Construction and Building Materials 72 (2014) 23–30

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Methodology for the design of controlled low-strength materials. Application to the backfill of narrow trenches

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HIGHLIGHTS

- Methodology for the design of optimised controlled low-strength materials mixes.
- Technical based assessment of the requirements by means of numerical modelling.
- Compressive strength required for backfill of trenches ranges from 2.0 to 2.5 MPa.
- 75 kg/m^3 of cement provide a compressive strength of 2.1 MPa.
- Methodology valid for any application provides the tools for the optimisation.

ARTICLE INFO

Article history:
Received 21 January 2014
Accepted 4 September 2014

Keywords:
Controlled low–strength materials
Design
Narrow trench
Backfill
Simulation

ABSTRACT

The design of controlled low-strength materials (CLSM) is generally based on experimental approaches without considering an efficient use of the component materials. The present study proposes a general methodology for the design of optimised CLSM that includes the definition of the mechanical requirements through numerical simulations with FEM and an experimental procedure to define the mix by optimising the aggregate skeleton, the content of cement and the use of admixtures and additions. Moreover, the methodology is applied to the backfill of narrow trenches.

1. Introduction

The use of narrow trenches for the installation of flexible pipelines of small diameter is a common technique for the construction of water, electricity, lighting and gas networks. One of the advantages of this technique is the limited interference with other services or traffic during construction. After the trench is excavated, a backfill material is used to fill the void left behind as well as to provide the support for the pipe and the surface elements. For that purpose, it is common to apply a controlled low-strength material (CLSM) as opposed to the use of traditional compacted granular fill.

As a backfill material, the CLSM requires a consistency close to that of self-compactability in order to reach tight or restricted-access areas [1] and a compressive strength that allows fast reestablishment of traffic without settling under traffic load, but also that may be easily excavated with conventional digging equipment [2]. These contradictory requirements represent a challenge when designing the mix proportions since both the deformability and the compressive strength of the material must be balanced and limited to a certain value.

In general, the definition of the mix proportions of CLSM are based on empirical approaches [3,4] that do not always consider the optimisation of the materials used. In order to develop an optimised CLSM, the design of the mix should be preceded by a technical base assessment of the requirements according to the application for what it is intended (e.g. backfills, structural fills, insulating or isolation fills, pavement bases, void filling, etc.). Afterwards, a series of tests should be performed to ensure that the resulting material fulfils the requirements.

Considering the abovementioned, the present study aims at defining a general methodology for the design of optimised CLSM. This approach proposes the assessment of the requirements through a numerical simulation of the application and an experimental procedure to optimise each of the components of the CLSM. Furthermore, this methodology is subsequently applied to a real case of a CLSM for the backfill of narrow trenches.

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http://dx.doi.org/10.1016/j.conbuildmat.2014.09.008
0950-0618/

The main interest of the study consists in the development of a straightforward methodology that may be employed for any application. The novelty of the methodology is the use of a numerical analysis by means of FEM for defining the mechanical requirements of the CLSM since this type of studies are found in the literature for traditional compacted granular fill (e.g. for trenches [5,6]) but are scarce for CLSM. Likewise, the methodology provides a series of tests for optimising the aggregate skeleton, the cement content and use of admixture that have proved to be convenient for the procedure.

2. Methodology for the design of optimised CLSM

The methodology proposed is summarized in the flow diagram presented in Fig. 1. The main requirements of a CLSM, according to what was previously exposed, are the workability in fresh-state and the compressive strength in the hardened-state. These two properties and, therefore, the requirements are dependant of the type of application for what the material is intended.

In general, the workability of the CLSM should be close to self-compactability to avoid the need of vibration. Hence, the design of the mix should be conducted to attain that consistency. In order to set the value of compressive strength that materials should reach to fulfil the requirements, a FEM analysis is performed. This type of analysis allows reproducing the loading and boundary conditions of the CLSM and identify the compressive strength required to guarantee no settlements and easy excavation.

Afterwards, when the desired workability and compressive strength have been defined, the optimisation procedure of the mix is conducted in three stages: first the aggregate skeleton is optimised, subsequently the amount of cement and, finally, the use of admixtures and additions.

The optimisation of the aggregate skeleton consists in finding the combination of the aggregates that provides the maximum compactness and the desired workability. For that, two tests are defined at this stage: a wet-packing test [7,8] and the consistency test according to UNE-EN 1015-3:2000 [9].

The first one allows determining the solid concentration and the voids ratio, which are key parameters in the optimisation since a reduction of the voids could contribute to reduce the consumption of cement and problems regarding segregation. Furthermore, a more compact matrix would be less deformable, which is very convenient considering the applications of CLSM. The second one provides information regarding the consistency through the extent of the flow. Notice that a small content of cement (e.g. 40 kg/m^3 [7]) may be used to perform such tests given that the assessment of the strength is not in the scope of this stage.

The subsequent stage of the methodology is the optimisation of the amount of cement considering the aggregate skeleton obtained from the previous stage. For that purpose, the compression test according to UNE-EN 12390:2009 [10] is proposed to assess mixes with different cement contents and determine which is adequate to fulfil the requirements set previously.

Finally, the last stage of the methodology summarized in Fig. 1 is the optimisation of the use of admixtures and additions. Besides the traditional admixtures and additions (e.g. air-entraining admixtures, foaming agents or fly ash [2]), CLSM support the use of recycled or reused components from diverse origin such as recycled fine aggregates [11], waste materials, industrial by-products [12–15] and mine tailings [16].

In case any of the abovementioned materials are used, the consistency test and compression test previously proposed should be performed to assess the influence of such materials on the workability and compressive strength of the mix. Furthermore, if the additive or admixture has a particular property (e.g. expansive

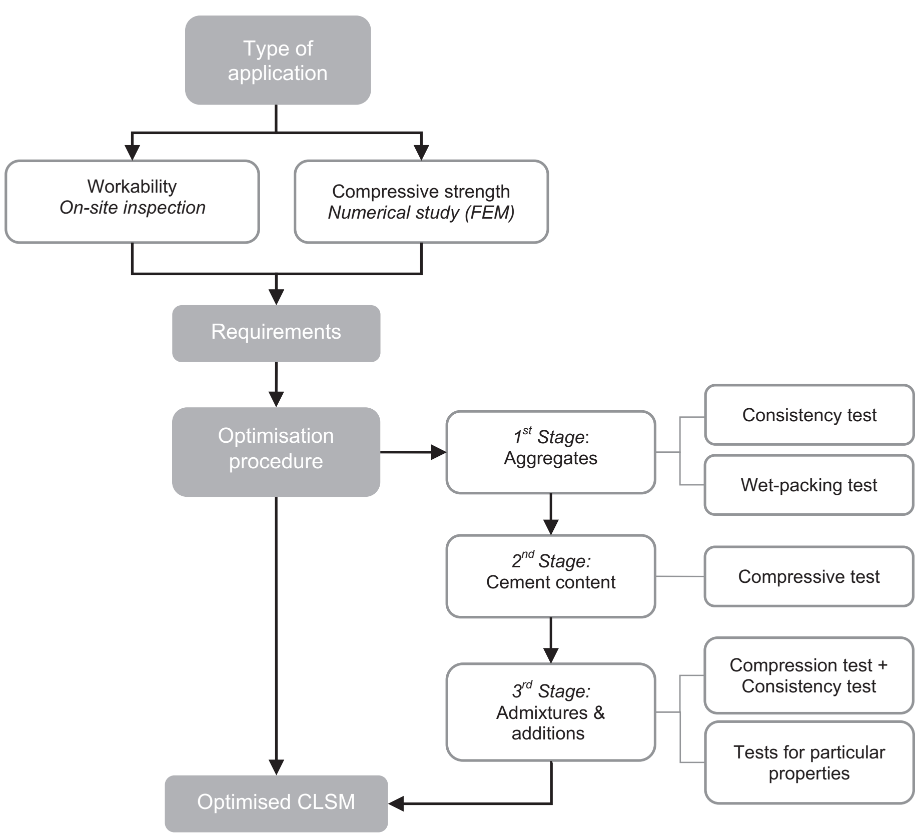

Fig. 1. General methodology for the design of optimised CLSM.