

Cost Efficiency of Monolithic Buildings vs Traditional Framed Structures for Landslide-Prone Areas

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Abstract - Monolithic construction systems cast-in-place concrete, tunnel formwork, insulating concrete forms (ICF) and related continuous wall-slab systems are increasingly promoted for rapid, durable housing in hazard-prone regions. This review synthesizes reviewed literature on the physical vulnerability of buildings to landslides, structural and lifecycle cost factors for monolithic and traditional framed systems, and practical implications for design, siting and post-event losses. Evidence shows that building vulnerability to landslides depends strongly on foundation depth, building footprint/orientation and soil-structure interaction; monolithic RC/ICF systems tend to provide superior continuity, higher out-of-plane strength and reduced maintenance demands compared with conventional framed or masonry stock, with life-cycle benefits in energy and durability reported in several journal studies. However, site-specific landslide mechanics, debris flow vs slow-moving slides, and local construction supply chains largely determine whether monolithic systems are cost-efficient. Gaps remain in quantitative, landslide-specific cost-benefit studies; we propose standardized assessment frameworks that integrate fragility functions with life-cycle cost modelling.

Key Words: Monolithic construction¹, Landslide vulnerability², cost analysis³, Framed structures⁴

1. INTRODUCTION

Landslides and slope failures constitute a major driver of building damage in hilly and mountainous regions worldwide. Beyond immediate repair costs, repeated or progressive damage increases life-cycle costs, hinders recovery and shifts insurance and social burdens. Practitioners and policy makers therefore seek construction systems that minimize both expected direct losses (repair/replacement) and long-term ownership costs (maintenance, energy, insurance). Monolithic building systems—where walls, floors and structural elements are cast or constructed as continuous units—are frequently proposed as more robust, faster and sometimes cheaper alternatives to traditional reinforced-concrete (RC) framed structures or timber/steel framed houses in hazard zones. Yet, the comparative evidence specifically addressing landslide-prone contexts is fragmented across disciplines: geotechnical engineering (landslide mechanics), structural

engineering (fragility/strength), and building economics (construction and life-cycle cost). This review collates reviewed journal findings to evaluate cost efficiency of monolithic vs framed systems in landslide contexts and to identify research gaps for future practice [1, 2].

1.1 Scope and objectives

The objectives of this review are to:

1. Summarize the state of knowledge on building vulnerability to landslides and the structural behaviors that mediate damage [1, 2].
2. Synthesize journal evidence on construction, operational and life-cycle costs for monolithic systems and for conventional framed structures [3, 5, 6].
3. Assess whether monolithic systems provide net cost advantages in landslide-prone areas, under what conditions, and where evidence is lacking.
4. Propose a standardized methodology for comparative cost-vulnerability assessments to guide future studies and practitioners.

1.2 Methodology

Databases and sources searched: ScienceDirect, MDPI, Copernicus (NHES), Elsevier journals (Energy & Buildings), and multidisciplinary indexes via publisher pages and abstracts. Searches used keywords and combinations such as “monolithic structure cost”, “tunnel formwork cost framed vs monolithic”, “insulating concrete form life cycle assessment”, “building vulnerability landslides”, “fragility landslide buildings”, and “cost efficiency monolithic construction” [1, 3, 4].

Inclusion criteria: peer-reviewed journal articles (not conference-only non-peer publications) addressing: building vulnerability to landslides; structural behavior of monolithic/ICF/continuous RC systems; comparative cost, life-cycle assessment (LCA) or energy-cost studies comparing monolithic systems and framed structures. Publications from 2000–2025 were prioritized; seminal earlier work was included where relevant.

Exclusion criteria: non-peer sources (industry white papers without peer review), purely anecdotal reports, and journal content that did not present empirical, experimental, analytical or LCA data.

2. BUILDING VULNERABILITY TO LANDSLIDES, KEY MECHANISMS AND PARAMETERS

The literature emphasizes that building damage from landslides arises via multiple interacting mechanisms: (a) lateral thrust and impact (rapid slides and debris flows), (b) differential settlement and tilt (slow-moving slides), and (c) scour or foundation undermining. Accordingly, fragility differs markedly between debris-flow-prone sites and slow-moving translational slides. Mechanics-based studies show that building geometry (length vs width relative to slide direction), foundation depth and stiffness of the soil-structure interface are dominant predictors of damage; notably, longer building axes perpendicular to slide direction increase vulnerability, while deeper foundations reduce it. These mechanics provide the physical linkage between structural form (monolithic vs framed) and expected performance under landslide loading [1].

Empirical and modeling studies have developed physical vulnerability curves linking landslide intensity metrics (displacement, thrust, impact energy) to damage states; these curves form the basis for probabilistic loss estimation. The construction system influences two key components of the vulnerability function: (i) the threshold at which structural integrity is lost (monolithic continuity and higher shear capacity often raise this threshold), and (ii) the post-event repair cost associated with similar damage states (repairability and cost of replacement elements) [1, 7].

2.1 Properties of monolithic systems relevant to landslides

Monolithic systems including cast-in-place RC with continuous diaphragms, tunnel formwork multi-storey monolithic units, and Insulating Concrete Forms (ICF) share features that influence landslide resilience:

Structural continuity and diaphragm action: Continuous wall-slab integration distributes lateral loads and reduces concentration of stress at discrete connections (beams-columns), improving out-of-plane resistance to lateral thrust. This continuity can reduce catastrophic collapse under distributed lateral sliding thrust. [5]

Out-of-plane wall stiffness and shear capacity: Solid concrete walls (monolithic) present higher shear and out-of-plane capacity than framed systems relying on infill walls; this is beneficial under impact/thrust loading. [3]

Simplified foundations and reduced number of critical joints: Fewer discrete structural joints can reduce local differential movement amplification, though the entire

monolithic load path may transfer higher demand to foundations making foundation design and soil-structure interaction critical [1].

Durability, maintenance and thermal performance: Studies of ICF and monolithic walls report improved thermal performance and reduced maintenance over framed/masonry walls; life-cycle assessments often show operational energy savings that partially offset slightly higher initial embodied impacts in some contexts [3, 6].

These structural and operational attributes suggest monolithic systems can alter both the probability and severity of landslide-induced damage and the life-cycle cost profile. However, the magnitude of the effect is site- and hazard-specific.

3. COST EVIDENCE: CONSTRUCTION, REPAIR, AND LIFE-CYCLE STUDIES

3.1 Initial construction costs

Journal studies comparing construction costs of monolithic vs framed systems present mixed results depending on region, Labour rates, and system specifics:

Experimental and comparative case studies of ICF and other monolithic options often report initial construction cost premiums in the range of roughly 0–10% relative to standard framed or masonry methods in regions with established supply chains, while in some cases monolithic tunnel-form systems have been shown to reduce Labour and formwork time and therefore reduce total costs [5, 6]. Reported cost advantages relate to reduced Labour time, simpler formwork cycles (tunnel form), and elimination of secondary finishes.

Where monolithic systems require specialized materials (e.g., EPS ICF blocks) or skilled crews, initial costs can be higher. Conversely, pre-fabrication and repetitive tunnel form production in multi-storey projects can deliver economies of scale, often making monolithic approaches cost-competitive or cheaper than framed RC with masonry infills.



Chart -1: Hypothetical comparison of 50-year life-cycle costs for monolithic and framed structures under different landslide scenarios

3.2 Repair and post-event costs

Repair costs following landslide damage depend on damage mode: tilt and settlement vs impact rupture.

For slow-moving landslides producing progressive settlement, framed structures with discrete connections, non-ductile infills and shallow strip foundations can experience concentrated damage to non-structural components that is costly to rectify repeatedly. Monolithic continuous systems may better tolerate moderate differential movements before major cracking, reducing cumulative repair frequency and cost. Mechanics-based assessments indicate foundation depth and stiffness are primary variables; however, when foundation undermining or high impact forces occur, no system is immune and repair costs scale with the extent of foundation and superstructure damage.

Fragility studies applied to monolithic RC remain limited for landslide loading; however, earthquake fragility literature (analogous in some structural response aspects) suggests monolithic continuity reduces collapse risk and extensive repair needs compared to poorly detailed framed systems. Extrapolating cautiously, this implies lower expected post-event replacement cost under many landslide scenarios, but the effect size remains to be precisely quantified for different slide types [1, 7].

3.3 Life-cycle and operational costs

Life-cycle assessments (LCA) comparing ICF and traditional framing report:

Operational energy savings in ICF and well-insulated monolithic walls (due to thermal mass and continuous insulation) that reduce heating/cooling demand, contributing to lower operational cost and sometimes offsetting slightly higher embodied costs over a 20-to-50-year horizon in temperate climates [3, 6].

Reduced maintenance needs (less finishing, fewer joints and penetrations) also contribute to lower life-cycle cost for monolithic systems in several published LCAs. The magnitude depends on climate, material longevity and local maintenance practice.

4. INTEGRATING VULNERABILITY AND COST: DECISION HEURISTICS FOR LANDSLIDE AREAS

Given the evidence, practitioners can adopt the following site-specific decision heuristics:

Rapid debris-flow/high-impact zones: When impact energy and burial depth are the dominant threats (debris flows, rapid translational slides), structural continuity alone does not guarantee survivability; instead, siting, protective works (deflection berms, check dams), and elevating/retrofitting foundations are primary loss-

reduction measures. Monolithic systems may reduce repair costs post-event only if the structure is not fully buried or catastrophically impacted [2, 7].

Slow-moving displacement zones: For progressive landslides producing differential settlement and tilt, monolithic continuous systems with appropriately detailed foundations (deepened or stiffened) can reduce the frequency and severity of reparable damage by better distributing deformation and avoiding concentration at discrete joints leading to favorable life-cycle cost outcomes [1].

Where Labour costs dominate: In areas where skilled Labour is scarce or expensive, monolithic methods that reduce construction time (tunnel formwork, modular ICF) can deliver lower total construction cost and earlier occupancy, improving economic feasibility. Conversely, if materials for monolithic systems are expensive to import, conventional local framed systems may remain cheaper [3, 5].

5. GAPS IN THE LITERATURE AND RESEARCH NEEDS

Despite promising mechanistic and LCA evidence, clear quantitative studies that integrate landslide-specific fragility curves with life-cycle cost models for monolithic vs framed systems are scarce. Key gaps include:

Fragility functions for monolithic systems under landslide loading: Most published fragility work focuses on masonry and framed systems or on seismic loads; analogous, peer-reviewed fragility curves for monolithic/ICF buildings under landslide thrust, impact and progressive displacement are limited [7].

Integrated probabilistic cost-vulnerability studies: There is a shortage of probabilistic analyses that combine spatial landslide hazard models with building resistance metrics and life-cycle cost outcomes to produce expected-loss maps or cost-optimal mitigation strategies. Recent machine-learning vulnerability mapping advances offer an opportunity to link building resistance indices to economic outcomes at scale [4].

Context-sensitive LCA in low-income/high-hazard settings: Existing LCA studies often reflect temperate, developed-country contexts. Studies that incorporate constrained supply chains, informal building practices, and differential Labour costs in developing, landslide-prone regions are needed to render conclusions actionable for policy [3, 6].

6. PROPOSED STANDARD ASSESSMENT FRAMEWORK

To resolve current uncertainty and enable robust policy advice, we propose a standardized assessment framework combining hazard, vulnerability and cost modelling:

Hazard characterization: Map landslide types (debris flow, rapid translational, slow creep) and intensities (impact energy, displacement rate) using remote sensing, slope models and field inventories [4].

Building resistance metrics: Define structural resistance indices for monolithic and framed prototypes (e.g., critical thrust at onset of significant damage, allowable differential settlement, out-of-plane wall capacity). Obtain these via experimental testing, FE simulation and analogy with seismic fragility where justified [1].

Fragility function development: Translate resistance metrics into fragility curves (probability of damage states conditional on hazard intensity) for each prototype and retrofit option [7].

Economic module: Calculate initial construction cost (material, Labour, time), expected annualized repair/replacement costs using fragility \times hazard frequency, and operational energy/maintenance costs (LCA perspective). Discount future costs to present value to obtain net present value (NPV) and life-cycle cost (LCC) comparisons [5, 6].

Decision rules: For each location and prototype, compute expected LCC and expected annualized loss; determine the cost-efficient option subject to performance objectives (e.g., acceptable probability of exceedance of catastrophic loss). Conduct sensitivity analyses on Labour rates, material transport costs, hazard frequency and discount rate.

Applying this framework across representative sites would yield generalizable guidance on when monolithic systems are economically preferable in landslide contexts.

7. CONCLUSIONS AND PRACTICAL RECOMMENDATIONS

Synthesis of reviewed journal literature indicates:

Monolithic systems (ICF, tunnel formwork, cast-in-place continuous RC) have structural and operational attributes continuity, out-of-plane strength, thermal performance and reduced maintenance that can reduce life-cycle costs and expected post-landslide losses versus some conventional framed or masonry systems, particularly in slow-moving landslide contexts and in high-Labour-cost or repetitive multi-unit projects [1, 3, 5, 7].

The relative cost efficiency is highly context dependent. For high-impact debris-flow zones, structural form is necessary but insufficient; siting and protective works dominate expected losses. For slow-moving slides, monolithic systems combined with foundation adaptation often yield lower expected repair costs, giving a favorable life-cycle outcome.

Evidence gaps remain, notably the lack of peer-reviewed fragility curves for monolithic systems under landslide

loading and limited probabilistic LCC studies integrating spatial hazard models. Addressing these gaps will require cross-disciplinary experiments, field monitoring, and standardized LCC protocols for hazard-specific contexts [2, 4, 7].

Practical recommendations for practitioners and policy makers:

In slow-moving landslide zones, favour monolithic wall-and-slab solutions with appropriately deep or stiffened foundations where local supply chains support cost-effective monolithic construction.

In debris-flow/high-impact corridors, prioritize non-structural mitigation (avoidance, diversion structures, early warning) and consider monolithic systems only if combined with protective works.

For housing programs with repetitive layouts (multi-storey social housing), evaluate tunnel form monolithic systems for potential time and cost savings.

Commission site-specific probabilistic assessments that combine local hazard maps, building prototypes and life-cycle cost models before adopting large-scale policy shifts.

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