**Assessment of Resonance Risk In Multi-Story Buildings Based on a Modern Seismic Monitoring System**

Bokhodir Khayriddinov1, a), Nurali Mukhammadkulov1, b),   
Sharofiddin Yodgorov1, c), Bekzod Aktamov1 and Shukhrat Avazov1

1*Institute of Seismology, Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan*

*a) Corresponding author:* [*xayriddinovbahodir69@gmail.com*](mailto:xayriddinovbahodir69@gmail.com) *b)* [*muhammadqulovnurali@gmail.com*](mailto:muhammadqulovnurali@gmail.com) *c)* [*sh.i.yodgorov@gmail.com*](mailto:sh.i.yodgorov@gmail.com)

**Abstract.** This article presents a dynamic analysis of the seismic response of a three-story reinforced concrete structure located in Uzbekistan. During the study, vibrations recorded by ETNA-2 accelerometers at the basement and roof levels of the building during a magnitude 4.4 earthquake in Tajikistan were analyzed using the H/V (Horizontal-to-Vertical Spectral Ratio) and FFT (Fast Fourier Transform) methods. The analysis identified the structure’s resonant frequencies, the distribution of seismic energy across floors, and the occurrence of dynamic softening during the earthquake. The results indicate that seismic energy is distributed unevenly throughout the building and that structural vulnerability increases, particularly on the upper floors. The use of H/V and FFT methods in such assessments provides high-accuracy results and has strategic significance for earthquake-resistant building design.

**Keywords:** seismic hazard, resonant frequency, experimental, H/V spectral ratio, frequency analysis, structural deformation, seismic monitoring, structure vibration, ground-resonant interaction, seismic resistance assessment, vertical energy distribution.

**INTRODUCTION**

Assessment of the impact of earthquakes on buildings is one of the priority scientific directions in the field of earthquake-resistant engineering and seismic safety. In densely populated cities, there is a growing need for accurate and real-time monitoring systems for the seismic resistance of multi-story buildings. Through such monitoring, the resonant behavior of structures, the response of structural elements to vibrations, and the state of dynamic stability are scientifically analyzed [1, 2, 3].

Experiments conducted in the scientific literature, especially in regions of Europe with moderate seismic activity, show that the determination of resonant frequencies through vibrations and their comparison with real earthquake records serves as a reliable tool for assessing the seismic state of buildings.

In this article, using the example of a three-story administrative building, dynamic analysis was carried out based on seismic recordings recorded on the upper (roof) and lower (floor) parts of the building using ETNA-2 accelerometer (USA) devices. The seismicity as a source is based on the recording of an earthquake with a magnitude of 4.4 that occurred on April 19, 2025, in the territory of Tajikistan. This earthquake was also felt in some regions of Uzbekistan, which served as the basis for a deep analysis of the seismic responses recorded by the installed devices. The goal is to study the structural distribution of seismic vibrations in multi-story buildings, determine resonant frequencies, and, based on them, assess the safety status of the building [5, 6].

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**FIGURE 1**. The epicenter of the earthquake in the mountainous territory of Tajikistan and its regional sensitivity and measurements recorded in the administrative building  
(1-ETNA2 accelerometer in the roof section, 2-ETNA2 accelerometer in the basement, ETNA2 in the free field ground)

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| Earthquake recorded in the basement section | Earthquake recorded in the Roff section | |
| Seismic recording recorded at the free field | |

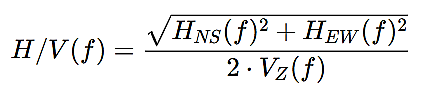
**FIGURE 2.** Accelerograms recorded using the ETNA 2 Accelerometer

**METHODOLOGY**

The dynamic response of multi-story buildings to seismic vibrations was studied experimentally. For this purpose, a real structure - a three-story reinforced concrete building - was selected, and accelerometer devices were installed on its roof and basement sections. The devices continuously recorded vibrations, which allowed comparing the building's structural response across the vertical section.

The micro vibrations detected by sensitive accelerometers installed during this earthquake created a resonant state in the building. This situation creates a favorable opportunity for a scientific analysis of how seismic energy is distributed to the structure [4, 7].

To determine the resonant frequency of the building, the H/V spectral ratio method proposed by Nakamura (1989) was used (1). The spectrum of the horizontal components measured by this method is determined relative to the vertical component by the following formula [8, 9]:

(1)

here: HNS (f) - HEW (f) horizontal components; VZ (f) - amplitude spectrum by frequency of the vertical component;   
f - frequency (Hz).

As a result, the peak of the H /V spectrum indicates the resonant frequency of the building. This resonance frequency is an important indicator in assessing structural compatibility, deformation resistance, and the level of potential risk [10, 11, 12].

**RESULTS**

As part of the study, H/V (Horizontal-to-Vertical Spectral Ratio) and FFT (Fast Fourier Transform) analyses were carried out based on seismic recordings recorded by ETNA-2 accelerometers installed in the upper (roof) and lower (floor) parts of the three-story building.

H/V analysis, based on vibrations recorded before the earthquake occurred, revealed differences in resonant frequency and amplitude behavior at different heights of the building. On the roof, the resonant frequency was 4.589 Hz, and the maximum H/V ratio was 6.934, which indicates the concentration of vibrations in the upper part of the structure and the presence of a high level of resonance risk. On the basement floor, the resonant frequency is 2.416 Hz, the H/V ratio is 2.519, which indicates the presence of ground resonance, but the level of structural hazard is relatively low [13, 14].

Based on background vibrations recorded in the soil (open ground), the analysis performed in the Geopsy (Geophysical Signal Database for Ambient Noise Analysis, Switzerland) program showed a resonant frequency of 2.598 Hz and a maximum H/V ratio of 3.63. These values indicate the natural vibration frequency of the soil layer. The fact that these values are very close to the resonant frequencies in the basement proves that the soil resonance directly affected the lower part of the building.

Spectral analysis of H/V during an earthquake revealed a dynamic change in vibrational behavior. On the roof, the resonant frequency decreased to 0.639 Hz, and the H/V ratio was 3.615. This sharp decrease in resonant frequency may have been caused by the dynamic softening of the structure, i.e., the temporary loss of material elasticity or the opening of microcracks. In the basement floor, the resonant frequency is 2.513 Hz, the H/V ratio is 2.568, which is very close to the values at rest. This means that stability is preserved in the lower part of the structure [15, 16].

To determine the frequency distribution of the seismic signal, FFT analysis was performed using the WinQuake (Windows Earthquake Data Analysis Program, USA) program. On the roof, the maximum spectral peak was observed at 4.899 Hz. This frequency is almost identical to the building's resting resonant frequency (4.589 Hz), indicating that the structure has reached a resonant state at a strong earthquake frequency and that energy has accumulated above. This caused a high structural risk. The main dominant frequency on the FFT graph in the flooring floor was detected at 2.954 Hz, which is also consistent with the H/V analysis. Despite the fact that the frequency characteristics of the earthquake in Padval were close to the resonance zone, the amplitude voltage was low, which indicates a lower level of danger compared to a higher one.

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| H/V analysis at rest on roof | H/V analysis at rest on the basement |
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| H/V analysis during earthquake in basement | H/V analysis on roof during earthquake |

**FIGURE 3.** Assessment of the building's vertical (roof-floor) resonant behavior in relation to seismic impact using the H/V method

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| FFT analysis during earthquake basement | FFT analysis on roof during earthquake |

**FIGURE 4.** FFT analysis of the earthquake spectrum recorded in the basement and roof parts of the building

**ANALYSIS AND DISCUSSION**

The research results show that the seismic responses that occur during earthquakes in multi-story buildings differ significantly in height. According to the H/V analysis at rest, the resonant frequency on the roof is 4.589 Hz, the maximum H/V ratio is 6.934, which indicates a high risk of resonant voltage in high structural zones. In Padval, the resonant frequency is 2.416 Hz and the H/V value is around 2.519, which indicates the presence of ground resonance, but not at a dangerous level [17, 18].

Spectral analysis of H/V measured during the earthquake revealed a sharp change in structural behavior, especially on the roof. The decrease in the resonant frequency to 0.639 Hz and the H/V ratio to 3.615 are explained by the temporary softening of the material, the appearance of microcracks, or a dynamic shift of the resonance. This indicates the occurrence of a resonance phenomenon in the upper part of the structure. In Padval, during an earthquake, the resonant frequency was 2.513 Hz, H/V 2.568, which indicates the preservation of stability and the unchanged resonant frequency.

The FFT analysis also reinforced these conclusions. The dominant earthquake frequency on the roof was detected at 4.899 Hz, which almost coincided with the resonant frequency at rest (4.589 Hz). This means that the structure has entered resonance with the seismic frequency, and the vibrational force has reached its maximum level on the upper floor. Such a state is called a resonance combination, and it is precisely such coincidences that can lead to high structural stresses. In Padval, the main frequency of the earthquake was 2.954 Hz, and although it was close to the resonant frequency, the amplitude voltage was low. This indicates that a large part of the energy is absorbed by the soil.

In general, these analyses show that seismic energy is not evenly distributed in the structure: the upper layers act as a zone of its accumulation, and it is precisely in the resonant frequency range that seismicity increases. When designing earthquake-resistant buildings, an important strategic aspect is the preliminary determination of resonant frequencies through H/V and FFT analyses, focusing on high structural zones, and designing reinforcing structures in relation to the most dangerous frequencies [19, 20].

**CONCLUSION**

This study was aimed at assessing the response of multi-story buildings to seismic impact based on modern seismic monitoring approaches. The obtained results show that seismic energy is not uniformly distributed over height in building structures. Especially the upper floors are more sensitive to earthquake waves, and the resonant states that occur there dramatically increase the level of danger.

Analysis showed a change in the state and mechanical properties of the structure under the influence of an earthquake, i.e., a temporary decrease in elasticity, an increase in sensitivity to vibrations. This means that during an earthquake, the probability of resonance in some parts of the building increases, and as a result, structural elements are subjected to overload.

The vibrational characteristics determined by spectral analysis and their relationship with the structural response confirm the necessity of frequency analysis in the seismic design of multi-story buildings. Earthquakes pose a danger not only in their strength, but also in their frequency composition. Structural resonances occur precisely when these frequencies coincide.

Also, some earthquakes, despite their small magnitude, can cause a structural resonance state. This means that when assessing the risk of any seismic event, it is necessary to pay attention not only to the magnitude, but also to the dynamic response of the building. Therefore, the introduction of monitoring systems, the use of vibration analysis methods in improving seismic safety, serves as an important strategic tool, especially in urban planning and engineering projects.

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