Use of representative values of geometrical properties of discontinuities in rock slope verifications according to EC7

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ABSTRACT: This work aims to obtain representative values for the geometrical properties of families of discontinuities, within the criteria set out in the final draft of Eurocode 7 (EC7), by a conservative estimation of the mean value and not as a purely average value, as it is done for the rest of the geotechnical properties. This paper describes how to use the EC7 methodology to obtain representative values for the geometrical properties of discontinuities. Moreover, an example is included to compare the safety factor of a wedge using this EC7 methodology and the derived from normal practice. This example deals with a typical issue where the data collection is done manually and the number of values is small. With the results obtained, some questions arise as to what should be the correct way to obtain a representative value for the case of wedges in rock.

Keywords: Geometrical properties, Eurocode, rock slope stability.

1 INTRODUCTION

For stability analysis of rock slopes (wedges, plane failure, toppling, etc.), the data chosen for the calculation concerning the spatial orientation of each of the families (dip and dip direction) are decisive. Moreover, the orientation and characteristics of the families influence the stability of a slope much more than the properties of the rock matrix. Thus, the spatial relationship between the orientation of the joint families and the slope is crucial for rock slope stability.

To obtain the spatial properties of joints, the most common method is to carry out geomechanical stations on the outcrop, obtaining multiple orientation data for all the existing joints in the rock mass. These geomechanical stations will provide, also, the joint characterization. Normally, the lack of parallelism, roughness, etc., means that, for each family, there is a great dispersion of data.

The joint orientation data are plotted in stereographic projection, to group them by their proximity, and to obtain a single representative value of dip and dip direction for each of the families. This single representative value is usually obtained by finding the purely average value of each parameter (dip and dip direction) for the different families observed with the stereographic projection.

Another way to obtain these values is by using pole density diagrams that show the concentrations of poles in a given area (usually 1%). In these diagrams, greater weight is given to poles that are closer together. This is the method recommended by the ISRM but also suggests that probabilistic methods should be used (without indicating which) to make a more accurate analysis since the value obtained with the density diagram differs from the average (Figure 1).

> The central value of highest concentration of poles can be taken as representing the mean orientation of the given set of discontinuities. However, since there are variations from the mean, orientation is strictly a random variable with a certain dispersion associated with each mean value. Probability techniques are recommended for a more precise analysis. (It should be noted that density contours obtained by the Schmidt method violate probability theory since poles are counted more than once.)

Figure 1. The recommended method by ISRM “ISRM Suggested Methods for rock characterization (2007)”.

The future Eurocode 7 (EC7) (CEN, 2022) establishes a methodology to determine the value of the geotechnical properties to be considered as representative of such a property, through the so-called "representative value", that can be obtained in two ways, as explained later.

While for other geotechnical properties, such as friction angle or undrained shear resistance, there are tables with indicative values as a reference for these properties, this is not the case for the values of dip and dip direction of discontinuities that can occur with any orientation and inclination and also depend on the spatial orientation of the slope under study.

2 REPRESENTATIVE VALUES OF GROUND PROPERTIES ACCORDING TO EC7

According to EC7, the "representative value" (X_{rep}) of a geotechnical property must be determined by the designer from the set of "derived values" obtained during the geotechnical investigation campaign (Estaire and Santana, 2022). It is defined as the value of the soil property that affects the occurrence of a limit state.

In most cases of geotechnical engineering, including either slope or wedge stability analysis, the representative value must correspond to a conservative estimation of the mean value as it is the value that generally affects the possible occurrence of a limit state. Figure 2 explains this fact: in this case, the value of the total shear strength along the failure surface is the sum of the individual shear strengths on each portion of the surface, which equals the mean value multiplied by the length (L) of the failure surface, so it is clear to understand that the value to be used in the calculations is an estimation of the mean value of the shear strength along the failure surface.

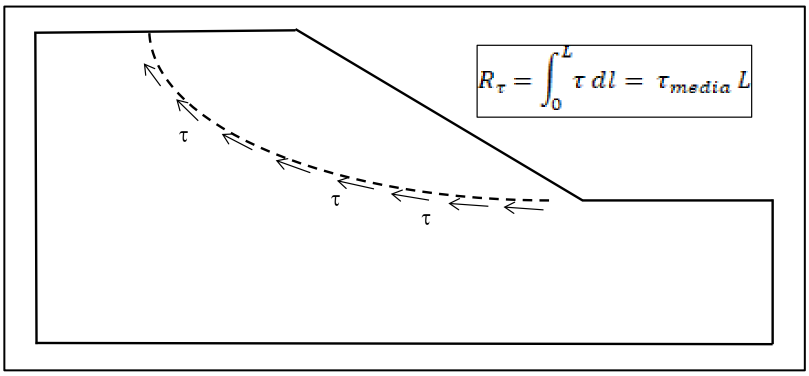

Figure 1. Mean value as the “representative value” of the slope stability.

As said before, the future Eurocode 7 (EC7) establishes a methodology to determine the value of the geotechnical properties to be considered as representative of such a property, through the so-called "representative value", that can be obtained in two ways:

- selecting a value based on the designer's engineering judgement, possible knowledge of the site and experience of comparable cases; following this way, the value obtained is called "nominal value"; or
- evaluating the value by statistical methods; following this way, the value obtained is called "characteristic value".

However, for the cases analysed in this work (rock wedge stability), the representative value of the geometrical properties of the discontinuities will be equal to their characteristic value. For this purpose, the procedure that should be used to determine the characteristic value of the geometrical properties of a discontinuity by statistical methods is described below. It should be noted that the procedure described is based on the more general method for determining characteristic values for ground properties given in Annex A of the future Part 1 of EC7.

These statistical methods ensure that the probability of the existence of a worst value governing the occurrence of the limit state under consideration is not greater than 5%, taking into account the statistical uncertainty. The values to be used to determine the characteristic value are the geometrical values obtained from the different families of discontinuities during the geotechnical investigation campaign.

The determination of the characteristic value of a geometrical property must be done using Equation 1, which assumes, from a purely statistical point of view, that the values follow a Normal distribution and there is no prior knowledge about the mean value.

$$X_k = X_{mean}(1 \mp k_n\, V_x) = \frac{\sum_{i=1}^{n} X_i}{n}(1 \mp k_n\, V_x) \tag{1}$$

where:

- X_k is the characteristic value of the geometrical property X;
- X_{mean} is the mean value of the geometrical property obtained from a number (n) of sample values;
- k_n is a coefficient that depends on the number of sample values (n) used to calculate the mean value of X;
- V_x is the coefficient of variation of the geometrical property X
- ± denotes that the product [k_n V_x] must be added when the lower value of X_k is critical and subtracted when the upper value is critical, and
- x_i is the i-value used to calculate X_{mean}.

In the determination of the geometrical properties, the value of the coefficient of variation (V_x) is unknown a priori and must therefore be calculated using Equation (2).

$$V_X = \frac{s_x}{X_{mean}} \; ; \; s_x = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_{mean})^2}{n-1}} \tag{2}$$

where s_x is the standard deviation of the sample values.

The value of k_n can be obtained from Equation 3.

$$k_n = t_{95,n-1}\sqrt{\frac{1}{n}} \tag{3}$$

where: $t_{95,n-1}$ represents the Student's t-distribution, tested for a 95% confidence level and n-1 degrees of freedom, where n is the number of values in the sample.

3 APPLICATIONS OF EC7 FOR ROCK SLOPE STABILITY

The stability analysis of a rock slope needs the determination, among others, of strength and spatial properties (orientation: dip and dip direction) of the joints in the rock mass. The usual practice of determining the representative value of geotechnical properties such as cohesion or friction angle is done by taking a value which is generally not a strict mean value but a conservative estimate of the average of the values derived during the geotechnical investigation. However, the representative value for the orientation of discontinuities is usually taken, in real practice, as the mathematical mean value or the value obtained from a pole density diagram using some software, such as the popular Dips (RocScience, 2022) (see Figure 4).

This section shows and compares an example of the determination of the level of safety of wedge stability in which the representative values of dip and dip direction were determined both in the traditional way and in the way proposed by EC7. In this example, the data were obtained by manual measurement in geomechanical stations, placed directly at the slope discontinuities (see Figure 3). Doing so, 113 dip and dip direction data were available. Joint dip and dip direction data were plotted in stereographic projection and grouped in two families: 49 data were considered to belong to the family of discontinuities J1 while the rest 64 data to J2 (Figure 4 (left)).

In this respect, it is important to note that, in the case of dip data, this procedure is applied to take into account that the higher the dip, the lower the safety level, so that in equation (1) the sign "+" was used. For the dip direction data, it must be taken into account that, in the wedges, in one of the planes that form it, as the dip direction (J1) increases, the safety level will decrease. In contrast, on the other side, the safety level will be lower as the dip direction (J2) decreases. This is explained by the fact that the greater the angle between J1 and J2, the steeper (dip) the line of intersection between planes will be, which directly affects the safety level. To take this fact into account when obtaining the characteristic value with equation (1), the ± sign of the equation will be changed depending on which discontinuity family (J1 or J2) is under analysis. After applying this procedure (according to EC7 criteria) the characteristic values obtained for dip and dip direction are shown in Table 1.

Figure 3. Outcrop where the geomechanical stations were performed.

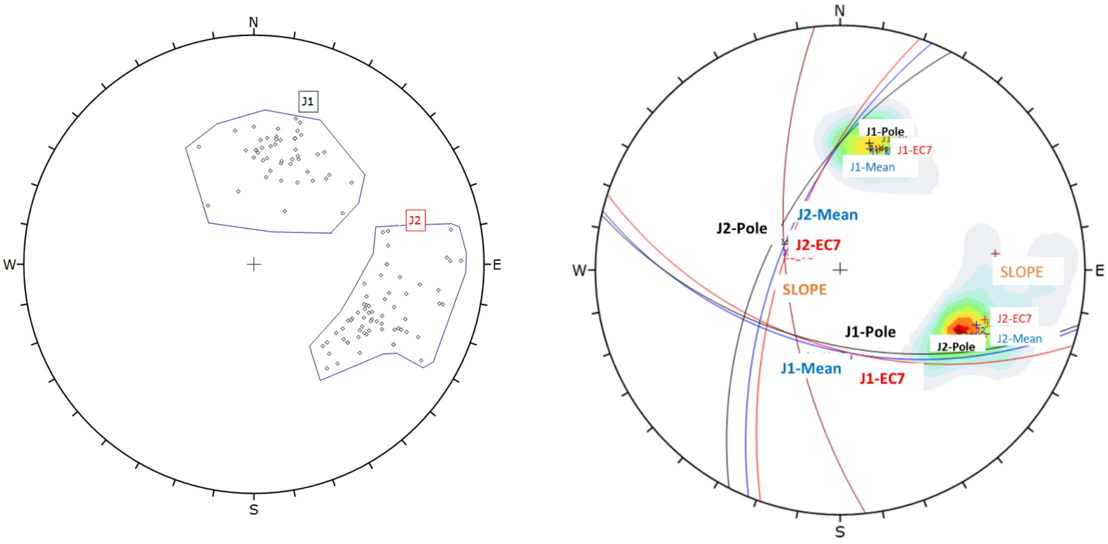

Figure 4. Representation of the data of each family in stereographic projection (left) and representation of the resulting poles obtained by the three calculation methods.

The values obtained were represented in stereographic projection in Figure 4 (right) for better visualisation. This figure shows the differences, both in the location of the poles and, therefore, of the resulting planes, for the three procedures for obtaining the representative value. The mathematical mean value is shown in blue, the value with the highest concentration of poles in black and the characteristic value according to EC7 in red. The pole and plane corresponding to the slope under study were also drawn.

The determination of the dip characteristic value of discontinuities by the EC7 method will always be higher than the one calculated by the usual mathematical mean value or pole density methods. On the other hand, the characteristic values of dip direction obtained with the EC7 method result in a more open wedge, i.e. with a larger angle between planes and a steeper line of intersection. This is because the EC7 method performs a "conservative evaluation" of the mean value, so the characteristic value is not exactly equal to the mathematical mean value as deduced from equation (1).

With the data from the three resulting wedges, a stability analysis was carried out with Swedge 7.01 software (Rocscience). The analysis was carried out deterministically, using the following representative values for the shear strength of all the discontinuities present in the problem in the calculations: friction angle of 35º and zero cohesion, according to the Mohr-Coulomb failure criterion. In addition, the existence of joint undulation and the presence of water were not considered.

The results obtained (Table 1) show that with the procedure based on the criteria established in EC7, a 16% lower safety factor is obtained, compared to the calculation carried out traditionally (mathematical mean value and pole density).

Table 1. Results obtained with the three calculation methods.

	Mean value		Pole density value		Characteristic value (EC7)	
	Dip	Dip Direc.	Dip	Dip Direc.	Dip	Dip Direc.
J1	54	194	56	193	55	198
J2	62	292	57	297	64	289
Slope	55	264	55	264	55	264
Safety Factor	0,8756		0,9988		0,7547	

4 CONCLUSIONS

The final draft of the future Eurocode 7 sets out a method for determining the representative value of the ground properties. In the specific case of discontinuities, the geometrical properties that determine the stability of a slope are, among others, dip and dip direction. The usual practice to determine the design value of these geometrical properties is through the mathematical mean value or the value corresponding to the highest pole density obtained in its stereographic representation.

This work shows, by one real example, the variation in the safety level obtained in stability analysis of a wedge when the values of dip and dip direction are obtained by the usual methods (mathematical mean value and pole density) or by applying the method of the future EC7 (characteristic value determined by statistical calculation).

Usually, this is an example of a slope where the data were collected manually and the sample size was small.

The example analysed in this work shows that, following the EC7 method, the values of dip and dip direction of the discontinuities involved in the stability verifications are somewhat more conservative than those used in normal practice.

The determination of the values of dip and dip direction of the discontinuities involved in the stability analysis by the method set out in EC7 has a certain degree of caution which is lacking in those used in normal practice, as the latter is simply the average values of the available data.

It is necessary to point out that, if the data collection is carried out with techniques such as LiDAR or photogrammetry, the number of data obtained in each plane would be so large that the characteristic value would be similar to the average. A good example of the use of these techniques to identify the different planes of discontinuities in a rock outcropping is given in Riquelme et al. (2014). And in this case, a key question arises: should each taken point be considered individually, regardless of the visible plane they belong, to determine the family geometrical properties? or would it be better to first obtain an average value of the points in each visible plane and then use only these average values to determine the family geometrical properties?

Furthermore, in this case, the dip and dip direction data were obtained separately, as independent values, and perhaps it would be more appropriate to do them as dependent values.

The use of the geometrical values in the example analysed (small sample size), and estimated with a certain degree of caution (EC7), leads to lower safety factors than those usually calculated.

Finally, although the use of EC7 for slopes where the data were obtained manually would be recommended, some questions remain to be solved, such as what to do if the data have been obtained automatically (LiDAR and photogrammetry) and whether it is valid to obtain the values of dip and dip direction separately or whether it should be done together.

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