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CLIFF RECONSTRUCTION AT JASTRZĘBIA GÓRA

Abstract

The process of cliff erosion in Jastrzębia Góra is a superposition of two phenomena: the abrasion at the foot of the cliff and slope failures of its upper part. Prior to the reconstruction works the stability analysis was done. Obtained results clearly documented reasons of slope failures observed during years. Based on the results five methods of slope protection were discussed. The chosen method for reconstruction of a one cliff's stretch consists of a drainage system installation and slope support by means of reinforced sand blocks. During construction works the emergency laser system at the edge of the cliff was installed. The construction works were successfully completed in the middle of November 2000.

Introduction

The cliff at Jastrzębia Góra is one of the most beautiful stretches of the Polish coastline, attracting many tourists. The land, which on a length of about one kilometre rises to some 30 metres above sea level, drops suddenly at a distance of 40 to 80 m from the waterline, forming a wild, in places nearly vertical slope with numerous old and new landslide steps and periodically intense seeping of groundwater. The seepage is caused both by precipitation and by incorrect water and sewage management at the top of the cliff. The basic part of the cliff is built up of laminated clay with sand. At both sides of the cliff the clay is gradually replaced by sandy clay, the cliff becomes lower and finally passes into a dune coast.

The process of cliff erosion, proceeding since many centuries, is a superposition of two phenomena: the abrasion at the foot of the cliff, which in the period 1987-1992 reached the rate of 1.6 m/year, and the slides of the upper parts of the cliff on the surfaces of cohesive soils, weakened by watering the cliff body from the upper part of the cliff by means of the small sandy layers. The first phenomenon was practically eliminated by a gabion revetment with an anti erosion mattress in front of the structure. In spite of that, after construction the revetment, landslides still took place. However, these phenomena occurred exclusively in the upper part of the cliff, indicating that the only reason for their generation was infiltration of groundwater.

Fig. 1. Landslide in front of Villa "Mewa" – spring 1999

Fig. 2. Landslide viewed from the level of coluvium – spring 1999

For about ten years since a large landslide occurred in front of the Rehabilitation and Rest Centre "Horyzont" in 1988, slope failure appeared mainly along the wooded part of the cliff, where there is no development near the cliff edge. In spring 1998 the western part of the cliff became active, directly in front of recreation houses area, where the height of the cliff varies from 30 m on the east side (near the "Mewa" villa) to 20m a.s.l. at the Bałtycka Street. The first large landslide occurred in front of the Bałtycka Street, and resulted in a 5-metre retreat of the cliff edge. Then the neighbouring stretches became active, and a number of small surface slides took place. In spring 1999 the cliff edge retreated significantly in the region of km 134.315 of the kilometre of the Polish coastline. In effect, the promenade running along the cliff was destroyed, and the edge of the precipice moved to only 13 m from the nearest building – the "Mewa" (Figs. 1 and 2).

The rate and length of retreat of the cliff edge in the years 1998 and 1999 caused that both the villa "Mewa" and the promenade in front of the hotel "Viktor" became directly endangered. After many years of investigations and observation it was decided to stabilise the cliff along the about 200 m long stretch. The Maritime Institute in Gdańsk was contracted by the Maritime Office in Gdynia to develop the concept of cliff stabilisation and protection.

Stability of the cliff

Along the discussed stretch of the cliff, the clay bed, which forms the main part of the Jastrzębia Góra cliff body, is gradually eliminated. In general, the upper part of the cliff (between the top and ca. 12 m a.s.l.) is built of two medium stiff clayey sand layers. If the cliff were built exclusively of such sediments, then its stability would be maintained even at the present slopes. However, at the base of each clayey sand layer there is a thin lamination of water-bearing sand. Groundwater flows through the sand, during some periods quite intensively, washes out the fines from this layer. In results the shear strength parameters both the sand and cohesive layers at the contact with the water-bearing layer are drastically reduced. Due to the loss of shear strength, the clayey sand are sheared at their base in the form of soil wedge, and the material is displaced over the horizontal failure surfaces. When the soil wedge becomes finally separated from the cliff's body, the described process of stability loss of the cliff's upper part starts from the beginning, indicating that the process of cliff erosion is still progressing.

In order to document this phenomenon, stability of the cliff slope was calculated at the most disadvantageous section, where the edge of the cliff was only 13 metres from the nearest building (June 22, 1999), and the height of the cliff is about 29 m a.s.l.

The calculations were made using the Morgenstern-Price method and program SLOPE/W, assuming a broken line of slope failure, reflecting the observed shear surfaces. In the lower part the line runs horizontally along the surfaces weakened due to seepage of water through the sandy layers. In each test several hundred potential slip surfaces were analysed. For the calculation, parameters of each layer were assumed from laboratory tests, and the unknown parameters in the area of weakening (at the base of the soil wedge) were selected in such a way that they led to a loss of stability.

Calculations were made for the base of the soil wedge, at the +17.2 m a.s.l., in a thin clay layer, located directly under the upper water-bearing lamination found in geotechnical field investigation, and also under the lower occurring water-bearing layer, at the +10.85 m a.s.l. For strength parameters of the soil at the base of the soil wedge, assumed as for a soft soil, i.e. $c = 25$ kPa, $\Phi = 0^0$ in clay, and $c = 6$ kPa, $\Phi = 11^0$ in clayey sand, the calculated coefficients of stability were:

F_{min} = 1.000 (slip surface at the first water-bearing layer)
F_{min} = 1.079 (slip surface at the second water-bearing layer).

This means that, for such shear strength parameters of the layers, over which the soil wedge is displaced, the slope of the cliff is in an unstable state.

It should be mentioned that the observed range of the consecutive landslides in the vicinity of the "Mewa", of the order of several metres towards the foundations of the villa, confirmed the correctness of the model of cliff deterioration, developed basing on earlier observed landslides. The observations also confirmed the correctness of assumed shear strength parameters.

Additional calculations of cliff stability at km 134.365, where the recreation centre of the Ministry of Finances is closest to the cliff edge, for the same geotechnical conditions as at calculation profile km 134.315, resulted in coefficient of stability F_{min} = 1.092. It should be pointed out that at km 134.365 the height of the cliff is 6 m lower. In this case the slip surface is at a distance of ca. 5 m from the cliff edge, while for the higher cliff the distance is about 10 m.

Calculations of stability confirmed that the basic cause of deterioration of the cliff along the investigated stretch is the decrease of shear strength of cohesive soil at the contact with thin water-bearing sandy layers.

Due to the complicated geotechnical structure of the cliff, insufficient knowledge about the paths along which the water filters into the cliff body, and because it was impossible to predict the volume of water infiltration into the cliff, exact determination of the dimension of the risk zone at the top of the cliff was impossible. However, it was found that the "Mewa" and the promenade in front of Hotel "Viktor" are directly endangered, and that without taking radical action, the process of cliff deterioration will continue.

Method of protecting the cliff

Since the earlier constructed gabion revetment completely eliminated abrasion, which destroyed the foot of the cliff, the only objective of the protection was to eliminate slope failures occurring in the upper part of the slope. The following methods of protection were considered:

1. Regulation of groundwater conditions in order to increase the shear strength of the soft cohesive soil layers, along which runs the slip surface, without changing the geometry of the cliff slope.
2. Change of the slope inclination of the upper part of the cliff together with drainage and protection works in the coluvium zone.
3. Anchoring or nailing the upper part of the cliff with simultaneous drainage and protection works in the coluvium zone.
4. Retaining walls, palisades or concrete cascades with drainage system.
5. Reconstruction of the cliff slope using reinforced soil after removing a part of the coluvium and constructing a draining system on the whole surface of natural soil.

Increasing the shear strength of the soft cohesive soil, along the slip surface, would require a complicated horizontal drainage system, penetrating into the cliff body outside the potential slip surfaces. The drainage system would catch the groundwater inside the cliff body, and would lead it outside the cliff slope, thereby eliminating the phenomenon of the shear strength decrease in cohesive soil at contact with the groundwater-bearing sand lamination. Construction of the basic horizontal drainage system to a depth of ca. 20 metres into the cliff body would be very difficult technically. It should be pointed out that the whole work would have to be carried out in the high risk zone of slope failure, and the drilling works could accelerate these processes. With such a complex system of groundwater-bearing layers, and in effect with unknown paths of seepage, there would be a significant risk that not all groundwater-bearing layers would be taken over by the installed drains. Therefore the method did not give satisfactory certainty that slope failure phenomena on the cliff slope would be stopped.

Stabilisation of the cliff by reducing its slope would, at minimum, require cutting the upper part of the cliff to a 30^0 slope. The promenade on the top of the cliff would be removed, and the cliff edge would be shifted much closer to the existing buildings, including the removal of the terrace in front of Hotel "Viktor". The Villa "Mewa" would have to be disassembled. What's more, the geometry of the cliff along this stretch would become significantly different from the shape of the cliff along the neighbouring stretches, completely losing its natural landscape values. Besides, this method would not allow protecting the cliff slope against surface erosion. Such protection would require additional surface strengthening of the cliff slope.

The anchoring/nailing method would require drying the zone of anchoring/nailing before installing the nails. Apart of the technical difficulties of the draining operation, the draining alone of the upper part of the cliff would result in improved strength parameters of the soft cohesive laminations, sufficient to ensure stability of the upper cliff. In effect, nailing would prove unnecessary. Similar problems would appear with the anchoring method. In this method the profile of the cliff would have to be changed, and a capping with a drainage layer, to provide safe outflow of water from the water-bearing layers, would have to be constructed. Carrying out such works under constant danger of further landslides could cause serious difficulties during construction work.

For technical, economical and safety reasons, and also because the cliff would lose completely its landscape values, the retaining wall and palisade concept was not considered.

In this situation, it was evaluated that for the conditions of the discussed stretch of the Jastrzębia Góra cliff, the most proper and safe method consists in reconstruction the cliff slope with reinforced soil, to its natural shape with two or three landslide steps.

To obtain this objective, first a part of the coluvium is removed, and a horizontal draining system and draining cuts are made. Next, a slope is built of medium and coarse sand and protected from the ouside with three or four blocks of reinforced soil, each of 6 metres height, about 6 metres width and a 60^0 slope. The adopted length of reinforcing (block width) is determined by the condition that this angle of the slope must be maintained. The berms between the consecutive blocks are models of landslide steps occurring in the natural cliff. In this method, the maintenance of cliff slope stability is influenced by three elements:

- horizontal draining system, separating the natural soil from the reconstructed slope, and the drainage cuts, which together drain the cliff face and improve the shear strength parameters of cohesive soil at contact with the groundwater-bearing layers;
- additional support of the natural cliff slope;
- reinforcement of the front part of the reconstructed slope.

The advantages of such a concept of reconstruction consist in:

- ensuring stability of the cliff slope independently of partly unknown groundwater conditions in the cliff body;
- widening of the cliff top and maintaining the natural landscape values since the cliff would be reconstruct to its natural shape, and the destroyed promenade along the cliff top could be rebuilt;
- ensuring safety of existing objects;
- protecting the surface of the rebuilt slope against surface erosion;
- simple technique of reconstruction and easily accessible material;
- carrying out the work in relatively safe conditions, since the stability of the cliff improves with the height of the reconstructed slope.

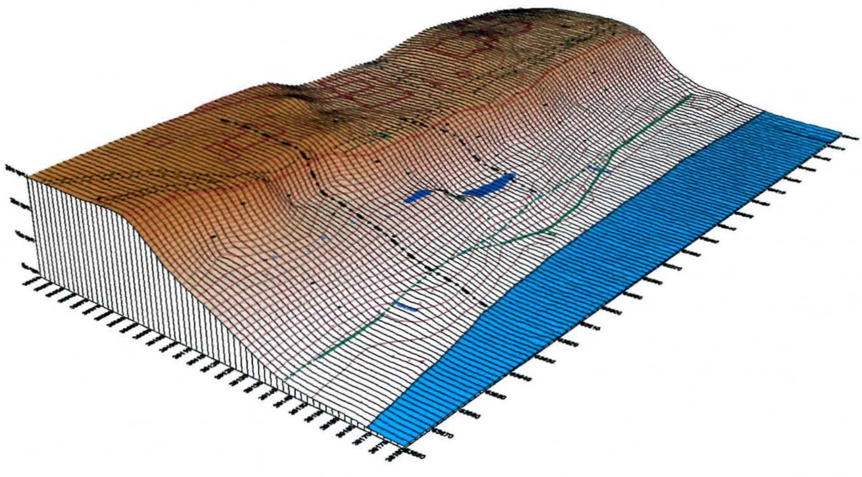

Fig. 3. Numerical model of the cliff surface before reconstruction

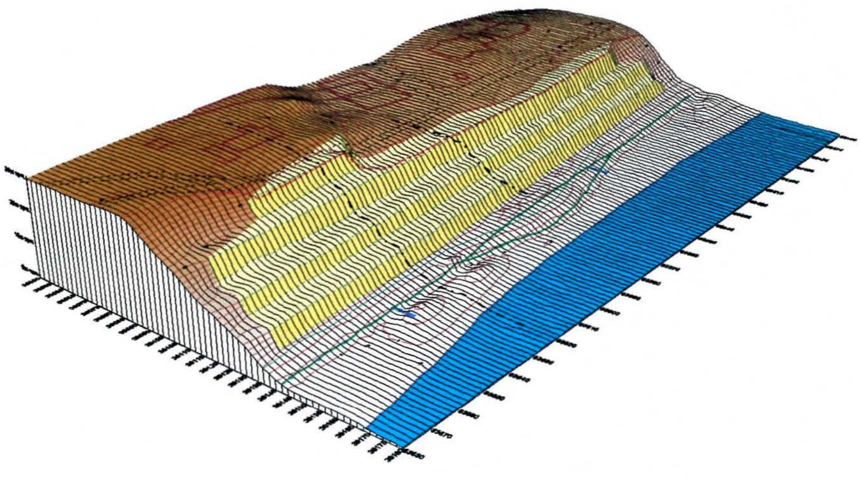

Fig. 4. Numerical model of the cliff surface after reconstruction

It should be also pointed out that the selected method allowed leaving the existing objects in place on top of the cliff, i.e. there would be no cost of disassembling them and income from their touristic exploitation would not be lost. Therefore, the method was not only the safest, but also the most economically justified concept of protecting the cliff slope. For these reasons the Maritime Office in Gdynia, acting as the Investor, accepted it for execution. The design documentation was worked out by the Maritime Institute in Gdańsk. The models of the cliff slopes before and after the reconstruction are shown in Figs. 3 and 4.

Description of proposed solution

The proposed solution of the cliff reconstruction includes construction the reinforced soil blocks (using GreenTerramesh with double twisted zinc coated wire mesh), drainage layer on natural cliff face and sand fill between the reinforced soil blocks and the drainage system.

Because of the variable height of the cliff, it was designed that the structure will consist of 3 or 4 reinforced soil blocks ('A', 'B', 'C', 'D') with the front sloping at 60^0, width (length of reinforcement) = 6 m, and height 6 m. Each block is composed of 10 layers of compacted sand in a Terramesh. The five lower layers of the lowest block 'A', which may be subjected to water action, have a geotextile coating on their front wall. The front walls of all the remaining layers of all the blocks are covered with coconut matt, which decomposes and stimulates quick development of vegetation. The foot of the first block 'A' begins outside the sloping Reno mattress forming the upper part of the existing revetment, at a distance of about 8 m from the revetment front. The width of the berms changes depending on the distance between the top of the cliff and the gabion revetment. The length of the reinforcement was adopted in such a way that a sufficiently high coefficient of stability was obtained within the reinforcement of the slope. The shape of the face was selected to obtain a sufficient coefficient of stability for the soil wedges and the whole height of the cliff.

The plane drainage system, which collects all seepage and outflow from the cliff body, consists of a continuous, 1 m thick, crushed stone layer in a geotextile envelope, from the top of the cliff to the gabion revetment. The drainage system rests on the newly profiled surface of the cliff's soil and on the drainage cuts located below blocks 'B' and 'C'. The drainage cuts are oriented perpendicularly to the gabion revetment and they are spaced about 10 m apart. The drainage cuts have a width of minimum 0.5 m, reach minimum 2 and maximum 5 m into the cliff soil, and they are filled with crushed stone in a geotextile envelope.

The space between the plane drainage system and the reinforced soil blocks is filled with the same compacted sand material as is used for the blocks.

For such solution, the calculated coefficients of inner stability within reinforced soil blocks changes between 1.46 and 2.59, and the coefficients of stability for the soil wedges were 1.98 and 1.46 respectively. Calculations of global stability for the slip surface running outside the reinforcing system of the slope gave $F_{min} = 1.3$ (Fig. 5).

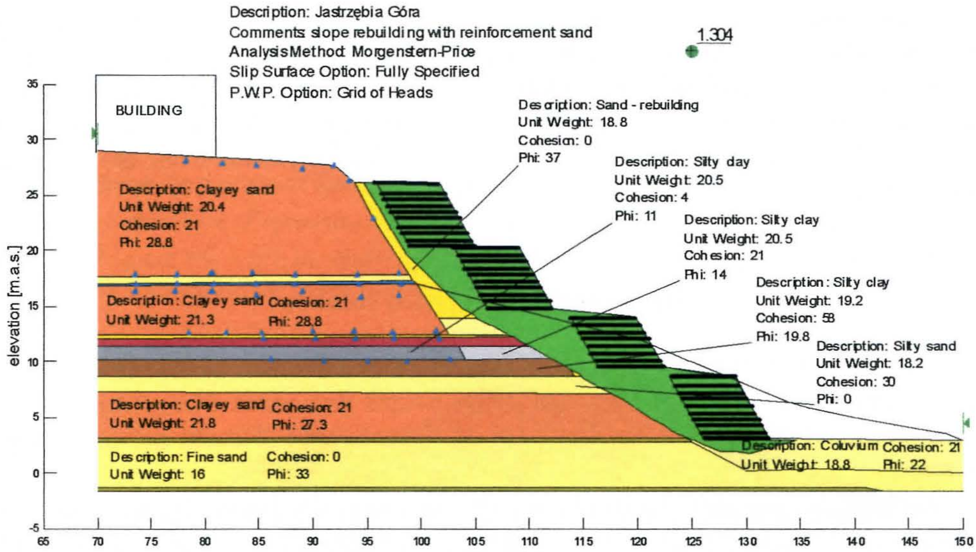

Fig. 5. Characteristic cross-section assumed for calculations of cliff stability after the reconstruction – global stability

Technique of reconstruction

1. Making a cut within the planned profile of slope reconstruction for block 'A' with plane drainage.

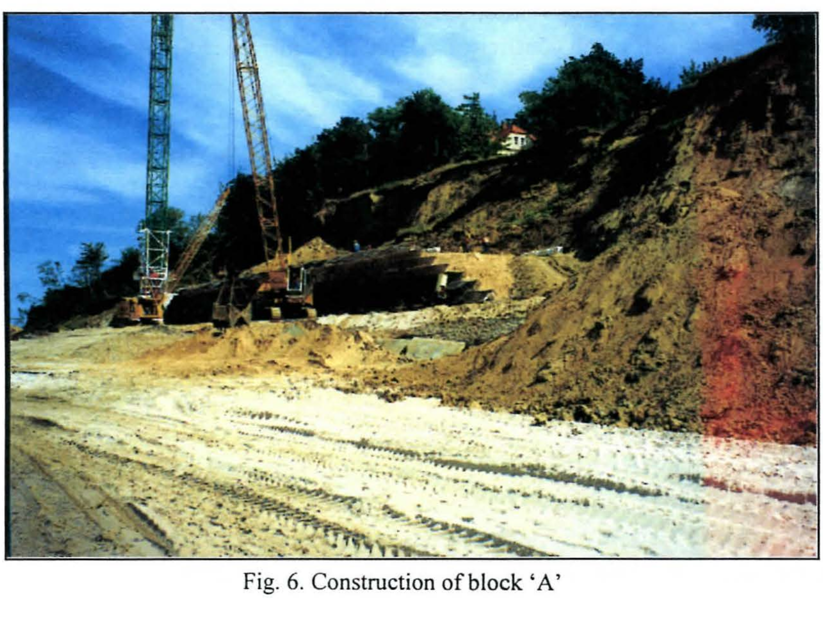

Fig. 6. Construction of block 'A'

Fig. 7. Outer slope of block 'A' – the Green Terramesh system

Fig. 8. Beginnings of work on block 'B'

2. Making drainage cuts filled with crushed stone in geotextile envelopes under the base of block 'B' as far into the slope as available equipment allows.
3. In the base of the excavation – making the 1 m thick plane drain of broken stone in geotextile envelope.
4. Placing of the first layer of *Green Terramesh* elements with backfill compacted to $I_s \geq 0.95$, and simultaneous making of crushed stone plane drain in geotextile envelope on the wall of the excavation.
5. Placing of consecutive layers as in p. 4 until block 'A' is formed (Figs. 6 and 7).
6. Constructing blocks 'B', 'C' and 'D' in a similar way, maintaining the continuity of draining cuts under block 'C' (Fig. 8).
7. Strengthening of the cliff slope by hydro-planting of seeds of selected grass and other plants.
8. Covering the berms with fertile soil and planting appropriate bushes with well-developed roots and small weight of the crown.
9. Reconstructing of the promenade and protective barriers on top of the cliff.

Emergency system

To ensure safety of people working directly under the uncovered slope of the cliff, the Maritime Institute developed and installed a laser emergency system. The principle of operation of the system consists in starting visual, sound and telephone alarms at the moment of appearance of some cliff edge displacement, indicating that a landslide may occur. The signals are generated by a break in the reception of a laser beam at one of the measurement sections installed along the top of the cliff. (Fig. 9). Each 20 m long section consists of 5 benchmarks placed along a straight line. On the outer benchmarks are fixed, on the opposite sides of the section, a laser light emitter and receiver. The benchmarks between the emitter and receiver have shields with a hole in their centre, through which passes the laser beam. If any of the benchmarks is displaced, the beam falls out of the hole causing a break in the reception of the beam at the receiver. This in turn, by means of an optical wave-guide system and electronic system installed in each section, generates a visual alarm (alarm lamp), an audible alarm (warning horn) and a telephone communication with information directed to the Construction Manager. To protect against unnecessary alarms caused by covering the laser beam by e.g. animals and people, the alarm is delayed 30 s from the moment the laser beam is broken.

Each measurement section is connected to a main line running along the edge of the cliff. The main line is connected to a computer with a power pack. The computer program in the Windows98 environment allows for: automatic restarting of the system, testing of operation of all measurement sections, indication of the section in which the alarm was started, generation of the danger communicate (repeated every 30 s), transmission of the communicate to the cellular phone, recording on disk of all the occurrences in each section (switching on and off measurements for calibration, loss of continuity of laser beam, starting of the alarm).

Fig. 9. The laser emergency system on top of the cliff

Construction works

Construction works began in early May 2000, and were ended in the middle of October 2000. The laser alarm system was installed in July, when work on block 'B' began, and the work was carried out directly at the foot of the precipice. In the construction works a tower crane with electro/hydraulic grab, Brawal caterpillar excavators, wheel bulldozers and loaders, four-wheel drive self-unloading trucks and vibration cylinders and plates are used. The coluvium was displaced from the construction site to the waterline to be successively removed by the sea. No significant realisation problems occurred.