

CALCULATION TOOL FOR REINFORCED CONCRETE RETAINING WALL ANALYSIS AND ASSESSMENT

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ABSTRAKT

Byl vytvořen výpočetní nástroj pro analýzu a posouzení železobetonové úhlové opěrné stěny v prostředí Excel. Uživatel tohoto výpočetního nástroje je k dispozici široká nabídka parametrů k nastavení geometrie úhlové stěny, charakteristik a úrovní zemin v blízkosti konstrukce, hladiny vody, materiálu konstrukce i zeminy a zatížení. Všechny nastavitelné parametry jsou pro jednoduchost popsány v panelu komentářů, v němž jsou uvedené rovněž rovnice použité ve výpočtu. Výstupem analýzy je posudek posunutí a překlopení stěny, únosnosti základové spáry a rozhodující vnitřní síly pro následný návrh a posouzení vyztužení konstrukce. Postup výpočtu je proveden dle Eurokódu. Výpočetní nástroj poskytuje výsledky pro odvodněné i neodvodněné podmínky. Konstrukce je posouzena pro tři návrhové situace. Tento článek popisuje zmíněný výpočetní nástroj a ukazuje šíři jeho uplatnění.

KLÍČOVÁ SLOVA

Úhlová opěrná stěna • Analýza konstrukce

ABSTRACT

A calculation tool for reinforced concrete retaining wall analysis and assessment was prepared in Excel spreadsheet environment. The user of the calculation tool is able to set wide range of parameters describing the geometry of the wall, the soil and water conditions and levels, material characteristics of both the wall and soil and loading. For convenience of the user, all the input parameters are described and explained in the comment panel as well as the formulas used in the analysis. The calculation output includes assessment of wall slide, overturn and bearing of the underbase soil. Decisive internal forces of the structure are calculated for their further use in reinforced concrete assessment. The methodology used for the analysis is in line with Eurocode. Both drained and undrained conditions of the soil are considered, and three loading scenarios are assessed. This article describes the calculation tool, and shows its abilities and range of use.

KEYWORDS

Retaining wall • Structural analysis

1. INTRODUCTION

The price, low variety in input parameters and obscurity in calculation methods are the three handicaps that commercial software products for structural analysis often have. For that reason, in many cases, it is worth creating own calculation tool, and avoiding incorrect input or misinterpretation of output of the analysis. Such tool was created for the analysis of reinforced concrete retaining wall in Excel spreadsheet environment. The spreadsheet environment is undemanding on software, enables the user to check and truly understand the processes used in the analysis, and is easy for editing when it comes to possible changes in the methodology.

2. USER INTERFACE

The user has access to the „input“ tab, where all the parameters are to be set. For the convenience of the user, the parameters are described and explained in the comment panel and summarized in the schematic sketch of the structure, see Figure 1. The actual geometry is also plotted to obtain graphic visualization of the specific measures that are set.

The mid-steps of the calculation are visible to the user in twenty-eight processing tabs of the spreadsheet, but are frozen to prevent their editing.

The output of the analysis along with the assessment and summary of the input setting are presented in the „print“ tab which is condensed into seven printable pages summarizing the assignment and results.

To avoid illogical or incorrect setting, the spreadsheet marks the wrongly set parameters with an alert. In the comment panel, an explanation of how to set the parameters correctly can be found.

3. LOADING SCENARIOS

Three loading scenarios are considered in the calculation tool:

- Flood – water level on one side of the wall reaches its maximal possible level
- General – any condition of soil, water and loading can be set
- Dry – the structure is not affected by water level from any side

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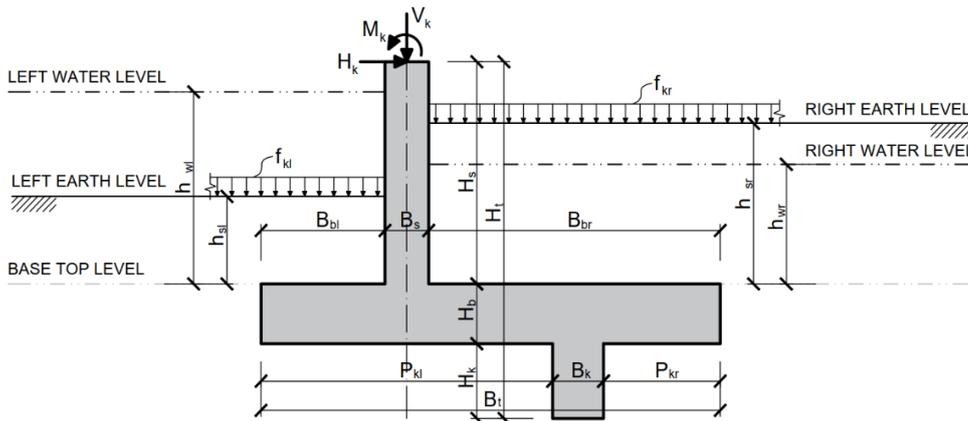


Figure 1: Analyzed structure of a retaining wall - geometry and loading.

3.1. Flood Loading Scenario

This loading scenario was the impulse for creation of the spreadsheet, as one of the most commonly used commercial software (called a benchmark software further in the text) was not able to fully cover this area.

In real application, it often happens that a retaining wall has permanent function of carrying an elevated earth level from one side, but the the water source is located on the other side of the wall, so, when the flood comes, the driving and resisting side of the wall switch, moving also the overturn point, see Figures 2 and 3.

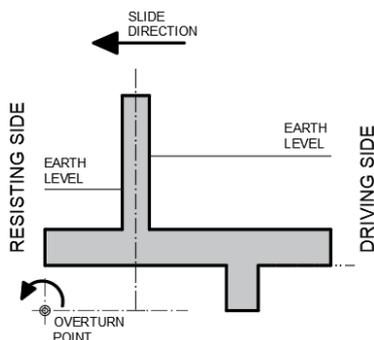


Figure 2: Driving and resisting side for normal conditions

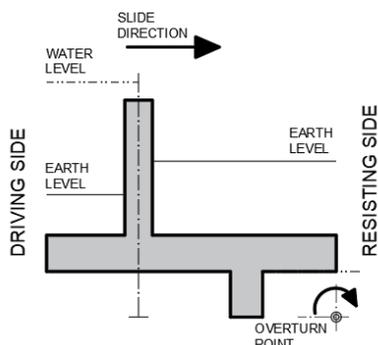


Figure 3: Driving and resisting side for flood scenario

The benchmark software was not able to simulate this situation in one model, as it has fixed overturn point. It does not reflect the fact, that in normal conditions the driving side is where the dominant earth load is, but for extreme flood, the water load from the other side of the wall may prevail and change the polarity of driving/resisting side.

The proposed calculation tool is able to cover both these scenarios in one setting. It recognizes the driving and resisting side for both of these cases, places the overturn point.

In the flood loading scenario, it is also possible to set the overtopping, that considers possible overspill over the top of the wall as additional loading.

3.1. General Loading Scenario

This loading scenario enables the user to set normal conditions for the retaining wall, and is also flexible to set any user-chosen conditions that may occur to the structure.

Unlike the benchmark software, as well as in case of flood scenario, the spreadsheet decides what side of the wall is driving/resisting based on the given input, and appropriately assigns correct safety factors. This brings much more flexibility into the analysis. It also eliminates the possibility of user-induced error, as the user does not have to decide what side of the wall is driving/resisting, which can be difficult for some geometrical and loading conditions.

3.1. Dry loading Scenario

As the water levels set for the general loading scenario may drop in time, this loading scenario should not be omitted. The geometry, ground levels and loading of the structure would remain the same as in general loading scenario, but the water would no longer affect the structure. Again, in the benchmark software, this would have to be simulated in separate model. The spreadsheet calculation tool does the assessment for dry conditions automatically along the assessment of flood and general loading scenario.

4. INPUT PARAMETERS

4.1. Geometry

The geometry of the retaining wall can be set as it is shown in Figure 1. In case of any accidental inconsistency in the geometry (e.g. the shear key is set outside of the base length), the spreadsheet flashes red alert for the incorrect parameter. For easy check, the actual geometry is plotted.

4.2. Soil and Water Levels

In this section of input tab, any soil and water levels can be set on both sides of the retaining wall.

The flooded side of wall is assigned in this section. The user can choose to set their own value of flood overtopping on the flooded side, or can use the default setting which places the water level 20 cm above the wall top. Also, the user can choose to set their own level of water on the unflooded side, or can use the default setting which places the water level to the lower surface of the base.

How the water uplifts the structure is considered is also set in this section, see Figure 4. Three approaches are commonly used in the analysis of retaining walls. For linear course along the base, the uplift pressure in the left edge of the base corresponds to the water level on the left side of the wall, and the the uplift pressure right edge of the base corresponds to the water level on the right side of the wall. Between these two edges, the course of the uplift is considered linear, and reflects the placement of the shear key.

For constant course of uplift, the linear compound of uplift is neglected. It is assumed that only the fully submerged part of the structure is uplifted.

There is also a third approach – a parabolic course of uplift – however, it is not incorporated in this calculation tool.

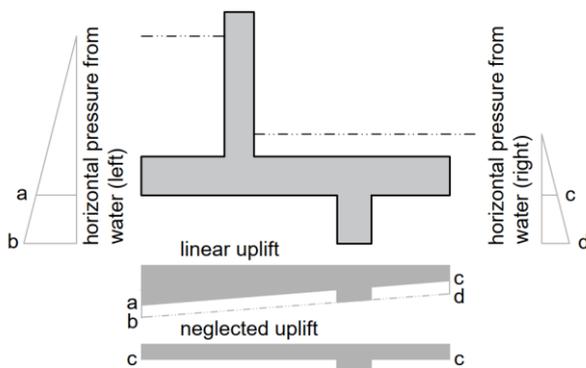


Figure 4: Uplift of the structure

4.3. Loading

In the loading section of the input tab, point loadint of the wall top can be set. Vertical force, horizontal force and moment can

load the wall with any value and polarity. The user can set whether the forces are permanent or variable loading; the spreadsheet automatically assigns correct safety factors for both favourable and unfavourable actions.

Surfaces on both sides of the wall can be loaded by linear surcharge. It also can be considered as permanent or variable loading.

The spreadsheet is designed so that it automatically solves inconsistencies in setting, including the loading. For example, for the flood scenario, it neglects the wall top loading forces, as it is impossible that the wall top would be loaded when overflooded. Or, when the water level is set above ground level on either side, the variable surface surcharge is neglected, as it is illogical to have live load on a surface that is under water.

4.4. Material Parameters

The soil parameters can be set separately on both sides of the wall. The parameters include weight of dry soil, weight of saturated soil, Poisson ratio, effective friction angle, effective cohesion, total cohesion, and adhesion to the structure. For the calculation at rest pressure coefficient, Jaky or Terzaghi theory can be used.

The parameters of the soil under the base are set in this section as well. The bearing capacity of the soil under the base can be set manually by the user, or can be computed by the spradsheet. There is possibility of using granular bedding under the base for increased slide resistance.

The weight of concrete and water are defaultly set.

4.5. Load Scenario Specific Setting

For each loading scenario, the user chooses the type of the horizontal earth pressure (active/passive/at rest) on both sides of the wall. In many cases, it is difficult for the user to decide what type of earth pressure he should use, as it may not be clear which side is driving and which is resisting. For that, the spreadsheet itself recommends what pressure type should be used, based on a calculation of balance of the two sides of the wall. However, it is up to the user if they choose to respect the recommended values.

In the loading scenario specific setting section, it can also be set if the user wishes to lower the ground level on the resisting side by 10% of retained height, as it is recommended in Eurocode.

5. ANALYSIS AND OUTPUTS

The analysis respects Eurocode 7. Design approach DA1 is used, which means that two load combinations are used,

$$CO1 = A1 + M1 + R1 \quad (1)$$

$$CO2 = A2 + M2 + R1 \quad (2)$$

where CO1/2 is set of factors used in combination 1/2; A1/2 are factors for load actions 1/2; M1/2 are factors for material parameters 1/2; and R1 are factors for resistance.

The spreadsheet cells with the Eurocode factors are marked as recommended to be kept default. However, they are not locked, so the user can adjust the factor in case they need to use a different code.

The analysis is provided for both drained and undrained conditions. It is up to the user to choose which case applies to their assignment.

Three major assessments are performed by the calculation tool:

- Slide stability – it is assessed that the horizontal driving forces are sufficiently balanced by resisting forces so that the structure does not slide on the formation level
- Overturn stability – it is assessed that the driving forces are sufficiently balanced by resisting forces so that the structure does not overturn about its edges
- Bearing capacity – it is assessed that the bearing capacity of the soil under the base is sufficient so that it can resist the vertical pressure from the structure

In addition, the extreme values of internal forces (normal force, shear force, bending moment) in all structural parts are calculated, so that they can be used for design of reinforcement of the concrete retaining wall.

6. SUMMARY

A calculation tool was created for the analysis of a retaining wall structure.

The proposed tool provides user friendly environment allowing wide range of parameters and conditions to be set. The user is guided by descriptions in a comment panel, explaining the input parameters and processes of the analysis. The spreadsheet environment makes the tool very approachable for any user. All mid-steps of the analysis are locked to avoid accidental overtyping, but are visible to the user, making the whole calculation clear and understandable. The results are summarized in a compact printable tab.

The outcomes of the calculation are the assessment of the slide and overturn of the retaining wall, assessment of the loading bear capacity of the soil under the base, and calculation of decisive internal forces for reinforcement design.

One of the strong features of the proposed calculation tool is its applicability in universal geometrical and loading conditions. This is achieved through deciding algorithm of what side of the wall is driving (i.e. dominant in a sense of prevailing effects of load) and what side is resisting. Very often, it is not clear from the geometry and loading conditions what would be the direction of slide of the retaining wall, or where the overturn point is placed. However, that is crucial for the correct composition of the assessment equation, and correct assignment of the safety factors to loading values. The proposed spreadsheet tool was designed to be able to recognize the driving/resisting side of the wall and, therefore, is universal in geometry and loading setting with no demand on the user to make any unsubstantiated presumptions.

The analysis is performed in line with Eurocode 7. Three loading scenarios are considered – flood, general conditions and dry conditions. The analysis is provided for both drained and undrained conditions.

ACKNOWLEDGEMENTS

The financial support of grant project SGS20/041/OHK1/1T/11 is acknowledged. The calculation tool was prepared within Geotechnic and Tunnels department of Mott MacDonald. Professional support of the Geotechnic and Tunnel team gratefully appreciated.

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