J. S. Afr. Inst. Min. Metall., vol. 89, no. 4.
Apr. 1989. pp. 111-115.

Potential rockfalls in conventionally supported stopes—a simple probabilistic approach

by T.R. STACEY*

SYNOPSIS

This paper considers the probability of the occurrence of potential rockfalls in deep-level gold mines where there is point support (props, pipesticks, and timber sticks). The investigation described gave rise to the following implications: natural joints subparallel to the direction of strike have a controlling influence on the potential occurrence of rockfalls; with discrete types of support such as props at typical sparings, there is a significant probability of the occurrence of potential rockfalls; the use of headboards oriented in the direction of strike reduces the probability; and loss of support from a prop increases the probability.

SAMEVATTING

Hierdie referaat skenk aandag aan die waarskynlikheid van die moontlike voorkoms van rotsstortings in diepgoudmyne waar daar puntbestutting (stutte, pypstokke en houtstokke) is. Die ondersoek wat beskryf word, het die volgende implikasies gehad: natuurlike nate subparallel met die strekkingsrigting het 'n beherende invloed op die moontlike voorkoms van rotsstortings; met nie-deurlopende bestutting soos stutte met tipiese spasiëring, is daar 'n aansienlike waarskynlikheid van die moontlike voorkoms van rotsstortings; die gebruik van kopplanke wat in die strekkingsrigting aangebring is, verminder die waarskynlikheid; en die verlies van steun deur 'n stut verhoog die waarskynlikheid.

Introduction

The deep-level stopes of South African gold mines are surrounded by jointed and fractured rock. The disposition of fractures has been studied in some detail, a representation of this fracturing being shown in Fig. 1. It has been shown[1] that both shear and extension fractures are formed parallel to the stope face, and that the spacing of these fractures in the immediate hangingwall of the stopes is very close. Fractures do not, in general, form in directions other than sub-parallel to the stope face. With this fracture geometry, there is no potential for falls of rock from the hanging unless failure also takes place through intact rock, or natural joints occur that cut across the induced face-parallel fractures to define blocks. Since joints are weaker than intact rock, the latter case will lead to a greater probability of a potentially unstable block. This paper deals with a simple probabilistic assessment of the potential occurrence of rockfalls in conventionally supported stopes.

Mechanism of Potential Rockfalls

Conventional support consists of packs, which provide a certain amount of areal support, and of props, pipesticks, and timber sticks, which provide point support. For the purposes of this paper, only point support is considered since this is generally the only form of support that is installed in the working area adjacent to a stope face.

As a result of the discrete location of the support points, areas of unsupported hangingwall are defined by the spacing of the supports. If the strike spacing of the fractures is closer than the strike spacing of the supports, and the dip spacing of the joints is closer than the dip spacing of the supports, then a block of rock is defined that can potentially fall. In addition, for the block to represent a potential rockfall, its location must be such that it can fall between the supports. This paper is concerned only with the geometric probability of the occurrence of rockfalls—the probability of the failure of such blocks will depend also on the magnitude of the disturbing forces (such as gravity, ejection by a seismic shock wave, vibration as a result of the passage of seismic waves), the strength of the joints and fractures, and the size of the block and the unsupported span, and the depth of 'beam'[2]. However, it is logical to assume that, the greater the probability of potential rockfalls, the greater will be the probability of actual rockfalls occurring.

Distribution of Fracture and Joint Spacings

The face-parallel fractures are generally very closely spaced in deep mines, their spacing being very much closer than the strike spacing of the supports commonly used. The distribution of their spacings can therefore be considered to be irrelevant in the context of this paper—the probability, P_1, that the spacing of the fractures is less than the spacing of the supports is 1,0, i.e. a certainty.

The characteristics of naturally occurring joints have been reviewed by Kulatilake[3]. The distribution of joint spacings has been shown to follow either a negative exponential[4] or a lognormal[5] form. There are no published records of systematic mapping of joints in stopes of gold mines, if such have been carried out. Based on the published data on the distribution of joint spacings, it was therefore assumed that the distribution of their spacings will be lognormal, which is a more conservative assumption than that of negative exponential. For the purposes of this paper, three representative lognormal forms were considered, use being made of the more

* Steffen, Robertson and Kirsten, P.O. Box 8856, Johannesburg 2000.
 ISSN 0038-223X/$3.00 + 0.00. Paper received 4th October, 1987.

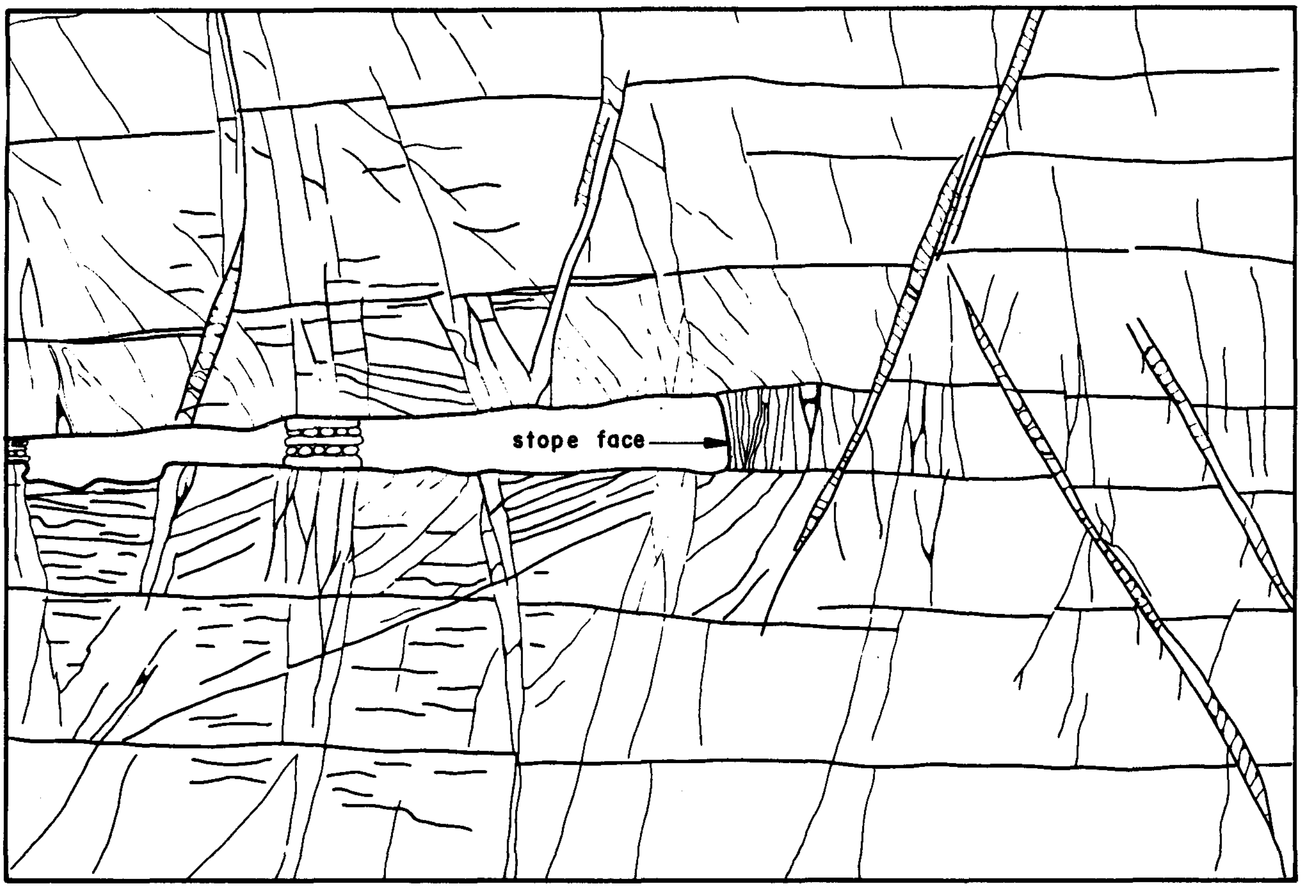


Fig. 1—Cross-section through a typical stope (after Roberts and Brummer[1])

general beta-distribution function. These are shown in Fig. 2, and are based on mean spacings of 1, 1,5, and 2,0 m. These mean spacings are considered to be realistic assumptions[6] for the likely dip spacing of joints in the stopes of deep-level gold mines. From these distributions, it is possible to determine the probability of the occurrence of joints with a spacing less than a specified value.

Probable Occurrence of Potential Rockfalls

Since the probable occurrence of fractures with spacings of less than the spacing of supports, P_1, is 1,0, the fractures can be considered to be ubiquitous. To define a potentially unstable block at any position with respect to the joints, two probabilities must be considered:

(1) the probability, P_2, that the spacing of the joints is less than the spacing of the supports, and
(2) the probability, P_3, that the block can fall between the supports.

Probability P_2 can be obtained directly from the distribution curves shown in Fig. 2. Probability P_2 is analogous to that of a particle of sand passing through a sieve, i.e. the particle either hits the mesh or passes through[7]. As shown by Fig. 3, the probability, P_3, of a

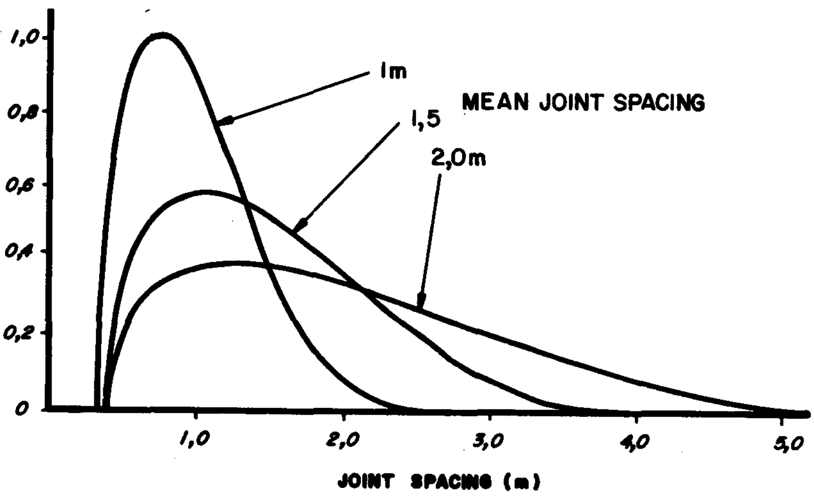


Fig. 2—Lognormal distribution of joint spacings (obtained by use of a beta distribution function)

block 'hitting' the opening between supports is given by

$$P_3 = 1 - (JDS \times JSS)/(DSO \times SSO),$$

where *JDS* is the joint dip spacing
JSS is the joint strike spacing
DSO is the dip support opening
SSO is the strike support opening.

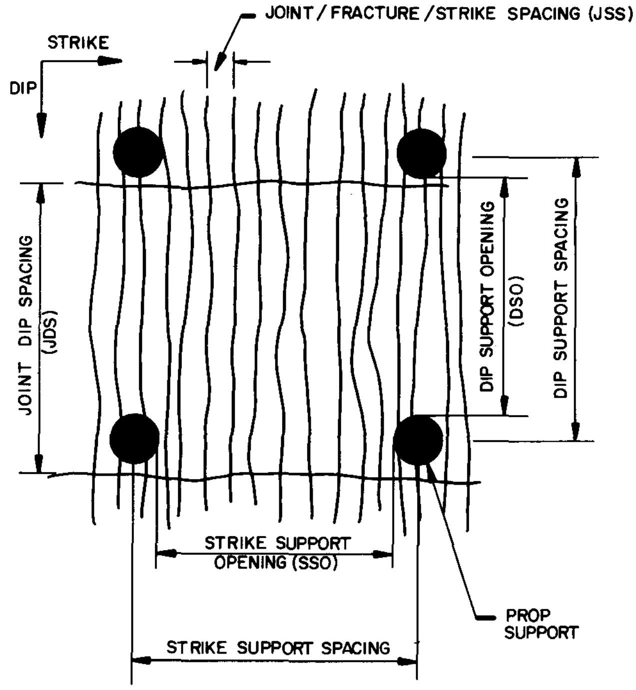


Fig. 3—Geometry of the supports and joints

Owing to the frequency of the dip fractures, there are always likely to be fractures coincident with the strike support opening. Therefore, effectively, the value of *JSS* will always equal the value of *SSO*, and the above equation reduces to

$$P_3 = 1 - JDS/DSO.$$

Since the two probabilities P_2 and P_3 are independent, the probability of occurrence of potential rockfalls is given by

$$P = P_2 \times P_3.$$

The probability of the occurrence of closely spaced joints is small, but small blocks have a high probability of passing between supports. Therefore, as P_2 increases, P_3 decreases, and *vice versa*. *P* will therefore show a peak value at some intermediate value of joint spacing. The distributions of *P* for different dip support spacings are shown in Figs. 4 to 6, and the peak probabilities are plotted in Fig. 7 as a function of the spacing of point supports.

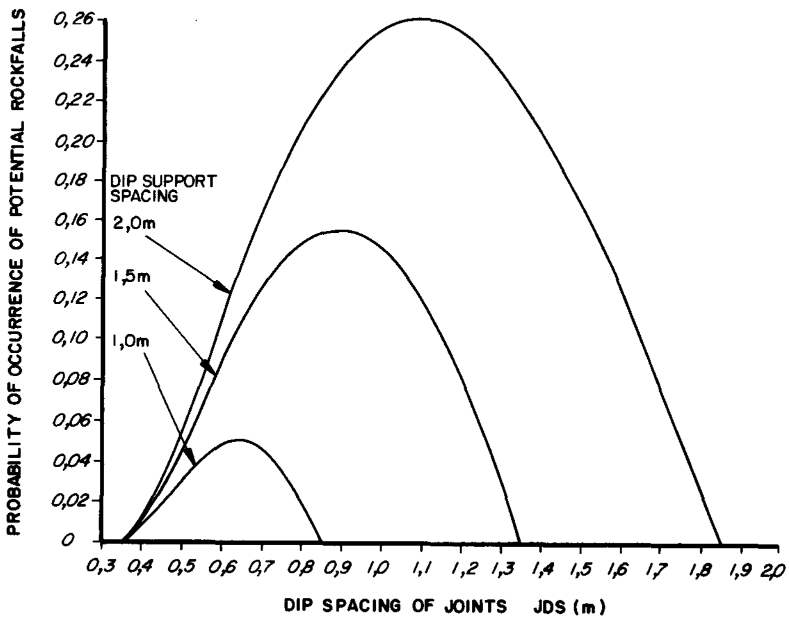
Implications

The simple investigation described in this paper revealed the following important implications regarding rockfalls in the stopes of deep-level gold mines.

(1) The presence of natural joints sub-parallel to the direction of strike is important since they have a controlling influence on the potential occurrence of rockfalls. Investigations should therefore be instigated to gather detailed information on the characteristics of these joints.

(2) With discrete types of support such as props at typical spacings, there is a significant probability that potential rockfalls will occur. The arrangement of props and sticks in rows parallel to the stope face results in long unsupported spans between the rows parallel to the face. The close spacing of face-parallel frac-

Fig. 4—Probabilities of the occurrence of potential rockfalls for a mean dip spacing of joints of 1,0 m



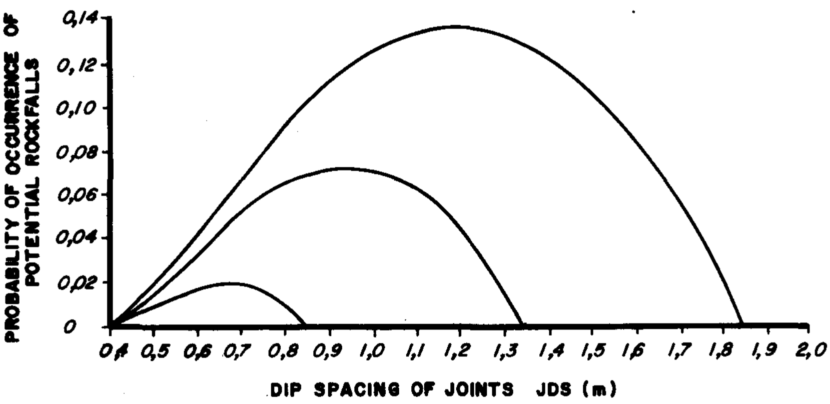


Fig. 5—Probabilities of the occurrence of potential rockfalls for a mean dip spacing of joints of 1,5 m

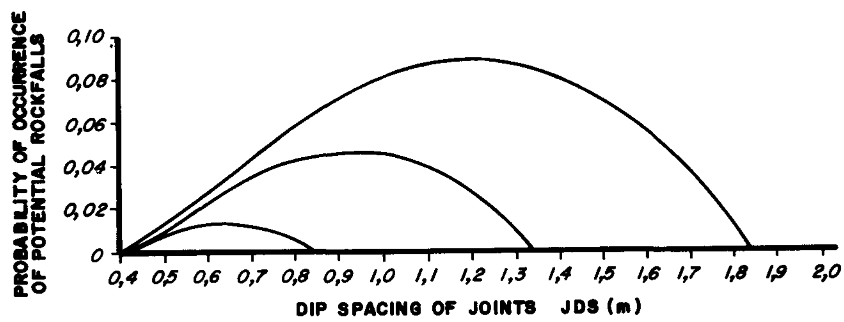


Fig. 6—Probabilities of the occurrence of potential rockfalls for a mean dip spacing of joints of 2,0 m

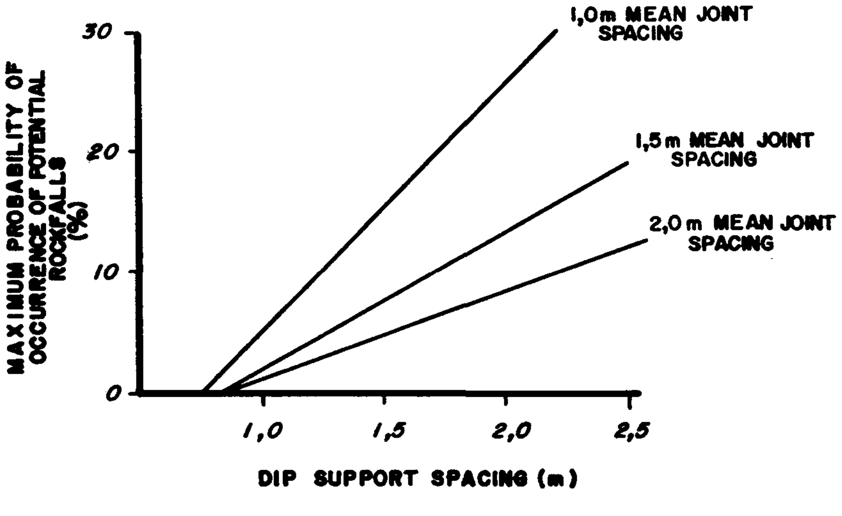


Fig. 7—Maximum probabilities of the occurrence of potential rockfalls

tures ensures that there are potential release planes on either side of this 'long beam'. It can therefore be expected that rockfalls will occur with this support geometry. The probability of the occurrence of potential rockfalls for such long spans is 1,0, i.e. it is a certainty. If props are installed on a square pattern, there is the potential for 'long beams' in the strike direction as well, as shown in Fig. 8(a). The off-setting of props will reduce the length of these potential beams to twice the strike spacing of the props, as shown in Fig. 8(b).

(3) Headboards reduce the likelihood of props punching into the hangingwall and footwall and, if the hangingwall surface is sufficiently planar, will increase the area of action of each prop. It follows from (2) above that the use of headboards oriented in the strike direction will reduce the unsupported spans in the dip direction, as shown in Fig. 8(c). This will therefore reduce the probability of the occurrence of potential rockfalls to that which has been calculated as in (2) above. For example, from Fig. 7, a probability of 15,5 per cent exists for a dip support spacing of 1,5 m and a mean joint spacing of 1,0 m. If the headboards do not overlap in the strike direction, a narrower 'beam', at least, will result, and rockfalls will be less likely than without the headboards. The use of headboards oriented in directions other than the strike direction may have greater potential for the reduc-

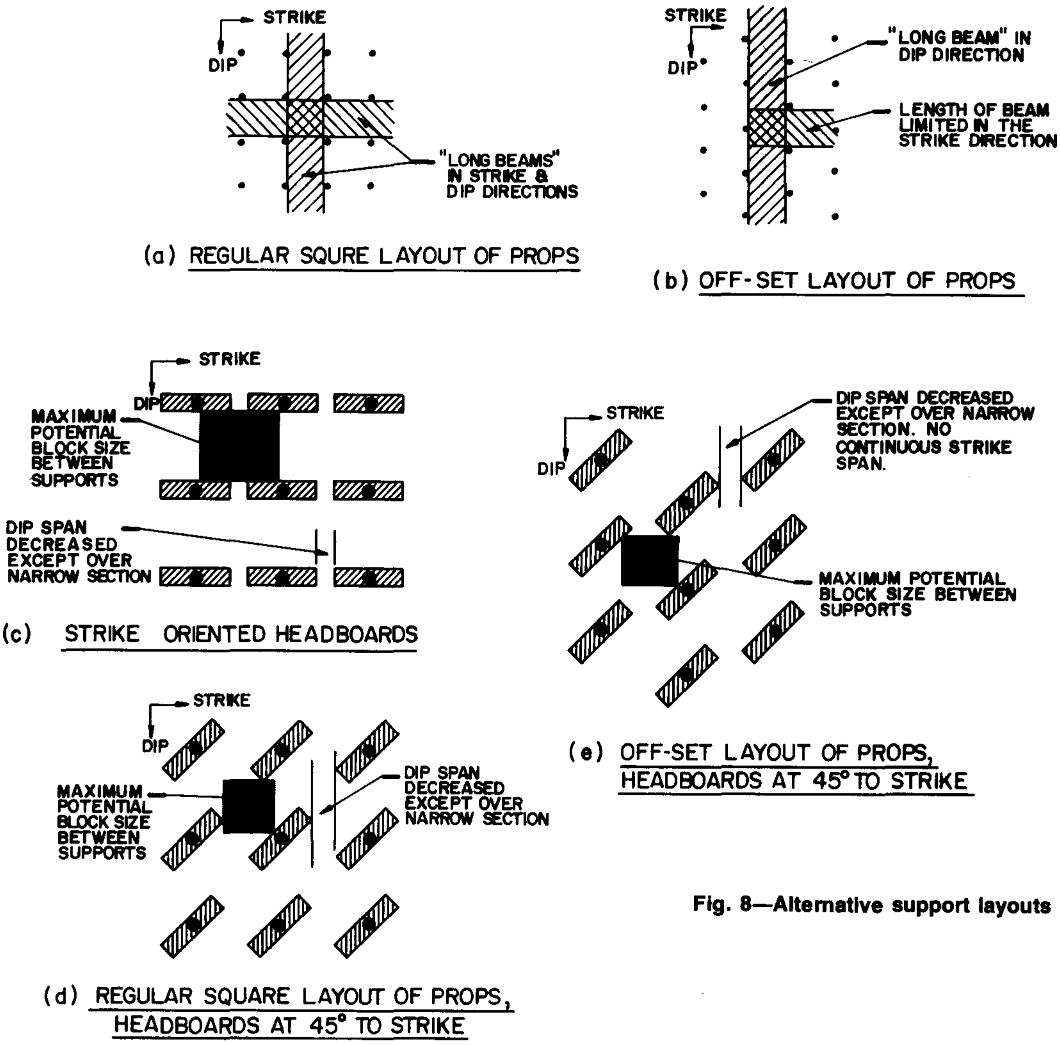


Fig. 8—Alternative support layouts

tion of the probability of rockfalls, as shown in Fig. 8(d) and (e). For example, the probability values for these headboard orientations, comparable with the 15,5 per cent above, are both only approximately 3,5 per cent.

(4) The loss of support from a prop as a result of poor installation, loss of pressure, blasting, or seismic action increases the probability of the occurrence of potential rockfalls very significantly. In the case of joints with a mean spacing of 1,0 m, the loss of a prop increases the support spacing from 1 to 2 m and, from Fig. 7, the probability of the occurrence of a potential rockfall increases from 5 to 26 per cent. In comparison, with 800 mm long headboards oriented at 45 degrees to strike, as shown in Fig. 8(d) and (e), the effective dip spacing increases to 1,3 m, and the probability of the occurrence of a potential rockfall to 11,5 per cent.

References

1. ROBERTS, M.K.C., and BRUMMER, R.K. Support requirements in rockburst conditions. *J. S. Afr. Inst. Min. Metall.*, vol. 88, no. 3. Mar. 1988. pp. 97–104.
2. KIRSTEN, H.A.D., and STACEY, T.R. Hangingwall behaviour in tabular stopes subjected to seismic events. *J. S. Afr. Inst. Min. Metall.*, vol. 88, no. 5. May 1988. pp. 163–172.
3. KULATILAKE, P.H.S.W. State of the art in stochastic joint geometry modeling. *Proceedings 29th US Rock Mechanics Symposium, Key Questions in Rock Mechanics*, 1988. pp. 215–229.
4. PRIEST, S.D., and HUDSON, J.A. Discontinuity spacings in rock. *Int. J. Rock Mech. Min. Sci. Geomech. Abstr.*, vol. 13. 1976. pp. 135–148.
5. STEFFEN, O.K.H., KERRICH, J.E., and JENNINGS, J.E. Recent developments in the interpretation of data from joint surveys in rock masses. *Proceedings 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering.* vol. 2. 1975. pp. 17–26.
6. LADEIRA, F.L., and PRICE, N.J. Relationship between fracture spacing and bed thickness. *J. Structural Geology*, vol. 3, no. 2. 1981. pp. 179–183.
7. HARR, M.E. *Reliability-based design in civil engineering.* New York, McGraw-Hill, 1987. 290 pp.