Stability analysis of the Baltic cliff landslide

Lesław Zabuski, Waldemar Świdziński
IHEPAS - Institute of Hydro-Engineering of the Polish Academy of Sciences, Gdańsk, Poland

ABSTRACT

The phenomenon of the cliff landslide in Jastrzebia Gora at the Baltic coast has been studied. Stability calculations have been carried out to evaluate its actual stability. Numerical simulations aimed at verification whether the potential landslide is dangerous for the construction of the building located near the cliff edge and if so, how far has this building to be replaced to avoid its damage and to reach the safety conditions. Such safe distance has been determined.

Keywords: landslide, Baltic cliff, stability calculations

1. INTRODUCTION

Jastrzebia Gora cliff at Baltic coast belongs to so called active cliffs which from time to time undergo landslide processes. The last large landslide occurred there in 2002 (Fig.1). Many years investigations allowed to identify the main reasons of these landslides which can be divided into two basic elements, i.e. seaside and landside ones. Seaside factor is mainly generated by sea activity specifically during the storms and storm surges when undercutting of the cliff toe takes place, changing its geometry. In recent years this factor has been practically eliminated due to the construction of the support on the level of the beach composed of gabions (Fig. 1). In turn, landside factors are mostly related to unfavorable geological and hydrogeological conditions of the soil mass inside ca. 30 m high cliff.

The cliff in the lowest, basal parts generally built of impermeable clays and loams. These soils are covered by permeable sands and silts in the upper part. Geological layers are slightly inclined in the direction of the sea. Such arrangement of the soils causes that the water infiltrates into the cliff mass penetrating permeable soils and lubricating cohesive clays and loams along the border of non-cohesive and cohesive spoils, causing its weakening.

Figure 1. General view of the cliff with the landslide and analyzed cross-section

The effect of the landslide is serious damage of the building located in the nearest vicinity of the cliff crown. Earth works stabilizing the cliff were undertaken in 2006-2008 and now the shelf between the building and cliff is 7 meters wide. In that time no quantitative stability analysis was performed.

Different circumstances cause that now is a need of reconstruction of this building. Thus the questions arose: is the cliff in this section stable and if it is possible to reconstruct the building at the same place without additional massive stabilization measures.

In order to answer on the above questions actual stability has been estimated. For this purpose computer code FLAC2D [1] was used allowing for determination of the displacement and stress fields as well as current safety factor. Analyzed cross-section is shown in figure 1. In numerical simulations several new positions of the building have been analyzed corresponding to its landward movement 3, 5 and 7 m to verify which distance satisfies minimum safety requirement.

2. STABILITY ANALYSIS

2.1. Geotechnical calculation model

The geotechnical layers are shown in figure 2 and their parameters are set in table 1. Letter P in the figure denotes supporting lump, built of sand, gravel and reinforced by Tensar mesh (each band 7.5 m long, spacing between bands equal to 75 cm). Moreover, water table has been lowered to the bottom of IVA layer due to drainage system (pipes) installed inside the supporting lump. The gabion “fence” on the beach level has also additional supporting effect, except of isolating the slope from the sea.

Figure 2. Geotechnical profile of the model
2.2. Calculation results

“Basic” model (building 7 m distant from the cliff edge (Fig.3)

Potential landslide covers large part of the cliff, reaching the level below the beach. The building is inside the potential landslide space. Safety factor \( F = 1.06055 \) means that the slope is stable, however the safety margin is low. According to Polish law it should be greater than 1.30, to be accepted.

Table 1: Geotechnical parameters of the soil layers

(\text{acc. W. Świdziński, 2006, supplemented})

<table>
<thead>
<tr>
<th>Layer number</th>
<th>Soil</th>
<th>( \rho^{(2)} ) [t/m(^3)]</th>
<th>( c^{(2)} ) [kPa]</th>
<th>( \phi^{(2)} ) [(^\circ)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Silty loam</td>
<td>2.05</td>
<td>40.0</td>
<td>15.0</td>
</tr>
<tr>
<td>II</td>
<td>Loamy sand</td>
<td>1.80</td>
<td>15.0</td>
<td>29.0</td>
</tr>
<tr>
<td>III</td>
<td>Clay</td>
<td>2.05</td>
<td>45.0</td>
<td>10.0</td>
</tr>
<tr>
<td>IVA</td>
<td>Fine sand</td>
<td>1.80</td>
<td>0</td>
<td>33.0</td>
</tr>
<tr>
<td>IVB</td>
<td>Fine sand</td>
<td>1.80</td>
<td>0</td>
<td>35.0</td>
</tr>
<tr>
<td>V</td>
<td>Silty loam</td>
<td>2.05</td>
<td>58.0</td>
<td>19.0</td>
</tr>
<tr>
<td>VI</td>
<td>Loamy sand</td>
<td>2.18</td>
<td>21.8</td>
<td>27.0</td>
</tr>
<tr>
<td>VII</td>
<td>Clay</td>
<td>2.15</td>
<td>50.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Support</td>
<td>Reinforced soil</td>
<td>1.90</td>
<td>100.0</td>
<td>36.0</td>
</tr>
</tbody>
</table>

Additional calculations were done for the model without the building. In such case safety factor is almost identical as in above model. It means that the building was and will not be the reason of the landslide.

The calculations for dry slope proved that value \( F = 1.30 \) is reached only if the water table is lowered to the beach level.

3. FINAL REMARKS

Results of the cliff stability calculations proved that stability of the cliff is near the limit equilibrium so there are potential conditions for landslide. The safety factor for the case of building located at the actual place is equal to \( F=1.06055 \), so it is significantly lower than \( F=1.30 \) accepted by Polish law.

Relocation of the building landwards, i.e. increasing its distance from the cliff scarp by 3, 5 and 7 m causes small increments of the safety factor, however for the model without the building it is still low (\( F = 1.10 \)). It means that the loading generated by building has almost negligible influence on the cliff stability.

Relocation of the building at 7 m causes favorable situation, since the failure mechanism does not include the building (see fig.4). However, it should be noted that the safety factor in this case is lower than the value accepted. In the case of the potential landslide occurrence the building will be directly above its main scarp.

It can be concluded as well that the supporting construction does not provide sufficient safety margin of the cliff, what means that its effectiveness is limited.

Drainage of the slope improves stability conditions, but the value \( F = 1.30 \) will be reached only in case of the water table lowering to the beach level. Such drainage is practically impossible.

References

