COMPREHENSIVE STRUCTURAL-MECHANICAL AND REGULATORY ANALYSIS OF THE SEISMIC RESISTANCE OF VERNACULAR ARCHITECTURE IN UZBEKISTAN: TRIBOLOGY OF THE SINCH AND PAKHSA SYSTEMS

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Abstract

Uzbekistan occupies a seismically hazardous territory shaped by the long-term collision of the Indian and Eurasian lithospheric plates and governed by the active Tien Shan and Pamir-Alai seismogenic systems. This research presents an IMRAD-adapted English version of a comprehensive analytical paper on the seismic performance of local architecture in Uzbekistan, with specific focus on two historically significant structural systems: monolithic earthen *pakhsa* and timber-framed *sinch*. The study incorporates historical evidence from major earthquakes, including the 1966 Tashkent earthquake and the 1976–1984 Gazli earthquake sequence, with cadastral and GIS-based housing figures, vulnerability matrices, structural-mechanical interpretation, and an assessment of the progression of seismic codes. The findings indicate that *pakhsa* buildings, despite their historical low cost and ecological merits, behave as massive and rigid monoliths with minimal tensile capacity, weak shear resistance, and high propensity for out-of-plane failure. Conversely, *sinch* systems display distinctly better seismic response owing to distributed friction, localized impact absorption, semi-ductile joint pivots, and stiffness decay that extends the structural duration and lessens inertial requirement. Vulnerability matrices for individual housing types confirm that at intensities of 8 points on the MSK-64 scale, *pakhsa* and adobe structures tend toward collapse states, whereas *sinch* buildings generally maintain structural soundness with minor to moderate degradation. The study contends that the main practical objective for Uzbekistan is not the abandonment of indigenous materials as such, but the formalization of friction-based, energy-dissipative structural concepts, coupled with cost-effective upgrading techniques and hybrid design approaches for low-rise dwellings in seismically active zones.

Keywords

Uzbekistan; vernacular architecture; seismic resistance; pakhsa; sinch; earthen construction; vulnerability assessment; seismic regulations

1. Introduction

The region of the Republic of Uzbekistan lies within an area of highly intricate geodynamic interplay brought about by the continuous continental impact between the Indian and Eurasian lithospheric slabs during the Cenozoic period. The seismotectonic foundation of this macro-area is chiefly dictated by active uplift structures, amongst which the Tien Shan and Pamir-Alai seismogenic belts hold paramount significance. This tectonic junction produces considerable pressures in the Earth's crust, which are relieved via extensive fracturing and the repeated occurrence of devastating seismic events. The geographical spread of tremors is irregular; nevertheless, the bulk of heavily inhabited and built-up locales, encompassing the capital metropolis and chief cultural hubs, are positioned in areas where projected seismic force might attain or surpass 7, 8, and 9 units on the MSK-64 scale.

The seismic risk of Uzbekistan is intensified not only by tectonic conditions, but also by engineering-geological factors. A considerable share of settlements is located on thick strata of collapsible loess soils. According to the adopted classification, soils are divided into three categories by their seismic properties. Category I soils, represented by rock formations, may reduce the design seismic intensity by one point, while Category III soils, including clays, loess, and soils with limited seismic bearing capacity, increase seismic intensity by one point. Consequently, even earthquakes of moderate magnitude may produce severe damage where loose surficial loess deposits amplify low-frequency ground motion. Under these conditions, the objective assessment of the seismic resistance of the existing building stock, especially vernacular buildings made of local materials, becomes a matter of public safety and strategic planning.

Within this context, the present study addresses a central contradiction in the traditional architecture of Uzbekistan. On the one hand, monolithic earthen construction, especially pakhsa, has historically been widespread because of its material availability and thermal efficiency. On the other hand, timber-framed sinch systems have demonstrated a significantly higher capacity to survive strong earthquakes. The aim of this study is to translate and reorganize the original manuscript into a journal-oriented IMRAD structure while preserving its substantive analytical contribution. The article therefore seeks to identify the structural reasons for the different seismic behavior of pakhsa and sinch systems, to connect these observations with historical earthquake evidence and cadastral data, and to formulate implications for the modernization of the national regulatory framework.

Figure 1. Given geometrical, material, structural and construction heterogeneity of the vernacular heritage, understanding the vernacular construction requires a deep knowledge and investigation of the place, the traditional techniques and materials

Materials and Methods

Research design

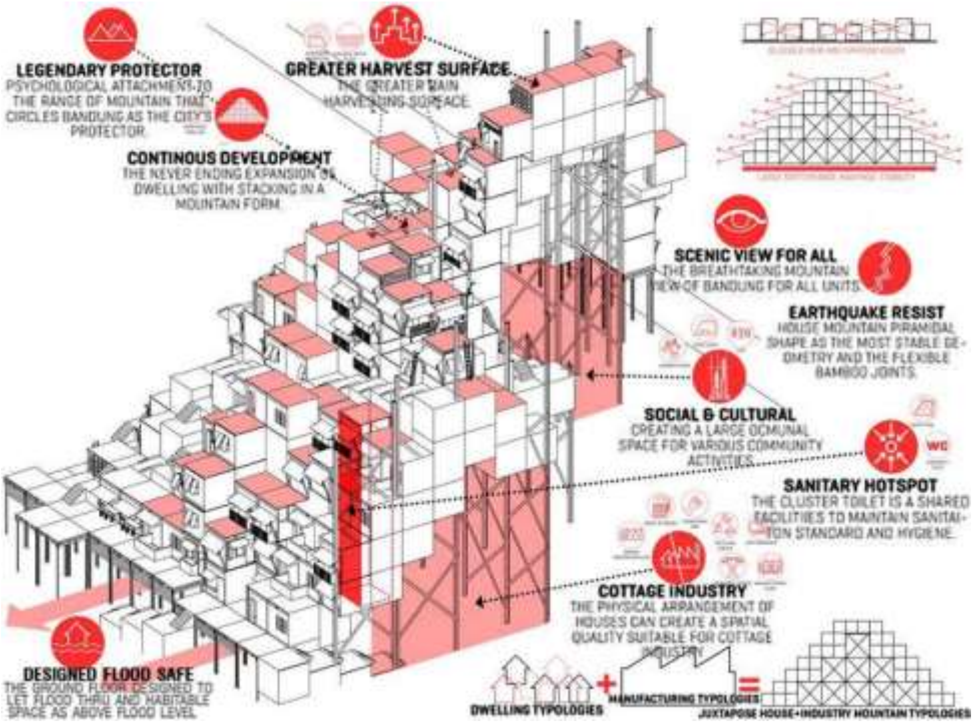
This study uses a qualitative-comparative and analytically synthetic research design. The argument is constructed through the integration of four layers of evidence: (1) the seismotectonic and historical record of destructive earthquakes in Uzbekistan; (2) inventory and cadastral data describing the structure of the national housing stock; (3) structural-mechanical interpretation of the behavior of pakhsa and sinch systems under seismic loading; and (4) comparative analysis of the evolution of seismic regulations, including Soviet and post-Soviet codes. The study does not introduce new instrumental testing or laboratory measurements; rather, it systematizes and interprets the evidence already presented in the source manuscript.

Historical-seismological source base

The historical and macroseismic portion of the analysis is based on the documented consequences of two key seismic cases: the 1966 Tashkent earthquake and the 1976–1984 Gazli earthquake sequence. These events were selected because they provide both urban and rural evidence of the behavior of vernacular construction under strong seismic excitation. The Tashkent earthquake is used to assess the vulnerability of traditional urban housing on loess soils under shallow-focus conditions, whereas the Gazli sequence is used to analyze high-energy intraplate seismicity and its impact on rural earthen settlements.

Inventory and typological analysis

For the assessment of the building stock, the study relies on the integrated cadastral and GIS platform developed during the preparation of the seismic risk map of the Republic of Uzbekistan. This platform combined seismological and macroseismic databases of the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan with the data of the State Cadastral Agency. As of 1 February 2021, the electronic database contained information on 7,135,881 residential real-estate objects across the country. Within this framework, the total stock of residential and public buildings was divided into five principal structural types: (1) buildings made of local earthen materials, including adobe and pakhsa; (2) fired-brick buildings, both older and more recent; (3) timber buildings, including traditional sinch systems; (4) metal-frame buildings; and (5) modern reinforced-concrete buildings.



Vulnerability assessment logic

The seismic-risk methodology combines seismic hazard, structural vulnerability, and concentration of material values, the latter expressed through cadastral value. The hazard level used in damage estimation corresponds to a 90% probability of non-exceedance over a 50-year period, which is equivalent to a mean return period of 475 years. Building vulnerability is interpreted through specialized software approaches, including GESI-based calculations, and through empirically derived vulnerability curves and damage probability matrices for different structural types.

Structural-mechanical interpretation

The comparative structural analysis is grounded in continuum mechanics, structural dynamics, tribology, and thermodynamic concepts of energy dissipation. For pakhsa, the study considers the consequences of high mass, high stiffness, negligible tensile strength, low shear resistance, and the absence of ductile reinforcement. For sinch, the study interprets seismic performance through distributed friction, the controlled degradation of infill, localized impacts, joint compliance, and macro-level dissipation of input energy.

Regulatory analysis

The regulatory dimension of the study compares the older framework represented by KMK 2.01.03-96 and related norms with the newer generation of standards, especially KMK 2.01.03-19 (also transcribed in some sources as ShNK 2.01.03-19) and ShNK 2.01.20-16 for transport structures. The analytical objective is to determine whether current regulations sufficiently address the nonlinear and friction-based behavior of low-rise vernacular and hybrid housing systems.

Results

Seismic and geotechnical preconditions of building vulnerability in Uzbekistan

The first result of the analysis is that the seismic vulnerability of vernacular architecture in Uzbekistan cannot be understood apart from the combined action of tectonic and near-surface conditions. The country is exposed to strong seismic excitation generated by the Tien Shan and Pamir-Alai systems, while many settlements are founded on loess soils that amplify seismic motion. In practice, this means that an already vulnerable construction type may experience an additional increase in effective seismic intensity because of site conditions. This contextualizes why low-engineered earthen housing remains especially dangerous in many populated regions of the country.

Historical evidence: the 1966 Tashkent earthquake

One of the most consequential seismic events in the modern history of Uzbekistan was the Tashkent earthquake of 26 April 1966, which occurred at 5:23 a.m. local time. Although the earthquake had only a moderate energy magnitude, the hypocenter was extremely shallow, at a depth of approximately 3 to 8 km directly beneath the central and historically developed part of the city. As a result, macroseismic intensity in the epicentral zone reached 8 points.

The consequences for the traditional building stock were catastrophic. More than 78,000 families, or over 300,000 people out of a population of approximately

1.5 million, were left without shelter. Emergency tent settlements were erected on sidewalks and in urban green spaces. Macroseismic surveys demonstrated that the overwhelming majority of buildings that suffered heavy damage or complete collapse were constructed from non-engineered local materials, above all adobe brick and monolithic pakhsa. During the earthquake, these buildings frequently exhibited separation of longitudinal walls from transverse walls, total collapse of non-load-bearing enclosures, failure of corner zones, delamination of masonry masses, and the formation of through diagonal and horizontal cracks.

The reconstruction of Tashkent was unprecedented in scale. By the beginning of winter 1966, housing for more than 300,000 people had been erected by builders from across the former Soviet Union. By 1968, the city had effectively been rebuilt, with modernly planned districts in the center, new residential zones on the periphery, and the satellite city of Sergeli. Both the area and the population of the city increased by approximately 1.5 times. In 1976, the architectural and artistic complex Courage was erected to commemorate the recovery effort. From the standpoint of seismic engineering, however, the most important conclusion was the demonstrated fatal vulnerability of unreinforced earthen construction subjected to shallow-focus earthquakes on loess foundations.

Historical evidence: the Gazli earthquake sequence, 1976–1984

If the Tashkent earthquake represented a localized urban catastrophe, the earthquake sequence in the Gazli area of Bukhara Region demonstrated the extraordinary power of intraplate tectonic processes in a zone previously considered relatively aseismic. Prior to 1976, historical and instrumental records did not document events of comparable magnitude in this region. The situation changed abruptly with a sequence of three major shocks.

The first two destructive earthquakes occurred on 8 April and 17 May 1976, each with a magnitude of approximately $M_s \approx 7.0$ and with reverse-fault focal mechanisms trending generally east-west. They were followed by a moderate event in 1978 ($M_s = 5.7$) with a similar mechanism. The culminating event took place on 19 March 1984 ($M_s = 7.0$). Detailed inversion of long-period and short-period seismograms showed that the 1984 earthquake involved a thrust fault with a small left-lateral strike-slip component on a fault striking northeast-southwest and dipping northwest. The mean rupture depth was approximately 9 km. The total rupture duration was about 13 seconds, with the fracture propagating mainly from southeast to northwest through several high-stress asperities. The mean scalar seismic moment calculated from long-period waves was 2.5 × 10^19 N ·m.

A later seismological survey conducted in 1991, using a network of 16 seismic stations over an area of 70 by 50 km, identified more than 300 aftershocks with magnitudes from -0.3 to 4.0. Analysis showed that both the aftershock hypocenters and the rupture planes of the main shocks were limited by a critical depth of 20–25 km, probably marking the thickness of the brittle crust in the area. One of the most distinctive features of the Gazli sequence was the unilateral migration of seismic activity: from April 1976 onward, activity shifted by about 90 km along an azimuth of N240°E along an arcuate fault zone. Such behavior indicates activation of a structurally immature fault system capable of generating multiple large earthquakes with different fault-plane orientations. About one-third of these earthquakes occurred without the formation of visible surface ruptures.

For the building stock of the region, the consequences were devastating. Field observations following the 1976 and 1984 earthquakes documented that vernacular pakhsa dwellings failed more rapidly and more completely than any other structural type, ranking lowest in seismic resistance. Rural settlements built of monolithic earthen structures were effectively erased by the peak ground accelerations generated by the release of 2.5 × 10^19 N ·m of seismic energy.

National housing inventory and local urban transformation

The national-scale risk picture is clarified by the housing inventory. The integrated cadastral database contains information on 7,135,881 residential buildings and allows vulnerability assessment to be connected to building type, location, and value. Its typological classification distinguishes local earthen buildings, fired-brick buildings, timber systems including sinch, metal-frame structures, and reinforced-concrete systems. This makes it possible to compare vulnerability not only in abstract engineering terms, but also in relation to the actual composition of the national housing stock.

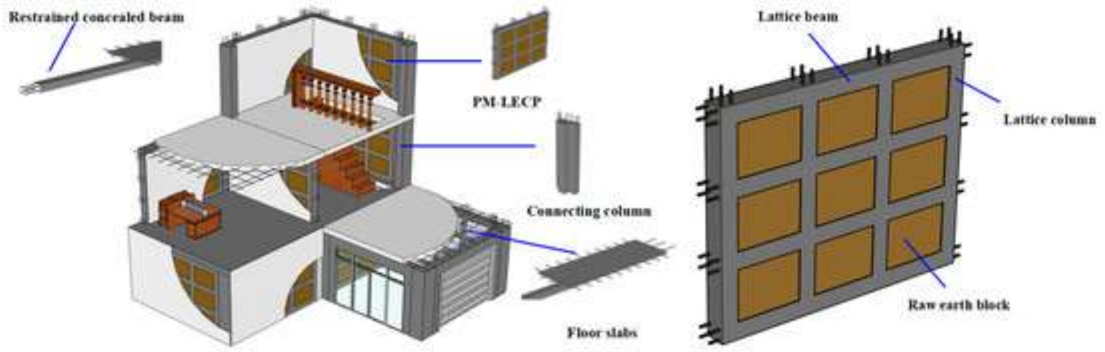
The evolution of housing in the Shaykhantakhur district of Tashkent illustrates the transformation of the urban fabric over time. The total territory of Tashkent is 32,850 ha, of which individual residential construction occupies 15,570 ha, or approximately 47.4% of the city area. Despite modernization, houses built of local traditional materials such as adobe, pakhsa, and sinch still account for a substantial share of private-sector development, exceeding 30% in some territorial balances. Within that segment, approximately 20% is adobe, 7% is fired brick, and at least 3% consists of classical sinch and pakhsa structures.

Before the 1966 Tashkent earthquake, only 9% of individual houses in Shaykhantakhur district were built of durable fired brick. The main body of the housing stock consisted of adobe houses (33.7%) and houses with heavy timber floors and walls of loam and adobe (30.3%). By 1 January 2001, the situation had changed considerably as household prosperity rose and new construction standards were introduced. The number of fired-brick houses increased fourfold, while the share of pakhsa and adobe buildings with timber floors declined. Even so, the continued presence of historical vernacular buildings in 7-, 8-, and 9-point seismic zones means that their scientific study remains essential. In built-up areas where such earthen structures are present, the seismic vulnerability index ranges from 0 to 0.75, with pakhsa buildings consistently demonstrating the highest fragility.

Structural-mechanical behavior of monolithic earthen pakhsa

The traditional pakhsa technology is rooted in antiquity and reflects the historical scarcity of commercial timber and dressed stone in the plains and foothill zones of Central Asia. The structural system consists of load-bearing walls erected by layer-by-layer placement and compaction of moist clay or loam, sometimes mixed with chopped straw. From the perspective of continuum mechanics and the mechanics of materials, a hardened pakhsa wall behaves as a quasi-isotropic but extremely brittle monolithic block. Its central weakness lies in a catastrophic asymmetry of mechanical properties: while it can bear compressive loads from heavy earthen roofs, it possesses almost no tensile strength and critically low shear resistance.

The interaction of a pakhsa building with a seismic wave field can be interpreted through the basic equations of structural dynamics. Thick monolithic earthen walls have substantial mass M and high initial stiffness K. According to the classical expression for the natural period, $T = 2\pi\sqrt{(M/K)}$, this combination leads to a short vibration period. On the response spectrum, the building therefore falls within the high-frequency plateau where spectral accelerations are large. As a result, the structure attracts substantial inertial forces proportional to its large mass.



(a) PM-LECS (b) P-LECP

Because pakhsa contains no elements capable of plastic flow comparable to steel reinforcement in reinforced concrete, exceeding its shear strength leads immediately to the formation of intersecting X-shaped diagonal cracks. Failure develops in a rapid and cascading manner. The absence of effective seismic ties and diaphragm action causes walls to rock independently out of plane. One of the most frequent fatal scenarios, widely documented in Tashkent and Gazli, is the separation of heavy longitudinal walls from transverse walls followed by overturning inward or outward and the immediate collapse of a roof made of logs and a 10–20 cm layer of compacted earth. Such buildings have almost no structural redundancy and virtually no capacity to dissipate energy without losing load-bearing ability.

Thermodynamic and tribological behavior of the sinch system

The structural opposite of brittle pakhsa in the traditional architecture of Uzbekistan is the sinch system. Sinch consists of a spatial timber frame formed by vertical posts, horizontal beams, and diagonal braces; the cells of the frame are filled with adobe brick, rubble, or earthen material laid in weak clay mortar. Depending on function, architectural requirements, and the status of the owner, the system may appear as yakka-sinch, a single integrated wall frame, or kush-sinch, a double spatial frame with greater moment resistance and greater dissipative capacity. The superior seismic behavior of sinch contradicts linear-elastic intuition and is best explained through kinematic flexibility, macro-friction, and thermodynamic energy dissipation.

At low amplitudes and accelerations, the timber frame and earthen infill behave as a quasi-elastic whole. As the amplitude increases, the rigid linkage between them begins to degrade. The weak clay mortar functions as a sacrificial layer: it cracks and crushes early, after which large-scale frictional sliding develops between adobe units and, more importantly, along the wood-clay interfaces. From the viewpoint of energy balance, the external work of the earthquake is partitioned into kinetic energy, recoverable elastic deformation, and irreversible work associated with friction and inelastic deformation. In this system, dissipation occurs not because the building remains rigid, but because it allows controlled internal movement.

The mechanism can be interpreted using tribological analogies from layered systems under dynamic loading. In such systems, the interfacial friction coefficient is decisive. Very low friction results in excessive mobility and local penetration, whereas moderate friction allows more favorable dispersion of stress waves. Sinch walls work in precisely this way. The weight of the traditional roof produces a significant normal force on the infill. During strong earthquakes, part of the input energy is dissipated through Coulomb friction under this normal pressure. Numerous microslides within the infill cells are accompanied by localized impacts. The coefficient of restitution of the wood-clay interface is low, meaning that a substantial share of kinetic energy is absorbed during repeated reversals of motion.

The survival of the frame depends not only on friction in the infill, but also on the behavior of the joints. Traditional carpentry joints, including tenon-and-mortise cuts and wooden dowels, do not create perfectly rigid restraints. Once static friction is exceeded, they permit micro-rotations and limited elastic-plastic pull-out. These joints thus behave as distributed plastic hinges that absorb rotational demand and prevent brittle shear failure of the posts.

The cumulative result is a programmed and controlled kinematic degradation of the structural system. Frictional sliding and microcracking in the earthen infill drastically reduce secant stiffness. Reduced stiffness lengthens the vibration period, allowing the building to migrate away from the high-frequency resonance zone into a range of lower accelerations. At this stage, the frame acts less as a source of rigidity than as a three-dimensional restraint system preventing out-of-plane expulsion of cracked earthen material. Consequently, while pakhsa buildings collapse under large lateral demands, sinch structures are capable of sustaining major horizontal drifts without immediate loss of geometric stability.

Comparative vulnerability matrix

The empirical implications of these mechanisms are reflected in vulnerability curves and damage probability matrices developed by specialists of the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan and related research groups. These matrices were derived from macroseismic mapping of the consequences of the Tashkent (1966), Gazli (1976, 1984), and Nazarbek (1980) earthquakes.

Table 1 presents the expected level of damage for three key types of individual residential buildings made of local materials under seismic intensities of 7, 8, and 9 points on the MSK-64 scale, where damage grades vary from 1 (slight damage) to 5 (complete collapse).

Table 1. Vulnerability matrix for individual residential buildings in Uzbekistan made of local materials

Typology of individual residential buildings	**Expected damage grade at 7 points**	**Expected damage grade at 8 points**	**Expected damage grade at 9 points**
I. Pakhsa-type buildings (monolithic earthen masonry)	3–4 (heavy wall damage)	4–5 (partial or complete collapse)	5 (total collapse)
II. Adobe buildings (adobe/guvala)	2–3 (moderate to heavy damage)	4–5 (partial or complete collapse)	5 (total collapse)
III. Timber-framed sinch buildings	0–1 (no damage	1–2 (slight to	3–5 (from heavy

	or slight cracking)	moderate damage to plastering)	damage to collapse)

This matrix provides strong empirical support for the frame-friction concept. At an intensity of 8 points, corresponding to the design seismicity of many districts of Tashkent and the Fergana Valley, pakhsa and adobe buildings typically enter damage states 4 and 5, implying collapse of load-bearing walls and falling roofs. Under the same conditions, timber-framed sinch buildings usually remain within states 1 and 2, characterized mainly by loss of plaster and superficial cracking, while preserving structural integrity and allowing evacuation. Only under extreme 9-point excitation do the kinematic reserves and dissipative capacity of weakly engineered vernacular sinch begin to be exhausted, at which point severe damage and even partial collapse become possible. Even then, the timber skeleton offers critical delay against instantaneous progressive failure.

Evolution of the regulatory framework

The analysis shows that understanding of seismic behavior was progressively reflected in the evolution of building codes in Uzbekistan. In the post-Soviet period, the main design document was KMK 2.01.03-96, Construction in Seismic Regions, together with the urban-planning document KMK 2.07.01-94. These norms were introduced by the State Committee for Architecture and Construction in 1994 and 1996, respectively. They established design requirements for new construction and the reconstruction of residential, public, and industrial buildings in zones with design seismicity of VII, VIII, and IX points on the MSK-64 scale.

KMK 2.01.03-96 covered the key principles of seismic design, including site seismicity based on seismic microzonation maps, mandatory soil corrections, dynamic and spectral methods of analysis, and detailed requirements for panel, frame, and masonry buildings. The appendices included data for 333 settlements in Uzbekistan, specifying normative seismic intensity and recurrence periods; for Tashkent, for example, the recurrence period for VII-point earthquakes was taken as 25 years, and for VIII-point earthquakes as 100 years. Despite the level of detail, however, these norms were historically oriented toward centralized industrialized construction and did not provide an adequate calculation framework for nonlinear vernacular structures made of local materials.

With advances in computational mechanics and the accumulation of new geophysical data, the need for regulatory revision became clear. By order of the Ministry of Construction of the Republic of Uzbekistan dated 23 December 2019, the new code KMK 2.01.03-19 was approved and entered into force on 1 March 2020. This 111-page document was prepared by the specialized institute

ToshuyjoyLITI in cooperation with leading research organizations, including the Institute of Seismology. Its scope includes design, reconstruction, strengthening, and restoration of load-bearing structures and foundations in regions with seismic intensity of 7, 8, and 9 points and above. The document introduced updated spectral and modal methods of seismic-load analysis, stricter requirements for spatial structural systems such as reinforced-concrete frames, ties, rigid cores, and diaphragms, and more detailed protocols for site investigation and material quality control.

In parallel, Uzbekistan has implemented strict standards for infrastructure, particularly through ShNK 2.01.20-16, Construction of Transport Structures in Seismic Regions. This norm was applied in the design and construction of contemporary bridges and overpasses, including the monolithic overpass at kilometer 1083 of the M-39 highway in Samarkand and a complex of three overpasses in the Sergeli district of Tashkent. Infrastructure projects increasingly use seismic isolation devices and dampers. This reveals a major technological gap: while state infrastructure is designed with advanced seismic-protection systems under strict codes, a large share of individual housing remains outside effective engineering control.

Crisis of contemporary private housing and strategic response

The study identifies a severe crisis in present-day individual housing construction, especially in densely populated regions such as the Fergana Valley. Despite the existence of advanced norms such as KMK 2.01.03-19, the practical culture of private construction shows a troubling decline in engineering discipline. Works by Uzbek scholars, including the monograph on seismic safety of private housing in the Fergana Valley published in 2016 under the guidance of Academician T. R. Rashidov and specialists of the Institute of Civil Protection, as well as methodological publications by S. A. Saidov, describe a critical situation. In the construction of the majority of contemporary private houses, fundamental seismic-safety principles are violated. Builders often abandon the historically verified sinch system but lack the resources and qualifications to construct full reinforced-concrete frames in compliance with current codes.

The result is the widespread construction of pseudo-engineered surrogate buildings. Such houses combine heavy concrete floors with walls of cinder blocks or low-quality brick, while neglecting the requirements for bond patterns, continuous reinforced-concrete seismic belts, and vertical confining elements. These hybrids possess neither the kinematic plasticity and dissipative capacity of traditional sinch nor the monolithic reliability of properly designed reinforced concrete. Even at intensities of 7–8 points, such heavy and rigid configurations are expected to fail in a brittle manner, with unpredictable collapse kinematics that may reproduce the tragic scenarios of past earthquakes.

Discussion

Why sinch outperforms pakhsa

The central analytical conclusion of this study is that the contrast between pakhsa and sinch is not merely a contrast between earthen and timber materials. It is a contrast between two fundamentally different seismic philosophies. Pakhsa resists gravity effectively but attempts to resist lateral dynamic loads through monolithic rigidity. In strong earthquakes, this strategy fails because large mass and short vibration periods attract high accelerations, while the material itself has almost no tensile reserve. Sinch, by contrast, survives not because it is strong in the conventional sense, but because it is capable of controlled internal movement. Its weak mortar, flexible joints, and timber frame generate a distributed frictional mechanism that dissipates energy and delays collapse. In modern engineering terms, sinch anticipates key ideas of capacity design and controlled energy dissipation.

Implications for risk management and regional housing policy

The practical significance of this conclusion is especially high for regions with dense low-rise housing, above all the Fergana Valley. The existing stock still contains a large number of vulnerable earthen buildings, while new private houses are frequently erected without adequate engineering supervision. The problem is therefore double: a hazardous inherited stock coexists with the ongoing production of new brittle structures. This means that seismic safety policy cannot be limited either to the conservation of traditional building forms or to the formal existence of advanced national standards. What is required is a bridge between empirical vernacular knowledge, affordable engineering practice, and enforceable regulation.

Retrofitting of existing earthen buildings

For the large stock of existing pakhsa, adobe, and weak-brick buildings, affordable seismic strengthening is critical. Because complete replacement of the housing stock is unrealistic, one promising approach is to reproduce the restraining effect of sinch through contemporary materials. This can be done by applying continuous reinforcing layers to the surfaces of brittle load-bearing walls in the form of light galvanized steel mesh or high-strength geopolymer mesh, followed by a cement-sand or fiber-cement plaster layer. Such an external jacket does not make the building absolutely rigid; instead, it allows nonlinear deformation and period elongation while preventing out-of-plane loss of wall fragments. During strong shaking, the masonry or earthen core may crack and undergo dry frictional macrosliding, thereby generating substantial equivalent viscous damping, while the mesh carries tensile stresses and prevents catastrophic roof collapse onto occupants.

Hybrid energy-dissipative systems for new low-rise construction

For new construction in rural and suburban Uzbekistan, the study supports the development of modern analogues of sinch. Standardized solutions may use light-gauge steel frames or engineered timber members with infill made of porous modern materials, arbolite, foam concrete blocks, or vibropressed stabilized earth. The critical condition for the success of such hybrids is the precise design of joint compliance. Engineers should not aim for perfectly rigid frame connections; instead, bolted or frictional joints should be designed to permit controlled sliding and rotation once a design seismic acceleration, for example 0.4 g, is reached. In this way, the system can dissipate kinetic energy through friction dampers and plastic-hinge-like mechanisms rather than through brittle fracture.

Regulatory modernization

For these solutions to be applied on a mass and legal basis, further modernization of the national regulatory framework is required. In particular, the study supports integrating Performance-Based Seismic Design into KMK 2.01.03-19. Under such an approach, the principal criterion of safety is not only the strength limit of materials, but also the ability of the system to withstand large kinematic drifts through controlled energy dissipation. The introduction of specialized reduction or behavior factors for structures with distributed friction would allow engineers to justify flexible composite solutions for individual housing while maintaining an adequate level of life safety at relatively low capital cost.

Limitations

This study has several limitations. First, it is based on an analytical synthesis of the source manuscript and does not include new laboratory tests, numerical simulations, or field surveys. Second, some of the cited sources belong to regulatory or institutional gray literature rather than to journal-indexed empirical datasets. Third, the structural interpretation of friction coefficients, hysteretic behavior, and energy dissipation is inferential and conceptual in the present form. These limitations do not invalidate the conclusions, but they indicate the need for future work involving full-scale testing, nonlinear time-history modeling, and regionally calibrated fragility functions for vernacular and hybrid low-rise systems.

Conclusion

The territory of Uzbekistan, exposed to the geodynamic action of the Tien Shan and Pamir-Alai orogenic systems, has historically served as a severe testing ground for construction technologies. The combined historical, structural-mechanical, and regulatory analysis demonstrates that the dichotomy within the vernacular architecture of the region—monolithic pakhsa versus timber-framed sinch—reflects two fundamentally different approaches to the mechanics of seismic interaction.

Pakhsa buildings, despite their ecological value and former affordability, behave as rigid and brittle monoliths. Their high mass, negligible tensile strength, and inability to deform plastically make them fatally vulnerable to inertial overloads, which explains their repeated catastrophic performance during the Tashkent and Gazli earthquakes. Sinch, by contrast, constitutes a genuine masterpiece of empirical seismic resistance. Its survival mechanism is based on microcracking of the infill, intensive frictional sliding, localized impacts, and elastic-plastic rotations of joints. These processes generate wide hysteretic loops, reduce secant stiffness, lengthen the natural period, and move the structure away from the high-frequency resonance zone.

Although Uzbekistan now possesses a more advanced and stricter regulatory framework for major civil and infrastructure projects, the sector of individual housing remains in a dangerous engineering condition. The abandonment of sinch principles in favor of unreinforced hybrid surrogates built from cinder blocks and weak brick creates a delayed threat to public safety. The principal scientific and practical task, therefore, is not the blanket rejection of local materials, but the engineering formalization of distributed-friction structural behavior. The integration of kinematic flexibility into national norms, combined with widespread retrofitting technologies and standardized hybrid systems, offers a realistic path toward economically accessible, environmentally balanced, and genuinely safe housing in the seismic regions of Uzbekistan.

REFERENCES:

1. Academy of Sciences of the Republic of Uzbekistan. (n.d.). Seismic risk assessment methodology and GESI software integration.
2. Government of the Republic of Uzbekistan. (1996). KMK 2.01.03-96: Construction in seismic regions. State Committee for Architecture and Construction.
3. Ministry of Construction of the Republic of Uzbekistan. (2016). ShNK 2.01.20-16: Construction of transport facilities in seismic regions.
4. Ministry of Construction of the Republic of Uzbekistan. (2019). KMK 2.01.03-19 (ShNK 2.01.03-19): Construction in seismic regions. ToshuyjoyLITI.

5. Rashidov, T. R. (2016). Ensuring the seismic safety of private housing in the Fergana Valley. Institute of Civil Protection of the Ministry of Emergency Situations.

6. Saidov, S. A. (2012). Methodological guidelines for seismic-resistant construction. Tashkent Architectural and Civil Engineering Institute.

7. ToshuyjoyLITI, & Institute of Seismology. (2021). Electronic cadastral database and seismic vulnerability index of the Republic of Uzbekistan.

8. Bazarovna, M. M. (2023). BUILDING MULTICULTURAL ARCHITECTURE IN THE CITY ENVIRONMENT FOR THE DEVELOPMENT OF SPIRITUALITY: sacred, multiculturalism, multicultural space, model. JOURNAL OF ENGINEERING, MECHANICS AND MODERN ARCHITECTURE, 483-490.

9. 15.Makhamova, M., & Azimova, D. (2025). Forerunners of the Study and Analysis of the Basics of the Typology of Buildings and Elements of Landscape Architecture of Modern Wellness Centers. TATALOKA Учредители: Institute of Research and Community Services Diponegoro University (LPPM UNDIP), 27(1), 95-115.

10. Rajapovna, R. G. (2025). IMPROVEMENT OF THE STAFF TRAINING SYSTEM AND REFLECTIONS ON NEW PEDAGOGY OF ARCHITECTURAL AND CONSTRUCTION EDUCATION. SHOKH LIBRARY, 1(12).