RECOMMENDED JUNCTIONS BETWEEN DIAPHRAGM WALL PANELS FOR DEEP EXCAVATIONS

Paul Vidil, Soletanche Bachy, Rueil-Malmaison, France, +33(0)147764262, paul.vidil@soletanche-bachy.com

ABSTRACT

Diaphragm walls are often used for permanent retaining walls and shafts; they are particularly suitable for deep projects under high water head. The work sequence of diaphragm walls leads to different adjoining panels. In this way, junctions between diaphragm wall panels are key points, whether it be for formwork, guidance or waterproofing.

This hereby document concerns the watertightness aspect and first provides positive and negative backgrounds of several junction types (stop end tubes, double or triple blade system, addition of pipe for aquareactive resin injection, watertight seals, milling) depending on the excavation tools’ type (hydrofraise, hydraulic or mechanic grabs).

This paper also lists the different junctions nowadays used for deep excavations, and gives a compendium of good practices, based on recent experience. Finally, it deals with the subject of the joint depth compared to the panel depth, and ends with the special case of diaphragm walls carried out under low clearance.

Keywords: diaphragm wall, panel, joint, watertightness, deep excavation, feedback, good practice

INTRODUCTION

It has been more than 60 years since diaphragm walls are carried out around the world, and of course the methods have improved. Diaphragm walls become more and more necessary in dense urban environments (whether it be above or under surface), and especially under high water head. The progresses in terms of depth and watertightness now enable to consider projects at very high depth, such as deep buried railway stations.

Junctions between diaphragm wall panels are key points. In general, they don’t have any structural purpose, but they are very often used as a hydraulic bar. The aim of this document is not to describe in detail the different stages to implement those joints: this hereby note rather lists the different junctions nowadays used for deep excavations, and that have proved to be the most efficient at depth. Some recent experiences are also given.

DRILLING MACHINES

A state of the art of structural diaphragm walls has been undertaken long ago by Puller (1994). Although it has been more than 20 years ago, two drilling machine categories still remain to achieve a diaphragm wall:

- on one hand, the rop/cable operated grab (mechanical clamshell) and the hydraulic grab (Kelly bar mounted),
- and on the other hand, hydraulic cutter machine, also called hydromill or hydrofraise.

The latest evolution relates to high depth, large thickness, progress in a verticality tolerance, electric excavation machine, and the hydrofraise with grippers for hard soil.

There are several ways to ensure watertightness between diaphragm wall panels: waterstop joints and milled joints.
WATERSTOP JOINTS

Description

Decades of feedbacks have allowed to find the best shape and method to assure watertightness at the panels’ butt joints.
Anecdotal techniques will be put aside, such as soldier beam stop ends, v-shape polystyrene blocs, tubes with fins, joints with cotters…

At the beginning, stop end tubes were used (Fig. 1); they lead to a semi-circular concreting surface.

![Fig. 1. Construction scheme with stop end tube (Vanel, 1992)](image)

It soon became clear that these stop ends were not the solution, mainly because of waterproof issues. The CETMEF (2002) points out that, by its nature, a joint implemented by juxtaposition of fresh concrete on indurated concrete is not waterproof. During its hardening, the concrete endures shrinkage that leads to the joint detachment; and during the excavation a thin layer of bentonite stands still at the previously cast panel. Moreover, this type of joint increase the risk of concrete by-pass and problem during the tube removal.

Then, flat stop end joints were experimented: the ones proposed by Fleming (Cementation), the Stopsol proposed by Vial (Solétanche) and the Bachy’s patented CWS (Complete WaterStop) Stop End. The incorporation of a waterbar ensures maximum watertightness between adjoining panels. The principle is that a temporary metal formwork is supporting the waterstop sealing strip (Fig. 2)
The typical dimensions of the PVC (polyvinyl chloride) waterstop joint (Fig. 3) are the following (in mm):

![Waterstop typical dimensions](image)

- tolerance ± 5%

**Fig. 3. Waterstop typical dimensions**

Another advantage of the waterbar is that it has a high breaking elongation.

Several other shapes have been tried (Fig. 4), but the single blade (15 to 20 cm long) turns out to be the best shape.

![Different blade systems](image)

**Fig. 4. Different blade systems (Vanel, 1992)**

As a matter of fact, the multiple blade system presents a risk of pollution between the blades (mud pocket, pebble nest) and it is very hard to clean. It finally leads to more pathologies that the single blade.
Full-scale watertightness tests have been carried out on site (Fig. 5) that confirms the single blade efficiency.

Fig. 5. Watertightness test in 2002 (Le HAVRE – Port 2000)

Moreover, the French National Standard DTU 14.1 (NF P 11-221) only mentions one watertight blade.

Finally, tests with longer blade (up to 25 cm) didn’t bring improvement, and quite the opposite in fact: the concrete put in place through hoppers produces high energy with a fall under mud that can bend longer blade.

The consequence of years of practice therefore comes to the withdrawal of the stop end tubes, the multiple blade system, and grouting tube.

The waterstop joint is particularly recommended when the water head is high for deep structures (shafts, railways stations…), and also for quay walls. The stop end is also used to guide the excavation and allows better deviation controls of the excavation device.

Waterstop can be used for an excavation with a grab or a hydrofraise.

When there is an angle between two panels in the diaphragm wall lay out (Fig. 6), a wedge (plasterboard and polystyrene) can be used to put the stop end in place.

Fig. 6. Extract of a panel lay out with a wedge
Implementation

This formwork is positioned at each end of the primary panels. The formwork is removed laterally after excavating the adjacent secondary panels (Fig. 7).

Fig. 7. Work sequence of diaphragm wall construction

The stop end formwork elements are put together by means of splines/pins at the edge (Figs. 8-9).

Depth of the waterstop joint with respect to the base of the excavation

There was no need so far to put in place a waterstop joint beyond 55 m. Deepening is of course feasible, providing one could guarantee an almost perfect verticality while the diaphragm wall completion. Anyway it remains a delicate operation: it requires a risk management of bypassing during concreting, obstruction of the formwork withdrawal, and blade tearing.

The latest evolutions of excavation machine enable to reach this high standard of performance.

It is not compulsory to take the waterstop down systematically to the diaphragm wall toe. It depends on what type of soil is the embedment. It is nevertheless recommended to take it down at least to the final excavation level.

Fig. 8. Stop end assembly                                                   Fig. 9 Stop end lifting
Between two panels, the upper part is therefore with a waterstop sealing strip, and the lower part is made up of a “dry” joint, that is to say a contact with two concreted surfaces.

In order to decide of the waterstop depth, two subjects should be studied: the absence of waterstop sealing strip from a certain depth may lead to

1. an increase of the water flow through the diaphragm wall,
2. and a washing out of fines.

It depends on the permeability and the layer distributions.

It is also possible to drill a hole in the ground behind the butt joint, and to equip it with a sleeved pipe on the height of junction without waterstop. Thereby, a cement/silicate grout can limit the potential leakage through the joint.

The waterstop depth should be decided on a case-by-case basis: weigh up the pros and the cons with respect to the related risks.

Recent experience

Vidil et al. (2015) describe a pumping station and an access shaft that have been carried out during the Liquefied Natural Gas terminal construction in Dunkirk (France). The access shaft diaphragm wall is 65 m high (Fig. 10), with waterstop joints up to 55 m deep. The embedment is in the Flanders clay, and the water head is 45 m. The final 10 m of diaphragm wall panels are connected by “dry” joints.

Besides, as part of the construction of the new metro system in Paris, Société du Grand Paris recently awarded a civil engineering contract for the works for Line 15 South on the section between Villejuif-Louis-Aragon (excluded) and Créteil-l’Échat (included). This operation is ongoing (Fig. 11), and in a few months, waterstop joints will be taken down to the diaphragm toe, for some stations. The objective is clearly to go beyond the present references on this new metro system.

Fig. 10. View from the bottom of excavation (access shaft - Dunkirk)  
Fig. 11. Sticking out formworks, in a primary panel (Line 15 south- Paris)
MILLED JOINTS

Description

There is another solution that avoid waterstop joints, while assuring watertightness; the joints between panels are realized by milling/grinding the hardened concrete at the edge of primary panels (Fig. 12): the closure panel consists in a single pass, also called unitary pass, and the joints are milled on both sides by the cutter.

Of course, this type of joint can only be used for an excavation with a hydrofraise.

![Milled concrete](image)

**Fig. 12. Milled concrete**

When it comes to circular enclosures, the milling can be facilitated by adding polystyrene or plastic castellated tubes at the edge of primary panels.

Recent experience

In 2006, a Hydrofraise rig with alignment correction was used to construct the Carrousel circular shaft in Versailles (France) up to a depth of 65 m, which achieved a verticality tolerance of less than 0.1 % (Fig. 13).

Recently, a diaphragm wall forming the enclosure of the Beckton overflow shaft (Fig. 14) has been completed: this is the first of the four shafts being constructed on Thames Water’s Lee Tunnel project (England). The 90 meters’ deep shaft, with 1.5 meter thick walls, was the first to be constructed. Then it was the turn of the construction of the 98 meters deep, 1.8 meters’ thick diaphragm wall of the Beckton pumping shaft, with a water pressure at the chalk base around eight bars.

![Carrousel shaft (Versailles)](image) ![Overflow Shaft – Excavation 73.6m deep](image)

**Fig. 13. Carrousel shaft (Versailles)** **Fig. 14. Overflow Shaft – Excavation 73.6m deep**
EXPANSION JOINTS

Description

It deals with combining the diaphragm wall carrying out by milling the hardened concrete at the edge (see previous chapter), with the placing of expansion joints that are pressed against adjacent primary panels’ facings (Fig. 15).

Thus this technique enables to put a physical bar between panels.

Expansion joints can be added in specific cases, for example when diaphragm walls are carried out under low clearance, preventing from putting stop ends in place.

There are two main systems to press joints against adjacent panels:

- an iron frame is fastened on the reinforcing cage; then this frame needs to be laid out, in order to put the joint against the adjacent panels. However, this system might have limitations when applied to cages made of multiple elements.

- a jacking system is installed in the steel reinforcement bearing water-swelling joints on light steel plates. The steel reinforcement and the joints are then installed at the same time into the excavated panel. A flexible water system simply controls the cylinder’s movement. The pistons go out under water pressure. The support plate is pushed until it reaches the adjacent panel on full height.

These systems have been implemented on hydrofraise excavation; a similar system for grabs or KS works is under discussion.

This technique can be combined with under pressure cement/silicate grouting in the ground behind the joint. In that case, grouting can be carried out by means of sleeved pipes putting in place in boreholes just behind the diaphragm wall.

Recent experience

This system (Fig. 16) was first installed on 3 panels on the works site of Saint Tropez (France).

Another application appeared when Société du Grand Paris awarded in 2016 a Contract for the works on the Fort d’Issy Vanves Clamart station (Line 15 South).
In the central area of this project, single bite panels were executed under a metallic railway bridge (Fig. 17). Junctions between panels were realized by concrete milling. Expansion joints were put in place in the reinforcing cages to increase watertightness.

For the moment, the technique of expansion joints only has been carried out for work sites under a low to medium water head.

**AVERAGE PERMEABILITY**

The diaphragm wall is considered as a relatively waterproof structure, according to the French National Standard DTU 14.1 (NF P 11-221).

First and foremost, it is obvious that the watertightness of the diaphragm wall is very much dependent upon the skill, experience and personnel of the specialized firm, in addition with a good quality control. In which case, the efficiency of those joint types in terms of watertightness can be estimated in Table 1.

**Table 1. Rough estimate of diaphragm wall permeability**

<table>
<thead>
<tr>
<th>Type of joint</th>
<th>Diaphragm wall permeability (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop end tubes</td>
<td>10-8</td>
</tr>
<tr>
<td>Formwork with Waterstop sealing strip</td>
<td>10-10 to 10-9</td>
</tr>
<tr>
<td>“Dry” joint</td>
<td>10-8</td>
</tr>
<tr>
<td>Milling</td>
<td>10-10 to 10-9</td>
</tr>
<tr>
<td>Milling and expansion joint</td>
<td>10-10 to 10-9</td>
</tr>
</tbody>
</table>

The DTU 14.1 gives limitations for the flow of seepage and leaks through the wall.

The hereafter values do not separate joints and walls; values are for the complete diaphragm wall:

- 0.5 l/m² per day on yearly average;
- 1 l/m² per day on weekly average;
Moreover, no area of 10 m² is allowed with more than 2 l/m² per day on weekly average. It means, that above those values, that is to say as soon as there is a noticeable leak, joints between panels should be treated (aquareactive resin injection in general).
In practice, those limitations are only applicable on the diaphragm wall height above final excavation level.

CONCLUSION

Junctions between diaphragm wall panels play a key role for formwork, guidance or waterproofing. The waterstop joint is particularly recommended when the water head is high for deep structures (shafts, railways stations…), and also for quay walls.

Their watertightness depends on the junction type; single blade waterstop or milling have proved to be the more efficient at depth. It is therefore absolutely necessary to guarantee an almost perfect verticality while the diaphragm wall completion

Expansion joints can be added in very specific cases.

The trend of the deepening of civil engineering structures makes even more essential to resort to high qualified and skilled contractors. The latest evolutions of excavation machine, and in particular the new generation of hydrofraise, enable to reach high standard of performance.

The construction of the new metro system in Paris is going to go beyond the present references of waterstop joint depth.

REFERENCES

Centre d’études techniques maritimes et fluviales (CETMEF), 2002. Fascicule 5, Surveillance, auscultation et entretien des ouvrages maritimes, Quais en parois moulées, Notice PM n° 02.02

NF P 11-221-1 alias DTU 14.1, 2000. Travaux de bâtiment - Travaux de cuvelage - Centre Scientifique et Technique du Bâtiment

Puller, M. 1994. The waterproofness of structural diaphragm walls, Geotechnical Engineering (ICE), January, 107-1

Vanel, P., 1992. Making Diaphragm wall joints watertight with the CWS system, ASTM 04-011290-38


398