Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-782

2nd Generation of Eurocode 7 - Reinforcing the ground or engineered fill

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ABSTRACT: The latest revision of Eurocode 7 is a significant milestone in the industry, as it incorporates essential geotechnical structures previously absent from European standards. This advancement towards a unified design practice in Europe is a crucial development that all professionals in the field should be aware of. The expanded scope of EN 1997-3 now covers reinforced fill structures, including reinforced walls, slope, basal reinforcement and veneer reinforcement, as well as soil nailed structures - these structures are the focus of this paper. The paper characterizes the geotechnical design framework and verification methods for ultimate and serviceability limit states. The calibrated partial factor system and the calculation models are also illustrated. Fundamental changes in Eurocode philosophy will reshape how to approach these geotechnical structures, particularly regarding design basis, numerical modelling and construction quality assurance. The importance of maintaining consistent reliability standards throughout the project lifecycle - from design conception through construction to performance verification - is also recognized and harmonized. Therefore, critical references to mandatory supplementary standards are also provided. The authors evaluate how these new Eurocode 7 provisions compare with established design guidelines and current construction practices across European nations. This paper considers various regional implementation approaches and practical rules encountered in different countries.

KEYWORDS: ground reinforcement, soil reinforcement, soil nails, reinforced fill structures, soil nailed structures.

1 INTRODUCTION

Second generation of Eurocode 7 with third part EN 1997-3 (2025) represents a major advancement in European geotechnical design by formally including reinforced fill structures in scope of Clause 9 and soil nailed structures in Clause 10. These techniques of ground reinforcing have been widely used in practice but were not previously covered by harmonized standards. The updated Eurocode 7 defines detailed requirements for material properties, durability, resistance verification, and limit state design checks, fostering greater consistency and reliability. It further emphasizes construction quality assurance and comprehensive verification throughout the project lifecycle.

This paper focuses on the new technical provisions and presents a critical comparison with established guidelines and national practices, highlighting the implications of this harmonized framework for the safe and durable design of reinforced fill and soil nailed structures across Europe.

2 COMMON ASPECTS

Structures in the scope of the paper function as composite system, which share the fundamental concept relying on the interaction between reinforcement, ground or engineered fill, and facing elements. Reinforced fill structures strengthen engineered fills using variety reinforcements systems, while soil nailed structures reinforce ground (soil, rock, and fill existing in place), both combined with the facing. Consequently, the design framework in EN 1997-3 shares similarities between these two types of structures.

Clauses 9 and 10 primarily focus on the limit states of individual elements, such as rupture of reinforcement or facing, failure at interfaces between ground and reinforcement, and resistance of any connections. They also provide detailed information on material properties, durability and long-term behavior, and testing requirements. The design approaches for individual elements show analogies in aspects such as pull-out resistance or wire mesh design

However for general limit states, including stability or bearing resistance, verification should be performed according to Clause 4 (Slopes, cuttings, and embankments), Clause 5 (Spread foundations), or Clause 7 (Retaining structures), depending on the structure type and considered failure mode, with beneficial effect of the reinforcement. These clauses use consistent verification methods that also determine forces in the reinforcing elements or soil nails. Finally, as structures in the scope often rely on groundwater control, guidance on its measures is given in Clause 13.

Both clauses reference extensively other parts of EN 1997 and related Eurocodes, especially the basic EN 1990, as well as the execution, material and testing standards, in line with increased harmonization of design rules and quality assurance procedures. This promotes enhanced reliability of geotechnical structures by ensuring close linkage of all stages from design through execution and testing

One notable improvement in the second generation of Eurocode 7 is the clarification and compilation of material requirements for geotechnical structures. Recognizing that durability is critical due to the mostly underground nature of these systems, the code provides detailed guidance on assessing corrosion effects and strength reduction over time, alongside prescribed corrosion protection measures.

3 REINFORCED FILL STRUCTURES – GENERAL CONSIDERATIONS

3.1 *General*

EN 1997-3, Clause 9 deals with all kinds of applications where engineered fill (not asphalt) is reinforced. Especially mentioned are reinforced walls and abutments, reinforced slopes, basal reinforcement for embankments (including load transfer platforms over inclusions and areas prone to development of voids) and reinforcement along slope surface (veneer reinforcement). Geotextile encased columns are covered in EN 1997-3, Clause 12 “Ground Improvement”.

To date, at the European level, a standard has existed solely for the execution of reinforced fill constructions – EN 14475 – but no dedicated design standard has been established. Clause 9 in the new generation of Eurocode addresses this gap by introducing provisions developed from various national design standards and recommendations, as well as setting rules for reinforcement materials. Thereby it ensures an equivalent level of reliability and robustness across Europe.

The fundamental provisions were outlined by Bräu (2024). This paper expands on these foundations by providing further details to illustrate the practical application of the new Eurocode 7 provisions in the design reinforced fill structures.

3.2 *Limit States*

For all ultimate limit states, the benefit of the reinforcement whenever it is involved in the failure mechanism, are addressed:

- rupture of the reinforcing element;
- rupture of any connection between a reinforcing element and a facing element of the structure (reinforcement at the connection, facing element at the connection, connector);
- rupture of any seam or joint between the reinforcements themselves;
- failure along slip surfaces that pass wholly or partially through the reinforced block, either through the fill or along a reinforcement (sliding);
- failure at the interface between the fill and the reinforcing element (pullout).

The clause shows a clear separation of failure mechanisms that affect the reinforced fill body and those that exclusively affect the facing and the connection of the reinforcement there. Therefore, possible ultimate limit states for the facing system are mentioned, mainly:

- structural and equilibrium failure of the facing element;
- connection failure between reinforcement and facing units;
- shear failure between face elements i.e. bulging;
- shear failure between face elements and reinforcements.

It is obvious that the most critical failure mechanism (whichever ULS it originates from) has to be found wherever it occurs in the reinforced fill structure.

The serviceability limit states deal with the different deformations that might occur. Settlement is covered by usual calculation methods, but most of the other deformations are subject to numerical methods and have to be calibrated with measurements.

3.3 *Materials*

Clause 9 gives specific requirements for all materials that are used as reinforcement or for the facing system. As reinforcement materials geosynthetics, steel and polymeric coated steel woven wire meshes are described with their different approaches and reduction factors due to creep, mechanical damage during installation, corrosion, wheathering, chemical and biological degradation and intense and repeated loading.

3.4 *Geotechnical Analysis and ultimate limit states*

For the calculation of external and compound failure mechanisms in a reinforced fill structure, the references are given to other clauses whereas the benefits of the reinforcing elements are described in Clause 9.

For internal failure mechanisms and for design procedures specific to the application, different approaches exist in Europe. They are mentioned with references to the national standards and recommendations, mainly (in alphabetic order):

- ASIRI, Recommandations pour le dimensionnement, l'exécution et le contrôle de l'amélioration des sols de fondation par inclusions rigides ;
- BS 8006-1, Code of practice for strengthened / reinforced soils and other fills;
- CUR 226 Design guideline basal reinforced piled embankments;
- EBGEO, Recommendations for design and analysis of earth structures using geosynthetic reinforcements;
- NF P 94 270 Calcul géotechnique - Ouvrages de soutènement - Remblais renforcés et massifs en sol cloué.

Reinforced slopes, walls, and bridge abutments should be verified using one or more of the following:

- coherent gravity method;
- tie-back wedge method;
- multiple wedge method or;
- slope stability methods.

Basal reinforcement for embankments, load transfer platforms over discrete ground improvement, overbridging systems and veneer stability are also listed in EN 1997-3, Clause 9 with their essential requirements. Detailed design approaches still have to be defined or developed by national bodies.

The effect of a reinforcing element for the calculation is based on the tensile resistance (determined specific for each type of reinforcing material), the pull-out resistance and the resistance in direct shear. The latter two resistance values are determined in EN 1997-3, Clause 9 for sheet and discrete reinforcement elements. Each value gets assigned a partial factor that are presented in Table 1. For the internal failure mechanisms, the references to EN 1990:2023 and the Verification Cases (VCs) are given. The following lines of the table present the partial factors to be adopted for the reinforcing and the facing elements whenever such an element is impacted by a failure mechanism. The presented values are the result of a European compromise leading to higher and lower values compared to the actual national standards. They are selected in such a way that a design with them enables a safe construction taking into account that the reduction factors are derived based on the procedure described in the "Material" section (e.g. for geosynthetics especially according to ISO/TS 20432).

Table 1. Partial factors for the verification of reinforced fill structures.

Partial factor on		**MFA**	**RFA**
Actions, Effects of Actions	γ_{F}, γ_{E}	VC3	VC1
Ground and fill properties	γ_{M}	M2 (1.25)	Not factored
Pull-out resistance of reinforcement	$\gamma_{R,po}$	Not factored	1,25
Resistance to direct shear along interface	$\gamma_{R,ds}$	Not factored	1,25
Tensile resistance of geosynthetic reinforcement	$\gamma_{M,gs}$	1,25	
Tensile resistance of structural steel per EN 10025-2 or EN 10025-4	γ_{M0}, γ_{M2}	EN 1993-1-1	
Tensile resistance of reinforcing steel per EN 10080,	$\gamma_{s,}$ γ_{t}	EN 1992-1-1 γ_{M2}	
Tensile resistance of polymeric coated steel wire mesh reinforcement	$\gamma_{M,pwm}$	1,25	
Tensile resistance at connection – reinforcement	$\gamma_{R,con,el}$	As specified in relevant standard	
Tensile resistance at connection – connector	$\gamma_{R,con,c}$	As specified in relevant standard	
Tensile resistance at connection – facing element	$\gamma_{R,con,f}$	As specified in relevant standard	

Values of the partial factors for Verification Cases (VCs) 3 and 4 are given in EN 1990:2023.

Values of the partial factors for sets M1 and M2 are given in EN 1997-1:2024.

As the table is NDP (national determined parameter), each country has the possibility to define other values in national standards. They can be defined e.g. by comparative calculations ensuring the continuity of their current level of safety.

3.5 *Final sub-clauses and annex*

The last sub-clauses of in EN 1997-3 Clause 9 are following the general structure of EN 1997-3 and give general hints and references for the implementation of design (inspection, monitoring and maintenance), testing and reporting.

The (informative) annex to this Clause 9 has a long history from a short version via a version as a handbook back again now to a very short version. The final consideration of the involved countries was that each country will prepare its own annex. Countries that want to adopt the annex directly should be warned that a design of reinforced structures with this standard and its default annex version will still require additional contribution from other guidelines regarding the details of design. The standard aims to provide only a general framework for design.

4 REINFORCED FILL STRUCTURES – CASE STUDIES

4.1 *Introduction*

The case studies of reinforced fill wall and slope are addressed in the JRC report (JRC, 2024), where they are described in details. For this paper the reinforced wall case based on earlier drafts of EN 1997-3, Clause 9 is summarized with additional conclusions. The purpose of the example is to compute the required tensile strength of the reinforcement. The assumptions given in Figure 1 indicate representative values of: ground parameters, variable load, the geometry of the wall and the reinforcement. For numerical reasons, the fill cohesion was assigned of 1 kN/m².

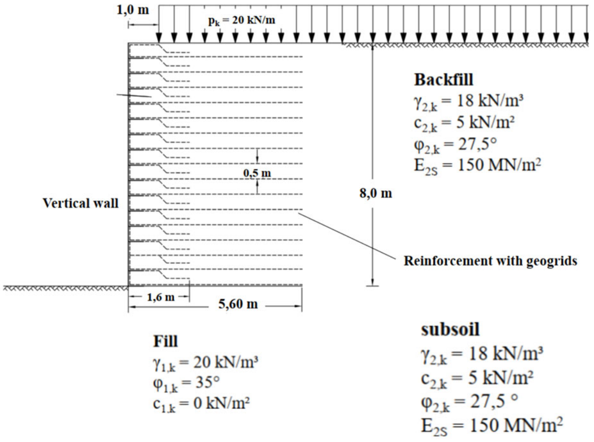

Figure 1. Graphical illustration of the case study and parameters assumed

4.2 *Analysis and results*

The required tensile resistance of the geosynthetic is determined through verification of both the compound failure mechanism and the internal stability. In this study, different calculation models are evaluated, including the multiple-part wedge method and the slope stability method (method of slices). Other potential failure mechanisms are also examined.

The representative tensile resistance of a geogrid is given by formula:

$$R_{\mathrm{t,rep,el}} = \eta_{\mathrm{gs}} T_{\mathrm{k}} \qquad (1)$$

where T_k is the characteristic tensile strength of the reinforcing element determined in accordance with EN ISO 10319 and η_{gs} is a reduction factor accounting for anticipated loss of strength with time and other influences:

$$\eta_{\mathrm{gs}} = \eta_{\mathrm{cr}} \cdot \eta_{\mathrm{dmg}} \cdot \eta_{\mathrm{w}} \cdot \eta_{\mathrm{ch}} \cdot \eta_{\mathrm{dyn}} \cdot \eta_{\mathrm{js}} \qquad (2)$$

where conversion factors η_{cr}, η_{dmg}, η_{w}, and η_{ch} are defined as the reciprocals of the reduction factors specified in ISO/TS 20432, denoted as $F_{R,CR}$, $F_{R,ID}$, $F_{R,W}$, and $F_{R,CH}$, respectively, η_{dyn} and η_{js} correspond to the reciprocals of the reduction factors specified in EBGEO as A_5 and A_3 respectively.

Finally, the design tensile resistance results from:

$$R_{\mathrm{t,el,d}} = \frac{R_{\mathrm{t,el,rep}}}{\gamma_{\mathrm{Rd,gs}} \gamma_{\mathrm{M,gs}}} \qquad (3)$$

where $\gamma_{M,gs}$ is given in Table 1 and $\gamma_{Rd,gs}$ is taken as the factor of safety f_s specified in ISO/TS 20432.

The required characteristic long-term strength of the geosynthetic was calculated once according to two approaches: EBGEO and the MFA of EN 1997-3. In the MFA, two observation periods were considered: 2.5 years and 12 years. The partial factors applied in these approaches were γ_M=1.4 in EBGEO, $\gamma_{M,gs}\gamma_{Rd,gs}$ =1.25 and $\gamma_{M,gs}\gamma_{Rd,gs}$ =1.21 for 2.5-year period years for 12-year period respectively in the MFA.

The calculation show that, in general, the required tensile resistance according to EBGEO are slightly higher than for the MFA w with differences ranging from approximately 10% to 15%. As expected for the MFA, the required long-term tensile resistance decreases by about 8–17%, depending on the calculation method, as the observation time increases, due to the corresponding reduction of the partial factor $\gamma_{Rd,gs}$.

However, the selection of the calculation model itself (e.g. circular slip surfaces with Bishop, multi-part wedge with different modes, two-part wedge) is even more critical in the design of geosynthetics. The variation in required tensile resistance between the models considered ranges from 7% to 25%. In all cases, the results consistently show that the multi-part wedge method, in which the failure surface also passes through the subsoil, yields the highest required geosynthetic tensile resistance.

Further analysis indicates that, when using the MFA, special care must be taken to avoid double factoring of the pull-out resistance. Even if the resulting utilisation factor E_d/R_d appears similar, the distribution of tensile forces along the reinforcement can differ significantly.

Verification of other general limit states – including bearing resistance, sliding, and loss of overall stability – has also been performed for the given input parameters and was implicitly confirmed through the stability analyses.

The calculation for the example was carried out with the value of $\gamma_{M,gs}$ =1.1 from earlier drafts of EN 1997-3 version. This value has now been changed to $\gamma_{M,gs}$=1.25 in EN 1997-3 (2025) which results in more similar results of EBGEO and MFA approach calculation results. Updated calculations are on the way in Germany as well as in many other European countries to ensure the same or a reasonable reliability level compared with the long-term experience.

4.3 *Final considerations*

The second generation of Eurocode 7 does not prescribe a specific calculation model. The sample calculation with simplified parameter variation shows that this requires particular focus on the stability calculation model chosen, as it significantly impacts design outcomes – comparable in influence to the choice of factoring approach. Consequently, there is a clear rationale for national-level recommendations to guide designers in selecting the most appropriate calculation model for local conditions and practice.

The standard also allows for a more detailed consideration of reinforcement material parameters; however, the National Annex can provide different $\gamma_{Rd,gs}$ values and uses different conversion factors than those in EBGEO and ISO/TS 20432.

For the considered case, MFA delivers similar results to the current EBGEO guidance, demonstrating that MFA can be a viable alternative for verification within reinforced fill design.

Similar evaluations have to be carried out by the the national standardization bodies for the other fields of application also mentioned in Clause 9 - reinforced slopes, basal reinforcement for embankments, load transform platforms and veneer reinforcement – to be able to define the appropriate calculation approach and partial factors. This should help the designer to select the right calculation model, correctly interpret the provisions of the National Annex or National guidelines and ensure the safety and optimization of the design.

5 SOIL NAILED STRUCTURES – GENERAL CONSIDERATIONS

5.1 *General*

EN 1997-3, in Clause 10 and Annex G, introduces new provisions and design procedures for soil nailed structures. It deals with cutting, slope, or existing structure reinforced with soil nails. There is no limitations regarding the technique or material of the soil nails (but it is focused on grouted nails) in the scope, when for facing wire mesh, plain and reinforced concrete, sprayed concrete, concrete panels and other facing elements are described.

Clause 10 incorporates the design-related aspects previously covered by EN 14490 and complements them with guidance that accommodates the various design methods and recommendations currently applied across EU member states. The basic provisions have been outlined by Maca (2024). In this paper, we provide additional details to illustrate the practical application of the new Eurocode 7 in soil-nailed structure design.

5.2 *Material and durability*

Clause 10 specifies detailed requirements for materials, corrosion aggressivity assessment, and protection measures for steel soil nails, following the provisions for tension piles given in EN 1993-5 and largely consistent with the current EN 14490 (CEN, 2010). It also introduces analogical requirements for facing systems, with particular attention to wire mesh solutions, aiming to harmonize this still non-standardized area of design. Thus, numeral references to EN and ISO standards related to materials, material testing, and corrosion protection are provided for various products. Where such standards are unavailable, relevant European Assessment Documents are cited.

5.3 *Verification methods and ultimate limit states*

The geotechnical analysis of a soil-nailed structure primarily involves stability analysis, pull-out and structural resistance of soil nails, structural resistance of facing, and their connections. All verification methods recognized in EN 1997-1 (2024). are permitted for the design of soil-nailed structure.

With respect to stability, the same general rules as for slope design in Clause 4 apply – no specific methods dedicated solely to soil nailed structures are prescribed. However, the standard explicitly allows the use of a single design method, provided it adequately addresses all relevant limit states.

For soil nail pull-out resistance $R_{po,d}$, Eurocode 7 provides a wide range of determination methods, accommodating current national practices across Europe. These are summarized in Table 2 (where $\gamma_{Rd}=\gamma_{Rd,nail}$). To ensure an appropriate level of reliability, the different methods are linked to specific sets of model factors presented in Table 3, along with additional testing requirements to address uncertainties.

Table 2. Soil nails pull-out resistance determination methods.

Method	The formula and factoring approach	
By testing	RFA $R_{po,d} = \frac{1}{\gamma_{R,po} \times \gamma_{Rd}} \min\left\{\frac{R_{test;mean}}{\xi_{mean}}; \frac{R_{test;min}}{\xi_{min}}\right\}$	(4)
By calculation - Model Pile method	RFA $R_{po,d} = \frac{1}{\gamma_{R,po} \times \gamma_{Rd}} \min\left\{\frac{R_{calc;mean}}{\xi_{mean}}; \frac{R_{calc;min}}{\xi_{min}}\right\}$	(5)
By calculation – Ground model method	MFA for effective stress analysis:	(6)
	$R_{po,d} = \frac{1}{\gamma_{Rd}} \int_0^{L_{po}} P(x) \cdot \frac{\mu_{po}}{\gamma_{\tan\varphi}} \cdot \sigma'_r(x) \cdot dx$	(7)
	MFA for total stress analysis:	
	$R_{po,d} = \frac{1}{\gamma_{Rd}} \int_0^{L_{po}} P(x) \cdot \frac{c_u}{\gamma_{cu}} \cdot \alpha \cdot dx$	
	RFA for effective stress analysis:	(8)
	$R_{po,d} = \frac{1}{\gamma_{R,po} \times \gamma_{Rd}} \int_0^{L_{po}} P(x) \cdot \mu_{po} \cdot \sigma'_r(x) \cdot dx$	(9)
	RFA for total stress analysis:	
	$R_{po,d} = \frac{1}{\gamma_{R,po} \times \gamma_{Rd}} \int_0^{L_{po}} P(x) \cdot c_u \cdot \alpha \cdot dx$	
	with RFA for comparable experience:	(10)
	$R_{po,d} = \frac{1}{\gamma_{R,po} \times \gamma_{Rd}} \int_0^{L_{po}} P(x) \cdot \tau_{po}(x) \cdot dx$	

Table 3. Model factor for soil nails pull-out resistance verification.

Verification of soil nail pull-out resistance by		Model factor $\gamma_{Rd,nail}$
Testing only		1,0
Calculation, Ground Model Method	Confirmed by suitability tests	1,2
	Extensive comparable experience without site-specific suitability tests	1,4
	Limited comparable experience, no testing	1,6
Calculation, Model Pile Method	Pressuremeter test	1,4
	Cone penetration test	1,4
	Profiles of ground properties based on other field or laboratory tests	1,4

Regarding structural resistance, the soil nail and its connection to the facing must comply with EN 1993, accounting for any anticipated long-term loss of strength. Formulas for determining the tensile and puncture resistance of wire mesh – in line with the general EC7 design philosophy and current practice – are provided, while for other facing types, reference is made to the relevant Eurocodes. There is currently no direct EC7 guidance on calculating loads acting on the facing; instead, references are given to BS 8006-2 or FHWA.

Both the Material Factor Approach (MFA) and Resistance Factor Approach (RFA) may be applied to the soil nailed structure, giving flexibility to adopt a wide range of design strategies. The assigned partial factors are given in Table 4. For transient design situations, γ_M or γ_R may be multiplied by a transient design situation reduction factor k_{tr} according to EN 1997-1 (2024).

Table 4. Partial factors for the verification of soil nailed structures.

Partial factor on		MFA	RFA
Actions, Effects of Actions	γ_F, γ_E	VC3	VC1
Ground and fill properties	γ_M	M2 (1.25)	Not factored
Pull-out resistance	$\gamma_{R,po}$	Not factored	1,25
Structural steel per EN 10025, EN 10210, EN 10219	γ_{M0}, γ_{M2}	EN 1993-1-1	
Reinforcing steel per EN 10080, pre-stressing steel per EN 10138	γ_s	EN 1992-1-1	
Tensile resistance of steel wires or ropes		EN 1993-1-1	
Tensile and puncture resistance of wire mesh	$\gamma_{M,wm}$	1,25	
Connection of adjacent wire mesh panels	$\gamma_{R,con}$	1,25	
Connection to soil nails		EN 1993-1-1	
Structural resistance of sprayed and any connections	γ_F, γ_E	EN 1992-1-1	

Partial factor on		MFA	RFA
Structural resistance of other facing and any connections	γ_M	As specified in relevant standard	
Values of the partial factors for Verification Cases (VCs) 3 and 4 are given in EN 1990:2023.			
Values of the partial factors for sets M1 and M2 are given in EN 1997-1:2024.			

Table 3 and Table 4 present the European consensus on the reliability level. However, these values are Nationally Determined Parameters (NDPs), meaning that each country may define alternative values in its national standards to maintain continuity with existing practice or its desired level of safety. In their national annexes, countries may also specify the preferred factoring approach for the calculation methods.

Serviceability limit states concern potential deformations and are usually assessed numerically. They are typically evaluated using numerical methods; however the verification may be omitted if ULS are satisfied and no specific serviceability criteria apply.

5.4 *Testing and implementation of design*

The critical role of testing in ensuring reliability throughout the entire process from design to execution is emphasized. Investigation, suitability, and acceptance tests of soil nail must comply with ISO 22477-6 (2025), while the number of tests, acceptance criteria, and proof load are specified in Clause 10, essentially consistent with current EN 14490 (2010) provisions.

It should be noted, that for geotechnical category GC3, $R_{po,d}$ must be determined from investigation tests and verified by suitability tests exclusively. Even in cases of other geotechnical categories, where $R_{po,d}$ may be derived solely from calculations, verification through suitability testing is still recommended. In all scenarios, acceptance testing should be performed. However, additional considerations are necessary when interpreting test results if no debonded length is developed, as such tests generally do not confirm the pull-out resistance decisive for design.

To ensure proper implementation of the design both during execution and throughout the service life, compliance with general EN 1997-1 regulations must be complemented by EN 14490. This standard is currently under revision to update provisions, reflecting recent technological advancements and alignment with the new generation of Eurocodes.

6 SOIL NAILED STRUCTURES – CASE STUDY

6.1 *Introduction*

The case study considered is addressed in the JRC report (JRC, 2024) where it is described in details. The purpose is to verify a nearly vertical soil nailed wall, with an arranged layout of soil nails of given pull-out resistance. The assumptions given in Figure 2 and indicate representative values of ground parameters, variable load and pull-out resistance $R_{po,rep}$ which are based on extensive comparable experience without site specific suitability tests.

6.2 *Analysis and results*

For the determination of $R_{po,d}$, the calculation was based on comparable experience with RFA, using Equation (9) with $\gamma_{Rd,nail}$=1.4. For the last row $R_{po,d,11}$=193kN.

No shear stress (dowel effect) or bending effects were considered. Therefore, the tensile structural resistance of the steel soil nail is verified only against the tensile load $R_{t,el,d}$, in accordance with EN 1993-5:2023, 8.11, taking into account the anticipated loss of strength over time. Corrosion protection is provided by allowing for a sacrificial steel thickness ($\Delta e/2$=0.60 mm for undisturbed natural soils, acc. to EN 1993-5:2023, 6.3(4)), resulting in $R_{t,el,d}$=220 kN.

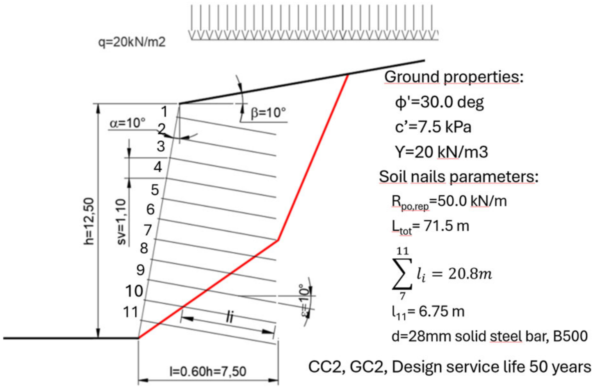

Figure 2. Graphical illustration of the case study and parameters assumed

Overall and compound stability were verified in accordance with Clause 4 as for simple slopes. The limit state was checked using the limit equilibrium method with several calculation models, typical in most European countries. The analysis was performed using both MFA and RFA, as both are applied in different national standards. The summary of calculations for the decisive stage – full excavation with all nails installed (construction stage not considered) – and for the chosen calculation model is presented in Table 5, in terms of the utilization factor E_d/R_d.

Table 5. Utilization factor for different calculation models.

Calculation model	Factoring approach	
	MFA VC3+M2	RFA VC1
Bishop (circular slip surfaces)	E_d/R_d=0.99	E_d/R_d=0.84
Janbu (polygonal slip surfaces, the shear forces not considered)	E_d/R_d=1.07	E_d/R_d=0.90
General wedge method (internal slip lines, shear force considered)	E_d/R_d=0.90	E_d/R_d=0.73
Vertical slice method (multiple body, shear forces considered)	E_d/R_d=0.91	E_d/R_d=0.74
Two-Part Wedge (the failure surface shown in Figure 1)	E_d/R_d=1.09	E_d/R_d=0.86

It is evident that the critical design approach is the MFA, in which ULS condition is not satisfied and the soil nail lengths must be increased. For the governing mechanism, the required soil nail length is approximately 5% greater than the original design length, and may be up to 16% greater when using a conservative assumption with φ_{d12}'=0 in the two-part wedge method after BS 8006-2.

It can also be observed that the choice between the MFA and RFA affects the utilization factor E_d/R_d by up to 23%. However, the selection of the calculation model itself is even more critical, with variations in E_d/R_d of up to 30%. As further calculations show, this difference in E_d/R_d directly affects also the total required soil nail length (variations up to 18%) and their tensile resistance (variations up to 15%).

Another important factor influencing the design outcome is the determination method for the design pull-out resistance which affects the model factor $\gamma_{Rd,nail}$ in the range 1.0 to 1.6 (see Table 3). This, in turn, significantly impacts $R_{po,d}$ of the soil nails, and consequently the overall stability of the structure as well as the optimal soil nail length and tensile resistance.

Therefore, for the critical MFA approach and for the two selected calculation models, additional verification analyses were performed for varying $\gamma_{Rd,nail}$ values. The results of these verification calculations are summarized in Table 6.

Table 6. Design results for different R_{po} verification methods.

Model factor $\gamma_{Rd,nail}$	**1.0**	**1.2**	**1.4**	**1.6**
$R_{po,d,11}$, kN	270	225	193	167
E_d/R_d two-wedge method	0.88	0.94	1.09	1.25
E_d/R_d Bishop method	0.93	0.95	1.00	1.04
Maximum nail force $N_{max,d}$, kN	248	222	207	189
Min required total nail length $L_{tot,min,req}$, m	61.7	67.5	73.0	78.6
$L_{tot,min,req}/L_{tot}$, %	86	94	102	110

For the case study, the choice of model factor influences the total required soil nail length by up to 29% and the maximum soil nail force by up to 24%. Therefore, conducting investigative testing or employing suitability tests to validate the design assumptions can lead to a significantly more optimized and efficient solution.

Verification of other general limit states (bearing resistance, sliding, loss of equilibrium) are also all fulfilled for the input parameters and implicitly checked in the performed stability analysis.

6.3 *Final considerations*

The case study demonstrates that the adequacy of the stability calculation model requires focused attention, as it influences the design results as significantly as the choice of factoring approach (the applicability of calculation models shall be considered according to EN 1997-1, clause 7.1). This suggests that national-level recommendations could help selecting the preferred calculation model.

Similarly, the favored method for determining R_{po}, including the associated model factor $\gamma_{Rd,nail}$ could be specified, as it significantly affects the final design outcome. From a practical standpoint, since design verification based on comparable experience remains the main approach, additional guidance may be needed to establish typical values for τ_{po}. However it is clear that Eurocode 7 promotes testing for complex ground conditions, while calculation-based methods provide a conservative alternative when testing data is limited.

Additionally, the design example in this study deliberately excludes the construction stage. In practice, considering the construction stage is mandatory, and when the default k_{tr}=1.0 applies, this stage is always critical in design verification. Therefore, it is reasonable to distinguish partial factors for persistent and transient situations or to provide additional guidance on the application of the k_{tr} at the national level.

7 CONCLUSIONS

The second generation of EN 1997-3 harmonizes, at the European level, the construction methods that are widely recognized, often already established in national standards, and valued for its economic efficiency and sustainability. This achievement, the result of many years of work, makes these methods accessible to a wider community of practitioners.

While the need to accommodate a variety of national practices across the EU has meant that not all issues have been fully resolved, the new standard provides a robust and modern framework for design. It addresses not only calculation procedures but also sets out requirements for materials, durability considerations, and the treatment of long-term strength reduction. Further, it emphasizes maintaining consistent reliability throughout the entire project lifecycle.

At the same time, clauses 9 and 10 do not provide detailed procedures or prescribe a mandatory calculation model, allowing the continued use of different models currently applied in various countries.

Some aspects – particularly the specification of target reliability levels by defining partial factors – remain to be determined at the national level. The flexible nature of the standard allows national bodies to define the most suitable verification methods or calculation models, while enabling designers to apply the tools that best reflect the specific project conditions, needs, and their own expertise.

In parallel, related standards, including EN 14475, EN 14490, and ISO 22476, have to be revised to ensure coherence across the entire European geotechnical design framework.

8 ACKNOWLEDGEMENTS

Many people have contributed to developing the second generation of the Eurocodes. We are especially indebted to the members of Task Group CEN TC250/SC7 TG-D3 and TG-B2, with whom we were privileged to work together from 2011 to 2023 and who provided a significant contribution to the development of the Clauses 9 and 10 of EN 1997-3.

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