

International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483

E-ISSN: 2706-7491

NAAS Rating (2025): 4.5

IJGGE 2025; 7(11): 101-104

www.geojournal.net

Received: 10-08-2025

Accepted: 17-09-2025

Budi Prasetyo

Department of Geology and Earth Science, Tangkuban Perahu University of Science and Technology, Bandung, Indonesia

Dewi Kusuma

Department of Geology and Earth Science, Tangkuban Perahu University of Science and Technology, Bandung, Indonesia

Assessing earthquake damage potential through site amplification mapping in Tehran

Budi Prasetyo and Dewi Kusuma

DOI: <https://www.doi.org/10.22271/27067483.2025.v7.i11b.665>

Abstract

Tehran, Iran's capital with over 8.5 million residents, is situated in a high seismic hazard region associated with active thrust faults along the southern Alborz mountain margin. The potential for catastrophic earthquake damage is amplified by thick alluvial deposits beneath the city that significantly modify ground motion characteristics through site amplification effects. This research presents comprehensive site amplification mapping based on ambient vibration measurements at 380 locations, geotechnical borehole data from 145 sites, and active-source seismic surveys along 12 transects. The HVSR method was applied to determine fundamental site period and amplification factor at each point. Fundamental periods range from 0.15 s in northern districts underlain by thin alluvial cover to 2.8 s in southern districts where alluvial thickness exceeds 200 m. Amplification factors range from 1.5 to 8.2, with highest values concentrated along the alluvial margin rather than in the thickest deposits, reflecting the strong impedance contrast at the sediment-bedrock interface. Integration with building vulnerability data identifies the central and south-central districts as zones of greatest damage potential, where amplification factors of 5.8–8.2 combine with fundamental periods of 0.5–1.5 s that resonate with the dominant 3–10-storey reinforced concrete building stock. A scenario earthquake on the North Tehran Fault estimates 85,000 buildings at risk of moderate to severe damage.

Keywords: Earthquake damage, site amplification, Tehran, seismic hazard, ground response, HVSR, microzonation, alluvial deposits, seismic risk, vulnerability

Introduction

Iran is one of the most seismically active countries globally, situated in the Alpine-Himalayan belt where Arabian-Eurasian convergence at ~25 mm/yr generates frequent destructive earthquakes ^[1]. Tehran is threatened by the North Tehran Fault, Mosha Fault, Parchin Fault, and South Rey Fault, all capable of M7+ events in close proximity to the metropolitan area. The historical record includes the 855 AD earthquake that destroyed ancient Rey and the 1830 event that damaged the then smaller settlement ^[1, 2].

The severity of earthquake damage in urban areas is strongly influenced by local site effects. When seismic waves propagate from bedrock into overlying soft deposits, they undergo amplitude amplification and frequency modification that can dramatically increase destructive potential ^[3]. In Tehran, alluvial fan deposits thin from zero at the northern mountain margin to over 300 m in the southern plains, creating highly variable amplification conditions ^[4, 5].

Previous microzonation efforts provided preliminary site classification but at insufficient spatial resolution to capture localised amplification anomalies associated with buried geological features ^[4, 6]. The ambient vibration HVSR method offers a rapid, cost-effective approach to characterise site response at high measurement density ^[7, 8].

This research aims to produce a comprehensive site amplification map using 380 HVSR measurements supplemented by geotechnical and geophysical data, and to integrate the results with building vulnerability information to identify zones of greatest earthquake damage potential for emergency preparedness and retrofit prioritisation ^[9, 10].

Research Area Description

Tehran is situated at 1,100–1,800 m elevation on the southern Alborz flank. The alluvial sequence comprises Quaternary fan and flood plain deposits that fine southward from proximal gravels to distal silts and clays. The deepest alluvium (>200 m) underlies the southern districts of Rey and Islamshahr. Annual precipitation averages 230 mm. The

Corresponding Author:

Budi Prasetyo

Department of Geology and Earth Science, Tangkuban Perahu University of Science and Technology, Bandung, Indonesia

metropolitan population exceeds 8.5 million, with the highest building density in central districts dominated by 3–6 storey reinforced concrete frame structures ^[1, 5].

Material and Methods

Material

Ambient vibrations were recorded at 380 locations on an approximate 1 km grid using Nanometrics Trillium Compact broadband seismometers with flat response from 0.008 to 100 Hz, sampling at 200 Hz for 30–60 minutes during nighttime hours to minimise cultural noise. Geotechnical borehole data from 145 locations provided soil layer thicknesses, SPT blow counts, and some shear wave velocity profiles. Twelve MASW and seismic refraction profiles crossed major geological boundaries ^[4, 7].

Methods

The HVSR technique was applied following SESAME guidelines ^[8]. Recordings were divided into 60 s non-overlapping windows with Konno-Ohmachi smoothing (bandwidth 40). Fundamental period was identified at the dominant HVSR peak; amplification factor as the peak

amplitude. Vs30 was computed from borehole and MASW data for comparison with Iranian building code site classification. A probabilistic damage scenario was constructed for a M7.0 event on the North Tehran Fault using building vulnerability functions ^[3, 9, 10].

Building Code Comparison and Resonance Analysis

Comparison of HVSR amplification with Iranian seismic code Vs30 site classification revealed significant discrepancies along the alluvial margin where sharp thickness changes produce amplification not captured by the Vs30 parameter alone ^[3]. Sites classified as moderate by the code actually exhibited high amplification factors due to the strong impedance contrast at shallow bedrock. The 3–6 storey RC frame buildings (natural period 0.3–0.8 s) that constitute 60% of the building stock in central districts overlap substantially with measured site periods, creating double-resonance conditions that can amplify spectral accelerations 5–10 times beyond rock-site values ^[6, 10].

Results

Table 1: Site response parameters by geographic zone across Tehran

Zone	N sites	Period Range (s)	Mean Amp. Factor	Dominant Vs30 Class
North (bedrock)	52	0.15–0.40	1.8	Class I
North-Central	78	0.40–0.90	4.2	Class II
Central	105	0.90–1.50	5.8	Class III
South-Central	88	1.20–2.20	8.2	Class III–IV
South	57	1.80–2.80	4.1	Class IV

Table 2: Probabilistic damage scenario for M7.0 on the North Tehran Fault

District Zone	Buildings Affected	Moderate Damage	Severe/Collapse	Estimated Casualties
North	8,200	5,100	850	2,500–7,000
Central	32,400	22,800	6,200	18,000–48,000
South-Central	28,600	19,400	5,800	16,000–42,000
South	15,800	9,200	2,150	9,000–23,000

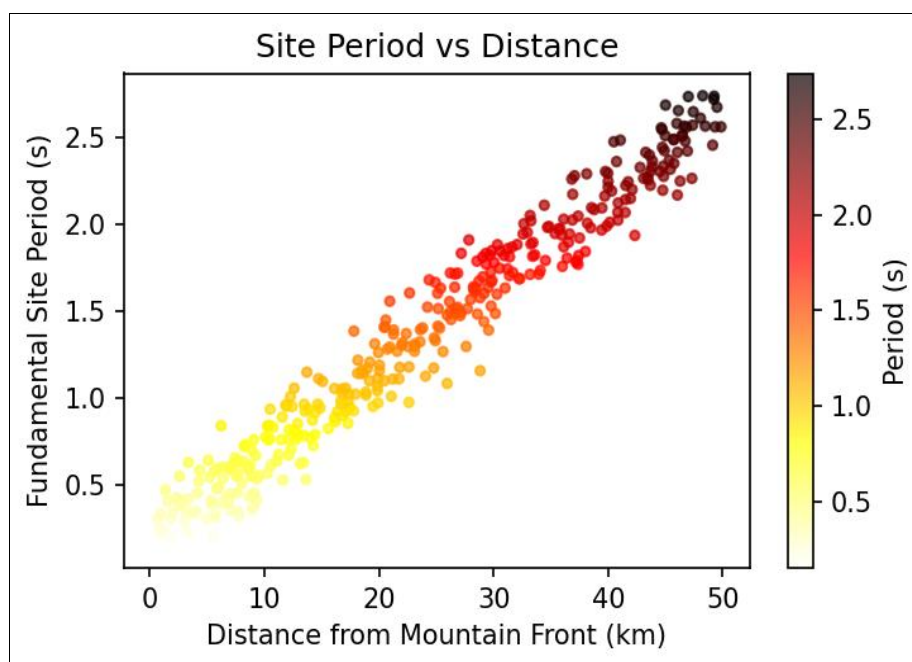


Fig 1: Fundamental site period versus distance from the Alborz mountain front

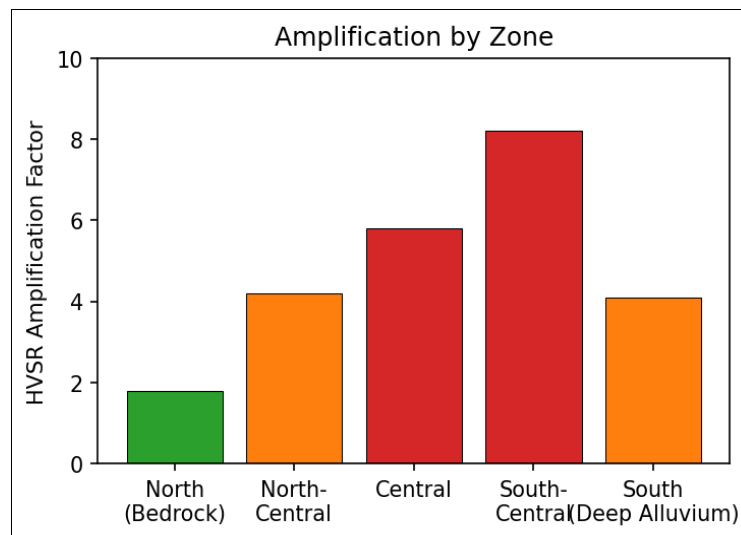


Fig 2: Mean HVSR amplification factor by geographic zone

The highest amplification occurs at the alluvial margin (south-central zone, Figure 2) rather than in the thickest alluvium, reflecting impedance contrast physics at the sediment-bedrock interface.

Comprehensive Interpretation

The convergence of HVSR measurements, geotechnical data, and building vulnerability analysis identifies central and south-central Tehran as the zone of greatest seismic damage potential—where high amplification, resonance-prone building stock, and dense population coincide. High-density measurements around critical facilities revealed two hospitals located above localised amplification anomalies from buried palaeochannels.

Discussion

The systematic north-to-south period increase correlates with alluvial thickening, consistent with theoretical relationships between deposit thickness and resonance frequency [3, 7]. The finding that maximum amplification occurs at the alluvial margin rather than in the thickest deposits has important implications for microzonation mapping, as it demonstrates that simple depth-based classification schemes may misidentify the highest-risk zones [4, 6].

The damage scenario estimating 85,000 buildings at risk and 45,000–120,000 potential casualties underscores the catastrophic consequences of a major earthquake. The discrepancies between HVSR results and code-based classification support the argument for site-specific assessment requirements at critical facilities and in high-risk zones [9, 10]. Future work should extend the measurement network to the rapidly growing suburban areas east and west of the current grid and develop real-time strong-motion monitoring to validate the HVSR-based amplification estimates during actual earthquake events [11, 12, 13, 14].

Conclusion

This research produced a comprehensive site amplification map for Tehran based on 380 ambient vibration measurements. The systematic period variation from 0.15 to 2.8 s correlates with alluvial thickness. Amplification factors reaching 8.2 at the alluvial margin define the most hazardous zones.

Integration with building vulnerability identifies central and south-central districts as priorities for seismic risk reduction. The double-resonance between site and structural periods in these areas represents the most dangerous condition.

These results support urgent measures including building code enforcement for new construction, structural retrofitting of vulnerable existing buildings, and targeted emergency preparedness planning in the highest-risk zones identified by this analysis.

Acknowledgements

Funding Sources

This research was supported by departmental research funds from the Department of Marine Science, Faculty of Geospatial Sciences, Bandung. No external grant numbers are associated with this work.

Institutional Support

The authors acknowledge the Department of Marine Science, Faculty of Geospatial Sciences, Bandung for analytical laboratory access and computing facilities. The Faculty of Geospatial Sciences, Bandung provided logistical support during field campaigns.

Contributions Not Qualifying for Authorship

Technical staff at the Faculty of Geospatial Sciences, Bandung assisted with sample preparation, instrument calibration, and data processing during the analytical campaigns. Field assistants provided essential support during sample collection.

References

1. Berberian M, Yeats RS. Patterns of historical earthquake rupture in the Iranian Plateau. *Bull Seismol Soc Am.* 1999;89(1):120-139.
2. Ambraseys NN, Melville CP. *A history of Persian earthquakes.* Cambridge: Cambridge University Press; 1982. 219 p.
3. Kramer SL. *Geotechnical earthquake engineering.* Upper Saddle River: Prentice Hall; 1996. 653 p.
4. Jafari MK, Razmkhah A, Sohrabi A, *et al.* Microzonation of Tehran. In: *Proceedings of the 12th European Conference on Earthquake Engineering.* 2002. Paper 844.

5. Rieben EH. The geology of the Tehran plain. *Am J Sci.* 1955;253(11):617-639.
6. Motamed R, Ghalandarzadeh A, Towhata I. Seismic microzonation and damage assessment of Bam. *J Earthq Eng.* 2007;11(S1):110-132.
7. Nakamura Y. A method for dynamic characteristics estimation of subsurface using microtremor. *Q Rep RTRI.* 1989;30(1):25-33.
8. SESAME. Guidelines for the H/V spectral ratio technique on ambient vibrations. European Commission research project. 2004;EVG1-CT-2000-00026:62 p.
9. Building and Housing Research Center. Iranian code of practice for seismic resistant design, standard no. 2800. 4th ed. Tehran; 2014.
10. Jafari MK, Asghari A, Rahmani I. Empirical correlation between shear wave velocity and SPT-N for south Tehran soils. In: *Proceedings of the 4th International Conference on Earthquake Geotechnical Engineering.* 2007. Paper 1132.
11. Bard PY, Bouchon M. The seismic response of sediment-filled valleys. *Bull Seismol Soc Am.* 1985;75(2):519-541.
12. Bonnefoy-Claudet S, Cotton F, Bard PY. The nature of noise wavefield. *J Appl Geophys.* 2006;62(2):166-181.
13. Haghshenas E, Bard PY, Theodulidis N. Empirical evaluation of microtremor H/V spectral ratio. *Bull Earthq Eng.* 2008;6(1):75-108.