Study on Pre-stressed Concrete Grain Silo Based on Non- cohesive Properties

Hairong Huang
Civil and Architectural Engineering
Wuhan University of Technology, WuHan, China
e-mail: 282437249qq.com

Runrun Dong
Civil and Architectural Engineering,
Henan University of Technology, Zhengzhou, China
e-mail:1158049082@qq.com

Abstract—For the design of grain silo, the amount of steel bar used in structure will be very large. And with the height and diameter of bulkhead increasing, there will be a serious problem that the requirement of crack will not meet the demand according to the code even though using much more steel bar. Using totally prestressed structure or partially structure, this problem can be solved. The design and construction for one partially prestressed structure case is presented in this paper.

Keywords-non-cohesive prestress; grain silo; case analysis

I. INTRODUCTION

With the development of the theory and technology of prestressed concrete structure, free of all kinds of bonded prestressed complete technology is applied in bridge and industrial architecture. In recent years, the unbonded prestressed technology is also applied in cabin structures (such as coal bunker, cement silo) and pool structures (such as a liquid storage tank, a sewage treatment pool), silo construction diameter is from 10 meters to 20 meters, or 30 meters- 40 meters, which shows that the diameter and height of domestic and foreign cylindrical silos is growing, using reinforced concrete silo unbonded prestressed technology, which makes full use of the compressive strength of concrete and high-strength steel wire, steel strand tensile strength high characteristics, applying prestress to the silo wall can prevent the silo wall cracking, reduce wall thickness and save the purpose of concrete. Internal force calculation is main links of circular silo design. Because tube wall thickness and diameter of the silo is much smaller compared to the present, the calculation of internal force of silo usually adopts the housing unit to calculate the film internal force, if it is designed into a housing unit cylinder wall, cylinder wall of the prestress reinforced cannot reflect. In this article, finite element method is used to design the bin body become entity, internal non real constant processing method of ratio of reinforcement by prestressed reinforcement.

A double-conjuncted concrete grain silo is planned to be constructed in one port. The silo needs to meet the air tightness requirement of fumigation for desinsection. The section is shown in Picture 1. The design height of grain loading the structure is 30 m, the outside diameter is 10.4 m and the inside diameter is 10 m. The concrete grade is C30. The crack control level is II, so that the silo must be a pre-stressed structure. And in this case non-cohesive prestress technology is adopted.

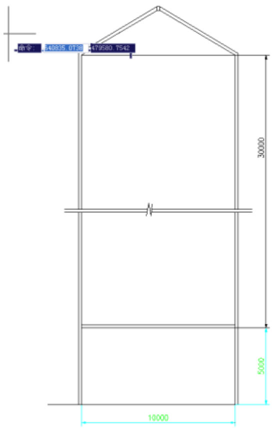

Figure 1. Silo structure cross-sectional schematic

II. TECHNICAL SOLUTIONS

In this project, the use of reinforced concrete silos, since the diameter, height are larger, the design requirements are not cracks, which needs to increase a lot of steel and increase the thickness of the wall of the warehouse.

III. DESIGN PRINCIPLE

As mentioned above, the crack control level is II grade. This means the tension stress must meet two index: 1. under long- term load effect combination there should be no tension stress in the concrete; 2. under short- term load effect combination the tension stress level should not exceed 0.3fte. (Note: in the calculation of loading under long-term load effect combination, the index of load quasi-permanent value, Wq is 0.8). In the non-cohesive prestressed concrete grain silo, the ratio of reinforcement in the circle direction should not be lower than 0.4%, and the diameter of the steel bar is better not bigger than 18 mm., the space between steel bars is better not bigger than 200 mm and at the same time not smaller than 70 mm. For the vertical steel bar, the ration of reinforcement should not be smaller than 0.4% and the diameter of the steel bar should not smaller that 10 mm. And it should not be less than 3 steel bars per meter. The steel bars in both circle and vertical direction should be placed in double sides. For the bulkhead, the tension zone of concrete is allowed to have crack under serviceability limit state analysis in two cases: one is long- term load effect combination another is short-term load effect combination, and the maximum crack should be meet the demand according to the code.

IV. DESIGN CONDITIONS

Wheat density:γ= 8 kN /m3; internal frictional angle: φ=25 ; friction coefficient between wheat and concrete:μ= 0. 4; the grade of concrete: C 30 and the tensile strength of standard value: f tk = 2. 01 N /mm2; steel bar(I) design strength: fy = 210 N /mm2; Prestressed steel strand: stander value of tension strength: fpk = 1860 N /mm2 ,tension strength design value: fpy = 1320 N /mm2; the area of section: Ap =139. 98 mm2; elastic modulus: Ep = 1. 95*105 N /mm2 ; the thickness of the concrete cover; the diameter of steel bar is 25 mm; anchorage system: Porous anchorage OVM15- 71. The prestressed steel strands are stretched at both ends. The circle prestressed strand in every section that should be analized is shown in the picture 2.

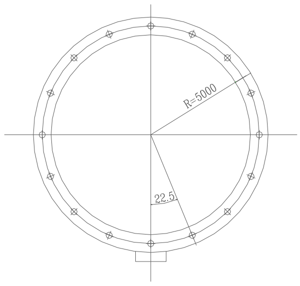

Figure 2. cylinder wall prestressing tendons ring plane indicate the calculated point

V. SILO DESIGN

A. Internal Force Calculation

According to "reinforced concrete silo design specifications" GB50077-2003 [1] calculates for each cross-section rings silo Rally standard values as shown in Table 1.

S— Storage material cone section at the center of gravity to the distance calculation;

e—Natural logarithm of the bottom;

μ—friction coefficient;

k—Lateral pressure coefficient;

$k = tg^2\left(45^0 - \phi/2\right)$;

ρ—Hydraulic radius horizontal silos net section;

C_h — Storage material level pressure correction factor;

P_h—Storage material effect on the level of pressure standard value per unit area of the warehouse wall。

Warehouse wall circumferential and vertical non-prestressed reinforcement using 2φ12 @ 200 spreadsheet.

TANLE I. SILOSRALLY STANDARD VALUE FOR EACH CROSS-SECTION TINGS

S(m)	$1-e^{-\mu ks/\rho}$	C_h	P_h (kN/m^2)	N_{pk} (kN/m)	A_s (mm^2/m)
5	0.399	1.65	32.9	164.7	1130
10	0.639	2.2	70.3	351.5	1130
15	0.783	2.2	86.1	430.8	1130
20	0.870	2.2	95.67	478.4	1130
25	0.921	2.2	101	507	1130
30	0.953	2.2	104.9	524	1130

B. Prestressing strand tension control stress

$$\sigma_{con} = 0.7 f_{pk} = 0.7 \times 1860 = 1302\left(N/mm^2\right)$$

C. The prestressing loss

(1) Deformation and loss within unbonded prestressed tension caused by muscle contraction end anchorage

$$\sigma_{l1} = \frac{a}{l} E_p$$

Among them: α—Tension end anchorage within the deformation and unbonded prestressing tendons shrink value, $\alpha = 5mm$;

$l = \pi d/2 = 3.14 \times 10.2/2 = 16.01(m)$;

$$\sigma_{l1} = \frac{\alpha}{l} E_p = \frac{5}{16010} \times 1.95 \times 10^5 = 60.56 N/mm^2$$

(2)Friction loss unbonded tendons and wall caused

$$\sigma_{l2} = \sigma_{con}(1 - 1/e^{kx+\mu\theta})$$

k — Unbonded tendons wall partial deviation influence coefficient of friction, k=0.004;

x—From the tension side to calculate the length of the section of the curve,

$$x = \pi \frac{d}{2} = 3.14 \times \frac{10.4}{2} = 16.014(m);$$

μ—Unbonded tendons friction coefficient between the wall, $\mu = 0.09$;

θ—The sum of the tension from the end part of the curve to calculate the cross section of the tangent angle (rad) of, $\theta = \pi = 3.14$;

$$kx + \mu\theta = 0.004 \times 16.014 + 0.09 \times 3.14 = 0.3466$$

$$\sigma_{l2} = \sigma_{con}\left(1 - 1/e^{kx+\mu\theta}\right) = 1302 \times \left(1 - 1/e0.3466\right) = 381.36\left(N/mm^2\right)$$

(3)Loss of unbonded tendons caused by stress relaxation

$$\sigma_{l4} = 0.2\left(\sigma_{con}/f_{pk} - 0.575\right)\sigma_{con} = 0.2 \times \left(\frac{1029}{1470} - 0.575\right) \times 1302 = 32.55\left(N/mm^2\right)$$

(4)Concrete shrinkage, creep damage caused by change σ_{l5} (The section is shown in the table 2.

$$\sigma_{l5} = (35 + 280\sigma_{pc} / f'_{cu})/(1+15\rho);$$

Among them: σ_{pc} —Tensioning force area unbonded tendons at the point of law to the stress of concrete, prestressed loss values considering only the first loss of preload ago; σ_{pc} had more than $0.5f'_{cu}$,

$$\sigma_{pc} = (\sigma_{con} - \sigma_{l1} - \sigma_{l2})A_p /(A_c + \alpha_{ES}A_S)$$

f'_{cu} —Prestressed concrete cube compressive strength when, to take concrete design strength rating of 75%, $f'_{cu} = 0.75 \times 30 = 22.5(N/mm^2)$;

ρ —For reinforcement ratio, the ratio of the tension zone by unbonded tendons and non-sectional area of the tendons and the components of net cross-sectional area.

D. The total loss of prestress

As the middle section of the tension ring is the end of each adjacent ring, so the loss of value of the two averages.

$$\sigma_{l\text{I}} = \sigma_{l1} + \sigma_{l2}$$

$$\sigma_{l\Pi} = \sigma_{l4} + \sigma_{l5}$$

$$\sigma_l = \sigma_{l\text{I}} + \sigma_{l\Pi}$$

E. Crack calculation

(1) When calculating according to the standard combination of load effects, allow concrete tensile stress, but not to exceed the tensile stress0.3 f_{tk} .

$$\sigma_{sc} - \sigma_{pc\Pi} \le 0.3 f_{tk}$$

Among them: $\sigma_{sc} = N_{pk} / A_0$

$$A_0 = A_c + \alpha_{ES}A_S + \alpha_{EP}A_P$$

$$\alpha_{ES} = E_S / E_C = 2.1 \times 10^5 / 3.00 \times 10^4 = 7$$

$$\alpha_{EP} = E_P / E_C = 1.95 \times 10^5 / 3.00 \times 10^4 = 6.5$$

$$\sigma_{PC\Pi} = [(\sigma_{CON} - \sigma_l)A_P - \sigma_{l5}A_s]/(A_C + \alpha_E A_S)$$

$$0.3 f_{tk} = 0.603 N/mm^2$$

(2) When you press a combination of long-term effects load calculations, concrete tensile stress does not appear, $\sigma_k - \sigma_{pc} \le 0$

Among them: $\sigma_k = N_1 / A_0$

F. Use phase capacity calculation

The section is shown in the table 2.

$$\gamma_Q N_p \le f_y A_s + f_{yp} A_p$$

VI. CONSTRUCTION INTRODUCTION

List and number all bibliographical references in 9-

The project tensioning the tendons using two jacks are tensioned up from both ends at the same time stretching tension using YKC240 feedthrough jack. Jack and the fuel gauge supporting calibration, calibration status and working conditions of their agreement.

Set in the silo wall stud tensioning only one strand bundles as Zhang refuse anchor seat, per lap for a prestressing strand bundle, wrap angle 360 degree, the two ends of the same strand bundle while tensioning ring. When using spacer tension tension, tension that start with the bottom up, from the top down tension. All post-tensioning tendons in the end, are quickly cut off the excess strand, and micro-expansion with C40 fine aggregate concrete block hole, and the surface compaction, trowel.

Tension Control with stress, supplemented elongation value check. Theoretical elongation values are calculated by the following formula can stretch tendons value of each curve segment stack.

$$\Delta L_p = F_{px}L_p / A_{px}E_p = 187.75 \times 10^3 \times 32020 / 140 \times 1.95 \times 10^{-5} = 220.21mm;$$

Among them: The average pull-tensioned tendons, the length of the Prestressed reinforcement mm Tendon area, mm, Modulus of elasticity of Prestressed reinforcement, N/mm. Tensioning tendons difference measured and calculated elongation values should be within the range.

TABLE II. CALCULATED SILO

Computing content	Section S=30m	Section S=25m	Section S=20m	Section S=15m	Section S=10m	Section S=5m
A (mm^2)	200000	200000	200000	200000	200000	200000
Central to the non-prestressed reinforcement	2 Φ 12@200	2 Φ 12@200	2 Φ 12@200	2 Φ 12@200	2 Φ 12@200	2 Φ 12@200
A_s (mm^2)	1130	1130	1130	1130	1130	1130
Prestressed reinforcement	1 Φ^{j}15@200	1 Φ^{j}15@200	1 Φ^{j}15@200	1 Φ^{j}15@200	1 Φ^{j}15@400	1 Φ^{j}15@400
A_p (mm^2)	695	695	695	695	347	347

$A_c=A-A_s-A_p$（mm^2）	198175	198175	198175	198175	198523	198523
$A_n=A_c+\alpha_{Es}A_s$（mm^2）	206085	206085	206085	206085	206433	206433
$A_0=A_c+\alpha_{Es}A_s+\alpha_{Ep}A_p(mm^2)$	210602.5	210602.5	210602.5	210602.5	208688.5	208688.5
$N_{PC\,I}=[\sigma_{con}-(\sigma_{11}+\sigma_{12})]A_p$	597769.5	597769.5	597769.5	597769.5	298454.7	298454.7
$\sigma_{pcI}=N_{pcI}/A_n$	2.9	2.9	2.9	2.9	1.45	1.45
$0.5f_{cu}^{'}$	15	15	15	15	15	15
$\sigma_{pc1}\le 0.5f_{cu}^{'}$	ok	ok	ok	ok	ok	ok
$\rho=(A_s+A_p)/A_n$	0.008856	0.008856	0.008856	0.008856	0.007155	0.007155
$\sigma_{l5}=(35+280\sigma_{pcI}/f_{cu}^{'})/(1+15\rho)$	62.75972	62.75972	62.75972	62.75972	47.85578	47.85578
$\sigma_{lI}=\sigma_{l1}+\sigma_{l2}$	441.92	441.92	441.92	441.92	441.92	441.92
$\sigma_{l\Pi}=\sigma_{l4}+\sigma_{l5}$	95.31	95.31	95.31	95.31	80.41	80.41
$\sigma_l=\sigma_{l1}+\sigma_{l\Pi}$	537.23	537.23	537.23	537.23	522.33	522.33
N_{pk}	524	507	478.4	430.8	351.5	164.7
$\sigma_{sc}=N_{pk}\times 10^3/A_0$	2.4881	2.407379	2.271578	2.04556	1.684329	0.789215
$N_{pc\Pi}=(\sigma_{con}-\sigma_l)A_p-\sigma_{l5}A_s$	460596.9	460596.9	460596.9	460596.9	216469.9	216469.9
$\sigma_{pc\Pi}=N_{PC\Pi}/A_n$	2.234985	2.234985	2.234985	2.234985	1.048621	1.048621
$\sigma_{sc}-\sigma_{pc\Pi}$	0.253115	0.172394	0.036593	-0.18943	0.635708	-0.25941
$0.3f_{tk}$	0.603	0.603	0.603	0.603	0.603	0.603
$\sigma_{sc}-\sigma_{pc\Pi}\le 0.3f_{tk}$	ok	ok	ok	ok	ok	ok
$\sigma_k=0.8N_{pk}\times 10^3/A_0$	1.99048	1.925903	1.817262	1.636448	1.347463	0.631372
$\sigma_k-\sigma_{pc\Pi}$	-0.24451	-0.30908	-0.41772	-0.59854	0.298842	-0.41725
$\sigma_k-\sigma_{pc\Pi}\le 0$	ok	ok	ok	ok	ok	ok
$\gamma_Q N_{pk}(kN/m)$	681.2	659.1	621.92	560.04	456.95	214.11
$f_yA_s+f_{yp}A_p(kN/m)$	1154.7	1154.7	1154.7	1154.7	695.34	695.34
$\gamma_Q N_{pk}\le f_yA_s+f_{yp}A_p$	ok	ok	ok	ok	ok	ok

VII. CONCLUSIONS

Conclusion as a result, from analysis for one grain silo, it can be seen that the inside diameter is 10m and the height of grain loading is 30m, the amount of steel bar is decreased and the ability of crack resistance is also improved by using prestressed strand in the bulkhead. For the larger grain silo, the economic and social benefits will be improved insignificantly. The result of analysis for this case is sure to be as a reference for the design of similar grain silo.

REFERENCES

[1] People's Republic of China National Standard. Reinforced Concrete Design Specification （GB50077-2003） Beijing: China Building Industry Press，2003

[2] People's Republic of China national standards. Unbonded prestressed concrete structures technology（J409-2005.Beijing: China Building Industry Press，2005

[3] People's Republic of China national standard concrete structural design. Beijing: China Building Industry Press，2002

[4] Hao Ruqing.Large diameter silos unbonded prestressed concrete structure application. Cement Guide.2003 Phase III

[5] CHEN zengjing, Larry Epstein. Ambiguity, Risk, and Asset Returns in continuous Time[J]. Econometrica, 2002, vol. 70(2): 1403-1443.

[6] Irwin, T. Public money for private infrastructure: deciding when to offer guarantees, output-based subsidies and other fiscal support[R]. Washington, D.C.: World Bank. World Bank Working Paper No.10, 2003

[7] Irwin T, Klein M, Perry G E, et al. Managing government exposure to private infrastructure risks [J]. World Bank Research Observer, 1999, vol. 14 (2): 229-241

[8] L lantoG.. Managing government guarantees and contingent liabilities [J]. Philippine Institute for Development Studies, 2000(17): 1-10

[9] Lehman G Tregoning I. Public- Private Partnerships Taxation and a Civil Society [J]. Journal of Corporate Citizenship, 2004 (15): 77- 89

[10] Hansen L P, Sargent T J. Robust control and model uncertainty [J]. American Economic Review, 2001(91): 60-66.