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RESEARCH ARTICLE

REGIONAL CLASSIFICATION OF BUILDINGS AND STRUCTURES FOR SEISMIC RISK ASSESSMENT IN KAZAKHSTAN

N.V. Surovtseva^{1,2*}, T. Abakanov², V.A. Lapin¹, G.M. Nigmatov³,
S.A. Khokhlov⁴, A.T. Agishev⁴, K.A. Turekulova¹, A.F. Ramazanov¹

¹National Scientific Center for Seismological Observations and Research, 050060, Almaty, Kazakhstan

²International Educational Corporation, 050043, Almaty, Kazakhstan

³All-Russian Research Institute for Civil Defense and Emergencies, 121352, Moscow, Russia

⁴Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan

Abstract. *Reliable seismic risk assessment requires the systematic organization of information on built assets, taking into account regional construction practices and international approaches. A regional engineering classification of the building stock is proposed for seismic risk assessment in Kazakhstan. The empirical basis comprises building-passportization data for Almaty, combining the 2017-2018 surveys with supplementary work conducted in 2024. Building-stock data, regulatory documents, and findings from engineering investigations of earthquake consequences were used. The classification was organized into a hierarchical framework comprising 22 categories covering residential and public buildings, industrial facilities, and special engineering structures. The scientific novelty lies in formalizing regional categories with consideration of structural characteristics and design seismic resistance, and in developing classification rules for assets with mixed structural systems, reconstructed assets, and assets with insufficient documentation. A distinction is made between the established absence of earthquake-resistant design provisions and unknown design seismic resistance. Load-bearing material and structural system are used to identify structural type, while technical condition, construction period, strengthening, and seismic isolation are considered supplementary attributes. The classification was compared with EMS-98, HAZUS, RISK-UE, and the GEM Building Taxonomy. GOST R 57546-2017 was considered as a framework for assessing seismic intensity and damage to built assets. The classification is intended to harmonize passportization data for urban building stocks, support the development of GIS-based exposure databases, and facilitate the selection of vulnerability models. The Almaty data characterize the structural diversity of the country's building stock, supporting the potential application of the proposed classification in other regions of Kazakhstan.*

Keywords: *seismic risk, building stock, classification of buildings and structures, seismic vulnerability.*

*Corresponding author
Nataliya Surovtseva, e-mail: natali.s71@mail.ru

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ҒЫЛЫМИ МАҚАЛА

ҚАЗАҚСТАНДАҒЫ СЕЙСМИКАЛЫҚ ТӘУЕКЕЛДІ БАҒАЛАУ ҮШІН ҒИМАРАТТАР МЕН ҚҰРЫЛЫСТАРДЫҢ ӨҢІРЛІК ЖІКТЕМЕСІ

Н.В. Суровцева^{1,2*}, Т. Абаканов², В.А. Лапин¹, Г.М. Нигметов³,
С.А. Хохлов⁴, А.Т. Агишев⁴, К.А. Турекулова¹, А.Ф. Рамазанов¹

¹Сейсмологиялық байқау және зерттеулер ұлттық ғылыми орталығы, 050060, Алматы, Қазақстан

²Халықаралық білім беру корпорациясы, 050043, Алматы, Қазақстан

³Азаматтық қорғаныс және төтенше жағдайлар жөніндегі бүкілресейлік ғылыми-зерттеу институты 121352, Мәскеу, Ресей

⁴Әл-Фараби атындағы Қазақ ұлттық университеті, 050040, Алматы, Қазақстан

Андатпа. Сейсмикалық тәуекелді сенімді бағалау өңірлік құрылыс тәжірибесі мен халықаралық тәсілдерді ескере отырып, құрылыс нысандары туралы мәліметтерді жүйелеуді талап етеді. Қазақстандағы сейсмикалық тәуекелді бағалау үшін құрылыс қорының өңірлік инженерлік жіктелімі ұсынылды. Эмпирикалық негіз ретінде 2017-2018 жылдардағы тексерулерді қамтитын және 2024 жылы жүргізілген жұмыстардың нәтижелерімен толықтырылған Алматы қаласындағы нысандарды паспорттау деректері пайдаланылды. Құрылыс қоры туралы мәліметтер, нормативтік құжаттар және жер сілкіністерінің салдарын инженерлік зерттеу нәтижелері қолданылды. Санаттар тұрғын және қоғамдық ғимараттарды, өнеркәсіптік нысандарды және арнайы инженерлік құрылыстарды қамтитын 22 атаудан тұратын иерархиялық құрылымға жүйеленді. Жұмыстың ғылыми жаңалығы конструктивтік сипаттамалар мен жобалық сейсмикаға төзімділікті ескере отырып, өңірлік санаттарды формалдандырудан, сондай-ақ конструктивтік жүйелері аралас, реконструкцияланған және құжаттамасы жеткіліксіз нысандарды жіктеу ережелерін әзірлеуден тұрады. Жобада сейсмикаға қарсы шаралардың көзделмегені расталған жағдайлар жобалық сейсмикаға төзімділігі белгісіз жағдайлардан ажыратылды. Көтергіш конструкциялардың материалы мен конструктивтік жүйе конструктивтік типті анықтау үшін пайдаланылады; техникалық жай-күйі, құрылыс кезеңі, күшейту және сейсмикалық оқшаулау қосымша ескеріледі. EMS-98, HAZUS, RISK-UE және GEM Building Taxopotu жүйелерімен салыстыру жүргізілді. ГОСТ Р 57546-2017 сейсмикалық қарқындылықты және құрылыс нысандарының зақымдануын бағалау тәсілі ретінде қарастырылды. Жіктеме қалалық аумақтардағы құрылыс нысандарының паспорттық мәліметтерін біріздендіруге, ГАЖ негізіндегі экспозиция дерекқорларын қалыптастыруға және осалдық модельдерін таңдауға арналған. Алматы бойынша деректер елдің құрылыс қорының конструктивтік әртүрлілігін сипаттап, ұсынылған жіктемені Қазақстанның басқа өңірлерінде қолдану мүмкіндігін көрсетеді.

Түйінді сөздер: сейсмикалық тәуекел, құрылыс қоры, ғимараттар мен құрылыстардың жіктелімі, сейсмикалық осалдық.

*Автор-корреспондент

Наталия Суровцева, e-mail: natali.s71@mail.ru

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НАУЧНАЯ СТАТЬЯ

РЕГИОНАЛЬНАЯ КЛАССИФИКАЦИЯ ЗДАНИЙ И СООРУЖЕНИЙ ДЛЯ ОЦЕНКИ СЕЙСМИЧЕСКОГО РИСКА В КАЗАХСТАНЕ

Н.В. Суровцева^{1,2*}, Т. Абаканов², В.А. Лапин¹, Г.М. Нигметов³,
С.А. Хохлов⁴, А.Т Агишев⁴, К.А. Турекулова¹, А.Ф. Рамазанов¹

¹Национальный научный центр сейсмологических наблюдений и исследований, 050060, Алматы, Казахстан

²Международная образовательная корпорация, 050043, Алматы, Казахстан

³Всероссийский научно-исследовательский институт по проблемам гражданской обороны и чрезвычайных ситуаций, 121352, Москва, Россия

⁴Казахский национальный университет имени аль-Фараби, 050040, Алматы, Казахстан

Аннотация. Надёжная оценка сейсмического риска требует систематизации сведений об объектах строительства с учётом региональной строительной практики и международных подходов. Предложена региональная инженерная классификация строительного фонда для оценки сейсмического риска в Казахстане. Эмпирической основой послужили данные паспортизации Алматы, объединяющие обследования 2017–2018 годов, дополненные проведенными работами в 2024 году. Были использованы данные о строительном фонде, нормативные документы и инженерные исследования последствий землетрясений. Категории были систематизированы в иерархическую структуру из 22 наименований, охватывающую жилые и общественные здания, промышленные объекты и специальные инженерные сооружения. Научная новизна состоит в формализации региональных категорий с учётом конструктивных характеристик и проектной сейсмостойкости, а также в разработке правил классификации смешанных, реконструированных и недостаточно документированных объектов. Разграничены установленное отсутствие антисейсмических мероприятий в проекте и неизвестная проектная сейсмостойкость. Материал несущих конструкций и конструктивная система используются для определения конструктивного типа; техническое состояние, период строительства, усиление и сейсмоизоляция учитываются дополнительно. Выполнено сопоставление с EMS-98, HAZUS, RISK-UE и GEM Building Taxonomy. ГОСТ Р 57546-2017 рассмотрен как подход к оценке интенсивности и повреждений объектов строительства. Классификация предназначена для унификации паспортных сведений застройки городских территорий, формирования ГИС-баз экспозиции и выбора моделей уязвимости. Данные Алматы характеризуют конструктивное разнообразие строительного фонда страны, что определяет возможность применения предложенной классификации в других регионах Казахстана.

Ключевые слова: сейсмический риск, строительный фонд, классификация зданий и сооружений, сейсмическая уязвимость.

*Автор-корреспондент
Наталия Суровцева, e-mail: natali.s71@mail.ru

1 INTRODUCTION

Earthquakes are among the most hazardous natural phenomena and can cause loss of life, severe damage to buildings and structures, disruption of critical infrastructure, and major economic losses. With increasing urbanization and concentration of population and assets in seismically active regions, the reliability of earthquake consequence assessment depends not only on seismic hazard but also on the quality of information on the building stock and its seismic vulnerability [1-3].

A key stage in seismic risk assessment is the engineering characterization of the existing building stock. Buildings differing in load-bearing material, structural system, construction period, seismic design provisions, and technical condition may respond differently to the same level of seismic intensity. Therefore, combining structurally heterogeneous assets within a single analytical group can increase uncertainty in estimates of damage and losses [3, 4].

Building classification systems are used to organize exposure information, link structural types to vulnerability and fragility models, and support quantitative seismic risk assessment [4, 5]. International and reference approaches considered in this study include EMS-98, HAZUS, RISK-UE, and the GEM Building Taxonomy [4, 6-8]. GOST R 57546-2017 was considered separately as a framework for macroseismic intensity and earthquake-damage assessment [9]. These approaches differ in purpose and level of detail: EMS-98 is mainly intended for macroseismic assessment, HAZUS reflects U.S. construction practice, RISK-UE was developed for European urban seismic-risk studies, while GEM uses a flexible multi-attribute description of buildings. Their direct application may therefore require adaptation to regional building-stock characteristics [4, 6-10].

Independent exposure studies provide methodological precedents for this regional adaptation. The GEM Building Taxonomy separates material, lateral-load-resisting system, height, occupancy, and other attributes [11]. Its GED4ALL extension also distinguishes building and infrastructure exposure [12]. The European exposure model combines residential, industrial, and commercial building classes with information on occupants and replacement costs [13]. For Central Asia, Scaini et al. [14] integrate regional information with national census and construction data. Together, these studies support retaining regional construction knowledge within an explicit attribute-based exposure framework, while avoiding an automatic equivalence between a regional category and a vulnerability class.

This issue is particularly relevant for Kazakhstan, where the building stock was formed over different historical and regulatory periods. Buildings constructed without specific seismic provisions coexist with objects designed for seismic intensities of 7, 8, and 9 points. Even within the same general structural system, differences in detailing, construction practice, age, and regulatory requirements may result in different seismic performance [15, 16].

The structural diversity of the national building stock is particularly evident in Almaty, where detailed building-passportization data are available. The city includes masonry, frame, large-panel, monolithic reinforced-concrete, and other structural systems formed during different stages of urban development [17–19]. This makes the Almaty dataset a useful empirical basis for identifying the range and diversity of structural systems relevant to the proposed classification. However, the quantitative composition of the Almaty building stock is not assumed to be statistically representative of Kazakhstan as a whole; regional proportions of structural types should be determined independently for each territory.

Another important feature of Kazakhstan's built environment is the presence of industrial buildings and special engineering structures, including silos, cooling towers, chimneys, tanks, gas holders, and water towers. Their inclusion requires asset-specific engineering descriptions; the distinction between building and infrastructure exposure is also adopted in GED4ALL [12]. Regional exposure and seismic-risk models have already been developed for Central Asia [20–22], demonstrating the feasibility of harmonizing building and population data. The present study addresses a complementary task: formalizing engineering categories used in Kazakhstan and defining the attributes needed to connect them with such exposure models.

Kazakhstan has a regulatory framework for earthquake-resistant construction, including SP RK

2.03-30-2017, which distinguishes structural systems and establishes requirements for seismic design and safety assessment. However, these regulatory categories are intended primarily for design purposes and do not constitute a unified national taxonomy for seismic exposure, vulnerability, and risk modelling.

The present study addresses this gap by proposing a classification of buildings and engineering structures specifically intended for subsequent seismic risk assessment in Kazakhstan. The classification is not a modification of an existing national seismic-risk taxonomy but is developed by integrating national seismic design regulations, Almaty building-passportization data, engineering studies, post-earthquake observations, and international classification principles.

A key methodological feature is the separation of structural type from additional vulnerability-related attributes. In particular, design seismic resistance is treated as an independent characteristic rather than as a direct vulnerability class. Construction period, technical condition, reconstruction, strengthening, and seismic isolation can be considered as additional modifiers.

The scientific contribution of this study lies in the development of a hierarchical engineering classification framework for seismic-risk assessment in Kazakhstan that integrates residential and public buildings, industrial buildings, and special engineering structures, establishes reproducible structural-type assignment rules, and enables comparison with GEM, EMS-98, HAZUS, RISK-UE, and GOST R 57546-2017.

The aim of this study is to develop a classification of buildings and engineering structures for the formation of exposure models and subsequent seismic risk assessment in Kazakhstan, using the structurally diverse building stock of Almaty as the principal empirical basis and supplementing it with national seismic design regulations, engineering evidence, and international classification principles. To achieve this aim, the study identifies the principal classification attributes, develops a hierarchical engineering framework, formulates structural-category assignment rules, separates design seismic resistance from structural type, assesses the applicability and engineering consistency of the proposed framework, and compares it with established international classification approaches.

2 MATERIALS AND METHODS

2.1 Data sources and characteristics of the building stock

The proposed classification was developed using several complementary groups of data describing the structural composition of Kazakhstan's building stock, the evolution of seismic design requirements, and the observed performance of buildings and engineering structures under seismic action. According to official statistics, the housing stock of the Republic of Kazakhstan comprises more than 2.56 million residential buildings with a total floor area exceeding 434 million m² [23]. The national building stock was formed during different historical and regulatory periods and therefore includes a wide range of construction materials, structural systems, and seismic design solutions relevant to exposure and seismic risk assessment.

The principal empirical information was derived from the large-scale passportization of buildings and structures in Almaty [17-19, 24, 25]. The published dataset used in Table 1 combines the 2017-2018 inventory of 8,171 multi-apartment residential buildings with the 2024 passportization additions covering 1,777 records [17, Tables 1-3]. Thus, the aggregate dataset contains 9,948 records and incorporates information collected through the 2024 update; the source was published in 2025.

The dataset comprises large-panel, brick and masonry, frame, monolithic reinforced-concrete, timber, and less common structural systems, together with three records listed as unfinished in the source. Table 1 reproduces the published aggregate structural composition. It represents the combined survey database, rather than a new census of the city's building stock in 2026.

The Almaty dataset was used primarily to identify the range and relative diversity of structural systems represented in the existing urban building stock and to assess the applicability of the proposed classification framework. However, its quantitative structural composition is not assumed to be statistically representative of Kazakhstan as a whole. The proportions presented in Table 1 characterize the available Almaty residential dataset and should not be extrapolated directly to other

regions. When the proposed classification is applied elsewhere in Kazakhstan, the prevalence of individual engineering categories should be established using corresponding regional inventory data.

Table 1 – Structural composition of the Almaty multi-apartment residential passportization dataset from the 2017–2018 inventory and 2024 additions [17].

Structural group	Number of buildings	Share, %
Large-panel	2666	26.8
Brick and masonry	1645	16.5
Frame	2155	21.7
Monolithic reinforced-concrete	2822	28.4
Timber	639	6.4
Metal-frame	18	0.2
Unfinished / structurally incomplete	3	<0.1
Total	9,948	100.0

A second group of sources comprises engineering-seismological surveys of the consequences of strong earthquakes summarized by Abakanov et al. [26]. These materials provide information on the observed seismic response and characteristic damage of different structural systems and were used as engineering evidence supporting the selection and interpretation of the proposed classification attributes and categories.

A third group comprises current and historical regulatory documents of the Republic of Kazakhstan and the former USSR governing construction in seismic regions [15, 16]. These documents were analysed to identify structural systems recognized in national seismic design practice and to trace the evolution of seismic design requirements. Particular attention was given to design seismic resistance (DSR), which is treated in the proposed framework as an independent attribute rather than as a direct measure of the actual seismic vulnerability of an existing asset.

Analytical, experimental, and survey-based studies of structural systems used in Kazakhstan were additionally considered [17-19, 24, 25, 27-32]. These sources provided supplementary information on the engineering significance of load-bearing material, structural system, construction period, dynamic characteristics, structural detailing, and technical condition.

Finally, EMS-98, HAZUS, RISK-UE, and the GEM Building Taxonomy were analysed to assess the compatibility of the proposed classification with established international approaches to seismic exposure and vulnerability modelling [4, 6-8, 11-13]. GOST R 57546-2017 [9] was considered separately as a framework for macroseismic intensity and earthquake-damage assessment. These approaches were not used to transfer foreign building types directly to Kazakhstan; rather, they provided a basis for comparing classification principles, levels of engineering detail, and the attributes required for subsequent interoperability with internationally recognized classification frameworks.

The sources serve distinct purposes. The regional publications document local inventories, construction practice, and experimental observations, whereas the independent international studies inform attribute selection and exposure-model interoperability. The source engineering classification is explicitly attributed below; its repeated use is not treated as independent validation of the proposed framework.

Taken together, these sources provide complementary information at national, urban, structural, regulatory, and international levels. National statistics characterize the overall scale of the building stock, while the Almaty passportization data provide the principal object-level empirical basis for identifying its structural diversity. Engineering-seismological observations, regulatory documents, and published studies support the engineering interpretation of the selected attributes, whereas international systems provide the basis for assessing interoperability. This combination of sources forms the methodological basis for the proposed classification of buildings and engineering structures for subsequent seismic exposure and risk assessment in Kazakhstan.

The principal data sources and their roles in developing the proposed classification are summarized in Table 2.

Table 2 – Main data sources used to develop the proposed classification [Author's material]

Data source	Main information provided	Use in this study
Almaty building-passportization data	Object-level information on the existing building stock and structural systems	Identification of principal structural systems and assessment of the applicability of the proposed classification framework
National construction statistics	Scale and general characteristics of the building stock of Kazakhstan	General characterization of the national building stock and seismic exposure
Engineering-seismological earthquake surveys	Observed seismic response and characteristic damage of different structural systems	Engineering substantiation of the selected classification attributes and categories
Regulatory documents of Kazakhstan and the former USSR	Structural systems and evolution of seismic design requirements	Interpretation of structural characteristics and design seismic resistance (DSR)
Analytical, experimental, and survey-based studies	Behaviour and engineering characteristics of structural systems	Supplementary engineering substantiation of the selected classification attributes
EMS-98, HAZUS, RISK-UE, and GEM Building Taxonomy	International classification and seismic exposure/vulnerability frameworks	Comparison of classification principles, interoperability requirements, and level of engineering detail
GOST R 57546-2017	Macroseismic intensity and earthquake-damage assessment framework	Comparison of damage- and vulnerability-related principles

2.2 Selection of classification attributes

The proposed classification framework was developed using three principal classification attributes and one independent seismic-design attribute relevant to subsequent vulnerability assessment:

1. functional use;
2. material of load-bearing structures;
3. structural system;
4. design seismic resistance (DSR).

The principal classification attributes and their roles are summarized in Table 3.

Table 3 – Principal attributes of the proposed classification of buildings and engineering structures [Author's material]

Attribute	Role in the proposed classification	Examples
Functional use	Defines the upper classification level	Residential and public buildings; industrial buildings; special engineering structures
Material of load-bearing structures	Principal engineering attribute characterizing the material of the load-bearing system	Masonry; reinforced concrete; steel; timber; local earthen materials
Structural system	Principal attribute defining the mechanism of resistance to vertical and horizontal loads	Wall system; frame system; frame-wall system; large-panel system; volumetric-block system
Design seismic resistance (DSR)	Independent supplementary attribute characterizing the seismic design requirements applicable to the asset	NS; 7; 8; 9; UNK

The attributes were organized hierarchically according to their role in the classification. Functional use defines the upper classification level and distinguishes residential and public buildings, industrial buildings, and special engineering structures. Material of load-bearing structures and structural system represent the principal engineering attributes used to identify the structural type of an asset.

Design seismic resistance (DSR) is treated separately from the structural type. It characterizes the seismic design requirements applicable at the time of construction and is recorded as an additional attribute. The proposed values include construction without documented specific earthquake-resistant provisions (NS), design seismic resistance of 7, 8, or 9 points, and unknown design seismic resistance

(UNK). This distinction is important because the design seismic resistance level alone does not directly determine the actual seismic vulnerability of an existing asset.

The proposed framework therefore separates the characteristics defining the structural system from those modifying its expected seismic performance. Where additional information is available, construction period, number of storeys, technical condition, reconstruction or strengthening, and seismic isolation may be introduced as supplementary attributes. These characteristics do not change the principal structural type but can subsequently be used to refine vulnerability or fragility assignments.

This hierarchical approach reduces ambiguity in structural-category assignment and allows the classification to be applied to datasets with different levels of detail. It also facilitates subsequent interoperability with international classification systems and supports its use in seismic exposure and vulnerability modelling.

Where available, additional attributes such as construction period, number of storeys, technical condition, reconstruction or strengthening, and seismic isolation can be incorporated into the exposure database to provide a more detailed characterization of seismic vulnerability.

2.3 Methodology for developing the proposed classification

The proposed classification was developed through six sequential stages, as illustrated in Figure

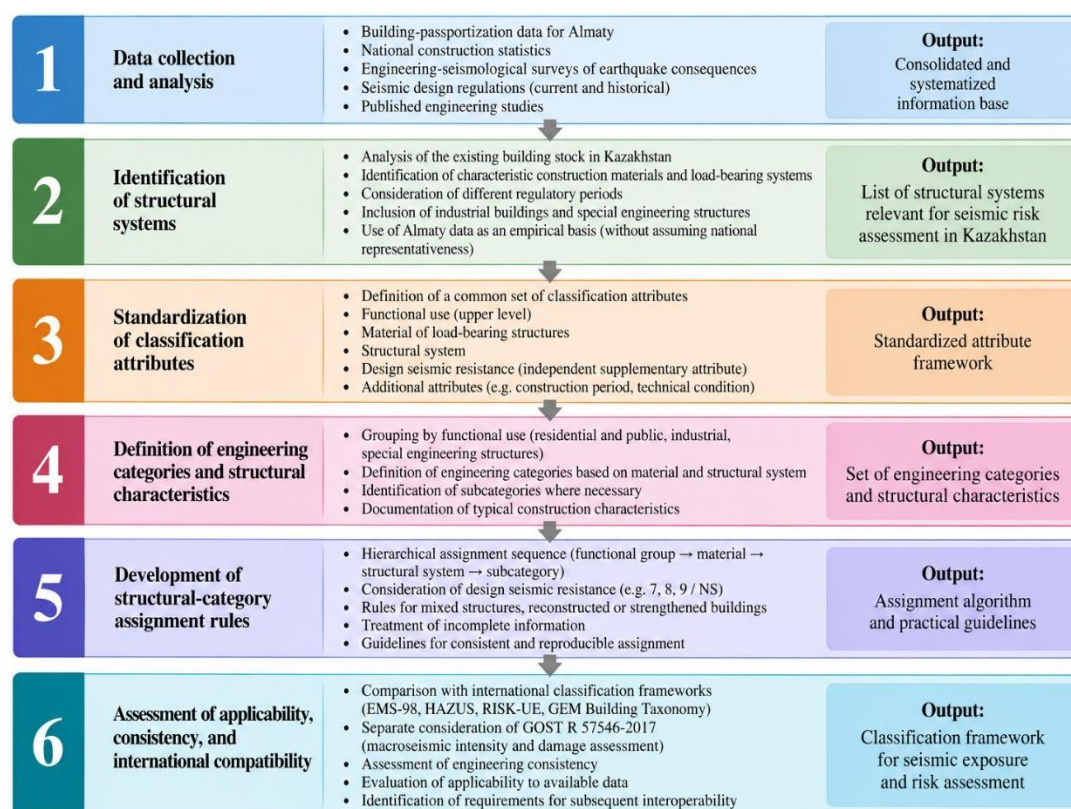


Figure 1 – Methodological framework for developing the proposed classification of buildings and engineering structures [Author's material]

At the first stage, the source information was collected and analysed. The data included building-passportization records for Almaty, national construction statistics, engineering-seismological surveys of earthquake consequences, current and historical seismic design regulations, and published engineering studies. EMS-98, HAZUS, RISK-UE, and the GEM Building Taxonomy were additionally considered as international reference frameworks, while GOST R 57546-2017 was considered as a framework for macroseismic intensity and earthquake-damage assessment.

At the second stage, the available building-stock data were analysed to identify the principal structural systems relevant to seismic exposure and risk assessment in Kazakhstan. Particular

attention was given to the diversity of construction materials and load-bearing systems, differences associated with historical and regulatory periods, and the inclusion of industrial buildings and special engineering structures. The Almaty passportization dataset was used as the principal object-level empirical basis for identifying the range of structural systems represented in the existing urban building stock. Its quantitative composition was not assumed to be representative of Kazakhstan as a whole.

At the third stage, the source information was standardized using a common set of classification attributes. Functional use was applied at the upper classification level, while load-bearing material and structural system were used as the principal attributes for structural identification. Design seismic resistance (DSR) was treated separately as an independent seismic-design attribute rather than as a criterion defining an independent structural type. Where available, construction period, number of storeys, technical condition, reconstruction or strengthening, and seismic isolation were considered supplementary attributes relevant to subsequent vulnerability assessment.

At the fourth stage, the engineering categories and their structural characteristics were defined. Buildings and engineering structures were organized according to their functional and structural characteristics, with separate consideration of residential and public buildings, industrial buildings and engineering structures, and special engineering structures. The engineering categories presented by Abakanov et al. [26] were used as the principal engineering basis, while their interpretation was refined to distinguish structural characteristics from DSR and other supplementary attributes. The original category designations were retained where appropriate to preserve traceability to the source engineering classification and accumulated engineering-seismological information.

At the fifth stage, a hierarchical procedure for assigning assets to the proposed framework was established. Functional group is identified first, followed by load-bearing material and structural system and, where sufficient information is available, structural subtype. DSR is recorded independently from the structural category. For mixed structural systems, classification is based on the system providing the principal resistance to horizontal seismic actions where this can be reliably identified. For reconstructed or strengthened buildings, the current structural system is used when the intervention has modified the principal load-resisting system; otherwise, reconstruction or strengthening is recorded as a supplementary attribute. Assets with insufficient information for reliable structural identification are retained as incomplete or uncertain records rather than being assigned to a category solely by assumption. Seismic isolation is recorded as a supplementary attribute rather than as a separate structural category.

At the sixth stage, the applicability, engineering consistency, and international compatibility of the proposed classification were assessed. The categories were compared with the structural systems represented in the Almaty passportization data to determine whether the principal systems identified in the available inventory could be represented within the proposed framework. Engineering consistency was assessed using seismic design regulations, published engineering studies, and available earthquake-damage observations. The proposed framework was also compared with EMS-98, HAZUS, RISK-UE, and GEM to identify similarities, differences, and the attributes required for interoperability with established seismic exposure and vulnerability approaches. This assessment was intended to evaluate the applicability and engineering consistency of the classification framework and does not constitute statistical validation of classification completeness or seismic vulnerability.

The resulting methodology provides a structured transition from heterogeneous national and object-level source information to an engineering classification framework suitable for seismic exposure modelling and subsequent vulnerability and seismic risk assessment in Kazakhstan.

2.4 Engineering assessment and comparative evaluation of the proposed classification

The proposed classification was evaluated using three complementary procedures: assessment of engineering consistency, comparison with available earthquake-damage evidence, and comparison with established international classification approaches.

First, engineering consistency was assessed with respect to the hierarchical attributes defined in Section 2.2 and the assignment procedure described in Section 2.3. Functional use defines the

upper classification level, while load-bearing material and structural system provide the principal characteristics for structural identification. Design seismic resistance (DSR) is recorded independently as NS, 7, 8, 9, or UNK. The applicability of the framework was additionally examined against the range of structural systems represented in the Almaty building-passportization data. This comparison was used to determine whether the principal structural systems identified in the available inventory could be represented within the proposed classification and was not intended as a statistical test of classification completeness or mutual exclusivity.

Second, the engineering relevance of the proposed categories was assessed using available post-earthquake observations [26] and analytical, experimental, and survey-based studies conducted in Kazakhstan [17-19, 29-32]. These sources were used to evaluate whether the selected classification attributes and structural distinctions were consistent with documented differences in seismic response and characteristic damage. They were considered engineering evidence rather than quantitative validation of seismic vulnerability.

Finally, the proposed classification was compared with GEM, EMS-98, HAZUS, and RISK-UE, while GOST R 57546-2017 was considered separately as a macroseismic intensity and earthquake-damage assessment framework [4, 6-9]. The comparison focused on classification principles, structural attributes, seismic-design information, level of engineering detail, and the representation of industrial buildings and special engineering structures. Particular attention was given to the attributes required for subsequent interoperability with established seismic exposure and vulnerability frameworks.

3 RESULTS AND DISCUSSION

3.1 Proposed regional classification of buildings and engineering structures

The proposed classification was developed using the engineering classification presented by Abakanov et al. [26] as its principal engineering basis, supplemented by building-passportization data, seismic design regulations, published engineering studies, and available post-earthquake observations. The purpose was to preserve the engineering information accumulated in national practice while formalizing it for seismic exposure modelling and subsequent seismic risk assessment in Kazakhstan. The contribution of the present study is the explicit separation of inherited category codes from structural descriptors and DSR, the formulation of assignment rules for incomplete and modified assets, and the demonstration of conditional correspondence with GEM attributes. The category names themselves are not presented as newly invented structural types.

The resulting classification comprises 22 engineering categories of buildings and structures (Figure 2 and Table 4). To maintain traceability to the source classification and accumulated earthquake-consequence data, the designations A, B, V, KK, KP, KMZh, PKO, SGBDT, PR, ChZR, NEGR, and VNB were retained. Their interpretation was clarified in accordance with the hierarchical classification principles adopted in this study.

The categories are organized into four groups: buildings without documented specific earthquake-resistant design provisions; buildings designed in accordance with seismic requirements; industrial buildings and engineering structures; and special engineering structures. Functional use defines the upper classification level, while load-bearing material and structural system provide the principal engineering characteristics for structural identification.

The A, B, and V categories were retained primarily to preserve compatibility with the source engineering classification and available earthquake-consequence observations described by the source classification. These broad categories are less structurally homogeneous than the categories of seismically designed buildings. In particular, category V includes several systems with different load-resisting mechanisms. Therefore, where object-level information is available, the specific load-bearing material and structural system are recorded as additional attributes for subsequent vulnerability modelling.

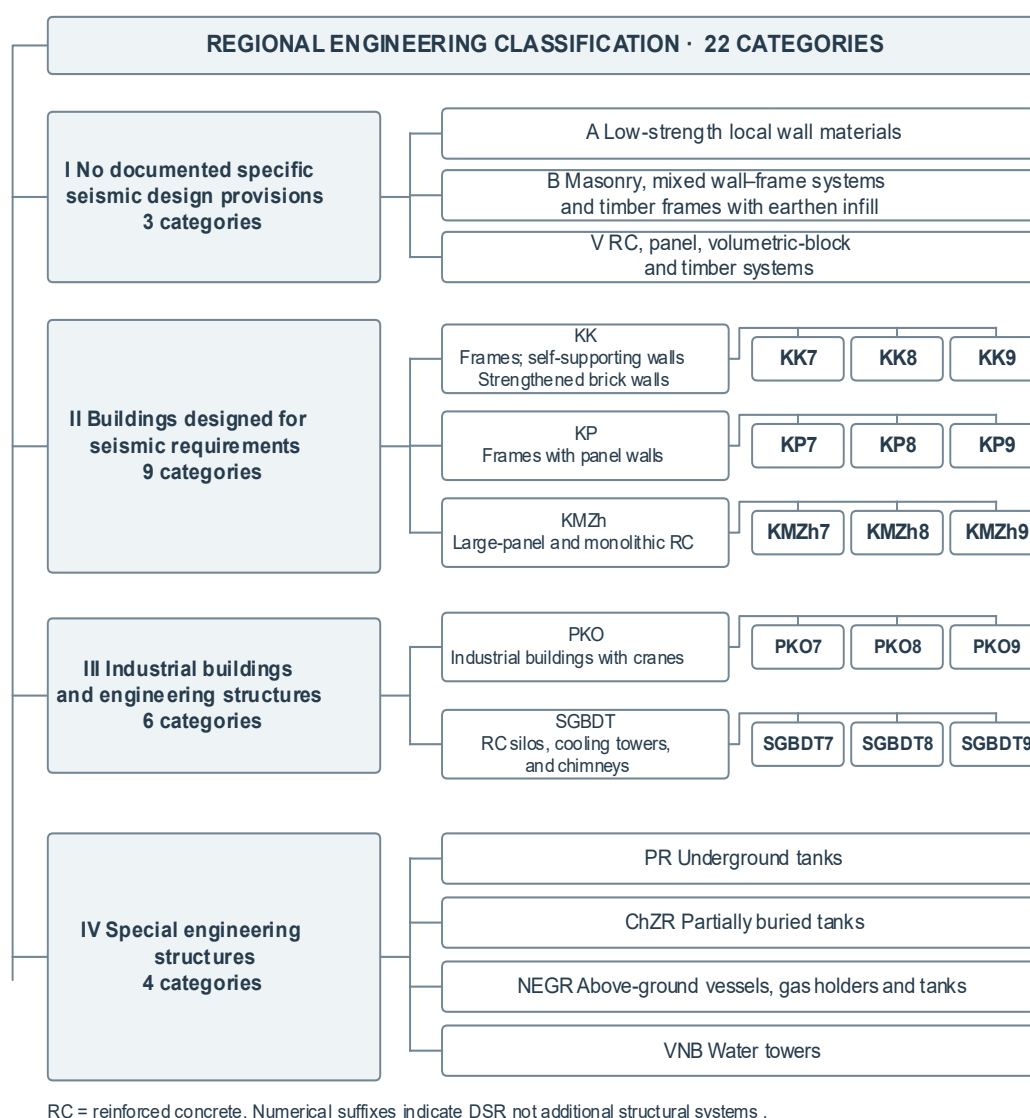


Figure 2 – Hierarchy of the 22 regional engineering categories listed in Table 4, based on [26]. DSR is recorded separately: NS for group I; 7, 8, or 9 for the coded variants; NS or 7 within PKO7 and SGBDT7; and the documented value or UNK for group IV. Full category definitions are given in Table 4.

For the KK, KP, and KMZh groups, differentiation by design seismic resistance of 7, 8, and 9 points was retained to preserve correspondence with the source classification and historical engineering data. In the proposed framework, however, the numerical suffix is interpreted as a design seismic resistance (DSR) attribute rather than as an independent structural characteristic. Thus, KK7, KK8, and KK9 represent the same principal structural group KK with different DSR levels; the same interpretation applies to KP7-KP9 and KMZh7-KMZh9.

DSR is retained because buildings belonging to the same structural group but designed for different seismic intensities may differ in member dimensions, reinforcement, joint detailing, and prescribed earthquake-resistant measures [15, 16]. Nevertheless, DSR does not directly determine the actual seismic vulnerability of an existing asset. Seismic performance may also depend on construction period, construction quality, technical condition, deterioration, reconstruction, strengthening, and other characteristics. These factors are therefore considered separately when assigning vulnerability or fragility models. The same principle is applied to industrial buildings with crane equipment (PKO) and reinforced-concrete silos, cooling towers, and chimneys (SGBDT). The source PKO7 and SGBDT7 categories included both construction without specific seismic design provisions and design for 7-point seismic intensity. In the proposed framework, these cases are distinguished analytically as DSR = NS and DSR = 7, respectively, while the original category codes

are retained for traceability to the source classification.

Table 4 – Proposed regional engineering classification categories for seismic risk assessment in Kazakhstan based on Abakanov et al. [26]

No.	Code	Principal structural / engineering characteristics	DSR
Buildings without documented specific earthquake-resistant design provisions			
1	A	Buildings with load-bearing walls of adobe, rubble stone, natural-stone masonry on low-strength mortar, and other low-strength local materials	NS
2	B	Buildings with load-bearing brick, dressed-stone, or concrete-block walls; mixed wall-frame systems with incomplete internal frames; timber-frame buildings with earthen infill	NS
3	V	Frame, large-panel, volumetric-block, and monolithic reinforced-concrete buildings; timber-frame, prefabricated-panel, and log buildings	NS
Buildings designed in accordance with seismic design requirements			
4	KK7	Reinforced-concrete or steel frames with self-supporting walls; brick-wall systems with structural seismic-strengthening elements	7
5	KK8	Same principal structural group as KK7	8
6	KK9	Same principal structural group as KK7	9
7	KP7	Reinforced-concrete or steel frames with panel walls	7
8	KP8	Same principal structural group as KP7	8
9	KP9	Same principal structural group as KP7	9
10	KMZh7	Large-panel and monolithic reinforced-concrete buildings	7
11	KMZh8	Same principal structural group as KMZh7	8
12	KMZh9	Same principal structural group as KMZh7	9
Industrial buildings and engineering structures			
13	PKO7	Industrial buildings with crane equipment	NS or 7*
14	PKO8	Industrial buildings with crane equipment	8
15	PKO9	Industrial buildings with crane equipment	9
16	SGBDT7	Reinforced-concrete silos, cooling towers, and chimneys	NS or 7*
17	SGBDT8	Reinforced-concrete silos, cooling towers, and chimneys	8
18	SGBDT9	Reinforced-concrete silos, cooling towers, and chimneys	9
Special engineering structures			
19	PR	Underground tanks	Recorded separately where available
20	ChZR	Partially buried tanks	Recorded separately where available
21	NEGR	Above-ground vessels, gas holders, and tanks	Recorded separately where available
22	VNB	Water towers	Recorded separately where available

**Note: DSR - design seismic resistance; NS - no documented specific earthquake-resistant design provisions. The original engineering codes and principal categories are retained from Abakanov et al. to ensure traceability to accumulated engineering-seismological data. In the proposed framework, the structural/engineering group and DSR are treated as separate analytical attributes; therefore, the numerical suffixes 7, 8, and 9 indicate DSR rather than independent structural systems. *In the source PKO7 and SGBDT7 categories, construction without specific seismic design provisions and design for 7-point seismic intensity were combined; in the proposed framework, these cases are distinguished analytically as DSR = NS and DSR = 7, respectively. For the broad A, B, and V categories, more detailed information on load-bearing material and structural system is recorded whenever available. For PR, ChZR, NEGR, and VNB, DSR is recorded separately where it can be established from design or technical documentation.*

Special engineering structures include underground tanks (PR), partially buried tanks (ChZR),

above-ground vessels, gas holders and tanks (NEGR), and water towers (VNB). For these categories, DSR is recorded as an additional attribute where it can be established from design or technical documentation. Their inclusion enables industrial and infrastructure assets to be incorporated into regional seismic exposure and risk models.

Thus, the proposed classification preserves the engineering basis and principal designations of Abakanov et al., while providing a more explicit structure for seismic-risk applications. The 22 engineering categories are used to organize exposure information, whereas structural characteristics, DSR, and supplementary attributes are distinguished analytically. Assignment to a category does not constitute a direct quantitative estimate of seismic vulnerability; rather, it provides a basis for forming analytical groups that can subsequently be linked to damage probability matrices, vulnerability functions, and fragility models.

3.2 Engineering interpretation and consistency with published evidence

The engineering interpretation of the classification is consistent with the attribute-based approach of GEM and the material- and structure-related distinctions used in EMS-98 [4, 6, 11]. These frameworks support recording the load-resisting system and relevant detailing separately. They do not, by themselves, validate the boundaries or vulnerability of the regional categories.

For the broad A, B, and V categories, earthquake-consequence data provide engineering support for distinguishing buildings according to their principal material and structural characteristics [26]. These categories are retained primarily for compatibility with the source engineering classification and accumulated damage observations, while more detailed information on load-bearing material and structural system is recorded where available.

For the KK, KP, and KMZh groups, design seismic resistance is considered an additional attribute relevant to subsequent vulnerability assessment. Buildings belonging to the same principal structural group but designed for different seismic intensities may differ in member dimensions, reinforcement, joint detailing, and prescribed earthquake-resistant measures [15, 16]. The same principle applies to the PKO and SGBDT engineering groups, while DSR is treated separately from the principal structural or engineering category.

Building-passportization data and published studies of Kazakhstan's building stock [17–19, 24, 25] provide additional support for considering structural system, design characteristics, construction period, and technical condition in exposure and vulnerability modelling. Industrial buildings and special engineering structures are considered separately because their structural configurations, loading conditions, and seismic response characteristics differ from those of conventional residential and public buildings.

Overall, the available engineering and earthquake-damage evidence supports the engineering relevance of the selected classification attributes and categories, but does not constitute statistical validation of seismic vulnerability for all 22 engineering categories. Quantitative validation requires sufficiently representative earthquake-damage datasets and the subsequent development and calibration of damage probability matrices, vulnerability functions, or fragility functions.

3.3 Comparison with international classification systems

The proposed regional classification was compared with EMS-98, HAZUS, RISK-UE, and the GEM Building Taxonomy to assess its compatibility with established approaches to seismic exposure and vulnerability modelling [4, 6–8]. GOST R 57546-2017 was considered separately as a framework for macroseismic intensity and earthquake-damage assessment [9], rather than as a building-stock taxonomy directly equivalent to the other systems. The results of the comparative analysis are presented in Table 5.

Table 5 – Comparison of the proposed regional classification with international classification and damage-assessment frameworks

Criterion	EMS-98	HAZUS	RISK-UE	GEM	GOST R 57546-2017	Proposed classification
Primary purpose	Macroseismic intensity and vulnerability assessment	Seismic loss and risk assessment	Urban seismic vulnerability and risk assessment	Multi-attribute building description	Macroseismic intensity and damage assessment	Regional exposure classification for subsequent seismic risk assessment
Classification principle	Vulnerability-related building typologies	Structural type + design level	Building typology + vulnerability class	Independent building attributes	Damage and vulnerability characteristics used in intensity assessment	Engineering categories + hierarchical attributes
Load-bearing material	Considered	Considered	Considered	Explicit attribute	Considered in damage assessment	Principal classification attribute
Structural system	Generalized	Detailed structural classes	Considered	Explicit attribute	Considered in damage assessment	Principal classification attribute
Seismic design	Indirect / generalized	Design-level dependent	Considered where relevant	Represented through attributes	Not a building-taxonomy design level	DSR recorded separately
Construction period / height / occupancy	Limited	Partly included	Used depending on typology	Explicitly representable	Not principal taxonomy attributes	Supplementary attributes
Regional specificity	European macroseismic context	Mainly U.S. building stock	European urban building stock	Flexible through attribute combinations	Macroseismic assessment framework	Reflects Kazakhstan engineering practice
Industrial and special engineering structures	Limited	Partly covered	Limited	Extensible through attributes	Not intended as exposure taxonomy	Separate engineering categories
Relation to vulnerability	Integral to macroseismic vulnerability assessment	Linked to fragility / damage functions	Linked to vulnerability functions	Taxonomy does not define vulnerability	Used for damage / intensity assessment	Classification precedes vulnerability / fragility assignment

The comparison indicates that these approaches differ in purpose, classification logic, and level of engineering detail. EMS-98 groups buildings primarily according to characteristics relevant to macroseismic vulnerability; HAZUS combines structural building types with seismic design levels; RISK-UE uses building typologies developed for vulnerability and seismic-risk assessment of European urban areas; and GEM provides a flexible multi-attribute description of buildings. The proposed classification, in contrast, retains engineering categories relevant to Kazakhstan while distinguishing structural characteristics from design seismic resistance and supplementary vulnerability-related attributes.

Among the considered systems, the GEM Building Taxonomy provides the most suitable basis for subsequent interoperability because its multi-attribute structure allows load-bearing material, lateral-load-resisting system, height, occupancy, construction period, and other characteristics to be represented separately. However, correspondence between the proposed regional categories and international taxonomies cannot always be established solely from the category code. This is particularly relevant for the broad A, B, and V categories and for industrial and special engineering

structures, for which additional information on load-bearing material, structural system, construction characteristics, and functional use may be required.

The broad regional categories do not imply a unique GEM class. Table 6 therefore demonstrates two conditional mappings using explicitly specified asset characteristics and GEM Building Taxonomy v2.0 terminology [11]. These are illustrative examples of the assignment procedure, not individual records claimed to have been extracted from the Almaty database.

For category B, the example is restricted to an unreinforced solid-brick wall building; the mixed systems also included in B require different GEM attributes. For KMZh9, the example is restricted to a cast-in-place reinforced-concrete wall building. Neither the wall system nor ductility can be inferred from KMZh9 alone. The material and load-resisting system must be checked independently in each principal horizontal direction.

Table 6 – Illustrative mapping of two regional categories to GEM Building Taxonomy v2.0 attributes [11]

Attribute	Example 1 Category B	Example 2 Category KMZh9
Specified asset	Two-storey multi-unit residential building with unreinforced solid fired-clay brick walls.	Ten-storey multi-unit residential building with cast-in-place reinforced-concrete load-bearing walls; documented DSR = 9.
Material and technology	MUR + CLBR Unreinforced masonry; solid fired-clay bricks.	CR + CIP Reinforced concrete; cast-in-place construction.
Lateral-load-resisting system	LWAL Wall system in both principal directions.	LWAL Wall system in both principal directions.
Number of storeys	HEX:2 Exactly two storeys above ground.	HEX:10 Exactly ten storeys above ground.
Occupancy	RES2 Multi-unit residential, unspecified subtype.	RES2 Multi-unit residential, unspecified subtype.
Regional DSR field	NS, retained outside the GEM attribute correspondence.	9, retained outside the GEM attribute correspondence.
Information still needed	Mortar, construction year, floors, roof, connections, irregularities, and condition.	Ductility and detailing, construction year, floors, roof, irregularities, and condition.

**Note: The codes are individual GEM v2.0 attribute values, not complete serialized taxonomy strings. Storey counts and occupancy are stipulated solely for these examples. Missing information remains unknown. No automatic conversion of DSR to a GEM ductility or code-compliance level is assumed.*

The examples demonstrate practical interoperability at the attribute level while preserving the original regional code in the exposure database. A complete mapping of all categories requires more detailed asset information, documented treatment of mixed systems, and testing against actual inventory records. Selection of vulnerability or fragility functions remains a separate step. Infrastructure categories should be compared with dedicated infrastructure taxonomies, such as GED4ALL, rather than forced into a building-only classification [12].

3.4 Practical application, limitations, and directions for further research

The proposed regional classification provides a structured framework for developing and updating building-stock databases for subsequent seismic vulnerability and risk assessment in Kazakhstan. Its coding system allows buildings and engineering structures to be organized according to engineering-relevant characteristics and provides a basis for their subsequent association with appropriate damage probability matrices, vulnerability functions, and fragility models.

Potential applications include building passportization and inventory, GIS-based seismic exposure and risk modelling, earthquake-consequence scenario assessment, and identification of asset groups requiring more detailed investigation. The inclusion of industrial buildings and special

engineering structures extends the applicability of the classification beyond conventional residential and public building stocks. Compatibility with international approaches is supported by the attribute-based comparison presented in Section 3.3, with the GEM Building Taxonomy providing the most flexible basis for subsequent interoperability.

The proposed classification has several limitations. The available object-level data are concentrated primarily in Almaty; therefore, the distribution of structural categories observed in the Almaty building stock should not be directly extrapolated to Kazakhstan as a whole. Although the classification framework can be applied to other regions, the prevalence of individual categories and the possible presence of additional regional construction types should be established using local inventory data. Rare, mixed, reconstructed, and highly specialized structures may require additional attributes or further refinement of the assignment rules.

Further research should focus on the development and statistical validation of damage probability matrices, vulnerability functions, and fragility models for the proposed engineering categories using sufficiently representative earthquake-damage data. Particular attention should be given to quantifying the influence of design seismic resistance, construction period, technical condition, deterioration, reconstruction, and strengthening on expected damage. Further development of the framework should also include its application to building inventories from different regions of Kazakhstan, assessment of regional construction characteristics, and implementation of automated GIS procedures for structural-category assignment and seismic exposure modelling.

4 CONCLUSIONS

The following conclusions were drawn from the study:

1. The study provides a regional formalization of existing engineering categories for seismic exposure modelling in Kazakhstan. Its methodological contribution is the organization of accumulated construction knowledge into an explicit framework that preserves the connection between historical category codes and the information required for subsequent risk assessment.
2. Separating structural characteristics from design seismic resistance and supplementary vulnerability-related attributes clarifies the interpretation of regional categories. The proposed assignment rules provide a basis for documenting mixed, reconstructed, and incompletely described assets without treating category membership as a quantitative estimate of seismic vulnerability.
3. The two illustrative GEM examples demonstrate how regional category descriptions can be associated with internationally defined building attributes when sufficient object-level information is available. They identify the additional data required for interoperability and show that regional category codes alone are insufficient for complete GEM mapping or direct assignment of vulnerability models.
4. The proposed framework can support the preparation of passportization forms, the harmonization of building and infrastructure inventories, and the development of GIS-based exposure databases. Its practical value lies in structuring engineering information for subsequent vulnerability modelling, earthquake-loss assessment, and identification of assets requiring more detailed investigation.
5. The Almaty passportization data provide an empirical basis for identifying structural diversity, while nationwide applicability requires evaluation using inventories from other regions. Further research should assess the consistency of category assignments and develop, calibrate, and independently validate damage probability matrices, vulnerability functions, and fragility models using appropriate engineering and earthquake-damage data.

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AUTHOR CONTRIBUTIONS

N.V. Surovtseva – Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft.

T. Abakanov – Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft.

V.A. Lapin – Supervision, Validation, Writing – Review & Editing.

G.M. Nigmatov – Supervision, Validation, Writing – Review & Editing.

S.A. Khokhlov – Calculations, Formal Analysis, Formatting, Translation

A.T. Agishev – Calculations, Formal Analysis, Formatting, Translation

K.A. Turekulova – Data preparation, Formal Analysis

A.F. Ramazanov – Data preparation, Formal Analysis

INFORMATION ABOUT THE AUTHORS

- N.V. Surovtseva
- Master, Leading Researcher, National Scientific Center for Seismological Observations and Research, PhD student
- School of Construction, International Educational Corporation
- Almaty, Kazakhstan
- natali.s71@mail.ru
- <https://orcid.org/0009-0004-0782-400X>
- T. Abakanov
- Professor, Doctor of Technical Sciences
- School of Construction, International Educational Corporation
- Almaty, Kazakhstan
- tabakanov@mail.ru
- <https://orcid.org/0000-0003-1680-6458>
- V.A. Lapin
- Candidate of Technical Sciences, Head of Laboratory
- National Scientific Center for Seismological Observations and Research
- Almaty, Kazakhstan
- lapin_1956@list.ru
- <https://orcid.org/0000-0002-1669-5332>

- G.M. Nigmatov
- Candidate of Technical Sciences, Leading Researcher, All-Russian Research Institute for Civil Defense and Emergencies
- Moscow, Russia
- tagirmaks@mail.ru
- <https://orcid.org/0000-0001-8138-332X>

- S.A. Khokhlov
- PhD
- Al-Farabi Kazakh National University
- Almaty, Kazakhstan
- skhokh88@gmail.com
- <https://orcid.org/0000-0001-5163-508X>

- A.T. Agishev
- PhD
- Al-Farabi Kazakh National University
- Almaty, Kazakhstan
- aldiyar.agishev@gmail.com
- <https://orcid.org/0000-0001-9788-7485>

- K.A. Turekulova
- Master, Researcher
- National Scientific Center for Seismological Observations and Research
- Almaty, Kazakhstan
- kulyanda007@gmail.com
- <https://orcid.org/0000-0001-9709-6413>

- A.F. Ramazanov
- Senior Researcher
- National Scientific Center for Seismological Observations and Research
- Almaty, Kazakhstan
- ramazanov.abay75@mail.ru
- <https://orcid.org/0009-0009-9967-0381>

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