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SEISMIC RESISTING ARCHITECTURE ON BUILDING SCALE - (A Morphological Answer)

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ABSTRACT:

The principal aim of this paper is to present a new and conclusive report related to Seismic-resistant Architecture. It is, in fact, an answer concerning the field of architecture.

This new approach involves an architectural design in which all the composing units of the building are interactively organized so as to provide a positive and efficient answer working as a integral seismic-resistant system.

The suggested architectural answer, is meant to simplify the existing troublesome criteria to achieve a real compatibility between architectural and structural design.

Such an answer has been stated from a morphological point of view and, consequently, it is a completely different methodology from the one which has been in use so far. In other words, a generalized morphological answer is being considered for each seismic conditioning situation to obtain an "Adjusted Final Shape" for each particular case. The so called Adjusted Final Shape involves an architectural design of the building in which all the elements can efficiently interact during an earthquake. This abstract includes a summary of the criteria proposed.

The Adjusted Final Shape undoubtedly represents the final goal of Seismo-resistant Architecture as well as a comprehensive solution to the seismo-resistant capacity of the building during an earthquake.

KEYWORDS:

Integral Seismo-resistant System; Interacting elements; Compatibilization; Final Adjusted Shape; Morphological.

INTRODUCTION:

"Seismo-resistant Architecture" refers to an architecture engaged in the necessity of optimizing the design and materialization processes of human sites located in highly risky seismic zones, based on the compatibility of interrelationships among its components or interacting subsystems, during the seismic actions.

In short, the Seismo-resistant Architecture represents the role taken on by architecture in order to provide a global comprehensive solution to the "Seismic Problem".

In general, it covers four areas of knowledge:
-Seismic Emergency.
-Urban design for seismic zones.
-Seismo-resistant Architecture at a building scale.
-Aesthetic or morphological representation of Seismo-resistant Architecture.

This paper deals with "Seismo-resistant Architecture at a building scale", that is, Seismo-resistant building design, and its objective is a compatibilized structural and architectural design. This means, that during an earthquake all its structural and non-structural components must contribute to its seismo-resistant capacity.

Thus, a comprehensive solution to the seismic problem is being looked for since it is believe that a structural analysis by itself is not enough to ensure the seismo-resistant stability of buildings. This integral solution must have as its starting point a global conception of the building, i.e., an Integral Seismo-resistant System, in which all its parts or components can interact during the seismic action and, consequently, can contribute either positively or negatively to the seismo-resistant response. In other words, it is necessary to analyze such interrelationships and their compatibility, in order to avoid a stepping of the seismo-resistant capacity (not simultaneously) of the building which would even cause the building to collapse.

In fact, the unexpected interaction of the seismo-resistant structure with non-structural elements of the building modifies the relationship of the stiffness of the structural elements.

In this situation, the structure is unlikely to provide all its seismo-resistant capacity simultaneously and as required during the seismic action.

A rational theoretical background has been developed based on this particular approach.

Two basic principles are considered:
- Global conception of the building, in which all components interact during the seismic action.
- The interacting elements must be able to behave with the stiffness, ductility and synchronization expected in the design and structural analysis, during the seismic action. That is to say, they must be able to offer all their seismo-resistant capacity simultaneously. Otherwise, the stepping of the seismo-resistant capacity of the building will be produced, causing the whole building to collapse.

The stepping of the seismo-resistant capacity of the buildings caused by: seismic torsion, short columns, pseudo-resonance, rattling, flexible floors, sudden stiffness changes either plan and elevation, are responsible for the architectural design.

There are other four important basic principles besides the two mentioned before:
- The seismic coefficient corresponding to the different floors of a building increases in relation to their height.
- The resistant elements may be placed with a certain degree of independence from the vertical load.
- Seismic forces are proportional to the building weight.
- Efficiency and optimization of the seismo-resistant response of the building.

Even if the latter one does not refer to the causes of stepping of the seismic resistance, it is highly important because it intends to optimize the seismo-resistant capacity of the buildings. It can be achieved by means of two procedures: by reducing the seismic forces, or by increasing the efficiency of the seismo-resistant capacity of the buildings.
The reduction of the forces can be obtained in different ways:
- Weight reduction can be obtained by using lighter materials or by reducing fillings and other heavy fittings not essential for building construction.
- Heavier weights relocation such as files, swimming-pools, etc., at lower levels.

- Pseudo-resonance avoidance: it involves, preventing the fundamental period of the building from coinciding with the predominant period of the foundation soil.

The principal aim of seismo-resistant architecture is the optimization of seismo-resistant capacity, which can be obtained by sketching suitable configurations for the building.

Important developments have been achieved by this means. In fact, not only the basics, objectives, basic principles and the methodology to deduce the compatibility criteria have already been set forth, but also the proper compatibility criteria themselves. However, there has been "a great missing answer" in architecture which would imply its own synthesis in order to meet the seismo-resistant requirements.

A maturity period which would involve assimilation, comprehension and some consideration was a natural requirement. This answer means organizing and optimizing all the elements or subsystems constituting the building in order to resist the earthquake positively and efficiently. That is, it is like a trained army ready to fight, making use of its best potential, organization and efficiency against the enemy.

The required but, up to now nonexistent architecture, should evidence clarity, strength and transparency. It should be a self-evident architecture; an architecture which would strongly simplify the troublesome compatibility criteria between the architectural design and the seismo-resistant structural design. It should be an architecture which protects the architect from the seismo-resistant engineering dictatorship, since its "answer" would simplify and minimize the complex seismo-resistant engineering knowledge, necessary to the present state of Seismo-resistant Architecture.

This architectural "answer" has been naturally formulated from the morphological area introducing a totally different point of view.

In order to lay down a morphologically adjusted answer, called "Final Adjusted Shape", some general criteria or morphological answers have been established for each seismic determinant. This methodology involves changing the seismo-resistant engineering requirements in terms of morphological requirements easily interpreted and handled by architects. **Figure 1** outlines the process followed to reach the morphological solution proposed.

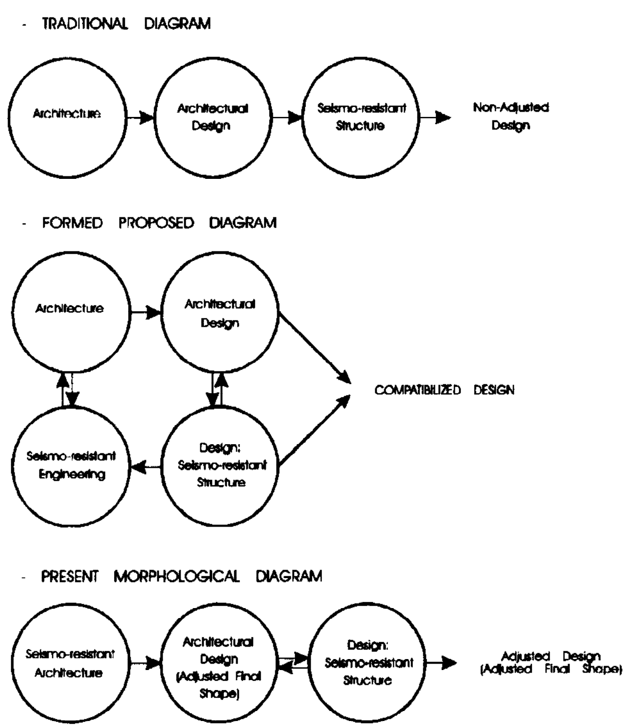


FIG. 1: Outlines the process followed to reach the morphological solution proposed

Anyway, it is the result of an interdisciplinary work between Architecture and Engineering, based on the global conception of the building as a Seismo-resistant System linking both the Architectural and the Structural Design to achieve a common objective.

ADJUSTED FINAL SHAPE:

The "**Adjusted Final Shape**" is an architectural design of the building in which the interacting components work positively and efficiently, during the earthquake, so as to optimize its seismo-resistant architecture.

The methodology suggested demands a radical transformation of every and each seismo-resistant determinant into morphological ones, for every particular architectural design.

This objective constitutes the basis of the morphological method used. The referential variables which are to be morphologically compatibilized are consireded at the very beginning.

- Flexible Floor
- Building Collision
- Seismic Torsion
- Pseudo-resonance
- Sudden stiffness changes in plan and elevation
- Stiffness-Flexibility
- Concentrated Weight
- Short Columns
- High buildings
- L-U-and T- shaped story buildings.

Now, the morphological answers for each variable. The following table is a first attempt which would admit an immediate application of the solution suggested.

Flexible Floor:

This situation arises when, at a certain floor, the stiffness of a high building is considerably reduced in relation to the contiguous floors.

This situation causes a strong concentration of seismic forces on the site giving rise to a dangerous stepping mechanism of the building resistance.

The morphological answer consists in avoiding this situation in the architectural design. Whenever a floor with big separations of the columns is required, it will have to be the last one or it will have to be placed outside the tower site, preferably conceived at a single level.

Building Collision.

This occurs when there are no joints between the buildings and the collision is produced when the oscillations are displaced. This is a completely normal situation which must be definitively avoided. The morphological answer consists in building separation, as current rules specify. It is recommended to design the different functions for the completely separated bodies in the case of the same building, preventing building collision, providing a uniform structure and also avoiding sudden stiffness changes in plan and elevation.

Seismic Torsion

This effect is produced when the Stiffness Center (SC) and the Torsion Center (TC) do not coincide. This situation elicits additional requests specially in those ones which are far removed from the SC, which might lead to a stepping of the seismo-resistant capacity of the building.

Although this problem is considered in the structural analysis, it is completely unwanted since it generates strong additional and uneven seismic forces in the set of columns, giving rise to the stepping of the seismo-resistant capacity of the building.

The morphological answer is achieved by designing buildings with symmetrical plan and elevation. In addition, the structural and non-structural interacting elements symmetry is required. It is also necessary the functional symmetry of the architectural site.

Pseudo-Resonance

This situation is produced whenever the period of the building coincides with the predominant period of the foundation soil. This condition remarkably increases the seismic action. On the other hand, if the fundamental vibration period of the buildings is the function of its dimensions and structure stiffness, then, the morphological answer specifically consists in the handling of these parameters.

Sudden Stiffness Changes in Plan and Elevation

This situation can be prevented by using compact, uniform and homogeneous spatial shapes of the architectural design.

Stiffness-Flexibility

Whenever a rigid or flexible building is required, that is to say, that can be deformed to a higher or lesser degree, is naturally used either rigid structures such as: partition walls made up of reinforced concrete and/or high density and high resistance masonry walls, 0.20 m. thick, or the opposed adequate materials required for flexible buildings.

Undoubtedly, both cases influence the spatial morphology of such buildings.

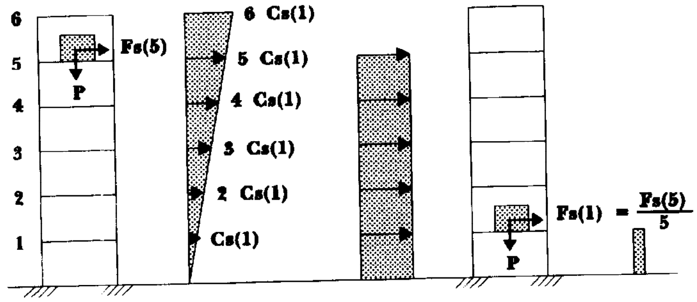
Concentrated Weight

In most of the current seismo-resistant norms, the seismic coefficient increases almost proportionally to the floor level with respect to the terrain. Consequently, in Architectural Design, this principle must be borne in mind, not only to avoid using heavy materials, subfloors, partition walls, coverings, etc., at higher levels, but also to place the sites designed for files, swimming pools or heavy equipment at lower levels. In so doing, two purposes are achieved: firstly, a reduction of the seismic forces since the seismic coefficient increases at higher levels and, then, a logical reduction of the seismic shear and moments.

The following example clearly illustrates the importance of this last concept.

It shows a six-level construction comparing the seismic effect caused by a certain P weight, which is firstly placed at the fifth level and, then, at the first level of the same construction.**(Figure 2)**

The results are conclusive. In the case of P placed at the fifth level, the overturning moment becomes 25 times greater than for P placed at the first level. Besides, the seismic shear affects from levels 1 to 5, whereas, in the second case, only the first level is affected but to a lesser extent (5 times less).



$$Fs(5) = P * 5\ Cs(1)$$

$$Fs(1) = P * Cs(1) \qquad \text{then: } \frac{Fs(5)}{Fs(1)} = 5 \ ;$$

$$Mv(5) = P * Cs(1) * 5h = 25\ P * Cs(1) * h$$

$$Mv(1) = P * Cs(1) * h \qquad \text{then: } \frac{Mv(5)}{Mv(1)} = 25 \ ;$$

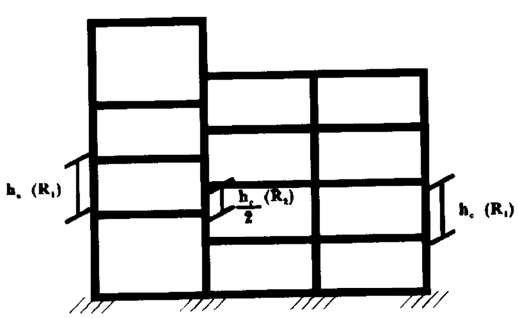
FIG. 2: Concentrated Weigth

Short Columns

Another point related to the resistance-stiffness problem has been called "Short Column". In this case, the seismic shear increases inversely proportional to the cube of its height for columns of equal cross section area. In addition, this situation becomes worse for short columns due to the fact that concrete is unsuitable to resist strong tangential stress, remarkably decreasing its ductility.

These instances are produced by a particular disposition of masonry which reduces the columns height and, consequently, their stiffness becomes greatly increased. This causes the seismic shear to concentrate is logically unable to resist. The breaking of the resistant elements leaves the rest of the elements defenseless which could bring about the total collapse.

This situation can be easily avoided when it is the result of the openings' shape and location. On the other hand, when it is the consequence of differences of elevation among medium-height mezzanines, its elimination is practically impossible, so these differences of elevation must be removed from the seismo-resistant architectural design.**(Figure 3)**



$$R_1 = k \frac{I}{h_c^3}$$

$$R_2 = k \frac{I}{\left(\frac{h_c}{2}\right)^3} = 8\ k \frac{I}{h_c^3}$$

FIG. 3: Short Columns

High Buildings

In high buildings (over 10 floors), an almost 100% of this ideal adjusted shape must be required.

L-U and T-Shaped Story Buildings

Due to the flexibility of the mezzanines, L, U and T shapes bring about torques even if TC = MC. This is because the flexibility of the mezzanines reduces the stiffness of the columns, especially at the extremes of the corresponding slabs.

CONCLUSIONS:

The "**Adjusted Final Form**" certainly represents the final goal of Seismo-resistant Architecture and an integral solution to the seismo-resistant problem of buildings.

The methodology used facilitates its practical application by architects and, by no means, implies losing originality or creativity. On the contrary, even though too deeply-rooted concepts will have to be rejected, Seismo-resistant Architecture will generate new and original ones, thus, finding its own way of expression.

It is also evident that the mechanical application without the necessary knowledge about seismo-resistant structural design and, especially, about seismo-resistant architecture would result in a loss of originality and creativity leading back to the traditional situation.

In case of building seismo-resistant consolidation, the first step to be taken must include an evaluation of the architectural design so as to state the compatibility maladjustments in the interrelationships of interacting components, during the seismic action. This task demands a thourough knowledge about the seismo-resistant structural design and, especially, about seismo-resistant architecture, in order to determine the causes of stepping of the seismo-resistant capacity and the possible solutions, modifying, if possible, the architectural and/or structural design. It is precisely in those cases in which a mechanical application would be worthless and would inevitably turn to be faulty.

REFERENCES:

Giuliani H., Aladro S., Benavidez H. B. (1988) Objetives and Fundamental Principles of A Seismic Resistant Architecture. Proceeding of the Nineth World Conference on Earthquake Engineering. Tokyo - Kyoto, Japan.

Giuliani H., (1992). A new Approach for the Integral Solution a Building Design. Proceeding of the TenthWorld Conference on Earthquake Engineering. Madrid, Spain.