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EC 7: Ground-Structure Interaction

EC 7: Interaction entre sol et structure

EC 7: Wechselwirkung zwischen Boden und Bauwerk

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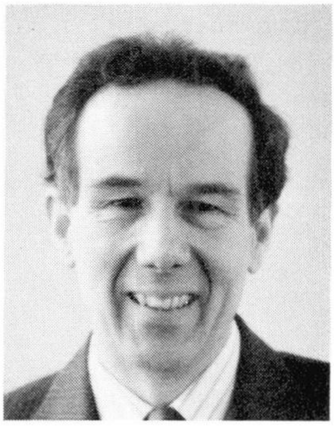

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SUMMARY

The limit state format provides an ideal framework for the study of geotechnical design problems, including those involving significant ground structure interaction. When the partial factor method is applied to geotechnical problems, however, it is necessary to reconsider some of the simplifications conventionally adopted in structural engineering design. In this paper, three particular problems which have been studied by the Eurocode 7 drafting panel, are described and some solutions are proposed.

RESUME

Les principes du calcul aux états limites offrent un cadres idéal pour l'étude des problèmes de géotechnique, y compris les problèmes importants d'interaction sol-structure. Toutefois, lorsqu'on applique la méthode du coefficient partiel aux problèmes de géotechnique, il est nécessaire de revoir les simplifications conventionelles utilisées pour le calcul des structures. Cet article décrit les trois problèmes particuliers qui ont été étudiés par l'équipe rédactionelle de l'Eurocode 7 ainsi que les solutions proposées.

ZUSAMMENFASSUNG

Das Konzept der Grenztragzustände bietet einen idealen Rahmen zur Behandlung geotechnischer Bemessungsprobleme, einschliesslich erheblicher Boden-Bauwerk-Wechselwirkung. Bei der Anwendung der Methode der Teilsicherheitsbeiwerte müssen jedoch einige Vereinfachungen, wie sie im konstrucktiven Ingenieurbau üblich sind, neu überdacht werden. Der Beitrag beschreibt drei ausgewählte Bemessungsaufgaben, die von der Bearbeitergruppe des EC 7 studiert wurden, und schlägt einige Lösungen vor.

1. INTRODUCTION

Soil-structure interaction occurs when the deformation of the ground affects the distribution of stresses at the ground/structure interface or within structures supported by the ground or which support it. The limit state method provides an excellent framework within which to carry out both the structural and geotechnical aspects of design, but it may be necessary to reconsider some of the simplifications conventionally adopted when the method is applied to structural design. In this paper, three problems which have been considered at length by the drafting panel of Eurocode 7 Part 1 are described and their treatment in the present draft of EC7 is presented. The topics are also under debate in a Eurocodes ad hoc group on Soil-Structure Interaction, and a summary of the preliminary conclusions of that group will be presented at the Conference.

The three questions to be considered are as follows:

a) In a limit state, partial factor system, what load factors are appropriate for the geotechnical design (sizing) of foundations, particularly for gravity loads?

b) How should design proceed in situations where soil strength and stiffness significantly affect internal structural forces and bending moments?

c) How should design proceed for retaining structures in which the load to be born by the structure reduces as deformation occurs?

2. LOAD FACTORS FOR GEOTECHNICAL DESIGN OF FOUNDATIONS

2.1 Consistent system for geotechnical design

The 'geotechnical design' of foundations is taken to mean the determination of the size of foundation elements required to transmit loads from a structure into the ground. The internal strengths of these members is not the main concern here, but will be considered briefly at the end of this section.

Geotechnical design is concerned with foundations, earth retaining structures, slope stability and similar problems. Frequently these aspects of design overlap: for example, foundations may be placed on a slope or on ground supported by a retaining structure. Despite this, few countries, if any, have codes which present a philosophy of design which is consistent for each of these situations. Eurocode 7 attempts to achieve this.

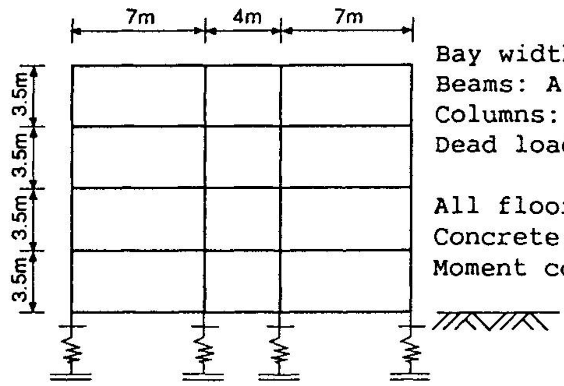
Geotechnical design is often concerned with the balance between the weights of large bodies of material and with soil strength derived from frictional properties; slope stability problems are an example of this. It is often not obvious which weights are favourable and which are unfavourable in a calculation. Even weight which, by its location, acts in a generally unfavourable manner increases the shear resistance of frictional soil. Fortunately, the density of the ground is usually fairly well defined so it is reasonable to apply unit load factors to the weight of soil and, implicitly, allow for minor variations in density within the partial factors on the strength components of the soil. In exceptional cases where there is genuine, major uncertainty about the distribution of weight of materials in the ground, special procedures are needed, probably using parametric studies.

If a slope supports a building or other structure, the weight of the structure is involved in the stability calculations in the same way as the weight of the ground. There is no reason to treat its weight differently in design, unless there is a genuine fear that it could be significantly heavier than its nominal weight. The same applies when soil and a supported structure together load a retaining wall.

2.2 Foundations of structures

The Eurocode 7 panel have understood that a reasonable factor to allow for the uncertainty in weight of structures would be about 1.1 to 1.15. Further components of the factor of 1.35 used on gravity loads in structural design are related to uncertainty in the distribution of forces between individual structural elements, that is, uncertainty in the loading model. The uncertainty about structural weight is therefore little more than that of the density of the soil and it is convenient to treat it in the same way, particularly as it may be unclear whether it acts favourably or unfavourably in geotechnical calculations.

Problems of bearing capacity are fundamentally similar to those of slope stability, and the two often merge into each other. It is therefore desirable to use a consistent approach to both. Furthermore, the loads on the ground at individual foundations are often governed by the stiffness of the ground itself.



Bay width in third dimension = 6m
Beams: A = $0.675m^2$ I = $0.046m^4$
Columns: 400mm x 400mm
Dead loads: Floors: 7.5 kPa
Roof: 5.0 kPa
All floors suspended
Concrete: E = 28 kN/mm^2 ν = 0.15
Moment continuity at all connections

Fig. 1 2D frame used as example

Figure 1 shows a simple 2-dimensional frame which has been used to study this, using an elastic analysis. Spring stiffnesses were first determined to give equal settlements (20mm) of all four foundations and individual spring stiffnesses were then varied by factors of 2. The changes of settlement were in the range -7.5mm to +8.4mm and the forces transmitted to the foundations varied by -38% to +44%. The 'poorer' foundations, represented by softer springs, received lower loads and the stiffer foundations received higher loads. Differential settlements were not serious in this case, but would have been reduced if the stiffer foundations had yielded slightly in response to the higher loads imposed on them.

This example illustrates how ground stiffness may have a large influence on the loads transmitted to each foundation supporting a reasonably stiff redundant structure. Significantly, there was no possibility that the poorer foundations would be pushed towards failure by forces greater than the nominal values for which they would normally have been designed. A foundation which yields because it is on poorer ground tends to shed load rather than to become overloaded. The same applies to a foundation which settles more than others because of its location, at the centre of a loaded group, for example. For structures which have little redundancy, the only uncertainty in the internal forces comes form the actions at source. The load factors applicable to these are thought to be less than the values adopted for structural design in general.

The yielding or failure of the ground beneath a foundation is a different limit state from that of structural failure of the foundation or the structure it supports. The forces which would be in the structure as the limit state approached would be different.

2.3 Load factors in Eurocode 7

These considerations have led the drafting panel of Eurocode 7 to propose that the load factor on the weight of supported structures should generally be unity for ultimate limit state design. Exceptions would occur where there is genuine, major uncertainty about the actual weight of the structure or about the distribution of load transmitted to the ground, for reasons other than ground stiffness itself.

Similar considerations apply to variable actions, but it is likely that these are more uncertain at source than is structural weight. A factor of 1.3 has therefore been proposed for these in Eurocode 7, though it might be argued that the ratio between factors on permanent and variable loads should be the same as in other Eurocodes.

The structural design of the foundation elements themselves should allow for the possibility that they carry significantly more than the nominal load. It is anticipated that structural design will therefore use the load factors given in the structural Eurocodes.

3. SITUATIONS WHERE SOIL STRENGTH AND STIFFNESS AFFECT STRUCTURAL STRESSES

The bending moments in laterally loaded piles are greatly affected by the strength and stiffness of the ground. This problem has been addressed in Eurocode 7 and will be used here as an example of a broader class of situations.

In many design calculations, two sets of variables and their uncertainties are involved, usually actions and structural strength. Values of partial factors have been derived for these situations. Generally the stiffness of the structure has a fairly small influence on action effects and mean values can be used for its properties without serious error. For laterally loaded piles, and similar design situations, the strength and stiffness of the ground greatly affect the action effects (bending moments) and are also significant uncertainties. Eurocode 7 proposes that it is not sufficient to assume mean values for these, but it would be unduly severe to assume extreme design values for the actions, the ground properties and the structural resistance simultaneously.

The wording adopted in Eurocode 7 requires that two separate design checks should be made. In the following extract, the 'characteristic' soil properties are to have a target probability of 5%, as discussed by in the Conference by Baguelin.

> It shall be demonstrated that the piles can withstand the stresses and bending moments derived by both the following methods:
>
> - Use design actions and soil parameters as specified for geotechnical design in Chapter 2 of this Eurocode.
>
> - Use design actions as specified in the relevant material Eurocodes for structural design, together with characteristic soil properties, as specified in Chapter 2 of this Eurocode.
>
> In both methods, the design parameters for structural materials shall be as specified in the relevant material Eurocodes.

It is foreseen that an approach of this type could be used in other situations in which ground properties significantly affect structural stresses. In design of retaining walls, it is proposed that factored values of soil properties and structural resistance should be used, with unit factors on all gravity actions.

4. SITUATIONS WHERE THE LOAD ON THE STRUCTURE REDUCES AS DEFORMATION OCCURS

Unlike most of the other forms of loading on structures, disturbing earth pressures on retaining walls generally reduce as the wall deflects. Thus the loads on a wall in service often exceed those as collapse approaches, to an extent which depends heavily on the type of soil and its geological or construction history. In these circumstances, the definitions of ultimate limit states require careful attention.

A wall yielding in bending might deflect more, allow the soil to mobilise more of its strength which would ensure stability. Failure of a concrete wall in shear would be more immediate and serious. However, even a failure in bending could lead to very large displacements, which would be more severe than a serviceability limit state. Eurocode 7 needs guidance from colleagues in the other Eurocodes on the significance of attainment of ultimate resistance in bending in situations where this leads to larger movements, but not to collapse. This topic is under review in the ad hoc group on ground-structure interaction.

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