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Design philosophy for reinforced soil walls. Noteworthy aspects of European standards

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ABSTRACT: The paper first outlines the concerted process of the development of new norms in Europe, especially the ones about reinforced soil, of which a few aspects, thought of particular interest, are then selected. Attention is paid to the concern for sound conceptual design and careful quality control of work, deemed often more important for safety than accurate calculations. Topics related to computation are nevertheless discussed. Differences between ultimate and serviceability limit states, as understood in Europe, are clarified. The need for both internal and compound stability analyses is commented. Lastly, attention is drawn to the requirement for durability samples.

1 INTRODUCTION

Before attempting to highlight, in a second part of this paper, a few key features and outstanding points of some design standards recently formalized in Europe for reinforced soil structures, it is likely useful, at least for the non-European readers, to first outline how such standards are now established.

2 THE EUROPEAN STANDARDIZATION SYSTEM

2.1 *The CEN organization*

A considerable effort is made throughout the European Union in order to progressively develop, in all possible domains, a series of common norms. It is managed by CEN, i.e. the "Comité Européen de Normalisation" or, European Committee for Standardization. The main purpose of the European standards is to promote free trade within the Union, together with safety of workers and consumers, public procurement, environmental protection, as well as exploitation of "R and D" programmes and, interoperability of networks.

This effort presently involves the standards bodies of 30 countries, including 3 which are not (or not yet?) members of the European Union. The European norms, also known as EN, are developed through a consensus process. Participants in the technical committees and working groups represent (mainly through their national standards bodies) all interests concerned: industry, authorities and civil society.

Draft standards are made public for consultation. The final, formal vote is binding on all members. The EN Standards must be then transposed into national standards and conflicting standards withdrawn.

2.2 *The Eurocodes*

Of course, the European standardization effort also concerns the building and civil engineering industry.

As far as design is concerned, civil and structural engineering works will be based on the principles set by a series of 10 Eurocodes, also known as EC, which are now all published.

The Eurocodes are applicable to whole structures and to individual elements of structures and cater for the use of all the major construction materials. Some have a broad-spectrum subject, such as EC0 and EC1 which respectively deal with "Basis of design" and "Actions on structures". Others have a specific field: for example EC2 relates to "Design of concrete structures", while EC7, issued in 2005, is about "Geotechnical design", i.e. the geotechnical aspects of the design of buildings and civil engineering works.

2.3 *Execution of special geotechnical works*

The EC7 Eurocode regarding geotechnical design is intended to be used in combination with other standards that cover the construction, or execution, of special geotechnical works (as well as laboratory and field testing of soil).

Special geotechnical works for which EN execution standards have already been issued include, for example, sheet-pile walls, ground anchors and, since early 2007, reinforced fill structures, known as EN 14475.

3 NATIONAL NORMS COMPLYING WITH EN STANDARDS

3.1 *National annexes to Eurocodes*

Although they establish the fundamental principles and requirements, the Eurocodes still leave a few options open for a national endorsement or, adjustment (such as the values to be given to some design factors, so that every country may keep a chance of sticking more or less to the level of safety it was used to). So, every country is meant to issue its own National Annex to every Eurocode.

In France, for example, the National Annex to EC7 was published in 2006. It does not deviate from the preferred and recommended options.

3.2 *Application standards*

As said above, the Eurocodes essentially set the basic principles, define good engineering practices and highlight what should be cared about in design. But, they generally do not lay down precise design procedures for particular types of structures. They are mainly a basis for working out further specific European or national standards (in the same way as EC0 and EC1 were primarily a basis for elaborating the other Eurocodes).

This is why a lot of application standards now need to be developed, or updated, in true compliance with the Eurocodes.

For example, as far as the design of special geotechnical structures is concerned, France is currently in the process of elaborating several "national application norms", supplementary to EC7, which respectively deal with topics such as embedded walls, shallow foundations, piled foundations, or, of uppermost interest to us, reinforced soil. The latter, provisionally known as Pr NF P 94-270, is presently submitted to the traditional public enquiry. It will cover soil nailing as well as reinforced fill walls, using all types of reinforcement, geosynthetics, metals (sheets, grids, and strips) and meshes. If, one day, a will arises to work out a common European standard for the design of reinforced soil structures, P 94-270 might be one of the helpful reference manuals.

4 IDENTIFICATION OF KEY ISSUES FOR REINFORCED SOIL DESIGN

Now that things are likely clearer and we have a better understanding of the ramification of the norms about reinforced soil which closely fit in with the CEN framework and principles, let us point out in this group of standards a few aspects which may be found particularly significant, or even excellent, regarding the design of reinforced soil structures, as the theme of our special session suggests.

We will first focus on conceptual design and quality of construction, then give attention to computational design.

5 CONCEPTUAL DESIGN AND QUALITY OF CONSTRUCTION

5.1 *Relevance*

When a discussion is launched, or a panel is invited to debate about the topic of design, the "academics" generally instinctively think about design models, limit states or working stress methods, load and resistance design factors, computer programs and so on.

However, although there is now, throughout the world, a good number of records and case stories about failures of reinforced soil walls, of all kinds, the fact is that, so far, very few (really very few, if any) can be attributed to a deficient computational design of the reinforced soil body itself, properly speaking.

On the other hand, those who would rather introduce themselves as "practitioners" (the ones who are often the first ones called to the sites, in order to look at the damages and try to figure out the causes and the remedies…) would likely first put other concerns forward. Their experience is that real failures are often a consequence of such causes as defective drainage (resulting for instance in washing out of soil or, should water be polluted, accelerated corrosion). Or else, improper identification of the in-situ soil properties (resulting in excessive settlements or, worse, punching shear failure or, overall sliding). Or, lack of care regarding the compaction requirements and/or the fill specifications (resulting in large deformations or, over-stresses or, in other circumstances, untimely degradation). Or, unwise combinations of mismatched structures, systems or technologies (resulting in converging loads and, ruptures).

This list is certainly not exhaustive and it would be fair to further comment, illustrate and scrutinize every allusion. Imperfect though it is, it shows that the problems which are actually encountered mainly lie with the conceptual design of the whole work and the quality of its implementation. One good thing with the set of standards which we are looking at here is that it does acknowledge it and, emphasize it.

5.2 *EC7 and NF P 94-270*

From the very beginning indeed, EC7 strongly states the following in an introductory chapter (clause 2.4.1(2)) about the basis of geotechnical design:

"It should be considered that knowledge of the ground conditions depends on the extent and quality of the geotechnical investigations. Such knowledge and the control of workmanship are usually more significant to fulfilling the fundamental requirements than is precision in the calculation models and partial factors".

This is repeated, in the exact same terms, in the foreword of the French norm P 94-270 regarding the design of reinforced soil structures.

It is quite significant that norms which essentially deal with calculation models and procedures, partial safety factors and so on, modestly acknowledge that there are more important things to look at for insuring the resistance, stability, serviceability and durability of the structures.

5.3 *EN 14475*

The subject of EN 14475 is execution, not design. It applies to the construction of all types of reinforced fill structures, for practically all possible applications, using nearly all existing technologies. As one can easily imagine, working it out was quite a challenge because of such a wide and varied scope (not to mention the contrasted origins, experiences and motivations of the working group members …).

So, it soon became obvious that the norm ought to be limited to common and essential requirements. It also turned out that, among them, one had to mention several stipulations or recommendations related to the proper selection of materials and products as well as to the suitable ways of combining them in a same structure, depending on its function and environment. This was initially somewhat disputed, on the grounds that such matters may rather come within design than within execution. But it was finally agreed, for two main reasons.

First, "conceptual design" is usually not addressed by the true design standards (maybe because it is viewed as a matter of engineering judgment, or expertise, which should not be codified?). So, if there are things which do need to be stated, the norm about execution is the only place available for that.

Second, the contractor in charge of building a reinforced fill wall often has some latitude for selecting the materials he will use. This is routinely the case for the fill, almost up to the last moment, but sometimes also for the reinforcement and facing, when the contract makes allowance for alternatives. It is therefore important that the norm about execution draws both the contractor's and owner's attentions to the necessary compatibility of the various materials, between them, as well as regarding the performance of the structure.

5.4 *EN 14475 and differential settlement*

As a matter of example, one issue which is particularly stressed in this respect in the EN 14475 standard and its informative annexes is the risk of differential settlement between the reinforced fill mass and the facing,

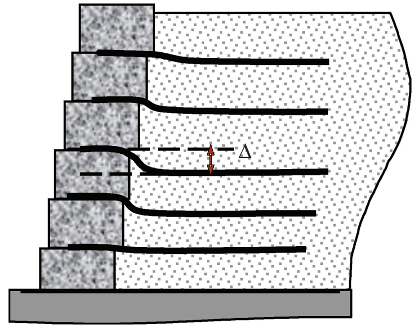

Figure 1. Potential differential settlement between reinforced fill mass and facing.

which may result from the compression of the fill during, and sometimes after, construction. What the norm states is, in short, as follows:

If the reinforcement is structurally connected to the facing units, without allowance for potential differential movement, then additional loads may be imposed on the fill reinforcement (fig.1). Such differential movement will mainly be affected by the quality of the selected fill, and the way it is compacted.

More stringent specifications should therefore apply to a fill material used with a less flexible facing system. Or, conversely, a facing system should be more flexible if the selected fill is prone to settle or not easy to compact.

For semi-flexible systems made of partial height facing panels, moderate differential movements are usually accommodated by the use of compressible bearing pads installed in the horizontal panel joints.

For rigid facing systems such as full height panels without moving connections, and segmental blocks packed without compressible filler, deformation in the region of the face connections may occur. Additional loads imposed on the connections and reinforcements should be mitigated, as far as possible, by proper selection, placement and compaction of the fill material. Otherwise, it is clear that such additional loads could not be reasonably estimated and, moreover, they might be incommensurable with the tensile loads computed according to the routine design procedures and standards. This is not all imagination: it did happen in several cases and resulted in the collapse of walls. It does confirm that conceptual design and quality control of execution may prevail over theoretical design models and partial factors.

6 COMPUTATIONAL DESIGN

6.1 *Preconditions*

Of course, the importance of conceptual design and quality control does not make it exempt from running any calculations. For them to be valid, EC0 and EC7 lay down a few major prerequisites:

– Data needed for design should be collected and interpreted, structures designed and execution carried out by qualified personnel having the appropriate skill and experience
– Adequate continuity and communication should exist between the personnel involved in data collection, design and construction
– Adequate supervision and quality control should be provided in plants and on site.

This being born in mind, let's now pick out from the future French P 94-270 application design standard a few noteworthy features.

6.2 *Ultimate and Serviceability Limit States*

As already mentioned, the NF P 94-270 norm is meant to apply to soil nailed as well as reinforced fill walls (including bridge abutments) made with polymeric as well as metal reinforcements, of any shape in use. Therefore, the core of the norm focuses on concepts and principles which do apply to all of them, while details pertaining to particular subjects, materials or products are to be found in annexes.

Coming at the head of the general rules for the justification of the works, is the differentiation between Ultimate Limit States (ULS) and Serviceability Limit States (SLS), which are linked with different sets of partial factors.

In strict compliance with EC0, the norm reminds that, by definition, ultimate limit states are associated with the conditions of collapses caused either by the loss of stability, the rupture, or excessive deformation of either some parts or, of the entirety of the structure, including those due to the effects of time.

On these grounds, there is no doubt that the tensile breakage of the reinforcements, especially when resulting from ageing or corrosion, relates to ULS (and so does the loss of adherence). But, it must be also acknowledged that large elongations of the reinforcements which could result in detrimental deformations must also be considered under the ULS heading. We are not contemplating here deflections which would only affect the aspect or, aesthetics of the wall. We are thinking of deformations which could, for example, possibly bring about some dislocation of the facing, hence result in progressive leaching and washing out of the soil, then eventually lead to collapse.

For that reason and, as a matter of example, as far as steel reinforcements are concerned, the NF P 94-270 norm concurrently takes into account for ULS design:

– The rupture stress, in cross-sections of the steel members where their tensile resistance might be locally most affected by corrosion (fig.2)

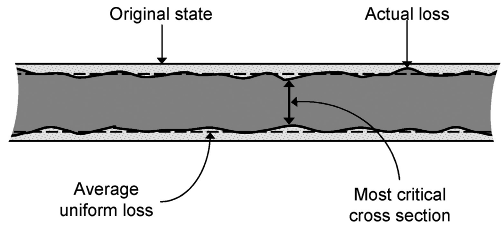

Figure 2. Schematic effect of corrosion along a reinforcing steel member.

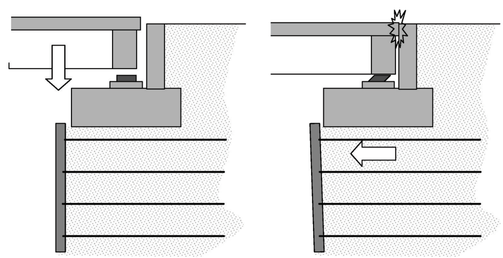

Figure 3. Example of a potential serviceability limit state at the top of a reinforced soil bridge abutment.

– The yield stress, supposing it prevails over a certain length where corrosion is assumed to be virtually uniform. Yield, if exceeded, might indeed entail elongations well in excess of 10%. It is understandable that the yield criterion controls as long as corrosion is small in comparison with the cross section.

As to serviceability limit states, the norm reminds that they relate to situations which might be harmful to a proper utilisation of the structure (or the ones in its vicinity) in its habitual conditions of service. The relevant criteria essentially concern the deformations, movements or displacements of the reinforced soil body or its foundation (which may not be easily assessed, but with numerical models) in place of the loads and stresses.

An instructive example of serviceability limit state is described in the annex of the norm which deals with bridge abutments. It is aimed at the strain which may almost instantly affect the upper reinforcing layers (all the more so if extensible) when the bridge deck is put down on its bearings. It can be anticipated that the elongation of the top reinforcements could bring about a frontward displacement of the beam-seat, hence a distortion of the bearing pads or a closing of the bridge joint unacceptable for a good functioning of the bridge (fig. 3).

In short, the main point which we wanted to emphasize here is that, in the EN meaning, a serviceability limit state should not be confused with what may be

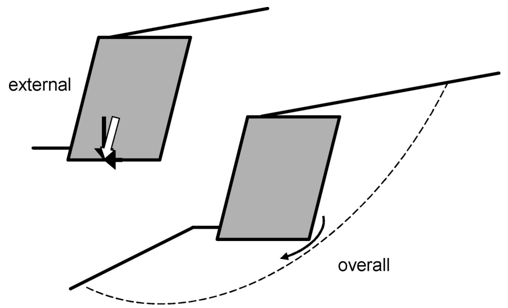

Figure 4. ULS design of external and overall stabilities of the reinforced soil body.

called in other codes either “in service” or “working stress” conditions.

6.3 *Four stages ULS design*

The French P 94-270 design standard states that the ultimate limit states justifications of a reinforced soil structure should be presented in four successive stages.

The first two deal with the shape of the reinforced soil body, considered as a block (fig. 4): “external stability” (sliding on the base, bearing capacity) and “overall stability” (potential failure surfaces outside the block). Up to a certain point, they could be considered as a kind of pre-sizing of the reinforced soil structure, which, at least, sets the lengths of the reinforcing layers.

The others relate to two different ultimate limit states but both deal with the arrangement of the reinforcements inside the block: types, spacing and numbers.

First, the “internal stability” is based on what is known, from experimental data, about the actual behaviour of similar structures, i.e. the likely distribution of stresses and forces once in service and, as a result of the construction procedure. Second, the “compound stability” analyses the potential risk of shear failure along lines which intersect some reinforcing layers (fig. 5).

6.4 *Internal and compound: both necessary*

The P 94-270 norm stresses that designing for internal stability and checking compound stability are both necessary but, none is sufficient.

On one hand, internal stability aims at placing what is needed where it is actually needed, in order to balance the maximum forces which are expected to build up in the reinforcing layers and keep more or less steady over the whole service life of the structure. The ULS is clearly linked in that case to the long-term ageing of the reinforcements. However, the

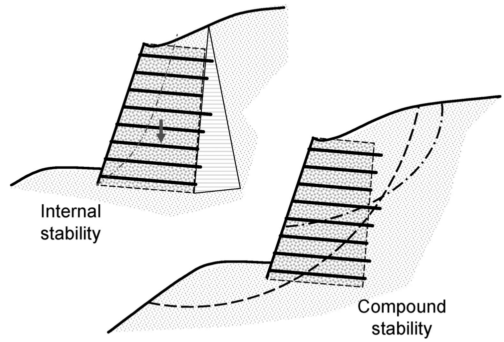

Figure 5. ULS design of internal and compound stabilities of the reinforced soil structure.

usual procedures (such as the so-called “coherent gravity method” for reinforced fill walls) only take into account simplified effects of the soils retained by the structure. What is more, they can’t consider at all the characteristics of the foundation and their possible impact on the response of the structure.

On the other hand, whereas the usual compound stability models can take into account the varied natures of the layers or zones of in-situ soils and imported fills which compose and surround the structure, they often only consider sorts of global equilibriums, without worrying about any particular layout of the reinforcements. Therefore, some models might possibly validate a distribution which is unsuitable regarding internal stability. Above all, the usual “at-failure” models are generally based on assumptions which are somewhat disputable or unrealistic. Some assume that both the maximum tensile capacity and pull-out capacity can be mobilised simultaneously, which is doubtful. Yet, they impose on the pull-out capacity of some layers to not exceed a given long-term tensile capacity, which is illogical or (so to speak …) unfair. Others derive the calculated forces from assumed displacements, which do not and cannot take place, unless the structure is failing and is already beyond an ultimate limit state.

So, the P 94-270 norm, having warned against the limits and deficiencies of both the internal and compound stability analyses, advises to use both of them, provided the most is made of sound engineering judgment and previous successful experience. In unusual cases, resorting to numerical models is allowed.

Before moving to the closing subject, let’s go back to at-failure models (without displacement) for a final remark. It could make sense to cope successively with the pull-out capacity of the reinforcements, recognized as a short-term issue (in a non geotechnical sense of the word) then with their tensile capacity, which definitely is a long-term issue. In the short term, once the structure is completed and subjected to its service loading, one can first and only see to it that there is no

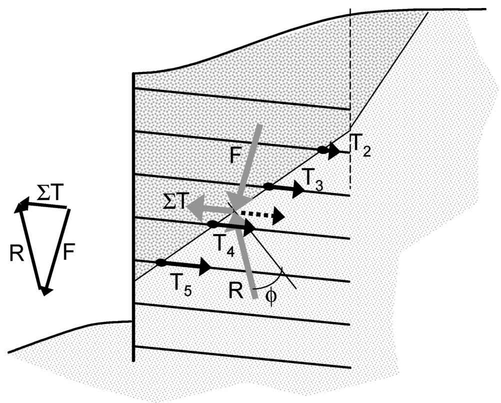

Figure 6. Equilibrium of forces and moments in a potential slip failure analysis.

risk of sliding. This involves the pull-out capacity of the intersected reinforcing layers and allows determining what their minimum width or perimeter should be, without yet worrying about their tensile capacity. One hypothesis has to be made, however, for sharing out the total required force between the intersected layers, depending on what the shortest resisting lengths merely can bear up, so that the equilibriums of forces and moments are satisfied (as suggested on figure 6 for a simple example with bilinear failures lines).

A series of potential failure lines can thus lead for each layer to the maximum tensile load it has to withstand up to the end of the service life and, in a second step, to its required minimum tensile capacity. Starting from the top can even allow optimising the reinforcing layers one after the other (and better understand how the pull-out capacities which are available here affect the tensile loads there).

7 DURABILITY SAMPLES

In closing, let's discuss something at the junction of design and construction. In its chapter about "Design and construction considerations" for retaining structures (Ch. 9.4), the Eurocode EC7 sets the following requirement: "As far as possible, retaining walls should be designed in such a way that there are visible signs of the approach of an ultimate limit state. The design should guard against the occurrence of brittle failure, e.g. sudden collapse without conspicuous preliminary deformations".

This is faithfully implemented in the French P 94-270 by requiring that durability samples are installed, during construction, in all types of permanent reinforced soil structures. They are meant to be extracted at scheduled intervals (after 10, 30, 50 years or so) and monitored in order to make sure that nothing abnormal is taking place. Should the case occur, the owner would have plenty of time for thinking about what can be done. The only exempt walls are those whose collapse would merely entail negligible consequences and the ones which would be no longer accessible once built.

8 CONCLUSION

It is obviously impossible to summarise, in just a few leaves, a set of three thorough norms which, in total, weigh round about four hundred densely made up pages. Claiming that their major points, as far as reinforced soil is concerned, have been all clearly spotted above would be by far quite pretentious. At least, it is hoped that those which have been selected and addressed here will contribute towards a stimulating panel debate and, hopefully and later on, towards some further progresses and international harmonization of the design principles and standards.

REFERENCES

EN 1990:2002. Eurocode (0). Basis of structural design
EN 1991-1:2002. Eurocode 1. Actions on structures (7 parts).
EN 1992. Eurocode 2: Design of concrete structures (3 parts).
EN 1997-1:2004. Eurocode 7. Geotechnical design. Part 1: General rules.
EN 1997-2:2007. Eurocode 7. Geotechnical design. Part 2: Ground investigation and testing.
EN 14475:2006. Execution of special geotechnical works. Reinforced fill.
Pr NF P 94-270. Geotechnical design. Retaining structures. Reinforced fill and soil nailed structures.