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Uplift Capacity of Fixed Shallow Anchors Subjected to Vertical Loading in Rock

Dae Hong Kim
Korea Electric Power Research Institute (KEPRI)
Korea Electric Power Corporation (KEPCO), Daejeon, Korea

Seung Rae Lee
Department of Civil & Environmental Engineering
Korea Advanced Institute of Science and Technology, Daejeon, Korea

This paper presents the results of full-scale loading tests performed on 54 passive anchors and 4 group-anchored footings grouted to various lengths at several sites in Korea. Various rock types were tested, ranging from highly weathered shale to sound gneiss. In many tests, rock failure was reached and the ultimate loads were recorded along with observations on the shape and extent of the failure surface. Laboratory tests were also conducted to investigate the influence on the bond strength of the corrosion protection sheath. Based on test results, the main parameters governing the uplift capacity of the rock-anchor system were determined. Through evaluation of the ultimate uplift capacity of anchor foundations in a wide range of in situ rock masses, a rock classification suitable for a transmission tower foundation was developed. Finally, a very simple and economical design procedure is proposed for rock-anchor foundations subjected to uplift tensile loads.

INTRODUCTION

In foundation design for transmission towers, live loads such as wind are considered the dominant major load causing uplift tensile forces to the foundation (EPRI, 1992). To resist such uplift loads, conventional pad-and-pier footings require very deep foundations, resulting in high construction costs. In an effort to reduce costs, rock-anchor footings have been implemented. This rock-anchor system consists of vertical grouted anchors tied into a foundation at shallow depth, thus transmitting the uplift tensile forces to a load-bearing structure (BS8081, 1989).

Design of rock-anchor foundations requires the specifications of the diameter, length and spacing of the individual anchors. These design parameters are normally determined so as to insure the overall stability of foundations, considering the nature of the surrounding rock mass, the allowable displacements, and the risk of tendon corrosion. In order to assess the overall safety factors for the anchored foundations, the following failure modes (Xanthakos, 1991) must be examined:

- Structural failure of steel tendon
- Bond failure at tendon/grout interface
- Shear failure at grout/rock interface
- Rock pull-up failure
- Inoperable system deterioration

Fig. 1 shows the first 4 failure modes schematically. The stability of a rock-anchor system is related to the volume of rock mass mobilized to resist the uplift force. The shape of such failure volume is commonly assumed to be an inverted cone with its apex at the top, middle or bottom of the fixed anchor, and an included angle of 60° or 90°, depending on the rock type (Littlejohn and Bruce, 1977). Then, the embedment depth is obtained by equating the applied load either to the weight of failure volume, or to the shearing strength mobilized on the conical failure surface.

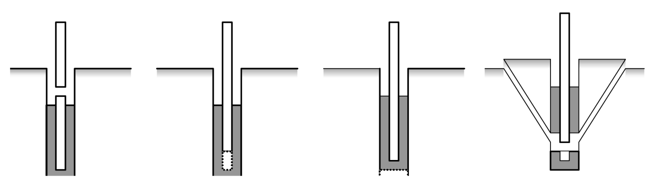

Fig. 1 Uplift failure modes of rock anchor

Extensive studies on the strength and behavior of grouted anchors are available in the literature (Ballivy and Dupuis, 1980; Goris and Conway, 1987; Hassani and Rajaie, 1990; Hassani et al., 1992; Littlejohn, 1992). Most of these show a strong correlation between bond strength, tendon, grout and rock-mass properties. The current design practice of rock anchors is rather conservative, mainly because of difficulties in accurate determination of in situ rock properties.

In this study, we performed a large number of extensive full-scale field tests as well as small-scale laboratory tests in order to develop a practical and economical design method, which is necessary for rock-anchor foundations to be used for transmission towers. From a detailed analysis of the test results, we have determined the main parameters governing the uplift capacity of rock-anchor systems. By evaluating the ultimate uplift capacity of anchor foundations in a wide range of in situ rock masses, we have developed a rock classification suitable for application to transmission tower foundations. In particular, a number of full-scale group-anchor tests demonstrated the practical applicability of rock-anchor foundations in terms of their capacity to resist the uplift design load of a 154-kV transmission tower (lower than 1.2 MN per leg). Laboratory tests were also performed to investigate the influence of a corrosion protection sheath on the bond strength at the tendon/grout interface when the sheath is installed in cement-based grout. Finally, we have proposed a very sim-

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