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Blast induced rock mass damage around tunnels

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ABSTRACT

Drilling and blasting is a preferred method of rock excavation world-wide due to low initial investment, cheap explosive energy, easy acceptability among the blasting engineers and, possibility to deal with different shapes and sizes of openings. Although, drill and blast method has witnessed significant technological advancements, it has inherent disadvantage of deteriorating surrounding rock mass due to development of network of fine cracks in it leading to safety and stability problems. The damage in the peripheral rock mass culminates in the form of overbreak and damaged zone beyond overbreak. In some cases the projects cost has increased more than 15% because of overbreak. Although significant efforts have been made to assess damage to the surrounding rock mass using different methods, the solution based on easily available site parameters is still lacking. Authors have carried out field investigations at five different tunnels located in Himalaya, India to study blast induced damage for wide range of rock mass quality Q values (0.03–17.8). In addition to Q, specific charge, perimeter charge factor, maximum charge per delay, advancement and confinement factors have also been used. Data sets of 113 experimental blasts are collected from the five tunnel sites. All the parameters, easily available to the site engineers, have been used for developing an empirical correlation to estimate the rock mass damage around the tunnel, which is discussed in the paper. The proposed empirical correlation has been validated using ultrasonic tests on rock core samples obtained from one of the experimental location.

1. Introduction

Rock excavation using drill and blast method (DBM) is commonly used in mining, quarrying and tunnelling world-wide. The drill and blast method is economical as compared to other mechanical methods utilizing rock breakers, tunnel boring machines and road headers especially with regards to tunnels excavation in varying geological conditions. Low initial investment, cheap explosive energy, easy acceptability among the blasting engineers, possibility to deal with different shapes and sizes of openings and reasonably faster advance rate in a suitable geotechnical mining condition collectively make DBM preferred method of rock excavation (Innaurato et al., 1998; Murthy and Dey, 2003 and Verma et al., 2015).

The drill and blast method has witnessed considerable technological advancements particularly in the area of explosives, initiating devices, automation in drilling techniques and blast designs (Dey and Murthy, 2011). Despite the technological advancement, DBM has the inherent disadvantage of damaging the surrounding rock mass resulting in the development of network of blast-induced cracks in the surrounding rock masses leading to safety and stability problems.

Blasting for underground excavation and tunnelling are difficult operations compared to open pit excavation due to lack of free face (Gupta et al., 1988; Adhikari and Babu, 1994 and Murthy and Dey, 2002). Practicing engineers attempt to achieve faster advancement in tunnel and underground excavation by employing drill jumbos. Such drill machine significantly reduces drilling time with improved accuracy. Faster advancement rate using higher amount of explosives leads to greater extent of blast induced rock mass damage (Murthy and Dey, 2003). Perimeter blasting techniques, such as smooth blasting (Holmberg and Persson, 1980) are commonly used to minimize damage to surrounding rock mass beyond the designed profile of tunnel. Despite the improvement in blasting techniques, rock mass damage is still inevitable and is evident in the form of increased support cost, slow tunnel advancement, unstable rock mass, prolonged incubation period of the projects and enhanced post-construction tunnel maintenance cost.

Various researchers have studied and given emphasis on determining the extent of unwanted damage induced by blasting beyond the desired perimeter of the tunnel. The significance and importance of this damage have been deliberated by various researchers (Langefors and Kihlstrom, 1963; Bauer and Calder, 1978; Oriad, 1982; MacKown, 1986; Singh, 1993; Scoble et al., 1997; Backblom and Martin, 1999;

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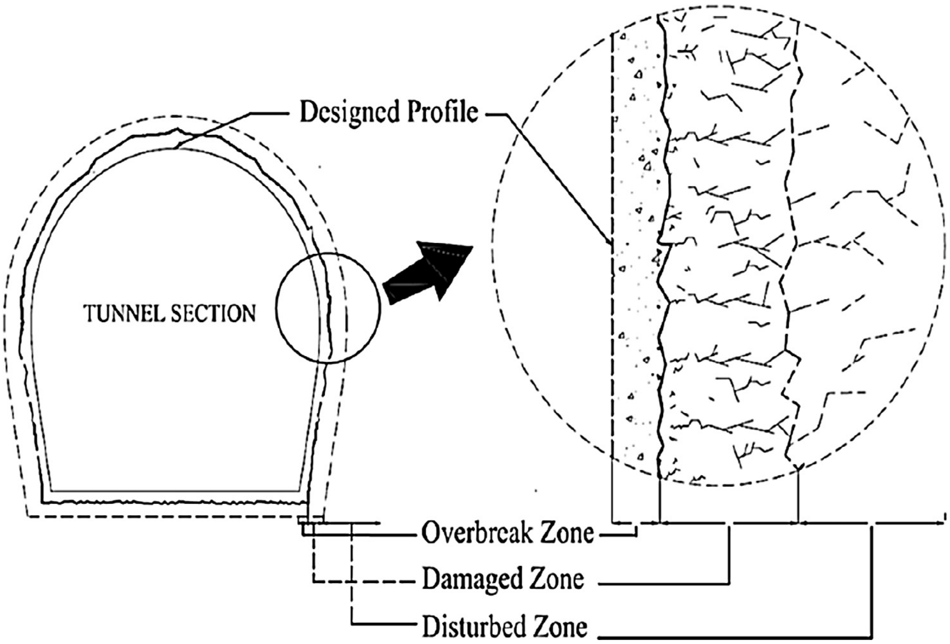

Fig. 1. Blast induced Rock Mass Damage Zone Tunnels (Adapted from Singh and Xavier, 2005).

Raina et al., 2000; Ouchterlony et al., 2002; Singh and Xavier, 2005; Warneke et al., 2007; Ramulu et al., 2009 and Fu et al., 2014). Damage around an opening in underground has been described by using terminology such as blast induced rock mass damage (BIRD), blast induced damage (BID), excavation damage zone (EDZ), rock mass damage zone (RMD) etc. Blast induced rock mass damage zone surrounding an underground opening consists of overbreak zone (failed zone), damaged zone and a disturbed zone. In the present research work, the definition and significance of the three zones are as discussed below and shown in Fig. 1.

The overbreak zone represents the zone beyond the minimum excavation line of the designed periphery from where rock blocks/slabs detach completely from the rock mass. It is a measure of difference in excavation between 'as designed profile' and 'as excavated profile'. Overbreak zone is undesirable and leads to cost over-run due to extra excavation and backfilling, shotcrete, concrete or other material as per designed support system. Overbreak varies from 5% to 30% which incurs significant cost and increases cycle time of the tunnelling operation (Ramulu et al., 2009).

The damaged zone is a zone around tunnel beyond overbreak zone. The irreversible changes in the rock mass properties take place in this zone due to presence of network of micro-cracks and fractures induced by the blasting excavation process. This zone is characterized by deterioration in mechanical and physical properties and increase in transmissivity properties (Saiang and Nordlund, 2009).

The disturbed zone is a zone in the rock mass immediately beyond the damaged zone where changes in the rock mass properties are insignificant and reversible. This zone is dominated by changes in stresses and hydraulic permeability (Palmström and Singh, 2001).

Overbreak as well as damaged zone has significant impact on the project cost, construction time, safety and performance of the underground structures. During construction of tunnels and caverns, damaged zone can adversely affect the stability of underground openings Enlarged extent of the damaged zone endangers safety of the front line workers as it may considerably reduce stand-up time of the rock mass. Functionality and post-construction performance of the structure will also be affected with enlarged extent of the damaged zone.

The acceptable limit of damage to the rock mass varies with the importance and requirement of the excavation in different industries (Olsson and Ouchterlony, 2003; Mandal et al., 2005). During construction of a high level nuclear waste disposal system, even the smallest disturbance to the rock mass may have significant implications due to possible percolation of contaminants along the fine cracks. Rock mass damage in mining and dimensional stone industries causes ore dilution. In tunnels too, rock mass damage has significant influence on cost and safety aspects. Extent and characterization of damaged zone pertaining to design and development of high level nuclear waste disposal repositories have been extensively studied (Martino and Chandler, 2004 and Hudson et al., 2009; Waltona et al., 2015). Daemen (2011) have emphasized on the importance of excavation damage zone (*EDZ*) assessment in design of nuclear waste repositories, especially at locations where permanent seals are to be installed. Importance to the blast induced rock mass damage in underground mining and tunnelling has, however, received relatively less attention (Scoble et al., 1997).

In rock mass damage studies pertaining to tunnels, overbreak zone alone has been considered invariably as damage zone, whereas it has been found that the damage by blast extends beyond overbreak zone and plays vital role in the stability of underground structures in the long-term sometimes. Mandal and Singh (2009) suggested that the damaged zone beyond overbreak zone should be considered in the design of the tunnel support systems.

Although significant efforts have been made to assess damage to the surrounding rock mass using different methods, the solution based on easily available site parameters is still missing. Review of available literature reveals that the results obtained from various blast induced damage estimation methods are inconsistent (Raina et al., 2000). Most of the methods are based on few cases and applicable to limited range of rock types (Raina et al., 2000).

The evaluation of rock mass damage from the surface geometry of the tunnel can be done by various methods such as manual measurements, standard surveying, laser surveying with reflectors, photographic sectioning and light sectioning methods. The limitations of these methods are that they are too subjective, manually intensive, time-consuming and often provide information only for a limited sections (Warneke et al., 2007). Moreover, in some cases this will provide the information about the overbreak and not the extent of damage in peripheral rock mass.

Some of the damage prediction models are based on laboratory investigations only wherein a single hole blast is considered. In actual field conditions because of number of holes, the quantity of explosive and interaction of different parameters make the problem complex and hence the simplistic laboratory scale study may not be able to