Damage Observed in Chilean Hospitals during the 2010 M_w 8.8 El Maule Earthquake

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ABSTRACT

This paper presents a summary of damages observed in the hospitals of the Chilean public health network during the 2010 M_w 8.8 El Maule earthquake, and the subsequent tsunami. This earthquake affected the most populated areas of the country and 135 hospitals in the public health network. Fifty-six of these hospitals exhibited some type of damage. This work describes the conclusions of the visits made to the affected buildings, the analysis of the damage reports, a description of the reinforcement studies carried out, and the summary of interviews with the staff of several hospitals. From the existing information, the characterization of the buildings that presented damage is carried out, identifying their common characteristics and patterns. A comparison is made of the structural and non-structural seismic performance of buildings structured using reinforced concrete moment-resisting frames and shear walls. Finally, the measures adopted by the Chilean Ministry of Health for the development of new highly complex hospital infrastructure are described. The new measures are oriented to achieve continuity of operation of the critical and strategic health infrastructure.

1 INTRODUCTION

The 2010 earthquake caused damage to 84 out of 135 Hospitals located in the affected area, which represented the loss of service of 4,249 beds out of a total of 19,439 (22%), which had a significant impact on the country's health system and implied a large investment in provisional solutions to meet the needs of the population. This article describes the level of damage to hospital buildings.

2 OBSERVED DAMAGE

The hospital buildings are classified according to their number of stories as: buildings with less than 2 floors; and buildings with 3 to 10 floor levels. Table 1 shows the distribution of buildings according to number of floors.

Following the earthquake, it was observed that, in general, the more rigid structures experienced less damage to structural and non-structural components and systems. After the large amount of damage observed, that resulted in the loss of continuity in the operation of the different Hospitals, measures were taken regarding the requirement of seismic base isolation in all new hospital infrastructure and the application of seismic design of non-structural components and systems, which were in the current standards of the time, but were barely applied in the Hospital infrastructure design.

Table 1: Number of storeys per building

Number of storeys	Number of buildings
10	1
9	0
8	4
7	16
6	13
5	25
4	10
3	33
2	51
1	164
Total	317

2.1 Seismic Performance of hospital buildings with less than two story levels

In the area affected by the February 27, 2010, earthquake, there were a large number of low-complexity hospital buildings, with one and two storey levels, of various types of construction, most of which have structures made up of confined and unconfined masonry. Table 2 shows the types of structural systems observed in the affected hospital buildings.

Table 2: Quantity of buildings per structural system

Structural system	Number of buildings
Adobe	9
Confined masonry	144
Unconfined masonry	8
Steel structures	9
Mixed structure	4
Timber	8
RC moment resistant frames	8
RC shear walls	25
Total	215

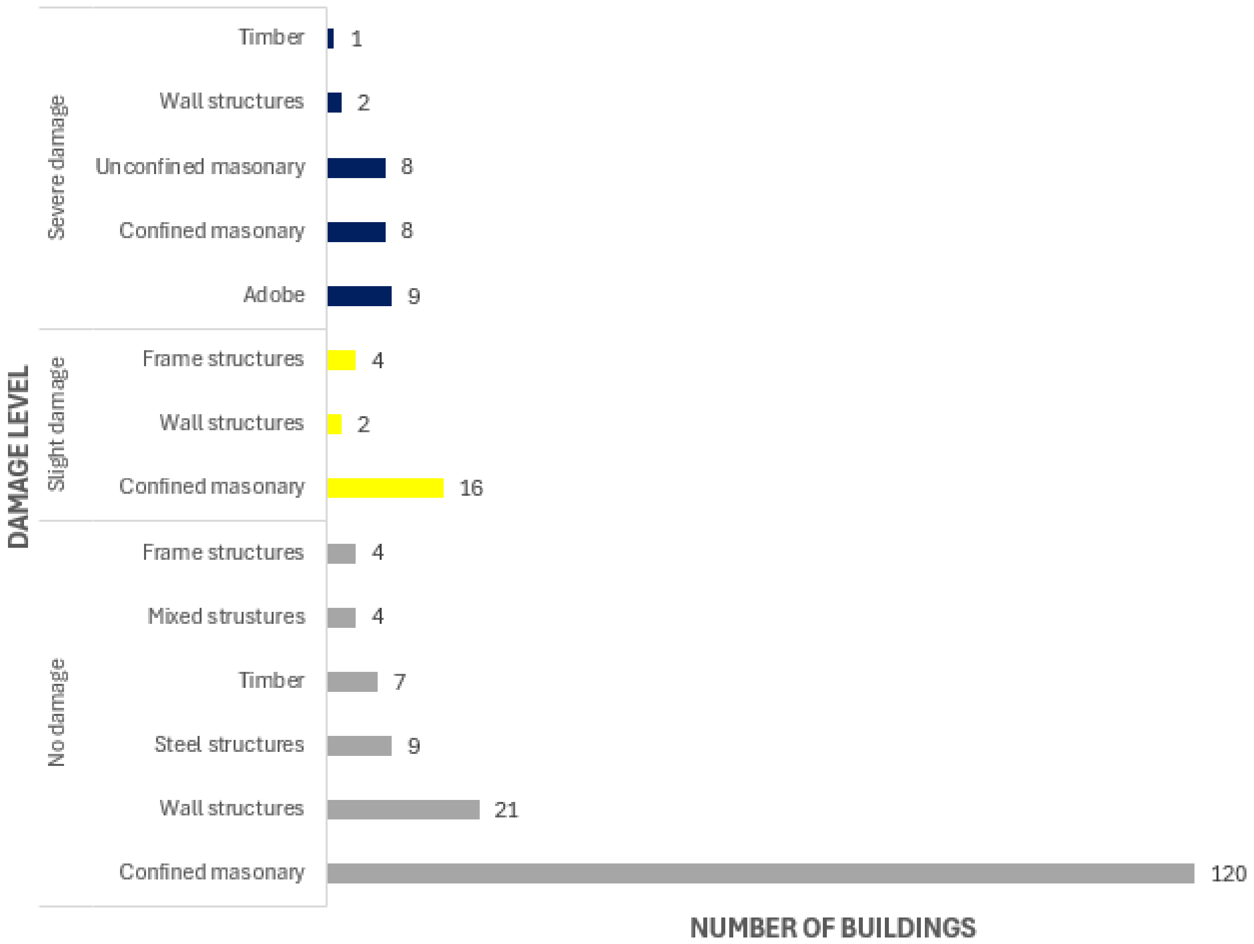
In general, the one- and two-storey level hospital buildings performed well during the earthquake. The most affected buildings were the oldest and the ones with structural systems that do not fulfill design standards, such as adobe and unconfined masonry constructions. It is worth highlighting the good performance of the confined masonry structures in this earthquake and during the seismic events that occurred in 1965, 1971, and 1985.
Figure 1 presents a summary of the level of damage of the buildings under study, these levels are classified as:

No damage: Correspond to those structures where no damage was reported.

Slight damage: Correspond to those structures where some damage was reported. The damage was observed in a few elements, and it does not affect the stability of the structure or the continuity of operation of the building.

Severe damage: Correspond to those structures where a large amount of damage was reported. The damage observed affected the continuity of the building's operations, and they had to be evacuated to be subsequently demolished.

Figure 1: Structural system and observed damage



2.2 Seismic Performance of hospital buildings with three to ten storey levels

This group of buildings includes the most complex hospitals, that contain most beds lost after the earthquake. These Hospitals were built at different times, as shown in Table 3. Table 3 shows the type of material used in the structures. It is observed that the most used material is reinforced concrete.
The comparison of damage was carried out considering reinforced concrete (RC) buildings. RC buildings consist of a mixed structural system, composed of bearing shear walls surrounding stairs and elevator shafts, and frame systems elsewhere.
Regarding the unconfined masonry buildings, they correspond to 7 buildings built in the 1940 decade, with 3 floors belonging to the same Psychiatric Hospital. This psychiatric hospital exhibited severe structural damage, had to be evacuated, and it was disabled until 2022, when the reinforcement works were completed. The confined masonry buildings correspond to two 3-storey buildings from different Hospitals, which had some structural and non-structural damage. These buildings were repaired and nowadays continue providing healthcare services.

Figure 2: Construction year

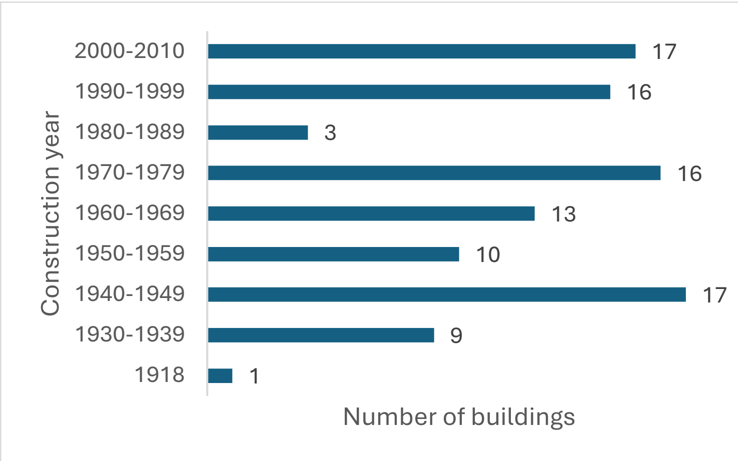


Table 3: Quantity of buildings per structural system

Structural system	Number of buildings
Confined masonry	3
Unconfined masonry	7
Mixed structure	5
RC moment resistant frames	27
RC shear walls	60
Total	102

The structural behavior of reinforced concrete buildings can be observed in Figure 3. In Figure 3 it can be observed that the RC moment resistant frame buildings presented a higher level of damage in comparison to reinforced concrete bearing shear wall systems. The only RC shear wall building that presented severe damage was a 6-storey building that exhibited differential settlements caused by soil liquefaction. Due to the visible resulting inclination, this building had to be evacuated. The repair project consisted of the execution of a new pile system which was estimated complex to be executed and unfeasible from the economic point of view. The building had to be demolished.

The mixed structural systems, composed by shear bearing walls in cores and moment frames in the perimeter, also presented good performance. These buildings consider 3, 5, 6 and 8 floors.

On the other hand, the oldest shear wall building in the registry, consisting of 3 storeys high building built in 1930, and the tallest 10-storey shear wall building built in 1948, did not exhibit any structural damage.

Figure 4 shows the damage observed in non-structural components and systems in terms of the structural system considered.

Figure 3: Structural system and observed damage

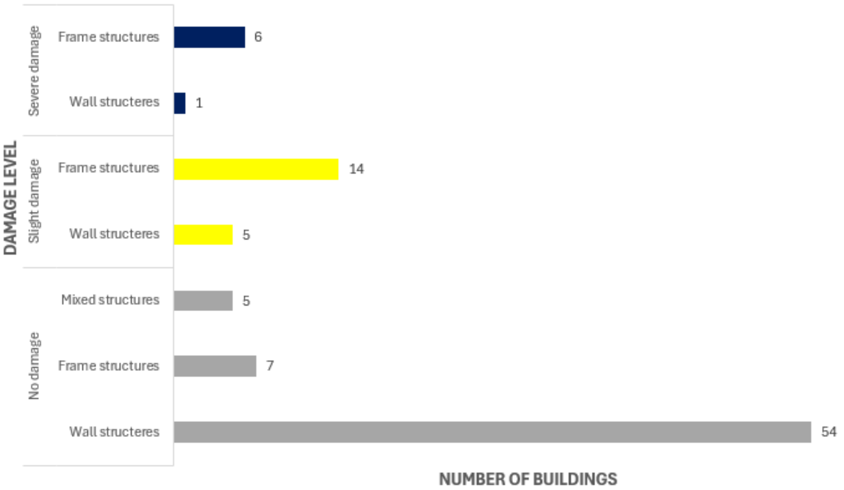
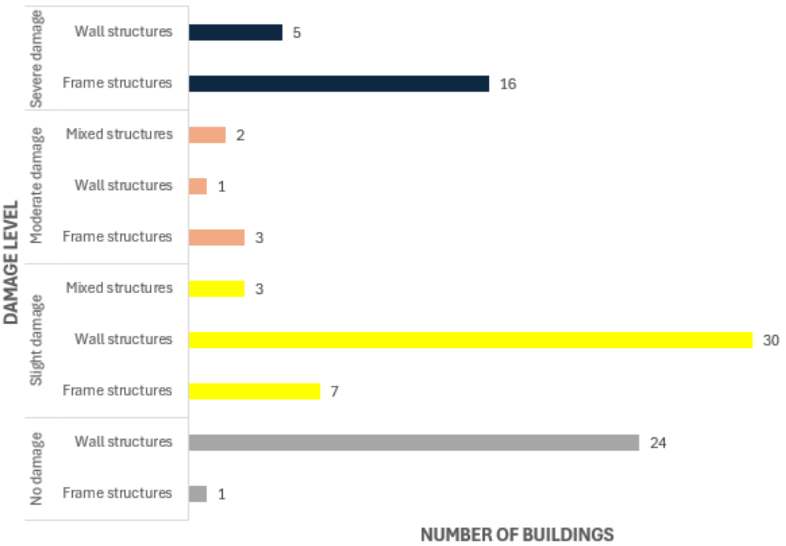


Figure 4: Non-structural damage per structural system type



As in the case of structural damage, moment resistant frame buildings are the ones that exhibited the greatest damage of non-structural components and systems. Sixteen out of 27 RC moment resistant buildings exhibited severe damage and had to be evacuated.
Five hospital buildings with shear wall structural system presented severe damage: In three cases the damage was caused by differential settlements.

It should also be noted that three Hospitals presented severe damage to their non-structural elements during the 1985 earthquake and had to be evacuated. In these three cases, no reinforcements were carried out but only replacement of the damaged elements. In consequence, during the 2010 earthquake, the 3 buildings were evacuated again, one with severe structural damage and had to be demolished. Another building was evacuated and so far, has not been re-occupied. This building is still under study to decide whether to retrofit or not. The third building was re-occupied pending the construction of the new Hospital that will replace it.

3 CONCLUSIONS

The conclusions of the survey carried out are the following:

- For buildings with less than 2 storeys, the confined masonry system has mostly exhibited a good seismic performance at both a structural and non-structural levels.
- Most buildings structured with shear bearing wall systems have experienced good seismic performance, regardless of their time of construction.
- Structures with mixed structural systems have experienced good seismic performances.
- In the decade of the seventies and nineties, seeking greater flexibility in architectural design, the moment resistant frame systems were adopted. Moment resistant systems have exhibited inferior performance in comparison to the shear wall systems, at both structural and non-structural levels.
- Although according to literature wall buildings should exhibit greater accelerations, there is no evidence from the 2010 Chile earthquake that this produces more failures in non-structural elements than in other structures. The main cause of nonstructural damage is the lack of seismic design.
- There is evidence that from previous earthquakes the structures presented failures, however, these were repaired without taking into consideration complete engineering studies to guarantee the rehabilitation or the need for reinforcing the buildings.
- Although wall buildings have experienced good seismic performance, it is necessary to implement seismic isolation systems and perform seismic design of non-structural components and systems to achieve continuity of operation during and after major earthquakes.

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