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Aspecte privind calculul pereților structurali din zidărie

Aspects on the masonry structural walls computation

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Rezumat.
Codul romanesc CR6-2013, pornind de la EC6, propune 3 tipuri de pereți structurali din zidărie, care pot sa fie utilizați la clădirile cu structura de rezistenta din zidărie. Prezentul articol, își propune identificarea răspunsurilor acestor tipuri de pereți, pentru diferite niveluri de forte axiale N_{Ed} si dimensiuni ale pereților structurali.

Cuvinte cheie: structuri, zidarie, pereti, momente incovoietoare

Abstract.
The Romanian code CR6-2013, starting from EC6, proposes 3 types of structural masonry walls, which can be used for buildings with masonry resistance structure. This article aims to identify the answers of these types of walls, for different levels of axial forces N_{Ed} and dimensions of structural walls.

Key words: structures, masonry, walls, bending moment

1. Introduction

Traditional design is mainly based on increasing capacity in proportion to demand and increasing ductility. The structures are designed according to the principle "Strong columns and weak beams" so as to develop an optimal plasticity mechanism. An acceptable level of building performance during a seismic motion is the intrinsic ability of the structure strength to absorb and dissipate energy in the most stable manner and for as many cycles as possible. In the case of masonry buildings, although the oldest as a building material, this is quite little understood and calculated.

The three types of masonry presented in CR6 were considered, namely: URM, CM and WRM.

Taking into account all the CR6 recommendations, in all the case studies considered we have:

For Unreinforced Masonry (URM)
According to CR6-2013, for M_{Rd} the relations are:

- The compressed area is $A_{zc} = \frac{N_{Ed}}{0.85 f_d}$;
- The eccentricity of axial force is y_{zc};
- The compression design strength is $f_d = \frac{f_k}{\gamma_M} = \frac{K f_b^{0.7} f_m^{0.3}}{\gamma_M}$;
- The M_{Rd} become: $M_{Rd} = N_{Ed} y_{zc} = N_{Ed}\left[\frac{l_w}{2} - \frac{A_c}{2t * 0.85 f_d}\right] = \frac{N_{Ed}}{2}\left(l_w - \frac{N_{Ed}}{0.85 t f_d}\right)$

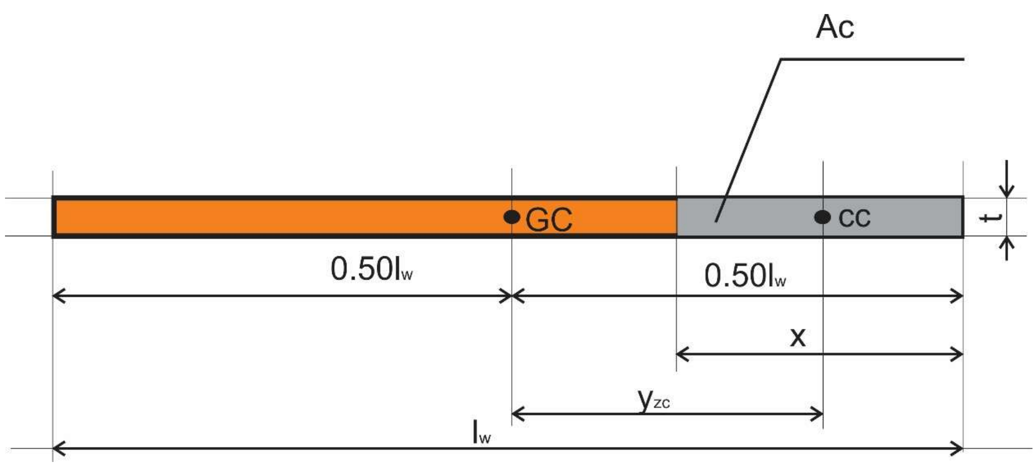


Figure 1 – URM masonry wall

For Confined Masonry (CM)
According to CR6-2013, for M_{Rd} the relations are:

- Equivalation of RC to masonry equivalent area into relation of the ratio $n = \frac{f_{cd}}{f_d}$;
- From n ratio we obtain $A_{em} = (n-1)A_{cc}$ so $b_e = \frac{A_{em}}{t} = \frac{(n-1)A_{cc}}{t}$
- The compressed area is $A_{zc} = \frac{N_{Ed}}{0.85 f_d}$;
- The eccentricity of axial force is y_{zc};
- The compression design strength is $f_d = \frac{f_k}{\gamma_M} = \frac{K f_b^{0.7} f_m^{0.3}}{\gamma_M}$;
- $M_{Rd} = M_{Rd}(URM) + M_{Rd}(As)$ where $M_{Rd}(URM) = N_{Ed} y_{zc}$ and $M_{Rd}(As) = A_s l_s f_{yd}$

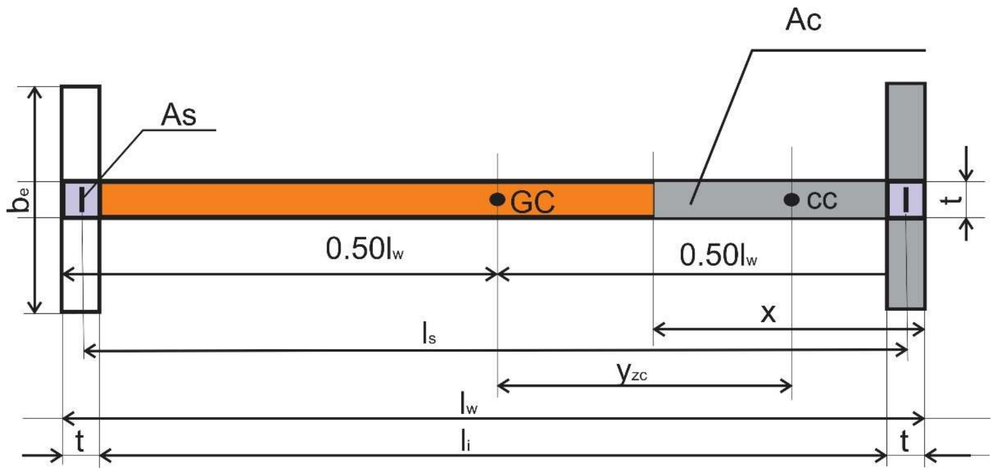


Figure 2 – CM masonry wall

For Web Reinforced Masonry (WRM)

According to CR6-2013, for M_{Rd} the relations are:

- Equivalation of RC to masonry equivalent area is proposed into relation of the ratio $n = \frac{f_{cd}}{f_d}$ so the dimensions of $t_{c,equivqlent}$ become $t_c n$
- The compressed area is $A_{zc} = \frac{N_{Ed}}{0.85 f_d}$;
- The eccentricity of axial force is y_{zc};
- The compression design strength is $f_d = \frac{f_k}{\gamma_M} = \frac{K f_b^{0.7} f_m^{0.3}}{\gamma_M}$;
- $M_{Rd} = M_{Rd}(URM) + M_{Rd}(As)$ where $M_{Rd}(URM) = N_{Ed} y_{zc}$ and $M_{Rd}(As) = 0.25 l_w^2 f_{yd}$

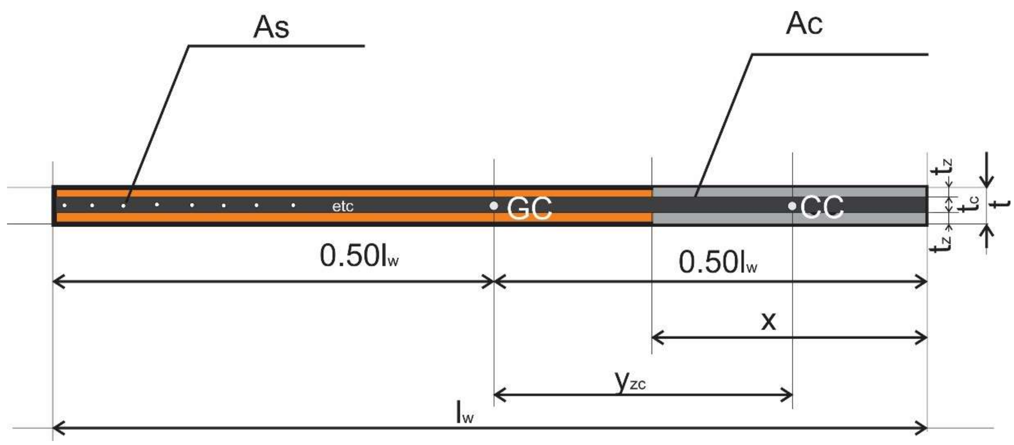


Figure 3 – WRM masonry wall

2. Proposed and completed case studies

The case studies (1365) we focused on consisted of:

- 455 studies for **URM**, wall lengths l_w between 1 and 10 m (every 10 cm), thickness t=0.25m, for 5 levels of axial force N_{Ed} (100, 200, 200, 400 and 500 kN), for a masonry with f_d=200 kN/m^2; The relations from CR6-2013 were considered using the MS Excel program.
- 455 studies for **CM**, wall lengths l_w between 1 and 10 m (every 10 cm), thickness t=0.25m, for 5 levels of axial force N_{Ed} (100, 200, 200, 400 and 500 kN), for a masonry with f_d=200kN/m^2, one reinforced concrete tie column (with f_{cd}=2000kN/m^2) at each end of the wall (with dimensions 25x25 cm) and with 4 reinforcements ϕ12 of a steel with f_{yd}=300000kN/m^2; The relations from CR6-2013 were considered using the MS Excel program;
- 455 studies for **WM**, wall lengths l_w between 1 and 10 m (every 10 cm), a total thickness t=0.25 m (of which 10 cm concrete web and on the outside two layers of masonry having 7.5 cm each), for 5 levels of axial force N_{Ed} (100, 200, 200, 400 and 500 kN), for a masonry with f_d=200kN/m^2, concrete in the web with f_{cd}=2000kN/m^2, with reinforcements ϕ8/100mm from a steel with f_{yd}=300000kN/m^2. Because the relationships in CR6-2013 were considered too simple, the Sekon® program was used for the calculations (developed at UTCB by Daniel Stoica) and which uses reinforced concrete theories. In this case, instead of equating concrete with masonry, masonry was equated with concrete. Three walls were selected (with 3, 6 and 9 m length for N_{Ed} = 100, 200, 300, 400 and 500 kN) for which other answers obtained with Sekon ® are presented.

All calculations were made only to determine the M_{Rd} capable bending moments (regardless of capable axial forces N_{Rd}).

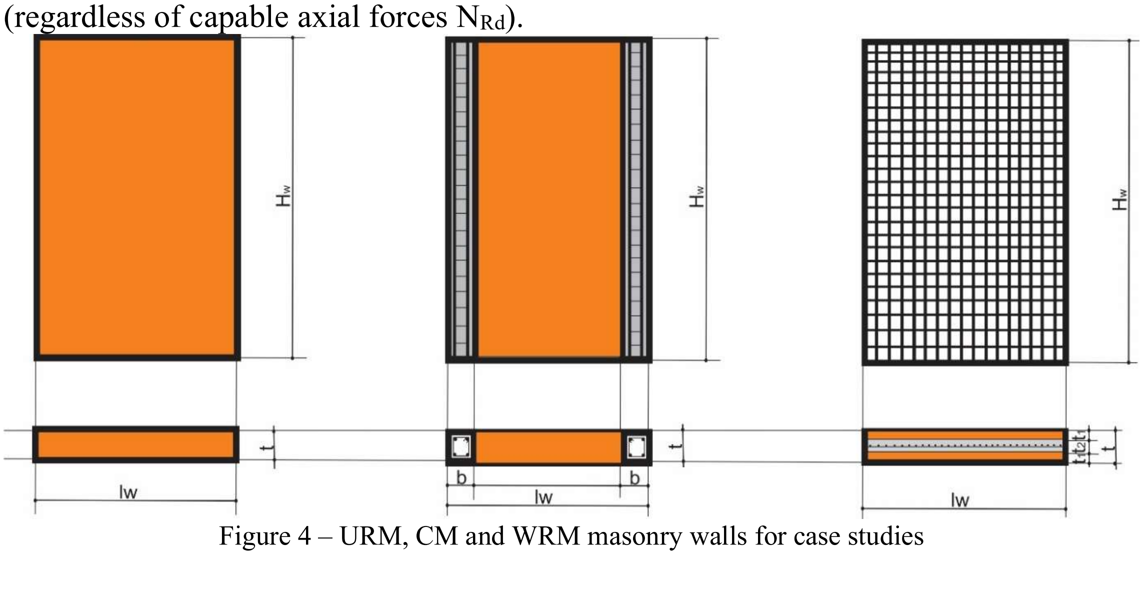
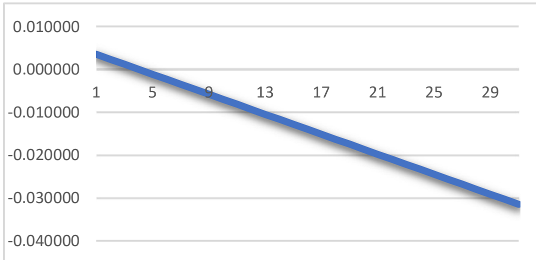
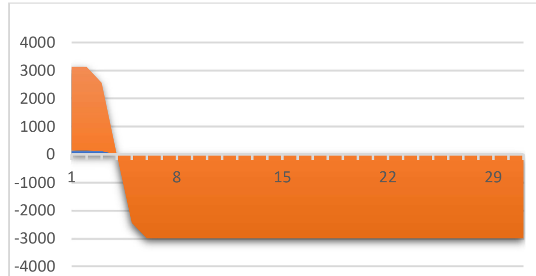


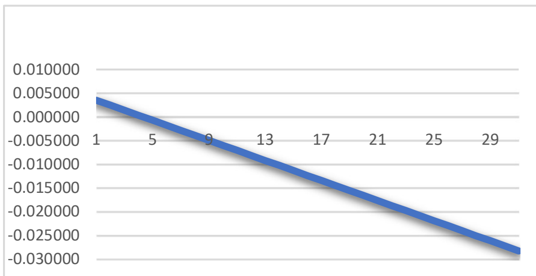
Figure 4 – URM, CM and WRM masonry walls for case studies

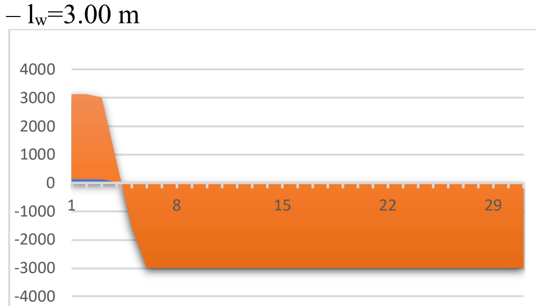
Strain | Stresses in concrete and reinforcement



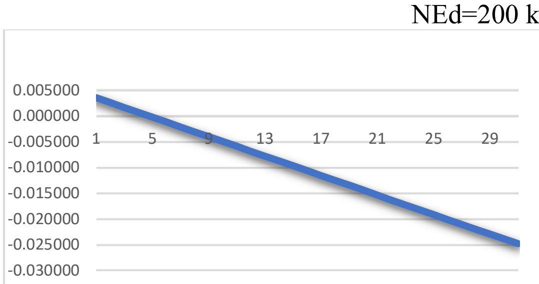


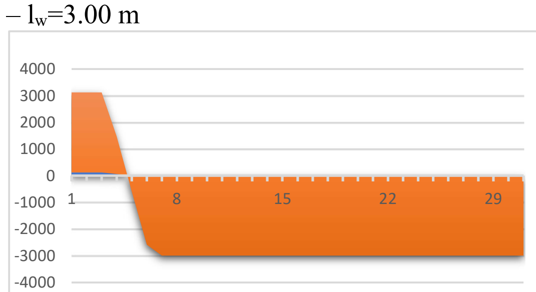
NEd=100 kN – l_w=3.00 m



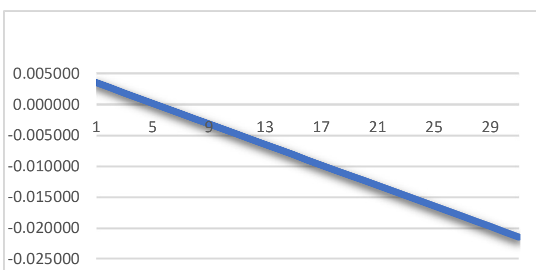


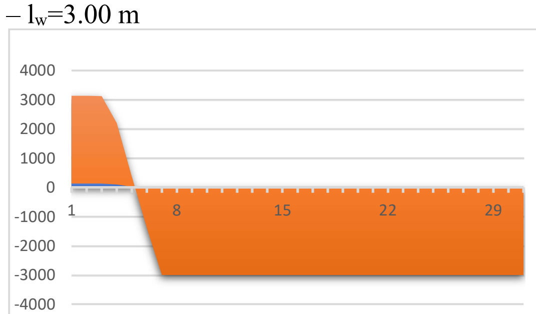
NEd=200 kN – l_w=3.00 m



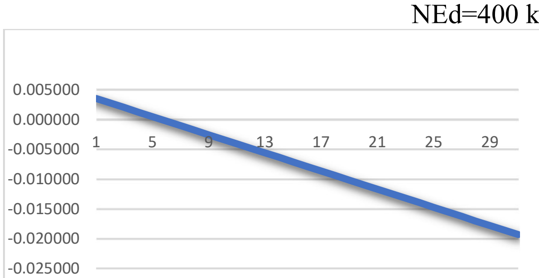


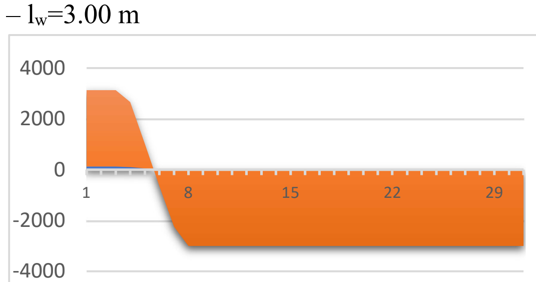
NEd=300 kN – l_w=3.00 m





NEd=400 kN – l_w=3.00 m

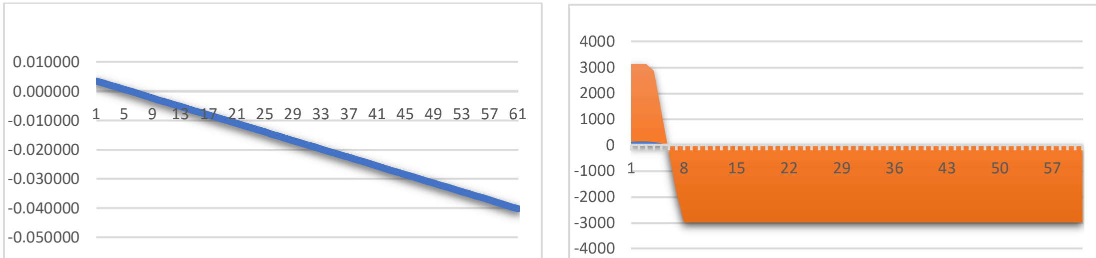




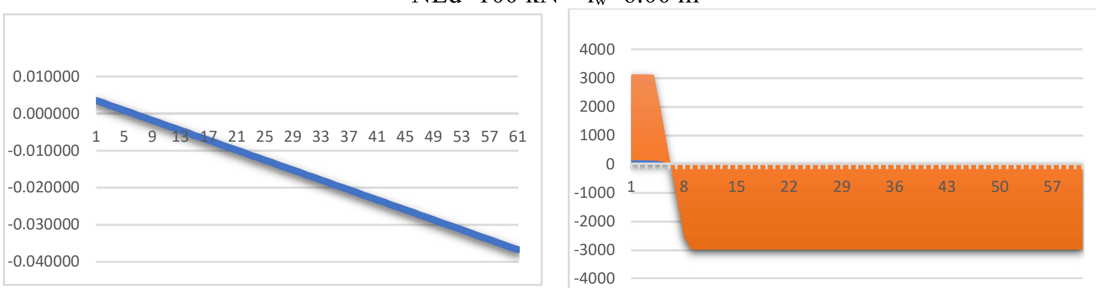
NEd=500 kN – l_w=3.00 m

Figure 5 – WRM – l_w=3.00 m

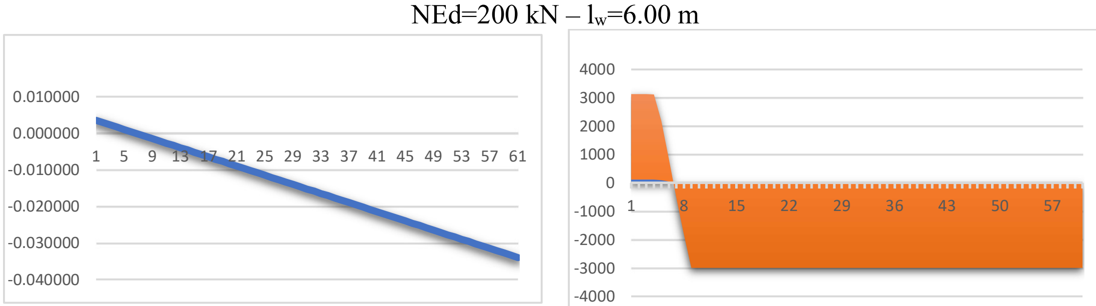
Strain | Stresses in concrete and reinforcement



NEd=100 kN – l_w=6.00 m



NEd=200 kN – l_w=6.00 m



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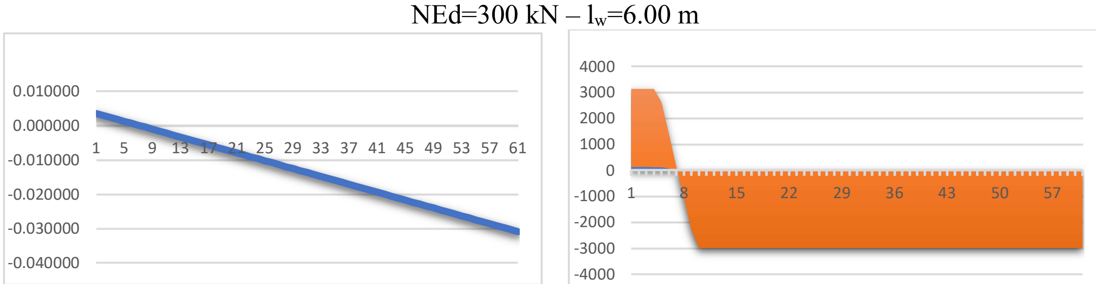
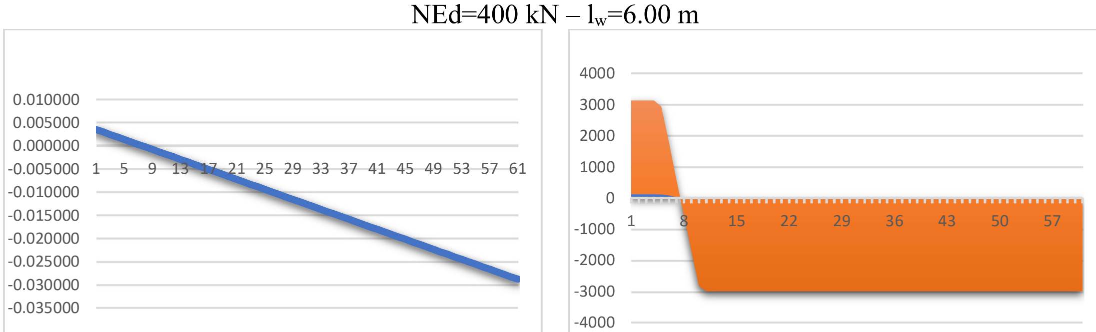


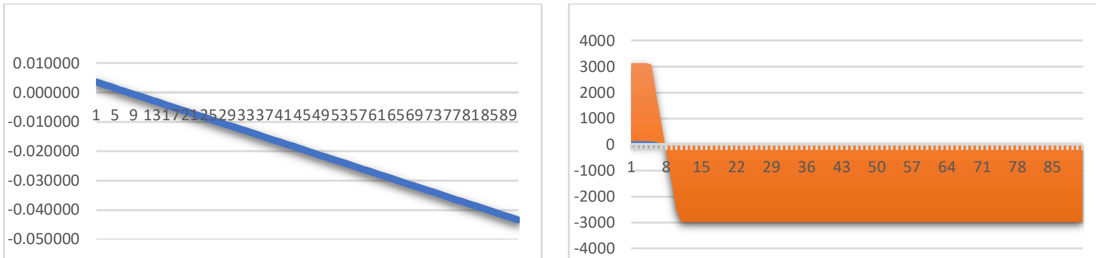
NEd=400 kN – l_w=6.00 m



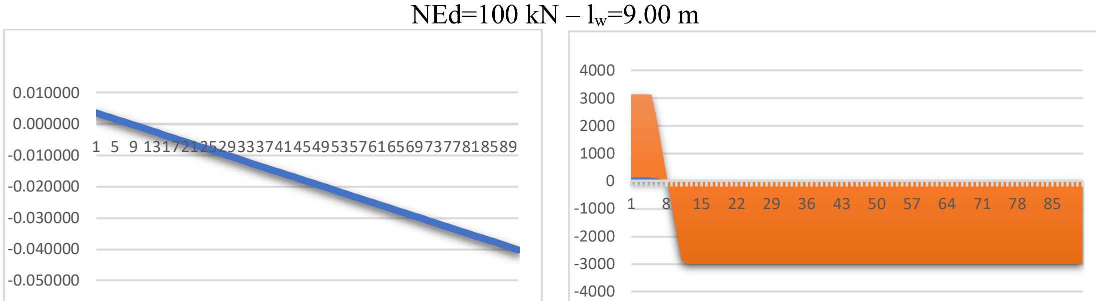
NEd=500 kN – l_w=6.00 m

Figure 6 – WRM – l_w=6.00 m

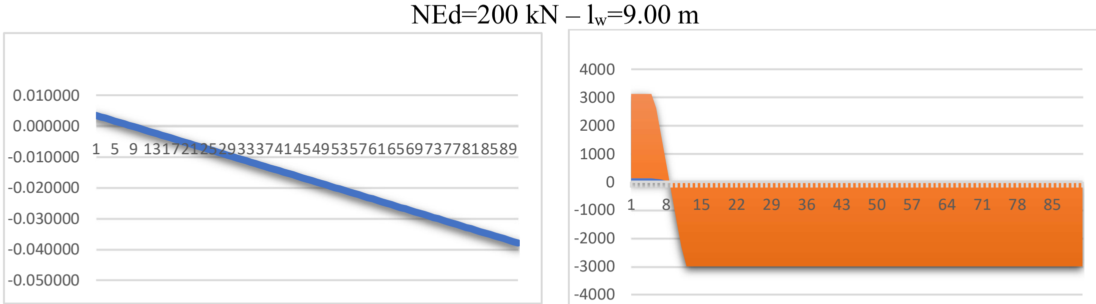
Strain | Stresses in concrete and reinforcement



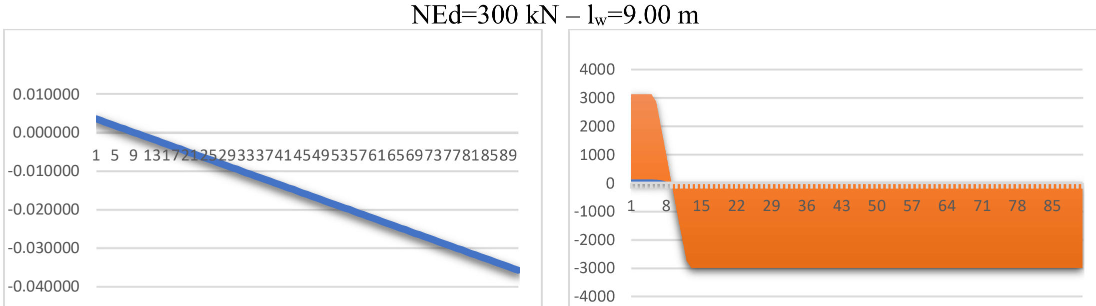
NEd=100 kN – l_w=9.00 m



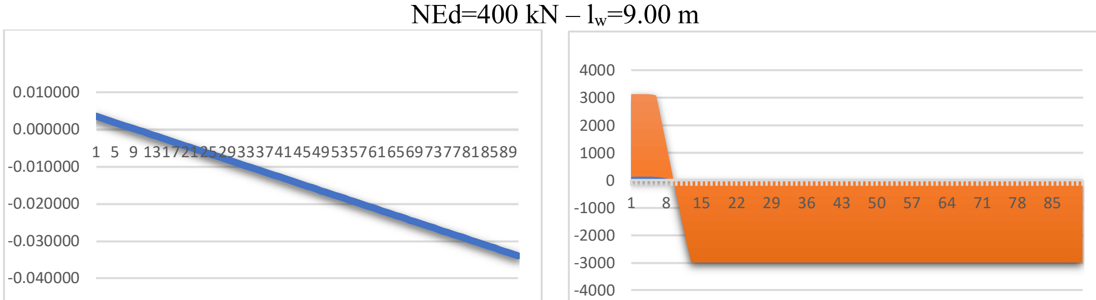
NEd=200 kN – l_w=9.00 m



NEd=300 kN – l_w=9.00 m



NEd=400 kN – l_w=9.00 m



NEd=500 kN – l_w=9.00 m

Figure 7 – WRM – l_w=9.00 m

3. Comparisons between calculations performed for the three types of masonry, according to case studies

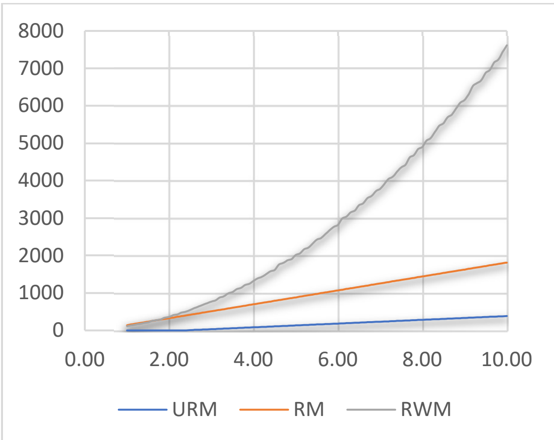


Figure 8 -M_{Rd} for N_{Ed}=100 kN

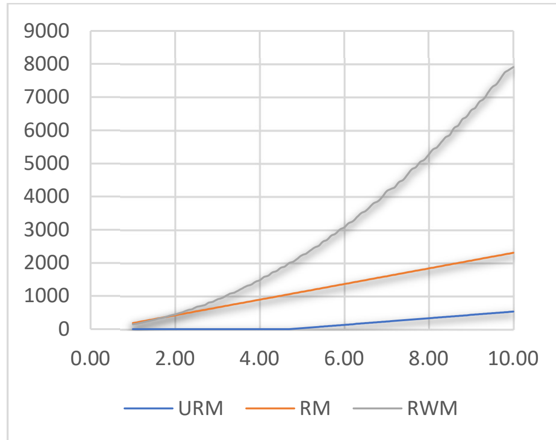


Figure 9 -M_{Rd} for N_{Ed}=200 kN

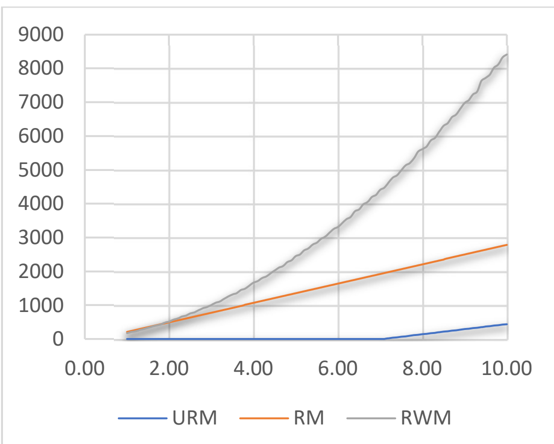


Figure 10 -M_{Rd} for N_{Ed}=300 kN

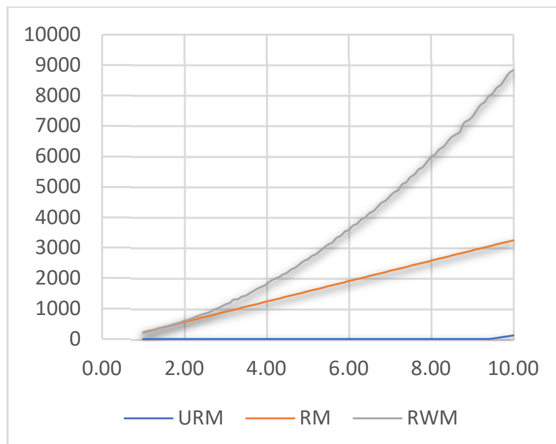


Figure 11 -M_{Rd} for N_{Ed}=400 kN

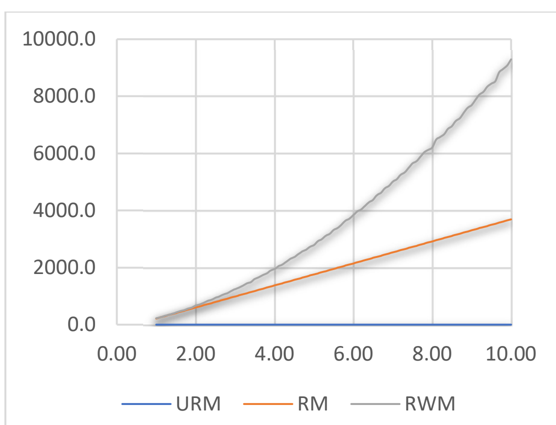


Figure 12 -M_{Rd} for N_{Ed}=500 kN

4. First attempt to obtain simple, empirical relationships to obtain M_{Rd} capable bending moments

Conclusions about the case studies comparisons:

- Looking at the diagrams of M_{Rd} capable bending moments, for the 3 types of masonry walls, it can be seen immediately that the lowest values are for URM and the highest values for WRM. A maximum possible for CM compared to URM and WRM being about half.
- It can also be seen that the formulas in CR6 are absolutely "linear" compared to the calculations made with the Sekon ® program.
- Also, although we do not take into account the N_{Rd}, it is observed that with the increase of the axial forces N_{Ed} on the walls, the M_{Rd} becomes zero at some point, for URM.
- Therefore, it is very clear that the walls of the URM respond poorly to seismic actions, even if out-of-plane actions are not taken into account.
- Considering the trendlines resulting for all the case studies performed, we tried to obtain some simpler relations for the M_{Rd} calculation, in the followings:

Considering all the numerical simulations performed for URM, CM and WRM, the following empirical relations of approximation of the capable bending moments (M_{Rd}) resulted:

For URM:

- If $l_w < 2.4P$ it turns out that $M_{Rd} = 0$;
- If $l_w \geq 2.4P$ it turns out that $M_{Rd} = 50P(l_w - 2.30P)$

For CM:

$$M_{Rd} = (0.1n + P^{0.90})l_w^2 + (2.50mA_S + P^{3.15})l_w$$

For WRM:

$$M_{Rd} = (0.93mA_{Sw} + P^{0.741})l_w^2 + 4nPl_w$$

Where:

$n = \frac{f_{cd}}{f_d}$ first transformation factor

$m = \frac{f_{yd}}{f_{cd}}$ second transformation factor

$$P = 20\frac{N_{Ed}}{f_d}$$

With:

- f_{cd} – design compressive strength of concrete in [kN/m^2]
- f_d – design compressive strength of masonry in [kN/m^2]
- f_{yd}- design tensile strength of the reinforcement in [kN/m^2]
- N_{Ed} – axial force on the masonry element in [kN]
- l_w – the length of the masonry wall in m

- A_S – the area of the reinforcements in the tensioned tie column in [cm^2]
- A_{Sw} – total vertical reinforcement area on the linear meter of WM concrete web in [cm^2]

5. Conclusion

Conclusions about the case studies comparisons:

- For the new generation of design codes, we believe that the relationships in CR6 should be improved and updated, trying to be homogeneous and not starting from things established in various other codes in the world.
- The objectives of this article were only about M_{RD} and we intend to continue this study, so as to obtain structural answers as close as possible to reality, possibly with simple but consistent calculation relationships.
- Here I used as a correct comparison the Sekon® program, made by one of the authors of the article, but also other calculation programs, postprocessors such as CSICol, Graitec, etc. can be easily used.

6. References

- CR6-2013 - DESIGN CODE FOR MASONRY STRUCTURES (COD DE PROIECTARE PENTRU STRUCTURI DIN ZIDĂRIE CR6-2013)
- P100/1-2013 - SEISMIC DESIGN CODE - PART I - DESIGN PROVISIONS FOR BUILDINGS (COD DE PROIECTARE SEISMICĂ – PARTEA I – PREVEDERI DE PROIECTARE PENTRU CLĂDIRI)
- Daniel Stoica - User guide for calculating the strength capacity of reinforced concrete elements – Sekon®
- MS – Excel