Available online at www.sciencedirect.com
ScienceDirect
Physics and Chemistry of the Earth 32 (2007) 907–916
PHYSICS and CHEMISTRY of the EARTH
www.elsevier.com/locate/pce

A study on the dynamic behavior of the Meuse/Haute-Marne argillite

M. Cai [a,*], P.K. Kaiser [a], F. Suorineni [a], K. Su [b]

[a] Geomechanics Research Centre, MIRARCO, Laurentian University, Sudbury, Ont., Canada P3E 2C6
[b] Agence nationale pour la gestion des déchets radioactifs (ANDRA), France

Received 5 May 2005; received in revised form 3 March 2006; accepted 15 March 2006
Available online 18 October 2006

Abstract

Excavation of underground tunnels can be conducted by tunnel boring machines (TBM) or drill-and-blast. TBMs cause minimum damage to excavation walls. Blasting effects on excavation walls depend on the care with which the blasting is executed. For blast-induced damage in excavation walls, two issues have to be addressed: rate of loss of confinement (rate of excavation) and dynamic loading from wave propagation that causes both intended and unintended damage. To address these two aspects, laboratory dynamic tests were conducted for the determination of the dynamic properties of the Meuse/Haute-Marne argillite.

In the present study, 17 tensile (Brazilian) and 15 compression split Hopkinson pressure bar (SHPB) tests were conducted. The test revealed that the dynamic strengths of the argillite are strain rate dependent. The average dynamic increase factors (ratio of dynamic strength to static strength) for tensile and compressive strength are about 3.3 and 2.4, respectively. A high-speed video camera was used to visualize the initiation of failure and subsequent deformation of the specimens. The direct compression specimens were found to deform and fail uniformly around the circumference of the specimen, by a spalling process. The SHPB Brazilian tests indicated that failure occurred in tension along the line of load application. Radial fractures were also observed. The test results can be used for the development of a dynamic constitutive model for the argillite for the prediction of damage in underground excavation utilizing the drill-and blast method.

Keywords: Argillite; High strain rate; Split Hopkinson pressure bar test; Dynamic strength; Fracturing; Brazilian test

1. Introduction

Clay shale, in general, is a porous sedimentary rock with relatively modest strength and anisotropic material properties. It is well known that the mechanical properties of shales depend on a variety of parameters including porosity, grain size, grain shape, grain and crystallographic preferred orientation, mineralogy, moisture content, and strain rate. This generally leads to a wide range of material properties for a given class of rock material and test condition.

For a few decades, the French National Radioactive Waste Management Agency (ANDRA) has worked out a specific concept for the deep geological disposal of radioactive waste. The Callovo-Oxfordian argillite (clay shale) investigated by ANDRA is a sedimentary rock without significant anisotropic material properties (Hoteit et al., 1999; Su et al., 2003). Drill-and-blast excavation method is the principal method used by ANDRA during the construction of the Meuse/Haute-Marne Underground Laboratory. In order to estimate the perturbations induced by excavation, the dynamic response of the argillite due to blasting needs to be investigated. When rock is blasted, it is subjected to strain rates in the range 10^{-4}–10^{3} l/s (Chong et al., 1980; Grady and Kipp, 1980) depending on the type of explosive and other factors. Blasting effects on excavation walls depend on the care with which the blasting is executed. However, independent of care, blasting generates dynamic waves in the rock mass that result in both fracturing of the rock mass, as desired in the excavation process, and

* Corresponding author. Tel.: +1 705 675 1151x5092; fax: +1 705 675 4838.
E-mail address: mcai@mirarco.org (M. Cai).

1474-7065/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pce.2006.03.007

additional dynamic loading with potential adverse consequences. Predicting the excavation-induced damage to the gallery by drill-and-blast method is important for the long-term stability and functionality requirement of repositories. To achieve this goal, it requires knowledge of the dynamic mechanical properties of the argillite because the determination of strength and constitutive relations of rock material for this purposes must be made at strain rates identical to those to which the rock will be subjected when blasted.

This study focuses on the determination of the dynamic properties of the Meuse/Haute-Marne argillite in surface laboratory. In underground excavation using the drill-and-blast method, two types of dynamic processes are involved, i.e., rapid confinement drop and tangential stress increase, and dynamic pressure waves due to blasting. To address these issues, dynamic laboratory tests were conducted for the determination of the dynamic properties of the Meuse/Haute-Marne argillite using split Hopkinson pressure bar (SHPB) tests. Both tensile (Brazilian) and compression SHPB tests were conducted. The stress–strain curves of the argillite at higher strain rates were obtained and the dynamic strength increase factors determined. These testing conditions approximate the impact of blasting on rock and represent the closest approximation of excavation. The dynamic failure processes of the argillites were also captured by a high-speed video camera.

2. Review of previous experimental study on dynamic behavior of rocks

2.1. Dynamic testing methods

Dynamic loads are characterized by a high amplitude and short duration stress pulse or a high strain rate. The strain rate effect on many engineering materials such as concrete, rock, ceramics, silicon carbide, polymeric fiber, composite materials, etc., has been studied experimentally by many researchers (e.g., Kumar, 1968; Chong et al., 1980; Lankford, 1981; Olsson, 1991; Gomez et al., 2001). Strain rates reported to be of relevance in rock mechanics range from 10^{-14} to 10^{8} l/s (Olsson, 1991) and indicates the large variations in strains to which rocks can be subjected depending on the mode of fracturing or excavation. The strain rate spectrum for engineering application is illustrated in Fig. 1 along with the common testing methods to obtain the dynamic properties. The strain rate achievable depends on the type of loading devices used. Ordinary hydraulic testing machines can load specimens at strain rates up to 10^{-3} l/s but specially designed testing machines can load up to 10 l/s. The strain rate obtainable by SHPB is on the order of 10–10^{4} l/s. Besides the laboratory testing method, in-situ blasting tests are usually conducted to examine the dynamic wave propagation and rock mass damage due to blasting (Wu et al., 1998; Zhao et al., 1999). The response of the rock is measured with accelerometers and relationships between peak particle velocity and blasting charge and distance established for either qualitative or quantitative damage assessment.

2.2. Strain rate dependent rock properties

Early tests on limestone indicated that the dynamic compressive strength of limestone is proportional to strain rate $\dot{\varepsilon}$ (Lankford, 1981). Zhao et al. (1999) tested the dynamic uniaxial compressive strength of granite in the strain rate range of 10^{-4}–10^{0} l/s, using a loading frame system. An average increase of 15% was observed in the strength when the strain rate increased from 10^{-4} to

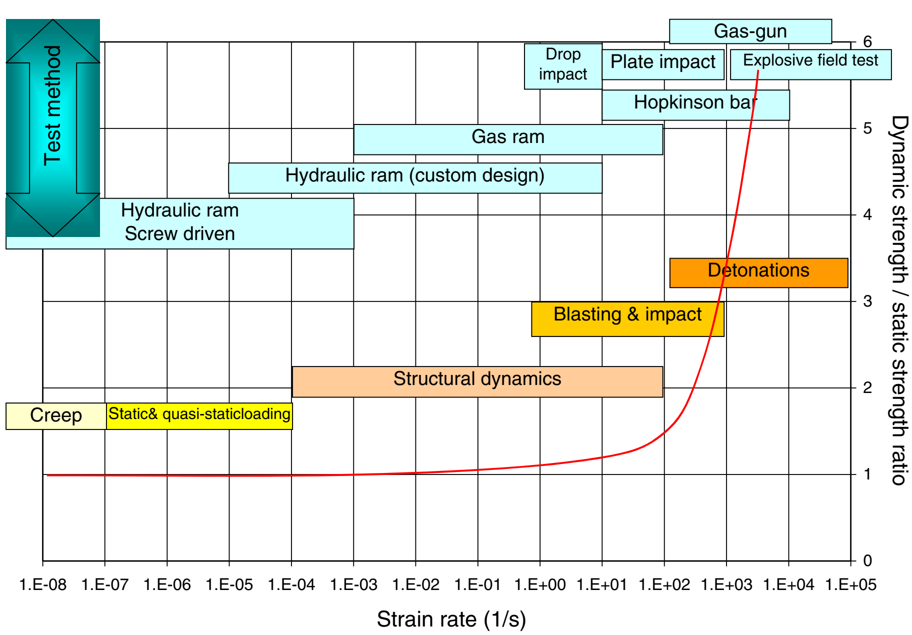

Fig. 1. Classification of dynamic problems and testing methods.