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ماجستير التأهيل والتخصص/قسم الهندسة الزلزالية
السنة الثانية

منشآت حجرية

مثال 1 على التصميم الزلزالي للجدران الحجرية المسلحة

Lec.04

Seismic Design of Reinforced Masonry Walls (Example1)

According to Canadian Concrete Masonry Producers Association CCMPA

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Problem 1

Seismic design of a flexural shear wall of limited ductility

Perform the seismic design of a shear wall X_1. The wall is four storeys high, with the total height of 14 m, and due to its height must be designed either as a “limited ductility” or a “moderate ductility” shear wall.

The section at the base of the wall is subjected to the total dead load of 1800 kN, the in-plane seismic shear force of 1450 kN, and the overturning moment of 14500 kNm.

Select the wall dimensions (length and thickness) and the reinforcement ,

seismic design requirements for limited ductility shear walls are satisfied. Due to architectural constraints, the wall length should not exceed 10 m, and a rectangular wall section should be used. Neglect the out-of-plane effects in this design.

Use hollow concrete blocks of 20 MPa unit strength and Type S mortar. Consider the wall as solid grouted. Grade 400 steel reinforcement (yield strength f_y = 400 MPa) is used for this design.

Solution 1

1. Material properties:

Steel (both reinforcing bars and joint reinforcement):

$\phi_s = 0.85 \quad f_y = 400$ MPa

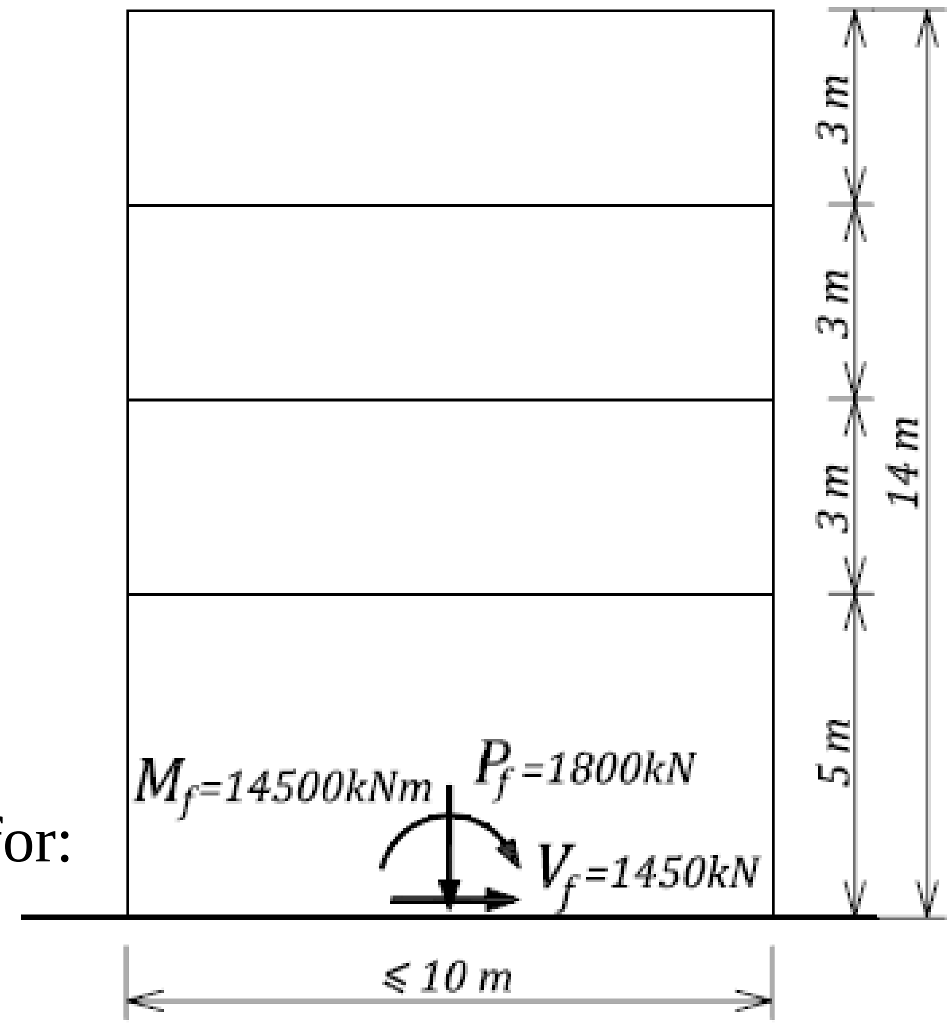
Masonry:

$\phi_m = 0.6$

20 MPa concrete blocks and Type S mortar:

f'_m = 10.0 MPa (assume solid grouted masonry)

2. Load analysis:



The section at the base of the wall needs to be designed for:

- P_f = 1800 kN axial load
- V_f = 1450 kN seismic shear force
- M_f = 14500 kNm overturning moment

Solution 1

1- تحديد نوع الجدار (على الانعطاف أو جدار قص قصير)
2- تحديد سماكة الجدار
3- تحديد طول الجدار
4- متطلبات التسليح الدنيا (مساحات تسليح الدنيا أفقي وشاقولي والتباعدات بين القضبان).
5- حساب التسليح الشاقولي.

Solution 1

h_w = 14000 mm height, l_w= 10000 mm length, Then:

$$\frac{h_w}{l_w} \geq \frac{14000}{10000} \geq 1.4 > 1.0$$

➡ flexural shear wall

seismic design requirements for limited ductility (flexural) shear walls should be followed.

Solution 1

3. Determine the required wall thickness:

based on the height-to-thickness requirements:

<u>limited ductility shear walls:</u>

$$h\ (t + 10) < 18$$

h = 5000 mm (the largest unsupported wall height)

So,

$t \geq 18/h - 10 = 268$ mm

$$t = 290 \text{ mm}$$

Solution 1

4. Determine the wall length:

based on the shear design requirements.

The length can be determined from the maximum shear resistance for the wall section. The shear resistance for flexural walls cannot exceed the following limit:

$$V_r \le \max V_r = 0.4\phi_m \sqrt{f'_m}\, b_w d_v \gamma_g$$

$$V_r = V_f = 1450 \text{ kN}$$

γ_g = 1.0 solid grouted wall.
b_w = 290 mm overall wall thickness.
$d_v \approx 0.8l$ effective wall depth.

$$l_w > \frac{V_f}{0.4\phi_m \sqrt{f'_m}\, b_w (0.8)\gamma_g} = \frac{1450 * 10^3}{0.4 * 0.6 * \sqrt{10} * 290 * 0.8 * 1.0} = 8235 \text{ mm}$$

$$\mathbf{l_w = 8.4m}$$

a minimum wall length of nearly 10m was required, thus for l_w = 10000mm which gives max Vr = 1760 kN

Solution 1

5. Minimum seismic reinforcement requirements

the seismic hazard index I_E F_a S_a (0.2) is 0.95.

$$I_E F_a S_a(0.2) = 0.95 > 0.35$$

Thus, it is required to provide minimum seismic reinforcement

- Seismic reinforcement area:

shear walls, shall be reinforced horizontally and vertically with steel having a minimum area of

$A_{smin} = 0.002A_g = 0.002*(290*10^3\ mm^2/m) = 580\ mm^2/m$

for 290 mm block walls, where: $A_g = (1000mm)*(290mm) = 290*10^3\ mm^2/m$

gross cross-sectional area for a unit wall length of 1m

Solution 1

Minimum area in each direction (one-third of the total area):

$$A'_{hmin} = A'_{vmin} = 0.00067A_g = \frac{A_{s\,min}}{3}$$

$A`_{hmin}=A`_{vmin}=580/3=193.3mm^2/m$

Thus the minimum total vertical reinforcement area:

$A_{vmin}= 193.3* l_w= (193.3mm^2/m)(10m)=1933mm^2$

In theory, 1/3rd of the total amount of reinforcement can be placed in one direction and the remainder in the other direction.

Solution 1

Vertical reinforcement (area and distribution):

spacing of vertical reinforcing bars shall not exceed the lesser of:

- $6(t+10)=6(290+10)=1800mm$
- 1200mm
- $L_w/4=10000/4=2500mm$.

Therefore, the maximum permitted spacing of vertical reinforcement

is equal to $s = 1200$ mm.

Solution 1

Horizontal reinforcement (area and distribution):

the maximum spacing of bond beams is 2400 mm

Solution 1

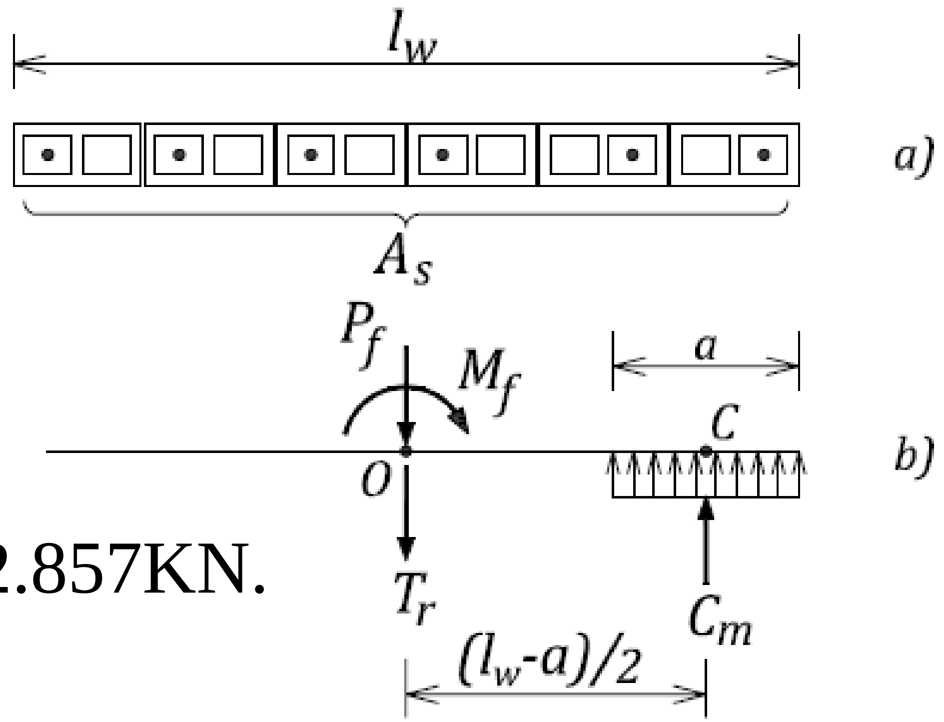
An approximate method to estimate the wall reinforcement

$$T_r = \phi_s f_y A_s$$

$$a \cong 0.3 l_w$$

$$T_r = \frac{M_f - P_f (l_w - a)/2}{(l_w - a)/2}$$

$$A_s = T_r / \phi_s f_y$$



T_r=14500-1800 (10-0.3(10))/(10-0.3*10)/2=2342.857KN.

A_s= 2342.857*10^3/(0.85*400)=6890.75mm^2

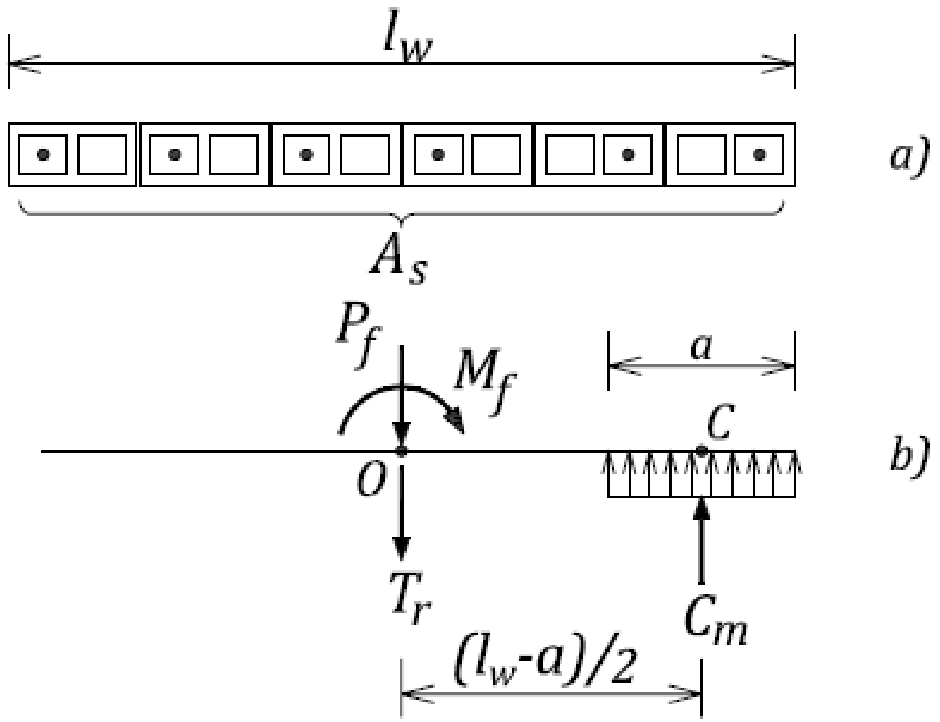
Solution 1

An approximate method to estimate the wall reinforcement

15T25 reinforcing bars can be used

A_v= 490.87* 15= 7363.05mm^2 >6890.75

$S \leq \frac{(10000-200)}{14}$=700mm>600mm ok



Solution 1

Since the amount of vertical reinforcement is significant, it is required to check the maximum reinforcement area. Since

$S = 670mm < 4t = 4*290 = 1160mm$

$A_{smax} = 0.02Ag = 0.02(290*10^3) = 5800mm^2/m.$

to the total reinforcement area of approximately 58000 mm^2 for a 10 m long wall> 7602.65mm^2 (the estimated area of vertical reinforcement).

Solution 1

Moment capacity for rectangular wall sections with distributed vertical reinforcement

$$M_r = 0.5\phi_s f_y A_{vt} l_w \left(1 + \frac{P_f}{\phi_s f_y A_{vt}}\right)\left(1 - \frac{c}{l_w}\right)$$

where

A_{vt} - the total area of distributed vertical reinforcement

c - neutral axis depth

$$\omega = \frac{\phi_s f_y A_{vt}}{\phi_m f'_m l_w t}$$

$$\alpha = \frac{P_f}{\phi_m f'_m l_w t}$$

$$\frac{c}{l_w} = \frac{\omega + \alpha}{2\omega + \alpha_1 \beta_1}$$

$\alpha_1 = 0.85$ $\beta_1 = 0.8$ $\omega = 0.144$ $\alpha = 0.1$ $c \approx 2520.7\text{mm}$

$$M_r = 0.5\phi_s f_y A_{vt} l_w \left(1 + \frac{P_f}{\phi_s f_y A_{vt}}\right)\left(1 - \frac{c}{l_w}\right) = 0.5 * 0.85 * \frac{400}{1000} * 7363 * \frac{10000}{1000}\left(1 + \frac{1800 * 10^3}{0.85 * 400 * 7363}\right)\left(1 - \frac{2520.7}{10000}\right)$$

M_r= 16093.4kNm> $M_f = 14500$ kNm OK

Solution 1

Moment capacity for the section with concentrated and distributed reinforcement

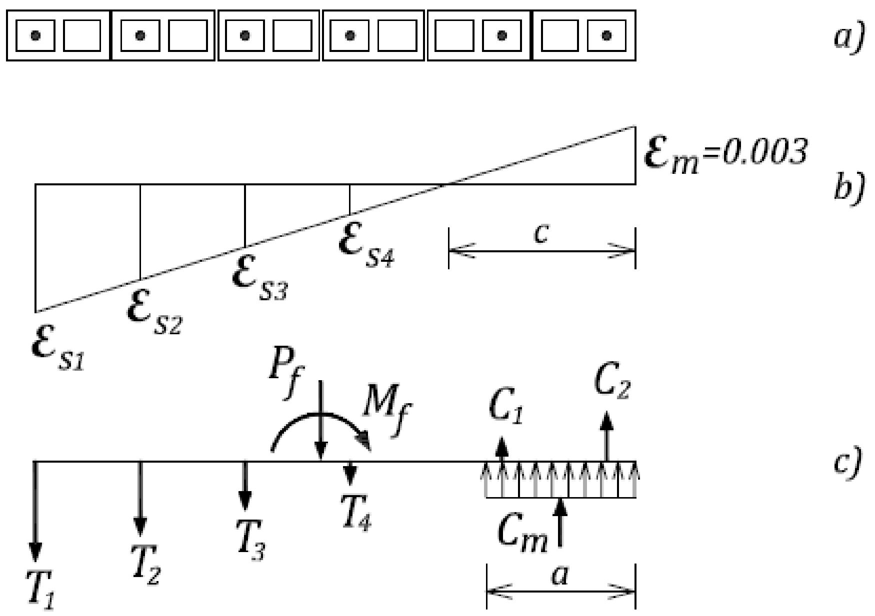
19T22 reinforcing bars can be used

A_v= 380.132* 19= 7222.5mm^2 > 6890.75

3T22 in each column (400mm): A_c=1140.4mm^2

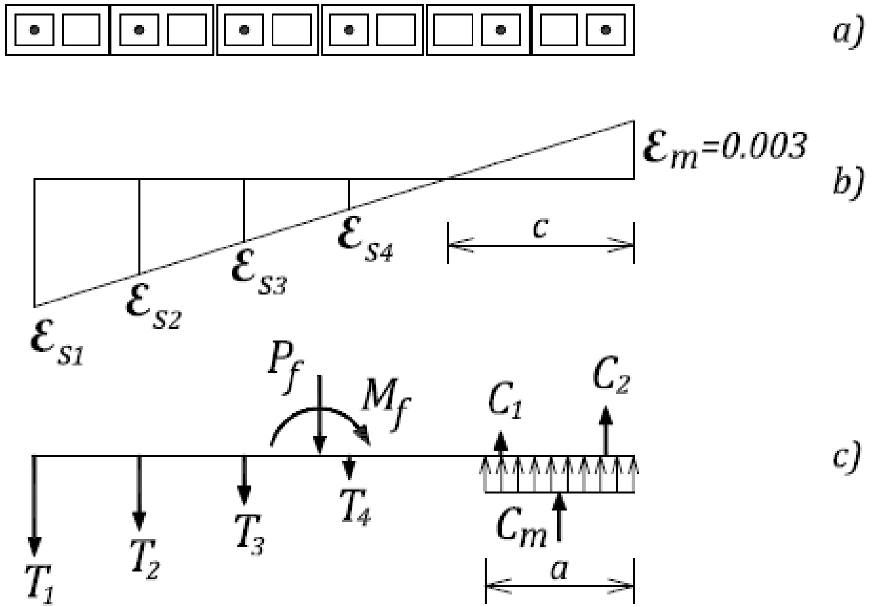
13T22 distributed: Ad=4941.7mm2

$$S \leq \frac{(10000-400*2+200)}{19-6} = 723 = 720\text{mm} > 600 \text{ ok}$$



Solution 1

Moment capacity for the section with concentrated and distributed reinforcement



- The axial load P_f = 1800 kN.
- The compression zone depth, a , can be determine as follows

$$a = \frac{P_f + \phi_s f_y A_d}{0.85\phi_m f'_m t}$$

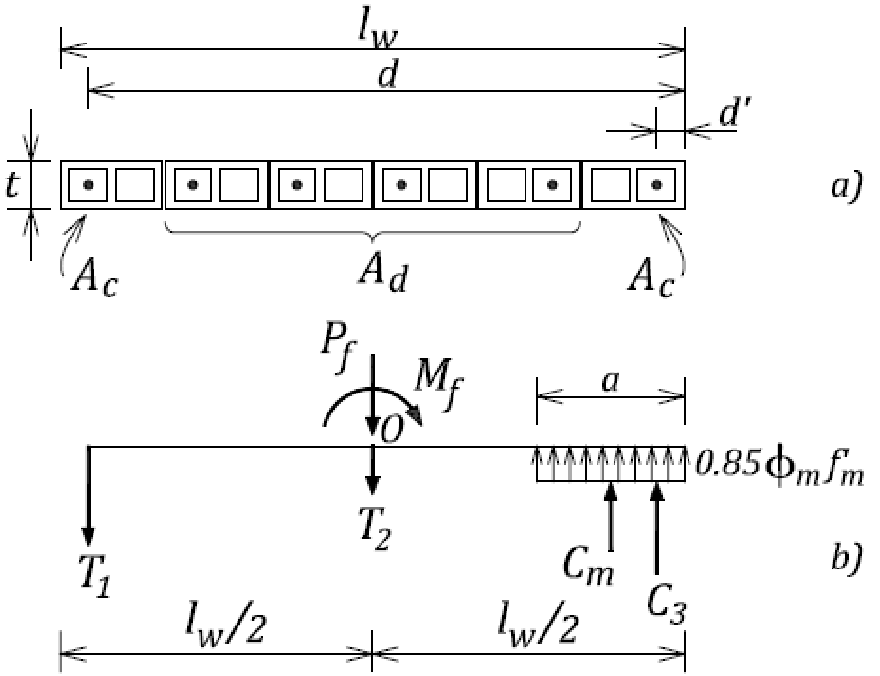
=$(1800*10^3+0.85*400*4941.7)/(0.85*0.6*10*290)$=2353.06mm

$\beta_1 = 0.8$ when $f'_m < 20$ MPa

The neutral axis depth, c : $c = a/\beta_1$ c=2353.06/0.8=2941.33mm

Solution 1

Moment capacity for the section with concentrated and distributed reinforcement



$$C_m = (0.85\phi_m f'_m)(t \cdot a)$$

C_m=(0.85*0.6*10)(290*2353.06)*10^{-3}=3480kN.

Next, the factored moment capacity,

$$M_r = C_m(l_w - a)/2 + 2\left[\phi_s f_y A_c\left(l_w/2 - d'\right)\right]$$

Mr=3480*10^3*(10000-2353.06)/2+2[0.85*400*1140.4(10000/2-100)]*10^{-6} =17105.5kN.m

Solution 1

7. Ductility check

Design To satisfy the ductility requirements for limited ductility shear walls neutral axis depth ratio (c/l_w) should be less than the following limit:

$$c/l_w < 0.2 \text{ when } h_w/l_w < 6$$

In this case, the neutral axis depth

c = 2941.33 mm

c/l_w= 2941.33/10000=0.29>0.2 not satisfied.

Solution 1

7. Ductility check

1) Find the required wall length such that the c/l_w limit ductility criteria is satisfied.

The wall length can be estimated from Table D-2, which provides c/l_w ratios for different input parameters (α and ω). By inspection, it can be concluded that $c/l_w < 0.2$ when $\alpha \leq 0.1$.
the wall length based on this criterion.

$$\alpha = \frac{1667 * P_f}{f'_m l_w t}$$

set

$$\alpha = 0.09 < 0.1$$

$$l_w = \frac{1667 * P_f}{f'_m * \alpha * t} = \frac{1667 * 1800}{10.0 * 0.09 * 290} = 11496 \text{ mm}$$

Therefore, we can select an increased wall length l_w = 11600 mm.

Solution 1

7. Ductility check

Table D-2. c/l_w ratio, f_y = 400 MPa

ω	α										
	0.000	0.025	0.050	0.075	0.100	0.150	0.200	0.250	0.300	0.350	0.400
0	0.000	0.037	0.074	0.110	0.147	0.221	0.294	0.368	0.441	0.515	0.588
0.01	0.014	0.050	0.086	0.121	0.157	0.229	0.300	0.371	0.443	0.514	0.586
0.02	0.028	0.063	0.097	0.132	0.167	0.236	0.306	0.375	0.444	0.514	0.583
0.03	0.041	0.074	0.108	0.142	0.176	0.243	0.311	0.378	0.446	0.514	0.581
0.04	0.053	0.086	0.118	0.151	0.184	0.250	0.316	0.382	0.447	0.513	0.579
0.05	0.064	0.096	0.128	0.160	0.192	0.256	0.321	0.385	0.449	0.513	0.577
0.06	0.075	0.106	0.138	0.169	0.200	0.263	0.325	0.388	0.450	0.513	0.575
0.07	0.085	0.116	0.146	0.177	0.207	0.268	0.329	0.390	0.451	0.512	0.573
0.08	0.095	0.125	0.155	0.185	0.214	0.274	0.333	0.393	0.452	0.512	0.571
0.09	0.105	0.134	0.163	0.192	0.221	0.279	0.337	0.395	0.453	0.512	0.570
0.1	0.114	0.142	0.170	0.199	0.227	0.284	0.341	0.398	0.455	0.511	0.568
0.11	0.122	0.150	0.178	0.206	0.233	0.289	0.344	0.400	0.456	0.511	0.567
0.12	0.130	0.158	0.185	0.212	0.239	0.293	0.348	0.402	0.457	0.511	0.565
0.13	0.138	0.165	0.191	0.218	0.245	0.298	0.351	0.404	0.457	0.511	0.564
0.14	0.146	0.172	0.198	0.224	0.250	0.302	0.354	0.406	0.458	0.510	0.563
0.15	0.153	0.179	0.204	0.230	0.255	0.306	0.357	0.408	0.459	0.510	0.561
0.16	0.160	0.185	0.210	0.235	0.260	0.310	0.360	0.410	0.460	0.510	0.560
0.17	0.167	0.191	0.216	0.240	0.265	0.314	0.363	0.412	0.461	0.510	0.559
0.18	0.173	0.197	0.221	0.245	0.269	0.317	0.365	0.413	0.462	0.510	0.558
0.19	0.179	0.203	0.226	0.250	0.274	0.321	0.368	0.415	0.462	0.509	0.557
0.2	0.185	0.208	0.231	0.255	0.278	0.324	0.370	0.417	0.463	0.509	0.556

Solution 1

8. The diagonal tension shear resistance and capacity design

Masonry shear resistance ($\dot{V}_m$):

$b_w = 290$ mm overall wall thickness

$d_v \approx 0.8 l_w = 8000$ mm effective wall depth

$\gamma_g = 1.0$ solid grouted wall

$P_d = 0.9 P_f = 1620$ kN

$$v_m = 0.16\left(2 - \frac{M_f}{V_f d_v}\right)\sqrt{f'_m} = 0.51 \text{ MPa}$$

$$\frac{M_f}{V_f d_v} = \frac{14500}{1450 * 8.0} = 1.25 > 1.0$$

use $\dfrac{M_f}{V_f d_v} = 1.0$

$$V_m = \phi_m (v_m b_w d_v + 0.25 P_d)\gamma_g = 0.6(0.51*290*8000+0.25*1620*10^3)*1.0 = 953 \text{ kN}$$

Solution 1

8. The diagonal tension shear resistance and capacity design

ductile reinforced masonry shear walls should be designed according to the capacity design approach that, the shear capacity should exceed the shear corresponding to the nominal moment resistance as follows:

$$M_n = \frac{M_r}{\phi_s} = \frac{17105.5}{0.85} = 20124.12\text{kN.m} \qquad M_r = 17105.5 \text{ kNm} \quad \text{the factored moment resistance}$$

Shear force acts at the effective height h_e ,

$$h_e = \frac{M_f}{V_f} = 10.0 \text{ m}$$

Solution 1

8. The diagonal tension shear resistance and capacity design

The shear force V_{nb} that would cause the overturning moment equal to M_n can be found as follows

$$V_{nb} = \frac{M_n}{h_e} = \frac{20124.12}{10.0} = 2012.4\text{kN}$$

$$\max V_r = 0.4\phi_m \sqrt{f'_m} b_w d_v \gamma_g = 1760 \text{ kN}$$

Thus the required steel shear resistance is

$$V_s = V_r - V_m = 1760 - 953 = 807 \text{ kN}$$

The required amount of reinforcement can be found from the following equation

$$\frac{A_v}{s} = \frac{V_s}{0.6\phi_s f_y d_v} = \frac{807 * 10^3}{0.6 * 0.85 * 400 * 8000} = 0.49$$

Solution 1

8. The diagonal tension shear resistance and capacity design

Try 2-15M bond beam reinforcing bars at 800 mm spacing ($A_v = 400$ mm^2 and $s = 800$ mm):

$$\frac{A_v}{s} = \frac{400}{800} = 0.5 > 0.49 \quad \text{OK}$$

Steel shear resistance Vs :

$$V_s = 0.6\phi_s A_v f_y \frac{d_v}{s} = 0.6 * 0.85 * \frac{400}{1000} * 400 * \frac{8000}{800} = 816 \text{ kN}$$

Total diagonal shear resistance:

$$V_r = V_m + V_s = 953 + 816 = 1769 \text{ kN}$$

Since

$$V_r = 1769 \text{kN} > V_f = 1450 \text{kN} \qquad \text{OK}$$

In conclusion, both the shear design requirements and the capacity design requirements have been satisfied.

Solution 1

9. Sliding shear resistance

The factored in-plane sliding shear resistance V_r is determined as follows:

μ = 1.0 for a masonry-to-masonry or masonry-to-roughened concrete sliding plane

A_s = 6000 mm^2 total area of vertical wall reinforcement

$T_y = \phi_s A_s f_y$ = 0.85 7222.5 *400 = 2455.65kN.

$P_d = 0.9 P_f$ = 1620 kN

$P_2 = P_d + T_y$ = 1620+ 2455.65=4075.65kN

$V_r = \phi_m \mu P_2$ = 0.6*1.0*4075.65=2445.39kN

V_r = 2445.39 > V_f = 1450 kN OK

Also,

V_r = 2445.39 > V_{nb} = 2012.4kN (capacity design check)

Solution 1

10. seismic detailing requirements for limited ductility walls – plastic hinge region

The required height of the plastic hinge region for limited ductility shear walls (for which special detailing is required) must be greater than:

$$l_p = l_w / 2 = 10.0/2 = 5.0 \text{ m}$$

or

$$l_p = h_w / 6 = 14.0 / 6 = 2.3 \text{ m}$$

(note that h_w denotes the total wall height)

Thus,

$l_p = 5.0$ m governs

Solution 1

10. seismic detailing requirements for limited ductility walls – plastic hinge region

Reinforcement detailing requirements for the plastic hinge region of limited ductility shear walls are:

1. The wall in the plastic hinge region must be solid grouted.
2. Horizontal reinforcement requirements

a) Reinforcement spacing should not exceed the following limits

$s \le 1200$ mm or

$s \le l_w/2 = 10000/2 = 5000$ m

Since the lesser value governs, the maximum permitted spacing is

s ≤ 1200 mm

According to the design, the horizontal reinforcement consists of 2T15M bars at 800 mm spacing - OK

Solution 1

10. seismic detailing requirements for limited ductility walls – plastic hinge region

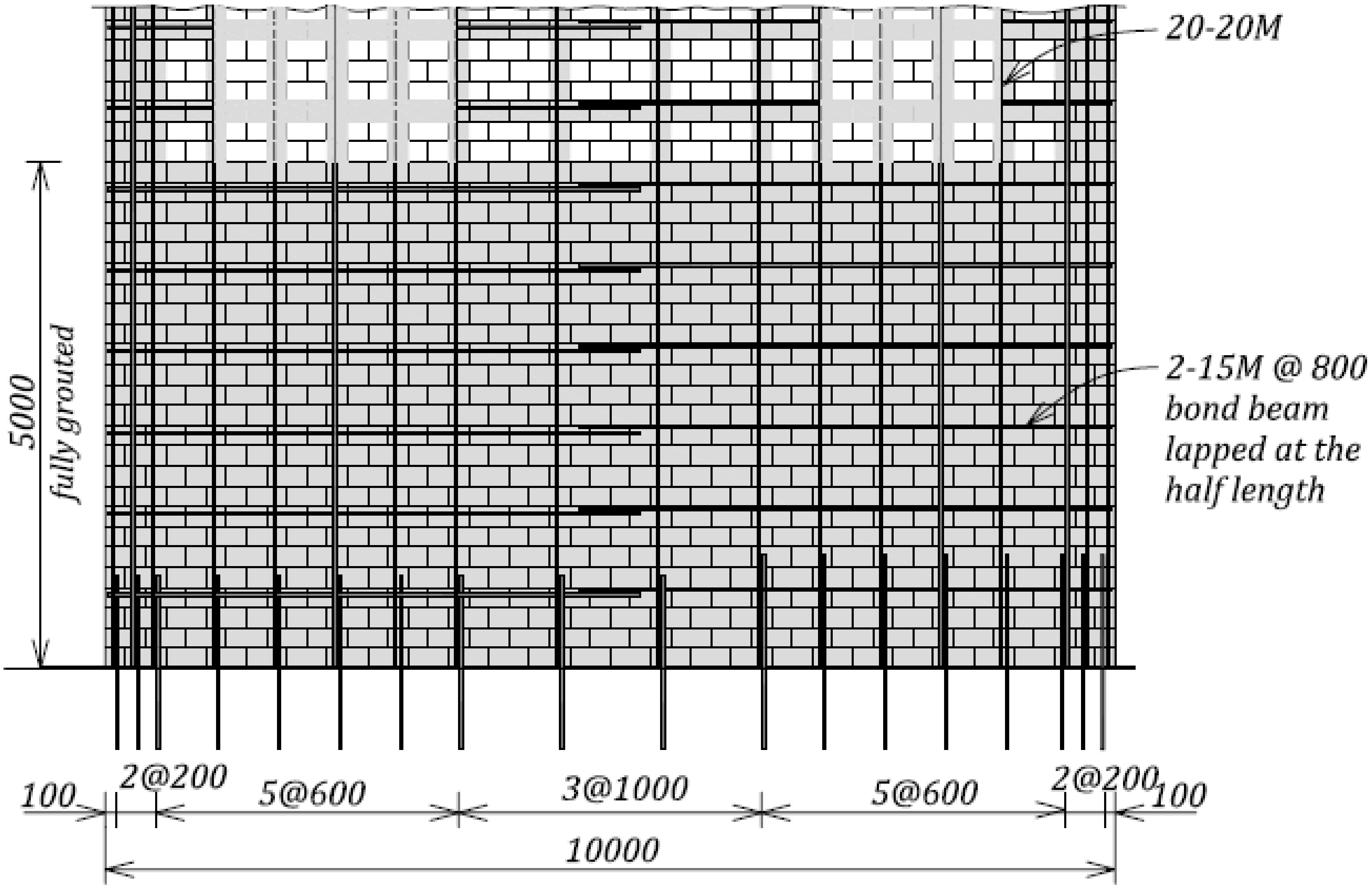
b) Detailing requirements:

Horizontal reinforcement shall not be lapped within
600 mm or
c = 2941.33 mm (the neutral axis depth)
whichever is greater, from the end of the wall. In this case, the reinforcement should not be
lapped within the distance c = 2941.33 mm from the end of the wall. The horizontal reinforcement can be lapped at the wall half-length.

3. Vertical reinforcement requirements

There are no special detailing requirements for vertical reinforcement in limited ductility shear walls.

Solution 1


20-20M
2-15M @ 800
bond beam
lapped at the
half length
5000
fully grouted
100
2@200
5@600
3@1000
5@600
2@200
100
10000