SILO & HOPPER ENGINEERING

SILO & HOPPER THICKNESS–WEIGHT–QUICK SOLUTION

INPUT DATA 계산실행 ***V2.0*** ***By Ryu-ChangMyong/P.E***

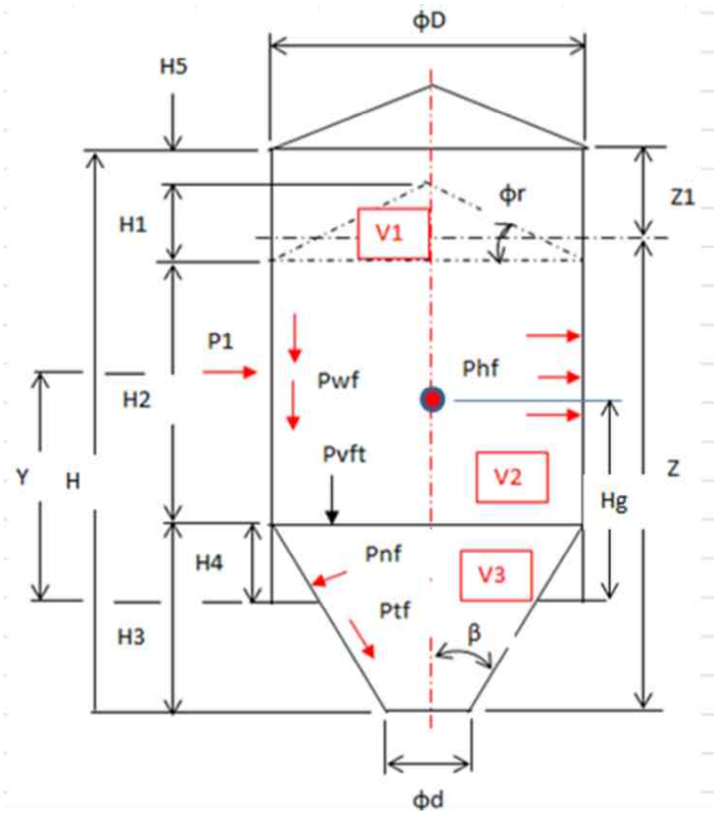
* ITEM NO	POWDER		* Description	SILO	

A. GEOMETRY DESIGN DATA

* D : Silo Diameter	7.6	m	* d1 : Hopper diameter	2.1	m
* ts : Silo lower shell thickness (corroded)	9.0	mm	* ϕa : Roof angle	30.0	Deg
* th : Hopper wall thickness (corroded)	6.0	mm	* β : Hopper angle	30.0	Deg
* Rt : Roof thickness (corroded)	6.0	mm	* Z : Height	19.0	m
*'V1 : Internal Hopper Volume	0.0	m^3	* H1 : Height	0.0	m
* ts : Used thickness of skirt	0.012	m	* H2 : Height	9.85	m
* C.A : Corrosion Allowance	3	mm	* H3 : Height	4.85	m
* Hw : Overall height that is exposed to wind pressure	15.0	m	* H4 : Height	1.3	m
⊏150x75x6.5x10	Rafter Size		* H : Height	11.15	m

B. LOAD DESIGN DATA

* Vo : Basic wind speed	35	m/sec	* Solid unit weight, (γ)	13	kN/m^3
* Yield strength, Fy	235	Mpa	* We : Max. silo weight (Empty)–Assumed	339	kN
* Wb : Weight of bulk goods	7099	kN	* Wf : Weight of Equipment (Bag Filter)	30	kN



RESULT OF CALCULATION

1. WIND LOAD CALCULATION

1) Kzr : Altertude distribution factor = 0.71*Z0.15 at Z	1.1		1) Pf : Wind pressure = qz * Cf	0.7	kN/m^2
2) Vz : Design Velocity = Vo*Kzr*Kzt*Iw	38.6	m/sec	2) Wf : Wind load = Shear(V) = Pf*D*Hw	74.5	kN
3) qz : Velocity pressure = 0.5*σ*Vz^2/1000	0.9	kN/m^2	3) Mw : Maximum Moment at the base = 2*V*Hw/3	745	kN-m
				76,021	Kgf-m

2. SEISMIC LOAD CALCULATION

1) T : Fundamental period of vibration = CT*H3^(3/4)	0.29	sec	13) Weight of Hopper skin = (Ah+π*d1^2/4) * ω	40.8	kN
2) SDS : Short period design spectral acceleration = 2.5*S*Fa*2/3	0.43		14) Ar : Roof area of surface	60.49	m^2
3) SD1 : Design spectral acceleration = S*Fv*2/3	0.23		15) Ld : Roof weight	27.9	kN
4) SD1/(R/IE)/T	0.41		16) Sd : Snow load	67.1	kN
5) SDS/(R/IE)	0.22		17) Ws : Weight of roof = Ld+Sd	95.1	kN
6) Cs : Seismic response coefficient = SD1/(R/IE)/T ≤ SDS/(R/IE)	0.22		18) Wo : Max. operating weight of Silo (We+Wb+Ws+Wf)	7,563	kN
7) ω : Unit weight of silo skin per m^2 = 0.077 * ts	0.693	kN/m^2	19) Ve : Total design base shear = Cs*Wo	1,693	kN
8) Wn : Weight of silo skin = ω * π * D * H	184	kN	20) V2 : Volume (π*D^2/4*H2)	447	m^3
9) ω : Unit weight of hopper skin per m^2 =	0.46	kN/m^2	21) V3 : Volume (0.2618*H3*	99.2	m^3

0.077 * th

10) a1=(D−d1)/2 | 2.75 | m

11) C : (a1^2+H3^2)^0.5 | 5.58 | m

12) Ah : Hopper area of conical surface = 1.5708*C*(D+d) | 84.95 | m^2

(D^2+D*d+d^2))

22) Hg : Height of center of gravity= | 9.2 | m

23) Ms : Maximum moment at the base = Ve*Hg | 15,581 | kN−m

| 1,589,862 | Kgf−m

3. LOWER SHELL THICKNESS

1) Allowable shear stress, τa	791	kg/cm^2
2) Section Area, A	2,146	cm^2
3) Max. Shear Moment−Total weight, Mwtm	318,431	Kgf−m
4) Max. Shear Moment−WInd load, Mwm	69,980	Kgf−m
5) Max. Shear Moment−Seismic load, Msm	1,589,862	Kgf−m
6) Sectional Modulus, Z	305,486	cm^3
7) Interial Moment, Ve*Hg	154,596,484	cm^4
8) Shear Stress, σ wt=Mwtm/z	104	kg/cm^2
9) Shear Stress, σ w=Mwm/z	23	kg/cm^2
10) Shear Stress, σ s=Msm/z	520	kg/cm^2
* Judgement	O.K	

4. LOADS ON THE VERTICAL WALLS OF SILO

1) Pressure due to reduction in ambient atmospheric temperature, Pht = CT * α w * ΔT * Ew / {(r/t)+(1−v)(Ew/Esu)}	0.45	kN/m^2
2) Upper characteristic value of Angle of Internal friction(ϕi)=αϕ*ϕim	36.6	Deg
3) Lower characteristic value of Angle of Internal friction(ϕi)=ϕim / αϕ	24.6	Deg
4) Upper characteristic value of Lateral pressure ratio (K) = αK * Km	0.65	
5) Lower characteristic value of Lateral pressure ratio (K) = Km / αK	0.45	
6) Upper characteristic value of Wall friction coefficient (μ) = αμ * μm	0.44	
7) Lower characteristic value of Wall friction coefficient (μ) =μm / αμ	0.38	

Nom	z	μ	K	zo	z/zo	Pho	Yj(z)	Press.
Phf(z)	1.41	0.38	0.65	7.65	0.18	64.46	0.17	10.86
	2.81	0.38	0.65	7.65	0.37	64.46	0.31	19.90
	4.22	0.38	0.65	7.65	0.55	64.46	0.43	27.41
	5.63	0.38	0.65	7.65	0.74	64.46	0.52	33.65
	7.04	0.38	0.65	7.65	0.92	64.46	0.60	38.84
	8.44	0.38	0.65	7.65	1.10	64.46	0.67	43.16
	9.85	0.38	0.65	7.65	1.29	64.46	0.73	46.75
	14.70	0.38	0.65	7.65	1.92	64.46	0.85	55.09
Pwf(z)	1.41	0.44	1.07	4.05	0.35	56.30	0.29	7.28
	2.81	0.44	1.07	4.05	0.70	56.30	0.50	12.41
	4.22	0.44	1.07	4.05	1.04	56.30	0.65	16.03
	5.63	0.44	1.07	4.05	1.39	56.30	0.75	18.58
	7.04	0.44	1.07	4.05	1.74	56.30	0.83	20.38
	8.44	0.44	1.07	4.05	2.09	56.30	0.88	21.66

Nom	z	μ	K	zo	z/zo	Pho	Yj(z)	R.C.V
	9.85	0.44	1.07	4.05	2.43	56.30	0.91	22.55
	14.70	0.44	1.07	4.05	3.63	56.30	0.97	24.05
Pvf(z)	1.41	0.38	0.45	11.02	0.13	64.46	0.12	17.23
	2.81	0.38	0.45	11.02	0.26	64.46	0.23	32.39
	4.22	0.38	0.45	11.02	0.38	64.46	0.32	45.73
	5.63	0.38	0.45	11.02	0.51	64.46	0.40	57.46
	7.04	0.38	0.45	11.02	0.64	64.46	0.47	67.78
	8.44	0.38	0.45	11.02	0.77	64.46	0.54	76.85
	9.85	0.38	0.45	11.02	0.89	64.46	0.59	84.84
	14.70	0.38	0.45	11.02	1.33	64.46	0.74	105.70

Nom	z	μ	K	zo	z/zo	Pho	Yj(z)	R.C.V
nzsk1	1.41	0.38	0.45	11.02	0.13	64.46	0.12	−28.56
	2.81	0.38	0.45	11.02	0.26	64.46	0.23	−45.82
	4.22	0.38	0.45	11.02	0.38	64.46	0.32	−53.59
	5.63	0.38	0.45	11.02	0.51	64.46	0.40	−53.40
	7.04	0.38	0.45	11.02	0.64	64.46	0.47	−46.55
	8.44	0.38	0.45	11.02	0.77	64.46	0.54	−34.14
	9.85	0.38	0.45	11.02	0.89	64.46	0.59	−17.10
	14.70	0.38	0.45	11.02	1.33	64.46	0.74	67.09

5. LOADS ON THE VERTICAL WALLS OF HOPPER

Item	Value	Unit
1) 7)Pvft = Cb * Pvf	101.8	kN/m^2
2) For discharge condition, Max. Pv = Pvft	101.8	kN/m^2
3) μh : μheff is the lower characteristic value of wall friction coefficient	0.38	
4) For under filling condition, F=Ff=1−{b/(1+tanβ / μh)}	0.97	
5) Upper characteristic value of Angle of Internal friction(ϕi)	0.64	Rad
6) ε : ϕwh + sin−1 (sinϕ wh / sinϕi)	1.01	
7) For discharge condition, n=S*(Fe*μheff * cot β + F) − 2	4.21	
15) Max. Ptf = μh * Ff * Pv	37.7	kN/m^2
8) For under filling condition, Max. Pv = Pvft	101.8	kN/m^2
9) β : the hopper apex angle	0.52	Rad
10) ϕr : the Angle of internal friction of the stored solid	0.63	Rad
11) For under filling condition, n=S*(Ff*μheff * cot β + F) − 2	1.21	
12) ϕwh =tan−1 μh	0.37	Rad
13) For under discharge condition, F=Fe=(1+sinϕ i*cosε)/(1−sinϕr*cos(2 β))	1.87	
14) Max. Pnf= Ff * Pv	98.3	kN/m^2
16) Max. Pne = Fe * Pv	189.9	kN/m^2
17) Max. Pte = μh * Fe * Pv	72.8	kN/m^2

6. STRESS CALCULATION AND VERIFICATION

1) σa : Allowable Stress (0.66*Fy)
2) σΘ : −r / tm*Max.(Phf , Phe)
3) σz : −r / (2*tm) * {Max. Pvf , Pwf)+Pwe} − Ws / (2π * r * tm)+M/(π*r^2*tm)+(0.66*Fp)/(2π*r*tm)

4) σe : $(\sigma\Theta^2 + \sigma z^2 - \sigma\Theta * \sigma z)^{0.5}$, If $\sigma e < \sigma a$, then ---O.K
5) Ws : Weight of roof + Snow + Silo weight per each Height
6) M : Ws*z
7) Fp : Wind load+ Silo weight per each Height
8) σc : $-r / (2*tm) * \{Max.\ Pvf , Pwf)+Pwe\} - Ws / (2\pi * r * tm)+M/(\pi*r^2*tm)+(0.66*Fp)/(2\pi*r*tm)$
9) σcr : 135*Fy* tm / D, If $\sigma cr<0.8$ Fy then O.K for Result-1 and If, $\sigma c<\sigma cr$ then O.K for Results-2
10) tm : Corroded Condition

6-1. COMBINED TENSILE AND COMPRESSIVE STRESS

z	1.41	2.81	4.22	5.63	7.04	8.44	9.85	m
1) Phf	10.86	19.90	27.41	33.65	38.84	43.16	46.75	kN/m^2
2) Phe	12.49	22.88	31.52	38.70	44.67	49.64	53.76	kN/m^2
3) Pvf	17.23	32.39	45.73	57.46	67.78	76.85	84.84	kN/m^2
4) Pwf	7.28	12.41	16.03	18.58	20.38	21.66	22.55	kN/m^2
5) Pwe	8.00	13.65	17.63	20.44	22.42	23.82	24.81	kN/m^2
6) Ws	118	142	165	188	211	235	258	kN
7) M	166	398	696	1,059	1,487	1,981	2,540	kN-m
8) Fp	98	121	144	168	191	214	237	kN
9) tm	6	6	6	6	6	7	9	mm
10) σΘ	-7.9	-14.5	-20.0	-24.5	-28.3	-26.9	-22.7	Mpa
11) σz	1.3	2.2	3.4	4.9	6.6	7.3	7.1	Mpa
12) σe	8.6	15.7	21.9	27.3	32.1	31.2	27.0	Mpa
13) Result	O.K	O.K	O.K	O.K	O.K	O.K	O.K	
14) σc	1.3	2.2	3.4	4.9	6.6	7.3	7.1	Mpa
15) σcr	25.0	25.0	25.0	25.0	25.0	29.2	37.6	Mpa
16) 0.8*Fy	188.0	188.0	188.0	188.0	188.0	188.0	188.0	Mpa
σc<σcr then O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K	
σcr<0.8Fy then O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K	
tm1=(σc/σr) *tm+C.A	3.3	3.5	3.8	4.2	4.6	4.7	4.7	mm
tm2=(σ cr/0.8Fy) *tm+C.A	3.8	3.8	3.8	3.8	3.8	4.1	4.8	mm
tm=Max (tm1,tm2)	3.8	3.8	3.8	4.2	4.6	4.7	4.8	mm
Used THk	9.0	9.0	9.0	9.0	9.0	10.0	12.0	mm

6-2. STRESS ON THE HOPPER

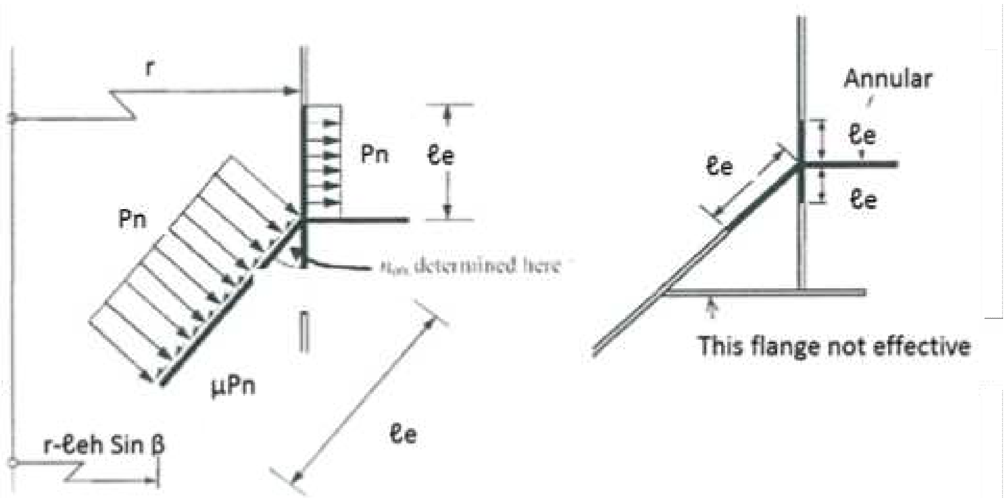
1) $\sigma\Theta = -r /(tm*\cos\beta)*Max.(Pnf , Pne)$
2) $\sigma z = -r / (2*tm*\cos\beta) * (Max.\ Pnf , Pne) * (r2/r)^2 - Ws / (2\pi * r * tm * \cos\beta)+M/(\pi*r^2*tm*\cos\beta)+(0.66*Fi)/(2\pi*r*tm*\cos\beta)$
3) $\sigma e = (\sigma\Theta^2 + \sigma z^2 - \sigma\Theta * \sigma z)^{0.5}$, If $\sigma e < 145$ Mpa, then ---O.K
4) Fi =Wind load+ hopper weight
5) tm : Corroded Condition

Pnf	Pne	Ws	M	Fi	tm	σΘ	σz	σe	Result
98.3	189.9	40.8	578.0	115.3	6	-38.4	-7.6	35.2	O.K

kN/m^2	kN/m^2	kN	kN-m	kN	mm	Mpa	Mpa	Mpa	

1) Ratio : σe/σa	0.23	2) Req. thk	4.4	mm
		3)Recommended THk	9	mm

6-3. TRANSITION JUNCTION AND SUPPORT RING



Pvft	ɣ	V2	Ws	teqA	teqB	μ	(teq) thinner	(teq) Thicker	
101.8	13.0	446.8	257.9	0.012	0.015	0.38	0.012	0.015	
kN/m^2	kN/m^2	m^3	kN	m	m		m	m	

α : The ratio of the thinner part to the thicker equivalent plate group'= (teq) thinner / (teq) thicker	0.8	
Pnc : Mean local pressure on the effective length of the cylinder segment'= Pnf for transition junction	98.3	kN/m^2
Pnh : Mean pressure on the effective length of the hopper segment'= Pne for transition junction	189.9	kN/m^2
ℓeh : Effective length of segment of the hopper segment'= 0.389 * {1+3α^2-2 α^3} * (r * t/cosβ)^0.5	0.077	m
ℓec : Effective length of segment of the cylinder above the transition'= 0.778 * (r * t/cosβ)^0.5	0.081	m
Aep : Effective cross-sectional area of the annular plate'= b * tp / (1+0.8*b/r)	0.003	m^2
nhed : Meridional tension per circumference at the top of the hopper'= {(Pvft * D/4) + (V2*ɣ+Ws) / (π*D)} / sinβ	895	kN/m
Effective Circumferential compressive force (N) = nhed * r * sinβ - Pnc * ℓec - pnh * (cosβ - μ * sinβ) * r * ℓeh	448.6	kN
Effective Area of the Annular plate ring (Aet) = ℓec * min (teqA, teqb) + ℓeh * max(teqA, teqB) + Aep	0.005	m^2
Stress σ = N/Aet	91.4	Mpa
If, σ is less than σa, then O.K	O.K	

7. ANCHOR BOLT AND SKIRT THICKNESS

7-1. ANCHOR BOLT

1) Bolt spacing	612.6	mm	3) Bolt root area	380.1	mm^2
2) Max. Induced load per bolt, P=Wo/NB	19,294	kgf	4) Required bolt Area, Ar = P/SBO	1,837	mm^2

7-2. BASE PLATE

1) Sectional Modulus, Z = π*(D2^4 - D1^4)/(32*D2)	6,944,187,6	mm^3	3) The greater of N1 or N2	250	mm
2) Section Area, A = π* (D2^2 - D1^2) / 4	3,652,098	mm^2	4) Mx. Bearing stress, Fc =(MB/Z) + (WB/A)	0.047	kgf/mm^2

			5) Required base plate thickness, T1 = N*(3*(FC/SB)^0.5	34.4	mm

7-3. COMPRESSION PLATE

1) Allowable bending stress, So	7.5	kgf/mm^2	2) Max. Bending Stress, MB	1,590	kgf-mm
			3) Tc = [6*(MB / So)^0.5]	35.7	mm

7-4. GUSSET PLATE

			1) 3/8 * Tc	13.4	mm

7-5. REQUIRED SKIRT TH'K REACTION OF CHAIRS

1) Max. Induced load per Bolt, P	19,293.5	kgf	4) Skirt mean radius	3,950	mm
2) Allowable bending stress, Fa	7.5	kgf/mm^2	5) Bolt Spacing, BS	613	mm
3) * M = BS/2	306	mm^2	6) Required skirt thickness, TS =0.2*(P*A/(M*H*FA)^(2/3) * Rm^(1/3)	10.8	mm
			7) Skirt thickness Check	O.K	

8. FABRICATION WEIGHT CALCULATION

1) Roof	27.9	kN	6) Skirt	28.7	kN
2) Body	173.2	kN	7) Comp. Plate	7.5	kN
3) Hopper	40.8	kN	8) Base Plate	10.6	kN
4) Rafter	11.0	kN	9) Gusset Plate	3.0	kN
5) Shell stiffener	8.0	kN	10) Anchor Bolt	1.6	kN
			TOTAL WEIGHT(FAB)	312.2	kN

9. LOADING DATA SUMMARY

9-1.Dead Weight Summary

1) Empty Weight	339	kN	3) Bulk Load	7,099	kN
2) Snow Load	67	kN	4) Bag Filter	30	kN
CENTER OF GRAVITY	9.2	m	5) Total Dead Load	7,535	kN

9-2.Loading Data

DEAD LOAD		7,535	kN	LIVE LOAD		1,062	kN
HOR(Fx)	HOR(Fy)	VERT(Fz)		HOR(Fx)	HOR(Fy)	VERT(Fz)	
0	0	942		0	0	133	
WIND LOAD		75	kN	SEISMIC LOAD		1,693	kN
HOR(Fx)	HOR(Fy)	VERT(Fz)		HOR(Fx)	HOR(Fy)	VERT(Fz)	
9	9	37	kN	212	212	423	kN

9-3. Over Turning Moment

1) EMPTY + WIND	3,806	kN-m	2) OPERATING + SEISMIC	84,944	kN-m

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