Analysis of the influence of the block in the dynamic properties of domestic buildings with masonry structure.

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ABSTRACT

The modal analysis of a building, performed by finite element method, is usually made in a building isolated model. In the case of traditional buildings with masonry structure, this simplification can be very unrealistic, particularly in the case of buildings with shared party walls. The influence of the adjacent buildings, in the modal results of domestic masonry buildings is discussed in this paper.

The ultimate goal of the presented work is to quantify the influence of the block in modal results, compared with traditional calculation of isolated buildings. And we are very interested in seeing how the block affects the modal results of damaged buildings, for example, with a significant crack between bearing walls and shear walls due to an important settlement of the foundation. For this work, we have focused on the traditional Sevillan building with a masonry structure. We found that, in the case of buildings with flexible floor disconnected from shear walls and with cracks between bearing walls and shared walls, the dynamic response perpendicular to facade rise hugely. For this particular case, the block has little effect on the response in that direction.

Keywords: Masonry; Clustered buildings; Ambient vibration test; Damage detection; Steady state analysis.

1. INTRODUCTION

This study is part of a research project, which studies the application of vibration analysis technique on damaged auscultation in domestic buildings with masonry structure. The purpose of the research project is to verify the possibility of making a diagnosis of integrity of masonry structures, using simple dynamic tests in specific areas of the building. Unlike studies in more important buildings, rather than testing the entire structure and analyze it using operational modal analysis (OMA) techniques, we intend to make only a few assays at appropriate points and make sure these readings correspond to expected ones but if on the contrary, they are very far from that expected value. This idea comes after the work done in the church of *Santa María la Blanca* in Seville[4], [5] and after analyzing some anomalous results in the dynamic tests performed in traditional buildings in Seville.

Therefore, before running the tests, we need to know how the behavior of buildings, in a situation of structural integrity, should be and in case with various damages. Following this reasoning, the project is being developed in two phases. In the first one the behavior of these structures will be analyzed

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using finite element method (FEM). Later, in a second phase, the results of these models will be compared with those obtained on real buildings using an accelerometer test (Fig. 1).
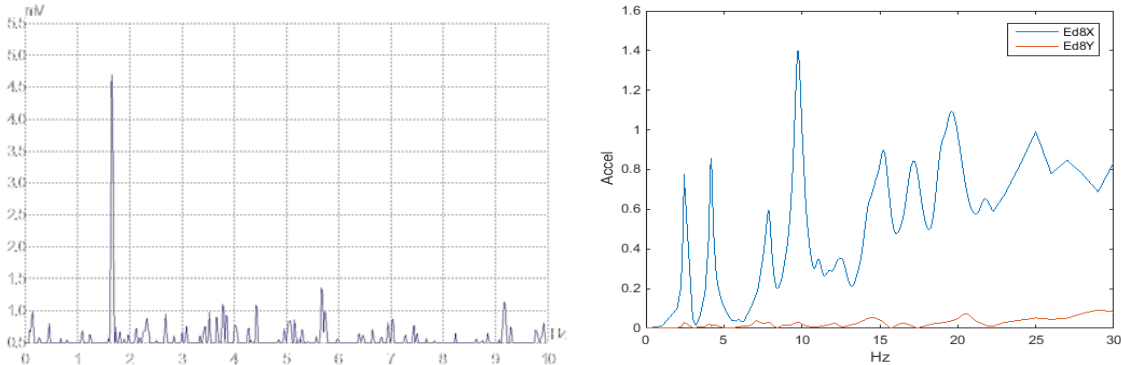

Figure 1. *Response diagrams obtained by accelerometer (left) and FEM (right).*

In order to simplify the problem, we have reduced the study focus. We have focused on traditional residential buildings with masonry structures, located in the historic center of Seville. This has simplified quite a number of variables, such as the construction type, the usual catalog of damages, etc. These variables have been synthesized from the work of Perez Galvez *et al.*[1], [2] and Huete Fuertes *et al.*[3].

In particular, we studied the effect of a very common problem in Seville and this structural type: the differential settlement between bearing walls and shear walls. This phenomenon has two main causes: On one hand, the ground on which the foundation is located is very poor, soft, with a first layer which can be defined as anthropic stuffing and also has variable thickness; and on the other hand, an improperly designed foundation, with minimal and too similar dimensions in bearing walls and shear walls. During our professional activity in structural diagnosis and repair of this kind of building we have seen how these events cause higher settlement at bearing walls than shear walls and therefore breakages occur in the walls.

Figures 2 y 3. *Offset between tiled baseboards.*

In the case of Seville, these fractures usually occur at the junction between load-bearing walls and shear wall, probably because there is little joining between them.

The seats on the walls, can be seen in the tiled plinth (fig. 2, 3 and 4). We suppose that this coating was not constructed with the gap we can see today.
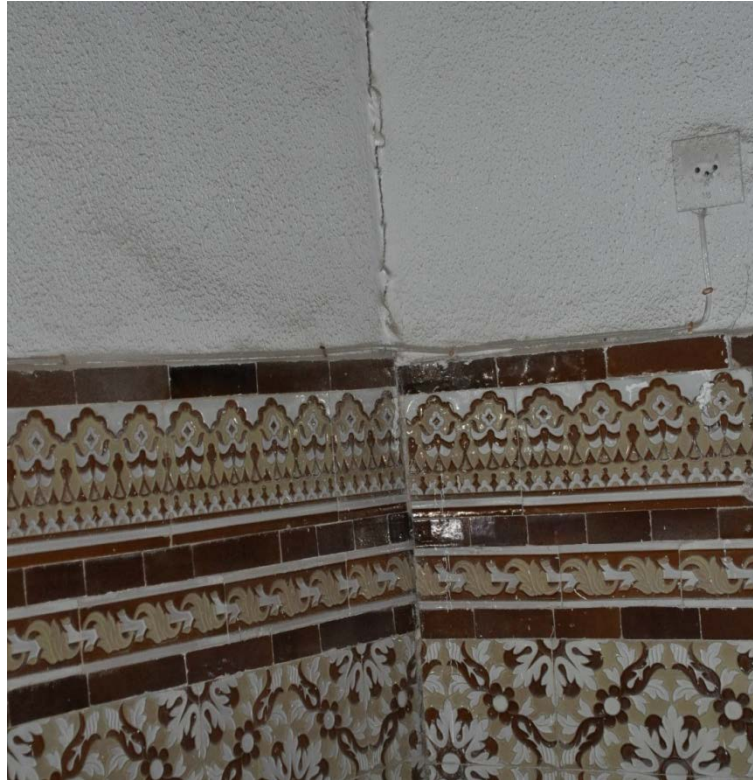

Figure 4. *Offset between tiled baseboards and cracks in the ground floor walls.*

However, the results still depend on many factors, eg the architectural type, the characteristics of the materials, the dimensions of the construction elements (walls and floors) or the position of the building within the block and the features of the surrounding buildings .

One of the most interesting aspects in the main research is the influence of the other buildings of the block in the dynamic response of the building under study. The influence of the clustered buildings in the structural behavior and in the proposal for repair of a building has been studied by Binda y Saisi[6], [7], Da Porto[8], or Valluzi[9], [10]. In order to simplify some decisions, our study is based on the findings of Da Porto [8].

This paper discusses just this influence and focuses on the following issues:

- How are the dynamic responses of a building modified, by it's position inside the block?
- How much change results between an analysis of an isolated building and another building within a block?
- Do clustered buildings affect the results of damaged buildings?

All these issues have been studied in combination with various floor solutions and with several states of structural integrity. More precisely, we have studied the case, described above, in which there is a crack in the joint between the bearing walls and the shared party walls.

2. METHODS

We carried out various dynamic analysis on a FEM model of a building located within a block. To this end, we have chosen a medium type block and we have selected a building located in the middle of one of its edges.
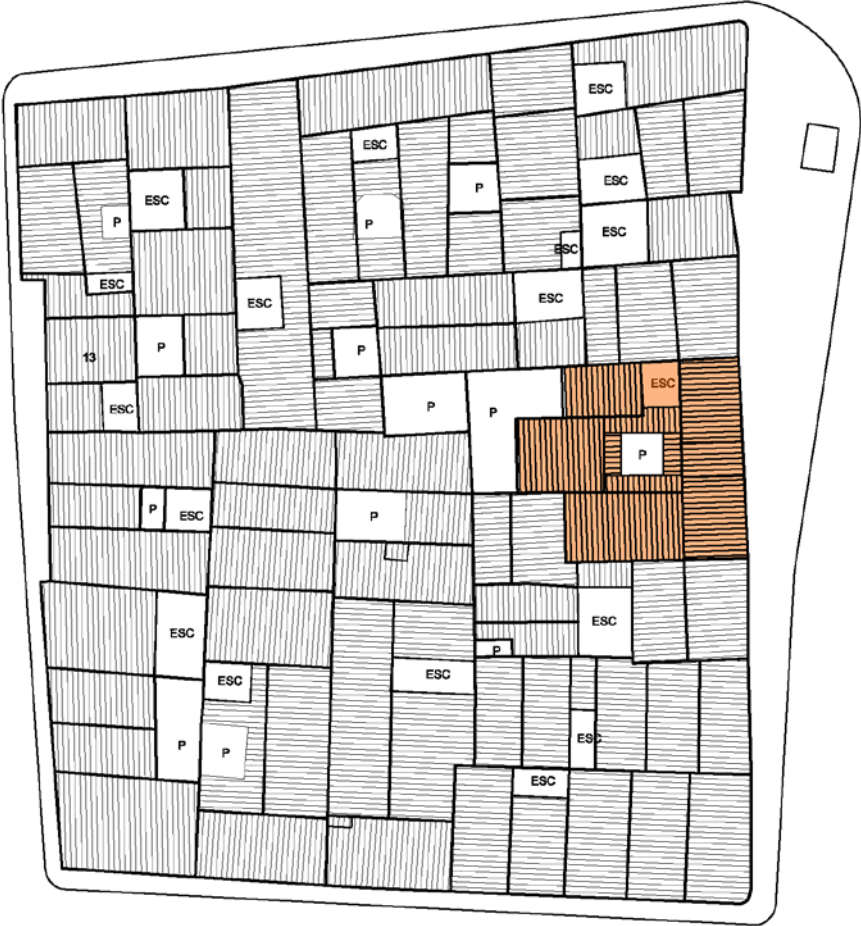

Figure 5. *Block scheme, indicating the situation of the selected building.*

The selected building fits the target of the research project: It is a three-storey building with traditional masonry structure. It has a first span parallel to the facade, a central courtyard with a perimeter gallery, two lateral bays and one end bay perpendicular to the facade.
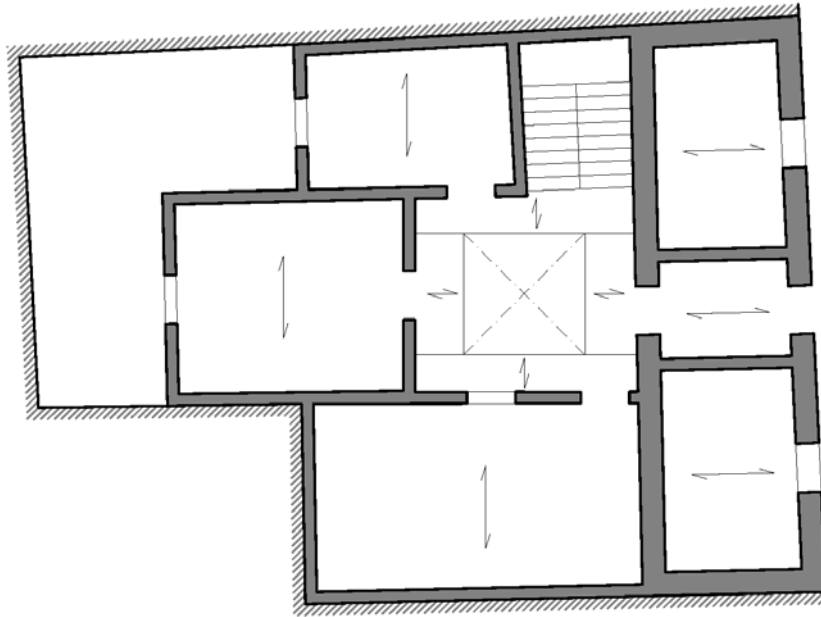
Figure 6. *Floor scheme of the selected building.*

The dynamic response analysis was carried out by the finite element method (FEM), using the computer program Sap2000. On all calculated models, we have discretized walls and floors with surface elements (*shell)* and beams with linear elements (*frame*). In fig. 7 and 8 there are represented FEM models of the isolated building and the full block.
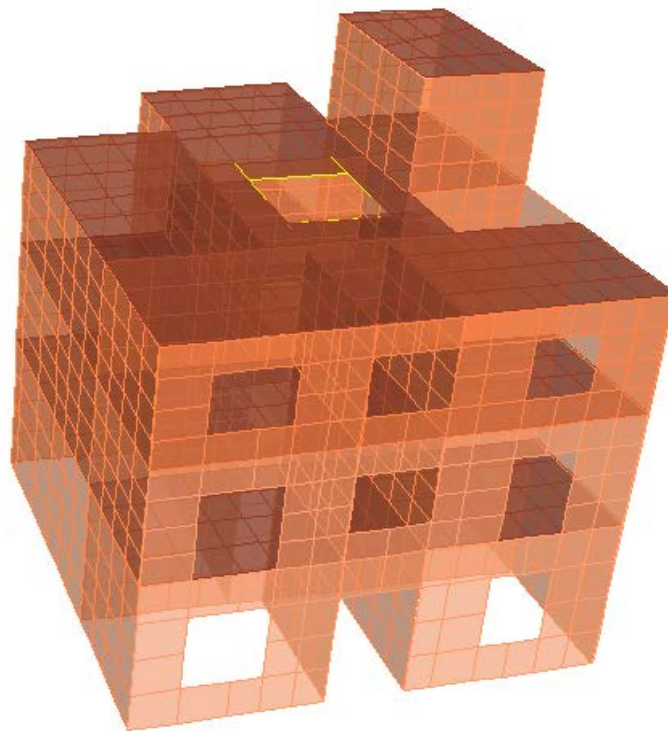

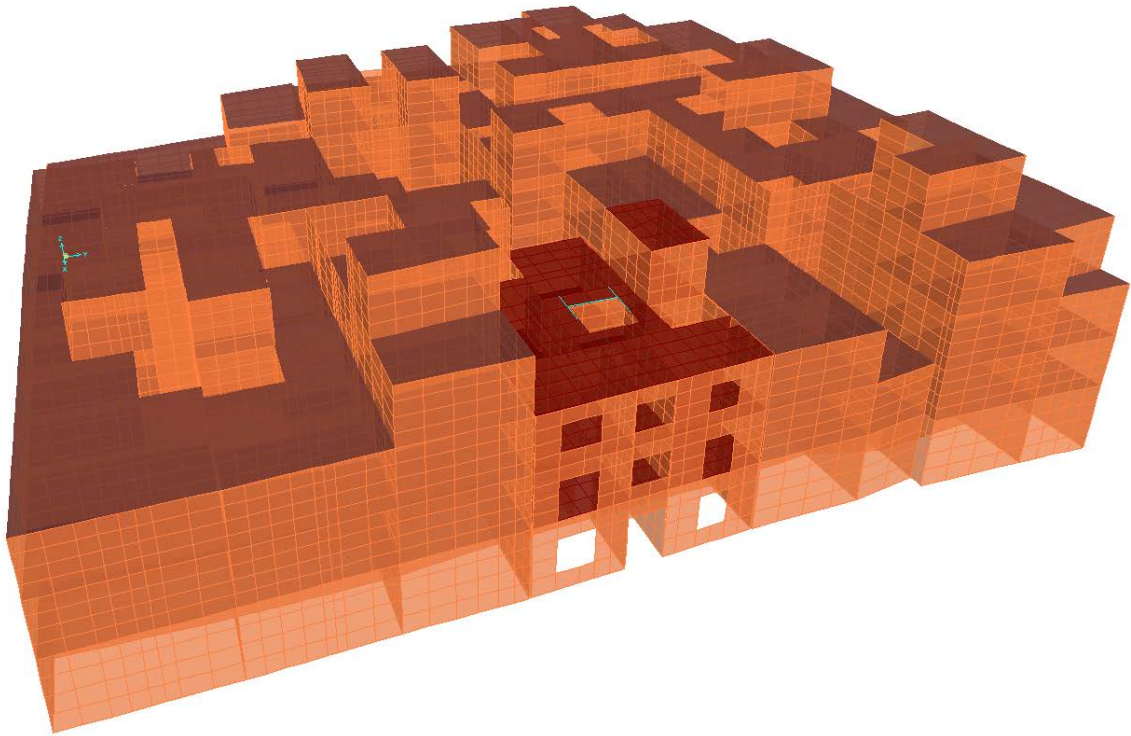**Figure 7.** *3D presentation of isolated building FEM model.*

Figure 8. *3D presentation of the block FEM model.*

The walls have been disconnected from the floors, as the bearing walls has been disconnected from the shear wall. It is easy to simulate the efforts transfer between slabs and bearing walls, a disconnection between floor and shear wall or a cracks between walls. To do this, we have created constraints between nodes, which allow to define the kind of effort that is transmitted.

We have applied a two-foot section on the first two floors of bearing walls and a foot on the upper floors walls and on the entire shear wall.

Figure 9. *Floor constructed with wooden beams and planking.*

The floor has been discretized by assimilation to a flat slab. We have used a constant modifier for the longitudinal bending stiffness (M11). In the several calculations, we have used modifiers to reduce transverse bending stiffness (M22) and the floor stiffness to tangential stresses (F12). In this way we can simulate slabs and one way slabs with or without a compression coat (Fig. 9).

Obviously, the diaphragm effect of the floor will affect the dynamic response of the building, as the numerous specific bibliography (Tena-Colunga & Abrams[11], [12]; Brignola, Pampanin & Podestà[13]–[15]), or international standards shows(ASCE/SEI 41-06 2007; FEMA 356 2000). In the case study we are dealing with, to simulate a floor constructed by joists and simple wooden planking (Fig. 8), we have used a value of 0.0025 for the F12 modifier. This value is a simplification of the results presented in (Brignola, Pampanin & Podestà[13]–[15]).

As we discussed above, some of the damages that can significantly modify the results of dynamic response are those that deconstruct the building, eg. cracks between bearing walls and shear walls, or disconnection between shear walls and flexible floor.

Of the various damages, we have selected those located on the first bay (Fig. 10). In this position and due to the positioning of the joists perpendicular to the facade, the stiffening effect of the block is obviously lower than the inner region.
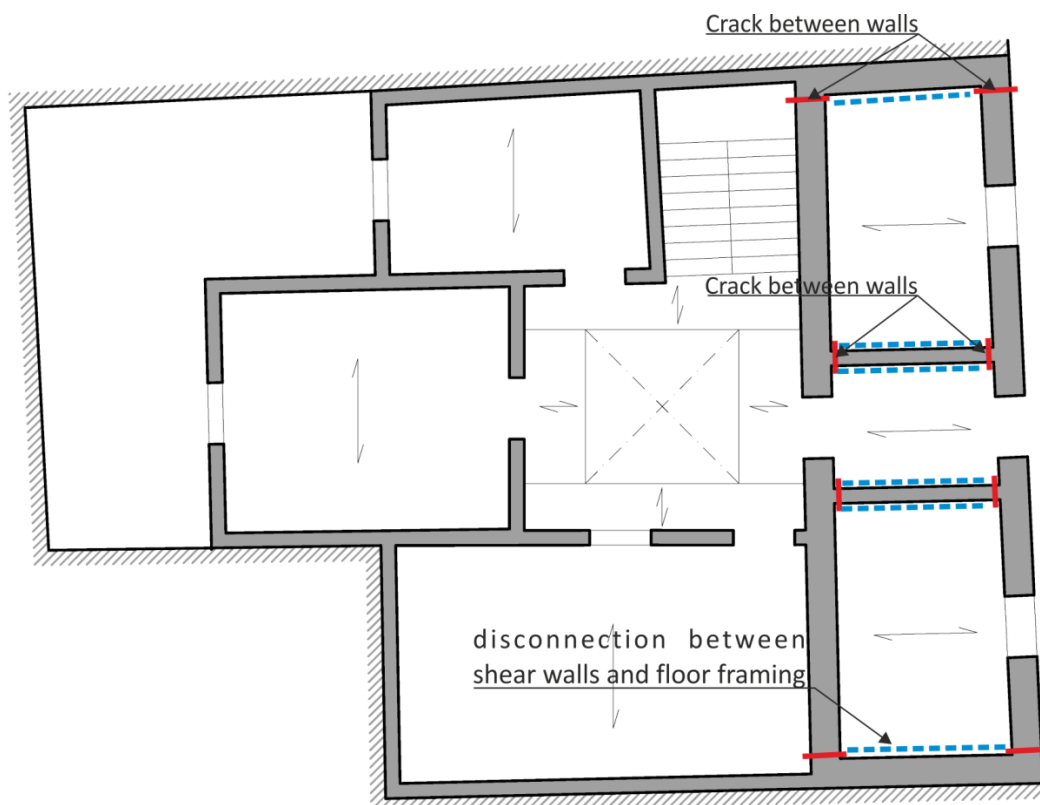

Figura 10. *Esquema del edificio con indicación de las lesiones que se han introducido.*

Tthe purpose of this research project is to verify whether it is possible to diagnose the integrity of this kind of masonry structure by running simple dynamic tests at selected points of the building. To this end, we propose to compare the frequency/acceleration graphics obtained by FFT analysis

of the signal obtained by the accelerometers transducer, with the graph obtained in the FEM model.

Specifically, we propose to compare the FFT graph, with the results of a Steady State analysis. As described in Sap2000 user handbook[16] and exposes clearly Barret[17], This analysis calculates the dynamic response to a set of harmonically varying loads at specified frequency increments. It seeks the steady state response, thus assuming an indefinite harmonic loading and all transient response has died down.

SteadyState analysis was performed at a point on the roof of the building, near the north end of the facade, in two orthogonal directions, perpendicular to front (X direction) and parallel to front (Y direction).

So far the test program was completed for only 11 case studies. Half of them, with isolated building and the other half with the building included in the block. The type of floor framing, the inclusion or the omittance of the diaphragm effect, and the presence of various damages has been considered. Described below, in Table 1, the cases studied:

Tabla 1. Descripción de los casos analizados

Caso	Descripción
1	Isolated building with rigid floor. Without damages.
2	Clustered building with common party wall. Rigid floor. Without damages.
3	Isolated building with rigid floor. Cracks between bearing walls and shear walls.
4	Clustered building with common party wall. Rigid floor. Cracks between bearing walls and shear walls.
5	Isolated building with rigid floor disconnected from shear walls. Cracks between bearing walls and shear walls.
6	Isolated building with flexible floor. Without damages.
7	Clustered building with common party wall. Flexible floor. Without damages.
8	Isolated building with flexible floor. Cracks between bearing walls and shear walls.
9	Isolated building with flexible floor disconnected from shear walls. Cracks between bearing walls and shear walls.
10	Clustered building with common party wall. Flexible floor. Cracks between bearing walls and shear walls.
11	Clustered building with common party wall. Flexible floor disconnected from shear walls. Cracks between bearing walls and shear walls.

3. RESULTS

After calculating the 11 models by FEM software Sap2000, the dynamic response graphs, in the studied point and directions, has been obtained. The results can be better analyzed after being processed by Matlab, because we can overlay charts from different models.

First, we expose the graphs (fig. 11, 12, 13 and 14) corresponding to flexible floor cases.
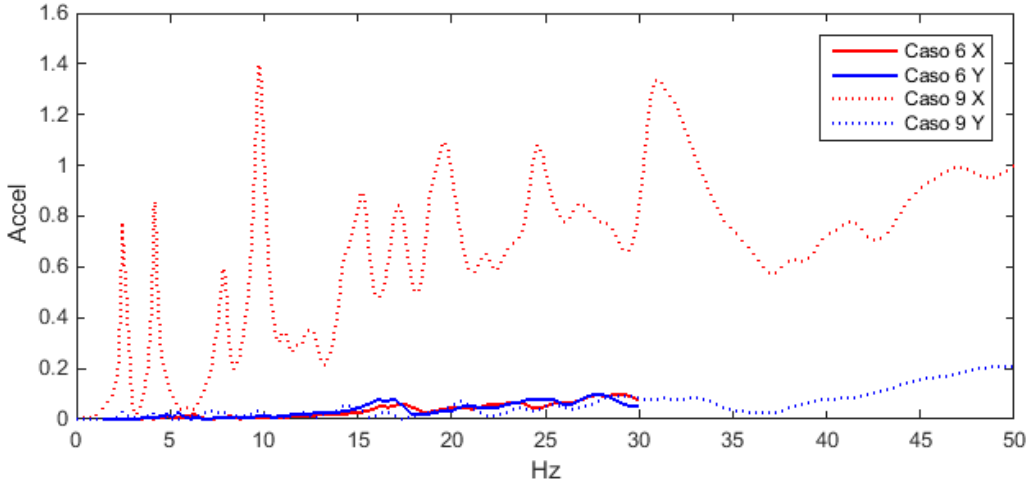

Figura 11. *Dynamic response graph for the studied point. Case 6 (isolated building with flexible floor and without damages) and case 9 (isolated building with flexible floor disconnected from shear walls and cracks between bearing walls and shear walls).*
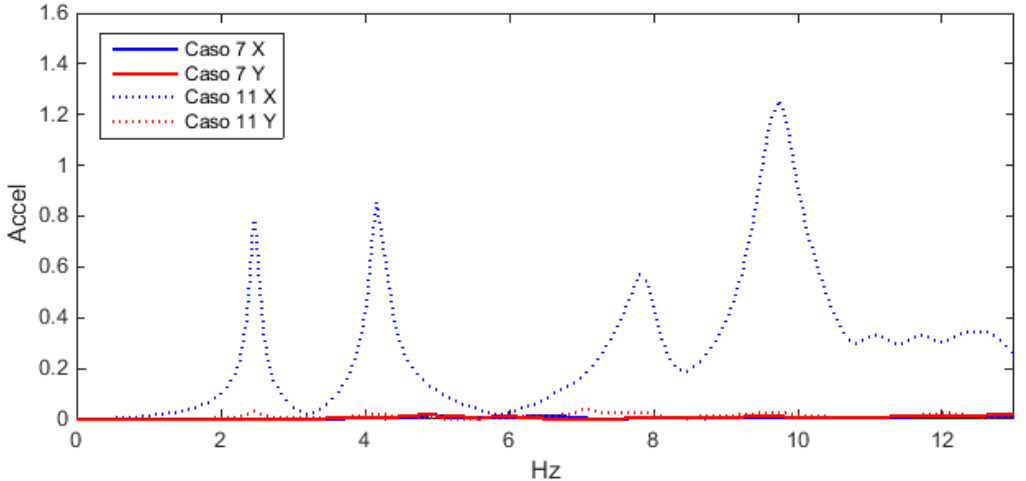

Figura 12. *Dynamic response graph for the studied point. Case 7 (Clustered building with common party wall, flexible floor and without damages) and case 11 (clustered building with common party wall, flexible floor disconnected from shear walls and cracks between bearing walls and shear walls).*

We found that when the floor only has a wood plank (without diaphragm effect) instead a compression layer, a significant difference in terms of scale appears on the curve corresponding to response in the X direction (perpendicular to facade). In Fig. 11, we can see the difference between case 6 (isolated building with flexible floor and without damages) and case 9 (isolated building with flexible floor disconnected from shear walls and cracks between bearing walls and shear walls).

In a similar study (Fig 12) including the block (cases 7 and 11), we can see that a great difference

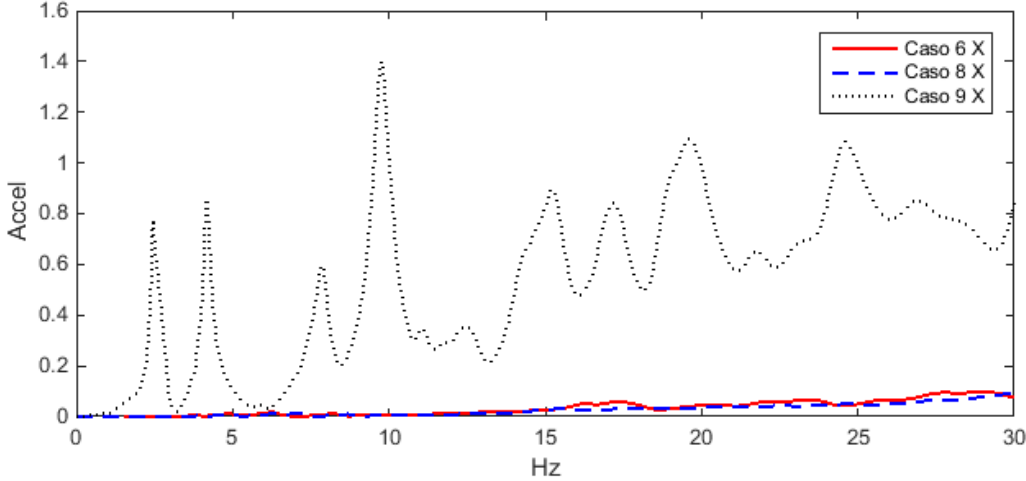appears again in X direction (perpendicular to facade).

Figura 13. *Dynamic response graph for the studied point. Case 6 (isolated building with flexible floor and without damages), case 8 (isolated building with flexible floor and crack between bearing walls and shear walls) and case 9 (isolated building with flexible floor disconnected from shear walls and cracks between bearing walls and shear walls).*
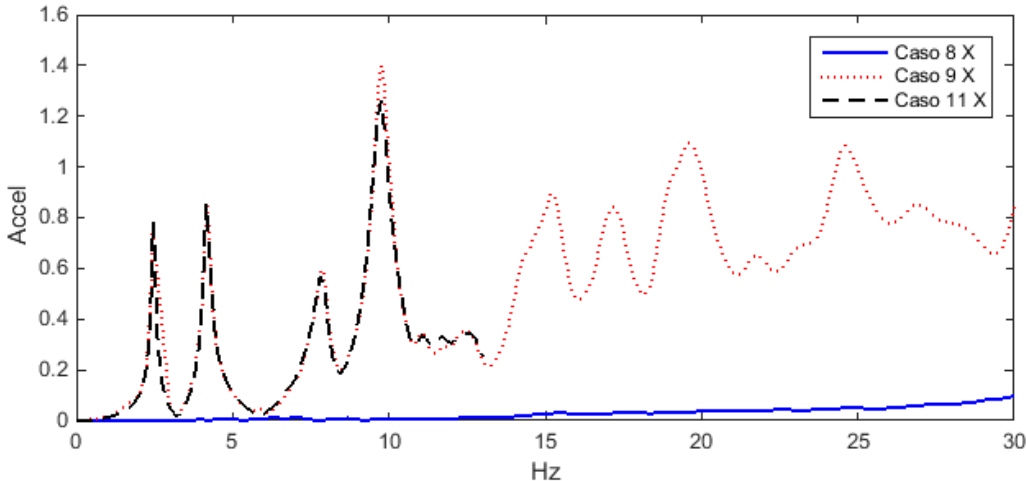

Figura 14. *Dynamic response graph for the studied point. Case 8 (isolated building with flexible floor and crack between bearing walls and shear walls), 9 (isolated building with flexible floor disconnected from shear walls and cracks between bearing walls and shear walls) and 11(clustered building with flexible floor disconnected from shear walls and cracks between bearing walls and shear walls).*

In figure 13 we have focused on the response in the X direction (perpendicular to facade) and cases 6, 8 and 9 have been overlapped. We can see that the response of Case 8 (isolated building

with flexible floor and cracks between bearing walls and shear walls) is very similar to Case 6 (isolated building with flexible floor and without damages).

Moreover, in Fig. 14 we can see how the block (case 11) does not affect the dynamic response of the building. Curves 9 and 11 almost directly coincide.
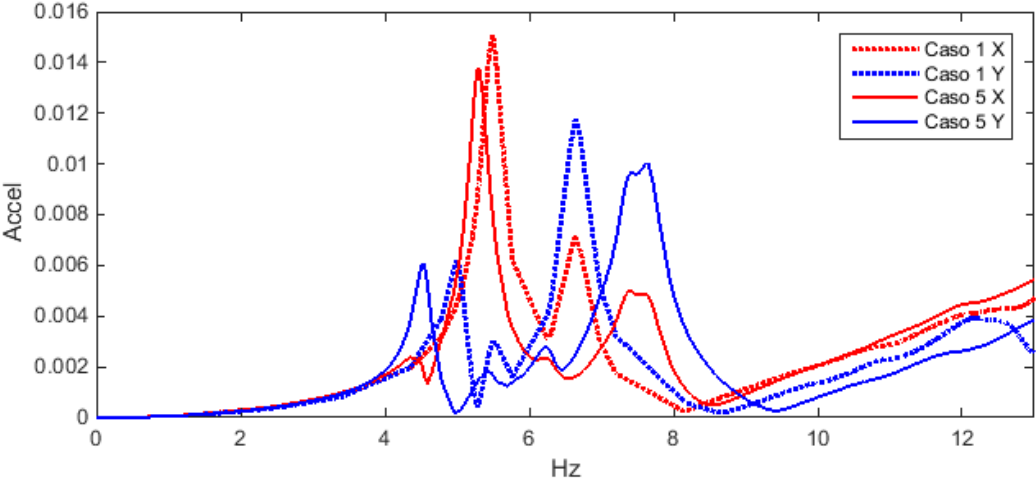

Figura 15. *Dynamic response graph for the studied point. Case 1 (isolated building with rigid floor and without damages) and case 5 (isolated building with rigid floor disconnected from shear walls and cracks between bearing walls and shear walls).*

Figura 16. *. Dynamic response graph for the studied point. Case 1 (isolated building with rigid floor and without damages), case 5 (isolated building with rigid floor disconnected from shear walls and cracks between bearing walls and shear walls) and case 11 (clustered building with flexible floor disconnected from shear walls and cracks between bearing walls and shear walls).*

Fig. 15 corresponds to cases with a rigid floor frame (with diaphragm effect). In it, we find that the difference between Case 1 (isolated building with rigid floor and without damages) and Case 5 (isolated building with rigid floor disconnected from s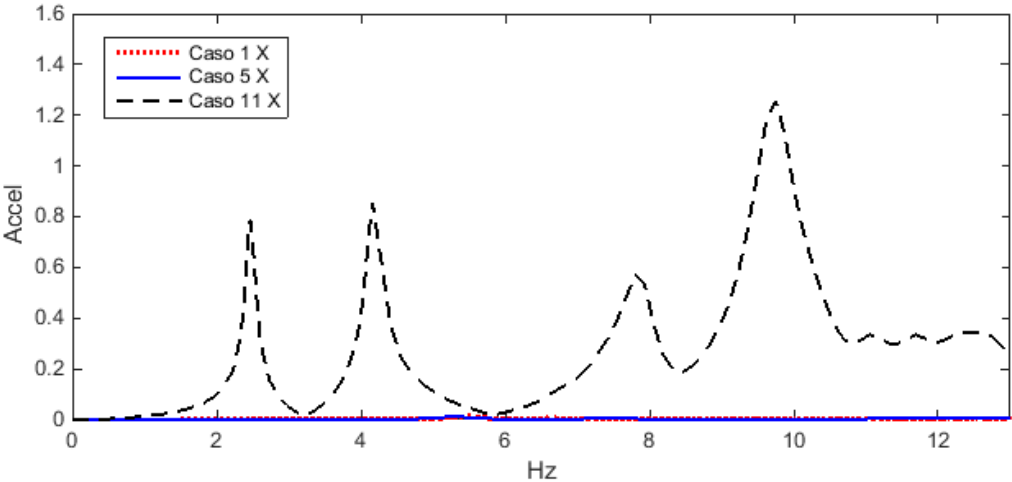hear walls and cracks between bearing walls and shear walls) are quite subtle. We have changed the vertical scale (accel.) to tell the difference.

In fig. 16 we have superimposed case 11 on the graph of fig. 15, in order to see the difference between the rigid and flexible floor framing, when the floor is disconnected from shear wal

4. CONCLUSIONS

In the results presented in the previous section, we note that, in the case of buildings with a flexible floor disconnected from shear walls and with cracks between bearing walls and shared walls, the dynamic response perpendicular to the facade rise hugely. For this particular case, the block has little effect on the response in that direction, as shown in Figure 14.

However, when the floor is connected with shear walls , or when the floor framing is rigid, the change in the dynamic response is too weak to identify by few simple tests, as we can deduce from the figures 15 and 16. Therefore, in these cases, the block doesn't causes significant effects on the dynamic response of the building.

REFERENCES

[1]   F. Pérez Gálvez, C. Rodríguez Liñan, and A. Jaramillo Morilla, "Las obras de fábrica en la arquitectura doméstica sevillana de los siglos XVIII y XIX: características constructivas y parámetros resistentes," Escuela Técnica Superior de Arquitectura, Departamento de Construcciones Arquitectónicas I, Sevilla, 2004.

[2]   F. Pérez-Gálvez, C. Rodríguez-Liñán, and P. Rubio, "Determinación de las características mecánicas de los muros de fábrica de ladrillo en la arquitectura doméstica sevillana de los siglos XVIII Y XIX," *Inf. la Construcción*, vol. 61, no. 514, pp. 19–28, Jun. 2009.

[3]   R. Huete Fuertes, A. Jaramillo-Morilla, C. Rodríguez-Liñán, V. Sanz Cuesta, and L. Suárez Samaniego, *Protocolo de inspección técnica de edificaciones ITE*. Sevilla, 2005.

[4]   E. Vázquez Vicente and J. M. Estero Tendero, "Análisis dinámico de edificios historicos. La espadaña de la Iglesia de Santa María de la Blanca, Sevilla," *Star Struct. Archit.*, vol. 9, 2004.

[5]   E. Vázquez Vicente, J. M. Estero Tendero, F. Escrig Pallarés, and J. Sánchez Sánchez, "Análisis dinámico de edificios antiguos. Una metodología para un caso concreto.," in *Master Erasmus*

Mundus Peritacion Reparacion Edificios 2008-2013, Sevilla. España: Starbooks, 2013, pp. 27–40.

[6]   L. Binda and A. Saisi, "Knowledge of the building, on site investigation and connected problems," in *Eurocode 8 perspectives from the Italian Standpoint Workshop*, 2009, pp. 213–224.

[7]   L. Binda and A. Saisi, "Research on historic structures in seismic areas in Italy," *Prog. Struct. Eng. Mater.*, vol. 7, no. 2, pp. 71–85, Apr. 2005.

[8]   F. da Porto, M. Munari, A. Prota, and C. Modena, "Analysis and repair of clustered buildings: Case study of a block in the historic city centre of L'Aquila (Central Italy)," *Constr. Build. Mater.*, vol. 38, pp. 1221–1237, Jan. 2013.

[9]   M. R. Valluzzi, "On the vulnerability of historical masonry structures: analysis and mitigation," *Mater. Struct.*, vol. 40, no. 7, pp. 723–743, Oct. 2006.

[10]   M. R. Valluzzi, G. Cardani, L. Binda, and C. Modena, "Seismic vulnerability methods for masonry buildings in historical centres: validation and application for prediction analyses and intervention proposals," in *13 th World Conference on Earthquake Engineering*, 2004, no. 2765.

[11]   A. Tena-Colunga, "Seismic Evaluation of Unreinforced Masonry Structures with Flexible Diaphragms," *Earthq. Spectra*, vol. 8, no. 2, pp. 305–318, 1992.

[12]   A. Tena-Colunga and D. P. Abrams, "Seismic Behavior of Structures with Flexible Diaphragms," *J. Struct. Eng.*, vol. 122, no. April, pp. 439–445, 1996.

[13]   M. Betti, L. Galano, and A. Vignoli, "Comparative analysis on the seismic behaviour of unreinforced masonry buildings with flexible diaphragms," *Eng. Struct.*, vol. 61, pp. 195–208, Mar. 2014.

[14]   A. Brignola, S. Pampanin, and S. Podestà, "Experimental Evaluation of the In-Plane Stiffness of Timber Diaphragms," *Earthq. Spectra*, vol. 28, no. 4, pp. 1687–1709, 2012.

[15]   A. Brignola, S. Pampanin, and S. Podestà, "Evaluation and control of the in-plane stiffness of Timber floor for the performance-based retrofit of URM buildings," *Bull. New Zeal. Soc. Earthq. Eng.*, vol. 42, no. 3, pp. 204–221, 2009.

[16]   I. Computers and Structures, *CSI Analysis Reference Manual*, no. April. 2009.

[17]   A. R. Barrett, "Dynamic Testing of In-Situ Composite Floors and Evaluation of Vibration Serviceability Using the Finite Element Method (unpublished PhD. thesis)," Virginia Polytechnic Institute and State University, 2006.