ACTA MONTANA IRSM AS CR (1996)
Series A, No.9 (100), 201–205

THE RELATION BETWEEN LABORATORY AND IN SITU DETERMINED DYNAMIC MODULI OF ROCK

Zuzana KRIŠŤÁKOVÁ and Blažej PANDULA*)

Institute of Geotechnics, Watsonova 45, 043 53 Košice, Slovakia
*)Technical University, Park Komenského 19, 04001 Košice, Slovakia

Abstract. Utilization of deformation characteristics of rocks has great importance in any geotechnical purposes. These techniques involving the propagation of acoustic or seismic waves are becoming of increasing importance since there are relatively inexpensive and quick in performance and suitable to apply in situ condition. However, in spite of this, such determined elastic moduli are not very common in rock engineering projects. For this reason there is an effort to find some correlation between static and dynamic constants of rocks to find their application in geotechnical praxes. In this paper we compared Young's moduli determined in situ with corresponding properties determined on samples subjected to testing in the laboratory of Technical University in Košice. In situ measurements were carried out by seismic signal enhancement instrument Bison in some Slovakian quarries. Data collection and analysis are discussed in detail and the results appeared to be promising.

1. Introduction

The development of mining industry is the foundation on which progress of many major branches of the economy depends. The adoption of new methods of surface mining and processing, however, is hampered by our knowledge of the physical and mechanical properties of rocks. Knowledge of these characteristics of rock is the necessary assumption for solving stability problems of any structure built in or from rock. Various techniques have been developed for determining important rock stress parameters such as dynamic moduli of material. Because deformation characteristic of material are also dependent on the velocity of propagation of elastic waves in material, some methods have been developed based on this relation. These techniques involving the propagation of acoustic or seismic waves are becoming of increasing importance because they are relatively simple, inexpensive and suitable to apply in situ conditions. However, in spite of this, dynamic moduli measurements are not common in engineering projects. The main reason for this is that most rock materials do not have behave in a perfectly linear elastic, homogeneous, isotropic manner, and because of this there is a difference between the static moduli that are required for design purposes and the dynamic moduli. Most of the studies show that dynamic moduli of elasticity E_d are higher than statical E_s. These differences in values of rock elastic properties obtained by static and dynamic methods can be explained by differences in testing conditions, especially in loadings applied on testing materials. Because of this differences there are efforts to find some good correlation between the static and dynamic moduli of rock material. According to the relation given by [Savich 1984].

$$\log E_s = a_1 \log E_d - b_1 , \tag{1}$$

where a_1, b_1 are stress–dependent parameters, it is possible to predict static modulus values from laboratory–determined dynamic values with an accuracy which could be acceptable for some practical purposes. According to this relation [Heerden 1987] subjected for testing different rock materials of range of modulus E_s from $7-150$ GPa. The rock material included a number of different sandstones, quartzites, norite and magnetite. An equation of the form

$$E_s = a\, E_d^b , \tag{2}$$

where a and b are dependent on the stress was fitted to the data points with a very good agreement. Thus this relation makes it possible to estimate the static modulus from laboratory– determined dynamic modulus with an accuracy which is acceptable for all practical purposes.

A logical expansion of studies on rock stress characteristics is to establish some correlation for in situ moduli where large volumes of rock are involved as the determination of the in situ static moduli of rock is an expensive and time–consuming operation while the determination of wave velocities is quick and inexpensive.

The main objectives of the present study is to compare in situ dynamic elastic moduli with the corresponding dynamic moduli obtained in laboratory on small samples. Having done this and to establish similar relation for this kind of moduli it could be then possible to obtain static moduli according to the above mentioned relationships.

2. Dynamically Determined Mechanical Rock Properties

For the computation of dynamic elastic constants, velocities of compressional and shear waves through the rocks and densities of rocks are required. Measurement procedures for density and compressional waves are reasonably standard and well known. Procedures for obtaining shear velocities are less straightforward. A simple economic method has been developed for determining the in situ compressional and shear velocities in rocks. In attempt to solve the problem of the shear waves, several steps were taken to provide unambiguous identification of shear wave arrival on the seismic waveform. This reliance on the distinctive features of shear–wave propagation. Technique used is described in the Report of investigation of the Institute of Geotechnics of SAS [Krišťáková 1990].

Dynamic elastic Young's modulus E_d can be calculated from the well–known relationship of isotropic materials, involving the velocities and the rock density

$$E = \rho V_s^2 \frac{3\left(\frac{V_p}{V_s}\right)^2 - 4}{\left(\frac{V_p}{V_s}\right)^2 - 1} , \tag{3}$$

where V_p is compressional and V_s shear velocity and ρ is rock density [Handbook of Engineering Geophysics 1985].

3. Young's Modulus Determined on Samples in the Laboratory

Laboratory experiments were carried out in conditions of the Technical University. Measurements were taken on different rock samples to search for manifold failure influence on ultrasonic waves as well as for comparing results in different rock surrounding. The rock material included a number of different limestone, andesite, and zeolite samples. These rock samples used in the research programme were received in the form of angular pieces with longitudinal diameter that was 5 times greater than the used wave length. The independence of reached results on geometry of rock samples was thus secured by this assumption. The rock specimen was mounted between the transmitter and receiver transducer holders and ultrasonic S and P waves were measured by using ultrasonic impulse instrument MATERIAL TESTER type 543 with an accuracy of $0.01\,\mu s - 0.02\mu s$ and frequency of 100 kHz and 40 kHz.

4. Young's Modulus Determined in situ Conditions

The in situ research was elaborated on the basis of laboratory measurements. Experiments were carried out in many Slovakian quarries with different physical and mechanical properties to compare the results with different rock surroundings. Seismic instrument BISON model 1580 was used for this experiment. The hammer blow served as a source of seismic waves. The impact was directed at the most compact part of the rock mass and two geophones were located in every station to obtain the reliable seismic waveform. The measured procedure is described in detail in the material of [Pandula 1995].

5. Results

Details of all results obtained during the investigation have been given elsewhere [Pandula 1995]. Dynamic elastic constants of both the laboratory and in situ conditions as well as the coefficient of failure were calculated. Typical values obtained are given in Tab. 1

In every case, the results show that $E_{\text{in situ}}$ is higher than E_{lab} and the amount of this depends on the coefficient of failure.

The plot of $E_{\text{in situ}}$ vs. E_{lab} is given in Fig. 1 for different coefficients of failure.

6. Discussion to the Results

In all cases, the results show that dynamic modulus determined in laboratory E_{lab} is higher than dynamical moduli obtained in situ $E_{\text{in situ}}$. The computation of deformation characteristics depends on propagation velocity of waves. Velocity measurements of waves propagating through a rock are influenced by rock type, texture, density, porosity, dimension of samples, stress level, fluid content, temperature, anisotropy etc. These are the factors that largely influence the values of

TABLE 1. Summary of Results

Locality	ρ kg.m^{-3}	V_p m.s^{-1}	V_s m.s^{-1}	E_{lab} Nm$^{-2}\cdot 10^{10}$	Coef. of failure	V_p m.s^{-1}	V_s m.s^{-1}	$E_{in\ situ}$ Nm$^{-2}\cdot 10^{10}$
Rohožník (limestone)	2708	6342	3670	9.11	24	3766	2394	3.60
B.Bystryca (limestone)	2659	5927	3193	7.02	49	3717	2123	3.01
Žirany (limestone)	2702	6148	3116	6.96	67	3448	1916	2.53
Tisovec (limestone)	2663	6038	3354	7.65	38	3143	1731	2.05
L.Lúčka (limestone)	2721	5732	3184	7.05	5	1923	1324	1.00
Margecany (limestone)	2696	6066	3370	7.82	74	3319	1971	2.57
Gombasek (limestone)	2699	5845	3247	7.27	69	2983	1449	1.53
Včeláre (limestone)	2690	6512	3238	7.54	40	3883	2549	3.92
Čamovce (andesite)	2415	5738	3188	6.27	30	3028	951	0.63
Vechec (andesite)	2630	5585	3102	6.46	34	3517	2350	3.19
Ruskov (andesite)	2672	5599	3110	6.60	60	2014	1228	0.97
Slanec (andesite)	2405	5296	2942	5.32	73	1875	1150	0.76
Vinne (andesite)	2425	4927	3889	4.95	22	4052	2447	3.52
N.Hrabovec (zeolite)	2401	2985	1667	1.70	52	2323	752	0.44

dynamic moduli. For that reason the coefficient of failure was also calculated for different kinds of rocks. In Fig. 1 both of these moduli – dynamically determined in laboratory and in situ – have been plotted for the different rock types as well as the coefficient of failure according to the above given legend of failure and quality of rock. A large variation was found between the two moduli and no correlation has been found yet.

7. CONCLUSION

The results obtained have their importance for solving stability problems of engineering projects built in or from rock as well as in the process of rock disintegration. The result shows that there may be some correlation between both moduli – dynamically determined on the samples in laboratory and in situ moduli but more research is needed in this area. The plots of both moduli must be investigated for different coefficients of failure respectively.

In addition, the obtained values of Young's modulus cannot be considered as a constant value with regards to many factors that influence these values (loadings, temperature, moisture content, presence of discontinuities, etc.). Additionally, it

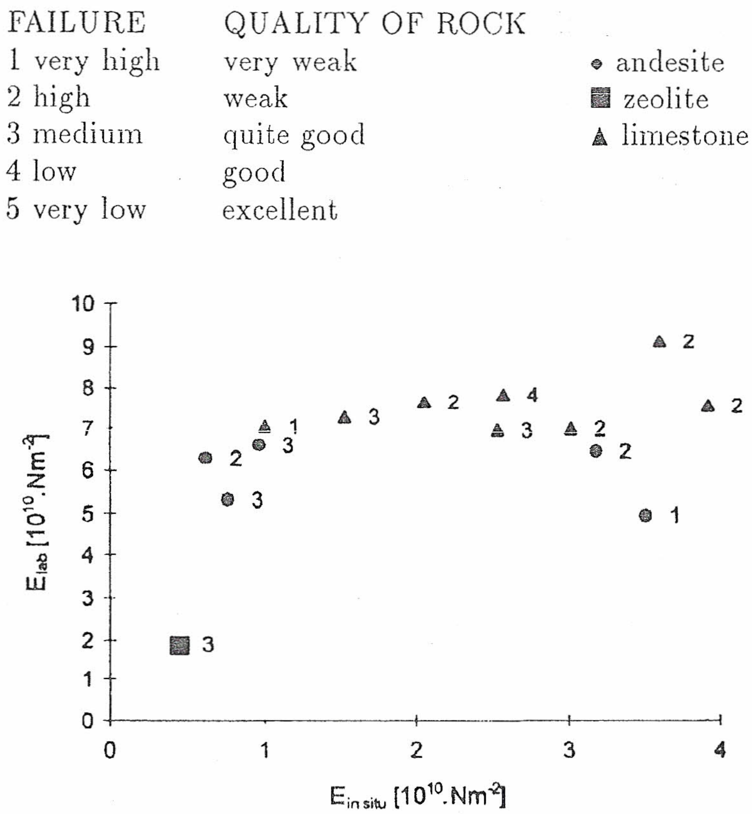

FIG. 1. $E_{\text{in situ}}$ vs. E_{lab} for different coefficients of failure

should be noted that the physical relationship from which Young's modulus is calculated holds only for homogeneous, linear, elastic and isotropic materials. Rock does not normally fulfil these conditions.

REFERENCES

Savich A.I. (1984), *Generalized relations between static and dynamic indices of rock deformability*, Translated from Gidrotechniceskoe Stroitelstvo 8, 50–54.

Heerden W.L. (1987), *General relations between static and dynamic moduli of rocks*, Int. J.Rock Mech. Min. Sci. and Geomech. abstr., 381–385.

Krišťáková Z. (1990), *Application of seismic methods for solving geotechnical tasks, Report of investigation*, Mining Institute of SAS Košice 1990.

Handbook of Engineering Geophysics (1985), Bison Instrument Inc. Minnesota, USA.

Pandula B. (1995), *Rock failure determination by seismic and ultrasonic methods and its application in rock blast disintegration*, Ph.D.Thesis, Košice.