Pilot Study on the Use of Self-compacting Backfill Material in Slope and Retaining Wall Works

GEO Report No. 374

C.C.W. Chan & R.L.Y. Ip

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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This report was originally produced in April 2023 as GEO Technical Note No. TN 1/2023

First published, February, 2024

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Preface

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet.

Raymond W M Cheung
Head, Geotechnical Engineering Office
February 2024

Foreword

The Landslip Preventive Measures Branch, in collaboration with the Innovation and Technology Task Force on Advanced Materials, has identified the opportunity of using self-compacting backfill material, in lieu of conventional soil backfill materials, in slope and retaining wall works with a view to enhancing constructability and site safety. A pilot study with site trials was carried out under the Landslip Prevention and Mitigation Programme.

This Technical Note summarises the findings of the pilot study and presents the benefits, limitations and design considerations for the use of self-compacting backfill material in slope and retaining wall works. The pilot study was carried out by Mr Chris C W Chan and Mr Rex L Y Ip under the supervision of Mr Y Lam and myself. The site trials and reviews are supported by Mr Victon W L Wong of AECOM Asia Company Limited, Mr Chris T L Lee of C M Wong and Associates Limited and Mr Stellan Y H Sum of Fugro (Hong Kong) Limited. The study and the preparation of this Technical Note are supported by Ms Florence L F Chu, Ms Venus M S Lau and Ms Lotty L Y Lee.

Various colleagues in the Geotechnical Engineering Office have also provided valuable comments on this Technical Note. All contributions are gratefully acknowledged.

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Abstract

In Hong Kong, the replacement of the top 3 m layer of loose fill is one of the options in upgrading loose fill slopes. However, it is usually difficult and time consuming to carry out compaction works and the necessary quality assurance tests with limited working space at steep terrain. With this background, a pilot study for the use of self-compacting backfill material in slope and retaining wall works was launched with a view to enhancing constructability and site safety of fill replacement operations in landslip prevention and mitigation works. This pilot study covers a review of the characteristics of self-compacting backfill materials, the quality control requirements for their use in slope and retaining wall works, together with a discussion on the benefits and limitations about their uses. The key design considerations for the use of self-compacting backfill material in slope and retaining wall works were also presented. The findings of this pilot study show that the self-compacting backfill material is a feasible alternative in the backfilling of pits, trenches and voids in slope and retaining wall works.

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1 Introduction

In Hong Kong, the stabilisation of loose fill slopes is usually challenging in terms of constructability and construction time. The replacement or re-compaction of the top 3 m layer of loose fill is one of the options for the slope upgrading works. The current practice for the replacement of loose fill typically involves re-compaction of the existing fill, replacement by cement-soil, replacement by no-fines concrete or replacement by mass concrete. To address concern on slope stability during the construction stage and preservation of existing trees on the slopes, the fill replacement is usually undertaken by pit-by-pit construction method. However, it is usually difficult and time consuming to carry out fill replacement and the necessary quality assurance test with limited working space at steep terrain, not to mention the site safety hazard in connection with manual handling and working in pits.

With this background, the Geotechnical Engineering Office (GEO) has identified the opportunity of using a self-compacting backfill material developed by Nano and Advanced Materials Institute Limited (NAMI) originally designed for trench backfilling for the Highways Department (HyD) in overcoming the challenges of pit-by-pit fill replacement works. A pilot study for the use of self-compacting backfill materials in slope and retaining wall works with site trials was launched with a view to enhancing constructability and site safety of fill replacement operations in landslip prevention and mitigation (LPMit) works.

This Technical Note summarises the findings of the pilot study and documents the quality control requirements for the use of self-compacting backfill material in slope and retaining wall works. The benefits, limitations and design considerations for the use of self-compacting backfill material in slope and retaining wall works are also discussed and presented in this Technical Note.

2 Background

HyD commissioned NAMI for the development of a self-compacting backfill material (SCM) for backfilling of trenches and voids in road works. The SCM developed by NAMI (i.e. SCM-NAMI) has equipped with self-compacting properties, thus eliminating the need of carrying out compaction tests as required for conventional soil backfill materials. HyD and NAMI proceeded with a number of site trials on the use of SCM for backfilling of trenches and voids in road works in 2020 and 2021. In January 2022, HyD issued a set of particular specification to allow the general use of the SCM-NAMI or equivalent, as an alternative backfill material for backfilling trenches and voids in road works (HyD, 2022). A summary of the technical information of SCM for backfilling trenches and voids in road works is at Appendix A.

In parallel, the Landslip Preventive Measures (LPM) Branch, in collaboration with the Innovation and Technology (I&T) Task Force on Advanced Materials, of the GEO has identified the opportunity of using SCM-NAMI, in lieu of the conventional soil backfill materials, in slope and retaining wall works with a view to enhancing constructability and site safety. After a preliminary review on the feasibility of using SCM-NAMI in LPMit works including initial laboratory tests conducted by the Public Works Central Laboratory to verify the properties and suitability of SCM-NAMI for slope application, a discussion paper was submitted to the GEO District Checking Panel on New Materials, Innovative Designs and Unconventional Systems, seeking endorsement to proceed with the pilot application of

SCM-NAMI at selected sites under the LPMit Programme. The proposal (GEO, 2020a) was endorsed by the District Checking Panel on 11 November 2020. A series of site trials was subsequently commenced in February 2021 (GEO, 2021).

With the observations and findings of the site trials, a set of particular specification (PS) for the use of SCM-NAMI or equivalent in slope and retaining wall works was prepared for submission to the Geotechnical Control Conference (GCC) for endorsement with a view to facilitating the wider use of the material. The PS sets out the quality requirements, standards of workmanship, testing methods and acceptance criteria of using SCM for backfilling of pits, trenches and voids in slopes and retaining walls. The PS supplements Section 7 – Geotechnical Works of the General Specification for Civil Engineering Works (GS) (HKSAR Government, 2020). As the SCM-NAMI exhibits self-compacting properties, the conventional compaction control requirements for fill material as laid down in Section 6 of the GS are not applicable. The proposal (GEO, 2022a) was endorsed by the GCC on 7 September 2022.

Following GCC's endorsement, the GEO promulgated the PS to government departments to allow the general use of SCM-NAMI or equivalent in backfilling of pits, trenches and voids in slope and retaining wall works in September 2022 (GEO, 2022b). The PS issued by the GEO is at Appendix B.

3 Site Trials

3.1 Composition and Properties of SCM-NAMI

The SCM-NAMI, with a material formulation named as "NAMI DM-4" as referred to by NAMI, is a mix of (i) cementitious material; (ii) fine aggregate; (iii) crushed rock fines; (iv) water; and (v) admixtures, with necessary optimisation in the mix formula to achieve a balance between workability and strength, while maintaining homogeneity. As the SCM-NAMI was originally developed for its intended use in backfilling of trenches and voids in road works, the mix was designed for a target maximum compressive strength of less than 1 MPa to allow future re-excavation while achieving high flowability, as well as self-levelling and self-consolidating properties. The SCM-NAMI also includes requirements about initial strength for load placement and thermal conductivity to support its use in road works.

Considering the composition and properties of the SCM-NAMI, it could be categorised as a kind of "Controlled Low-Strength Material (CLSM)" (American Concrete Institute (ACI), 2013), which is a collective term to describe a family of mixtures that compose of a self-consolidating cementitious material used primarily as a backfill as an alternative to compacted fill. Additional information about typical CLSM mixes are presented in Appendix C. The SCM-NAMI with a target maximum compressive strength of less than 1 MPa is classified as a lower-strength CLSM mix.

For the SCM-NAMI, the percentage of cement is about 2%, which is lower than the typical cement content of 3% to 6% for cement-soil used in slope and retaining wall works in Hong Kong. The SCM-NAMI or equivalent exhibits soil-like performance.

3.2 Site Information

Pilot applications, involving the use of over 1,350 m^3 of SCM-NAMI, have been carried out at eight trial sites endorsed by the District Checking Panel between February 2021 and March 2023. The pilot applications involved the replacement of about 3 m of existing loose fill as part of the slope upgrading works for the man-made slopes and retaining walls under the LPMit Programme. Summary of the pilot applications, including a list of the pilot sites and key findings from each pilot site, are given in Appendix D. Summary of tests carried out during the site trials are presented in Appendix E.

3.3 Key Findings

The key findings from the site trials (AECOM, 2022a, 2022b, 2022c & 2022d; CMWAL, 2022a &2022b and Fugro, 2022 & 2023) are summarised below:

(a) General – The SCM-NAMI produced by the concrete batching plant in commercial scale or by mixing on site has demonstrated self-compacting properties, and the respective material properties, including wet density and flowability, were largely consistent among the samples collected from the trial sites. In general, the ready-mixed SCM-NAMI demonstrates better consistency in material properties than SCM-NAMI mixed on site as expected. The batching and mixing of SCM-NAMI to be produced on site shall comply with the recommendations from the manufacturers / suppliers.

(b) Consistency – After placement and setting of the SCM-NAMI, no noticeable ground subsidence was observed. The interfaces of SCM-NAMI among pits (when pit-by-pit method was used) as well as the interfaces between the SCM-NAMI and the surrounding were in good contact without observable signs of distress or detachment. Moreover, no observable disturbance to the surroundings were identified.

(c) Strength – All SCM-NAMI samples achieved the intended shear strength required under individual design of LPMit works, as revealed from the results of laboratory testing. Unconfined compressive strength (UCS) tests of cube samples were adopted in the initial stage of the site trials as recommended by NAMI based on the technical information at Appendix A. The cube tests were subsequently migrated to UCS tests of cylindrical samples based on the PS at Appendix B. Elaborations on the observations about the strength of the SCM-NAMI are listed below:

(i) Both SCM-NAMI mixed on site and ready-mixed SCM-NAMI satisfied the minimum strength required in

UCS tests. The SCM-NAMI at 28 days achieves a compressive strength of at least 0.2 MPa consistently.

(ii) According to the triaxial tests of the SCM-NAMI applied at the pilot sites, the SCM-NAMI possesses a shear strength level which is comparable with or better than the strength levels of typical compacted soil fill as intended by the designers. The observations are considered reasonable due to the corresponding contribution of cementitious materials and the nature of the fine aggregates on the cohesion and the internal friction respectively.

(d) Flowability – The SCM-NAMI exhibited high flowability (i.e. slump greater than 200 mm) consistently at the trial sites. The self-levelling, self-consolidating and void-fillable characteristics enhanced the efficiency of the fill replacement operations significantly.

(e) Density – Wet density of the fresh SCM-NAMI ranges from 1.9 Mg/m^3 to 2.3 Mg/m^3. The bulk density of hardened SCM-NAMI is about 1.8 Mg/m^3 to 2.2 Mg/m^3, with a dry density of about 1.6 Mg/m^3 to 1.8 Mg/m^3. The properties fall within the expected range.

(f) Constructability – The SCM-NAMI allows horizontal pumping of over 250 m and vertical pumping of over 30 m by using typical concrete pumps, thus facilitating placement of the SCM-NAMI at sites with difficult access. There was also no observable excessive ingress of the SCM-NAMI into the surrounding loose fill materials. The setting time of SCM-NAMI was about 8 hours. The key quality control tests, i.e. checking of wet density and flowability, to be carried out on site are simple and straight-forward. The ease in placement and simple quality control of the material also led to a remarkable shortening of construction duration.

(g) Permeability – The SCM-NAMI is relatively impermeable, with a mass permeability generally between 5.2×10^{-6} m/s and 7.4×10^{-9} m/s, which is close to the lower bound value of the compacted soil fill.

(h) Laboratory Tests – There was no major difficulties in the preparation and arrangement of UCS tests for cylindrical specimens of the SCM-NAMI based on the laboratory testing method for determining UCS of cement stabilised soil cores commonly adopted in Deep Cement Mixing (DCM) works in accordance with Appendix B of the "Interim Guidelines on Testing of Unconfined Compressive Strength of Cement

Stabilised Soil Cores in Hong Kong" published by Geotechnical Division of The Hong Kong Institution of Engineers in October 2017. Notwithstanding this, early planning of the testing schedule and coordination with testing laboratories are recommended for the preparation of specimens and for the implementation of the UCS tests at the specified age of samples. Trial preparation of specimens with good communication with the testing laboratory is encouraged. In particular, the cylindrical samples should be sufficiently long to allow cutting of specimens as the prepared specimens shall have a minimum length to diameter ratio of 2.0 as required in the PS. Typical setup in laboratory for the UCS test is shown in Figure 3.1.

(i) Greening Capability – Vegetation growth on the SCM-NAMI is possible but apparently more difficult than compacted soil fill, likely due to its cementitious nature.

Figure 3.1 Unconfined Compressive Strength Tests of Cylindrical Specimen of Self-compacting Backfill Material

General views of a slope shortlisted for site trial requiring replacement of loose fill by SCM as part of the LPMit works are shown in Figure 3.2. Typical arrangements for the delivery and placement of ready-mixed SCM adopted in the site trials are shown in Figure 3.3. The production of SCM mixed in one of the trial sites is shown in Figure 3.4. The placement of SCM in a trench and in a pit on slopes is shown in Figure 3.5. The field testing and sampling of SCM on site are shown in Figure 3.6. General view of a slope with LPMit works involving fill replacement by SCM completed is shown in Figure 3.7.

(a) Slope Area Requiring Replacement of Loose Fill

(b) Loose Fill Replaced by SCM

Figure 3.2 General Views of Slope Requiring Replacement of Loose Fill by Self-compacting Backfill Material

(a) Delivery of Ready-mixed SCM by Concrete Truck

(b) Discharge of Ready-mixed SCM to Concrete Pump

(c) Use of Typical Pipelines for Concrete Pumping for Transportation of SCM within the Site

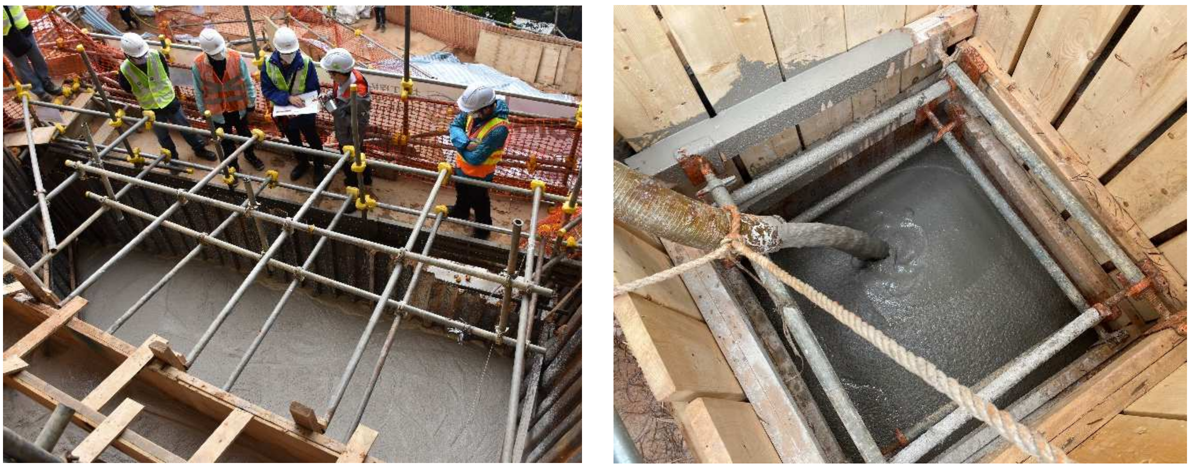
(d) Placement of SCM by Chutes

Figure 3.3 Delivery and Placement of Ready-mixed Self-compacting Backfill Material

(a) Production of SCM using Screw Mixer on Site

(b) SCM Discharged from the Screw Mixer

Figure 3.4 Production of Self-compacting Backfill Material Mixed on Site



(a) Placement of SCM for Fill Replacement in a Trench

(b) Placement of SCM for Fill Replacement in a Pit

Figure 3.5 Placement of Self-compacting Backfill Material on Site

(a)Flowability Test in accordance with ASTM D6103-17

(b)Sampling and Preparation of Cylindrical Sample for Laboratory Testing

Figure 3.6 Field Testing and Sampling of Self-compacting Backfill Material on Site

Figure 3.7 General View of Slope with Landslip Prevention and Mitigation Works involving Fill Replacement by Self-compacting Backfill Material Completed

According to the pilot study, including the site trials, the SCM-NAMI is found to be a feasible alternative to compacted fill (or other typical backfill material such as cement-soil, no-fines concrete, and mass concrete) for backfilling of pits, trenches and voids in slope and retaining wall works.

3.4 Comparison with Conventional Fill Replacement Methods

Based on the experience in the design and construction of LPMit works and the observations from the site trials, a comparison amongst different fill replacement methods, including re-compaction of the existing fill, replacement by cement-soil, replacement by no-fines concrete, replacement by mass concrete, and replacement by SCM, have been made. The pros and cons of the various methods are summarised in Table 3.1.

Table 3.1 Pros and Cons of Different Fill Replacement Methods

Method	Pros	Cons
Re-compaction of the existing fill	• Relatively low cost • Minimal generation of Construction and Demolition (C&D) waste • Facilitate future excavation	• Require large working area for stockpiling excavated soil • Time consuming for layer-by-layer re-compaction and compaction related tests • Involve laborious compaction works • Potential safety concern for conducting compaction works on sloping ground • Compaction works sensitive to weather conditions
Replacement by cement-soil	• Relatively low cost • Minimal generation of C&D waste	• Require large working area for stockpiling excavated material and on-site cement-soil mixing • Difficult to control the quality of cement-soil mixed on site • Time consuming for layer-by-layer compaction and compaction related tests • The need to develop project-specific quality control requirements (e.g. strength tests) • Involve laborious compaction works • Potential safety concern for conducting compaction works on sloping ground • Compaction works sensitive to weather conditions • Impose constraint for future excavation
Replacement by no-fines concrete	• Works less sensitive to weather conditions • Simple quality control	• Require import and export of materials • Involve extensive manual handling for transportation and with difficulties in the placement of no-fines concrete on steep slopes • Lack of flowability, hindering the use in site with a long travelling distance • Impose constraint for future excavation • Generation of C&D waste for disposal
Replacement by mass concrete	• Works less sensitive to weather conditions • Simple quality control	• Require import and export of materials • Involve extensive manual handling for transportation and with difficulties in the placement of mass concrete on steep slopes • Low flowability, hindering the use in site with a long travelling distance • Skillful concretor required • Impose constraint for future excavation • Impermeable • Generation of C&D waste for disposal
Replacement by Self-compacting Backfill Material	• Works less sensitive to weather conditions • Ease of placement • Simple quality control • Minimal manual handling • Shorter construction time • Facilitate future excavation (if compressive strength is capped below 0.7 MPa)	• Require import and export of materials • Generation of C&D waste for disposal • Relative costly material at present

Further to the comparison above, the potential benefits and limitations about the use of SCM in slope and retaining wall works are elaborated in Sections 3.5 and 3.6 below. Recommendations on the design considerations are presented in Section 5.

3.5 Potential Benefits

The most significant benefits about the use of SCM are the significant reduction of manual handling and the remarkable shortening of construction duration due to the elimination of compaction operations when compared with conventional fill replacement methods.

The self-levelling, self-consolidating and void-filling properties eliminate the compaction operations and necessary compaction tests required for soil re-compaction and replacement by cement-soil. The use of SCM is least affected by inclement weather, bringing further improvement of the overall site progress.

The pumpability of SCM expedites the backfilling process and helps to overcome access constraints. The placement of SCM is also easy. The use of SCM eliminates the manual operations in connection with the transportation and placement of no-fines concrete and mass concrete. The use of SCM also allows future manual excavation when compared with no-fines concrete and mass concrete.

Overall speaking, the site trials completed revealed that the use of the ready-mixed SCM had resulted in a notable improvement in site progress, with over 75% time saving and 50% labour reduction for the backfilling operation as compared with the conventional fill replacement methods. The use of SCM to be mixed on site provide similar benefits on labour reduction but with less time saving as production rate of SCM on site is much lower than the rate of placement of ready-mixed SCM.

Last but not least, the use of SCM in fill replacement operations was also observed to have enhanced the overall constructability and eliminated the labour intensive compaction works at the congested environment on steep slopes, which have improved construction site safety as a whole.

3.6 Limitations

Although the SCM can generally displace water, the SCM shall not be placed under submerged conditions as stated in clause (g)(5) in the PS at Appendix B. The requirement aims to avoid segregation, loss of constituents and adverse impact to the strength development of the SCM.

Currently, the material cost of the ready-mixed SCM produced by concrete batching plant is higher than that of no-fines concrete or mass concrete, likely due to limited demand at the current technical development stage. The material cost of the SCM to be mixed on site is marginally higher than that of ready-mixed SCM. At the time being, the SCM developed by NAMI has been licensed to four companies for commercial scale production and supply locally. Noting that SCM fulfilling both the requirements promulgated by HyD for trench backfilling in road works and the requirements in the PS for slope and retaining wall works at Appendix B is now available in the local market, it is believed that the cost of SCM-NAMI or equivalent can be reduced through market competition among suppliers and with wider application of the material in the future.

4 Self-compacting Backfill Material in Slope and Retaining Wall Works

4.1 Material Composition

With due consideration of the elaborations about the material and its properties in Section 3.1 above, market availability and typical quality control requirements adopted in Hong Kong, the SCM mix as specified in the PS issued by the GEO at Appendix B include the following components:

(a) Cementitious material, which shall be Portland Cement (PC) or Pulverized Fuel Ash (PFA), typically acceptable for concrete production.

(b) Fine aggregate in compliance with CS3:2013.

(c) Pulverized material, which shall be clean sedimentary rock material, with a grain size of not more than 100 μm and adequate calcium carbonate content, but without excessive clay content.

(d) Admixtures typically acceptable for concrete mixes.

(e) Clean fresh water taken from the public supply.

The SCM for use in slope and retaining wall works is considered as a geomaterial. Hence, the PS at Appendix B is prepared to supplement Section 7 – Geotechnical Works of the GS.

4.2 Material Properties

With a view to taking full advantage of the self-levelling and self-consolidating characteristics of the SCM in supporting its proposed use in fill replacement operations in lieu of conventional soil backfill, the required properties of the SCM focuses on maintaining consistency of the SCM mix with a reasonable range of wet density and on achieving high flowability without segregation. Moreover, the SCM shall provide an adequate level of strength, which is comparable or better than compacted soil backfill, to suit the intended use in LPMit works.

Other than the above, the SCM shall have no liquefaction potential and shall not have significant changes in properties in long term. Owing to the cementitious nature of the SCM, its liquefaction potential of the SCM is considered negligible. Concerning the long term performance, NAMI advised that their SCM is observed to have a marginal increase in compressive strength over a 12 month period. With due consideration of the composition of the SCM mixes based on the PS at Appendix B and the elaborations in Sections 3.1 and 4.1 above, no significant change of the properties of the SCM in long term is anticipated.

4.2.1 Strength

In view of the introduction of cementitious material in SCM mixes, the strength of SCM would develop with time. Following the practice of using cement grout in geotechnical works, the use of 28-day compressive strength to represent its ultimate strength is considered appropriate.

The compressive strength of SCM at 28 days is specified to be at least 0.2 MPa in the PS at Appendix B. As advised by NAMI, the SCM-NAMI should be capable of achieving the required minimum strength of 0.20 MPa. Nonetheless, the assessment of slope and retaining wall stability remains to be the responsibility of designers. Detailed assessment to determine the minimum strength of 0.20 MPa of the SCM for quality control purpose with justifications is given in Appendix F. The requirement on the maximum strength of the SCM, as specified in HyD's PS for use of the SCM in road works to facilitate future re-excavation, is not required for slope and retaining wall works.

For the compliance test of minimum strength level, UCS tests for cylindrical specimens has been specified with due consideration on the use of the SCM for geotechnical works, availability of suitable laboratory test methods and the respective HOKLAS (The Hong Kong Laboratory Accreditation Scheme) accreditation status of public and commercial laboratories in Hong Kong. The method of testing shall be in accordance with Appendix B of the "Interim Guidelines on Testing of Unconfined Compressive Strength of Cement Stabilised Soil Cores in Hong Kong" published by Geotechnical Division of The Hong Kong Institution of Engineers in October 2017.

4.2.2 Flowability

The flowability of the SCM is specified to be at least 200 mm without segregation according to ASTM D6103-17. The requirement is compatible with the flowability range of high flowability CLSM as recommended by the ACI (ACI, 2013) to ensure the exhibition of self-levelling and self-consolidating properties of the SCM.

4.2.3 Others

Checking the unit weight of fresh SCM is a simple method to control the consistency of SCM. With reference to HyD's PS for road works, the subsequent advice from NAMI and the recommendations about normal CLSM by ACI (ACI, 2013), a range of wet density of 1,900 kg/m^3 to 2,300 kg/m^3 according to CS1:2010 Section 5 is specified. Concerning the site application of the material, the SCM shall be placed in a manner to avoid segregation and loss of constituents.

The requirements on the thermal conductivity of the SCM as specified in HyD's PS for protecting the adjacent electric cables are normally unnecessary in slope and retaining wall works. Moreover, the ball-drop test for checking the development of early strength of SCM in road works are also considered unnecessary under normal circumstances in slope and retaining wall works.

5 Design Considerations

5.1 Scope of Applications

This pilot study and the site trials focused on the use of SCM as an alternative to other conventional materials for backfilling of pits, trenches and voids in fill replacement operations in slope and retaining wall works, with the basic quality control requirements formulated as detailed in Appendix B to facilitate its uses in suitable projects.

SCM is an artificial material with properties fall between soil and concrete. For low strength SCM, designers may consider the use of SCM as a geomaterial which exhibits more soil-like performance and behaviour in other geotechnical applications, subject to necessary geotechnical assessment and detailed geotechnical designs with due consideration of the properties of the SCM. The assessment and detailed design shall be supplemented by necessary material tests. Enhanced minimum strength requirements and / or other additional quality control requirements in addition to that in the PS at Appendix B shall be proposed as needed.

The measured groundwater levels of all sites under the trial were lower than the base levels of the SCM-NAMI. It is suggested avoiding placing or specifying the SCM under submerged conditions with a view to addressing the potential concerns about segregation and loss of constituent caused by persistent groundwater flow.

5.2 Overall Stability

In the design of conventional soil fill slopes, it is necessary for the designer to assess the overall stability of the slope. For SCM, which is primarily designed as an alternative to compacted soil, a similar design methodology for assessing the overall stability of the fill slope can be adopted. In general, SCM in compliance with the PS at Appendix B fulfils the typical shear strength levels of compacted soil fill with negligible liquefaction potential. The compressive strength of SCM at 28 days is specified to be at least 0.2 MPa with a view to avoiding the development of critical failure surfaces within the SCM in the general application of the SCM as an alternative to the conventional fill slope upgrading works involving fill re-compaction.

If designers choose to use SCM-NAMI, the shear strength of SCM-NAMI should be generally higher than compacted soil fill but lower than cement-soil, taking into consideration the amount of cementitious content in SCM-NAMI. Designers may also make reference to the results of UCS tests of SCM-NAMI in deriving the design shear strength parameters, with incorporation of suitable material factor to account for possible uncertainty involved in the material quality as discussed in Appendix F. For SCM other than SCM-NAMI, or where the designer would adopt higher design shear strength parameters, relevant laboratory tests should be carried out to justify the adopted design parameters.

Density of material is normally not a highly sensitive parameter in slope stability analysis. For the density of SCM-NAMI to be adopted in designs, designer can make reference to the typical values as documented in item (e) of Section 3.3 of this Technical Note. For SCM other than SCM-NAMI or where the designers consider necessary, site-specific tests to determine density of the material should be arranged. Designers may consider the potential use of alternative SCM mixes of lower density on a case-by-case basis to meet their design need.

The determination of design parameters, including but not be limited to strength, density and permeability, of the SCM in slope stability assessments shall remain the responsibility of designers. Designers shall consider specific circumstances of the slopes and retaining walls in determining the design parameters of the SCM.

5.3 Drainage Measures

The permeability of a SCM mix varies with the composition of mix. Based on the laboratory test results of site trials as summarised in Section 3.3, the lower range mass permeability of SCM-NAMI is marginally below 10^{-8} m/s. It is expected that SCM mixes satisfying the requirements in the PS at Appendix B would be relatively impermeable, with a mass permeability close to the lower bound values of the compacted soil fill as stated in Geoguide 1 (GEO, 2020b). Hence, designers shall consider the need for provision of subsurface drainage measures on a case-by-case basis to suit the design needs of individual slopes and retaining walls. In general, the designer should consider to provide surface drainage channels and / or subsurface drainage measures at crest of the slope, and provide prescriptive raking drains as far as practicable.

6 Further Work

6.1 Greening Capability

Based on the experience obtained so far, vegetation growth on SCM is considered possible but apparently more difficult than compacted soil fill due to its cementitious nature. Separate planting site trials and monitoring have been arranged to ascertain the capability and limitations of vegetation growth. In the interim, the provision of a layer of topsoil for hydroseeding or planting of shrubs is suggested.

6.2 Submerged Conditions

Currently, it is specified in the PS at Appendix B that SCM shall not be placed under submerged conditions with a view to avoiding segregation, loss of constituent and adverse impact on the strength of material. Preliminary results showed that there was a reduction in strength in UCS tests when the specimen of SCM-NAMI was soaked in water before the tests. Although such reduction has been catered by the material factor applied in the determination of the required minimum strength of the material, it is suggested to arrange further comprehensive control tests to evaluate the effect on the material properties of SCM-NAMI under different water conditions.

7 Conclusions

This pilot study with site trials as presented in this Technical Note has confirmed that the SCM is a technically feasible alternative to conventional fill materials in backfilling of pits, trenches and voids in slope and retaining wall works.

A set of PS setting out the quality control requirements for the use of SCM for backfilling of pits, trenches and voids in slope and retaining wall works has been compiled for reference by geotechnical practitioners as appended in Appendix B. Designers are encouraged to consider the use of SCM in suitable projects with a view to enhancing the constructability and site safety of slope and retaining wall works.

Notwithstanding this, designers' attention is drawn to the scope and limitations of this pilot study in connection with the use of SCM in slope and retaining wall works as documented in this Technical Note and provide case-specific design input involving the use of SCM accordingly.

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Appendix A

Technical Information of Self-compacting Backfill Material for Backfilling Trenches and Voids in Road Works

Contents

A1 General

Key technical information of the self-compacting backfill material for backfilling utility trenches and voids are summarised in this appendix with reference to HyD's particular specification for use of the self-compacting backfill material for backfilling utility trenches and voids (HyD, 2022) and the technical information shared by NAMI (Nissinen, 2021).

A2 Properties and Benefits in Road Works

- High flowability – easy for backfilling congested space such as underground voids or space between pipelines and cables
- Self-levelling and self-consolidating – no need for compaction during placing, thus shorten the overall backfilling time when compared with compaction of soil in layers
- Fast setting – allow application of the surfacing material (e.g. flexible pavements) shortly after it is hardened
- Suitable for pumping – overcome site access difficulties
- Low strength – easy for future re-excavation

A3 Technical Requirements for Backfilling Trenches and Voids in Road Works

Composition	Cementitious material, fine aggregates, crushed stone fines, water and admixtures
Density	Between 1,900 kg/m^3 and 2,100 kg/m^3
Flowability	$\geq$ 200 mm (without segregation)
Compressive Strength (Cube Strength at 28 days)	Not less than 0.3 MPa; and Not more than 1 MPa (for utility trench backfilling) or 2 MPa (for other void backfilling)
Hardening Time	8 to 24 hours
Initial Strength for Load Placement	No indentation with diameter larger than 75 mm is observed after ball-drop test (ASTM D6024-16)
Thermal Conductivity	> 1.1 W/mK, when moisture content is > 10%

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Appendix B

Particular Specification for Use of Self-compacting Backfill Material in Backfilling of Pits, Trenches and Voids in Slope and Retaining Wall Works

[Clauses to be incorporated in Section 7 – Geotechnical Works]

SELF-COMPACTING BACKFILL MATERIAL FOR BACKFILLING OF PITS, TRENCHES AND VOIDS IN SLOPE AND RETAINING WALL WORKS

(a) GLOSSARY OF TERMS FOR SELF-COMPACTING BACKFILL MATERIAL

(1) Self-compacting backfill material (SCM) shall be a mix of (i) cementitious material; (ii) fine aggregate; (iii) pulverized material; (iv) water; and (v) admixtures for controlling the rheology and setting time of the mix.

(2) This PS for use of SCM shall apply in backfilling of pits, trenches and voids in slope and retaining wall works when so ordered by the Engineer.

(b) MATERIALS

(1) Cementitious material shall be Portland Cement (PC) to BS EN 197-1:2011 or Pulverized Fuel Ash (PFA) to BS EN 450-1:2012.

(2) Fine aggregate shall be clean and hard complying with CS3:2013. Natural sand shall not be used unless with the prior agreement of the Engineer.

(3) Pulverized material shall be clean sedimentary rock material with the following requirements:

(a) grain size of not more than 100 μm as determined in accordance with Test Method 8.5 of Geospec 3 or equivalent;

(b) the clay content, determined by the methylene blue test in accordance with CS3:2013 shall not exceed 1.50 g/100 g; and

(c) Calcium carbonate ($CaCO_3$) content calculated from the calcium oxide content in accordance with BS EN 196-2:2013 shall be at least 75% by mass.

(4) Admixtures shall comply with the following: BS EN 12878:2014 for pigments, BS EN 934-2:2009 for accelerating admixtures, retarding admixtures and water-reducing admixtures and BS EN 934-2:2009 for superplasticising admixtures.

(5) Water shall be clean fresh water taken from the public supply. Wash water from concrete mixer washout operations (recycled water) shall not be used.

(c) SUBMISSIONS

(1) The following particulars of the proposed cementitious material, fine aggregate and pulverized material shall be submitted to the Engineer for approval at least 14 days before the SCM is placed:

(a) Certificate issued within 6 months for each type of cement or PFA showing the manufacturer's name, the date and place of manufacture and showing that the cement or PFA complies with the requirements, including results of tests for composition;

(b) Certificates/documents issued within 6 months for fine aggregate in accordance with Clause 6.2.2(2) of CS3:2013 showing the compliance of requirements; and

(c) Certificates/documents issued within 6 months for pulverized material showing the compliance with the requirements, including results of tests for grain size, methylene blue value and calcium carbonate content.

(2) The following particulars of the proposed admixtures shall be submitted to the Engineer for approval at least 14 days before the SCM is placed:

(a) Manufacturers' literature, description of physical state, colour and composition, recommended storage conditions and shelf life;

(b) Method of adding to the SCM mix, recommended dosage, effects of under-dosage and over-dosage; and

(c) A certificate issued within 6 months for each type of admixture showing the manufacturer's name, the date and place of manufacture and showing that the admixture complies with the requirements.

(3) The following particulars of each proposed designed SCM mix shall be submitted to the Engineer for approval at least 14 days before the SCM is placed:

(a) Grading of fine aggregates;

(b) Method of placing the SCM;

(c) Hardening time of the SCM; and

(d) Source, formulation, test data for designed SCM mix produced in the plant or plants and test reports of site trials for designed SCM mix proposed to be used, including results of tests in Clause (j) conducted on the site trial samples to demonstrate the appropriateness of their SCM formulation meeting the compliance criteria in Clause (i).

(4) For ready-mixed SCM, the following particulars shall be submitted to the Engineer for approval at least 14 days before the SCM is placed:

(a) The name of the supplier and the location of the plant from which the Contractor proposes to obtain ready-mixed SCM.

(5) For SCM to be produced on the Site, the following particulars shall be submitted to the Engineer for approval at least 14 days before the SCM is placed:

(a) The name of the supplier and details of the proposed plant to be used for producing SCM on the Site, including a layout plan and the output of the plant; and

(b) Method of batching and mixing SCM, including measures to maintain the quality of the SCM produced.

(d) <u>BATCHING AND MIXING</u>

(1) The batching and mixing of ready-mixed SCM shall comply with Clauses 16.37 and 16.38 of GS. In connection with the above, the term “concrete” in Clauses 16.37 and 16.38 shall refer to SCM. In addition, a mixer shall be thoroughly cleaned before mixing SCM if the mixer has been used to mix concrete beforehand.

(2) The batching and mixing of SCM to be produced on Site shall comply with the particulars submitted by the Contractor and approved by the Engineer mentioned in sub-clause (5)(b) of Clause (c).

(e) <u>TRANSPORTATION OF SELF-COMPACTING BACKFILL MATERIAL</u>

(1) SCM shall not be transported in a manner that will result in contamination, segregation, and loss of constituents.

(2) SCM batched off the Site shall be transported to the Site in purpose-made agitators operating continuously or in truck mixers.

(3) Truck mixers transporting SCM shall be thoroughly cleaned before loading and transporting fresh SCM.

(f) RECORDS OF SELF-COMPACTING BACKFILL MATERIAL

(1) Delivery notes shall be provided for each delivery of ready-mixed SCM to the Site. The delivery notes shall be kept on the Site and shall be available for inspection by the Engineer at all times. Delivery notes shall contain the following details:

(a) Serial number of delivery note;
(b) Date;
(c) Name and location of batching and mixing plant;
(d) Registration number of delivery vehicle;
(e) Name of purchaser;
(f) Name and location of the Site;
(g) Designation of SCM mix;
(h) Sources of cementitious materials and fine aggregate;
(i) Quantity of SCM;
(j) Time of introduction of water to the SCM; and
(k) Source, formulation and proprietor of SCM mix.

In the event that SCM is to be produced on the Site, the Contractor shall submit a proposed list of particulars about the SCM to be produced to the Engineer for approval at least 14 days before the SCM is placed. Details of the particulars shall be kept on the Site and shall be available for inspection by the Engineer at all times.

(2) Records of SCM placing operations shall be kept by the Contractor on the Site and shall be available for inspection by the Engineer at all times. Records shall contain the following details:

(a) Date;
(b) Designation of SCM mix;
(c) Total quantity of each SCM mix produced that day;
(d) Serial number of delivery note;
(e) Arrival time of delivery vehicle;
(f) Time of completion of discharge;
(g) Location(s) and position(s) where SCM is placed;
(h) Results of density tests and flowability tests; and
(i) Details of test cylinders made for compressive strength tests.

(3) Certificates/documents issued within 6 months showing the sources of cementitious material and fine aggregate mentioned in sub-clause (1)(h) of this Clause shall be kept by the Contractor on the Site and shall be available for inspection by the Engineer at all times.

(g) PLACING OF SELF-COMPACTING BACKFILL MATERIAL

(1) The permission of the Engineer shall be obtained before SCM is placed in any part of the permanent work. If the placing of SCM is not started within 24 hours of the permission being given, permission shall again be obtained from the Engineer. The Contractor shall inform the Engineer before placing operation starts and shall allow the Engineer sufficient time to inspect the work that is to be covered up.

(2) Fresh SCM shall be placed in its final position within 2½ hours of the introduction of water to the SCM mix.

(3) Additional protective sheets shall be used around the discharging area to avoid any splashing of SCM. Trunking or chutes, where being used, shall be clean and used in such a way to avoid segregation and loss of constituents of the SCM.

(4) SCM can be placed with concrete pumps, which shall be operated and maintained in accordance with the supplier's recommendations. The pumps and pipelines shall be maintained in a clean condition. Joints in pipelines shall be tightly fixed and shall not permit grout loss.

(5) SCM shall not be placed under submerged conditions.

(h) TESTING AND SAMPLING

(1) Samples of fresh SCM shall be collected from the first batch and from subsequent batches after discharge of every or less than 25 cubic meters. Samples are collected from the first vehicle delivering the SCM or the initially mixed SCM in the above batches. The number of tests for flowability, density of fresh SCM, and compressive strength of SCM may be reduced if in the opinion of the Engineer the standard of quality control is satisfactory.

(2) The density of fresh SCM shall be tested according to CS1:2010 Section 5 where two samples are collected from a batch.

(3) The flowability of the SCM shall be tested according to ASTM D6103-17 or equivalent, where two samples are collected from a batch.

(4) Two samples are collected from a batch for determination of compressive strength at 28 days, where a pair of testing cylinders shall be made from each sample by pouring the SCM into a non-reusable rigid clear Acrylonitrile Butadiene Styrene plastic mold.

The diameter of the cylindrical specimens shall be within 63mm to 100mm where the minimum length to diameter ratio is 2 to 1. The method of testing shall be in accordance with Appendix B of the "Interim Guidelines on Testing of Unconfined Compressive Strength of Cement Stabilised Soil Cores in Hong Kong" published by Geotechnical Division of The Hong Kong Institution of Engineers in October 2017. Two additional samples shall be provided from the same batch. The Engineer may order additional tests for reviewing the quality of the SCM.

(i) COMPLIANCE CRITERIA

(1) The compressive strength of the SCM at 28 days shall be not less than 0.20 MPa.

(2) The density of fresh SCM shall be in the range of 1900 kg/m^3 to 2300 kg/m^3.

(3) The flowability of the SCM shall be no less than 200 mm without segregation according to ASTM D6103-17.

(j) NON-COMPLIANCE

(1) If the result of either the flowability or density test carried out on a sample taken from the first vehicle of the batch does not comply with the specified requirements for flowability and density, the SCM in that vehicle shall not be placed. Another sample from the subsequent vehicle of the same batch shall be collected for testing the flowability and density until complying with the requirements.

(2) If the compressive strength at 28 days of the SCM does not comply with the specified requirements, the Contractor shall be required to propose rectification measures to the satisfaction of the Engineer.

Appendix C

Material Composition and Key Properties of Typical Mixes of Controlled Low-Strength Material

Contents

C1 General

Controlled Low-Strength Material (CLSM) is a collective term to describe a family of mixtures that compose of a self-consolidating cementitious material used primarily as a backfill as an alternative to compacted fill (ASTM, 1998). The history of CLSM and the development of its corresponding control standards are documented in a symposium paper prepared by Jennifer L. Hitch (Hitch, 1998).

C2 Material Composition

According to the American Concrete Institute (ACI, 2013), conventional CLSM mixes usually consist of the following components:

(a) Portland cement and fly ash – Cement provides cohesion and strength for CLSM mixes. Fly ash is sometimes used to improve flowability. The use of fly ash can also increase strength and reduce bleeding, shrinkage, and permeability.

(b) Aggregates and filler material – Aggregates are often a major constituent of a CLSM mix. The type, grading and shape of aggregates can affect the physical properties, such as flowability and compressive strength, of the CLSM mix. Filler material with adequate fines, which can be classified as mineral admixtures if natural filler is adopted, is typically incorporated in a CLSM mix for achieving high flowability without segregation.

(c) Water – Water that is acceptable for concrete mixes is acceptable for CLSM mixes.

(d) Other admixtures and additives – The inclusion of other suitable admixtures and additives in CLSM mixes can improve workability, reduce bleeding and segregation, and control strength development.

(e) Non-standard materials – According to the ACI, non-standard materials may be used in CLSM mixes depending on project requirements for achieving the desired properties and economy. However, the suitability of the material should be tested in a CLSM mix to determine whether it meets the quality requirements.

C3 Key Properties

The key properties of CLSM mixes recommended by ACI which are pertinent to their uses in slope and retaining wall works are summarised below:

(a) Strength – A CLSM is a mixture intended to result in a compressive strength of 8.3 MPa (i.e. 1200 psi) or less, while most applications require an unconfined compressive strength of 0.2 MPa to 1.0 MPa (i.e. 25 psi to 150 psi) at 28 days. A CLSM with a target maximum compressive strength of less than 1.0 MPa (i.e. 150 psi) is generally classified as a lower-strength CLSM mix. Lower-strength CLSM exhibits characteristic properties of soils.

(b) Flowability – Flowability of a CLSM can vary from stiff to fluid, depending on its intended uses. A CLSM with high flowability (i.e. slump greater than 200 mm) enables it to be self-levelling, self-consolidating and void-fillable. Highly flowable CLSM without segregation can be produced with adequate proportioning of fines (from mineral admixtures or other constituents) to achieve appropriate aggregate suspension and stability. However, plastic fines (such as clay) which lead to shrinkage should be avoided.

(c) Density – The typical wet density of a CLSM ranges from 1,840 kg/m^3 to 2,320 kg/m^3.

(d) Pumpability – A CLSM can be delivered by conventional concrete pumping equipment. Its pumpability can be enhanced by adequate proportioning of materials. For example, mineral admixtures and fly ash can act as micro-aggregate for void filling to enhance pumpability.

(e) Excavatability – In general, CLSM with unconfined compressive strength of 0.7 MPa (i.e. 100 psi) or less can be excavated with hand tools.

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Appendix D

Summary of Pilot Applications

Contents

List of Tables

Table D1 List of Pilot Sites

Feature No.	Location	Contract No.	Consultants	Contractor	Trial Period	Volume (m^3)
7SW-D/C454	Lei Uk Tsuen, Shatin	GE/2018/02	AECOM Asia Company Ltd.	China Geo-Engineering Corporation	02/2021 to 03/2021	166
15NE-A/F116	Tai Tam Road, Southern	GE/2019/02	Fugro (Hong Kong) Ltd.	Geotech Engineering Ltd.	04/2021 to 06/2021	22
7SE-C/F110	Near Pok Hong Estate, Shatin	GE/2018/11	AECOM Asia Company Ltd.	China Geo-Engineering Corporation	05/2021 to 08/2021	179
6NE-C/R45	Sung Shan New Village, Yuen Long	GE/2020/03	C M Wong & Associates Ltd.	China Geo-Engineering Corporation	07/2021 to 08/2021	50
8SW-A/R16	Tso Wo Hang, Sai Kung	GE/2019/02	Fugro (Hong Kong) Ltd.	Geotech Engineering Ltd.	08/2021 to 09/2021	50
14NW-D/FR53	Kwun Yam Wan Road, Cheung Chau	GE/2019/23	AECOM Asia Company Ltd.	China Geo-Engineering Corporation	05/2022 to 06/2022	30
14NW-D/FR54	Kwun Yam Wan Road, Cheung Chau	GE/2019/23	AECOM Asia Company Ltd.	China Geo-Engineering Corporation	08/2022 to 09/2022	10
11NW-D/FR141	King’s Park, Yau Tsim Mong	GE/2019/03	C M Wong & Associates Ltd.	Chi Wo Contractors Ltd.	02/2022 to 03/2023	855

Table D2 Key Findings of the Pilot Application at Feature No. 7SW-D/C454

Feature No.	7SW-D/C454
Location:	Lei Uk Tsuen, Shatin
Site Setting:	Slope with vehicular access and working area available at about 100 m away from the slope portion requiring fill replacement
Trial Period:	02/2021 to 03/2021
Volume (m^3):	166
Brief Description:	Use of ready-mixed SCM (placed with concrete pump) for replacement of top 3 m of loose fill on slope
Main Target of the Trial:	Initial trial for identifying the possible site arrangement for the application of the SCM on slope and other key issues requiring attention and further development
Key Findings:	Pumping of SCM for about 105 m horizontally and about 30 m vertically can be achieved with no difficulty. Conventional setup of concrete pumping equipment (i.e. concrete pump and pipes for concrete pumping) enables the placement of SCM at the site. SCM enables major time saving for the backfilling operations when compared with re-compaction of the existing fill. Manual handling is minimised due to the pumpability and the self-compacting properties of the SCM. The material cost of SCM is higher than that for conventional fill replacement methods.
Site Photographs:	 Pumping hose for SCM placement  Placement of SCM in a trench

Table D3 Key Findings of the Pilot Application at Feature No. 15NE-A/F116

Feature No.	15NE-A/F116
Location:	Tai Tam Road, Southern
Site Setting:	Catchwater slope with vehicular access available at over 200 m away from the slope portion requiring fill replacement with an existing lay-by on public road available for unloading of ready-mixed SCM
Trial Period:	04/2021 to 06/2021
Volume (m^3):	22
Brief Description:	Use of ready-mixed SCM (placed with concrete pump) for replacement of top 3 m of loose fill on slope
Main Target of the Trial:	Further trial for identifying the possible site arrangement for the application of the SCM on slope and other key issues requiring attention and further development, and for verifying the capability of the SCM for long distance pumping.
Key Findings:	Pumping of SCM for about 285 m horizontally and about 15 m vertically can be achieved with no difficulty. Conventional setup of concrete pumping equipment (i.e. concrete pump and pipes for concrete pumping) enables the placement of SCM at the site. SCM enables major time saving for the backfilling operations when compared with re-compaction of the existing fill. Manual handling is minimised due to the pumpability and the self-compacting properties of the SCM. The material cost of SCM is higher than that for conventional fill replacement methods.
Site Photographs:	 Pumping equipment for SCM placement  Placement of SCM in progress

Table D4 Key Findings of the Pilot Application at Feature No. 7SE-C/F110

Feature No.	7SE-C/F110
Location:	Near Pok Hong Estate, Shatin
Site Setting:	Roadside slope with convenient vehicular access and working area at the crest of the slope portion requiring fill replacement
Trial Period:	05/2021 to 08/2021
Volume (m^3):	179
Brief Description:	Use of ready-mixed SCM for replacement of top 3 m of loose fill on slope
Main Target of the Trial:	Further trial for identifying the possible site arrangement for the direct placement of ready-mixed SCM unloaded at slope crest without concrete pump and other key issues requiring attention and further development
Key Findings:	Direct placement of ready-mixed SCM unloaded at slope crest using chutes commonly used at construction sites is feasible with no difficulty. SCM enables substantial time saving for the backfilling operations when compared with re-compaction of the existing fill. Manual handling is minimised due to the self-compacting properties and ease of application of the SCM. The material cost of SCM is higher than that for conventional fill replacement methods.
Site Photographs:	 General view of the feature  Preparation for unloading of ready-mixed SCM

Table D5 Key Findings of the Pilot Application at Feature No. 6NE-C/R45

Feature No.	6NE-C/R45	
Location:	Sung Shan New Village, Yuen Long	
Site Setting:	Rural site requiring access through village roads with vehicular access and working area available at about 20 m away from the retaining wall requiring fill replacement	
Trial Period:	07/2021 to 08/2021	
Volume (m^3):	50	
Brief Description:	Use of ready-mixed SCM (placed with concrete pump) for replacement of loose fill behind retaining wall	
Main Target of the Trial:	Trial for identifying any key issues for replacement of fill by SCM behind retaining wall	
Key Findings:	•The application of SCM behind existing retaining wall is fast and easy with no difficulty. •The initial setting time of the SCM is relatively long (around 8 hours) when compared with conventional concrete. •The material cost of SCM is higher than that for conventional concrete or no-fines concrete.	
Site Photographs:	 Placement of SCM in a pit	 Completion of pit-by-pit fill replacement by SCM

Table D6 Key Findings of the Pilot Application at Feature No. 8SW-A/R16

Feature No.	8SW-A/R16
Location:	Tso Wo Hang, Sai Kung
Site Setting:	Rural site requiring fill replacement behind retaining wall surrounded by village houses with restricted vehicular access
Trial Period:	08/2021 to 09/2021
Volume (m^3):	50
Brief Description:	Use of SCM mixed on site for replacement of loose fill behind retaining wall
Main Target of the Trial:	Trial for identifying the possible site arrangement for mixing SCM on site and for reviewing the feasibility about the use of SCM to be mixed on site
Key Findings:	•Skilled labourer with experience in site mixing of cementitious material is demanded to ensure the application of the correct proportion of the constituents following the recommendation by the relevant manufacturer. •The quality of SCM mixed site using the screw mixer recommended by the relevant manufacturer is reasonably consistent. •Due to site constraints, considerable manual handling for transportation of plant and materials for the mixing of SCM to the works site is required. •The screw mixer for mixing SCM is not sizable which enables manual transport to the works site after unloading at the nearest vehicular access point. •The noise and dust impact arising from the site mixing of SCM is manageable. •The application of SCM behind existing retaining wall is easy with no difficulty. •The material cost of SCM is higher than that for conventional concrete or no-fines concrete.
Site Photographs:	 Production of SCM using screw mixer on site

Table D7 Key Findings of the Pilot Application at Feature Nos. 14NW-D/FR53 & 14NW-D/FR54

Feature No.	14NW-D/FR53 & 14NW-D/FR54
Location:	Kwun Yam Wan Road, Cheung Chau
Site Setting:	Roadside slopes adjacent to a public road on an outlying island requiring fill replacement located at more than 500 m away from public pier
Trial Period:	05/2022 to 06/2022 (14NW-D/FR53) 08/2022 to 09/2022 (14NW-D/FR54)
Volume (m^3):	30 (14NW-D/FR53) and 10 (14NW-D/FR54)
Brief Description:	Use of SCM mixed on site for replacement of top 3 m of loose fill on slope
Main Target of the Trial:	Trial for verifying the site logistic on the application of SCM to be mixed on site on an outlying island with remote access
Key Findings:	Skilled labourer with experience in site mixing of cementitious material is demanded to ensure the application of the correct proportion of the constituents following the recommendation by the relevant manufacturer. The quality of SCM mixed site using the screw mixer recommended by the relevant manufacturer is reasonably consistent. The screw mixer for mixing SCM is not sizable which enables transport to the works site from the public pier using village vehicles. The noise and dust impact arising from the site mixing of SCM is manageable. The application of SCM is easy with no difficulty. The site mixing of SCM enables application of the SCM at the slope portion requiring fill replacement in a continuous operation without interruption due to the restriction of the loading capacity of village vehicles. The overall cost for the application of the SCM under the concerned site setting is high.
Site Photographs:	 Placement of SCM at Feature No. 15NW-D/FR53 in progress  Placement of SCM in a pit at Feature No. 15NW-D/FR54 completed

Table D8 Key Findings of the Pilot Application at Feature No. 11NW-D/FR141

Feature No.	11NW-D/FR141	
Location:	King's Park, Yau Tsim Mong	
Site Setting:	Slope with vehicular access and working area available at about 50 m away from the slope portion requiring fill replacement	
Trial Period:	02/2022 to 03/2023	
Volume (m^3):	855	
Brief Description:	Use of ready-mixed SCM (placed with concrete pump) for replacement of top 3 m of loose fill on slope	
Main Target of the Trial:	Trial for identifying any issues related to a relatively large scale application (near 1,000 m^3) of SCM and for reviewing the constraints and limitations as identified in earlier trials	
Key Findings:	Pumping of SCM for about 100 m horizontally and about 30 m vertically can be achieved with no difficulty. Conventional setup of concrete pumping equipment (i.e. concrete pump and pipes for concrete pumping) enables the placement of SCM at the site. SCM enables major time saving for the backfilling operations. Manual handling is minimised due to the pumpability and the self-compacting properties of the SCM. The initial setting time of the SCM is relatively long (around 8 hours) when compared with conventional concrete. SCM with very high workability, say more than 350 mm in flowability tests, may exhibits lower strength near the minimum requirement in UCS tests with relatively higher potential of segregation. The routine preparation of cylindrical samples for testing is straight forward with no major difficulty. Early coordination with testing laboratories are recommended for the preparation of specimens and for the implementation of the UCS tests at the specified age of samples. The material cost of SCM is higher than that for conventional fill replacement methods.	
Site Photographs:	 Preparation for pit-by-pit fill replacement by SCM in progress	 Existing fill at feature replaced by SCM

Appendix E

Summary of Test Results

Contents

List of Figures

E1 General

Other than the checking of wet density and flowability of the fresh self-compacting backfill material developed by NAMI (SCM-NAMI), various tests including unconfined compressive strength tests, triaxial tests, direct shear tests and permeability tests were carried out during site trials to investigate the performance, including strength, shearing behaviour and permeability, of SCM-NAMI.

E2 Unconfined Compressive Strength (UCS) Tests of Cube Samples

As stated in Section 3.3(c), UCS tests of cubes samples at an age of 28 days were carried out for quality control at the initial stage of the site trials as recommended by NAMI. A total of 478 UCS tests on 100 mm x 100 mm x 100 mm size cube samples were carried out. The UCS of cube samples ranges from 0.3 MPa to 1.8 MPa, which satisfy the technical requirements promulgated by HyD for backfilling of trenches and voids in Appendix A. The distribution of UCS of cube samples as revealed from the tests is shown in Figure E1.

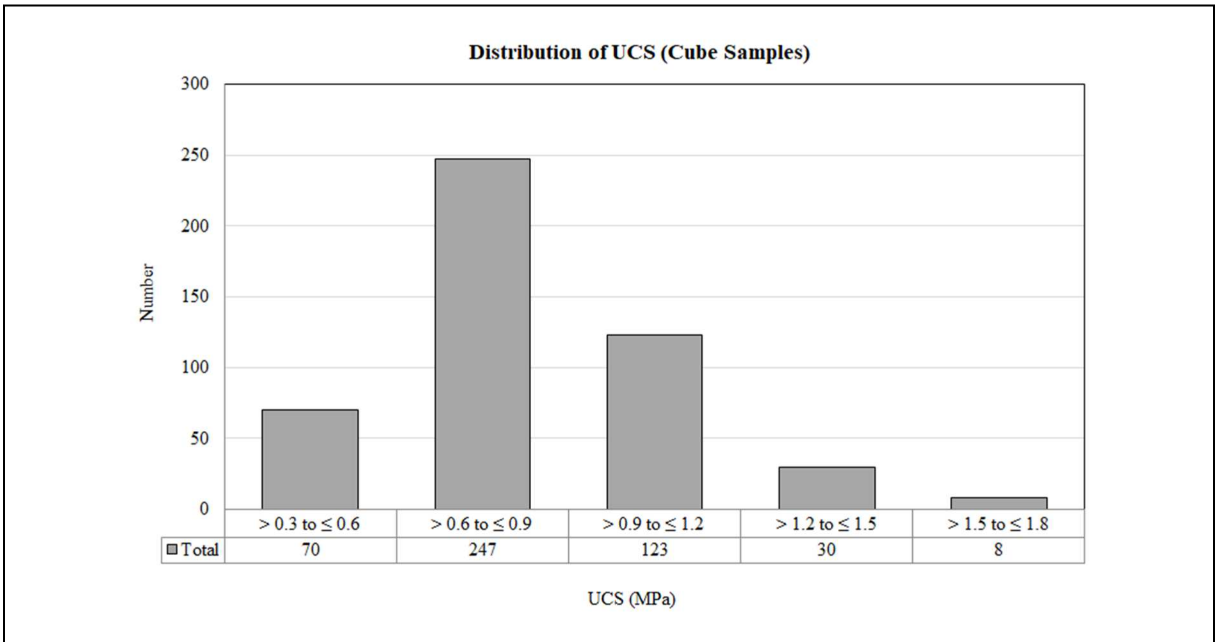

Figure E1 Distribution of UCS (Cube Samples)

E3 Unconfined Compressive Strength (UCS) Tests of Cylindrical Samples

As stated in Section 3.3(c), the cube tests as summarised in Section E2 above were subsequently migrated to UCS tests of cylindrical samples at an age of 28 days based on the particular specification in Appendix B. The size of the cylindrical specimens are typically about 75mm diameter with a length of about 150 mm. A total of 98 UCS tests on cylindrical samples were carried out. The UCS of the cylindrical samples ranges from 0.28 MPa to 0.94 MPa, which satisfy the compliance criteria of the particular specification in Appendix B. The distribution of UCS of cylindrical samples as revealed from the tests is shown in Figure E2.

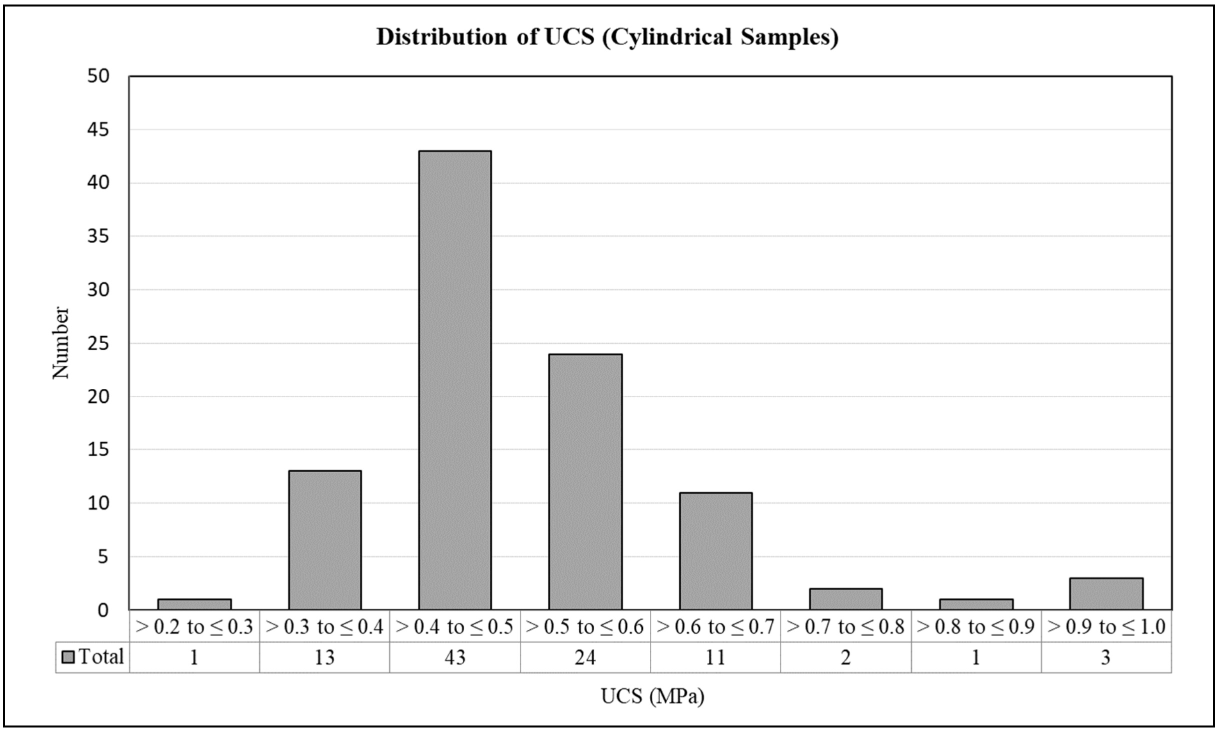

Figure E2 Distribution of UCS (Cylindrical Samples)

E4 Bulk Density of SCM-NAMI

Distribution of bulk density from 315 specimens are presented in Figure E3. More than 90% of the specimens had bulk density ranged from 2.00 Mg/m^3 to 2.20 Mg/m^3.

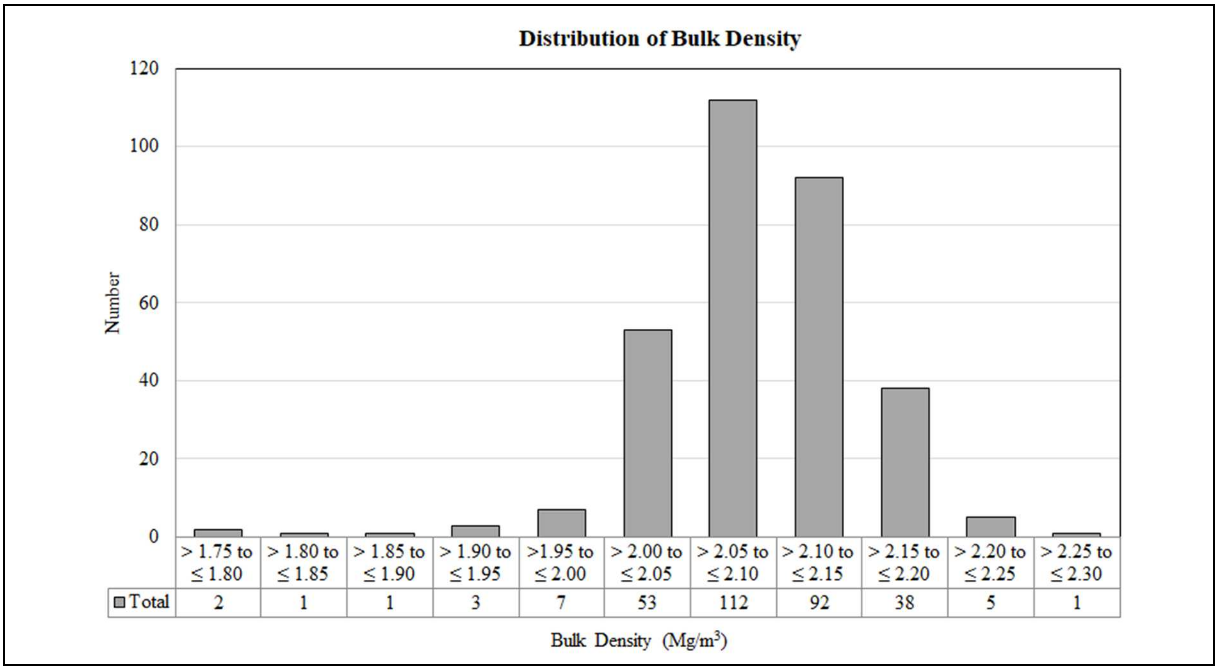

Figure E3 Distribution of Bulk Density

E5 Permeability Tests

A total of 95 permeability tests were conducted. 3 of them are in-situ falling head tests, with permeability ranged from 5.2×10^{-6} m/s to 1.8×10^{-7} m/s. Among the 92 laboratory tests, 81 are falling head tests while 11 are constant head tests with permeability ranged from 1.3×10^{-6} m/s to 7.4×10^{-9} m/s.

Appendix F

Determination of Required Minimum Strength of the Self-compacting Backfill Material

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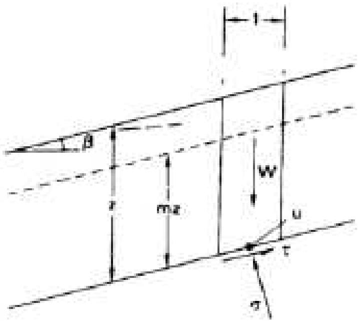
List of Figure

F1 Stability Assessment

Concerning the required minimum strength level of the Self-compacting Backfill Material (SCM), the required strength for the SCM is first determined through the stability checking of hypothetical slopes of varying slope angles formed by about 3 m thick of SCM against sliding failure under undrained conditions using infinite slope analyses. An extreme case with a slope angle of 45 degrees and a SCM thickness of 3.5 m to cater for local deepening is considered. A material factor of 2 is also included to account for any possible uncertainty involved in the material quality. The stability checking is shown in Figure F1.

Stability Analysis of Infinite Slope - Total Stress Case



- The FOS decreases with increasing slope angle and depth of failure surface

$$FOS = \frac{c_u}{\gamma z \sin\beta \cos\beta} = \frac{2c_u}{\gamma z \sin(2\beta)}$$

(Not Applicable to β > 45 degrees)

Assume m = 1 (i.e. the water table coincides with the surface of the slope)

γ_{soil} (kN/m3) =	20	20	20	20	20	20
β =	35	40	45	35	40	45
z (m) =	3	3	3	3.5	3.5	3.5
c' (kPa) =	39.47	41.37	42.00	46.05	48.26	49.00
m =	1	1	1	1	1	1
FoS =	1.4001	1.4003	1.4000	1.4002	1.4001	1.4000
Required UCS (MPa) =	0.079	0.083	0.084	0.092	0.097	0.098
Required UCS with Material Factor 2.0 (MPa) =	0.158	0.165	0.168	0.184	0.193	0.196

Figure F1 Stability Checking for Determination of Required Minimum Strength Level

With reference to the stability checking carried out, the SCM with a minimum unconfined compressive strength (UCS) level of 0.196 MPa shall provide adequate shear strength under undrained conditions for typical slopes requiring fill replacement works, achieving a factor of safety on slope stability of at least 1.4.

In addition, a supplementary checking against the drained shear strength levels of the SCM mix developed by NAMI (i.e. SCM-NAMI) applied in the pilot sites as revealed from the consolidated undrained triaxial tests has also been carried out. While varying drained shear strength parameters are adopted by designers of LPMit works of the trial sites, the SCM fulfilled the typical drained shear strength levels of compacted soil fill.

F2 Required Minimum Strength Level Adopted

Hence, a minimum UCS of 0.20 MPa at 28 days is specified in the Particular Specification (PS) to suit the intended purpose for backfilling of pits, trenches and voids in slopes and retaining wall works (GEO, 2022). The minimum UCS level is compatible with the strength level exhibited by the SCM-NAMI currently available in the local market. The proposed minimum UCS level of 0.20 MPa is also compatible with the lower bound 28-day minimum UCS level of 0.2 MPa to 0.3 MPa of typical mixes of Controlled Low-Strength Material (CLSM) as reported by the American Concrete Institute (ACI, 2013).

F3 References

ACI (2013). *ACI 229R-13 Report on Controlled Low-Strength Materials.* Reported by ACI Committee 229. American Concrete Institute.

Geotechnical Engineering Office (2022). *Particular Specification for Use of Self-compacting Backfill Material in Backfilling of Pits, Trenches and Voids in Slope and Retaining Wall Works.* Geotechnical Engineering Office, Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region.

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