Dynamic Load Assessment in Small Scale Blasting and Design of a Muffling System

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ABSTRACT

The paper reports a case where cautious blasting was done to remove 10,000 m^3 of granite very close to a running hydro-power plant without causing any damage to it due to fly rock. A muffle bucket has been designed on the basis of both dynamic and static loads experienced while its usage both for muffling and loading operations. The bucket displacement due to throw of rock fragments and the average fragment size were found to increase directly with the specific charge. Concept of muffle bucket design, its fabrication and application is presented in the paper.

***Key Words**: Hard rock excavation, static and dynamic loads, muffle blasting, muffle bucket design, peak particle velocity,*

1.0 INTRODUCTION

Tail pool widening at the Upper Kolab Hydro-electric Project in Orissa, India was required to reduce the back water pressure which is likely to damage one of the three operating turbines of 80 MW each. This required removal of 10,000 m^3 of granite block measuring 40m x 17m x 15m situated very close to the running power house complex.

2.0 GEOLOGY

In addition to some random joints, two major nearly vertical joint sets were observed in the granites. One of these joint sets was almost parallel to the direction of the water flow in the tail pool (Fig. 1) and the other one was nearly perpendicular to it. The joint spacing ranged from 0.5 to 1m. The joints were altered at the surface. These were, however, unaltered below a depth of 3m from the surface. The joint aperture was less than 2 mm. The granites were dry above the tail pool water level (Chakraborty et al., 1992). The uniaxial compressive strength of the granite formation was 146 MPa. The RQD varied from 65-80.

3.0 EXCAVATION METHODOLOGY

A method of excavation was designed to excavate the rock by drilling and blasting within six months without causing any damage to the powerhouse complex. The maximum distance of the work site from the transformer units and the power house was 15 m and 30 m respectively. The high tension power lines were 15 m above the work site. The place of excavation was surrounded by tail pool running 6 m below the surface at one side and a steep hillock at the other side. The complexity of the work site is shown schematically in Fig. 1. The proposed method of excavation required foolproof muffling system design apart from controlling ground vibrations.

3.1 Permissible Limits

To protect the power house complex from damage due to blast vibration, the permissible limit of peak particle velocity was assumed as 20 mm/sec considering the critical nature of the turbines, rock formation, frequency of shock waves and several case studies on structural damage due to blast vibration (Prakash et al., 1991). To be extremely safe against fly rock damage, the maximum permissible throw of rock towards the power house complex was restricted to 3 m.

3.2 Sequence of Excavation

The excavation was planned to progress from top to bottom depth-wise from three identical pits keeping a tapered rock barrier projecting above the water level. The width of this rock barrier at the top was kept as 1.5m and 4.5 m at the bottom to separate the tail pool and the excavation site (Fig. 2). The barrier was removed in two stages. In the first stage, 4.5m from the top was excavated.

The rest of the rock barrier was removed at the end of the rock excavation work when the powerhouse was kept under shutdown. The sequence of excavation is shown in Fig.5. This proposed sequence was aimed at minimum shutdown of the power house. Before each round of blasting the site was covered with muffle bucket. Two muffle buckets were fabricated for this purpose.

Application of heavy earth moving equipment combinations such as shovel-dumper, front end loader-dumper and dragline-dumper, etc. were not considered for mucking due to the limited working space. Therefore, the muffle bucket was used to perform an additional task of scooping the blasted rock besides muffling. The concept, design and execution of work with the help of a muffle bucket is discussed in the following paragraphs.

4.0 DESIGN OF MUFFLE BUCKET

Controlled blasting with foolproof muffling in such a complex and confined environment has perhaps not been reported earlier. The conventional muffling methods such as rubber mats, gunny bags, used out tyres, wire mesh and conveyor belts etc. do not provide foolproof muffling. Besides, these muffling materials need frequent replacement. Further, breakage of this hard rock by swelling cements could be prohibitive due to high cost and slow progress.

A muffle bucket (Fig.3), made of mild steel sheet, was used both for muffling and loading muck. It was designed on the basis of static load experienced while loading muck and dynamic load due to throw in blasting. The design is unique in this context. Anchoring was provided to prevent the bucket from excessive movement and overturning due to the dynamic loads. The salient features of the muffle bucket are in Table 1.

Table 1 - Salient features of the muffle bucket

S.No.	Parameter	Details
1	Size	5m X 2.5m X 0.02 m
2	Material	Mild steel plate, SAE 1035
3	Thickness	0.02m
4	Yield strength	367 N/mm^2
5	Ultimate strength	580 N/mm^2
6	Weight	20 KN (approximately)
7	Attachments	Teeth to facilitate mucking
8	Capacity	2.5 m^3

The concept of static and dynamic loads considered in bucket design are discussed in the following paragraphs:

4.1 Static Load Concept

The load exerted by the muck and the bucket on the vertical wall of the muffle bucket is computed and the bending moment and the section modulus are calculated for a factor of safety of 2 for static load and short life span of two years.

Volume of the bucket in cu.m. is given by,

$$V = (3.14\ R^2\ W)/2 \quad (1)$$

where, radius R and width W of the bucket are 0.8 m and 2.5 m respectively giving the bucket volume V as 2.5m^3

Assuming 0.6 as fill factor F_f and 1.5 as swell factor S_f, the bucket loading capacity L_c in cubic metres can be given as,

$$L_c = \frac{V F_f}{S_f} = \frac{2.5 \times 0.6}{1.5} = 1\,m^3 \quad (2)$$

With rock density as 2.5 t/m^3, the bucket capacity works out as 2.5 tonnes. The weight of the empty muffle bucket is estimated as 750 kg assuming that it is made of 20 mm thick mild steel plate. Referring to Fig. 4a, the centre of gravity of the loaded bucket is 630 mm to the left of vertical suspension line.

Therefore, bending moment M acting at line A-A is given by,

$$M = (2500 + 750) \times 0.63 = 2048 \text{ kgf-m} \quad (3)$$

and section modulus Z is given by,

$$Z = \frac{b\,d^2}{6} = \frac{2500\,d^2}{6} \quad (4)$$

where, d and b are thickness and width of the bucket in mm.

Considering the yield strength of mild steel (SAE 1035) as 36.7kg/mm^2 and factor of safety as 2 for a short life span of 2 years, the designed strength S_d can be computed as,

$$S_d = \text{yield strength/ factor of safety} = 35/2 = 18.3 \text{ kgf/ } mm^2$$

Since,

$$S_d = M / Z \quad (5)$$

where, M is bending moment and Z is section modulus

Substituting the values of S_d, M and Z in Eqn.5, d is obtained as 16.36 mm. Therefore, the muffle bucket was made of 20 mm thick mild steel plate (Fig.2).

4.2 Dynamic Load Concept

Besides the static load, the muffle bucket must not deform under the dynamic loads of the blast. The forces acting on the muffle bucket are shown in Fig.4 b. Energy of throw E_t, for short delay rounds (round ii), for a specific charge of 0.35 kg is taken from Fig.5 (Langefors and Kihlstrom,1973) as 28,000 NM/m^3. The horizontal component E_{th} of the throw energy, dissipated per m^3 of the rock was equated to the kinetic energy associated with rock movement and the velocity of throw was computed from Eqn.6.

$$E_{th} = E_t \cos 20^0 = (t\ V^2)/2 \tag{6}$$

where t is the rock density in kg/m^3 and V is the velocity of throw in m/sec.

Assuming the rock density as 2.5 t/ m^3, the velocity of throw, V, becomes 4.58 m/sec. From Fig.5, it is clear that the velocity of throw for a specific charge of 0.35 kg/m^3, closely matches with the above computed value. The throw energy E_{th} acting on the muffle bucket needs to be absorbed by the weight of the muffle bucket, the anchorage and by its controlled displacement. In the design, a bucket displacement of 20 cm is allowed by providing slots in the bucket for a specific charge of 0.35 kg/m^3. With the increase in specific charge, this permissible displacement has to be higher. A displacement value of 3 m is assumed in such cases. This assumed value matched with the observations taken during actual blasts with the muffle bucket. The design has been explained in two cases.

Case I: When the allowed bucket displacement is 0.2 m

The driving and resisting forces were computed to arrive at the equilibrium position of the bucket.

Driving force

Considering the throw energy for a specific charge of 0.35kg/cu.m. as 0.28 x 10^5 N m /cu.m. from Fig.5 (Langefors and Kihlstrom,1973), the total throw energy associated with 6 m^{3}of rock is obtained as,

$$E_{tt1} = 0.28 \times 10^5 \times 6 = 1.68 \times 10^5 = 168000 \text{ N-m} \tag{7}$$

Therefore, the energy component acting in the horizontal direction, along the bucket motion E_{th1} is given by,

$$E_{th1} = 168000 \cos 20^{\circ} = 157868.36 \text{ N-m}$$
(8)

This energy is assumed to be absorbed during the forward motion of bucket through 1.59 m which is the distance between the centre of gravity of the rock block before blasting and outer edge of muffle bucket after blasting (Fig.4b).

Therefore, driving force F_{tf1} is

$$F_{tfl} = \frac{57868.36}{1.59} = 99288.2 \text{ N} \qquad (9)$$

Resisting force

The velocity of throw for a specific charge of 0.35 kg/m^3 was computed as 4.58 m/sec. Assuming this as initial velocity, the acceleration was computed from Newton's laws of motion as 6.36m/sec^2. Now, the two resisting forces viz., inertial and frictional are computed as below.

(i) Inertial resistance F_{i1}

The inertial resistance F_{i1} is given as,

$$F_{i1} = m \text{ x } a$$
(10)

Since, the moving mass is 17000 kg (6 m^3 or 15000 kg of rock and 2000 kg of muffle bucket) and the acceleration is 6.36m/sec^2, the inertial resistance becomes,

$$F_{i1} = 17000 \text{ x } 6.36 = 108120 \text{ N}$$

(ii) Frictional resistance F_{f1}

Assuming a vertical lift of 0.5 m, the vertical upward force F_{uf} due to blast is given as,

$$F_{uf} = E_{tv}/0.5$$
(11)

where E_{tv} is the vertical component of throw energy.

$$F_{uf} = \frac{0.28 \text{ x } 10^5 \text{ x } \sin 20^{\circ}}{0.5} = 1.149 \text{ x } 10^5 = 114900 \text{ N}$$

Similarly, the downward force due to bucket weight is given as

$$F_{df} = 17000 \times 9.81 = 166770 \text{ N.}$$

Therefore, the resultant downward force F_{rf} is given as,

$$F_{rf} = F_{df} - F_{uf} = 166770 - 114900 = 51870 \text{ N}$$

Now, the frictional resistance, $F_{f1} = \mu .\ F_{rf}$ N = 0.2 x 51870 = 10374 N

Therefore, the net resisting force,

$$F_{rf1} = F_{i1} + F_{f1} = 108120 + 10374 = 118494 \text{ N}$$

Net throwing force, $F_{ntf1} = F_{rf1} - F_{tf1}$ =118494-99288.2 = 19205.8 N

A thin rod can guide the bucket without failure since, the forward throwing force N is less than the net resisting force.

***Case II*:** When the allowed bucket displacement is greater than 3 m

Driving force

The energy of throw for specific charge of 1 kg/ m^3 from Fig. 5 can be computed after extrapolation as, 1.4 x 10^5 N - m. Total energy of throw associated with 6 m^3 of rock is given by,

$$E_{tt2} = 1.4 \times 10^5 \times 6 = 840000 \text{ N - m} \tag{12}$$

Therefore, energy acting in the horizontal direction, along the motion of the bucket (E_{th2}) = E_{tt2} cos20°

or $$E_{th2} = 840000 \times \cos 20^\circ = 789341.8 \text{ N - m} \tag{13}$$

This energy is assumed to be absorbed during 4.399 m travel of the bucket which is the distance between the centre of gravity of the rock mass before blasting and the outer edge of the muffle bucket after blasting (Fig.4b).

$$F_{tf\,2} = \frac{789341.8}{4.399} = 179436.64 \text{ N}$$

The forward force acting on bucket can be given as,

(14)

Resisting force

Since the moving mass is 17000 kg (6 m^3 or 15000 kg of rock and 2000 kg of muffle bucket) and the acceleration is 10.258m/sec^2, the inertial resistance is given by,

(i) Inertial resistance (F_{i2}) = m x a = 17000 x 10.2 = 174386.22

(ii) Frictional resistance (F_{f2})

Vertical upward force = 840000 sin20˚ = 287296.92 N

Vertical downward force due to weight = 166770 N

Since the vertical upward force is greater than the vertical downward force, the bucket is above ground, and hence friction between the ground and the bucket remains absent.

Therefore, the net resisting force, $F_{rf2} = F_{i2}$ = 174386.22 N

Hence, the net resultant forward force F_{ntf2} is,

$$F_{ntf2} = F_{tf2} - F_{rf2} = 179436 - 174386 = 5050.4 \text{ N} \quad (15)$$

This force is to be opposed by the rod which is provided for guiding. SAE 1035 steel rod with a yield strength S_{yt} of 36.7 kgf/mm^2 and ultimate strength S_{ut} of 58 kgf /mm^2 is used for guiding the bucket.

Stress induced in the rod due to the above force is given by,

$$S_{is} = \frac{5050.4 \text{ x } 0.8 \text{ x } 10^3}{\frac{p}{32} \text{ x } 253} = 2633.8 \text{ N/mm}^2 \text{ or } 268 \text{ kg/mm}^2 \quad (16)$$

The induced stress of 2633.8 N/mm^2 is several times greater than ultimate strength of the rod 367 N/mm^2. Therefore, the rod bends and allows the bucket to slip off smoothly to the designed distance.

5.0 TRIAL BLASTS

Trial blasts were carried out to find the efficacy of the muffling cum loading bucket. The blast results like bucket displacement BD_o and the average fragment size L for various specific charge, q, are given in Table 2. The burden, the spacing and the depth of blast holes in all the cases were maintained as 0.7m, 1m and 1.5m respectively.

5.1 Bucket Displacement

For an equilibrium, the bucket displacement was computed for different specific charge. The calculated values (BD_p) in case of higher specific charge were very close to the results observed during trials (BDo) (Murthy et al., 1994) but those with smaller specific charge seem to be conservative in comparison to the observed results (Table 2).

Table 2 - Displacement of bucket and average fragment size for various specific charge

S.No.	Specific charge, q (kg/m^3)	Observed bucket displacement, BD_o (m)	Predicted bucket displacement, BD_p (m)	Average fragment size, L (m)
1	0.26	0.25	0.64	0.70
2	0.31	0.50	0.78	0.45
3	0.41	0.80	0.92	0.36
4	0.42	0.50	1.30	0.36
5	0.52	0.75	1.78	0.22
6	0.68	1.70	2.31	0.13
7	0.72	1.85	1.95	0.12
8	0.86	1.60	2.60	-
9	1.02	3.00	3.00	-
10	1.01	2.80	2.80	-

Analysing the data on observed bucket displacements BD_o, a correlation between the specific charge, q, and the bucket displacement, BD, at 50 per cent confidence level (Fig. 6) obtained is given below,

$$BD = 3.29q - 0.68 \qquad (r = 0.96) \qquad (17)$$

where,

BD = bucket displacement, m,
q = specific charge, kg/m^3, and
r = correlation coefficient of the equation.

It can be estimated from Eqn. 17 that a specific charge of $1.11 kg/m^3$ will be required for a bucket displacement of 3m at 50 per cent confidence level.

5.2 Ground Attenuation

The peak particle velocity V was also observed during the trial blasts and the following ground attenuation equation was obtained by regression analysis:

$$V = 419\,(D/Q^{0.5})^{-1.43} \quad (r = 0.83) \tag{18}$$

where,

V	=	peak particle velocity, mm/sec
$D/Q^{0.5}$	=	scaled distance,
D	=	distance from the blast site, m
Q	=	maximum charge per delay, kg, and
r	=	correlation coefficient of the equation.

Thus the maximum charge per delay for a peak particle velocity of 20mm/sec at the nearest point of the transformer housing (D = 15m) works out to be 3.2 kg (Eqn.18).

5.3 Fragmentation

The fragment size should be optimum for efficient loading. The optimum fragment size L_{op} is related to the loading bucket capacity as shown below (Rzhevsky, 1985):

$$L_{op} = 0.15(E)^{1/3},\ m \tag{19}$$

where E is the capacity of the loading bucket in cubic metres.

Thus, the optimum fragment size works out to be 20 cm (Eqn.19) as the capacity of the muffling bucket is 2.5 cubic metres. It is apparent from Table 2 that a specific charge of about 0.55 kg/m^3 is required for such fragmentation. Thus, the designed specific charge of 0.6 kg/m^3 (Fig. 8) should be adequate from fragmentation view point.

Further, it can be seen (Table 2) that the boulder size decreases with the increase in the specific charge. The relation between the boulder size and the specific charge in this case (Fig. 7) matches closely with that provided by Langefors and Kihlstrom (1973). The thick dotted line in Fig. 7 represents relation in the present case study. On the basis of above analyses, an optimum blast pattern (Fig.8) was suggested considering the safety of the power house and productivity.

6.0 MONITORING

More than 300 blasts were supervised and monitored during the execution. The measured peak particle velocity in each case was within the safe limit.

The muffle bucket was successfully used to control fly rock and for loading the muck into 7 tonne dumpers.

7.0 CONCLUSIONS

Blasting was conducted very close to the power house complex of Upper Kolab Project, Orissa in India to remove 10,000 m^3 of granite for widening of tail pool. The safe limits of ground vibration and throw of rock were fixed as 20 mm/sec and 3 m respectively towards the power house side. A muffle bucket was used both for loading the blasted muck and to protect the power house complex from fly rock. 20mm thick MS plate was used to fabricate the muffle bucket considering the static and dynamic load to be experienced by it while loading and throw of muck.

The static load concept analyses the adequacy of mild steel plate thickness subject to the load experienced by it while handling muck. The dynamic load exerted by throw of muck on the bucket was computed. The necessary bucket displacement to absorb this force was determined for varying specific charge.

Analysing the trial blasts results, relations were obtained between (i) the muffle bucket displacement and the specific charge and (ii) the peak particle velocity and the scaled distance. Moreover, the average fragment size was found to be inversely dependent on the specific charge and the obtained relation between the two closely matches with that provided by Langefors & Kihlstrom (1973). More than 300 blasting events were monitored during execution. No damage to the power house complex was reported due to fly rock and ground vibration.

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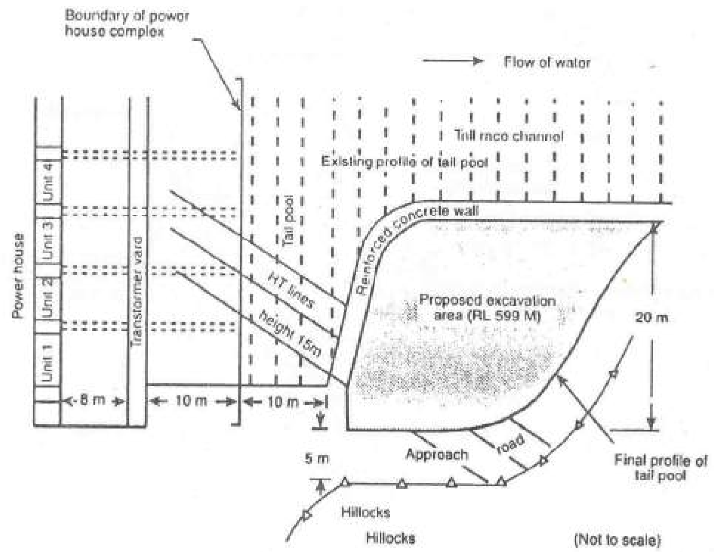

Fig. 1 - Schematic details of problem associated with tail pool widening at Upper Kolab Hydo-electric Project

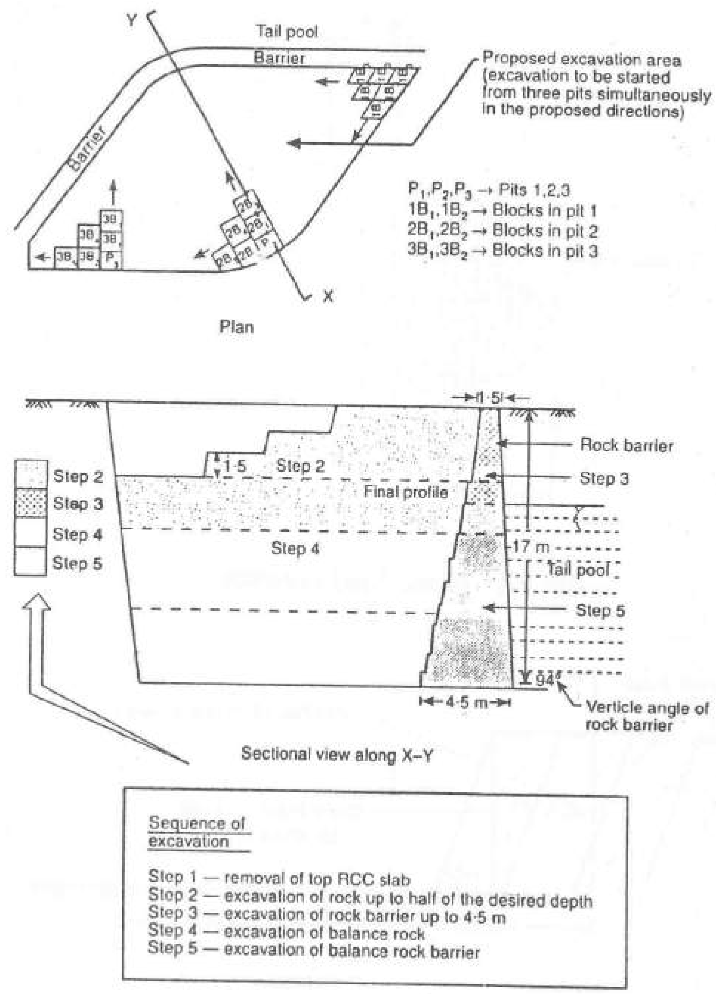

Fig. 2 - Sequence of excavation

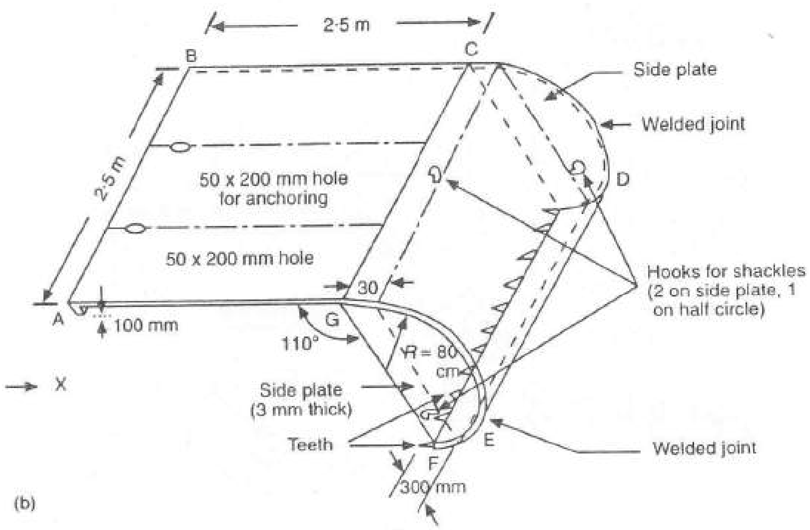

Fig. 3 - Muffle bucket

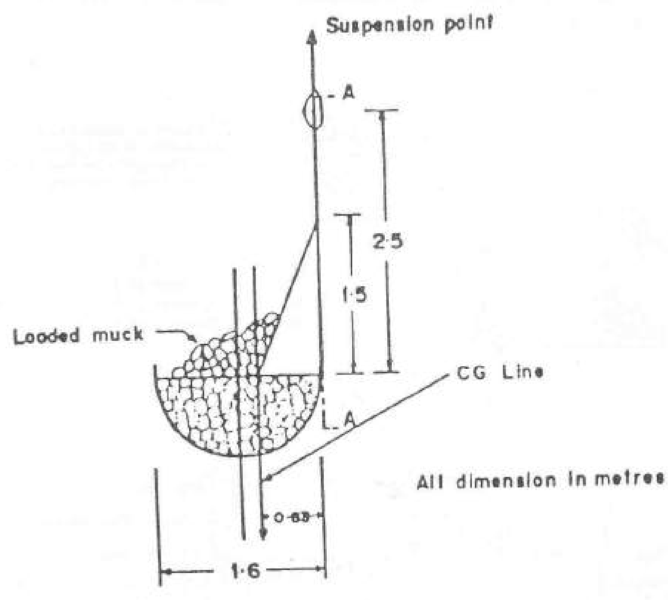

Fig. 4a - Static load concept

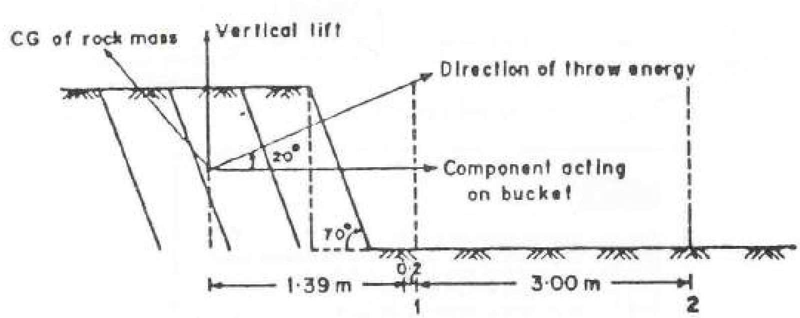

Fig. 4b - Dynamic load concept

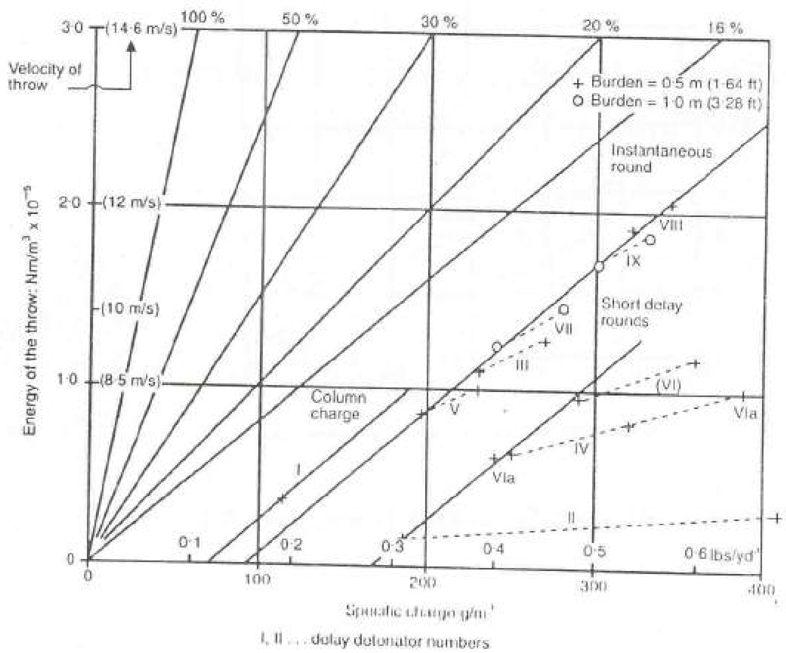

Fig. 5 - Energy of throw vs specific charge (Langefors & Kihlstrom, 1973)

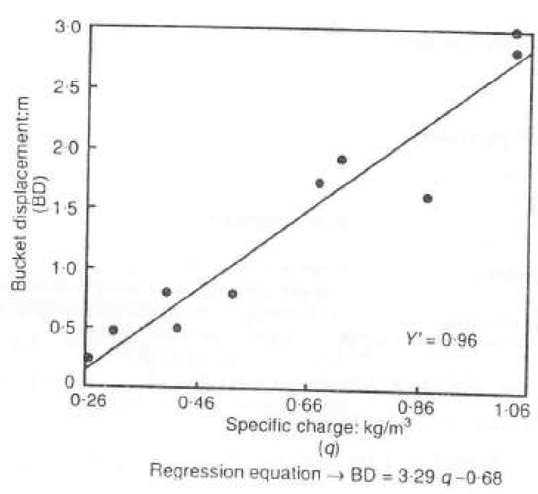

Fig. 6 - Bucket displacement vs specific charge

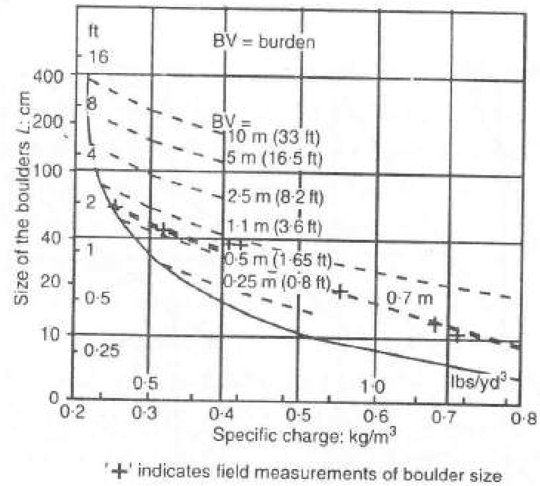

Fig. 7 - Fragment size vs specific charge (Langefors & Kihlstrom, 1973)

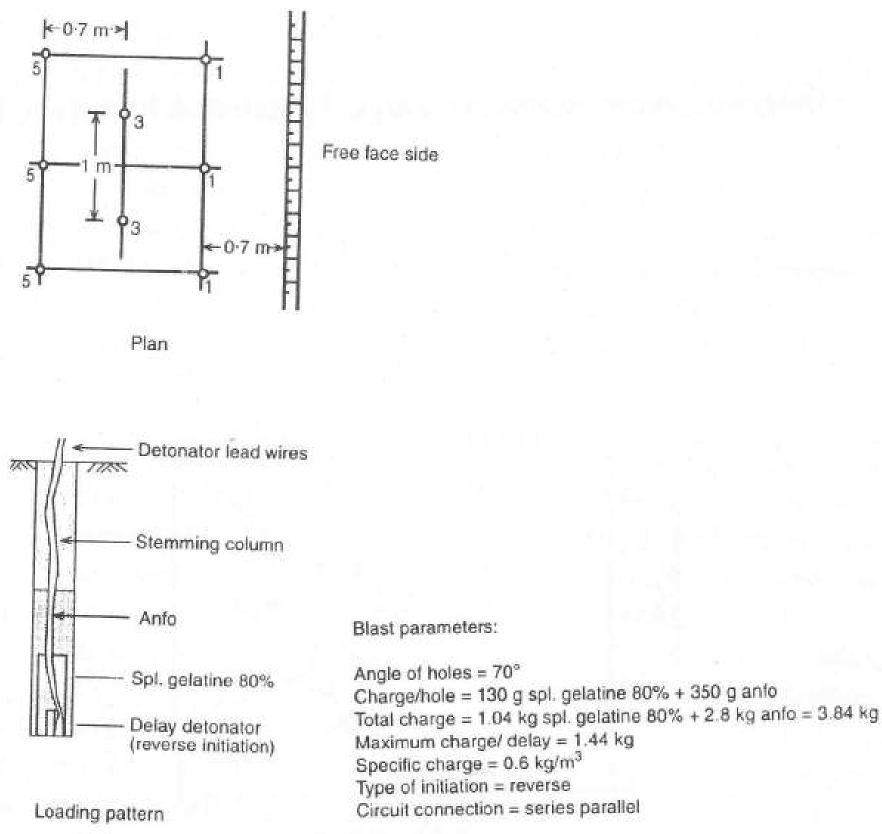

Fig. 8 - Blast design