



CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation



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DETERMINATION OF BLAST INDUCED DAMAGE ZONE DURING TUNNEL EXCAVATIONS IN CARBONATE ROCKS

Hrvoje Antičević, Hrvoje Perković
Croatian Motorways Ltd., Širolina 4, Zagreb, Croatia

Abstract

Tunnel excavation by blasting inevitably results in the rock mass damage around the excavation profile. The rock mass damage immediately next to the tunnel profile emerges as the expanding of the existing cracks and the appearance of new cracks, i.e. as the change of the physical and mechanical properties of the rock mass. Measurements were obtained from the surface and from the tunnel opening by using geophysical and visual methods.

Keywords: blast induced damaged zone, underground excavation, in situ investigations, rock mass physical and mechanical properties

1 Introduction

In underground structures, unlike in other structures, the ground (soil and rock mass) acts not only as the loading mechanism, but as the primary supporting medium as well [1]. When an excavation is made, if the ground respond elastically, the strength of the ground keeps the hole open until support elements are installed. Even after support is in place, the ground provides a substantial percentage of the load-carrying capacity. The rock mass surrounding an underground structure is a construction material and its characteristics are as important as those in other aspects of civil engineering.

When an underground object is excavated in rock mass, the equilibrium state within a rock mass prior to the excavation is disturbed and the material particles surrounding the opening have to resist that pressure as an excess pressure which before was supported by the excavated material. The excavation boundary becomes a principal stress plane with one of the principal stresses (of zero magnitude) being normal to the surface, which causes a major disturbance of the pre-existing stress field in the principal stress magnitudes and their orientations [2]. The original stress field in a rock mass is deviated by the opening of a cavity and channelled around it to create a zone of increased stress deviator around the walls of the excavation. This natural phenomenon of channelling of stresses around the cavity (an arch effect) ensures the stability and the duration of the cavity [3]. Another effect of excavation is that any fluid pressure existing in the rock mass prior to the excavation will be reduced to atmospheric pressure at the boundary of an excavation open to the atmosphere, so any fluid within the rock mass will tend to flow into the excavation.

When an underground excavation is carried out by drilling and blasting, it inevitably results in the damage of the rock mass around the excavation profile [4]. The damage is manifested in the form of opening the pre-existing fractures, creation of new fractures and redistribution of stresses [4, 5, 6]. Consequences of these processes are considerable changes in physical, mechanical and hydraulic properties of the rock mass. The region in which irreversible changes to the physical, mechanical and hydraulic properties of the rock mass occur is referred to as Blast-Induced Damage Zone (BIDZ) [4, 7].

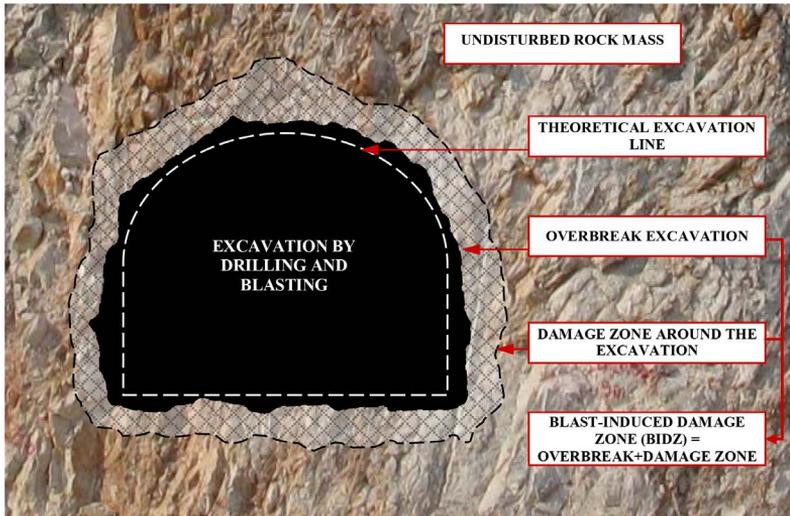


Figure 1 Schematic view of Blast-Induced Damage Zone (BIDZ)

Since the stability of the underground structure is dependent upon the integrity of the rock mass immediately surrounding the excavation, it is usually considered that the presence of the BIDZ can seriously affect the stability and performance of an underground excavation. However, this consideration is largely based on methods related to overbreak (which represents only a part of the damage zone), rather than accounting for the actual features of the damage [4, 7]. To be able to assess the significance of the BIDZ and its influence on the performance and stability of an excavation, the mechanical properties of this zone must be understood, especially the inherent properties of damaged rock such as its strength and stiffness [4, 7]. The importance of BIDZ depends on the sort, purpose and the required life span of an object, and BIDZ is present during the following works:

- surface and underground excavations in the exploitation of mineral resources;
- excavations in civil engineering (construction of roads, geotechnical and hydro-technical objects, foundation pits, road, railway and road tunnels);
- excavations for deep underground repository for dangerous materials (nuclear, medical and chemical waste, oil and gasses).

2 State of the art

In spite of the fact that many of the present and future major civil engineering underground projects are planned and executed in jointed carbonate rocks, only a few studies for civil engineering structures (road tunnels, railway tunnels, hydropower caverns, underground storage caverns) have considered the influence of excavation by drilling and blasting on the extent and properties of the BIDZ. Most of the investigations of BIDZ were carried out in hard rocks such as granites and gneisses, which are completely different in terms of physical, mechanical and hydraulic properties from carbonate rocks, so that the extent of the BIDZ and its influence on the excavation contour stability, support costs and safety of the workers and equipment are much smaller than those in carbonate rocks. In BIDZ research for nuclear waste repositories, BIDZ is treated from the perspective of potential path for the nuclear waste leakage, so only the hydraulic properties of BIDZ were the main subject of the research. Important research of rock mass damage around the excavating profile was done by Kujundžić in 1970's. In 1979 the measurement results using the cross-hole method in gallery tunnels 5 meters in diameter, during the construction of the Martinje dam were published.

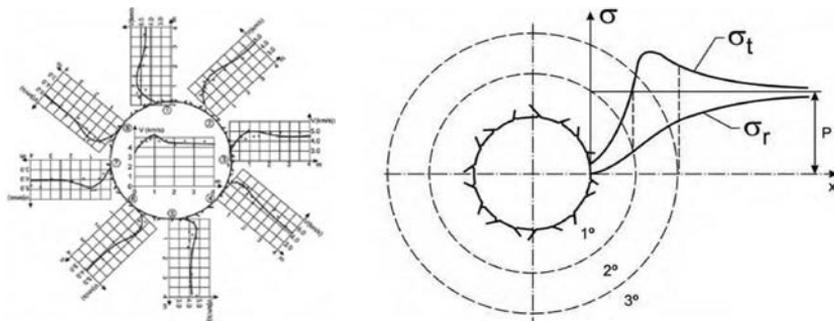


Figure 2 Graphical presentation of v_p wave velocity changes from the tunnel boundary and the characteristic zones around the excavation profile [6]

The measurements showed changes in the values of v_p wave velocities from the edge of the profile to the rock mass, and the authors defined three characteristic zones around the tunnel profile: the loosened zone (with lowest velocities), the stress bearing ring (with highest tangential stress and velocities) and the uninfluenced zone (with declining velocities and background stresses), Figure 2.

Capozza has made similar research to determine the damage zone around the excavation profile in a tunnel by using seismic cross-hole method [8]. The measurements consisted of P wave velocity changes in the first several meters from the profile edge (Figure 3). The values of P wave velocities in the vicinity of the excavation contour were reduced by 25-50% as compared to a more distant rock mass, so that the depth of the rock mass damage was three meters in the tunnel located at the depth of 2100 m.

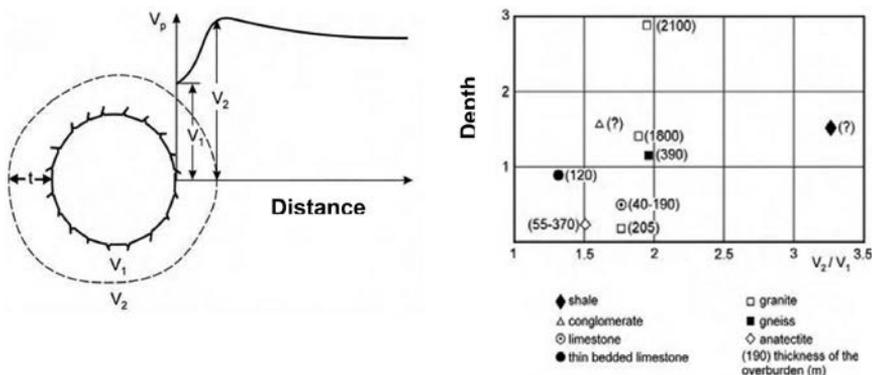
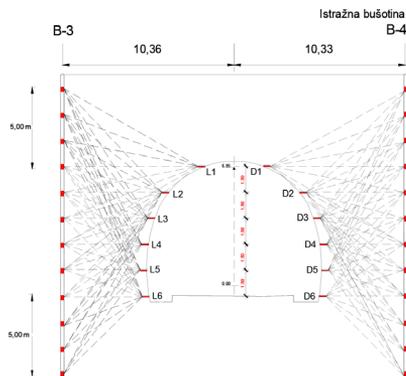


Figure 3 Graphical presentation of damage zone depth around the tunnel profile by comparing the propagation P wave velocities in different materials [8]

Investigations done in an iron mine in Sweden by using the cross-hole seismic method, spectral analysis of surface waves SASW and borehole video prospection (BIPS) resulted in blast damage zone depth of 0.5 to 1 m in eruptive rocks [9].

A recent significant research of BIDZ in carbonate rocks has been done on several road tunnels in Croatia by geodetic recording of the excavation profile, visual inspection of trial boreholes by means of a video camera, seismic cross-hole tomography, measuring the ground vibrations and recording the blasting parameters [4]. The damage zone was measured in carbonate rocks, and the detected damage depth was up to 3 m. This study has shown a potential influence of BIDZ on the stability of the excavation contour and increased construction costs, and has indicated the need to further study this phenomenon.



Građevina: TUNEL MALI PROLOG - postije iskopa
 Lokacija: Lijeve tunelaka cijev
 Burašine: L,D - pobudne; B3_B4 - prisludne
 Metoda: Seizmička cross-hole tomografija, Young-ov modul

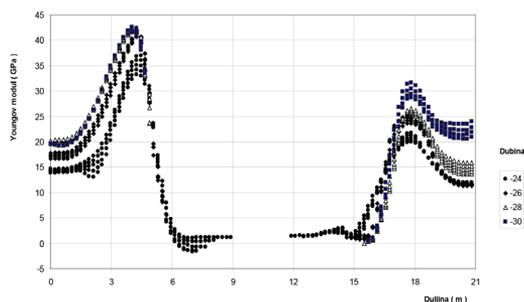


Figure 4 Rock mass stiffness reduction around the tunnel excavation profile detected by seismic refraction [4]

The in-situ methods of BIDZ investigation applied so far used the principle of drilling core mapping and registration of blasting parameters [10, 11], drilling core mapping and measuring peak particle velocities [12], measuring the visibility of traces of contour blastholes, overbreak and peak particle velocity [11, 13, 14, 15], applying visual methods [4, 9, 16, 17] and applying geophysical methods [4, 5, 6].

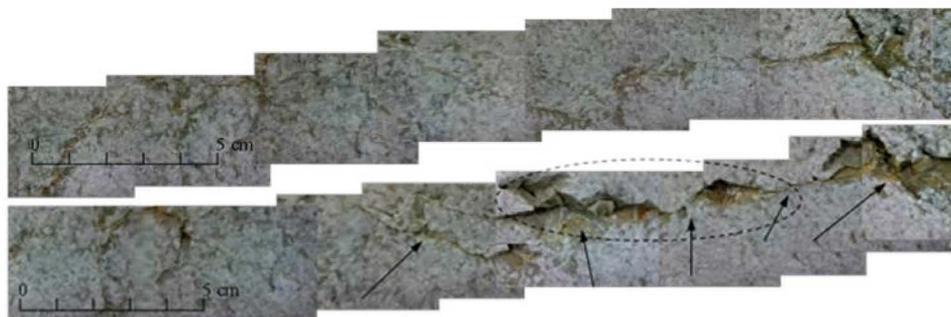


Figure 5 Borehole video prospection of rock mass damage around tunnel profile before and after blasting [4]

According to available literature, there does not seem to be a common opinion in selecting adequate research methods to define, classify and characterize the BIDZ [4]. Besides, the majority of the damage zone research has been done on laboratory models, which cannot properly estimate in situ rock mass conditions.

3 Proposed methodology of research

Regarding the complexity of the phenomenon, the research of BIDZ must be characterized by a multidisciplinary approach, i.e. the cooperation of different branches of science (civil engineering, mining, geology, geophysics and geodesy), which has not been applied in any research so far. The multidisciplinary approach includes in situ and laboratory research, analysis and interpretation of the results and numerical modelling. In situ investigations of an underground object should be planned in each geotechnical unit (zone with uniform rock mass properties) in two phases:

- 1 prior to drilling and blasting – measurements from the surface and from the tunnel profile;
- 2 after drilling and blasting – combined measurement from the tunnel profile and from the surface and measurements after placing a primary support.

The purpose of in situ measurements in two stages is to compare the state of the rock mass around the underground excavation contour before and after the excavation, i.e. to detect the BIDZ by the changes in the physical and mechanical properties of the rock mass. During in situ research, one should consider specific character of the underground space, such as difficult accessibility from the surface, limited working space, poor illumination and ventilation and other obstructions (electrical installations, water, machine vibrations due to transport, fan noise), which can negatively influence the research results and interpretation. Since different research methods should be combined for the first time, measuring equipment and research methodology ought to be modified. The measuring devices and equipment should be modified by changing the measuring characteristics of the sensors (adaptation of their sensibilities in the desired frequency spectres and the measuring range), by adapting length of seismic cables to the desired depth of work, and to carry out additional structural solutions and adaptations which will provide optimum working and measuring conditions.

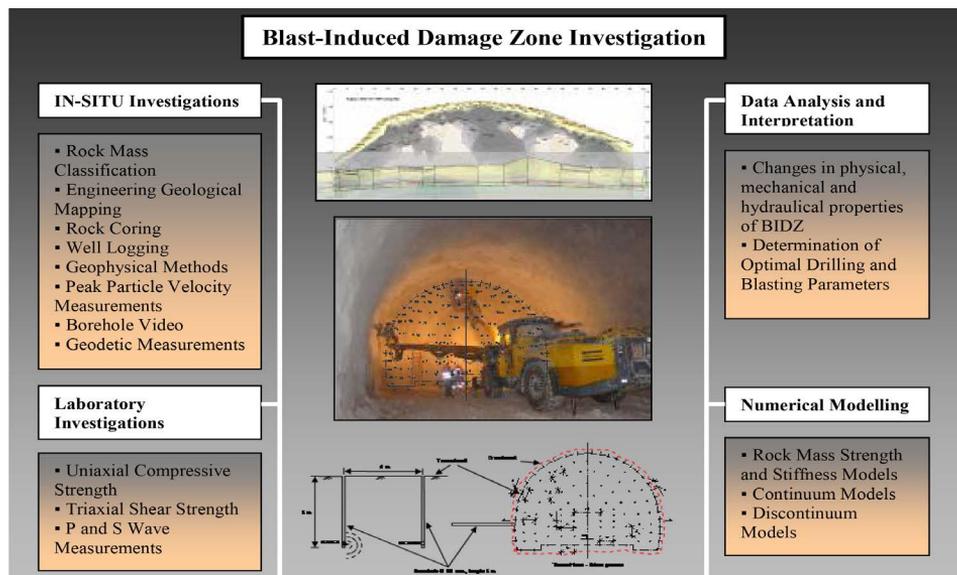


Figure 6 Proposed methodology of BIDZ research

The goals of proposed research methodology are:

- to obtain a more realistic picture of the medium complexity in order to detect BIDZ;
- to evaluate efficiency of various geophysical methods during the tunnel excavation;
- to compare results from standard and modified research methods;
- to establish and recommend the new methodology of in situ BIDZ research suited to underground space and all its limitations.

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