is obtained, it will indicate how the structure is expected to be damaged due to seismic demand. This possible damage level is a good indicator to make decisions on retrofitting.

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OBJETIVES

Understand the differences and advantages which are obtained by applying nonlinear methods in the evaluation of building structures.

Make use of a nonlinear method to determine the probable damage level and performance to be presented at an important structure such as a hospital in Peru due to the seismic demand.

Understanding the need to reinforce (or not) a structure from its analysis.

APPLICATION OF CAPACITY SPECTRUM METHOD (CSM)

Although an elastic analysis gives a good indication of the elastic capacity of structures and indicates where first yielding will occur, it cannot predict failure mechanisms and account for redistribution of forces during progressive yielding.

Two key elements of a performance-based design procedure are demand and capacity. ***Demand*** is a representation of the earthquake ground motion. ***Capacity*** is a representation of the structure ability to resist the seismic demand.

The ***Performance*** is dependent on the manner that the capacity is able to handle the demand.

There are many methods, in these times, to carry out this purpose. In the Bibliography Reference it is possible to find further explanation about some of these methods. From now on we are going to focus in the application of the Capacity Spectrum Method (CSM) which is well explained on BR-2.

In summary, after obtaining the capacity curve (pushover), it must be transformed into the capacity spectrum (in acceleration-displacement format). In the construction of the pushover curve there is some discussion about the distribution of forces over the building to represent the most appropriate structural response to the inertial forces due to seismic demand.

The main formulation used in the development of this method, to build up the capacity spectrum, is presented below:

$$PF_1 := \frac{\sum_{i=1}^{n} \left[\left(\omega_i \cdot \phi_{i,1}\right) \div g\right]}{\sum_{i=1}^{n} \left[\left[\omega_i \cdot \left(\phi_{i,1}\right)^2\right] \div g\right]}$$

$$\alpha_1 := \frac{\left[\sum_{i=1}^{n} \left[\left(\omega_i \cdot \phi_{i,1}\right) \div g\right]\right]^2}{\left[\sum_{i=1}^{n} \left(\omega_i \div g\right)\right] \cdot \left[\sum_{i=1}^{n} \left[\left[\omega_i \cdot \left(\phi_{i,1}\right)^2\right] \div g\right]\right]}$$

$$Sa := \frac{V \div W}{\alpha_1}$$

$$Sd := \frac{\Delta_{roof}}{PF_1 \cdot \phi_{roof,1}}$$

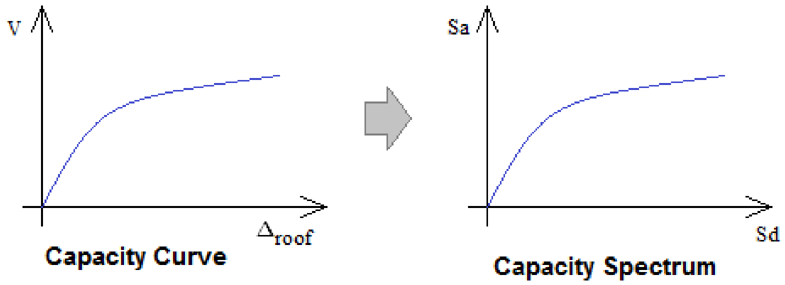


Figure 01. Conversion from the Capacity Curve to the Capacity Spectrum

Where:

PF_1 = Modal Participation Factor for first natural mode
α_1 = Modal Mass Coefficien for first natural mode
g = Gravity acceleration
$\phi_{i,1}$ = Amplitude level "i" in mode "1"
V = Base Shear Force
W = Permanent Load plus a percentage of live load
Δ_{roof}=Displacement at the top of the structure
Sa = Spectral acceleration
Sd = Spectral displacement

After building up the capacity spectrum, the next step is to join the demand spectrum (elastic demand with 5% of damping) with the capacity spectrum in the same format (acceleration-displacement). From the demand spectrum, it will be necessary to generate a family of curves (of reduced demand) that depend on the effective damping of the equivalent structure. Through an iterative process it is possible to find the appropriate reduced demand curve that intersects the capacity spectrum; in this way here we will get the performance point.

Thus, the performance point is found by the intersection of the capacity spectrum curve and a reduced demand spectrum to estimate maximum displacement.

Another important aspect in the development of this methodology is that we can follow the damage-level progression (degradation) in the structure as we are building the capacity curve. This means that, for displacement controlling, we can identify the appearance of plastic hinges and the associated damage-level.

HOSPITAL STRUCTURE TO BE EVALUATED

Edgardo Rebagliati Martins Hospital (**HERM**) was built in 1957 and, until today is one of the most important in Peru. Original structural design was designed to be a reinforced concrete frame structure but, as it can be seen today, there is a significant presence of masonry walls. In a previous study done by CISMID, in 1997 (see BR-4), it was determined that masonry has an important contribution in the rigidity of the structure and, in case of earthquakes, it would be affected in some way. In spite of the fact that the masonry walls were not planned to be part of the structure, their damage could mean the suspension of the Hospital functions. But in Peru, as in the rest of the world, hospitals should be designed to remain standing, even after the expected earthquake.

The Hospital is composed of several buildings as seen in *Figure.02.* However, the objective of this study is focused on buildings "A" and "C" (they are identical in construction).

The results, we are going to remark, will be those referred to weakest direction (axis "Y") and, they will be referred to the framed structure (as was originally planned). This is because we are looking for the original structure capacity.

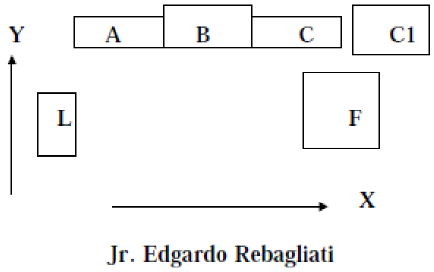


Figure 02. General Plan View – HERM

From studies of natural vibration of the structure (Microtremor measurement) and the study made by CISMID in 1997 (see BR-4) we know that the masonry component present in the current structure increases the stiffness system and reduces its natural period. Nevertheless, the masonry would suffer damage during an important earthquake and it could mean the suspension of the Hospital functions.

For this reason, while the current structure has masonry partitions which are contributing to the structural behavior, one might wonder how such a structure would respond, as it was planned, if the masonry were separated from the current structure.

RESULTS

As follows, it is presented the most important data in the analysis of the Hospital structure. The capacity curve (pushover) has been obtained by using a computer software SAP200-12. The input data, referred to materials and the geometry of sections, have been taken from the original plans that were provided for this purpose.

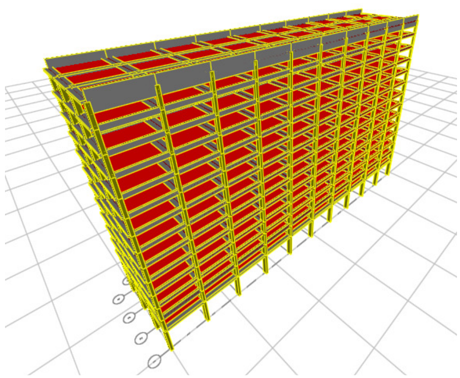
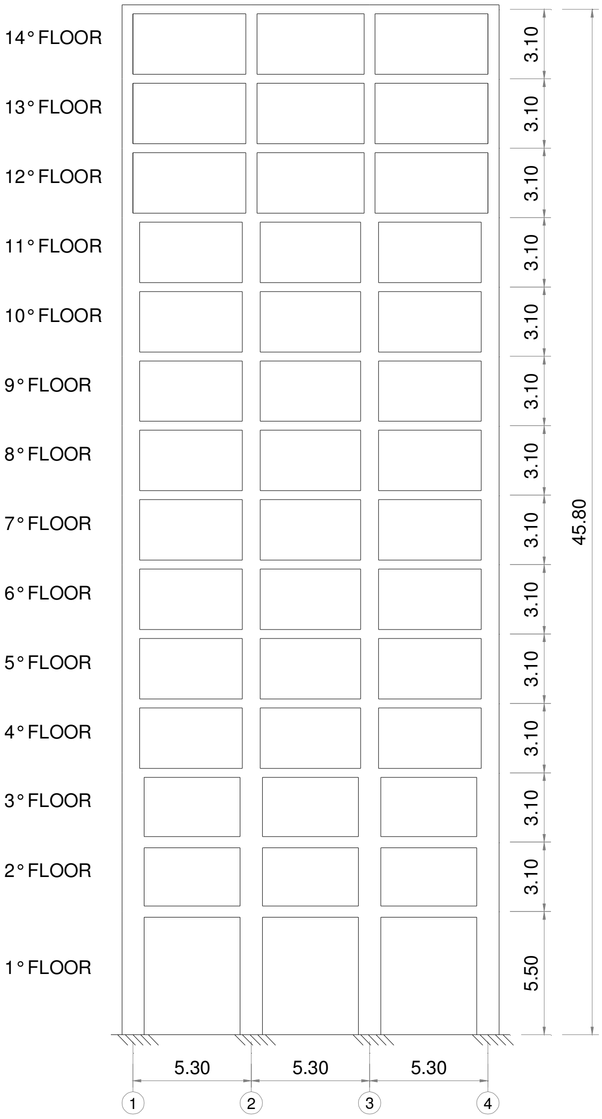


Figure 03. 3D Model view – Made up in SAP2000-12



Building Features

System: Concrete Frame Structure

Number of stories: 14

Concrete Strength (f'c) 210-350 kg-f/cm^2

Steel Yield Strength (fy) 2'800 kg-f/cm^2

Weight on the first floor 2'237.00 ton-f

Weight on typical floors 2'166.00 ton-f

Weight on top floors 955.00 ton-f

First floor height 5.50m

Typical floor height 3.10m

Figure 04
Analyzed-Profile View. Structural weakest direction (axis "Y").

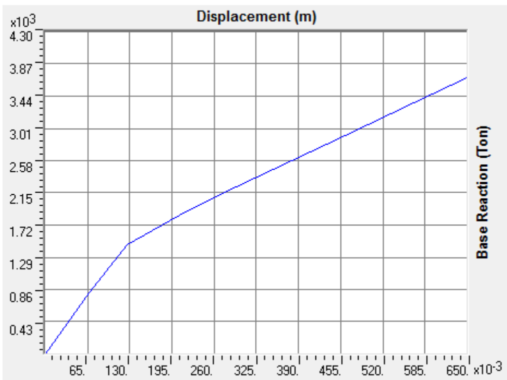


Figure 05. Pushover Curve - Y Direction

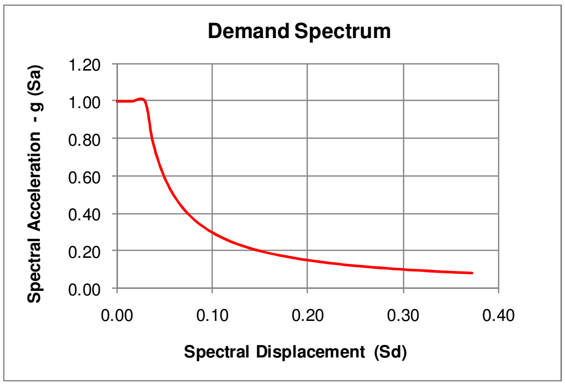


Figure 06. Elastic Demand Spectrum(β=5.00%)

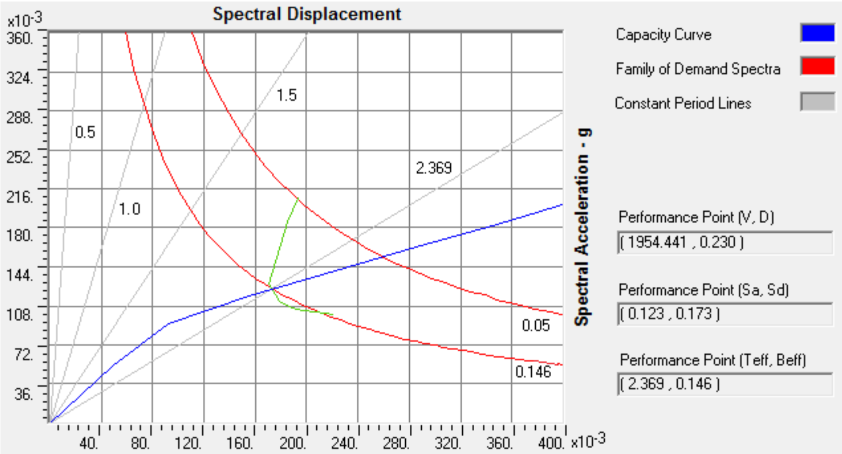


Figure 07. Performance point location at the intersection of the reduced Demand Spectrum and Capacity Spectrum. In this graphic it is possible to note the capacity of the structure to reach some level of displacement even further the demand for the considered reduced spectrum.

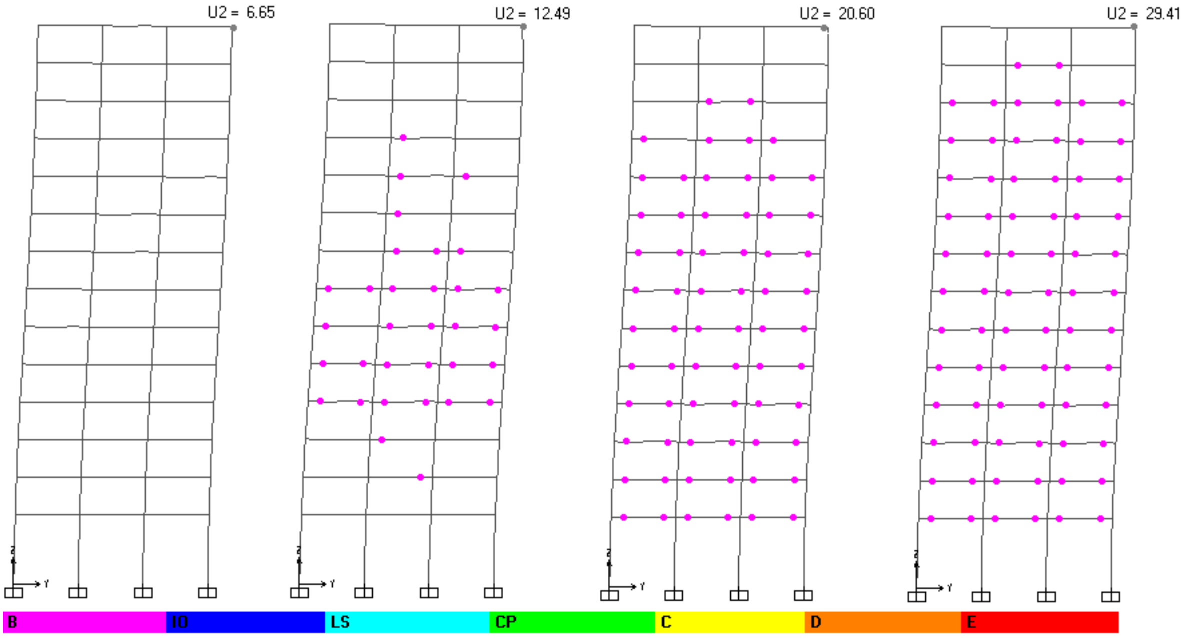


Figure 08. History of formation of plastic hinges with the displacement (in cm) at the top of the structure.

As we can see, in the above picture, the failure mechanism is of the desirable kind. The possible plastic hinges are going to appear, first, at the beams extremes before appearing at any columns extremes. This is consistent with the known philosophy, which suggests, "strong column and weak beam" (when their strengths are compared). Besides, the damage level of these plastic hinges is low -immediate occupancy (IO)-; see BR-2 and BR-3. Nevertheless, the order of experimented displacements could make the people inside the building have uncomfortable feelings. Besides, complements, doors and windows could suffer damage that means their inability.

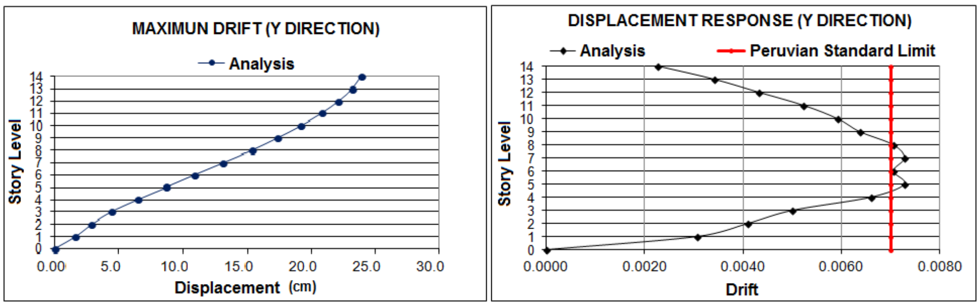


Figure 09. Structural Response in "Y" direction of analysis.

IMPORTANT

1. To apply a nonlinear analysis, in order to know the performance of any particular structure, nowadays we count with many methods. All of these methods have its own advantages and disadvantages; these are explained in several articles and reports. See BR-1; BR-2; BR-3; BR-5; BR-6.

2. To make up the pushover curve, it is important to determine every possible point in which a plastic hinge could take place. See BR-1; BR-7; BR-8.

3. The Pushover curve depends on the supposed distribution of forces to be applied over the building structure. Some of most convenient shapes for distributing the forces at each story are proposed in many studies. See BR-2; BR-3; BR-5.

CONCLUSIONS

The use of nonlinear methods, which reveals the capacity of the structure and demand due to seismic excitation, helps to understand more clearly the expected damage level to such demand. Knowing the structure damage level, due to the seismic demand, for instance, helps in the decision of reinforcing or maintaining the system to ensure its expected performance (according to its importance).

In previous studies (see BR-4) it has been determined that the masonry component of the structure would suffer damage if subjected to a common earthquake excitation. However, as seen in the present analysis, the structure as originally designed (concrete framed system) would have sufficient capacity to respond to such earthquake (and even stronger) without showing damage that means the suspension of its functions. For these reasons, we conclude that the current structure should be reinforced with the replacement of some masonry walls by concrete walls to give greater rigidity to the structure (reducing the original drift level) and avoid further damage to the masonry remaining.

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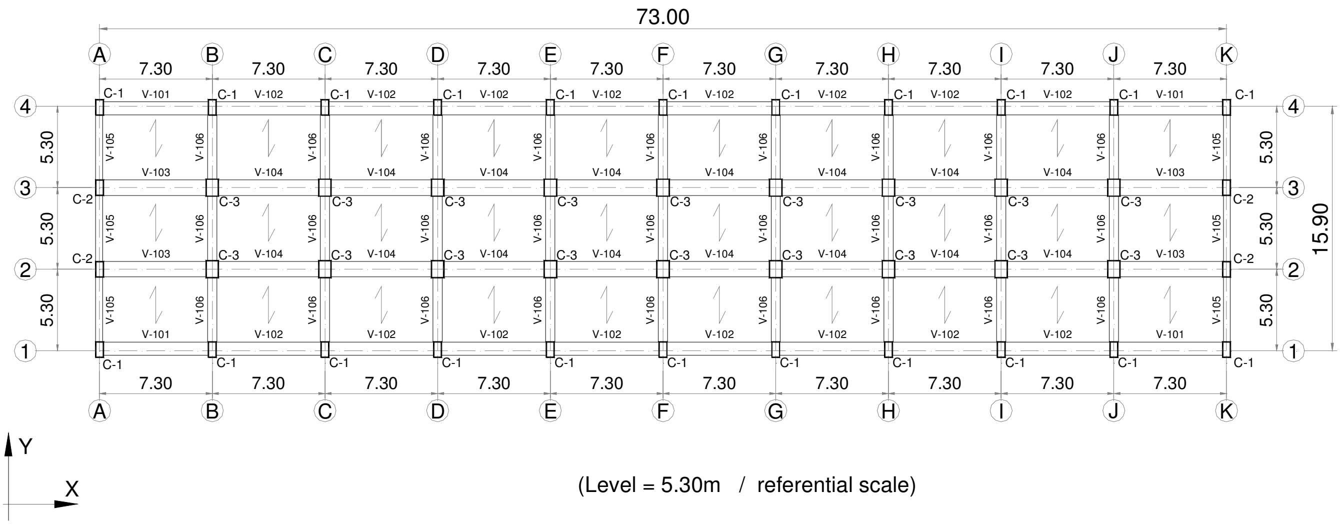
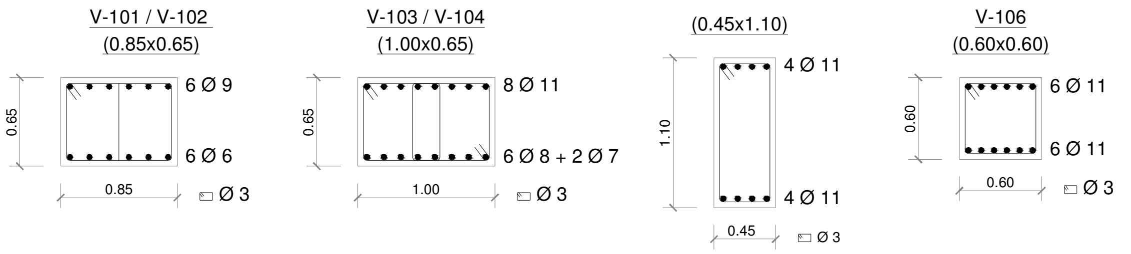
APENDIX

A-1 FIRST FLOOR – PLAN VIEW



(Level = 5.30m / referential scale)

A-2 FIRST FLOOR – TYPICAL BEAMS SECTIONS



A-3 FIRST FLOOR – TYPICAL COLUMNS SECTIONS