ABSTRACT

Rock bolt is the primary active support essential to ensure safe working conditions during succeeding excavations in mines, tunnels and underground structures and other excavations. A rock bolt support enhances the mechanical properties of rock masses and reduces deformation. In this study, an extensive experimental study was conducted to determine the mechanical behaviour of bolt under axial and transverse loading conditions. For a pull-out test, rebar type rock bolts of 22 mm diameter and length of 600 mm were instrumented with four strain gauges along the length. The embedded length of the bolt was 450 mm and it was grouted with either resin, white cement or cement grouted inside a cement mortar cylindrical sample of diameter 250 mm. The diameter of the drill hole was varied as 32, 36 and 42 mm. The shear rate was varied in three groups viz. 60-80 μm/s, 130-160 μm/s and 200-250 μm/s for obtaining the effect of loading rate, if any, on the bond strength and stiffness. Apart from load-deformation relationships, the variation in axial strains was also measured with the pull load until debonding occurred. The study found that resin and white cement provided high bond strength over 4000 kPa for 32 mm diameter hole while cement grout provides resistance hardly up to 2100 kPa. Similarly, bond stiffness data revealed that hole diameter should be kept as low as possible for better performance of bolt if resin were to be used as grout material. Generalized equations of axial displacement and strain for bolt rod were also derived by modifying the equation proposed by Farmer, 1975. Two new parameters, α and β were introduced and the analytical results were compared with the measured values of 4 strain gauge locations. It was found that in most of the cases, the error of estimation ranges between 1/20 and 1/10 of the measured data signifying that the proposed equation can be used for predicting axial strain along the bolt rod. The importance of these two parameters was identified for the generic equation of pull displacement and axial strains.

The resistance of bolt in dowel action (bending of bolt) and strain development on the bolt rod were also determined by creating two joint surfaces and by applying transverse load in the middle. Joint apertures of 0+, 3 mm, or 6 mm between consecutive blocks of side 150 mm were casted with three type grout materials. The study provided an insight about the bending pattern of the bolt, especially the tensile and compressive zones in the convex and concave curvatures, and condition of grout in the inflection zone. It was also found that resin grout shears along the joint plane whereas cement and white cement grout are crushed near the inflection zone.

Numerical models were developed to validate the results obtained from the pull and flexural experiments. The major idea was to understand and evaluate the progressive debonding phenomena between the bolt-grout-rock interfaces in pull-load experiments. For this purpose, a cohesive damage model was implemented in the interfaces in the numerical models and a damage parameter for three grout types was determined. Similarly, bending patterns of bolt rod, shearing/crushing of grout and location of inflection zone in numerical flexural experiments were also validated with those of experimental results. The study showed that inflection zones, where curvature changes from concave to convex, were near the joint surface and experienced high plastic strains.

Keywords: Instrumented rock bolts, Bond strength and stiffness, Bending of bolt, Debonding, Inflection zone, Damage parameter.