# Dynamic Impact Scales (SWD-I and SWD-II): A Simplified Method for Assessing Building Vibrations

Alicja Kowalska-Koczwara[1*)], Tadeusz Tatara[2)]

[1*)] Cracow University of Technology, Faculty of Civil Engineering, Warszawska 24St., 31-155 Krakow, Poland, E-mail: akowalska@pk.edu.pl; ORCID: 0000-0001-8088-7729
[2)] Cracow University of Technology, Faculty of Civil Engineering, Warszawska 24St., 31-155 Krakow, Poland, E-mail; ttatara@pk.edu.pl, ORCID: 0000-0002-4071-2358

https://doi.org/10.29227/IM-2025-02-02-044

Submission date: *2025-05-20* | Review date: *2025-06-18*

## *Abstract*

*Vibrations caused by construction activities, transportation, and industrial sources can adversely affect buildings, especially those constructed from masonry or large prefabricated elements. In order to ensure structural safety and environmental protection, it is necessary to assess the impact of such vibrations in both the design and diagnostic stages. While full dynamic analysis provides accurate results, it is often impractical for routine assessments due to the complexity of modeling, lack of vibration data, or the urgency of the evaluation process. In response to this need, simplified procedures have been developed in the Polish engineering practice in the form of Dynamic Impact Scales SWD-I and SWD-II. The SWD-I and SWD-II scales offer an approximate yet practical method for evaluating vibration-induced structural damage in buildings, based on empirical classification into five vibration zones ranging from "imperceptible" to "structural failure." The classification is derived from the measured peak values of ground acceleration and frequency, and the structural characteristics of the building. The SWD-I scale applies to compact, regular-shaped masonry or panel buildings of up to two storeys, while SWD-II is designed for more general low-rise buildings of up to five storeys, with certain limitations on height-to-width ratios. Both scales are based on engineering judgement and are aligned with the framework of the Polish standard PN-B-02170:2016. This paper presents a detailed description of both scales, including the criteria for their use, methodology for assigning buildings to the correct zone, and proper sensor placement to capture representative vibration input. A comparative example is provided to demonstrate how a real-world vibration scenario (induced by a nearby compressor) can be evaluated using the SWD-II scale. The case illustrates that even a relatively small source can lead to measurable vibrations that may affect building integrity depending on the frequency content and local amplification effects. The results confirm that SWD scales can serve as reliable screening tools for preliminary assessment of structural vulnerability to environmental vibrations. Although not a substitute for detailed numerical modeling in complex or high-risk cases, the SWD approach provides a valuable, cost-effective method for engineers, designers, and decision-makers engaged in environmental impact assessments or construction planning. In addition, the scales can be used to support regulatory compliance and community communication in vibration-sensitive areas. The use of SWD-I and SWD-II scales fills a methodological gap by offering an intermediate level of assessment between qualitative expert judgement and full-scale structural simulations. This contribution aims to bring these effective tools to a broader international audience and encourage their adaptation or further development in the context of local regulatory frameworks and engineering standards.*

**Keywords:** *building vibrations; structural damage assessment; dynamic impact scales; environmental vibration*

## 1. Introduction

Environmental vibrations generated by human activities—such as construction works [1], railway and road traffic [2-3], or industrial operations [4]—can significantly affect the structural performance of nearby buildings. The increasing density of urban development has brought these issues into sharper focus, as infrastructure projects and heavy machinery are often located in close proximity to sensitive structures. In particular, buildings constructed from masonry or large-panel prefabricated elements, which are common in Central and Eastern Europe, are vulnerable to vibration-induced cracking and other forms of degradation [5-6]. Protecting such buildings requires reliable and efficient assessment methods that balance engineering accuracy with practical usability.

While detailed dynamic analysis remains the most accurate method for evaluating vibration impacts, it requires advanced numerical modelling [7-8], precise boundary conditions, and complete dynamic input data. These requirements make such analysis expensive and often inaccessible for routine diagnostics, early-phase planning, or situations with limited data availability. In response to these limitations, engineering practice has developed simplified, experience-based methods that enable preliminary assessments without sacrificing essential safety margins.

In Poland, one such approach is based on Dynamic Impact Scales—referred to as SWD-I and SWD-II [9-11]. These scales have been developed through engineering experience and practice-oriented interpretation of the Polish standard PN-B-02170:2016 [12], which governs the assessment of the impact of vibrations on building structures. The SWD scales provide a framework for interpreting vibration measurements (particularly peak ground accelerations and frequency content) in relation to the structural characteristics of buildings. They divide vibration severity into five zones—from imperceptible to critically damaging—allowing for rapid categorization of the risk level.

The SWD-I scale is designed for regular-shaped, compact buildings of up to two storeys, while the SWD-II scale extends the methodology to include more general low-rise structures up to five storeys. Both scales rely on simplified geometric criteria and do not require detailed numerical modeling. Despite their practical value, these scales remain undocumented in the international literature and are not widely known outside of Polish engineering circles.

The main objective of this paper is to present the SWD-I and SWD-II scales to the international audience and demonstrate how they can be used for efficient and reliable assessment of building vibrations. The paper outlines the origin and scope of the scales, describes the

methodology and assumptions behind them, and illustrates their application with a representative case study. In doing so, it aims to fill a methodological gap between qualitative judgment and full dynamic simulations, and to contribute to the global toolbox of vibration impact assessment techniques.

## 2. Legal and Normative Background

The transmission of vibrations from external sources to buildings is not only a technical concern but also an environmental and legal issue. Many countries, including Poland, treat vibrations generated by construction equipment, road and rail traffic, or industrial activity as a form of environmental nuisance, requiring regulation and control. The adverse effects of such vibrations may include structural degradation of buildings, as well as reduced comfort and well-being of occupants. Consequently, legal frameworks often require that new developments demonstrate compliance with acceptable vibration thresholds to protect both people and property.

In Poland, the assessment of vibration impact on buildings is governed by the national standard [12]. This standard establishes guidelines for measuring, interpreting, and classifying vibrations transmitted through the ground to structures. It outlines the procedures for evaluating dynamic effects based on vibration parameters such as peak particle velocity (PPV), frequency content, and exposure duration, and defines permissible values for different building types and usage categories.

Internationally, the most commonly adopted approach for assessing the impact of vibrations on buildings focuses on limiting particle velocities or accelerations based on empirical damage thresholds. For example, standard [13] provides damage criteria for buildings based on PPV values and has influenced many national regulations across Europe. Similarly, British Standard [14] defines threshold levels for cosmetic and structural damage due to transient and continuous vibrations. These standards are primarily used for evaluating vibrations from construction and blasting activities, and are typically referenced in environmental impact assessments.

In the context of seismic risk, various simplified damage scales have also been proposed. In Italy, following the L'Aquila earthquake of 2009, researchers developed empirical vulnerability indexes for masonry buildings, such as the Index of Seismic Vulnerability (IV) [15] and the Seismic Damage Grade Scale, which attempt to correlate building typology and configuration with probable damage levels [16]. While primarily used in seismic risk assessment, these methods share conceptual similarities with the SWD scales, as they aim to provide an approximate, yet practical, classification of expected structural performance under dynamic loads.

Despite these developments, there remains a lack of internationally recognized simplified scales specifically designed for environmental or anthropogenic vibrations affecting typical residential buildings. Most global approaches are either purely regulatory, based on threshold exceedances, or are highly specialized and limited to seismic contexts. The SWD-I and SWD-II scales therefore represent a unique engineering tool, filling the gap between qualitative judgment and full dynamic simulation, and offering a middle ground that combines empirical knowledge with normative interpretation.

In this context, the SWD scales—grounded in [12] and rooted in practical experience—can serve both as diagnostic instruments and as tools for regulatory compliance. By providing an efficient and structured method for classifying vibration impacts, they offer real-world utility that could be adapted to other national contexts or used as a model for further research in this domain.

## 3. Characteristics of the SWD-I and SWD-II Scales

The SWD-I and SWD-II scales were developed to provide a simplified yet practical method for assessing the dynamic impact of ground-transmitted vibrations on buildings, particularly in cases where full dynamic analysis is not feasible or necessary. Both scales are based on long-term engineering practice and empirical interpretation of dynamic measurements in the context of Polish design guidelines and structural typologies. They complement the formal procedure described in [12] by offering an accessible classification method for common residential structures.

The SWD scales define five vibration impact zones, labeled from Zone I to Zone V, which describe increasing levels of vibration intensity and potential structural effects. The classification is based primarily on two parameters: the peak acceleration and the dominant frequency of the vibrations. Interpretation of these parameters is made in the context of building geometry, construction system, and stiffness characteristics.

### *3.1 SWD-I Scale*

The SWD-I scale is intended for compact masonry or panel buildings of up to two storeys, characterized by small horizontal dimensions and regular geometric form. Such buildings typically have good stiffness and low dynamic amplification, which allows for a relatively straightforward interpretation of vibration impact.

Buildings qualifying for assessment under SWD-I must meet the following geometric conditions (Fig.1):

- Width and length: up to 15 meters,
- Maximum height to width or length ratio: 1:1,
- Masonry or prefabricated panels buildings,
- Simple plan layout, symmetrical in at least one axis.

Due to the uniformity of these structures, the scale offers a reliable correlation between vibration parameters and potential damage. Sensor placement is typically at the foundation level, on the side of the building facing the source of vibration.

### *3.2 SWD -II Scale*

The SWD-II scale extends the methodology to include more diverse low-rise buildings of up to five storeys, with less restrictive geometrical conditions. It accounts for variability in mass distribution, foundation types, and dynamic response.

Buildings assessed using SWD-II must meet these simplified conditions (Fig. 1.):

- Maximum height-to-width ratio: 2:1,
- Masonry or prefabricated panels buildings,
- Buildings not equipped with deep foundations or significant structural irregularities.

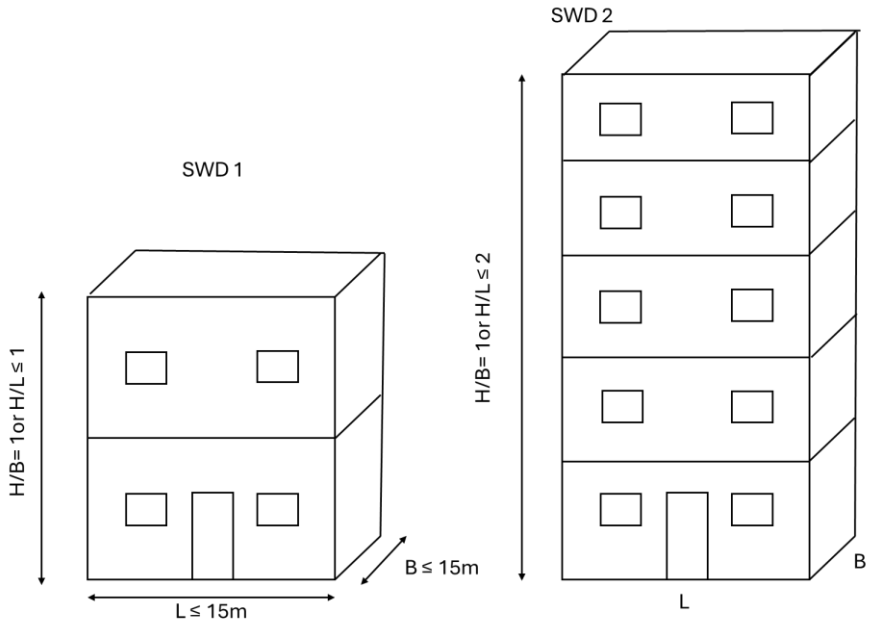


Fig. 1. Comparison of conditions that building should met acc. SWD 1 I SWD 2 scales.

### *3.3. Characterization of both SWD scales.*

Both scales use a classification system (Fig.2), where:

- Zone I indicates vibrations that are imperceptible or negligible,
- Zone II corresponds to perceptible vibrations with no expected structural effects, suggests a risk of microcracking or plaster damage,
- Zone III indicates possible damage to structural or non-structural elements,
- Zone IV damages in structural elements possibly dangerous for peopple,
- Zone V corresponds to a high probability of structural failure.

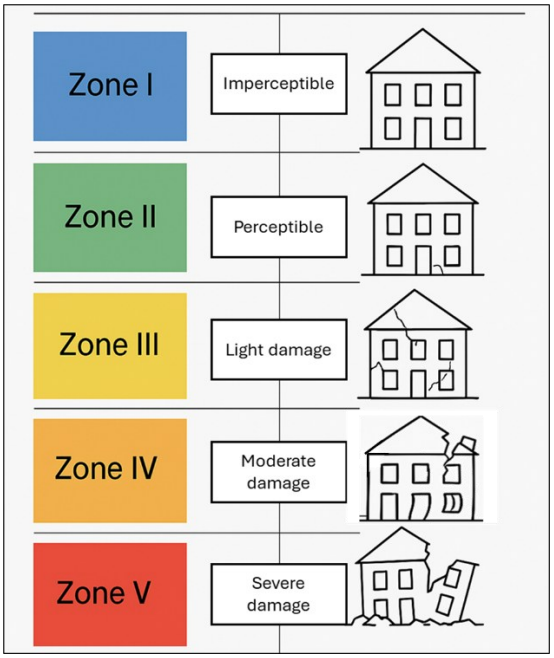


Fig. 2. Classification system SWD scales.

These zones allow for a quick diagnostic interpretation and can inform engineers, planners, and regulatory bodies about the severity of the impact and the need for further action.

It is important to note that the SWD scales are intended for initial screening and do not replace detailed structural analysis in cases of irregular, high-rise, or historically significant buildings. However, for standard residential construction, they offer a practical and repeatable method that can be used effectively in field assessments and environmental reporting.

Both scales are divided by the border lines for displacement, velocity and acceleration. Mostly because simplicity of measurements the acceleration scales are used (Fig.3.).

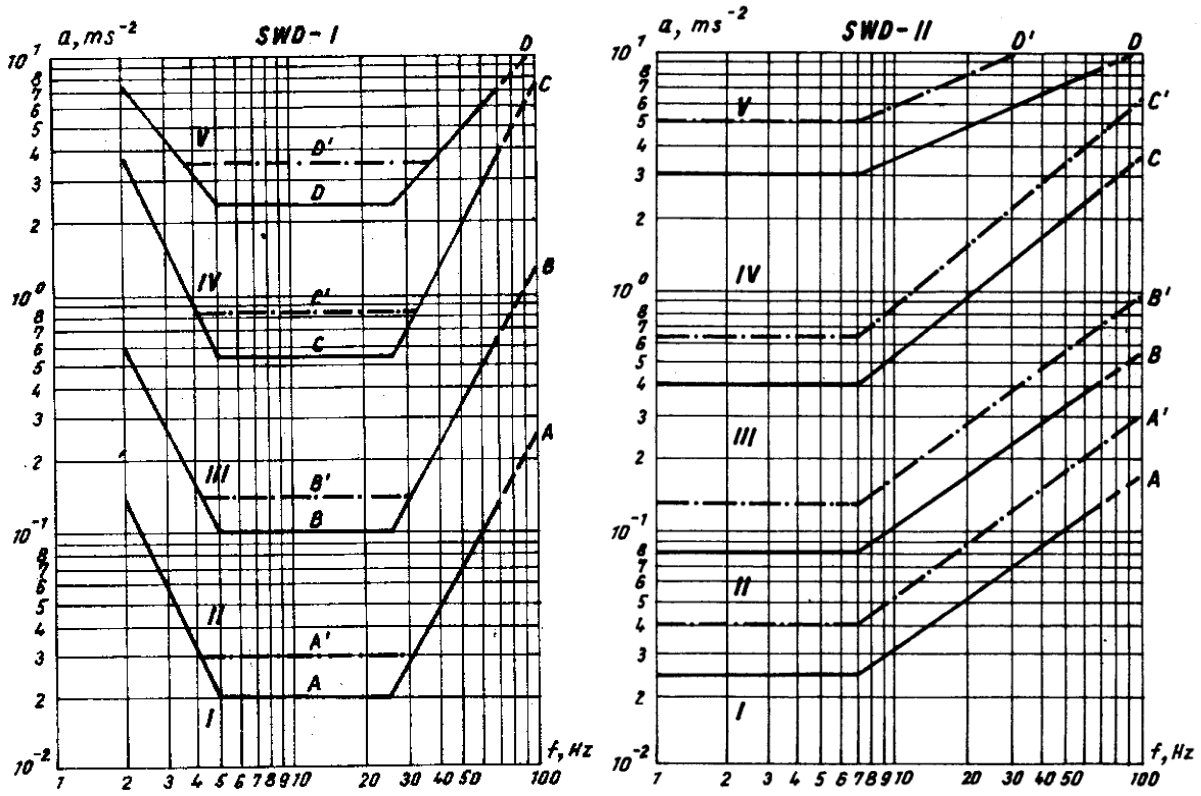

Fig. 3. SWD scales in acceleration.

As could be seen from Fig. 3 there are borders from A to D which divide the SWD zones from I to V. But there are also shown borders A' till D' which could be used in the case when building is new and the soil is typical.

**4. Case study**

Building chosen for analysis is three-storey masonry building located in Warsaw and subjected to vibrations from metro trains excitation (Fig. 4).

Fig. 4. Building chosen for analysis.

According to SWD it met SWD 2 scales conditions. The analysis of metro trains vibration influence on this building is shown in Fig. 5.

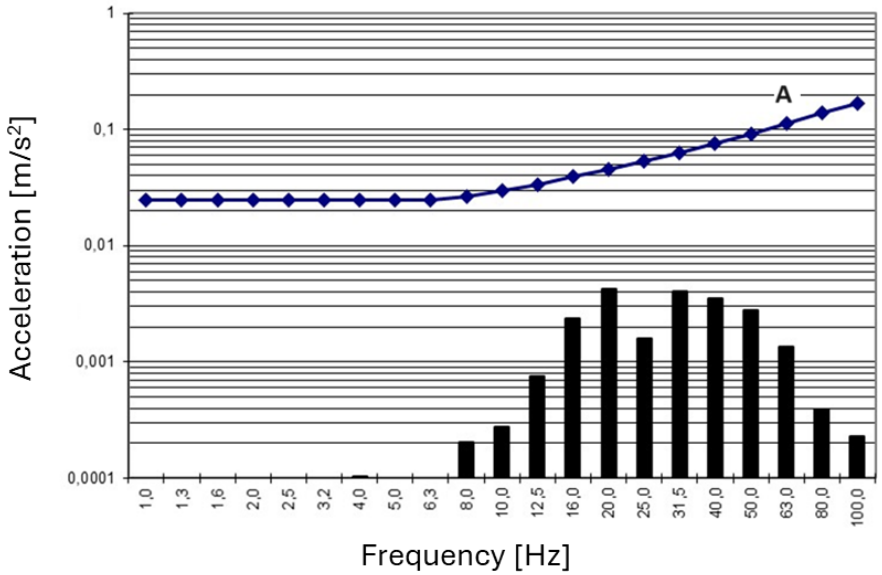


Fig. 5. The SWD analysis for selected building.

As could be seen from the Fig. 5 vibrations in all octave bands are below A border which means that there are not perceptible for building and there will be no accelerated wear because of vibrations coming from metro train passing.

**5. Conclusion**

This paper introduces and discusses the Dynamic Impact Scales SWD-I and SWD-II as simplified, experience-based tools for assessing the structural effects of ground-transmitted vibrations on buildings. Developed in the context of Polish engineering practice and aligned with the national standard [12], these scales provide a valuable alternative to full numerical simulations, particularly for masonry and prefabricated low-rise buildings.

The main advantage of the SWD approach lies in its practicality. While time history analysis combined with finite element modeling remains the gold standard for accurate assessment of dynamic structural behavior, it is often too complex, data-intensive, and time-consuming for many real-world applications. In contrast, SWD-I and SWD-II allow engineers to quickly evaluate vibration risk based on peak ground acceleration and frequency, offering a classification into five zones of increasing severity—from imperceptible effects to potential structural failure. These zones enable rapid, repeatable diagnosis of environmental vibration impacts without the need for complex simulations.

A case study of a three-storey masonry building exposed to metro train vibrations demonstrates how the SWD-II scale can be applied effectively. In this example, all measured values fell within the lowest classification zone, confirming that the vibrations were not perceptible and posed no structural concern. Such analyses, when the building meets the geometric and structural criteria of the SWD scales, can be conducted significantly faster and more easily than full dynamic studies—without compromising reliability in standard conditions.

Looking forward, further work should aim to validate the SWD method across a broader range of building types and soil conditions, including comparative studies with numerical modeling and in-situ measurements. There is also potential for adapting the scales to international contexts by adjusting thresholds and classification zones to local construction practices and regulatory requirements. Additionally, integrating SWD methods into environmental impact assessments could streamline planning and approval processes, especially in vibration-sensitive urban areas.

In conclusion, SWD-I and SWD-II fill a critical methodological gap between qualitative expert judgment and full-scale numerical simulation. They offer engineers, designers, and decision-makers a reliable and cost-effective framework for vibration assessment, suitable for both diagnostic and planning applications. Their broader international recognition and adoption could enhance vibration risk management practices in civil engineering worldwide.

**References**


1. Svinkin Mark R. “Minimizing Construction Vibration Effects”, Practice Periodical on Structural Design and Construction, 108-115 (2004).
2. A. Colaço, P. A. Costa, P. Amado-Mendes, R. Calçada, “Vibrations induced by railway traffic in buildings: Experimental validation of a sub-structuring methodology based on 2.5D FEM-MFS and 3D FEM”, Engineering Structures, Volume 240, (2021),
3. Zou C, Wang Y, Tao Z. “Train-Induced Building Vibration and Radiated Noise by Considering Soil Properties”. Sustainability. (2020); 12(3):937.
4. V. Kovrova, V. Volkova and L. Pakrastins “The impact of vibration on buildings: Problems and solutions”

   E3S Web Conf., 534 (2024) 01010
5. J. Renshaw, S. D. Holland, R. B. Thompson, J. Anderegg, “Vibration-induced tribological damage to fracture surfaces via vibrothermography”, International Journal of Fatigue, Volume 33, Issue 7, 2011, Pages 849-857,
6. Khan, M.I.M.R. and Sooriyaarachchi, H.P. (2009) ‘Vibration Induced Damage to Existing Masonry Structures Caused by Heavy Construction Activities’, Engineer: Journal of the Institution of Engineers, Sri Lanka, 42(4), p. 86-94.
7. Radnić, J., Matešan, D., Harapin, A., Smilović, M., & Grgić, N. (2012). Numerical model for static and dynamic analysis of masonry structures. Mechanics and Properties of Composed Materials and Structures, 1-33.
8. Lucchesi, M., & Pintucchi, B. (2007). A numerical model for non-linear dynamic analysis of slender masonry structures. European Journal of Mechanics-A/Solids, 26(1), 88-105.
9. M Kraszewski 2019 IOP Conf. Ser.: Earth Environ. Sci. 261 012021
10. B. Kożuch and T. Tatara, Impact of the vibrations on the environment caused by passages of trains at variable speed

    E3S Web Conf., 10 (2016) 00047
11. J. Pyra and A. Sołtys, “Method for studying the structure of blast-induced vibrations in open-cast mines,” Journal of Vibroengineering, Vol. 18, No. 6, pp. 3829–3840, Sep. 2016,
12. PN-B-02170:2016: Evaluation of the Harmfulness of Building Vibrations Due to Ground Motion
13. DIN 4150-3:2016-12, Vibrations in buildings - Part 3: Effects on structures
14. BS 7385-2:1993, Evaluation and measurement for vibration in buildings Guide to damage levels from groundborne vibration
15. D. D’Ayala, Assessing the seismic vulnerability of masonry buildings, Editor(s): S. Tesfamariam, K. Goda,

    In Woodhead Publishing Series in Civil and Structural Engineering, Handbook of Seismic Risk Analysis and Management of Civil Infrastructure Systems, Woodhead Publishing, 2013,
16. Cosenza, E., Del Vecchio, C., Di Ludovico, M. et al. The Italian guidelines for seismic risk classification of constructions: technical principles and validation. Bull Earthquake Eng 16, 5905–5935 (2018)