

# Mass Soil Mixing for Temporary Trench Support in Contaminated Groundwater

**Adnan Sahyouni, Alexandre Hubaut**

*Menard Oceania, Sydney, Australia, [asahyouni@menard.com.au](mailto:asahyouni@menard.com.au)*

**ABSTRACT:** Early applications of Mass Soil Mixing (MSM) focused on stabilizing peats, soft clays and organic soils. Environmental and economic considerations, particularly in-situ treatment of challenging soils without excavation, have further supported the global use of MSM. This paper presents a detailed case study on the use of MSM as a temporary works solution within a large-scale infrastructure project. Over a 1.5-kilometer corridor consisting of uncontrolled fill, clay, and sand, the wet MSM technique was used to enable open trench excavations required for subsurface water pipelines and associated utilities. By forming a stiffened soil–cement matrix around the trench perimeter, the MSM provided effective lateral support and maintained trench stability, thereby eliminating the need for conventional shoring systems such as sheet piles. In addition to structural stability, the reduced permeability of the treated soils removed the necessity for dewatering operations, thereby mitigating the risks and costs associated with contaminated groundwater. A concise literature review situates this application within current geotechnical practice. Furthermore, Finite Element Modelling (FEM), alongside site performance data, is discussed. The findings highlight the technical and environmental benefits of MSM in temporary excavation support and provide practical guidance for similar infrastructure applications.

**KEYWORDS:** ground improvement, MSM, trench stability, sustainability, FEM.

## 1 INTRODUCTION

Ground improvement methods have become a key component of geotechnical engineering practice, enabling safe and economical construction in soils that would otherwise present significant challenges. These techniques aim to enhance the engineering properties of in-situ materials, delivering tailored solutions to site-specific conditions while addressing growing demands for sustainability and construction efficiency. Among these methods, MSM has gained prominence as a versatile solution for stabilizing problematic soils such as peats and soft clays, as well as for improving a broader range of soil types to increase bearing capacity and reduce settlement. While MSM is relatively well established in the context of permanent structures, its application is also expanding in temporary works, such as excavation support and groundwater management. The process involves in-place mixing of existing soils with cementitious binders to produce a composite material with enhanced strength and reduced permeability. However, despite its advantages, case studies specifically addressing MSM in temporary excavation support remain limited. Most existing studies have focused on alternative techniques, such as Deep Soil Mixing and Jet Grouting. One of the earliest examples dates back to 1976 in Sweden, where lime columns were successfully used to replace sheet pile retaining walls (Broms & Boman 1976). Subsequent works, including those by Andromalos & Bahner (2003) and Hamidi et al. (2010), have continued to explore these alternatives, with comparatively less emphasis placed on MSM in shallow, short-term applications.

This paper presents a case study involving the application of the wet MSM technique as a temporary retention system and water barrier to enable utilities installation. The site conditions comprised heterogeneous fill materials overlaying firm Estuarine Silts, underlain by the Botany Sands formation, which in turn rested on Quaternary sediments with interbedded compressible clays and silts transitioning into residual soils and bedrock. The MSM treatment was designed to achieve an unconfined compressive strength (UCS) of at least 800 kPa at 28 days, with specific sections requiring strengths up to 1.2 MPa. A key design objective was also to minimize groundwater ingress into the open trench. The design process began with an off-site trial program to verify strength targets before full-scale field implementation.

### 1.1 Literature review

The development of soil mixing technology can be traced back to independent innovations in Japan and Scandinavian countries during the 1970s (Coastal Development Institute of Technology, 2002). In Japan, the method was formalized as the Deep Mixing Method (DMM), which involves in-situ soil stabilization to improve strength and reduce settlement in soft soil deposits. Scandinavian countries developed a parallel technique referred to as lime column stabilization, targeting very soft clays and silty soils (Broms, 1991). These regional developments eventually converged as the technology evolved to address increasingly complex geotechnical challenges worldwide. By the late 1980s, advances in mechanical equipment and binder agents, alongside growing interest in environmental remediation, led to renewed global adoption of soil mixing. The international recognition of the technique was significantly enhanced by the Second International Conference on Ground Improvement Geosystems, held in Tokyo in 1996, where Japanese mechanical advancements were prominently showcased. That same year, the Japanese Geotechnical Society and the ISSMGE Technical Committee TC-17 co-organized the first International Conference on Deep Mixing, followed by two international symposia held in Stockholm (1999) and Helsinki (2000), and several technical workshops in the United States (Bruce, 1996).

The evolution of soil mixing techniques has led to clear distinctions in terminology and practice. Deep Soil Mixing (DSM) now encompasses both wet and dry methods: in the wet method, a binder–water slurry is mixed with soil, while in the dry method, dry binder is introduced directly into water-saturated soils (Jendrysik et al. 2021). Mass Stabilization (MS), a related approach, focuses on treating large volumes of soft or organic soils using low energy mixing tools and a broad range of stabilizers (Larsson et al. 2005). Soil mixing is now widely applied for foundation improvement, slope stabilization, earth retention, liquefaction mitigation, and seepage control (Kitazume & Terashi 2013). In the United States, the Federal Highway Administration (Bruce et al. 2013) has issued comprehensive design and construction guidelines to support its adoption in transportation projects. In Europe, the EuroSoilStab project (2002), grounded in Eurocode 7 principles, established design methodologies for soft soil stabilization, incorporating both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) criteria to guide safe and efficient application.

## 1.2 Principles and applications

Mass Soil Mixing operates on the principle of in-situ soil improvement through mechanical mixing of existing soil with stabilizing agents using specialized equipment. The process creates composite material with improved mechanical characteristics compared to natural ground, addressing issues of low strength and stiffness, high compressibility, and susceptibility to liquefaction.

The MSM technique treats large near-surface soil volumes by blending binders directly into the soil in-situ using lightweight, excavator-mounted mixing heads fitted with binder injection nozzles. These mixing heads rotate at high speeds in both vertical and horizontal planes to ensure uniform blending through either wet or dry mixing processes (Jendrysik et al. 2021). The lightweight equipment enables operation in constrained sites or areas with low bearing capacity where heavier deep mixing rigs would be impractical.

MSM construction typically proceeds as a sequence of adjacent stabilized panels as shown in Figure 1, where each new block is mixed adjacent to previously completed ones to create a continuous, reinforced mass suitable for structural support and hydraulic control. This methodology ensures continuity of the improved zone while maintaining construction efficiency and quality control.

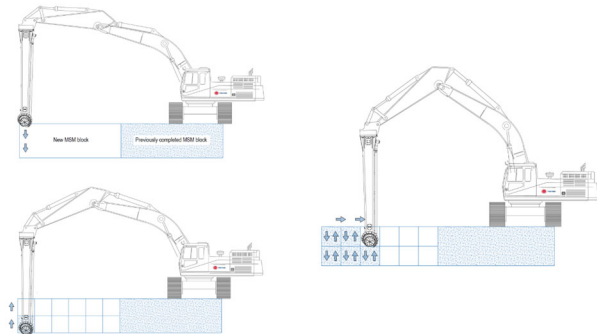


Figure 1. MSM – construction methodology.

Portland cement remains the most widely used binder in MSM applications due to its predictable hydration behavior and well-established performance history. The hydration process produces calcium silicate hydrate (C-S-H) gel, which provides the primary binding mechanism in cement-stabilized soils (Kitazume & Terashi 2013). Optimal cement contents typically range from 90 to 300 kg/m<sup>3</sup> of treated soil, depending on soil type, target strength requirements, and environmental conditions. Cement-treated soils commonly achieve unconfined compressive strengths in the range of 0.5 to 4 MPa, with 28-day strengths generally two to three times higher than 7-day values, reflecting typical cement hydration kinetics (Terashi, 2003).

The fundamental parameters characterizing cement-admixed soils include the after-curing void ratio and cement content, which together control the strength and compressibility characteristics of the treated material (Larsson et al. 2005). Quality control is primarily based on unconfined compressive strength testing at multiple curing ages, supplemented by permeability measurements and long-term stability assessments.

Soil mixing methods have demonstrated significant effectiveness in temporary construction applications and water barrier systems. The technology provides stability and seepage control for deep excavations without requiring extensive excavation, conventional shoring, or dewatering systems, offering advantages in terms of cost and minimizing environmental disturbance.

For excavation support applications, soil-cement systems have been successfully implemented as temporary retaining structures. Research on soil-cement installations has demonstrated superior efficiency in terms of both construction time and cost for excavations up to 4.5 m deep, achieving factors of safety exceeding 1.3 (Hoy et al. 2023). When properly designed with appropriate geometric configurations, MSM systems can serve as efficient excavation support while simultaneously providing water cut-off capabilities.

The dual functionality of MSM systems as both structural support and hydraulic barriers makes them particularly suitable for utility installations, temporary works, and urban construction projects where space constraints and environmental considerations limit the use of conventional support systems. However, design approaches for such applications require careful consideration of both ultimate limit state and serviceability limit state criteria, following established geotechnical design principles.

## 2 CASE STUDY

### 2.1 Project Overview

The project includes the installation of drainage pipes and water quality devices along a 1.5-kilometer alignment in the Botany area, as shown in Figure 2. The alignment passes through ground characterized by uncontrolled fill, Botany sand, and Botany clay, underlain by a high groundwater table with tidal influence and known contamination. Conventional excavation and shoring methods, such as benching or sheet piling combined with continuous dewatering, were deemed impractical due to safety risks, extended construction time, and the high cost of managing contaminated groundwater. To address these challenges, MSM was adopted as a temporary works solution. The method was designed to stabilize trench walls, reduce groundwater ingress, and allow safe excavation for the installation of subsurface pipelines and Gross Pollutant Traps as shown in Figure 2. Menard Oceania was engaged to undertake the detailed design and construction of the MSM works, tailored to the specific geotechnical, environmental, and operational constraints of the site.



Figure 2. MSM layout.

### 2.2 Ground conditions

The geological data of the site in Figure 3 shows Quaternary anthropogenic deposits, including reclaimed estuarine sands, muds, and fill materials, as well as estuarine sediments and interbarrier creek deposits comprising fine- to medium-grained sands, silts, and clays. Beneath these surficial soils, the profile transitions into Middle Triassic bedrock, with Shale of the Wianamatta Group overlying Sandstone bedrock, providing a competent foundation stratum beneath the softer upper layers.



Figure 3. Geological features (source Min View), project location marked in dashed red box.

The design parameters in Table 1 correspond to one of the modelled sections along the alignment and are not indicative of the entire project. This section comprises fill, estuarine deposits, Botany Sand and Clay units, residual soils, and weathered sandstone, with each layer characterized by its strength and stiffness properties for use in stability and deformation analyses of the MSM works.

Table 1. Ground model of one of the geotechnical sections.

Unit	Top of Unit (m AHD)	Undrained shear strength (kPa)	Oedometer Modulus (MPa)
Uncontrolled Fill	2	-	20
Botany medium dense Sand	-0.5	-	25
Botany soft Clay	-2	25	6
Botany medium dense Sand	-2.5	-	30
Botany firm Clay	-3	35	8
Botany dense Sand	-5	-	100
Botany firm Clay	-7.5	45	10
Botany stiff Clay	-8	100	35
Residual Clay	-8.7	200	80
Bedrock	-9.5	-	135

### 2.3 Laboratory mix trial

The laboratory mix trials were conducted on representative soil samples, shown in Figure 4 to determine the optimal binder content for MSM works. Three binder dosages were tested across nine sampling locations, with unconfined compressive strength (UCS) measured at multiple curing ages (3, 7, 14, 28, and 56 days) to assess both early and long-term strength development. Additional testing included Atterberg limits, organic content, modulus determination, indirect tensile strength, direct shear, and undrained triaxial tests to evaluate mechanical behavior. The results confirmed that the selected binder ratios met or exceeded the target 28-day UCS of 800 kPa, with some mixes achieving values over 1.2 MPa, as shown in the plotted curves in Figure 5. As part of the design strategy, a safety factor of two was applied to the laboratory UCS results to estimate the corresponding field performance. These findings validated the binder mix design for achieving the required trench stability and permeability reduction, providing confidence in its full-scale implementation.



Figure 4. Photographs – Laboratory Mix Trial Samples.

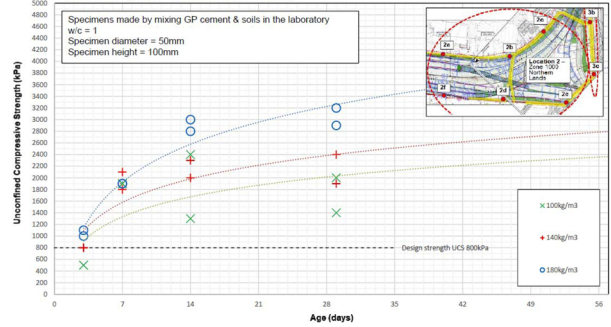


Figure 5. Strength development curve.

### 2.4 MSM parameters

Localized variability in subsoil stratigraphy, particularly the presence of interbedded silt and clay layers, is expected to influence the strength and stiffness characteristics of the constructed MSM blocks. Target unconfined compressive strengths (UCS) at 28 days were set at 800 kPa across most of the alignment, with 1.2 MPa specified for a designated high-performance section. The elastic modulus ( $E$ ), representing the stiffness of the stabilized soil, was estimated using Equation (1), as a function of 28-day UCS, consistent with laboratory test results. Shear strength was assumed as 40% of the UCS, in line with FHWA guidelines (Bruce et al. 2013).

$$E = 300 \times UCS_{(28 \text{ days})} \quad (1)$$

where UCS is in kPa and the resulting  $E$  is also expressed in kPa.

Tensile strength was estimated as 15 % of UCS, and allowable stress values incorporated a safety factor of 2 relative to design strengths. Numerical modelling of MSM blocks was undertaken in PLAXIS using a finite element method (FEM) framework and a Mohr–Coulomb constitutive model, with shear strength parameters directly applied as model inputs. A summary of one MSM section parameters is shown in Table 2.

Table 2. Properties of the MSM block used in PLAXIS modelling.

UCS (MPa)	Elastic Modulus (MPa)	Allowable shear strength (kPa)	Allowable compressive strength (kPa)	Allowable tensile strength (kPa)
0.8	240	160	400	60
1.2	360	240	600	90

### 2.5 MSM design

Two-dimensional finite element (FE) analyses were performed using PLAXIS 2D to define the design parameters of the MSM blocks for temporary excavation support and to assess short-term trench stability. Plane strain models were developed for representative cross-sections along the treatment alignment, simulating trench wall displacements, stress distribution within the MSM blocks, and overall stability performance. The design objectives were to: (i) limit lateral wall deflection, (ii) ensure internal stresses in the MSM block including the wall and base

plug remained below allowable design strengths, and (iii) achieve a global factor of safety (FoS) of at least 1.3 against trench instability, as determined using the  $c'-\phi'$  reduction method. Short-term undrained analyses were adopted, reflecting the limited excavation and installation duration. Subsurface soils were modelled with the Hardening Soil model (drained for granular soils; undrained A for cohesive soils), while MSM blocks were modelled with the Mohr–Coulomb model. Representative FE output for one of the analyzed sections is presented in Figure 6. The modelling also incorporated construction load effects, including adjacent machinery operations and pipe storage loads, to account for their influence on MSM block stability following excavation.

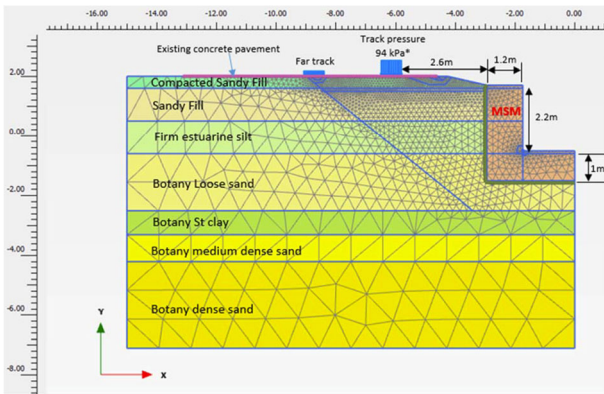


Figure 6. Geometry of the FEM model for one of the MSM sections.

### 2.5.1 Lateral displacement

The lateral movement of the trench wall at the end of the excavation stage is illustrated in Figure 7. The predicted lateral displacement at the top of the wall is approximately 3 mm.

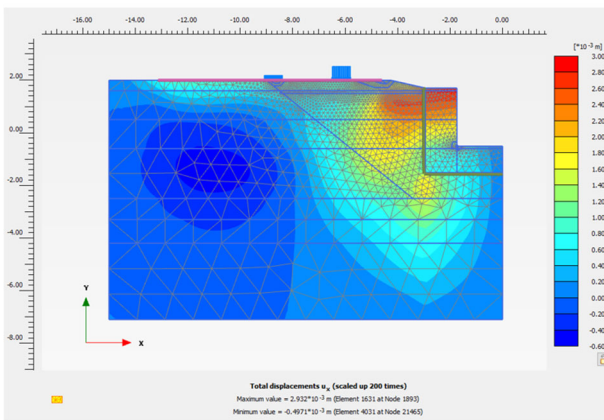


Figure 7. Lateral displacement of the MSM trench wall.

### 2.5.2 Stresses inside MSM block

Figure 8 and Figure 9 present the mobilized shear strength and the tensile and compressive stresses developed within the MSM block at the end of the excavation stage. Compressive stresses are relatively low compared to the allowable compressive strength of the MSM and rarely govern the design. In contrast, shear and tensile stresses are more critical and have been evaluated as follows.

The allowable shear strength of the MSM material, calculated as the undrained shear strength divided by the FoS of 2, is 160 kPa. From the PLAXIS output, the mobilized shear stresses along the central portion of the MSM walls and plugs are approximately 54 kPa, as shown in Figure 8, which is well below the allowable limit. Minor stress concentrations occur at

the wall–plug interface but are confined to a small, localized area.

Similarly, the allowable tensile strength, taken as 15% of the UCS divided by the FoS of 2, is approximately 60 kPa. As shown in Figure 9, the maximum tensile stress, approximately 58 kPa, occurs near the trench wall edges and remains within the allowable limit.

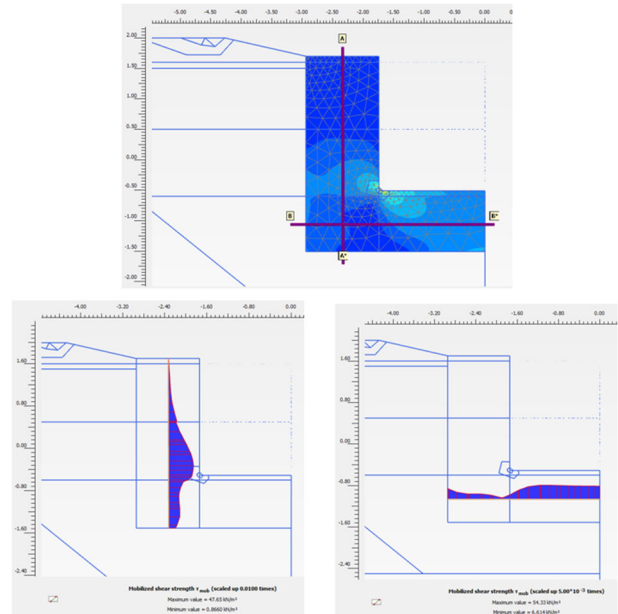


Figure 8. Mobilized shear stresses in the MSM trench wall and bottom plug (critical sections).

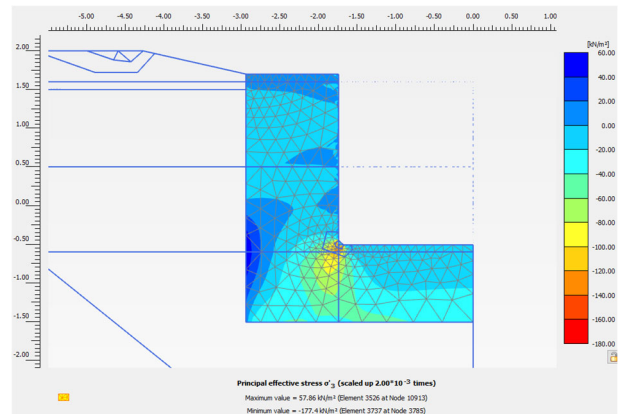


Figure 9. Tensile stress developed in the MSM block.

### 2.5.3 Safety analysis

The global stability of each modelled cross-section was evaluated in PLAXIS 2D using the  $c'-\phi'$  reduction method. For one representative section, the computed FoS was 2.5, which satisfies the short-term design requirement. The total deviatoric strain contours, presented in Figure 10, are consistent with the computed failure mechanism and support the stability interpretation.

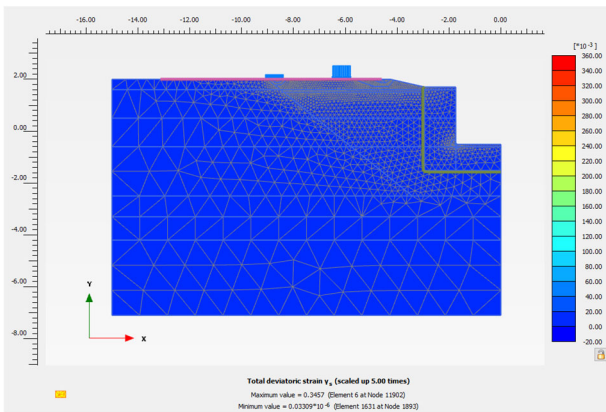


Figure 10. Total deviatoric strain in the model at SB21.

The MSM design comprised 11 distinct sections, tailored to site-specific ground and loading conditions. One typical section, illustrating the MSM block with the installed pipeline, is presented in Figure 11.

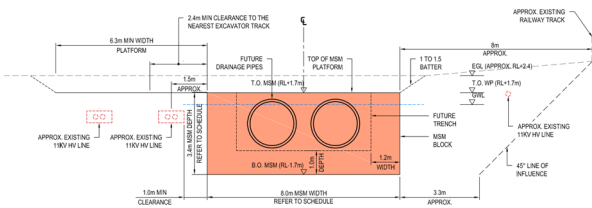


Figure 11. Typical MSM detail.

### 2.6 Coring - Field trial

As part of the quality control and verification process, core sampling was conducted at five locations using a track-mounted drilling rig with water-assisted techniques. The objective was to extract continuous samples through the full depth of the MSM blocks to assess in-situ homogeneity, verify binder distribution, and obtain specimens for laboratory testing. Figure 12 shows examples of the recovered core samples, which were subsequently tested to confirm compliance with the specified strength and stiffness parameters. This exercise provided confidence in the consistency and performance of the MSM works following field implementation.



Figure 12. MSM core samples.

### 2.7 Simplified construction sequence

The ultimate objective of the overall project is the safe installation of the underground conduits. The simplified construction sequence, illustrated in Figure 13, was implemented on site.

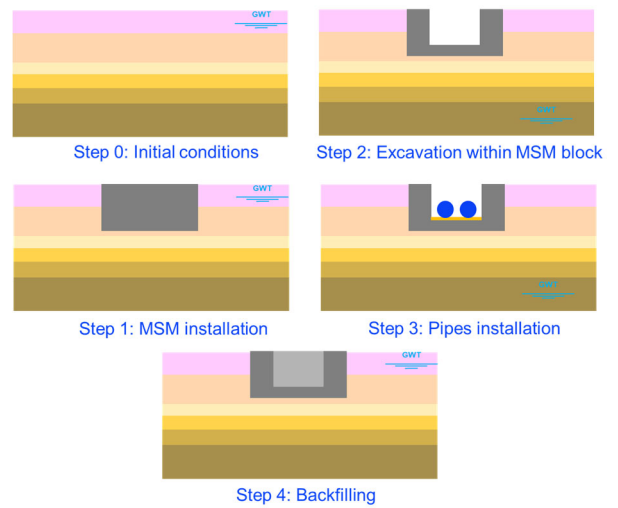


Figure 13. Simplified construction sequence.

### 2.8 MSM – final product

The photographs in Figure 14 illustrate trench excavation within the MSM block, along with a series of construction activities safely carried out by the main contractor. Notably, groundwater ingress was effectively controlled; the water visible in the images is attributed to rainfall, as the region experienced continuous wet weather during this period.

Visual inspections and on-site monitoring conducted during and after excavation confirmed that the MSM blocks provided stable trench walls and effective groundwater cutoff, with no signs of distress or deformation. These observations validated the performance of the MSM treatment in the field and its suitability as a temporary excavation support system under the prevailing geotechnical conditions.



Figure 14. MSM block after excavation and during pipe installation.

### 3 CONCLUSIONS

Ground improvement techniques provide an effective means of enabling construction on sites with challenging soil conditions, reducing reliance on traditional methods that are often more costly and less sustainable. This study has demonstrated the successful use of MSM as a temporary works solution for trench excavation under complex geotechnical and environmental constraints. By integrating laboratory mix trials, advanced finite element modelling, and stringent quality control measures, MSM blocks were engineered to achieve specific strength, stiffness, and permeability targets, ensuring excavation stability and effective control of water ingress. Field observations during excavation confirmed the stability and integrity of the MSM blocks, validating the design approach.

The adoption of MSM removed the need for conventional shoring and continuous dewatering, thereby reducing construction risks, environmental impacts, and schedule delays. The outcomes support the wider use of MSM for temporary support in urban infrastructure works. A follow-up publication will present an additional case study involving MSM in the construction of an underwater tank in high groundwater conditions.

#### 4 ACKNOWLEDGEMENTS

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