Demolition technique of high thin-wall hyperbolic reinforced concrete cool tower by directional controlled blasting

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Abstract: Based on blasting demolition of high thin-wall hyperbolic reinforced concrete cool tower, by virtue of engineering practice of blasting the tube concrete structures, the analysis and research were made on the mechanism of cool tower collapse through selecting blasting parameters and selecting gap form, gap size and gap angle. The cool tower was twisted, collapsed directionally and broken well according to the design requirements. The expected results and purposes of blasting were obtained with no back blow, total blasted pile approximates to 4 ~ 5 m, no occurrence of flying stones and no damage to fixed buildings and equipment, the large-sized hyperbolic thin-wall reinforced concrete cool towers are twisted during blasting and it collapses well with good breaking. The test and measurement of blasting vibrating velocity was carried out during blasting and the measuring results are much less than critical values specified by *Safety Regulations for Blasting*. The study shows that gap form, gap size and gap angle are the key factors to cool tower collapse and will give beneficial references to related theoretical study and field application.

Key words: cool tower; blasting demolition; directional blasting; gap

1 General situation

In order to rebuild and reconstruct the power plant, a thin-wall hyperbolic reinforced concrete cool tower, which is situated at plant district and 84.8 m in height, must be demolished by blasting. In the north of the cool tower, a ditch lies 46 m away and a substation capacity lies 90 m away. There are office buildings and garages in the south of the cool tower and the distance is 32 m. The dormitory area is 95 m in the east of the cool tower and Badu River is 103 m away from the cool tower in the same direction. In the southwest direction of the tower, a repair shop lies 33 m away. In the surrounding region of the tower, there are no buried pipelines and no overhead power cables. Surrounding conditions of blasting area are shown in Fig. 1.

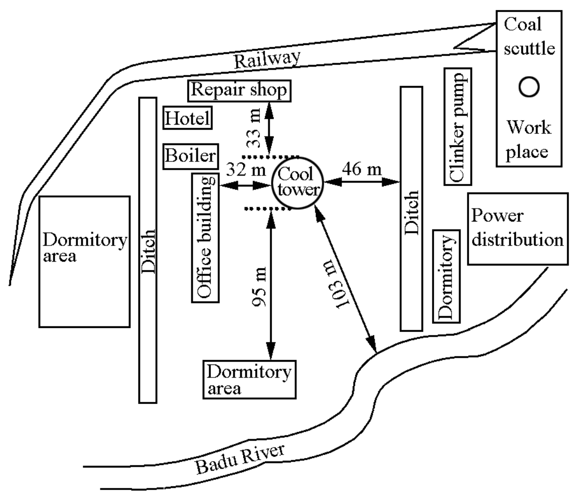

Fig. 1 Surrounding conditions of blasting area

The cool tower is a reinforced concrete structure and the concrete grade is C_{30}, the cumulative volume of ground reinforced concrete is about 1 954 m^3 and the weight is 4 885 t according to related calculation.

The base diameter of the cool tower is 68.56 m and the top diameter is 38.50 m, the throat diameter is 35.8 m (in the level of +67.8 m). From tower's bottom to its top, the wall thickness varies from 0.50 m to 0.16 m. The groundwork of the cool tower is annular. There are 40 pairs of Λ-shaped pillars, which are constructed with C_{30} reinforced concrete and uniformly distributed on the groundwork. The vertical and gradient heights of Λ-shaped pillar are 5.6 m and 5.92 m, the area of its cross-section is 0.40 m × 0.40 m. In each pillar, there are 10 main manganese steel bars and the diameter is 28 mm. The diameter of all hoop steels is 10 mm and the spacing is 200 mm, but in the range of 1.0 m, i.e. from the top (bottom) of pillars to its middle part, the spacing is 100 mm. Ring beam of Λ-shaped pillars is in the level of +5.6 m, its gradient length is 2.0 m. From 1.3 m on the left of

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hinged ends of ∧ -shaped pillar to 1.3 m on its right, the ratio of reinforcement is high. Inside the tower, there is an 8.85 meter-high drip water platform, which is constructed with reinforced concrete and there are no coupling structure between platform and tower wall. There are 130 vertical props under the drip water platform.

In this demolition blasting, the volumes of reinforced concrete, plain concrete and broken stone are respectively 3 630 m^3, 964.4 m^3 and 7 339 m^3 by analysis and calculation.

2 Scheme of demolition blasting

The cool tower is a high thin-wall hyperbolic reinforced concrete structure and the upper part is narrow and the lower part is wide, so there are many difficulties in blasting demolition. Therefore, the following gists[1-3] must be attached primary importance to the blasting scheme:

1) The base diameter of the cool tower is too large, so it may be destabilized after blasting but does not collapse, or it collapses directionally but does not break well so the blasting piles is too high to dispose quickly and conveniently.

2) The cool tower is a thin-wall structure, it is difficult to drilling and charging and stemming holes become more difficult accordingly, at the same time, the flying stones make protection work more complex.

3) Drilling is excessive, which leads to the fact that the blasting circuit is very complex, so the reliable blasting technique, i. e. non-electric millisecond short delay blasting is adopted generally.

4) Besides the effect of blasting vibration, the ground vibration cannot be neglected.

In general, the scheme of blasting towers borrows ideas from ways and means of blasting tube concrete structures. In order to make the cool tower collapse directionally and break well according to the design requirements, and decrease the secondary disaggregation accordingly, the destroying height must be enough[1,2].

According to the circumjacent environment of the cool tower and its structure, the cool tower collapses eastward in this blasting scheme. Orientation opening should be cut exactly according to the blasting design. In the scope of trapezoidal gap, some plates of tower wall should be predisposed and the other should be preserved to underprop the blasting plates before blasting so that the cool tower collapse directionally after blasting. The drip water platform and vertical props under the platform should be disposed by machinery.

3 Technical design of demolition blasting

3.1 Weight of the cool tower and height of gravitational center

According to the engineering data provided by owner and the results of calculation, the weight of reinforced concrete is 4 885 t; the weight of ∧ -shaped reinforced concrete pillars is 195.84 t and weight of hand ladder of cool tower is 5 929.41 kg; so the total weight of cool tower is 5 086.77 t.

The height of gravitational center of the cool tower, H_0, can be calculated by the following Eq.(1):

$$H_0 = \sum_{i=1}^{n} G_i h_i \Big/ \sum_{i=1}^{n} G_i \tag{1}$$

Where, G_i is weight of part i and h_i is the height of gravitational center of part i.

The height of gravitational center $H_0 = 32.3$ m, is determined by calculation according to Eq.(1).

3.2 Design of blasting gap

From the point of view of blasting engineering practice, gap form, gap size and its position are very important to the tower's directional collapse according to the design requirements, in order to obtain the expected results, the following points must be attached importance to blasting design.

The cool tower should collapse directionally and successfully according to the design requirements under the overturning moment formed by gravity force. Demolition and blasting plates' numbers should be optimized sufficiently, only in this way can the expected blasting results be obtained and blasting workload be reduced obviously, and can the cool tower collapse directionally with good breaking and low blasting piles, at the same time, only in this way can the side-effect of blasting be availably controlled and engineering safety be assured[1-3].

Because the blasting method is economical, convenient and can save time for a project, several cool towers were demolished by blasting and more and more importance is attached to the method. At the present time, normal-trapezium gap, inverted-trapezium gap and complex gap are the three main gaps in demolishing cool towers by blasting. According to amply analyzing the cool tower to be demolished, normal-trapezium gap is adopted and the destroying height is determined to be 13.30 m after borrowing ideas from numerous engineering projects[1-4]. In general, the central angle of blasting part is 210° ~ 225° After analyzing and contrasting across-the-board, the related parameters in the scheme are as follows according to engineering practice of blasting the tube concrete structures[3], the central angle is determined to choose 216°. The perimeter of cool tower in the level of +11.8 m is 186.26 m, arc length of upper edge (in the level of 11.8 m) of blasting gap is 117.5 m and the arc length of preserved plates, which sustain the blasting plates, is 68.76 m. There are 40 pairs of Λ-shaped reinforced concrete pillars, so 24 pairs of Λ-shaped pillars should be blasted away according to the designed central angle (216°).

3.3 Pretreatment and distribution of blasting gap

In order to decrease drilling workload and control charges detonated one time, blasting areas are distributed in the boundary of trapezoidal blasting gap according to the structure characteristics of hyperbolic cool tower. By this way, the cool tower can be directionally collapsed without large-area blasting in the tower wall in trapezoidal gap. Blasting gap and pretreatment parts are shown in Fig. 2. Work should be done before blasting is as follows:

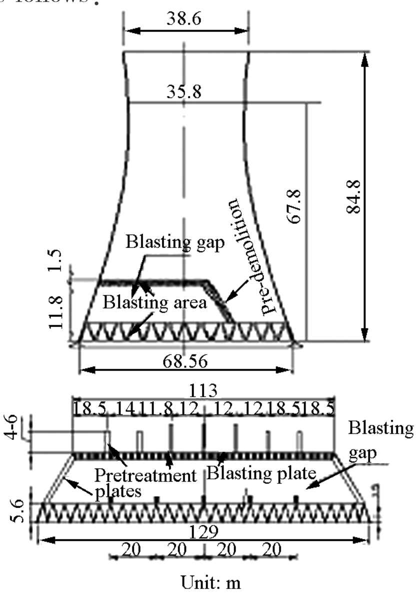

Fig. 2 Schematic plan of blasting notch

1) In the range of 1.5 m outward sloped edges of gap, concrete should be disposed by blasting or hand hammer pick;

2) Construction bench should be built to the level of +11.8 m, and the pretreatment plates and blasting plates are distributed intervallicly and circumferentially along tower wall between the level of +11.8 m and +13.30 m, the width and height of pretreatment plates are all 1.5 m and the same as blasting plates.

3) The destroying height of Λ-shaped pillars in groundwork is 2.1 m.

4) In order to better the breaking effect, 11 joint-cuttings are cut above the level of +13.3 m in the collapse direction and the joint-cutting is 1.0 m in length and 9 m in height.

5) The height and thickness of ring beam (in the level of +5.6 m) of Λ-shaped pillars are 2.0 m and 0.5 m, respectively. In order to obtain the expected blasting effect, ring beam in blasting gap should be destroyed, so 7 blasting areas, which are all 1.5 m in length and 2.3 m in height, are distributed at intervals of 15 m according to the scheme.

3.4 Parameters of boreholes and its distribution

In order to obtain reliable blasting parameters, experimental blasting must be carried out in tower wall and blasting areas of ring beam.

The distribution of reinforcing bars and the average thickness of tower wall in blasting plates (25 cm) should be considered thoroughly before determining blasting parameters. After pretreatment, 39 blasting plates (1.5 m × 1.5 m) were distributed in blasting area of tower wall, there are 5 × 7 = 35 boreholes in every blasting plate. In 40 pairs of Λ-shaped reinforced concrete pillars around the cool tower, 24 pairs of Λ-shaped pillars should be blasted away according to the designed central angle (216°). In blasting scheme, the destroyed height of Λ-shaped pillar is 2.1 m and 7 boreholes distributed in a single-row in one pillar. As for the 7 blasting areas of ring beam, there are 6 × 8 boreholes in every blasting area. The blasting parameters are shown in Table 1.

Table 1 Blasting parameters

Item	Borehole parameter /mm					Explosive consumption /g		
	Diameter	Colum spacing	Row spacing	Charging length	Stemming length	Specific/(g· m^{-3})	In one hole	Sum
Tower-wall	36	250	250	160	1/3 of hole length	2 560	40	54 600
Pillar	40	300	/	250		1 500	75	25 200
Ring-beam	40	300	300	300		1 560	75	25 200

3.5 Blasting of annular groundwork of the cool tower

After the cool tower collapses, annular groundwork of the cool tower should be demolished by loose blasting in order to quicken demolition and cleaning up of groundwork. The cross section of annular groundwork is ⊥-shaped, as shown in Fig. 3.

The annular groundwork in the level of ±0.0 ~

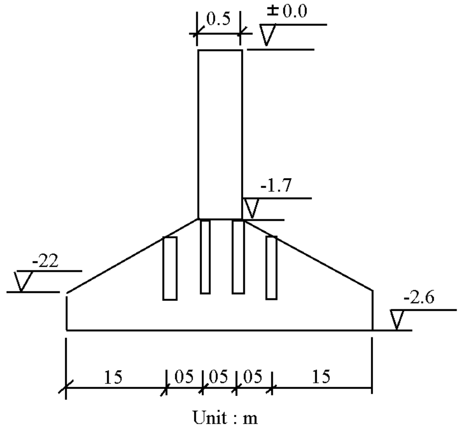

Fig. 3 Sectional schematic plan of cyclic basis

−1.7 m is disposed by machinery because it is thin, the thickness of groundwork under the level of −1.7 m is 0.4 ~ 0.9 m, so it is demolished firstly by loose blasting and then by machinery. In this blasting region, the blasting parameters are as follows: column spacing and row spacing are all 50 cm, boreholes' depth is 60 cm or 70 cm and explosive loaded in one borehole is 150 g.

3.6 Blasting circuit

Workload of drilling holes is excessive, which leads to the fact that the blasting circuit is very complex, so the reliable blasting technique, i.e. the non-electric millisecond short delay blasting is adopted generally.

For the sake of engineering safety, the non-electric millisecond short delay blasting is adopted in the blasting scheme. The delay periods are as follows: the blasting delay period of the blasted plates of tower wall in the level of +11.8 ~ +13.3 m is 200 ms, and the blasting delay period in other blasted area is 600 ms. The whole blasting circuit is connected with bunch connectors. The number of shock-conducting tube in every bunch connector is less than 20, all bunch connectors are connected with shock-conducting tube and four-passage connectors and then form complex and closed cross network. The blasting circuit is initiated by electric detonators, as shown in Fig.4.

In this blasting, the exhausted explosive device are as follows: 300 detonators of 2 ms delay periods with shock-conducting tube, 5 000 detonators of 7 ms delay periods with shock-conducting tube, 1 000 detonators of 12 ms delay periods with shock-conducting tube, 500 instantaneous electric detonators, 5 000 m shock-conducting tube and 300 kg emulsion explosive.

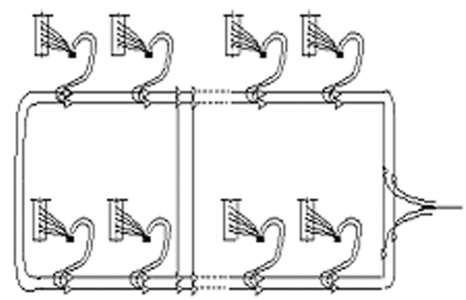

Fig. 4 Schematic plan of blasting circuit

4 Collapse condition and checking calculation

4.1 Eccentric distance in cross section of tower wall

The outer radius (R) and perimeter of cool tower in blasted area are 30.34 m and 186.3 m, respectively. The arc length of blasting gap is 117.5 m, the arc length of preserved plates is 68.76 m and the central angle in preserved area is $\beta_0 = 144°$. The inner radius (r) and wall thickness (δ) are 30.07 m and 0.27 m. On the basis of material mechanics, the centroidal position in cross section of tower wall, i.e. eccentric distance is calculated by the following express[4]:

$$e = \int_A x\mathrm{d}A/A = 2\int_{R-\delta}^{R}\int_{0}^{\beta_0/2} r^2\cos\theta\mathrm{d}r\mathrm{d}\theta =$$

$$\frac{4[R^3 - (R-\delta)^3]\sin(\frac{\beta_0}{2})}{3\beta_0[R^2 - (R-\delta)^2]} = 22.835\ \mathrm{m} \qquad (2)$$

Where, e is the eccentric distance; A is the area of tower wall in preserved part, $A = 25.768\ \mathrm{m}^2$; x is the symmetry axis of preserved area in cross section. r and θ are variables in axis coordinate system.

4.2 Overturning moment

The instant the explosives in boreholes are initiated, the cool tower begins to overturn. At the moment, overturning moment (M) equals gravity force (mg) times the eccentric distance (e):

$$M = mge = 1\,094.5\ \mathrm{MN\cdot m} \qquad (3)$$

Where, m is the mass of cool tower above the blasting gap, $m \approx 4\,890.93$ kg; g is the acceleration due to gravity.

4.3 Critical moment of flexion

According to theories of material mechanics, stress (σ) of cross section under load can be expressed[5]:

$$\sigma = \frac{Mx}{I} - \frac{mg}{A} \qquad (4)$$

$$I = R\delta[e^2\beta_0 - 4Re\sin(\beta_0/2) + R^2\sin(\beta_0)/2 + R^2\beta_0/2] \quad (5)$$

Where, x is the distance between the centroidal position and neutral axis, $x = 30.34 - 22.835 = 7.51$ m; I is the inertia moment of center of form in the cross section on principal axis, $I = 1\,053.72$ m^4.

Tension stress in edge of tensile region ($x = R - e$) will be greater than tensile strength of concrete if the overturning moment (M) is enough, so the concrete will be damaged and destroyed. Afterwards, the tension stress in original concrete will be diverted to the reinforcement bars in that region. According to equivalent theory, the tension stress in the reinforcement bars of that region can be calculated by the following equation.

$$\sigma_t = \frac{f_\mu}{\mu} = \frac{1.6}{0.005} = 320 \text{ MPa} \quad (6)$$

Where, σ_t is the tension stress in the reinforcement bars when the concrete is damaged; μ is ratio of reinforcement, $\mu = 0.5\ \%$; f_μ is the tensile strength of concrete, $f_\mu = 1.6$ MPa.

If the tension stress (σ_t) is greater than the yield strength of reinforcement bars ($f_y = 235$ MPa), the reinforcement bars in tensile region will be destroyed gradually, and become hinged supports finally. Critical moment of flexion (M_c) is calculated by the expression:

$$M_c = \frac{I(mg/A + f_c)}{R - e} = 538.46 \text{ MN}\cdot\text{m} \quad (7)$$

Where, f_c is the bigger of f_μ and $\mu \cdot f_y$, $f_c = 1.6$ MPa.

In sum, the ratio of overturning moment (M) to critical moment of flexion (M_c) is $M/M_c = 1\,094.5/538.46 = 2.03$. Obviously, the cool tower can be collapsed directionally by blasting.

5 Blasting vibration

In order to protect major buildings and structures effectively, blasting vibration must be controlled under related critical values specified by *Safety Regulations for Blasting* (GB6722-2003). So test and measurement must be carried out during blasting. On the basis of *Safety Regulations for Blasting*, some related constants are determined according to blasting engineering practice[1-4] and field test before blasting. In this blasting, maximum charge weight per delay interval for the protected objects at different distance is 61.2 kg. The main structures to be protected are office buildings and substation capacity. When the distance is 32 m, which is the distance between cool tower and office building, the blasting vibrating velocity by computing is 2.4 cm/s (the specified critical value is 3.0 ~ 4.0 cm/s) ; when the distance is 150 m, which is distance between cool tower and substation capacity, the blasting vibrating velocity by computing is 0.45 cm/s (the specified critical value is 0.5 cm/s), which are both less than the related critical values specified by *Safety Regulations for Blasting* in the circumjacent environment of the cool tower and surrounding buildings and structures. Obviously, the blasting cannot damage the surrounding buildings and structures need to be protected according to the computing results. In the measuring scheme, two measurement stations are installed before blasting, one (station 1) is installed in office buildings, which is in the south of the cool tower and the distance between them is 32 m; the other (station 2) is installed in the substation capacity which lies 150 m in the north of the cool tower. The blasting vibrating velocity measured in station 1 is 1.9 cm/s; in station 2, the blasting vibrating velocity measured is 0.149 cm/s. The differences between computing and measuring values are great; the reason may be lie in the related constants which are chosen in computing. The measuring values are much less than that of specified values, which shows the designed blasting scheme is feasible.

6 Primary safety measures

The primary safety measures adopted in this blasting are as follows:

1) The blasting and charging parameters should be designed firstly according to cool tower's structure, ratio of reinforcement and its strength, and then be determined by test and engineering practice.

2) The cool tower is a thin-wall structure and the blasted region is large and workload of drilling boreholes are excessive, so their positions and lengths must be strictly controlled.

3) The blasted region in tower wall are immediately covered by used belts or wet straw bags, and then by double shielding of wattle and dab and protected by guard net. Prevent bents and multi-layer shielding of wattle and dab are constructed around Λ -shaped pillars. In order to protect major buildings and structures and prevent flying rock, multi-layer bent, wattle and dab and guard net are installed in related positions before blasting.

7 Conclusions

The cool tower is collapsed directionally and broken well as expected in the blasting scheme, and satisfactory results and purposes of blasting were obtained. The whole blasting time is about 8 s and it completely collapses with no back blow, the distance of setting forward is about 20 m and the total blasted pile approximates to 4 ~ 5 m, there are no damage to fixed buildings and equipments. According to blasting demolition of the high thin-wall hyperbolic reinforced concrete cool tower, some experience gained is as follows:

1) For blasting demolition of the high thin-wall hyperbolic reinforced concrete cool tower, the tower must be collapsed according to the expected results and purposes as long as the blasting scheme is designed and constructed carefully and prevention measures with adequate safety are sufficient.

2) Blasting gap form, gap size and its position are the keys to assure that the tower directionally collapse according to the design requirements. The optimization gap can be determined by theoretical analysis and blasting engineering practice, with the designed blasting gap, the cool tower can collapse directionally and the drilling workload can be reduce greatly and blasting circuit become simple.

3) In order to obtain the expected blasting results, the drip water platform inside of the tower and the vertical props under the platform must be predisposed and cleaned up before blasting.

4) The high thin-wall hyperbolic reinforced concrete cool tower must be collapsed directionally with good breaking as long as it twists during its directional collapse. According to the related theories and mechanics analyses, the twist is the key that leads to the trouble-free collapse of cool tower, so it is regarded as the characteristic identification of successful blasting with expected results in blasting cool tower.

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