Application of controlled blasting technology in mountain excavation under complex conditions

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Abstract. The blasting conditions of the site leveling project of a green power and renewable energy limited company are extremely complex. There are construction facilities on both sides of the excavated hill, and expressways and county roads on the front of the excavated hill. In order to control the impact of rolling stones, blasting vibration, blasting flying stones on surrounding buildings, bridges and culverts, pre-embedded industrial water pipes, highways and roadbeds during the excavation of mountain bodies, precise controlled blasting and comprehensive vibration reduction techniques such as weak loosening, controlling the maximum single-shot (single-segment) charge, hole-by-hole blasting, dispersed charge sectional blasting, axial spacing and radial uncoupled charge are proposed. Pre-splitting blasting technology is used to stabilize the slope in slope engineering and trench blasting technology is used in excavation of cut-off ditch. The technology guarantees the normal opening of the frontal expressway and county road during the excavation operation, and does not affect the safe production of the company. This technology guarantees that the excavation of mountain body will not affect the normal opening of frontal expressway and county road, and will not affect the safety of production of the company.

1. Project overview  
A Green Power Renewable Energy Co., Ltd. upgraded and rebuilt the plant area, and it is necessary to excavate and remove parts of the mountain on the east and north sides of the plant. The mountain to be excavated is mainly composed of strong-micro-weathered breccia-containing fused tuffs of the Upper Jurassic Jiuliping Formation (J3j), with residual slopes containing gravel and silty clay on the top of the mountain. The rock and soil composition of the mountain can be divided into 2 engineering geological layer groups and 4 engineering geological sublayers. The physical and mechanical properties of each rock and soil layer are described as follows:  
(1) One layer of gravel containing silty clay (Qel+dl): grayish yellow, slightly wet-wet, loose-slightly dense, gravel angular, size 2~15cm, content about 5~20%, thickness 1.0~5.2m. It belongs to ordinary soil, with excavation level (II). It is recommended that the characteristic value of foundation bearing capacity \([f_{ao}] = 140\)kPa.
(2) Two layers of strongly weathered breccia-bearing fused tuff: grayish yellow, mineral weathering alteration is strong, most of the structure has been destroyed, weathering fissures are well developed, the rock quality is weak, the rock mass is broken, and it shows a fragmented loose structure. The layer thickness is 1.5~3.0m, which belongs to soft rock and the excavation level (IV). It is recommended that the characteristic value of foundation bearing capacity \( [f_{a0}] = 400 \text{kPa} \).

(3) Weathered breccia-containing fused tuff in three layers: gray, gray-purple, hard, massive structure, joint fissure development-relatively developed, slightly stretched-closed, rough rough surface, iron manganese rendering, rock The body is more fragmented-more complete, showing a block-like mosaic structure-a block-like structure. Rock saturation compressive strength \( R_c = 116.6 \text{MPa} \). The layer thickness is greater than 10.0m. The basic quality grade of rock mass is grade III, which belongs to hard rock and excavation grade (VI). It is recommended that the characteristic value of foundation bearing capacity \( [f_{a0}] = 1500 \text{kPa} \).

(4) Four-layer micro-weathered breccia-containing fused tuff: gray, gray-purple, hard, massive structure, joint fractures are more developed and closed, the gap surface is rough and uneven, the rock body is more complete, showing a block masonry structure, partially broken. The basic quality grade of rock mass is grade II, which belongs to hard rock, and the excavation grade (VI). It is recommended that the characteristic value of foundation bearing capacity \( [f_{a0}] = 2000 \text{kPa} \).

The total volume of the project is about 189828m³, including the excavation of slope engineering, intercepting ditch, platform ditch and drainage ditch. The specific engineering quantities are shown in Table 1.

| Project name          | Square volume /m³ | Total volume /m³ |
|-----------------------|-------------------|------------------|
| Earthwork             | 27667             | 189828           |
| Stonework             |                   |                  |
| Stone excavation      | 132278            |                  |
| Slope                 | 28842             |                  |
| Intercepting ditch    | 1041              |                  |

2. Mountain excavation environment and blasting plan

The blasting construction conditions of the company's site excavation are extremely complex, and the site is flat on three sides that need to be protected. Among them, the company's factory building and trestle are 15m on the north side of the site; the factory building and drainage channel are 72m on the northeast side. Buried industrial water pipes. 63m and 98m to the west are county roads and highways. 22m southwest of the company office building. 9m to the south is the building and road facilities to be demolished. Because the blasting operation area is close to office buildings, factories and highways, when designing a blasting plan, it is necessary to strengthen monitoring and monitoring. While strictly controlling the amount of charge, determining the minimum resistance line and selecting the blasting action index are the keys to controlling flying stones. Use small-diameter dispersion charge or non-coupling charge to ensure that the packing length is not less than 1.2 times the minimum resistance line to improve the quality of blast hole blockage.

Strictly control the amount of primary detonation to meet the vibration safety control standard, adjust the time of blasting to increase the frequency of blasting vibration, adjust the direction of blasting, and adopt different shock-absorbing measures such as different charge structures for shock absorption, while considering the construction (structure) of the structure For dynamic response, comprehensively consider the blasting effect and blasting duration design on the basis of safety. Due to the rainy local conditions, the choice of emulsified explosives was determined based on market supply. When in use, the local civil explosive company directly distributes it to the construction site. Weak loose blasting is adopted. In the vicinity of blasting, shallow-hole small-diameter (38mm) dispersed charge can reduce vibration by 60%~75% than conventional concentrated charge blasting. However, the shallow-hole dispersed charge blasting cannot meet the requirements of the construction period. Therefore, under the principle of "more drilling and less charge", deep-hole (90mm and 110mm) blasting is mainly used as a
supplement to shallow-hole blasting, and the maximum single-shot charge is strictly controlled. Volume and control are super-deep. When blasting, slash and V-shaped initiation method should be selected.

3. Blasting design

3.1. Design of slope cracking and smooth blasting

According to the conditions of topography, lithology, structural structure, the relationship between the occurrence of joint fissures and slope direction, weathering and fragmentation, no unfavorable geological phenomena such as collapse and landslides are seen on the hilly slopes, and the natural slope stability is good. It has the conditions to excavate slope with deep hole pre-splitting blasting. The slope is divided into five grades, of which the vertical height of the first grade, second grade and third grade slopes are all 10m, the slope angles are 73.3°, 73.3°, 63.4°, and the vertical height of the fourth grade and fifth grade slopes is up to 15m, and the slope is 53.1°. The first-, second-, and third-grade slopes are treated by deep-hole presplit blasting at one time. The fourth and fifth grades are treated by smooth blasting for 2~3 times due to the small slope angle. Each stage slope is provided with a platform with a width of 2m, and a drainage ditch and an intercepting ditch are provided at the top and bottom of the slope.

Due to the different heights of the original slopes (23~55m), the slope smooth and pre-split blasting use the slope platform as the borehole reference to determine each smooth, pre-split blasting angle and drilling depth. Before blasting the slope, clear the trailing edge and loosely accumulated soil on the slope. When loading medicine, avoid causing the medicine roll to be pressed toward the bottom of the hole or bent in the hole. The blast holes are loaded with axial air gaps, radial gaps, bamboo straps, and the detonating cord detonates. The main blasting parameters are shown in Table 2 (taking the first-grade slope as an example, the blasting treatment of other slopes is subject to the design).

| Table 2. Main blasting parameter table |
|----------------------------------------|
| Main blasting parameters               | Unit | Parameter value |
| Pre-crack hole depth                   | m    | 10~11           |
| Hole diameter                          | mm   | 90              |
| Drilling angle, angle with the ground  | °    | 73              |
| Uncoupling coefficient                 | /    | 2.8             |
| Line charge density                    | g/m  | 420~505         |

The charge structure includes three aspects: the length and method of clogging of the orifice, the realization of the density of the linear charge, and the reinforced charge at the bottom of the hole. The hole is sealed with yellow mud, and the blocking length is 3 to 3.5m. In the process of clogging, try not to over-tighten, keep the medicine roll in the center of the hole, 50cm at the bottom of the hole is the reinforced charge section, and the remaining section is an emulsified Φ=32mm interval tied to the bamboo piece, blocking the section 1 by the orifice 1~2m is for weakening the charge, and it is only tied with one emulsified Φ=32mm medicine roll. Initiation network: Initiate in sections, with every 4 holes as a section. The detonating cord was used to detonate in the same period of time, and 5 sections of detonator detonators were used to detonate between each section.

3.2. Shallow hole blasting design

For areas with an excavation thickness of less than 5m, which cannot meet deep-hole blasting and areas where the mountain is very close to buildings, special blasting effects need to be controlled. Shallow hole loose blasting combined with mechanical crushing is used for excavation. Cloth hole type: single hole or plum shape. Charge structure: continuous charge. Drilling: 90mm drilling is used in areas with blasting thickness above 3m and less than 5m, and 38mm drilling is used in areas below 3m. The main blasting parameters are shown in Table 3.
Table 3. Shallow hole controlled blasting parameter table

| Blasting thickness/m | Aperture/mm | Hole pitch/m | Row spacing/m | Drilling depth/m | Charge length/m | Clogging length/m | Single-hole dose/kg |
|----------------------|------------|--------------|---------------|-----------------|-----------------|-------------------|--------------------|
| 1.0                  | 38         | 1.0          | 0.8           | 1.2             | 0.40            | 0.80              | 0.40               |
| 2.0                  | 38         | 1.0          | 0.8           | 2.2             | 0.75            | 1.45              | 0.75               |
| 3.0                  | 90         | 2.2          | 1.8           | 3.5             | 1.10            | 2.40              | 5.00               |
| 4.0                  | 90         | 2.2          | 2.0           | 4.5             | 1.75            | 2.75              | 7.00               |

3.3. Deep hole control blasting design
For areas with an excavation thickness greater than 5m, deep hole loosening controlled blasting is used to implement blasting excavation. Pattern of cloth holes: plum-shaped or rectangular arrangement. Charge structure: air gap charge at the bottom of the hole and radial gap charge. Drilling method: Φ90mm for shallow hole drilling. The main blasting parameters are shown in Table 4.

Table 4. Deep hole bench blasting parameter table (D=90mm, q=0.35kg/m³)

| Step height/m | Super deep/m | Drilling depth/m | Air column/m | Charge length/m | Clogging length/m | Single-hole dose/kg |
|---------------|--------------|------------------|--------------|-----------------|-------------------|--------------------|
| 5.0           | 0.5          | 5.5              | 0.4          | 2.1             | 3.0               | 8.4                |
| 6.0           | 0.6          | 6.7              | 1.2          | 2.5             | 3.0               | 10.0               |
| 7.0           | 0.7          | 7.7              | 1.2          | 3.0             | 3.5               | 11.8               |

Charge structure: continuous charge structure and air space charge structure are shown in Figure 1. Blast hole layout: plan view and section view of the hole layout, as shown in Figure 2.

Figure 1. Schematic diagram of continuous charging

Figure 2. Schematic diagram of blasthole layout
3.4. Initiation network and initiation sequence

(1) Blasting time: The main parameters that determine the vibration intensity of the differential blasting are the subsection charge and the delay interval, and determining the reasonable interval of the differential blasting plays an important role in improving the blasting effect and reducing the seismic effect. There is an optimal value for the interval between the delays. In this project, the millisecond detonator is selected, and the network delay is 75~380ms.

(2) Blasting network: The direction of detonation has a significant effect on the blasting seismic effect, and the blasting seismic effect increases in the direction of the propagating detonation of the cartridge. The order of detonation of the cartridges affects the formation of the plane end of the wavefront carrying the basic energy of the blasting earthquake. The main blasthole blasting network is shown in Figure 3. This project uses hole extension blasting. All Ms-10 detonator detonators are installed in the holes, Ms-5 detonator relays are used for relay transmission between the holes, and Ms-6 detonator relays are used for detonation between the rows. In order to ensure safe and reliable blasting, two rounds of millisecond detonator detonators are installed in deep holes.

![Figure 3. Schematic diagram of the main blasthole blasting network and initiation sequence](image)

(3) Blasting scale: Strictly control the unit consumption of explosives, and control the blasting scale by zones. In the blasting area of 20~30m away from the production plant and office building of the power plant, 1 to 2 rows of blast holes are blasted each time, the total number of blast holes does not exceed 30, and the total blasting charge does not exceed 350kg. In the 30~40m blasting area, each blasting does not exceed 3 rows of blast holes, the total number of blast holes does not exceed 60, and the total blasting charge does not exceed 700kg. In other blasting areas, each blasting does not exceed 4 rows of blastholes, the total number of blastholes does not exceed 150, and the total blasting charge does not exceed 2000kg. Shallow hole blasting, the total charge per blasting does not exceed 200kg.

4. Blasting safety protection

Due to the particularity of this blasting operation, the surrounding environment is extremely complex, including the continuous operation of the power plant, and the highway cannot be closed, so flying stones must be eliminated. Analyze and modify the blasting parameters during the blasting process. An explosion-proof video camera was used to analyze the blasting process. Through the sandbags and the trajectory of the gun, the possibility of flying stones was analyzed using its own software. The production of flying stones can be controlled by choosing a reasonable blasting effect index, improving the quality of the blockage, uncoupling charge, air interval charge, sand bag covered by the orifice, colloidal gun cover and high-strength net coverage. Set a reserved rock body to block the lateral flying stones in the explosion area. The muzzle was blocked with sandbags and covered with guns. The shot area is covered with high-elasticity Brook net.

In addition, the closest distances from the explosion source to the power plant building and pre-buried water pipes, office buildings, Hongshan Line County Road, power plant central control room equipment, S26 Zhuyong Expressway Subgrade, Houjiang Tunnel are 20m, 27m, 68m, 69m, 103m and
215m. According to the threshold of blasting vibration control of the protected object, calculate the allowable maximum blasting amount at different distances from the blasting point, as shown in Table 5.

Table 5. The maximum allowable single dose of the protected object at different distances (kg)

| Object of protection       | Allowable vibration control value/cm | Distance from the edge of the blasting area/m | Distance from blasting point/m |
|----------------------------|-------------------------------------|-----------------------------------------------|-------------------------------|
| Power plant building       | 4                                   | 20                                            | 12  40  94  184               |
| Office building            | 3                                   | 27                                            | 25  58  114                    |
| Central control room equipment | 0.6                           | 69                                            | 13  21  32  46                |

From the Table 5: (1) The maximum single-segment dose within 30m from the plant is controlled at 12kg (79m from the central control room equipment) to ensure the safety of the protected objects; the largest single-segment within 30~40m from the plant The dose is controlled at 39.8kg to ensure the safety of the protected object. (2) The maximum single-segment dose in the area within 30m from the office building is controlled at 12kg, and the maximum single-segment dose in the area within 30~40m is controlled at 24.6kg to ensure the safety of the protected object. (3) The maximum single-stage drug volume in other areas is controlled at 40kg to ensure the safety of the protected objects.

5. Conclusion

(1) The amount of blasting works is large, and the blasting environment is extremely complex. A variety of controlled blasting techniques are used to solve the problem of tight progress in mountain excavation engineering.

(2) By setting the blasting action index, high-efficiency plugging quality, uncoupling charge, air interval charge, sand bag covered by orifice, colloidal gun cover and high-strength Bruker net, the generation of flying stones during the blasting operation was controlled and solved. The nearby company is operating normally and the highway is running normally, and the maximum single-stage charge is optimized to meet the threshold of the blasting vibration control of the protected object, ensuring the safe development of the blasting operation.

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