Worked examples of retaining wall design to BS8002

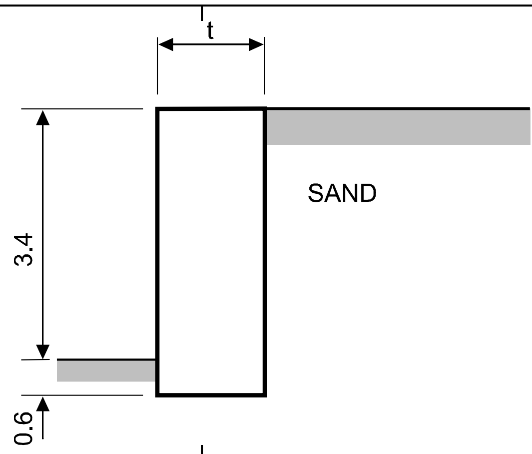
The following worked examples have been prepared to illustrate the application of BS8002 to retaining wall design. They are not full detailed calculations such as might be prepared for a real wall design but are limited to the calculation of earth pressure and bearing capacity, showing how the recommendations of BS8002 are applied in practice.

BS8002 introduces radical changes in the design of retaining walls. Traditionally, the forces applied to a wall have been calculated using representative values of key parameters such as soil strength and then safety and satisfactory service performance are ensured by applying suitable safety factors to the results of the calculations. BS8002 takes a completely different approach: there are no formal safety factors and instead safety and satisfactory performance in service are ensured by using applied forces and soil strengths which are conservative estimates, in order to produce what is effectively a 'worst case' analysis.

To assist understanding of the changes introduced by BS8002 and how they affect design, in the examples each wall is first designed in accordance with the traditional method (CP2) and it is then designed again in accordance with BS8002 and the results are compared. It is hoped that this will assist engineers changing over to the new Code, by letting them see how the new design method works and also giving them some ‘feel’ for how it compares with past practice.

1.0 **Mass Concrete Wall**

1.1 **H = 4m, retaining compact medium sand, no water pressure.**



CP2 Design No Surch.

Ref.	Calculation	Result
Table 2, Table 3	Soil properties (Table 2) compact sand: ϕ = 35º-40º, loose sand ϕ = 30º-35º;	assume ϕ = 35º Density = $19kN/m^3$
Cl 1.4321	wall friction	δ = 20º
Table 1	Active Earth pressure coefficient	K_a = 0.23
Cl. 1.4922	For overturning stability, the load resultant in a gravity wall must be kept within middle third of wall; a safety factor of 2 against sliding is required	
1500mm thick wall	Consider base moments about wall centre line (all forces kN/m)	

		P	W	l_a	M
Active pressure P_{an}	½×0.23×19×4²	35		1.33	46.7
Self weight	4.0x1.5x23		138	-	
wall friction	35×tan20º		12.7	0.75	-9.5
TOTALS		**35**	**150.7**		**37.2**

Load eccentricity = 37.2/150.7 = 0.247m,
middle 1/3 limit = 1.50/6 = 0.25m — overturning e= 0.247m < 0.25m OK

Peak ground bearing pressure = 150.7/1.5)(1+(6x0.247/1.5)) = 199
Minus overburden - 0.6x19 = - 11

Peak net ground bearing pressure — 188kN/m²

Table 8 — Allowable net bearing pressure = 2-4t/ft² = 215-430kN/m² — 188 < 215kN/m² OK

Cl. 1.4922 — Sliding: base friction = tan35º.
Sliding force = 35kN/m,
resistance = 150.7tan35º = 105.5kN/m.
Safety Factor = 105.5/35 = 3.01 — F of S = 3.01> 2 OK
(Note: passive resistance also from soil in front of wall.)

1500mm thick wall OK

CP2 Design with Surch.

Consider with 10kN/m² surcharge

1750mm Thick wall

		P	W	l_a	M
Active pressure P_{an}	½×0.23×19×4²	35		1.33	46.7
Surcharge	0.23x10x4	9.2		2.0	18.4
Self weight	4.0x1.75x23		161	-	
wall friction	(35+9.2)×tan20º		16.1	0.875	-14.1
TOTALS		**44.2**	**177.1**		**51.0**

Load eccentricity = 51.0/177.1 = 0.288m
middle 1/3 limit = 1.75/6 = 0.292m — overturning e=0.288m <0.292m OK

1750mm thick wall OK

BS8002	**BS8002 Design**	
Table 1	Dense medium sand, moderate grading: Assume sub-angular soil particles, SPT 'N' = 20 at 3m depth	density = 18.5kN/m³
Cl 2.2.4 Fig. 2 Table 3	A = 2º, B = 2º, Overburden pressure = 3.0×18.5 = 55.5kN/m²: N´/N = 1.7 so N´ = 1.7×20=34, so C = 4.8º ϕ'_{max} = 30+2+2+4.8 ϕ'_{crit} = 30+2+2	 ϕ'_{max} 38.8º $\tan\phi'_{max}$ 0.804 ϕ'_{crit} 34º $\tan\phi'_{crit}$ 0.675
Cl. 2.2.8	Wall friction	δ = 20º
Cl. 3.2.5	design tanϕ´ = $\tan\phi'_{max}$/M or $\tan\phi'_{crit}$. = <u>0.670</u> or 0.675 (M = 1.2)	design tanϕ´ = 0.670 design ϕ´ = 33.8º
Cl. 3.2.6	design tanδ = tan 20º or 0.75xdesign tanϕ´ = 0.364 or 0.503	design tanδ = 0.364
From table	design ϕ´ = 33.8º, design δ = 20º	K_a = 0.242
<u>Case A</u>	10kN/m² surcharge on retained soil behind wall. <u>Try 1400mm thick wall.</u>	

1400mm thick

		P	W	l_a	M
Active pressure	= ½x0.242x18.5x4²	35.8		1.333	47.8
Surcharge	= 0.242x10x4	9.7		2.0	19.4
Wall self weight	= 4.0x1.40x23		128.8	-	
Wall friction	= 45.5x0.364		16.6	-0.70	-11.6
TOTAL		**45.5**	**145.4**		**55.6**

	Load eccentricity e = 55.6/145.4	e =0.382m
Serviceability	Net bearing pressure at toe = 145.4/1.4 + 6x55.6/1.4² - 0.6x18.5 = 263kN/m². Dense sand, allowable pressure = 600kN/m²	 263 < 600 kN/m² OK
Ultimate	Check ultimate allowable bearing pressure to CIRIA C516 Base effective breadth B´ = 1.40 - 2×0.382 = 0.635m Average bearing pressure = 145.4/0.635 = 228.9kN/m² Bearing capacity = $q'N_q i_q + \frac{1}{2}\gamma' B' N_\gamma i_\gamma$ Horizontal/Vertical F_H/F_v = 45.5/145.4 ϕ'_{design} = 33.8º $i_q = (1 - 0.7\ F_H/F_v)^3 = 0.476$, $i_\gamma = (1 - F_H/F_v)^3 = 0.324$ design ϕ´ = 33.8º N_q = 28.7, Nγ = 37.1, q´= 0.6×18.5 = 11.1kN/m² Bearing cap. = 11.1×28.7×0.476 + 0.5×18.5×0.635×37.1×0.324=	 231.5kN/m² > 228.9 OK
Cl. 2.2.8, 3.2.6	Sliding: base coefficient of friction = $\tan\phi'_{crit}$ or 0.75(design tanϕ´) = 0.675 or <u>0.503</u>. Vert. load x friction = 145.4x0.503 = 73.1kN/m Sliding force = 45.5kN/m,	 45.5 < 73.1kN/m. OK
<u>Case B</u>	Unplanned excavation in front of wall but no surcharge behind. Depth of excavation = 10% of clear height of wall = 0.34m.	

1400mm thick

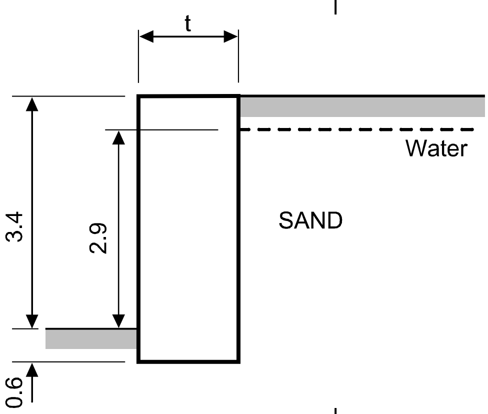
		P	W	l_a	M
Active pressure	= ½x0.242x18.5x4²		35.8	1.333	47.8
Self weight	= 4.0x1.40x23		128.8	-	
wall friction	= 35.8x0.364		13.0	-0.70	-9.1
		35.8	**141.8**		**38.7**

Serviceability	Bearing pressure at toe = 141.8/1.4 + 6x38.7/1.4² =	220 < 600 kN/m² OK

Ultimate	Load eccentricity = 35.8/141.8 = 0.252m Effective breadth B´ = 1.40 - 2×0.252 = 0.895m Bearing pressure = 141.8/0.895 = 158.4kN/m² Bearing capacity = $q'N_q i_q + ½\gamma' B' N_\gamma i_\gamma$ F_H/F_V = 35.8/141.8 ϕ'_{design} = 33.8° i_q = 0.558, i_γ = 0.418, q´ = 0.26×18.5 = 4.81kN/m² Bearing capacity = 4.81×28.7×0.558 + 0.5×18.5×0.895×37.1×0.418 = 205.6kN/m²	158.4 < 205.6 kN/m² OK
Cl. 2.2.8, 3.2.6	Sliding force = 35.8kN/m resistance = 141.8×0.503 = 71.3kN/m	35.8 < 71.3kN/m OK
	Case A (surcharge) is critical, 1400mm thick wall required.	
Comments	If there is a 10kN/m² surcharge behind the wall, BS8002 requires a thinner wall than CP2 (1400mm thick compared with 1750mm). However if there is no surcharge, the two codes give similar results (BS8002: 1400mm, CP2: 1500mm), because BS8002 requires a surcharge to be considered in all cases. (If the wall designed for surcharge to BS8002 is checked to CP2, the calculated load eccentricity on the foundation is 0.26t, approximately on the edge of the 'middle half' of the section, rather than the 'middle third'.)	

1.2 **<u>Mass concrete wall as 1.1 but with water behind wall</u>**

(Assume soil below base of wall has low permeability; assume water table at front of wall is at ground level. Assume head of water at front of wall varies linearly between 0 and 0.6m and at back between 0 and 3.5m.)



<u>CP2</u> <u>CP2 Design</u>

Table 3 — Buoyant density of soil = 11kN/m²

No surcharge — <u>Try 3000mm thick wall.</u>

3000mm thick

			P	W	I_a	M
	Active pressure	½×0.23×19×0.5²	0.5		3.67	2.0
		0.23×19×0.5×3.5	7.6		1.75	13.4
		½×0.23 ×11 ×3.5²	15.5		1.17	18.1
	Water pressure	½×9.81×3.5²	60.0		1.17	70.0
			83.6			103.5
	Self weight	4.0×3.0×23		276.0	-	
	Wall friction	(0.5+7.6+15.5)tan20º		8.6	-1.5	-12.9
	Water uplift	(1) 2.9×9.81×3.0/2		-42.7	-0.5	21.3
		(2) 0.6×9.81×3.0		-17.7	0.0	0
	TOTALS		**83.6**	**224.2**		**111.9**

Load eccentricity = 111.9/224.2 = 0.499m
middle 1/3 limit = 3000/6 = 0.50m — e= 0.499 <0.50 OK

Peak bearing pressure = (224.2/3.0)x(1+6×0.499/3.0) = — 149.3kN/m²

Table 8 — Allowable pressure (submerged) = 1-2t/ft² = 107-215kN/m² — say OK

Sliding: force = 83.6kN/m
base friction resistance = 224.2tan35º = 157.0kN/m
passive resistance + water pressure in front of wall — K_p = 6.0
P_p = ½×6.0×11×0.6² + ½×9.81×0.6² = 11.9+1.8 = 13.7kN/m
total resistance = 157.0 + 13.7 = 170.7kN/m

Cl. 1.4922 — Fof S against sliding = 170.7/83.6 = 2.04 — 2.04 > 2 OK

Surcharge	Consider with 10kN/m² surcharge behind wall					
CP2	CP2 Design					
Table 3	Buoyant density of soil = 11kN/m²					
3300mm thick	Try 3300mm thick wall.					
			P	W	l_a	M
	active + water pressure		83.6			103.5
	surcharge pressure	0.23x10x4	9.2		2.0	18.4
	self weight	4.0x3.3x23		303.6	-	0.0
	wall friction	(0.5+7.6+15.5+9.2)tan20º		11.9	-1.65	-19.6
	Water uplift	(1) 2.9×9.81×3.3/2		-46.9	-0.55	25.8
		(2) 0.6×9.81×3.3		-19.4	0.0	0.0
	TOTALS		**92.8**	**249.2**		**128.1**

	Load eccentricity = 128.1/249.2 = 0.514m middle 1/3 limit = 3300/6 = 0.55m	0.55m<0.514m OK
Table 8	Peak bearing pressure = (249.2/3.3)x(1+6×0.514/3.3) = Allowable pressure (submerged) = 1-2t/ft² = 107-215kN/m²	146.1kN/m² say OK
	Sliding: force = 92.8kN/m base friction resistance = 249.2tan35º = 174.5kN/m passive resistance + water pressure in front of wall P_p = ½×6.0×11×0.6² + ½×9.81×0.6² = 11.9+1.8 = 13.7kN/m total resistance = 174.5 + 13.7 = 188.2kN/m	K_p = 6.0
Cl. 1.4922	Fof S against sliding = 188.2/92.8 =	2.03 > 2 OK
	With surcharge, 3300mm thick wall required	

BS8002

BS8002 Design

Table 1

Soil saturated density = 21.5 kN/m³;
buoyant density $\gamma' = 21.5 - 9.8 = 11.7$kN/m³

Assume variation of water pressure below wall same as CP2 example.

Case A

surcharge 10kN/m²

2900mm thick wall

		P	W	I_a	M
Active pressure	½×0.242×18.5×0.5²	0.6		3.67	2.1
	0.242×18.5×3.5/2	7.8		1.75	13.7
	½×0.242×3.5²×11.7	17.3		1.17	20.2
Water pressure	½×9.81×3.5²	60.1		1.17	70.1
Surcharge	0.242×10×4	9.7		2.0	19.4
Self weight	4.0×2.9×23		266.8	-	0
Wall friction	(0.6+7.8+17.3+9.7)tan20º		12.9	1.45	-18.7
Water uplift	(1) 2.9×9.81×2.9/2		-41.3	-0.483	19.9
	(2) 0.6×9.81×2.9		-17.1	0	0
TOTALS		**95.5**	**221.3**		**126.7**

Serviceability

Pressure under toe = 221.3/2.9 + 6x126.7/2.9² = 166.7kN/m²

Ultimate

Load eccentricity = 126.7/221.3 = 0.573m
$B' = 2.9 - 2\times0.573 = 1.755$m
Average effective bearing pressure = 221.3/1.755 = 126.1kN/m²
Bearing capacity = $q'N_q i_q + \frac{1}{2}\gamma' B' N_\gamma i_\gamma$
$F_H/F_v = 95.5/221.3$
$i_q = (1 - 0.7\, F_H/F_v)^3 = 0.340$
$i_\gamma = (1 - F_H/F_v)^3 = 0.184$
$\phi' = 33.8^\circ$ $N_q = 28.7$, $N_\gamma = 37.1$, $q' = 0.6\times11.7 = 7.0$kN/m²
Bearing capacity = 7.0×28.7×0.340 + 0.5×11.7×1.755×37×0.184 = 138.4 kN/m² > 126.1 OK

Sliding: force = 95.5kN/m
friction resistance = 221.3×0.503 = 111.3kN/m   95.5<111.3kN/m OK

Case B

0.34m deep unplanned excavation in front of wall

2900mm thick wall

Assume water table at front of wall is at ground level.

		P	W	I_a	M
Active pressure	½×0.242×18.5×0.5²	0.6		3.67	2.1
	0.242×18.5×0.5×3.5	7.8		1.75	13.7
	½×0.242×3.5²×11.7	17.3		1.17	20.2
Water pressure	½×9.81×3.5²	60.1		1.17	70.1
Self weight	4.0×2.9×23		266.8	-	
Wall friction	(0.6+7.8+17.3)tan20º		9.4	-1.45	-13.6
Water uplift	(1) 3.26×9.81×2.9/2		-46.4	-0.483	22.4
	(2) 0.34×9.81×2.9		-9.7	0	0
TOTALS		**85.8**	**220.1**		**114.9**

Serviceability

Pressure under toe = 220.1/2.9 + 6x114.9/2.9² = 157.9kN/m²

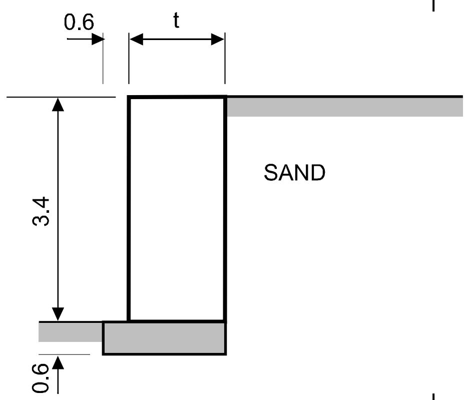
Ultimate	Load eccentricity = 114.9/220.1 = 0.522m $B' = 2.9 - 2\times0.522 = 1.856$m Average effective bearing pressure = 220.1/1.856 = 118.6kN/m² Bearing capacity = $q'N_q i_q + \frac{1}{2}\gamma' B' N_\gamma i_\gamma$ H/V = 85.8/220.1 $i_q = (1 - 0.7\ F_H/F_v)^3 = 0.384$ $i_\gamma = (1 - F_H/F_v)^3 = 0.227$ $\phi' = 33.8°$ $N_q = 28.7$, $N_\gamma = 37.1$, $q' = 0.26\times11.7 = 3.04$kN/m² Bearing capacity = 3.04×28.7×0.384 + 0.5×11.7×1.856×37×0.227 = 125.2kN/m²	 118.6<125.2kN/m² OK
	Sliding: force = 85.8kN/m, friction resistance = 220.1×0.503 = 110.7kN/m	 85.8<110.7kN/m OK
Comments	Where there is a surcharge, BS8002 allows a thinner wall than the CP2 wall (2900mm compared with 3300mm).However if there is no surcharge, BS8002 requires about the same wall thickness as CP2 (2900mm compared with 3000mm). (If the BS8002 design is checked to CP2, the load eccentricity on the foundation amounts to 0.2t. This is outside the middle third but still inside the middle half of the section.)	

2.0 Brickwork wall

Note: CP2 gives recommendations for allowable stresses for masonry in retaining walls. An alternative CP2 design has also been prepared with the masonry designed to BS5628:1.
The BS8002 design is prepared using BS5628:1.

2.1 Arrangement as 1.1.

H = 4m, retaining compact medium sand, no water pressure.



CP2 — CP2 Design

Consider brick wall base

Table 2 — Soil properties: compact sand: ϕ = 35º-40º loose sand ϕ = 30º-35º — assume ϕ = 35º, density = 19kN/m³

Cl 1.4321 — wall friction δ = 20º

Table 1 — Earth pressure coefficient — K_a = 0.23

No surcharge, 900mm thick — Consider base moments taken about wall centre line (all forces kN/m)

		P	W	l_a	M
Active pressure P_{an}	(½×0.23×19×3.4²)	25.3		1.13	28.6
Self weight	3.4x0.9x20		61.2	-	
wall friction	25.3xtan20º		9.2	0.45	-4.2
TOTALS		**25.3**	**70.4**		**24.4**

Vertical stress = 70.4/900 = 0.078N/mm²,
bending stress = 24×1000×6/900² = 0.178N/mm²
net tension = 0.10N/mm²

Cl. 2.225 — allowable tension (1:3 mortar) = 15psi = 0.103N/mm² — 0.10 < 0.103N/mm²OK

<u>Use 900mm thick masonry wall</u>

Surcharge — Consider with 10kN/m² surcharge behind wall.

1100mm thick

		P	W	l_a	M
Active pressure P_{an}	(½×0.23×19×3.4²)	25.3		1.13	28.6
Surcharge	0.23x10x3.4	7.8		1.7	13.3
Self weight	3.4x1.1x20kN/m³		74.8	-	
wall friction	(25.3+7.8)tan20º		12	0.55	-6.6
TOTALS		**33.1**	**86.8**		**35.3**

Vertical stress = 86.8/1100 = 0.079N/mm²
bending stress = 35.3x1000x6/1100² = 0.175N/mm²
net tension = 0.096N/mm² — 0.096 < 0.103N/mm² OK

<u>Use 1100mm thick wall</u>

CP2/ BS5628	Consider same wall but designed to BS5628, factored loads. Load factor = 1.4 (CP2 earth pressure), 0.9 (dead load), 'normal' materials and construction, so materials factor = 3.5 (compression), 3.0 (flexural tension)	
No surcharge		
900mm wall	Factored vertical load = 0.9x61.2 + 1.4x9.2 = 55.1+12.9 = 68.0 Factored O/T moment = 1.4x(28.5 - 4.1) = 34.1kNm/m	
Cl. 36.5.3	Check moment resistance f_{kx} = 0.5N/mm^2, f_k = 11.4N/mm^2, g_d = 68/900 = 0.075N/mm^2 Z = 0.1x90²/6 = 135cm³/mm M_r = (0.5/3.0 + 0.075)Z = 32.7kNm/m	34.1 > 32.7kNm/m not OK
Use 950mm wall	<u>Increase to 950mm thick wall</u>	
Surcharge		
1100mm wall	Factored vertical load = 0.9x74.8 + 1.4x12 = 67.3 + 16.8 = 84.1 Factored O/T mom. = 1.4x(28.6+13.3 - 6.6) = 49.4kNm/m	
Cl. 36.5.3	Check moment resistance f_{kx} = 0.5N/mm^2, f_k = 11.4N/mm^2, g_d = 84.1/1100 = 0.076N/mm^2 Z = 0.1x110²/6 = 217cm³/mm M_r = (0.5/3.0 + 0.076)Z = 52.7kNm/m	49.4 < 52.7kNm/m OK
	<u>Use 1100mm thick wall</u>	

BS8002

BS8002 Design

Masonry design to BS5628: load factor = 1.2 (earth and water pressure), 0.9 (dead load).

Reference	Calculation	Output
Table 1	Dense medium sand, moderate grading: Assume sub-angular soil particles, SPT 'N' = 20 at 3m depth Cl 2.2.4 A = 2º, B = 2º, Fig. 2 N´/N = 1.7, so N´ = 34, C = 2º ϕ'_{max} = 30+2+2+4.8 = 38.8º ϕ'_{crit} = 30+2+2 = 34º	density = 18.5kN/m³ $\tan\phi'_{max}$ = 0.804 $\tan\phi'_{crit}$ = 0.675
Cl 2.2.8	Wall friction	δ = 20º
Cl. 3.2.5	design $\tan\phi'$ = $\tan\phi'_{max}$/M or $\tan\phi'_{crit}$ = <u>0.670</u> or 0.675. (M=1.2) $\tan^{-1}$0.670 = 33.8º	design ϕ' = 33.8º
Cl. 3.2.6	design $\tan\delta$ = tan 20º or 0.75×design $\tan\phi'$ = <u>0.364</u> or 0.75×0.670 = 0.503	
Table		K_a = 0.242
Case A	Design for 10kN/m² surcharge on retained soil behind wall.	
1100mm wall		

		P	W	I_a	M
Active pressure	½x0.242x18.5x3.4²	25.9		1.13	29.3
Surcharge	0.242x10x3.4	8.2		1.7	14.0
Wall self weight	3.4x1.1x20		74.8	-	
Wall friction	34.1x0.364		12.4	-0.55	-6.8
TOTAL		**34.1**	**87.2**		**36.5**

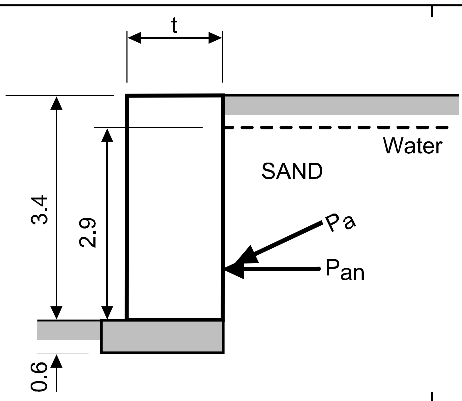
Factored vertical load = 0.9x74.8 + 1.2x12.4 = 67.3 + 14.9 = 82.2kN/m
Factored O/T moment = 1.2x(29.3+14.0) - 1.2x6.8 = 52 - 8.2 = 43.8kNm/m

Cl. 36.5.3 — Check moment resistance f_{kx} = 0.5N/mm², f_k = 11.4N/mm²,
g_d = 82.2/1100 = 0.0747N/mm² Z = 0.1x110²/6 = 201.7cm³/mm
M_r = (0.5/3.0 + 0.0747)Z = 48.7kNm/m — 43.8 < 48.7kNm/m OK

Comments

Where there is a surcharge behind the wall, BS8002 requires the same wall thickness as CP2. If there is no surcharge, BS8002 requires a thicker wall than CP2 (1100mm instead of 950mm thick wall (using BS5628 masonry stresses) or 900mm thick wall (using CP2's own permissible stresses).

2.2 **Ground conditions as 1.2.**



Consider base of brick wall. BS8002 Cl. 4.2.4.4.2 recommends that unreinforced masonry walls are waterproofed, so for the purposes of this example, the rear face of the wall is assumed to be waterproofed with bitumen-coated polythene sheet. The friction between fill and the back of the wall is taken as zero in this case.

<u>CP2</u> <u>CP2 design</u> — $K_a = 0.23$

Soil dry density 19kN/m²
buoyant density 11 kN/m²
$\phi = 35°$, $\delta = 0°$
$K_a = 0.27$

No surcharge

<u>1550m thick</u>

	P	W	l_a	M
Active pressure ½×0.27×19×0.5²	0.6		3.67	2.4
0.27×19×0.5×2.9	7.4		1.45	10.8
½×0.27 ×11 ×2.9²	12.5		0.967	12.1
Water pressure ½×9.8×2.9²	41.3		0.967	39.9
Self weight 3.4×1.55×20		105.4	-	
TOTALS	**61.8**	**105.4**		**65.2**

Axial stress in brickwork = 105.4/1550 = 0.068N/mm²
Bending stress = $(65.2\times6\times10^3)/1550^2$ = 0.163N/mm² net tension — 0.095<0.103N/mm² OK

Surcharge <u>Consider wall with 10kN/m² surcharge</u>

1700mm thick

	P	W	l_a	M
Active pressure ½×0.27×19×0.5²	0.6		3.67	2.4
0.27×19×0.5×2.9	7.4		1.45	10.8
½×0.27 ×11 ×2.9²	12.5		0.967	12.1
Water pressure ½×9.8×2.9²	41.3		0.967	39.9
Surcharge 0.27×10×3.4	9.2		1.7	15.6
Self weight 3.4×1.7×20		115.6	-	-
TOTALS	**71.0**	**115.6**		**80.8**

Axial stress in brickwork = 115.6/1700 = 0.068N/mm²
Bending stress = $(80.8\times6\times10^3)/1700^2$ = 0.168N/mm² net tension — 0.10<0.103N/mm² OK

<u>Use 1700mm thick wall</u>

CP2/BS5628 no surcharge

1550mm thick

Consider same wall but designed to BS5628, factored loads.
Load factor = 1.4 (water & CP2 earth pressure), 0.9 (dead load).

	P	W	l_a	M
Active pressure	20.5			25.3
Water pressure	41.3		0.967	39.9
Self weight (3.4×1.55×20)		105.4	-	
TOTALS	**61.8**	**105.4**		**65.2**

Factored vert. load = 0.9x105.4 = 94.9
Factored O/T moment = 1.4x65.2 = 91.3kNm/m

factored axial stress = 94.9/1550 = 0.061N/mm²
Z = 0.1x155²/6 = 400cm³/mm, bending stress = 0.228N/mm²
net bending tension = 0.167N/mm²

allowable = 0.5/3.0 = 0.167N/mm² — 0.167=0.167N/mm² OK

use 1550mm thick wall

Surcharge

1750mm thick

Consider wall with 10kN/m² surcharge

	P	W	l_a	M
Active pressure	20.5			25.3
Water pressure ½×9.8×2.9²	41.3		0.967	39.9
Surcharge 0.27×10×3.4	9.2		1.7	15.6
Self weight 3.4×1.75×20		119.0	-	-
TOTALS	**71.0**	**119.0**		**80.8**

Factored vert. load = 0.9x119 = 107.1
Factored O/T moment = 1.4x80.8 = 113.1kNm/m

factored axial stress = 107.1/1750 = 0.061N/mm²
Z = 0.1x175²/6 = 510cm³/mm, bending stress = 0.222N/mm²
net bending tension = 0.161N/mm²

allowable = 0.5/3.0 = 0.167N/mm² — 0.161<0.167N/mm² OK

Use 1750mm thick wall

BS8002

BS8002

design $\phi' = 33.8°$ design $\tan\delta = 0$ — $K = 0.285$

Soil saturated density $\gamma = 21.5$ kN/m³;
buoyant density $\gamma' = 21.5-9.8 = 11.7$kN/m³

1700mm thick

		P	W	I_a	M
Active pressure P_{an} =	(½×0.285×18.5×1.5²)	5.9		2.5	14.8
	(18.5×1.5×0.285×2)	15.8		1.0	15.8
	(½×0.285×(21.5-9.8)×2.0²)	6.7		0.67	4.4
water =	(½×9.81×2.9²)	41.3		0.967	39.9
surcharge =	0.285×10×3.5	10.0		1.75	17.5
self weight=	3.5×1.7×20		119.0		
TOTAL		**79.7**	**119.0**		**92.4**

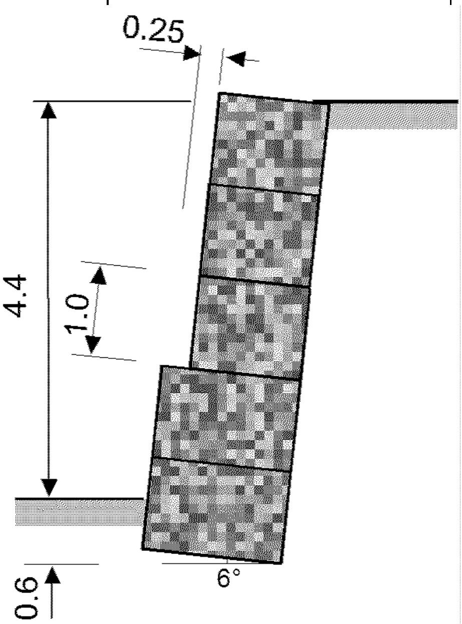
Load factors 1.2 (unfavourable), 0.9 (favourable)
Factored vert. load = 0.9x112 = 107.1kN/m
Factored O/T moment = 1.2×92.4 = 110.9kNm/m
$g_d = 107.1/1700 = 0.063$N/mm², $Z = 482$cm³/mm
net tension= 0.230- 0.063 = 0.167 allowable = (0.5/3.0) = 0.167 — 0.167=0.167N/mm² OK

<u>Use 1700mm thick wall</u>

Comments

Where there is a surcharge, the BS8002 wall design is the same as CP2 (1700mm thick). Where there is no surcharge, CP2 allows a slightly thinner wall (1550mm thick).

3.0 Gabion wall



CP2 does not give specific recommendations for gabion walls. However it does give recommendations for the design of crib walls, which are similar to gabion walls. The crib wall rules recommend that the vertical force resultant is kept inside the middle quarter of the wall, i.e. e < 0.125b (Cl. 5.322).

An alternative CP2 design has also been prepared in accordance with recommendations of one of the main gabion manufacturers, Maccaferri, who recommend that the variation in pressure across the wall base is limited to 50kN/m².

BS8002 recommends that the resultant vertical force is kept inside the middle third, i.e. 0. (Cl. 4.2.6.4.2).

3.1 Gabion wall retaining broken brick fill, bearing on firm clay (c_u = 75kN/m³).

(Resolve forces into horizontal and vertical components in design calculations.)

CP2 Design No surcharge

Table 2 — Soil properties broken brick: ϕ = 35º-45º, Density = 11-17.3kN/m³, assume dense — assume ϕ = 40º, density = 17kN/m³

Cl 1.4321 — wall friction $\delta = \phi$ = 40º. α = 6º. From table*, α = 0º K_{ah} = 0.161, θ = -10º K_{ah} = 0.123 — δ = 40º, K_{ah} = 0.138

No surcharge — Density of filling = 60%×23kN/m³ = 13.8kN/m³.

try 1250mm thick

		P	W	l_a	M
Active pressure P_{ah} =	½×0.138×17×5.0²	29.3		1.667	48.9
Self weight =	2.0×1.25×13.8		34.5	-0.105	-3.6
	3.0×1.0×13.8		41.4	-0.493	-20.4
wall friction =	(29.3) × tan(40º-6º)		19.8	-0.800	-15.8
TOTAL		**29.3**	**95.7**		**9.1**

CP2 1250mm — eccentricity = 9.1/95.7 = 0.095m < 1.25/8 =0.156m — 0.095<0.156m OK to CP2

Bearing pressure = 95.7/1.25 +/- (6×9.1/1.25²) = 76.6+/-34.9kN/mN² — +/-34.9>25kN/m² not OK (Maccaferri criterion)

M'ferri 1500mm — 1500mm thick wall to meet Maccaferri criterion.

1500mm thick **10kN/m² surcharge**

		P	W	l_a	M
Active pressure P_{ah} =	½×0.138×17×5.0²	29.3		1.667	48.9
Surcharge	0.138×10×5.0	6.9		2.5	17.2
Self weight =	2.0×1.5×13.8		41.4	-0.105	-4.3
	3.0×1.25×13.8		51.8	-0.493	-25.5
wall friction =	29.3 × tan(40º-6º)		19.8	-0.80	-15.8
	6.9 × tan(40º-6º)		4.7	-1.013	-4.7
TOTAL		**36.2**	**117.7**		**15.8**

eccentricity = 15.8/117.7 = 0.134m < 1.5/8 = 0.188m OK

Bearing pressure = 117.7/1.5 +/-(6×15.8/1.5²)
= 78.5 +/- 42.1kN/m²
<u>1500mm OK for CP2 but 1750mm for Maccaferri limits.</u>

BS8002

Table 1 — Brick hardcore density = 17.5kN/m³

Table 3 — Critical state friction angle (well graded) ϕ'_{crit} = 30+4+4 = 38º
Say N = 15 at 4m; N´ = 1.7×15 =25.5 ϕ' = 30+4+4+3.1 = 41.1º
$\tan\phi'_{crit}$ = 0.781, $\tan\phi'/1.2$ = 0.727, $\tan^{-1}0.727$ = 36º — ϕ' = 36º
wall friction tan δ = 0.75design $\tan\phi'$ = 0.545 — δ = 28.6º
α = -6º
From table, α = 0º K_{ah} = 0.208, α = -10º K_{ah} = 0.163 — K_{ah} = 0.181

1750mm thick — Min. surcharge 10kN/m²

		P	W	l_a	M
Active pressure P_{ah} =	½×0.181×17.5×5.0²	39.6		1.667	66.0
Surcharge P_{ah} =	0.181×10×5.0	9.0		2.5	22.5
Self weight =	3.0×1.5×13.8		62.1	-0.493	-30.6
	2.0×1.75×13.8		48.3	-0.105	-5.1
wall friction =	39.6 × tan(28.6º-6º)		16.5	-1.05	-17.3
	9.0 × tan(28.6º-6º)		3.7	-1.138	-4.3
TOTAL		**48.6**	**130.6**		**31.2**

eccentricity = 31.2/130.6 = 0.239m; limit = 1.75/6 = 0.292m — 0.239m<0.292m OK

Serviceability — Toe bearing pressure = 130.6/1.75 + 6x31.2/1.75² = 135.8 — 135.8 < 150 kN/m² OK

Ultimate — bearing capacity
Base effective breadth B´ = 1.75 - 2×0.239 = 1.272m
Average bearing pressure = 130.6/1.272 = 102.7kN/m²
Bearing capacity = $5.14c_u i_c + q$
c_u = 75kN/m² i_c = 0.85 q = 10.5kN/m²
Bearing capacity = 5.14 x 75 x 0.85 + 10.5 = 338kN/m² — 102.7<338kN/m² OK

To comply with Maccaferri limit, try 2250mm thick wall

		P	W	l_a	M
Active pressure P_{ah} =	½×0.181×17.5×5.0²	39.6		1.667	66.0
Surcharge P_{ah} =	0.181×10×5.0	9.0		2.5	22.5
Self weight =	3.0×2.0×13.8		82.8	-0.493	-40.8
	2.0×2.25×13.8		62.1	-0.105	-6.5
wall friction =	39.6 × tan(28.6º-6º)		16.5	-1.30	-21.4
	9.0 × tan(28.6º-6º)		3.7	-1.388	-5.2
TOTAL		**48.6**	**165.1**		**14.6**

eccentricity = 14.6/165.1 = 0.088m limit = 2.25/6 = 0.375m OK

Pressure variation across base = +/-(6×14.6/2.25²)
= +/-17.3kN/m². — +/-17.3<+/-25kN/m² OK

<u>**Comparison**</u> — BS8002 requires a 1750mm thick wall and this increases to 2250mm if the Maccaferri pressure limits are imposed. For CP2 designs, the corresponding thicknesses are 1500mm and 1750mm; where there is no surcharge, CP2 would permit a 1250mm thick wall.