Concrete retaining walls

Types of retaining walls:-

1. Gravity retaining walls.
2. Semi-gravity retaining walls.
3. Cantilever retaining walls.
4. Counterfort retaining walls.

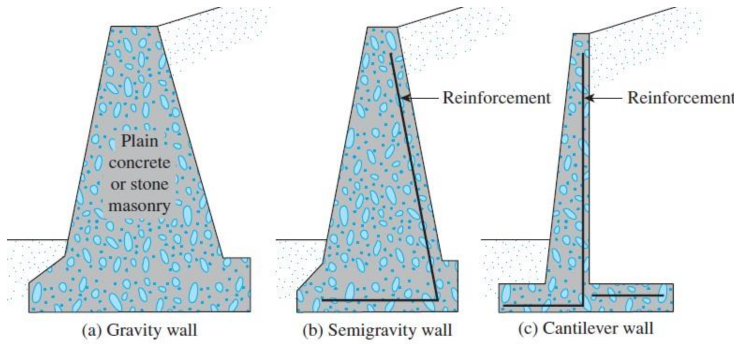
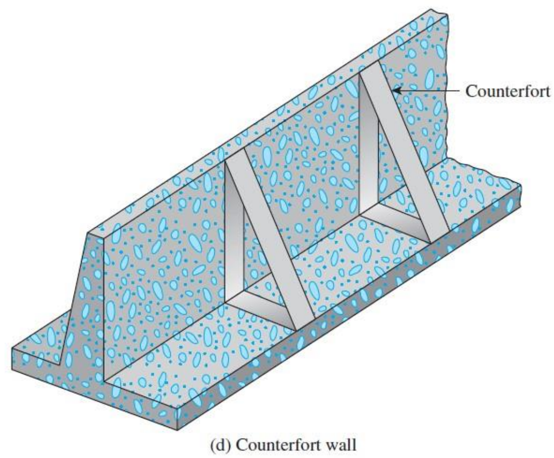


Fig.1 Types of retaining walls



Design considerations

There are two phases in the design of a conventional retaining wall.

1- With the lateral earth pressure known, the structure as a whole is checked for *stability*. The structure is examined for possible *overturning*, *sliding*, and *bearing capacity* failures.

2- Each component of the structure is checked for *strength*, and the *steel reinforcement* of each component is determined.

هناك مرحلتان في تصميم الجدار الساندة التقليدية.

1- مع معرفة الضغط الأرضي الجانبي، يتم فحص الهيكل ككل للتأكد من ثباته بحثًا عن حالات الانقلاب والانزلاق وفشل قوة تحمل التربة المحتملة.

2- يتم فحص قوة كل جزء من اجزاء الهيكل، وتصميم حديد التسليح .

Gravity and Cantilever Walls

Proportioning retaining walls

تناسب الجدران الساندة

In designing retaining walls, an engineer must assume some of their dimensions. Called *proportioning,* such assumptions allow the engineer to check trial sections of the walls for stability. If the stability checks yield undesirable results, the sections can be changed and rechecked. Fig.2 shows the general proportions of various retaining-wall components that can be used for initial checks. Note that the top of the stem of any retaining wall should not be less than about 0.3 m for proper placement of concrete. The depth, *D,* to the bottom of the base slab should be a minimum of However, the bottom of the base slab should be positioned below the seasonal frost line. For counterfort retaining walls, the general proportion of the stem and the base slab is the same as for cantilever walls. However, the counterfort slabs may be about 0.3 m thick and spaced at center-to-center distances of 0.3*H* to 0.7*H.*

عند تصميم الجدران الساندة يجب على المهندس أن يفرض بعض أبعادها. تسمى هذه الافتراضات بالتناسب، وهي تسمح للمهندس بفحص الأجزاء المفروضة من الجدران للتأكد من ثباتها. إذا أسفرت عمليات التحقق للاستقرار عن نتائج غير مرغوب فيها، فيمكن تغيير الابعاد وإعادة فحصها. يوضح الشكل 2 النسب العامة لمكونات الجدار الساند المختلفة التي يمكن استخدامها في الفحوصات الأولية. لاحظ أن الجزء العلوي من جذع أي جدار استنادي يجب ألا يقل عن حوالي 0.3 متر لوضع الخرسانة بشكل صحيح. يجب أن يكون العمق، D، إلى أسفل لوح القاعدة كحد أدنى، ومع ذلك، يجب وضع الجزء السفلي من لوح القاعدة أسفل خط الصقيع الموسمي. بالنسبة للجدران الساندة المضادة، فإن النسبة العامة للساق والقاعدة هي نفسها بالنسبة للجدران الكابولية. ومع ذلك، قد يبلغ سمك الألواح المضادة حوالي 0.3 مترًا ومتباعدة على مسافات من المركز إلى المركز تتراوح من 0.3 إلى 0.7H.

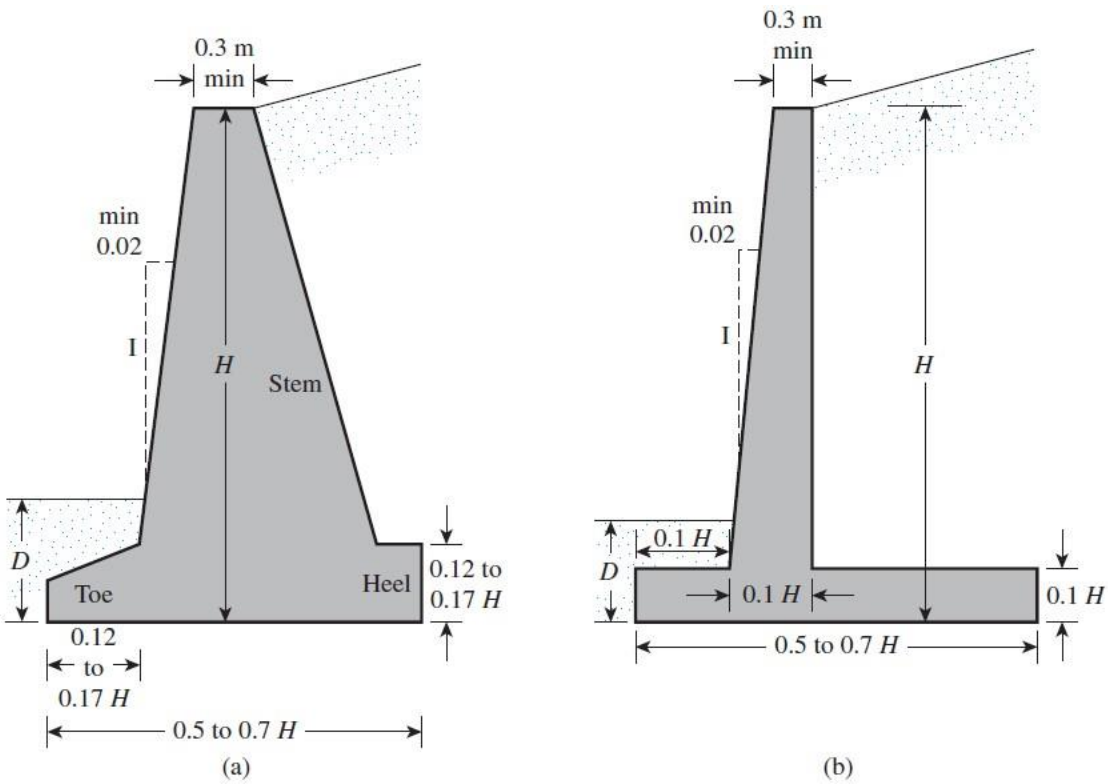


Fig.2 Approximate dimensions for various components of retaining wall for initial stability checks:
(a) gravity wall; (b) cantilever wall

If Coulomb's theory is used, it will be necessary to know the range of the wall friction angle δ with various types of backfill material. Following are some ranges of wall friction angle for masonry or mass concrete walls:

Backfill material	Range of δ' (deg)
Gravel	27–30
Coarse sand	20–28
Fine sand	15–25
Stiff clay	15–20
Silty clay	12–16

In the case of ordinary retaining walls, water table problems and hence hydrostatic pressure are not encountered. Facilities for drainage from the soils that are retained are always provided.

Design criteria

1- Check for overturning.
2- Check for sliding.
3- Check for bearing capacity.

Design Example:

A full design of the retaining wall is required.

Factor safety for overturning moment

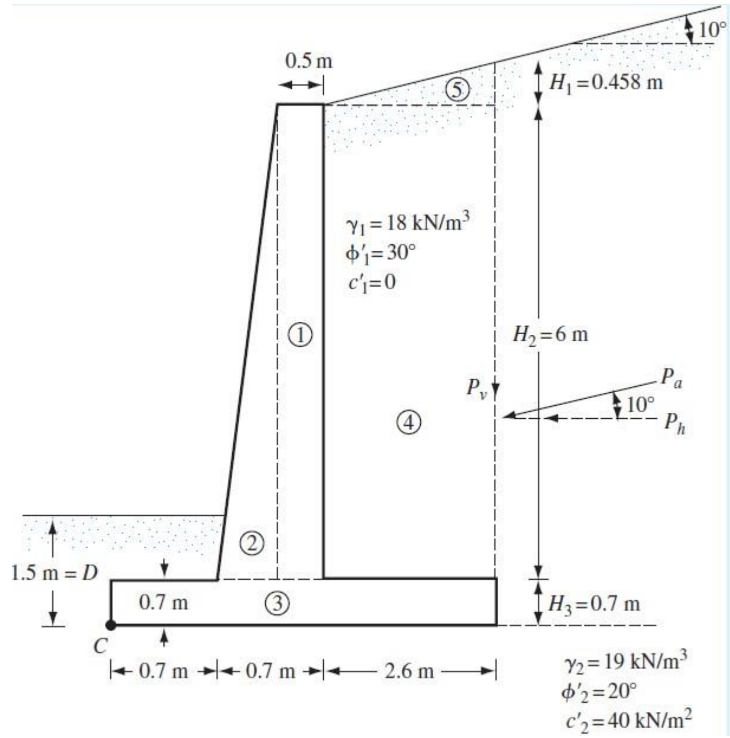
$H = 0.7 + 6 + 2.6tan10 = 7.158m$

For $\emptyset = 30$ *and* $\alpha = 10,\ ka = 0.3495$

$P_a = k_a \frac{1}{2}\gamma h^2 = 0.3495 * \frac{1}{2} * 18 * 7.158^2 = 162.9KN/m$

$P_h = 162.9\cos(10) = 160.4\ KN/m$

$P_V = 160.4\sin(10) = 27.85KN/m$



The following table can now be prepared for determining the resisting moment:

Section no.[a]	Area (m²)	Weight/unit length (kN/m)	Moment arm from point C (m)	Moment (kN-m/m)
1	$6 \times 0.5 = 3$	70.74	1.15	81.35
2	$\frac{1}{2}(0.2)6 = 0.6$	14.15	0.833	11.79
3	$4 \times 0.7 = 2.8$	66.02	2.0	132.04
4	$6 \times 2.6 = 15.6$	280.80	2.7	758.16
5	$\frac{1}{2}(2.6)(0.458) = 0.595$	10.71	3.13	33.52
		$P_v = 28.29$	4.0	113.16
		$\Sigma V = 470.71$		$1130.02 = \Sigma M_R$

$\gamma_{cr} = 23.58$ kN/m

$Overturning\ moment = 160.4 * \frac{7.158}{3} = 382.7\ KN.m/m$

$F_s(overturning) = \frac{1130.02}{382.7} = 2.95$

Factor of safety for sliding

$k_p = \tan^2(45 + \frac{\emptyset}{2}) = 2.04$

$P_p = \frac{1}{2}k_p\gamma D^2 + 2C\sqrt{k_p}D = \frac{1}{2} * 2.04 * 19 * 1.5^2 + 2 * 40 * \sqrt{2.04} * 1.5 = 215KN/m$

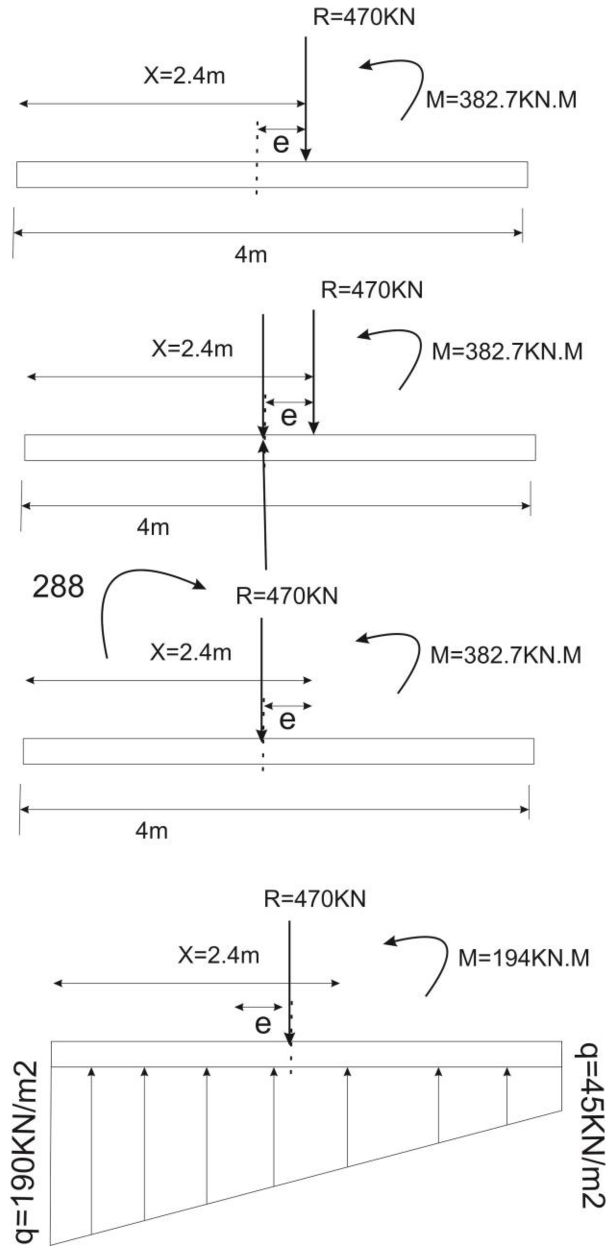
$Fs(sliding) = \frac{470.71+40*4*\left(\frac{2}{3}\right)+215}{162.4} = 2.7 > 1.5\ ok$

Factor of Safety against Bearing Capacity Failure

$X = \frac{\sum M}{R} = \frac{1130}{470} = 2.4m$

Eccentricity analysis

$$\boldsymbol{e = \frac{M}{R} = \frac{194}{470.7} = 0.4121m < \frac{B}{6} = \frac{4}{6} = 0.66m}$$



$q = \frac{\sum V}{A} \mp \frac{My}{I}$, Let $\sum V = R$

$$q = \frac{R}{1 * B} \mp \frac{eR\frac{B}{2}}{\frac{1 * B^{32}}{126}} = \frac{R}{B} \mp \frac{6eR}{B^2} = \frac{R}{B}\left(1 \mp \frac{6e}{B}\right) =$$

$$= \frac{470}{4}\left(1 \mp \frac{6*0.4121}{4}\right)$$

$q1 = 190KN/m2 \, , q2 = 45KN/m2$

Bearing capacity by Terzaghi

$q_u = 1.3CN_C + qN_q + 0.4\gamma BN_\gamma$

For $\emptyset = 20$, $N_c = 11.85$, $N_q = 3.88$, $N_\gamma = 1.12$

$q_u = 1.3 * 20 * 11.85 + 10 * 1.5 * 3.88 + 0.4 * 19 * 4 * 1.12 = 400$

$F_s = \frac{400}{190} = 2.1$ oK

Reinforcement Design

Design of Stem

Mu on the stem =$\boldsymbol{162.9kN * 2.39m = 389\ KN.M/m}$

$\rho = \frac{A_S}{bd}$

$M_U = \emptyset \rho b d^2 f_y (1 - \frac{\rho f_y}{1.7 f_C}),$

$1.7 * 389 = 0.85 * \rho * 1 * 1.2^2 * 428 * 1000(1 - \frac{\rho * 428}{1.7 * 28})$

$\mathbf{0.00126 = \rho(1 - 9\rho)}$ **,** $\mathbf{\rho = 0.00128,}$ $\mathbf{0.00128 = \frac{A_S}{1*1.2,}},$ $\mathbf{A_S = 0.001536m2 = 1536m2}$

Use 5#20mm

Design of Toe

$$\boldsymbol{M_U = \frac{\frac{(190-45)}{4}*3.3+45+190}{2} * 0.7 = 124KN.m/m}$$

Design of Heel

$$\boldsymbol{M_U = \frac{\left[\frac{(190-45)}{4}*2.6\right]*\frac{2.6^2}{3}+45*\frac{2.6^2}{2}}{1} = 364KN.m}$$

Home work

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Table 3.2 Terzaghi's Modified Bearing Capacity Factors N_c', N_q', and N_γ'

ϕ'	N_c'	N_q'	N_γ'	ϕ'	N_c'	N_q'	N_γ'
0	5.70	1.00	0.00	26	15.53	6.05	2.59
1	5.90	1.07	0.005	27	16.30	6.54	2.88
2	6.10	1.14	0.02	28	17.13	7.07	3.29
3	6.30	1.22	0.04	29	18.03	7.66	3.76
4	6.51	1.30	0.055	30	18.99	8.31	4.39
5	6.74	1.39	0.074	31	20.03	9.03	4.83
6	6.97	1.49	0.10	32	21.16	9.82	5.51
7	7.22	1.59	0.128	33	22.39	10.69	6.32
8	7.47	1.70	0.16	34	23.72	11.67	7.22
9	7.74	1.82	0.20	35	25.18	12.75	8.35
10	8.02	1.94	0.24	36	26.77	13.97	9.41
11	8.32	2.08	0.30	37	28.51	15.32	10.90
12	8.63	2.22	0.35	38	30.43	16.85	12.75
13	8.96	2.38	0.42	39	32.53	18.56	14.71
14	9.31	2.55	0.48	40	34.87	20.50	17.22
15	9.67	2.73	0.57	41	37.45	22.70	19.75
16	10.06	2.92	0.67	42	40.33	25.21	22.50
17	10.47	3.13	0.76	43	43.54	28.06	26.25
18	10.90	3.36	0.88	44	47.13	31.34	30.40
19	11.36	3.61	1.03	45	51.17	35.11	36.00
20	11.85	3.88	1.12	46	55.73	39.48	41.70
21	12.37	4.17	1.35	47	60.91	44.45	49.30
22	12.92	4.48	1.55	48	66.80	50.46	59.25
23	13.51	4.82	1.74	49	73.55	57.41	71.45
24	14.14	5.20	1.97	50	81.31	65.60	85.75
25	14.80	5.60	2.25				

α (deg)	ϕ' (deg) →												
↓	28	29	30	31	32	33	34	35	36	37	38	39	40
0	0.3610	0.3470	0.3333	0.3201	0.3073	0.2948	0.2827	0.2710	0.2596	0.2486	0.2379	0.2275	0.2174
1	0.3612	0.3471	0.3335	0.3202	0.3074	0.2949	0.2828	0.2711	0.2597	0.2487	0.2380	0.2276	0.2175
2	0.3618	0.3476	0.3339	0.3207	0.3078	0.2953	0.2832	0.2714	0.2600	0.2489	0.2382	0.2278	0.2177
3	0.3627	0.3485	0.3347	0.3214	0.3084	0.2959	0.2837	0.2719	0.2605	0.2494	0.2386	0.2282	0.2181
4	0.3639	0.3496	0.3358	0.3224	0.3094	0.2967	0.2845	0.2726	0.2611	0.2500	0.2392	0.2287	0.2186
5	0.3656	0.3512	0.3372	0.3237	0.3105	0.2978	0.2855	0.2736	0.2620	0.2508	0.2399	0.2294	0.2192
6	0.3676	0.3531	0.3389	0.3253	0.3120	0.2992	0.2868	0.2747	0.2631	0.2518	0.2409	0.2303	0.2200
7	0.3701	0.3553	0.3410	0.3272	0.3138	0.3008	0.2883	0.2761	0.2644	0.2530	0.2420	0.2313	0.2209
8	0.3730	0.3580	0.3435	0.3294	0.3159	0.3027	0.2900	0.2778	0.2659	0.2544	0.2432	0.2325	0.2220
9	0.3764	0.3611	0.3463	0.3320	0.3182	0.3049	0.2921	0.2796	0.2676	0.2560	0.2447	0.2338	0.2233
10	0.3802	0.3646	0.3495	0.3350	0.3210	0.3074	0.2944	0.2818	0.2696	0.2578	0.2464	0.2354	0.2247
11	0.3846	0.3686	0.3532	0.3383	0.3241	0.3103	0.2970	0.2841	0.2718	0.2598	0.2482	0.2371	0.2263
12	0.3896	0.3731	0.3573	0.3421	0.3275	0.3134	0.2999	0.2868	0.2742	0.2621	0.2503	0.2390	0.2281
13	0.3952	0.3782	0.3620	0.3464	0.3314	0.3170	0.3031	0.2898	0.2770	0.2646	0.2527	0.2412	0.2301
14	0.4015	0.3839	0.3671	0.3511	0.3357	0.3209	0.3068	0.2931	0.2800	0.2674	0.2552	0.2435	0.2322
15	0.4086	0.3903	0.3729	0.3564	0.3405	0.3253	0.3108	0.2968	0.2834	0.2705	0.2581	0.2461	0.2346
16	0.4165	0.3975	0.3794	0.3622	0.3458	0.3302	0.3152	0.3008	0.2871	0.2739	0.2612	0.2490	0.2373
17	0.4255	0.4056	0.3867	0.3688	0.3518	0.3356	0.3201	0.3053	0.2911	0.2776	0.2646	0.2521	0.2401
18	0.4357	0.4146	0.3948	0.3761	0.3584	0.3415	0.3255	0.3102	0.2956	0.2817	0.2683	0.2555	0.2433
19	0.4473	0.4249	0.4039	0.3842	0.3657	0.3481	0.3315	0.3156	0.3006	0.2862	0.2724	0.2593	0.2467
20	0.4605	0.4365	0.4142	0.3934	0.3739	0.3555	0.3381	0.3216	0.3060	0.2911	0.2769	0.2634	0.2504
21	0.4758	0.4498	0.4259	0.4037	0.3830	0.3637	0.3455	0.3283	0.3120	0.2965	0.2818	0.2678	0.2545
22	0.4936	0.4651	0.4392	0.4154	0.3934	0.3729	0.3537	0.3356	0.3186	0.3025	0.2872	0.2727	0.2590
23	0.5147	0.4829	0.4545	0.4287	0.4050	0.3832	0.3628	0.3438	0.3259	0.3091	0.2932	0.2781	0.2638
24	0.5404	0.5041	0.4724	0.4440	0.4183	0.3948	0.3731	0.3529	0.3341	0.3164	0.2997	0.2840	0.2692
25	0.5727	0.5299	0.4936	0.4619	0.4336	0.4081	0.3847	0.3631	0.3431	0.3245	0.3070	0.2905	0.2750