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CONSTRUCTION AND GEODETIC OBSERVATION OF A GABION WALL FOR PREVENTIVE DUMP FIRE PROTECTION

Summary. Paper presents construction and geodetic observation of Gabion Wall. Analyzed gabion wall is located on slope of dump. In the dump are storing coal refuse with content of coal about 20 percent. This coal is source of fire in dump. For fire protection are using gabion wall described in this paper.

KONSTRUKCJA I OBSERWACJE GEODEZYJNE ŚCIANY GABIONOWEJ WYKONANEJ W CELU OGRANICZENIA ZAGROŻENIA POŻAROWEGO W HAŁDACH

Streszczenie. Artykuł prezentuje konstrukcję i pomiary geodezyjne ściany gabionowej. Analizowana ściana zlokalizowana jest na zboczu hałdy zawierającej około 20% zawartości węgla. Węgiel zawarty w hałdzie może ulec zapaleniu. W celu przeciwdziałania zagrożeniu pożarowemu możliwe jest zastosowanie metody polegającej na zabudowaniu zbocza hałdy ścianą gabionową, co przedstawione zostało w artykule.

1. Old Coal Refuse Dumps

Older coal preparation refuse dumps have a coal content of up to 20 percent. The coal washing was not better before 1970. Newer coal preparation refuse dumps have a coal content of less than 7 percent. This is the minimum coal content for a dump fire [1].

On older dumps the material was dumped over an edge. So as a result of slope dumping, a graded bedding of the material took place. At the dump foot oxygen may get into the coarse material and ignite the coal warmed up by pyrite oxidation. Modern dumps are built with trucks in layers of two meters thickness and very good consolidated. Only little amounts of oxygen are able to get into the material, not enough for a fire.

The slope angle of old dumps is almost the same like the sliding angle of the material. The surface of old dumps is often steeper than thirty or more degrees. So every event, for example a fire, leads to surface sliding. Modern dumps have slope angles less than 26 degrees.

2. The Dump Site Rheinelbe

The dump site Rheinelbe is situated in Gelsenkirchen at the boarder of Bochum. In the south the area is bordered by a railway and in the east by a small river.

The north part of the dump Rheinelbe was burnt out several years ago. There is no more coal in this part of the dump. Dangerous was the fire in the south. Only ten meters there were temperatures of up to 756 degrees Celsius and concentrations of carbon monoxide of up to 200.000 ppm [2]. The surface was sliding in the direction of two houses. A lot of gases got into the atmosphere.

In the south of the dump was enough place to do the fire fighting by covering the dump slope. More than one million tons of soil were brought on the dump site to seal the 33 m high south slope of the dump and parts of the top. The influx of oxygen from the south could be stopped [3,4]. But than the fire drifted into the direction to the east slope. Here was a small river and no room for a stable sealing of the dump slope with soils.

3. The Gabion Wall

In the view of the narrowness of room, a stable sealing of the approximate 28 m high dump flank was provided by four rear-anchored gabion wall sections, each 7 m high. The total length of the wall is 350 m (Fig. 1 and 2).

The ground for the first gabion wall section was a very wet clay. It was sure that it would fail under the weight of the gabion wall. So a concrete wall was built and stabilised with 18 m long anchors (Fig. 3). Behind the concrete wall a drainage was installed. In front of the concrete wall the first gabion wall section was built up with an angle of 85 degrees.

The first wall itself is rear-anchored in four layers with a length of 11.5 m.

The gabion baskets are made in steel with point connections (Fig. 4). For the filling graywacke is used with dimensions 50/150 mm. Only the layers between two lines of gabion baskets were filled with smaller coarse of graywacke. More than 2.000 tons of graywacke were used.

To seal the dump material a layer of clay, 1.5 m thick, with a $k_f \leq 1 * 10^{-8}$ m/s was used. This layer stops the influx of oxygen.

For the stability of the wall it is necessary to drain it. So the next layer above the clay is a recycling material 0/8 mm with $1 * 10^{-7} \leq k_f \leq 1 * 10^{-5}$ m/s. This material has to hold the layers of the rear-anchors. Therefor it must have a friction angle of minimum 35 degrees.

The last layer before the wall is a recycling material 8/45 mm with $k_f \geq 1 * 10^{-4}$ m/s. It has a friction angle of 35 degrees, too. With this system it is guaranteed, that hte water can flow the gabion wall without any pressure on it.

The gabion wall is rear-anchored with the same material like the baskets are made of. Only because of the friction angle of the covering recyclig material of 35 degrees the layers of the rear-anchoring system can hold the wall (Fig. 5).

Such a high gabion wall was built the first time in the Ruhr-district. Therefore a geodetic observation was necessary to be sure that it will not fail on the soft ground.

4. Geodetic Task

The pricipal objective od the geodetic surveys was the detection of significant changes which may become apparant for example by three dimensional movements and deformations. Generally speaking such engineering surveys are important for:

- influencing construction procedures to prevent feared or consequential damage which cannot be totally avoided, or
- detecting abnormal changes at an early stage to take counter measures in order to minimize damage and to prevent economic disadvantages.
- preserving evidence in order to clarify construction damage,
- learning more about local conditions (behaviour of buildings and land plots),
- providing description data etc. to control the calculation in order to improve movement predictions.

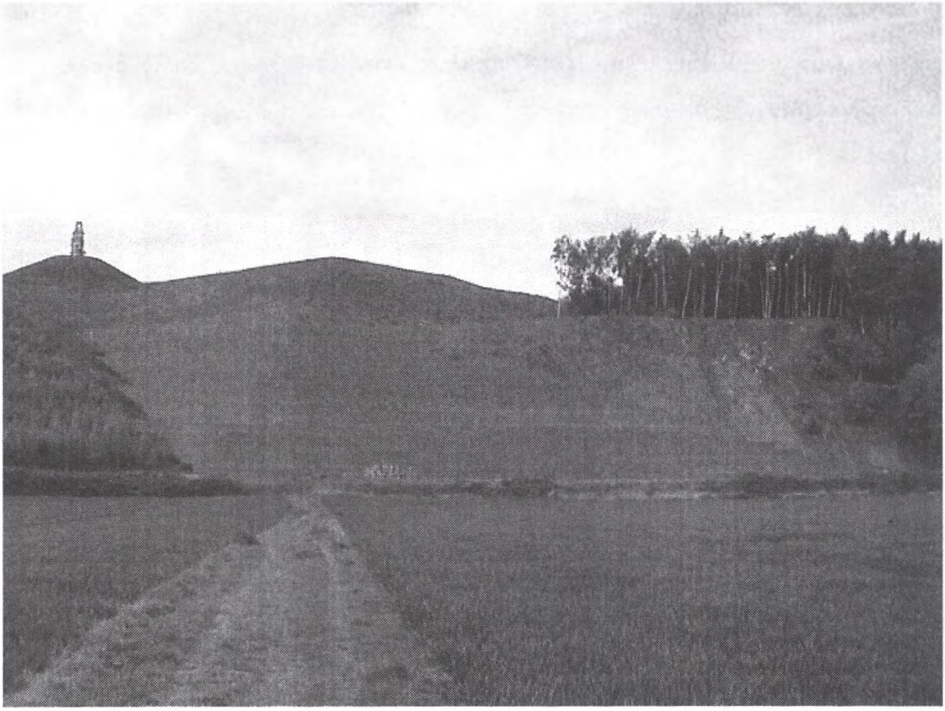

Fig. 1. Gabion Wall (View from the east)
Rys. 1. Ściana gabionowa (widok od strony wschodniej)

These movements can result from:

- normal movement behaviour due to soil consolidation,
- abnormal movement,
  - caused by increased earth and soil pressure
    - due to inflow of water
    - due to shaking
    - due to changing of the land plots
  - caused by material faults (gabion baskets)
  - caused by aging and corrosion (gabion baskets)
  - caused by damp landfill fires.

For engineering surveys a reference system has to be installed, i.e. a basic system for fixing one, two or three dimensional postions of points. A reference system consists of a system of coordinates and an area of surveying points. This must be a suitable geometrical system to describe the position of points. For practical application the coordinates are mostly indicated by horizontal postion coordinates X, Y and a height value H. The calculation usually is made within a special (free) system to prevent constraints to the coordinate fixing, possibly with assignment to the national net.

The area of survey points consists of surveying and object points. The survey control points should be in a movement free range and serve as basic points to the geodetic controlling. The building is idealized by a representative number of supervision points.

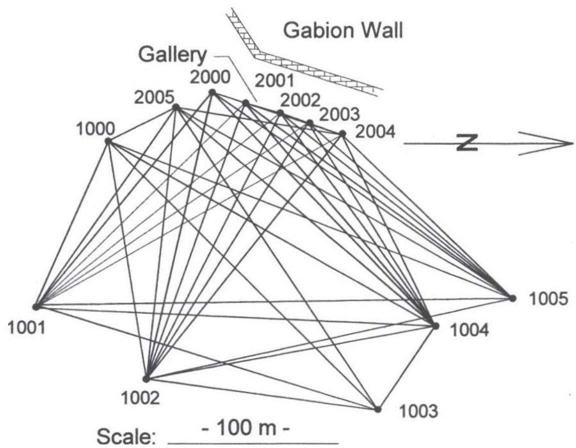

Fig. 2. Network of surveying points
Rys. 2. Sieć punktów pomiarowych

The survey points were determined by classical geodetic methods i.e. the combined measurement of direction and distance as well as the levelling of height. In front of the dump base there is a ditch with embankment. On this embankment 7 survey points were marked (gallery). We intended to use these points especially to carry out comparative photogrammetric measurements. However, because of the height of the construction only test measurements have been made, the results of which did not turn out to be very satisfactory.

In general, fixing of survey points is orientated towards

- the given surroundings,
- the measuring method (conventional geodetic surveying, via GPS or by photogrammetric methods),
- the duration of the planned observation time.

Due to these given conditions a network which is shown in the drawing could be created. The medium distance is about 200 m.

The survey points were marked by concrete pylons which are 0.3 m * 0.3 m wide, ground levelled and frost resistant. An interior iron pipe with a cap and round head bolt served as centering.

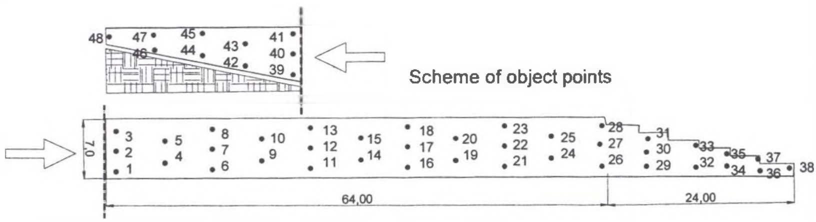

Fig. 3. Fixing of object points in building phase 1 (wall 1)
Rys. 3. Zamocowanie punktów pomiarowych w pierwszej fazie budowy (ściana 1)

The order of points in this picture illustrates how object points were fixed for the 4 building phases. Supervising the 1st building phase was most important. Therefore 48 points were marked. In the 2nd, 3rd and in the 4th building phase fewer markings were fixed.
For the markings we used plastic boards as shown in the picture with an edge length of 8 cm. They were chosen with a view to the planned photogrammetric measurements. They were fixed by cable links.

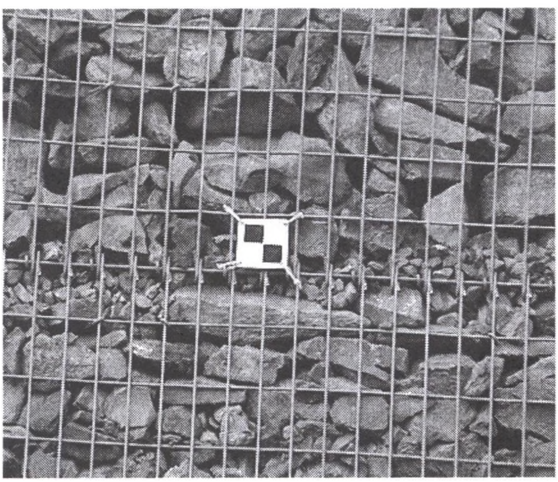

Fig. 4. Marking of object points
Rys. 4. Punkty pomiarowe

In our first survey object points were determined via intersection as well as radiation with refelectorless distance measurement.

5. Measurements

In order to determine the required measuring accuracy it can be helpful to assign the object to one of the categories established by the German institute for standardisation (DIN). According to DIN 18710-1 nominal accuracies (standard deviation for position and height) are classified into 5 groups.

Table 1

Classification of horizontal measurement accuracy

Class	Standard deviation σ_L (horiz. measurements) (σ_L in X- or Y- coordinate axis)	Comment
L-1	50 mm $> \sigma_L$	very low accuracy
L-2	15 mm $< \sigma_L \leq$ 50 mm	low accuracy
L-3	5 mm $< \sigma_L \leq$ 15 mm	medium accuracy
L-4	0,5 mm $< \sigma_L \leq$ 5 mm	high accuracy
L-5	$\sigma_L \leq$ 0,5 mm	very high accuracy

Table 2

Classification of vertical measurement accuracy

Class	Standard deviation σ_H for height measurements	Comment
H-1	20 mm $> \sigma_H$	very low accuracy
H-2	5 mm $< \sigma_H \leq$ 20 mm	low accuracy
H-3	2 mm $< \sigma_H \leq$ 5 mm	medium accuracy
H-4	0,5 mm $< \sigma_H \leq$ 2 mm	high accuracy
H-5	$\sigma_H \leq$ 0,5 mm	very high accuracy

Starting from a medium or a low accuracy (class L3 (position) and H2 (height)), the measurment accuracy could be determined as follows:

Standard deviation of an object point determination (horizontal position): $\sigma P = \sigma L * \sqrt{2} = 10$ mm. Standard deviation of an object point determination (vertical position): $\sigma H = 10$ mm. The accuracy of the survey points had to be chosen, so that these standard deviations were reached.

The network measurements (position) were done with Total station Sokkia SET 2 and Total station Leica TCR 1101 (reflectorless). Accuracy for both instruments: measurement of direction σ_R = 0,6 mgon, measurement of distance σ_D = 3 mm + 2 mm/km. For the network measurement (height) the digital levelling instrument Leica NA 3000 was used.

Accuracy height measurement: $\sigma_H \sim 1$ mm / km. The object point measurements (horizontal and vertical position) were also done with Sokkia and Leica total stations by automatic data registration.

The redundant measurements took place in so-called sessions:

1st measurement after finishing the 1st construction phase (Zero measurement) in June and December 1998.

2nd measurement after finishing the 2nd and 3rd construction phases in June 1999.

3rd measurement after finishing the construction building in June 2000.

Further measurements at yearly intervals.

The horizontal position of the net was observed in form of measurement sets, n = 2, the height by double levelling (forward and backward).

The object points are three dimensional, measured by controlled intersection (3 stations) or reflectorless by controlled radiation (2 stations).

6. Data Evaluation

The calculations were done with the program systems Cremer (Fa. Dr. Cremer, Munich) and KAFKA (Prof. Benning RWTH Aix la Chapelle).

As an example of a network measurement (horizontal position and height) the results are listed and shown in the picture. The standard error of position (Helmert error) is $\sigma P = 2.5$ mm, at a max. value of $\sigma P = 3.3$ mm. No significant difference was observed between measurements taken with the Sokkia – Tachymeter and the Leica – (reflectorless) instrument. The height accuracy of the points is at an average of $\sigma H = 2.6$ mm. The results are representative of all sessions.

The object points near the survey points (center, gallery) have the same accuracy as the net points, but the ellipses on the periphery are bigger. However, the average accuracies $\sigma P = 2.8$ mm, not exceeding a maximum value of 5 mm (points of the 1st wall-buiding phase). This value σP rises to 8 to 9 mm for higher and thus farther points in the other building phases.

A difference in accuracy could not be detected for the two measuring methods intersection and radiation. Both chosen methods fulfilled the requirement $\sigma P \leq 10$ mm, so that movements exceeding 14 mm could be detected as being of significance. The results of height measurement were not so satisfactory.

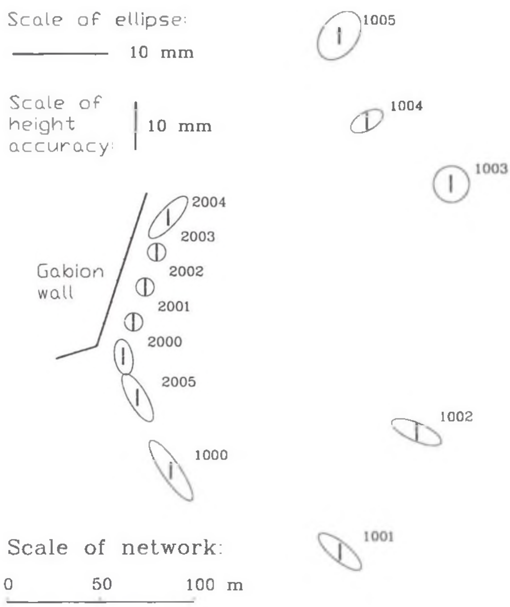

Fig. 5. Picture 8. Results of network measurments, Confidence ellipses
Rys. 5. Wyniki pomiarów, elipsy ufności

Based on an accuracy of the network points of $\sigma H = 2.6$ mm the accuracy of the object points dropped down to 17.7 mm max (average value of measurement taken in June 2000 $\sigma H = 14$ mm). These results apply to both measuring methods. This means that only height variantions > 20 mm could be detected as significant.

7. Deformation Analyses

Two measurement sessions t_0 and t_1 with identical basis are necessary: zero measurement (time t_0) and repeated measurement (time t_1).

Deformation analysis is made separately for position and height in 3 steps:

1. Checking the individual sessions (t_0 und t_1) to verify
   - gross errors in measurements
   - internal accuracy of observations

Determination by free adjustment furnishes: adjusted coordinates and heights as well as accuracies and standard errors of local positions.

2. Checking stability of survey points

   either - survey point is significantly unstable (=> future object point), or - survey point is stable within measurement accuracy.

   The standard errors of local position of the points determined by free adjustment for session t_0 are introduced into the free adjustment for session t_1 (Free adjust - ment with variable junction points). A point position is regarded to have changed significantly if the normed correction exceeds a preset confidence limit. Generally speaking, there is a significant deformation, if the correction of the distance is greater than a border $t_s{*}\ \sigma_D$ (t_s – Student distribution value as a function of red- undance and preset probability P = 95 or 99 %).

3. Checking stability of object points by free adjustment of sessions t_0 and t_1:

   either - object point is significant unstable (=> deformation) or - object point is stable within measurement accuracy

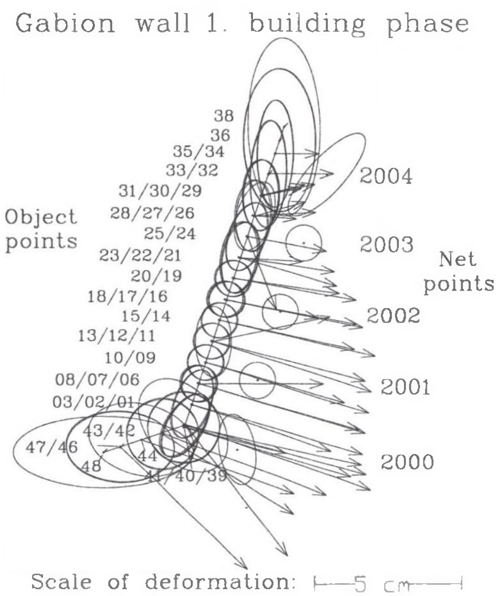

Fig. 6. Significant horizontal deformations (time periode June 1998 – June 1999)
Rys. 6. Odkształcenia poziome (okres czasu czerwiec 1998 – czerwiec 1999)

Changes ranged between 1 and 6.5 cm, the highest values being reachend to the right of the wall bend. For the time period between June 1998 and June 2001 it must be noted that movements had not yet subsided. The largest determined movement sector was 11.4 cm, the next largest 10.0 cm. In general, results showed the same tendency as those of the aforementioned time period.

The settlement values for the time period June 1998 - June 1999 were about the same size as the positional changes. The highest values up to 7.5 cm were detected to the right of the bend, getting smaller towards the edges. The settling values for the time period June 1998 – June 2001 were about the same size as the positional changes. The highest value increased slighty to a maximum of 9.2 cm.

Unfortunately only about ten points of the original 48 points of the 1st building phase are left. In the other sections even more points have disappeared. New points have been marked. However, they cannot be taken for continuous observations.

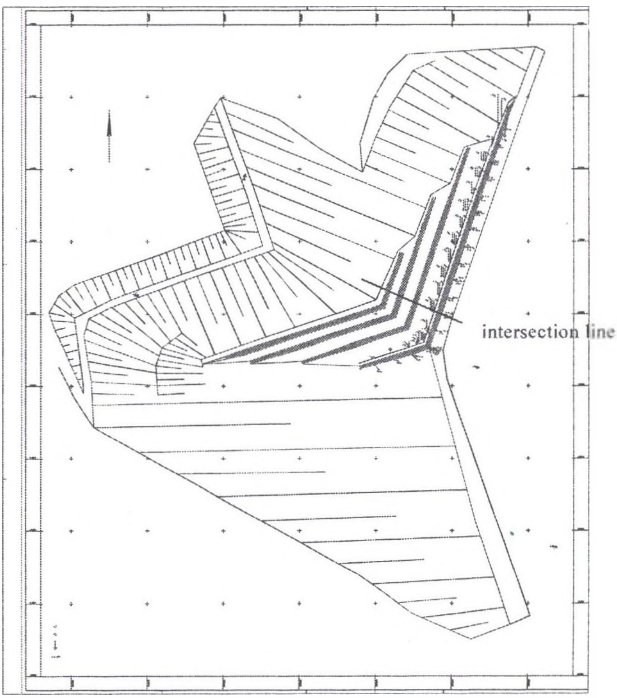

Fig. 7. Horizontal projection of the gabion wall
Rys. 7. Rzut poziomy ściany gabionowej

Apart from showing geometric conditions the picture 8 also indicates by the arrows where significant movements (in position and height) were detected for the time periode June 1998 – June 2001.

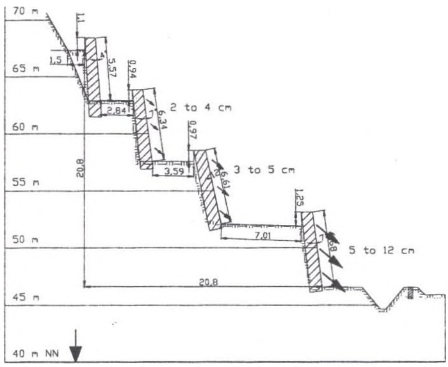

Fig. 8. Vertical section of the gabion wall slighty above the bend
Rys. 8. Pionowy przekrój poprzeczny przez ścianę gabionową bezpośrednio nad zgięciem

This applies to the lower section, the second section up to 5 cm, the 3rd section up to 4 cm. In the 4th section movements stayed within the range of measurement accuracy.

The results can be summarized as follows:

- Accuracy of horizontal measurments for each time section of survey points network $\sigma P = \sim 2\text{-}3$ mm.
- Accuracy of height measurements for each time section of survey points network $\sigma H = \sim 2\text{-}3$ mm (geometric observations).
- The deformation analysis showed no deformation for the survey points.
- Accuracy of horizontal measurments for each time section of points at gabion wall $\sigma P = \sim 3\text{-}5$ mm.
- Accuracy of height measurements for each time section of points at gabion wall $\sigma H = \sim 10\text{-}20$ mm (trigonometric observations).
- The statistical analysis showed horizontal and vertical deformations for the gabion wall points between zero measurement and 3rd repeated measurement (June 1998 - June 2001). The maximum horizontal movements were < 12 cm, the maximum vertical movements were < 10 cm. The measurements will be continued.

Literature

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Recenzent: Dr hab. inż. Jan Drenda, prof. nzw. Pol. Śl.

Streszczenie

Artykuł prezentuje konstrukcję i pomiary geodezyjne ściany gabionowej. Hałdy usypane przed 1970 zawierają około 20% węgla, młodsze usypywane z materiału po zastosowaniu bardziej nowoczesnych metod wzbogacania węgla zawierają poniżej 7% węgla, jednak i tak są do wystarczające ilości, aby wywołać pożar. Kąt nachylenia skarp jest równy kątowi zsuwu danego materiału, jednak wiele ze starych hałd posiada kąty nachylenia wynoszące ponad 30 stopni, co może powodować ich utratę stateczności i powstanie osuwiska. Dodatkowym czynnikiem wpływającym na utratę stateczności mogą być pożary występujące w materiale skarpy. Przedstawiono także metodę zabezpieczenia skarpy hałdy przez wykonanie ściany gabionowej. Przedstawiony został konkretny przypadek hałdy zlokalizowanej na peryferiach Bochum, którą zabezpieczono murem gabionowym. Mur posiadał długość 350 m i sumaryczną wysokość 28 m. Zbudowany był z 3 pięter przykotwionych gabionów, każde piętro miało wysokość 7 m.

Po wykonaniu ściany gabionowej prowadzony był monitoring jej przemieszczeń za pomocą pomiarów geodezyjnych. Pomiary te wykazały, że maksymalne przemieszczenia w ciągu 3 lat (1998 – 2001) wynosiły 12 cm.