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Seismic Behaviour Study of Primary Schools in Algarve and Huelva Cities. Case Study of Three Different Building Technologies

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Abstract—**A project named PERSISTAH *(Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva,* in Portuguese*)* is being developed. It aims to cooperatively assess the seismic vulnerability of primary schools of the Algarve (Portugal) and Huelva (Spain). Primary school buildings have been selected due to their low adult/child ratio and the fact that many of these buildings were constructed prior to the current seismic resistant codes. To determine the seismic behaviour of primary schools in both regions, this has been studied with building seismic performance analysis through the capacity-demand spectrum method. One of the main difficulties of the project has to do with the large amount of buildings to analyse. This paper is focused on obtaining and comparing the performance point of different types of buildings and different structural systems (reinforced concrete frames, unreinforced masonry walls and mixed). The goal is to be able to extrapolate the results from the buildings analyzed (type and structural system) to others where the information is not available. Different types and structural systems have been calculated and their seismic behaviours have been compared. The results show that the type and the structural system are outstanding for calculating the performance point and that an acceptable correlation can be inferred from similar types and structural systems. The comparison of the different structural systems for the same typology has shown that for the same shear force, the Reinforced Concrete (RC) frames buildings are able to get deformed significantly more than the Unreinforced Masonry (URM) walls.**

Index Terms— **school vulnerability, seismic risk, reinforced concrete frames, load-bearing walls, capacity spectra, performance point**

I. INTRODUCTION

The Iberian Peninsula (IP) seismic activity is moderate [1]. However, the southern IP is characterised by large earthquakes (Mw≥6) of long-return periods [2], making the population unaware of the hazard. This is due to the convergence between the Eurasian and the African tectonic plates and the proximity to the Gibraltar-Azores fault [3]. According to the earthquake record, it is established that the south of the IP is the most seismic area [4][5].

The Algarve-Huelva region is located in the southwestern IP. It is close to faults that originated some of the most severe earthquakes that have affected the IP, such as the San Vicente Cape and Horseshoe faults. This is the case of the 1755 Lisbon earthquake and tsunami (M_w=8.5) [6] and the 1969 earthquake (M_w=8)[7]. Both earthquakes were originated by the aforementioned faults, respectively. Moreover, the former is the largest documented seismic event to have affected Europe, killing up to 100,000 people [8].

The seismic intensity of this region is between 6 (slightly harmful) and 7 (harmful) in the Medvedev-Sponheuer-Kárník scale (MKS-98) [9]. Despite its significant seismic hazard, the majority of the seismic studies of the IP are focused on the east and the southeastern IP [10]. This has led to a lack of seismic studies for the southwestern area.

Nevertheless, the seismicity of the region has been assessed by proposing new estimation methods, such as the SIRCO [11] or the ERSTA [12] methods. They conclude that it is possible to reduce the seismic risk by improving the prevention and the emergency plans [13]. Moreover, a rigorous vulnerability assessment of the existing buildings and the implementation of appropriate retrofitting solutions can help to reduce the levels of physical damage, losses of life and the economic impact of future seismic events [14].

A project named PERSISTAH (*Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva*, in Portuguese) is being developed in compliance with the Hyogo 2005-2015 [15] and Sendai 2015-2030 [16] agreements. This aims to cooperatively assess the seismic vulnerability of primary schools for both the Algarve and Huelva. Its importance lies in the fact that, in the case of an earthquake, both regions will be affected equally.

Primary school buildings have been selected since they play a key role in creating resilient communities [17] and have a low adult/child ratio. Furthermore, many of these

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buildings were constructed prior to the current seismic resistant codes. Likewise, the typology of these buildings is generally simple and repetitive.

Schools seismic vulnerability has been studied by using predictive data mining models [18] and performing probabilistic [19] and macroseismic [20][21] analyses in order to obtain their fragility curves. However, none of these research works performs an exhaustive assessment of the seismic behaviour of schools, either in this region or of this variety of buildings typologies.

One of the main difficulties of the project has to do with the large amount of buildings to analyse: a total of 276 different primary schools have been identified for both regions and more than 400 buildings. Moreover, the information is extremely disperse and incomplete.

The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to an earthquake scenario [22]. Therefore, several studies after performing the seismic behaviour analysis of an individual building have found that buildings belonging to the same typology differ slightly from each other [23]. Furthermore, structures belonging to the same type and built in the same period may share similar geometrical and spatial characteristics [24].

So, this paper is focused on obtaining and comparing the capacity curves and the performance points of different types of buildings and different structural systems (reinforced concrete –RC- frames, unreinforced masonry –URM- walls and mixed). Different types and structural systems have been calculated and their seismic behaviours have been compared. The buildings' seismic behaviours have been studied by several authors. The RC frames and the URM walls buildings have been analyzed in [25][26][27][28] and in [29][27][30][31], respectively. Mixed buildings have been reviewed in [27][32].

The goal is to be able to extrapolate the results from the buildings analyzed (type and structural system) to others where the information is not available. This paper shows the first step for that goal.

The rest of the paper is structured as follows. In Section 2, the methodology used to obtain the performance point is described. Also, the buildings analyzed are presented. In Section 3, the results are shown. Next, the analysis of the results is reported. Finally, the conclusions are summarised.

II. METHODOLOGY

The seismic collapse capacity of building structures has been studied worldwide and there are many types of analysis as shown in [25]. In this research, the building seismic performance has been analyzed through the capacity-demand spectrum method [26]. This is established as the most efficient methodology to describe the seismic performance of structures [33]. In order to perform this method, it is necessary to get the buildings' response spectra and the schools' capacity curves.

The buildings capacity curves have been obtained from a nonlinear pushover analysis (POA) in the two orthogonal directions of the buildings with different software. Although dynamic analyses are more accurate, they require higher amounts of computational effort, data and time than static procedures [34]. Therefore, POA has been selected since it is more appropriate considering the project's scale and main goal.

The response spectra have come from the Eurocode-8 (EC-8) [35]. The basic acceleration for Spain has been selected from the Spanish code (NCSE-02) [5][36]. The conversion to the Acceleration Displacement Response Spectrum (ADRS) format has been performed according to the ATC-40 method [37], whereas the buildings' performance points have been calculated with the N2 method [38], as indicated in [39].

Three schools corresponding to three different building typologies have been selected. These typologies represent some of the most repetitive school types of the Algarve and Huelva. These buildings have been chosen because each of them has a different structural system (RC frames, URM walls and mixed) and in order to achieve the seismic behaviour of each one. Furthermore, to study the differences between the three structural systems selected, the structural system of the buildings has also been transformed into the other systems. Therefore, three performance points have been acquired for each building according to each structural system. In total, nine performance points have been determined.

According to the EC-8 [35], there are five types of soils, whose values affect the response spectrum. In this research, the type of soil has been obtained from the building project -when available- or from geotechnical studies performed in the area nearby. According to these studies, there is soft soil for the three buildings, which corresponds with the type of soil D in the EC-8. The a_{gR} (reference peak ground acceleration on type A ground) has been achieved according to the a_b (basic acceleration) from the Spanish code NCSE-02 [5][36]. The response spectrum is shown in Fig. 1.

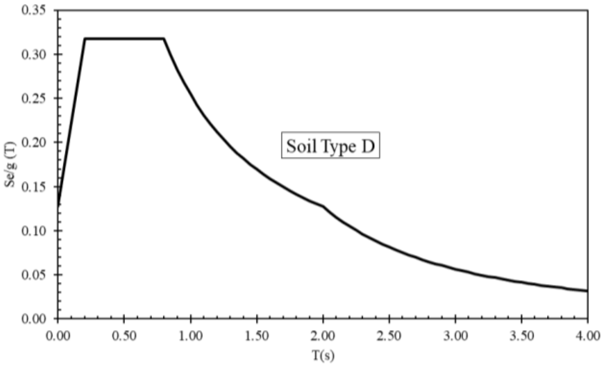


Figure 1. Type 1 elastic response spectra for type of soil D according to the EC-8 (5% damping). S_e/g is the elastic response spectrum and T is de frequency in seconds.

Primary schools data (building plans and characteristics) have been obtained from the building projects located in the Local Archives by compiling their structural and constructive characteristics. The value of the structural parameters have come from the schools data -if available- the review of the literature [29] and the codes: the Spanish Building Code (CTE) [40], the Spanish Reinforced Concrete Standard (EHE-08) [41] and the EC-8 [35]. The structural characteristics used in the calculation are shown in Table I.

TABLE I. PARAMETERS USED IN THE CALCULATION *CONCRETE (H-175 CORRESPONDS TO C16/20 REINFORCED CONCRETE ACCORDING TO EUROCODE-2 [42]) **REBAR STEEL (AEH-400 CORRESPONDS TO B400S ACCORDING TO THE CURRENT SPANISH CODE) ***EXPECTED YIELD AND TENSILE STRESS DEPEND ON THE STANDARD COEFFICIENTS.

Parameters	Material		
	H-175*	AEH-400**	Masonry
Specific weight (kN/m^3)	24.51	76.47	18
Modulus of Elasticity (MPa)	25,018	200,000	5,000
Compressive Strength (MPa)	17.5	-	5
Shear Strength (MPa)	-	-	0.20
Shear Modulus (G) (MPa)	10,424	-	2000
Minimum Yield Stress (F_y) (MPa)***	-	420	-

RC frames 3D models assessment has been carried out with SAP2000 v.19 software [43]. The URM walls and the mixed structures 3D models have been calculated with TreMuri [44]. The RC elements' nonlinear behaviour has been simulated by introducing default plastic hinges according to the ASCE-41-13 [45] at the ends of both beams and in columns as in [27][35]. Similarly to [24], plastic hinges have been introduced in columns for the PM2M3 direction and shear/moment failure. Plastic hinges for beams have been introduced in the M3 direction. Likewise, the rigid diaphragm effect of slabs has been considered, similarly to [30].

The RC frames' behaviour improves if the contribution of the infill walls is considered, as pointed out in [28]. In this case, similarly to [27], this has not been considered, producing conservative results. The URM walls' simulation has been performed according to the equivalent frame method [32], which is implemented in TreMuri [44].

Gravity loads have been obtained from the real available building data, the Spanish CTE [40] and the EC-8 [35]. Their values are listed in Table II.

TABLE II. GRAVITY LOADS

Type of load	Constructive element	Value
Dead loads	Concrete ribbed slabs	4.3 kN/m^2
	Non-structural walls	1 kN/m^2
	Gable roof of roof tiles	3 kN/m^2
	Flat roof (non-accessible)	2.5 kN/m^2
	Envelope walls	8.2 kN/m
Live loads	Public use	3 kN/m^2
	Roof maintenance	1 kN/m^2

A. Building Type A (O-Shape)

This compact building was constructed in 1988 (Fig. 2). It is a three-story reinforced concrete building that has an O-shape plan. It is based on a double symmetry design with two parallel strips and a central yard. It has ribbed floor slabs. The foundation was built with on-site piles. The classrooms are located in the outer part of the bays whereas the corridors are situated in the inner part.

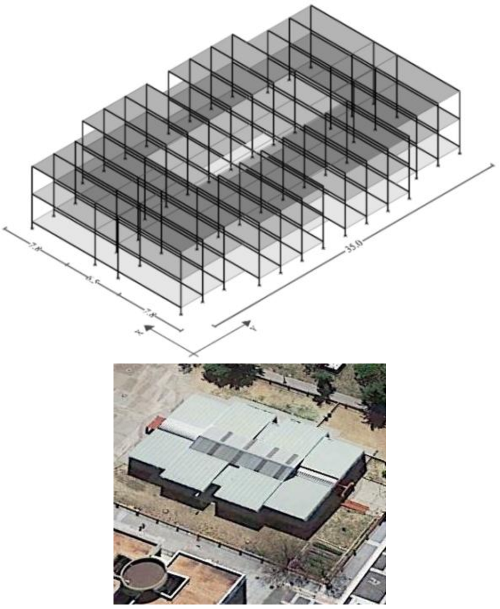


Figure 2. Building type A (O-shape): RC frames structural system (dimensions in meters).

B. Building Type B (L-Shape).

The structural system of this building consists of URM walls (Fig. 3). It was built in 1969 and it has two storeys. The building has an L-shape and a lineal geometry. Each side of the building is characterised by a similar order: a classrooms line and an entrance gallery. Common spaces, such as the staircases, are located in the intersection of each wing. The 25 cm wide structural walls are composed of clay brick and mortar, while the floor structure is of ribbed floor slabs. The foundation is made of concrete on strip footings.

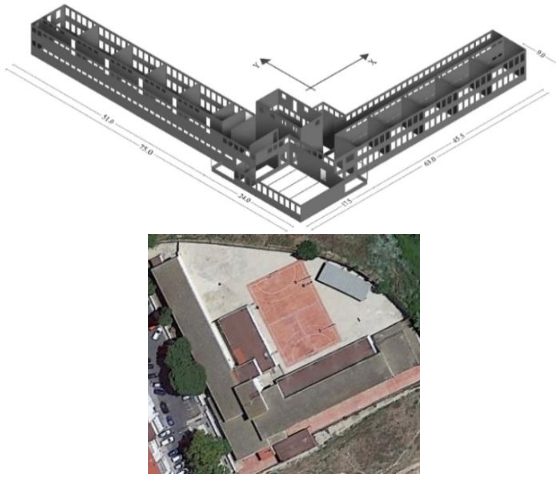


Figure 3. Building type B (L-shape): URM walls structural system (dimensions in meters).

C. Building Type C (irregular Shape).

This building is characterised by its mixed structural system (both RC frames and URM walls). It has two storeys and was built in 1969 (Fig. 4). It has an irregular plan due to the intersection of three lineal blocks. Two of them contain classrooms, similarly to building B (classrooms and an entrance gallery), while common spaces are located in the third block with steel trusses. The structure is complex. The classroom blocks are built with masonry columns and RC beams. However, the structure of the common spaces block is composed of RC columns and steel trusses. The columns and the walls foundation are constructed with isolated and strip RC footings, respectively.

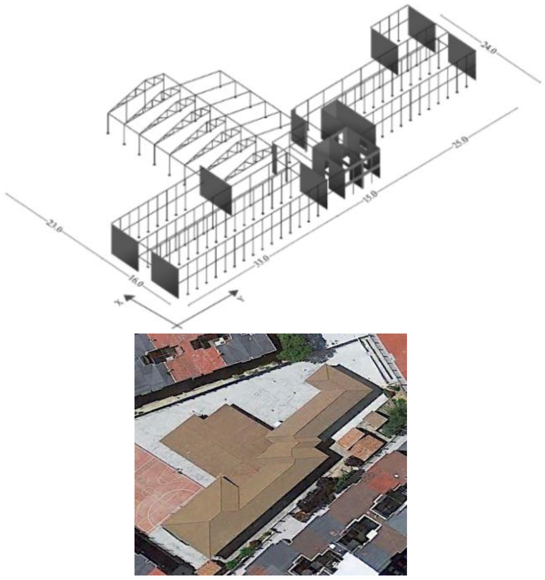


Figure 4. Building type C (irregular shape): mixed structural system (dimensions in meters).

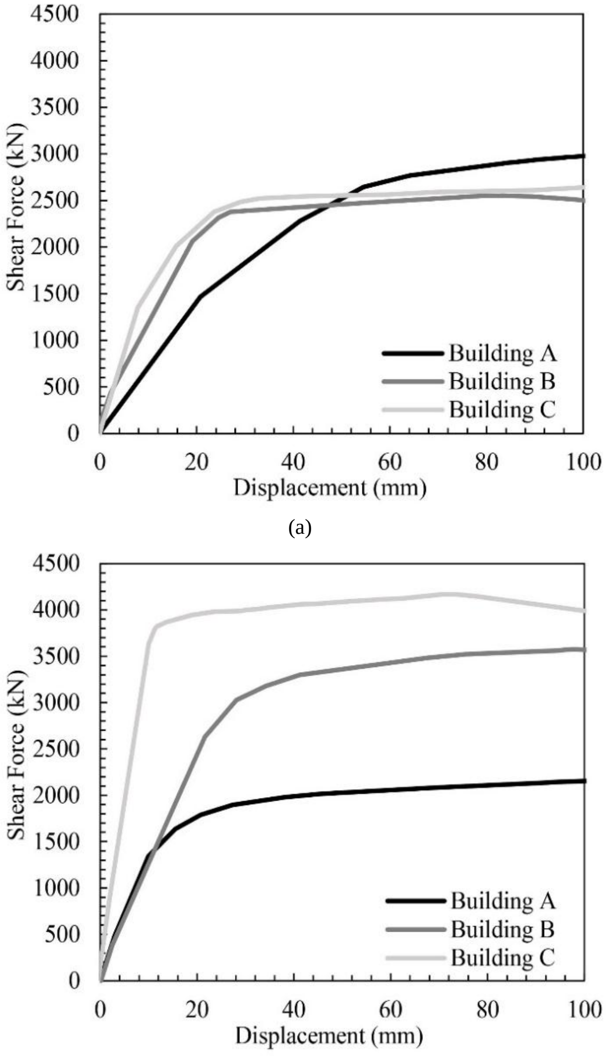
III. RESULTS

The capacity curves for each building in both directions have been obtained. Later, for comparison purposes, the capacity curves of the building considering the other structural systems have been determined (Fig. 5-7). Finally, the performance points (Table 3) have been obtained intersecting the response spectrum (Fig. 1) and the capacity curves (Fig. 5-7), both in spectral coordinates, according to the ATC-40 [37] and the N2 [38] methods.

Building A, RC frames. There is a significant difference in the curves for each direction. The building presents a higher capacity in the loading portico direction (X), for higher displacements. Likewise, the X-direction curve presents a significant range of elastic behaviour in terms of smaller displacement. When considering the URM and the mixed capacity curves, it can be observed that the difference in both directions is significantly higher than for the RC frames.

Building B, URM walls. The capacity curves for both directions are very similar for the three structural systems analyzed.

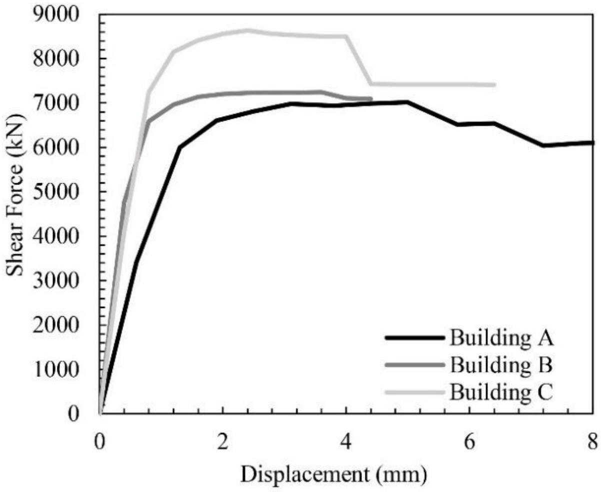
Building C, mixed. There is a significant difference in the capacity curves for both directions. The building presents a higher capacity in the X-direction. When considering the URM system, the results are similar. Nevertheless, in the case of RC frames, the higher capacity is obtained in the Y-direction.



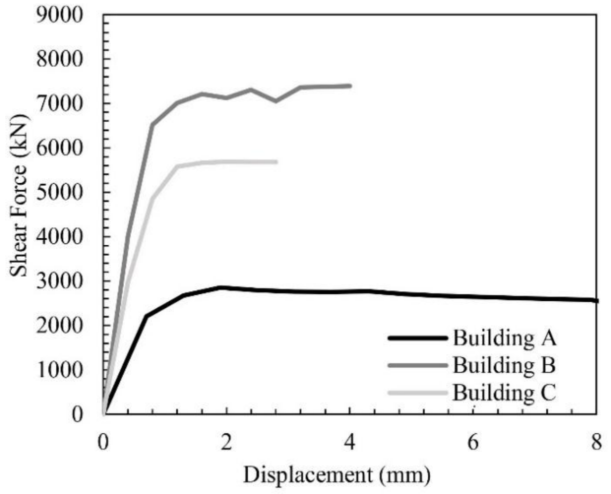
(a)

(b)

Figure 5. RC frames buildings capacity curves obtained for each orthogonal direction. (a) X direction; (b) Y direction.

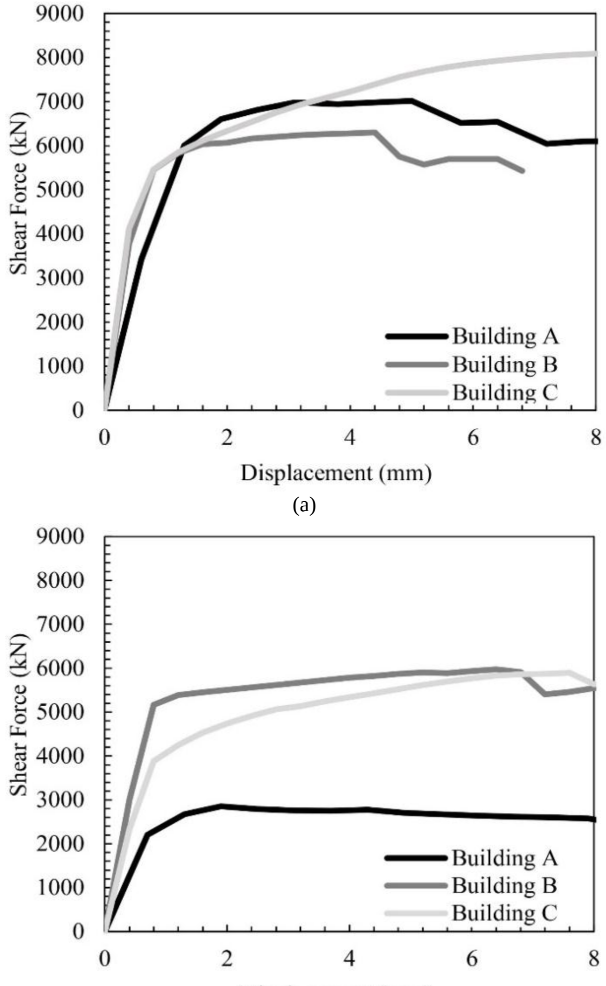


(a)



(b)

Figure 6. URM buildings capacity curves obtained for each orthogonal direction. (a) X direction; (b) Y direction.



(a)

(b)

Figure 7. Mixed buildings capacity curves obtained for each orthogonal direction. (a) X direction; (b) Y direction.

The URM walls and the mixed structures capacity curves are in agreement with those obtained by [31], where the authors studied two school buildings with URM walls in Italy. For the case of RC frames, the capacity curves are similar to that obtained by [24]. These authors studied several Italian school buildings of two/three-storeys.

By contrast, it can be observed that the performance point obtained for the RC frames rates between 29 and 58 mm. For the URM walls, it ranges between 0.5 and 0.8 mm. This result is similar for the mixed structures except for the building type C.

TABLE III. TYPE SIZES FOR CAMERA-READY PAPERS

Schools	Structural System					
	RC frames (mm)		URM walls (mm)		Mixed (mm)	
	X	Y	X	Y	X	Y
Building type A	58	56	0.5	0.8	0.5	0.8
Building type B	35	29	0.6	0.7	0.5	0.7
Building type C	53	37	0.5	0.7	1.3	3.4

IV. ANALYSIS OF THE RESULTS

Building A presents a higher capacity in the X-direction, where the number of columns is four compared to the Y-direction, which has 14 columns. This could be due to fact that the short direction is the direction of the loads. Moreover, this is also where the main beams are located.

The results of building B have shown a great similarity in both directions owing to the building geometry. Both building wings are of similar length and the walls distribution is symmetrical. Therefore, they have the same stiffness and the same shear-force capacity in both directions.

Building C presents the most irregular behaviour. The performance point is much larger than in the other buildings for the same structural system. This is due to the use of numerous clay brick pillars which causes a weakness of the structure, especially in the Y-direction. In this direction, the building is larger. Yet, there are few URM walls and stiffness should be provided by the brick pillars that are not rigid. Building C, which has an irregular geometry and various structural systems, shows the worst seismic structural behaviour.

The behaviour of building C improves notably when changing the structure to URM walls. In this case, the performance point is significantly reduced. It also improves when changing to RC frames. In this case, in the Y-direction there are many close columns, which results in a higher capacity curve. Contrariwise, the behaviour of building A is much worse in the case of URM walls. It shows very different capacity curves for both directions in spite of its compactness and regularity. It can be observed that its capacity is worse in the Y-direction. This is due to the loss of stiffness that the columns give.

V. CONCLUSIONS

The comparison of the different structural systems for the same typology has shown that for the same shear force, the RC frames buildings are able to get deformed significantly more than the URM walls. This is due to the plasticity of the reinforced concrete compared to the non-plasticity of the URM walls. It has been observed that the behaviour of the mixed buildings is very similar to the URM walls buildings, even when there are few URM walls owing to the existence of brick pillars. This can be due to the rigid predominant behaviour of the URM walls.

It can be observed that for the RC frames buildings, all the buildings have a higher capacity in the direction of the load bearing portico than in the tied direction.

The buildings with structural and geometrical symmetry have shown a very similar behaviour in both directions. By contrast, irregular buildings present very dissimilar results. The authors have also observed that the structural system (type and loading direction) is predominant to the geometry of the building.

Finally, it should be noted that this study has been done with buildings of few storeys where horizontality is predominant.

It has been shown that there are significant differences depending on the typology and on the structural system. Therefore, to extrapolate the results from a well-known building to others where the data is incomplete there must be both very similar structural and geometrical characteristics.

This analysis has been performed with real data (structural, constructive and geometrical parameters) of various real school typologies. Therefore, its reliability is high since, as mentioned before, no metrics except the material properties have been estimated. These results will be used for the classification of the buildings' vulnerability in order to retrofit the cases that present the worst seismic behaviour. In future analyses, the number of buildings and typologies will be increased to establish a representative capacity curve for each building typology.

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