Using raster GIS for slope stability analysis

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\textbf{Abstract.} The main goal of this article was to establish a suitable raster GIS (Geo Information System) for the slope stability analysis. A case study area of Brežice municipality was selected. The recent landslides events in the selected area increases the fears of Brežice habitants and its authorities in land slope stability. The municipality authorities have the obligation to estimate the land risk in phase of issuing the building permissions. Using the low cost raster GIS the municipally authorities should get the possibility to perform a fast land stability check. A three phase process is selected in land slope stability analysis. Using the geological data a strength map and rock slope stability map were made. In combination with DEM (Digital Elevation Model) data the slope stability map is produced. The impact of the rain was not taken in consideration, so the more conservative approach was selected; this means that the lower inner angles of strength for different rock type were selected. At the end a comparative test of slope stability map with on field data was made with the quite good results.

\textbf{Keywords:} GIS, slope stability analysis, stability map, stability classes, applied geology
1 Introduction

Long-term impact of exogenous factors such as surface weathering, river and stream erosion, and groundwater flow, cause changes on the surface of the terrain and weaken the rock strength [1]. Such action can cause a kind of balance collapse between the gravity and the inner strength of rock [2]. These two reasons are the main factors for development of the landslides. GIS – Geographical Information System is designed to work with databases or, for integration, observation, analyses, processing and plotting of spatially oriented data, as well [3]. Using the raster GIS software the process can be divided into three steps following one after the other. In the first step translation of lithological map information into rock strength has been made, in the second the slope map is build and finally in the third step a slope stability map on the basis of combinations of first two maps is made.

2 Background and methods

While defining areas that can be used for building, we have to consider the consequences that can be brought by interfering with nature. We also have prevent or at least reduce the risk of various natural catastrophes, such as rainfall, earthquakes, landslides and settlements. With all these requirements we need to find the most optimal integration of the buildable areas in this space and at the same time achieve a mutual correlation between the desired high degree of safety and quality at an acceptable price of execution. A map of the strengths of rocks helps us, when examining the learning about the desired problems, as strength is one of the more important parameters that we have to consider in the process of building as well as in the safety of the buildable areas.

<table>
<thead>
<tr>
<th>CLASSIFICATION LEVEL</th>
<th>NAME</th>
<th>ROCK RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCKS</td>
<td>VERY HARD</td>
<td>TONALITE</td>
</tr>
<tr>
<td></td>
<td>HARD</td>
<td>CARBONATES</td>
</tr>
<tr>
<td></td>
<td>SEMI-HARD</td>
<td>CLASTITIS</td>
</tr>
<tr>
<td>SEMI - ROCKS</td>
<td>SOFT ROCKS</td>
<td>TERTIARY SEDIMENTS</td>
</tr>
<tr>
<td>SOILS</td>
<td>GRAVELY SOILS</td>
<td>GRAVEL FILL</td>
</tr>
<tr>
<td></td>
<td>MIXED SOILS</td>
<td>CLAY AND GRAVEL FILL</td>
</tr>
<tr>
<td></td>
<td>MARSH AND LAKE SOILS</td>
<td>MARSH, LAKE AND MARINE SEDIMENTS</td>
</tr>
</tbody>
</table>

Fig. 1. A map of the rock strengths (Unit: Strength classification class from Table 1)

Strength can be valued as tensile or compressive strength and represents, mainly, the cohesion between the basic components of the rocks. In general, greater strength is mainly present in metamorphic and igneous rocks, although carbonates can also be regarded as solid rocks [4]. Soft rock show less strength, the reasons for which can vary, from the degree of the diagenesis to the presence of anisotropic phenomena, stratification and the presence of fossil inclusions [5].
In assessing the specific location that might be suitable for construction, it is necessary to have a good look at the geological structure, which will form the basis for buildable areas. The base must satisfy two basic technical criteria, namely the terrain must be stable and the bearing capacity of the ground must be sufficient [4, 5]. In the event that these two conditions are not met, there is no need to evaluate the location as inappropriate, because we can eliminate some geotechnical constrain with different construction interventions. Any deposition of material on the surface affects the geosphere, so it is important that we seek the optimal location on solid rocks and good load-bearing ground of smaller inclinations, so that we eliminate breakages, slippage and excessive subsidence [1, 2], [4, 5].

To assess the suitability of the rocks based on the strength, we had to firstly classify the rocks into individual functional classes and evaluate their strength. After that, based on the strength and inclination, we evaluated their suitability. Strong and solid rocks have the highest score, the lower the score gets, the less solid the rock is [6, 7].

Based on their lithological types, we have classified the rocks into seven classes (Table 1). According to their strengths (resistivity) the rocks were classified into five classes (Table 1), from very strong rocks to very weak ones (Figure 1).

The rocks short descriptions on the basis of their lithological types are [6, 7]:

- Very hard rocks are very suitable in the correlation to their bearing capacity, but their problem is that the difficulty of working with them is often connected to their high inclination.
- Hard rocks have a good bearing capacity, but construction requires building a plateau by blasting on inclined areas.
- Rocks of medium strength have a fairly good ground bearing capacity, that decreases on areas with a thick eluvial cover.
- Soft rocks have a very low bearing capacity, when choosing the terrain it is necessary to check the stability and to lay down the conditions of founding. Big, heavy objects have to be founded deeply.
- Gravel like soils have very good circumstances for construction. It is only mandatory to protect the slopes in the implementation of deep pits.
- Mixed soils - the allowable bearing capacity of the ground is low and the construction circumstances are tough, many times founding is needed.
- Marsh lake grounds - the allowable bearing capacity of the ground is low and there is a danger of soil subsidence. Therefore special founding and dams are required.

Table 2: Display of the classification of inclination classes [6, 7]

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>NAME</th>
<th>INCLINATION CLASSES</th>
<th>STABLE INCLINATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCKS</td>
<td>IGNEOUS AND METAMORPHIC</td>
<td>ROCK</td>
<td>ABOVE 50°</td>
</tr>
<tr>
<td></td>
<td>CARBONATES</td>
<td>ROCK</td>
<td>TO 50°</td>
</tr>
<tr>
<td></td>
<td>CLASTITES</td>
<td>SOIL</td>
<td></td>
</tr>
<tr>
<td>SOFT ROCKS</td>
<td>TERTIARY SEDIMENTS</td>
<td>ROCK</td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td>GRAVELY SOILS (GRAVEL FILL)</td>
<td>PREVAILING CLAY</td>
<td>TO 40°</td>
</tr>
<tr>
<td></td>
<td>MIXED SOILS (CLAY AND GRAVEL FILL)</td>
<td>PREVAILING GRAVEL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LAKE, MARSH AND MARINE SEDIMENTS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In literature, a variety of limit values appear, depending on the purpose and the accuracy of the classification and the professional profile [4], [6, 7]. These are relatively uniform in establishing of the turning point boundaries, such as the construction suitability limit. The inclination varies from one rock
to another, as strong rocks are resistant to sliding at
greater inclinations, consequently, less strong rocks
have lower limit values [4], [6, 7] (Figure 2).

![Rock slope stability map](image1)

**Fig. 2.** Map of rock slope stability (Unit: Degrees)

In the third phase, we have produced an
inclination map (Figure 4) out of the elevation map
(Figure 3) of the test area; this is made possible by
specific operations in GIS tools. The inclination
affects the relief shaping greatly and it is a dominant
landscape exclusion factor in mountainous areas.
Depending on the purpose of the map and the
accuracy of the classification, different limit values
appear. The values are relatively uniform in
establishing allowable limits, such as the allowable
limit for construction. That fluctuates around 30°.

When we calculate the inclinations of the slopes
(Figure 4), we combined them with the map of rock
inclination stability (Figure 3). The method of
combining raster maps presented in Figures 3 and 4 is
shown by the following equation (equation 1).

\[
\left(1 - \frac{RSM}{USL}\right) = \text{norm. value}
\]

RSM – the actual inclination on the map (Fig. 4),
USL – the upper inclination limit (Fig. 3),
norm. value – the calculated normalized value of
the inclination

**3 Discussion and results**

As we can see, based on equation (1), the greatest
value we can get is 1. Cells that reach the value 1 are
the most stable, which means that the lower the value
is the lower is the stability of the area of a 5 x 5 meter
cell.

![Elevation model](image2)

**Fig. 3.** Elevation model with the cell size being 5 m x 5 m (Unit: m)
We have defined the values from 0.1 to 1 at class 3, the values from -0.5 to 0.1 as class 2 and all values lower than -1.5 as class 1 (Fig. 5 and Table 3) [8, 9]. The defined values form the basis for plotting the stability map. It represents three classes, the best one being class 3, which takes up the areas with rocks with the best stability. Class 2 takes up areas, where the rocks are already on the limit of stability given their geomechanical properties, or they overcome that limit by up to 50%. Class 3 is the worst group, as the stability limit is crossed by more than 50%.

<table>
<thead>
<tr>
<th>Class</th>
<th>Value</th>
<th>Description</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.1 to 1</td>
<td>Area of greatest stability</td>
<td>Building on these areas is allowed. Before construction, a detailed engineering-geological and geotechnical report on the conditions of the founding has to be made.</td>
</tr>
<tr>
<td>2</td>
<td>-0.5 to 0.1</td>
<td>Area of deteriorated stability</td>
<td>Building on these areas is not recommendable, but it is possible with the implementation of remedial actions that prevent the instability of certain areas. An engineering-geological and geotechnical report with the analysis of the stability of the area has to be made. Reducing the vegetation cover can strongly increase the problems considering the instability of the area.</td>
</tr>
<tr>
<td>1</td>
<td>less than -0.5</td>
<td>Unstable area</td>
<td>Building on this area is practically impossible. Interventions in this area should be avoided. Reducing the vegetation cover in these areas is not acceptable.</td>
</tr>
</tbody>
</table>
4 Conclusions

Because of the fact, that rainfall precipitations were not included in the process of slope stability analysis, the demands of stability were placed higher as they would be [10]. Considering these facts the classes of stability were made on the more conservative approach than they would be in case the data on intensity of rainfall precipitations were available. Analyses and maps like these presented are generally helpful especially for urbanists for creation of urban plans. At the same time they are very helpful for prediction of landslide occurrence especially in the populated areas in the period of heavy rainfall. At the end, we only have to look at how useful the stability map made is together with the previously presented methodology. Figure 6 gives us the best answer to this, as it contains the stability map as well as a map of landslide locations. As is apparent the locations of to date land movements and landslides completely coincide with the map.

Fig. 6. Stability map of the Brežice Municipality together with the locations of landslides marked in yellow (Unit: Class - Table 3)

References