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Comparison on the behavior of confined masonry structures made with ceramic vertical hollow blocks in correlation with CR6-2013 and P2-85 design codes requirements

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Abstract: Considering the provisions of the new design codes P100/1-2013 and CR6-2013 in this paper a comparison between structural responses for a building with structural masonry walls made of vertical hollow ceramic blocks calculated according to CR6-13 and P2-85 design codes requirements.

Keywords: Hollow, blocks, CR6-13, P2-85

1. Computation hypothesis

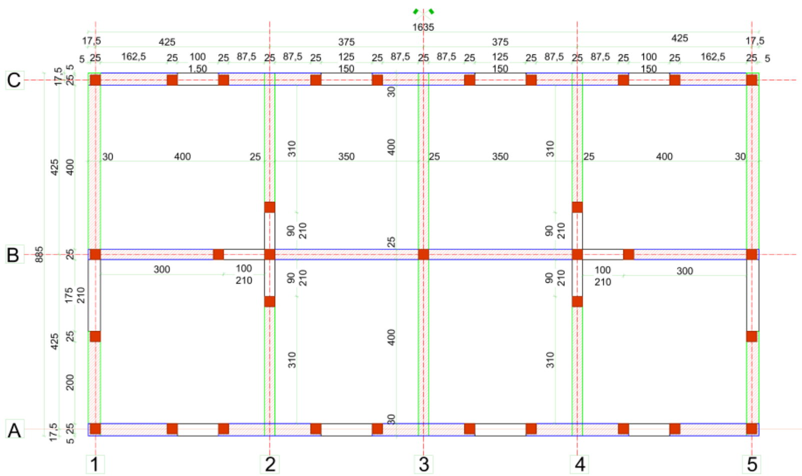
There has been realized two study cases for a building with 3 levels with confined masonry structure, having the dimensions in plan about 16.35m with 8.85m and the levels height of 2.75m. As a location Bucharest was considered which is characterized by a peak ground acceleration a_g=0.30g and with the control period (corner period) T_c=1.6 seconds.

For the first study case computation vertical hollow ceramic blocks were considered; for the external walls the thickness t = 30cm respectively for the interior walls t = 25cm. The specific weight of the masonry was considered 1050 kgf/m^3. The masonry is made with a general purpose masonry mortar M5 and ceramic blocks with a standardized compression strength f_b = 10N/mm^2, resulting the compressive strength of masonry f_k=3.65 N/mm^2 according to Table 4.2.b of CR6- 2013 code.

For the second study case were considered the same geometrical and weight ceramic blocks. The masonry is made with a general purpose masonry mortar M5 (M50 according R=2.30 N/mm^2 (see table 3 of STAS 10109/1-82), shear resistance R_f = 0.16 N/mm^2 and characteristic strength for the main stretching efforts R_p = 0.11 N/mm^2 (see table 5 of STAS 10109/1-82).

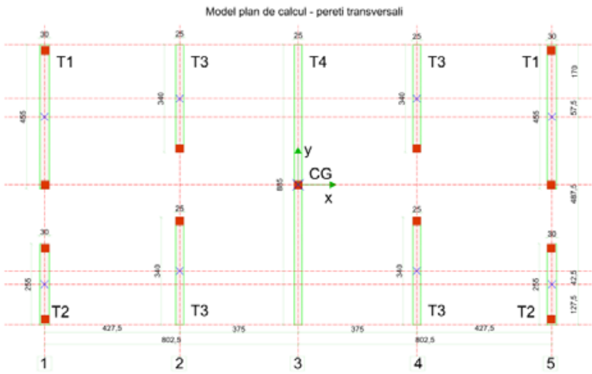
For both study cases were determined the loads, level weights and the seismic base coefficient.

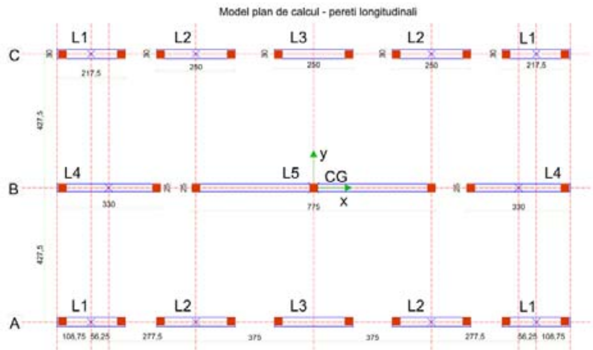
- The maximum ordinate for the elastic spectrum $\beta_0 = 2.50$;
- The reduction factor for buildings with more than 2 levels λ=0.85;
- The reduction factor which take into account the masonry critical damping (ξ=8%) is η=0.88;
- The importance-exposure factor is γ_{Ie}=1.0 (current building type according to table 4.2 from P100-1/2013 code;
- The behavior factor q=2.0 (according to paragraph 8.3.4(5) from code P100-1/2013);
- The global seismic coefficient $c = \gamma_{Ie} \frac{\beta_0 \times \lambda \times \eta}{q} \times \frac{a_g}{g} = 1.0 \times \frac{2.5 \times 0.85 \times 0.88}{2} \times \frac{0.30g}{g} = 0.28$
- There was also calculated the horizontal levels seismic forces as $F_i = F_b \frac{m_i \times z_i}{\sum_{j=1}^{n} m_j \times z_j}$ (according to equation 4.5 from P100-1/2013 code).



2. Establishing the 2D models for seismic computation

The building shows geometric and structural symmetry in the plan and meets also the elevation conditions of regularity. It can be used to calculate it the equivalent static seismic forces using two planar models; building - regardless of the used blocks type - fit into the type 1.1 (Table 5.1. from CR6-2013 code). The two models are illustrated below:





Checking the structural walls density

Transverse	Longitudinal
Ax 1 + Ax 5 => 2 x (4.55 x 0.30 + 2.55 x 0.30) = 4.26m^2 Ax 2 + Ax 4 => 2x (3.40 x 0.25 + 3.40 x 0.25) = 3.40m^2 Ax 3 => 8.85 x 0.25 = 2.2125m2 Total => A_{walls} =9.8725m^2 => p = 6.82%	Ax A + Ax C => 2 x (2 x 0.3 x 2.175 + 3 x 0.30 x 2.50) = 7.11 m^2 Ax B => 2x 0.25 x 3.30 + 0.25 x 7.75 = 3.5875 m^2 Total => A_{walls} = 10.6975m^2 => p= 7.39%

According to Table 8.9 from P100-1/2013 code for a 3 levels building located in a site with the a_g=0.30g, the minimum density of structural walls is p_{min} = 6.0% for confined masonry structural system.

There were checked each wall ρ ratio (between the openings length and fullness masonry length according to table 8.11 of P100-1/2013 code - checking were done for a site with horizontal design acceleration a_g=0.30g. Requirements: exterior walls $\rho \leq 0.8$, interior walls $\rho \leq 0.25$ respectively.

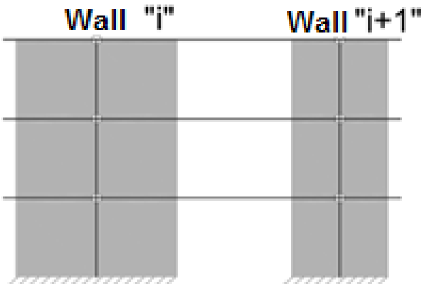
Transverse	Longitudinal
Ax 1 sau Ax 5 => $l_{openings}$ = 1.75m $l_{masonry}$= 7.10m =>ρ = 0.246 ≤ 0.80 (exterior walls) Ax 2 sau Ax 4 => $l_{openings}$ = 1.80m $l_{masonry}$ = 7.05m =>ρ = 0.25 ≤ 0.25 (interior walls)	Ax A sau Ax C => $l_{openings}$ = 4.50m $l_{masonry}$=11.85m =>ρ = 0.38 ≤ 0.80 (exterior walls) Ax B => $l_{openings}$ = 2.00m $l_{masonry}$ = 14.35m =>ρ = 0.14 ≤ 0.25 (interior walls)

The conditions from code P100-1/2013 - Table 8.11 are satisfied.

Structural analysis models take into account the connections made between the wall (cantilevers), which are made at every level by rigid floors (horizontal diaphragms) in their plan. In this case, the shear distribution between the structural walls stemming

came from the lateral displacement compatibility condition of the walls at each floor. Spandrels effect is negligible.
The connections between the walls were modeled as compressed strut articulated at both ends.
The walls were modeled as elastic rectangular bar (with respective values of the area, the shear area and moment of inertia) at the ± 0.00 fixed support.
With this model from the equal condition translational displacements using a computer program for 2D analyses were calculated the sectional efforts (shear and bending moment) on each wall.

Because the torsion components depend only on the geometry and geometric properties of the walls, their values were considered proportional to those obtained by the method of independent cantilevers.



The calculation scheme for compressed struts

Design values of shear and bending moment for each wall are given in the below tables (for the transverse walls the values include increases from the torsional effect).

First level pier	Positive sense seismic action		
	V_{Ed}	M_{Ed}	V_{Ed}/M_{Ed}
	tf	tfm	
T1	22.4	136.8	0.164
T2	10.1	54.7	0.185
T3	10.6	64.8	0.164
T4	34.5	265.7	0.130

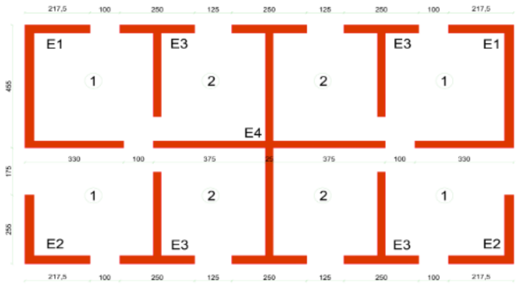
Transverse (including the torsional effects)

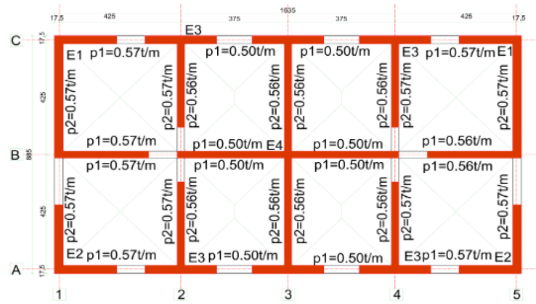
First level pier	Positive sense seismic action		
	V_{Ed}	M_{Ed}	V_{Ed}/M_{Ed}
	tf	tfm	
L1	8.0	45.5	0.176
L2	9.7	58.8	0.165
L3	9.7	58.7	0.166
L4	9.8	64.2	0.153
L5	30.4	284.9	0.107

Longitudinal (neglected torsional effects)

Further structural safety checks will be carried out using values obtained by applying the cantilever sectional efforts attached to each level.

3. The vertical loads for structural walls





Total loads and compression unitary efforts on walls groups

Walls groups	n_e	Area	G_{slab}	$G_{masonry}$	G_{level}	$G_{1^{st}\ level}$	$G_{2^{nd}\ level}$	$G_{3^{rd}\ level}$	$\sigma_{0\ 1^{st}\ level}$	$\sigma_{0\ 2^{nd}\ level}$	$\sigma_{0\ 3^{rd}\ level}$
		m^2	tones	tones	tones	tones	tones	tones	N/mm^2	N/mm^2	N/mm^2
E1	2	2.6775	7.69	8.84	16.53	49.58	33.05	16.53	**0.185**	**0.123**	**0.021**
E2	2	1.3275	3.163	4.38	7.54	22.63	15.09	7.54	**0.170**	**0.114**	**0.024**
E3	4	1.525	5.84	5.03	10.87	32.61	21.74	10.87	**0.214**	**0.143**	**0.019**
E4	1	5.4375	20.88	17.94	38.83	116.48	77.65	38.83	**0.214**	**0.143**	**0.019**

4. The capable bending moments calculation (1st level – Ceramic blocks masonry-CR6-2013)

TRANSVERSAL

Wall	Group	f_k	γ_M	f_d	t	l_w	$A=t \times l_w$	$\sigma_{0\ parter}$	$S_d=\sigma_0/f_d$	$N_{Ed}=\sigma_0 \times A$	l_s	A_{st}	x_{Rd}
		N/mm^2		N/mm^2	m	m	m^2	N/mm^2	---	tone	m	cm^2	m
T1	E1	3.65	1.9	1.92	0.30	4.55	1.365	0.185	0.096	25.28	4.25	6.15	0.585
T2	E2	3.65	1.9	1.92	0.30	2.55	0.765	0.170	0.089	13.04	2.25	6.15	0.302
T3	E3	3.65	1.9	1.92	0.25	3.40	0.850	0.214	0.111	18.18	3.15	6.15	0.505
T4	E4	3.65	1.9	1.92	0.25	8.85	2.213	0.214	0.112	47.4	8.60	6.15	1.315

Wall	M_{Rd} (ZNA)	$M_{Rd}(A_s)=l_s\ A_{st}\ f_{yd}$	M_{Rd} (ZC)= $M_{Rd}(A_s)+M_{Rd}$ (ZNA)	M_{Ed}	OBS	V_E/M_E	$V_{Edu}=M_{Rd}$ (ZC) x V_E/M_E
	tm	tm	tm	tm		m-1	tone
T1	50.11	78.41	* 128.53	136.8	NOK	0.164	21.05
T2	14.66	41.51	56.17	54.7	OK	0.185	10.37
T3	26.32	58.12	84.43	64.8	OK	0.164	13.81
T4	178.55	158.67	337.22	265.7	OK	0.130	43.79

LONGITUDINAL

Wall	Group	f_k	γ_M	f_d	t	l_w	A=t x l_w	$\sigma_{0\ parter}$	$s_d = \sigma_0/f_d$	$N_{Ed} = \sigma_0 x A$	l_s	A_{st}	x_{Rd}
		N/mm^2		N/mm^2	m	m	m^2	N/mm^2	---	tone	m	cm^2	m
L1	E2	3.65	1.9	1.92	0.3	2.2	0.653	0.170	0.089	11.12	1.875	6.15	0.257
L2	E3	3.65	1.9	1.92	0.3	2.5	0.750	0.214	0.111	16.04	2.25	6.15	0.371
L3	E4	3.65	1.9	1.92	0.3	2.5	0.750	0.214	0.112	16.07	2.22	6.15	0.372
L4	E1	3.65	1.9	1.92	0.3	3.3	0.825	0.185	0.096	15.28	3.00	6.15	0.424
L5	E4	3.65	1.9	1.92	0.3	7.8	1.938	0.214	0.112	41.5	7.50	12.05	1.152

Wall	**M_{Rd} (ZNA)**	**$M_{Rd}(As)=l_s A_{st} f_{yd}$**	**M_{Rd} (ZC)= $M_{Rd}(As)+M_{Rd}$ (ZNA)**	**M_{Ed}**	OBS	**V_E/M_E**	**$V_{Edu}=M_{Rd}(ZC) \times V_E/M_E$**
	tm	tm	tm	tm		m^{-1}	tone
L1	10.67	34.59	45.26	45.5	OK	0.176	7.96
L2	17.07	41.51	58.59	58.8	OK	0.165	9.66
L3	17.10	41.51	58.51	58.7	OK	0.166	9.69
L4	21.97	55.35	77.32	64.2	OK	0.153	11.80
L5	135.92	271.13	408.05	284.9	OK	0.107	43.54

Conclusions available for the masonry structure made of ceramic blocks according to design code CR6-2013.

The requirement of structural resistance to compression and bending is satisfied for the whole building both directions.
* Transversely the T1 wall has insufficient strength M_{Rd} =0.94 M_{Ed}. Since this strength is less than 15%, it is acceptable that the difference is covered by redistributing the total resistance $\Sigma M_{Rd} = 1.15\ \Sigma M_{Ed}$

5. The structural walls design shear strength computation

Failure mechanism by sliding in horizontal beds

The design slip strength in horizontal beds of confined masonry walls, V_{Rd} is calculated by adding:

• The design slip strength in horizontal beds of URM masonry panel corrected to take into account the effect of confinement elements (V_{Rdl} *);

• The design shear strength of reinforcement corresponding to compressed belt column from the compressed wall edge (V_{Rd2});

• The design shear strength of compressed belt column (V_{Rsc}).

$V_{Rd} = V_{Rdl}* + V_{Rd2} + V_{Rsc}$ according to relation (6.35) from CR6-2013

V_{Rdl}* corrected strength calculation was made using the equation:

$V^*_{Rd,l} = \frac{1}{\gamma_M} f_{vk0} t l_{ad} + 0.4 N^*_{Ed}$ according to relation (6.35a) from CR6-2013

where $N^*_{Ed} = N_{Ed} + 0.8 V_{Ed} \frac{h_{pan}}{l_{pan}}$ according to relation (6.35b) from CR6-2013

h_{pan} and l_{pan} are the confined masonry panel dimensions.

In the following tables there used the notations:

$$V_{ad} = \frac{1}{\gamma_M} f_{vk0} t l_{ad} \qquad V_\mu = 0.4 N^*_{Ed}$$

The compressed belt column reinforcement shear strength where computed according to CR6-2013, where for the longitudinal reinforcement of Ø14 f_{yd}= 300N/mm^2, 2nd strength category, and the stirrups of Ø8 f_{yd}= 210N/mm^2, 1st strength category, it was considered a λc=0.25 (table 6.3 from CR6).

$V_{Rd2} = \lambda_c A_{asc} f_{yd}$ according to relation (6.36) from CR6-2013

The shear strength value for the belt column concrete where computed with:

$V_{Rsc} = A_{bsc} \times f_{cvd}$ according to relation (6.37) from CR6-2013

$f_{cvd} = f_{cvk}/\gamma_C = 0.27$ N/mm^2 / 1.5 = 0.18N/mm^2 (concrete class C12/15 according to table 3.2 from EC 6)

It result the total shear strength of the compressed belt column as: $V_{Rstc} = V_{Rd2} + V_{Rsc}$

TRANSVERSE

Element	V_{Ed}	N_{Ed}	N_{Ed}*	l_w	h	l_{ad}	V(μ)	V_{ad}	V_{Rdl}*	V_{Rd2}	V_{Rsc}	V_{Rstc}	$V_{Rd,l}$ (ZC)	OBS
	tone	tone	tone	m	m	m	tone	tone	tone	tone	tone	tone	tone	
T1	22.39	25.28	35.12	4.55	2.50	0.00	14.05	0.00	14.05	4.61	1.13	5.74	**19.79**	NOK
T2	10.10	13.04	20.96	2.55	2.50	0.00	8.38	0.00	8.38	4.61	1.13	5.74	**14.12**	OK
T3	10.64	18.18	24.44	3.40	2.50	0.00	9.78	0.00	9.78	4.61	1.13	5.74	**15.50**	OK
T4	34.53	47.40	55.20	8.85	2.50	0.00	22.08	0.00	22.08	4.61	1.13	5.74	**27.81**	NOK

LONGITUDINAL

Element	V_{Ed}	N_{Ed}	N_{Ed}*	l_w	h	l_{ad}	V(μ)	V_{ad}	V_{Rdl}*	V_{Rd2}	V_{Rsc}	V_{Rstc}	$V_{Rd,l}$(ZC)	OBS
	tone	tone	tone	m	m	m	tone	tone	tone	tone	tone	tone	tone	
L1	8.00	11.12	18.48	2.18	2.50	0.00	7.39	0.00	7.39	4.61	1.13	5.74	**13.13**	OK
L2	9.69	16.04	23.79	2.50	2.50	0.00	9.52	0.00	9.52	4.61	1.13	5.74	**15.26**	OK
L3	9.72	16.07	23.85	2.50	2.50	0.00	9.54	0.00	9.54	4.61	1.13	5.74	**15.27**	OK
L4	9.79	15.28	21.21	3.30	2.50	0.00	8.48	0.00	8.48	4.61	1.13	5.74	**14.22**	OK
L5	30.42	41.50	49.35	7.75	2.50	0.00	19.74	1.00	19.74	7.23	1.13	8.36	**28.09**	NOK

Failure mechanism in inclined section

The design strength for inclined failure mechanism for the confined masonry walls (**V_{Rd}**) is computed by assuming:

- The design strength for inclined section of a URM masonry panel corrected to take into account the interaction with the confinement elements (VRdi*);
- The design shear strength due to compressed belt column reinforcement from the compressed wall edge (VRd2);
- The design shear strength for the compressed belt column (VRsc).

$$VRd = VRdi^* + VRd2 + VRsc$$

The V_{Rd2} and V_{Rsc} values are identical with those determined for the horizontal slip mechanism.

Characteristic tension strength of burned clay elements were considered as: $f_{bt} = 0.035f_b$ according to (4.5a) from CR6-2013

Standardize compression strength of burned vertical hollowed clay blocks were considered: $f_b = 10N/mm^2$

Resulting that: $f_{bt} = 0.035f_b$ so $f_{bt} = 0.035 \text{ x } 10N/mm^2 = 0.35N/mm^2$

Characteristic unitary inclined strength for ceramic masonry where computed by:

$f_{vk,i} = 0.22f_{bt}\sqrt{1+5\frac{\sigma_d^*}{f_{bt}}} = 0.077\sqrt{1+14.285\sigma_d^*}$ according to (4.4a) from CR6-2013

The design inclined strength became:

$V_{Rd,i} = \frac{A_w}{b} \times \frac{f_{vk,i}}{\gamma_M} = \frac{A_w}{b} \times f_{vd,i}$ according to (6.34) from CR6-2013

b – correction coefficient that takes into account the aspect ratio of the masonry panel

b = 1.5 for $h/l_w \geq 1.5$

b = 1.0 for $h/l_s<1.0$

b = h/l_w for $1.0 \leq h/l_w <1.5$ according to 6.6.4.1.2. from CR6-2013

$h=H_{tot}$ for all the cantilever walls => $H_{tot} = 8.25m$

The values V_{Rdi*} and the confined masonry inclined strength appear in the following tables:

TRANSVERSE

Element	n_e	V_{Ed}	l_w	Area	N_{Ed}*	σ_d*=N_{Ed}*/A	$f_{vk,i}$*	$f_{vd,i}$*	b	$V_{Rd,i}$*	V_{Rstc}	$V_{Rd,i}$ (ZC)	OBS
		tones	m	m^2	tones	N/mm^2	N/mm^2	N/mm^2	---	tones	tones	tones	
T1	2	22.39	4.55	1.37	35.12	0.257	0.166	0.0876	1.50	7.97	5.74	**13.71**	NOK
T2	2	10.10	2.55	0.77	20.96	0.274	0.170	0.0898	1.50	4.58	5.74	**10.32**	OK
T3	4	10.64	3.40	0.85	24.44	0.288	0.174	0.0915	1.50	5.19	5.74	**10.93**	OK
T4	1	34.53	8.85	2.21	55.20	0.249	0.164	0.0866	1.00	19.15	5.74	**24.89**	NOK

LONGITUDINAL

Element	n_e	V_{Ed}	l_w	Area	N_{Ed}*	σ_d*=N_{Ed}*/A	$f_{vk,i}$*	$f_{vd,i}$*	b	$V_{Rd,i}$*	V_{Rstc}	$V_{Rd,i}$ (ZC)	OBS
		tones	m	m^2	tones	N/mm^2	N/mm^2	N/mm^2	---	tones	tones	tones	
L1	4	8.00	2.18	0.65	18.48	0.283	0.173	0.0910	1.5	3.96	5.74	**9.70**	OK
L2	4	9.69	2.50	0.75	23.79	0.317	0.181	0.0953	1.5	4.77	5.74	**10.50**	OK
L3	2	9.72	2.50	0.75	23.85	0.318	0.181	0.0954	1.5	4.77	5.74	**10.51**	OK
L4	2	9.79	3.30	0.83	21.21	0.257	0.166	0.0876	1.5	4.82	5.74	**10.56**	OK
L5	1	30.42	7.75	1.94	49.35	0.255	0.166	0.0873	1.07	16.91	8.36	**25.27**	NOK

Associated shear force for bed joints reinforcement

The shear force taken by the horizontal bed joints reinforcements is calculated using the equation: $V_{Rd3} = 0.8 l_w \frac{A_{sw}}{s} f_{yd}$ according to (6.41) from CR6-2013. In the case of ceramic with vertical hollow masonry block with reinforcement in the horizontal bed joints will be with OB37 2Ø8 and f_{yd}=210N/mm^2 (Asw = 100.48mm^2) from two rows on the 1st floor s=2x250mm=500mm, respectively at the 2nd and 3rd floor from row to rows s=250mm. V_{Rd} (ZC) = min ($V_{Rd,l}$; $V_{Rd,i}$) and V_{Rd} (ZC+AR) = V_{Rd}(ZC) + $V_{Rd,3}$

1st LEVEL - TRANSVERSE

Horizontal reinforcement design strength computation:

Element	l_w	n_{bars}	diameter	A_{sw}	nr rows	h row	s	f_{yd}	V_{Rd3}
	m	---	mm	mm^2	---	mm	mm	N/mm^2	tones
T1	4.55	2	8	100.48	2	250	500	210	**15.36**
T2	2.55	2	8	100.48	2	250	500	210	**8.61**
T3	3.40	2	8	100.48	2	250	500	210	**11.48**
T4	8.85	2	8	100.48	2	250	500	210	**29.88**

The masonry walls shear strength
1st LEVEL – ceramic blocks masonry – CR6-2013

Element	$V_{Rd,i,ZC}$	$V_{Rd,l,ZC}$	$V_{Rd,AR}$	V_{Rd} (ZC+AR)
T1	13.71	19.79	15.36	29.07
T2	10.32	14.12	8.61	18.93
T3	10.93	15.50	11.48	22.40
T4	24.89	27.81	29.88	54.77

1st LEVEL - LONGITUDINAL

Horizontal reinforcement design strength computation:

Element	l_w	n_{bars}	diameter	A_{sw}	nr rows	h_{row}	s	f_{yd}	V_{Rd3}
	m	---	mm	mm^2	---	mm	mm	N/mm^2	tones
L1	2.175	2	8	100.48	2	250	500	210	7.34
L2	2.5	2	8	100.48	2	250	500	210	8.44
L3	2.5	2	8	100.48	2	250	500	210	8.44
L4	3.3	2	8	100.48	2	250	500	210	11.14
L5	7.75	3	8	150.72	2	250	500	210	39.25

The masonry walls shear strength
1st LEVEL – ceramic blocks masonry – CR6-2013

Element	$V_{Rd,i,ZC}$	$V_{Rd,l,ZC}$	$V_{Rd,AR}$	V_{Rd} (ZC+AR)
L1	9.70	13.13	7.34	17.04
L2	10.50	15.26	8.44	18.94
L3	10.51	15.27	8.44	18.95
L4	10.56	14.22	11.14	21.70
L5	25.27	28.09	39.25	64.51

The shear safety check relation is: $V_{Rd} \geq 1.25V_{Edu}$ according to 8.8 from P100-1/2013 Where V_{Edu} is the the associate shear force value to eccentric compression failure which were determined in the previous tables. The values comparison appear in the following tables:

Ceramic masonry			
Element	V_{Rd} (ZC+AR)	V_{Edu}	$1.25*V_{Edu}$
	tones	tones	tones
T1	29.07	21.05	26.31
T2	18.93	10.37	12.96
T3	22.40	13.81	17.26
T4	54.77	43.79	54.73

1st LEVEL - TRANSVERSE

Ceramic masonry			
Element	V_{Rd} (ZC+AR)	V_{Edu}	$1.25*V_{Edu}$
	tones	tones	tones
L1	17.04	7.96	9.95
L2	18.94	9.66	12.08
L3	18.95	9.69	12.11
L4	21.70	11.80	14.75
L5	64.51	43.54	54.43

1st LEVEL LONGITUDINAL

Units shear safety check is carried out for all masonry walls of the structure.

6. Shear safety check

Responses according to CR6-2013:

TRANSVERSE DIRECTION									
1st Level Pier	CR6-2013								
	Positive seismic sense								
	N_{Ed}	V_{Ed}	M_{Ed}	$V_{Rd,l}$	$V_{Rd,i}$	$V_{Rd,ZC}$	$V_{Rd,AR}$	$V_{Rd,ZC+AR}$	M_{Rd}
	tf	tf	tfm	tf	tf	tf	tf	tf	tfm
T1	25.28	22.40	136.80	19.79	13.71	13.71	15.36	29.07	50.11
T2	13.04	10.10	54.70	14.12	10.32	10.32	8.61	18.93	14.66
T3	18.18	10.60	64.80	15.50	20.93	15.50	11.48	26.98	26.32
T4	47.40	34.50	265.70	27.81	24.89	24.89	29.88	54.77	178.55

LONGITUDINAL DIRECTION									
1st Level Pier	CR6-2013								
	Positive seismic sense								
	N_{Ed}	V_{Ed}	M_{Ed}	$V_{Rd,l}$	$V_{Rd,i}$	$V_{Rd,ZC}$	$V_{Rd,AR}$	$V_{Rd,ZC+AR}$	M_{Rd}
	tf	tf	tfm	tf	tf	tf	tf	tf	tfm
L1	11.12	8.00	45.50	13.13	9.70	9.70	7.34	17.04	45.26
L2	16.04	9.70	58.80	15.26	10.50	10.50	8.44	18.94	58.59
L3	16.07	9.70	58.70	15.27	10.51	10.51	8.44	18.95	58.51
L4	15.28	9.80	64.20	14.22	10.56	10.56	11.14	21.70	77.32
L5	41.50	30.40	284.90	28.09	25.27	25.27	39.25	64.52	408.05

Responses according to P2-85:

TRANSVERSE DIRECTION										
1st Level Pier	P2-85									
	$T_{cm,ZNA}$	$T_{cf,ZNA}$	$T_{cp,ZNA}$	$T_{min,ZNA}$	$T_{cm,c}$	$Tc_{m,ZC}$	$T_{cf,ZC}$	$T_{cp,ZC}$	$T_{min,ZC}$	$T_{min,ZC+AR}$
	tf	tf	tf	tf	tf	tf	tf	tf	tf	tf
T1	42.51	9.44	10.01	9.44	85.37	127.88	17.49	40.70	17.49	32.85
T2	13.35	4.87	5.61	4.87	58.97	72.32	12.60	22.80	12.60	21.21
T3	19.78	6.79	6.23	6.23	73.28	93.06	14.65	30.40	14.65	26.13
T4	134.03	17.70	16.23	16.23	77.18	211.21	44.79	91.50	44.79	74.67
1st Level Pier	LONGITUDINAL DIRECTION									
	P2-85									
	$T_{cm,ZNA}$	$T_{cf,ZNA}$	$T_{cp,ZNA}$	$T_{min,ZNA}$	$T_{cm,c}$	$Tc_{m,ZC}$	$T_{cf,ZC}$	$T_{cp,ZC}$	$T_{min,ZC}$	$T_{min,ZC+AR}$
	tf	tf	tf	tf	tf	tf	tf	tf	tf	tf
L1	9.71	4.15	4.79	4.15	50.94	60.65	11.83	19.46	11.83	19.17
L2	12.83	5.99	5.50	5.50	54.36	67.19	13.80	22.36	13.80	22.24
L3	12.83	6.00	5.50	5.50	54.32	67.15	13.81	22.36	13.81	22.25
L4	18.64	5.70	6.05	5.70	75.26	93.90	13.49	29.52	13.49	24.63
L5	102.79	15.49	14.21	14.21	89.23	192.02	42.43	81.63	42.43	81.68

Comparisons between the responses:

TRANSVERSE DIRECTION																	RATIO P2-85 la CR6-13	
1st Level Pier	CR6-13						P2-85											
	$V_{Rd,l}$	$V_{Rd,i}$	$V_{Rd,ZC}$	$V_{Rd,AR}$	$V_{Rd,ZC+AR}$	M_{Rd}	$T_{cm,ZNA}$	$T_{cf,ZNA}$	$T_{cp,ZNA}$	$T_{min,ZNA}$	$T_{cm,c}$	$Tc_{m,ZC}$	$T_{cf,ZC}$	$T_{cp,ZC}$	$T_{min,ZC}$	$T_{min,ZC+AR}$	D1	D2
	tf	tf	tf	tf	tf	tfm	tf	tf	tf	tf	tf	tf	tf	tf	tf	tf	...	...
T1	19.79	13.71	13.71	15.36	29.07	50.11	42.51	9.44	10.01	9.44	85.37	127.88	17.49	40.70	17.49	32.85	1.13	1.28
T2	14.12	10.32	10.32	8.61	18.93	14.66	13.35	4.87	5.61	4.87	58.97	72.32	12.60	22.80	12.60	21.21	1.12	1.22
T3	15.50	20.93	15.50	11.48	26.98	26.32	19.78	6.79	6.23	6.23	73.28	93.06	14.65	30.40	14.65	26.13	0.97	0.95
T4	27.81	24.89	24.89	29.88	54.77	178.55	134.03	17.70	16.23	16.23	77.18	211.21	44.79	91.50	44.79	74.67	1.36	1.80
Average ratio for transverse																	1.15	1.31
LONGITUDINAL DIRECTION																		
1st Level Pier	CR6-13						P2-85											
	$V_{Rd,l}$	$V_{Rd,i}$	$V_{Rd,ZC}$	$V_{Rd,AR}$	$V_{Rd,ZC+AR}$	M_{Rd}	$T_{cm,ZNA}$	$T_{cf,ZNA}$	$T_{cp,ZNA}$	$T_{min,ZNA}$	$T_{cm,c}$	$Tc_{m,ZC}$	$T_{cf,ZC}$	$T_{cp,ZC}$	$T_{min,ZC}$	$T_{min,ZC+AR}$	D1	D2
	tf	tf	tf	tf	tf	tfm	tf	tf	tf	tf	tf	tf	tf	tf	tf	tf		
L1	13.13	9.70	9.70	7.34	17.04	45.26	9.71	4.15	4.79	4.15	50.94	60.65	11.83	19.46	11.83	19.17	1.13	1.22
L2	15.26	10.50	10.50	8.44	18.94	58.59	12.83	5.99	5.50	5.50	54.36	67.19	13.80	22.36	13.80	22.24	1.17	1.31
L3	15.27	10.51	10.51	8.44	18.95	58.51	12.83	6.00	5.50	5.50	54.32	67.15	13.81	22.36	13.81	22.25	1.17	1.31
L4	14.22	10.56	10.56	11.14	21.70	77.32	18.64	5.70	6.05	5.70	75.26	93.90	13.49	29.52	13.49	24.63	1.14	1.28
L5	28.09	25.27	25.27	39.25	64.52	408.05	102.79	15.49	14.21	14.21	89.23	192.02	42.43	81.63	42.43	81.68	1.27	1.68
Average ratio for longitudinal direction																	1.17	1.36
Average ratio for both directions																	1.16	1.34
Total average ratio																	1.25	

Final responses comparisons:

TRANSVERSE DIRECTION	RATIO P2-85 la CR6-13	
1^{ST} LEVEL PIER	D1	D2
T1	1.13	1.28
T2	1.12	1.22
T3	0.97	0.95
T4	1.36	1.80
Average ratio for transverse	1.15	1.31
DTRANSVERSE DIRECTION		
1^{ST} LEVEL PIER	D1	D2
L1	1.13	1.22
L2	1.17	1.31
L3	1.17	1.31
L4	1.14	1.28
L5	1.27	1.68
Average ratio for longitudinal direction	1.17	1.36
Average ratio for both directions	1.16	1.34
Total average ratio	**1.25**	

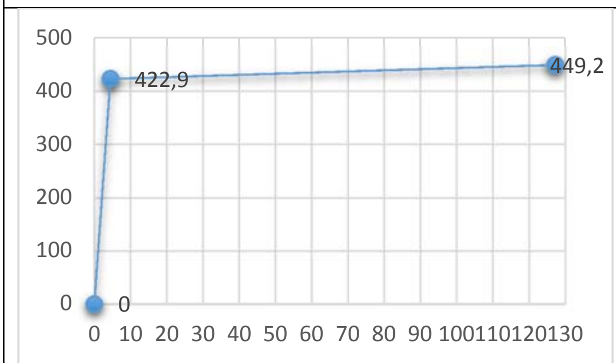
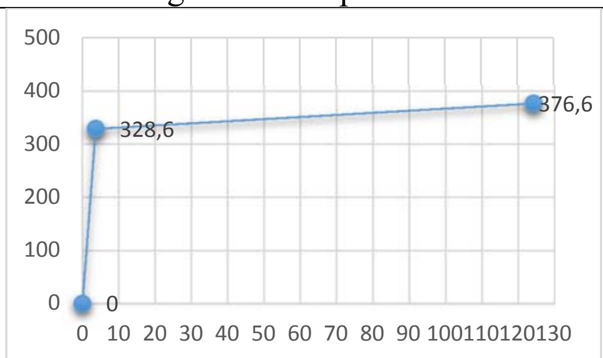
So there is a noticeable difference in overall average of 25% in addition to values derived from calculations resilience made according to P2-85 and those completed under CR6-13.

It can be said that in terms of structural responses obtained that the CR6-2013 design code provides an increase of 25% versus safety requirements P2-85 former design code.

7. Using the pushover models

2 models were carried out for structural analysis, one for each type of structure (longitudinally or transverse direction).

After pushover analyses the base shear force-displacements curve were obtained:

Transverse direction	Longitudinal displacements
	

The followings values may be observe:

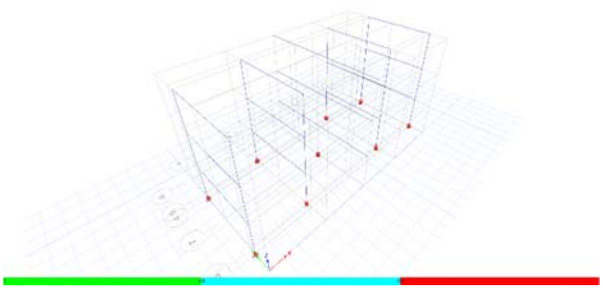
- Transverse direction:
  - V_y=422.9 tf and Δ_y=4.44 mm respectively V_u=449.2 tf and Δ_u=127.2 mm
- Longitudinal direction:
  - V_y=328.6 tf and Δ_y=3.65 mm respectively V_u=376.6 tf and Δ_u=124.2 mm
- The differences between the both masonry direction structures are:

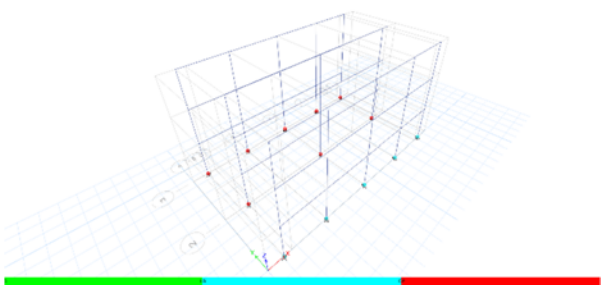
Characteristic	**Difference between longitudinal/ transverse**	**Average for characteristic**
V_y	28.69%	23.99%
V_u	19.28%	
Δ_y	21.64%	12.03%
Δ_u	2.42%	

It can be seen that the average differences for the two directions (longitudinal and transverse) are approximately 23.99% between base shear forces and 12.03% between deflections.

Ultimate plastic mechanisms

Transverse direction **Longitudinal direction**





8. Conclusions

The safety for shear is satisfied on the whole building, ensuring the favorable energy dissipation mechanism by ranking seismic resilience of the structure used for the type of masonry (vertical hollow ceramic blocks). This can be seen both in the simplified calculations but also in pushover analysis.

Since confined masonry by some walls and some levels do not meet the requirement of shear safety, a reinforcement in the horizontal bed joints was considered made with 2Ø8 OB37 (local 3Ø8 OB37 in walls T4 – 3rd floor and L5 – 1st and 2nd floor), arranged in two rows on the 1st floor and on a rows for 2nd and 3rd floor. So finally, for both types of calculations were considered ZC + AR-type structure.

Using the simplified calculation models (structural regularity permitting the 2D and elevation of the structure considered), leading to a structural conformation, neglecting a significant component show a computing collaboration on spatial structure.
The structural compliance can be optimized by the choice of models and methods for calculating the minimum allowed higher, applied in this paper.
To obtain a safe structural conformation under the seismic action and economic and functional optimal, were used models for nonlinear static behavior. To obtain more reliable results it is recommended structural models using 3D and modal calculation, to capture more accurately the real behavior of the structure.
It finds that structural responses obtained for the two types of calculations performed for masonry structure made with ceramic vertical hollow blocks are quite close even for normal or superior level analysis or different design strengths.
It can be said that in terms of structural responses obtained from CR6-2013 in force design code provides an increase of 25% safety versus the requirements of P2-85 former code.

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