Estimating seismic resistance of fibrous plastering effect on mortarless interlocked masonry walling with finite element modelling

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Abstract

Recently, the out-of-plane lateral resistance of mortarless interlocked masonry walling with plain and natural-fibrous plaster was experimentally determined. A significant improvement was observed in seismic resistance with natural-fibrous plaster. In this paper, the behaviour of typical configurations of non-plastered and plastered mortarless interlocked masonry walling with non-linear finite-element (FE) model was numerically studied in TNO DIANA due to number of available crack models. Smeared crack approach was adopted to develop the FE model of masonry column. Experimental material and geometric properties were used. Failure mode, failure load and elastic-stiffness were numerically investigated. The results were compared to check the accuracy of developed model. It was found that, for typical configurations of walling, the experimental results were in good agreement with that of FE model, particularly the failure modes. The percentage difference was up to 20%. Thus, the developed model can be used to predict the seismic behaviour of natural-fibrous plastered mortarless interlocked masonry structures.

Keywords: Non-linear finite element, Interlocked masonry column, natural fibres, seismic resistance, failure load, plaster;

INTRODUCTION

Masonry is a common term for a composite material made of various separate small elements (units) bonded together by some binding filler (mortar) or interlocked mechanisms for mortarless construction (Giamundo,2014a). Historical masonry structures are normally classified as low strength due to number of reasons and these low strength masonry structures can be broadly divided into following three categories;

a. Masonry with poor mortar strength
b. Masonry with poor unit strength
c. Masonry with poor unit and mortar strength

Masonry with poor mortar strength refers to the structures where unit/mortar/interlocked interface governs the formation of cracks and collapse mechanism. Masonry with poor unit strength related to the structures where strength of unit dominant the mechanical behaviour. Tuff blocks are prime example of this case. Whereas in the third case, strength of bond and unit is considered comparable and both have dominant effect on failure mode. The type of the material and the bond strength affect the mechanical performance of the overall masonry structure. Masonry walls are considered to be strong in resisting of vertical axial load (Gihad 2007) but there is always a need to improve their lateral resistance when subjected to lateral load (Khonsari 2018) like wind and earthquake. Evaluation of the safety of masonry structures against seismic loading is a complex problem and computational linear and non-linear methods are used in different studies (Cakti,2016). For modelling, finite element method is the most well-known analysis technique for elements when subjected to static and dynamic loading conditions. For a numerical model to effectively represent the behaviour of a real structure, both constitutive model and the input material properties must be selected carefully to consider the variation of masonry properties. Analysis was carried out using the computational software TNO DIANA for the application of finite element method. For masonry structure FEM analysis can be performed using different modelling approaches. The more refined approach used by other researcher is micro modelling approach (Parisi,2011). In this approach, different mechanical parameters and different constitutive laws can be utilised and also it allows for local failure of the units and the bonding mechanism and they can be modelled separately. In addition, it is possible to model the units with or without interfaces according to the smeared cracking approach. Smeared crack approach means that it doesn't track individual crack but smears their effect over the FE by modifying its mechanical properties (Soto, 2017 & Bejarano-Urrego, 2018). This approach is considered better than discrete crack approach, which require to update the mesh configuration as the cracks develop within FE model.

NUMERICAL SIMULATION

The FEM analysis of the interlocked masonry column 1.5 m high as shown in the Figure 1a was carried out in 3D using software TNO DIANA v9.3. Three different types of model were produced based on the experimental work as detailed in Table 1. For blocks only model, the interaction between interlocked and blocks were modelled using the detailed micro-modelling approach (Giamundo,2014b & Lourenco,1996). The geometry of the experimental tests was reproduced modelling blocks and interlocked mechanism with interface elements between them as shown in Figure 1b. The selection of element types and material cracking and plasticity models were already successfully employed in other studies (Lignola, 2009 & Basili,2016) and will be applied in this study. A regular and dense discretization was used based on the CQ16M eight-node quadrilateral isoparametric plane stress elements with an average dimension of 25 mm have been used for meshing both the blocks and the plaster as per previous studies (Lignola, 2009, Lignola 2012 & Basili,2016). Boundary conditions reproduced the experimental setup. The base sections of the masonry columns were fixed and load was applied by means of an imposed displacement at height of 1.0m as applied in experimental work. In the Figure 2, adopted fine mesh and load application is shown. The elastic in-plane behaviour of both block and plaster was defined by means of young modulus E, whereas post elastic in-plane behaviour was defined by the multidirectional fixed crack model, which is based on fracture energy. In particular linear softening model in both tension and compression were adopted as compared to exponential tension softening and parabolic compression softening models, as used in other studies by Lignola, 2012 and shown in Figure 3. Modulus of elasticity and compressive strength for blocks and plaster were obtained from experimental work and fracture energy calibrated from these experimental works. Tensile strength is assumed 10% of compressive strength as per findings from other studies by Mohamad, 2007. All values used for material parameters obtained from experimental work are reported in Table 2.

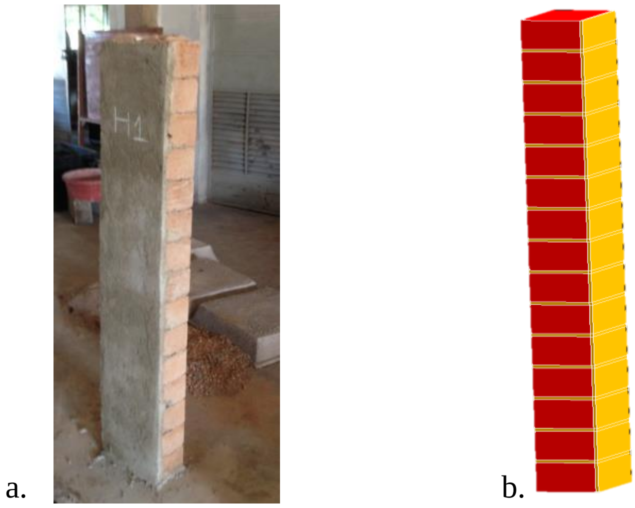


Figure 1: a:1.5m high interlocked plastered column, b. 3D model of column in TNO DIANA.

Table 1: Labelling of TNO DIANA Models

Combinations	**Model Symbol**
Block only unplastered	M1
8 mm thick Plain plastered column	M2
8 mm thick sisal plastered column	M3

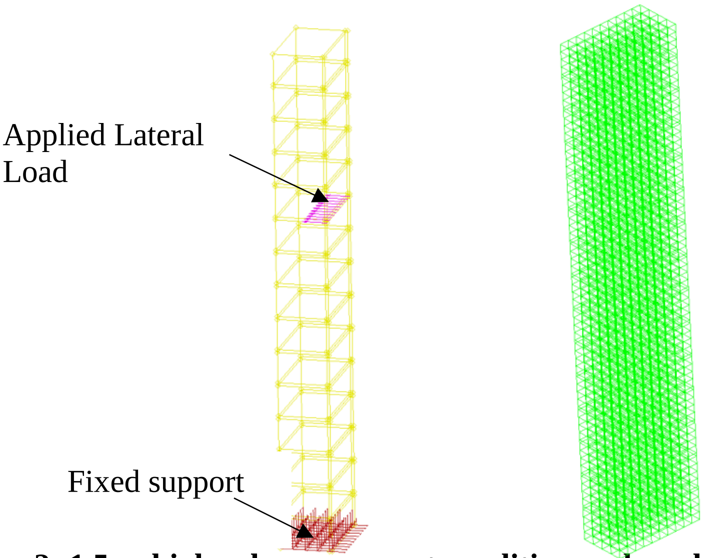


Figure 2: 1.5 m high column support condition and mesh size in TNO DIANA

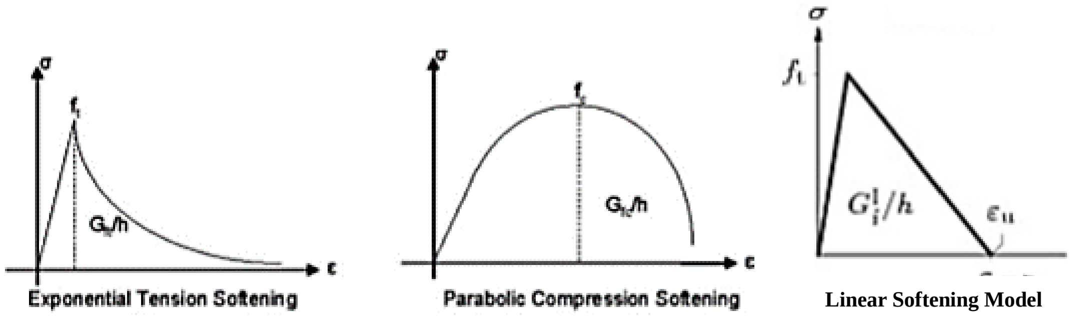


Figure 3: Material model used in TNO DIANA (Lignola, 2012)

Table 2: Material properties for block and plaster used in TNO DIANA

Material	Modulus of Elasticity E (MPa)	Poison's Ratio V	Compressive strength f_c (MPa)	Tensile Strength f_t (MPa)	Fracture energy G_f
Block	201	0.15	0.83	0.080	0.0441
Plain Plater	2990	0.15	19.33	1.933	0.065
Sisal Plaster	7175	0.15	19.88	1.988	0.657

VALIDATION OF FE MODEL

Experimental work was carried out for all the cases mentioned in Table 1 and the lateral peak/failure load for each case with FEM comparison is detailed in the Table 3. FEM analysis were carried out and compared with experimental values to validate the analysis.

Table 3: Comparison of experimental and TNO DIANA results

Model	Experimental lateral peak/failure load (N)	TNO DIANA lateral Peak/failure load (N)	Difference (%age)
M1 (Block only unplastered)	20	19	5
M2 (8 mm thick plain plastered)	192	134	44
M3 (8 mm thick sisal plastered)	261	154	41

For block only unplastered case, good agreement was achieved with only 5% difference. Whereas for all other cases, the values obtained from TNO DIANA was found 40-45% lower than the experimental values. This difference can be attributed to unknown behaviour of interface between block and paster which is considered as a perfect bond with a finite stiffness whereas in reality the value of stiffness could be higher than the value considered in the model. The failure and crack development in TNO DIANA models were also evaluated and found comparable with the experimental work failure as shown in Figure 5(a-c). For block only unplastered cases, cracks developed at the base of column with progression from tension to compression face similar to experimental results as shown in the Figure 4a. Similar crack development was observed in all other cases as shown in the Figure 4b and 4c, i.e. starting from tension to compression face. It was observed for the plain and sisal plastered columns, uniform propagation of cracks at the tension face of columns due to the presence of plaster and was also found stress concentration at the point of lateral load application.

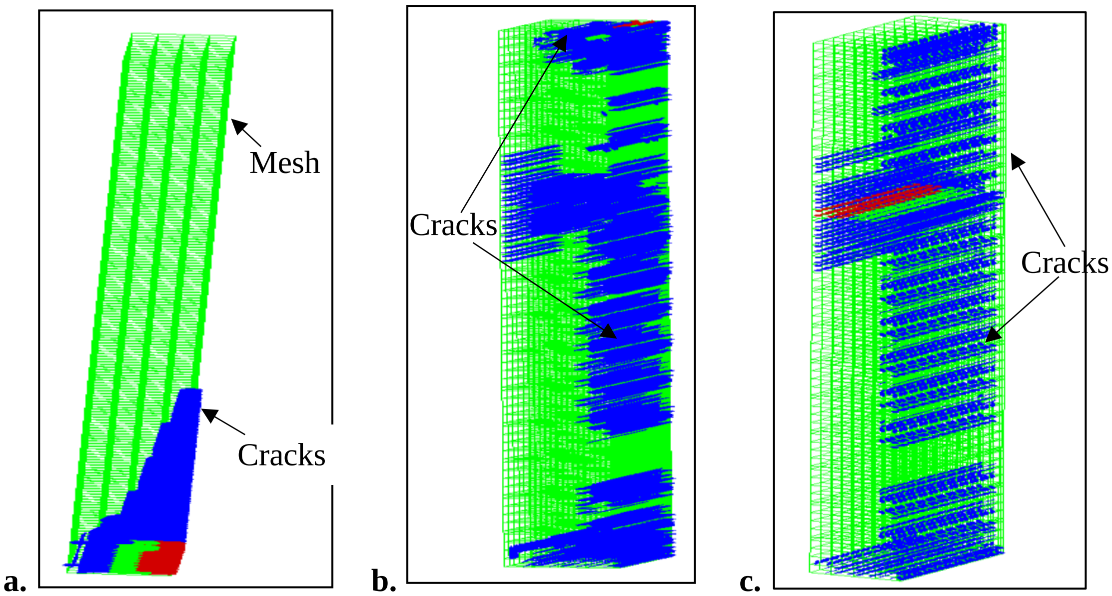


Figure 4: crack development a. block only model; b. plain plastered model; c. sisal plastered model

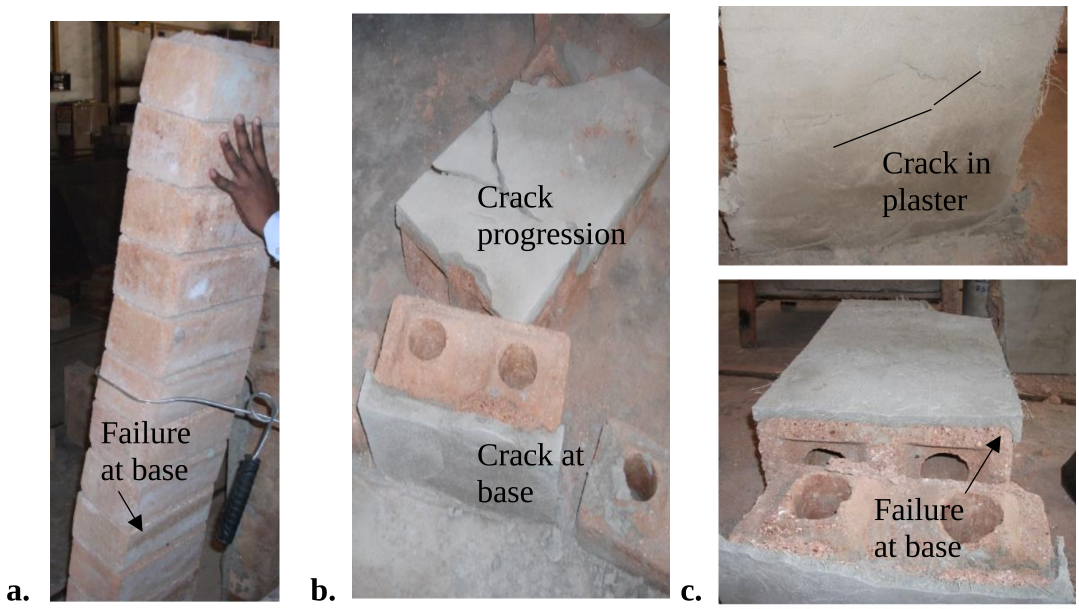
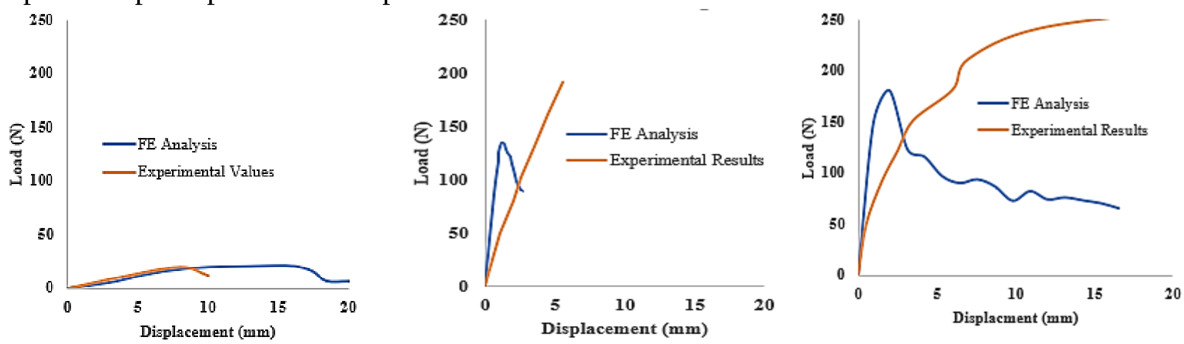


Figure 5: Experimental failure a. block only unplastered; b. plain plastered; c. sisal plastered

Discussion

Figure 6 (a-c) shows the load displacement curves for FE analysis and experimental work. Figure 6a curves represents the unplastered block only sample and Figure 6b & c shows the plain and sisal fibrous plastered samples. It was observed that the FE analysis curves for unplastered samples showed similar behaviour, whereas, for both plain and fibrous cases showed higher stiffness as compared to the experimental curves which might be related to the unknown behaviour of plaster and block interface included in the model. The comparison of displacement for all cases with experiments showed good agreement i.e. for unplastered block only sample was comparable up to 10 mm, for plain plastered samples ranged between 3-5 mm and for fibrous samples was observed between 16 -20 mm. The peak lateral load for unplastered was 20 N for both experimental and FE analysis, plain plastered sample was found 192 N for experimental work and 134 N from FE analysis which showed 30% difference, whereas, for sisal fibrous plastered column peak lateral load was observed 154 N for FE analysis and 261 N for experimental work which showed 40% difference between the two. The addition of fibres showed similar behaviour in experimental and FE analysis and showed increased ductility as compared to plain plastered sample.



a. b. c.

Figure 6: Load displacement curves a. unplastered block only; b. plain plastered; c. sisal fibrous plastered

CONCLUSION

In this paper results of experimental work for interlocked masonry column with fibrous plaster and un plaster were evaluated using non-linear FEM analysis using TNO DIANA and following conclusion are observed;

1 3D FEM analysis using TNO DIANA software for non-plastered and fibrous plastered column were produced as per previously executed experimental work.
2 Lateral failure load was compared with the experimental work and found in good agreement for unplastered block only model with 5 % difference.
3 The outcome from analysis agreed with the experimental work showing enhanced failure resistance by adding plaster and sisal fibres to interlocked masonry column
4 The cracks propagation within FE model matched with the experimental work showing failure at the base for unplastered block only model.

The development and validation of these FE models will allow to carry out the parametric studies including the variation of plaster strength and thickness. These can also be utilized in future study to evaluate the seismic parameters for masonry structure.

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