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CONSTRUCTION OF BLAST-FILL DAMS

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INTRODUCTION

Dams construction in mountainous regions by use of strong explosions is the promising technology that can be applied for the dams designed for various purposes, for water retaining in particular. Such projects have been realised successfully for the erection of the Nurek HPP cofferdam, the Medeo debris flow protection dam, the Baipasa HPP dam, the experimental Burlykia and Uch-Terek dams, of several dams in China. The constructed blast-fill dams are up to 90-m high. In favourable conditions (deep narrow valleys with steep slopes) this technology allows to reduce construction time and laboriousness, to simplify its technology and organisation and to reduce its cost comparatively to the embankment and concrete dams (Bagdasarov *et alii*, 1974; Korchevsky & Petrov, 1989).

PRINCIPLES OF CHARGES DESIGN

The design and implementation of explosions for dam construction is a complex technical problem. Use of the linear charges placed in the adits parallel to the slope surface is practically most feasible. In general charges can be placed at one or both banks at a single, two and even more levels, but the one-bank placement of two charges at the same level (Figure 1) prevails. Such scheme allows to construct the production and transportation structures at the opposite bank of the river simultaneously with the explosion preparation.

Estimation of charges position and mass is often performed by use of well-known formula, proposed by M.M. Boreskov. By this the required dam dimensions are not included in the formulae, but are taken into consideration by comparison of the expected amount of the exploded rock mass. Such analytical model complicates optimisation of charges parameters.

It is convenient to develop methods of charge design taking into consideration the characteristic features of such explosions that were determined in the course of purposeful systematic experiments performed at the vacuum simulator of the IDG RAS. This experimental method (Rodionov *et alii*, 1971) allows to predict dimensions of the blast-fill dams with reasonable accuracy as far as it reflects processes that take place during the explosion and slope failure adequately.

Two peculiarities that govern the blast-fill dam height are more important of those found during the above modelling. The first one is that the lengthening of charge with constant linear mass of explosives (t/m) up to certain value leads to the dams height increase (Zykov *et alii*, 1993) (Figure 2). The critical value of the charges relative length L_{ch}/W is 2.5, where L_{ch} - charges length, W - drill-hole burden. Up to this value its increase leads to the gradual growth of the relative height of the dam H/W, where H is the dams height. But its further increase does not lead to the dams' heightening. From the physical point of view it can be explained by gradual decrease of the exploded debris spreading along the canyon as charge becomes longer. We should note that since $l_{ch} \leq 2{,}5W$ range is typical of real blast-fill dam sites, the above relationship should be taken into consideration, unlike it was done previously.

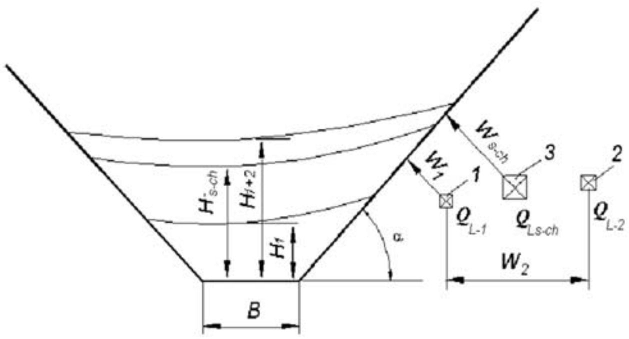

Figure 1 - Scheme of two charges placed at the same level and their main parameters (for explanations see the text)

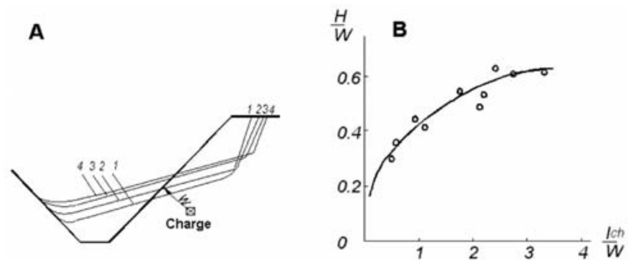

Figure 2 - Dams profiles for different charge length (A) and relationship of the relative dams height H/W from the l_{ch}/W value (B). 1, 2, 3, 4 - gradual changes of the dams height with charges lengthening

The second important peculiarity that governs dam heightening in case of charges placement as on figure 1 is the dam height dependence on the ratio of linear masses (Q_L) of the 1st and 2nd charges

Q_{L-1}/Q_{L-2} and of their drill-hole burden values ratio W_1/W_2. It was found by modelling that, depending on the above parameters' values, height of the dams H may vary from (0.8 ÷ 1.1) H_{s-ch}, where H_{s-ch} is the height of the dam that would be created by the explosion of an optimally placed single charge with linear mass $Q_{s-ch} = Q_1 + Q_2$ (see figure 1). Therefore use of two charges instead of a single one allows increasing the dam height for about 10% (ETKIN *et alii*, 1999).

Well-grounded analytical model of the charges placement and linear mass assessment was developed on the basis of both simulations and natural experiments analysis. It is covered by Russian patent No 2122066 (AZARKOVITCH *et. alii*, 1998).

The design equations that include the designed dam height H and charges length l_{ch} and can be used in the most common cases of the one or two linear charges located on the one bank at the same or nearly the same levels are as follows:

When only single linear charge is exploded its drill-hole burden is:

in the case of $l_{ch\,(3)} / W_{s-ch} < 2,5$

$$W_{s-ch} = \left(0{,}13 / l_3^{0,5}\right)\left\{H\left[5{,}57 + \left(B/H\right)^{1,1}\right]\right\}^{1,5} \tag{1}$$

in the case of $l_{ch\,(3)} / W_{s-ch} \geq 2,5$

$$W_{s-ch} = 0{,}23H\left[4{,}63 + \left(B/H\right)^{1,1}\right] \tag{2}$$

Linear mass of charge

$$Q_{s-ch} = \frac{10^{-6}}{e}\varPi^{0,3} \cdot W_{s-ch}^2\left(3{,}18 - H/W_{s-ch}\right)\left[\rho \cdot g \cdot W_{s-ch}(1-\sin\alpha) + P_a\right] \tag{3}$$

When two linear charges are exploded their drill-hole burdens are:

$$W_1 = 0.74 \times W_{s-ch}\,(1.3 - \sin\alpha) \tag{4}$$

$$W_2 = 0.74 \times W_{s-ch} \tag{5}$$

$$Q_{L-1} = 0.16 \times Q_{Ls-ch} \tag{6}$$

$$Q_{L-2} = 0.57 \times Q_{Ls-ch} \tag{7}$$

Besides symbols described above, B - width of the valley bottom (m); e - blasting efficiency coefficient of the utilised explosives; $\varPi$ - rock shooting index (dm^3/kg); ρ - rock density (kg/m^3); $g \cong 10$ m/s^2 - acceleration of gravity; α - slope angle (degrees); $P_a \cong 10^5$ Pa - atmosphere pressure.

According to the above formulae, calculations for the double-charge scheme is performed in two stages: at first the parameters of the equivalent optimal single charge are estimated; then these parameters are used for calculations of the double-charge scheme parameters.

Results of calculations of charges required for construction of the dam 40, 60 and 80 m high according to the above formulae when B = 10 m, $\alpha = 45°$, $\varPi = 9$ dm^3/kg, $\rho = 2{,}5 \times 10^3$ kg/m^3, $e = 1$ are sited in table 1. Total amount of explosives in both charges Q and the specific consumption of explosives for dams' volume were estimated.

H (m)	l_3/H	W_1 (m)	W_2 (m)	Q_{L1} (t/m)	Q_{L2} (t/m)	Q (t/m)	(kg/m^3)
40	1	33	54	2.8	10.1	519	3.24
40	2	23	38	1.0	3.5	356	2.25
40	3	20	33	0.6	2.2	346	2.16
60	1	48	79	8.5	30.3	2330	3.99
60	2	34	56	2.9	10.2	1568	2.69
60	3	30	49	1.9	6.6	1532	2.62
80	1	63	104	19.0	67.7	6938	4.50
80	2	45	73	6.3	22.5	4609	3.00
80	3	39	65	4.2	15.0	4596	2.99

Table 1 - Examples of calculations performed by use of the above formulae

Dependencies of the explosion parameters from the designed dam height H and relative charge length l_{ch}/H are shown in figures 3 and 4.

According to relationships shown on figure 3, as the dam height increases the drill-hole burden values W_1 and W_2 increase nearly linear, linear charge masses Q_{L-1} and Q_{L-2} increase proportionally to the dam height at the exponential order 2.7, total amount of the explosives - at the exponential order 3.7, and the specific consumption of explosives - at the exponential order of about 0.5.

On the other hand, all above parameters' values decrease as the charge length l_{ch} grows if the dam height is constant (see figure 4). At that curves gradually plateau as lch increases. Such relationships are typical of the conditions when $l_{ch}/W_{s-ch} \leq 2{,}5$.

According to formula (2), if $l_{ch}/W_{s-ch} = 2.5$, $W_{s-ch} \cong H$ and, correspondingly, instead of $l_{ch}/W_{s-ch} \leq 2.5$ l_3 one can use $l_{ch} / H \leq 2.5$.

It is indicative that charge lengthening leads to the decrease of both linear and total mass of charges Q required for construction of the dam with the given height (see figure 4-D). The required specific consumption of explosives decreases significantly as well (see figure 4-E).

Two conclusions can be derived, which are of significant importance for the blast-fill dams construction practice when $l_{ch} / H \leq 2.5$:

1 - previously utilised methods of linear mass of charges calculations that ignored charges length do not allow to obtain well grounded values.

2 - the optimal charge length should be about *2.5 H*, if it does not contradict to the design requirements of the dam dimensions.

If $l_{ch} \geq 2{,}5\ H$ then all relationships shown on figure 4 change according to formula (1-7). Parameters W_1, W_2, $Q_{L\,1}$, $Q_{L\,2}$ become constant (extrapolations shown by dashed lines). However, total amount of the explosives Q starts increasing linearly and its optimum corresponds to the $l_{ch} = (2.5 \div 3.0)\ H$.

	Parameters	Medeo (right-bank explosion)	Baipaza	Burlykia
1	Actual dam height, H (m)	62	67	50
2	Drill-hole burden of the first charge (series of charges) W_1 (m)			
	actual	46 – 54	19 – 35	8 – 22
	designed	39	24	25
3	Drill-hole burden of the second charge (series of charges) W_2 (m)			
	actual	84	60	40
	designed	59	56	42.5
4	Length of the first charge (series of charges) $l_{ch\text{-}1}$ (m)			
	actual	170	388	265
	designed	185	201/388*	150
5	Length of the second charge (series of charges) $l_{ch\text{-}2}$ (m)			
	actual	93	125	183.5
	designed	155	168	125
6	Linear mass of the first charge $Q_{L\text{-}1}$ (t/m)			
	actual	9.8	1.72	0.54
	designed	3.70	1.75	1.15
7	Linear mass of the second charge $Q_{L\text{-}2}$ (t/m)			
	actual	38.8	9.47	2.55
	designed	13.2	6.2	4.1
8	Mass of the first charge Q_1 (ton)			
	actual	1668	668	142.25
	designed	684	352 /679*	172.5
9	Mass of the second charge Q_2 (ton)			
	actual	3605	1184	469.1
	designed	2046	1042	512.5
10	Total mass of charges $Q = Q_1 + Q_2$ (ton)			
	actual	5273	1854	611.4/702.8**
	designed	2730	1400/1721*	685

Table 2 - Actual and designed parameters of the Medeo, Baipaza and Burlykia explosions.
**) Numerator - length of the 1st charge equal to 3H; denominator - actual length of the 1st charge;*
***) Considering the additional charge on the opposite (right) bank*

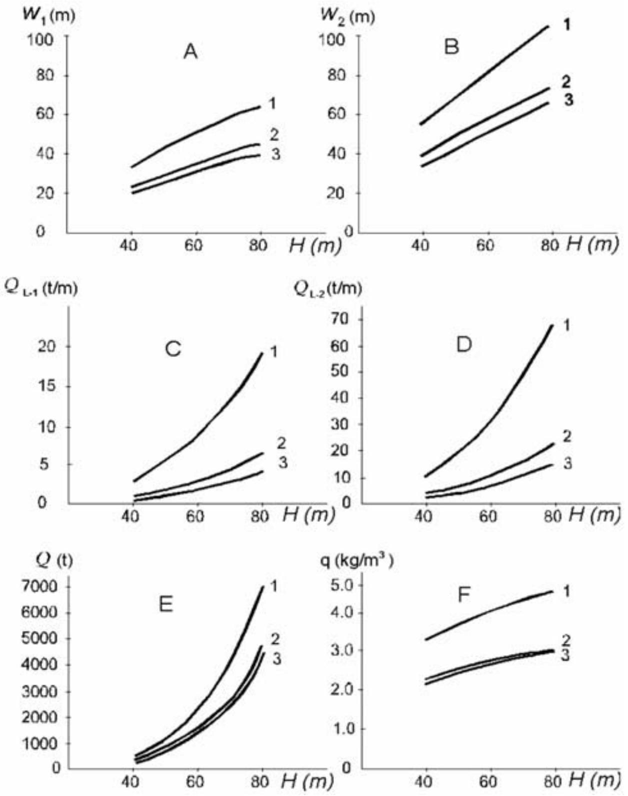

Figure 3 - Relationships of the explosions parameters and the designed dam height (H). A, B - drill-hole burden of the first (W1) and the second (W_2) charges; C, D - linear masses of the first (Q_{L-1}) and the second (Q_{L-2}) charges; E - total amount of the explosives (Q); F - the specific consumption of explosives required for the designed dam profile (q). 1, 2, 3 - l_{ch}/H ratio

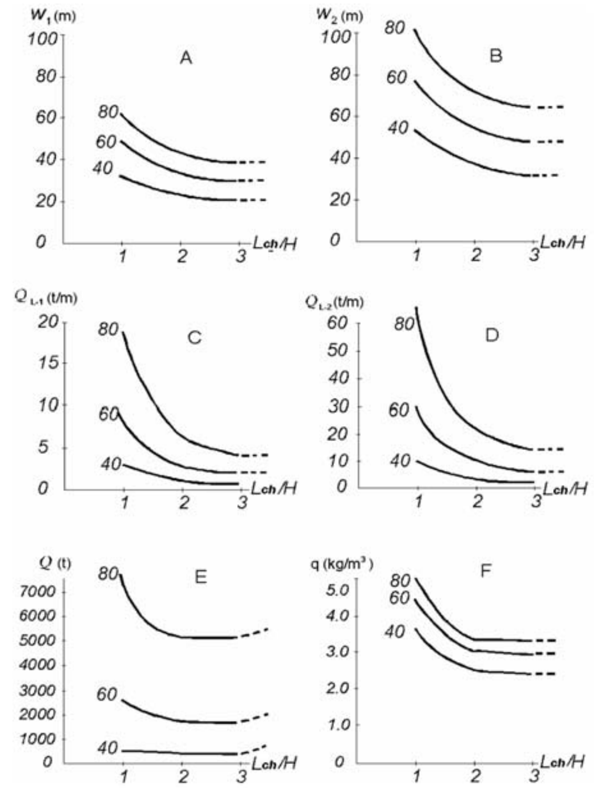

Figure 4 - Relationships of the explosions' parameters and the charge length/designed dam height ratio(L_{ch}/H). A, B - drill-hole burden of the first (W_1) and the second (W_2) charges; C, D - linear masses of the first (Q_{L-1}) and the second (Q_{L-2}) charges; E - total amount of the explosives (Q); F - the specific consumption of explosives required for the designed dam profile (q). 40, 60, 80 - the designed dam height

Table 2 summarises results of back-analyses performed for three well-known blast-fill dams, where explosions were performed in the same or nearly similar conditions as the above described blasting scheme, considering the analogy between several concentrated charges and one linear charge of corresponding length.

We should mention that parameters of the explosion used for the Medeo Dam erection were not optimal - it was the first large-scale experiment of blast-fill dam construction and the charge design methods had not been well developed. Results of the back analysis of this explosion carried out by use of the vacuum camera are described by ADUSHKIN *et alii* (1983). Calculations performed on the basis of the proposed methods give almost similar results as the above modelling (H = 77 m versus 75 m).

CONCLUSIONS AND RECOMMENDATIONS

1) New well-grounded method of the linear charges optimal parameters was developed. It can be applied for blast-fill dams construction. The design equations take into account the designed dam height and charges length that was not considered by previously utilized methods and, thus, reduced their reliability.
2) Plots shown on figures 3 and 4 can be used for the preliminary assessment of the explosions required for dams ranging from 40 to 80-m high erection efficient parameters.
3) Refinement of the technical and economic indexes of explosions utilized for dams construction can be achieved by use of charges that are at least 2.5 times longer them the designed dam height if it is not impede by the dams dimensions specified by the design.

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