Original Research Paper | Published: 27 January 2018

Assessment of the influence of horizontal diaphragms on the seismic performance of vernacular buildings

Javier Ortega, Graça Vasconcelos, Hugo Rodrigues & Mariana Correia

Bulletin of Earthquake Engineering **16**, 3871–3904 (2018)

Abstract

The awareness and preservation of the vernacular heritage and traditional construction techniques and materials is crucial as a key element of cultural identity. However, vernacular architecture located in earthquake prone areas can show a particularly poor seismic performance because of inadequate construction practices resulting from economic restraints and lack of resources. The horizontal diaphragms are one of the key aspects influencing the seismic behavior of buildings because of their major role transmitting the seismic actions to the vertical resisting elements of the structure. This paper presents a numerical parametric study adopted to understand the seismic behavior and resisting mechanisms of vernacular buildings according to the type of horizontal diaphragm considered. Detailed finite element modeling and nonlinear static (pushover) analyses were used to perform the thorough parametric study aimed at the evaluation and quantification of the influence of the type of diaphragm in the seismic behavior of vernacular buildings. The reference models used for this study simulate representative rammed earth and stone masonry vernacular buildings commonly found in the South of Portugal. Therefore, this paper also contributes for a better insight of the structural behavior of vernacular earthen and stone masonry typologies under seismic loading.

References

Angulo-Ibáñez Q, Mas-Tomás Á, Galvañ-Llopis V, Sántolaria-Montesinos JL (2012) Traditional braces of earth constructions. Constr Build Mater 30:389–399

Barbisan U, Laner F (1995) Wooden floors: part of historical antiseismic building systems. Ann Geophys 38:775–784

Benedetti D, Petrini V (1984) Sulla Vulnerabilità Di Edifici in Muratura: Proposta Di Un Metodo Di Valutazione. L'industria delle Costruzioni 149(1):66–74

Betti M, Vignoli A (2011) Numerical assessment of the static and seismic behaviour of the basilica of Santa Maria all'Impruneta (Italy). Constr Build Mater 25(12):4308–4324

Blondet M, Garcia G, Brzev S, Rubiñós A (2011) Earthquake-resistant construction of adobe buildings: a tutorial. Earthquake Engineering Research Institute (EERI), Oakland

Bothara J, Brzev S (2012) A tutorial: improving the seismic performance of stone masonry buildings. Earthquake Engineering Research Institute (EERI), Oakland

Braga A, Estevão J (2010) Os Sismos e a Construção em Taipa no Algarve. In: Proceedings of Sísmica 2010 – 8º Congresso de Sismologia e Engenharia Sísmica, Aveiro, Portugal

Brignola A, Podestá S, Pampanin S (2008) In-plane stiffness of wooden floor. In: Proceedings of New Zealand Society for earthquake engineering conference, paper 49

Brignola A, Pampanin S, Podestà S (2012) Experimental evaluation of the in-plane stiffness of timber diaphragms. Earthq Spectra 28(4):1687–1709

Bui Q-B, Morel J-C, Hans S, Meunier N (2008) Compression behaviour of non-industrial materials in civil engineering by three scale experiments: the case of rammed earth. Mater Struct 42(8):1101–1116

Correia M (2002) A Habitação Vernácula Rural no Alentejo, Portugal. In: Memorias del IV Seminario Iberoamericano sobre vivienda rural y calidad de vida en los asentamientos rurales, Santiago del Chile, Chile

Correia M (2007) Taipa no Alentejo. Argumentum, Lisboa

Correia M (2016) Experiences from the past for today's challenges. In: The road to sustainable development. Chapter 6—traditional and generational change, La Fábrica, Fundación Contemporánea, Madrid, Spain

D'Ayala DF, Paganoni S (2011) Assessment and analysis of damage in L'Aquila historic city centre after 6th April 2009. Bull Earthq Eng 9(1):81–104

Fernandes J, Mateus R (2012) Energy efficiency principles in Portuguese vernacular architecture. In: International conference BSA 2012, Porto, Portugal

Ferreira F, Vicente R, Varum H, Costa A, Costa AA (2012) Out-of-plane seismic response of stone masonry walls: Experimental and analytical study of real piers. In: Proceedings of the 15th world conference on earthquake engineering, Lisbon, Portugal

Ferreira F, Vicente R, Mendes da Silva JAR, Varum H, Costa A (2013) Seismic vulnerability assessment of historical urban centres: case study of the old city centre in Seixal, Portugal. Bull Earthq Eng 11(5):1753–1773

Gallego R, Arto I (2014) Evaluation of seismic behaviour of rammed earth structures. In: Mileto C, Vegas F, Soriano L, Cristini V (eds) Earthen architecture: past, present and future. Taylor & Francis Group, London

Gattesco N, Macorini L, Benussi F (2007) Retrofit of wooden floors for the seismic adjustment of historical buildings with high reversible techniques. Seismic engineering in Italy. In: Proceedings of the XII national conference, 10–14 June, Pisa, Italy

Giongo I, Dizhur D, Tomasi R, Ingham J (2014) Field testing of flexible timber diaphragms in an existing vintage URM building. J Struct Eng 141(1):D4014009 **(special issue: field testing of bridges and buildings)**

GNDT (1994) Scheda di esposizione e vulnerabilità e di rilevamento danni di primo livello e secondo livello (muratura e cemento armato). GNDT (Italian Group for the defense against earthquakes), Rome, Italy

Gomes MI, Lopes M, de Brito J (2011) Seismic resistance of earth construction in Portugal. Eng Struct 33(3):932–941

ICOMOS (1999) Charter on the built vernacular heritage. International council on monuments and sites (ICOMOS), ICOMOS 12th general assembly, Mexico

Ingham J, Biggs D, Moon L (2011) How did unreinforced masonry buildings perform in the February 2011 Christchurch earthquake? Struct Eng 89(6):14–18

Jaquin P (2008) Analysis of historic rammed earth construction. Ph.D. dissertation, Durhan University

Lourenço PB (2009) Recent advances in masonry structures: micromodelling and homogenization. In: Galvanetto U, Ferri Aliabadi MH (eds) Multiscale modeling in solid mechanics: computational approaches. Imperial College Press, London, pp 280–300

Lourenço PB, Krakowiak F, Fernandes FM, Ramos LF (2007) Failure analysis of Monastery of Jerónimos, Lisbon: how to learn from sophisticated numerical models. Eng Fail Anal 14:280–300

Lourenço PB, Mendes N, Ramos LF, Oliveira DV (2011) On the analysis of masonry structures without box behavior. Int J Archit Herit Conserv Anal Restor 5(4–5):369–382

Lourenço PB, Trujillo A, Mendes N, Ramos LF (2012) Seismic performance of the St. George of the Latins church: lessons learned from studying masonry ruins. Eng Struct 40:501–518

Lourenço PB, Karanikoloudis G, Mendes N, Corallo C (2015) Assessment of the South aisle in Canterbury. In: Proceedings

of the 2nd international conference on preservation, maintenance and rehabilition of historical buildings and structures, Porto, Portugal

Lourenço PB, Karanikoloudis G, Greco F (2016) In situ testing and modeling of cultural heritage buildings in Peru. In: Proceedings of the 10th international conference on structural analysis of historical constructions, SAHC 2016, Leuven, Belgium

Lozano G, Lozano A (1995) Curso de técnicas de intervención en el patrimonio arquitectónico. Tomo 1. Reestructuración en madera. Ed. Cons. Técn. de Contrucción CB, Gijón, Spain

Magenes G, Penna A, Rota M, Galasco A, Senaldi I (2014) Shaking table test of a full-scale stone masonry building with flexible diaphragms. Int J Archit Herit 8(3):349–375

Mallardo V, Malvezzi R, Milani E, Milani G (2008) Seismic vulnerability of historical masonry buildings: a case study in Ferrara. Eng Struct 30:2223–2241

Mendes N, Lourenço PB (2009) Seismic assessment of masonry “Gaioleiro” buildings in Lisbon, Portugal. J Earthq Eng 14(1):80–101

Mendes N, Lourenço PB (2015) Seismic vulnerability of existing masonry buildings: nonlinear parametric analysis. In: Psycharis I, Pantazopoulou S, Papadrakakis M (eds) Seismic assessment, behavior and retrofit of heritage buildings and monuments. Computational methods in applied sciences, vol 37. Springer, Cham

Miccoli L, Oliveira DV, Silva R, Müller U, Schueremans L (2014) Static behaviour of rammed earth: experimental testing and finite element modelling. Mater Struct 48:3443

Mouyiannou A, Rota M, Penna A, Magenes G (2014) Identification of suitable limit states from nonlinear dynamic analyses of masonry structures. J Earthq Eng 18(2):231–263

Nakamura Y, Derakhshan H, Magenes G, Griffith MC (2017) Influence of diaphragm flexibility on seismic response of unreinforced masonry buildings. J Earthq Eng 21(6):935–960

Neves F, Costa A, Vicente R, Oliveira CS, Varum H (2012) Seismic vulnerability assessment and characterization of the buildings on Faial Island, Azores. Bull Earthq Eng 10(1):27–44

NTC (2008) Norme Tecniche per le Costruzioni. D.M. 14 gennaio 2008, S.O. No. 30, G.U. No. 29/2008. Rome, Italy

Ortega J, Vasconcelos G, Rodrigues H, Correia M, Lourenço PB (2017) Traditional earthquake resistant techniques for vernacular architecture and local seismic cultures: a literature review. J Cult Herit 27:181–196

Rota M, Penna A, Magenes G (2010) A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analyses. Eng Struct 32(5):1312–1323

Rudofsky B (1964) Architecture without architects: a short introduction to non-pedigreed architecture. Museum of Modern Art, New York

Saloustros S, Pelà L, Roca P, Portal J (2014) Numerical analysis of structural damage in the church of the Poblet Monastery. Eng Fail Anal 48:41–61

Shakya M (2014) Seismic vulnerability assessment of slender

masonry structures. Ph.D. dissertation, Universidade de Aveiro

Sorrentino L, Liberatore L, Liberatore D, Masiani R (2013) The behaviour of vernacular buildings in the 2012 Emilia earthquakes. Bull Earthq Eng 12(5):2367–2382

TNO (2011) DIsplacement method ANAlyser. User's manual, release 9.4.4. Netherlands

Tomazevic M, Lutman M, Velechovsky T (1991) The influence of rigidity of floor on the seismic behaviour of old stone-masonry buildings. Eur Earthq Eng 3:28–41

Vicente R (2008) Estratégias e metodologias para intervenções de reabilitação urbana. Avaliação da vulnerabilidade e do risco sísmico do edificado da Baixa de Coimbra. Ph.D. dissertation, Universidade de Aveiro

Vicente R, Parodi S, Lagomarsino S, Varum H, Mendes da Silva JAR (2011) Seismic vulnerability and risk assessment: case study of the historic city centre of Coimbra, Portugal. Bull Earthq Eng 9(4):1067–1096

Vintzileou E, Mouzakis C, Adami CE, Karapitta L (2015) Seismic behaviour of three-leaf stone masonry buildings before and after interventions: shaking table tests on a two-storey masonry model. Bull Earthq Eng 13(10):3107–3133

Whitney R, Agrawal A (2015) Seismic performance of flexible timber diaphragms: damping, force-displacement and natural period. Eng Struct 101:583–590

Wilson A, Quenneville P, Ingham J (2013) Natural period and seismic idealization of flexible timber diaphragms. Earthq Spectra 29(3):1003–1019

Wilson A, Quenneville PJH, Ingham JM (2014) In-plane orthotropic behavior of timber floor diaphragms in unreinforced masonry buildings. J Struct Eng 140(1):04013038

Acknowledgements

The work presented in this paper was partly financed by FEDER funds through the Competitivity and Internationalization Operational Programme—COMPETE and by national funds through FCT—Foundation for Science and Technology within the scope of the project POC1-01-0145-FEDER-007633. This work was also financed in the framework of the Portuguese Public Procurement Code, LOTE 3EC5—Escola Secundária da Anadia e Gafanha da Nazaré.

Author information

Authors and Affiliations

ISISE, Department of Civil Engineering, University of Minho, Campus de Azurém, 4800-058, Guimarães, Portugal

Javier Ortega & Graça Vasconcelos

RISCO, School of Technology and Management, Polytechnic Institute of Leiria, Leiria, Portugal

Hugo Rodrigues

CI-ESG Research Centre, Escola Superior Gallaecia, Vila Nova de Cerveira, Portugal

Mariana Correia

Corresponding author

Correspondence to Javier Ortega.

Rights and permissions

About this article

Cite this article

Ortega, J., Vasconcelos, G., Rodrigues, H. *et al.* Assessment of the influence of horizontal diaphragms on the seismic performance of vernacular buildings. *Bull Earthquake Eng* **16,** 3871–3904 (2018). https://doi.org/10.1007/s10518-018-0318-8

Received	Accepted	Published
12 July 2017	20 January 2018	27 January 2018

Issue Date
September 2018

DOI
https://doi.org/10.1007/s10518-018-0318-8

Keywords

Vernacular architecture **Seismic behavior**

Numerical analysis **Pushover parametric study**

Stone masonry **Rammed earth**

Horizontal diaphragms