The Effect of the Bedding Length of Lintel in Masonry Walls on Their Load Bearing Capacity

Jure Radnić, Vatroslav Čamber, Nikola Grgić and Domagoj Matešan

Abstract By using the previously developed numerical model of the authors for both, static and dynamic analysis of concrete and masonry structures, which can simulate their main nonlinear effects, the influence of the bedding length of lintel on the ultimate bearing capacity of some masonry walls with openings has been investigated. Three-storey masonry walls with door openings were analyzed. Unreinforced and confined masonry walls were considered. There were separately analyzed masonry walls under horizontal static forces at the floor levels and masonry walls under earthquake. The bedding length of the lintel reinforcement and quality of the masonry were varied. Characteristic displacements of the walls and crack states in the lintel's area are presented. Finally, main conclusions and recommendations for practical application are given.

Keywords Lintel reinforcement · Masonry wall · Numerical model · Static and dynamic loading

J. Radnić · V. Čamber (✉) · N. Grgić · D. Matešan
Faculty of Civil Engineering, Architecture and Geodesy, University of Split,
Matice Hrvatske 15, 21000 Split, Croatia
e-mail: vatroslav_camber@yahoo.com

J. Radnić
e-mail: jradnic@gradst.hr

N. Grgić
e-mail: ngrgic@gradst.hr

D. Matešan
e-mail: dmatesan@gradst.hr

A. Öchsner and H. Altenbach (eds.), *Design and Computation of Modern Engineering Materials*, Advanced Structured Materials 54,
DOI: 10.1007/978-3-319-07383-5_1, © Springer International Publishing Switzerland 2014

1 Introduction

Above the openings in masonry walls are usually low and relatively weakly reinforced beams—lintels. Lintel reinforcement is usually calculated only to take over vertical loads, without the effects of wind and earthquake.

The height from the top of the opening to the top edge of floor level is variable and depends on the building's floor. In some cases, this height is relatively large, so lintel and part of the wall above it contribute significantly to wall stiffness on the horizontal static and dynamic (seismic) activity.

The width of openings in the walls for doors and windows is variable, as well as width of supporting walls.

The bedding of rebars at the ends of the lintels is often very short (sometimes below 10 cm). In fact, lintels do not contribute much to seismic resistance of masonry walls with openings. It is well known that earthquakes may cause the hardest damage to the parts of the masonry walls above the openings. In fact, horizontal forces produce high horizontal tensile stresses and high vertical shear stresses in these wall areas. Thus, in the horizontal direction masonry walls barely have no compressive stresses from gravitational loads, and barely have no horizontal tensile bearing capacity. Therefore, the occurrence of damage in parts of the wall above openings is expected and occurs even due to small horizontal forces. Cracks typically occur at the junction of the lintel with wall supports, and are especially significant when lintel reinforcement is anchored very shortly above the opening. A significant reduction of damages in the lintel's area can be expected by increasing the bedding length of the lintel reinforcement on wall supports and by adequate increase of the amount of bottom and top lintel reinforcement. This way, greater rigidity and resistance of the wall to horizontal loads will be ensured.

Obviously, the resistance and load bearing capacity of the wall would be greatest when the horizontal lintels are extended to the neighboring vertical tie beams.

No experimental and numerical studies of the effects of the bedding length of the lintel reinforcement on the load bearing capacity of masonry walls exposed to horizontal static or dynamic load have been available to the authors of this chapter.

The influence of the bedding length of lintel reinforcement of some masonry walls on their behavior under horizontal static and dynamic (earthquake) loads has been numerically investigated in this chapter.

Three-storey masonry walls with door openings were analyzed. Unreinforced and confined masonry walls were considered. There were separately analyzed masonry walls under horizontal static forces at the floor levels and masonry walls under dynamic forces. The bedding length of the lintel reinforcement and quality of the masonry were varied. Characteristic displacements of the walls and crack states in the lintel's area are presented.

Table 1 Material nonlinearity included in numerical model

Steel	Concrete	Masonry	Soil
Nonlinear behaviour in tension and compression	Yielding in compression	Yielding in compression	Yielding in compression
	Opening of cracks in tension	Opening of cracks in tension	Opening of cracks in tension
	The mechanism of crack opening and closing under dynamic load	The mechanism of crack opening and closing under cyclic load	The mechanism of crack opening and closing under cyclic load
	Tensile and shear stiffness of cracked concrete	Tensile and shear stiffness of cracked masonry	Tensile and shear stiffness of cracked soil
	Nonlinear behaviour of the reinforcement	Transfer of shear stresses	Transfer of shear stresses
		Anisotropic properties of strength and stiffness in horizontal and vertical direction	Anisotropic properties of strength and stiffness in horizontal and vertical direction

1.1 Numerical Model

The previously developed numerical model for both static and dynamic analysis of concrete and masonry structures [1, 2], which can simulate their main nonlinear effects, was used. The main nonlinear effects are material nonlinearity (Table 1), geometrical nonlinearity of the structure (large displacements), the strain rate effects on the material properties of masonry, reinforced concrete and soil, soil yield under a foundation, soil structure dynamic interaction, construction mode—the stages of masonry walls, etc.

A macro and micro model of masonry can be used. In the macro model of the masonry, the complex behaviour of the masonry (masonry units connected by mortar) is modeled by the homogenous material of equivalent mechanical properties. In the micro model of the masonry, modelling at the level of the masonry units and mortar (joints) is possible, as well as simulation of connection of mortar and masonry units by contact elements.

Concrete behaviour is simulated with the isotropic material model. Masonry or concrete models can be used for soil simulation, with corresponding material parameters.

The basic data of the analyzed masonry walls are presented in Sect. 2, and some research results are presented in Sect. 3. Main conclusions are given in Sect. 4.

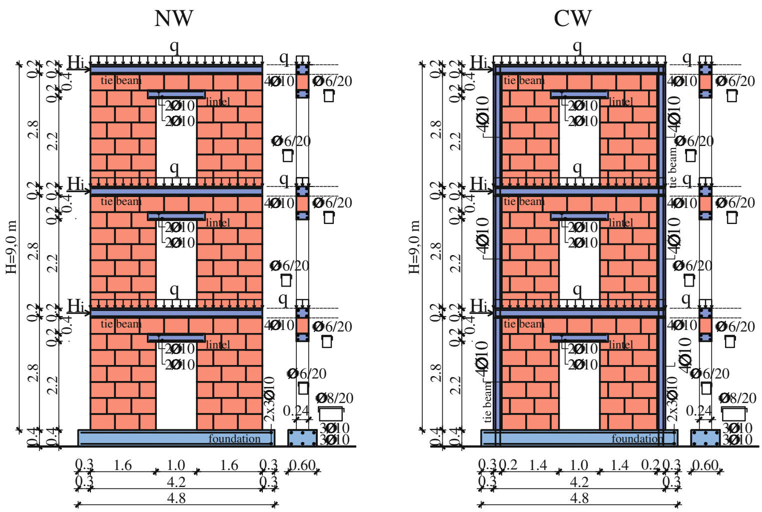


Fig. 1 Basic data about the analyzed masonry walls. **a** Unreinforced masonry wall. **b** Confined masonry wall

2 Basic Data of the Analyzed Masonry Walls

The basic data of the analyzed masonry walls are presented in Fig. 1. The walls are loaded by self weight and a uniform load $q = 35$ kN/m at floor levels. In the static analysis, the walls are additionally loaded by a horizontal force H at floor levels. The force has been applied in increments, until the collapse of the structure.

In the dynamic analysis, beside self weight and load q, the walls were exposed to a horizontal harmonic base acceleration according to Fig. 3. The period of excitation T corresponds to the first period of free oscillations of a particular wall. It was adopted that the duration of excitation is $T_p = 10T$, and the analysis was carried out for $T_a = 20T$. Implicit time integration with a time increment $\Delta t = T_1/100$ was adopted.

The walls with various lintel lengths were analyzed, i.e. with various bedding lengths of the lintel reinforcement (0.2, 0.4, 0.6, 1.6 m). Analyzed unreinforced masonry walls NW-20, NW-40, NW-60 and NW-160 are presented in Fig. 2a, and analyzed confined masonry walls CW-20, CW-40, CW-60 and CW-160 are presented in Fig. 2b. Variants of walls with rigid and soft masonry were considered. The rigid masonry has five times greater parameters of strength and stiffness compare to the soft masonry. The adopted basic material parameters for the numerical analysis are presented in Table 2.

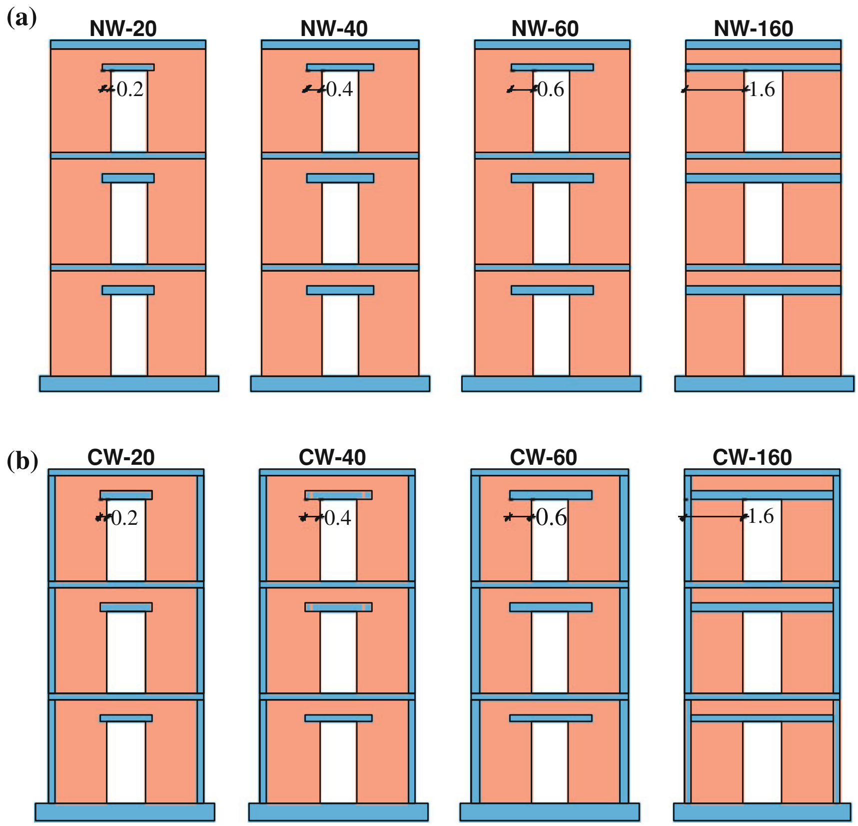
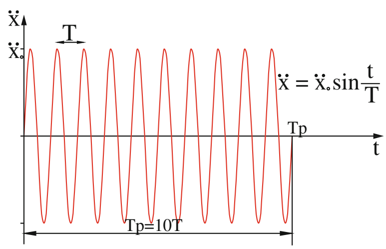


Fig. 2 Variants of analyzed masonry walls. **a** Unreinforced masonry wall. **b** Confined masonry wall

Fig. 3 Adopted base acceleration



It was accepted that the wall foundation is supported by a rigid base. Possibility of the foundation lifting from the base was included. For that purpose, the thin contact elements were used between base and foundation. The relatively rough spatial discretization of the walls according to Fig. 4 was adopted, especially for the tie beams and the lintels. All longitudinal and transverse rebars were modeled.

Table 2 The adopted basic material parameters for the numerical analysis

Parameters	Unit	Material			
		Rigid masonry	Soft masonry	Concrete	Reinforcement steel
Elasticity modulus	MPa	5,000	1,000	30,500	210,000
Poisson'ratio	–	0.00	0.00	0.15	–
shear modulus	MPa	1,000	200	13,260	–
Compressive strength	MPa	5.0	1.0	25	500.0
Tensile strength	MPa	0.15	0.03	2.5	500.0
Limit comp. strength	–	−0.01	−0.01	−0.0035	−0.02
Limit tensile strength	–	0.00003	0.00003	0.0001	0.02

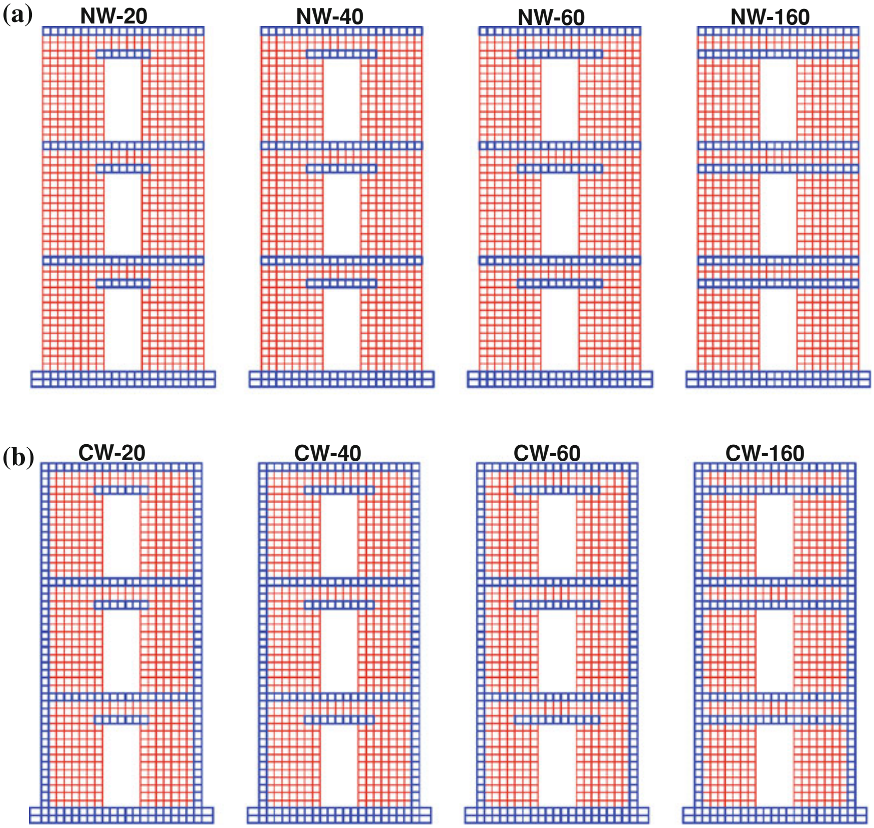


Fig. 4 Adopted spatial discretization of the walls. **a** Unreinforced masonry wall. **b** Confined masonry wall

3 Brief Comment on the Numerical Results

3.1 Static Analysis

3.1.1 Unreinforced Masonry Walls (NW)

The horizontal displacement of the top of the unreinforced masonry walls is shown in Fig. 5.

The big difference in the load bearing capacity and displacements of the wall can be noticed regarding the masonry quality, as well as the bedding length of lintel reinforcement.

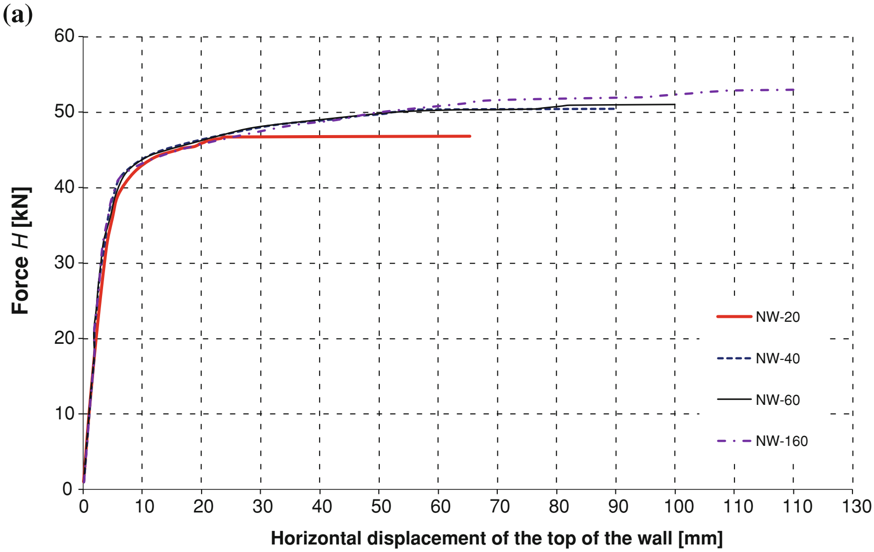
For the walls with soft masonry the load bearing capacity of the wall NW-160 is more than 35 % higher than the load bearing capacity of the wall NW-20. For these walls with rigid masonry, the difference in load bearing capacity is only about 10 %.

Crack states in unreinforced masonry walls for the work levels of force H is presented in Fig. 6. As can be seen, the extension of the lintels above the openings results in reduction of the cracking zone in the lintels and supporting walls.

3.1.2 Confined Masonry Walls (CW)

The horizontal displacement of the top of the confined masonry walls is presented in Fig. 7. Analogue comments as for previously discussed unreinforced masonry can be stated. A huge difference in the load bearing capacity and displacements for these walls also depends on the masonry quality. There is also a significant difference in the load bearing capacity of the wall depending on the bedding length of lintel reinforcement. So, for rigid masonry, the difference of the load bearing capacity of the walls for CW-160 and CW-20 is about 10 %, and for soft masonry it is about 45 %. For unreinforced masonry and confined masonry, greater bedding length of lintel reinforcement contributes to the greater load bearing capacity of the walls.

Crack states in the confined masonry walls for for the work levels of force H is presented in Fig. 8. Analogue conclusions as for unreinforced masonry can be stated. Greater bedding length of lintel reinforcement has a favorable effect on the crack states in the lintel's area and at the supporting walls. Even for the work levels of loads, increase of the bedding length of lintel reinforcement results in decrease of cracking zone in lintel and supporting walls.



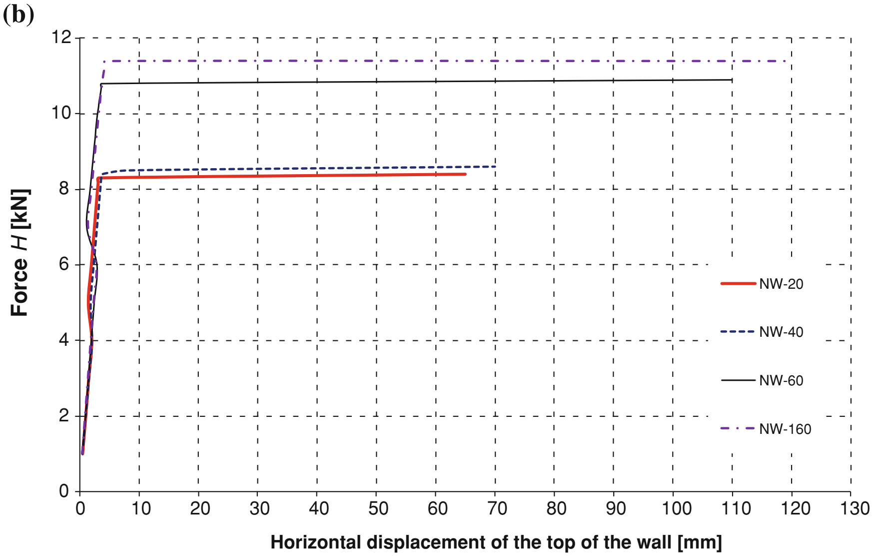


Fig. 5 Horizontal displacement of the top of the unreinforced masonry walls. **a** Rigid masonry. **b** Soft masonry

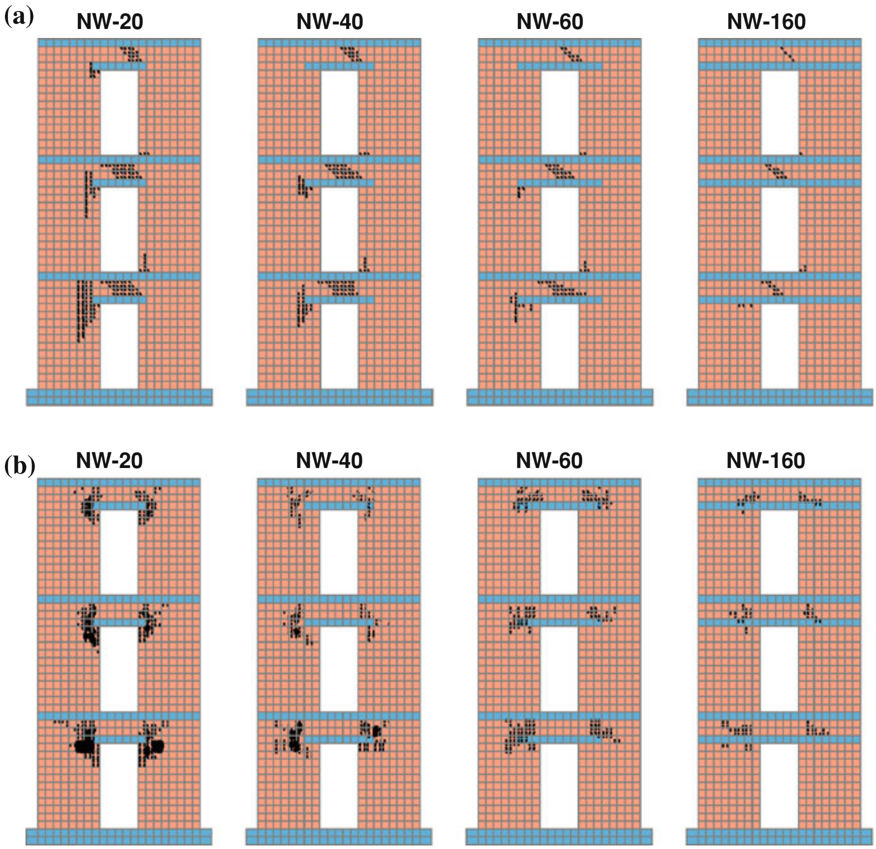


Fig. 6 Crack states in unreinforced masonry walls for work levels of force H. **a** Rigid masonry, H = 15 kN. **b** Soft masonry, H = 3 kN

3.2 Dynamic Analysis

3.2.1 Unreinforced Masonry Walls (NW)

It is obvious that the three-storey unreinforced masonry walls according to Fig. 1a have a small resistance to earthquake excitations, especially in the case of the soft masonry. At first, the dynamic analysis was performed for small values of a harmonic base acceleration $\ddot{x}_o$ according to Fig. 3. Then it was gradually increased to the walls collapse. So, it was determined which maximum base acceleration $\ddot{x}_o$ each wall could withstand (Table 3a). As it was expected, unreinforced masonry walls can withstand a low value of base acceleration, especially in the case of soft masonry.

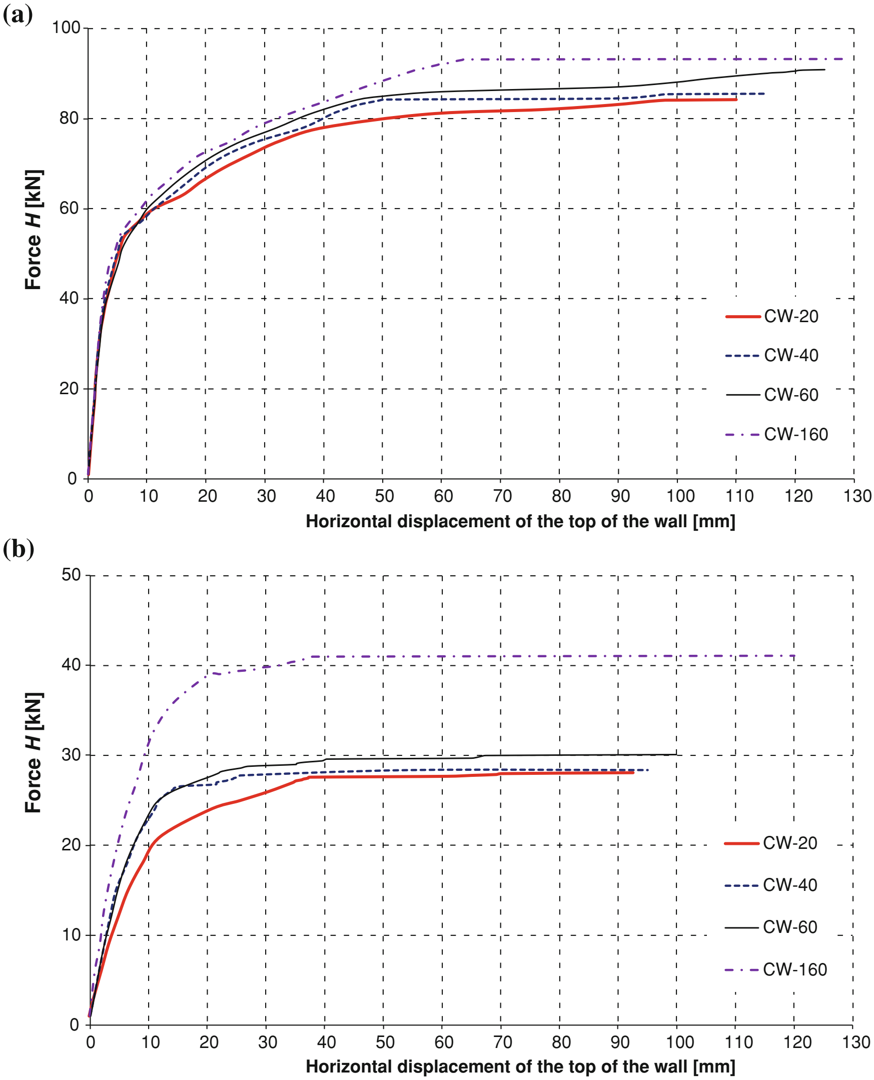


Fig. 7 Horizontal displacement of the top of the confined masonry walls. **a** Rigid masonry. **b** Soft masonry

The horizontal displacement of the top of the unreinforced masonry for the maximum base acceleration $\ddot{x_o}$ is presented in Fig. 9.

For the same dynamic excitation ($\ddot{x_o} = 0.04$ g for rigid masonry and $\ddot{x_o} = 0.001$ g for soft masonry), the walls have almost equal response (almost independent of the bedding length of lintel reinforcement).

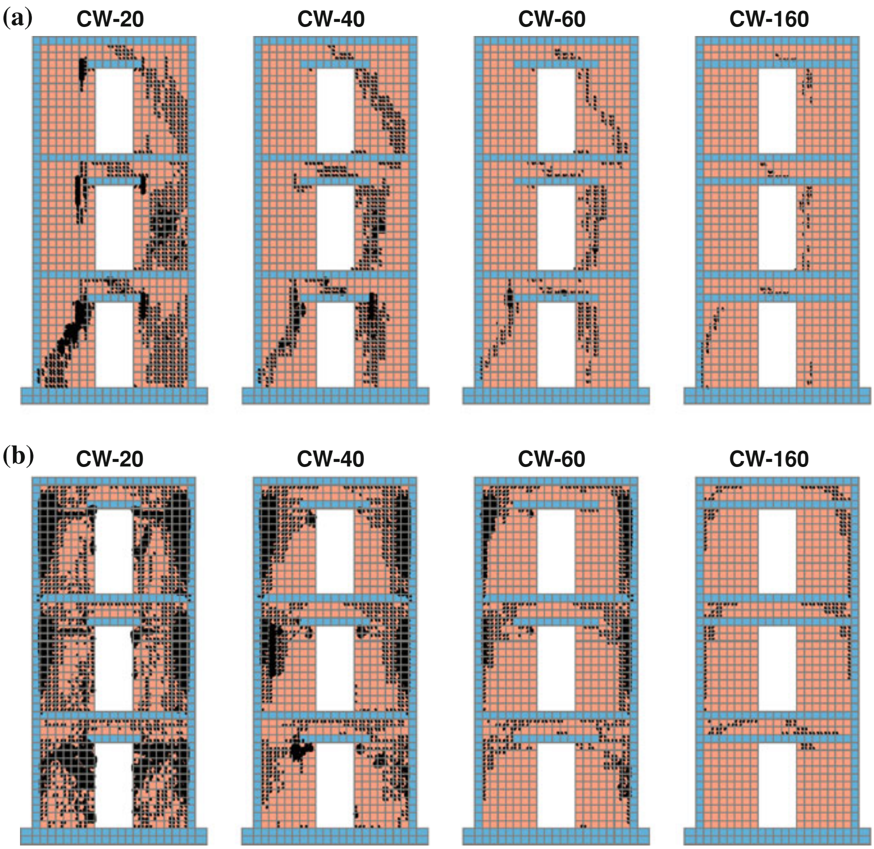


Fig. 8 Crack states in the confined masonry walls for work levels of force H. **a** Rigid masonry walls, H = 27 kN. **b** Poor masonry walls, H = 9 kN

Table 3a Maximum harmonic base acceleration $\ddot{x}_o$ which can withstand unreinforced masonry walls (NW)

			max $\ddot{x}_o$	
Masonry	NW-20	NW-40	NW-60	NW-160
Rigid	0.04 g	0.045 g	0.05 g	0.08 g
Soft	0.001 g	0.0015 g	0.002 g	0.004 g

However, for the same displacement, the walls have different crack states (Fig. 10). It is obvious that, as for the horizontal static force (Sect. 3.1), the bedding length of lintel reinforcement has a significant influence on the size of the cracking zone. Specifically, the extension of the lintel bedding length considerably narrowed the size of the cracking zone.

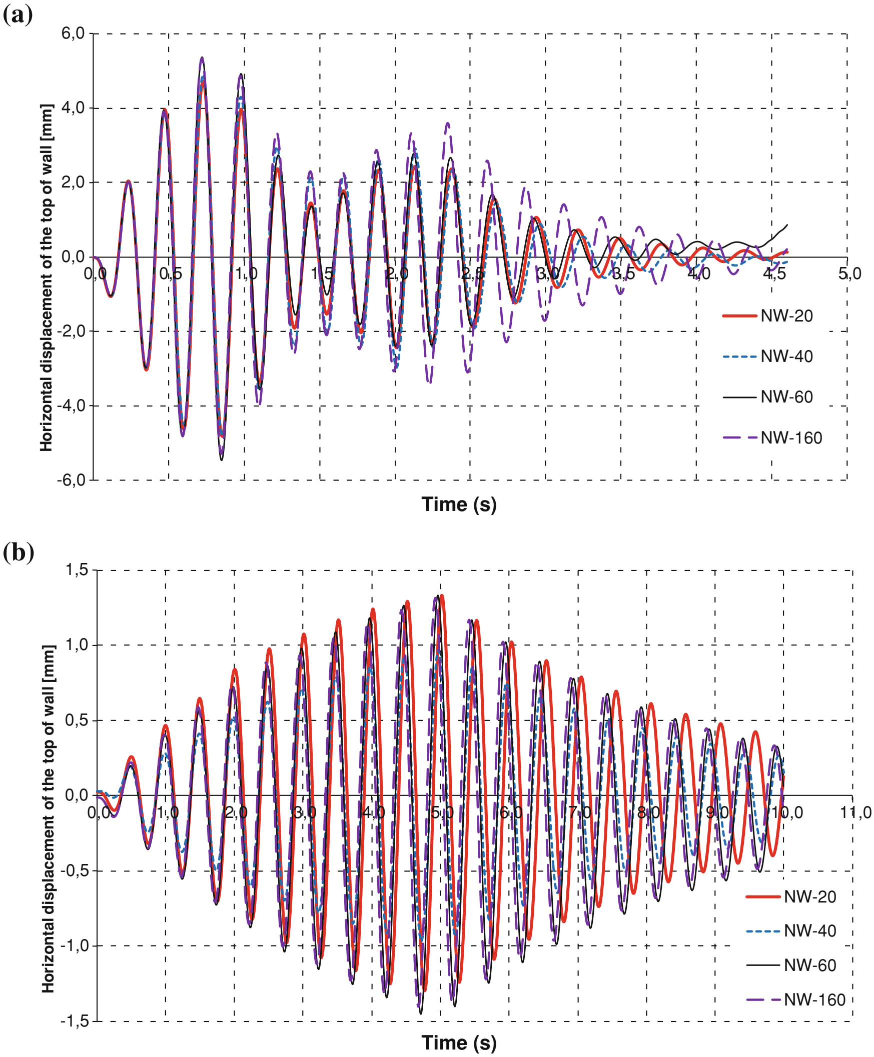


Fig. 9 Horizontal displacement of the top of the unreinforced masonry walls for the harmonic base excitation $\ddot{x}_o$. **a** Rigid masonry walls, $\ddot{x}_o = 0.04$ g. **b** Soft masonry walls, $\ddot{x}_o = 0.001$ g

3.2.2 Confined Masonry Walls (CW)

Analogously to specified in Sect. 3.2.1, it is also firstly determined which maximum base acceleration $\ddot{x}_o$ each wall could withstand (Table 3b). The horizontal displacement of the top of confined masonry wall for the maximum base

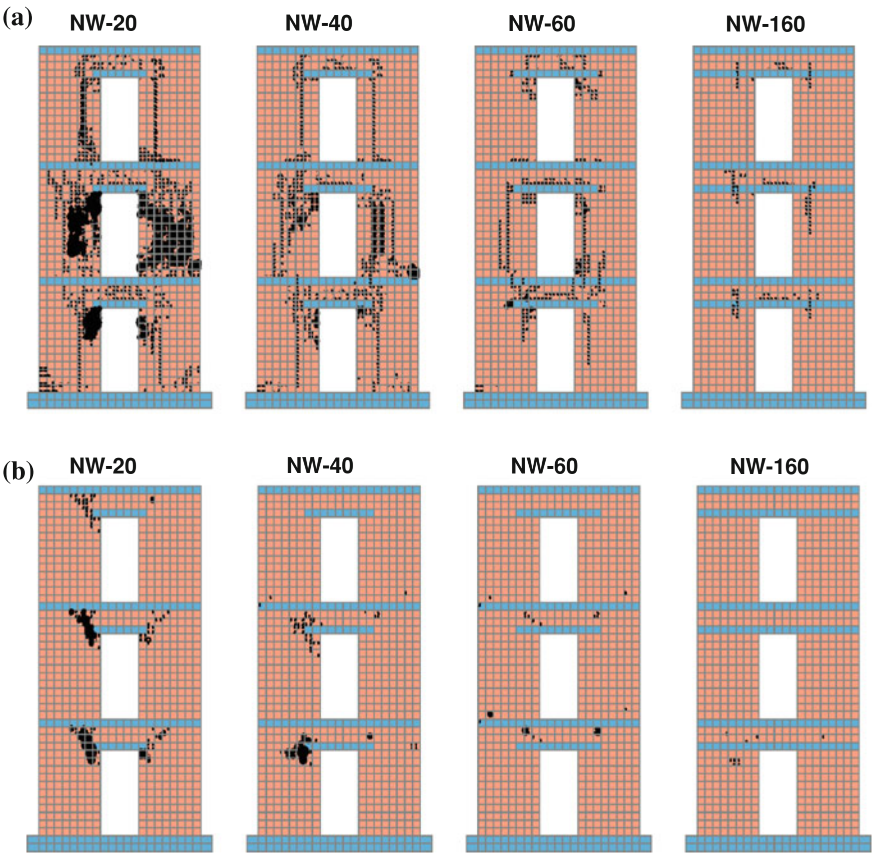


Fig. 10 Crack states in unreinforced masonry walls for the maximum base acceleration $\ddot{x}_o$. **a** Rigid masonry walls, $\ddot{x}_o = 0.04$ g, $t = 0.23$ s. **b** Soft masonry walls, $\ddot{x}_o = 0.001$ g, $t = 0.50$ s

Table 3b Maximum harmonic base acceleration $\ddot{x}_o$ which can withstand confined masonry walls (CW)

			max $\ddot{x}_o$	
Masonry	CW-20	CW-40	CW-60	CW-160
Rigid	0.24 g	0.25 g	0.27 g	0.30 g
Soft	0.02 g	0.03 g	0.04 g	0.10 g

acceleration $\ddot{x}_o$ is presented in Fig. 11. As it was expected, these walls can withstand greater maximum base acceleration $\ddot{x}_o$ compared to the unreinforced masonry walls. A huge difference in the load bearing capacity for cases of the rigid and the soft masonry is evident.

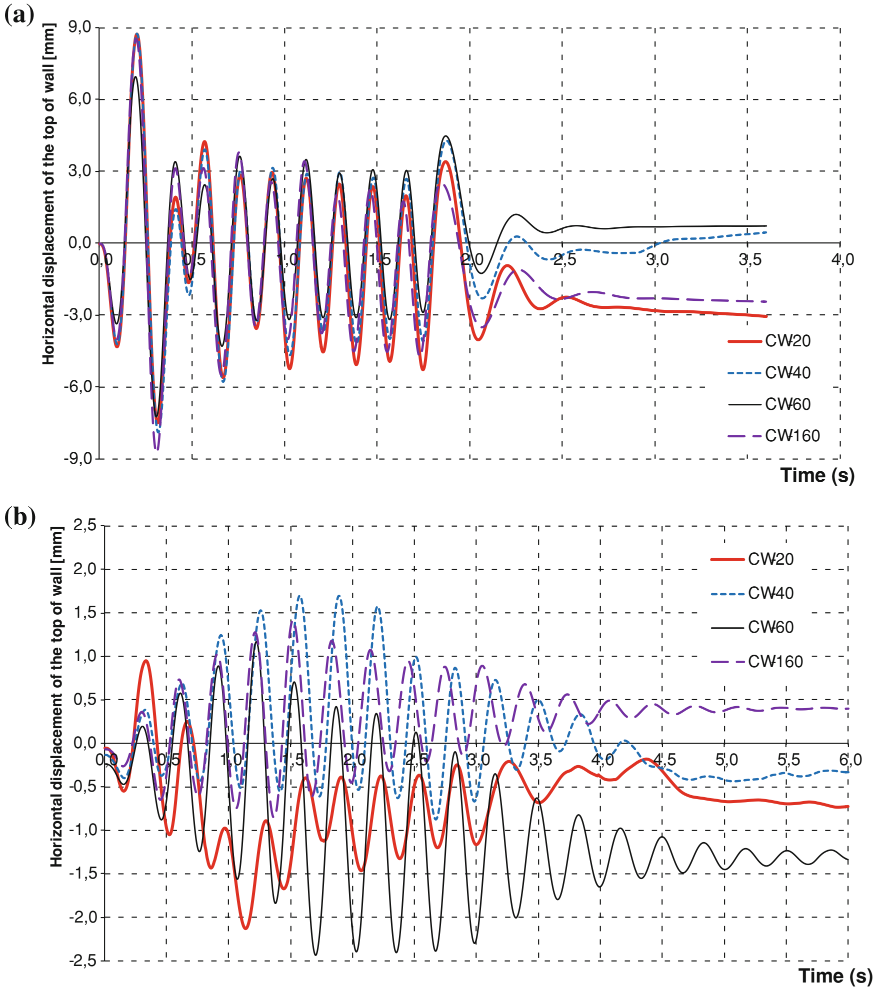


Fig. 11 Horizontal displacement of the top of the confined masonry walls for the harmonic base excitation $\ddot{x}_o$. **a** Rigid masonry walls, $\ddot{x}_o = 0.24$ g **b** Soft masonry walls, $\ddot{x}_o = 0.02$ g

Crack states in the confined masonry walls for the maximum base acceleration $\ddot{x}_o$ is presented in Fig. 12. The influence of the bedding length of lintel reinforcement on the crack states in the lintel and supporting walls is completely analogous to the previously mentioned for the unreinforced masonry walls.

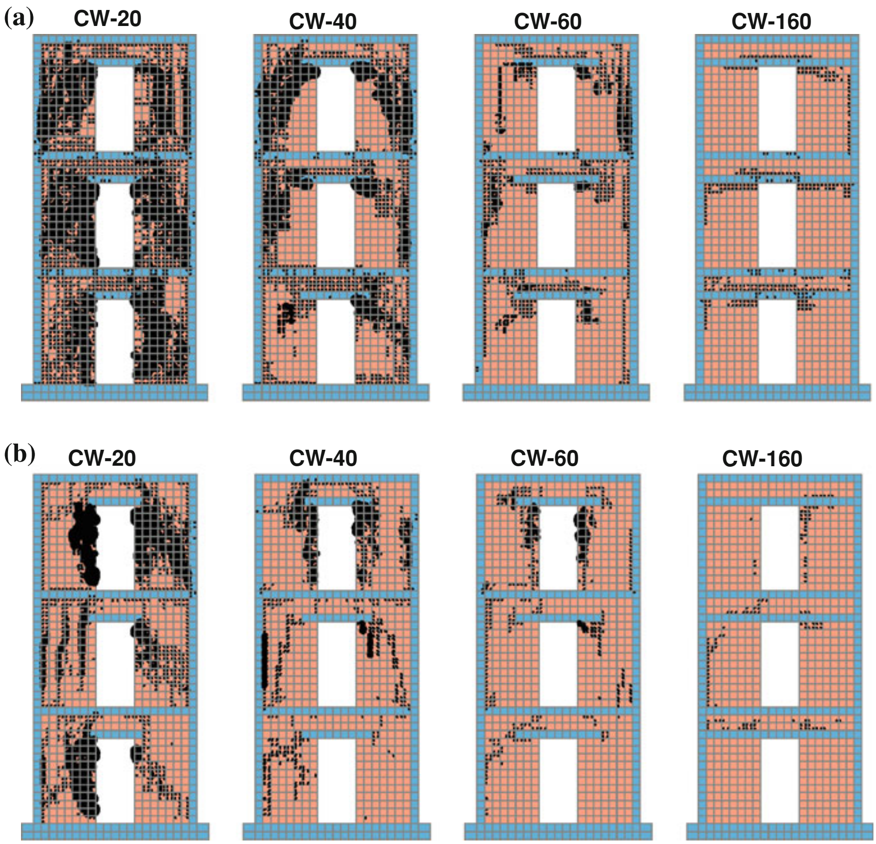


Fig. 12 Crack states in unreinforced masonry walls for the maximum base acceleration $\ddot{x}_o$. **a** Rigid masonry walls, $\ddot{x}_o = 0.04$ g, $t = 0.23$ s. **b** Soft masonry walls, $\ddot{x}_o = 0.001$ g, $t = 0.50$ s

4 Conclusions

By using the previously developed and verified numerical model for static and dynamic analysis of concrete and masonry structures, it was determined that the bedding length of lintel reinforcement may have a significant influence on the load bearing capacity and on the size of cracking zone of the unreinforced and confined masonry walls exposed to winds and earthquakes. Greater bedding length of lintel reinforcement contributes to the increase of load bearing capacity of the masonry walls, as well as to the reduction of size of cracking zones in lintel and supporting walls. That influence is greater if the quality of the masonry is softer. The quality of the masonry has a great influence on the load bearing capacity of the masonry walls, as well as on the size of cracking zones. If the masonry buildings are located in the zone with strong expected earthquakes, especially if the masonry supporting walls are relatively tight, it is recommended to extend the bedding length of lintel reinforcement to the neighboring vertical tie beams.

References

1. Radnić, J., Harapin, A., Matešan, D., Trogrlić, B., Smilović, M., Grgić, N., Baloević, G.: Numerical model for static and dynamic analysis of masonry wall. Građevinar **63**, 529–546 (2011)
2. Radnić, J., Harapin, A., Matešan, D., Smilović, M., Grgić, N.: Numerical model for static and dynamic analysis of masonry structure. In: 5th International Conference on Advanced Computational Engineering and Experimenting, Algarve (2011)