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Influence of the type of masonry construction on the dynamic, response spectrum analysis.

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Abstract

The influence of the type of masonry construction of traditional buildings on the dynamic behavior of old buildings with masonry walls is the subject of this work. Comparison of the eigenmodes, periods and the participation factors for each mode, permits us to find the relation between the type of masonry and the dynamic, response spectrum analysis. This is an important step to estimate the behavior of the structure due to earthquake loading. The strengthening methods which were examined consist of three basic types of masonry construction and are: reinforced concrete slabs, reinforced concrete tie-beams and reinforced concrete tie-columns. The influence of the plan geometry and the existence of internal shear wall is also examined.

1 Introduction

The particular nature of old buildings that use stone masonry walls is found in the characteristics of the material used (brittle behavior), the weight, the high stiffness and the lack of continuity (they are not monolithic). For the modeling a isotropic material was considered. The assumption of linear elastic behavior of the masonry is a good estimation because the non-linearity has been taken account to the properties of the material, like the low tensile strength.

The main cause of damage in building structures during an earthquake is usually their response to ground induced motion. For civil engineering structures, the uncertainties and the statistical nature of the loading sequence has led to the wide adoption of the modal analysis technique, which is based on appropriate earthquake design spectra, as the more appropriate design method. The modal, spectral analysis technique is based on the assumption that for a linear elastic system the dynamic behavior is described from the dynamic characteristics like the eigenvalues and the eigenmodes of the discretized system, e.g. Stavroulaki et. al. [1].

A three dimensional finite element model seems to be in general the most suitable for the discretization of the structure and the analysis. For a model of higher reliability specific simulation parameters, like the rotation capacity of the wooden floor connection with the masonry wall, the rigidity degree of connections between intersected walls, the influence of spandrel beams, etc. have always to be taken into account. The out of plane resistance and ductility is of a paramount interest in dynamic analysis.

In this paper the influence of the existance of some elements which are used to reinforce the masonry structure to the dynamic characteristics and in particular to the eigenmodes and the participation factors, is analyzed. As a case study, a small house with typical plan where the wooden roof has replaced from a reinforced concrete slab was examined.

2 Methods of strengthening.

As it is known the replacement of the wooden roof with a reinforced concrete slab affects the stiffness and the mass of the structure. The reinforced concrete slab connects the walls of the structure and the stiffness of the system. The transfer of the loads to the walls is analogous by to its stiffness. The slabs are considered as local reinforcements techniques which reduces the out of plane function of the walls. It permits a more harmonic cooperation between all the walls of the structure which, in turn, are assumed to have sufficient strength capacity to carry safety the additional loading.

Another fact is the replacement of big stones which were typically used over the windows and doors with reinforced concrete tie-beams. The horizontal reinforced concrete tie-beams and the vertical reinforced concrete columns decrease the stiffness of the out of plane behavior of a masonry wall which is important for the resistance under horizontal loads. Their construction on an old building require that the old structure has enough strength. They are considered a local reinforcement technique to relief the structure, by reducing the horizontal tensile stresses which are important to the out of plane bending. It must be noted that the use of concrete which has a shorter life than masonry reduce and the whole structural life. The existence of these strengthening elements in the upper and lower elements of the openings, lead to the reduction of the high tensile stresses which are developed at these places and are the beginning of the deterioration of the building, e.g. Spence & Coburn [2]. Several design codes indicate the construction of R.C. tie-beams, R.C. tie-columns or combination of the two, e.g. Sapounaki [3].

3 Models

3.1 Geometry, Material.

A rectangular shape building was considered with dimensions 12.00 m ×8.00m. Its height is about 3.50m. The thickness of the wall is about 0.50 m, of the roof is about 0.15 m and the depth of the foundation is about 0.65 m.

The finite element method is used with 4-node quadrilateral thick shell elements with membrane and bending capabilities. Six degrees of freedom (three translations and three rotations) per node are considered. In the final discretization all the necessary controls were done (for example the relationship between the dimensions of the elements and the angles must lie in acceptable ranges) in order to eliminate the numerical errors and to enhance the reliability of the model.
Three different types of material were considered as they are given in Table 1.

Table 1 : Material assumptions.

Material	Modulus of Elasticity (kg/m^2)	Poisson ratio	Density (kg/m^3)	Region
MP1	6.15×10^8	0.15	1700	Foundation
MP2	8.825×10^8	0.15	1944	Masonry walls
MP3	2.74066×10^9	0.20	2400	Roof

3.2 Description of the models.

The models which were examined are separated in the following categories.
A)Influence of the reinforced concrete slabs, tie-beams and tie-columns.

- **Model A1: Reinforced Concrete Slabs.** A reinforce concrete slab is considered at the level of the roof and the masonry walls are constructed using stone.
- **Model A2 : Reinforcement elements from big stones over the doors and windows.** In older times houses were built using big stones over the doors and windows. In order to model these reinforcement elements Beam 2D finite elements were used which are 2-node elements . Three degrees of freedom (two translations and one rotation) per node are considered.
- **Model A3 : Horizontal Reinforced Concrete tie-beams.** Reinforced concrete tie-beams were considered under the roof, over the door and over and under the windows. These elements belong to the same material as the roof.
- **Model A4: Vertical Reinforced Concrete tie-columns.** Vertical Reinforced Concrete tie-columns are considered in various places around the masonry walls (see Fig. 1).

- **Model A5: Vertical and Horizontal Reinforced Concrete tie-beams and tie-columns correspondly.** A combination of the models A3 and A4 is considered as it is shown in Fig. 2.

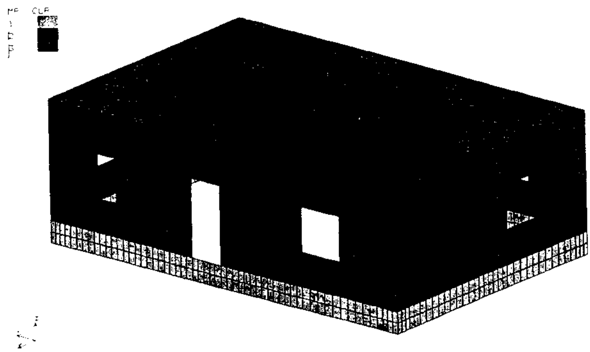

Figure 1 : Model A4. Vertical Reinforced Concrete tie-columns.

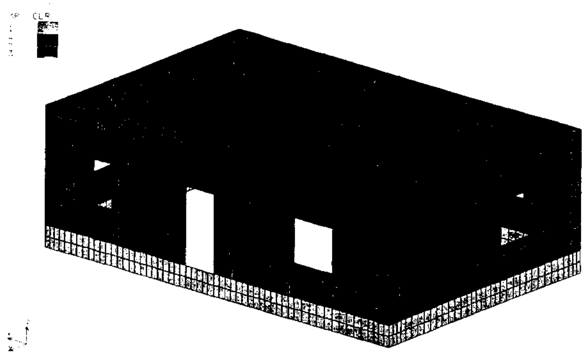

Figure 2: Model A5.Vertical and Horizontal Reinforced Concrete tie-beams and tie-columns.

B) **Influence of concrete walls and columns.**

- **Model B1: Reinforced Concrete Slabs.** It has been described before as Model A1.
- **Model B2: Reinforced Concrete wall.** A reinforced concrete wall was considered to a face of the structure as it is shown in Fig. 3.
- **Model B3: Reinforced Concrete columns and walls.** Reinforced concrete columns and walls are considered in different places in the perimeter of the building as it is shown in Fig. 4.

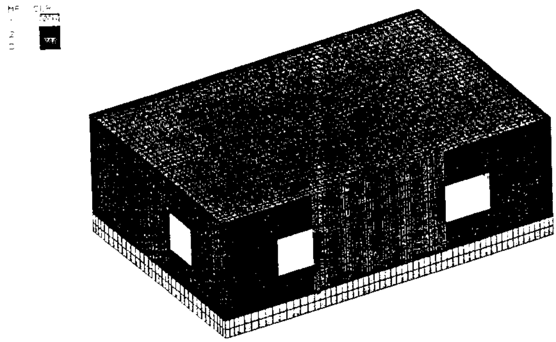

Figure 3: Model B2. Reinforced concrete wall.

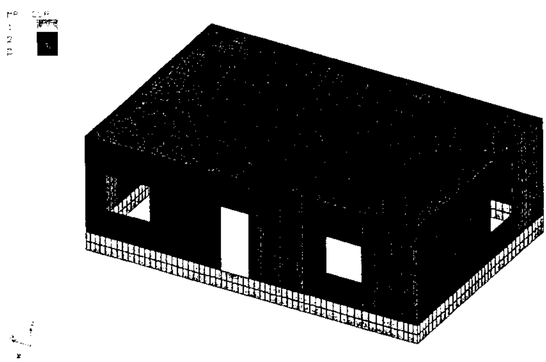

Figure 4: Model B3. Reinforced concrete columns and walls.

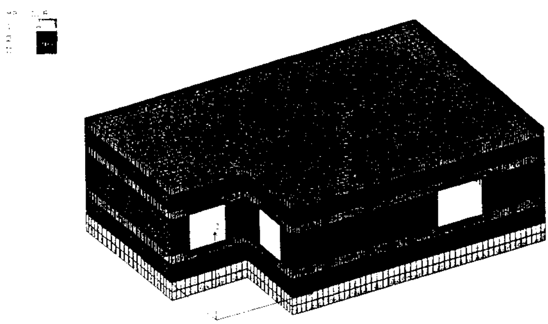

Figure 5: Model C3. : Non - orthogonal plane construction .

C) **Influence of shape-outline and the existence of an internal shear wall.**

- **Model C1 : Horizontal Reinforced Concrete tie-beams and orthogonal plan.** This model has been described in category A as Model A3.
- **Model C2: Horizontal Reinforced Concrete and internal shear wall.** Additional to the previous consideration an internal shear wall was placed.
- **Model C3: Non - orthogonal plane construction.** A different non-orthogonal plane construction is considered with the same assumptions as model C1. It was defined by subtraction of a section with length 2.80 meters from the directions x and y as it is shown in Fig. 5.

The F.E. models consist of 4269 elements and 4428 nodes except model C2 which has 4724 elements and 4870 nodes and model C3 with 5445 elements and 4450 nodes.

4 Response spectrum analysis and design spectrum.

The dynamic behavior of a linear elastic system can be described through its dynamic characteristics. Using frequency analysis the possible ways of vibration (eigenmodes) and the corresponding frequencies are calculated. So it is important to use a reliable model taking into account all the details which affect the system and are the cause of the damage that lead to collapse. The greater portion of damage or collapse of masonry structures during violent quakes are due a) to poor linkage between orthogonal walls, b) lack of rigid slabs, c) inappropriate roofs, d) settlement of foundations, e) hammering of adjacent structures, f) poor materials, etc., Benedetti & Castellani [4].

The calculation of dynamic characteristics of the structure is a good way for a reliable estimate of, the frequency range in which an earthquake excitation will seriously affect the structure. It is also important for the identification of the specific points of failure of the structures which lead to the proper selection of restoration or strengthening method, e.g. Leftheris et. al. [5]. In Figures 6-8 some of the calculated eigenmodes for the examined models are shown.

Dynamic loading is considered by means of modal analysis techniques based on appropriate design spectra adopted by most design specifications. Using the design earthquake spectrum the statistically expected earthquake is taken into account. This spectrum which describes the acceleration for different periods and depends on the characteristics of the region and of the building. (i.e. type of foundation, the damping defined by its structural system) is important for masonry construction. According to the New Aseismic Design Specification of Greece which is in accordance with the European Codes, the masonry construction is described by three categories e.g. NADCG [6].

They depend on the existence of horizontal reinforced concrete tie-beams and vertical reinforced concrete tie-columns or reinforced masonry. In Fig. 9 the seismic design acceleration spectrum in horizontal direction is shown for

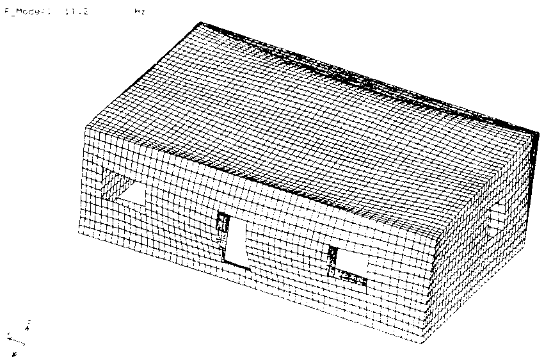

Figure 6 : First mode of Model A1.

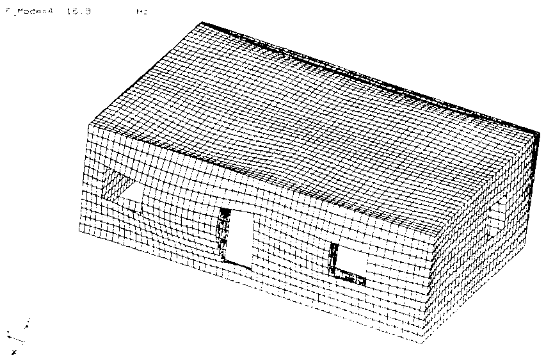

Figure 7 : Fourth mode of Model C2.

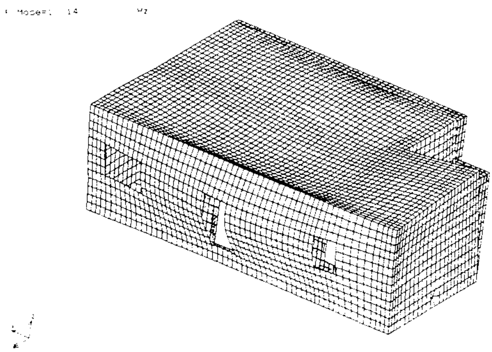

Figure 8 : First mode of Model C3.

these three types of masonry construction. The first branch of the spectrum is important, because the seismic loading is reduced significant, by especially in masonry structures with high stiffness. It is noted that in practice the masonry structures are not just one of these types, but instead they are a combination of them or something different (like the non-existence of any reinforcement element).

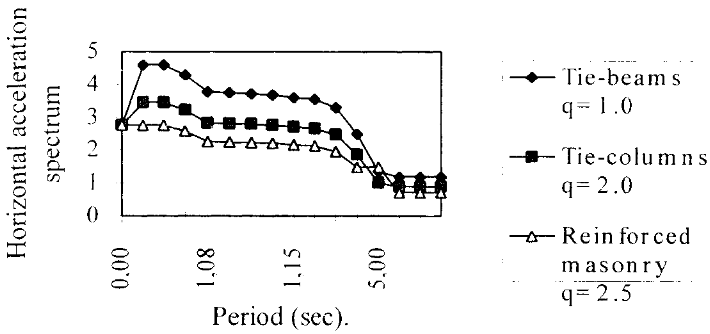

Figure 9: Acceleration design spectrum for three types of masonry construction.

For the seismic design spectrum the participation factors are estimated. These determine the extent of (energy based) participation of the eigenvibrations to the resultant vibration of the structure. The results indicate different participation factors for the two basic directions of seismic excitation. This means that the response depends on the direction of the seismic excitation. The basic reason for this difference is the particular characteristics of the geometry (dimensions of the plan, shape of plan, existance and place of windows and doors, connections between the walls etc.), the stiffness and the mass of the structure. The participation factors in conjunction with the design that definite the characteristics of the seismic excitation, permit us to estimate the significant contribution of each eigenvibration to the dynamic response of the structure. In Figures 10-11 the participation factors for the two directions (X, Y) and for the models according to the category in which they belong, are shown. It is important to note that for models in A category, the second mode for the X direction and the first mode for the Y direction are the significant participations. Their corresponding factors are given in tables 2-4.

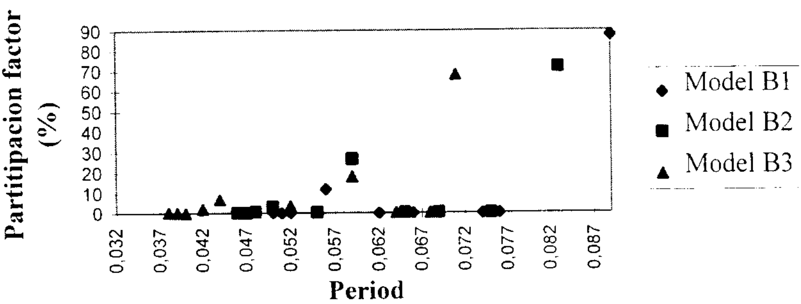

Figure 10 : Participation factors for Y direction of models in B category.

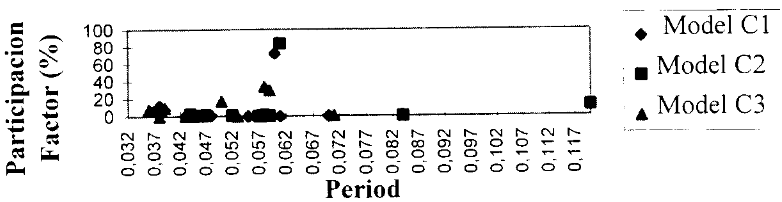

Figure 11: Participation factors for X direction of models in C category.

Table 2. Significance modes of models in category A.

	Direction X			Direction Y		
Model	Mode	Period	Part. Factor	Mode	Period	Part. Factor
A1	2	0,076	80,66%	1	0,089	87,65%
	9	0,051	7,22%	7	0,056	11,93%
A2	2	0.072	91,32%	1	0,087	91,49%
A3	3	0,060	72,14%	1	0,070	80,56%
	9	0,038	11,83%	7	0,043	18,58%
A4	2	0,067	79,38%	1	0,074	90,23%
	10	0,042	10,76%			
A5	2	0,054	71,35%	1	0,058	81,94%
	10	0,032	14,68%	7	0,037	12,66%

Table 3. Significance modes of models in category B.

	Direction X			Direction Y		
Model	Mode	Period	Part. Factor	Mode	Period	Part. Factor
B1	2	0,076	80,66%	1	0,089	87,65%
	9	0,051	7,22%	7	0,056	11,93%
B2	2	0,075	81,14%	1	0,083	71,82%
	9	0,047	8,48%	5	0,059	26,64%
B3	2	0,068	69,26%	1	0,071	68,03%
	8	0,040	14,49%	4	0,059	18,06%

Table 4. Significance modes of models in category C.

	Direction X			Direction Y		
Model	Mode	Period	Part. Factor	Mode	Period	Part. Factor
C1	3	0,060	72,14%	1	0,070	80,56%
	9	0,038	11,83%	7	0,043	18,58%
C2	3	0,061	83,36%	4	0,059	94,43%
	1	0,120	11,72%			
C3	3	0,058	33,99%	1	0,071	81,74%
	2	0,059	29,81%	7	0,043	8,57%
	5	0,050	17,33%			

5 Conclusions

For restoration analyses the geometry and the materials of the buildings are defined so we seek to find the best way to strengthen the structure with the purpose to have a better structural behavior under dynamic loading. The frequency analysis and the response spectrum for the earthquake design lead to a reliable estimation of the vibrational behavior of the system for the expected earthquake. The participation factors indicate the significant modes which will participate in the final vibration of the system. The additional elements like the reinforced concrete tie-beams, the reinforced concrete columns and the reinforced concrete slab increase the stiffness and the mass of the system, but their influence depend on the geometry and the scale of the structure. In the present paper the influence of the usually applied strengthening measures on masonry structures has been calculated by means of finite element computations. These results can be used either for the extraction of practical construction rules and for the choice of good reinforcement strategies for typical structures in a given area by means of parametric investigations, of they can be integrated into a structural optimization environment to be used to be used for more complicated (nonclassical) structures, e.g Stavroulaki et.al.[7].

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