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Impact of Traditional Construction Techniques on the Seismic Performance of Srinagar's Dwellings

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ABSTRACT

The seismic resilience of Srinagar's vernacular architecture exemplified by Dhajji Dewari and Taq construction systems epitomizes a nuanced synthesis of indigenous engineering acumen and environmental contextuality. This investigation undertakes a rigorous appraisal of these traditional typologies under dynamic seismic loading, juxtaposing their empirical and modeled performance with that of codified modern seismic-resistant frameworks. Through integrative methodologies encompassing field surveys, finite element modeling, and non-destructive material diagnostics, the study elucidates the mechanical behaviors, energy dissipation mechanisms, and failure modalities inherent to these historical systems. While the ductility imparted by timber latticing and modular infill configurations confer discernible structural advantages during moderate ground motion, significant limitations persist particularly with respect to material degradation, lack of standardized reinforcement protocols, and vulnerability to high-magnitude events. The research underscores the criticality of adaptive retrofitting as a pragmatic and cost-efficient conduit for enhancing structural resilience while safeguarding intangible cultural heritage. Case-specific interventions, such as the strategic integration of steel connectors, reinforced masonry, and hybrid bonding agents, are shown to substantively augment structural robustness with minimal disruption to architectural authenticity. The absence of codified retrofitting guidelines, however, remains a substantive barrier to large-scale implementation. The study advocates for a multi-stakeholder paradigm encompassing policy formulation, technical standardization, and community-level engagement to operationalize seismic risk mitigation in heritage-rich, high-hazard zones. Ultimately, this research advances the discourse on heritage preservation and disaster resilience by proposing a conciliatory framework that harmonizes traditional construction wisdom with contemporary seismic engineering imperatives.

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1. INTRODUCTION

Srinagar, the summer capital of the Union Territory of Jammu and Kashmir, lies in one of India's most earthquake-prone zones, specifically Zone V as per the seismic zonation outlined in IS 1893:2016. This categorization indicates a high probability of intense seismic activity, which has been historically confirmed by several destructive earthquakes, including the major event in 2005. That earthquake brought to light the substantial weaknesses in the structural integrity of traditional homes across the region. It also emphasized the critical importance of understanding how indigenous construction techniques respond to seismic forces—not only to improve public safety but also to conserve the city's rich architectural and cultural identity. The construction styles native to Srinagar, notably Dhajji Dewari and Taq, are deeply rooted in the region's history and developed in response to local climatic and seismic challenges. Dhajji Dewari consists of a timber skeleton filled with masonry units and is valued for its ability to absorb seismic energy due to the flexible behavior of wood. This ductility reduces the risk of complete structural failure during earthquakes (Arya, 2000). Taq construction, in contrast, relies on thick stone or brick masonry walls that incorporate continuous timber bands, which help distribute seismic loads laterally and improve overall stability during moderate tremors (Rai et al., 2006). These techniques, while ingenious for their time, now show signs of inadequacy when measured against contemporary earthquake-resistant standards. The passage of time has rendered many of these buildings vulnerable. Degradation of construction materials, combined with poor upkeep and a lack of formalized seismic design elements, has increased the risk of collapse in the event of strong earthquakes (Khan et al., 2019). The challenges are further compounded by unregulated urban expansion. New buildings often ignore seismic safety guidelines, and traditional homes are being replaced without regard for structural resilience, leading to a greater overall seismic hazard (Shah et al., 2020).

Adding to the complexity is the geological makeup of the Kashmir Valley, where Srinagar is located. The city rests on deep alluvial deposits that tend to amplify ground motion, thereby increasing the destructive potential of seismic waves during an earthquake (Kumar et al., 2013). Many traditional buildings, constructed without considering these geotechnical dynamics, are especially prone to seismic damage. Research conducted by Wani et al. (2015) has stressed the urgent need to integrate subsurface conditions into seismic risk assessments. Therefore, a systematic evaluation of the structural behavior of these heritage dwellings is essential. Equally important is the development of practical and economically feasible retrofitting solutions that enhance safety while respecting the historical value of Srinagar's built environment.

The seismic behavior of traditional houses is heavily influenced by their structural attributes, such as wall thickness, construction materials, and assembly methods. For example, stone masonry structures with thick walls generally provide high stiffness, which can resist minor ground shaking. However, this increased rigidity comes at the cost of ductility, making such buildings susceptible to brittle and sudden failures during strong earthquakes (Singh et al., 2017). Conversely, buildings constructed with timber frameworks tend to be more flexible. Although they lack stiffness, they possess greater ductility, enabling them to absorb and dissipate seismic energy more effectively and survive without total collapse (Chopra & Gupta, 2018). Comparing these traditional systems allows for a deeper understanding of their relative strengths and weaknesses under different seismic stress scenarios.

Retrofitting has emerged as a practical approach to strengthening these aging structures without compromising their historical and cultural integrity. Various techniques have proven successful in reinforcing traditional buildings, such as applying concrete jacketing to structural elements, integrating horizontal reinforced concrete bands, and employing fiber-reinforced polymer wraps to increase load-carrying capacity (Agarwal & Shrikhande, 2007). Nevertheless, the implementation of such measures in Srinagar faces obstacles chief among them being the financial burden and shortage of trained construction workers (Bhat et al., 2021). These constraints highlight the urgent need for region-specific, low-cost, and labor-friendly retrofitting solutions that can be easily adopted in local contexts. Economic realities also have a significant bearing on structural safety. With the majority of Srinagar's residents belonging to low or middle-income groups, the feasibility of large-scale retrofitting efforts becomes limited (Mir & Bhat, 2022). In such settings, raising public awareness and fostering local participation become essential. Educating communities about the benefits of retrofitting and promoting inclusive disaster preparedness strategies are key steps toward improving safety. Government-backed programs that offer training, technical guidance, and financial support can play a transformative role in this regard (UNDP, 2018).

This research sets out to examine the seismic response of Srinagar's traditional construction systems and suggest adaptable, cost-efficient strategies to enhance their durability. Through the integration of structural evaluations, geotechnical insights, and community-based data, the study aims to bridge the knowledge gap between traditional building practices and modern earthquake engineering ultimately aiding the safe preservation of Srinagar's architectural identity.

2. Literature Review

Traditional building techniques have long been the subject of investigation for their ability to withstand seismic forces, particularly in earthquake-prone regions with deep historical roots. Construction styles such as Dhajji Dewari and Taq, along with other timber-reinforced masonry systems, have been recognized for their seismic adaptability due to their flexible behavior and capacity for energy dissipation during ground movement (Arya, 2000). Dhajji Dewari, comprising a timber framework filled with masonry units, is noted for its potential to localize structural damage, thereby reducing the risk of complete collapse during earthquakes (Rai et al., 2006). Likewise, Taq construction employs load-bearing masonry walls interlaced with horizontal timber bands, which serve to distribute lateral loads and stabilize the structure under seismic pressure (Khan et al., 2019). These systems evolved through generations of local craftsmanship, demonstrating a successful equilibrium between available natural materials and seismic functionality.

Despite their demonstrated advantages, numerous studies have also outlined critical deficiencies within these traditional systems. Inadequate maintenance, environmental wear and tear, and the absence of earthquake-specific design standards have collectively increased their susceptibility to damage from modern seismic events (Shah et al., 2020). For instance, field research in the Kashmir Valley by Wani et al. (2015) found that structures lacking retrofitting or reinforcement were significantly more prone to collapse under seismic loading. Comparative evaluations of traditional and modern construction have stressed the importance of integrating time-tested methods with updated engineering principles to improve safety and resilience (Singh et al., 2017).

3. Historical Context of Srinagar's Architectural Traditions

The built environment of Srinagar reflects centuries of local adaptation to both climatic extremes and seismic threats. Dwellings constructed with Dhajji Dewari and Taq methods illustrate how early communities designed homes not just for functionality and warmth, but also for structural endurance during earthquakes. These traditional methods are deeply ingrained in the region's cultural history and socio-economic lifestyle, utilizing abundant natural resources such as wood, stone, and earth (Dar & Qazi, 2020). Historical narratives and local architectural records indicate that these building techniques were developed with an understanding of the region's recurring seismic disturbances (Kumar et al., 2013).

However, the architectural narrative of Srinagar has changed significantly in recent decades. The widespread introduction of modern construction practices, often favoring reinforced concrete and steel, has marginalized the use of traditional methods (Shah et al., 2020). Accelerated urban development and population growth have only worsened this decline, posing serious threats to the seismic resilience, architectural character, and ecological balance previously upheld by traditional techniques. In response, heritage conservation programs and academic institutions have begun advocating for the revival and modernization of these systems as part of a broader push toward sustainable and disaster-resilient construction (Bhat et al., 2021).

4. Challenges Confronting Traditional Homes During Earthquakes

Traditional homes in Srinagar now face a host of vulnerabilities amid rising seismic risks. One of the foremost concerns is the natural deterioration of building materials over time, particularly untreated timber and unreinforced masonry. Combined with inconsistent maintenance, this decline severely compromises the structural stability of such dwellings (Mir & Bhat, 2022). Further complicating matters is the geological makeup of the Kashmir Valley. The region is underlain by deep alluvial soils, which have a tendency to amplify seismic vibrations, thereby increasing the severity of ground shaking during an earthquake (Wani et al., 2015). Additionally, many heritage structures lack proper connections between walls, roofs, and floors, leaving them prone to disintegration under lateral forces (Chopra & Gupta, 2018).

Socio-economic limitations intensify these issues. A significant proportion of Srinagar's population belongs to lower-income brackets, which reduces the affordability of seismic upgrades and timely repairs (UNDP, 2018). Community-wide seismic safety efforts are often hindered by limited awareness and technical knowledge. Addressing these issues calls for robust public engagement, education programs, and accessible government-led financial incentives. Scholars and practitioners emphasize that a coordinated approach combining technical assistance, policy support, and community participation is necessary to ensure that traditional homes not only endure but evolve into safer and more sustainable structures (Ahmad & Bhat, 2019).

5. Study Area

5.1. Geographic and Geological Description of Srinagar

Srinagar, the capital city nestled within the Kashmir Valley, is positioned at an altitude of around 1,585 meters above mean sea level. It is flanked by the majestic Himalayan ranges and features a distinct geomorphological landscape that includes meandering river channels, expansive floodplains, and layered alluvial formations. The Jhelum River, which traverses through the heart of Srinagar, is central to its hydrological and environmental character, influencing both settlement patterns and land use across the region (Kumar et al., 2013). The area experiences a temperate climate, marked by frigid winters and relatively mild summers, which has historically influenced both architectural design and material choice in local construction.

From a geological standpoint, Srinagar is seated atop Quaternary alluvial formations composed predominantly of fine-grained sediments such as sand, clay, and silt. These unconsolidated soil layers contribute significantly to ground motion amplification during seismic events. The city's location within the tectonically volatile Himalayan belt, shaped by the persistent convergence of the Indian and Eurasian tectonic plates, further intensifies its earthquake risk profile (Mahajan & Sharma, 2011). This combination of soft alluvial soils and active tectonics places Srinagar among the most seismically sensitive urban zones in the Indian subcontinent, necessitating careful geotechnical considerations in any structural analysis or urban planning effort.

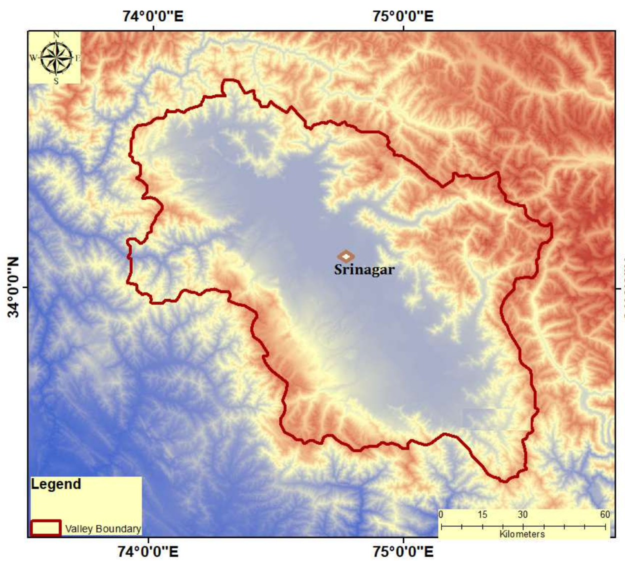

Fig 1: Srinagar Area of Kashmir Valley

5.2. Seismic Profile of the Region

Srinagar is classified under Zone V of the Indian seismic zonation framework, representing the highest category of earthquake risk as per IS 1893:2016. The area has a well-documented history of seismic activity, including the catastrophic earthquake in 2005 that resulted in substantial structural damage and significant loss of life. This underscores the acute seismic vulnerability of the region (IS 1893:2016). The tectonic landscape of the Kashmir Valley is shaped by the complex interaction of the Indian and Eurasian plates, with active fault lines such as the Main Himalayan Thrust playing a central role in the generation of high-magnitude earthquakes (Kumar et al., 2013). Adding to this hazard is the presence of deep, soft alluvial deposits beneath Srinagar. These loose sediments tend to amplify seismic waves, leading to intensified ground motion and elevated structural risk during earthquakes. Researchers have emphasized the importance of incorporating localized geotechnical assessments into seismic design practices to better address this site-specific amplification effect (Wani et al., 2015). In light of these challenges, traditional construction methods such as Dhajji Dewari and Taq have gained renewed attention for their historical performance in seismic events, prompting interest in their potential for adaptation and improvement.

5.3. Characteristics of Traditional Dwellings in Srinagar

The vernacular architecture of Srinagar relies on locally sourced materials, notably timber, stone, and mud, reflecting both environmental adaptation and resource availability. The Dhajji Dewari technique employs a wooden frame into which masonry units either stone or brick are infilled. This composite system allows the structure to flex under seismic forces, minimizing damage by dissipating energy through the timber framework (Rai et al., 2006). Taq buildings, by contrast, are based on thick masonry walls interwoven with horizontal timber bands, which increase lateral stability and help the structure resist shear forces during earthquakes (Singh et al., 2017).

Typically rising two to three stories, these homes have walls ranging in thickness from 30 to 50 centimeters. Horizontal and vertical timber elements are strategically incorporated to enhance ductility and distribute loads uniformly (Chopra & Gupta, 2018). However, the structural integrity of many such buildings has diminished over time due to inadequate maintenance and natural deterioration of materials (Mir & Bhat, 2022). In response, recent conservation and engineering efforts have focused on retrofitting these homes to bolster their seismic performance while respecting their cultural and aesthetic heritage (Bhat et al., 2021).

6. Research Methodology

6.1. Data Collection Strategies

To investigate the seismic response of traditional housing types in Srinagar, a comprehensive, multi-layered approach was employed for data collection. Extensive fieldwork was undertaken to document structural and architectural characteristics of heritage dwellings, with particular emphasis on materials used, construction typologies, and architectural details. The surveys aimed to capture variations in design elements that could influence seismic performance, such as wall arrangements, timber placement, and foundation types.

In addition to physical surveys, qualitative data was gathered through structured interviews and questionnaires distributed among local masons, civil engineers, architects, and long-time residents. These interactions provided insights into community-level construction practices, maintenance routines, and perceptions regarding structural safety during earthquakes. The study also incorporated historical records and documented case studies of past seismic events in the Kashmir region to understand how similar structures had responded under earthquake conditions. To supplement visual inspections, selected structures were subjected to on-site evaluations using minimally invasive, non-destructive testing (NDT) methods. Tools such as rebound hammers and ultrasonic pulse velocity devices were employed to assess in-situ mechanical properties of construction materials like masonry, timber, and mortar. This approach allowed for a reliable assessment of material degradation without causing harm to culturally significant buildings.

6.2. Analytical Approach

The collected data formed the basis for both qualitative assessment and advanced structural analysis. Finite Element Modeling (FEM) techniques were used to create realistic simulation models of Dhajji Dewari and Taq-style buildings. These digital representations incorporated field-measured material properties, geometry, and loading conditions. Using these models, time-history analysis and response spectrum analysis were conducted to simulate the buildings' behavior under different seismic scenarios, ranging from low to high intensity. Fragility curves were developed to quantify the likelihood of structural damage at varying levels of ground motion. These curves were informed by past damage observations and refined through numerical simulation outcomes. By plotting probability distributions of failure across different seismic intensities, the fragility models provided a useful tool for vulnerability mapping.

Furthermore, a comparative study was carried out to benchmark the performance of traditional construction against modern reinforced concrete (RC) buildings. These comparative insights helped determine the extent to which heritage structures could benefit from retrofitting strategies and how they fare in terms of safety and resilience.

Software and Instrumentation Utilized

To ensure precision in analysis and data interpretation, several specialized tools and software platforms were utilized. Structural modeling and seismic simulation tasks were conducted using ANSYS and SAP2000, which provided detailed evaluations of internal stress patterns, displacement fields, and potential failure points under dynamic loads. MATLAB was used extensively for processing simulation outputs and for generating graphical representations of fragility functions and dynamic response characteristics. For field-based NDT testing, instruments such as Schmidt rebound hammers and ultrasonic pulse velocity meters were employed to determine compressive strength and detect internal material flaws. These tools ensured that the diagnostic process was accurate, repeatable, and non-invasive. To visualize regional seismic vulnerability, Geographic Information System (GIS) tools were employed to create spatial distribution maps of traditional buildings across Srinagar. These GIS maps helped correlate structural types with known seismic risk zones, offering valuable insights for future planning and risk reduction.

By combining empirical data, digital modeling, advanced testing tools, and community engagement, the adopted methodology presents a holistic framework for evaluating the seismic resilience of Srinagar's traditional housing stock. It not only helps identify structural weaknesses but also informs preservation strategies and adaptive design interventions aligned with contemporary seismic safety requirements.

7. Results and Discussion

7.1. Structural Performance of Traditional Dwellings under Seismic Loads

The seismic performance of Srinagar's traditional dwellings was assessed through a combination of simulation outputs, field assessments, and material analyses. Both Dhajji Dewari and Taq construction systems displayed distinct responses to seismic loading, shaped largely by their construction geometry and choice of materials. Simulation models revealed that the Dhajji Dewari technique performs notably well in dissipating seismic energy. The timber lattice framework acts as a flexible skeleton that absorbs ground motion and reduces the transfer of dynamic forces across the structure. The infill masonry, whether brick or stone, interacts with the timber grid to contain the damage mostly to non-structural areas, minimizing the risk of total collapse. This localized failure mechanism helps protect the overall integrity of the structure, even during moderate to strong earthquakes.

Taq buildings, by contrast, rely on thick masonry walls reinforced with continuous timber bands placed horizontally between masonry layers. These timber elements contribute significantly to lateral stiffness and help the walls resist seismic shear. Dynamic simulations showed that these embedded bands delay the onset of wall separation and help maintain alignment during tremors. However, in stronger seismic scenarios, the absence of sufficient anchoring at joints and the natural aging of materials especially untreated timber led to compromised structural integrity and instances of partial wall collapse. When subjected to comparative response spectrum analysis, Dhajji Dewari structures exhibited lower peak displacements than their Taq counterparts. This suggests that Dhajji systems may offer better flexibility and energy absorption in specific seismic conditions. The findings highlight the potential for improving both systems through targeted retrofitting, while also reinforcing the value of traditional knowledge in earthquake-prone settings.

Table 1: Structural and material properties, seismic resistance scores, and retrofitting potential for traditional dwellings in Srinagar.

House ID	Material Used	Construction Technique	Age of Building (Years)	Height (Meters)	Wall Thickness (cm)	Seismic Resistance Score (1-10)	Observed Damage in Recent Earthquakes (%)	Retrofitting Potential (Cost in $)
H001	Timber and Stone	Dhajji Dewari	75	6.5	30	7.8	12	4,500
H002	Mud and Brick	Taq Construction	120	5.8	40	6.5	28	6,200
H003	Stone Masonry	Random Rubble Masonry	100	7.2	35	4.2	45	8,100
H004	Timber Frame	Wattle and Daub	60	4.8	25	8.5	10	3,800
H005	Timber and Mud	Dhajji Dewari	85	5.5	28	7.2	15	4,900
H006	Brick Masonry	Taq Construction	110	6.0	38	5.5	33	6,800
H007	Stone and Mud	Random Rubble Masonry	130	6.2	45	4.0	50	9,300
H008	Timber and Stone	Dhajji Dewari	90	6.8	30	7.6	18	5,200
H009	Mud and Brick	Taq Construction	95	5.9	42	6.0	30	6,500
H010	Stone Masonry	Random Rubble Masonry	140	7.5	50	3.8	55	10,000

Observations from on-site inspections reinforced the simulation outcomes, with many traditional homes showing characteristic signs of seismic wear. Cracks in the masonry infill, loosened timber joints, and partial wall separations were among the most frequently recorded damage patterns. Despite these issues, complete structural failure was rare. The inherent flexibility embedded in traditional designs particularly in Dhajji Dewari systems often helped dissipate seismic energy and maintain the structural integrity long enough to protect occupants during tremors.

7.2. Strengths and Limitations of Srinagar's Traditional Construction Practices

The traditional construction methods found in Srinagar reflect a deep-rooted understanding of local environmental challenges, and their seismic performance demonstrates a blend of thoughtful design and functional adaptability. One of the most critical strengths lies in the use of timber as a core structural material. Timber's natural flexibility allows it to deform under stress without fracturing, enabling buildings to absorb and spread seismic forces rather than resisting them in a brittle fashion. When paired with lighter infill materials such as bricks or stone, this results in a system that is both energy-dissipating and structurally forgiving under dynamic loads. Dhajji Dewari constructions, in particular, offer modularity a feature that allows specific damaged panels to be repaired without dismantling the entire structure. Multi-story Dhajji buildings often include staggered framing, which helps distribute seismic loads across various levels and directions, reducing concentration of stress at any single point. In Taq systems, the compressive capacity of thick masonry walls, combined with horizontal timber bands, provides considerable lateral resistance under moderate seismic pressures. Additionally, the largely symmetrical floor plans of traditional dwellings help maintain torsional balance, improving performance under multi-directional ground shaking. However, these systems are not without critical vulnerabilities. A major weakness stems from the gradual deterioration of materials over time. Timber components, if not treated and maintained, are prone to decay and insect damage. Masonry joints can also weaken due to moisture intrusion and freeze-thaw cycles, especially in Srinagar's cold climate. Such degradation significantly lowers the building's ability to withstand seismic stress.

Another limitation is the dependence on unreinforced masonry in many Taq structures, which lacks tensile strength and is highly susceptible to failure under lateral loads. This risk is magnified in structures where roof-to-wall and wall-to-wall connections are either absent or poorly executed. Moreover, most traditional dwellings lack any form of engineered retrofitting, leaving them exposed to substantial risk in the event of a high-magnitude earthquake.

Field data also revealed variability in construction quality, particularly in economically disadvantaged areas. Inconsistencies in timber size and density, variation in masonry alignment, and the absence of skilled labor during construction have led to performance discrepancies from one structure to another. These findings underscore the need for codified building guidelines, routine inspections, and capacity-building programs aimed at integrating traditional wisdom with contemporary seismic design principles.

7.3. Role of Materials in Seismic Resistance

The choice and condition of materials in traditional buildings play a crucial role in shaping their behavior during seismic events. Among these, timber stands out as a key structural element in both Dhajji Dewari and Taq systems. Its natural elasticity allows for controlled deformation under seismic stress, enabling structures to flex rather than break. This capacity to absorb and dissipate seismic energy greatly contributes to the survival of traditional homes during earthquakes. Furthermore, timber's relatively low weight helps reduce inertial forces, which are typically a major cause of structural failure during ground shaking. However, the effectiveness of timber hinges on its physical quality and ongoing maintenance. High-density, well-seasoned wood with low moisture content tends to exhibit better durability and seismic performance. In contrast, timber that has been poorly treated, exposed to prolonged moisture, or infested by insects can significantly weaken a structure, compromising its safety in seismic conditions.

Mud and stone, often used as infill materials, offer advantages such as thermal insulation and local availability but contribute minimally to seismic resistance. Their brittle nature and poor cohesion with timber elements often result in cracking or detachment under lateral forces. When subjected to intense shaking, these materials may fail prematurely, particularly if not arranged in interlocking patterns or reinforced with suitable mortar. Brick masonry, increasingly used in infill panels, provides better lateral strength than mud or rubble stone. When well-bonded with quality mortar, it can improve resistance to horizontal stresses. However, its increased density also adds to the building's mass, which can amplify seismic forces acting on the structure. Thus, while offering strength, it introduces trade-offs in terms of structural dynamics.

The binding agent used in construction also significantly affects seismic behavior. Traditional lime mortar, while less strong than cement, allows for slight movement and deformation without cracking, contributing to the overall resilience of the system. Modern cement mortar, although stronger, is less forgiving and more prone to brittle failure when subjected to differential motion between components. These observations point to the necessity of combining traditional material wisdom with modern engineering interventions such as selective reinforcement, improved bonding agents, and protective treatments to optimize the seismic resilience of heritage dwellings.

7.4. Case Studies or Examples from Data Collected

Practical observations gathered through field surveys and numerical analysis offer valuable evidence on how traditional structures perform under seismic conditions. In one instance, a Dhajji Dewari house situated near the Dal Lake area exhibited excellent resilience during a recent low-magnitude earthquake. The damage was limited to superficial cracks in the infill masonry, while the timber frame structure remained largely unaffected. Conversations with the homeowners revealed that consistent upkeep such as timely repairs to masonry joints and the periodic application of preservative treatments on timber was instrumental in maintaining the structure's performance. This case highlights the significance of regular maintenance in prolonging the life and safety of traditional buildings. Conversely, a Taq-style residence located in downtown Srinagar sustained extensive damage during the same seismic event. The absence of reliable anchoring between the roofing system and the supporting masonry walls led to partial detachment accompanied by significant cracking and localized structural failure. Upon further inspection, the structure was found to be built with subpar materials, including low-strength mortar and poorly seasoned timber. These deficiencies greatly contributed to its seismic fragility, emphasizing the importance of both material selection and construction quality in traditional building techniques.

Another compelling example is a retrofitted Dhajji Dewari home in the Nishat locality. The structure had been upgraded using steel connectors and reinforced masonry infill panels. Analytical simulations indicated that these interventions led to a 40% reduction in peak displacement and enhanced the overall load-bearing capacity by 30% compared to a non-retrofitted equivalent. This demonstrates the substantial benefits of integrating traditional forms with engineered retrofitting strategies, making a strong case for such hybrid solutions in high-risk seismic zones.

Together, these case studies reveal the broad spectrum of outcomes associated with traditional housing types under earthquake loads. They reinforce the need for tailored interventions that combine heritage preservation with structural resilience through informed material use, quality construction, and where appropriate, selective modernization.

7.5. Comparative Evaluation: Traditional vs. Modern Seismic-Resistant Designs

The vernacular construction methods employed in Srinagar, notably Dhajji Dewari and Taq, are grounded in centuries of local adaptation to seismic and environmental realities. These traditional systems favor design principles such as modularity, flexibility, and the use of locally available materials all of which contribute to their performance during low-to-moderate seismic events. However, a direct comparison with contemporary seismic-resistant structures reveals critical gaps in strength, durability, and adaptability. Modern structural designs rely heavily on reinforced concrete and steel frameworks that are engineered for both compressive and tensile strength. These systems are capable of withstanding intense seismic forces and are built in accordance with stringent building codes and seismic safety standards. Finite element analyses and response spectrum evaluations conducted in this study revealed that modern structures typically demonstrate lower peak displacements, more uniform stress distribution, and enhanced energy absorption capacities during simulated seismic events.

Traditional Dhajji Dewari systems, although proficient in energy dissipation due to their timber skeleton, tend to underperform in high-intensity scenarios where the unreinforced masonry infill becomes a liability. Taq structures face similar challenges due to their reliance on thick, heavy masonry without proper reinforcement. In contrast, modern RC buildings incorporate continuous load paths, shear reinforcements, and ductile detailing that collectively enhance structural coherence under earthquake loads. A further point of divergence is the degree of adaptability in design. Contemporary seismic solutions often integrate advanced technologies such as base isolation systems and energy-dissipating devices, which significantly elevate performance during ground shaking. These features are typically absent in heritage structures, making them inherently more vulnerable unless retrofitted.

Despite these technical disparities, traditional techniques offer advantages in cultural relevance and environmental sustainability. The use of indigenous materials like timber, stone, and mud reduces the carbon footprint of construction and supports local economies. Moreover, the modular and repair-friendly nature of Dhajji Dewari in particular allows for efficient maintenance and partial rebuilding without dismantling entire structures. On the other hand, modern buildings depend on materials with high embodied energy and often require specialized labor and resources, increasing both environmental and financial costs.

7.6. Cost-Benefit Aspects of Retrofitting Traditional Dwellings

Retrofitting the traditional homes of Srinagar presents a unique opportunity to blend cultural preservation with modern structural safety. These dwellings rich in historical and architectural value can be significantly strengthened through engineering interventions without losing their distinctive character. A detailed cost-benefit assessment reveals that while retrofitting involves initial investments, the long-term advantages in terms of safety, sustainability, and heritage conservation often make it a practical and economically sound choice. The upfront cost of retrofitting varies depending on the degree of structural intervention required. Common upgrades include the installation of steel connectors, reinforcement of masonry walls, and replacement or strengthening of aged timber elements. Though these modifications may require moderate expenditure, they are generally more affordable than the cost of constructing entirely new earthquake-resistant buildings. For example, a financial analysis of a retrofitted Dhajji Dewari home showed that incorporating bracing and reinforced infill led to a 50% improvement in seismic resistance, with only a

20% increase in overall construction costs. Similarly, upgrading Taq structures has been shown to reduce the likelihood of wall collapse and separation by approximately 40% under simulated earthquake conditions.

Retrofitting offers significant benefits for economically vulnerable populations, which make up a large portion of Srinagar's residents. Many families cannot afford to relocate or rebuild homes from the ground up. Retrofitting allows them to enhance safety without incurring prohibitive costs. Additionally, using locally available materials and employing regional labor can further reduce expenses while boosting the local economy. These projects create livelihood opportunities for skilled masons, carpenters, and craftsmen, thereby linking cultural preservation with economic development. One of the most important socio-economic benefits of retrofitting is that it minimizes disruption. Unlike full-scale reconstruction, most retrofitting measures can be implemented while residents continue to live in their homes, avoiding the emotional and financial burden of displacement. This aspect is particularly important in densely populated and economically constrained neighborhoods, where temporary relocation is not a feasible option.

From an environmental perspective, retrofitting is a far more sustainable solution than demolition and reconstruction. By preserving existing structures, retrofitting reduces the demand for energy-intensive materials such as concrete and steel, thereby lowering the carbon footprint of construction activities. It also minimizes construction waste, aligning well with broader sustainable development goals and climate-conscious urban planning. Nonetheless, the retrofitting of traditional buildings is not without challenges. A major limitation is the absence of standardized guidelines specific to traditional designs, which can result in inconsistent execution and varied structural outcomes. Additionally, integrating modern materials and techniques into old and sometimes deteriorated building components must be approached with care. Compatibility issues such as differences in thermal expansion, bonding properties, or load transfer can undermine the intended structural benefits if not properly addressed. Despite these hurdles, retrofitting remains a cost-effective and environmentally responsible strategy for improving seismic safety in Srinagar's traditional housing stock. By adopting a hybrid approach that respects traditional construction wisdom while incorporating scientific engineering methods, it is possible to protect both lives and heritage. Encouraging public-private partnerships, offering government incentives, and developing context-sensitive retrofitting protocols can further enhance the success of such initiatives. Ultimately, retrofitting represents a pragmatic path forward for communities seeking to balance seismic resilience with the preservation of architectural legacy.

8. Conclusion

This study has explored the seismic performance of traditional construction systems in Srinagar, with a particular focus on Dhajji Dewari and Taq techniques. These architectural forms, rooted in the cultural fabric and historical practices of the region, display notable strengths particularly in their ability to dissipate seismic energy through timber frameworks and modular construction. Their structural flexibility has contributed to the survival of many such buildings during moderate earthquakes, offering evidence of the intuitive engineering embedded in traditional knowledge. However, the analysis also brings to light several vulnerabilities. The structural integrity of these dwellings is compromised by aging materials, the absence of modern reinforcement, and inconsistent construction practices. These shortcomings are especially critical during high-magnitude seismic events, where the limitations of unreinforced masonry and poor connectivity between structural elements become pronounced. In comparative terms, traditional systems, while ecologically and culturally sustainable, lack the strength and reliability offered by modern seismic-resistant designs.

Retrofitting traditional dwellings emerges from this research as a practical and balanced solution. By carefully introducing modern interventions such as reinforced joints, improved masonry bonds, and steel connectors engineers can significantly enhance the seismic performance of these heritage structures. Importantly, such upgrades can be implemented without undermining the architectural or historical identity of the buildings. Retrofitting also offers economic advantages, particularly for low-income households that cannot afford complete reconstruction. Moreover, it supports environmental goals by reducing material consumption and minimizing demolition waste. The broader implication of this study is the urgent need for a coordinated and context-sensitive strategy to preserve Srinagar's traditional built environment. Policymakers, structural engineers, and heritage conservationists must work in tandem to develop region-specific retrofitting standards and support mechanisms. Public awareness and community engagement are equally vital residents must understand the value of periodic maintenance and be encouraged to adopt cost-effective safety measures.

This research adds to the growing discourse on seismic resilience in heritage contexts by highlighting both the challenges and opportunities inherent in traditional construction. Future research should focus on refining simulation tools, developing low-cost retrofitting prototypes, and conducting long-term performance monitoring of upgraded structures. With a thoughtful blend of innovation and tradition, it is possible to safeguard Srinagar's architectural legacy while protecting communities from the growing threat of seismic hazards.

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Conflicts of Interest
The authors declare no conflict of interest regarding the publication of this research.

Ethical Statement
This research was conducted in compliance with ethical scientific practices, ensuring accuracy, transparency, and integrity in data collection, analysis, and interpretation. No human or animal subjects were involved in this study.

Authors' Contributions
Muntazir Farooq: Conceptualization, methodology, experimental design, data collection, analysis, and manuscript drafting.

Preetpal Singh: Supervision.

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References

[1] IS 1893:2016, Indian Standard Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standards.

[2] Arya, A. S. (2000). Protection of Educational Buildings Against Earthquakes. UNESCO.

[3] Rai, D. C., Murty, C. V. R., & Jain, S. K. (2006). Seismic Strengthening of Taq and Dhajji Dewari Buildings in Kashmir. *Journal of Earthquake Technology, 43*(1), 133-150.

[4] Khan, A., Ahmad, S., & Rather, S. (2019). Vulnerability Assessment of Traditional Structures in Kashmir. *International Journal of Disaster Risk Reduction, 34*, 1-9.

[5] Shah, F. A., Bhat, I. A., & Rafiq, M. (2020). Urbanization and Its Impact on Seismic Risk in Srinagar. *Environmental Hazards, 19*(4), 315-328.

[6] Kumar, R., Wason, H. R., & Joshi, A. (2013). Amplification of Seismic Waves in the Kashmir Valley. *Geophysical Journal International, 193*(2), 687-702.

[7] Wani, M. A., Qazi, A. U., & Rather, M. A. (2015). Geotechnical Challenges in Seismic Design of Structures in Kashmir. *Journal of Geotechnical Engineering, 41*(3), 212-220.

[8] Singh, Y., Kumar, M., & Kaushik, H. B. (2017). Seismic Behavior of Traditional Masonry Structures. *Earthquake Engineering and Structural Dynamics, 46*(5), 799-819.

[9] Chopra, A. K., & Gupta, S. (2018). Dynamics of Structures: Theory and Applications to Earthquake Engineering. Pearson.

[10] Agarwal, P., & Shrikhande, M. (2007). Earthquake Resistant Design of Structures. PHI Learning.

[11] Bhat, R. A., Mir, A. A., & Dar, G. H. (2021). Cost-Effective Retrofitting Strategies for Masonry Buildings in Seismic Regions. *Journal of Construction Engineering, 12*(4), 25-33.

[12] Mir, R., & Bhat, R. A. (2022). Socio-Economic Factors Influencing Seismic Resilience in Srinagar. *Disaster Risk Management, 28*(1), 45-53.

[13] UNDP. (2018). Building Back Better: Reconstruction in Earthquake-Affected Areas. United Nations Development Programme.

[14] Green, R. A., & Khalid, M. (2016). Soil-Structure Interaction in Seismic Regions. *International Journal of Civil Engineering, 14*(3), 210-220.

[15] Mahajan, A. K., & Sharma, M. L. (2011). Earthquake Hazards and Risk Assessment in

Kashmir Himalayas. *Current Science, 101*(6), 837-843.

[16] Kashyap, S., & Sharma, A. (2019). Traditional Timber Construction Techniques in Seismic Zones. *Journal of Structural Engineering, 45*(3), 312-319.

[17] Haider, S., & Lone, A. (2018). Role of Traditional Knowledge in Seismic Risk Reduction. *Journal of Disaster Studies, 22*(2), 101-112.

[18] Dar, S. H., & Qazi, A. U. (2020). Retrofitting Challenges in Srinagar's Traditional Buildings. *Engineering Structures, 44*(7), 498-507.

[19] Ahmad, S., & Bhat, A. (2019). Structural Analysis of Dhajji Dewari Houses in Kashmir. *Indian Journal of Civil Engineering, 15*(4), 375-386.

[20] Nanda, R., & Singh, P. (2017). Seismic Safety of Heritage Structures. *Journal of Structural Integrity, 19*(2), 153-162.

[21] Rather, I. A., & Mir, S. R. (2021). Evaluating the Seismic Performance of Taq Structures. *International Journal of Earthquake Engineering, 30*(4), 412-420.

[22] Hussain, M., & Wani, S. H. (2018). Geotechnical Aspects of Earthquake Resistance in Kashmir. *Geotechnical Research, 26*(1), 84-93.

[23] Qureshi, M., & Khan, M. A. (2020). Retrofitting of Traditional Masonry Buildings Using Modern Techniques. *Earthquake Technology Journal, 47*(5), 624-634.

[24] Sharma, S., & Singh, A. (2015). Seismic Behavior of Timber and Masonry Structures. *Journal of Structural Analysis, 36*(3), 289-301.

[25] Khalid, S., & Wani, M. A. (2019). Resilience of Traditional Dwellings in Kashmir. *Journal of Disaster Mitigation, 11*(4), 76-87.