"Soft Story" and "Weak Story" in Earthquake Resistant Design: A Multidisciplinary Approach

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SUMMARY:
"Soft story" and "weak story" are irregular building configurations that are a significant source of serious earthquake damage. These configurations that are essentially originated due to architectural decisions have long been recognized by earthquake engineering as seismically vulnerable. In terms of seismic regulations their irregular condition requires the application of special considerations in their structural design and analysis. The majority of urban zoning regulations in contemporary cities, although, at present encourages and in some cases enforces the use of them not requiring special considerations. This paper analyses the architectural reasons why these configurations are present in contemporary cities and explains in conceptual terms their detrimental effects on building seismic response. These effects are presented from a multidisciplinary perspective -engineering, architecture and urban planning- because their treatment can only be achieved by an integrated approach that recognizes the interaction between these disciplines. Examples of damage due to these effects are analyzed.

Keywords: soft story and weak story, irregular building configurations, multidisciplinary perspective.

1. INTRODUCTION

In earthquake resistant design, the *soft story* and the *weak story* irregularities are reciprocal to a significant difference between the stiffness and the resistance of one of the floors of a building and the rest of them. Both configurations are known in architectural terms as: the *open floor*. The number of advantages given by this concept of modern architectural design, both aesthetical as functional, is the reason why it has been encouraged all around the world since the first half of the 20th Century. These conditions are present, when either the first story of a frame structure , known in some countries as "ground floor", is free of walls, while stiff non-structural walls are present in the upper ones, or when shear walls are located in the upper stories and they do not follow down to the foundations, but they interrupt at the second floor. The origin of this architectural configuration commonly used in modern cities is mainly derived from the three first points of the "Five points for a new architecture" published by Swiss-French architect Le Corbusier (LC) in 1926, that defines the tenets of modern architecture: (1) *pilotis* (open first floor); (2) the *free plan*; (3) the *free façade*; (4) *strip windows*; and (5) *roof terraces-roof gardens*. These postulates were possible due to the development since the 19th Century of new construction techniques and building materials, such as the innovative "reinforced concrete frame structure"(RCFS). The load-bearing structure consisted of solid slabs that transfer the gravity loads to the columns and finally to the footings, leaving behind the brick, mortar, stone and wood structural wall system, that prevailed until early 20th Century. In 1914 LC developed the Domino System in France for economic housing, characterized by: elemental RCFS, which consisted of slender columns or pilotis, and flat solid slab (cast in place or precast) that covered long spans between columns, without girders. The RC solid slabs transferred the gravity loads to the columns, and them, finally to the footings. This new structural system also allowed the use of a floor layout free of walls. Since interior partitions did not receive any load, this structural system gave the freedom for modifying the location of them (Guevara-Perez, 2009, pp. 518-519).

On the left of Fig. 1.1, LC compares features of traditional architecture and the modern ones suggested by him; the three first of the *five points* related to the studied configurations, stand out of the shade.
On the right, LC illustrates the disadvantages of traditional buildings that had functionally inflexible bearing walls with the benefits under the open first story modern proposal (Guevara 2009. p. 232). In the lower part of the figure, LC compares the design "paralyzed"(plan paralysé), unalterable, of traditional buildings, and some of its disadvantages: insalubrity, inefficiency and waste, with the open floor modern design t and some of its advantages: economy, hygiene, and, pedestrian circulation separated from vehicular traffic.

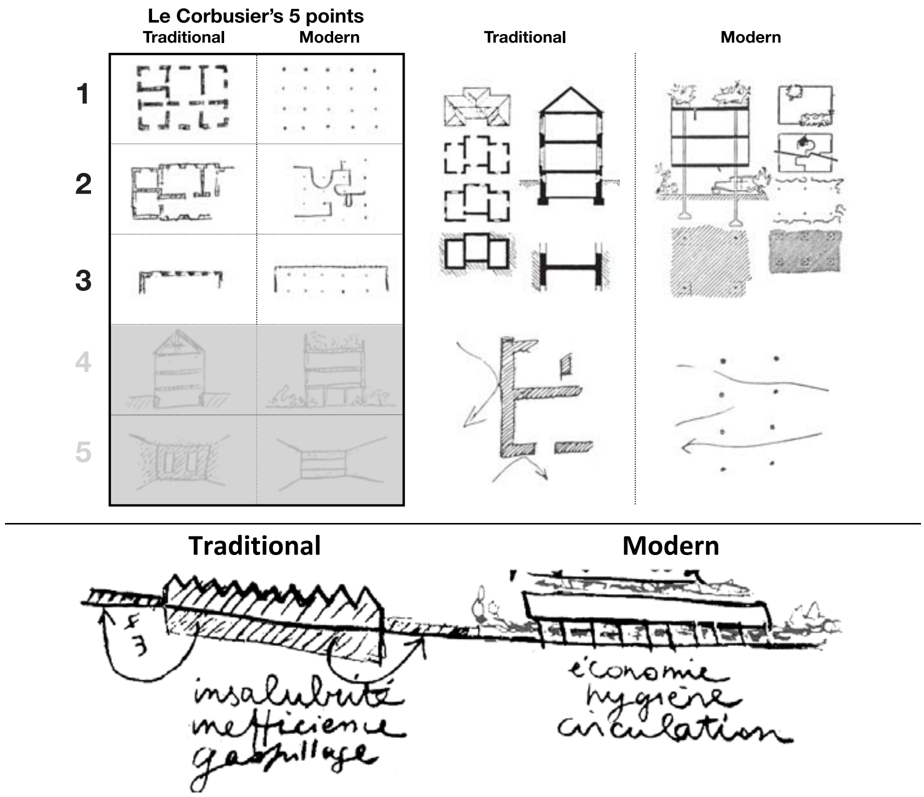

Figure 1.1. LC compares disadvantages of traditional architecture with advantages of open floor

Most UZR, consciously or unconsciously, encourage the use of the open floor configuration, since, when the first story is free of walls then the owner is rewarded, since, if this condition is present in the building, it is neither computable as part of the maximum allowable built area, nor for tax control, however, it is computable for selling purposes. But in seismic zones, from the beginning of the 20th Century this building configuration has been attributed as one important factor to the generation of seismic vulnerability in modern buildings. In reconnaissance reports, usually published shortly after each earthquake strikes contemporary cities all around the world, that evaluate the damage produced by earthquakes, the presence of it in damaged buildings is commonly mentioned, and it is also mentioned that it is closely linked to architectural decisions. These decisions usually are taken over, either from the initial steps of the design process, or as consequence of subsequent remodeling.

The results of studies that establish the link between the *open floor* architectural configuration and the effects produced by earthquakes on buildings with this configuration have been restricted to the academic and professional field of structural engineering, while architects and urban planners have continued to widely apply these modern pattern, not only on the design of new architectural forms, but as a provision in UZR, not understanding the interdependence between their decisions and the generation of seismic vulnerability that they produce in contemporary cities. In the 1970's, a group of architects from California participated in significant studies with earthquake engineers, to promote the inclusion in seismic codes of some special recommendations for the design and construction of building with modern architectural configuration. Also several articles and books were published with advices for architectural design in seismic zones (Guevara-Perez. 2009, pp. 64-73).Since then, authors such as Arnold and Reitherman, (1982) mentioned that size and geometric form were not enough parameters for defining the seismic irregularity of a building. They emphasized that in seismic design should be considered the relationship between seismic performance and the distribution of strength, stiffness and mass in the building, and also, the nature, size and location of structural and non-structural building components (Guevara-Perez. 2009, pp. 68-71). But, it was not until after the Michoacan, Mexico, earthquake of 1985, that the 1988 UBC edition included for the first time two tables for defining some parameters for the identification of "irregular" configurations, in plan and elevation. Since then in the majority of the international seismic provisions, the degree of irregularity in the configuration of a building is one of the most important factors that are established for defining the analysis procedure that should be used for the design of earthquake resistant buildings. The category vertical structural irregularities in seismic codes, usually includes the types: stiffness-soft story, and discontinuity in lateral strength–weak story. Even more, due to the concern generated among the specialists on earthquake resistant design, caused by the identification of recurrent presence of soft story and weak story in buildings damaged by earthquakes that occurred in late 20th Century, most new generation of seismic provisions, worldwide include two new types of irregularities known as *Extreme Soft Story* and *Extreme Weak Story* to the table of irregularities in elevation, in order to restrict the use of these configurations and even prohibit them for certain Seismic Design Categories. These concepts, *soft story* and *weak story*, are often mistaken for each other, and sometimes even used interchangeably, although each one of them is related to a different physical feature of the structure: the soft story or flexible story, with the difference of stiffness (resistance to deformation), between one building floor and the rest; and the weak story, with the difference of lateral strength or resistance to earthquake forces, between one building floor and the rest. These irregularities may be present simultaneously and each of them could be on the first story or at an intermediate level.

This paper summarises the results of a systematic study on the *soft story* and the *weak story* irregularities from the architectural and urban planning point of view (Guevara-Perez, 2012, Chap. 7). It includes examples of emblematic buildings that were damaged in well-known earthquakes, and some conclusions and recommendations.

2. SOFT OR FLEXIBLE STORY

The soft story irregularity, refers to the existence of a building floor that presents a significantly lower stiffness than the others, hence it is also called: *flexible story*. It is commonly generate unconscientiously due to the elimination or reduction in number of rigid non-structural walls in one of the floors of a building, or for not considering on the structural design and analysis, the restriction to free deformation that enforces on the rest of the floors, the attachment of rigid elements to structural components that were not originally taken into consideration. Because of the effects produced by non-structural components on the seismic performance of the building, the term *non-intentionally-nonstructural* has been assigned to these components since the end of the 1980's (Guevara, 1989). Table 12.3-2 in the *ASCE/SEI 7-10 document*, (p. 83) defines *soft story* as irregularity type 1. If the soft story effect is not foreseen on the structural design, irreversible damage will generally be present on both the structural and nonstructural components of that floor. This may cause the local collapse, and in some cases even the total collapse of the building.

The *soft first story* is the most common feature of soft story irregularity. It usually is present in modern frame buildings when a large number of nonstructural rigid components, such as masonry walls, are attached to the columns of the upper floors of a reinforced concrete frame structure while the first story is left empty of walls or with a reduced number of walls in comparison to the upper floors. The rigid nonstructural components limit the ability to deform of the columns, modifying the structural performance of the building to horizontal forces. In a regular building, the earthquake shear forces increase towards the first story. See Fig. 2. 1. The total displacement (Δ_T) induced by an earthquake tend to distribute homogeneously in each floor throughout the height of the building. Deformation in each floor (Δ_n) would be similar. When a more flexible portion of the lower part of the building supports a rigid and more massive portion, the bulk of the energy will be absorbed by the lower significantly more flexible story while the small remainder of energy will be distributed amongst the upper more rigid stories, producing on the most flexible floor, larger relative displacement between the lower and the upper slab of the soft story (interstory drift) and therefore, the columns of this floor will be subjected to large deformations. See Fig. 2.2.

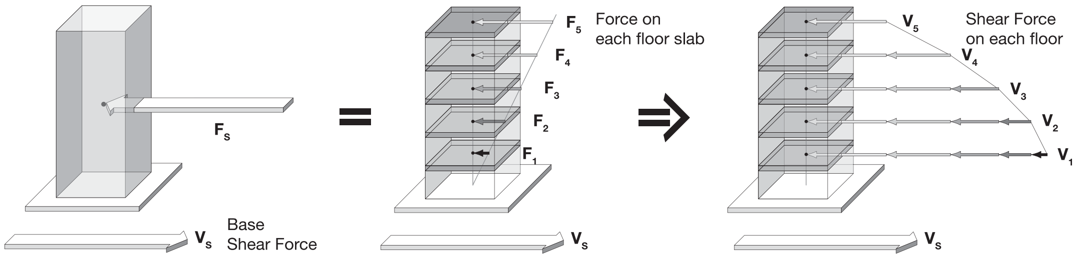

Figure 2.1. Lateral forces and shear forces generated in buildings due to ground motion

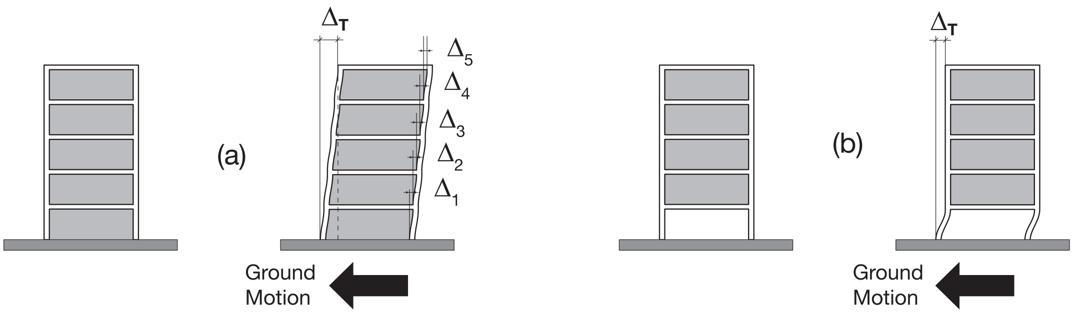

Figure 2.2. Distribution of total displacement generated by an earthquake in: (a) a regular building; and (b) an building with soft story irregularity.

The lowest more flexible portion, in the path of force transmission, at first story may create a critical situation during an earthquake; the stiffness discontinuity between the first and the second stories might cause significant structural damage, or even the total collapse of the building. One of the most common examples of soft story can be observed on the so called *"Open floor"* in the first story of modern residential buildings. The structural elements are homogenously distributed throughout the building, but the apartments are located on the upper floors with many masonry walls, while the lowest floor is left totally or partially free of partitions for parking vehicles and for social areas that require wide spaces. In the case of *double height first soft stories*, columns are very flexible not only due to the total or partial absence of walls but as a result of their significantly greater height in relation with those from the upper floors. This configuration is one of the characteristic models of modern design for office buildings, hotels and hospitals, in which the access for general public has a great importance. This configuration is also very common in mixed-use buildings, in which the urban code requires that the lower floors are of a greater height in order to accommodate shops with mezzanines for storage. As a variant of this configuration, we can find the use of columns of different heights in a corner of the building in order to give more importance to that space. Fig. 2.4 shows two examples of modern buildings with double height first soft story configuration. In most of the earthquakes that occur in contemporary cities, there are always cases of collapsed soft first story. Fig. 2.5 presents two examples of recent severe damage due to soft first story of irregularity in L'Aquila earthquake, Italy in 2009, and in the residential complex "San Fernando" of low cost housing in Lorca, Spain in 2011, where at the beginning the buildings didn't show apparent severe damage, though, all the buildings of this complex that had soft first story, were pulled down. The *covered sidewalk*, or arcade, is a configuration derived from soft story irregularity. It is a portico, like a cloister, in the first story of the front façade that is characteristic of buildings on commercial avenues. It is a common variation of irregularity in the distribution of the resistance, stiffness and mass of buildings, which is also included in UZR of contemporary cities as a heritage of the medieval city.

Another version of the covered sidewalks is the double height type. Most of the UZR include this configuration in mixed use buildings (commercial and residential), which allows to have double height first stories, a mezzanine for storage and double height showcase facing the covered sidewalk, in order to show the merchandise. The use in this case of very slender columns, as well as the use of double height empty spaces, creates an irregular distribution of the reactive mass, resistance and stiffness.

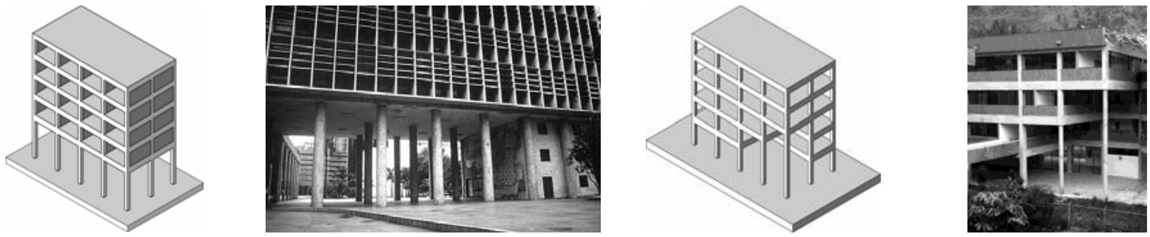

Figure 2.4. Modern building configuration with double height soft story, the main entrance of the Ministry of Education, Rio de Janeiro (Photo: Jose Luis Colmenares); and partial soft story with columns of different height in the corner of the building (Foto: Klaudia Laffaille).

Figure 2.5. Two recent examples of severe damage attributed to the soft first story irregularity in L'Aquila earthquake, Italy in 2009, (Photos, left: Holly Razzano, Degenkolb) and in Lorca, Spain in 2011.

Soft story also exists at intermediate floors. It is a typical configuration of massive low cost housing programs which follow the patterns of the Unité d'Habitation in Marseilles of Marseille (1947-1952) by LC. The concept which prevailed on the layout of this sort of isolated building was the self-sufficiency, as the residence features were included, communal facilities, such as, a library, nursery school, film club, recreational areas, businesses and others; some of which needed wide available spaces therefore an entire floor or a great section of it was left with no walls.

3. WEAK STORY

This irregularity refers to the existence of a building floor presenting a lower lateral structural resistance than the immediate superior floor or the rest of the floors of the building. The building's weakest part would suffer severe damages due to its inability to withstand the different types of loads (lateral, vertical and moments) produced by the ground motion. Current seismic regulations at the beginning of the 21st Century in most seismic countries, following the parameters initially established in the UBC-88, the recently 2009 NEHRP, and also recent versions of IBC, have included numeric values to the assessment of weak story. As an example, table 12.3-2: *Vertical Structural Irregularities* in the ASCE/SEI 7-10 document, (p. 83) illustrates this irregularity.

Weak story configuration is often generated in hotel and hospital buildings, in which not only the first floor is designed less walls than the other floors, but generally, do to its importance, it also has a greater height than the rest of the floors. Weak story can be generated by: (1) elimination or weakening of seismic resistant components at the first floor; (2) mixed systems: frames and structural walls, with wall interruption at the second floor or at intermediate floors. See Fig. 3.2. This irregularity can also be present at the first floor or at intermediate floors. There are numerous examples of many buildings presenting a combination of these types of irregularities, soft and weak story, making them particularly seismically vulnerable.

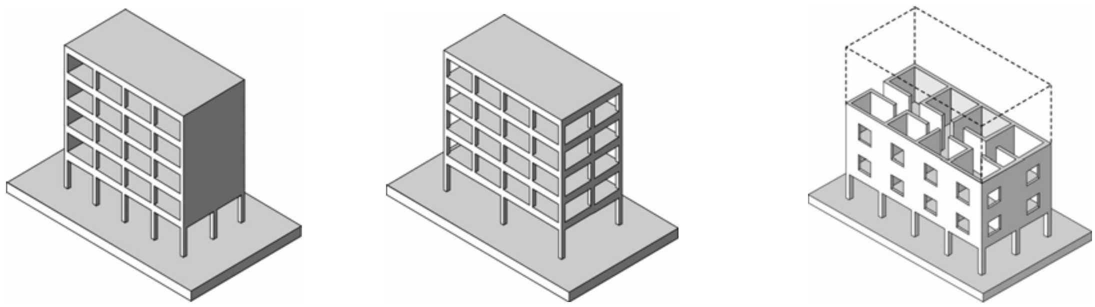

Figure 3.2. Examples of weak first story irregularity.

4. EMBLEMATIC DAMAGED BUILDING EXAMPLES

From the large collection of buildings that had suffered damages due to seismic forces, there are, some of them that have been used as emblematic examples of failure due to the effects of soft story.

The Palace Corvin, in the 1967 Caracas, Venezuela, earthquake is an internationally known historic example of a building in which the evidence of the unfavorable conditions of soft first story was revealed. It consisted of an H-shaped first floor. The two main bodies of the building housed residential apartments and were joined in the middle by the vertical circulation block. In the east wing, the first floor was left open for the parking lot, while apartments were located in the west wing, following the upper floors construction. This later block collapsed. Sozen, M.A., et al (1968, p. 39) refer that “the portion of the building on the east side collapsed completely while the part on the west side survived the earthquake without structural damage. Fig. 4.1 shows the remaining front part of the building and the elevator and staircase core.” They explain that “the reasons behind the widely divergent behaviour of the two portions of the building may be contained in the architectural drawings which show the plan at the ground level. The partition and cladding walls of hollow block masonry were discontinued in the west wing of the structure in order to make room for parking.” See Fig. 4.1.

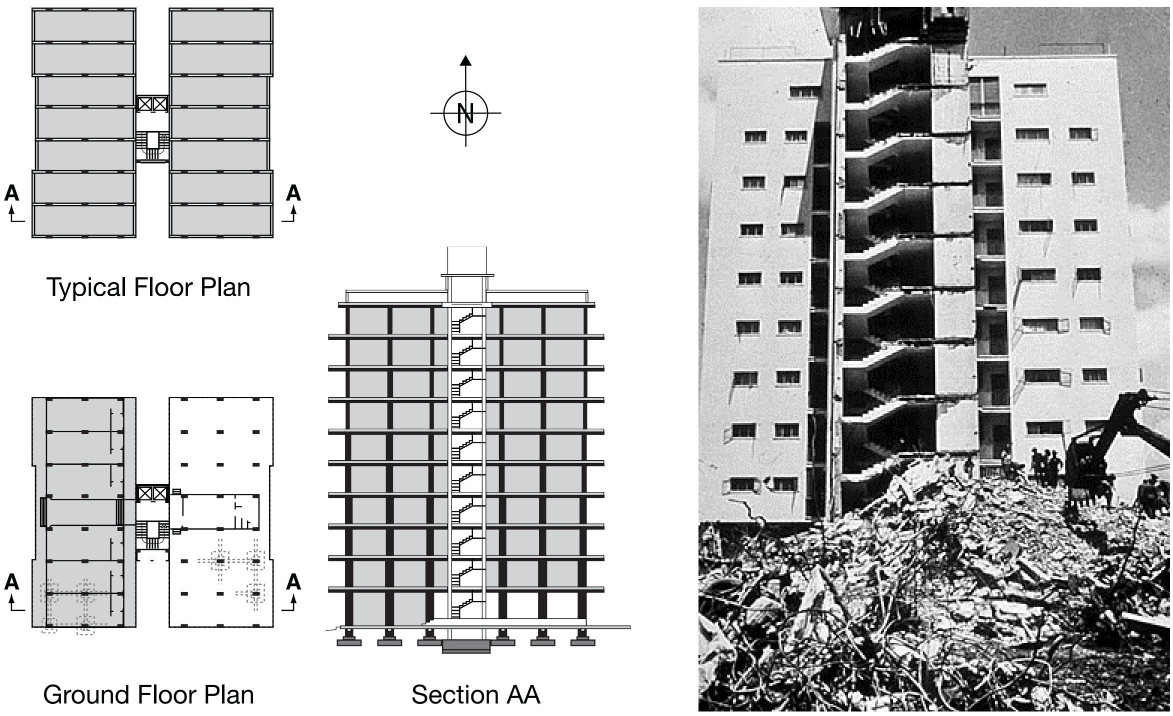

Figure 4.1. Architectural plans of the Palace Corvin building and photo illustrating the west wing that survived the earthquake without collapsing but that had to be demolished (Photo: Vitelmo V. Bertero).

The main building of the Sylmar Olive View hospital in the 1971 San Fernando, California earthquake consisted of four bodies joined around a courtyard, as shown at the structural layout in Fig. 4.2. Each body had six floors and a penthouse. Bertero (1978, p. 114) describes: “The structural system has significant discontinuities. While the upper four stories consisted of shear walls combined with moment-resisting space frames, the lower two stories had only a moment-resisti11'g space frame system. The floor system consisted primarily of a flat slab-column system with drop panels at the columns. Tied and spirally reinforced concrete columns were used. The shape and reinforcement of these columns differed from story to story.” Bertero (1997, Slide J72), explains that the large interstory drift in the main Treatment and Care Unit, which induced significant non-structural and structural damage and which led to the demolishing of the building, was a consequence of the formation of a soft story at the first story level because on the lower floors there were columns, while there were reinforced concrete walls above the second floor level. See Fig. 4.2.

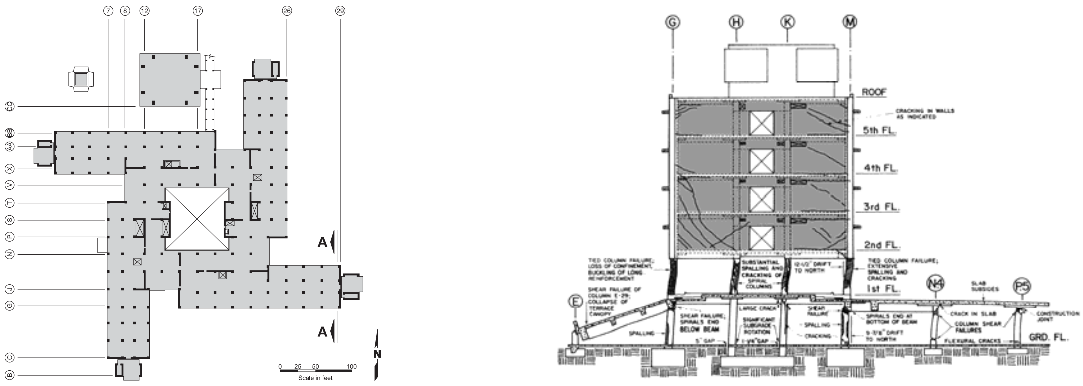

Figure 4.2. First floor layout of the main buildings of the Olive View Hospital and Schematic Diagram (by L. Hashizume, E. Loh) of damage to frame 29.

The Imperial County Services Building in the 1979 Imperial Valley, California earthquake. It consisted of six floors and a penthouse. Bertero (1997, slides J76-J77) mentions: “Lateral resistance of this building was provided by moment- resisting frame in the longitudinal direction (E-W) and shear walls used in transverse direction (N-S). Shear walls in the upper stories were provided for the full width of the building on its east and west faces. At the ground levels, the shear walls in the transverse direction were offset and considerably smaller. Because of the use of spandrel panel walls in the stories above the first, the building response in the E-W direction was that of a soft story. This, together with the discontinuity of the walls at their ends (offset) imposed by the desired architectural configurations, led to severe damage to the first story columns, particularly those located at the east end.” Arnold and Reitherman, (1982, p. 124) explain: “(...) this building suffered a major structural failure, resulting in column fracture and shortening - by compression- at one end (the east) of the building. This origin of this failure lies in the discontinuous shear wall at this end of the building. The entire building was subsequently demolished. The fact that the failure originated in the configuration is made clear by the architectural difference between the east and west ends. The difference in location of the first floor shear walls was sufficient to create a major behavioral difference in response to rotational, or overturning, forces on the large end shear walls.”

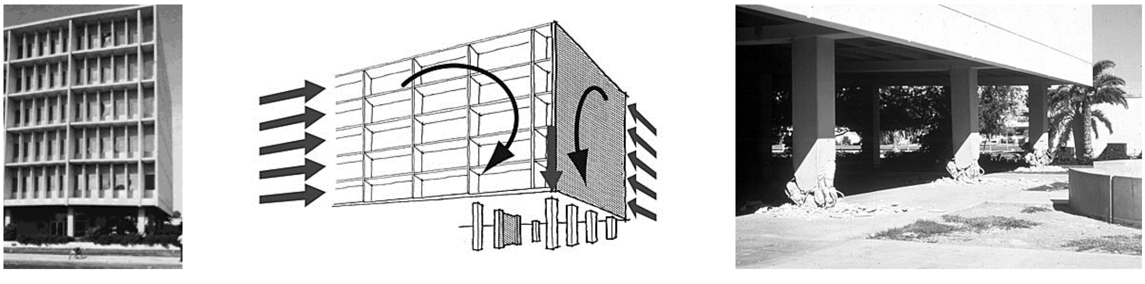

Figure 4.3. Left: corner column; center: Arnold, Ch. (1982) and V. Bertero (1997); right: (Photos: V. Bertero).

5. FINAL REMARKS

The open floor configuration is an architectural design feature that will not be easy to eliminate from architects design criteria. It gives to the designer a series of functional and aesthetic advantages that are encouraged in schools of architecture and urban planning. But, it has been recognized by worldwide specialists in structural engineering, that this architectural configuration leads to the formation of soft and weak story irregularities, when not treated in a special way could produce severe structural damage and even the collapse of buildings when an earthquake occurs.

Arnold and Reitherman (1982, p. 120) recommend:

> When shear walls form the main lateral resistant elements of the building, they may be required to carry very high loads. If these walls do not line up in plan from one floor to the next, the forces created by these loads cannot flow directly down through the walls from roof to foundation, and the consequent indirect load path can result in serious overstressing at the points of discontinuity. Often this discontinuous-shear-wall condition represents a special, but common, case of the weak first story problem. The programmatic requirements for an open first floor result in the elimination of the shear wall at that level, and its replacement by a frame. It must be emphasized that the discontinuous shear wall is a fundamental design contradiction: The purpose of a shear wall is to collect diaphragm loads at each floor and transmit them as directly and efficiently as possible to the foundation. To interrupt this load path is a fundamental error. To interrupt it at its base is a cardinal sin. Thus the discontinuous shear wall which stops at the second floor represents a "worst case" of the weak floor condition.

There exists a discrepancy between urban zoning regulations and seismic codes regarding vulnerable modern building configurations and the causes that originated the international dissemination of architectural and urban planning concepts that generate vulnerability in contemporary cities. Although since 1988 most seismic codes all around the world have included penalties for the use of these irregularities which results in the increase of the design lateral force or shear at the base, that since the beginning of the 21^{st} Century new categories were incorporated for controlling and even forbidding the use of these two types of configuration. meanwhile, UZR of most contemporary cities in seismic areas all around the world, continues to include incentives and in some cases the imposition on the use of the open floor architectural configurations without any limitation or structural restriction, not relating it to the soft and weak story irregularities that have been long recognized by earthquake engineering as seismically vulnerable. As an example of this practice, many paragraphs of the UZR of different modern cities, promote the use of open floors at the first floor as a royalty to the constructor, by stimulating the common practice of projecting buildings with this configuration, without any walls or only those needed for delineating the parking, party halls or other communal spaces (Guevara-Perez, 2012, pp. 241-242). This arrangement as a royalty to the builder, designer or developer, appears in almost every current UZR in contemporary cities. Also in mixed use buildings, shops and residences, located on major road corridors, the UZR usually obliges in mixed use buildings to have a first floor for shops or public activities that is higher than the upper floors, often with no internal partitions, thus allowing the free distribution of shops and other spaces at the lower floor. Another configuration in UZR is the use of *covered sidewalks,* with a single or double height story.

Lessons included in international post-earthquake reconnaissance reports, regarding the influence of architectural features in buildings' seismic performance, such as open floor, barely reach either architectural and city planning practice, or decisions taken by city officials and politicians that continue including this configuration in the design of UZR. There are very few courses in undergraduate and graduate levels in schools of architecture, urban planning and engineering around the world that teach not only conceptual knowledge in the design of earthquake resistant buildings but the transdisciplinary responsibility that these professionals have in the creation or mitigation of the seismic risk in contemporary cities. Most seismic codes that include special considerations for irregular configurations are written in analytical terms for engineers who are specialists in seismic design and difficult to be understood by architects and urban planners. For understanding the influence of architectural configurations on building seismic performance, conceptual knowledge on the effects of mass, stiffness and resistant distribution in buildings is necessary. Earthquakes lessons have taught that is not sufficient for reducing seismic vulnerability of contemporary cities to apply structural engineering oriented building codes in the design of building. The problem has to be untangled with a holistic approach where structural engineers, architects, urban planners, local authorities and community participate, not only in reducing existing vulnerability but avoiding the construction of future seismic risk. It is necessary to study how these precepts were generated in order to obtain interdisciplinary and transdisciplinary groups working together for establishing urban policies and official instruments for avoiding the construction of risk of disaster due to seismically vulnerable buildings. Lessons also teach the necessity of having well prepared and honest building inspectors.

As a final remark, it is necessary to: (a) Strengthening of communication and collaboration between earthquake engineering disciplines (structural engineering, seismology, lifelines engineering, emergency response and social sciences); architectural, urban planning and landscape architecture disciplines; and policy-makers and government authorities. (b) Establishing a common vocabulary of earthquake-resilience terminology across disciplines. (c) Active participation of architects and urban planners in the development of regulations that affect the earthquake-resilience of buildings. (d) Development and implementation of a cross-disciplinary approach in the design of cities, and the consideration of the city as a system where all components are interrelated. (e) Participation of city officials, decision makers and associations of architects and urban planners in controlling the application of seismic concepts in the design, planning and construction processes of the built components of cities. (f) Teaching cross-discipline courses in undergraduate and graduate schools of architecture, city urban planning and structural engineering, including the influence of urban planning and architectural configurations on seismic resilience of cities.

6. RECOMMENDATIONS

If in contemporary cities in seismic zones the widespread use of the architectural configuration of open first floor is unavoidable, the recommendation is to include prescriptions in the UZR as well as the obligation to take measures to avoid at any cost soft and weak story formation on the design of new buildings. Therefore, it is necessary either to prohibit them or to include prescriptions or restriction for designers in UZR, that allow them to reduce the vulnerability of buildings in those seismic hazardous zones that have been already identified as already is being done in California. There are cities such as Alameda, Berkeley, Fremont and Oakland, California (http://enginious-structures.com/pages/softstory.html) that are already including in their UZR some restrictions and in some zones prohibit the use of them. At present, there are many analytical studies available on this regard in the structural engineering field, worldwide. Below, a summary of few solutions given by Guevara, L. T. and M. Paparoni, (1996): (1) When the "soft first story" irregularity is present can be dealt with: (a) using strong and stiff complete elevator and staircase cores, which can take all but the total base shear, leaving the first story columns almost only with axial loads; (b) by using diagonals to stiffen the first story; (c) by specifically designing the first story for much larger loads and smaller induced displacements than the rest of the structure, keeping the overall framed character of the building; (d) by making "transitions" where the "softness" is distributed in several stories (this is very delicate and needs careful tuning). (2) The partial or total destruction of connectivities (beams and/or columns suppressed) at the lower stories, related but not equal to the previous, arises when the architect wants to modify the façade frames only, leaving the inside ones as regular frames, be it with higher apparent story heights, be it by suppressing connectivities at the façade only. There, the situation can be tolerated if the inner frames are complete, regular and sufficiently strong to dampen the local effects of the introduced framing irregularities (they must be at least on a 60% proportion of the total amount of framing.) In a totally framed structure, if we keep the value of the following quotient as constant as possible between successive floors, the effects of the irregularities will be minimized: Total sum of sectional Rigidities of all the columns/Total sum of Floor Shear Rigidity. Solutions based on the use of diagonal members in the soft first stories are feasible. All the foregoing assertions can be considered as reliable under the condition of having very weak walls in the uppers stories, that is, that they will not increase the rigidity of the structural elements. When we go to solid brick walls, or rigid walls, most of these rules are not valid. One influence which in many instances tends to be ignored is the large increase of the member forces in the first stories of buildings due to torsional effects. Besides the dynamic influences, the simple fact that most of the first stories of buildings are designed as if they had built-in columns and theoretically rigid foundations gives rise to very high concentrations of design forces there. In the case of seismic torsion, we have the additional effect of warping, due to the particular nature of most of the framing schemes in current use. When we add to that, sudden changes in rigidities caused by the disappearance of relatively rigid claddings over the soft story level, then large force concentrations appear which can be attributed to torsional effects. It is necessary to avoid abrupt changes.

For existing buildings Bertero (1997, slide text J80) recommends:

> There are many existing buildings in regions of high seismic risk that, because of their structural systems and/or of the interaction with non-structural components, have soft stories with either inadequate shear resistance or inadequate ductility (energy absorption capacity) in the event of being subjected to severe earthquake ground shaking. Hence they need to be retrofitted. Usually the most economical way of retrofitting such a building is by adding proper shear walls or bracing to the soft stories.

In 2010 Mayor Gavin Newsom of San Francisco proposed seismic mandates for retroffiting buildings with soft story buildings in the city. (See http://www.spur.org/book/export/html/1955 and ATC-52-3 Report in http://www.sfcapss.org/PDFs/CAPSS_522.pdf) Figures below illustrate some examples of methods that have been used in San Francisco to retrofitting buildings with first soft story. Fig. 8.1., shows a multistory building that has been retrofitted by adding steel diagonal braces in two of the first story bays; and the recent retrofitting of former Alcoa Building.

Figure 8.1. Left: building in San Francisco (Photo: V. V. Bertero); right: former Alcoa Bldg. in San Francisco.

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