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Pervious concrete fill in Pearl-Chain Bridges: Using small-scale results in full-scale implementation

M.S.M. Lund *, K.K. Hansen, R. Truelsen, L. Johansen

Technical University of Denmark, Department of Civil Engineering, Brovej 118, DK-2800 Kgs. Lyngby, Denmark

HIGHLIGHTS

- The void content follows a logarithmic tendency through layers compacted from above.
- Layer thicknesses of 27 cm before compaction give homogenous void contents in layers.
- The compressive strength of homogeneous specimens is linear with void content.
- Pervious concrete is implemented as fill in a 26 m long Pearl-Chain Bridge.
- European quality control regulations are needed for pervious concrete in the field.

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ABSTRACT

Pearl-Chain Bridge technology is a new prefabricated arch solution for highway bridges. This study investigates the feasibility of pervious concrete as a filling material in Pearl-Chain Bridges. The study is divided into two steps: (1) small-scale tests where the variation in vertical void distribution and strength properties is determined for 800 mm high blocks cast in different numbers of layers, and (2) full-scale implementation in a 26 m long Pearl-Chain Bridge. With a layer thickness of 27 cm, the small-scale tests indicated homogenous results; however, for the full-scale implementation, the same degree of homogeneity was not shown.

1. Introduction

Pearl-Chain Bridge technology is an innovative arch solution for highway bridges [1]. Despite its optimal shape, the arch is rarely used for highway bridges because of the extensive need for scaffolding that closes down the highway for weeks. With the Pearl-Chain Bridge technology, the highway is closed for a minimum period of time, which reduces traffic disturbances and carbon dioxide emissions. Furthermore, the material consumption is minimized due to the optimal arch shape. The Pearl-Chain arch is created by collecting and post-tensioning several Super-Light Decks on a wire, like pearls on a string. Subsequently a crane is used to lift the arch into place [2]. When the arch is placed, spandrel walls are installed, a filling material is laid out and possibly a post-tensioned concrete top plate is cast. The first Pearl-Chain Bridge ever built was constructed in 2015. Crossing Vorgod Stream in Jutland, Denmark, and connecting two gravel roads on each side, the bridge load is classified for 50 tonnes [3,4]. The bridge consists of a 13 m long arch and two 6.5 m long adjacent half arches as shown in Fig. 1. This gives the bridge a total span length of 26 m. The width of the bridge is 6.1 m and the pile height is 0.9 m.

The filling material in the bridge is shown as shaded areas in Fig. 1. The maximum placing depth of the filling material is 0.9 m and the filling material has a total volume of 45 m^3.

Portland cement pervious concrete (PCPC) is a concrete with a significant void content—typically 11–35% [5]—which gives it excellent drainage properties. Typically, the fill in arch bridges is cast with a granular material; however, for the Pearl-Chain Bridge shown in Fig. 1, PCPC was chosen as the filling material because of several considerations:

1. PCPC fill is expected to contribute positively to the lifetime of the bridge. A bridge is a sensitive point in a road construction because it is exposed to freezing from below as well as from

* Corresponding author.
E-mail addresses: msml@byg.dtu.dk (M.S.M. Lund), kkh@byg.dtu.dk (K.K. Hansen).

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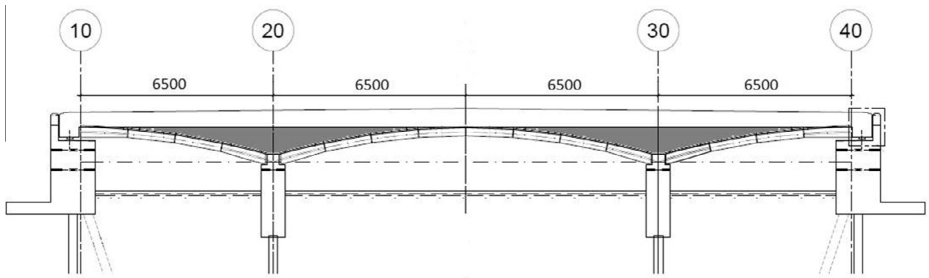

Fig. 1. Longitudinal section of Pearl-Chain Bridge over Vorgod Stream. The shaded areas mark the location of pervious concrete filling material. Dimensions are in mm.

above. The lower permeability of typical unbound filling materials such as gravel and soil may cause water accumulation, leading to potential frost damages when the bridge freezes. Using PCPC as a filling material improves arch bridge durability because such water accumulation is entirely prevented due to the large permeability of PCPC.

2. PCPC fill can be incorporated structurally because the strength properties are significantly improved compared to unbound filling materials. This means, for example, that the fill material is able to transfer shear stresses.
3. PCPC fill is easier to cast than typical unbound filling materials that need to be compacted in layers of 30 cm in thickness. It is expected that it is possible to design a self-compacting PCPC mix that can simply be cast by pouring it onto the arch in a single lift and only compact it from the top. However, this is outside the scope of the present study.

For the use of PCPC as fill in Pearl-Chain Bridges it is required that the 28-days compressive strength and the 28-days splitting tensile strength are minimum 10 MPa and 1 MPa, respectively. Furthermore, the freeze–thaw durability should be good. If PCPC fill has a permeability of at least 4×10^{-3} cm/s it is able to drain the rain from a 10-year rain event in Denmark [6]. Without compromising the quality of PCPC fill, it is desired that the mentioned strength and durability requirements are fulfilled with the highest possible void content to keep the PCPC cost at a minimum.

While the literature proves it is possible to design a PCPC mixture that meets filling material strength and durability requirements, such research is lacking on PCPC placed at high depths. The present paper investigates the use of PCPC as a fill in Pearl-Chain Bridges. Small-scale tests where PCPC is placed in layers of up to 800 mm serves three main purposes:

1. To investigate the feasibility of casting homogeneous pervious concrete in layers of up to 0.8 m.
2. To identify a suitable compaction method.
3. To determine the strength properties—compressive strength, Young's modulus, splitting tensile strength, and shear strength—and the variation of these strength properties through a 0.8 m deep pervious concrete layer.

Based on the findings and conclusions from the laboratory tests, PCPC is implemented as fill in the Pearl-Chain Bridge over Vorgod Stream in Denmark. The experiences, results and conclusions from this are also described herein.

2. Background

PCPC consists of cement, water, and a single-sized coarse aggregate that is used to maximize the void content. PCPC has less cement paste than conventional Portland cement concrete, which leaves space for the interconnected void structure. The cement paste typically has a low water-to-cement (w/c) ratio of 0.27–0.34, which causes stiff PCPC workability. The strength of PCPC increases significantly when substituting up to 7% of the coarse aggregate with sand [7]. Using chemical admixtures such as air entrainment (AEA), superplasticizers, and hydration stabilizers also improves strength properties and freeze–thaw durability [7,8]. Tests have shown that in order to obtain the best PCPC durability the AEA dosage should correspond to the use in regular concrete, whereas the retarder dosage should be much higher [9].

There is a linear correlation between the void content and the density of PCPC [7]. PCPC strength properties are strongly related to the void content and therefore to the density, and 28-days compressive strength values of 5.5–32 MPa are reported [5]. As far as can be ascertained, very little information about Young's modulus of PCPC is published, although studies have reported a static modulus of elasticity of 13–32 GPa for void contents of 15–35% [10]. Permeability coefficients of 0.20–0.54 cm/s are most common [11]. The freeze–thaw durability of PCPC is typically tested according to the American Society for Testing and Materials (ASTM) C666 standard [12]. However, several examples have shown that air-entrained PCPC performs much better in the field than in the laboratory, where the test method is often considered to be a worst-case scenario and not representative of on-site behavior, since drainage is not taken into account [13,14]. In the field, PCPC pavements perform well over several years in areas that undergo a large number of annual freeze–thaw cycles, provided it remains unsaturated [8].

PCPC is typically used for pavements as it helps reduce stormwater runoff [11]. This implies that its placing depth is rarely particularly large. In the field, PCPC is typically placed in a single lift followed by compaction from the top. This produces a vertical void distribution variation with the lowest content at the top of the layer and the highest at the bottom. The distribution of the void content and hence the properties of PCPC are highly dependent on the compaction method [15].

3. Experimental method

In the small-scale tests, pervious concrete was mixed and cast in 0.8 m high molds with a volume of 1 m^3 at two different Danish mixing plants, mixing plant A and mixing plant B. Different layer thicknesses were investigated to determine which was most appropriate for full-scale implementation. Table 1 summarizes the outline of the experimental plan for the small-scale tests.

Table 1
Outline of experimental plan for small-scale tests.

	Mix No. 1	Mix No. 2
Place	Mixing plant A	Mixing plant B
Date	Sep. 29, 2014	Nov. 10, 2014
No. 1 m^3 blocks	2	2
No. of layers	1 and 2	2 and 3
Layer thickness	80 cm and 40 cm	40 cm and 27 cm