Comparison of different approaches of modelling in a masonry building

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Abstract. The present work has the objective to model a simple masonry building, through two different modelling methods in order to assess their validity in terms of evaluation of static stresses. Have been chosen two of the most commercial software used to address this kind of problem, which are S.T.A. Data S.r.l. and Sismicad12 of Concrete S.r.l. While the 3Muri software adopts the Frame by Macro Elements Method (FME), which should be more schematic and more efficient, Sismicad12 software uses the Finite Element Method (FEM), which guarantees accurate results, with greater computational burden. Remarkably differences of the static stresses, for such a simple structure between the two approaches have been found, and an interesting comparison and analysis of the reasons is proposed.

1. Introduction
Modelling a structure is certainly a fundamental issue to tackle very carefully, in fact from that it depends, in large part, the reliability and the interpretation of the results obtained by the software of calculation. Often professionals choose superficially the software for carrying out the structures analysis, and especially in the case of historic structures of masonry, that could lead to underestimate structural problems. The model of the structure should be three-dimensional and adequately represent the spatial distribution of mass, stiffness and strength, in the other hand the discretization of the structure normally carried by the software should be carefully analysed to verify spatial distribution as well in restricted spaces where the discretization is difficult. With the objective to assess the reliability of the results of commercial software, a comparison between different types of approaches has been done, in particular between the methodology Finite Elements Methods (FEM)[1-3], already known and established, implemented in Sismicad12 software, and the new modelling technique elaborated from the University of Padua, Italy, called Frame Macro Elements (FME) implemented in 3Muri software [4-6]. The latter has been developed mainly to carry out analysis of masonry structures, and complies with international regulations as well as Sismicad12. A simple case of a masonry structure has been studied, and static analysis with the two softwares mentioned has been carried out.

2. Methodology
Below are exposed the theoretical basis of the two methods, which are then implemented in Sismicad12 and 3Muri software to determine stresses and deformations of the structure.
2.1. Finite element method
The FEM originally developed for complex problems in structural mechanics, it is the main method used for complex systems [7]. In the FEM, the structural system is discretized by a set of points called nodes interconnected between them. At the nodes can be applied physical properties such as coefficient of thermal expansion, Young's modulus, shear modulus, Poisson's ratio. The fundamental idea is to discretize a given object for obtaining a discrete problem, that is a system of equations with a finite number of unknowns that can be resolved by a solver [8].

2.2. Frame by macro element method
The FME is a strategy for three-dimensional analysis of masonry buildings [9]. As mentioned from the authors of the schematic model [10], structural element modelling strategies are based on the identification of macroscopic structural elements, defined from a geometrical and kinematic point of view through finite elements (solid, shell or frame) and described from a static point of view through their internal generalized forces [11]. Usually two main structural components may be identified: piers and spandrels. This idealization starts from the earthquake damage observation that shows as usually cracks and failure modes are concentrated in such elements (Figure 1) [9,12].

![Figure 1. (a) Identification of spandrels; (b) Identification of nodes; (c) Equivalent frame. Adapted from Lagomarsino et al. [9].](image)

3. Discussion and results
The building object of study is a simple masonry shell size, 4m×7m in plan (A), height 3m, and wall thickness 0.3m, with unidirectional rigid floor which is based on the walls P1, P3 and P5 (Figure 2), with masonry blocks of soft stone, tufa and limestone.

![Figure 2. Plan of the masonry box.](image)

Once has been developed the model with both software, and made the static analysis, applying a load q of 11.95kNm\(^1\), it can be clarifying the actual distribution of the loads on the whole structure. The walls P1 and P3, show a significant difference in terms of resistance action, \(Nu\), and applied action \(N\) (Table 1), which outlines a totally different approach referring to the perimeter walls, orthogonal to the
floor load. Analysing the results relating to the wall P5, \( Nu \) is basically the same between the two software, contrariwise \( N \) is significantly different.

Table 1. Result of the Static Analysis done with the two software.

| Wall       | Quote (m) | N (daN)    | Nu (daN)    | N/Nu | Verified |
|------------|-----------|------------|-------------|------|----------|
| P1 and P3  | 3         | 5050       | 8264        | 3Muri| Sism12   | 66263 | 32427 | 0.076 | 0.254 | yes | yes |
|            | 1.5       | 8723       | 10625       | 66263 | 53286 | 0.132 | 0.199 | yes | yes |
|            | 0         | 12395      | 13588       | 66263 | 32427 | 0.187 | 0.419 | yes | yes |
| P5         | 3         | 5050       | 16376       | 66263 | 67319 | 0.076 | 0.243 | yes | yes |
|            | 1.5       | 8723       | 16154       | 66263 | 67319 | 0.132 | 0.243 | yes | yes |
|            | 0         | 12395      | 16740       | 66263 | 67319 | 0.187 | 0.248 | yes | yes |
| P2 and P4  | 3         | 8804       | 278         | 115960| 17807 | 0.076 | 0.002 | yes | yes |
|            | 1.5       | 15232      | 10196       | 115960| 117807| 0.131 | 0.008 | yes | yes |
|            | 0         | 21659      | 19108       | 115960| 17807 | 0.187 | 0.16  | yes | yes |

Although the static analysis is satisfied, even in the walls P2 and P4 can be noticed a remarkable difference in terms of applied action \( N \). 3Muri software considered the schematization of the wall and its correspondent loads as shown in Figure 3. Considering the load applied uniformly on the floor, the yellow part falls upon the walls P1 and P3, the blue part upon the P5 and the red part upon P2 and P4.

![Figure 3. Allocation scheme of loads adopted by 3Muri software.](image)

Analysing the results, can be said that the walls P1, P3 and P5 at the top are loaded in the same way, instead, the side walls, P2 and P4, also take a share of the load. Figure 4 shows the complex stress distribution inside the building panels with Sismicad12, this type of modelling takes into account therefore the enchain between the walls, mutual wind bracing, mutual contrast respect to the instability, and collaboration between the walls to support vertical loads.

In addition, the elastic calculation can be done manually, considering areas of influence, and that can help to clarify and provide a meter of judgment for assessing the consistency of the results presented by the two software. Starting from the given scheme of the floor, the walls parallel to the warping load, P2 and P4, can be consider almost unloaded.

About the walls P1, P3 and P5 perpendicular to the warping load, the loading area can be assumed as in Figure 5, at the top of each bearing wall, thereafter the load on the side walls P1 and P3 can be assumed to be equal to \( P/4 \) and on the central wall \( P/2 \), being \( P \) the total weight on the floor (1).

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P = qA = 33460\text{daN}
\]
Figure 4. Isometric view of stresses and mapping colors, Sismicad12.

It can be immediately noted that the so found values (Figure 5) are quite similar to those resulting from the FEM analysis.

Figure 5. Load distribution on the load bearing walls.

Comparing the results with the FME modelling instead, it is shown a marked difference in the calculated values, in the case of the walls P2 and P4, it is found a value equal to 8800 daN, against an almost zero in the FME modelling. Furthermore, the walls P1, P3 and P5 have values equal to 5050 daN in the top, with 3Muri, against 16300 daN (wall P5) and 8300 daN (walls P1 and P3) of the FEM model.

Looking at the bottom of the bearing walls, where it is necessary to take into account the own weight of the masonry, further assessment can be done.

Table 2. Account of the own weight of the masonry walls P1, P2, P3, P4 and P5.

| Walls   | t (m) | Length (m) | ho (m) | limestone $\gamma_{masonry}$ (daN $m^{-3}$) | Safety factor $\gamma_{GI}$ | Weight of the Masonry (daN) |
|---------|-------|------------|--------|---------------------------------------------|-----------------------------|-----------------------------|
| P1, P3, P5 | 0.30  | 4.00       | 3.00   | 1600                                        | 1.3                         | 7488                        |
| P2, P4  | 0.30  | 7.00       | 3.00   | 1600                                        | 1.3                         | 13104                       |

In the FEM modelling, considering the wall P5, it can be seen that the loads in the upper part with the lower part are similar, while in the walls P1 and P3, the upper and lower loads are different, but that difference (5324 daN) is not equal to the weight of the wall panel P5 (see Table 2). In the walls P2 and P4 instead, the difference between the upper and lower loads in the FEM analysis, results to be higher (18830 daN) than the weight of the wall P2. Instead in the FME modelling the difference between the upper and lower loads on the walls P2 and P4 appears to coincide with the weight of the corresponding masonry piers. Discussing the results of this simplified structure, it seems that the FEM method takes into account the whole box and the redistribution of loads and stresses between the walls in a more complex and detailed way than it does the FME method, consequently leading to results that would seem more reasonable and close to the reality. It is in fact difficult to accept that the walls P2 and P4 in the
upper part are subjected to a load equal to 50% of the total load of the floor as in the case of FME modelling (Figure 3). On the other hand, however, in the FEM method, the fact that in the bottom of the wall P5 there is a load similar to the upper part of the same wall, is not convincing in full.

4. Conclusions

Some important conclusions on the modelling of buildings in masonry can be drown, in fact from what has emerged in the case of study, the two approaches used can lead to very different results, both from quality and quantity point of view. In the opinion of the authors such analysis seems to be more in conformity with reality if carried out with the finite element method model, in fact, this model allows to take into account the effects of mutual connection and mutual cooperation between the walls of masonry, with a redistribution of stresses in a more accurate way. The software 3Muri offers a rigid interpretation of the structure and it is impossible to interact with the creation of nodes and meshes, creating an inaccessible system. Otherwise in the case of the FEM method the integrations made to get from the matrix of the vectors of nodal displacements $\delta$ to the actions, are difficult to identify to understand the problem. It can therefore be concluded with some general directions as the fact that these types of modelling in the present state, cannot be generalized to any type of geometry of structure, and may lead to completely different results when applied to complex structures.

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