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EMBEDDED RETAINING WALL LIMIT STATE ANALYSIS ACCORDING TO EUROCODE 7

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Original scientific paper

The paper deals with the problem of criteria for choosing the proposed calculation approaches in Eurocode 7 with respect to current technical regulations and regular engineering practice. A new procedure for the implementation of a systematic analysis and mutual comparison of different project approaches is proposed. Parametric analysis of embedded retaining wall limit states is performed. Combining of partial coefficients, according to proposed design approach, results in a visible wide span of equivalent values of the safety factor. Conclusions and recommendations tied to the application of the optimal calculation method are also given as well as the original mode of the analysis results.

Key words: *design approaches, embedded retaining wall, equivalent safety factor, Eurocode 7, limit states, parametric analysis*

Analiza graničnih stanja potporne konstrukcije prema Eurokodu 7

Izvorni znanstveni članak

Razmatra se problem kriterija odabira predloženih proračunskih pristupa u Eurokodu 7 u odnosu na dosadašnju tehničku regulativu i uobičajenu inženjersku praksu. Predlaže se novi postupak za provedbu sustavne analize i međusobne usporedbe različitih projektnih pristupa. Provodi se parametarska analiza graničnih stanja potporne konstrukcije. Kombiniranjem parcijalnih koeficijenata, prema predloženim projektnim pristupima, vidljiv je široki raspon ekvivalentnih vrijednosti faktora sigurnosti. Prilažu se zaključci i preporuke, vezane za upotrebu optimalnog načina proračuna. Također daje se originalni način prikaza dobivenih rezultata analiza.

Ključne riječi: *ekvivalentni faktor sigurnosti, Eurokod 7, granična stanja, parametarska analiza, potporna konstrukcija, projektni pristupi*

1 Introduction
Uvod

Through coming into force of the Concrete Construction Technical Regulations [1], to the European standards were also added [2] and [3] (Attachment I.4, Standards) in civil engineering, i.e. construction and geotechnical regulations. Based on this, a need appeared for revising current technical regulations [4] and critical view of new standards. A certain number of comparable analyses on as large as possible number of geotechnical tasks are needed to be performed. This will allow inter-comparison of new approaches, but also confronting current procedures.

1.1 Limit state analysis
Analiza graničnih stanja

Introduction of European norms (Eurocode 0.9) is aimed at regulating the application of proof, where the designed construction will be safe enough not to reach the so-called "limit states". Each design must be proven for a range of ultimate limit states and a range of serviceability limit states. It must be removed enough from levels at which it may break/fracture or deform, and be safe enough to hold out against unforeseen events.

Through the use of limit states in construction, the outdated concept of permissible stress design has been replaced. The use of partial safety factors results in the same level of safety, regardless of load combinations, material characteristics and problem geometry. Calculable material characteristics are determined based on the implicit supposition on ensuring a limitless number of samples tested in controlled conditions. Loads are predictable with the known probability distribution. Using partial safety factors the distribution of reliability and/or risk distribution on the main calculation elements is determined.

Probability methods assume that the effects made through the actions being performed on the construction and its resistance, with taking into consideration material characteristics and problem geometry, have a certain probability of distribution emergence. Taking into consideration these active dispensation probabilities (action and resistance) allows the calculation of break-up probability. In such a calculation partial safety factors are not applied; all actions, material characteristics and resistance are part of the calculation with their own probability distribution. The application of partial safety factors (European norms) is aimed at building a bridge between calculations used so far and pure probability analysis. In that context, the use of Eurocode 7 (EC7) introduces a principle of limit state design into geotechnical engineering. The calculation of foundation and over-foundation construction is thus merged with phasing out of existing conceptual barriers.

1.2 Eurocode 7 and limit states
Eurokod 7 i granična stanja

Geotechnical engineering is faced with a problem of quantification of the reliability level. The reason for this is a limited number of samples, with frequently unknown probability distribution of examined values. Taking that into consideration, the use of one of the newly adopted systems is not primarily based on predetermined probability patterns as is the case in construction. Adoption of proposed procedures should be argued through coordination with results collected based on long-term experience from engineering practice, or on statistical calculation of experimental data and practical on-site observations. This statistical calculation should be performed using the method of probabilistic reliability theory [5].

The application of EC7 introduces the practice of using partial safety factors. Factored in are external load (temporary, permanent, favourable and unfavourable action), soil characteristics (parameters of non-drained and drained shear rigidity, bulk density), and resistance (bearing capacity, sliding). The means of factoring, i.e. the individual combination, is defined in advance according to appropriate proposed design approach. The total of 112 values of partial factors and 34 co-relation factors has been ascertained, giving a total of 146 values. Remaining controversial is the criterion used in choosing each individual approach. There is confusion caused by different approaches being used for the same physical task. Non-critical choice of factors within the chosen approach leads to the lack of assessing the physical nature of the analyzed task. Results of performed analyses should be coordinated with experiences from "typical" problems from practice, which can then be used as reference values. The question arises, what to do with tasks which are not typical, such as new types of actions, non-standard structural sizes, etc.? The criterion of individual approach evaluation does not exist for such non-standard situations.

The paper offers an analysis of one standard problem in geotechnical engineering. Equivalent value of the safety factor leads to certain conclusions tied to inter-comparison and criteria of choice of each proposed design approach.

2
Current practice of retaining structures design computations procedures
Dosadašnji postupci proračuna potpornih konstrukcija

In the classic limit analysis, the allocation of strain corresponds to limit conditions of soil break-up, due to the rotation of the solid matter. Strains behind the retaining structure achieve their minimal value (active limit strain), while they achieve their maximum at the front (passive limit strain). The designed retaining structure must be proven against reaching certain corresponding limit states. This condition is met using the *safety factor*. Some of the possible ways of factoring are shown in Fig. 1 according to [6]:

a) The *gross pressure method*, *FS* on total passive resistance;
b) The *net pressure method*, *FS* on net passive resistance diagram;
c) The *revised or Burland and Potts method*, *FS* on own weight beneath the dig level, bilaterally;
d) The *strength method*, *FS* on appropriate soil parameters

The calculation d) is conceptually the closest to EC7. The difference is that in EC7 external actions and resistance in various predetermined combinations are factored in with soil parameters. The example used in the paper is processed using method a). This is a special case of the LRFD – *Load and resistance factor design method* [7, 8], where, in this case, only the passive resistance is reduced. This approach is the one most frequently used in practice.

External actions on the retaining structure contain active pressure and passive resistance, created by soil weight and external load, as well as pore pressure both from the active and the passive sides. The paper contains the analysis for a water-free profile, with external uniform load.

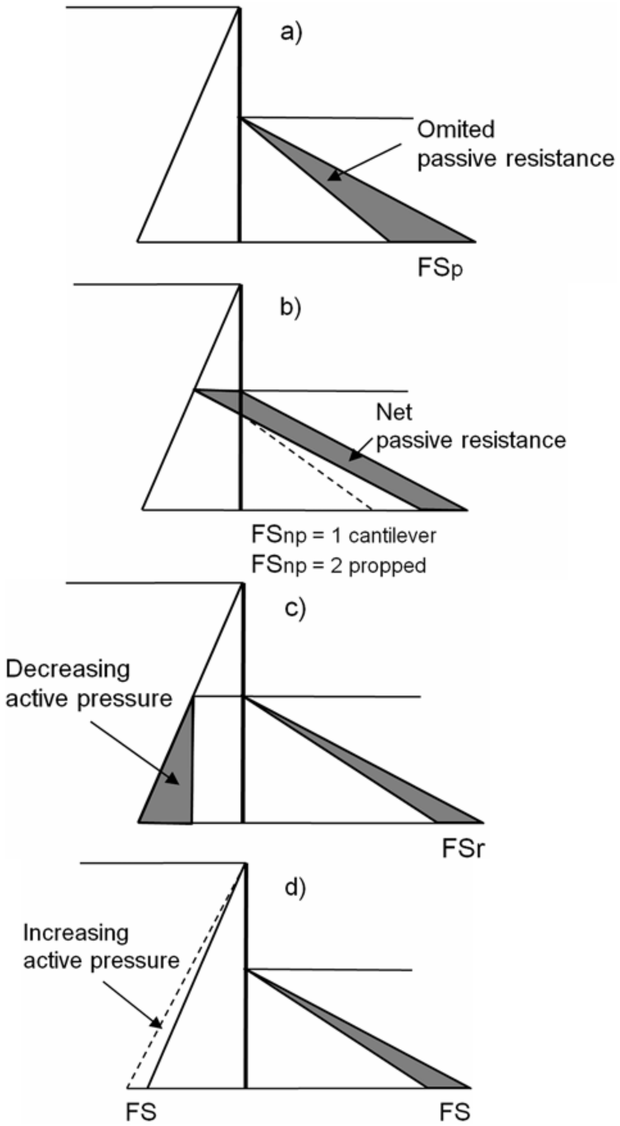

Figure 1 *Safety factor definition according to* [6]
Slika 1. *Definicija faktora sigurnosti prema* [6]

3
Design approaches in EC7
Projektni pristupi u Eurokod 7

The proposed EC7 approaches do not contain explicit calculations of the global safety factor; factoring is performed using appropriate coefficients. Three design approaches are used: DA1, DA2 and DA3 (Design approach 1, 2 and 3) with various factoring combinations to external actions, material characteristics and resistance (A – Action, M – Material, R – Resistance). Fig. 2 and Fig. 3 show the values of partial coefficients for all design approaches for the limit analysis of the retaining structure in coarse-grained soil. Double-underlined letters show those values *actually having* the influence in certain approaches, i.e., those not equal to 1.

Tab. 1 shows the schematic of partial combination factors ($\underline{\underline{\ \ }}$ ≠1) for design approaches (**DA1_j**, **DAi**):

Table 1 *Design approaches partial factor combinations*
Tablica 1. *Kombinacije parcijalnih faktora za projektne pristupe*

Pr.	DA1_1	DA1_2	DA2	DA3
Ko.	A1+M1+R1	A1+M2+R1	A1+M1+R2	A1(A2)+M2+R1

Where in DA3:
- A1 = *structural action*
- A2 = *geotechnical action*

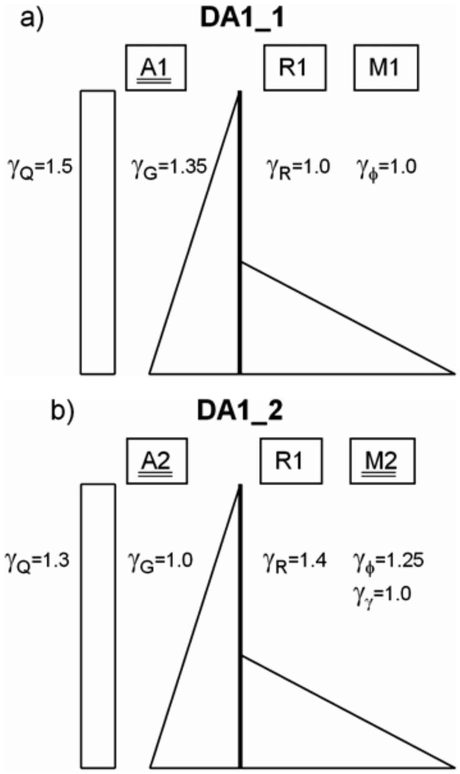

Figure 2 *Design approach a) DA1_1 and b) DA1_2*
Slika 2. *Projektni pristup a) PP1_1 i b) PP1_2*

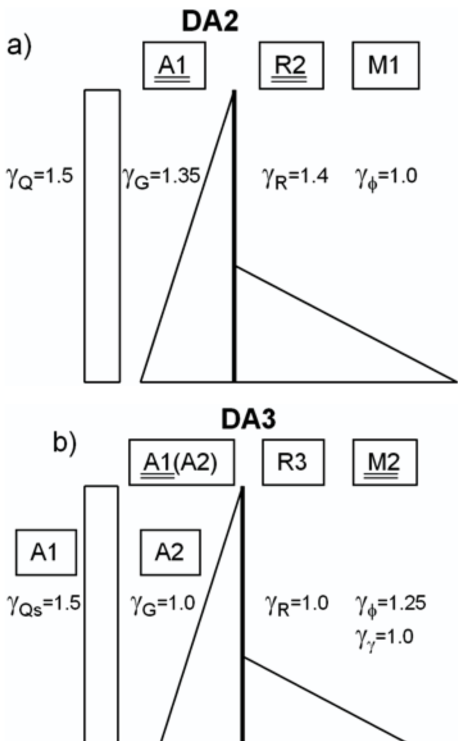

Figure 3 *Design approaches DA2 and DA3*
Slika 3. *Projektni pristupi PP2 i PP3*

DA3 defines the difference between the so-called *geotechnical* and *structural* actions. The exception is the calculation of slope stability, where all actions are considered *geotechnical*. In cases not faced with a slope stability problem, it is not defined when a particular approach is used. For example, in the paper the external uniform action is treated as *structural* action of variable and unfavourable character. In that case the partial coefficient is $\gamma_Q = 1,5$.

4
Passive resistance like resistance or action
Pasivni otpor kao otpor ili vanjsko djelovanje

EC7 does not explicitly state how to take passive resistance into consideration. With gravitational structures and shallow foundations it can be neglected, similarly to the classic calculation method. With analysis of retaining structures this is not possible because it represents a fundamental part of the analysis and not a certain influence on the increase of the safety factor. The question is if it should be considered as resistance or external action. The answer can mean significant differences in actual proof against limit states GEO and STR. The analysis of the influence of treating passive resistance as actual resistance, then as external favourable and unfavourable action, and finally without the effect of factoring, was performed in [9]. The conclusion of the author is that passive resistance is *at the same time* considered to be unfavourable action and resistance. In this case the characteristic passive resistance is factored using the quotient γ_G/γ_{Re} = 1,5/2,5 = 0,6. Arguments for such an approach are supported through ensuring consistency of adding to numerical analyses, but also to classic procedures, of net pressure or the revised Burland and Pots method.

The need for this type of analyses is determined by the fact that the EC7 does not explicitly specify the means of treating passive resistance, but also because of the introduction of the so-called *Single Source Principle* in [2] (§2.4.2(9) Note). It states the following: *In some cases it is permissible to assume that unfavourable (or destabilising) and favourable (or stabilising) permanent actions emerge from the same source. If that is the assumption, then one partial coefficient may be applied to the sum/total of these actions/effects.* It is not specified when and in which cases this principle can be used. If it can be applied to retaining structures, then passive resistance can be treated as external *unfavourable* action, since it stems from one source, which is the soil to the retaining structure.

In classic analyses passive resistance is calculated as resistance, where it is the only thing factored. If one considers all of the above, examples have passive resistance calculated as resistance, not as external action.

5
Numerical example
Numerički primjer

Fig. 4 shows an example in which a parallel analysis of proposed design approaches with the classic calculation method was performed. The EC7 does not strictly define the means of ascertaining soil pressure. *Attachment C* [2] offers formulae and corresponding diagrams. The paper chose the *Rankine* model, which excludes friction, thus allowing the analysis of the simplest possible case. Calculations have so far been performed for the ultimate limit state, for unfavourable action of permanent and periodical load, and for passive resistance. Serviceability limit state was not considered. The retaining structure is treated with *free earth support* [9].

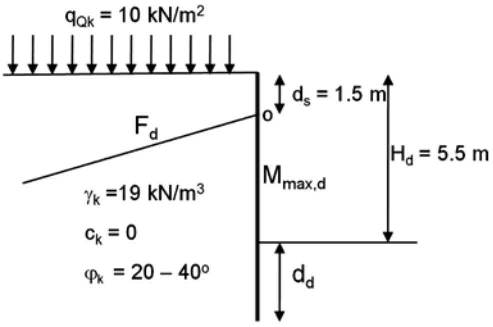

***Figure 4** Example for retaining structure analysis*
***Slika 4.** Primjer za analizu potporne konstrukcije*

Conditions for reaching the necessary values are:

1. $M_{Ed} = M_{Rd}$, equality of design moments on point 0 (GEO – geotechnical limit state, rotation around the anchor point), followed by the embedment depth d_d, where M_{Ed} – action of design moments in the direction of rotation, M_{Rd} – action of design moments in direction opposite to the direction of rotation
2. $F_d = H_{Ed} - H_{Rd}$, sum of design horizontal forces (GEO - geotechnical limit state on the horizontal shift, and for the anchor also the STR – structure limit state of the anchor), where F_d – design force in the anchor, H_{Ed} – horizontal design pressure, H_{Rd} – horizontal design resistance,
3. $V_{d,z} = 0$, place of action where the design transversal force = 0, and the design bending moment is at its maximum $M_{max,d}$ (STR – structural limit state of the retaining structure).

6 Equivalent safety factor
Ekvivalentni faktor sigurnosti

Comparison of individual approaches is determined using the following sequence: 1. Embedment depth d_d, 2. Design force in the anchor F_d, 3. Maximum design bending moment $M_{max,d}$. Conditions of determining equivalent factors of safety, for d_d, F_d i $M_{max,d}$:

1) $FS_d = M_{Rk}/M_{Ek}$ – for the rotation around the head of the anchor, where M_{Ek} – action of characteristic (gained using characteristic, unfactored soil parameters and unfactored resistance) moments in the direction of rotation, M_{Rk} – action of characteristic moments in the direction opposite to the direction of rotation
2) $FS_F = H_{Rk}/(H_{Ek} - F_d)$ – for translation of retaining structure, where H_{Ek} – horizontal characteristic pressure, H_{Rk} – horizontal characteristic resistance, $F_d = H_{Ed} - H_{Rd}$, design force in the anchor for each of the proposed approaches
3) FS_M from the condition of given embedment depth d_d and given design maximum moment $M_{max,d}$ for examined variant of design approach.

Equivalent safety factor FS_M is gained using the condition for determining the three unknowns: z' – depth where the horizontal force is equal to zero, i.e. where the maximum moment appears, F_d – design force in the anchor, FS_M – equivalent safety factor from the equation of equal design moments (Fig. 5). For all three safety factors, the embedment depth d_d is equal. For the security factor FS_F, the embedment depth and the force in the anchor are equal. For FS_M the depth d_d and the bending moment $M_{max,d}$ are equal, but not the point of the maximum moment and the force in the anchor.

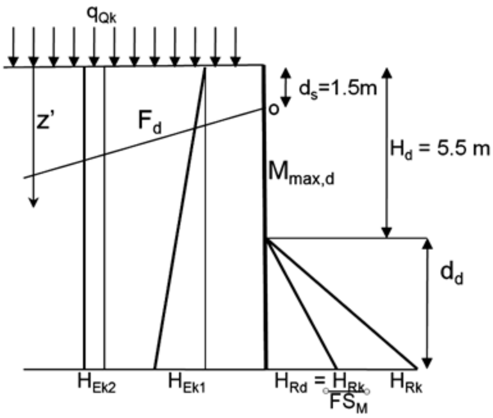

***Figure 5** FS_M computation for design approaches*
***Slika 5.** Izračun FS_M za projektne pristupe*

Next in line are conditions for the calculation of the three unknown values for the case in which the maximum design moment is beneath the level of the excavation. In case of this moment being beneath the dig level, another part of the design passive resistance must be included at the appropriate depth.

1) $$q_{Qk} \cdot z' \cdot K_A + \gamma \cdot z' \cdot K_A \cdot z' \cdot 0{,}5 - F_d = 0 \tag{1}$$
Condition of horizontal force balance at the depth z'

2) $$F_d = H_{Ek} - \frac{H_{Rk}}{FS_M} \tag{2}$$
Force in the anchor from the condition of equilibrium of horizontal forces

3) $$\begin{aligned} M_{max,d} &= q_{Qk} \cdot z' \cdot K_A \cdot z' \cdot 0{,}5 - \\ &- \gamma \cdot z' \cdot K_A \cdot z' \cdot 0{,}5 \cdot 0{,}33 \cdot z' - F_d \cdot (z' - d_s) \end{aligned} \tag{3}$$
Location of the maximum moment where $K_A = \tan^2(45° - \varphi/2)$ coefficient of active pressure, other according to earlier labels.

Fig. 5 also shows the quality allocation of external parts, external actions and sought values. Due to consistency, labels are according to EC7. Three statistical values are being determined: embedment depth d_d, force in the anchor F_d, and the maximum bending moment $M_{max,d}$. The design passive resistance H_{Rd} (corresponds to the classic mobilised resistance E_{pm}) is reached by factoring the characteristic resistance H_{Rk} (corresponds to the classic total resistance E_p). The values of external action on the active side H_{Ek1} – from the action of soil weight (corresponds to $E_{a,g}$), H_{Ek2} – from the action of the characteristic external equal load q_{Qk} (corresponds to $E_{a,q}$ from q), F_d – design force in the anchor (corresponds to S), $M_{max,d}$ – design maximum bending moment (corresponds to M_{max}).

FS = 1,5 was chosen as reference value of the global safety factor in the classic approach. For each friction angle and chosen FS there is a unique combination of $d_{d,1.5}$, $F_{d,1.5}$ and $M_{max,d,1.5}$, which are used as parallel values.

7
The results of analysis with comments
Rezultati provedenih analiza s komentarima

The results of performed analyses are presented according to gained statical values and equivalent safety factors. A common standardised view of values is also given. Finally, the amount of deviation of each individual calculation from the classic analysis is determined.

7.1
Depth of embedment, anchor force, max. bending moment
Dubina ukapanja, sila u sidru, maksimalni moment savijanja

Figures 6-8 show the values of embedment depth d_d, anchor force F_d and max. bending moment $M_{max,d}$ for proposed design approaches and for the classic calculation method and $FS = 1,5$.

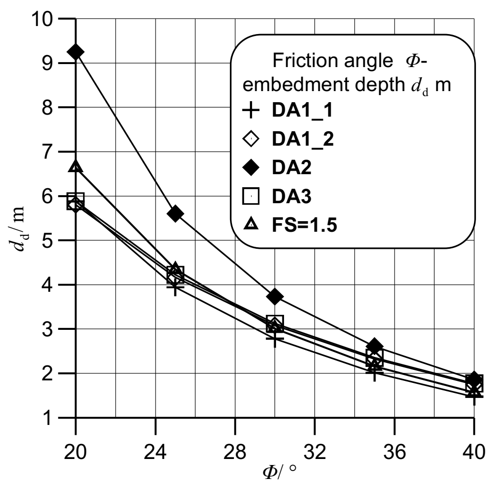

Figure 6 *Embedment depth d_d as a function of friction angle for different approaches and for the classic method of calculation with FS = 1,5*
Slika 6. *Dubina uklještenja d_d u funkciji kuta trenja za različite pristupe i klasičan način proračuna s FS = 1,5*

Fig. 6 shows a general expected trend of decreasing the depth d_d with the increase in the value of the friction angle for all methods of calculation. In relation to the classic calculation method, it is smaller for all approaches except for DA2 for smaller values of the friction angle (up to 30°). With the increase of the friction angle, DA1_2 and DA3 trend changes, i.e. depths increase with respect to the classic calculation. At the same time, the relative differences in ratio d_d decrease when the friction angle increases.

Fig. 7 shows that the classic method of calculation with FS=1,5, gives the smallest values of design anchor forces F_d, for all approaches. As is the case with d_d, the highest design anchor forces are reached with DA2. The difference with respect to d_d is that for all approaches except for DA2 there is no significant decrease in the difference of the anchor force with the increase of the friction angle.

Similarly to Fig. 7, in Fig. 8 the values of maximum design moments decrease with the increase of the friction angle. Moments are also minimal for the classic calculation. The highest values are measured for DA2.

The highest values of examined statical values are accomplished for DA2, for the entire span of friction angles. The reason for this is the multiplication of partial factors on

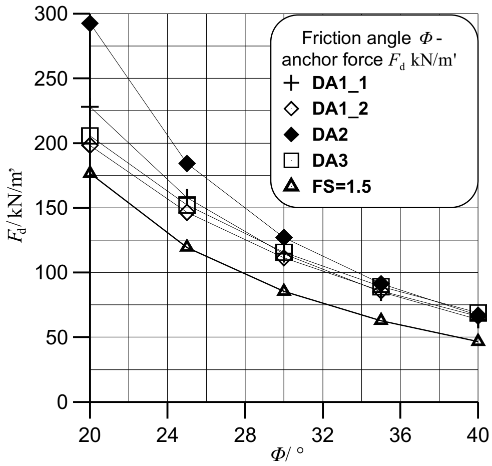

Figure 7 *Design anchor force F_d as a function of friction angle for different approaches and for the classic method of calculation with FS = 1,5*
Slika 7. *Projektna sila sidrenja F_d u funkciji kuta trenja za različite pristupe i klasičan način proračuna s FS = 1,5*

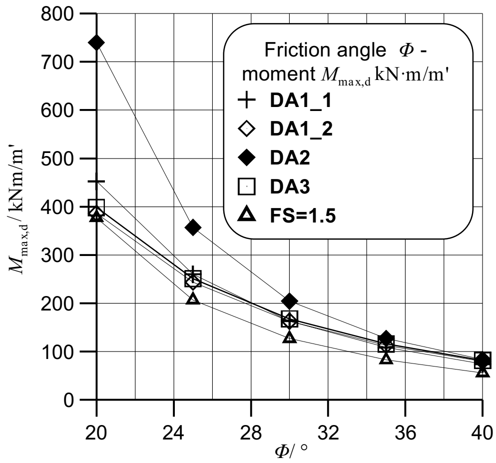

Figure 8 *Design maximum bending moment $M_{maks,d}$ as a function of friction angle for different approaches and for the classic method of calculation with FS = 1,5*
Slika 8. *Projektni maksimalni moment savijanja $M_{maks,d}$ u funkciji kuta trenja za različite pristupe i klasičan način proračuna s FS = 1,5*

external unfavourable permanent and temporary action with resistance on the passive side. Increase of sizes is, with respect to other approaches, approximately 50 %. Other approaches DA1_1, DA1_2 and DA3 give results which fall within relatively narrow parameters. Deviation with respect to the classic method of calculation is the smallest for d_d. For F_d and $M_{max,d}$, deviations with respect to the classic method of calculation are significant, especially for DA2.

7.2
Equivalent safety factors
Ekvivalentni faktori sigurnosti

Figures 9–11 show the values of equivalent safety factors according to described criteria of equal embedment depths, and pairs of embedment depth–design anchor force and embedment depth–maximum design bending moment.

Equivalent safety factors FS_d are constant for all friction angles for DA1_1 and DA2 (Fig. 9). The reason for this is that multiplication with partial factors is performed *after* the calculation of characteristic external actions and resistance. In that case, equivalent characteristic resistance in the classic calculation can be extracted and divided by the equivalent safety factor. In other words, characteristic

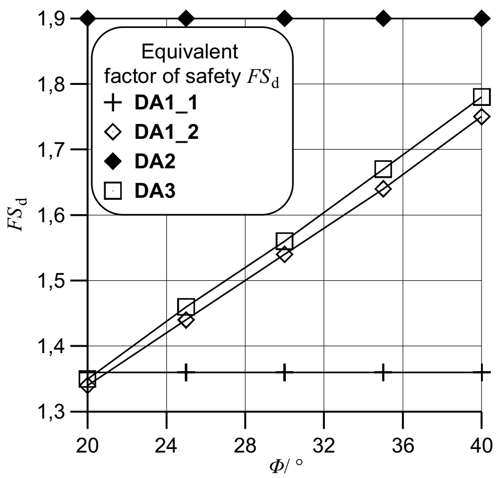

***Figure 9** Equivalent safety factors FS_d as a function of friction angle for different approaches according to the criterion of the same embedment depth d_d*

***Slika 9.** Ekvivalentni faktori sigurnosti FS_d u funkciji kuta trenja za različite pristupe prema kriteriju iste dubine uklještenja d_d*

actions are constant for the classic calculation and for DA1_1 and DA2. For DA1_1, FS_d = 1,6 appeared as the influence of the equal external periodical load and its factor γ_Q = 1,5 on the partial factor γ_G = 1,35 for permanent unfavourable external action. A similar case is put forth by DA2, where FS_d = 1,9. In DA1_2 and DA3 the factoring is performed *before* the calculation. Therefore, unlike for DA1_2 and DA3, characteristic actions cannot be extracted. FS_d for DA1_2 and DA3 has the tendency of rising with the increase of the friction angle. For smaller friction angles, the FS_d is less than 1,5, while for φ = 40° and more, its value grows to beyond 1,7.

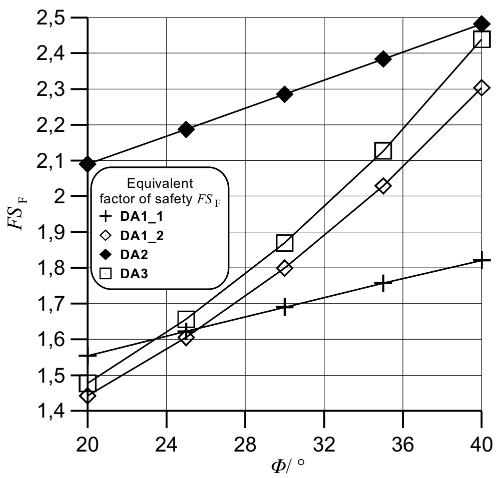

***Figure 10** Equivalent safety factors FS_F as a function of friction angle for different approaches according to the criterion of the same design anchor force F_d*

***Slika 10.** Ekvivalentni faktori sigurnosti FS_F u funkciji kuta trenja za različite pristupe prema kriteriju iste projektne sile u sidru F_d*

Fig. 10 shows the values of equivalent safety factor for the design anchor force FS_F. Here there is a recognisable trend of its increase as the friction angle increases. Its lowest values are registered for DA1_1 and the highest for DA2, even up to 2,5 for φ = 40°. The equivalent safety factor is similar to the classic calculation only at very small values of the friction angle (φ = 20 –22°). For all other friction angles it is significantly higher.

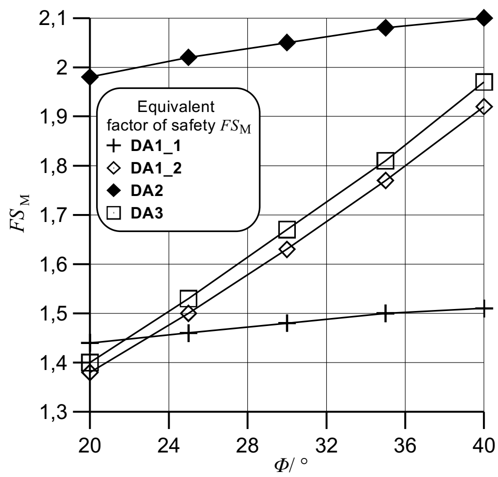

***Figure 11** Equivalent safety factors FS_M as a function of friction angle for different approaches according to the criterion of the same design bending moments $M_{max,d}$*

***Slika 11.** Ekvivalentni faktori sigurnosti FS_M u funkciji kuta trenja za različite pristupe prema kriteriju iste projektne momente savijanja $M_{max,d}$*

In Fig. 11, similar to anchor forces, equivalent safety factors FS_M from the conditions of equality of design maximum moments show a tendency to rise with the increase of the friction angle. Their absolute values in this case are lower than in the case of using the design anchor force. For DA1_1, FS_M is mostly lower than 1,5, except for higher friction angles. For other approaches, FS_M tends to be relatively large as the friction angle increases.

7.3 Normalized values
Normalizirane vrijednosti

Figures 12-14 show the values of equivalent safety factors divided by 1,5, in co-relation with relative embedment depths, or embedment depths for individual approaches divided by embedment depths in the classic method of calculation $d_d/d_{d,1.5}$ within the examined span of friction angles. This allows a direct comparison of individual approaches for the two criteria with respect to the classic solution. The classic solution with FS = 1,5 is presented by the point <1, 1> in the coordinate system. The farther the values get from the point in this system, the more the result of individual approach analysis deviates from the classic calculation. Another visible aspect is the comparison of the equivalent safety factor for a certain statical value and its change, all according to values found in the classic calculation.

Fig. 12 shows the allocation of relative embedment depth values d_d. For DA1_1 and DA2, the relative ratio of safety factors is constant, since the equivalent FS_d is constant. The difference is the trend, where for DA1_1 the relation (ratio) rises, while with DA2 the relative values of embedment depths fall as the friction angle increases. For DA1_1, the values are the closest to those found in the classic calculation, but with safety factor values smaller than 1,5. DA2 shows the tendency of decreasing the embedment depth as the friction angle gets wider, warning the values were noted for φ = 35°. For DA1_2 and DA3, relative values are less than one for smaller angles, while they grow for larger angles - but never over 1,2.

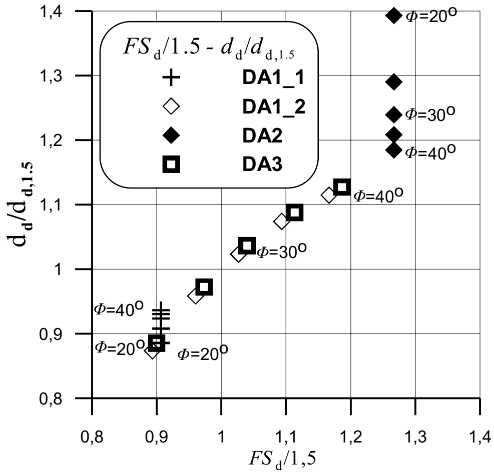

***Figure 12** The ratio of relative equivalent safety factors and relative embedment depths*

***Slika 12.** Odnos relativnih ekvivalentnih faktora sigurnosti i relativnih dubina ukliještenja*

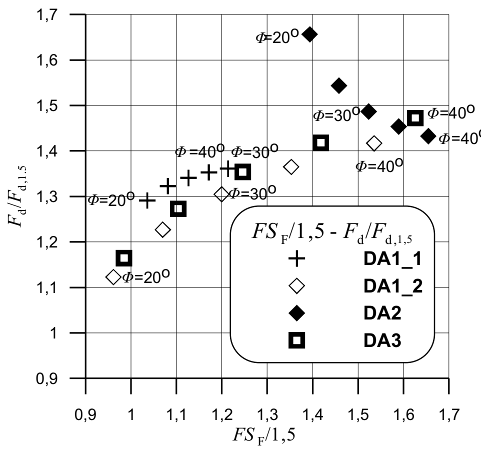

***Figure 13** The ratio of relative equivalent safety factors and relative design anchor forces*

***Slika 13.** Odnos relativnih ekvivalentnih faktora sigurnosti i sila projektnih sidrenja*

Fig. 13 shows the trend similar to the one found with embedment depth. The difference is that all values of design anchor force are above the ones gained through the classic calculation. For DA1_1, FS_F grows as the friction angle gets wider, with mild growth of the anchor force. For DA1_2 and DA3, relative values grow at the same time. A wide range of equivalent values of the safety factor FS_F for DA1_2 and DA3 was noticed. For those approaches smaller friction angles result in the anchor force better in tune with the classic calculation method. Increasing the friction angle also increases the differences with respect to the reference values. For DA2, the increase of the friction angle points to the decrease in the anchor force along with the equivalent safety factor. In general, for this approach all the values of the anchor force and the safety factor significantly deviate from the classic calculation method.

Relative values of equivalent safety factors for the maximum bending moment FS_M are lower than 1,5 for smaller friction angles for all approaches except DA2. For these approaches the increase of the soil friction angle means a parallel growth of equivalent safety factor values, but also of maximum moments themselves. The increase of maximum moments is the highest in DA2, the range being 1,5 – 2, but also showing a tendency of decreasing with the increase of the friction angle. A relatively large range of maximum moment increase is also noticed in DA1_2 and

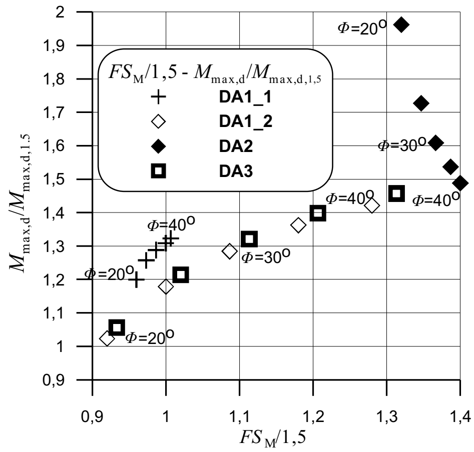

***Figure 14** The ratio of relative equivalent safety factors and relative maximum bending moments*

***Slika 14.** Odnos relativnih ekvivalentnih faktora sigurnosti i relativnih maksimalnih momenata savijanja*

Da3. The range of equivalent safety factors is the highest for DA1_2 and DA3: 0,9–1,3. For DA1_1 the range is the lowest: 0,95–1,0.

7.4 Deviation measure
Mjera odstupanja

Diagrams shown in Figures 15–17 determine the measure of deviation of relative values in diagrams in Figures 12–14**.** Individual values represent absolute distances from the point (1, 1), i.e. the unique solution gained using the classic calculation method for the safety factor FS=1,5. The ordinate in the diagram represents deviation under common criteria of the equivalent safety factor and corresponding calculated statistic value.

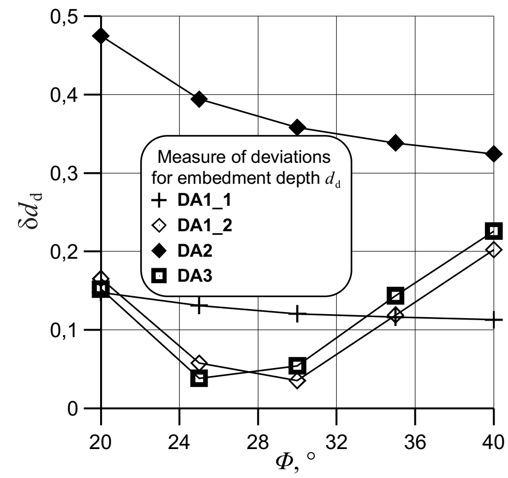

***Figure 15** The measure of deviation for the embedment depth d_d*

***Slika 15.** Mjera odstupanja od normiranih vrijednosti za dubinu ukapanja d_d*

Fig. 15 shows the most even although not the smallest (except for the largest friction angles) deviations for DA1_1. DA1_2 and DA3 show relatively smaller deviations with common values of the friction angle range being 25–30°, and larger deviations for other friction values. Most deviation is shown in DA2, but with the trend of decreasing the differential with the increase of the friction angle. All values of the safety factor and the embedment depth for DA1_1 are lower than the one the classic solution offers, which is also true for approaches DA1_2 and DA3 for friction angles smaller than 30°.

Fig. 16 shows somewhat different trends with respect to burying-in depth. Relative differentials grew for all approaches; more significantly for DA1_2 and DA3 and somewhat less for DA1_1. The DA2 shows the most even deviation, but also the largest value of the deviation.

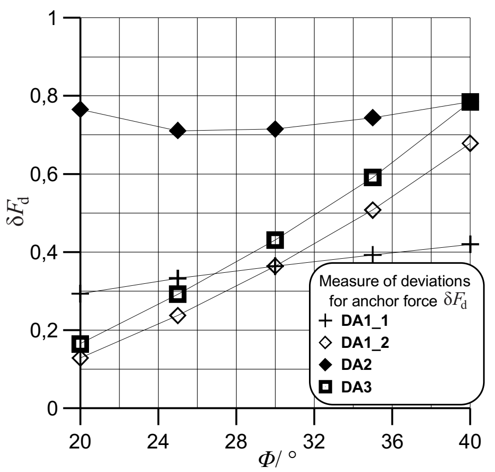

Figure 16 *The measure of deviation for the anchor force* F_d
Slika 16. *Mjera odstupanja od normiranih vrijednosti za silu u sidru* F_d

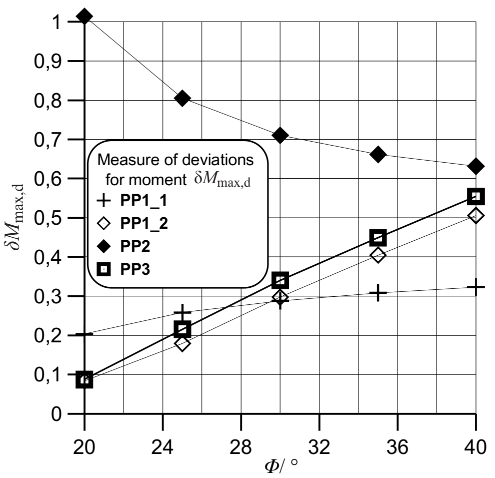

Figure 17 *The measure of deviation for the maximum bending moment* $M_{max,d}$
Slika 17. *Mjera odstupanja od normiranih vrijednosti za maksimalni moment savijanja* $M_{maks,d}$

Fig. 17 presents a situation not unlike the design anchor force, but also with higher deviation for DA2 and smaller friction angles, and lower deviation for increased friction. Other approaches posted the increase of deviation with the increase in the friction angle, but with somewhat smaller absolute values.

8 Conclusion
Zaključak

The paper deals with the proposed method of comparing new approaches in designing retaining structures. In general, the new approaches result in somewhat more conservative values than classic calculations. A wide spectrum of equivalent safety factors is uncovered as well as the statical values within each individual approach but also through their direct comparison. The design approach DA2 offers the most conservative results. The reason for this is the simultaneous factoring of external action and resistance. In DA1_2 and DA3 there is no factoring of permanent action (i.e. $\gamma_G = 1,0$); also, factoring resistance $\gamma_R = 1,4$ influences the decrease of passive resistance more than the effect of application of partial factors on the internal friction angle $\gamma_{\varphi'} = 1,25$. Other approaches show an increasing trend of equivalent safety factors as the friction angle increases. Exception to this is DA1_1 coupled with the embedment depth d_d, regardless of the value of the appropriate equivalent safety factor. Further multi-parameter analyses are needed, which would include friction angles between the structure and the soil, the effect of water (flowing and still), structure of soil levels, cohesion, etc. As is the case with passive resistance, analysis of the effect of various means of groundwater effects would also be necessary. Larger deviations in differences among the approaches shown in this paper are not expected. For smaller values of pressure angles, all approaches except DA2 fall within relatively close confines, with small deviations with respect to the classic analysis. As the friction angle widens, deviations increase, except for DA2, where the trend is the opposite of the aforementioned. In conclusion, DA2 offers overly conservative solutions, regardless of the value of soil shear rigidity parameters. When using other proposed procedures, it is possible to reach optimal results through adequate choice of characteristic values. For less wide friction angles more conservative characteristic values may be chosen, while wider angles demand the opposite. For DA2, the decrease of external action partial factor values is recommended, thereby moving closer to the classic method of calculation. The way of choosing the mentioned characteristic values and partial factors should be defined in revised current technical regulations through appropriate National annexes of EC7.

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