

Do partial factors have a role in verifying the ultimate limit state when adopting the Observational Method?

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ABSTRACT: Geotechnical design in accordance with Eurocode 7 can be completed by one of four methods; design by calculation, prescriptive measures, testing or adoption of the Observational Method. Of these four options, design by calculation is most common but the Observational Method when used successfully can offer potential programme, cost and carbon savings. When design by calculation is adopted, adequate reliability is achieved by the choice of characteristic parameters and the application of partial factors, making the occurrence of an ultimate limit state sufficiently unlikely that no further intervention by the designers should be required. When adopting the Observational Method, a range of design variants are considered with associated contingency measures that can be adopted based on the observed performance during construction. The second generation of Eurocode 7 (EN 1997-1, 2024) explicitly requires the designer to verify the ultimate and serviceability limit state for each design variant when adopting the Observational Method, although provides no further guidance. This paper has been prepared to address the conundrum of how the occurrence of an ultimate limit state is prevented when using the Observational Method, and when or if ever partial factors should be used in its application.

KEYWORDS: Eurocodes, The Observational Method, Partial Factors, Reliability

1 INTRODUCTION

Codes of Practice in geotechnical engineering have developed over the past 50 years as a means of undertaking design work in a safe and consistent manner. The degree of safety that is added to the design have evolved as a consensus on what is an acceptable likelihood of failure balanced against excessive conservatism and associated cost.

The Eurocode suite of documents is the predominant Code of Practice used in Europe and are based on the limit state design framework. For any geotechnical structure typically the Ultimate Limit State (associated with collapse or failure) and the Serviceability Limit State (associated with performance in service, displacements and appearance) must be verified.

Eurocode 7 (EN 1997 Part 1) for the design of geotechnical structures allows the limit states to be verified by one of the following methods: “*design by calculations*”, “*adoption of prescriptive measures*”, “*experimental models and loads tests*”, or the “*Observational Method*”. The most common of these is “*design by calculation*” where safety is achieved by applying partial factors in different combinations to soil strengths, resistances, actions and/or the effects of actions.

For the case of an embedded retaining wall (which is the focus of this paper) further robustness in the design is achieved through the choice of characteristic soil strength parameters as a “cautious estimate of the mean” and other considerations such as minimum pressures acting on the wall and accidental over excavation. By convention, if these measures are applied in the design the structure is considered sufficiently remote from failure such that no further intervention by the designer should be necessary during construction. Field monitoring that is undertaken is to verify design intents and assumptions, to safeguard third party assets, and to provide legal protections to asset owners. Data from field monitoring has rarely been used during construction to make beneficial changes in the design

(Liew et al, 2024), unless the Observational Method Design Approach C (CIRIA C760) is implemented.

When the observational method is adopted *ab initio* (C185), the same analyses that are used in the design by calculation approach are undertaken, but rather than adopting a single set of characteristic values, a range of behaviours are considered, typically including worst credible, characteristic and most probable and an appropriate design completed with mitigations for each. Trigger limits are set and through a process of observation and comparison with trigger levels, safety is achieved.

The application of the observational method can offer financial, programme and carbon benefits compared to the design by calculation approach but requires more design effort, the continued involvement of the designer throughout construction and a collaborative and “one team” approach on the part of the client and contractor to accept possible changes to design and construction as well as enhancements to the assurance process.

This paper has been prompted by discussion between TC206 committee members on the possible application of partial factors when adopting the observational method. The discussion is focused on the design of embedded retaining walls, however the principles are equally applicable to the application of the Observational Method for any other type of geotechnical structure.

2 CODE REQUIREMENTS

2.1 First generation of Eurocodes

The first generation of Eurocode 7 (EN 1997-1:2004) was the first Code of Practice that explicitly permitted the use of the Observational Method, although provided very little guidance on its implementation. By way of illustration, EN 1997-1

dedicates 12 pages to design by calculation but only 221 words on the observational method.

The code requires that a “range of possible behaviours” shall be assessed, and a monitoring plan devised “which will reveal whether the actual behaviour lies within the acceptable limits”. In response to the range of behaviours and monitoring data, “a plan of contingency actions shall be devised” that is to be implemented if the monitoring behaviour is outside the acceptable limits.

There is no requirement or discussion on the range of parameters that should be used in the design or if partial factors should be applied to them when making the assessment. There is also no mention of the requirement to satisfy either the serviceability or ultimate limit states, although Clause 2.1 (4) states that limit states should be verified by one or a combination of the four permissible approaches, including the observational method. Published Eurocode guidelines (Frank *et al.* 2005) also offer very little guidance on the matter.

2.2 Second generation of Eurocodes

The three parts of the second generation Eurocode 7 were published between October 2024 and April 2025. The main objectives of the second generation were to produce greater harmonization by reducing national choices, improve the ease of use and provide guidance on the more recent developments such as numerical methods and probabilistic design.

In the evolution of the second generation of Eurocode 7 there has been no change in the four approaches to undertaking geotechnical design; namely design by calculation, prescriptive measures, testing or the Observational Method. The amount of text dedicated to observational method has also not changed significantly (229 words), but there have been some subtle changes to the text. These include:

- The range of different design variants shall cover “all foreseeable relevant ground responses and ground-structure interactions”.
- Contingency measures shall be prepared in advance and applied when actual behaviour reaches “acceptance criteria or threshold values”.
- Clause 4.7 (5) states that “ultimate and serviceability limit states shall be verified for each design variant”.

There is no further discussion or requirement within the document on how the ultimate and serviceability limit states should be verified for each design variant.

2.3 CIRIA report C185

CIRIA Report R185 (Nicholson *et al.* 1999) was written following the 9th Geotechnique Symposium in Print “The Observational Method in Geotechnical Engineering”, organised by the Institution of Civil Engineers (ICE. 1996). At the time, the nascent Eurocode 7 was available in draft form and included the familiar text on the Observational Method. The document gave a history on the development of the Observational Method from Terzhagi and Peck to the draft Eurocode 7, as well as a number of case histories. There is much discussion on the definition of parameters used in different Codes of Practice when applying the observational method. Whilst the nomenclature varies, the choices reduce to most probable, moderately conservative and worst credible. Partial factors are discussed at length in the context of verifying the ultimate limit state, however the document does not state clearly that they should be applied when considering design variants as part of the application of the Observational Method.

2.4 CIRIA C580 Embedded Retaining Walls – Guidance for Economic Design

Report C580 was published in 2003 and proposed a design methodology for embedded retaining walls that included three approaches. These drew on the early versions of Eurocode 7 resulting in a similar but not identical limit state design approach. Design Approach A adopted “moderately conservative” soil parameters with partial factors greater than unity applied. Design Approach B adopted worst credible soil parameters with partial factors of unity. The third approach, Design Approach C was identified as “only being applied with an Observational Approach” and adopted Most Probable parameters. Critically, Table 6.1 in CIRIA C580 states clearly that when adopting Design Approach C and an observational approach, partial factors of 1.2 and 1.5 should be applied to effective stress and total stress strength parameters respectively. It is also noted that Approach C should never be used on its own, and an alternative design with appropriate contingency plans should be developed in parallel using Approach B with worst credible parameters and partial factors of unity on soil strength.

2.5 CIRIA C760 Guidance on embedded retaining wall design

Report C760 was published in 2017 as an update to C580 with the primary intention of bringing the guidance into line with Eurocode 7 that had been published and widely adopting in the intervening time. The document developed the application of the Observational Method in its application to the design of embedded retaining walls and introduced four categories for the observational method, *ab initio* A and B and *ipso tempore* C and D. It is important to note that the approaches A, B, C and D defined in C760 are different to the Design Approaches A, B and C defined in C580.

When adopting the observational method *ab initio* or *ipso tempore*, Section 7.4.3 of C760 is clear that for each of the design variants considered (for example most probable and characteristic), the design and mitigation measures should be designed in accordance with the requirements of design by calculation, i.e. completing Design Approach 1 Combination 1 and Combination 2 in accordance with the UK National Annex, and therefore by inference should include the application of the application of the appropriate partial factors.

2.6 Discussion

The introduction of Clause 4.7(5) in the second generation of Eurocode 7 that explicitly requires the verification of the serviceability and ultimate limit states when adopting the Observational Method triggered the discussion in TC206 and led to the drafting of this paper.

In the first generation of Eurocode 7 it was only indirectly implied that the application of the Observation Method satisfied the ultimate limit state. The inclusion of Clause 4.7(5) in the second generation of Eurocode 7 suggests that when adopting the Observational Method the ultimate and serviceability limits states still require verification but is silent on how that might be achieved.

From the review of Codes of Practice and design guidance documents presented in this paper, it is only the CIRIA guides for the design of embedded retaining walls that explicitly state that partial factors should be used to verify the ultimate limit state for each design variant. From informal discussions held by the authors it is apparent that this requirement is not widely understood. The remainder of this paper will examine this requirement and provide recommendations for a clear proposal

for the adoption of the Observational Method for the design of geotechnical structures.

3 HOW SAFETY IS ACHIEVED IN LIMIT STATE DESIGN

To understand if partial factors have a role in the application of the Observational Method, it is important to understand how safety is achieved in “design by calculation” and then systematically decide if the uncertainty they are addressing are applicable to the Observational Method. Table 1 summaries how safety is achieved for the design of embedded retaining walls.

Table 1. Design by calculation – how is safety achieved.

Measure	Relevance to Observational Method
Material properties – choice of characteristic	Not relevant – a range of parameters considered in the design
Partial factors on material properties	Requires further consideration
Geometrical variations (See Clause 7.2.2.2 EN1997-3)	Considered relevant, but could be reduced by better construction control.
Partial factors on loading	Considered relevant but can be rationalised during back-analysis
Partial factors on effects of loads	Requires further consideration
Other measures such as minimum pressures (see Clause 7.5.3.2 for $p'_{a,min}$ and $p_{a,min}$)	Not relevant provided its occurrence does not lead to a brittle failure

The design of any structural element, for example a reinforced concrete retaining walls or steel sheet pile, clearly needs to be designed in accordance with the Eurocode for the material under consideration with partial factors applied to their strength properties. As the application of partial factors on structural materials properties is required it will not be discussed further in this paper.

Application of partial factors on geotechnical material parameters and the effect of actions require further consideration as it is not obvious if they have a role to play in the application of the observational method.

The design value of the effect of actions, E_d , is defined as:

$$E_d = \gamma_{sd} E \left\{ \sum (\gamma_f \psi F_k); a_d; X_{Rd} \right\} \quad (1)$$

where γ_{sd} is a partial factor associated with the uncertainty of the actions and/or effect of the model and γ_f is a partial factor that takes account of unfavourable deviations of an action from its representative value. Normally these two factors are combined into $\gamma_F = \gamma_{sd} \cdot \gamma_f$ or $\gamma_E = \gamma_{sd} \cdot \gamma_f$.

The design value of the geotechnical resistance of a structure R_d for a specific design situation should be calculated from:

$$R_d = \frac{1}{\gamma_{Rd}} R \left\{ \frac{\eta X_k}{\gamma_m}; a_d; \sum F_{Ed} \right\} \quad (2)$$

where γ_{Rd} is a partial factor associated with the uncertainty of the resistance model, γ_m is a partial factor for a material property accounting for:

- Unfavourable deviation of the material from their representative values
- The random part of the conversion factor η

Here, η is a conversion factor accounting for scale effect, effects of moisture and temperature effects of aging of materials and any other relevant parameters. These two partial factors are typically combined into one $\gamma_M = \gamma_{Rd} \cdot \gamma_m$.

In the second generation of Eurocode 7, when using the Material Factoring Approach (MFA), the values of γ_M for effective stress and total stress strength parameters are 1.25 and 1.4 respectively. The value for γ_E is 1.35.

Through the process of observation, back analysis and calibration in the Observational Method, the designer is reducing the uncertainty in the calculation model (addressed by γ_{SRd} and γ_{Rd}) and the variability of the material properties from their representative values (addressed by γ_m), however they are not completely eliminated. There is no reduction in the uncertainty in the loading on the wall which is addressed by γ_f .

Taking these considerations into account, the use of partial factors when applying the observational method cannot be eliminated, however, on the basis of observation and back analysis they could justifiably be reduced as the uncertainty is reduced. This possibility will be addressed with practical examples in the next section.

4 MULTI-PROPPED EMBEDDED RETAINING WALL EXAMPLE IN STIFF CLAY

Using the example of a multi-propped embedded retaining wall in stiff clay, the ultimate limit state is likely to be governed by the structural capacity of the wall, which in turn is governed by the stiffness of the ground (referred to as the STR limit state in the first generation of Eurocode 7). The serviceability limit state in concrete structures may be governed by crack widths which is also a function of ground stiffness. The structural behaviour of the wall can be assessed by consideration of the deformed shape as measured by inclinometers and then the calculation of radius of curvature and associated bending moments and shear forces. This process of calculating structural forces has been made much simpler by access to real time back analysis tools.

In this situation, the occurrence of the structural ultimate limit state can therefore be controlled by observation, back analysis of deformation behaviour and calculation of the structural forces. The back analysis of the wall behaviour is unlikely to reveal any reliable information on the strength as the soil body is remote from failure in normal service.

In these circumstances the limit state is verified by the observations and there is no need to use any partial factors. Therefore development of the structural ultimate limit state by the observational method does not require the application of partial factors γ_M or γ_E , as the calculated structural forces can be directly compared to the structural capacities.

A geotechnical ultimate limit state could occur by a global failure of the type shown below (referred to as GEO limit state in the first-generation Eurocode 7).

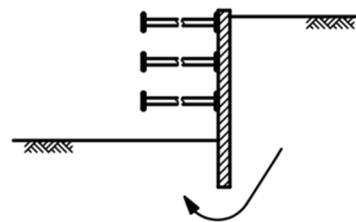


Figure 1. Example of geotechnical ultimate limit state mechanism for multi-propped embedded retaining wall (taken from EN 1997-3 (2025))

The occurrence of this type of failure is governed by soil strength. Observation and back analysis of the wall behaviour, which as previously noted is dominated by ground stiffness for over consolidated clays, would not provide useful information on soil strength to assess the development of a global failure of the type shown in Figure 1.

As the development of this type of global failure is governed by soil strength which cannot reliably be verified by

observation, the verification of this type of limit state must be undertaken by the use of partial factors. However, for stiff over consolidated clays such a failure mechanism is not critical and often verified by inspection.

5 EMBEDDED RETAINING WALL IN SOFT CLAY

For an embedded retaining wall in soft clay, the Observational Method is particularly useful when verifying the capacity of struts and anchors, which are known as supporting elements in the second generation of Eurocode 7 (Figure 2). The load effect on the supporting element is governed by a complex soil–structure interaction behaviour that depend on the degree of shear strength mobilisation in the clay due to deformation. Larger horizontal deformation result in less capacity being needed in the structural elements. This behaviour is difficult to predict in advance; in other words, it is associated with a considerable model error. This is the main uncertainty, rather than the soil properties themselves.

Using partial factors and the MFA in soft soils (or input factoring in numerical modelling) results in soil properties that are below worst credible. This represents an extreme worst-case scenario that triggers a very large horizontal deformation and a substantial load effect in the supporting elements, which require a high capacity to satisfy the code requirements. However, considering most probable soil conditions yield considerably less horizontal deformation and therefore considerably less capacity in the supporting elements. Using partial factors and the MFA can therefore yield substantial over-design of the supporting elements.

As a cost-effective alternative, the Observational Method can be used to verify the capacity of the supporting elements. By considering two design variants, where the first is based on characteristic ground conditions and the second is based on the partial factor verification using MFA, monitoring of strut forces and horizontal deformation during excavation can be used to determine the appropriate design variant by assigning relevant threshold values. Note that other limit states also need to be verified, such as global stability and rotational stability, for which partial factor verification may be well suited.

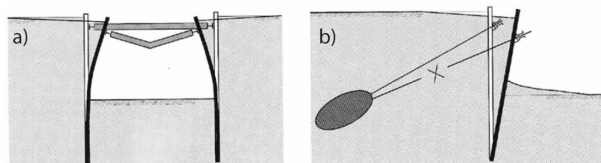


Figure 2. Failure modes for supporting elements: a) strut, b) anchor. (Swedish Commission on Pile Research, 2024)

6 ANALOGY WITH PILE DESIGN

In the UK National Annex to the first generation of Eurocode 7 and the base code for the second generation of Eurocode 7 the partial factors used in the design of piled foundations is a function of the type of pile testing that is undertaken. As an illustration, the derived values of the partial factors for pile design from the UK National Annex for the first generation of the Eurocodes are summarised in Table 2.

This approach recognises that undertaking working test on contract piles and/or preliminary test on sacrificial piles reduces the uncertainty in the calculation model and the ground parameters used in the pile design. The partial factors on end bearing and shaft capacity are reduced by around 12% if one type of test is undertaken and 24% if both are used.

The working test pile confirms workmanship and verifies the serviceability limit state and the preliminary test pile

verifies the ultimate limit state and because geotechnical failure is induced, ground strength.

Table 2. Partial factors used in pile design based on UK National Annex for first generation of Eurocode 7.

Partial Factor	No testing	Working test only	Prelim test only	Prelim and working
End bearing γ_b	2.38	2.1	2.04	1.8
Shaft (comp) γ_s	2.1	1.82	1.8	1.56

It can therefore be seen that within the framework of the Eurocode validating the relevant limit states by observation allows the reduction in the partial factors used as the uncertainty in the soil properties and the calculation model are reduced by the testing. It is however critical to note that for the geotechnical limit state it is the ground strength that is verified by inducing failure in the preliminary test pile, something that is not easily achieved for embedded retaining walls.

7 CONCLUSIONS

Through the discussion presented in this paper the following conclusions can be drawn when applying the Observational Method to the design of embedded retaining walls:

- The observations obtained from embedded retaining walls during construction are typically displacements in the wall itself and forces in associated support structures.
- These observations allow for a continuous assessment of the structure's behaviour and forces in the wall.
- These structural forces are a function of displacement which is governed by the ground stiffness and in-situ stresses (K_0)
- In stiff clay conditions during operation the ground is remote from failure and therefore the observations provide no insight in the ground strength.
- Therefore it can be concluded that the structural limits state is verified by the observations but the geotechnical limit state is not assessed.
- The geotechnical limit state should continue to be verified by the application of partial factors.
- It is acknowledged that for propped walls in stiff clay, the check on the geotechnical ultimate limit state is trivial and often satisfied by inspection.
- For single propped walls, cantilever walls or walls in soft ground conditions, the geotechnical limit state is often critical and required explicit verification.

Using the parallel of pile design where partial factors are reduced according to observations from testing, it may be possible to reduce the partial factors used in the verification as information on serviceability is provided. This would however required some changes to be made to Eurocode 7.

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