THE INTERNATIONAL CONFERENCE ON THE 120TH ANNIVERSARY OF THE BULNAY EARTHQUAKE: ADVANCES IN ASTRONOMY AND GEOPHYSICS

SEISMIC VULNERABILITY ASSESSMENT OF BUILDINGS AND ITS RELATION TO GEOLOGICAL CONDITIONS: THE CASE OF BAYAN-ULGII PROVINCE

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Abstract

The aim of this study is to assess the seismic vulnerability of the building stock in Bayan-Ulgii Province in relation to geological (soil) conditions and to determine the potential levels of damage under strong earthquake scenarios. The study covers a total of 445 buildings across 13 soums and 1 settlement of the province. A macroseismic vulnerability assessment based on the European Macroseismic Scale 1998 (EMS-98) and an index-based approach was applied. The seismic vulnerability index was determined by integrating structural characteristics, building age, construction quality, foundation type, and soil conditions, and was subsequently normalized. The mean damage grade was then calculated analytically for seismic intensities ranging from V to XII. The results indicate that the seismic vulnerability of buildings in the study area is generally moderate to high, and the mean damage grade increases following a logistic trend as earthquake intensity increases. In particular, wooden structures and old masonry buildings exhibit relatively high vulnerability. Furthermore, the widespread presence of loose (unconsolidated) sediments in Bayan-Ulgii Province contributes to seismic wave amplification, which may significantly influence building damage levels. The findings of this study are important for understanding the relationship between seismic vulnerability and geological conditions and can serve as a practical basis for earthquake risk reduction planning and structural strengthening measures.

Introduction

Earthquakes are among the most destructive natural hazards, causing significant impacts on human life, infrastructure, and socio-economic activities. Seismic risk is commonly defined by three components: hazard, exposure, and vulnerability. Building vulnerability represents the expected level of damage under a given earthquake intensity and is a key parameter in seismic risk assessment (Coburn & Spence, 1992). For regional-scale studies, vulnerability is often evaluated using simplified macroseismic approaches, such as the European Macroseismic Scale (EMS-98), which classifies buildings into vulnerability classes and enables damage estimation based on observed earthquake performance.

Bayan-Ulgii Province is located in the seismically active Altai–Sayan region of western Mongolia, where numerous active faults pose considerable earthquake hazards (Report, 2017). Previous studies indicate that strong earthquakes generated by nearby faults could produce ground shaking intensities of VIII–IX (MSK-64 scale) in Ulgii soum (Report, 2017). Seismic microzonation studies have also identified four soil zones with different amplification characteristics, which can significantly influence earthquake ground motion and building damage.

The building stock of Bayan-Ulgii consists mainly of masonry, block, and wooden structures whose seismic performance is affected by structural type, age, and local soil conditions. Most public and residential buildings are concentrated in areas underlain by loose sediments, where ground-motion amplification may occur.

This study evaluates the seismic vulnerability of the building stock in Bayan-Ulgii Province using the EMS-98 methodology and considers the influence of local soil conditions. The results provide important information for earthquake risk reduction and disaster preparedness in western Mongolia.

Methodology

The seismic vulnerability of buildings was assessed using the European Macroseismic Scale 1998 (EMS-98), a widely used macroseismic approach for regional-scale seismic risk assessment. This method enables the evaluation of a large number of buildings without detailed structural analyses by using basic building characteristics and vulnerability indices.

The normalized vulnerability index (**V**) was incorporated into the EMS-98 damage function to estimate the mean damage grade (**μD**) under a given earthquake intensity (Giovinazzi & Lagomarsino, 2004):

$$\mu_D = 2.5\left[1+\tanh\left(\frac{I+6.25V-13.1}{2.3}\right)\right]$$

where **μD** is the mean damage grade (0–5), **I** is the macroseismic intensity, and $\mathbf{V_{norm}}$ is the normalized vulnerability index. The function describes the nonlinear increase of damage with increasing earthquake intensity and building vulnerability. Average vulnerability values were subsequently calculated to evaluate the spatial distribution of seismic vulnerability across the study area.

Results and discussion

The seismic vulnerability of buildings in Bayan-Ulgii Province was assessed using the EMS-98 methodology. The spatial distribution of vulnerability indicates significant variations among soums.

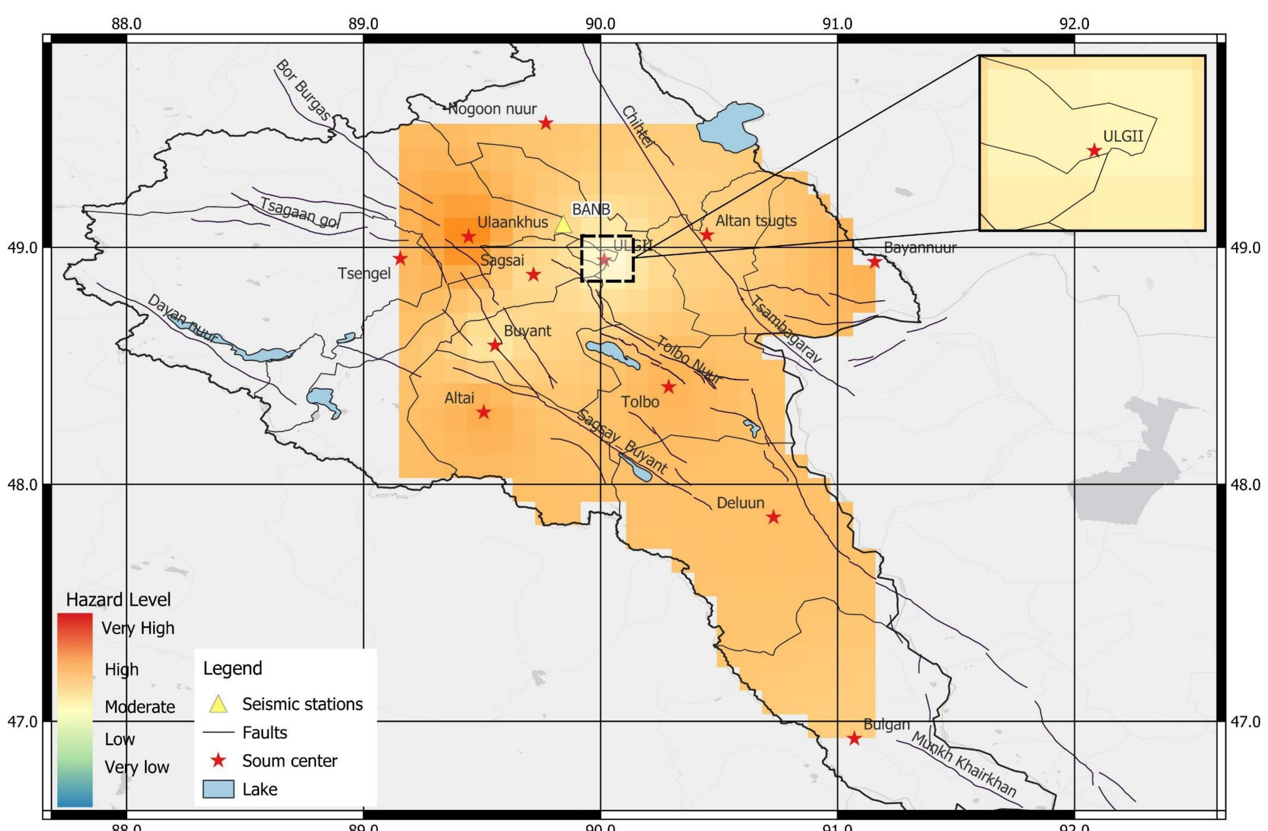


Figure 2. Spatial Distribution of Building Vulnerability

Vulnerability index values range from 0.511 to 0.773, with an average value of 0.630. Among the 14 administrative units assessed, 10 soums (71.4%) were classified as having high vulnerability, while 4 soums (28.6%) showed moderate vulnerability. The highest vulnerability was observed in Ulaankhus soum (V = 0.773), whereas Ulgii soum (V = 0.511) exhibited the lowest value.

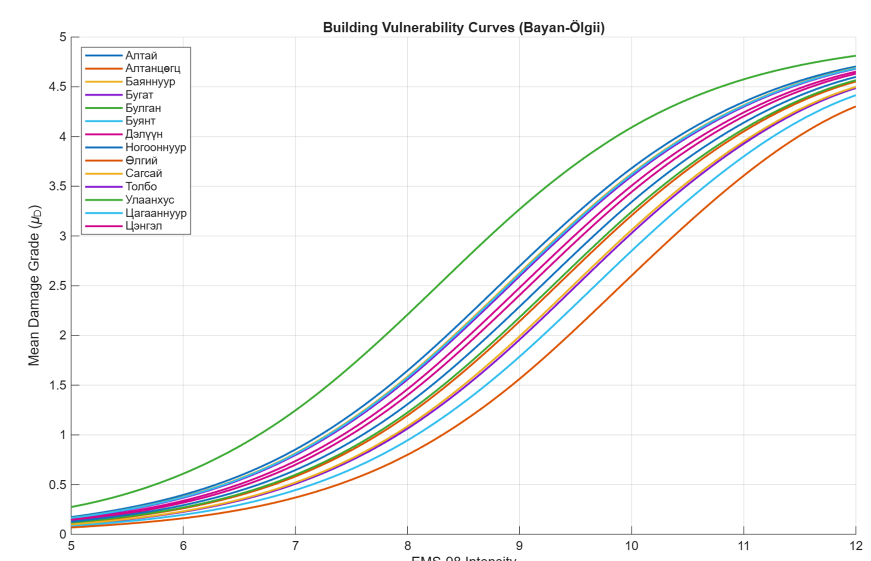


Figure 3. Mean Damage Grade as a Function of Earthquake Intensity

Damage probability curves indicate that the mean damage grade increases nonlinearly with earthquake intensity, following the EMS-98 vulnerability model proposed by Giovinazzi & Lagomarsino (2004). Soums with higher vulnerability indices are expected to experience more severe damage under strong earthquake scenarios.

Data collection

A seismic vulnerability database was developed for 445 buildings located in 13 soums and 1 village of Bayan-Ulgii Province. Building information was collected through field surveys and local records, including location, occupancy, structural type, construction period, foundation type, and soil conditions. These parameters were used to evaluate building vulnerability and characterize the regional building stock.

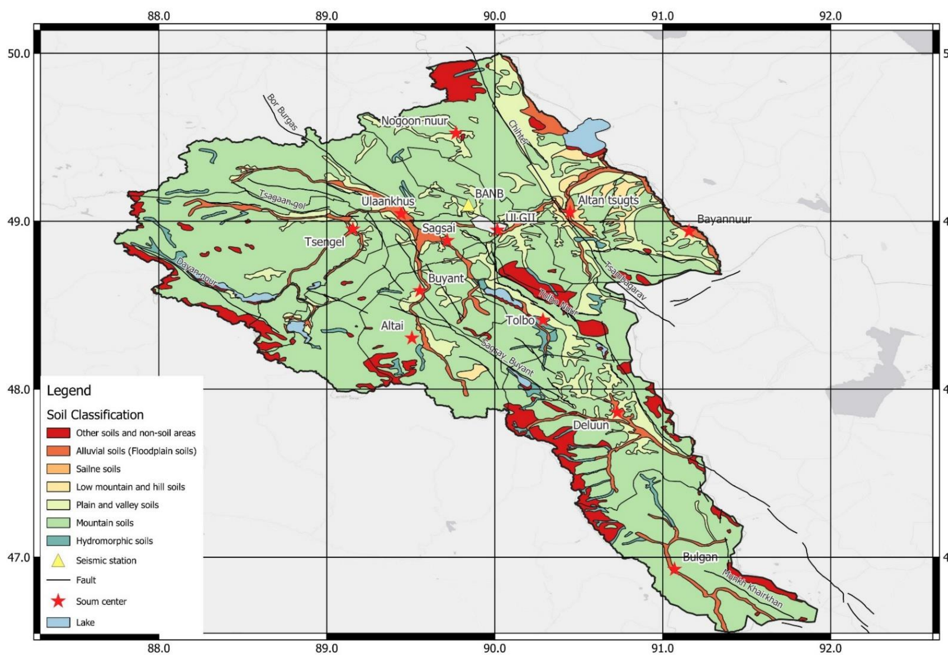
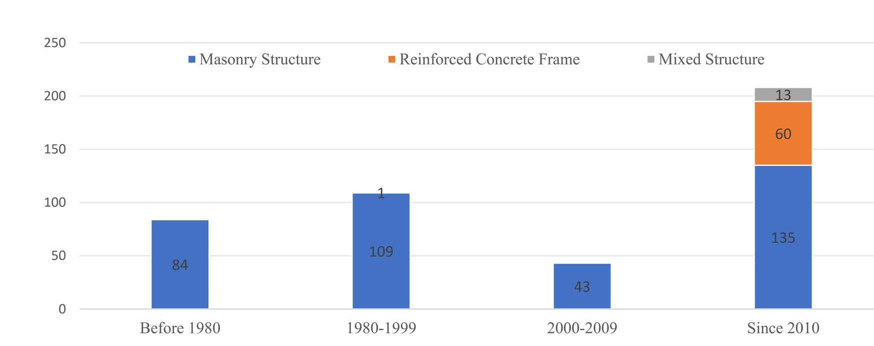


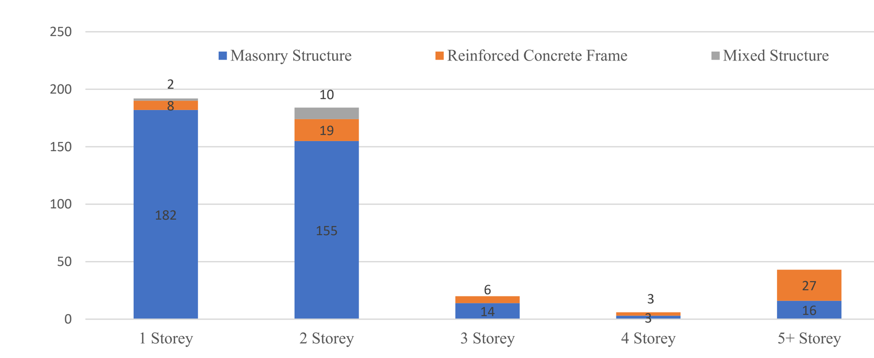
Figure 1. Soil Classification Map of Bayan-Ulgii Province

Spatial data were processed in a GIS environment and integrated with soil classification maps. Soil conditions were considered an important factor because local site effects can amplify seismic waves and increase potential earthquake damage, particularly in areas underlain by unconsolidated sediments.



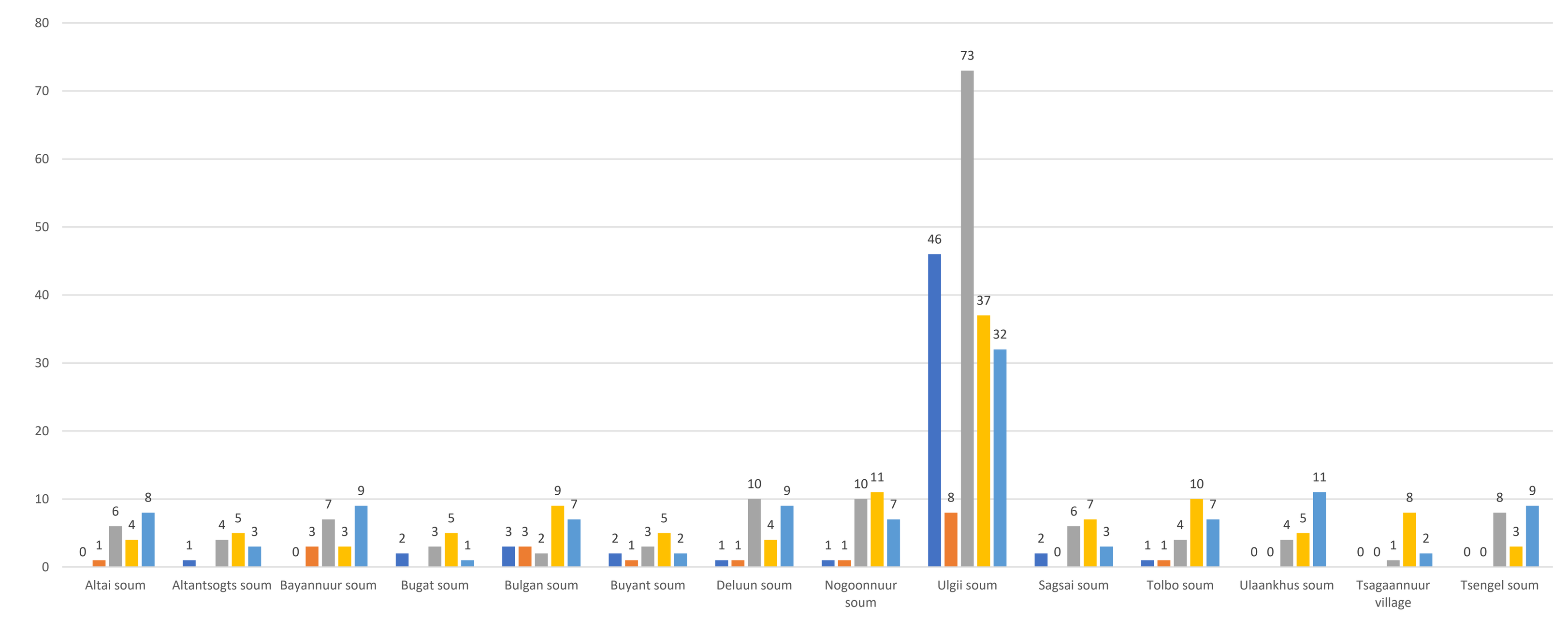
Graph 1. Distribution of Buildings by Construction Period

Buildings were grouped into three structural types: masonry structures (adobe, timber, stone, brick, and block buildings), reinforced concrete frame structures, and mixed structures (mainly sandwich-panel buildings).



Graph 2. Distribution of Buildings by Number of Storeys

Most surveyed buildings are 1–2 storeys and predominantly masonry structures. The proportion of reinforced concrete frame structures increases with building height, while mixed structures account for only a small share of the building inventory.



Graph 3. Distribution of Seismic Vulnerability Classes by Soum

Ulgii soum contains the largest building inventory, dominated by low and moderate vulnerability classes. Several other soums exhibit higher proportions of high and very high vulnerability buildings, indicating variations in seismic risk across the region.

Conclusions

This study evaluated the seismic vulnerability of the building stock in Bayan-Ulgii Province using the EMS-98 methodology. The results reveal significant spatial variations in vulnerability across the province, with several soums exhibiting high seismic risk. Building response to increasing earthquake intensity is nonlinear, and damage levels rise rapidly under strong shaking conditions. The findings highlight the importance of vulnerability-based risk assessment and support the need for seismic strengthening, improved building standards, and disaster risk reduction planning in highly vulnerable areas.

References

1. Coburn, A., & Spence, R. (1992). *Earthquake Protection*. John Wiley & Sons.
2. Giovinazzi, S., & Lagomarsino, S. (2004). A macroseismic method for the vulnerability assessment of buildings. *Proceedings of the 13th World Conference on Earthquake Engineering*, Vancouver, Paper No. 896.
3. Grünthal, G. (Ed.). (1998). *European Macroseismic Scale 1998 (EMS-98)*. Centre Européen de Géodynamique et de Séismologie, Luxembourg.
4. Ceroni, F., Caterino, N., & Vuoto, A. (2020). *Simplified seismic vulnerability assessment methods:A comparative analysis with reference to regional school building stock in italy.* Applied Sciences, 10(19).
5. D'Ayala, D., & Speranza, E. (2003). *Definition of collapse mechanisms and seismic vulnerability of historic masonry buildings. Earthquake Spectra*, 19(3), 479–509.
6. Lagomarsino, S., & Giovinazzi, S. (2006). *Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. Bulletin of Earthquake Engineering*, 4, 415–443.
7. Report, I., 2017. *Аймаг, сум, суурингуудын нутаг дэвсгэрийн газар хөдлөлийн бичил мужлалын зураглал хийх, газар хөдлөлийн эрсдэлийг тодорхойлоход чиглэсэн инженер-геологи, гидрогеологи, газар хөдлөлт, техникийн судалгаа,* Tech. rep., Улаанбаатар.