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Porous concrete in secant pile walls

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Abstract: Secant bored pile walls are frequently used as retaining walls in trough excavation pits to cut off ground water aquifers and are subsequently exposed to ground water pressure loading in addition to earth pressure loads. In order to avoid the extra loading due to ground water pressure in soils with limited permeability, it can be useful to arrange drainage windows within the secant-bored pile walls by means of single primary piles filled with porous concrete without reinforcement cage, which usually has to be placed within the casing under submerged conditions. This concrete may serve as a horizontal arch between the reinforced secondary piles, but it must enable vertical draining between the load carrying construction beams to the bottom of the excavated pit.

In the present submission, the results of several material tests using different mix designs of porous concrete with certain admixtures are presented as well as first and important experiences with a well-suited placement technique for porous concrete in cased boreholes by means of small- and large-scale laboratory tests. It can be shown, that the usual placement technique of employing a tremie pipe is not suited for this type of unsaturated concrete. Instead, pouring with a particular kind of cone and an open conductor pipe has been proven to give satisfying results.

Additionally, special testing methods have to be developed in order to judge the suitability of the desired concrete mix design in preparation for an upcoming real-scale experimental pile installation in Germany.

1 Introduction

Retaining walls are often built as secant bored pile walls in order to cut off aquifers saturated with groundwater against deep building pits. In soil types with relatively low permeability, however, a certain seepage flow may be permitted, because the quantity of groundwater to be pumped is limited, and the range of influence due to dewatering is not reaching far. Thus, the hydrostatic water pressure on the retaining wall can be omitted, leading to a more economic design (see Fig. 1).

In unsaturated soils, the dewatering effect can be achieved by means of porous, pervious concrete with a uniform grainsize distribution of aggregates, typically placed in a borehole under dry conditions. With regard to the use of porous concrete to be placed at the ground surface in road pavement applications, experience is sufficiently available, as shown, for instance, by Neithalath et el. (2010). However, placing the porous concrete in a bored pile using a tremie pipe under submerged conditions is a challenge and a completely new approach, because there is a considerable risk of segregation of the fresh concrete, which separates the cement paste lime from the aggregates when in contact with water. This leads to only neat gravel on the one hand as well as a tight cemented area at the bottom of the pile on the other hand. If this concrete placement is successful, additional dewatering by means of extra wells behind the retaining wall can be avoided. Of course the seepage flow in the adjacent soil needs to be regarded seriously.

This submission is dealing with laboratory investigations concerning the search for a well-suited mixture of porous concrete to avoid this kind of segregation and to create a drainage pile of structural integrity with the ability to transfer the earth pressure horizontally to the secondary piles as well as dewatering the adjacent soil.

2 Main Objectives

The placement of usual fresh concrete, saturated with cement paste, in bored piles with casing is regulated in DIN EN 1536 or the EFFC/DFI Guide (2018). Porous concrete is not saturated, but contains many voids filled with air so that the cement paste can be rinsed off the grains when the fresh concrete gets in contact with or flowing through ground water. Due to its stiff consistency, porous concrete – having a very narrow, steep grainsize distribution of aggregates – is usually not capable of flowing. Therefore, a placement under submerged conditions as a kind of self-compacting concrete does not appear to be possible. This has been confirmed by a real scale-test in Germany, where bored primary piles of 88 cm diameter were executed successfully with porous concrete above groundwater (see Fig. 2) by means of a conductor hose, but failed in the execution by means of tremie pipe method under submerged conditions, showing almost completely separated gravel at the top and tight cement stone at the bottom of the primary pile (see Fig. 3).

Hence, the main goal of this investigation is to find a placement method for unsaturated porous concrete in water as well as a suited mix design for this special purpose.

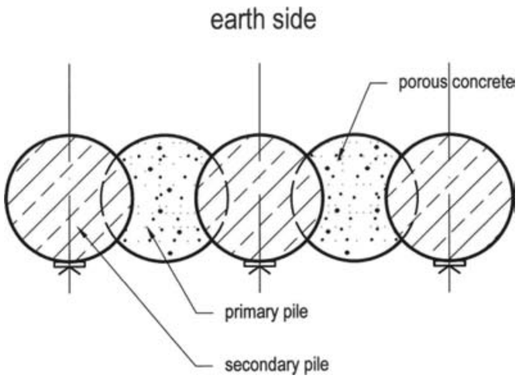

Figure 1a: Secant bored pile wall with pervious primary pile and usual secondary pile.

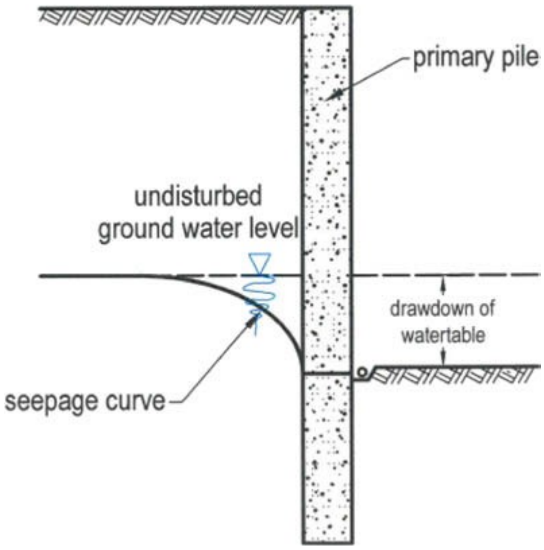

Figure 1b: Cross section through a permeable retaining wall.

The desired unconfined compressive strength of the concrete is chosen to be 5 MPa in order to achieve a sufficient degree of strength to be cut neatly by the secondary pile (see Fig. 1) and to be able to transfer the earth pressure horizontally to the reinforced secondary piles through arching effects. In contrast to applications with main vertical loading of the piles as regarded by Ni (2014), the needed concrete strength for horizontal load transfer is rather low due to the small span of the primary pile between two adjacent secondary piles. On the other hand, a minimum water permeability of $k_F > 1 * 10^{-4}$ m/s is chosen in order to guarantee vertical free groundwater flow through the drainage pile to a sampling pipe at the toe of the excavated wall.

Underwater concrete is usually saturated with cement and fly-ash paste, but also stabilized by special admixtures, so-called polymer compounds, which are used in order to glue the fresh concrete together and achieve a firm displacement front between flowing concrete and water (see e.g. Drinkgern (1999), Schaefer et al. (2006) or Tennis et al. (2004)). Consequently, a combination of porous concrete with these kinds of admixtures improves contact respectively adhesion between the surface of the aggregate grains and the cement paste. This can allow for placing the concrete flowing down a short circular slope using the cone repose method and leaving the tremie pipe mouth free (see Fig. 4).

Figure 2: Result of a large-scale test above groundwater level with primary piles made of porous concrete and secondary piles made of usual saturated concrete.

Figure 3: Core result with separated gravel at the top and tight cement stone at the bottom

3 Mix designs for porous concrete

Porous concrete is usually made of coarse aggregates in prototype scale with 8/16 mm, 8/22 mm or 8/32 mm. Typical mix designs are shown in Table 1.

Weight loss due to fresh concrete washed out in plain water has been quantified in preliminary lab tests by "bathing" samples placed in a coarse cage (see Fig. 5); different mixtures with aggregates of 4/8 mm or 5.6/8 mm were examined (as well). It could be shown that the amount of weight loss – determined to 0.5 to 4.0 mass-% depending on the mix design – has no significance as far as the performance of the concrete in the placement process under submerged conditions is concerned.

Finally, the optimal mix design in terms of weight loss, permeability and unconfined compressive strength was found at:

- Grainsize of Aggregates 8/16 mm
- Cement CEM III B 42.5 275 kg/m^3
- Water/cement ratio w/c 0.38
- Stabilizer (underwater-compound): 2.5% of cement mass
- Super plasticizer admixture: 1.0% of cement mass,

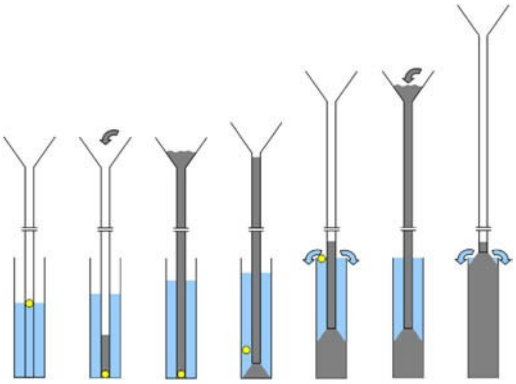

Figure 4: Schematic plot of concrete placement by means of the cone repose method at the mouth of a tremie pipe with continuous withdrawal of the pipe; shown with ball valve.

Table 1: Mix design for usual porous concrete in road pavement applications (FGSV, 2013).

		Porous concrete without polymers	Porous concrete with polymers
Compressive Strength (MN/m^2)		8–12	8–12
Aggregates/ Density (kg/m^3)	0/1 or 0/2 mm 8/22 or 8/32 mm	150–180[1)] 1500–1600	150–180 [1)] 1500–1600
Cement (kg/m^3)	32.5 R / 42.5 N	150–220	150–220
Water (l/m^3)		60–90	52–73
w/c-value (eq.)	–	0.35 – 0.40	0.35 – 0.40
Admixtures	Polymer dispersion (PM) (mass% of cement)	–	1.5 – 3.0
Other	Super Plasticizer (HRWR) Viscosity modifying (VMA)	as required	as required –
Consistency (in placing)	Compression value	1.30–1.45 (stiff, C 1)	1.30–1.45 (stiff, C 1)

A content of sand 0/1 mm can be advantageous.

Leading to a UC strength after 28 days of 3–4 MPa and a water permeability of more than $1.5 * 10^{-2}$ m/s. A considerable difference in the compressive strength was noticeable between 2, 7 and 28 days of curing time. An increase of the amount of cement to 300 kg/m^3 and the use of grainsize 5/8 mm was found to lead to a UCS of 5–8 MPa and a permeability of $1.0 * 10^{-2}$ m/s.

Additionally, the ability to core the cured porous concrete was tested. In these tests the mix design was used as given above, but the concrete specimen, which was placed under water in a scaffolding tube with a diameter of 500 mm and a height of 500 mm, was loaded using a steel plate in order to simulate the overburden of a fresh concrete column with a static compacting effect, as is usual in a pile borehole.

After a curing time of 2 days, the specimen could not be cored regularly (see Fig. 6). However, after 7 days of curing time, a smooth core could be gained over the total length of the tube of 500 mm (see Fig. 6). Naturally, after 28 days of curing time, coring was no problem at all.

The properties of the cured porous concrete as determined from these cores in the curing ages of 7 and 28 days are given in Table 2. In conclusion, a sufficient corability for the execution of the secondary pile in a secant pile retaining wall can be expected after a minimum of 7 days of curing time of the primary piles for this mix design of porous concrete. The desired values of compressive strength of >5 MPa can be achieved with cured concrete as well as the necessary permeability of $>1 * 10^{-4}$ m/s (Herten/ Pulsfort/Fierenkothen/Breitenbücher (2017)).

The slump value respectively the slump flow of the unsaturated concrete as recommended in then DFI/EFFC-guide (2018) as proven insignificant for judging the workability of porous concrete in the placement process.

4 Model tests concerning the placement process

In small-scale model tests, with tubes of 250 mm respectively 300 mm diameter and 1.0 m in length, the

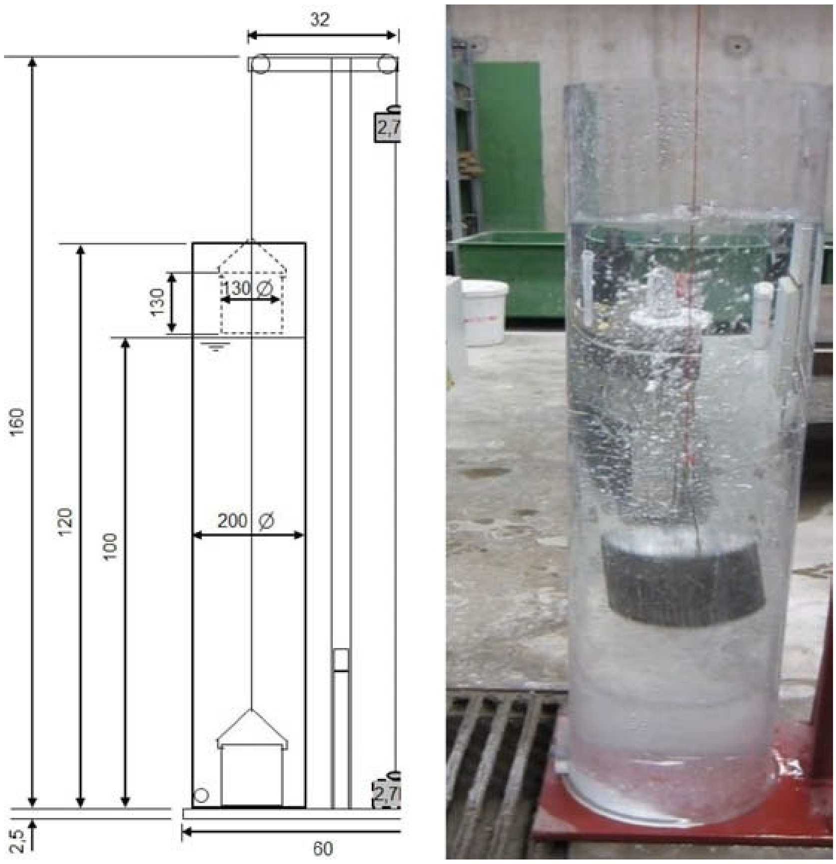

Figure 5: Test setup for determination of resistance against erosion (dimensions in mm).

Figure 6: Core-sampling trial after 2 days curing time under water – not successful!.

placement technique was examined with and without submerged conditions. The diameter of the tremie pipe was chosen to 70 mm respectively 100 mm, representing a geometrical scale of 1:5 up to approximately 1:2.5.

The porous concrete of the special mix design was placed into a scaffolding plastic tube vertically reaching into a basin filled with water by means

Table 2: Results for the optimal mix design as used in coring tests.

Curing age	Unconfined compressive strength	Water permeability
7 days	3.97 MPa	$6.4 * 10^{-3}$ m/s
28 days	6.90 MPa	

of a centrally arranged tremie pipe. The following parameters were varied in these tests:

- Grainsize of aggregates 4/8 mm, 5.6/8 mm, 8/16 mm
- Concrete mix design, as given above
- Placement technique free falling, with tube and repose, with and without ball valve
- Placement conditions dry or submerged
- Size of the tremie pipe: Ø 70 mm or 100 mm
- Size of the confining scaffold tube: Ø 250 mm, 300 mm, 1000 mm

For comparison, some examples of test results are shown in Table 3. It can be seen that the free fall placement method under water leads to a considerable loss of cement paste in the pile with a tight, cemented bottom of approximately 8 cm height (8% of pile length), whereas the cone repose placement method avoids this segregation almost completely (see middle column in

Figure 7: Successful coring after 7 days curing time under water.

Table 3: Cross sections of cured test piles.

Placement under submerged conditions		**Placement under dry conditions**
Free falling	Cone repose method with ball valve	Slow heave of ground water level after placement
		
Cement paste washed out!! 		

Table 3). Evidently, the reason is the movement of the fresh porous concrete through the water, as can be seen in the right column of Table 3.

The so-called cone repose method has been proven to be the best-suited placement method for fresh porous concrete, but in combination with a ball valve in order to separate fresh concrete from water in the first pouring step. However, even with this method, the optimal mix design given above can still lead to

Table 4: Cured model piles with different placement conditions and different plasticizers, all placed by cone repose method.

Admixtures A with ball valve	Admixtures A without ball valve	Admixtures B with ball valve
Grainsize 8/16 mm, Cement content 275 kg/m³ Water content 111 kg/m³ Density 1550 kg/m³		
Admixtures: Plasticizer 1.0 %, Stabilizer 2.5 % of cement mass		

differing results in the cured pile as can be seen in Table 4, depending on the manufacturing type of super plasticizer and stabilizer.

Admixture product A leads to a negligible segregation of about 1 cm cement deposit height at the bottom (see Table 4, left column), whereas product B in the same concentration leads to a cement deposit height of 15 cm = 15% of the pile length as can be seen in Table 4, right column.

5 Summary and Perspectives

The small-scale laboratory investigations reported here have shown a well-suited mix design of porous concrete to be placed in a pile under submerged conditions. The placement technique differs from the usual tremie pipe method as the mouth of the tremie pipe cannot be kept submerged. Instead, it has to be withdrawn continuously while the fresh concrete is poured over a cone of previously poured concrete. The use of a separating ball valve is highly recommended.

Due to the strong influence of the chosen type of additive material, it is necessary to examine the placement behaviour of the porous concrete of an intended mix design – at least in a type of placement test – as described in this paper. The usual test method for fresh concrete-like slump value or slump flow are not helpful to decide whether the mix is suitable for this very special application. Therefore, alternative testing methods have to be developed to check the quality of the porous concrete on a real-scale site, e.g. based upon the L-box test as e.g. described in the new EFFC/DFI guide (2018).

Based upon these experiences on the laboratory scale, another trial pile is going to be executed on a site of the Federal Waterways Engineering and Research Institute in Germany in a prototype scale in late 2019.

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