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CRITERIA FOR SAFETY AND DESIGN OF STRUCTURES SUBJECT TO UNDERGROUND BLASTS

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Indian Standard

CRITERIA FOR SAFETY AND DESIGN OF STRUCTURES SUBJECT TO UNDERGROUND BLASTS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 24 March 1973, after the draft finalized by the Earthquake Engineering Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Underground blasting operations have become almost a must for excavation purposes. It is of utmost importance to define the damage criterion in terms of maximum permissible vibrations for the safety of nearby structures during underground explosions.

0.3 This standard is intended for the safety of normal structures on/in more or less homogeneous medium. It covers the criteria for safety of such structures from cracking and also specifies the effective accelerations for their design in certain cases. In the case of important structures or complex soil and rock conditions, monitoring of vibrations is suggested.

0.4 If the existing structures have cracks and other defects due to various causes before blasting operations are carried out, further damage could occur during blasting. It would, therefore, be desirable to carry out survey of such defects in nearby structures before undertaking blasting operations and fix appropriate telltales across old cracks for monitoring widening of cracks, if any.

0.5 It is assumed that adequate precautions will be taken against flying debris due to the underground blast by installing shielding devices above the blast area.

0.6 This standard is based on the currently accepted principles and practices in this field in this country and in other countries of the world. In the formulation of this standard due weightage has been given to international literature on the subject.

0.6.1 For evaluating the effective charge per delay, while using milli-second detonators, reference may be made to 'LONGEFORS (SL) and KIHLSTROM (B). Modern techniques of rock blasting, 1963. John Wiley and Sons, New York' (*see* **4.2.2.2**).

1. SCOPE

1.1 This standard deals with the safety of structures during underground blasting and is applicable to normal structures like buildings, elevated structures, bridges, retaining walls, concrete and masonry dams constructed in materials like brickwork, stone masonry and concrete.

2. TERMINOLOGY

2.0 For the purpose of this code, the following definitions shall apply.

2.1 Charge — An explosive used in blasting in rock excavations and quarry blasts. Straight dynamite containing nitroglycerin (60 percent), sodium nitrate, wood meal and an antacid is the most common explosive used in blasting and the same is considered in this code.

2.2 Underground Blasting — Detonation of explosive in drill holes and bore holes for rock excavation and quarry blasts.

2.3 Detonator — Device used for exploding the charge.

2.4 Delay Datonator — Device for exploding charge in two or more volleys with one application of electric current.

2.5 Natural Frequency of Structure (N) — Frequency at which the amplitude of vibrations of the structure becomes maximum when forces of different frequencies and of same magnitude are applied.

2.6 Frequency of Ground Motion (f) — Predominant frequency in the seismic waves produced due to underground explosion.

2.7 Damping — The effect of internal friction, imperfect elasticity of material, slipping, sliding, etc, in reducing the amplitude of vibrations. It is expressed as a fraction of critical damping.

2.8 Critical Damping — The damping beyond which the motion will not be oscillatory.

2.9 Hard Rocks — Granite, basalt, quartzite, marble, crystalline schists, massive slates and other hard massive crystalline rocks.

2.10 Soft Rocks — Shale, sandstone phyllites, laminated slates, mica schist, weathered hard rocks and other soft rock material.

2.11 Threshold Damage — Formation of new plaster cracks, widening of old cracks.

3. GENERAL PRINCIPLES

3.1 Underground explosions cause movement of ground on which the structure is situated which sets the structure into vibrations. These vibrations can be resolved in three mutually perpendicular directions, longitudinal, transverse horizontal and transverse vertical. Usually the transverse horizontal component is much smaller than the other two. The longitudinal and transverse vertical components are comparable in magnitude, therefore either of the two could be taken as a measure of the safety criteria.

3.2 The parameters associated with ground particle vibrations are acceleration, velocity and displacement and their respective frequencies. It is observed that the peak ground particle velocity in the medium at the site of the structure represents a good general index of damage independent of the frequency. It may, therefore, be adopted for specifying the safety criteria against threshold damage.

3.3 The ground particle velocity (*v*) at any point mainly depends on the amount of charge exploded, distance between the shot point and the station of observation and the local geology of the medium. The other less important variables are the explosives used, its coupling state with the surrounding medium and structural peculiarities of the medium, which generally do not figure in velocity charge distance relationship.

3.4 The threshold of human perception of vibrations is far below the threshold of damage, whereas the vibrations become intolerable at ground velocities higher than the velocity of threshold damage. Therefore, if the vibrations are kept below threshold of damage, they though perceptible, will not be intolerable to human beings.

3.5 At short range a wave radiates spherically and the amplitude of vibration diminishes approximately inversely as the distance. At long range, the wave splits into different types travelling at different speeds and variations in medium cause scattering. Geological discontinuities, such as faults may prevent propagation in a particular direction.

3.6 As the range increases, the charge required to cause damage increases and also the duration of vibration increases with the result that the area of damage in the structure would increase. For large charges and long ranges, an earthquake type analysis will be appropriate using response spectra for the ground motion caused by underground blast.

3.7 The response of a structure to the ground vibration, as mentioned in **3.6**, is a function of the natural frequency of the structure (*N*), frequency of ground motion (*f*), the damping in the material of the structure and duration and the intensity of ground vibration. It may be assumed that resonance is not likely to occur since the explosion causes impulsive ground motion which is complex and irregular in character, changing in frequency and amplitude and lasting for small durations.

4. SAFETY CRITERIA AGAINST THRESHOLD DAMAGE

4.1 Assessment of Ground Particle Velocity — The value of ground particle velocity may be computed from the following expression:

$$v = K_1 \left(\frac{Q^{2/3}}{R} \right)^{1.25}$$

where

v = ground particle velocity in mm/s,
K_1 = constant which may be normally taken as given in the Note,
Q = charge per delay in kg, and
R = distance from blast point in m.

NOTE — Value of K_1 — Soils, weathered or soft rock = 880; and hard rock = 1 400.

4.1.1 *Safe Ground Particle Velocity* (v)

4.1.1.1 For safety of structures from threshold damage, the ground particle velocity (v) as computed from **4.1** shall not exceed the following values:

a) Soils, weathered or soft rock — 50 mm/s
b) Hard rock — 70 mm/s

4.1.1.2 Where monitoring of ground particle velocity by means of suitable instruments is adopted as a means of vibration control, the peak ground particle velocity may not exceed the following:

a) Soils, weathered or soft rock — 70 mm/s
b) Hard rock — 100 mm/s

NOTE 1 — The safe values of v given in **4.1.1.1** and **4.1.1.2** are lower than those which may be intolerable to human beings.

NOTE 2 — These values are appropriate for masonry and will be conservative for concrete of M 150 quality.

4.2 Safe Distance from Blast

4.2.1 For charges up to 100 kg per delay, the safe distance of the structure from the blast point may be obtained from Fig. 1.

4.2.2 If the delay time $\tau \geqslant R/4C$ the ground motions are governed by the total charge weight in a single delay,

where

τ = delay time in seconds,
R = distance from the blast point in m, and
C = longitudinal seismic wave velocity of the medium in m/s (*see* **4.2.2.1**).

NOTE — If the delay time is less than that given in **4.2.2**, the designer may look for references.

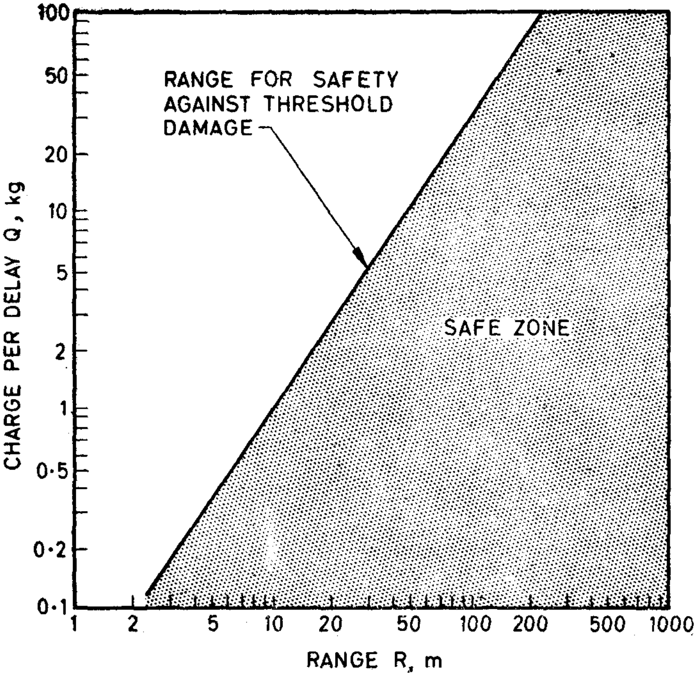

FIG. 1 CHARGE PER DELAY AS A FUNCTION OF RANGE *R* FOR SAFETY AGAINST DAMAGE DURING UNDERGROUND BLASTING

4.2.2.1 In the absence of actual data the values of longitudinal seismic wave velocity may be taken as follows:

Type of Medium	*Velocity C in* m/s	*Range of C*
Soils	1 000	200 to 1 800
Weathered and soft rocks	2 500	1 800 to 3 200
Hard rock	5 000	3 200 to 7 500

4.2.2.2 When use of millisecond delay detonators is contemplated for reduction of ground motion, the effective charge per delay may be computed as per accepted practice. However, for any combination of frequency and scattering time, the reduction factor may not be taken less than 0·5 (*see* **0.6.1**).

5. GROUND ACCELERATION FOR DESIGN

5.1 For large charges more than 100 kg/delay, where the safety criteria against threshold damage given in **4** are violated and it is desired to design structures for seismic effects of the blasts, the following equation may be used for finding the design acceleration in the horizontal direction:

$$\frac{a}{g} = \frac{K_2 Q^{0.83}}{R^2}$$

where

a = design acceleration in cm/s^2;
g = acceleration due to gravity in cm/s^2;
K_2 = constant (which may be taken as 4 for soil, weathered and soft rock and 6 for hard rock);
Q = charge per delay in kg; and
R = distance of structure from blast point in m.

5.1.1 The design acceleration so obtained should be uniformally applied to the structure.

6. MONITORING

6.1 Monitoring of ground vibrations may be necessary for various reasons as follows:

a) To determine by pilot tests, the maximum charge Q that may be used in blasting operations to keep the ground particle velocity at the site of structures within the safe values given in **4.1.1.1** or for determining the accelerations for design;
b) To determine by pilot tests the constant K_2 to be used in **5.1** and longitudinal wave velocity for use in **4.2.2**; and
c) To control the charge during actual excavation operations by keeping the ground particle velocity within the safe values given in **4.1.1.2**. This will particularly be useful for excavations in built up areas.

6.2 For measurement of ground vibrations, three types of instruments could be used, namely, accelerometer, velocity pick up or displacement meter. Of the three, the velocity pick up will be most appropriate for small charges and short ranges and the accelerometer for large charges and long ranges. The frequency response of velocity measurement should be flat above 10 c/s and in the case of acceleration measurement it should be flat in the range 0 to 100 c/s.

6.2.1 Where a threshold ground velocity is specified, peak velocity sensors could be used which would activate a warning system, either visual in the form of light indication or sound in the form of alarm.

6.3 In case a displacement meter is used, the peak ground particle velocity shall be obtained from the displacement *vs* time record by measuring the maximum slope of the curve.

6.4 Subsidence of the structure could also be monitored.

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