Increasing and Evaluating the Seismic Resistance of Low-rise Buildings Using Seismic Isolation Elements

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**Abstract.** The article presents the results of theoretical and experimental studies of the seismic resistance of single-story brick buildings with and without seismic isolation to seismic forces. The calculation of buildings was carried out in accordance with the construction regulations of QMQ 2.01.03-19. The calculations were carried out using the ETABS software. The results of the research show that the seismic resistance of low-rise buildings with seismic isolation increased compared to buildings without seismic isolation. Due to the increased plasticity of rubber-metal seismic isolation, the level of absorption of energy generated during vibrations increases, thereby damping vibrations. This, in turn, allows to reduce the estimated intensity of earthquakes by 1÷1.5 points when designing buildings in seismic areas. During the research, the stress-strain state of the building's structural elements under seismic load was determined and analyzed. Using the integrated ETABS program, stresses and strains arising in building structures with and without seismic isolation were calculated. When analyzing the stress-strain state of structures under seismic load, it was noted that stresses and forces were significantly reduced in building structures where seismic isolation elements were used. Also, new scientific data on displacement, velocity, acceleration, and stress-strain states in buildings were obtained using the ETABS program.

**Keywords:** Seismic resistance, low-rise building, seismic isolation, brick building, seismic force, acceleration, velocity, displacement

# INTRODUCTION

The construction of earthquake-safe and comfortable, energy-efficient and earthquake-resistant buildings based on the use of innovative technologies is becoming increasingly important in the world, which is considered the most important factor in seismically active regions [1, 2]. In the countries of Asia, Europe and America, special attention is paid to the issues of studying the impact of seismic force on buildings and structures, improving the design technologies and construction of earthquake-resistant buildings, as well as structures. As an example, we can cite modern projects and constructions in Japan, China, South Korea, Russia, Belarus, the USA, Germany, France, Italy, Turkey, Qatar, Egypt, Singapore and other developed countries. In this regard, one of the important tasks is to determine the basis of unfavorable conditions arising from various dynamic effects in building structures, the use of modeling in their study, ensuring compliance with seismic safety requirements in design and calculation. Existing statistics indicate that in developing countries, the percentage of damage is much higher [3, 4, 5]. For example, in densely populated areas of California in 1989 and 1994, 130 people died, and in two earthquakes of the same strength in Armenia (1988) and Sakhalin (1995), more than 27 thousand died, and in Turkey (02/06/2023) about 50 thousand. In view of this, the reason is obvious that in developed countries there is stricter control, higher responsibility of performers and the population is better prepared for a possible earthquake. In addition, world experience shows that an earthquake is inevitable, but its tragic consequences - loss of life and destruction of buildings - can be significantly reduced [6, 7, 8, 9, 10, 11, 12].

Also, at this time, the design of earthquake-resistant buildings and structures, in-depth study of the consequences of seismic vibrations, prevention of possible damage and losses are of great importance. At the same time, in general, the issue of increasing and ensuring seismic safety in general is acute. High-precision calculations show that the cross-sections of load-bearing structures of buildings increase with increasing earthquake strength. This, in turn, negatively affects the economy of construction and, therefore, leads to work on finding optimal options [1, 6, 7, 10].

Moreover, at present, in all countries, when solving the problem of ensuring seismic resistance of newly erected buildings, it is not sufficiently explained how to deal with previously constructed non-earthquake-resistant buildings. At present, there are no clear recommendations developed by researchers applicable to erected low-rise buildings. On the other hand, it should be considered that the task of developing recommendations for strengthening previously constructed buildings has a social nature and will give us the main result that we ultimately really want, where human losses will be significantly reduced and the task of preserving human life is solved [12].

# METHODS

The analysis of research papers conducted by the authors showed that research papers on the use of seismic isolation in brick buildings have not been sufficiently studied, including the lack of comprehensive research on the comparison of seismic safety and determination of seismic resistance of brick buildings with and without seismic isolation [1, 2, 4, 6, 7, 13].

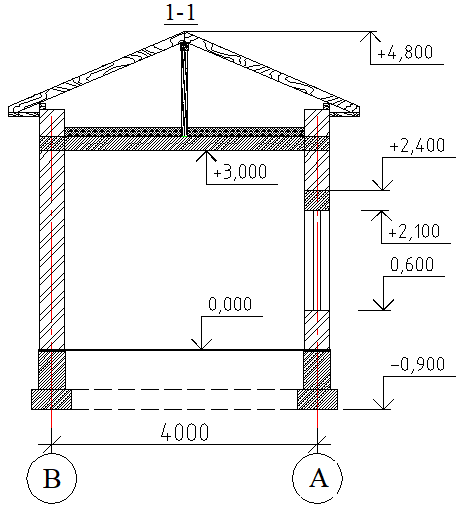
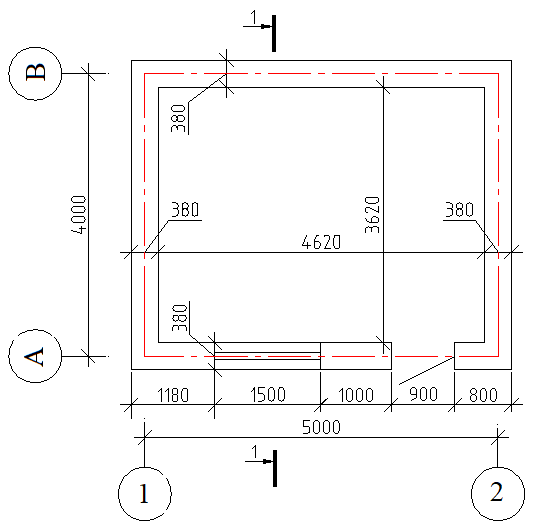
In this regard, based on the research objective, the research methodology included experimental and theoretical studies of optimal solutions for low-rise brick building models. Based on the research objective, experimental studies were conducted on a standard seismic platform located at the Turin University Technopark in Tashkent, and theoretical studies were performed using the ETABS program, as well as engineering techniques [2, 4, 5, 6, 7].

The assessment of the strength and seismic resistance of buildings(Figure 1) was carried out on the basis of the following main indicators:

a) buildings with seismic isolation elements;

b) without seismic isolation elements.

As well as on the basis of the provisions of QMQ 2.01.03-19 “Construction in seismic areas” and the provisions of the Standard of the Republic of Uzbekistan RST Uz 836-97 “Scale for determining the intensity of an earthquake in the range from 6 to 10 points”, developed on the basis of the well-known school “MSK-64” and put into effect on 01.01.1998.



**FIGURE 1.** Plan and section of the walls of a brick building

The brick building selected for the study is a single-story building with dimensions of 4000×5000 mm in plan, with a floor height of 3000 mm, the structural materials of the walls are made of burnt brick, the transferred load is Q1=291 kN, the modulus of elasticity was taken as E=0.3 103 MPa, the calculated compressive strength is R=2MPa, the façade part has openings (900×2100 mm; 1500×1500 mm).

Seismic resistance of brick buildings based on QMQ 2.01.03-19 was carried out according to the following sequence:

Stage 1: determining the calculation scheme.

Stage 2: determining permanent and temporary loads, while the values are multiplied by the combination coefficient (0.9 for permanent; 0.5 for short-term and 0.8 for long-term temporary loads).

Stage 3: determination of the rigidity of structural elements in longitudinal and transverse directions.

Stage 4: determination of potential and kinetic energy using formulas

(1)

here: *Ep* – potential energy; *Ek* – kinetic energy; *Хi* – amplitude of displacement of the *i*-th mass; *Qi* – mass at the *i*-th point

Step 5: determine the period of natural oscillations using the formula:

(2)

Stage 6: calculation of the estimated seismic load according to QMQ 2.01.03-19 p.2.13 in the selected direction, applied to point “*k*” and corresponding to the *i*-th tone of the building’s natural vibrations according to the formula:

(3)

here: *K0* – responsibility factor (*K0=1*) adopted according to Table 2.3; *Kn* – repeatability factor (*Kn=1.2* for 7 and 8 points, *Kn=1.25* for 9 points) adopted according to Table 2.4; *Ket* – number of storeys factor (*Ket*=1) determined according to clause 2.17; *Kр* – regularity factor determined according to clause 2.25; *α* – factor adopted according to Table 2.7; *Qk* – building weight, according to clause 2.1; *Wi* – spectral factor according to clause 2.14; *Kδ* – dissipation factor according to clause 2.16; *ηik* – coefficient of dependence on vibration mode according to clauses 2.18 and 2.19.

The dissipation coefficient Kδ should be determined using the formula:

(4)

here: *δ* is the decrement of oscillations determined during full-scale tests of buildings similar to those being designed; if it is impossible to determine experimentally, it is determined according to Table 2.9; *Ti* is the period of the fundamental tone of the building’s natural oscillations.

Stage 7: for buildings up to 5 storeys high inclusive with masses and storey rigidities changing slightly with height, at *Ti < 0.4* sec, the coefficient *ηk* may be determined using the simplified QMQ formula

(5)

here: *Xk* and *Xj* are the distance from points k and *j* to the upper edge of the foundations, *Qj* is the weight of the concentrated mass, determined considering the requirement of clause 2.1 of QMQ 2.01.03-19.

Stage 8: distribution of seismic load along the axes in the longitudinal and transverse directions, taking into account the cross-sectional areas of the walls in the plan [2, 6, 7, 8].

Also, in order to determine the theoretical vibration modes, calculations were made based on the ETABS software package, which are one of the most important characteristics of the dynamic state of buildings. They are used to calculate the response to seismic impacts using linear approximation. Since the studies used building models, the calculations were made for 4 vibration modes of buildings and the obtained vibration periods are given in Table 1.

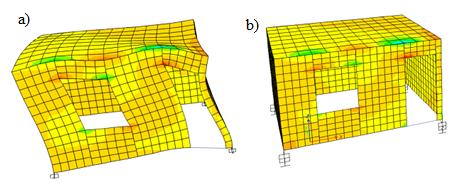
**TABLE I.** Periods of oscillations corresponding to the forms of oscillations of building models

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Indicators | 1st form | 2nd form | 3rd form | 4th form |
| The period of oscillation of a building without seismic isolation – T, sec | 0.059 | 0.053 | 0.034 | 0.029 |
| The period of oscillation of a seismically isolated building –T, sec | 0.077 | 0.0769 | 0.0579 | 0.049 |

# RESULTS AND DISCUSSION

We know that in practice of experimental researches when studying vibrations, the first form of vibrations is mainly predominant. The reason for this is mentally clear, firstly, one-story, and also because of small geometric dimensions of building models. Successive 2nd, 3rd and 4th forms of vibrations, in such situations are very difficult to catch even with super-sensitive devices. Of course, in this case we always get reliable results through registration with the help of appropriate super-sensitive seismic measuring devices. It is also meant that by registering the dynamic characteristics of buildings with the help of special seismometric equipment, it is possible to determine above the 2nd form of vibrations. But regardless of the floor, with the help of theoretical calculation we can determine the forms of vibrations for any objects taken, especially since ETABS has such capabilities [2, 4, 6].

Below are the results of the deformed state of buildings corresponding to the 1st form of oscillations, obtained on the basis of the calculation of the ETABS program (Figure 2).



**FIGURE 2.** The first form of oscillations caused by seismic force: *a* – oscillation period in buildings without seismic isolation T=0.059 sec; *b* – oscillation period in buildings with seismic isolation T=0.077 sec

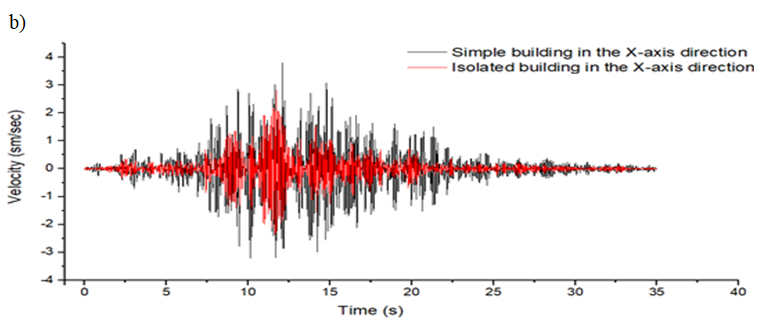
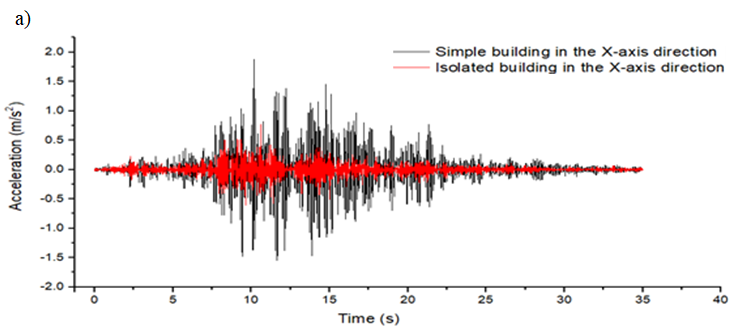
The first form of oscillations corresponds to the slowest initial oscillations. Forms 2-3-4 and higher correspond to horizontal oscillations of the building around the Z axis. During oscillations around the XYZ axis, torques are also observed at all points of the building.

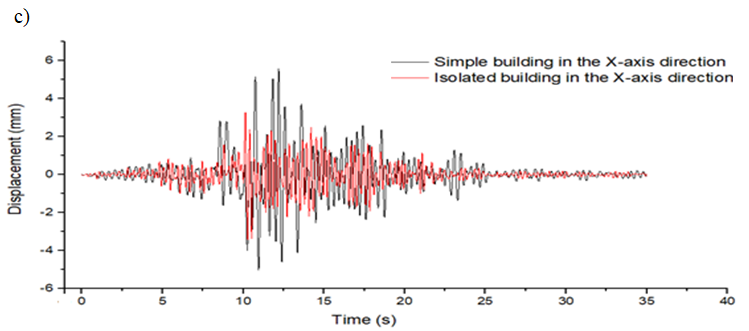
Also, acceleration, speed and displacement of oscillations in brick buildings with and without seismic isolation are determined. In particular, seismic loads on brick buildings are determined using the ETABS complex calculation program (Table 2).

**TABLE 2.** Results obtained based on the ETABS program

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| The Impact of Earthquake on Buildings | With seismic isolation | | | Without seismic isolation | | |
| acceleration, m/sec2 | velocity, cm/sec | displacement, mm | acceleration, m/sec2 | velocity, cm/sec | displacement, mm |
| X axis | 0.76 | 2.80 | 3.36 | 1.95 | 3.90 | 5.59 |
| Y axis | 0.38 | 0.41 | 0.56 | 1.24 | 0.69 | 0.78 |

Graphs of acceleration, velocity and displacement in buildings under the influence of seismic forces are shown below in Figure 3.





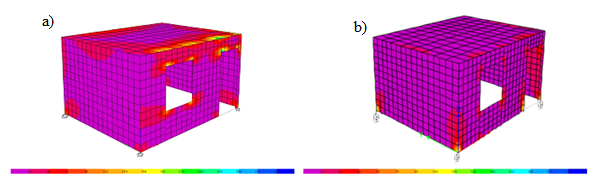
**FIGURE** **3.** Graphs of acceleration (a), velocity (b) and displacement (c) of seismically isolated and non-seismically isolated building models

The program specified seismic impacts in the same time interval (i.e., 35 sec) and based on the obtained results, the values of acceleration, speed and displacement were determined. Relative differences in using a seismic isolation element on a brick building compared to a building without seismic isolation were determined and analyzed.

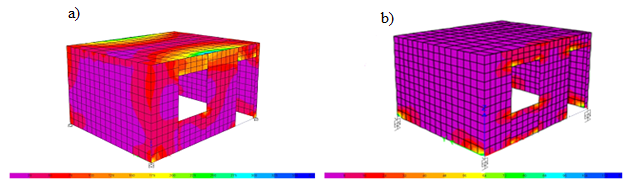
During the research, the stress-strain state of the building's structural elements under seismic load was determined and analyzed. Using the integrated ETABS program, stresses and strains arising in building structures with and without seismic isolation were calculated figure 4-5. During the analysis of the stress-strain state of structures under seismic load, it was noted that stresses and forces in building structures where the seismic isolation element was used were clearly reduced (Table 3).

**TABLE 3.** Stress-strain state in building structures under seismic force, obtained using the finite element method

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Building characteristics | Stress, MPa | | Tangential stress  τху, MPa | Force in building structures, kN/m |
| X axis | Y axis |
| with seismic isolation | 218 | 112 | 77 | 56.9 |
| without seismic isolation | 340 | 375 | 109 | 98 |
|  |  |  |  |  |

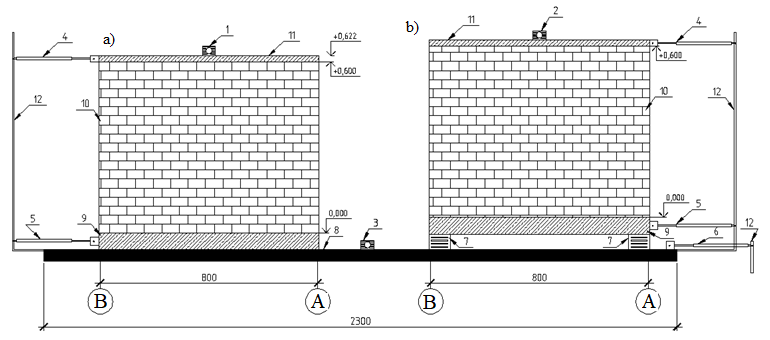


**FIGURE** **4.** Normal stresses in buildings caused by seismic force along the X-axis: a – without seismic isolation; b – with seismic isolation



**FIGURE 5.** Normal stresses in buildings caused by seismic force along the Y axis: a – without seismic isolation; b – with seismic isolation

Preparation of building models for seismic tests on the SP-116 Seismic Platform and obtaining results Figure 6-7.

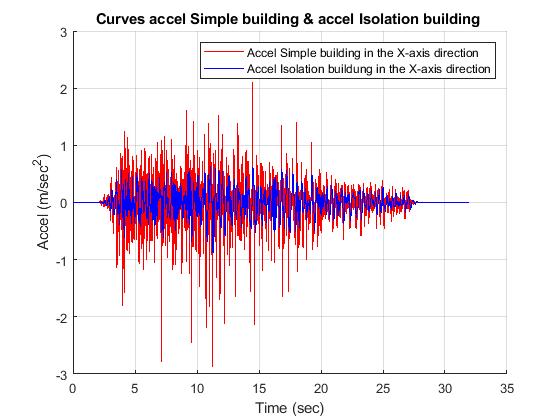


**FIGURE 6**. Layout of measuring instruments at characteristic points:  
(a) – without seismic isolation, (b) – with seismic isolation. 1- and 2- sensors installed on the building roof (accelerometers in the X and Y directions); 3- sensors installed on the seismic platform (accelerometers in the X and Y directions); 4- displacement potentiometers installed at the roof level; 5- displacement potentiometers installed at the foundation level; 6- displacement potentiometer on the seismic platform; 7- elastomeric supports; 8- seismic platform (SP-116); 9- building foundation; 10- brick wall; 11- roof structure; 12- metal bracket for attaching sensors

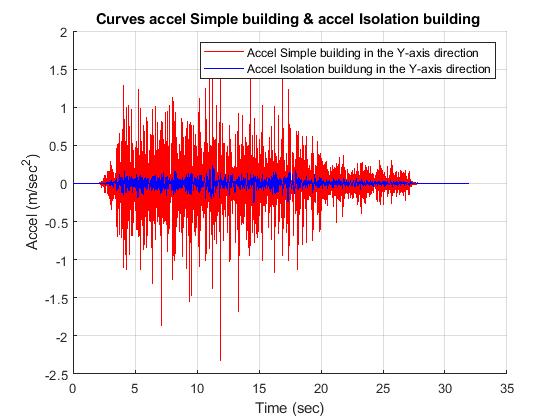


**FIGURE 7.** The process of experimentation on the seismic platform SP-116 and the appearance of recording devices

To record the acceleration and displacement of the building model under the influence of dynamic forces, single-axis accelerometer sensors (1) developed by the Japanese company Akashi, LVDT AML/EU 10+/150 mm position sensors (2), GOA linear displacement potentiometer sensors developed in the USA, and a WX-7000 128-channel recording device (3) from the Japanese company TEAC were used. Using the measuring complex, low-frequency, mid-frequency and high-frequency forced vibrations were fed to the building model and tested, and the corresponding graphs of displacements, accelerations and speeds at characteristic points were constructed using the Matlab program [2, 7, 8], figure 8-9.



**FIGURE 8**. Comparative graph of vibrations along the X and Y axes of buildings without seismic isolation and with seismic isolation under the influence of seismic force: Vibration comparison graph along the X-axis of the building model. Without seismic isolation - 2.108 m/sec2,with seismic isolation - 0.6271 m/sec2



**FIGURE 9.** Comparative graph of vibrations along the X and Y axes of buildings without seismic isolation and with seismic isolation under the influence of seismic force: Vibration comparison graph along the Y-axis of the building model. Without seismic isolation - 1.611 m/sec2, with seismic isolation - 0.2409 m/sec2

# CONCLUSIONS

Due to the increased plasticity of rubber-metal seismic isolation, the level of absorption of energy generated during vibrations increases, thereby damping vibrations. This, in turn, allows to reduce the estimated intensity of earthquakes by 1÷1.5 points when designing buildings in seismic areas.

Based on the theoretical and experimental approach, it was found that the use of structures with seismic isolation elements in brick buildings reduces the seismic force by 2÷3 times. This allows to reduce the seismicity level of the construction site by 1÷1.5 points (with a safety margin) during design work.

Taking into account the linear deformations of the seismic isolation element in the ETABS software package, comprehensive scientific results were obtained on the stress-strain state, strength, acceleration, speed and movement of buildings.

# FUTURE SCOPE

The amount of research in the region of seismic isolation systems, especially in low-rise masonry structures, has a tremendous potential of enhancing the strength and flexibility of building created in seismic areas. The current research has evidently given a clear indication of the fact that the use of elastomeric base isolators drastically reduces the dynamic response of structures such as the acceleration velocity, displacement and the parameters of the internal stress. Nevertheless, there are some several technical, theoretical, and practical areas that still need to be investigated to increase the theory and practical application of the seismic isolation technologies. Among the promising directions, the development of material science involved in isolation systems deserves mentioning. Although rubber-metal isolators were proved to be efficient in the present experiments, the future research can explore other composite materials, i.e., shape memory alloys (SMA), high-damping rubber compounds, or nano-reinforced polymers. These may present in better energy die, endurance in cyclic loading, aging and resistance to temperatures, as well as environments. An experimental test and use of finite element modeling (FEM) of these materials in the structural systems would add a lot to the same.

Moreover, it might prove essential to introduce systems of real-time health monitoring into seismic isolation mechanisms. It would be possible to monitor the seismic performance and damage accumulation by embedding smart sensors e.g.in fiber-optic strain gauges, MEMS accelerometers, or wireless displacement sensors in the isolators and superstructures and continuously record the seismic performance. Combining these technologies with platforms and machine learning algorithms would be capable of assisting in predictive and post-event diagnostics and instantaneous safety-verifications. With regards to numerical modeling, the future studies ought to be directed to the enhancement of precision and calculation performance of dynamic analysis processes in software platforms such as ETABS. The reliability of the predictions would be improved by the introduction of multi-scale modeling strategies: In which case the nonlinear behavior of isolator materials and interfaces is modeled in greater detail at a local scale and subsequently incorporated into global models. In order to standardise the use of such advanced numerical models, validation of the same by shake-table testing or hybrid simulation techniques will play a pivotal role. Moreover, the effects of other seismic input properties such as near-field effects, pulse-like ground motions, and multi-directions excitation could be the subject of the future investigated works. The study at hand employed a standardized time window (35 seconds), though seismic records in use can span a considerably broad range in terms of duration, frequencies coverage and amplitude. An evaluation of the performance of isolated and non-isolated building by a wider range of ground motions would give further inferences to the performance based design standards.

Apart from this great opportunity, another area that can be explored is the cost benefit analysis and life-cycle analysis of the adoption of the concept of seismic isolation to existing masonry structures and low rise building. Despite the performance benefits that are quite obvious, economic viability is one of the factors that hinders the adoption of performance to a large extent especially in the developing world. The development of research on optimising isolator design, retrofitting strategies over exiting buildings and policies on seismic resilience incentive can facilitate bridging this gap. Comparative investigation of the traditional strengthening procedures with the cost of the base isolation, estimated improvement in damage reduction, and service durability would be of extreme significance to interested parties. The topic of seismic isolation in the adaptive and sustainable construction also should be mentioned. Under the conditions of climate change and rising urban density, one could focus on the viability of isolation systems to multifactor hazards, that is, seismic event with a resulting aftershock, flood, or thermal exposure. The implication of incorporation of green building technologies and passive energy dissipation systems with base isolation could provide multi-functional advantages in enhancing the seismic and environmental performance.

Finally, although this study was based on low rise buildings composed of bricks, the study should be taken further to other types of buildings, including timber, steel, and composite buildings. Additionally, seismic codes and the way of construction should be taken into consideration in the areas where the seismic risk is high and the consistency of soil is inconsistent. Cooperation with local governments, engineering companies and universities might help to develop context-oriented seismic isolation design guidelines and modular solutions that can be applied on a mass scale.

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