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HOW MUCH OF KAZAKHSTAN'S URBAN BUILT STOCK PREDATES ITS SEISMIC CODES, AND WHERE DOES THAT STOCK SIT RELATIVE TO HAZARD?

Abstract: Kazakhstan introduced modern seismic design requirements in 1982, revised them in 2006 and replaced them with a Eurocode-harmonised code in 2017, yet no published study reports how much of the country's present urban built-up area was laid down before those rules existed, or how that older stock is distributed across seismic hazard. This study answers both questions for all 32 Kazakhstani urban centres using only open global data: the European Commission's GHS-AGE R2025A product, which records the epoch in which each 100 m cell first became built-up, masked by the GHS Urban Centre Database polygons, crossed with peak ground acceleration from the Global Earthquake Model hazard map and with the database's own macroseismic intensity classes. Of 180,745 hectares of urban built-up area, 47.9 per cent dates from before 1980 and 58.5 per cent from before 1990. Nine centres sit at a peak ground acceleration of 0.15 g or above; they hold 37.4 per cent of the national urban built-up area and 29.2 per cent of the pre-1980 stock. Exposure, defined as pre-code area multiplied by hazard, is extremely concentrated: the top three centres account for 79.1 per cent of the national total and Almaty alone for 61 per cent, 5.2 times the next city. The relationship between hazard and the age of the stock runs in the opposite direction to intuition: across the 32 centres a higher hazard is associated with a *lower* pre-1980 share (Spearman -0.53 ; regression coefficient on log hazard -0.028 , $p = 0.002$, controlling for city size), because the aseismic northern cities are the oldest by share while the high-hazard south has been rebuilt fastest. The practical implication is that a national seismic-retrofit priority cannot be set from either variable alone: the stock that is both old and shaken is a small, identifiable set of places, led by Almaty.

Keywords: seismic risk; built environment; construction era; Kazakhstan; remote sensing; GHS-AGE; urban exposure

Introduction

Shymkent is an old city, and it has many old apartment blocks that may not withstand a strong earthquake. The district where my grandparents live is literally called the Old Town. Many of its private houses are now being demolished and replaced by new residential complexes. Near my school there is a residential complex where the walls are visibly crumbling and there are large cracks, which worries me for the people who live there and for everyone who walks past. At the same time new blocks are going up in the city centre, such as Turan, Asar 2 and Nursat 2.

An earthquake does not damage a city uniformly. What it damages depends on how the buildings were designed, and that in turn depends on when they were built, because seismic design requirements change over time and apply only to what is built after them. Kazakhstan's

requirements have three dates. The Soviet code SNiP II-7-81, *Construction in seismic regions*, came into force on 1 January 1982. It was replaced for independent Kazakhstan by SNiP RK 2.03-30-2006, and that in turn by SP RK 2.03-30-2017, *Construction in seismic zones*, in force from 20 December 2017 and harmonised with Eurocode 8. Everything standing today that was built before 1982 was therefore designed to a weaker standard than everything built after it, and in many cases to no explicit seismic standard at all.

The hazard itself is unevenly distributed. The south-east of the country, along the Tian Shan front, carries peak ground accelerations above 0.4 g, comparable to the most seismically active parts of Central Asia, while the northern and western plains are effectively aseismic. Almaty, the largest city, sits in the highest-hazard zone; Astana, the capital, does not.

Both facts are known. What has not been published is the intersection: how much of the built-up area of each Kazakhstani city dates from before the codes, and whether the cities with the most pre-code construction are the cities that shake. That intersection is what determines where retrofit money would do most good, and it can now be estimated without a single field survey, because the European Commission's Joint Research Centre publishes a global satellite-derived product recording the epoch in which every 100 m cell first became built-up, and the Global Earthquake Model publishes a global hazard map on a comparable grid.

This study crosses those two products for all 32 Kazakhstani urban centres and asks three questions. What share of the present urban built stock predates the 1982 code? How is that pre-code stock distributed across hazard, and which cities concentrate it? And does the age of a city's stock relate to its hazard at all, once city size is accounted for?

Materials and Methods

Unit of analysis. The 32 Kazakhstani urban centres defined by the GHS Urban Centre Database R2024A (GHS-UCDB V1.2). The urban centre, rather than the administrative city boundary, is used because it is defined consistently worldwide from population and built-up density, so the comparison between cities does not depend on where an administrative line happens to fall. Each centre carries a population for 2025 and a macroseismic intensity class from the same database.

Construction era. GHS-AGE R2025A at 100 m resolution records, for every built-up cell, the five-year epoch in which it first became built-up, from before 1975 through 2015–2020. Each cell is one hectare. The product was masked by each urban-centre polygon and the cells tallied by epoch class, giving for every city the built-up area in each era. Four era bands are used, mapped onto Kazakhstan's code dates at the nearest class boundary: pre-code (before 1980, approximating the 1982 code), Soviet-code era (1980–2005), first Kazakh code (2005–2015, approximating 2006–2017) and Eurocode-based (2015–2020, approximating 2018 onward). The mapping is imperfect by up to two years at each boundary because the satellite epochs do not fall on the code years; a sensitivity analysis shifting every boundary one class later is reported.

Hazard. Peak ground acceleration with a 10 per cent probability of exceedance in 50 years, on rock, from the Global Earthquake Model global seismic hazard map v2023.1, averaged over each urban-centre polygon. The database's macroseismic intensity class is carried alongside as an ordinal check. Almaty is the only Kazakhstani centre that the database splits across two intensity classes, 7 and 8, with 1.09 million residents in the lower and 1.22 million in the higher.

Measures. For each city: total built-up area in hectares; the share of that area in each era band; and an exposure index defined as pre-code built-up area multiplied by hazard, $E = A_{\text{pre1980}} \times \text{PGA}$, in hectare-g. The index is deliberately simple and is not a loss estimate: it

is a ranking device that answers "where is there the most old building in the places that shake hardest".

Statistics. The association between hazard and the age of the stock is reported three ways: Pearson and Spearman correlations between PGA and the pre-1980 share, and an ordinary-least-squares regression of the pre-1980 share on log hazard and log population with heteroskedasticity-robust (HC1) standard errors. With $n = 32$ the regression is reported as a descriptive association, not as a causal estimate, and the rank correlation is given because it does not assume linearity.

Decision rules, fixed before the analysis was run. Exposure is called "concentrated" only if the top three centres hold at least half of the national total. The hazard-versus-age relationship is claimed only if the regression coefficient on log hazard and the Spearman correlation are both significant at 5 per cent and agree in sign; otherwise it is reported as no association.

What is not claimed. GHS-AGE records the surface age of built-up land, not the structural type, material or code compliance of any building; the paper therefore speaks of "built-up surface dating from era X", never of "buildings that violate code Y". The product records first appearance, so demolition and replacement on the same footprint are invisible and the pre-code share is, if anything, an overestimate of what physically stands from that era. The GEM hazard grid is coarse relative to a city, so within-city variation is captured only through the UCDB two-class split for Almaty. Nothing after the product's last observed imagery, about 2018, is asserted.

Reproducibility. The per-city class tallies, the analysis script (Python, standard library only) and the full numerical output are released with this paper.

Results

The national picture. The 32 urban centres hold 180,745 hectares of built-up area. Of that, 47.9 per cent dates from before 1980 and 58.5 per cent from before 1990. Just under half of urban Kazakhstan, by surface, therefore predates the first modern seismic code.

Where the hazard is. Nine of the 32 centres sit at a polygon-mean peak ground acceleration of 0.15 g or above. Together they hold 37.4 per cent of the national urban built-up area and 29.2 per cent of the national pre-1980 stock. The remaining 23 centres, including the capital, are at or below that threshold, and the 22 centres below 0.05 g are effectively aseismic.

Table 1 – The ten Kazakhstani urban centres with the highest seismic exposure of pre-code built stock, 2026. Exposure index = pre-1980 built-up area $\times$ peak ground acceleration.

Rank	Urban centre	Built-up, ha	Pre-1980 share, %	PGA, g	Exposure index, ha·g	Population 2025
1	Almaty	30,313	43.8	0.399	5,300	2,315,538
2	Shymkent	21,598	28.5	0.165	1,017	1,239,663
3	Taraz	8,675	56.2	0.106	517	234,775
4	Taldykorgan	3,609	43.2	0.223	347	146,374
5	Esik	1,408	40.8	0.437	251	53,719
6	Zharkent	1,683	58.5	0.250	246	54,229
7	Sayram	2,472	29.4	0.167	122	71,026
8	Aqsukent	2,954	23.9	0.163	115	65,489
9	Jetisay	1,303	49.8	0.171	111	61,507
10	Ust-Kamenogorsk	5,516	54.6	0.036	108	240,226

Exposure is concentrated, and it is concentrated in one city. The national exposure total is 8,643 hectare-g. The top three centres hold 79.1 per cent of it and the top five 86.0 per cent, so the pre-registered threshold for "concentrated" is passed comfortably. Almaty alone accounts for 61 per cent, an exposure index 5.2 times that of Shymkent, the next city. Almaty holds 13,283 hectares of pre-1980 built-up area, 15.3 per cent of the national pre-1980 stock, and it sits at the highest hazard of any large Kazakhstani city. No other city combines the two.

Age runs against hazard, not with it. Across the 32 centres, higher hazard is associated with a *lower* pre-1980 share. The Spearman correlation is -0.53 and the Pearson correlation -0.45 ; in the regression, the coefficient on log hazard is -0.028 ($p = 0.002$) while city size is irrelevant (log population, $p = 0.965$), with an R^2 of 0.28. Both pre-registered conditions are met and they agree in sign, so the association is reported as real. The mechanism is visible in the extremes: the nine high-hazard centres average 38.3 per cent pre-1980 stock, the 22 aseismic centres 54.8 per cent. The oldest cities by share are Kostanay (73.4 per cent), Oral (67.1), Kokshetau (67.0), Semey (65.4) and Atyrau (64.2), all of them in the aseismic north and west. The fastest-renewing large cities are Shymkent, where 38.7 per cent of the built-up area appeared after 2005, Aktau (36.7) and Astana (32.2).

Table 2 – The hazard-versus-age association under three definitions of the pre-code era. All specifications control for log population with HC1 robust standard errors, $n = 32$.

Specification	Coefficient on log PGA	p	Spearman	R^2
Pre-1980 share (baseline)	-0.0278	0.002	-0.53	0.28
Pre-1990 share	-0.0228	0.006	-0.49	0.24
Boundary shifted one class later (pre-1985)	-0.0234	0.003	-0.48	—

Sensitivity. Moving the era boundary one class later, to pre-1985, leaves the association intact (coefficient -0.023 , $p = 0.003$; Spearman -0.48), as does using the pre-1990 share instead (-0.023 , $p = 0.006$). The finding is therefore not an artefact of where the code year is mapped onto the satellite epochs.

Almaty split by intensity. Almaty is the single centre the database divides between intensity classes 7 and 8, with 1.22 million of its 2.32 million residents in the higher class. The city's overall pre-1980 share, 43.8 per cent, is above the average for high-hazard centres, and its absolute pre-code area exceeds that of the next nine high-hazard centres combined. Resolving the era composition of the two intensity bands separately requires the intensity polygons rather than the aggregate class counts and is the natural extension of this work.

Discussion

Half of urban Kazakhstan, by built surface, predates the country's first modern seismic code, and that fact alone says little about risk, because most of that old surface stands where the ground does not shake. The distribution matters more than the total, and the distribution turns out to be lopsided in two ways at once.

First, it is lopsided between cities. Three centres hold four-fifths of the national exposure and one city holds three-fifths of it. A national retrofit programme that treated all old building as equally urgent would spend most of its money in Kostanay, Oral and Semey, the cities with the oldest stock by share, where the hazard is close to zero. The exposure ranking points instead

at a short list led by Almaty, with Shymkent and Taraz behind it and several small southern towns, Esik and Zharkent among them, appearing far above their population weight because they are both old and close to the Tian Shan front.

Second, it is lopsided in a direction that is easy to get backwards. The high-hazard south is not the country's oldest built environment; it is among its newest, because Shymkent, Taldykorgan and Turkestan have been rebuilt and extended rapidly since 2005, while the aseismic north has grown slowly and kept what it had. The negative association between hazard and age is therefore not a comforting result. It means that the aggregate national statistic, "half the stock is pre-code", is a poor guide to anything, and that the cities which most need attention are the exceptions to it, above all Almaty, which combines the highest hazard among large cities with an absolute pre-code area unmatched anywhere in the country.

The limits of the method should be read alongside these results. The satellite product sees the first appearance of built-up surface, not buildings; a 1960s footprint rebuilt in 2015 still counts as pre-1980, which biases the pre-code share upward and makes this an upper bound rather than a point estimate. Hazard is taken as a single value per city from a grid coarser than a city, so within-city differences, which are exactly what a municipal engineer needs, are beyond this design except for the Almaty split. And code dates are mapped to five-year epochs, so the boundary is approximate by up to two years, though the sensitivity analysis shows the conclusion does not hinge on it.

The epoch assignment was not checked against dated buildings on the ground. Comparing the satellite epoch of named buildings with their known construction years is the most direct next test of the upper-bound bias described above, and is left for further work.

Conclusion

Across Kazakhstan's 32 urban centres, 47.9 per cent of the 180,745 hectares of built-up area predates the 1982 seismic code and 58.5 per cent predates 1990. Nine centres sit at a peak ground acceleration of 0.15 g or above and hold 29.2 per cent of that pre-code stock. Exposure, measured as pre-code area times hazard, is concentrated to an unusual degree: 79.1 per cent of the national total in three cities and 61 per cent in Almaty alone, 5.2 times the next city. Across cities, hazard and the age of the stock are negatively associated (Spearman -0.53 ; -0.028 on log hazard, $p = 0.002$), because the aseismic north is the oldest by share while the high-hazard south has renewed fastest, and this holds under every alternative definition of the pre-code era tested. The policy reading is narrow and, for that reason, usable: the question "where is Kazakhstan's seismically exposed old building" has a short answer with a named list at the top of it, and that list can be produced for any country from open global data in a day, without a field survey.

Acknowledgments

Built-up epoch data are published by the European Commission Joint Research Centre (GHS-AGE R2025A, GHS Urban Centre Database R2024A) and the hazard map by the Global Earthquake Model Foundation (Global Seismic Hazard Map v2023.1); both are openly licensed and available to any reader. The analysis script and the full numerical output are released with this paper. The author declares no conflict of interest and received no funding for this work.

Use of AI tools. The author used generative AI tools to help write the analysis code, run the computations and edit the English text. The research direction, the observations of Shymkent in the author's own account and the choice of question are the author's. Every number reported here is produced by the released analysis script from the published JRC and GEM data; none was generated by a language model.

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ШЕКАРАСЫЗ ФИЗИКА: ӘР ЕЛДЕГІ ФИЗИКАЛЫҚ БІЛІМДІ САЛЫСТЫРУ 347