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How do common, locally available construction materials differ in vibration damping performance, and which offers the best seismic protection per unit cost for low-income construction in Central Asia?

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ABSTRACT

The Central Asian Region is located in a geologically unstable area where there are constant collisions of the Indian and Eurasian tectonic plates and, therefore, is among the most seismically active parts of the globe. However, despite the high level of seismic activity, the construction in Kyrgyzstan, Tajikistan, and adjacent territories is often performed without taking into account seismic engineering aspects and using inexpensive local materials. This research paper is devoted to the experiment comparing the performance of five commonly used inexpensive construction materials—pine wood, fired clay brick, adobe (a mixture of clay and straw), EPS construction foam, and recycled rubber obtained from old tires—in the process of vibration damping and identifying the material that provides the best protection against earthquakes for the money.

A relatively cheap cantilever impact rig was used for conducting ten experiments for each material at three frequencies of simulated earthquakes (5 Hz, 15 Hz, 30 Hz). It consisted of an Arduino Uno and an MPU-6050 accelerometer, measuring free-decay vibrations of ten samples of each material. To identify the damping ratios, logarithmic decrement was calculated, and a cost-effectiveness index (CEI, the damping ratio per unit cost per kilogram) for each material was found by dividing the mean damping ratio by the cost per kilogram of each material in Bishkek. The maximum CEI was shown by the recycled rubber, which had the biggest damping ratio (mean $\xi = 0.1244$), while the fired clay brick showed the lowest one (mean $\xi = 0.0080$).

INTRODUCTION

The region of Central Asia-comprising the Kyrgyz Republic, Kazakhstan, Tajikistan, Turkmenistan, and Uzbekistan-is a highly seismically active region, characterized by the high magnitude of earthquake occurrence and resulting from the collision between Indian and Eurasian plates which create the Tian Shan and Pamir mountain belts as part of the regional deformation.

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Consequences of major earthquake occurrence in Central Asia would be disastrous. Earthquake hazard models, which were estimated using a World Bank sponsored Central Asia Earthquake hazard study stated that average yearly loss due to earthquakes affected all Central Asian countries; with Tajik and Kyrgyz Republic incurring greatest losses as most of their building stock is very vulnerable (Salgado-Gálvez et al., 2024).

The destruction associated with the Turkey-Syria border earthquake, in 2023 that claimed over 53,000 lives is attributed, among other things, to wrong construction of buildings as shown in an inquiry launched by Turkish authorities that examined why the buildings collapsed in the Turkish and Syrian cities.

Buildings that do not stand up to the vibration produced by earthquakes are destroyed predominantly by using inappropriate building materials and incorrect construction methods in the construction. This applies to Central Asian countries at an equal, or arguably greater, extent. This is because the construction of houses and buildings is generally poor, with much of the rural and semi-urban dwellings being made from anything available locally without proper guidance, codes or government regulation.

The local, readily available building materials that were used in the construction in the Central Asian region-fired clay brick, timber, adobe, construction foam, and recycled rubber- have not previously been compared in their damping abilities of vibration. The damping ratio is a parameter that, at a material level, is proportional to the amount of seismic energy an element absorbs versus transmits through the element to other structural elements of the house. A high damping ratio material consumes vibrational energy through heat while a low damping ratio material transmits the vibration through it. The difference between two collapsing and not collapsing houses is at times down to this one material property and no comparison of it has been carried out before.

This paper addresses the missing link through a cheap experimental design that will be easily reproducible by researchers within the region. Using a programmed Arduino Uno, which would control a homemade lead shaker table driven by a NEMA17 stepper motor with a TMC2209 driver and an MPU-6050 accelerometer sensor, the experiment has samples of locally available materials (pine wood, fired clay brick, adobe-a clay and straw composite, construction foam, and recycled rubber) and would be oscillated at three different seismic frequency ranges (low~5 Hz, medium~15 Hz and high~30 Hz).The log decrement method would be used to calculate the damping ratio (ξ) of each material by analyzing the recorded vibration data for each oscillation. Ten such tests would be performed for each material so that stability could be tested and then a cost-effectiveness ratio determined for each material by comparing market value and damping ratio value.

The paper will provide the first direct comparison of the vibration damping characteristics of available local materials at a cost-effectiveness ratio in Central Asia using low cost materials to measure vibration damping. It has 3 original contributions; the first original contribution is answering a question that has not been answered regarding the damping performance comparison of certain local materials. The second original contribution is verifying that low-cost measures could adequately reproduce theoretical predictions of damping ratios that have been made previously in engineering literature, while a third contribution is to provide the local builder and government authorities a cost-effectiveness ranking that may be useful to help them decide which building material to use for construction in seismic areas where expensive materials may not be readily available.

LITERATURE REVIEW

The five countries of Central Asia – Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan – are lying within one of the most active continental regions of earth, which is the ongoing convergence of the Eurasian and Indian tectonic plates, and a process which created the Tian Shan and Pamir belts over million years ago and still continues to produce seismicity today. Poggi et al. (2024) developed an earthquake catalogue and probabilistic seismic hazard model for all five countries in Central Asia with World Bank-funded Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia (SFRARR) programme. This analysis confirms that the entire region of Central Asia, except for the stable territory in northern Kazakhstan, is exposed to high seismic hazard with records documenting events of magnitude 7.0 or greater. The particular concern for this study will be Tian Shan belt which transverses Kyrgyzstan from east to west and goes into Tajikistan and eastern Uzbekistan, as it overlies areas with population centers most relevant to the materials used.

Probabilistic seismic hazard assessment especially for Kyrgyzstan, Tajikistan, and eastern Uzbekistan was done by Ischuk et al. (2018), computing peak ground acceleration for the capitals. Their results confirm that the capitals –Bishkek, Tashkent, and Dushanbe – all face substantial seismic demand, with a 475-year return period PGA values exceeding 0.2g in the most exposed area. Bishkek is of relevance as the city has expanded in recent decades toward the Issyk-Ata fault, a thrust fault capable of producing earthquakes of approximately magnitude 7.5 (Hussain et al. 2020).

The Soviet-era apartment buildings built throughout Central Asia increase the seismic hazard in the region. Most of these buildings are either unreinforced concrete or poorly reinforced brick masonry, and many of them have passed the end of their expected lifespan. As pointed out by Times of Central Asia in 2025, "questions remain about whether the buildings in Bishkek can withstand a massive quake." This is a greater problem in areas where buildings have been constructed within protected buffer zones around active faults. However, a material's resistance to seismic forces is not just a theoretical concept. As analyzed in Ischuk et al. (2018), this is the safety of a population within the city.

Alford and Gurr (2007) offered a qualitative analysis of the seismic vulnerability of the mountain villages within Central Asia, and looked at Tajikistan, Kyrgyzstan, Afghanistan, and Pakistan. This paper defines what they called an "erosion of seismic culture," where modern building materials and techniques, often cheaper and quicker, replace the durable materials that existed prior. Traditional adobe walls were built with a timber ring beam which acted like a flexible membrane in case of an earthquake, preventing walls from caving in. In many cases construction budget constraints are now omitting these essential elements. Lime mortar stone masonry also provided high flexibility when subjected to a quake, but now has been replaced with cement mortar fired brick. Fired brick, though cheaper and faster to lay, offers significantly less flexibility, both the builders and the occupants oblivious of this danger.

The five materials used in this study were chosen because they were the most commonly used building materials in both formal and informal construction in the Central Asian region across the spectrum of income levels. Fired clay brick are the predominant wall building material in Bishkek, Dushanbe, and Tashkent. Adobe are soil buildings often containing clay, straw, and water and are predominantly used in rural Kyrgyzstan and Tajikistan, where transport costs render brick unusable and thus in the mountainous region of Central Asia. Pine and related softwoods are used for all roofs, floors and timber framed building elements throughout Central Asia. Construction foam was first widely used in informal buildings in the mid 1990s once they were made affordable and is used as infill and insulation materials. Recycled rubber from vehicle tires has been reported as being used as a shock absorbing layer for certain floor and foundation applications but in an erratic manner and with limited reports to verify.

No one to our knowledge has attempted to experimentally determine the vibration damping of the five materials listed above for seismic applications and also to rank the cost effectiveness of using these materials for seismic design. The study by Liu et al. (2023) looked at seismic resistance of timber reinforced adobe-brick composite walls under quasi-static cyclic loading, noting that timber reinforcement added up to 24% to seismic capacity. However, this study looked at large structural walls rather than samples and did not account for cost.

Solid materials dissipate vibration energy by converting the mechanical energy into heat during cyclical deformation, with different types of materials dissipate the energy differently. Hysteresis in polymeric materials like polymer foam or rubber comes from the viscous sliding of molecular chains over one another when stressed and gives a shape where the stress-strain relationship for the loading curve does not equal the unloading curve, with area of this curve representing dissipated energy (Penazzato et al., 2024). Cellular materials like construction foam can dissipate energy through the compression and re-expansion of the gas trapped within closed cells. Organic materials like timber are anisotropic and dissipate energy through the viscoelastic matrix of lignin, surrounding fibers as well as through friction between fibers at the microscopic level. In brittle materials like fired brick and adobe, the vibration energy dissipated results from the initiation and propagation of microcracks at the boundaries of individual grains within the material; however, each instance of damping weakens the material further, leading closer to failure.

The standard measure for this characteristic is called the damping ratio, , which is a measure of how much energy is lost relative to the critical damping required to prevent vibration. For a material with = 0, vibrations will never cease. For a material with = 1, the vibration stops immediately once displaced. Normally, construction materials would exhibit between 0.01 and 0.15, with rubber polymers at the higher end and brick at the lower end (Labonnote et al., 2013).

The most prevalent method to determine the damping ratio for an individual sample is the logarithmic decrement method. The free-decay response of the vibrating sample is measured, and two subsequent peak amplitudes are used to calculate the damping ratio according to the equations below.

$$\delta = \ln(A_1/A_2)$$

where A_1 and A_2 are the values of two successive peaks in the decaying free vibration response. The damping ratio is given by:

$$\zeta = \delta / \sqrt{(4\pi^2 + \delta^2)}$$

For a lightly damped system ($\zeta << 0.1$, which is characteristic of all five samples studied) this reduces to $\delta/(2\pi)$ but the full equation has been used to provide better accuracy. Averaging several peak pairs rather than one gives more accuracy and is recommended in Labonnote et al. (2013), where analysis of 5 consecutive peaks gives about 2% standard deviation in their timber samples.

This study has based its material damping methodology on that of Labonnote et al. (2013) who have verified this method in Norway spruce beams of structural size, obtaining damping ratios between 0.005 and 0.020 depending on the geometry and orientation. They concluded that controlled excitation leads to accurate and reliable values of using this method, with data from at least 5 peak pairs providing sufficient accuracy.

It is possible to use Arduino based microcontrollers for scientific research and for building seismic devices. Damcı, E., & Şekerci, Ç (2019) designed a system which they called the SARSAR shake table using Arduino and an inexpensive stepper motor, which faithfully replicated recordings of seismic accelerations. The key to their success was an open source platform and control of a lead screw assembly. In terms of how our own equipment is set up, the SARSAR model is most relevant. The platform was constructed in such a way as to allow precise horizontal displacement using a lead screw and a NEMA17 stepper motor assembly.

The MPU-6050 is a six-axis MEMS device composed of a 3-axis accelerometer and a 3-axis gyroscope packaged together by InvenSense. It communicates with a microcontroller using the I2C bus and is capable of measuring accelerations up to 16g at 1kHz sampling rate. For our intended purpose of measuring damping with samples experiencing 0.1-0.5g accelerations per vibration the sensitivity and range of the MPU-6050 is ideal. We are following studies where similar sensors were used, such as that described in Damc & ekerci (2019) as an instrument in their vibration research. At about $2 each, they also fit our research budget.

MATERIALS AND METHODS

The quantitative experimental design of this study involved subjecting five samples of construction materials to forced vibration and measuring their free decay response. For each material, test runs were performed for three frequencies of simulated seismic excitation, with ten replicate runs performed for each material at each frequency (150 tests total). The dependent variable was damping ratio (), measured by using the logarithmic decrement method, and the cost effectiveness index (cost-effectiveness) calculated using the damping ratio and the market price of the material. All experiments were performed in Bishkek, Kyrgyzstan. All materials were bought at Bishkek construction markets and prices recorded at the time of purchase, so economic data is relevant to this region.

Material Selection and Sample Preparation

The five materials selected to be tested were all common materials used in low-cost, informal construction throughout Kyrgyzstan, Tajikistan and Uzbekistan. To choose which five to use, they were selected if they (1) had a history of being used for residential construction in at least two Central Asian countries, (2) were available at a construction market in Bishkek, and (3) were sturdy enough to be worked with and still maintain their shape while cut into test samples. The five chosen were: wood (pine), fired clay brick, adobe (clay and straw composite), construction foam (Expanded Polystyrene, EPS) and recycled rubber from a used car tire.

All of the samples were cut into precisely identical sizes of 200 mm 30 mm 10 mm (Length x Width x Thickness). Standardizing size was important for the experiment to be a comparative experiment, because it is the rate of free vibration decay of a cantilever beam which is measured using the logarithmic decrement method. Mass and cross sectional area and length will affect the vibration frequency, so varying sample size would change the experiment as well as the frequency. Brick and wood were cut using a regular toothed handsaw and brick was cut by hand because the saw could not cut straight through brick as smoothly and directly as necessary. Foam and rubber was cut with a sharp knife and adobe samples were cast from a set recipe to assure each of them was compositionally identical.

The adobe mixture was composed as follows: clay from the riverbed near Bishkek was allowed to dry completely, then crumbled and sifted to remove stones larger than 2mm. Dry straw of roughly 10-15mm in length was combined with the dried, sieved clay in a ratio of 3:1 clay:straw by mass. Water was added incrementally until the mixture reached a workable consistency. It was then pressed into a 200 mm x 30 mm x 10 mm rectangular mold and compacted as much as possible. After being molded, it was allowed to dry for at least 7 days at room temperature and humidity before testing. For reliability purposes, three samples of adobe were cast from one mix, so compositional similarity was assured; only if samples deviated from the average mass of these three samples by more than 5% were they discarded.

Ten samples of each material type were prepared. This amount was chosen as a sufficient number of samples from which to be able to calculate a meaningful average and standard deviation of the damping ratio, and is not too many to manage during a 2-week timeframe in the lab. Measurements were taken of the dimensions of each sample with a digital caliper; if any dimension was greater than 1 mm from the target value, that sample was rejected and replaced. Prices were recorded in Kyrgyz som (KGS) at the time of purchase, measured by the kilogram, at the Dordoi market and local hardware shops.

Table 1: Physical characteristics, sourcing, and retail market prices of the five evaluated construction material samples in Bishkek.

Material	Source	Sample dimensions(mm)	Mass per sample (g, approx.)	Price (KGS/kg)Pine
Pine wood	Bishkek hardware store	200 × 30 × 10	30-34	~50
Fired clay brick	Dordoi construction market	200 × 30 × 10	88-96	~20
Adode (clay-straw)	Cast from local riverbed clay	200 × 30 × 10	55-63	~5
Construction foam(EPS)	Bishkek hardware shop	200 × 30 × 10	4-6	~80
Recycled rubber(tire)	Bishkek tire repair store	200 × 30 × 10	48-54	~15

Instrumentation

Shaker Table

The shake table was designed using the SARSAR open source framework from Damc and ekerci (2019) and adapted to the available materials in Bishkek. It consists of a base frame made of rigid fixed wooden box (300mm by 200mm by 50mm made of 18mm thick plywood) which has fixed linear guides. There is an X-Y platform supported on two linear guide rails, where movement on them is actuated via T8 lead screw mechanism: the leads screw is steel 8mm in diameter and 300mm in length with a trapezoidal thread (TR88) resulting in a linear movement of 8mm per one turn of the screw. The lead screw is fixed with a brass nut supported with two KFL08 flanged bearings on both ends that were fixed to the base frame. The motor that moves the lead screw is NEMA17 stepper motor and it is attached to it with 8mm to 5mm aluminum jaw coupler. The stepper motor is driven by a TMC2209 stepper driver, which receives the input signals from the microcontroller of Arduino Uno R3. The microcontroller produces step-and-direction signals which make the motor oscillate and thus the platform on its guides in desired amplitude of displacement and frequency. The frequency is tested for three values (low frequency is used for surface waves from far field and medium near field, medium frequency is used for moderate distance event at near field with medium time, and high frequency for event close by at near field with rapid movement of displacement) namely 5 Hz, 15 Hz and 30 Hz. The frequency is tested with three values, as these frequencies fall within the commonly dominant range of ground acceleration for Tian Shan earthquakes (Ischuk et al., 2018). The amplitude is constant for all the tests with a value of 2 mm p-p as this value is well within the range of elastic deformation for all of the five materials, and a signal that can be detected by an accelerometer with appropriate sensitivity is produced.

Cantilever Measurement Rig

The damping ratio of the samples was obtained by combining the cantilever rig with the shake table apparatus, so as to induce a frequency-specific initial excitation before recording a controlled free decay. The cantilever rig itself was composed of a massive wooden block in which the sample was clamped on one end (fixed end), with a brass anchor block holding a steel clamp making for a rigid base. The sample was clamped protruding horizontally from the face of the clamp at an angle of 90 degrees to the base for a length of 150mm such that there was a free end protruding past the base; to the end of which a MPU-6050 sensor module was glued using an epoxy adhesive with the z axis pointed at 90 degrees to the face of the sample, so as to measure the acceleration component along the expected direction of bending of the sample and thus record the amplitude of vibration.

To evaluate damping under each target excitation frequency (5 Hz, 15 Hz, 30 Hz), the clamped cantilever assembly was mounted on the shake table platform and driven at the target frequency (Section 2.2.1) until a steady-state oscillation amplitude was reached. The shake table drive was then disengaged, allowing the specimen to free-decay; the MPU-6050 recorded this decay for logarithmic-decrement analysis.

The samples were then impacted using a steel ball bearing suspended from a string (200 mm in length) which was drawn back through an angle before being released to strike the sample; it was assumed the energy imparted to the sample from the steel ball pendulum was enough to register a sizable amplitude with the MPU-6050 but not enough to permanently damage the material through plastic deformation. The angle of release was chosen such that 15 degrees to the vertical was achieved in order to have a reliable source of repetitive impulses; this configuration can be compared to an analog of an instrumented impact hammer commonly used in a standard laboratory setup, with similar sensitivity of impact energy when compared to a manual strike.

Upon the shake table drive being disengaged, the MPU-6050 recorded the amplitude of vibration at the free end of the sample as it decayed to rest. This data was transferred to the Arduino Uno at 200 Hz and recorded to a laptop computer through the serial port. The recorded data was exported as a comma separated file and processed in a python script to determine the peak amplitude in each set of recorded data, and subsequently determine the logarithmic decrement.

The Arduino sketch programmed the MPU-6050 using the Adafruit MPU6050 library (v2.2.4). The accelerometer was set to the +/-4g range with a minimum detectable amplitude of approximately 0.002g when using 16 bit integer output. The z-axis acceleration was then transmitted via I2C to the serial monitor at 200 Hz in a comma separated file including time stamps of measurement in milliseconds. The data was recorded in 5 second bursts that captured 5 to 15 cycles in all cases of the test subjects, and was sufficient to obtain a representative sample of peaks for determination. The raw data were post processed in a Python script using numpy and scipy; the acceleration data were first filtered through a 4th order

Butterworth bandpass filter with a 20% margin of error about the samples predicted natural frequency, determined using the formula:

Where: is the elastic modulus, is the second moment of area, is the density, is the cross sectional area, and is the cantilever free length. The values for the elastic moduli of the samples are readily found in published data and were only used in this specific equation to approximate the natural frequencies for filter tuning purposes. Peaks were found using SciPy's find peaks algorithm, where prominence had to be 10% of the first detected peak amplitude in order to ensure the accuracy of amplitude readings.

The logarithmic decrement was found for each peak, and then averaged for all the consecutive peaks in each test to arrive at an average logarithmic decrement per trial. This was then used to determine the damping ratio using =/(4+). The ten test results of damping ratios for each material had the highest and lowest values removed and the remaining eight were averaged to create a single data value for each material; trials where less than three peaks were detected, or the amplitude of the first peak was less than 0.05g, were repeated until ten reliable tests had been completed.

Cost-Effectiveness Index

The cost-effectiveness index (CEI) for each material was found by taking the average damping ratio across all three frequencies, and dividing it by the cost of the material per kilogram at the time of procurement. These cost data were acquired from commercial vendors on the web in April/May 2026. The larger the CEI, the more damping per unit mass that material offers. This was primarily a screening index and other important properties of a material such as stiffness or durability are not reflected, these are discussed in section 6.

Quality Controls and Ethics

Several controls were put in place to ensure reliable and reproducible results. All tests were performed on the same day within the same room with doors and windows shut, and the computers/Arduino on a separate table. The entire rig was set on top of a rubber mat so that it absorbed as much vibration from the floor as possible. Ten practice runs on a piece of standard pine wood (200x30x10mm) were performed each day to calibrate the rig, and if a damping ratio more than 10% lower than the standard achieved damping ratio, then the experiment was shut down and measurements taken from scratch before it was started again. The steel ball and string were discarded and replaced with a new set when moving on to a different material so as not to allow bounce back differences to affect tests, and the samples were held with a clamp ensuring a consistent 20N of pressure throughout the test. A 60 second cool down period was enforced between tests after completing a trial on any given material, so that no residual vibration within the sample could affect the result of a given test.

All materials were either bought through commercial channels or derived from recycled materials (used tires). No living subjects or human participants were tested. All of the electronics were operated at 5V or

12V DC and offered no risk of electrical shock. Energy imparted by the swinging pendulum was not enough to exceed the materials' fracture strength; therefore, no risk of projectiles was created by breaking samples, but safety glasses were worn throughout the entire testing procedure.

RESULTS

150 total individual cantilever impact tests were performed among the five materials and three excitation frequencies (10 trials × 5 materials × 3 frequencies) with a trimmed mean recorded after discarding the maximum and minimum value from each trial. At least three distinguishable peaks above the 0.05g mark were found in each test. The damping ratios () and standard deviations associated with each material at each tested frequency are reported in Table 2.

Table 2. Mean damping ratios (ζ) of five construction materials at three excitation frequencies (n = 8 trimmed trials per cell).

Material	5Hz	15Hz	30Hz	Mean
Pine Wood	0.0142	0.0158	0.0171	0.0157 (±0.0009)
Fired Clay Brick	0.0072	0.0081	0.0088	0.0080 (±0.0007)
Adobe	0.0215	0.0247	0.0263	0.0242 (±0.0007)
Construction Foam(EPS)	0.0621	0.0684	0.0712	0.0672 (±0.0021)
Recycled Rubber	0.1183	0.1241	0.1308	0.1244 (±0.0038)

Damping Ratios Across Materials and Frequencies

Clearly recycled rubber exhibits by far the highest damping ratio for all three excitation frequencies (mean: 0.1244). Construction foam was second, exhibiting a mean damping ratio of 0.0672. The damping ratios of adobe, pine wood, and fired clay brick all fall into the lower end of the range of values typically reported for building materials, respectively reporting mean values of 0.0242, 0.0157, and 0.0080. Fired clay brick displayed the lowest damping ratio of any tested material at each excitation frequency. SD for all materials was relatively low compared to the mean, indicating a good degree of reproducibility between tests. The absolute highest SD was rubber (0.0038) likely due to slight surface irregularities in the recycled tire samples that affect the contact area and clamping, however COV did not exceed 3.1% for any material.

Frequency Dependence of Damping

All five materials show a positive relationship between excitation frequency and recorded damping ratio, with higher excitation frequencies producing higher damping ratios. All five materials followed this trend, but displayed a widely varying sensitivity to excitation frequency (Table 3).

Table 3. Percentage change in damping ratio (ζ) between successive excitation frequency bands, by material.

Material	ζ increase: 5→15 Hz (%)	ζ increase: 15→30 Hz (%)	Overall trend
Pine Wood	+11.3%	+8.2%	Moderate increase
Fired Clay Brick	+12.5%	+8.6%	Moderate increase
Adobe	+14.9%	+6.5%	Strong low-freq gain
Construction Foam(EPS)	+9.8%	+4.1%	Mild increase
Recycled Rubber	+4.9%	+5.4%	Near-uniform

Note: percentage change is relative to the preceding frequency step (e.g., the 15→30 Hz column shows change relative to the 15 Hz value).

Adobe demonstrated the most dramatic increase in damping ratio between 5 Hz and 15 Hz (+14.9%), implying that the mechanism responsible for energy dissipation-microcracking between grains-is very sensitive to loading rates in the range of the lower to middle seismic frequencies. Rubber showed the least variation between frequencies (+4.9% from 5 to 15 Hz; +5.4% from 15 to 30 Hz). This is consistent with the viscoelastic nature of vulcanized rubber, which tends to dissipate energy over a broad range of frequencies rather than at a single resonance peak. Construction foam also displayed a relatively flat frequency response; gas-compression damping in closed-cell EPS materials is less sensitive to excitation rate within the tested frequency range. Intermediate frequency sensitivities were observed for pine wood and fired clay brick.

Cost-Effectiveness Index

Market prices for materials were obtained from Bishkek markets and Dordoi during the sample procurement time. Cost-effectiveness was calculated by dividing the mean damping ratio by the material's market price per kg (in KGS) to yield the CEI. The results, sorted from highest CEI to lowest, are shown in Table 4. Recycled rubber presented with the highest CEI (0.00829). This is due to a very high mean damping ratio and extremely inexpensive material price. Adobe demonstrated the next highest CEI (0.00484). Although adobe did not have an exceedingly high damping ratio, its very low material price led to the second highest CEI. The CEI for construction foam was 0.00084, followed by fired clay brick and pine wood, which scored 0.00040 and 0.00031, respectively. Considering structural suitability, both rubber and foam cannot function as load bearing materials. If structural functionality (for a load bearing wall), is included in the calculation, then Adobe may actually offer the most benefit for the lowest price. The problem with Adobe, however, is it suffers progressive damage as discussed in Section 5.

Table 4. Cost-effectiveness index (CEI) for each material, ranked by seismic damping per unit cost.

Material	Cost (KGS/kg)	Mean ζ	CEI (ζ per KGS/kg)	Rank
Recycled rubber	~15	0.1244	0.00829	1
Adobe	~5	0.0242	0.00484	2
Construction Foam(EPS)	~80	0.0672	0.00084	3
Fired Clay Brick	~20	0.0080	0.00040	4
Pine Wood	~50	0.0157	0.00031	5

DISCUSSION

Interpretation of Damping Results in a Seismic Context

The damping ratios calculated in this study are in accordance with or even on the higher side of published engineering literature on these classes of materials. The mean of 0.1244 for recycled rubber is well within the 0.08-0.16 range published for vulcanized natural rubber compounds in seismic isolation applications (Penazzato et al., 2024) and the mean for the EPS foam construction material of 0.0672 lies within the range published in engineering literature for cellular polymer foams loaded dynamically at low frequencies. The adobe damping ratio of 0.0242 is consistent with reported adobe masonry damping ratios in the literature (typically 0.02-0.05 under small amplitude vibration) and the value for pine wood (0.0157) lies within the 0.005-0.020 range specified for Norway spruce beams under steady state dynamic excitation by Labonnote et al. (2013) and the value of 0.0080 measured for fired clay brick is comparable to the lower end of brick masonry values reported in national seismic codes (typically 0.005-0.02).

The fact that all five materials exhibit consistent and comparable damping ratios with existing literature is itself significant, indicating that this low-cost Arduino-based cantilever setup can produce material damping data that would otherwise only be available via expensive lab equipment such as a Dynamic Mechanical Analyzer or servo-hydraulic testing rig. This has important implications for replicability of research under limited resources across Central Asia and the wider Global South.

Practical Implications for low-income construction in Central Asia

The most important practical result from this study is the potential for using recycled rubber as a low-cost seismic energy dissipation material for informal construction in Central Asia. Rubber is not a structural material in itself, but there are at least three practical ways to incorporate it into a building design: (1) as an isolation layer between the foundation slab and the first course of bricks (base isolation strips), (2) as vibration damping pads inserted between timbers and masonry bearing walls, and (3) as internal filling strips in adobe walls to break crack paths. All of these applications are well within the technical capability and cost limit of the typical informal builder in Bishkek or rural Kyrgyzstan, and the material is readily available in abundance from waste tire pile-up resulting from the extensive auto repair sector in the country.

Adobe's high performance on the CEI scale is significant, but also must be interpreted with care. Adobe's energy damping mechanism is in essence microcrack initiation and propagation along grain boundaries, a process that inherently weakens the adobe itself. Unlike rubber and EPS foam, adobe does not return to its original state after dissipating energy-in the process of doing so, new microcracks form, permanently reducing the integrity of the wall. Thus, adobe's advantage in damping over brick (+202%), should be balanced by its greater susceptibility to cumulatively higher seismic damage over a series of tremors. This inherent drawback to adobe is counteracted in traditional Central Asian vernacular architecture through the use of timber ring beams built into the adobe walls (Alford & Gurr, 2007); this traditional technique increases the ductility and overall robustness of the adobe wall to accommodate microcracking during an earthquake event, and therefore this study can be seen as quantitative evidence for the ongoing benefit of such a method.

Fired clay brick consistently exhibited a low damping ratio (average of 0.0080) across the range of frequencies tested and is only a moderately expensive material, contributing to its 4th best CEI score out of the five materials tested. This finding does not imply that brick should no longer be used in seismic zones, but highlights the lack of inherent seismic energy dissipation capacity at the material level in plain brick masonry construction, which helps explain the poor seismic performance of brick apartment blocks from the Soviet era common throughout the region (Ischuk et al., 2018).

Frequency Sensitivity and Realistic earthquake input

The positive dependence of all five material damping ratios on frequency is directly relevant to the response of buildings of different types to tremors in the Tian Shan mountains. Earthquakes in the Tian Shan region-especially in the near-field, such as those originating on the Issyk-Ata fault near Bishkek-have ground motions characterized by higher frequency components (typically 10-30Hz) than surface waves from farther afield earthquakes (Ischuk et al., 2018). The performance results shown here suggest that all five materials will generally perform slightly better at higher frequencies; while this is a modest improvement, the materials which showed some benefit from higher frequencies were also those which performed most poorly at lower frequencies. This means that the materials that were weakest at low frequencies become slightly more effective at precisely the frequency regimes most dominant in a nearby earthquake such as those threatening Bishkek.

The strong frequency dependence of adobe, particularly between 5 and 15 Hz, suggests that its unique damping mechanism is likely most engaged in moderate near-field seismic events similar to the 1992 Bishkek earthquake sequence. This helps make a partial case for the use of adobe as a

How do common, locally available construction materials differ in vibration damping performance, and which offers the best seismic protection per unit cost for low-income construction in Central Asia?

seismic building material for this specific threat regime, provided traditional reinforcement measures like ring beams are integrated into its use.

LIMITATIONS AND FUTURE RESEARCH

It is necessary to recognize several limitations:

1. Logarithmic decrement is used to measure damping, which is a cantilever beam specimen. This method accounts for material damping during small amplitude elastic vibration, rather than large amplitude nonlinear material behavior, as they fail near structural level failure during a seismic event. At seismic level, building element damping would be affected by such features as connection details, mortar quality, and wall geometry-none of which are tested in this sample level test. Therefore, test results should only be regarded as relative ranks of material damping and not as design values to be used in structural calculations.

2. The sample size of the specimens tested is 200x30x10 mm. While this is a suitable size to test for logarithmic decrement, it is not to the full scale size of a building element. Sample damping ratio is a function of geometry, particularly in anisotropic materials like pine wood, thus results are valid for this sample size only and could be different at structural scale.

3. The adobe samples are cast in the laboratory in a uniform manner. The composition of field mixed adobe varies in rural Kyrgyzstan and Tajikistan, depending on soil conditions and builder's methods, so the measured material damping may not reflect actual field conditions.

4. Material costs used for CEI index are based on current market prices for construction materials in Bishkek at the time the materials were bought. Costs of materials are highly susceptible to exchange rate changes of USD, as well as seasonal fluctuations in supply and availability, so this ranking will not remain valid indefinitely or even be correct for other locations and at later times when transport costs will considerably raise prices for materials purchased in remote areas.

The problem can be addressed in three additional areas. First, large-scale testing or testing of actual walls should be performed to determine whether the sample-level damping ranks are applicable to the structural scale and whether mortar joints significantly affect overall damping. Second, cyclical loading testing on brick and adobe samples to simulate repeated seismic events can identify potential decrease in damping due to accumulating damage, thus leading to a more accurate service life estimate for earthquake resistant adobe structures. Third, real-time earthquake simulation using recorded ground motion data of past Kyrgyz earthquakes, available on the IRIS database, rather than sinusoidal excitation, on an Arduino shake table will provide for greater test reliability.

CONCLUSION

This paper presents the first set of experimentally determined, comparable damping ratios for five commercially available construction materials used in low-cost residential construction in Central Asia; specifically pine wood, fired clay brick, adobe, construction foam (EPS), and recycled rubber. Five distinct materials are characterized using a low-cost Arduino-based cantilever impact setup under three excitation frequencies (5, 15, and 30 Hz), reflecting characteristics of Tian Shan seismic ground motions. Key conclusions of this study include:

1. Recycled rubber demonstrated significantly higher damping ratios than any of the tested materials (mean=0.1244) at over 15 times the damping of fired clay brick (mean=0.0080), and achieved by far the best CEI (due to virtually free material cost as a waste material). This strongly suggests recycled rubber is the best potential candidate supplementary seismic energy dissipation measure for informal construction.

2. Construction foam (EPS) ranked second in material damping characteristics (mean=0.0672). Like recycled rubber, EPS is not a structural element and has not been used in low-income housing construction in Central Asia until recently, but it is already a common infill and insulating material in informal constructions in Bishkek and would readily integrate well with a wall-infill shear connection for energy dissipation.

3. Adobe material had the third best CEI (due to near zero material cost) and third highest material damping ratio (mean=0.0242), though it exhibits progressive failure that is problematic for repeated seismic events. Though less advantageous than the tested non-structural alternatives, it remains technically justifiable to implement combined timber ring beam construction – a widely practiced Central Asian seismic adaptation – and its technical advantages supported here are supported by quantitative damping results.

4. Fired clay brick displayed the least material damping (mean=0.0080) of all five tested materials, quantitatively demonstrating the low energy dissipation potential of unreinforced brick masonry prevalent throughout Bishkek and Dushanbe, and indicating inherent vulnerability of existing brick masonry structures.

5. This low-cost, Arduino-based test setup reliably reproduced relative material damping ratios, agreeing well with data found in existing engineering literature across all five material types. Thus, it appears to be a well-established and valuable approach for a low-resource seismic material characterization in regions like Central Asia.

Overall, these data may helping for local builders, non-profit organizations, and government agencies responsible for housing policy throughout seismically active Central Asia; the inclusion of a rubber damper at the foundation or within wall systems has the potential to be a cost-effective method of improving the seismic performance of informal housing, which may warrant further research at a larger structural scale.

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