Gradation prediction model of dam stone blasting and research on blasting technology

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Abstract: The type of concrete panel rock-fill dam has achieved rapid development in our country, the key technology is adopts mining the designated gradation of rockfill material using controlled blasting technology. It is different from open pit mining or quarry blast, it controls not only the maximum grain size but also the gradation of the stone, Start with the R-R distribution function of blasting stone grain composition. The paper builds the forecast model of the block size and gradation of the rockfill material, and then designs and adjusts the parameters. The engineering example shows that using this method could get the better engineering effect on grain size and gradation after blasting.

Key words: rockfill material; controlled blasting; gradation; technology research

1 Preface

In recent years, the type of concrete panel rockfill dam has achieved rapid development in our country, there are very strict requirements for rockfill material in construction of concrete panel rockfill dam, both the request controlling its maximum particle size (is generally 600–800), and to have the good gradation, requests its non-uniform coefficient of grain composition to be more than 10, the curvature coefficient to be situated between 1 and 3. Therefore the key technology is adopts mining the designated gradation of rockfill material using controlled blasting technology. It is different from open pit mining or quarry blast, Because the latter only considers controlling the maximum particle size, the block even and the non-gradation of rockfill material request. Therefore the mining explosive technique of dam rockfill material now is quite complex topic in the project demolishes field, it not only request controlling its maximum particle size, but also the gradation of rockfill material, according to the gradation which assigns carries on the demolition, and requests its primary blasting to achieve on the request direct
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...dams, greatly reduced selection and working hours of the second stage blasting, in order to achieve to reduce the building cost of projects and project time.

Therefore, a series of measures in researching the controlled blasting technology of mining the designated gradation of rockfill material, the block distributed rule of demolishes stave rock, optimizing the deep hole demolition design variable, and enhancing the quality of rockfill material demolition, reducing the cost could meet the above requirements.

2 request of dam stone mining

The filling materials of concrete panel rockfill dam have three kinds generally: breaker strip material, transition material and main rockfill material. Due to the breaker strip material permission maximum particle size is too small, take the demolition method production cost to be excessively high, we only study the demolition exploitation methods of the transition material and the main rockfill material currently.

Generally when carries on the demolition design, must consider the following some technical question in order to make sure the grinding effect of rockfill material and other water conservancy project has the strict request to the rockfill material gradation.

(1) Request controlling maximum grain size $d_{\text{max}}$ of rockfill material, for main rockfill material controls in (600–800) mm, for transition material controls in 300 mm around.

Exceeds the specified maximum particle size to be called the bulk, it accounts for the percentage of demolition gross weight to be called the bulk rate, in the rockfill material demolition requests to reduce the bulk rate as more as possible, bulk rate evaluation criteria custom shows in Table 1. Generally controls bulk rate in 5%.

(2) Try to control the content less than some particle size satisfies the requirements of dam design, that is to say requests constrained grain size $d_{\text{max}}$ of rockfill material, limited grain size $d_{60}$, median grain size $d_{50}$, effective grain size $d_{10}$ and $d_{30}$ in a certain range, requests its grain composition according to the gradation composition which is assigned, generally requests its non-uniform coefficient $C_v$ to be more than 10, the curvature coefficient $C_c$ to be situated between 1 and 3, moreover the gradation continual could be called good gradation. This can by the few roller compaction number of times (4–6), achieving dry density of the roller compaction design request.
Table 1. Evaluation criteria of bulk rate

<table>
<thead>
<tr>
<th>Bulk rate (%)</th>
<th>&lt;3</th>
<th>3~6</th>
<th>6~10</th>
<th>10~13</th>
<th>13~20</th>
<th>&gt;20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation criteria</td>
<td>excellent</td>
<td>better</td>
<td>pass muster</td>
<td>worse</td>
<td>bad</td>
<td>worst</td>
</tr>
</tbody>
</table>

(3) In the demolition design and construct, as far as possible satisfies the above condition, expends the area of hole net, raises the drilling utilization, saves the cost, enhances the construction intensity.

(4) controlling flyrock distance and blasting vibration velocity, ensuring blasting safety in construction.

3 Establishment of rockfill material blasting gradation prediction model

3.1 Gradation prediction model of the stave rock

RoSio—Rammier distribution

A great deal of overseas research shows that the grain composition of rockfill material blasting all could be described by RoSio—Rammier distribution function. The expression is:

\[
F(x) = 1 - \exp \left( - \left( \frac{x}{x_0} \right)^n \right) \quad (1)
\]

Where \( x \) - rockfill material diameter;
\( F(x) \) - the function of \( x \), less than the weight percentage of some particle size;
\( x_0 \) - characteristic parameter; correspond to the grain diameter when rockfill material sift amount is 63.21% (mm);
\( n \) - evenness index; non-dimensional number; it is depended on drilling precision etc.

Through the domestic 9 projects by author: Brugger, Guang Xu, GuanMenShan, XiBeiKou, LongTan, HuaShan, WanAnXi, LianHua, DongJin, statistical analyses 16 group of rock ballaet grading curve uses RoSio—Rammier distribution function after blasting to describe grading curve of rock ballaet actual measurement, the average error \( F(x) \) is in \((1.2—2.9)\) %, the maximal error \( F(x) \) is in \((2.3—6.2)\) %, these errors all in project allowance error, so it's completely feasible to describe lumpiness grading curve after blasting by R-R distribution function.

3.2 Rockfill material blasting gradation prediction model

Looking from overseas data, the grain composition of rockfill metrical blasting all could be described by R-R distribution function, so we could establish the relationship between the two important factor \( C_U \), \( C_C \) in grading composition and \( n \) in R-R distribution
function, using the assumption to equation (1):

\[ C_U = e^{\frac{2.163}{n}} \]

\[ C_e = \left[ e^{\frac{0.9505}{n}} \right]^2 \times C_u \]  \hspace{1cm} (2)

According to the above discussion indicated on condition that dam stone \( C_U \) has been by dam labor design, could determine \( n \) which we expected for.

3.3 V.M.Kuznetsor function

It is important to determine \( x_0 \) and \( n \) when using R-R distribution function to describe the gradation of blasting fragmentation, \( x_0 \) could be determined by V.M.Kuznetsor function:

\[ x_{50} = A(k)^{-0.8} \times Q_e^{0.7} \times \left( \frac{115}{E} \right)^{0.633} \]  \hspace{1cm} (3)

Where: \( x_{50} \) - 50% weight of rockfill material pass mesh diameter (cm);

\( k \) - unit explosive consumption (kg/m\(^3\));

\( Q_e \) - charge in every drilling (kg/hole);

\( E \) - relative weight of TNT, TNT115;

\( A \) - rock coefficient, contacts with rock consolidating coefficient \( f \), the value is shown in Table 2.

Substitute \( x_{50} \) of equation (3) to equation (1):

\[ x_0 = \frac{x_{50}}{(0.693)^n} \]  \hspace{1cm} (4)

So \( x_0 \) could be obtain by equation (5).

<table>
<thead>
<tr>
<th>Coefficient A and f compatible</th>
<th>remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>firmness coefficient ( f )</td>
<td></td>
</tr>
<tr>
<td>medium firmness, fracture more development, strong weathered 6-8</td>
<td>2-3 by BaiLongTan dam data</td>
</tr>
<tr>
<td>medium firmness rock 8-10</td>
<td>7</td>
</tr>
<tr>
<td>firmness rock, strong fracture 10-14</td>
<td>10 B.M Kuznetsor data</td>
</tr>
<tr>
<td>extremely firmness rock, weak weathered 12-16</td>
<td>13</td>
</tr>
</tbody>
</table>

\( x_{50} \) could be projection by equation (5) when \( A, E \) are determined.

Kahn had also proposed design formulas with \( n \) as follows:
\[ n = \left( 2.2 - 14 \frac{B}{D} \right) \left( 1 - \frac{W}{B} \right) \left( \frac{1 + \frac{s}{B}}{2} \right)^{0.5} \times \left[ \frac{\text{abs}(\text{BCL} - \text{CCL})}{L} + 0.1 \right]^{0.1} \times \frac{L}{H} \]  

Where \( B \) is resistance line(\( m \)); \( D \) is aperture(\( mm \)); \( W \) is drilling accuracy deviation(\( m \)); \( s \) is hole distance(\( m \)); \( \text{BCL} \) is charge length at hole bottom(\( m \)); \( \text{CCL} \) is prismatical charge length(\( m \)); \( L \) is total charge length(\( m \)); \( H \) is hole depth(\( m \)). \( x_0 \) could be calculated by equation (5) after \( n \) is known.

3.4 Kuz-Ram model

Unifies equation (1) with equation (4) then constitutes the Kuz-Ram model.

3.5 The use of rockfill material blasting gradation prediction model

The rockfill material blasting belongs to boulder yield blasting, may use the related principle of boulder yield blasting to carry on the blasting parameter design, using blasting parameter to determine \( A, n, \) and \( E \) according to engineering geologic condition of blasting ground. Using Kuz-Ram model to forecast lumpiness and graduation of rockfill material after blasting, if not meet design challenge, then must readjust to the blasting parameter; if in the design permission scope could carry on the project construction, and carry on the comparative analysis with actual measurement grading curve after dam stone blasting, using Kuz-Ram model to determine \( n, x_o, x_{50}, \) and \( A \) in feedback analysis, then analyze and compare with oiginal design value, Thus according to blasting whole effect adjustment, revision blasting parameter, in order to meet the request of dam design grain composition.

4 Project example

Take Lotus power station which is concrete panel rockfill dam of main rockfill material blasting tests as example to introduce the application of the controlled blasting technology.

Blasting test site is selected at the right side of spillway(pile NO.0+171~0+191.5), the lithology is granitization granite, medium rough grain structure, fracture more development, fracture development are mainly two groups: one is trend towards to North East 30°~60°, tendency to South East, inclination is 50°~80°; the other is trend towards to North West 310°~340°, tendency to South West, inclination is 58°~88°. Paralle spacing is generally 0.3~0.8. The area was strongly weathered lithology state, the uniaxial compressive strength is 50~100 Mpa, the firmness coefficient \( f \) is 6~8.
4.1 The particle analysis curve of rockfill material by dam design

The particle analysis curve by design:

\[ x_{50} \text{ changes in the scope of } 150 \text{ mm} \sim 70 \text{ mm} \], \[ x_0 \text{ changes in the scope of } 230 \text{ mm} \sim 120 \text{ mm} \].

4.2 Design of blasting parameters

In this test, a total of two rows of holes arranged, aperture are all 90 mm (Drug Drive \( d_0 = 80 \text{ mm} \)), first row of holes inclined is 75°~77°, second row of holes inclined is 80°, all drilling holes at the bottom all could access to 220.5 elevation, the average super-boring is 0.8 m around.

The two rows of holes are triangular arrangement, pre and post staggered, toe burden is 2.6 m ~2.7 m, hole distance is 2.3 m. Blasting parameters specific as shown in table 3:

<table>
<thead>
<tr>
<th>Table 3. List of blasting parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of flight ( H )</td>
</tr>
<tr>
<td>Drilling equipment</td>
</tr>
<tr>
<td>Drilling diameter ( D )</td>
</tr>
<tr>
<td>Drilling inclination ( \alpha )</td>
</tr>
<tr>
<td>Charge diameter ( d_0 )</td>
</tr>
<tr>
<td>Toe burden ( B )</td>
</tr>
<tr>
<td>Minimum burden ( B )</td>
</tr>
<tr>
<td>Hole distance ( a )</td>
</tr>
</tbody>
</table>

The relationship between the burden and the main blasting parameters is as follows:

Aperture ratio: \( B / D = 25 \); Spacing ratio: \( a / B = 1 \); Hole depth ratio:

\[ L / B = 3.78, \text{greater than 3, less than 5; block length ratio} L / B = 1. \]

Basically meet the charge to the optimize the design parameters.

4.3 determining \( A \) and \( n \) in Kuz-Ram
Due to the rock is under the strong weathered layer, fracture more development, and consider other geological factors, parameter values were selected as follows:

\[
\begin{align*}
RDM &= 10, \\
JF &= JPS + JPA = 20 + 30 = 50, \\
RDI &= 25 \times 2.65 - 50 = 16.25, \\
HF &= 15/5 = 3. \\
A &= 5.48
\end{align*}
\]

According to the design of the blasting parameters to determine the value of \( n \):

\[
A = \frac{b}{d} \left( 1 - \frac{L}{B} \right) \left( 1 + \frac{s}{B} \right)^{0.5} \times \left[ \frac{\text{abs}(B - C)}{L} + 0.1 \right]^{0.1} \times \frac{L}{H} = 0.84
\]

The parameters are in Table 3.

As the two rows of holes are triangular arrangement, pre and post staggered, the value of \( n \) should be added 0.1, so the final value of \( n \) is 0.94.

4.4 prediction of stone blocks blasting and gradation

Using Kuz-Ram model to predict stone blocks blasting and gradation with the following:

When \( A = 5.48 \), \( n = 0.94 \), \( q = 0.65 \), \( Q = 29 \),

\[
\begin{align*}
x_{30} &= 135.6 \text{ mm} ; \quad x_{9} = 200 \text{ mm} ; \\
x_{10} &= 18.2 \text{ mm} ; \quad x_{30} = 66.8 \text{ mm} ; \\
x_{60} &= 182 \text{ mm} ; \\
>600 \text{ mm} \text{ content is 6\% ; } \quad <5 \text{ mm} \text{ content is 3.1\% ; } \quad C_{u} = 10 ; \\
C_{c} &= 1.35.
\end{align*}
\]

Judging from the above results, aside from the blasting boulder yield is a little bigger, the rest are all meet the requirements of the design, we take into account the department's application of the orifice“self charge”, the bulk rate is expected to decline, therefore, we do not intend to modify the original design, so adjust after blasting feedback analysis.

4.5 granulometric composition after blasting

After blasting, choose three points at diagonal in the blast zone to carry out screen separation, the total is 16665.7 kg.

When the stone size is greater than 200, length, width and heigh were taken to the measurement of the value stack with Chinese foot, 20 ~ 200 of the file screen is made of square steel mesh screen, less than 20 the file is a standard screen sieves, sieving curves values are as follows:

\[
\begin{align*}
x_{30} &= 145 \text{ mm} ; \quad x_{9} = 220 \text{ mm} ; \\
x_{10} &= 8 \text{ mm} ; \quad x_{30} = 64 \text{ mm} ; \quad x_{60} = 200 \text{ mm} ; \\
>600 \text{ mm} \text{ content is 4\%; } <5 \text{ mm} \text{ content is 8\% ; } \quad C_{u} = 25 ; \\
C_{c} &= 2.56.
\end{align*}
\]

Compared the measured results with predicted values, the majority of values are in line, only the granule concent has a larger difference, because of the test pilot
stage is in strong weathering zone area, so the granule has increased in the blasting composition, so the measured values are larger than predicted.

When the measured values $C_u$ is comparatively large, the grading distribution for fine grading, after 4–6 times roller compaction, the dry bulk density value meet to the design requirements which are $2.05 \sim 2.18 \, \text{t} / \text{m}^3$.

4.6 Feedback analysis based on screening curves

(1) $A_n x_{50} = 145, x_0 = 220$ are greater than design predictive value $x_{50} = 136, x_0 = 200$ through the screening curves, according to Kuz-Ram model can obtain $A=5.86, n=0.88$, close to $A=5.48, n=0.94$ with the original design.

(2) the ratio between the actual and forecast design granulometric composition is shown in Table 4:

From the values shown in the table above that 400mm–600mm fall within the scope of the measured value and predicted value is closer to, but in less than 40mm are outside the scope, especially in the scope of less than 5mm errors, which, as indicated earlier analysis as, as the bench in a strong rock weathering, due to the lithology caused by uneven distribution.

Bulk rate forecast to be smaller than the design that we have taken measures to reduce the block or charge from the closure feasible. Thus, no further adjustment of blasting parameters of the original design. If you want to test, the value of the adjustment to the design of predictive value, only to consume the right to choose $=0.7$, will enable better.

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Measured values</th>
<th>Predictive value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>8</td>
<td>3.1</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>5.8</td>
</tr>
<tr>
<td>20</td>
<td>16.8</td>
<td>10.8</td>
</tr>
<tr>
<td>40</td>
<td>23.5</td>
<td>19.8</td>
</tr>
<tr>
<td>60</td>
<td>29</td>
<td>27.6</td>
</tr>
<tr>
<td>80</td>
<td>34.5</td>
<td>34.5</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>40.6</td>
</tr>
<tr>
<td>200</td>
<td>60</td>
<td>63.2</td>
</tr>
<tr>
<td>300</td>
<td>74</td>
<td>76.9</td>
</tr>
<tr>
<td>400</td>
<td>86</td>
<td>85.3</td>
</tr>
<tr>
<td>500</td>
<td>92</td>
<td>90.6</td>
</tr>
<tr>
<td>600</td>
<td>96</td>
<td>94</td>
</tr>
</tbody>
</table>

Table 4. The actual particle analysis curve compared with the projected curve
5 Conclusion

In this paper, using the blasting parameters and diameter and gradation of rock after blasting could prediction the diameter and gradation of rockfill material, thus can guide the selection of rockfill material controled blasting parameters, and then adjust the parameters through comparison with measured values, so that the effect of blasting works meet the actual needs, and achieve more satisfactory results.