# Evaluation of Masonry Modelling Elements

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**ABSTRACT**

***In recent decades, software available provide different elements for modelling of structure. Among them, using plate elements for modelling slab and beam or line elements for modelling beams and columns is a common trend. Masonry structures composed of blocks and mortar are heterogeneous. Choosing appropriate elements for modelling masonry structures pose a greater challenge. Critical assessment will provide a better understanding for selecting suitable element for modelling of masonry structures. Insights on different masonry modelling elements available in MIDAS GEN are provided herein. The paper also focuses on knowing ability of element to incorporate with in-plane and out of plane load along with giving due consideration to material heterogeneity. Analysis have been carried out considering different load cases and different elements and comparative results are presented. Comparatively similar analysis results are obtained for plate and solid elements.***

***Keyword : - Masonry elements, material heterogeneity, modelling, analysis, MIDAS GEN***

## 1. INTRODUCTION

Masonry structures constitute of systematically arranged units called as blocks which may be stone, brick or concrete blocks; bonded by mortar which may be lime mortar, cement mortar etc. Such combination of units and mortar makes the masonry to be called as made of heterogeneous material. Analysis of masonry structures needs such heterogeneity to be properly taken into account. Not only this, but there exists header joints which are usually staggered in nature. Considering all such non-linearity and analysis of masonry structure perfect with all such attributes is a challenging task.

Analysis of complex structures is tedious and time consuming. Several software packages have been developed to make such task easier and faster. Modelling the exact structure and to obtain exact results may not be economical in case of analysis using software. Several assumptions are made and complex structures are simplified so as to get approximate but reliable solutions. Homogenization of masonry makes it possible to be modelled in several commercial software. Also, due consideration needs to be given for element to be used for modelling, meshing, connectivity and other geometrical and material parameters.

Several sophisticated finite element softwares are available for modelling complex structures. Discrete element approach may represent correct geometry of masonry structure. For modelling masonry by discrete element approach it requires a good finite element software and also requires a sufficient time to model masonry. In order to reduce time many often make use of simplified modelling approach. Simplified approach means masonry is treated as homogeneous and modelling is done using plate or shell elements. This conservatively reduces time required for modelling.

The availability of different software provides different elements for modelling of the structure. Among them using plate elements for modelling slab and beam or line elements for modelling beams and columns is a common trend. Masonry structures composed of blocks and mortar makes it heterogeneous. Choosing the appropriate elements for modelling such complex structures pose a greater challenge for the user. Critical assessment in this regard will provide a better understanding for selecting suitable element for modelling masonry structures. It is better to get insights on different masonry modelling elements available in a particular software before implementing them for analysis. In case of masonry modelling elements, it is important to know ability of an element to incorporate with in-plane and out of plane load along with giving due consideration to material heterogeneity. Analysis have been carried out considering different load cases and different elements and comparative results have demonstrated.

## 2. COMMON MASONRY ELEMENT MODELLING APPROACHES USED IN THE PAST

There are ample of elements in the software to be used for modelling and their choice depends upon the level of accuracy needed for results and efficiency of the element to represent the behavior and properties of the original element. Different user uses different elements based on their convenience to use a particular element. Frequently, plate elements are used to model masonry structures which assumes masonry to be homogeneous. Several past analysis work have mentioned below.

S. Ahmad et al. [1] have studied seismic performance of school- masonry heritage building. Analysis was carried out using finite element technique and assuming homogeneous material and also considering material non-linearity property. The building 3-D model was prepared using plate elements in STAAD PRO and plates were finely divided using meshing tool. Building was than analysed under gravity and seismic loads.

R. Marques [2] in the study about masonry box behaviour had modelled dwelling house unit using software code developed by Gruppo Sismica. Orthotropic slab element was used to model the floors. Also elastically deformable diaphragm were simulated. The structure was later analysed for pushover load to identify failure mechanisms.

M. Shariq et al. [3] have carried out analysis of masonry heritage building – Jama masjid situated at Aligarh city. El-Centro time history data was used to study the seismic performance of the structure. Plates and shells were used for finite element modelling of the building. Arches were modelled using triangular plate elements and domes ere modelled using quadrilateral plate elements. Meshes of different sizes were defined to ensure proper connectivity between the nodes. The structure was analysed and locations of critical tensile stresses were identified.

B. Gunes et al. [4] have carried out assessment of existing masonry structure using linear and non-linear models. Masonry walls were modelled using 3 and 4 node thick shell elements in MIDAS GEN 2017 software using finite element modelling technique. Frame elements were used to model reinforced concrete members. Seismic assessment was done for both linear and non-linear case and results were compared.

N. Ademovic et al. [5] have carried seismic evaluation an existing masonry building in Sarajevo. The building was modelled in DIANA and 3MURI software applying finite element and equivalent frame model concept. Curved shell quadrilateral CQ40S type element was used to model the structure. Total strain fixed crack model available in DIANA was used to consider for non-linear material properties. Pushover analysis and time history analysis were carried out to know seismic vulnerability of the building.

## 3. ELEMENTS AVAILABLE FOR MASONRY MODELLING

Various elements available in MIDAS GEN are different types of plate elements, various wall elements and solid elements. The choice of wall modelling element will depend upon the material properties to be considered, degrees of freedom or nodes required to define material, meshing requirements and accuracy of results required.

### 3.1 Plate Element

Plate element as shown in Fig -1(a) is a 2-D element with three or four nodes. It can cater for out of plane bending, in-plane and out-of-plane shear and in-plane tension and compression. Plate elements are of two types- thin plate and thick plate. Thin plates are developed based on Kirchhoff thin plate theory whereas thick plates are developed based on Mindlin Reissner thick plate theory. Output can be obtained at connecting nodes for element forces and stresses and also stresses at centres of the element.

### 3.2 Wall Element

Wall element as shown in Fig -1(b) is also a 2-D element. Wall elements are of two types – plate type and membrane type. Plate type element can account for stiffness in out-of-plane bending and stiffness about vertical direction in rotation and in-plane. Membrane type can only account for stiffness about vertical direction in rotation and in-plane direction. Forces can be obtained for element at floor level.

### 3.3 Solid Element

Solid elements are of three types:– 4-noded tetrahedron, 6-noded hexahedron and 8-noded solid element (as shown in Fig -1(c). Element forces and components of stresses can be obtained at connecting nodes. Stresses can be also obtained at center of the element. Each element has got translational degrees of freedom at each node.

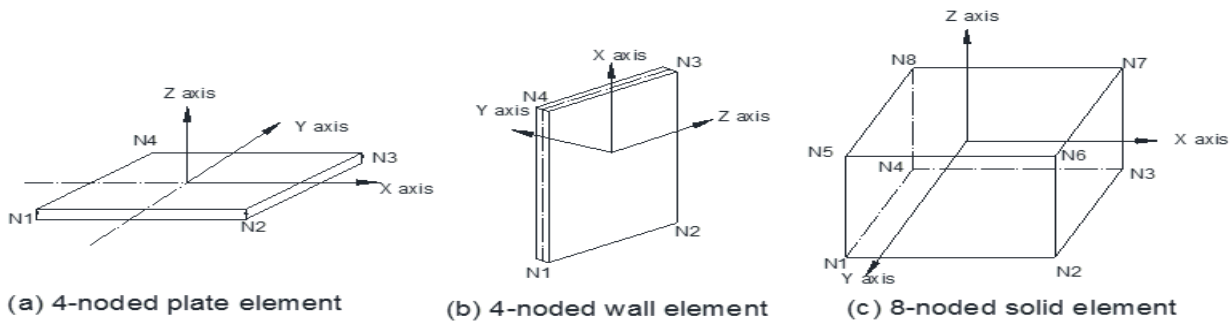


**Fig -1:** Element co-ordinate system for different elements

## 4. MODELLING AND ANALYSIS

Masonry is a brittle material. Hence tensile failure in case of masonry is sudden. Masonry is strong in compression but weak in tension. Sudden failure is mostly reported under lateral loads. Also, failure pattern is not certain. Software analysis may present idealised failure pattern if modelled properly. Hence proper modelling is important. Continuum models may not represent the actual case but fairly well structural behaviour may be obtained. Modelling exact masonry parameters will involve complexities and will be more time consuming and may not be viable for practicing engineers. Using any random element for faster analysis purpose without knowing its actual applicability to represent particular model may also give misleading results. A masonry wall model is generated using various elements available in MIDAS GEN and analysis is carried out.

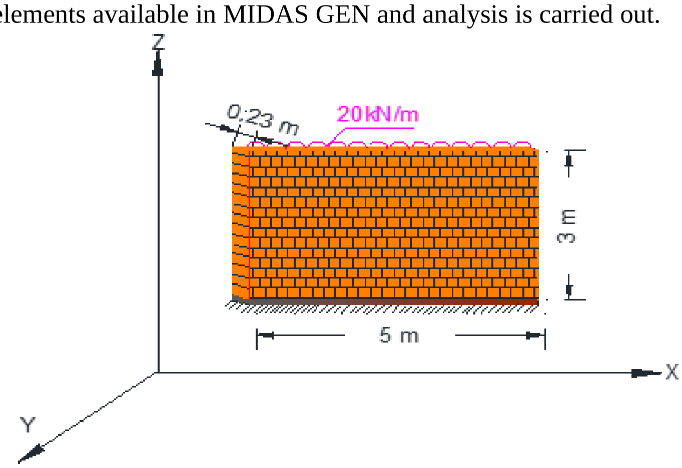


**Fig -2**: Geometrical representation of modelled wall

Modelling of a wall consists of simple steps like defining geometry, defining and assigning material properties and boundary conditions. A 5m x 3m laterite masonry wall of thickness 0.23m and density 20 kN/m$^3$ is considered for study as shown in Fig -2. The considered wall is modelled with different elements like plate elements, wall elements and solid elements from MIDAS GEN. the wall was assumed to be fixed at its base. Analysis have been carried out for various load cases such as its own self-weight, uniformly distributed load of 20 kN/m. The results obtained for Stress distribution in wall have demonstrated in Fig -3 to 7 below for above mentioned cases in kN/m$^2$. Geometrical and material properties considered for defining masonry model are listed below:

Material properties of the wall are:

- Modulus of Elasticity = 20000N/mm$^2$
- Poissons Ratio = 0.185

Laterite Stone Properties:

- Youngs modulus = 20000N/mm$^2$
- Tensile strength = 2.5 N/mm$^2$

Joint Material Properties:

- Youngs modulus = 22000N/mm$^2$
- Tensile Strength = 2.5N/mm$^2$

## 5. RESULTS AND DISCUSSION

Linear analysis was carried out for three different elements- solid, plate and wall elements. Total five different models were analyzed- Solid elements, thick plate element, thin plate element, wall membrane element and wall plate element. The considered wall was analyzed under its self-weight (DL) and uniformly distributed load (LL) of 20kN/m. Stress values at each node and stress distribution pattern was observed. Stresses for various elements for considered loading cases and combination of both (DL+LL) are listed below in table I.

**Table -1**: Stresses in Different Elements

| Sr. No. | Element type | Stresses for DL case(kN/m$^2$) | Stresses for LL case (kN/m$^2$) | Stresses for DL+LL casse (kN/m$^2$) |
|---|---|---|---|---|
| 1. | Solid elements | 57.8 | 82.7 | 140.5 |
| 2. | Thick plate element | 55.8 | 82.9 | 138.7 |
| 3. | Thin plate element | 55.8 | 82.9 | 138.7 |
| 4. | Wall membrane element | 12.16 | 0 | 12.16 |
| 5. | Wall plate element | 14.54 | 0 | 14.54 |

The non-realistic results of wall element either of membrane type or plate type can be attributed to failure of the wall element to take assigned masonry model. These elements are specially used for modelling of shear walls or RCC retaining walls. Hence inefficiency in taking up masonry model gives no stresses under uniformly distributed load as it fails to take applied in-plane load.

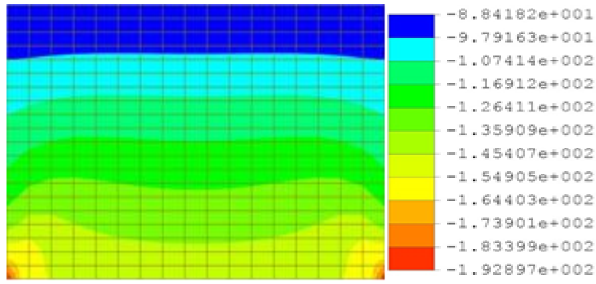


**Fig -3**: Stresses for Solid Element

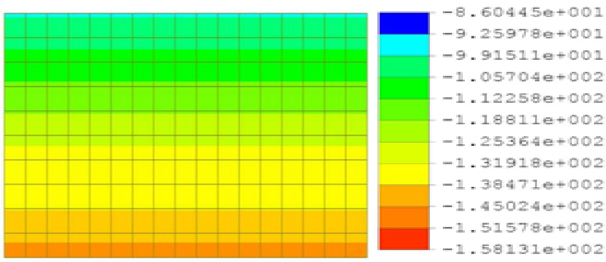


**Fig -4**: Stresses for thick plate element

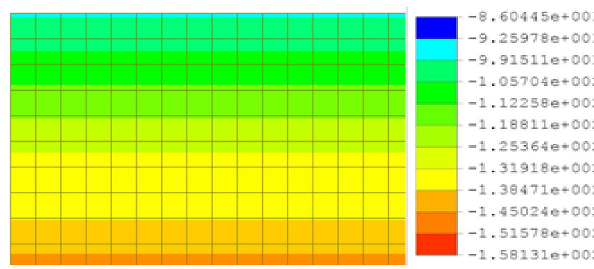


**Fig -5**: Stresses for thin plate element

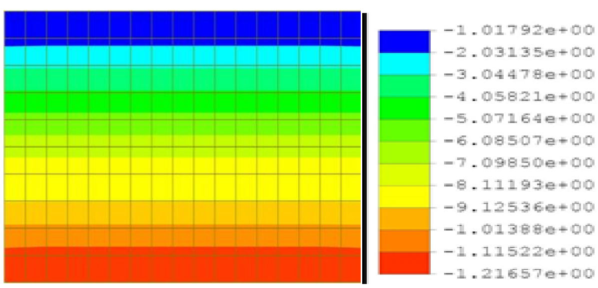


**Fig -6**: Stresses for wall membrane element

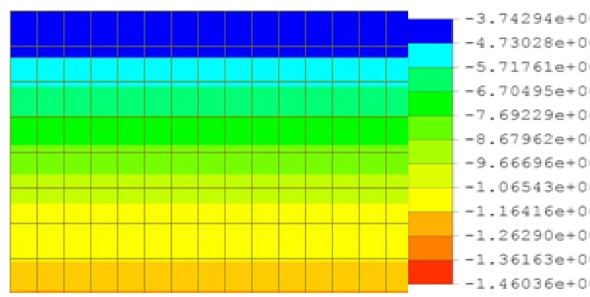


**Fig -7**: Stresses for wall plate element

The solid elements can take assigned masonry model and fairly good analysis results were obtained. Same case is with the thin plate and thick plate elements. The values of stresses for first three cases of solid and plate elements match with each other with small variations.

The accuracy in analysis depends on the type of modelling elements used. The choice of elements depends upon the type of results needed, purpose of analysis and accuracy in modelling is required. Use of plate elements will provide wall forces and moments along with stresses and hence these elements can be used when forces and moments are also of concern. Use of solid elements will provide stress values at different locations and can be used when detailed modelling is required for analysis.

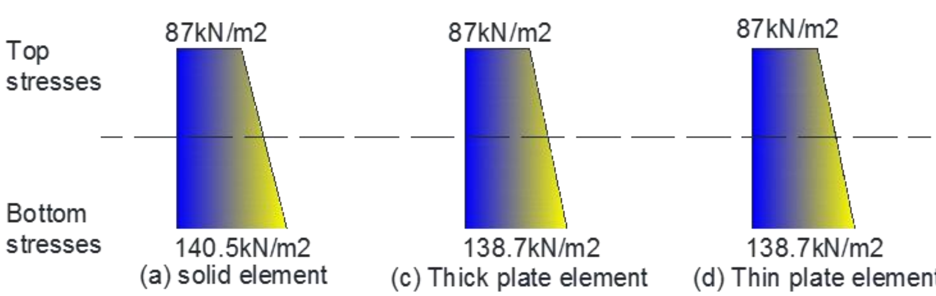


**Fig -8**: Vertical stress distribution along z-axis for combined load case for various elements

In thin plate and thick plate elements higher stress values were reported at bottom under combined load case (DL+LL). The stress values were found to be uniformly increasing from top to bottom of the element as shown in Fig -8. In case of solid elements, stress distribution for DL+LL case is also increasing from top to bottom with its height due to increase in self-weight from top to bottom. However, values of overall average stress values were obtained to be similar for solid elements and thick and thin plate elements.

The obtained self-weight stresses are similar for solid element model, thick plate element and thin plate element. Self-weight Stresses for solid element model are higher by 3.46% than thick and thin plate elements. Also, the obtained stress values for LL case are similar in value for solid element model, thick and thin plate elements. The stress value for solid element model is 0.24% lower than thin plate element model for uniform load case. Also, solid element model shows 1.28% higher stresses than thick and thin plate element under combined action of self-weight stresses and stresses under uniform load.

## 6. CONCLUSIONS

Plate and solid elements gives comparatively similar analysis results. The elements such as plate elements either thick plate or thin plate by defining proper plate thickness can be used for analysis of masonry structure. Results also shows that Solid elements with proper meshing can also be another alternative used for analysis of masonry structures. The analysis results depend on the type of modelling adopted and ability of the element to configure defined the masonry material. The solid elements and plate elements - thick and thin plate type performed well under self-weight and uniformly distributed load case. Also, time required for analysis by use of various elements was almost similar.

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