

Method and assembly for constructing a diaphragm wall

The present invention relates to the field of civil engineering, and in particular to the excavation and construction of cast concrete structures, such as diaphragm walls, below ground level.

5 Diaphragm walls, also known as slurry walls, are constructed to form a water-blocking and earth-retaining barrier surrounding underground structures such as tunnels, basements or roadway cuttings.

 A diaphragm wall is essentially an impermeable vertical concrete wall which is cast *in situ* in the ground. In order to construct such a diaphragm wall,
10 a trench is first excavated which defines the casting volume for the concrete. The trench is kept full of slurry until the concrete is poured, in order to keep the sides of the trench from falling in. After the trench has been excavated, reinforcing steel is lowered into the trench, and the concrete is then poured, displacing the slurry and filling the volume around the reinforcing steel.

15 In prior art methods of constructing diaphragm walls, the wall is conventionally constructed in alternating sections. First, a number of spaced-apart primary wall panels are excavated, poured and allowed to harden. In the following description, the panels which are cast first are referred to as primary panels or primary sections. The spaces between the hardened primary panels
20 are then excavated and filled with concrete to form a set of secondary panels, also known as closing panels. In both cases, rebar cages are usually placed into the trenches before the concrete is poured. When the secondary panels are excavated, using a hydromill, for example, the side faces of the primary panels can also be milled to remove any soil from the concrete, and to create a
25 clean, textured surface against which the concrete of the secondary panel can be cast. The milling removes concrete from the side face of the primary panels and creates a cutter-milled joint, or similar profile, which will ensure a soil-free joint with the concrete of the adjacent secondary panel when it is poured.

 The excavation of the secondary panels is conventionally performed
30 using a hydromill, which is a large vertical excavation machine, lowered into the

trench by crane. Hydromills are typically 2.8m in width, and from 60cm to 1.5m in thickness. At its lower extremity, a conventional hydromill has two sets of counter-rotating toothed wheels which remove material from the trench. The hydromill's toothed wheels also remove some material from the sides of the adjacent primary panels, creating the cutter-joint profiles referred to above. The milled profile may for example consist of a series of vertical grooves milled deep (50mm to 100mm) into the concrete of the primary panels. The purpose of these recesses is to create a clean interlocking bond between the primary and secondary panels when the concrete for the latter is poured. The shape of the milled profile may be a regular pattern of grooves or indentations, or simply a roughened surface, depending on the type of milling wheel and teeth arrangement used.

Once the milling and excavation of the casting volume for the secondary panels is complete, the secondary reinforcement cage is lowered into the excavated secondary casting volume, and the concrete is poured around it and allowed to cure.

After curing, the primary and secondary panels form a continuous concrete wall in the ground, each pair of neighbouring panels being strongly mechanically joined to each other by the cutter joint profile described above.

In some constructions, such as a curved diaphragm wall, it may be necessary for some or all of the primary and secondary panels to be positioned at an angle to each other. However, conventional hydromills or cutters generally have fixed-orientation milling heads with toothed wheels which are designed to cut a rectangular section, which means that, where such a hydromill or cutter is used to excavate a secondary panel which is angled to its neighbouring primary panel, the milling will be performed at an angle to the side face of the primary panel.

As a result of this angled milling, the amount of material to be removed during milling of the primary panel sides will vary significantly across the side face of the primary panel. Instead of milling all across the joint at a roughly equal depth into the primary panel concrete (generally 50mm to 200mm

in the case of coplanar abutting panels), the angle of the hydromill may be such that the depth of milling may be as much as 600mm at the inner edge of the milled joint, or even more, depending on the angle and thickness of the wall panels. Milling such a large amount of material out of the primary panel is time-
5 consuming, wasteful of good quality concrete, increases the amount of waste material to be removed and shortens the life of the cutter tools.

The invention proposes the use of sacrificial void formers, also referred to as displacement elements, which can be milled away to create a clean edge against which the adjacent section can be cast. It is known to use
10 sacrificial elements in the casting of concrete structures. WO2003/006750, for example, discloses the use of corrugated tubular elements which fill the width of an empty trench, acting as temporary shuttering for successive sections. The empty, open-ended tube is fixed to the reinforcing cage and placed in the trench. The tube is then filled with gravel or sand to give it enough strength to
15 withstand the pressure of the concrete during casting. During the excavation of the adjacent section the tube is broken up and removed, together with its contents. This method has the disadvantage that the tube must be sealed and filled with gravel or sand after it is placed in the trench. This is a time-consuming process and can lead to gravel and sand falling into the trench,
20 thereby compromising the integrity of the casting in the lower region of the trench. Once the reinforcement cage and the tube have been lowered into the trench, there is no longer any way of excavating material which subsequently falls into trench. Furthermore, the bentonite slurry normally used to fill the trench before casting can begin to "cake" on to the walls of the trench, and any
25 delay in the pouring of concrete results in increased caking, with consequently reduced concrete coverage. For this reason, it is important to minimise the amount of time between the placing of the reinforcement cage and tube, and the pouring of the concrete. Having to fill the tube with sand and gravel adds significantly to this time. Furthermore, the concave faces which remain once the
30 tube and its contents have been excavated using the method of WO2003/006750 cannot be milled directly, so a two-stage excavation process is used, in which half of the tube is removed using a convention grab or hydromill, and the other half is excavated using a specially-shaped grab with a semi-circular profile.

The object of the present invention, therefore, is to provide a method of constructing a diaphragm wall which will enable the side faces of the primary panels to be milled more quickly, while affording maximum clearance for fitting
5 the rebar cage, without the need for specially shaped excavation tools, without the risk of spilling foreign matter into the trench, while reducing wastage of good concrete and with reduced wear of the cutter tools, even when the milling cutter is oriented at an angle to the primary panel.

In this application the terms primary panel and primary section are
10 used interchangeably, as are the terms secondary panel and secondary section. The term milling is used to mean any process for removing material from the surface of the primary panels. Such processes can include mechanical abrasion by the toothed wheels of a hydromill, for example, or high-pressure water jets or other suitable mechanical processes.

15 In order to overcome the above and other disadvantages of the prior art, the invention envisages a method for casting a diaphragm wall comprising two primary sections joined by a secondary section, the method comprising a first step of excavating a casting volume for each primary section, a second step of casting the primary sections in the primary casting volumes, a third step
20 of excavating a secondary casting volume for casting the secondary section, a fourth step of forming a joining surface profile on each primary section by milling an adjoining region (16) of each adjacent primary section, the second step comprising casting a sacrificial displacement element in each of the adjoining regions, and the third and/or fourth steps comprise removing the
25 sacrificial displacement elements.

According to a variant of the method of the invention, the third and fourth steps are performed simultaneously. Excavating and milling in the same operation, for example, saves time and equipment.

According to another variant of the method of the invention, the
30 primary and secondary sections are substantially planar and vertical, and the

secondary section is cast in a plane which is at an angle other than 180° to the plane of at least one of the primary sections. Angled sections such as these are often used in the construction of containment tanks, for example, or deep shafts.

5 According to another variant of the method of the invention, the second step includes constructing a casting preparation assembly comprising a reinforcement element for reinforcing each primary section, securing the sacrificial displacement elements to the reinforcing element, and arranging the casting preparation assembly in the respective primary casting volume. In this
10 way, the reinforcement and the sacrificial displacement elements can all be lowered into the trench at once, and casting can begin without any delay.

 According to another variant of the method of the invention, the second step includes arranging separator elements to hold each sacrificial displacement element in position at a predetermined distance from the
15 reinforcing element.

 According to another variant of the method of the invention, each prefabricated sacrificial displacement element is made of a material which is more easily millable than the concrete used for casting the primary section in which said each prefabricated sacrificial displacement element is cast.

20 The invention also envisages a casting preparation assembly for placing into an excavated primary casting volume for casting a primary section of a concrete diaphragm wall, the primary section having at least one adjoining region, the or each adjoining region being a region of the primary section to be milled for creating a joining surface profile for joining the primary section to an
25 adjacent secondary section of the diaphragm wall, and at least one prefabricated sacrificial displacement element, the or each sacrificial displacement element being made of a more easily millable material than the concrete used for casting the primary section, the or each sacrificial displacement element being positioned in the casting preparation assembly
30 such that, when the casting preparation assembly is placed into the primary

casting volume and the primary section has been cast, the or each sacrificial displacement element is in an adjoining region.

According to another variant of the invention, the assembly comprises a reinforcement structure for providing reinforcement for the primary
5 section when the primary section is cast, the or each sacrificial displacement element being secured to the reinforcement structure.

According to another variant of the invention, the material of each prefabricated sacrificial displacement element is softer, or more brittle, or more friable, or less dense than the concrete used to cast the primary sections.

10 According to another variant of the invention, the joining surface profile comprises one or more grooves formed in the material of the primary section.

According to another variant of the invention, each prefabricated sacrificial displacement element comprises at least two more prefabricated
15 modules. By assembling the sacrificial displacement elements in modular fashion, the assembly process can be simplified and speeded up.

According to another variant of the invention, each prefabricated sacrificial displacement element has a prism shape of substantially triangular or trapezoidal cross-section. The shape of the displacement elements can be
20 selected to suit an angled orientation between the primary and secondary sections, for example, thereby reducing the amount of casting concrete which must be milled in order to create the required angled joint.

According to another variant of the invention, the or each sacrificial displacement element comprises one or more void forming members for
25 excluding concrete from one or more regions of the primary casting volume.

According to another variant of the invention, one or more of the prefabricated sacrificial displacement elements or modules encloses a hollow void.

According to another variant of the invention, one or more of the prefabricated sacrificial displacement elements or modules comprises a solid block.

According to another variant of the invention, the secondary section
5 volume is excavated using a hydromill.

According to another variant of the invention, one or both of the primary casting volumes are excavated using a hydromill.

According to another variant of the invention, the hydromill is slightly wider than the distance separating the two primary casting volumes. The
10 relative widths can be predetermined so that a single pass of the hydromill can achieve the desired (angled, if appropriate) milling on both of the adjacent primary sections.

The invention will now be described with reference to the accompanying drawings, in which:

15 Figure 1 shows a schematic cross-sectional view of a typical prior art method of constructing the primary panels for a diaphragm wall.

Figure 2 shows in schematic cross-section a view of the prior art method of constructing the secondary panels, and milling the edges of the primary panels, to create a diaphragm wall.

20 Figures 3a and 3b show schematic elevation and plan views illustrating the regions to be milled when the primary and secondary panels are mutually angled.

Figures 4a and 4b show in schematic plan and perspective view an example of diaphragm wall sections constructed according to the present
25 invention.

Figures 4c, 4d and 4e show in schematic plan view a sequence of constructing a closing (secondary) panel using a method according to the present invention.

Figures 5a, 5b and 5c show in schematic elevation view an example
5 of how a primary panel casting can be prepared according to the invention.

Figure 6 shows in more detail a schematic elevation view of the prepared primary section casting assembly according to the invention.

The accompanying figures are intended as an aid to understanding the invention, and are not intended to imply any limitation of the scope of the
10 invention. Where the same reference signs are used in different drawings, these reference signs are intended to refer to the same or corresponding features.

The prior art method of constructing a diaphragm wall will now be described in more detail with reference to figures 1, 2, 3a and 3b. In figure 1,
15 the process of excavating, preparing and casting the primary panels is shown. Regions 10, 11, 12, 13 and 14 are five primary section casting regions in the ground 3 which show successive stages of excavating and casting the primary panels. Region 10 shows a primary panel region before excavation, while region 11 shows a primary panel region being excavated using a crane-
20 mounted (8) scoop grab tool, although a hydromill 9 can also be used for this excavation step. The excavated trench is kept filled with water or slurry (not shown) to prevent the sides of the trench from falling inwards. Region 12 is shown fully excavated, and having a steel reinforcement (rebar) cage 4 lowered into it. Region 13 shows the concrete 5 being poured into the primary casting
25 region around the steel of the reinforcement cage 4, with the concrete being introduced using pipe or chute 6, and region 14 is shown after the casting is completed and the primary panel has been allowed to cure. Figure 1 also shows four regions 20, 21, 22 and 23 which are to be excavated for the casting of secondary panels.

Figure 2 shows the arrangement of figure 1 in which the casting of the primary panels has been completed ready for the casting of four secondary panels 20 to 23 between primary panels 10 to 14. Region 20 shows a secondary panel casting region before excavation. Region 21 is shown in the process of being excavated using a hydromill 9 which removes the soil and mills the side faces of the neighbouring primary panels, in order to facilitate a good bond between the two adjacent sections, and thereby achieve a joint which has good water-blocking properties. The hydromill 9 is shown being lowered down into the excavation zone 21 by crane 8. Secondary panel 22 is shown in the process of being cast, with the rebar cage already in position, and panel 23 is shown in its cured and completed state, forming a continuous diaphragm wall with neighbouring primary panels 13 and 14.

Figure 3a illustrates how, when primary panels 10, 11, 12 are set at an angle to their neighbouring secondary panels, the amount of material 16 to be milled from the side faces of the primary panels is less towards the outer edge of the side and greater towards its inner edge. "Inner" in this case refers to the side of the panels on which the joining angle of two adjacent panels is less than 180 degrees. "Outer" refers to the side of two adjacent panels on which the joining angle of two adjacent panels is greater than 180 degrees. Reference 15 in the figures indicates the cutter joint profile to be milled into the side face of each primary panel.

A plan view of the arrangement of figure 3a is shown in figure 3b, which also indicates where the material for secondary panels 20 and 21 is to be excavated and milled. In the illustrated example, a great deal of material 16 must be removed from the primary panels 10, 11, 12 in order to achieve the desired cutter joint profile 15 across the whole side faces of the primary panels 10, 11, 12. The concrete used for casting the primary panels is usually of a high specification, being very hard and impermeable to water. Removing the wedges 16 of very hard concrete presents a tough challenge to the hydromill 9, which must consequently be lowered much more slowly than when the neighbouring panels are aligned with each other in coplanar fashion. The removal of so much hard concrete also means significantly increased wear on the expensive hydromill milling machinery. Varying the depth of concrete to be milled also

means that there is an increased risk of the hydromill being diverted from the vertical plane as it progresses downwards.

Figures 4a, 4b, 4c and 4d show the principle behind the present invention. Figures 4a and 4b show, in plan and perspective views respectively, a primary panel rebar cage 30 which has two sacrificial displacement elements 31 secured to it. Sacrificial displacement elements 31 are essentially means for excluding the concrete used for casting the primary panels from predetermined regions of the primary panel casting volume, and in particular from the regions which are to be removed when the joint milling is to be performed. The sacrificial displacement elements need not be hollow – their function is to create a region of the casting volume from which the high-specification concrete is excluded when it is poured. As such, the sacrificial displacement elements 31 can be prefabricated, solid blocks of lightweight concrete, for example, or they can be prefabricated hollow shapes such as lengths of hollow pipe pre-sealed against the ingress of concrete, and optionally pre-filled with soft concrete or soft, loose materials such as sand. The sacrificial displacement elements 31 are fixed to the rebar cage 30 for convenience, using fixing elements 32, so that the prefabricated sacrificial displacement elements 31 and the rebar cage 30 can be lowered together into the trench in a single operation, and concrete pouring can commence immediately. Fixing elements 32 can be pieces of steel rebar tacked to the rebar cage 30, for example. Since it is likely that the fixing elements 32 will intrude into the area to be milled, they must be of such shape and material that they do not significantly interfere with the milling of the cutter joint 15.

The sacrificial displacement elements 31 are positioned so that, when the rebar cage assembly 30 (complete with attached sacrificial displacement elements 31) is lowered into its primary panel casting volume, and the high-specification concrete is cast around the rebar 30 and the sacrificial displacement elements 31, the sacrificial displacement elements 31 will form regions 16 of the primary panel which will be removed when the neighbouring secondary sections are excavated. Figure 4c shows in plan view where the joint profile 15 is to be milled by removing the material of the sacrificial displacement elements 31 and milling into the hard concrete of the

primary panels 10, 11. In figure 4c, primary panels 10 and 11 are in their completed, ready-to-be-milled state, after the concrete 25 has been cast around the rebar cages 30 and the sacrificial displacement elements 31 and after the cast concrete has been allowed to cure. The casting volume for
5 secondary panel 20 is then excavated/milled as previously described, removing the material of the sacrificial displacement elements 31 and creating joint profile 15 in the hard material of the primary panels 10, 11. A certain amount of the dense, high-specification concrete must in any case be removed in order to achieve a sound joint between adjacent panels, but the method of the invention
10 minimises the amount of this dense, high-specification concrete which must be milled, especially when the adjacent panels are at an angle to each other.

Figure 4d then shows the completed excavation of the secondary casting volume 20, with the milled joint faces 15 ready for casting the secondary panel. Figure 4e shows the secondary panel 20, including rebar
15 cage 26, cast and cured between primary panels 10 and 11. Panels 10, 11 and 20 should now be mechanically bonded by the joints 15 to form a continuous, more impermeable diaphragm wall structure.

Figures 5a, 5b and 5c illustrate an example of how the sacrificial displacement elements can be assembled prior to lowering the primary panel
20 rebar into the trench. In these figures, the sacrificial displacement elements 31 are shown secured to the rebar cage 30 by means of fixings 32, but held away from the rebar cage by separator elements 33. By keeping the sacrificial displacement elements 31 away from the rebar cage 30, it can be ensured that the subsequent joint milling is performed in a region which does not run the risk
25 of intruding into the region of the rebar cage 30. If such an intrusion happens, this could damage the milling machinery and/or significantly compromise the strength and integrity of the primary panel being cast.

The separator elements 33 are preferably attached to the rebar cage 30, and can be shaped not only to create a space between sacrificial
30 displacement elements 31 and rebar cage 30, but also to support the sacrificial displacement elements 31 before and during casting. Before casting, the separator elements are required to be able to support the weight of the

sacrificial displacement elements 31. During casting, the separator elements 33 must also be capable of holding the sacrificial displacement elements 31 in position against any upward buoyancy forces exerted on the sacrificial displacement elements 31 when they are immersed in the slurry, and/or when
5 the relatively more dense concrete is poured around the sacrificial displacement elements 31. The separator elements 33 can also be made of an easily-millable, void-forming material such as lightweight concrete. As shown in the example of figures 5a to 5c, the sacrificial displacement elements 31 can be attached in modular fashion, with each successive set of modules being
10 attached as the rebar cage is lowered into the excavated trench 12. Note that figure 5c shows a particular example situation, in which the sacrificial displacement elements 31 are fitted in the lower and mid-sections of the panel, but not in the upper section. Many hydromills only work effectively when the milling head is submerged in the slurry. In the upper section of the panel,
15 therefore, the joints between the primary panel and its neighbouring secondary panels are formed using conventional temporary "stop-end" steel joints which are then removed before starting excavation of the secondary panels. This is just one variant of the invention, however, and the sacrificial displacement elements 31 may be positioned wherever required.

20 While the present invention has been described in the context of structures fabricated in the ground using reinforced concrete, the invention may be used to construct any structure in which a milled-type joint is required to be created between two adjacent cast elements, and in which at least one of the elements can be cast so that it has a joint-forming region comprising a
25 sacrificial void-forming element.

Claims

1. Method for casting a diaphragm wall comprising two primary sections (10, 11) joined by a secondary (20) section, the method comprising

a first step of excavating a primary casting volume for each primary
5 section (10, 11),

a second step of casting the primary sections (10, 11) in the primary casting volumes,

a third step of excavating a secondary casting volume for casting the secondary section (20),

10 a fourth step of removing a sacrificial joining region (16) of one or both adjacent primary sections (10, 11),

the method being characterised in that

the second step comprises arranging a prefabricated sacrificial displacement element (31) in the sacrificial joining region (16) of one or both of
15 the primary casting volumes (16), positioned such that the casting material of the primary sections (10, 11) is displaced by the sacrificial displacement element (31) in the or each joining region (16) and such that the removal of the or each sacrificial joining region (16) performed in the fourth step includes the removal of the or each sacrificial displacement element (31).

20 2. Method according to claim 1, in which the primary (10, 11) and secondary sections (20) are substantially planar and vertical, and in which the secondary section (20) is cast in a plane which is at an angle other than 180° to the plane of at least one of the adjacent primary sections (10, 11).

25 3. Method according to claim 1 or claim 2, in which the second step includes constructing a casting preparation assembly comprising a reinforcement element (30) for reinforcing each primary section (10, 11),

securing the prefabricated sacrificial displacement elements (31) to the reinforcing element (30), and arranging the casting preparation assembly in the respective primary casting volume.

4. Method according to claim 3, in which the second step includes
5 arranging separator elements (33) to hold each sacrificial displacement element (31) in position at a predetermined distance from the reinforcing element (30).

5. Casting preparation assembly for placing into an excavated primary casting volume for casting a primary section (10) of a concrete diaphragm wall, the primary section having at least one adjoining region (16),
10 the or each adjoining region (16) being a region of the primary section (10) to be milled for creating a joining surface profile (15) for joining the primary section (10) to an adjacent secondary section (20) of the diaphragm wall,

the casting preparation assembly being characterised by

at least one pre-fabricated sacrificial displacement element (31), the
15 or each sacrificial displacement element (31) being made of a more easily millable material than the concrete used for casting the primary section (10),

the or each sacrificial displacement element (31) being positioned in the casting preparation assembly such that, when the casting preparation assembly is placed into the primary casting volume and the primary section (10)
20 has been cast, the or each sacrificial displacement element (31) is in a joining region (16) for being removed during milling of the adjacent secondary section (20).

6. Assembly according to claim 5, comprising a reinforcement structure (30) for providing reinforcement for the primary section (10) when the
25 primary section (10) is cast, the or each sacrificial displacement element (31) being secured to the reinforcement structure (30).

7. Method according to one of claims 1 to 4, or assembly according to one of claims 5 or 6, in which the material of each prefabricated sacrificial

displacement element (31) is softer, or more brittle, or more friable, or less dense than the material used to cast the primary sections (10, 11).

8. Method according to one of claims 1 to 4, or assembly according to one of claims 5 or 6, in which the joining surface profile (15) comprises one
5 or more grooves formed in the material of the primary section (10).

9. Method according to one of claims 1 to 4, or assembly according to one of claims 5 or 6, in which each prefabricated sacrificial displacement element (31) comprises at least two prefabricated modules.

10. Method according to one of claims 1 to 4, or assembly according
10 to one of claims 5 or 6, in which each prefabricated sacrificial displacement element (31) has a prism shape of substantially triangular or trapezoidal cross-section.

11. Method according to one of claims 1 to 4, or assembly according to one of claims 5 or 6, in which one or more of the prefabricated sacrificial
15 displacement elements (31) or modules encloses a hollow void.

12. Method according to one of claims 1 to 4, or assembly according to one of claims 5 or 6, in which one or more of the prefabricated sacrificial displacement elements (31) or modules comprises a solid block.

13. Method according to one of claims 1 to 4, or assembly according
20 to one of claims 5 or 6, in which the secondary section volume is excavated using a hydromill (9).

14. Method according to one of claims 1 to 4, or assembly according to one of claims 5 or 6, in which one or both of the primary casting volumes are excavated using a hydromill (9).

25 15. Method or assembly according to claim 13 or 14, in which the hydromill (9) is slightly wider than the distance separating the two primary casting volumes.