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Discussion: How Eurocode 7 has affected geotechnical design: a review

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Contribution by P. J. Vardanega

The discusser read the author's paper with great interest, and acknowledges his contributions to the Eurocode 7 development process and the associated academic commentary (e.g. Orr, 2000, 2012a, 2012b). The paper is an excellent summary of the present state of Eurocode development. The Eurocodes cannot be allowed to ossify. In this spirit there are a few points from the paper worthy of discussion with regard to future code development.

ULS against SLS

The author, in reference to Vardanega *et al.* (2012a) and other papers, summarises

> Model factors have been introduced in the UK NA to EN 1997-1, so that the overall safety level of pile designs to Eurocode 7 is similar to former practice, and the occurrence of an SLS as well as a ULS is sufficiently unlikely.

Although this is an accurate description of what the national annex (NA) (BSI, 2007) may achieve in practice, it shows confusion between the two limit states, ultimate limit state (ULS) and serviceability limit state (SLS).

SLS design requires that settlements, and hence strains, be prevented from exceeding some value. Recent work describing the link between mobilised strength and soil strains mathematically is worth mentioning. Using a large laboratory database, Vardanega and Bolton (2011) have shown that a power-law function can be used to describe strength mobilisation in clays and silts

$$\frac{1}{M} = \frac{\tau_{\mathrm{mob}}}{c_{\mathrm{u}}} = \frac{1}{2}\left[\frac{\gamma}{\gamma_{M=2}}\right]^{b} \qquad (5)$$

where M is the mobilisation factor (equivalent to a factor of safety on shear strength, BS 8002 (BSI, 1994); τ_{mob} is the mobilised shear strength; c_{u} is the undrained shear strength; γ is the shear strain; $\gamma_{M=2}$ is the mobilisation strain (defined as the shear strain at a shear stress of $0{\cdot}5c_{\mathrm{u}}$); and b is a power exponent.

Vardanega *et al.* (2012b) conducted a laboratory study, and reported that, for kaolin, b and $\gamma_{M=2}$ both correlate with overconsolidation ratio. Equation (5) is used in Vardanega *et al.* (2012c) along with a 'Randolph-style' calculation method (e.g. Fleming *et al.*, 2009) to estimate settlements of bored piles in stiff clays.

For a ULS calculation, a characteristic value should be used to determine the design resistance, with no further factors being applied to the characteristic value itself. If this is followed, then a reduction of DAs in Eurocode 7 may be possible. Factoring the computed resistance allows for the inevitable uncertainty in the calculation method itself – aside from uncertainty in the soil parameters (e.g. undrained strength). On the other hand, for SLS calculations, a mobilisation factor is needed to control settlements.

Characteristic values and assignment of partial factors

The author reports that 94% of UK engineers require more general guidance on the selection of characteristic values. For piled foundations in stiff clays, Vardanega *et al.* (2012c) advocate a 5th percentile design line (c_{u} with depth) for base resistance, and a 50th percentile design line for shaft friction. Future developments in Eurocode 7 concerning the determination of characteristic values should require that the design calculation in question (e.g. pile base or shaft resistance) inform the method used to determine the characteristic value (alongside issues of data availability, variability and the 'limit state being considered'). Values of partial factors should be informed on the basis of risk, not merely the country that the design project is being completed in.

Poulos (2004, 2011) presented a new approach for assigning geotechnical reduction factors (GRF) (similar to partial factors) that has been incorporated in the Australian Piling Code AS2159-2009 (Standards Australia, 2009). A risk analysis matrix is used to determine the geotechnical reduction factors (similar to partial factors in the Eurocode), and an example applying the method to piles in stiff clays is detailed in Vardanega *et al.* (2012b).

This approach allows the engineer to adjust the GRF in relation to the design circumstances. The code gives a range of values for the GRF, with the final value selected by the risk analysis exercise. A similar methodology could be adapted within the Eurocode 7 framework to determine each partial factor on a job-by-job basis.

Designers who are prepared (or able) to do more extensive field investigations, detailed design calculations and laboratory studies would inevitably be more confident in specifying lower partial factors for a specific project if they thought it safe to do so.

Author's reply

The discusser has provided interesting comments on aspects of Eurocode 7 that are indeed worthy of discussion regarding its future development and are, in fact, currently being addressed by the SC7 Evolution Groups referred to in the paper.

The discusser's point – that model factors have been introduced in the UK NA so that the overall safety level of piles designed to Eurocode 7 is similar to former practice, and the occurrence of both an SLS and a ULS is sufficiently unlikely – shows confusion between these two limit states. There should be no such confusion when designing to Eurocode 7, because Eurocode 7 clearly states in Section 2.1(1)P that 'it shall be verified that no relevant limit state . . . is exceeded.' SLS verification can be either by a direct method, comparing calculated settlements to the allowable values, or by an indirect method that ensures that a sufficiently low value of the shear strength is mobilised to keep the settlements within the SLS limits. In pile design, owing to installation effects and uncertainties in the calculation models and ground properties, calculations in most cases provide only an approximate estimate of the pile settlements. Therefore increased factors, as in the UK NA, may be used in a bearing calculation to ensure that a sufficiently low shear strength is mobilised, and prevent an SLS as well as a ULS. The discusser's example of a power-law function relating soil shear strain to mobilised strength is interesting, in that it offers a direct method to estimate pile settlement. However, it should not be overlooked that the SLS requirements in Eurocode 7 relate to the supported structure, and not to the settlement of an individual pile.

Regarding selection of characteristic values, the discusser recommends the 50th percentile of c_u with depth to determine the characteristic pile shaft friction. This is not consistent with Eurocode 7's definition of the characteristic value as a cautious estimate of the mean value, which must be less than the 50th percentile. How cautious this mean value should be depends on the data available and the nature of the design situation. A number of authors have provided guidance on the selection of characteristic soil properties: for example, Schneider and Schneider (2012) have published a statistical method that takes account of the failure surface extent, soil variability and scale of fluctuation.

The discusser states that the partial factor values should be related to the risk, and not merely to the country in which the project is being constructed. However, the responsibility for setting safety levels for structures in a particular country is a national issue: hence NAs have been prepared by each country, with partial factor values providing the safety level judged appropriate for that country. A system of reliability differentiation related to the risk level is offered in the head Eurocode, EN 1990 (CEN, 2002), in the form of reliability classes and consequences classes to modify the partial factor values, depending on the design situation. This system has not been adopted in the UK NA, but has been adopted in the NAs of some countries where the partial factor values vary depending on the design situation (Orr, 2012a, 2012b). An alternative method for taking account of the risk level is offered in Section 2.4.6.2(1)P, which permits the design values of soil parameters to be assessed directly, instead of being obtained by applying specified partial factors to selected characteristic values. Hence, by choosing this method, the discusser could avail of the reduced risk arising from more extensive field investigations, detailed design calculations and laboratory studies when designing piles to Eurocode 7.

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