Journal of Rock Mechanics and Geotechnical Engineering 8 (2016) 248–255

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Technical note

Safety of engineered structures against blast vibrations: A case study

G.R. Tripathy*, R.R. Shirke, M.D. Kudale

Vibration Technology Division, Central Water & Power Research Station, Khadakwasla, Pune 411024, India

ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form
26 October 2015
Accepted 27 October 2015
Available online 27 January 2016

Keywords:
Engineered structures
Safe vibration levels
Attenuation relation
Safe charges
Blasting pattern

ABSTRACT

Blasting used for rock excavation is associated with ground vibrations having potential damage to surrounding structures. The extent of damage produced in a structure depends largely on ground motion characteristics, dynamic characteristics of structure and the type of geological strata on which it is founded. The safety of surrounding structures against blast vibrations is a cause of concern. However, use of a systematic approach to rock blasting helps to complete the excavation safely in time without endangering the safety of surrounding structures. Various steps are commonly adopted at construction sites to ensure safety of engineered structures against blast vibrations, e.g. adopting a suitable safe vibration level, developing site-specific attenuation relation, estimating safe charges for different distances, designing blasting pattern, and monitoring vibrations during actual blasting. The paper describes the details of studies conducted for ensuring safety of an 85 years old masonry dam and green concrete of varying ages during excavation of about 30,000 m^3 of hard rock in Maharashtra, India. The studies helped to complete the rock excavation safely in time and the safety of the dam was ensured by monitoring blast vibrations during actual rock excavation.

1. Introduction

Blasting is used as an economical tool for rock excavation in construction, quarry and mining projects. However, a part of the explosive energy is always exhibited in the form of elastic waves during rock excavation by blasting. These waves traveling in all directions from the blasting site give rise to ground vibrations, which in excess may cause damage to the nearby structures (Ak et al., 2009; Elevli and Arpaz, 2010; Nateghi, 2011). Completion of excavation work without endangering the safety of surrounding structures is of great concern to all. Ground vibration is mainly affected by various blast design parameters, distance between the blast and observation points, geological characteristic properties of the rock mass and explosive characteristics (Elevli and Arpaz, 2010; Liang et al., 2011). Blast-induced ground vibrations are characterized by two important parameters, i.e. the peak particle velocity (PPV) and frequency. The damage potential of ground vibrations is largely quantified either in terms of only PPV (Edwards and Northwood, 1960; Duvall and Fogelson, 1962; Chae, 1978; Esteves, 1978; Langefors and Kihlstrom, 1978) or PPV and its associated frequency (Siskind et al., 1980; Dowding, 1985; BS 7385, 1993; Khandelwal and Singh, 2006; Ozer, 2008). Therefore, prediction of ground vibration levels at different distances from blasting location, assessment of their impact on surrounding structures and various means used to minimize ground vibration levels play important roles in successful application of drilling and blasting for rock excavation in construction, quarry and mining projects.

Over the last six decades, Central Water & Power Research Station (CWPRS), Pune, India has been associated with several case studies involving rock excavation at different construction sites close to various engineered structures such as gravity dams, bridges, tunnels, nuclear power houses, etc. The experiences helped to outline the general methodology of blasting to ensure safety of structures against blast vibrations. In this methodology of blasting, safe vibration level that a structure could withstand without producing any damage is adopted, attenuation relations describing propagation characteristics of blast vibrations are developed, safe charge weight per delay for different distances is estimated, and the blasting pattern used for rock excavation is optimized based on field trials with vibration monitoring. This methodology has been successfully used in a number of construction projects to ensure the safety of a wide spectrum of structures including engineered structures, residential and commercial buildings in urban areas, village houses, historical monuments, etc. The use of this generalized method not only helps to ensure the safety of structures against blast vibrations but also is equally effective in minimizing other unwanted effects associated with blasting such as airblast, flyrock, over-breakage. The paper describes in detail the application of this generalized methodology for excavation of about 30,000 m^3

* Corresponding author. Tel.: +91 02024103328.
E-mail address: grtripathy@yahoo.co.in (G.R. Tripathy).

Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2015.10.007

of rock for providing energy dissipation arrangements to an 85 years old masonry dam. The adopted methodology not only was able to complete the rock excavation in time without affecting the safety of the old dam as well as green concrete of different ages but also would find useful applications in solving various issues associated with blasting at construction, quarry and mine sites.

2. Methodology

Blast studies for excavation of rock at a civil engineering project site are mainly concerned with establishing safety criteria, developing site-specific attenuation relations for ground vibration, and predicting the quantities of charge weight that could be used without endangering the safety of nearby structures and the environment. The safe charges thus estimated are employed to design the blasting patterns with suitable delay intervals so that the maximum explosive energy is utilized in breaking and displacing the rock with the minimum unwanted effects, like ground vibration, airblast and flyrock. In many cases, it is also desired to achieve a smooth final surface at the perimeter of excavation. For this purpose, the blasting pattern has to be supplemented with an appropriate technique, like line drilling, pre-splitting, smooth blasting or cushion blasting. The following steps were adopted in the present study:

(1) Pre-blast survey was conducted for inspection and documentation of the condition of the dam and to examine the type of the rock to be excavated.
(2) Nine experimental blasts with varying charge weight per delay (Q) were conducted at the actual excavation site. The ground vibration data were recorded at different distances (R) using three component engineering seismographs, and were analyzed for PPV (V_P) and predominant frequency of the ground motion.
(3) Six concrete cubes of M-15 grade were cast at site. Using ultrasonic pulse transmission technique, P-wave velocity for all the cubes was measured at different ages of curing (1.25–7 days).
(4) The vibration data obtained were analyzed by the least square regression method to develop the empirical relationship between the scaled distance $R/\sqrt{Q}$ and V_P.
(5) Based on the information collected in steps (1)–(3), by reviewing the various safety criteria published in the literature, site-specific safety criteria were established.
(6) Safe charge weights for different distances of excavation from the various structures around the blasting site were estimated and used for design of the blasting patterns.
(7) During actual blasting operation, ground vibrations were measured on the dam and green concrete to ensure safety of these structures by modifications in blasting patterns, if necessary.

3. Site description

The Mulshi dam is located at latitude 18.5441°N and longitude 73.4650°E across the downstream confluence of two rivers, Nila Nala and Mula, near Pune City in Maharashtra, India. The construction of 1533.38 m long and 48.8 m high dam, a stone masonry structure in lime surkhi mortar, was completed in 1927 by the Tata Electric Companies (TEC), Mumbai (CWC, 2014). After the devastating Killari earthquake on 30 September 1993 in the western part of Maharashtra, the dam was reinforced by providing 36 buttresses along its length during 1995–1996. During this period, new reinforced cement concrete (RCC) spillway with gated structure was also provided. The spillway section of the dam is about 100.5 m long and has seven radial gates. Over the period of time, the rocks in the downstream side of the spillway gates have suffered deep erosion. To arrest further erosion in rocks, it was proposed to provide energy dissipation arrangements in the stilling basin area, which requires excavation of about 30,000 m^3 of hard rock. Fig. 1 shows the satellite image of the Mulshi dam with newly constructed energy dissipation arrangements in the stilling basin area (Google earth satellite image dated 11 January 2015).

The excavation area shown in Fig. 2 approximately spreads over 100 m × 150 m. However, in the stilling basin No. 1, which extends up to CH. 50 m (Fig. 2), no excavation was required. The required depths of excavation between CH. 50 m and 70 m, CH. 70 m and 125 m, and beyond CH. 125 m were about 11 m, 6 m and 3 m, respectively. Simultaneous blasting and concreting were carried out to complete the project in scheduled time. In addition to the old dam, safety of concrete of varying ages (green concrete) against blast vibrations was also required to be ensured. The rock formation at the dam site is of Deccan Trap basalt.

4. Damage potential of blast vibrations

The extent of structural damage produced from blast vibration depends largely on the quantity of explosive charge used, the distance from the blasting site, the properties of the media through which vibrations are transmitted, and the various blast design parameters adopted in addition to the characteristic properties of the concerned structure (Siskind et al., 1980; Dowding, 1985). From analysis of a large number of data on blast damage, investigators from various countries have established that the damage produced in a structure could be related to the PPV of ground motion (Edwards and Northwood, 1960; Duvall and Fogelson, 1962). In addition to the PPV, the associated frequency also plays a significant role in causing blast-induced damages in the structures (Siskind et al., 1980; Dowding, 1985; Khandelwal and Singh, 2006; Ozer, 2008). It is a well established fact that if a structure is subjected to ground vibrations near its fundamental frequency, the structure will amplify the vibrations. However, the ground vibrations below the fundamental frequency of the structure will cause the structure to vibrate at the most as much as the ground vibration level. If the frequency of the ground vibration is 40% higher than the fundamental frequency of the structure, the structure will vibrate with

Fig. 1. Satellite image of Mulshi dam (Google earth satellite image).