C.W.S. system provides load-bearing and watertight joints between diaphragm wall panels

by PAUL DUPEUBLE

This is the first Paper on the CWS system of diaphragm walling to be published in English. Bachy have been awarded the second prize in the "Prix de l'Innovation" competition held by the Fédération des Travaux Publics for this development. Accordingly, a Paper will be published in French by the Fédération as an appendix to its official journal Travaux.

Abstract

Diaphragm walls, owing to their method of construction, are discontinuous structures. A new technology for the formation of joints between panels has been developed. This new process allows for the construction of diaphragm walls with mechanical and watertight continuity.

Within the last thirty years diaphragm walling has become a construction technique frequently used for the design of major underground works, often in water-bearing grounds, e.g. quay walls, excavation supporting, shaft lining, etc.

1. Previous state of the art

1.1. General principle
Underground diaphragm walls are composed of panels, cast alternately or successively.

Fig. 1. Construction scheme with alternating panels

Primary Panels

<table>
<thead>
<tr>
<th>2n − 1</th>
<th>2n + 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td>Excavation</td>
</tr>
<tr>
<td>Concreting</td>
<td>Concreting</td>
</tr>
</tbody>
</table>

Secondary Panels

<table>
<thead>
<tr>
<th>2n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
</tr>
<tr>
<td>Concreting</td>
</tr>
</tbody>
</table>

Concreting a panel against the CWS form

Excavating a panel against the CWS form
In the first case, the construction begins by excavating and concreting primary panels (i.e. 1, 3, 5... regularly spaced along the structure. Then the construction is completed by excavating and concreting secondary panels (i.e. 2, 4, 6...) in the space (Fig. 1).

In the second case, the panels are excavated and concreted one after another, i.e. panel n + 1 against panel n.

In both cases, forms are set up at the sides of the panels, i.e. at both ends of primary panels, or at the earth end of successive panels. These forms create a hollow along the whole depth of the panel. The adjacent panel is therefore excavated and concreted against this hollow.

The stop end forms utilised until now have various sections, the simplest being a cylinder. Whatever their sections, they must be used as sliding forms, and must be pulled out lengthwise; therefore they must be extracted before the final setting of the concrete. Selecting the proper time for this extraction is not easy — too early, and chances are that the concrete will collapse into the hollow left under the form — too late and friction may prevent extraction under normal conditions.

Whichever method is selected, a diaphragm wall is an assembly of elementary independent panels placed side by side. As regards mechanical strength and watertightness, there is a break in continuity at each joint, despite the tongue and groove effect provided by the usual technique.

In addition to this theoretical situation, practical construction of the joint calls for care to secure:
1. a correct geometrical continuity of the wall
2. a correct quality of the joint itself concerning geometry and surface finish.

**Fig. 2. Extracting the stop end form at the end of the concreting and before excavating the next panel**

1.2. Object of the development
We have sought and developed effective practical solutions to the problem posed by the discontinuous construction of the wall, i.e.:
1. Restoring the continuity of watertightness by installing additional water barriers; and
2. Restoring the mechanical continuity by being able to transmit forces between elementary panels.

But we have also considered the technological problem of the construction of the joint itself.
These two subjects have proved to be complementary since the solution to the problem of restoring the continuity is initiated by the solution to the problem of the construction of the joint.

For the construction of the joint, the technique used until now is based on the extraction of a sliding stop end form immediately after concreting, and prior to excavating the next panel (Fig. 2).

This technique does not automatically guarantee the geometrical continuity of the wall between panels, since no positive guiding of the excavating tool is possible along the previous panel. Nor does it allow the installation in the joint of complementary devices such as waterstops, since these elements usually do not survive the extraction of the sliding form.

2. Diaphragm wall with CWS joint
2.1. General principle
The CWS form is not extracted as a sliding form before excavating the adjacent panel. It is extracted laterally after the adjacent panel has been excavated.

This change may seem of little importance. On the contrary, it is fundamental because it makes it possible to do away with a barrier which has stopped the specialised contractors in their constant quest to improve the quality of diaphragm walls.

It may seem evident, and yet some thirty years have gone by before breaking with the usual practice.

It may seem simple and yet we took three years to complete its development, and reach its present state of simplicity. It is the lateral extraction after excavating the adjacent
panel which allows the presence, while the excavation is carried out, of an actual rail temporarily sealed in the concrete of the previous panel. This rail is a guide for the excavating grab, and secures a perfect geometrical continuity of the wall and good quality of the joint between panels.

It is the lateral extraction after excavating the adjacent panel which allows installation in the joint of additional equipment restoring mechanical continuity and watertightness of the diaphragm wall.

2.2. Practical realisation

Fundamentally, the CWS form is composed of a caisson beam made of high strength steel. After the panel is excavated, the CWS form is installed against the ground at the end of the excavation. It is not extracted as a sliding form before complete setting of the concrete. It is left in place until completion of the excavation in the adjacent panel (Fig. 3).

It is then pulled aside by the actual excavating tool, especially adapted to slide down the wings of the form. The progression of the blades thus pushed between metal and concrete from top to bottom of the panel secures the detachment of the form, allowing its lifting out.

The CWS technique allows freedom from
the constraints related to concreting, since extraction of the form is not controlled by the concreting routine.

Being left in place while the next panel is excavated, the form protects the surface of the concrete in the joint against the impacts of the excavating tool.

As the CWS form is left in place while the next panel is excavated, it can be used as a guide, guaranteeing the geometrical continuity of the wall.

To this effect, the excavating tool is locked on to the form at regular intervals throughout the excavation operation. Thus, each excavation elementary sequence includes an excavation run, followed by a guidance run, which brings proper calibration of the panel as construction progresses. Any tendency to deviation is thus corrected as soon as it appears. At the end of the excavating operation, the form is practically free and can be readily extracted.

3. Restoring continuity of watertightness

The positive protection that the CWS form provides at the end of the previous panel secures a remarkable quality and an excellent geometry of the joint between panels.

Moreover, the lateral extraction allows currently the installation of impervious devices such as waterstop blades in the joint. To this effect, the CWS form can be fitted with an additional grooved caisson in which can be inserted one or several plastic or rubber waterstop blades. These waterstop blades jam in the grooves owing to the elasticity of the central duct. The free half of these blades will be sealed in concrete when the panel is concreted.

The lateral extraction uncovers the other half of the blades to be sealed in the concrete of the adjacent panel.

The CWS technique therefore allows restoring the continuity of the watertightness, by installation in the joint of waterstop blades, whether single, twin or triple. Twin blades is the usual arrangement.

4. Restoring mechanical continuity

Structures founded on, or composed of
4.2. Disposition
The basic element is a single acting ram of which the cylinder is the anchorage in a panel and the rod, after extending, is the anchorage in the adjacent panel.

Each elementary ram is therefore composed of:
1. A fixed part which is the cylinder of the ram fitted at its end with an anchoring plate and connected to a pipeline.
2. A moving part composed of the piston and rod. The rod is fitted at its end with an anchoring plate. It is pushed out of the cylinder by a fluid fed into the cylinder, until the piston rests on the thrust block at the end of the cylinder. (Fig. 5)

The various components of the ram (cylinder, anchor plates, piston, rod, thrust block) are of suitable dimensions to carry the design loads.

4.3. Installation
To make it simple, the sketch of the installation shows rams in the axis of the wall. Panel n has been excavated (Fig. 6), and the CWS form is installed as usual at the end of the panel (1).

At the time of construction, the reinforcement cage has been fitted with the rams necessary to transmit the design load. Each ram is installed in the cage facing panel n + 1, with the piston and rod pulled in. All the rams located near the same vertical plane are connected to the same vertical line which will feed pressure to them.

The reinforcing cage is installed in the panel against the CWS form (2). The anchoring plates at the end of the rods are pressed against the CWS form by connecting the pipeline to a low pressure source.

Panel n is concreted (3). Adjacent panel n + 1 is normally excavated while the CWS form protects the anchoring plates. The form is extracted. The reinforcing cage is lowered into panel n + 1 and care is taken to install it so that no part of it can prevent the rods from extending later (4). As the cage has been constructed for that purpose, this is achieved by just installing the cage at the proper level.

The rams sealed in panel n are then grouted with a non-shrink cement by the means of a double packer set in the pipeline opposite each ram in succession (5). It is thus possible to make sure each rod and anchoring plate is pushed into the reinforcing cage of panel n + 1 until the piston rests on the thrust block.

The panel is then concreted, and the rods and anchoring plates achieve a permanent mechanical bond between the two successive panels (6).

4.4. Practical operations
No major problem is engendered by the method, regarding the usual rules of reinforced concrete design. A few practical points had to be checked, in particular the correct embedment of the various components in concrete.

Field testing has confirmed that the method is well adapted to the usual conditions of the construction of diaphragm walls. In fact, the rams can be installed in the reinforcing cages without significant alterations. It is enough to add a few stiffeners and improve accuracy in installation. Installation of the rams does not alter in any way the standard operating procedures for the construction of diaphragm walls, and operation of the rams themselves has little influence on the sequence of work.

The method is very flexible, as the rams can be installed at the places where forces are located, and only at these places. Once the characteristics of the rams are chosen (in the range of 50 to 100 tonnes in tensile strength) their location can be adjusted to suit the nature and intensity of the forces.

In conclusion, we must also explain that corrosion protection of the rams at the joint between panels is achieved by an epoxy resin coating a few inches long on both sides of the joint.

Installation of waterstop blades as described in the previous section is totally compatible with the tie rods.

5. Prospects
The CWS technique is a radical change in the method for the construction of diaphragm walls. It can be carried out with all existing excavation equipment—cable grabs, hydraulic grabs, kelly equipment, rock mills, etc.

It represents an important step forward in the quality of diaphragm wall construction. It contributes to widening the field of applications for diaphragm walls by bringing a practically effective answer to problems connected with their discontinuous nature.

To this date 100 000 m² of walls have been constructed by this method both in France and abroad in ten different countries in a great variety of materials and, until now, as deep as 35 m.