Ground movements caused by tunnelling in chalk

S. D. PRIEST

Dr B. C. Burman, Coffey and Partners Pty Ltd, Sydney

The Author has made good use of a unique opportunity to measure the reaction of a jointed rock mass to changing support conditions. In particular, the recording of movements across discontinuities and the horizontal strains across the tunnel line provide data on the basic deformation modes of jointed rock that, to my knowledge, have not previously been reported in the geotechnical literature. However, the subsequent analysis of these movements in terms of a simple elastic continuum is not consistent with the irregular deformation modes and the known discontinuous nature of the rock mass. It can only be justified in terms of mathematical convenience and even then the analysis offers little to the understanding of the behaviour of jointed rock masses. I believe that more meaningful results can be achieved by explicitly recognizing the discontinuous nature of rock masses in numerical analyses of such situations. I wish to present selected results from a study of the behaviour of discontinua¹⁰ which are in general agreement with the Author's mechanistic interpretations, to comment on the modelling of discontinua by continuum mechanics and to indicate the features of discontinuum behaviour which are significant to the understanding of jointed rock masses.

43. As part of a study of the mechanics of discontinua I developed a numerical model¹¹ suitable for representing jointed masses. The approach, based on finite element procedures, models the interaction of discrete blocks in the jointed mass via special contact elements. These elements are capable of representing non-linear normal and shear behaviour of the contact zone in terms of relative translational and rotational displacement of block centroids. The approach is described as the 'discrete element method' and, in two dimensions, represents the jointed medium as an interconnected structural framework in which the nodes or discrete element centroids have two degrees of translational freedom and one degree of rotational freedom. This arrangement produces an efficient numerical technique in which a large jointed mass can be modelled at minimal cost.

44. The discrete element method is well able to model the separate development of normal and parallel movements along discontinuities given in Figs 3-5. In addition, results available from the analysis of idealized slope and underground opening situations confirm the Author's contention that 'discrete relative movement and rotation of blocks' is a basic deformational mechanism for jointed media. Unfortunately, it is not possible to present results which relate directly to the tunnel situation described by the Author but available results for an idealized slope configuration are pertinent.

45. Figure 16 shows the distribution of normal and shear stresses along a continuous jointed plane intersecting the toe of an excavation in regularly jointed, blocky

DISCUSSION

material. The mass is comprised of a continuous joint set dipping into the excavation at an inclination of 1 in 2 and a discontinuous set of perpendicular cross joints. The important feature of these results is the non-uniformity of stress distribution due to the rotation of individual blocks forming the jointed mass. It is significant that, even though block rotations are extremely small (of the order of one tenth degree), the normal stress distribution at the toe of the slope shows variations of about 100% above and below the average value at that location. This non-uniformity of load distribution due to rotation of individual blocks is a basic feature of the behaviour of discontinua. The non-uniformity can be of significant proportions even where the jointed medium is composed of ideally regular and smooth blocks which are packed together without imperfections. These idealized conditions are not likely to be achieved in naturally occurring rock masses.

46. An indication of the sort of non-uniformity in load distribution within real masses can be obtained from a series of model wedge tests. The models were constructed from uniformly sized, cylindrical blocks, accurate to within 0.1% of their diameter and arranged in 30° wedge configurations. Fig. 17 shows the boundary load distribution from a typical test and the extreme non-uniformity that can result even where the individual blocks are within relatively close tolerance limits. The results

Fig. 16. Distribution of normal and shear stresses along potential failure plane in jointed rock slope

Fig. 17. Boundary stress distribution for wedge of cylindrical blocks

from this set of model tests indicate that load distribution within a nominally regular mass can vary by at least $\pm 50\%$ from the average because of packing imperfections. Subsequently, it was possible to predict this non-uniform load distribution by incorporating the major packing imperfections into the numerical models using the discrete element technique. Cylindrical blocks remove imperfections associated with rough contact surfaces and hence additional non-uniformities would be introduced by this factor into any real discontinuum.

47. The Author's results in Fig. 7 for horizontal strain profiles across the tunnel line show non-uniform distributions similar to those I have reported for boundary loadings. These results confirm my belief that non-uniformity of load distribution is a fundamental feature of the behaviour of jointed rock masses. However, variations of several hundred per cent of the 'average' value can be achieved in a closely jointed, weak rock mass. It is commonly proposed that such rock masses can be treated as homogeneous, isotropic materials and their response to load judged in terms of averaged conditions for an equivalent pseudo-elastic continuum. The use of averaged conditions is likely to be even further in error for widely jointed, competent rock masses and hence the concept of an equivalent continuum must be treated with caution because fracture of individual rock blocks and subsequent behaviour of the mass will be governed by local concentrations rather than by averaged conditions.

48. The Author has chosen to represent the closely jointed weak rock mass as a homogeneous, isotropic, elastic continuum in attempting to predict ground movements with a numerical model. However, this approach can represent neither the non-uniformity of load distribution within the mass nor the basic deformational mechanisms

which occur within a jointed medium. It is strongly suggested to the Author that he reconsider the analysis of this unique set of ground movements incorporating the discontinuous nature of the rock mass explicitly into the numerical treatment.

Dr Priest

The main objective of the work described in the Paper was to obtain actual data on the ground movements caused by tunnelling; much of the tunnelling research carried out or sponsored by the Transport and Road Research Laboratory is devoted to this end. Such measurements provide a true basis from which to judge the usefulness of existing theoretical models.

50. The analysis of the results obtained at Chinnor was carried out using existing relatively simple techniques in order to back calculate values of ground modulus rather than produce a detailed model of ground behaviour. The assumption that the ground mass near the tunnel behaved as a continuum, with a modulus considerably less than that of its component intact elements, is clearly an over-simplification. The approach has, however, given some insight into the complicated relation between site investigation results, tunnelling methods and ground behaviour, and has pointed the way for further research.

51. The approach described by Dr Burman, based on an analysis of the interaction between discrete blocks, is particularly suited to slope stability problems in cases where block sizes are large and discontinuity orientation patterns are simple and easily determined. Such an approach may also provide a useful basis for analysis of the behaviour of a tunnel in discontinuous rock. In the case of the tunnel at Chinnor, however, the highly varied and complicated pattern of discontinuity orientation, with discontinuity spacings of approximately 0.1 m, could mean that construction of a theoretical block model of the ground above and around the tunnel would be complicated and necessarily involve considerable extrapolation from existing data.

References

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