A Computer simulation of noise of construction machinery operating in parallel

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Abstract. Prolonged, repeated or very intense noise exposure can damage human health. To reduce any dangerous effects of noise on human health, policies and restrictions are enshrined in national law and legislative regulations. In the Czech Republic, this issue is subject to the Ministry of Health. In other states it can be the Ministry of Health or more often the Ministry of the Environment. The protection of human health against noise and vibration is enshrined in Act No. 258/2000 Coll., on Protection of Public Health, specifically in §§ 30-34 of this Act. Other restrictions are described in Act No. 309/2006 Coll., which regulates other requirements for safety and health protection at work in labour relations and on ensuring safety and health protection in activities or the provision of services outside of labour relations. Furthermore, hygienic limits for workplaces, protected indoor areas of buildings and protected outdoor areas are set in the new Regulation of the Government of the Czech Republic, No. 272/2011 Coll. as amended. This Regulation also sets limits for construction noise. They set limitations in so-called outdoor protected areas and the so-called outdoor protected areas of buildings. The hygienic limit of the equivalent sound pressure level A for noise from construction activities is set here by adding a correction of 5dB or 15dB according to the type of protected space to the basic value of the equivalent sound pressure level A 50dB. This limit must be adhered to. For buildings nearby, the term „protected facades“ is used, i.e. „protected façades“ include the nearest buildings that are inhabited and their occupants could be exposed to noise for a long period of time. We can measure the intensity of noise in these places if we have a "sound level meter". Predicting the intensity of noise and its longevity for future construction is more challenging. The computational evaluation of the noise load of the outdoor area of the monitored territory is based on the recommended theoretical acoustic relations for the transmission of sound from stationary noise sources according to ČSN ISO 9613/1-2. One of the possibilities of calculating the intensity of noise is the application of software programmes used for determining traffic noise, which, in contrast to construction noise, is handled very carefully and predicted in detail during the construction of transport infrastructure. Because here are the values and methodologies for the calculation of noise indicators set correctly and in detail, it is possible to use them also, provided that we work well with the background and input data. The calculation indicators are the values of the equivalent sound pressure level falling in front of the façade, on which we determine various measuring points. If the noise sources and acoustically significant elements are entered correctly, we obtain both correct values and also the possibility of displaying a map of the area with colour isophones, which expresses the level of noise in the construction site and its surroundings.
1. Introduction

Part of the construction planning is always a design of used construction machinery and so-called machine assemblies. The machines in the machine assemblies usually work in parallel during the construction process. In the case of processes involving construction machines with a high sound pressure level, excessive noise pollution can occur in the environment. Health protection is enshrined in government laws and regulations. Noise pollution in the area is being monitored, modelled, measured and evaluated. The modelled and measured values are compared with the allowed limit. If the values exceed, suitable measures are then defined.

The protection of human health against noise and vibration is enshrined in Act No. 258/2000 Coll., on Protection of Public Health, specifically in §§ 30-34 of this Act. [1]

Other restrictions are described in Act No. 309/2006 Coll., which regulates other requirements for safety and health protection at work in labour relations and on ensuring safety and health protection in activities or the provision of services outside of labour relations (Act on Ensuring Additional Conditions of Safety and Health at Work) [2]. In the case of noise and vibration, securing this protection must be given numerically in order to be controllable and measurable.

Furthermore, hygienic limits for workplaces, protected indoor areas of buildings and protected outdoor areas are set in the new Regulation of the Government of the Czech Republic, No. 272/2011 Coll. as amended. [3]

This Regulation sets limits within each category. One of the categories is the noise from construction site, but we also evaluate other areas of noise pollution e.g., aircraft noise or noise from the traffic and highways. In the case of noise from construction site, we look at the noisiness caused by the usage of construction machinery.

Areas are determined for which the detected noise is evaluated in relation to the limit values. They set limitations in so-called outdoor protected areas and the so-called outdoor protected areas of buildings. The outdoor protected areas are determined open areas, outdoor protected areas of buildings are defined by the contour line of residential buildings near the construction site. However, this line is suspended 2 meters in front of the façade. If it was laid closer to the façade, the exact values would be affected by the reflection of sound from the measured façade. In the mentioned government regulation, we can find particular hygienic limits, which differ according to the type of protected area and which also differ according to the area of noise origin, all being divided by the time periods of the day.

The noise pollution affecting the inhabitants of the surrounding buildings must not be evaluated within one random measurement per day or night, but for the entire period of time specified in the government regulation [3]. For construction work and work with machines, we usually do not include the night-time, but only the time of day, specifically a period between 7 to 21 o’clock. For this time period, the so-called equivalent sound pressure level is compared with the limit. In addition to the above-mentioned government regulation [3], the precise methods of measurement and evaluation are also set out in a methodological guide [4].

The hygienic limit of the equivalent sound pressure level A for noise from construction activities is set here by adding a correction of 5 dB or 15 dB according to the type of protected space to the basic value of the equivalent sound pressure level A 50 dB. This limit must be adhered to. For buildings nearby, the term „protected facades“ is used, i.e. „protected façades“ include the nearest buildings that are inhabited and their occupants could be exposed to noise for a long period of time. [3]

2. Possible modelling and measuring of the acoustic situation during a construction

Adherence to the limit must be ensured by the construction contractor. The contractor can measure the intensity of noise at required locations if he has a “sound level meter”. The limit can be controlled by their own technical measurements, furthermore the control body Regional Hygiene Station can use their accredited measurements [4].
If the construction is already ongoing and the values of noise measurements are found to be above-limit, it is quite problematic for the contractor to react. From economic, organizational and time-management perspective it is preferable to propose adequate corrective measures if he had known the acoustic situation of the construction beforehand.

To predict the noise intensity and its longevity for planned construction is challenging. The computational evaluation of the noise load of the outdoor area of the monitored territory is based on the recommended theoretical acoustic relations for the transmission of sound from stationary noise sources according to ČSN ISO 9613/1-2. [5]. The proximity of surrounding buildings, their position and height, terrain configuration, properties of the ground surface and also climatic conditions, for example, can have an impact. The construction contractor usually does not have a suitable worker with knowledge of physics and acoustics to help him calculate the model situations. He can therefore use any from various software programmes where the calculations are user-friendly and simulations would be as close as possible to the reality of the construction in question.

One of the options of calculating the intensity of noise is the application of software programmes used for determining traffic noise, which, in contrast to the construction noise, is handled very carefully and predicted in detail during the construction of transport infrastructure. Because here are the values and methodologies for the calculation of noise indicators set correctly and in detail, it is possible to use them as well, provided that we work correctly with the background and input data. The calculation indicators are the values of the equivalent sound pressure level. For example, technically and economically available software programme is Hluk+ (Noise+) [6].

The main prerequisite for successful modelling of the future acoustic situation is the knowledge of noise-significant mechanisms and their parallel use in construction.

If the construction site is known, it is possible to use, for example, publicly accessible addresses of map materials [7], which offers a bird's eye view function with the possibility of rotation and tilt, as shown in (Figure 1). This function allows us to define the position and height of the surrounding buildings and greenery in case we do not have this data from the project documentation or if we cannot conduct a local survey.

![Figure 1. Possibility of visualization of the future construction site in on website map [7, 8]](image)

3. Computer simulation of noise

If the contractor decides to use the Hluk+ software [6] to simulate the future acoustic environment of the construction site, he must prepare quality background data. In order to be able to model the situation, he must know the value of the sound power or the sound pressure level at a certain distance for the source in question. This value must be found in the product sheets provided by the manufacturer of the machinery.
It is necessary to know the positions of the machines in use combined, which need to be determined while planning the construction according to the correct technological methods. While it can be included in the documentation only as text descriptions, we can find also drawings, e.g. in a drawing of a construction site equipment, as shown in Figure 2. From Figure 2 to Figure 9 we can see screenshots from SW Hluk+ during modelling.

**Figure 2.** Drawing of construction site equipment with indicated crane position, concrete pump and concrete mixer [8]

Subsequently, it is necessary to define acoustically significant elements such as buildings and greenery, including their height, to model a specific situation in this bitmap framework. An example of this step is shown in (Figure 3). Both buildings and absorbent surfaces are numbered and can be edited.
Figure 3. Entering acoustically significant elements in a construction site situation [8]

The next step is to define the sources of noise, for which it is necessary to know the position of the machine and also its noise intensity. This can be found in the technical data sheets of the specific machines, namely the $L_{WA}$ sound power level (dB). It is also necessary to define the height of the noise source in the model, not only its position.

Position the building machine as source of noises is in model marked with violet colour and in setting SW Hluk + stated as it is called industrial source, how we see in the figure 4. Figure 5 is presentation generated table of field entering SW Hluk + with selected 3 industrials sources incl. exact coordinates and the level of acoustic pressure in dB.
The next step is to determine the reception points, i.e., the points for which we want to perform a calculation. In the case of outdoor protected areas of buildings, the points are usually close angles of facades with window openings. All the measuring points are marked with numbers. After the calculation a value of the equivalent sound pressure level LAeq (dB) is assigned to each number.

We perform a calculation for each of the measuring points. For the selected calculation, the table of values is displayed directly on the screen of the modelled acoustic situation, as can be seen in Figure 6. The noise limit value for day hours between 7–21 is 65 dB, and according to the table in Figure 6 we can see that the limit is exceeded in point 2, 3, 4, 5, 6 and 9.
Figure 6. Example of design of possible measuring points with a table of values [8]

Figure 7. Drawing of isophones while using colour bands [8]

We get a better idea of the acoustic situation if we have the individual bands for isophone levels displayed in colour, as shown in (Figure 7), using a colour scale, where one band has a range of 5 dB. Blue colour shows values above 65 dB.
Using the colour isophones showing the whole situation in question, the processor acquires an overview of the overall acoustic situation in a visualized form and thus can respond better to the refining of the model situation in critical areas. If the author has the whole concept of construction site in front of him, he can better simulate the real most unsuitable positions of construction machines in relation to specific measuring points. He can thus design a more suitable localization of machines which is more advantageous for noise reduction, but concurrently the technicalities of the construction will not be affected. At the same time, various precautions can be proposed, e.g., noise barriers, and the calculations can be edited. If we want to take into account the additional modification of the environment in the given modelling, as for example by including the mentioned noise barrier, we will design it in the exact length and height in the programme and place it in the model situation as assumed.

Sometimes it is appropriate to remove the background from the model after entering all acoustically significant elements, working and editing of the objects is then clearer. The position of the noise walls is also easier to read, as we can see in (Figure 8).

![Figure 8. Model of the acoustic situation of the construction site after removing the bitmap base [8]](image-url)
4. Results and discussions
After the editing followed by a recalculation, it is possible to compare the acoustic situation of the whole environment in respect to specific measured points. (Figure 9) shows the acoustic situation of the construction site after the addition of the noise barrier in order to reduce the noise values at the measured points 1, 2, 5 and 6. If compared with (Figure 7), the difference is visible.

![Figure 9. Drawing of isophone bands after inserting a noise barrier [8]](image)

5. Conclusions
For the purposes of noise simulation and its modelling, generally any available software for calculating noise in the outdoor environment (for road, rail and air transport) can be used, as long as we adhere to and work with correct values of input data and if we take into account the specifics of construction activities in specific acoustic situations.

While working with construction machinery, the equivalent sound pressure level must not exceed the limit values according to government regulations [3]. If the acoustic situation of the construction site and the surrounding areas is modelled, it is possible to simulate the situation where we use any embedded elements can function as an acoustic barrier. This way, the noise pollution can be effectively reduced and this reduction be quantified.

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