Seismic structural performance of concrete blocks with steel and aluminum alloy fiber aggregates for building construction

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ABSTRACT

Concrete is a highly versatile construction material thanks to its behavior and mechanical properties. However, little is known about improving its properties through including additives in its manufacture. Concrete also has drawbacks, such as brittleness, low ductility and poor flexural strength. This material is used in many parts of the structures and may be manufactured on site or prefabricated, e.g. in the form of blocks. Including steel and aluminum alloy fibers in concrete would improve the ductility and flexural strength. This study analyzed and compared the mechanical behavior of normal concrete blocks with others made with aggregates of steel and aluminum alloy fibers. Mechanical lab tests were carried out on blocks with five, four and three layers of fibers, taking into account the requirements of the Chilean Regulations.

Keywords: *seismic performance; fibers; ductility; blocks; concrete; aluminum.*

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1. INTRODUCTION

The budget in construction industry has become one of the main problems in society over the years. Currently, the increase in knowledge due to the improvements of construction technologies and techniques has made society more demanding as regards the investment in housing. This problem has become widespread, not only at a constructive level but at a social level in areas such as: schools, homes, buildings, bridges, tunnels, among others.
The use of concrete in the Chilean construction industry is notable, where 52.9% of the existing structures are made with this material. This preference is due to its high resistance, its durability over time and its moldability and being an easy-to-use material.
The desire to improve the behavior and properties of this material (s. XIX) has led to numerous studies and investigations. For this reason, the introduction of additives in its manufacture has increased in the last decade. Fibers are among the elements most commonly incorporated in the mix (carbon fibers, glass fibers, aluminum fibers, among others) in an attempt to improve some its properties, such as its resistance, its deformation or shrinkage.
One of the biggest problems that has not been treated in depth is the shrinkage that generates damages such as fissures or cracks, due to fragile concrete properties. Incorporating aluminum in the concrete dosage can be one of the solutions. It is mainly used for its low weight, corrosion resistance and ductility; however, its use is not widespread due to its high cost.
Including large amounts of this material in construction is thus not feasible due to its high cost. However, even small amounts of steel and aluminum alloy fibers in hollow concrete blocks improve the deficient properties of the concrete without excessively increasing construction costs. Since adding these fibers when manufacturing concrete blocks can improve seismic performance, the present paper studies the enhancement of the seismic response of buildings using concrete block walls where the concrete in the blocks is mixed with steel and aluminum fibers coming from recycled metal sponges as the ones used when cleaning dishes in any home, so contributing to sustainability, reducing costs and providing a second alternative use for this product in building construction.

2. BACKGROUND

The use of walls in frame buildings has been one of the most widely used solutions to improve structural capacities [1-2] in the world of construction.
The materials mostly used in walls and in construction in general are concrete, cement and clay, elements that have demonstrated their effectiveness and efficiency in buildings. These materials are manufactured directly on site or are brought directly from the factory as precast elements and can be found in greater or lesser sizes, depending on the construction element to be built.
For example, walls or partitions can be totally precast or made manually with smaller elements such as blocks or bricks.
Brick or concrete blocks with thicknesses between 15 - 30 cm have been widely used due to their functionality, good structural behavior and speed of execution in construction [3].
However, there are deficiencies in some properties of these elements and in the material itself, such as its seismic resistance behavior, flexural-tensile stresses or shrinkage in certain climatic conditions [4]. Due to this, several researchers have studied the influence of additives on these elements, in order to improve the thermal [5,6], acoustic [7] and mechanical [8] properties, among others. Among the added materials is the addition of metal or polypropylene fibers to the mixture, increasing the load capacity [9-11], resistance to shear or ductility properties [12]. Wood is also one of the materials used in additives to improve deficient properties in cement or concrete, and has interesting properties from the seismic point of view [25–27], with good flexural and compressive strengths [28], low thermal [29], acoustic [30], and electrical conductivities [31], providing interesting seismic properties to blocks and walls [69]. From the environmental point of view [damage caused by the extraction of raw materials and/or CO_2 emissions], some mixtures have considered the addition of volcanic ash [13], wood [14], or recycled concrete [15 –17], among others.
It has been shown that the contribution of walls in the seismic behavior of low-height frame buildings can be beneficial [18], so improving their seismic performance using aggregates would result in better response. However, this cannot be said for medium and high-rise buildings, due to the great rigidity and weight that these elements provide to the structures. To solve these problems, these elements have been replaced in high-rise buildings by more complex ones that do not depend on these characteristics; dissipators [19], braced frames [20], base isolators [21], among others. Although these elements have shown good performance, the complexity, cost and training required for their placement has been affected by their massive use in structures.
For this reason, traditional walls continue to be the most widely used solution in construction [22], with the introduction of a large amount of steel to modify the ductile characteristics of this solution, as specified in some earthquake regulations [23-24] on medium and highly ductile walls. The aim of this work is, thus, to contribute to the study of aggregates to improve the structural characteristics of concrete blocks and walls for buildings in seismic areas using moderate amounts of steel and aluminum at a reasonable cost in the form of recycled fibers to promote sustainability.

3. MATERIALS AND METHODS USED

3.1. Considerations and Previous Calculations

The additive dosage in concrete mixes determines their final properties (for example, resistance, ductility or workability). The specifications of the Chilean Standard for the manufacture of concrete and aggregates were followed to make the blocks [32, 33]. This Regulation is in line with most European or American countries. The Chilean standard proposes carrying out different granulometry tests for fine and coarse aggregates to determine properties such as density and water absorption. Table 1 shows the values of some properties of the concrete samples made in the laboratory of the University of Talca (Chile).

Table 1. Properties of a sample type of concrete manufactured for the study.

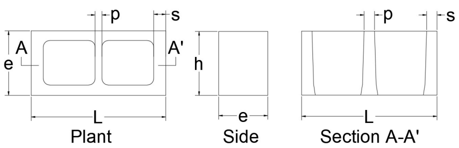
Property	Fine Aggregate	Coarse Aggregate
Real density of dry saturated surface aggregate [kg/m^3]	2591.20	2628.46
Net density [kg/m^3]	2745.61	2716.68
Water absorption [%]	2.17	1.23

Both ordinary blocks and blocks containing a certain percentage of aluminum and steel alloy fibers were considered.

3.2. Manufacture of the blocks

The Chilean standards specify the water, cement, gravel and sand proportions for the preparation of one m^3 of concrete, as well as the appropriate dimensions for structural use [34]. The dimensions of the blocks are shown in Figure 1 and the values appear in Table 2, meeting the requirements established by Standard NCh181 [34] for a 190 mm block, suitable for structural use.

Figure 1. Block dimensions [69]



The blocks were labeled with two letters and a number: BO0 indicated ordinary blocks and BA "n" those with steel and aluminum alloy, where "n" is the number of layers added to the composition of the blocks.

Table 2. Dimensions of the blocks tested

Block	Width [mm]	High [mm]	Length [L] [mm]	[p] [mm]	[s] [mm]	Weight [N]
BO0	191.03	188.33	390.25	25.94	32.76	159.59
BA3	190.51	189.25	389.32	26.01	32.63	149.93
BA4	190.83	190.02	390.32	25.92	32.82	146.74
BA5	191.05	189.21	189.75	25.89	32.68	143.55

The Chilean standards NCh1019 [35] and NCh1037 [36] were also considered to make the block samples. The mixes replaced part of the gravel with steel and aluminum alloy fibers. The concentrations were according to the number of layers or rows of a certain thickness. Figure 2 shows the type of fibers used in the different concrete layers. This type of fiber comes from the reuse of metal sponges widely used in dish cleaning in any home. In this way, extra life and second use is achieved for this material contributing to a more sustainable construction. As commented in Section 1, the choice of these metallic aggregates has been taken in order to improve the ductile behavior of the blocks and, therefore, of the walls made with these elements, enhancing the structural behavior of the buildings.

Figure 2. Aluminum and steel alloy fibers used in mixtures.

These recycled fibers from metal dish cleaning sponges are made up of 76.16% iron, 5.13% aluminum, 9.22% silica, 0.145% chromium, 0.075% zinc, 0.573% copper, 0.041% arsenic and 0.811% manganese.

The fibers were introduced as the concrete was vibrated in layers of 2 to 4 millimeters, which are the standard size values provided in the technical specifications for the sponges. This procedure was repeated "n times" depending on the number of layers introduced [from 3 to 5].

It should be noted that the alloy fibers reduced mix density. Since seismic actions induce inertial forces that are proportional to the mass of the building, reducing the weight of the structures will improve anti-seismic behavior under the same structural conditions.

Water absorption and the distance between particles in the material will vary the density when the water evaporates. As the water absorption in mixtures with these fibers was higher, they resulted in lighter concretes. This explains the volumetric expansion observed in the concrete.

Table 3 shows the percentage amounts of the materials used for each dosage per m^3 of concrete and their final densities. The mixtures were initially made for a classification of medium weight (1680 - 2000 kg/m^3).

The blocks were poured into a metal formwork and the mixture was left to rest for a few minutes to achieve a homogeneous texture. Pouring was in layers (between three and five, depending on the number of fiber layers) and the mixtures were vibrated. Hours later, the blocks were removed from the mold and immersed in water for 28 days for curing and subsequent homogeneous drying, after which mechanical strength tests were performed (Figure 3).

Figure 3. Hydraulic machines used (left. Compression, right. flexural strength) [69]

Table 3. Dosage used in the manufacture of concrete blocks.

Material	BO0	BA3	BA4	BA5
Water [%]	8.08	8.08	8.08	8.08
Cement [%]	18.33	18.33	18.33	18.33
Gravel [%]	33.96	33.82	33.77	33.72
Sand [%]	39.63	39.63	39.63	39.63
Additive [%]	-	0.14	0.19	0.24
Concrete density [kg/m^3]	1701	1598 (-6.1%)	1564 (-8.1%)	1530 (-10%)

4. MECHANICAL CHARACTERIZATION OF CONCRETE BLOCKS.

Five samples of each type of block described in Table 3 were made. The results shown in Table 3 are the average of the 5 samples tested in the laboratory of the Engineering Faculty of the University of Talca (Chile).
In the compression and flexural strength tests the requirements of the Chilean code NCh 181 were followed [34]. The results of each test were represented by the capacity curves according to displacement, compression load and flexural strength.
For the compression tests, a uniform load distribution was applied to the upper surface of the block. A layer of plastic mortar 3 mm thick and a 1 cm metal plate was added to both surfaces to avoid measurement errors caused by possible irregularities.
For the bending tests, the center of the blocks was marked out together with two other points 7.5 cm from the center. These were the support points at which the loads were applied (Figure 3, right).
All the mechanical results obtained for blocks with aggregates (BA3, BA4, BA5) have been compared to the traditional blocks (BO0) without any type of aggregate, using the same dosage for their manufacture as the industrial blocks used in buildings. In this way, the results shown in tables relative to the blocks with recycled metallic additives will have in parentheses a percentage (higher or lower) related to the results of the traditional blocks. The steel and aluminum additives modified the compression strength, flexural strength, ductility and stiffness in the blocks in a way closely related to the amount of fibers, with magnitude as shown in Tables 4, 5 and 6.

4.1. Compressive and Flexural strength tests

The compression tests were carried out at 28 days according to the conditions stipulated by the Chilean standard NCh 181. All the geometrical dimensions and the average values are shown in Table 2. The blocks were positioned so that the hydraulic jack applied a uniform compressive load on the upper surface.
Table 4 shows the average results of the 5 samples. As expected, the samples without aggregates had the highest compressive strength. The blocks lose resistance as more fibers are added. The results of the 5-layer of fibers were discarded for structural use due to their low resistance and not meeting the minimum 12 MPa limit established by the Regulation [35].
Prior to testing, the 3 sample blocks were measured, plotted and weighed. Table 4 shows the average results for compressive and flexural strength tests carried out on the blocks.

Table 4. Average compressive (1st data row) and flexural (2nd data row) strength of the blocks 28 days after their elaboration.

BO0 [MPa]	BA3 [MPa]	BA4 [MPa]	BA5 [MPa]
15.25	13.79 (-9.6%)	12.02 (-21.2%)	10.08 (-33.9%)
3.19	3.52 (+10.3%)	3.85 (+20.7%)	4.08 (+27.9%)

4.2. Capacity curves and ductility

Figure 4 shows the compression capacity curves [force-displacement] of concrete blocks obtained according to the Chilean standard NCh 1037 [36] 28 days after their manufacture. The results obtained were under a constant load of 0.25 MPa/s ± 0.05 MPa/s until failure.
The BA5 blocks were not considered because they did not meet the minimum resistance required by the NCh181 Standard. The BO0 blocks had 9.6% and 21.2% higher compressive strength than the BA3 and BA4 blocks, respectively, and 33.9% higher than BA5. Their ductilities increased significantly with the addition of aluminum and steel alloy fibers, as shown in Table 5.

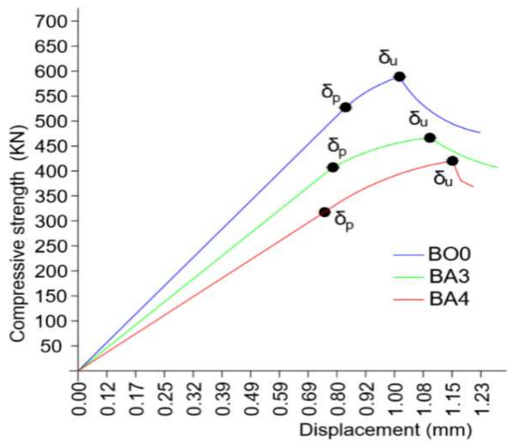


Figure 4. Average resistance of BO0, BA3 and BA4.

Reduced stiffness of the block can be seen in the elastic zone of the capacity curve in the blocks with added fibers due to the low mechanical compression properties of metals with respect to concrete. To calculate ductility, the yielding point of each block was estimated according to the criteria in ATC-40 [37] and FEMA P-1050-1 [38]. Table 5 shows the yielding displacement (δ_p), ultimate displacement (δ_u) and the ductility obtained as the relationship between both deformations ($\mu = \delta_u/\delta_p$). Ductility in BA3 and BA4 specimens was 15% and 28% higher, respectively, than in BO0 specimens.

Table 5. Ductility, yielding and ultimate displacement of compression strength tests

Block	Yielding displacement (δ_p) [mm]	Ultimate displacement (δ_u) [mm]	Ductility (Δ%)
BO0	0.83	1.01	1.22
BA3	0.78	1.09	1.40 (+15%)
BA4	0.74	1.15	1.56 (+28%)

Table 6. Stiffness, yielding and ultimate forces of compression strength test

Block	Yielding force (F_p) [kN]	Ultimate force (F_u) [kN]	Yielding and effective stiffness [kN/mm]
BO0	533	582	642/576
BA3	405	462	519/424
BA4	315	423	426/368

The yielding and ultimate forces applied to each block as well as its stiffness are shown in Table 6. As expected, the ordinary blocks are more resistant than those with layers of fibers due to the lower aggregate content in the mixes.

These results offer interesting applications in structures exposed to high and/or moderate seismic forces. Although ordinary concrete blocks have higher compressive strength than blocks with aggregates (Figure 4), they are less ductile (Table 5) and heavier (Table 3), which are important aspects to consider in seismic design. However, it is still necessary to analyze how the blocks can be connected to each other and to the structure itself.

5. STRUCTURAL MODEL OF BUILDINGS USING CONCRETE BLOCKS WITH ALUMINUM AND STEEL ADDITIVES.

This section describes the modeling of some typical frame buildings in countries with moderate seismic risk using static and dynamic nonlinear analyses. The analysis was implemented on Seismostruct v.7.0.2 Seismosoft ® (Pavia, Italy) [39] FE software. This software can estimate the displacement of structures under static and dynamic loads considering geometrical and material non-linear behavior. Non-linear static analysis (Pushover) was used for a representative analysis of the structural performance of concrete blocks in buildings, plotting capacity curves that represent the relationship between the displacements on the top floor and the shear at the base of the building. Dynamic analyses were conducted using records of a medium intensity earthquake (described in Section 6.3).

5.1. Description of buildings

The structures analyzed were based on frame structures [beams and columns] due to the large quantity of this structural typology in many Latin American and European countries [40,41]. These structures are characterized by fast execution times and few resources, both aspects directly related to the reduction of construction costs.

As the structural behavior of beams and columns in frame constructions during earthquakes had not been satisfactory, even in low-rise buildings, the incorporation of brick walls or concrete blocks was necessary to mitigate the possible damage caused [40,41].

As most European countries have adapted their national [structural] codes to European codes (Eurocodes), the Eurocode of Structural Design [42] was considered for the design of these buildings. This research focused on low-rise structures, and the results obtained can thus be considered representative of a significant percentage of existing buildings in Europe and part of Latin America.

As shown in Figure 5, the frame structures were made up of three 5 m x 5 m bays (X, Y). Two of these bays were filled with block walls while the third was empty. This bay corresponded to the openings, e.g. windows, which are considered to have null stiffness.

The blocks and openings that made up the bay frames were located from the bottom of the beams to the upper beam without any anchorage to the primary structural elements except for the reinforcements, which are placed every four lines of blocks anchored to the columns.

The height of each floor was 3 m, except for the ground floor, which was 4 m. This means that the models used in the analysis had a height of 7 and 13 m in height for the 2 and 4-story buildings, respectively. The configuration of the frame buildings was regular and symmetrical in elevation and plan. The walls (2-BO, 2-BA3, 2-BA4, 4-BO, 4-BA3, 4-BA4) were on the exterior bay of each building, corresponding to the enclosures in the directions X and Y.

The horizontal structural elements that join the columns were 30 cm wide and 40 cm high beams, while the vertical elements were 30x30 cm columns.

Table 7. Building configuration (NW, 'no walls'; 2- and 4-, 'story number')

Building	Total height [m]	Total length [m]	Beams [cm^2]	Columns [cm^2]	Total weight [kN]	Fundamental period [s]
2 – NW	7	15.5	30x40	30x30	2149	0.215
2 – BO0	7	15.5	30x40	30x30	2965	0.144
2 – BA3	7	15.5	30x40	30x30	2916	0.145
2– BA4	7	15.5	30x40	30x30	2900	0.148
4 – NW	13	15.5	30x40	30x30	4298	0.42
4 – BO0	13	15.5	30x40	30x30	5931	0.27
4 – BA3	13	15.5	30x40	30x30	5832	0.28
4 – BA4	13	15.5	30x40	30x30	5800	0.29

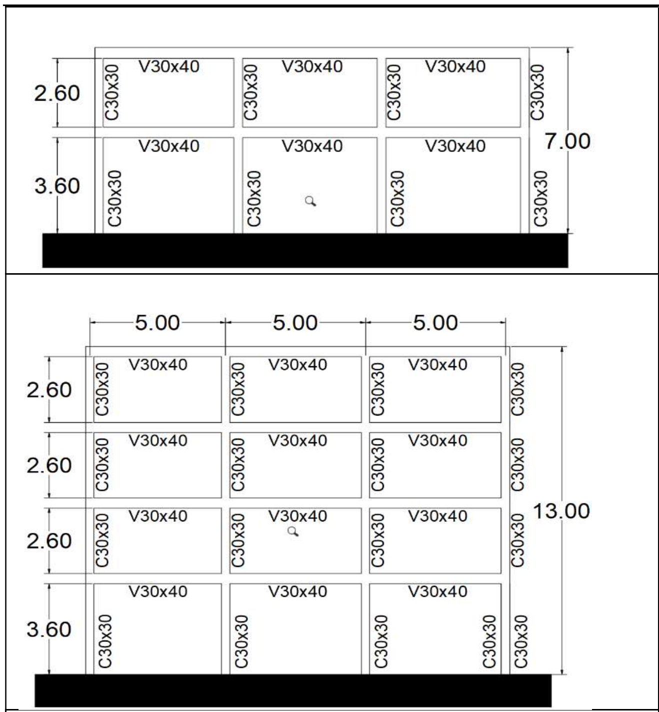


Figure 5. Models used in structural analysis

The continuity of the structure was achieved through reinforcements (longitudinal and transversal reinforcements) in addition to horizontal reinforcements between the blocks and the columns. The design of the structural elements complied with the requirements of the European codes.

The walls were made up of 19 cm thick blocks separated by a 1 cm thick mortar layer and with ladder-type transverse steel reinforcements every four rows of blocks.

The characteristics and properties of the models used in this study are summarized in Table 7. The materials used for the structural elements (beams and columns) were: HA-25 concrete (f_{ck} = 25 MPa) and B-500 steel- S (f_{yk}= 500 MPa), both materials are defined in CTE DEB SE AE [43]

In Table 7, each structural model is denoted by a number and two letters and a number. The first number indicates the number of heights and the sequence of two letters and a number, the type of block used in the filling of the walls described and defined in Table 2 ('NW' means 'no wall'). This table shows the configuration of the primary structural elements (columns and beams) of each floor, the weight of each model with the G + 0.3Q approach (G gravity load, Q live load), according to Eurocode 8, and the fundamental periods of the analyzed structures.

Given their low stiffness, we did not take into account the possible collaboration of the windows. Finally, it should be noted that the selected models belong to a residential typology, administrative buildings and small businesses, with a live load on each floor of 2 kN/m^2 [43], apart from the roof, which was 1 kN/m^2 [43], for maintenance in areas that are not for public or private use.

5.2. Earthquake

The medium intensity earthquake that occurred in Lorca (Spain) in 2011, was chosen as the register for the nonlinear dynamic analyses. Seismic vulnerability studies have become more important in some European countries such as Spain [44-45], France [46-47] and Italy [48], with similar types of structures. According to the Spanish Institute of Geology and Mining, the Lorca earthquake was one of the most destructive earthquakes recorded in Spain, despite its moderate magnitude (M_w = 5.1). The details and effects of this earthquake are described in detail in [49].

5.3. Structure modeling

The 3D structure was modeled using finite beam elements [50-51]. Each structural element [columns and beams] was individually detailed following those proposed by the Mander model for concrete [52] and Ferrara's bilinear model [53] for steel.

The beams and columns were represented by nonlinear finite beam elements [54], with the nonlinearities concentrated in the plastic hinge joints at the ends, at a distance of approximately 15% of the total length of the element [50]. According to [55], the joints/connections between the wall and the primary structural elements are considered rigid, while the hysteretic behavior of each in the model was represented by fiber models, based on the properties of the material and the geometry of the structural elements (each section was discretized with 300 fibers). Loads were applied to the beams.

The tolerances used for displacement and rotations were in the order of 10^{-5} in both cases. The maximum number of iterations was 300.

The Newmark-β method [56] was used for the numerical analysis. This model is based on a numerical integration method widely used in the numerical analysis of structures. The Beta (β) and Gamma (γ) factors used in these analyzes are coefficients that depend on the natural frequency (w) and the damping (ϛ) of the structures. For this work, the values β = 0.25 and γ = 0.5 were used, as they make the system implicit and stable [57]. The Rayleigh model was considered with 4% (mode 1) and 6% (mode 2) [58]. The complete quadratic (CQC) method was used for the modal combination with a damping of 0.04.

For the concrete and steel failure, the default values provided by Seismostruct were used [59-61]: concrete cracking (0.0001), detachment of the concrete shell (−0.002), crushing of concrete core (-0.002), steel creep (0.0025) and steel fracture (0.06). The criteria referring to curvature and rotations were verified by the Mergos and Kappos model [62] and the shear capacity established by the EC 8.

The structural results of the different structural analysis, following the previous prescriptions, considered the shear at the base of the structures and the elastic and yielding displacements of the model in the "push-over" analysis and the displacements and absolute accelerations in the dynamic analysis.

5.4. Modeling of infill walls (concrete block walls)

The presence of infill walls considerably modifies the structural behavior of RC structures. To model these, non-linear inelastic behavior, mechanical properties and interaction with the structure are considered [63]. Many techniques can be used for this. In this work, the Crisafulli et al. model was implemented [64-66] on Seismosoft® software. The criterion considered for the selection of the model was its good results in the panel-structure interaction, in relation to the computational time required by the calculations. The model's double strut approach has been successfully applied for predicting seismic response in multi-story reinforced concrete frames. Crisafulli proposes a macromodel that measures the overall response of the structures, implementing a four-node "panel" element which is connected to the frame (Figure 6).

Internally, the element panel represents separately the compression and shear behavior of the masonry, with two parallel struts and a cutting spring in each direction. This spring considers the stiffness and lateral resistance of the masonry panel when a shear failure occurs along the mortar joints or an expected diagonal tension failure. Some geometric and mechanical parameters are required to define the behavior of the masonry panel for the calibration of the model in terms of block walls. More numerical details of this model and full explanation of the variables involved can be found in [67-68]. The parameters obtained in the laboratory tests by direct or indirect measurements are given in Table 8.

Figure 6. Infill wall model [69]

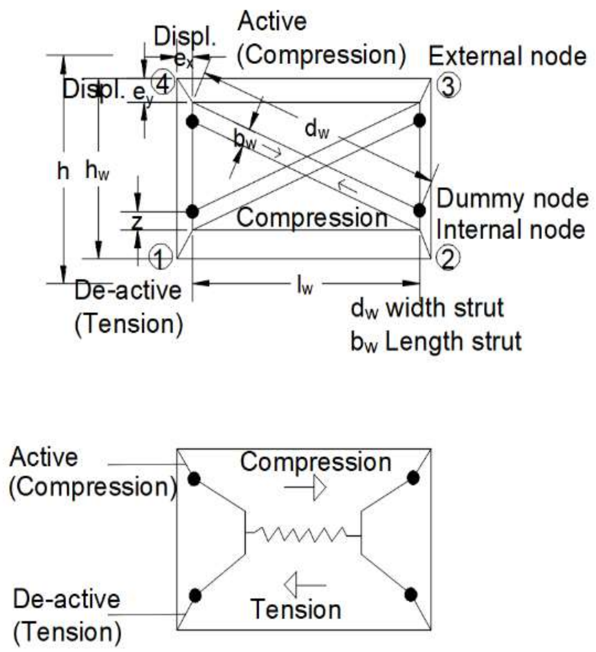


Table 8. Numerical values of geometry and mechanical behavior obtained in the laboratory

Units	BO0	BA3	BA4
t [mm]	191	191	191
A_1 [mm^2]	276970.21	276970.21	276970.21
d_w [mm]	5830.95	5830.95	5830.95
b_w [mm]	1457.74	1457.74	1457.74
E_b [N/mm^2]	7165	6945	6335
b [mm]	192	192	192
j [mm]	10	10	10
E_m [N/mm^2]	7229	6944	6364
h_w [mm]	3000	3000	3000
E_j [N/mm^2]	40696	40696	40696
h [mm]	3400	3400	3400
f_t [MPa]	3.19	3.52	3.85
$f_{m\theta}$ [MPa]	15.25	13.79	12.02
τ_{max} [MPa]	2.89	2.81	2.71
Υ_p [KN/m^3]	13.32	13.04	12.68
z [mm]	852.81	1055.68	1087.43
λ	0.00180	0.00149	0.00144
θ [°]	30.96	30.96	30.96
I_c [mm^4]	675e6	675e6	675e6

6. BUILDING PERFORMANCE

The different structural design codes specify different procedures for a seismic building analysis.

The calculations were conducted according to two standards using a) regular methods, b) a more advanced static non-linear analysis (push-over) and c) dynamic nonlinear analysis and their responses were compared.

6.1. Analyses according to Standards

In this case, the Chilean (NCh433) and European (EC-8) Regulations were considered using an average soil type (type C) and ground acceleration a_b = 0.4g to obtain the seismic forces, the displacement at the top of the frame and the base shear.
The results in Tables 10 and 11 show the shear at the base of the frame [kN], the displacements at the top [m] and their variations [%] between both Standards, respectively. The results show differences between the two Regulations, which were more significant with increasing height. Regardless of the walls, the results of the EC-8 Standard are more demanding than those of NCh433, as is in all cases of the 4-story building.
Considering walls in buildings significantly reduces the displacement of the structures, while shear increases.
The addition of aluminum and steel fibers in the wall blocks of 4-story buildings reduces shear and displacement, with little difference in 2-story buildings. This is due to the reduction of the seismic forces caused by the decrease in weight of the structures, as a result of the lower block density.
These results are compared in the following sub-section with the static and non-linear dynamic analyses.

Table 9. Base shear of buildings (NW, 'no walls'; 2- and 4-, 'story number')

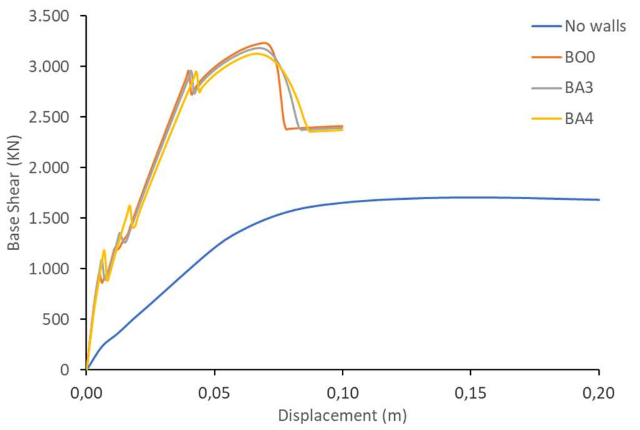
Building	NCh433 [kN]	EC-8 [kN]	Δ [%]
2 – NW	476	548	+15.12
2 – BO0	869	755	-13.12
2 – BA3	850	745	-12.35
2– BA4	840	739	-12.02
4 – NW	603	653	+8.29
4 – BO0	1153	1398	+21.25
4 – BA3	1073	1325	+23.49
4 – BA4	1040	1275	+22.60

Table 10. Displacement of buildings (NW, 'no walls'; 2- and 4-, 'story number')

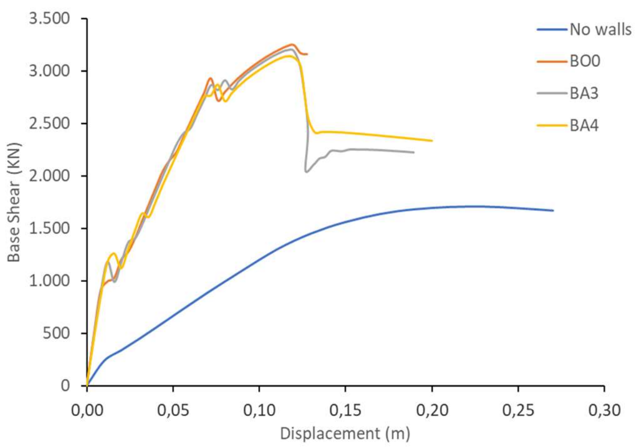
Building	NCh433 [m]	EC-8 [m]	Δ [%]
2 – NW	0.0217	0.0256	+17.97
2 – BO0	0.0053	0.0045	-15.09
2 – BA3	0.0054	0.0046	-14.81
2– BA4	0.0056	0.0048	-14.29
4 – NW	0.063	0.069	+9.52
4 – BO0	0.021	0.032	+52.38
4 – BA3	0.015	0.029	+93.33
4 – BA4	0.0148	0.026	+75.68

6.2. Non-linear static analysis (Push-over)

Non-linear analysis (Push-over) calculates the maximum resistance capacity of the structures whose dynamic response is not significantly affected by the levels of displacement experienced. Nonlinear static analysis is one of the four structural performance analysis procedures built into FEMA 356 and ASCE 41.



a) 2 - Story building



b) 4 – Story building

Figure 7. Capacity curves

The structural analyses carried out in this work for all buildings concentrates the failures in the plastic hinge joints that appear in the areas near to the nodes of each structural element (beams and columns). These analyses assumed a triangular load distribution pattern which increases proportionally with a factor (λ) until structural instability is reached. The control parameter used in these analyses is based on the displacement of the top floor nodes.
Figures 7a and 7b show the capacity curves of the models described in Table 7, using H-25 (25 MPa) concrete, B-500-S (500 MPa) corrugated reinforced steel, and infill walls composed of ordinary blocks and blocks with aluminum alloy and steel fibers. These curves can evaluate the influence of ductility and resistance on the structural behavior of the models.
The elastoplastic behavior of the structures is shown at the beginning of each curve. Large differences were found in this part of the plot between the block structures because this initial part of the curve is obtained from the resistance of the most rigid

elements, i.e. the walls. However, as the applied force increases, the differences are smaller in the curve for the same load level because the same primary structural element (beams and columns) are resisting in all the cases analyzed. During the increase in load from 0 kN to the first peak or first plastic hinge joint (approximately 1100 kN), the block walls alone determine the building´s structural behavior, increasing the initial stiffness of the structure and failing before the primary structural elements govern the response. From then on, there is a significant reduction in structural stiffness due to the structural collapse of the walls.
The change in the slope of the capacity curves is mainly generated by cracks in the concrete and the plasticity of the steel reinforcement. These effects are represented in the model by the formation of plastic hinge joints in each element. The length of these curves depends on the number of plastic hinge joints generated in the structural elements of the model, prior to becoming an unstable structure.

Table 11 shows the values of yield displacement, ultimate displacement and ductility for all the models analyzed. The results show that the blocks with steel and aluminum alloy fibers provide greater ductility to the structural systems, as in the behavior of individual blocks. Quantitatively, the static non-linear analysis determines that buildings with block walls including additives increase their ductility by up to 10.9% and 11.2% with respect to 2 and 4 story buildings with ordinary blocks, respectively, showing that increasing the fiber layers raises building ductility.
Table 12 shows the results of base shear of each case analyzed. It can be seen that increasing aluminum and steel layers in the blocks slightly reduces their resistance, while including walls in buildings significantly increases the shear compared to no-wall [NW] buildings.

Table 12. Yielding and ultimate base shear of buildings (NW, 'no walls'; 2- and 4-, 'story number')

Building	Yielding base shear [kN]	Ultimate base shear [kN]
2 – NW	1512	1707
2 – BO0	2697	3235
2 – BA3	2643	3184
2– BA4	2620	3124
4 – NW	1515	1711
4 – BO0	2933	3252
4 – BA3	2867	3200
4 – BA4	2767	3139

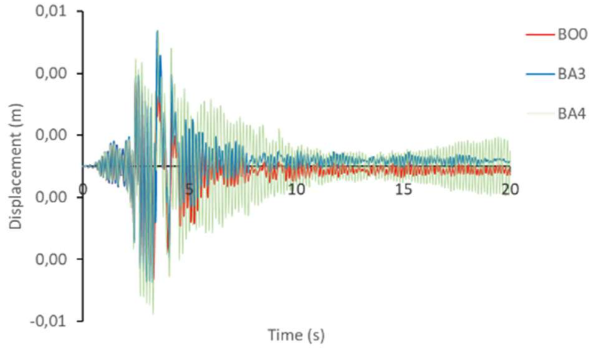
Observing Table 10 and 12, the displacements obtained from the usual Standards' analyses compared to the push-over analyses are far from yielding.

6.3. Dynamic analysis: "Time history"

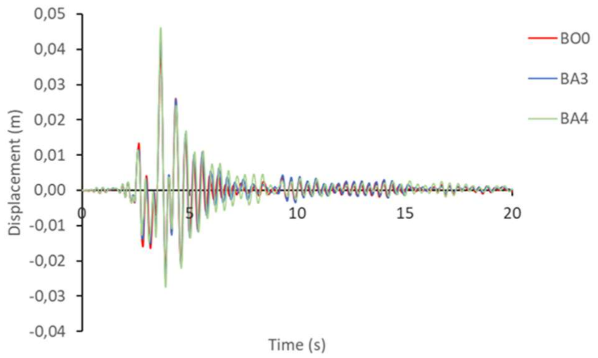
Dynamic analysis can be used to predict the nonlinear inelastic response of a structure subjected to a seismic event. For the calculations carried out here, the Lorca earthquake accelerogram (Spain 2011) was used. Interested readers can find a brief description of the method in [40, 59]. In this work, the direct integration of the equations of motion was developed using the well-known Newmark method [56], which introduces accelerations in the supports [base of the columns] for a short time interval coinciding with the seismic record. The time interval (Δt) in the analysis was 0.01s from the record of the Lorca earthquake (2011) in both directions (X, Y). As the recorded information indicated that the most catastrophic accelerations were in the North-South direction, the dynamic analysis were performed using the recording for the N-S direction. Structural damping was represented by the Rayleigh model at a damping factor of 5%, a value used in many studies for this type of building.
Figure 8 shows the seismic response behavior [time-history diagrams] of the models. These graphs show the displacements of the upper floor of the buildings for the Lorca seismic record. To avoid scale effect due to one order of magnitude in the values, the displacements for the 'no-walls' model are not included in the plot. It shows the 'flexibility' effect caused by the fiber layers, particularly 2-BA4 model, allowing larger displacements. The graphs in Figure 9 show the absolute accelerations for each building including 'no-walls' model; not big differences are found among the models with blocks. There is stronger effect of the number of fiber layers in buildings with 2 stories both for the displacement and acceleration cases.
The values in Table 13 show the maximum displacements at the top and the absolute accelerations of each structural model. These results were compared with the static non-linear "Push-over" analysis.

Table 11. Ductility, yielding and ultimate displacement of buildings (NW, 'no walls'; 2- and 4-, 'story number')

Building	Yielding displacement [m]	Ultimate displacement [m]	Ductility
2 – NW	0.074	0.152	2.03
2 – BO0	0.045	0.066	1.46
2 – BA3	0.042	0.067	1.59 (+8.9%)
2– BA4	0.041	0.068	1.62 (+10.9%)
4 – NW	0.120	0.251	2.08
4 – BO0	0.076	0.120	1.57
4 – BA3	0.072	0.122	1.70 (+7.9%)
4 – BA4	0.071	0.124	1.75 (+11.2%)

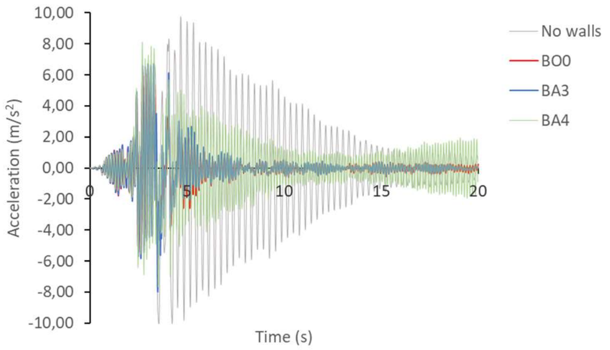


a) 2- story building

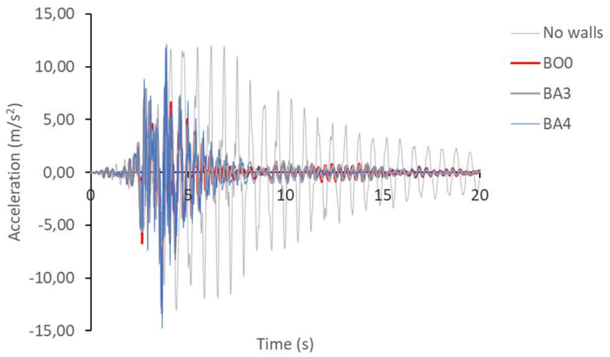


b) 4- story building

Figure 8. Displacement at the top floor of the building



a) 2- story building



b) 4- story building

Figure 9. Absolute acceleration at the top floor of the building

Table 13. Seismic response of maximum absolute displacements and accelerations of buildings (NW, 'no walls'; 2- and 4-, 'story number')

Building	Maximum displacement [m]	Maximum absolute acceleration [m/s^2]
2 – NW	0.030	9.77
2 – BO0	0.0028	6.51
2 – BA3	0.0044	6.74
2– BA4	0.0045	8.10
4 – NW	0.141	12.12
4 – BO0	0.040	7.55
4 – BA3	0.044	8.61
4 – BA4	0.046	12.10

Summarizing, the results obtained show that the seismic behavior of the structures with added fibers in the blocks are more flexible than structures with ordinary blocks. Because of the stiffening effect provided by walls, the maximum displacements obtained from the dynamic calculations show a significant reduction of one order of magnitude in buildings with walls but not so intense in the maximum absolute acceleration. The effect of fiber layers in blocks is more pronounced in 2-story buildings, where a stiffer structure reflects better the flexibility provided by the fiber.

7. DISCUSSION OF RESULTS

Precast concrete blocks are widely used in construction due to their high resistance, thermal and acoustic insulation, fire resistance and low moisture absorption. Seismic-prone countries such as Japan, Chile or Turkey require additional properties such as ductility or structural weight reduction.

The use of lighter ductile materials, such as steel and aluminum alloy fibers in the blocks, can improve structural seismic resistance.

A comprehensive study of the properties of the elements using the proposed material was conducted, experimentally measuring their mechanical properties as well as water absorption and block density.

Throughout the study, all the registered values were compared with the requirements established in the regulations of the Chilean structural code, selected for their strict structural requirements valid for a large number of countries, such as the United States (ASTM 2004), Mexico (NTC-M 2004), Spain (CTE DEB SE F 2006) or Europe (Eurocode 6 (2005)).

The dimensions of the blocks used in this study complied with the minimums established by NCh181 for structural use. Nineteen cm thick blocks were used because they are inexpensive and widely used in construction with good results.

The density of the concrete in the ordinary blocks was classified as 'medium' (between 1680 - 2000 kg/m^3) according to Standard NCh181. However, the addition of the steel and aluminum alloy layers in both cases changed the density of the blocks to 'light' according to the Standard (<1680 kg/m^3), which is positive from a seismic point of view. This reduction is obviously more significant as the number of layers increases, as can be seen in Table 3. In numerical terms, 3, 4 and 5 layers reduce the weight of the blocks by 6.1%, 8.1 and 10%, respectively.

On the other hand, the compressive strength of blocks with added fibers decreases as the number of layers increases (9.6%, 21.2% and 33.9% for 3, 4 and 5 layers, respectively). The latter number was not tested in this study for failing to meet the minimum structural requirements of NCh181 (12 MPa).

However, the fibers increase flexural strength and ductility. For flexural strength these increases are 10.3% and 20.7% and for ductility they are 15% and 28% for blocks with 3 and 4 layers, respectively.

The results obtained from the structural models with the different blocks by means of nonlinear static and dynamic analyses indicate that ductile materials have a greater capacity to dissipate energy during a seismic event.

The results of the static "non-linear" analysis (Push-over) of the models that analyzed blocks with fibers showed better seismic resistance than ordinary blocks. These models were less rigid but more resistant, as was confirmed by the dynamic results. The fiber blocks' greater flexibility produced fewer brittle cracks in the structural elements.

Comparing the results for the maximum displacements of the non-linear static and dynamic analysis, it can be concluded that the Lorca buildings could have been expected to behave better during the earthquake had they been built of the blocks proposed in this paper, as can be seen in the maximum displacements obtained from the dynamic analyses, which in no case exceeded the maximum displacements obtained from the capacity curves of the "push-over" analyses. All the studies carried out, with the exception of building 4 – NW, remained in the elastic state.

In the displacements caused by the seismic forces obtained from the Standards' analyses (EC-8 and NCh433), as expected from the design, the elastic limit was not exceeded when compared to the non-linear static analyses.

In general, the use of walls significantly reduces the absolute acceleration and building displacement.

From the economic perspective, the introduction of steel and aluminum alloy fibers in the composition of the blocks does not reduce the cost of the mixture, but it does have structural benefits as regards seismic resistance without excessively increasing the building cost. In addition, the volumetric expansion of the concrete in the blocks with added alloys helps to reduce the amount of material used on site.

8. CONCLUSIONS

In this work a study was carried out on the mechanical and structural behavior of concrete blocks with additional steel and aluminum alloy fibers.

These mixtures improve some of the earthquake-resistant properties of concrete blocks, in addition to the requirements of the Regulations. The method used included the production of the blocks in the laboratory, the determination of their physical and mechanical properties and a comparison of their performance with ordinary concrete blocks in 2 and 4-floor buildings.

The following conclusions can be drawn from the results:

• The compressive strength of ordinary concrete blocks is greater than that of blocks with steel and aluminum alloy fibers. Only the blocks with 3 and 4 layers of fibers comply with the Chilean code NCh181 for structural use, since those with 5 layers were discarded because they did not comply with the minimum resistance required by the Standard.

• The flexural strength of blocks with fibers is higher than that of ordinary blocks.

• The ductility of traditional concrete blocks is significantly lower than fiber blocks.

• The reduced density of the fiber blocks changes the classification of the concrete used to prepare the blocks from 'medium' to 'light', which is beneficial for seismic structural behavior.

• Non-linear static push-over analysis in the models confirms a better structural performance in buildings with walls made of mixed blocks, increasing ductility.

• Except for buildings without walls, the most ductile buildings are those with block walls with 4 layers of fibers.

• Designing according to the Standards provides structures with good performances and seismic displacements well below yielding.

• In terms of displacements, the effect of fiber layers in blocks is more pronounced in 2-story buildings, where a stiffer structure reflects better the flexibility provided by the fiber.

• The dynamic analyses using the North-South direction of the Lorca earthquake recordings do not show large differences in structural displacements, regardless of the type of block used. This can be explained by the fact that the Lorca earthquake was not a particularly strong one and did not transfer enough energy to carry the structures into the plastic range.

• Including 4 layers of fibers in the structures does not guarantee a significant reduction in the absolute accelerations of the buildings.

This study was merely exploratory. Blocks with fibers seem to exhibit better structural seismic resistance properties than ordinary blocks. In future work, the authors hope to include a parametric study with main variables, changing the grain size or the alloys. Different concrete and steel strengths, as well as more stories would provide more information about the seismic performance of this type of mixed block.

REFERENCES

[1] Tamboli, H. R., Karadi, U. N., & Tamboli, H. R. (2012). Seismic analysis of RC frame structure with and without masonry infill walls. Indian Journal of Natural Sciences International Bimonthly ISSN, 0976-0997.Korkmaz, K. A., Demir, F., Sivri, M. (2007). Earthquake assessment of R/C structures with masonry infill walls. *International journal of science & technology*, *2*(2), 155-

164.
[2] Korkmaz, K. A., Demir, F., Sivri, M. (2007). Earthquake assessment of R/C structures with masonry infill walls. *International journal of science & technology*, 2(2), 155-164.
[3] Ahmad, R., Malik, M. I., Jan, M. U., Ahmad, P., Seth, H., Ahmad, J. (2014). Brick Masonry and Hollow Concrete Block Masonry–A Comparative Study. *International Journal of Civil and Structural Engineering Research (IJCSER)*, *1*(1), 14-21.
[4] Hori, N., Inoue, N., Purushotam, D., Nishida, T., Kobayashi, J. (2006). Experimental and analytical studies on earthquake resisting behaviour of confined concrete block masonry structures. *Earthquake engineering & structural dynamics*, *35*(13), 1699-1719.
[5] Zhu, L., Dai, J., Bai, G., Zhang, F. (2015). Study on thermal properties of recycled aggregate concrete and recycled concrete blocks. *Construction and Building Materials*, *94*, 620-628.
[6] Miličević, I., Bjegović, D., Siddique, R. (2015). Experimental research of concrete floor blocks with crushed bricks and tiles aggregate. *Construction and Building materials*, *94*, 775-783.
[7] Pastor, J. M., García, L. D., Quintana, S., Peña, J. (2014). Glass reinforced concrete panels containing recycled tyres: Evaluation of the acoustic properties of for their use as sound barriers. *Construction and Building Materials*, *54*, 541-549.
[8] Ergün, A. (2011). Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. *Construction and building materials*, *25*(2), 806-812.
[9] Mindess, S., Vondran, G. (1988). Properties of concrete reinforced with fibrillated polypropylene fibres under impact loading. *Cement and Concrete Research*, *18*(1), 109-115.
[10] Bayasi, Z., McIntyre, M. (2002). Application of fibrillated polypropylene fibers for restraint of plastic shrinkage cracking in silica fume concrete. *Materials Journal*, *99*(4), 337-344.
[11] Ashour, S. A., Wafa, F. F. (1993). Flexural behavior of high-strength fiber reinforced concrete beams. *Structural Journal*, *90*(3), 279-287.
[12] Oh, B. H. (1992). Flexural analysis of reinforced concrete beams containing steel fibers. *Journal of structural engineering*, *118*(10), 2821-2835.
[13] Sabir, B. B., Wild, S., Bai, J. (2001). Metakaolin and calcined clays as pozzolans for concrete: a review. *Cement and concrete composites*, *23*(6), 441-454.
[14] Quaranta, N., Caligaris, M., López, H., Unsen, M., Di Rienzo, H. (2008). Adición de aserrines de descarte en la producción de mampuestos cerámicos. In *Actas del Octavo Congreso Internacional de Metalurgia y Materiales.*
[15] Evangelista, L., & de Brito, J. (2007). Mechanical behaviour of concrete made with fine recycled concrete aggregates. Cement and concrete composites, 29(5), 397-401.
[16] Xie, J., Zhao, J., Wang, J., Wang, C., Huang, P., Fang, C. (2019). Sulfate resistance of recycled aggregate concrete with GGBS and fly ash-based geopolymer. *Materials*, *12*(8), 1247.
[17] Liu, W., Cao, W., Zhang, J., Qiao, Q., Ma, H. (2016). Seismic performance of composite shear walls constructed using recycled aggregate concrete and different expandable polystyrene configurations. *Materials*, *9*(3), 148.
[18] Tomaževič, M., Lutman, M., Petković, L. (1996). Seismic behavior of masonry walls: experimental simulation. *Journal of Structural Engineering*, *122*(9), 1040-1047.
[19] Restrepo, J. I., Rahman, A. (2007). Seismic performance of self-centering structural walls incorporating energy dissipators. *Journal of Structural Engineering*, *133*(11), 1560-1570.
[20] da Silva Bertolini, M., de Morais, C. A. G., Christoforo, A. L., Bertoli, S. R., dos Santos, W. N., & Lahr, F. A. R. (2019). Acoustic absorption and thermal insulation of wood panels: Influence of porosity. BioResources, 14(2), 3746-3757.
[21] Kalantari, S. M., Naderpour, H., Vaez, S. H. (2008, October). Investigation of Base-isolator type selection on seismic behavior of structures including story drifts and plastic hinge formation. In *The 14th World Conference on Earthquake Engineering, Beijing, China*.
[22] Hashemi, S. A. (2007). *Seismic evaluation of reinforced concrete buildings including effects of masonry infill walls*. University of California, Berkeley, ProQuest Dissertations Publishing, 2007.
[23] Code, P. (2005). Eurocode 8: Design of structures for earthquake resistance-part 1: general rules, seismic actions and rules for buildings. Brussels: European Committee for Standardization.
[24] Oficial, N. C. (1996). Diseño sísmico de edificios. Instituto Nacional de Normalización INN-Chile. NCh433. Of96.
[25] Kirkham, W. J., Gupta, R., Miller, T. H. (2014). State of the art: Seismic behavior of wood-frame residential structures. *Journal of Structural Engineering*, *140*(4), 04013097.
[26] Ellingwood, B. R., Rosowsky, D. V., Li, Y., Kim, J. H. (2004). Fragility assessment of light-frame wood construction subjected to wind and earthquake hazards. *Journal of Structural Engineering*, *130*(12), 1921-1930.
[27] Ellingwood, B. R., Rosowsky, D. V., Pang, W. (2008). Performance of light-frame wood residential construction subjected to earthquakes in regions of moderate seismicity. *Journal of structural engineering*, *134*(8), 1353-1363.
[28] Alengaram, U. J., Salam, A., Jumaat, M. Z., Jaafar, F. F., Saad, H. B. (2011). Properties of high-workability concrete with recycled concrete aggregate. *Materials Research*, *14*(2), 248-255.
[29] Tarasov, D., Shahi, C., Leitch, M. (2013). Effect of additives on wood pellet physical and thermal characteristics: A review. International Scholarly Research Notices, 2013.
[30] Tiina Pöhler, Petri Jetsu, Heikki Isomoisio. (2016). Benchmarking new wood fibre–based sound absorbing material made with a foam-forming technique. Building Acoustics, Volume: 23 issue: 3-4, page(s): 131-143. https://doi.org/10.1177/1351010X16661564
[31] Otten, K. A., Brischke, C., Meyer, C. (2017). Material moisture content of wood and cement mortars–electrical resistance-

based measurements in the high ohmic range. Construction and Building Materials, 153, 640-646.
[32] Of, N. (2013). Áridos para morteros y hormigones–Requisitos.(2013). Instituto Nacional de Normalización.
[33] Of, N. (77). Áridos para morteros y hormigones–Tamizado y determinación de la granulometría.(1977). Instituto Nacional de Normalización.
[34] Of, N. (2006). Bloques de hormigon para uso estructural. Requisitos generales.(2006). Instituto Nacional de Normalización.
[35] Of, N. (2009). Hormigón-Determinación de la docilidad-Método del asentamiento del cono de Abrams.(2009). Instituto Nacional de Normalización.
[36] Of, N. (2009). Hormigón-Ensayo de compresión de probetas cúbicas y cilíndricas.(2009). Instituto Nacional de Normalización.
[37] Comartin, C., Niewiarowski, R., & Rojahn, C. (1996). ATC-40 Seismic evaluation and retrofit of concrete buildings. SSC 96, 1.
[38] Council, B. S. S. (2015). NEHRP recommended seismic provisions for new buildings and other structures (FEMA P-1050), 2015 edition. FEMA report P-1050.
[39] Seismosoft, S. (2013). v6. 5,“. A Computer Program for Static and Dynamic Nonlinear Analysis of Framed Structures.
[40] López-Almansa, F., Domínguez, D., Benavent-Climent, A. (2013). Vulnerability analysis of RC buildings with wide beams located in moderate seismicity regions. *Engineering structures*, *46*, 687-702.
[41] Domínguez Santos, D. J., López Almansa, F., & Benavent Climent, A. (2014). Behavior, for the Lorca earthquake on 11-05-2011, of wide beam building designed without seismic considerations. Informes de la Construcción, 66(533).
[42] Mosley, W. H., Hulse, R., & Bungey, J. H. (2012). Reinforced concrete design: to Eurocode 2. Macmillan International Higher Education.
[43] CTE-DB-SE, F. (2007). Código Técnico de la Edificación. Documento Básico, Seguridad Estructural: Fábrica. Ministerio de la Vivienda. España.
[44] Barbat, A.H.; Pujades, L.G.; Lantada, N. Performance of Buildings under Earthquakes in Barcelona, Spain. Comput. Civ. Infrastruct. Eng. 2006, 21, 573–593.
[45] Barbat, A. H.; Carreño, M. L.;Pujades, L. G.;Lantada, N.;Cardona, O. D.;Marulanda, M. C. Seismic vulnerability and risk evaluation methods for urban areas. A review with application to a pilot area. Struct. Infrastruct. Eng. 2010, 6, 17–38.
[46] Guéguen, P.; Michel, C.; LeCorre, L. A simplified approach for vulnerability assessment in moderate-to-low seismic hazard regions: Application to Grenoble (France). Bull. Earthq. Eng. 2007, 5, 467–490.
[47] Michel, C.; Guéguen, P.; Lestuzzi, P.; Bard, P.-Y. Comparison between seismic vulnerability models and experimental dynamic properties of existing buildings in France. Bull. Earthq. Eng. 2010, 8, 1295–1307.
[48] Dolce, M.; Kappos, A.; Masi, A.; Penelis, G.; Vona, M. Vulnerability assessment and earthquake damage scenarios of the building stock of Potenza (Southern Italy) using Italian and Greek methodologies. Eng. Struct. 2006, 28, 357–371.
[49] Dominguez-Santos, D.; Ballesteros-Perez, P.; Mora-Melia, D. Structural Resistance of Reinforced Concrete Buildings in Areas of Moderate Seismicity and Assessment of Strategies for Structural Improvement. Buildings 2017, 7, 89.
[50] Scott, M.H.; Fenves, G.L. Plastic Hinge Integration Methods for Force-Based Beam–Column Elements. J. Struct. Eng. 2006, 132, 244–252.
[51] Zienkiewicz, O. C., Taylor, R. L., Taylor, R. L., & Taylor, R. L. (2000). The finite element method: solid mechanics (Vol. 2). Butterworth-heinemann.
[52] Mander, J. B., Priestley, M. J., & Park, R. (1988). Theoretical stress-strain model for confined concrete. Journal of structural engineering, 114(8), 1804-1826.
[53] Ferrara, E.;Bosco, M.;Ghersi, A.;Marino, E. M.;Rossi, P. P. Improvement of the Model Proposed By Menegotto and Pinto for Steel. Eng. Struct. 2016, 124, 442–456.
[54] Wriggers, P. (2008). Nonlinear finite element methods. Springer Science & Business Media.
[55] Scott, M. H.;Fenves, G. L.;McKenna, F.; Filippou, F. C. Software Patterns for Nonlinear Beam-Column Models. J. Struct. Eng. 2008, 134, 562–571.
[56] Newmark, N.M. A Method of Computation for Structural Dynamics. J. Eng. Mech. Div. 1959, 85, 67–94.
[57] Gavin, H. (2001). Numerical integration for structural dynamics. Department of Civil and Environmental Engineering, Duke University: Durham, NC, USA.
[58] Haldar, A.; Mahadevan, S. Probability, Reliability, and Statistical Methods in Engineering Design; John Wiley: Hoboken, NJ, USA, 2000.
[59] Paulay, T.; Priestley, M.J.N. Seismic Design of Reinforced Concrete and Masonry Buildings; John Wiley: Hoboken, NJ, USA, 1992.
[60] Kent, D.C.; Park, R. Flexural members with confined concrete. J. Struct. Div. 1971, 97, 1969–1990.
[61] Menegotto M., Pinto P.E. (1973) "Method of analysis for cyclically loaded R.C. plane frames including changes in geometry and non-elastic behaviour of elements under combined normal force and bending" Symposium on the Resistance and Ultimate Deformability of Structures Acted on by Well Defined Repeated Loads, International Association for Bridge and Structural Engineering, Zurich, Switzerland, pp. 15.22.
[62] Mergos, P.E.; Kappos, A.J. Estimating fixed-end rotations of reinforced concrete members at yielding and ultimate. Struct. Concr. 2015, 16, 537–545.
[63] Priestley, M. N., Calvi, G. M., Kowalsky, M. J. (2007). *Displacement-based seismic design of structures*. IUSS press, Pavia, 670 pp.
[64] Crisafulli, F. J., Carr, A. J., Park, R. (2000). Analytical modelling of infilled frame structures. *Bulletin of the New Zealand Society for Earthquake Engineering*, *33*(1), 30-47.
[65] Crisafulli, F. J., Carr, A. J. (2007). Proposed macro-model for the analysis of infilled frame structures. *Bulletin of the New*

Zealand Society for Earthquake Engineering, *40*(2), 69-77.
[66] Crisafulli, F. J. (1997). Seismic behaviour of reinforced concrete structures with masonry infills. Engineering: Theses and Dissertations. University of Canterbury. Civil Engineering. http://hdl.handle.net/10092/1221.
[67] Crisafulli, F.J.; Carr, A.J. Proposed macro-model for the analysis of infilled frame structures. Bull. N.Z.Soc. Earthq. Eng. 2007, 40, 69–77.
[68] Chopra, A. K. (2012). Dynamics of structures (pp. 174-196). Upper Saddle River, NJ: Pearson Education.
[69] David Dominguez-Santos, Daniel Mora-Melia, Gonzalo Pincheira-Orellana, Pablo Ballesteros-Pérez, and Cesar Retamal-Bravo. Mechanical Properties and Seismic Performance of Wood-Concrete Composite Blocks for Building Construction. *Materials* (2019).