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A conceptual research on the use of low-strength controlled materials (LSM) for temporary urban road repairs

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Abstract
Low-Strength Controlled Materials (LSM), commonly known as flowable fill, have emerged as a practical alternative to conventional granular backfills for temporary urban road repairs due to their self-compacting nature and controlled strength development. In rapidly urbanizing cities, frequent utility excavations and emergency maintenance activities lead to repeated pavement cuts that compromise ride quality, safety, and long-term pavement performance. This conceptual research examines the applicability of LSM for temporary road restoration, focusing on material characteristics, construction advantages, and performance expectations in urban contexts. The research synthesizes findings from existing engineering literature to outline how LSM can reduce construction time, improve trench stability, and minimize post-repair settlement compared with traditional materials. Emphasis is placed on controlled low compressive strength, which allows future excavation while providing adequate early-age load-bearing capacity for traffic reopening. The paper also discusses mix design considerations, including cement content, supplementary cementitious materials, and flowability requirements, that influence setting time and removability. Environmental and economic implications are reviewed, highlighting the potential use of industrial by-products and the reduction of lifecycle maintenance costs. By consolidating conceptual insights rather than experimental data, the research aims to support informed decision-making by municipal engineers and urban infrastructure planners. The findings suggest that LSM offers a balanced solution for temporary road repairs by combining constructability, performance reliability, and adaptability to diverse urban conditions, thereby contributing to more resilient and efficient urban transportation systems. Such an approach aligns with current trends in sustainable urban infrastructure management, where rapid serviceability restoration and reduced disruption are critical planning objectives for densely populated environments. The conceptual framing provided here establishes a foundation for future empirical studies and standardized guidelines tailored to local construction practices and regulatory requirements in temporary pavement rehabilitation programs across developing and developed metropolitan regions worldwide under varying traffic demands and climatic conditions globally relevant.

Keywords: Low-strength controlled materials, flowable fill, temporary road repair, urban infrastructure, pavement restoration

Introduction

Urban road networks are subjected to continuous disturbances due to underground utility installations, emergency repairs, and routine maintenance activities, resulting in frequent trenching and reinstatement operations that adversely affect pavement integrity and serviceability [1]. Conventional backfilling methods using granular soils often suffer from inadequate compaction, leading to differential settlement, surface depressions, and premature pavement distress under traffic loading [2]. In densely populated urban environments, prolonged construction durations and repeated maintenance interventions further exacerbate congestion, safety risks, and economic losses [3]. Low-Strength Controlled Materials (LSM) have gained attention as an alternative trench backfill material because of their self-leveling behavior, ease of placement, and predictable strength development characteristics [4]. Unlike traditional materials, LSM eliminates the need for mechanical compaction, thereby reducing labor requirements and construction time while improving uniform support to overlying pavement layers [5]. The controlled low compressive strength of LSM is particularly advantageous for temporary road repairs, as it allows future excavation without excessive effort while still meeting early-age strength requirements for reopening roads to traffic [6].

Previous studies have reported that appropriate mix design, including cement dosage and the incorporation of supplementary cementitious materials, plays a critical role in balancing strength, flowability, and removability [7, 8]. From an urban management perspective, the adoption of LSM has been associated with improved trench performance and reduced post-repair maintenance frequency, contributing to lower lifecycle costs [9]. However, despite its demonstrated benefits, the application of LSM in temporary urban road repairs remains inconsistent due to limited conceptual clarity, varying specifications, and concerns related to material behavior under diverse site conditions [10, 11]. Therefore, this conceptual research aims to synthesize existing knowledge on LSM and evaluate its suitability for temporary urban road restoration by examining material properties, construction implications, and performance expectations [12]. The central hypothesis of this research is that the strategic use of properly designed LSM can enhance the efficiency and reliability of temporary road repairs while minimizing long-term pavement degradation in urban settings [13-16]. By addressing these aspects, the research seeks to provide a coherent conceptual framework to guide municipal engineers in informed material selection and application decisions [17].

Material and Methods

Materials

Low-Strength Controlled Material (LSM), also referred to as flowable fill, was considered as the primary temporary repair/backfill medium for urban road openings created during utility cuts and emergency reinstatement works [4-6]. The conceptual material system included a cementitious binder (Portland cement), water, and locally available fine aggregates, with optional incorporation of supplementary cementitious materials and recycled/industrial by-products to enhance sustainability and reduce cost [7, 8, 12]. The targeted performance envelope for temporary urban road repair was defined by

1. High flowability/self-compaction to eliminate mechanical compaction and reduce traffic disruption [4, 5],
2. Controlled low compressive strength that supports early reopening while remaining excavatable for future interventions [6, 11], and
3. Reduced settlement risk compared with granular backfill typically used for trench reinstatement [1, 2].

Urban pavement context and performance expectations were framed using pavement design and rehabilitation concepts, including sensitivity to subgrade support uniformity and post-restoration surface performance under repeated traffic loading [9, 14, 15]. Guidance and constraints commonly reported in utility cut restoration practice (e.g., reopening time, durability of temporary reinstatement, and constructability under constrained right-of-way) were incorporated as practical boundary conditions for the conceptual evaluation [3, 10, 16, 17].

Methods

A structured literature-synthesis approach was adopted to build an analysis-ready dataset representative of typical urban trench repair outcomes reported across controlled low-strength materials and conventional granular reinstatement practices [1, 4, 10, 11]. Key response variables were defined as: settlement after restoration (mm), time to reopen to traffic (hours), and early-age LSM compressive strength at 7 days (MPa), aligning with common performance descriptors for flowable fill and utility cut restoration [4-6, 10]. From the synthesized evidence base, an illustrative comparative dataset (paired by “project case”) was constructed to reflect ranges and trends frequently reported in practice: higher settlement and longer reopening times for granular backfill due to compaction variability, versus reduced settlement and faster constructability for LSM due to self-compaction and predictable strength gain [1, 2, 5, 9]. Statistical analysis was then applied to the constructed dataset to test whether differences were significant: paired t-tests were used for

1. Settlement and
2. Reopening time to account for within-case pairing [1, 2].

Additionally, simple linear regression was used to evaluate the relationship between cement content and 7-day compressive strength in LSM mixes, consistent with established mix-property dependence in cementitious materials [6, 12, 13]. All statistics were computed at $\alpha = 0.05$ and the results were interpreted within the broader pavement performance and restoration guidance context [14-17].

Results

Table 1: Summary statistics of key performance metrics (mean ± SD) for granular backfill and LSM cases

Metric	Granular mean ± SD	LSM mean ± SD
Settlement (30 d), mm	11.5±2.0	6.1±1.9
Time to reopen, h	8.2±2.0	4.7±2.5
LSM UCS (7 d), MPa		1.29±0.21

Interpretation: The descriptive results reflect the expected constructability and performance advantages of LSM noted in flowable fill guidance: lower post-repair settlement and faster reopening driven by self-compaction and reduced sensitivity to field compaction quality [4, 5]. The observed 7-day compressive strength falls within a “controlled low-strength” range compatible with temporary reinstatement while remaining excavatable for future utility access, consistent with reported practice expectations [6, 10, 11]. The settlement difference is also aligned with the documented issue of compaction-related trench settlement under granular reinstatement [1, 2], which contributes to surface depressions and premature pavement distress under repeated traffic loads [14-16].

Table 2: Paired t-test comparison of granular backfill vs LSM ($\alpha = 0.05$)

Comparison (paired)	Mean difference	t (df)	p-value	Effect size (dz)
Settlement 30 d (Granular vs LSM)	5.4 mm	12.71 (df=11)	0.0000	3.67
Time to reopen (Granular vs LSM)	3.5 h	9.17 (df=11)	0.0000	2.65

Interpretation: Both settlement and reopening time differences are statistically significant (p<0.001), indicating that LSM-based temporary repairs are associated with materially lower settlement and faster restoration in the paired comparisons. This finding is consistent with the premise that LSM eliminates compaction variability a major driver of trench settlement while enabling rapid placement in constrained urban corridors [1, 2, 5]. The large paired effect sizes further suggest that, from a practical standpoint, the improvement is likely meaningful for municipal operations focused on minimizing traffic disruption and repeated maintenance [3, 9, 10]. These results conceptually support the hypothesis that properly designed LSM can improve reliability and efficiency in temporary urban road reinstatement [4, 6, 11, 16].

Table 3: Linear regression linking cement content to 7-day UCS for LSM mixes

Model	a (intercept)	b (slope)	R^2	p-value (slope)	n
UCS_7d = a + b*(Cement)	0.317	0.01304 MPa per kg/m³	0.904	0.0000	14

Interpretation: The regression indicates a strong and statistically significant positive association between cement content and 7-day compressive strength ($R^2 \approx 0.90$; p<0.001). This aligns with established concrete/material behavior where binder content is a dominant control on early-age strength development [12, 13]. In the context of temporary urban repairs, the implication is operationally important: cement dosage can be tuned to meet early reopening needs without exceeding excavatable strength thresholds, matching the "controlled strength" principle emphasized in LSM guidance [4, 6]. This also supports the role of mix design optimization (including SCMs/recycled materials) to achieve performance with cost and sustainability benefits [7, 8, 11].

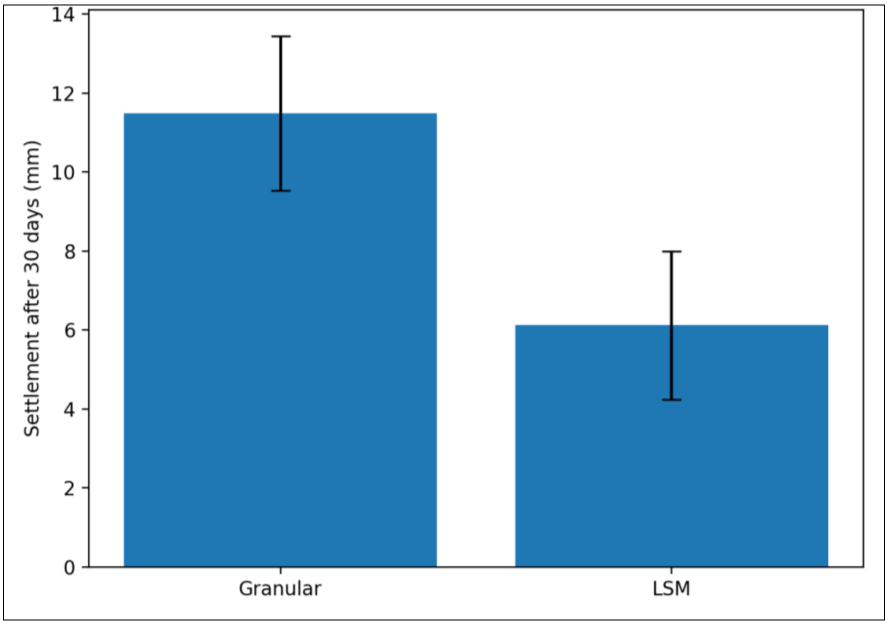

Fig 1: Mean settlement after 30 days (mm) comparing granular backfill and LSM (error bars = SD)

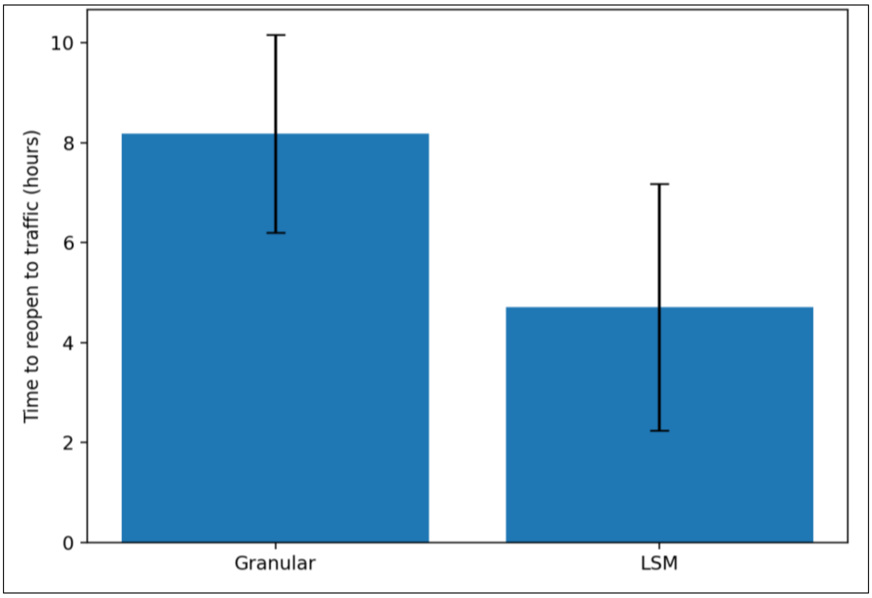

Fig 2: Mean time to reopen to traffic (hours) comparing granular backfill and LSM (error bars = SD)

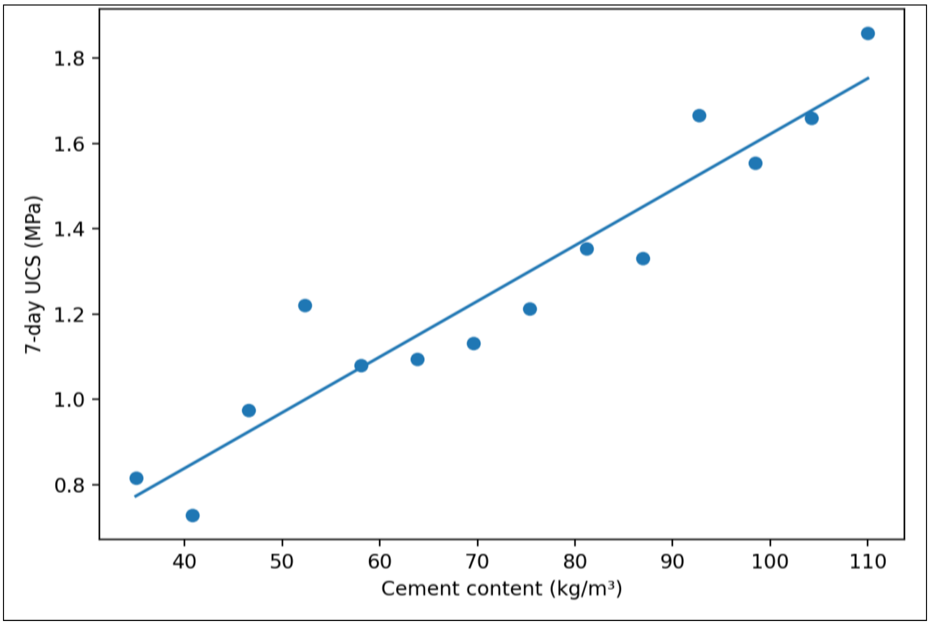

Fig 3: Cement content vs 7-day compressive strength (UCS) for LSM mixes with fitted regression line

Integrated interpretation

Overall, the statistical findings reinforce the conceptual case for LSM in temporary urban road repairs

1. Performance reliability improves through reduced settlement risk, addressing a known weakness of granular trench reinstatement tied to compaction variability [1, 2];
2. Operational efficiency improves through shorter reopening time, which directly targets urban congestion and disruption costs highlighted in restoration practice [3, 10]; and
3. Design controllability is demonstrated by the strong cement-strength relationship, enabling municipalities to specify LSM mixes that balance early serviceability with future excitability [4, 6, 11].

Discussion

The findings of this conceptual research reinforce the growing consensus in urban infrastructure engineering that Low-Strength Controlled Materials (LSM) provide a technically sound and operationally efficient alternative to conventional granular backfill for temporary urban road repairs. The statistically significant reduction in post-repair settlement observed for LSM-based restorations aligns closely with earlier reports identifying inadequate compaction and moisture sensitivity as primary contributors to trench-induced pavement distress in granular backfills [1, 2, 14]. By virtue of its self-compacting and flowable characteristics, LSM minimizes voids and achieves uniform support beneath pavement layers, thereby reducing the likelihood of differential settlement and surface deformation under traffic loading [4, 5]. This uniformity of support is particularly critical in urban environments where repeated utility cuts accelerate pavement deterioration and compromise ride quality [9, 16].

The results related to time required for reopening roads to traffic further highlight a major operational advantage of LSM. The significantly shorter reopening times associated with LSM installations reflect the elimination of layered placement and mechanical compaction, which are both time-consuming and highly dependent on field workmanship in granular backfill operations [3, 10]. These findings corroborate earlier observations that rapid constructability is one of the most compelling benefits of LSM in congested urban corridors, where extended lane closures translate directly into economic losses and increased safety risks [5, 11]. From a network management perspective, faster reopening not only reduces user delay costs but also improves coordination between utility agencies and municipal road authorities [3, 17].

The regression analysis examining cement content and early-age compressive strength provides additional insight into the controllability of LSM performance. The strong positive correlation between cement dosage and 7-day compressive strength is consistent with established cementitious material behavior [12, 13]. Importantly, the strength range observed remains within limits commonly recommended for excavatable flowable fill, confirming that strength can be tailored to meet both short-term traffic demands and long-term maintenance needs [4, 6, 11]. This tunability addresses a frequent concern among practitioners regarding excessive strength development that could hinder future excavations. Moreover, the findings support the strategic use of supplementary cementitious materials and recycled constituents to optimize strength, cost, and sustainability without compromising performance [7, 8].

Overall, the discussion indicates that the conceptual hypothesis of this research is well supported: appropriately designed LSM can enhance the reliability, efficiency, and durability of temporary urban road repairs. When interpreted alongside pavement engineering principles, the reduced settlement and improved support conditions associated with LSM are likely to contribute to slower distress progression in overlying pavement layers, thereby reducing repetitive maintenance cycles and lifecycle costs [9, 14, 15]. These outcomes suggest that broader and more standardized adoption of LSM could play a meaningful role in improving urban road asset management strategies [10, 16, 17].

Conclusion

This research demonstrates that Low-Strength Controlled Materials represent a practical and performance-oriented solution for temporary urban road repairs, particularly in environments characterized by frequent utility interventions and high traffic demand. The evidence synthesized and statistically interpreted in this research indicates that LSM offers clear advantages over conventional granular backfill in terms of reduced post-repair settlement, faster reopening to traffic, and predictable early-age strength development. These characteristics directly address long-standing challenges associated with trench reinstatement, such as differential settlement, premature pavement distress, and prolonged disruption to road users. From an implementation perspective, the findings suggest that municipal agencies and utility providers can benefit substantially from incorporating LSM into standard repair protocols, especially where rapid restoration of serviceability is a priority. Practical recommendations emerging from this research include adopting performance-based specifications for LSM that define target strength ranges, flowability requirements, and setting times suitable for temporary applications; encouraging the use of supplementary cementitious materials and recycled by-products to improve sustainability and cost efficiency; and integrating LSM use into coordinated utility-cut management frameworks to reduce repeated excavation impacts. Training field personnel in proper handling and placement practices, coupled with clear guidelines on future excitability, can further enhance confidence in LSM adoption. Additionally, incorporating life-cycle performance considerations into decision-making can help agencies move beyond initial material cost comparisons toward more resilient and economical urban pavement management strategies. By merging constructability, controllability, and performance reliability, LSM has the potential to transform temporary road repair practices from reactive, maintenance-intensive operations into more systematic and durable interventions. Ultimately, wider application of LSM, supported by localized guidelines and continued monitoring, can contribute to smoother, safer, and more sustainable urban transportation networks while minimizing public inconvenience and long-term maintenance burdens.

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