Construction of vertical cut-off walls for reducing exposure to floods

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ABSTRACT

Climate change and growth of the population worldwide increase the risk of floods occurrence in urban areas, as was experienced in Kazakhstan in 2024. Flood prevention needs a complex approach which consists of monitoring, rivers regulation, dams and soil flood embankments engineering, construction and maintenance as well as international agreements.
This article presents the current state-of-the-art methods of cut-off walls construction for new projects and improvement of existing hydrotechnical and flood protection structures and gives a compact overview of available geotechnical methods to help reduce population exposure to floods. Selected geotechnical technologies are presented. The final choice of design solution and proper geotechnical technology depends on many aspects discussed in this work.

Keywords: cut-off walls, flood protection, filtration, soil flood embankments

1 INTRODUCTION

Climate change has been observed worldwide in recent years. One of its many consequences is an increased risk of flooding. However, uncontrolled water release can also result from other factors, such as poor maintenance, inadequate monitoring, and lack of river regulation. These events consistently lead to environmental damage and economic losses.
Extensive floods hit Kazakhstan in 2024, a dam failure occurred at the Sardoba Reservoir in Uzbekistan in 2020. These are only examples of widespread flooding that devastated surrounding landscapes and affected many residents.
One method to reduce flood risk is the use of vertical low-permeability barriers, also known as cut-off walls. These can be implemented in existing structures to enhance safety or incorporated into newly designed projects.

2 DEFINITION AND ROLE OF CUT-OFF WALLS

Vertical cut-off walls are low-permeability barriers constructed underground to control or limit groundwater flow. Cut-off walls are commonly used in civil engineering projects as well as environmental ones to control the movement of contaminants. Various construction methods of cut-off walls are presented in this article.
The main advantages of cut-off walls installed in the earth dams are:
a) decrease of the water flow speed (m/day) and volume (m^3/day) at the land side;
b) increase of earth dam stability;
c) extended time of first leakages on the land side.
To illustrate the influence of cut-off walls installed in the earth dam, simple comparison of a steady-state situation is presented for cases with and without cut-off wall. Calculations were done for one of the already completed projects for Vistula River in Poland (Topolnicki, 2005). Cut-off wall has been executed with soil mixing technology. The results are presented in table 1 and schematic cross-section is shown in figure 1.

Table 1. Comparison earth dam calculation results.

Case	Dam stability safety factor	Max. flow speed (m/day)	Volume (m^3/day)
Without cut-off wall	0.92	9.5	6.0
With cut-off wall	1.64	5.3	0.6

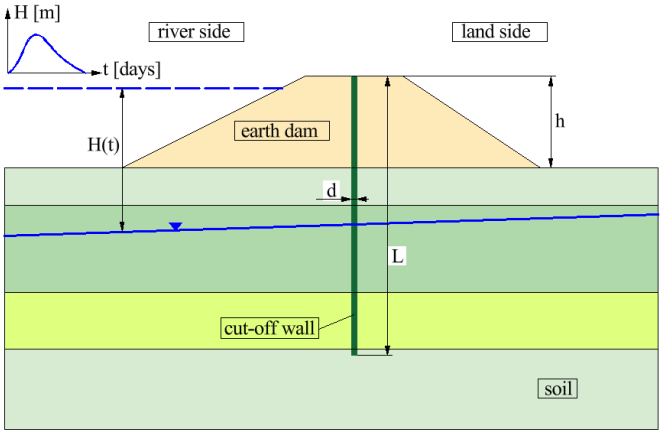

Fig. 1. Schematic cross section of the earth dam with vertical cut-off wall.

3 CLASSIFICATION OF CUT-OFF WALLS

Cut-off walls can be constructed in various configurations to control the flow of groundwater. The vertical barrier can either be keyed into a low-permeability layer or be hanging, where the wall does not extend into such soils. The appropriate geometry and location of the cut-off wall should be determined by consultants based on a hydrogeological analysis. Advanced software and models are nowadays available and can deliver precise results; however, accurate geotechnical soil parameters must be obtained and provided. This often is an issue during the engineering process.

The role of cut-off walls is to reduce seepage and potential washing effect, thereby reducing the risk of flooding. To achieve this, the appropriate cut-off wall technology must be selected. Several geotechnical technologies are available for use:

a) slurry walls (clay, soil-bentonite, cement-bentonite, soil-cement-bentonite),
b) soil mixing walls,
c) grouted barrier walls (jet grouting, permeation grouting),
d) sheet pile walls,
e) other types of cut-off walls.

The choice of proper technology depends on many aspects, e.g., type of soil, wall depth, geometry of the dam, project requirements.

4 GEOTECHNICAL TECHNOLOGIES FOR CUT-OFF WALLS EXECUTION

4.1 Grabbed slurry walls

The grabbed slurry cut-off wall means that excavation is done with the slurry which after hardening process creates a wall body (single phase cut-off wall) or slurry has supporting function only and is later replaced by the concrete or other material (double phase cut-off wall). Slurry used for single phase cut-off walls is usually mixture of cement (usually CEM III/B), bentonite, water and chemical additives. The UCS is typically less than 1MPa, filtration coefficient $k<1x10^{-8}$ m/s and Young Modulus is expected to be low to assure joint work of cut-off wall and surrounding dam body.

In general, there are three main types of slurry cut-off walls: soil-bentonite, cement-bentonite, and soil-cement-bentonite. Depending on the type, the backfill material contains a mixture of bentonite, cement, clay, fly ash, and ground granulated blast furnace slag. Typical equipment used for the construction of slurry wall is shown in Figures 2.

4.2 Soil mixing cut-off walls

Soil mixing cut-off walls are constructed by mixing the existing soil with the slurry, what creates the cut-off wall body. The choice of construction method depends on the available equipment and project requirements.

Fig. 2 Equipment for grabbed cut-off slurry wall (1).

There are three main methods for constructing soil mixing cut-off walls, depending on the equipment used:

a) cutter soil mixing method with mixing tools rotating about horizontal axes (Figure 3),
b) vertical trenching method (Figure 4),
c) soil mixing method with mixing tools rotating about vertical axes (Figures 6 and 7).

Fig. 3 Cutter soil mixing with mixing tools rotating about horizontal axes (1).

Fig. 4 Equipment for vertical trenching method (12).

The soil mixing method with mixing tools rotating about vertical axes, popularly called DSM (Deep Soil Mixing), became very common in CIS countries recently. DSM technology is widely used across various construction sectors under foundations, road embankments, for cut-off walls and retaining structures.

The DSM cut-off walls consist of overlapping columns created by rotating augers that mix in-situ soils with a low-permeability slurry. The slurry is injected through nozzles during the mixing process, producing a hardened mass (a mixture of soil and slurry). A continuous cut-off wall is formed by overlapping individual columns (Figure 5). The column diameter, pattern, and slurry types vary depending on site conditions and specific design requirements. Common slurry materials include bentonite, cement, lime, fly ash, among others.

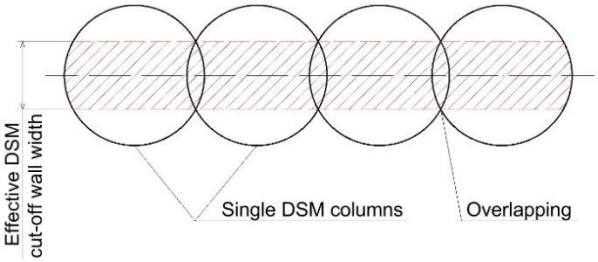

Fig. 5 DSM cut-off wall created by overlapping DSM columns

Execution of DSM cut-off wall typically requires the use of a rig fitted with either one, or a multiple mixing augers. Figures 6 and 7 show typical equipment for DSM cut-off wall production.

4.3 Grouted cut-off walls

The application of grouting techniques in geotechnics has limitations depending on the soil type and its grains size. The general limits are shown in figure 8.

Permeation grouting and jet grouting techniques are sometimes used for creating cut-off walls, however due to their high costs and relatively low productivity, those methods are not very popular. The application of these methods is common practice in combination with other methods in rock formations, soils which contain boulders as well as in case of any underground obstacles (e.g., underground pipelines or concrete structures).

Fig. 6 Equipment for DSM technology – single mixing tool.

Fig. 7 Equipment for DSM technology – multiple mixing tools (12).

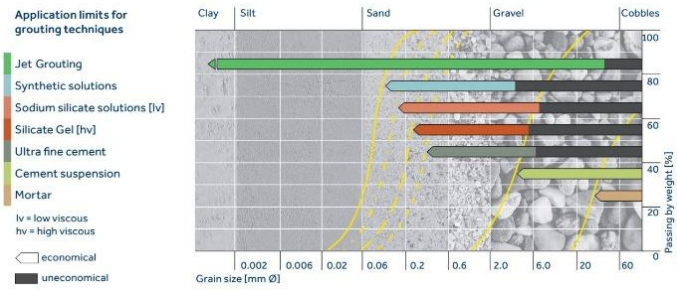

Fig. 8 Application limits for grouting techniques (5).

Jet grouting is one of the most flexible soil treatment methods to create structures for sealing and load bearing in geotechnics. In general, this technique injects the

grout mixture at very high pressure and velocity directly into the pore spaces of the soil or rock. The grout being injected cuts, replaces, and mixes the in-situ soil, destroying the soil structure and forming a homogeneous mass.
Permeation grouting is a low-pressure method, in general, a hole is drilled into the ground and a fluid is injected under pressure into the soil or rock, permeating the voids.
Type of grout depends on the soil type and the design requirements. Synthetic materials, silicate gels, ultra fine cements are often used in fine soils (grain sizes less than 2 mm), what makes grouting methods economically less attractive compared to other ones.
The advantages of grouted cut-off walls are flexibility in creating different grouted mass shapes as well as small size and weight of the equipment.


Fig. 9 Example of small-size drilling rig for jet grouting method (5).

4.4 Sheet piles walls

Steel sheet pile walls are commonly used in the construction sector mainly as excavation or slopes stability protection and are not good solution as a cut-off wall. This is because of high costs, its potential corrosion and leakages of the joints. However, relatively new and good to mention alternative for steel sheet pile walls is vinyl sheet piling. Vinyl sheet piles are an environmentally friendly, lightweight and extremely durable and advanced alternative to traditional materials such as steel. The commonly used method of vinyl sheet piles installation is the use of vibratory hammers and pre-installed templates. The type of equipment depends on the soil type, the depth of the installation and the durability of the sheet pile. In the case of hard, dense surfaces, or when long elements need to be hammered, steel mandrels are additionally used. Mandrels are special guide bars of shape and length reflecting the used PVC elements.


Fig. 10 Example of already installed vinyl sheet piles (10).

4.5 Other types of cut-off walls

There are other methods of cut-off walls construction available in different regions depending on local practice, experience, available equipment and material.
Application of ball-clay (instead of cement-bentonite slurry), in the grabbed slurry cut-off wall method is common practice in CIS countries. As material cost comprises the majority of all cut-off wall cost, this approach is very popular in the regions where the specific ball-clay is naturally present. Besides financial advantage, this type of cut-off wall has low deformation modulus what assure joint work of cut-off wall and surrounding dam body. However, the application of this method at higher depths leaves many doubts as to the quality of construction and the continuity of the cut-off wall.
Vibro methods using either the so-called “wing vibrator” or a suspended H-beam are also popular in some parts of Europe. This technique involves installing the wing vibrator or suspended H-beam into the dam body. During the extraction process, the resulting space is filled with slurry material. This is a quick method for creating cut-off walls, though it has limitations related to the depth and dam’s geometry. The impact of vibration on the dam body and surrounding area must also be taken into account. Examples of these vibro methods are shown in Figures 11 and 12.

5 CONCLUSIONS

Cut-off walls are constructed on river earth protection dams and retention reservoirs to enhance flood protection safety. The maintenance of existing flood protection structures is often at a low level, leading to their degradation, and in the event of a flood, the risk urban areas of flooding increases. The use of cut-off walls is a common global practice for renovating and

improving safety of flood embankments.
It is worth noting that anti-filtration barriers are also used to control groundwater flow in areas where underground contamination occurs. These barriers help control and limit the migration of contaminated groundwater into undesired areas.
A brief overview of available geotechnical methods for constructing cut-off walls is presented in this article. The choice of appropriate technology always depends on soil conditions, design requirements, and the local availability of materials. Recent floods in Kazakhstan and the failure of a retention reservoir in Uzbekistan have shown that implementing complex appropriate protective measures in this area is a necessary task.

Fig. 11. Example of vibro method using wing vibrator (Gluszkiewicz, 2002).

Fig. 12. Example of vibro method using hanged H-beam (Gluszkiewicz, 2002).

REFERENCES

(1) Bauer Spezialtiefbau GmbH (2020) *Diaphragm and cut-off walls.*
(2) Borys M., Mosiej K., Topolnicki M. (2006). *Projektowanie i wykonawstwo pionowych przegród przeciwfiltracyjnych z zawiesin twardniejących w korpusach i podłożu wałów przeciwpowodziowych,* Instytut Melioracji i Użytków Zielonych w Falentach.
(3) Boulange J., Hanasaki N., Yamazaki D., Pokhrel Y. (2021) *Role of dams in reducing global flood exposure under climate change,* Nature Communications.
(4) Głuszkiewicz A., *Wykonywanie przesłon przeciwfiltracyjnych w technologii WIPS i DSM* (2002), Keller Polska Sp. z o.o.
(5) Keller UK, *Jet Grouting (Soilcrete)* brochure 67-01E_18.
(6) Maslak C.C., Ibuk H., Beckhaus K. (2021) *Development of plastic concrete for deep cut-off walls and study on QC testing,* COLD Symposium on Sustainable Development of Dams and River Basins, 24-27 February, 2021, New Delhi
(7) O'Brien S., Dann C., Hunter G., Schwermer M., *Construction of the Plastic Concrete Cut-off Wall at Hinze Dam,* ANCOLD conference 2009.
(8) Otero M., Quintal D. (2013). Vertical Impermeable Barriers (Cutoff Walls), CEE 549-Geoenvironmental Engineering, University of Michigan
(9) Pearlman, L. (1999). *Subsurface Containment and Monitoring Systems: Barriers and Beyond.* U.S. EPA, National Network of Environmental Management Studies, Washington, DC
(10) Pietrucha Group, www.pietrucha.pl (2025)
(11) Topolnicki M., *Analiza obliczeniowa stateczności i filtracji dla prawobrzeżnego obwałowania Wisły z uwzględnieniem zastosowania przesłony przeciwfiltracyjnej* (2005), Keller Polska Sp. z o.o.
(12) Topolnicki M. *General overview of Deep Soil Mixing Method for Ground Improvement Projects (2017)*
(13) Van Deuren, J., Lloyd, T., Chhetry, S., Lious, R. and Peck, J. (2002). *Remediation Technologies Screening Matrix and Reference Guide*, 4th Edition. U.S. Army, Environmental Center, Platinum International, Inc.