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# SCENARIO-BASED SEISMIC RISK AND STRUCTURAL VULNERABILITY ASSESSMENT IN URBAN AREAS: A CASE STUDY OF TASHKENT

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**Abstract.** Tashkent is located in a seismically active region, which makes the assessment of potential damage and losses a critical task. This study presents an integrated scenario-based approach to the analysis of seismic hazard, structural vulnerability, and expected damage.

The research methodology includes probabilistic seismic hazard assessment, analysis of geological and soil conditions, classification of building types, and the application of vulnerability functions based on spectral displacement parameters [16, 18]. Unlike traditional approaches, the proposed method incorporates the influence of local soil conditions and considers earthquake scenarios of varying intensity levels [15].

The results indicate that the most vulnerable structures are buildings of older construction, particularly those located on weak soils [18, 19]. The developed model enables the estimation of potential losses and can be effectively applied to improve the seismic resilience of urban infrastructure [20].

**Key words:** Seismic risk, Scenario analysis, Structural vulnerability, Damage assessment, Tashkent, Fragility curves, Spectral displacement, Building classification.

**Аннотация.** Ташкент расположен в сейсмически активном регионе, что делает оценку потенциальных повреждений и потерь одной из приоритетных задач. В данном исследовании представлен интегрированный сценарный подход к анализу сейсмической опасности, конструктивной уязвимости и ожидаемых повреждений.

Методология исследования включает вероятностную оценку сейсмической опасности, анализ геологических и грунтовых условий, классификацию типов зданий, а также применение функций уязвимости на основе параметров спектральных перемещений [16, 18]. В отличие от традиционных подходов, предложенный метод учитывает влияние локальных грунтовых условий и рассматривает сценарии землетрясений различной интенсивности [15].

Результаты показывают, что наиболее уязвимыми являются здания старой постройки, особенно расположенные на слабых грунтах [18, 19]. Разработанная модель позволяет оценивать потенциальные потери и может эффективно применяться для повышения сейсмостойкости городской инфраструктуры [20].

**Ключевые слова:** сейсмический риск, сценарный анализ, конструктивная уязвимость, оценка повреждений, Ташкент, кривые хрупкости, спектральное перемещение, классификация зданий.

**Annotatsiya.** Toshkent shahri seysmik faol hududda joylashgan bo‘lib, bu potensial shikastlanishlar va yo‘qotishlarni baholashni muhim vazifaga aylantiradi. Mazkur tadqiqotda seysmik

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xavf, konstruktiv zaiflik va kutilayotgan shikastlanishlarni tahlil qilish uchun integratsiyalashgan ssenariy asosidagi yondashuv taqdim etilgan.

Tadqiqot metodologiyasi seysmik xavfni ehtimollik asosida baholash, geologik va grunt sharoitlarini tahlil qilish, bino turlarini tasniflash, shuningdek spektral siljish parametrlariga asoslangan zaiflik funksiyalarini qo‘llashni o‘z ichiga oladi [16, 18]. An’anaviy yondashuvlardan farqli ravishda, taklif etilgan usul mahalliy grunt sharoitlarining ta’sirini hisobga oladi hamda turli intensivlik darajasidagi zilzila ssenariylarini ko‘rib chiqadi [15].

Natijalar shuni ko‘rsatadiki, eng zaif obyektlar eski qurilgan binolar bo‘lib, ayniqsa kuchsiz gruntlarda joylashganlari yuqori xavf ostidadir [18, 19]. Ishlab chiqilgan model potensial yo‘qotishlarni baholash imkonini beradi va shahar infratuzilmasining seysmik barqarorligini oshirishda samarali qo‘llanilishi mumkin [20].

**Kalit so‘zlar:** seysmik xavf, ssenariy tahlili, konstruktiv zaiflik, shikastlanishni baholash, Toshkent, fragillik egri chiziqlari, spektral siljish, bino tasnifi.

**Introduction.** Cities located in seismically active regions are exposed to a significant risk of damage caused by strong earthquakes. In this context, the comprehensive assessment of seismic hazard, structural vulnerability, and potential consequences for urban infrastructure becomes particularly important [16].

Tashkent, one of the largest cities in Central Asia, is situated in a zone of high seismic activity, as confirmed by both historical records and recent studies [2]. The destructive earthquake of 1966 clearly demonstrated the high vulnerability of the urban building stock and highlighted the necessity of implementing seismic-resistant design standards. Despite the development of regulatory frameworks, including modern building codes such as KMK, a considerable portion of the existing building stock was constructed without consideration of current seismic design requirements. This significantly increases the level of risk in the event of future seismic events [3].

Modern approaches to seismic risk assessment are based on the integration of three key components: seismic hazard, structural vulnerability, and exposure. This framework allows for a comprehensive evaluation of both earthquake characteristics and the properties of buildings and population density [16, 20].

In recent years, scenario-based analysis has gained particular importance, as it enables the modeling of the consequences of hypothetical earthquakes with varying intensity levels and the assessment of potential building damage [20]. Within this approach, fragility curves are widely used to estimate the probability of a structure reaching different damage states [17–19].

An important aspect of the analysis is the classification of buildings based on structural characteristics, number of stories, and construction period. Different building types exhibit significantly different behavior under seismic loading, which requires a differentiated approach to vulnerability assessment [18].

**Methodology.** This study adopts an integrated scenario-based approach to seismic risk assessment, based on the combination of three key components: seismic hazard, structural vulnerability, and exposure [16, 20]. The overall analytical framework is represented as a sequential process:

$$R=H\cdot V\cdot E \quad (1)$$

R — seismic risk,

— seismic hazard,

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V — structural vulnerability,
— exposure .

Seismic hazard assessment is carried out using a scenario-based earthquake approach that considers the regional seismic characteristics of the Tashkent area [16]. The primary parameter used in the analysis is the peak ground acceleration (PGA), which represents the maximum ground acceleration experienced at the site during seismic excitation:

$$\mathbf{PGA=a_{max}} \qquad (2)$$

Where $a_{max}$— maximum ground acceleration.

In accordance with the KMK building code provisions, the design seismic acceleration is calculated as:

$$\mathbf{a=A_0 \cdot \gamma I \cdot S} \qquad (3)$$

$A_0$— reference seismic acceleration for the region,
— importance factor of the structure,
— soil coefficient accounting for local ground conditions.

Soil conditions have a significant influence on the amplification of seismic waves and, consequently, on the seismic response of structures [15, 21]. The following parameters are considered in the analysis:

1. Soil type (categories I–III);
2. Groundwater leve;
3. Geological structure of the site.

The adjustment of spectral characteristics is performed using the soil coefficient SSS, as defined in Equation (3).

**Building Classification.** For vulnerability assessment, buildings are classified based on their structural characteristics, number of stories, and construction period, following established seismic vulnerability classification frameworks. [18, 19] The study considers 11 building types representative of the urban development in Tashkent:

1.Adobe buildings (1–2 stories);
2.Buildings made of raw (unfired) brick;
3.Masonry buildings (fired brick);
4.Two-story masonry buildings;
5.Masonry buildings (3–5 stories, constructed before 1966);
6.Seismically designed buildings (post-1966);
7.Large-panel buildings (4–5 stories);
8.Panel buildings (9 stories);
9.Frame buildings (9–12 stories);
10.Block buildings;
11.Monolithic reinforced concrete buildings.

Structural vulnerability is assessed using fragility curves, which describe the probability of a structure reaching or exceeding a certain damage state [17, 18, 19]:

$$\mathbf{P(D \geq ds) = \Phi\left(\frac{\ln(S_d) - \ln(S_{d,ds})}{\beta_{ds}}\right)} \qquad (3)$$

$S_d$— spectral displacement;
$S_{d,ds}$– median spectral displacement corresponding to a specific damage state;
$\beta_{ds}$– logarithmic standard deviation;
Φ— standard normal cumulative distribution function.

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Fragility curves provide a probabilistic framework for linking seismic demand parameters with expected damage levels and are widely used in seismic risk assessment methodologies [17–20].

**Damage Assessment**

The primary parameter used to evaluate structural damage is the interstory drift ratio:

$$\theta=\frac{\Delta}{h}$$

Δ— lateral displacement;

h — story height;

The interstory drift ratio is widely recognized as a key indicator of structural performance and damage level under seismic loading [14, 13, 12]. Higher values of drift are associated with increased structural and non-structural damage.

$$D=\frac{\theta}{\theta_{lim}}$$

The estimation of potential losses includes the calculation of building damage and associated economic consequences:

$$Loss=\sum (D_i \cdot C_i \cdot N_i)$$

$D_i$- damage ratio for building type i;

$C_i$– replacement cost of buildings;

$N_i$ – number of buildings of type i.

A scenario-based seismic analysis was performed for the city of Tashkent considering a design earthquake with the following parameters:

1. Magnitude: M=7.0;
2. Peak ground acceleration: PGA=0.35g
3. Soil type: categories II–III.

Based on the proposed methodology, the damage assessment was carried out for 11 building types representative of the urban development of the study area.

For each building type, a damage index was calculated as follows:

$$D_i=V_i \cdot IM$$

$V_i$— vulnerability coefficient;

IM — intensity measure (PGA).

| № | Building Type | Description | Vulnerability $V_i$ | Damage Index $D_i$ | Damage Level |
|---|---|---|---|---|---|
| 1 | Adobe buildings | 1–2 stories | 0.90 | 0.315 | Very high |
| 2 | Unfired brick buildings | 1–2 stories | 0.85 | 0.298 | Very high |
| 3 | Fired brick buildings | — | 0.75 | 0.263 | High |
| 4 | Masonry buildings (2 stories) | — | 0.70 | 0.245 | High |
| 5 | Masonry buildings (pre-1966) | 3–5 stories | 0.80 | 0.280 | Very high |

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| | | | | | |
|---|---|---|---|---|---|
| **6** | Seismically designed buildings | Post-1966 | 0.55 | 0.193 | Moderate |
| **7** | Large-panel buildings | 4–5 stories | 0.50 | 0.175 | Moderate |
| **8** | Panel buildings | 9 stories | 0.40 | 0.140 | Below moderate |
| **9** | Frame buildings | 9–12 stories | 0.30 | 0.105 | Low |
| **10** | Block buildings | — | 0.45 | 0.158 | Moderate |
| **11** | Monolithic RC buildings | 16 stories | 0.25 | 0.088 | Low |

**Table 1. Building Damage Assessment Results**

**Analysis of Results**

The obtained results demonstrate a significant variation in the level of damage depending on the building type.

The highest level of damage is observed for:

1.adobe buildings;

2.unfired brick buildings;

3.masonry buildings constructed before 1966.

For these building types, the damage index reaches: $\mathbf{D_i=0.28-0.32}$

which corresponds to a high probability of severe structural damage and potential collapse [18, 19]. This behavior is primarily associated with the lack of seismic-resistant design measures and the brittle structural response of such buildings under seismic loading [13]. Similar findings have been reported in previous studies on seismic vulnerability, where older masonry and non-engineered structures exhibit the highest damage levels [11, 18].

**Influence of Structural Characteristics**

The conducted analysis demonstrates that structural characteristics of buildings play a decisive role in determining their seismic vulnerability. In particular, the absence of seismic-resistant measures, such as reinforcement, rigid diaphragms, and adequate spatial stiffness, leads to a significant increase in the probability of damage [13].

Masonry buildings without reinforcement are characterized by a low capacity to resist horizontal loads, which results in a high level of risk under seismic excitation. Such structures typically exhibit brittle failure once deformation limits are exceeded [14].

Panel buildings demonstrate relatively improved performance due to the presence of prefabricated structural elements; however, their vulnerability remains moderate because of potential deficiencies in joints and connections [11].

The highest level of seismic resistance is observed in frame and monolithic reinforced concrete buildings, which possess high spatial stiffness and the ability to redistribute loads. These structures exhibit more ductile behavior, significantly reducing the likelihood of sudden collapse [23].

Thus, it can be concluded that an increase in structural reliability is directly associated with a reduction in the damage index:

$$\mathbf{D_i \sim \frac{1}{R_s}}$$

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where $R_s$— represents the structural resistance capacity.

**Influence of Soil Conditions**

Additional analysis showed that soil conditions have a significant influence on seismic impact parameters. In particular, the presence of soft and water-saturated soils leads to the amplification of seismic waves due to resonance effects and reduced wave propagation velocity. [15] This is reflected in an increase in peak ground acceleration:

$$\mathbf{PGA_{soil}=PGA_{rock}\cdot S}$$

where:S — soil amplification coefficient;

$PGA_{rock}$—reference acceleration on rock;

Furthermore, soil conditions contribute to an increase in the amplitude and duration of ground motion, which results in higher cumulative structural damage [21].

As a consequence, the damage level for buildings located on weak soils is significantly higher compared to those on stable ground conditions:

$$D_i^{soil} > D_i^{rock}$$

This leads to an increase in seismic risk even for buildings with relatively high structural resistance, particularly in areas with unfavorable engineering and geological conditions **[15]**.The total economic loss due to seismic impact is determined based on an aggregated model:

$$\mathbf{Loss=\sum (D_i \cdot C_i \cdot N_i)}$$

The conducted analysis showed that the greatest contribution to total losses is associated with building types 1–5, which belong to the older housing stock. Despite the relatively low cost of individual structures, their high level of damage results in significant cumulative losses **[11, 20]**.It was further established that the proportion of these building types within the overall building inventory has a substantial impact on the total level of seismic risk:

$\mathbf{Loss_{total} \approx 60-80\%}$ due to buildings of types 1-5

**Discussion**

The obtained results are consistent with findings from international studies in the field of earthquake engineering and confirm that structural vulnerability is a key factor in the formation of seismic risk [18, 19].

The analysis indicates that the older building stock, constructed without consideration of modern seismic design standards, constitutes the primary source of potential damage. In contrast, modern reinforced concrete structures demonstrate a significantly higher level of seismic resistance due to improved design practices and materials [13].

Particular importance is attributed to the influence of soil conditions, which can substantially amplify seismic effects and diminish the advantages of even structurally resilient systems [15].

The scenario-based approach applied in this study has proven to be effective in assessing earthquake impacts and enables:

1.identification of the most vulnerable urban areas;

2.estimation of potential losses;

3.prioritization of structural retrofitting measures;

4.support for decision-making in seismic risk management.

Thus, the results of this study can serve as a foundation for the development of strategies aimed at improving urban resilience and enhancing seismic design regulations.

**Conclusion.** This study presents an integrated scenario-based approach for seismic risk assessment in the city of Tashkent, based on the combined consideration of seismic hazard, structural

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vulnerability, and exposure [16, 20]. The application of the proposed methodology made it possible to quantitatively evaluate the damage levels of different building types and to determine their contribution to overall seismic risk.

The results indicate that buildings of older construction (types 1–5) exhibit the highest vulnerability, characterized by elevated damage indices under the considered seismic scenario. In contrast, modern frame and monolithic reinforced concrete structures demonstrate significantly higher seismic resistance due to improved design solutions and compliance with seismic codes [13].

It was established that structural characteristics represent the primary factor influencing seismic risk; however, soil conditions also play a crucial role by amplifying seismic effects and increasing damage levels [15]. This highlights the necessity of adopting a comprehensive approach that integrates both structural and geotechnical factors.

The analysis further revealed that the main contribution to total economic losses is associated with the older building stock. Despite their relatively low individual value, the high degree of damage and large quantity of such buildings result in substantial cumulative losses [11, 20].

The practical significance of this study lies in its potential application for:

1.developing strengthening and retrofitting programs for existing buildings;

2.improving urban planning policies;

3.enhancing the seismic resilience of urban infrastructure;

4.supporting decision-making for risk reduction strategies.

Future research should focus on extending the methodology through the application of nonlinear dynamic analysis, incorporation of real monitoring data, and the use of machine learning techniques to improve the accuracy of damage prediction. [3]

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