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FINITE ELEMENT APPROACHES TO ANALYZE FRP STRENGTHENED MASONRY STRUCTURES

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Masonry buildings, FRP, seismic analysis, Multifan element, plasticity

ABSTRACT

Masonry structures have always been used since the dawn of construction, and nowadays, due to aging, material degradation, settlements, and structural alterations, usually some members need strengthening to re-establish their performances. In this frame, fiber-reinforced polymer (FRP) composites can be a viable solution, provided they comply with the cultural value of the building. In the first part of this work, numerical approaches to model FRP strengthend masonry structures are discussed and in particular a material model suitable for micro-modelling of the FRP-masonry interfacial behaviour implemented in the Diana FEM program is presented. This micro-modeling approach based on interface elements is then used to develop and validate the global behaviour of a different type of Finite Element that was implemented in the Opensees framework. This new element is extremely effective for the seismic analysis of masonry buildings because it drastically reduces the number of degrees of freedom of the FEM model. Numerical results are validated by comparison to experimental results from tests performed at the University of Pavia and the Georgia Institute of Technology. In particular, it shows a satisfactory degree of accuracy at the global level, and is efficient enough, to analyze complex assemblages of masonry buildings including cyclic load effects and FRP strengthening.

INTRODUCTION

Considering almost half of all construction spending goes into renovation and restoration and much of the world's architectural heritage consists of historic buildings in masonry, the field of masonry research deserves greater attention than it usually receives in the past. Moreover, in addition to their historical and cultural values, such monuments often have also important social and economical values. As an example, the partial collapse of the vaults in the Basilica of St. Francis in Assisi during the 1997 earthquake in Italy, caused the destruction of irreplaceable and priceless frescos by Giotto and Cimabue of the early 14th century. Even more tragically, four people lost their lives when the masonry vaulting collapsed.

MICROMODELLING

The micro-modelling strategy for masonry, in which the units are discretized with continuum elements and the joints are discretized with interface elements is a very powerful tool to understand the behaviour of masonry. Lourenço 1997 developed a constitutive model for the monotonic behaviour of interface elements within the incremental theory of plasticity, including all the modern concepts used in computational plasticity, such as the implicit return mapping and consistent tangent operators, see Fig.1. The existing interface model was successfully used to simulate the interfacial behaviour of FRP-masonry joints in direct shear bond tests showing that a good agreement with experimental and analytical results can be achieved (Maruccio 2008). When the model is applied to simulate the strengthening effects of FRP strips bonded to curved masonry elements some differences exist between numerical results and experimental evidence, probably because the bond mechanism of these substrates requires a different description. Aiming at improving the existing interface model, a new multi-linear hardening law was proposed for shear and tension failure modes and implemented, see Fig.2. (Maruccio 2009)

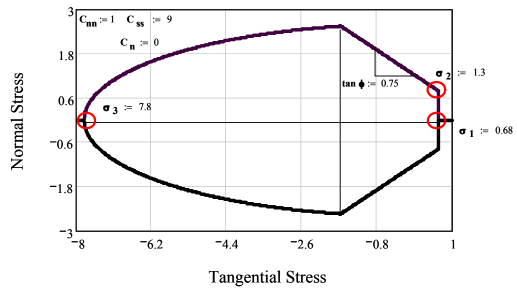


Figure 1: Multi-surface interface model (stress space)

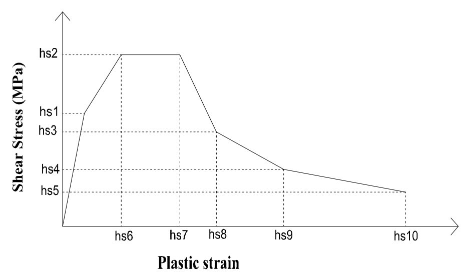


Figure 2: New hardening/softening law

The results obtained to simulate bond tests on plain and curved substrates are provided in Fig. 3.

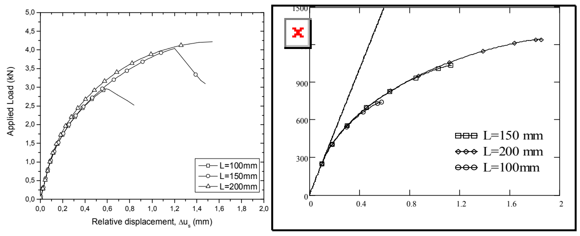


Figure 3: Numerical load displacement diagrams to predict bond strength of plain and curved FRP-Masonry joints as a function of the bond length.

MACROMODELLING

The micro-modeling approach described is used to validate the macro-modeling implementation of a Multifan element originally developed by Braga and Liberatore (1990) and extended to cyclic analysis and FRP strengthened masonry buildings. Each masonry panel in the structure can be accurately modeled by a single element where the panel represents a rectangular part of the wall with free lateral edges. It assumes that the stress field of the panel follows a Multifan pattern. The material behavior is assumed linear elastic in compression and non-reacting in tension. In addition, it is assumed that: the upper and lower faces of the panel are rigid, and there is no interaction in the circumferential direction among the fans. The cyclic Multifan element is then used to simulate the structural behavior of two prototypes of masonry buildings experimented at the University of Pavia and at the Georgia Institute of Technology. It shows a satisfactory degree of accuracy to analyze complex assemblages in 3D under cyclic loads, see Fig.4., also including strengthening effects, see Fig.5. and Fig.6., (Maruccio 2010).

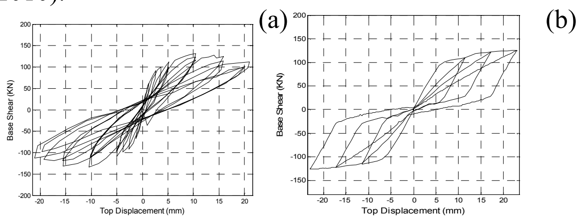


Figure 4: Cyclic response of door wall B2 of Pavia building: a) experimental; b) MF numerical simulation

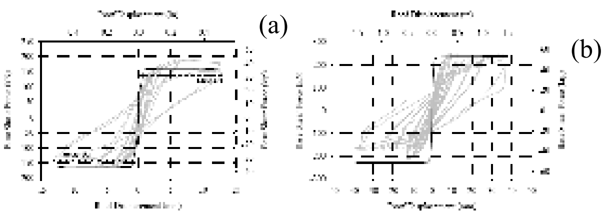


Figure 5: Experimental base shear versus roof displacement response of wall B of the Georgia prototype prior (a) and after to retrofit (b).

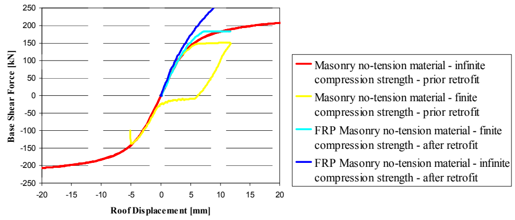


Figure 6: Numerical base shear versus roof displacement response of Wall B prior and after to retrofit.

CONCLUSION

The primary contributions of this work are the development of a material model for the analysis of the FRP-masonry interface and of a suitable finite element for analysis of masonry buildings under seismic actions even in the case of cyclic loads and FRP strengthening.

REFERENCES

Lourenço P.B., Rots J.G., "A multi-surface interface model for the analysis of masonry structures". Journal Engineering Mechanics, Vol. 123, No. 7, 1997, pp. 660–668.

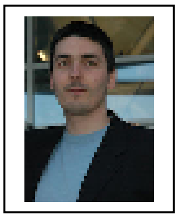
Braga, F., Liberatore D., "A Finite Element for the Analysis of the Response of Masonry Buildings under Seismic Actions". Proc. of the 5NAMC, Urbana, U.S.A., 1990.

Maruccio C., Lourenço P. B., Oliveira D.V., "Development of a constitutive model for the masonry-FRP interface behaviour". Proc. of the 8th World Congress on Computational Mechanics, Venice, 30 June-4 July 2008.

Maruccio C., Oliveira D.V., Lourenço P. B., "Nonlinear finite element analysis of FRP strengthened masonry arches". Proc. of the the third Italian Conference of Mechanics of masonry structures strengthened with composite materials (MuRiCo3), Venice, 22-24 April, 2009.

Maruccio C., Zhi Xiong C., Oliveira D.V., Monti G., Lourenço P. B., "Nonlinear finite element analysis of FRP strengthened masonry buildings under sismic action". Proc. of the CST2010 Conference, Valencia, September 2010.

AUTHOR BIOGRAPHIES



CLAUDIO MARUCCIO was born born in Galatina (Lecce, Italy) in the 1981. He is an Industrial Engineer since 2006, when he completed the bachelor and master of science (5-year) course in the School of Engineering of the University of Lecce with a final degree of 110/110. During this time, he spent around one year of study in Karlsruhe (Germany) at the Department of Mechanical Engineering within the Erasmus programme and a semester in Guimaraes (Portugal) at the Department of Civil Engineering where he developed a dissertation on the nonlinear finite element analysis of the interfacial behaviour of FRP and masonry materials. Afterwards, he started in the 2007 his PhD in structural engineering (still running) at the department of civil engineering of the University of Minho and the department of structural engineering at the University of Rome.