Protection against vibroacoustic impacts on example of high-tech research centre

PhD
MARTA KNAWA-HAWRYSZKÓW
Wrocław University of Science and Technology
Faculty of Civil Engineering
ORCID: 0000-0003-0413-8130

In this paper the elastic support of building structures is discussed as one of the advanced technical solutions for protecting buildings against vibrations and structure-borne noise. Two of several possible variants of solutions are described on the example of special-purpose facility built in Cracow, Poland.

In the conditions of heavy urban traffic and well-developed rail infrastructure in cities (tramways, railways or metro lines) there is an increasing need to protect buildings and people staying inside buildings against vibrations and structure-borne noise [1–2]. In the case of buildings with special functionality and utility purposes, equipped with technical precise machines or specialized vibration-sensitive devices, such protection is also required [3]. Therefore the assessment of the risk of adverse vibroacoustic influences should be considered in relation to: I) the building structure, because vibrations imply additional dynamic forces acting on the structure, II) people inside buildings regarding their health and comfort, III) vibration-sensitive devices that need to work without any external disturbances. Depending on the type of the vibration source, soil and groundwater conditions, terrain configuration and the building structure, the range of the impact zone may be on average [4]: a) approx. 80 m (in individual cases up to 100–120 m) for a rail line of a freight or mixed freight-passenger trains, b) approx. 65 m for a rail line of passenger trains, c) approx. 25 m (in unusual cases up to 30–35 m) for tram line, d) approx. 40 m for metro line, e) approx. 25 m for a road. The range of the impact zone in case of vibration-sensitive equipment should be determined individually.

The Vibration Criterion (VC) curves, developed in the early 1980s by Ungar and Gordon [5], define the requirements which need to be met for certain types of sensitive equipment to be used in the specific area. The comparison of the data acquired from the measurements and the curves is typically done for the RMS (Root Mean Square) value of the total vibration velocity integrated over the 1/3 octave bands within the frequency range 1–80 Hz. The highest VRMS over this range determines the actual VC range for the tested area. Figure 1 shows VC curves and limit velocity values which are required in order to satisfy defined vibration criteria. The VC curves are commonly used in the assessment of the ambient vibration of facilities with vibration-sensitive instruments or devices localized inside [6].

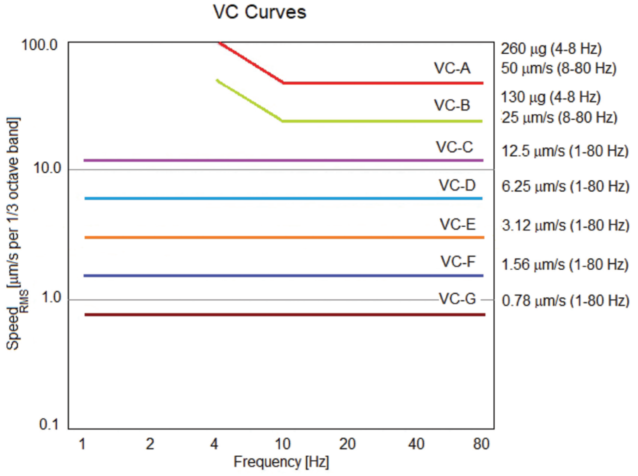

Figure 1. VC curves for vibration-sensitive equipment (by Ungar and Gordon [5])

Arch. author's archive

It is very important to identify the problem of the vibration influence on contemporary, newly built facilities in advance and to apply a comprehensive approach to this issue. It involves the correct identification of the existing source or the evaluation of the expected source of vibroacoustic impacts that is designed in the same time as a building or it is planned in the nearest future. These are design tasks, in which dynamic characteristics of the vibration sources are recognized on the basis of results of in-situ measurements and the prognosis of emissions using the collected database [7].

Technical solutions and mitigation measures

Nowadays, protecting buildings against vibrations and structure-borne noise (secondary air-borne sound) is possible owing to the existing economic conditions and the high level of technology. Structure-borne noise occurs when vibrations generated by the internal or external source can propagate through the building structure or through the ground into the building foundations and after that can be transmitted to other structural elements. It excites structural members to vibrate and it is re-radiated as the secondary air-borne sound. To reduce such influences, there are many technical solutions and mitigation measures available, and the primary common task is to provide effective protection meeting the determined requirements. It is also a challenge to assure an optimized and long-lasting solution. Well-developed technology used for this purpose is the resilient foundation of buildings on elastic elements. The elastic support is a passive method of the vibration reduction, i.e. undertaken directly at the “recipient” (contrary to an active method undertaken at the vibration source, e.g. in a construction of railway track).

In the case of typical external vibration sources as rail traffic (trains, trams, subways) and road traffic, there are a few possible options of the elastic support of buildings. The application depends on type and use of the building. It differs in the size of separated structure area and in the system of the execution. In Fig. 2 six different variants of the elastic support are presented [8], mainly implemented in the buildings' structures. As a rule, protected areas of the building must be separated completely by a flexible layer (marked in blue) to avoid the transmission of vibrations and structure-borne noise (marked by red arrows). These parts of the structure that need to be insulated should be separated from unprotected ones, whether by adjacent substructure or subsequent building components. Only option (3) shown in Fig. 2 is an exception in this respect.

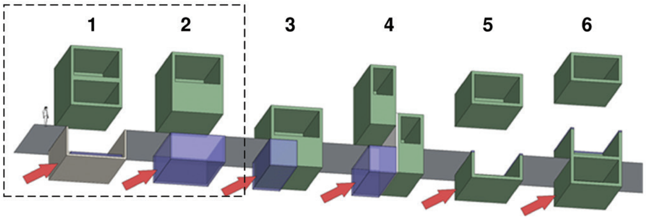

Figure 2. Different variants of buildings protection using elastic support technique [8]

The example of protection against vibration presented in this paper is the elastic support performed according to options (1) and (2) shown in Fig. 2. The underground part of the building (a technical tunnel) is elastically supported in a foundation concrete cage and the rest of the building is insulated over the entire surface of the foundation slab. The building structure must be insulated from the surrounding ground to assure protection against the vibrations transmission into the building. The variants applied in the considered structure are less complicated than other options, both in the dimensioning and execution phases. The presence of an elastic layer has almost no effect on the building structure. Therefore it is also a suitable solution if the need of protection is recognized in a very late stage of the project, because it can be still applied without major changes in the already designed structure.

Example of implementation – National Synchrotron Radiation Centre "Solaris"

Synchrotron is a device that finds a wide range of applications in interdisciplinary researches, in many fields of science: physics, chemistry, materials science, geology, mineralogy, biochemistry, pharmacology, biology and medicine. It can be used to carry out investigations that cannot be performed using other sources of electromagnetic radiation.

The National Synchrotron Radiation Centre "Solaris" is localized at the Third Campus of the Jagiellonian University in Cracow, Poland. It is equipped with the third generation synchrotron, which has a circumference of 96 m. There are several dozen such devices in the world – most in Japan and the USA. The synchrotron in Cracow is similar to the very modern one in Sweden. It is located in a building which consists of three main segments (Fig. 3):

- segment A – technical tunnel (approx. 20 m × 64 m), housing an electron source, pre-accelerator (linear accelerator), booster-synchrotron and storage and technical facilities,
- segment B – 3-storey (with one underground) administrative and social part of the building,
- segment C – synchrotron hall with storage ring and research stations (approx. 50 m × 60 m).

The highly specialized and very sensitive research equipment is installed in the building. The correct operation of the research equipment depends on the vibration level in its direct vicinity. Then in the design process the subject of protecting this building against vibrations was one of the priorities. There were several different sources of mechanical vibrations and structure-born noise taken into consideration: I) external (urban traffic, passage of vehicles on local roads – up to 10 m from the building, power transformers, media flow in underground pipelines and fast tram line being under construction) and II) internal (media discharge, operation of power transformers, devices such as fans, compressors, pumps, air conditioners etc.). In order to protect the building against vibrations transmitted through the soil, the elastic support technique was implemented. Requirements related to the accepted vibration level in the building were very high. Permissible amplitudes of vibrations below 1,6 m at frequencies up to 10 Hz and below 0,3 m at frequencies up to 50 Hz were expected. The accepted values of the vibration velocity (the resultant of three directions) were below the value 0,0001 m/s. To fulfill such requirements, a complex analysis was undertaken. First of all, the background of the dynamic impacts was examined on the basis of measurements in the area of the building foundations. Then the numerical analysis of the entire building was made, assuming 3-D model of the building and using the Finite Element Method (FEM). As the result of the adopted assumptions and performed analyses, the application of anti-vibration materials was recommended.

Segment A of the building was protected in a way described in option (1) – using the elastic support in a concrete cage (see Fig. 4). For the horizontal vibration insulation on the level -8.20 m (marked in blue in Fig. 4, detail B), one-side profiled, 30 mm thick elasto-

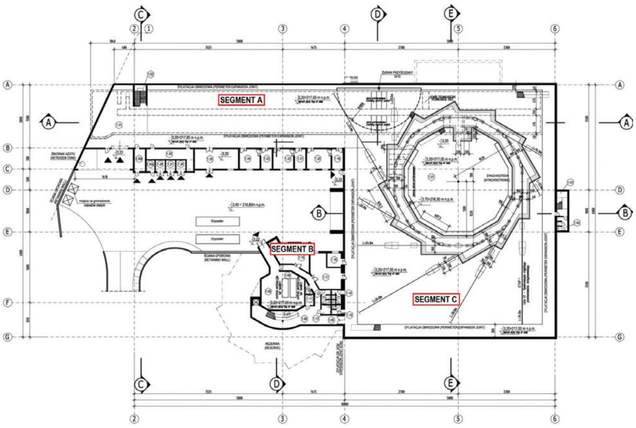

Figure 3. Plan view of the building "Solaris" (level - 3.20 m) [9]

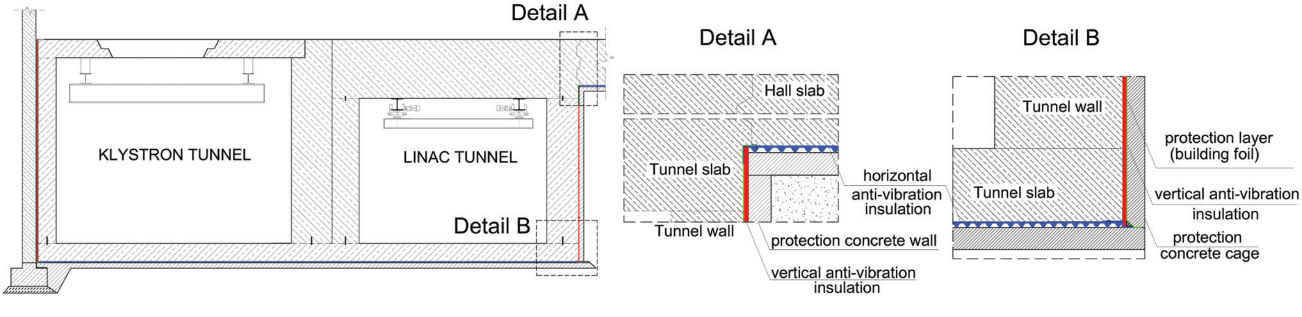

Figure 4. Solution of anti-vibration insulation of the technical tunnel (segment A)

Figure 5. Installation of anti-vibration mats in segment A of the building: building-site overview; horizontal anti-vibration insulation; vertical anti-vibration insulation protected with foil

meric mats Cibatur were selected. The strong advantage of elastomers is that the properties can be created in a way ensuring an optimal vibration-, emission-response, immission protection by different material compositions, geometrical shapes (profiles) or geometrical dimensions. The specific geometric design of mats used in this project, having truncated cone-shaped studs on the underside, is that the local transverse tensile forces cancel each other vectorially. It provides even transfer of the vertical load and more controlled deflection behaviour in comparison to homogenous mats – especially if large areas are insulated. Moreover, the characteristic feature of the material is a slight variation of the natural frequency values over a wide range of compressive stresses. Due to the fact that much smaller stresses were obtained due to the horizontal loads, the vertical anti-vibration insulation layer (marked in red in Fig. 4, detail B) was made of homogenous elastomeric mats, which have a lower load capacity and consist of closed-cell cellular rubber.

Under the concrete slab of the synchrotron hall (segment C), on the level -3.70 m, horizontal vibration insulation was installed as described in option (2). On the walls, separating segment C from the environment, anti-vibration mats were installed to the height up to the ground level (marked in red in Fig. 4, detail A). The assumption of using such protection measures in numerical analysis (prognosis of the vibration immission) resulted in the predicted vibration velocity value 0,000062 m/s in a whole range of frequencies (0–100 Hz) – much more lower than the permissible 0,0001 m/s. Predicted amplitudes of vibrations were also below permissible levels required in the project.

Also technical solutions of protection against vibration produced by internal sources including: electric power generators, machines and devices (fans, compressors, pumps), ventilation and air conditioning equipment etc., were applied inside the building. These units were installed on foundations/slabs isolated from the floor by the elastic support as well.

The building execution phase also deserves a short mention. The structure was erected and protected in stages, paying special attention to the details on the building site. In order to prevent acoustic bridges during concreting, which negatively affect the effectiveness of the vibration insulation, all joints with the horizontal and vertical anti-vibration mats and the connections of mats' sheets were carefully protected. In Fig. 5. photos from the building site present an overview of the segment A and anti-vibration mats installed over the vertical and horizontal surfaces of the concrete cage.

All implemented technical protective measures assure that the effect of mitigation of vibrations and structure-borne noise within the building is satisfactory. Control measurements after the realization of the research centre revealed that the finally achieved effects are close to the requirements defined by VC-B curve (see Fig. 1). Solution of this crucial issue ensures exploitation of the building (see Fig. 6) consistently with the intended use and in a long-term perspective.

General conclusions

The increasing intensity of sources of dynamic influences in the human environment together with the general awareness about the problem of protection against noise and vibration calls for better recognition of each individual situation in which this protection is needed. The evaluation should result in the usage of effective, modern mitigation measures. The technical solution to apply, which is based on the assessment of dynamic impacts and the prognosis of immission, can be optimized adequately to the needs, possible implementation conditions and necessary financial outlays. If the problem is identified in time and taken into account at the early stage of the investment, financial resources required to solve it can be included in the budget. The anti-vibration insulation planned in advance, correctly assessed and realized reliably is definitely more economic. Protection of buildings after the completion of construction is always more complicated and expensive impossible. From the point of view of the sustainable development postulate promoted in civil engineering, techniques used to protect facilities exposed to noise and vibration influences should bring long-term social and economic benefits. It is then a part of performance-based management of the investment.

The presented method of the protection against vibrations of the "Solaris" research centre constitutes the example of rational approach to the considered problem and reflects the appropriate application of the elastic support technique. The solutions based on in-situ measurements, numerical analyses and prognoses of the dynamic impacts (existing and being under construction), reliable execution of the anti-vibration insulation and use of high-quality, durable materials, led to very satisfactory results in reduction of the ground- and structure-borne vibrations. Meeting the relevant requirements regarding limit values was confirmed in the control measurements.

Acknowledgements

Acknowledgements to Probadex Kraków and Jordahl & Pfeifer companies, and Institute of Building Mechanics of Cracow University of Technology for a cooperation on the project of NSRC "Solaris".

References

[1] Clemente P., 1995, Traffic-induced vibrations on structures, Proceedings of IABSE Symposium "Extending the Lifespan of Structures", IABSE, Zurich, Vol. 2, p. 1111–16.

[2] Connolly D.P., Marecki G.P., Kouroussis G., Thalassinakis I., Woodward P.K., 2016, The growth of railway ground vibration problems – a review, Science of The Total Environment, Vol. 568, p. 1276–1282.

[3] Sitharam T.G., Resmi S., Febin F., 2018, Vibration isolation of buildings housed with sensitive equipment using open trenches – case study and numerical simulations, Soil Dynamics and Earthquake Engineering, Vol. 115, p. 344–351.

[4] Stypuła K., Kozioł K., 2016, Vibration influence on building design, Builder, No.12, p. 98–102 (in Polish).

[5] Ungar E., Gordon C., 1983, Vibration Challenges in Microelectronics Manufacturing, Shock and Vibration Bulletin, Vol. 53 (I), p. 51–58.

[6] ISO/TS 10811-2, June 2000, Mechanical vibration and shock - Vibration and shock in buildings with sensitive equipment. Part 2: Classification, the International Organization for Standardization.

[7] Yanga J., Zhua S., Zhaia W., Kouroussis G., Wangc Y., Wanga K., Lanc K., Xu F., 2019, Prediction and mitigation of train-induced vibrations of large-scale building constructed on subway tunnel, Science of The Total Environment, Vol. 668, p. 485–499.

[8] Müller-Boruttau F., 2009, Elastische Lagerung eines Gebäudes mit elastischen Elementen von Calenberg Ingenieure. Teilflächige Gebäudelagerung unter widrigen Umständen, Proceedings of Seminar „Protection buildings against vibration", Wrocław, Poland.

[9] Project of National Center of Electromagnetic Radiation for Research Purpose in the area of Revival's 600th Anniversary Campus of Jagiellonian University in Cracow, Discipline: Architecture, Drwg. no 565–10: Level -3.20, Probadex-Kraków.

[10] https://synchrotron.uj.edu.pl/dla-gosci-i-mediow/zdjecia-do-pobrania.

DOI: 10.5604/01.3001.0014.8838

CORRECT QUOTATION FORMAT
Knawa-Hawryszków Marta, 2021, Protection against vibroacoustic impacts on example of high-tech research centre, „Builder" 6 (287).
DOI: 10.5604/01.3001.0014.8838

Abstract: In this paper the elastic support of building structures is discussed as one of the advanced technical solutions for protecting buildings against vibrations and structure-borne noise. Two of several possible variants of solutions are described on the example of special-purpose facility built in Cracow, Poland. The specificity of the building of the "Solaris" research centre is the use of high-tech measurement technologies and vibration-sensitive equipment. Then a restrictive criterion of the permissible level of vibroacoustic impacts on the building was set at the early design stage. To ensure effective reduction of vibrations transmitted through the ground, the necessary activities are described. The protection method by using appropriate mitigation measures (anti-vibration materials) is shown. The presented example draws attention to the problem of a rational and comprehensive approach to the subject of protection against vibrations, which is part of the concept of sustainable development in civil engineering.

Keywords: elastic support, sensitive devices, vibroacoustic impacts, anti-vibration insulation

Figure 6. Outside view of the "Solaris" building and high-tech sensitive equipment inside [10]

Streszczenie: OCHRONA PRZED ODDZIAŁYWANIAMI WIBROAKUSTYCZNYMI NA PRZYKŁADZIE OBIEKTU CENTRUM BADAWCZEGO ZAAWANSOWANYCH TECHNOLOGII. W artykule omówiono technikę elastycznego posadowienia konstrukcji budowlanych stosowaną jako jedno z zaawansowanych rozwiązań w zakresie ochrony budynków przed drganiami i hałasem wtórnym. Dwa z kilku możliwych wariantów rozwiązań zaprezentowano na przykładzie obiektu specjalnego przeznaczenia do celów badawczych, wybudowanego w Krakowie. Specyfiką ośrodka badawczego „Solaris" jest używanie nowoczesnych technologii pomiarowych oraz najwyższej jakości aparatury wrażliwej na drgania. Zatem na etapie projektowania postawiono restrykcyjne kryterium dopuszczalnego poziomu oddziaływań wibroakustycznych na budynek. W pracy opisano konieczne działania w celu zapewnienia skutecznej redukcji drgań przenoszonych przez grunt. Zaprezentowano sposób zabezpieczenia konstrukcji poprzez zastosowanie odpowiednich materiałów wibroizolacyjnych. Przedstawiony przykład zwraca uwagę na problem racjonalnego oraz kompleksowego podejścia do zagadnień ochrony przed drganiami, wpisującego się w koncepcję zrównoważonego rozwoju w budownictwie.

Słowa kluczowe: elastyczne posadowienie, czuła aparatura, oddziaływania wibroakustyczne, izolacja przeciwdrganiowa