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A SUSTAINABLE ALTERNATIVE FOR RAILROAD NOISE BARRIER

UDK: 656.2+502/504

SUMMARY:

Noise barriers are structures that inhibit the direct transmission of airborne noise emitted by traffic. They play an important role along railroad lines to protect residential areas from high noise pollution. Noise barriers are currently made of very energy-intensive materials such as concrete, glass, aluminum, impregnated wood, etc. In addition to the high costs and large amount of energy input during construction, a recycling process is rarely possible when the noise barriers should be replaced or demolished. Therefore, it is necessary to develop inexpensive and sustainable alternatives. With its low primary energy requirement, regional availability and complete recyclability, loam can be a best suitable alternative. Loam is produced in large quantities as excavated material during railroad and road construction. Hence, rather than disposing excavated material expensively, the direct utilization of it should be found out. In addition, loam offers an optimum sound insulation because of its mass and porous surface. The study identified and compared possible noise barriers techniques using loam. This contribution gives insight into (i) the building techniques could be suitable for noise barriers; (ii) the standards and regulatory frameworks as well as (iii) lifecycle costing and advantage of loam noise barrier as compared to the conventional ones.

Key words: Railway Infrastructure, loam, circular economy, excavated soil

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1. INTRODUCTION

Traffic noise is one of the major environmental nuisances. It increases drastically with increasing mobility. In Austria, there are numerous regulations governing noise abatement measures. In the case of active noise reduction, infrastructure operators primarily rely on structural measures at the noise source. In this regard, the Austrian Federal Railway, ÖBB Infrastruktur AG, for example, has built 950 kilometers of noise barriers along railroad lines. Over the past ten years, ÖBB has invested more than 20 million euros per year in noise protection measures (ÖBB INFRA, 2023). There are 1.393 km long (4,66 square kilometers) noise barriers along Austrian motorways and expressways (ASFINAG, 2020).

Noise barriers are mostly made of aluminum, concrete, wood, glass, gabions or a combination of those. In general, the construction sector requires enormous amounts of resources that accounts for about 50 % of all excavation material. The sector is responsible for over 35 % of total waste generation, 40 % of energy consumption and 36 % of greenhouse gas emissions in the EU (EC, 2022, EURACTIV, 2019). Life cycle assessment and ecoprofile comparison of noise barriers (4 m x 3 m) made of lava concrete and wood (Werner, 2019) shows that the cumulative primary energy consumption over the whole life cycle for concrete is 12726,7 MJ, for wood 10616 MJ as well as in terms of greenhouse gas emissions 895,7 kg CO2-eq and 176,4 kg CO2-eq respectively. The hot-spot analysis in the study shows that for wood, copper cover makes a total contribution of 60 % of the environmental impact points, with the subcategories of "heavy metal emissions" and "air emissions" and "land occupancy" being the main contributors. For concrete, the highest contributions are caused by the subcategories "global warming potential," various "emissions to air and water" from energy production, and "use of fossil energy resources." cement is the most significant contributor. The construction industry is urgently seeking ways to achieve sustainability and is pinning its hopes on new construction using recycled or renewable building materials.

One of the most promising materials for a sustainable construction is clay. Clay is one of the oldest building materials and has been used for thousands of years. Clay is available in almost all parts of the world. Clay is also produced as a waste product in road and rail construction that is deposited. However, instead of disposing of the excavated material at high cost, it could be used as a building material in a completely climate-neutral way. Clay can be 100 percent recycled and reused and is suitable for circular economy. This would have a positive effect on overall construction costs. Furthermore, clay is considered a particularly suitable nesting material for various insect species, which can contribute to the preservation of species and biodiversity. Clay is non-flammable, anti-allergenic and mold-inhibiting due to its pH value. Due to its permeable (porous and open to diffusion) structure, it also has a good acoustic behavior (Knapp, 2022). Although the use of clay to build houses or to seal foundations and walls is one of the oldest and most natural processes in construction, clay has not yet become a suitable alternative as a building material for noise barrier construction. The objectives of this contribution are to show to which extent clay can be used as an alternative sustainable building material for noise barrier construction. During the explatory study, the following research questions could be investigated: (i) which clay technologies can be considered and built as prototypes, (ii) which technical requirements and framework conditions in noise control construction in the railway system are to be considered, (iii) how the technical and economic efficieny of the clay noise barrier differes from the conventional ones.

2. METHODS

To answer the above research questions: an intensive literature review was conducted. That was strengthend by discussion with experts both from the field of railways (from Austrain and German Federal Railways - ÖBB and DB) as well as from clay construction fileld. This was implemented by organizing two expert's workshops. Moreover, statistical and acoustic calculations were performed followed by prototype development and simulations.

First general legal requirements (national and international (EU)) for specific construction measures were assessed. Furthermore, it is analyzed how far the legal basis can be adapted to noise protection construction made of clay. In the case of technical requirements, specific characteristics of clay construction as a noise barrier and its application in railroads are considered. Through an intensive exchange with stakeholders from the field, the framework conditions and possible synergies for the implementation of clay as a noise barrier in railroads are identified.

The project furthermore analysed clay construction techniques and their suitability for the puropose as noise barriers. The construction techniques such as tamped clay, cob walling, clay bricks, as well as composite clay are considered. The calculation of load carrying capacity as well as serviceability of the noise barriers in relation to the exerted mechanical loads such as wind load, aerodynamic loads due to train speed were calculated in rference to EUROCODE.

Those construction techniques are analysed and compared based the parameters such as stability (height-to-width ratio, maximum height, risk of tipping over, foundation, etc.); load-carrying capacity in Load-bearing capacity in relation to the pressure and impact of passing trains as well as weather resistance. Furthermore, a simplified life cycle cost (LCC) analysis is performed to compare the economic viability of clay noise barriers to the conventional noise barriers.

3. RESULTS AND DISCUSSION

3.1. Railroad noise barrier technical requirements

Noise barriers used in rail traffic have different requirements than those used on highways. Dynamic loads from pressure-suction effects, their fatigue effectiveness and resonance effects, design specifications, standards and guidelines on acoustic properties and stability are different from those for highways.

The operational and technical specifications specific to railroads are regulated by various national and international standards. In Austria, the following standards apply: (i) clearance gauge regulated by EisbBBV, (ii) danger space, safety space, lateral safety distance regulated by EisbAV, (iii) approval procedure regulated by EisbG among others. In addition, the Austrian Federal Railways - ÖBB Infrstruktur AG has special specifications for clearance gauges based on EN 15273-4. There are different railway track cross-sections depending on such as the type of the railway line, the clearance gauge used, the maximum permissible speed. Figure 1 shows an example of a standard ballast cross-section for a double-track railroad line. This comprises the entire superstructure, including overhead contact lines, control and safety technology and noise barriers.

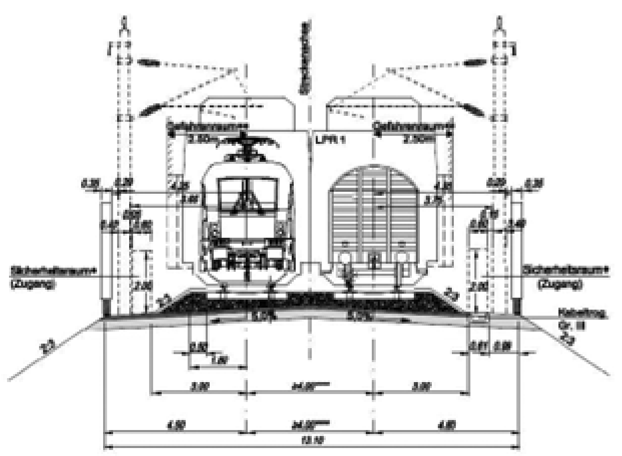

Figure 1. Standard railway double track crosssection of the ÖBB Infrastruktur AG

Noise barrier systems in the rail network are subjected to cyclic pressure/suction alternating stresses due to aero-dynamic excitations from passing trains. These stresses depend on the train speed and the distance of the noise barrier from the track axis among others. The design of the noise barriers for mechanical loads is carried out according to EN1990 and EN 1991.

3.2. Dimensioning and structural design

In this study four types of noise barrier types are analysed. The purpose is to estimate the dimensions of a noise barrier made of clay, the load carrying capacity and serviceability. Hence, the loads to be considered are divided into permanent, variable and extraordinary loads as described below.

3.2.1. Static stability

Regarding to the use of clay walls as noise barriers, the wall is required, not to tilt due to trains passing by or wind blows. For that, it is important to experience the dead weight of the compacted clay material, the required height of the building itself and the mechanical load acting on the building.

Height

Relating to the construction height, the size of the noise barrier in figure 1 is taken as a practical example to illustrate different noise barrier heights in relation to the distance to track axis as shown in figure 2 below. Considering the shielded area of the noise barrier; the minimum necessary height in reference to the distance to the track axis can be calculated by equation 1.

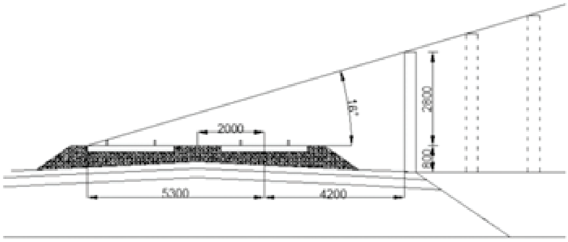

Figure 2. The relation of track distance and noise barrier height

$$h(a_g) = (a_g + 5{,}3) * \tan(16°) + 0{,}8\ [\mathrm{m}] \tag{1}$$

Mechanical load

Forces and loads are taken from official standardisations as mentioned below. Those values are always multiplied by the prescribed safety factor 1,5.

Wind load

Using the EN 1991-1-4, the maximum value of wind load (q_w) is calculated for Vienna Simmering as an example for a windy place in Austria.

$$q_w = 0{,}982 \frac{kN}{m^2} \tag{2}$$

Mechanical load of passing trains

Due to the pressure-suction wave generated by trains at higher speed, noise barriers are stressed by another aerodynamic quantity. Likewise, EUROCODE is used to calculate those loads. The following graph (figure 3) shows the values of pressure-suction load at different speeds and distances to the track axis, taken from EN 1991.2:2003. In this study, a maximum speed of 250 km/h was assumed, referring to the highest velocity on train lines in Austria.

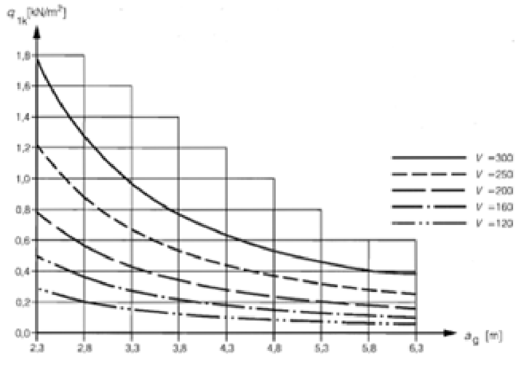

Figure 3. Pressure-suction-load, taken from EN 1991.2:2003

Mechanical calculation

To calculate the dimension and stability of a clay wall, following static system is used.

Noticeably, those loads (figure 4) cause bending stress on the clay wall. So, to finally prove its static stability the following conditions must be fulfilled.

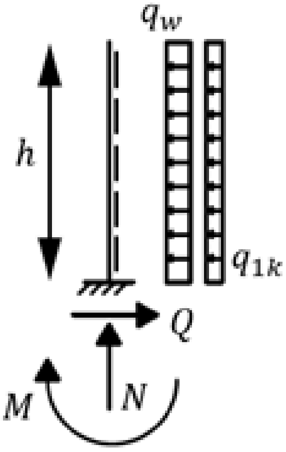

Figure 4. The static system applied for a noise barrier

N = Normal force, Q = shear force, M = Moment, h = height of noise barrier, qw = wind force, q1k = compression and suction force)

$$\sigma_{erf} < \sigma_{zul} \tag{3}$$

$$\sigma_{erf} = \frac{M}{W} \tag{4}$$

σ_{erf} = resulting maximum stress (tension or pressure) [N/mm^2]

σ_{zul} = maximum possible stress (tension or pressure) [N/mm^2]

M = maximum torque [m]

The value of σ_{zul} of clay material regarding tension is practically 0. Therefore, dead weight is used to compensate all tension stress in the building. Following figure 5 illustrates the idea. (σ_{Druck}= pressure stress)

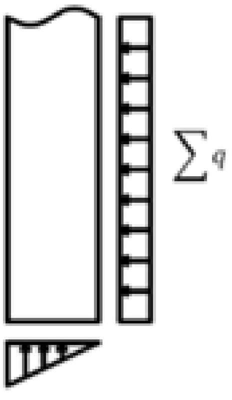

Figure 5. Elastostatic principle for a stable wall

To conclude, dimension and static stability are achieved by compensation of tension stress in the clay wall. This can be done by higher density of the material or wider structure.

3.3. Clay noise barrier prototypes

Rammed clay

This clay technology is built by using concrete formwork. The material is brought into the formwork and gets stamped. After demoulding, the compacted clay material stays in form by itself and can be used as a wall. The dead weight is 2,050 kg/m^3. The necessary width of structure (b) depending on the distance to the track axis (ag) is shown in the following figure.

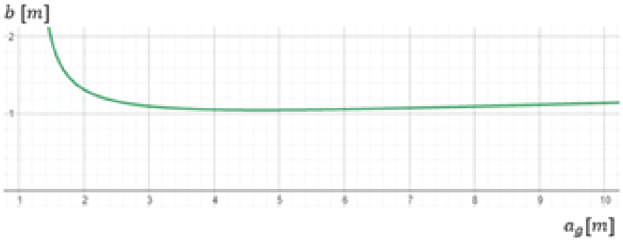

Figure 6: Width of the wall in dependence to track axis distance (rammed clay)

Cob clay

Different to rammed clay, cob clay does not require any formwork. The material is backfilled and gets brought in form by a spade. The dead weight is 1,550 kg/m^3. The calculated necessary width of the wall (b) in dependence to the track axis distance (ag) is shown next.

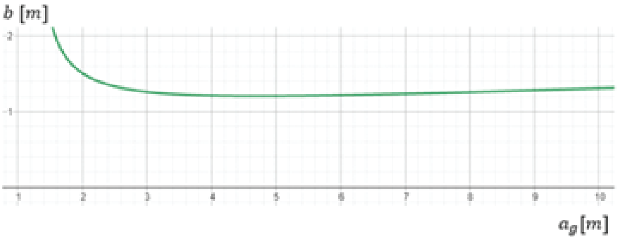

Figure 7: Width of the wall in dependence to track axis distance (cob)

Clay bricks

Clay bricks are blocks of clay, pressed in advance, and used as common bricks. The dead weight is 1,305 kg/m^3. Following figure shows the required width (b) in dependence to the track axis distance (ag).

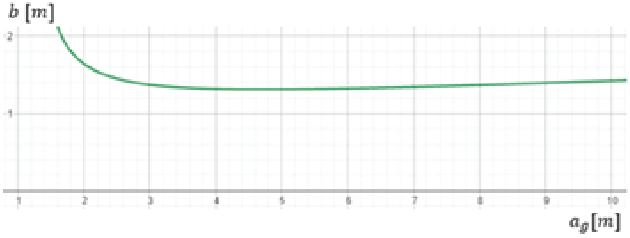

Figure 8: Width of the wall in dependence to track axis distance (clay bricks)

Clay fill

As a fourth technology, clay fill was investigated as a method that does not need any foundation. As the previous wall building methods always require a foundation out of concrete due to water sensitifity of clay, clay fills can be placed anywhere, no matter if the ground is wet or not. To achieve a smaller width, clay fills get supported by a gabion basket, shown in figure 9 below.

Figure 9: Possible gabion concept used as a noise barrier (Rau.de)

Clay walls can definitively be used as noise barriers and find their place in railway crosssections as shown in the figure below. However, it must be considered, that pure clay buildings must not be built without a water insensitive foundation. To leave out an environmentally harmful concrete foundation, gabions can be used to support clay fills.

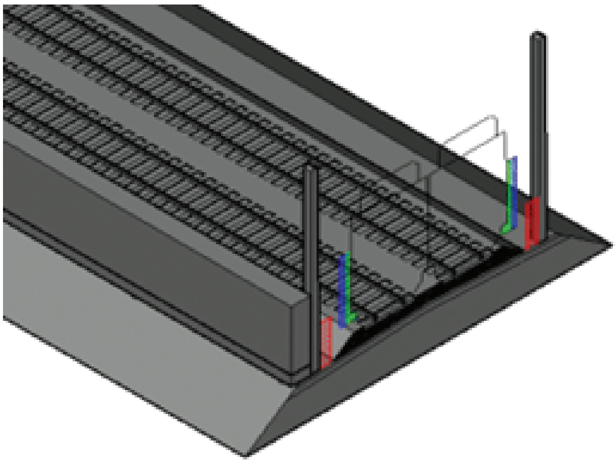

Figure 10: 3D model of a clay wall in a track crosssection

3.4. Applicable structural dimensions

According to a static calculation, the different types of clay construction techniques result in varied construction widths and heights. The corresponding values are: Rammed clay width 0,97 m and height 3,51 m; Weller clay width 1,12 m and height 3,51 m; Clay blocks Width 1,22 m and Height 3,51 m; Supported clay fill Bottom width 1,3 m and Height 3,51 m.

In regard to the placement of the noise barriers along the track line; positioning the clay noise barriers at the location where the conventional noise barriers usually be placed, i. e directly adjacent to the mast alley appears to be the most suitable from the economic point of view. That also fullfills the legal and technical railroad engineering requirements.

3.5. Lifecycle costing

The life cycle cost (LCC) analysis is used to compare the economic viability of clay noise barriers and the conventional noise barriers. The LCC analysis covers (i) investment costs (tendering, design and commissioning, and fabrication and erection), (ii) service life phase over life, (iii) end of life costs (demolition, deconstruction and disposal). The result of the comparison schows that a clear difference of € 6,34 per running meter annualy in favor of the noise protection wall made of clay.

4. CONCLUSION

Static calculations show that all types of clay building technologies and systurcutral design considered fullfill the mechanical requirements and can be used as noise barriers on railway lines. The above results show the necessary building dimensions and the placement of the noise barrier directly on the mast alley taking different design types of clay barriers in to consideration. Placement at a greater distance from the track axis does not make sense from an economic perspective, since the volume of the structure increases with increasing distance from the placement closest to the track on the mast alley. Hence the closest distance was considered in the calculation of the requeíred volumes of the clay mass.

The calculation of the LCC didn't take major uncertainties, including the removal of the material and the actual installation and removal situation into account. Those factors must therefore be checked individually with much more precise input values.

For the implementation of such a structure in a pilot project, only railroad lines with maximum line speeds of more than 160 km/h are recommended due to the aforementioned need for empirical investigations of the dynamic behavior.

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