Optimization of embedded rail slab track with respect to the environmental vibrations

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Abstract
This paper is geared toward selection of the trough geometry (width and height) and elastic surrounding materials (elasticity modulus) as the optimization parameters along with selection of minimum environmental vibrations in the critical point of pavement system. The optimum trough geometry and specification of surrounding materials were evaluated as the objective function. To this, a numerical finite element model of embedded slab track rail system was developed in consideration of the components of the substructure and superstructure of system under the plain strain conditions. In the first step, the numerical model was calibrated by comparing it with static lab results. In the next step, the vibration behavior was investigated after applying a harmonic load to the system at various amplitudes and frequencies corresponding to the real operation conditions. Maximum velocity of particles vibrations was evaluated at different points in the vertical direction, and the critical point of pavement determined. Then, the best trough section and elasticity modulus of surrounding materials corresponding to the load amplitude and frequency were determined by designing the experiments using the surface response method and limiting the maximum vibrations of critical points to 65 Decibel.

Key words: Optimization, Embedded slab track rail system, Trough geometry, elasticity modulus, surrounding materials, Vibration environmental, Design of experiments

Introduction
Factors like life cycle cost, construction period, availability and durability play an important role in designing the rail lines. This matter has gained more importance due to the increased traffic and travelling speed. Other points relating to development of rail transport within the cities between them which should be considered are the vibration noise and the resultant complaints of people residing adjacent to these tracks. Dealing with these problems in populated urban areas with surface tracks or inside low-depth tunnels is particularly important.

As it was previously pointed out, the demand for less maintenance works has drawn an ever-increasing attention to the ballast-less track systems. Suitable loading capacity and durability of the geometrical parameters are among advantages of these tracks. However, the biggest disadvantage of these systems is their higher vibration level and their high cost of construction.
Some improvements have been made in ballast-less systems in the previous years in order to reduce the noise and vibration emission in particular.

One of the ballast-less track types with continuous supports and concrete slabs is the embedded rail slab track. This system has a variety of forms, which are suitable for various types of rail transport. Development of the embedded rail system was commenced in early 1960 in the Netherlands and continued until the technological advances resulted in production of the continuous supports for embedded slab track systems. Although the embedded rail systems have similar performance as other types of rail system, they have had significant progresses in particular applications. These systems provide more opportunities for execution of a complete and advanced plan in addition to a more effective maintenance plan, which are the reasons why the processes in construction industry have focused on them [1].

In recent years, various studies have been undertaken on embedded rail systems. In 1988, K.H.Oostermeijer evaluated the dynamic behavior of this system in high-speed tracks [2], while R.M.Siderius investigated the possibility of using expanded poly styrene as sub-base material for embedded rail systems [3]. Also in 1988, projects entitled “silent traffic of trains” in relation to designing of particular embedded tracks along with compatible profiles, which were intended to reduce the noise, were evaluated and launched [4]. During 2001-2005, a study was conducted on using Asphalt [5] in these systems in order to develop the embedded rail systems. In another research in 2001,[6] investigated the elastic behavior of embedded rail system by carrying out lab experiments. However, a study was undertaken with the objective of optimizing the ballast-less track systems during 1999-2003 by Esveld et al (2003). In this project which concerned the emitted noise, maintenance tasks and volume of the elastic compound of embedded rail system was optimized. In this research, static modeling of embedded rail system (ERS) was carried out with ANSYS software, while dynamic modeling was performed with RAIL software and the optimization process with MOPT software using MARS method. For an optimized designing of ERS, three principal constraints of lateral displacement, structural strength of elements and lateral buckling of tracks were considered [6].

After careful reviewing of technical literature, one can say that the optimization of rail seat (trough) dimensions and elastic surrounding materials as a function of applied load amplitude and frequency with the aim of limiting the environmental vibrations is an important issue, which has not been considered yet. Therefore, this research is aimed at selection of trough geometry (width and height) and elastic surrounding materials (elasticity modulus) as optimization parameters. By selection of minimum environmental vibrations as a critical point of pavement system as the objective function, the most optimum trough dimensions and elastic surrounding materials are evaluated. A 2D finite element model of embedded slab track rail system was developed under the plain strain condition, which was comprised of pavement and bedding elements of the system. In the first step, the numerical model was calibrated by comparing its results with the static lab results. In the next step, harmonic loads were applied to the system at various amplitudes and frequencies corresponding to actual operation conditions, and maximum vibration speed of particles at different points in the vertical direction was determined along with the critical pavement point. Then, RSM algorithm was used for selecting the best trough section
and elasticity modulus of surrounding materials corresponding to the load amplitude and frequency by limiting the maximum vibrations of critical points to 65 Decibel.

2. Development of a numerical finite element model for analyzing the static behavior of embedded rail systems

In this section, a 2D finite element model of embedded slab track rail system comprising UIC54 rail and surrounding elastic compound was developed in order to compare its results with those of the research undertaken by Esveld et al. (2003) using ABAQUS software. In the next section, more details of the embedded rail system relating to bedding and pavement will be added to the model in order to evaluate its behavior under dynamic loads.

In the research undertaken by Esveld et al., UIC54 rail embedded in an elastic compound was used. Geometrical specifications and elastic compound are given in Table 1. Elasticity modulus of rail and Poisson’s ratio are $2 \times 10^5$ N/mm$^2$ and 0.3, respectively. Moreover, elasticity modulus of rail and Poisson’s ratio of compound are 5.6 N/mm$^2$ and 0.46, respectively.

Supports are positioned on both sides and below the elastic compound to prevent from any movements in the horizontal and vertical directions and rotations about Z axis. Various mesh sizes were used, and the maximum mesh size was 50 mm. Figure 1 shows the discretization of the rail and elastic surrounding materials along with the conditions applied to support constraints. Considering the intended conditions in the research undertaken by Esveld et al., two static load types were applied on the model. These loads are applied in order to obtain the static response values of the structure for evaluation of the ERS design. In the first problem, a 12.2 kN horizontal load and 30.4 kN vertical loads were applied at the level 0.5 m of the rail. In order to optimize the lateral displacement of the rail $U_x$, maximum stresses (Von Mises) of the elastic compound should be less than the allowable values. In this case, $U_{x,allow}= 0.002$ m and maximum tensile stress in each point of the compound should be less than $\sigma_{allow}$. In the second question, the upward buckling of rail $p_{buckl}$ was evaluated. Upward buckling occurs when there is no cohesion and connection between the rail and elastic compound. In order to control upward buckling, an upward vertical load 10 kN was applied to the rail crest [6].

Table 1 shows lateral displacement and maximum stress values with the buckling force resulting from the research model and existing model in the aforementioned reference. As it can be seen, the results have a good agreement with each other except for negligible differences. Hence, we can say that the current numerical model may be developed as a valid model for evaluation of the vibration behavior of ERS in the next section.

3. Development of a numerical finite element model for vibration analysis of embedded rail system

In this section, substructure and superstructure elements of embedded rail system are added to the previous model and then the vibration behavior is evaluated under 2D plain strain conditions after applying a harmonic load to the model. In this model, the embedded rail system comprises SA42 rail, elastic compound, concrete slab, continuous concrete layer, hydraulically bonded layer, frost protection layer and sub-grade which will be considered in the following section, complete with details.
3.1 Element geometry and discretization
In this section, substructure and superstructure elements of embedded rail system are added to the model. As it can be seen in Figure 2, these elements are embedded in an elastic compound. Considering the common sections of embedded rails, width and height of this compound were obtained from CROW (2001) guidelines. In the structure of embedded rail, concrete slab is positioned on a concrete layer of sufficient strength. Other bedding layers are the hydraulically bonded layer, frost protection layer which will be placed on sub-grade layer with a density of 98 percent and elasticity modulus of 45 N/mm\(^2\) \[7\]. The lay-out of the bedding and pavement system of embedded rail is shown in Figure 3, and the specifications of the system components are shown in table 2. The mesh size in all elements is 50 mm, and it is 100 mm in the sub-grade layer. The model is considered as 2D and under plain strain conditions. There are some roller supports on the left side of the model, which prevent from movement along X axis and rotation about Y and Z axes. Also, movement and rotation of dampers below and to the right of the subgrade layer along and about all axes are constrained. All elements are completely tied together.

3.2 Harmonic loading resulting from the train pass
Considering the investigations made, it has been revealed that one of the trains used in the embedded rail system is the high-speed Thalys with a speed of 223-314 km/h. This train is comprised of 2 locomotives, 8 carriages with a total length of 200.18 m. The locomotives have two bogies and four axles. The carriage which is connected to locomotive has only one joint bogie with the next carriage, and other six carriages share the other two bogies which each other. This train has 13 bogies, and thus 26 axles. Also, wheel load of this train ranges between 1.5 to 9 KN with a load frequency of 5 to 250 Hz \[8\].

In this research, harmonic loads were applied to the model with an amplitude and frequency similar to those of Thalys train at the center of the rail crest (Figure 4). Wheel loads is assumed 1.5, 5 and 9 tons. Load frequencies are 10, 20, 35 and 50 Hz, and more. Sensitivity analysis was carried out for these loads. The necessary time for sensitivity analysis of applied loads and frequencies is 2 seconds (Figure 5) \[8\].

3.3 Determining the point with critical vibration in the pavement system
In order to identify the critical points of the system, a sensitivity analysis was carried out for 5, 9 ton loads with a loading frequency of 10 Hz. The loading time was assumed 2 seconds. Results of the analysis were obtained as the vertical vibration speed in points A to J. Results of the vibration speed are recorded on the edges of the model, concrete slab, concrete layer, hydraulically bonded layer, frost protection layer and at 2 m distances on the sub-grade layer as shown in Figure 4. The maximum speed is determined in each point, which is calculated using decibel vibration equation 1 in these points. Results of these analyses are given for points (A to J) as shown in Figure 5.

\[
\text{dB} = 20 \times \log_{10} \frac{V_2}{V_1} \tag{1}
\]

In this equation, \(V_1\) and \(V_2\) are reference speed and speed at the point, respectively. Reference speed is selected from the existing codes, which is \(10^{-8}\) m/s \[9\] in this case.
As it can be seen in this figure, the vibration Decibel and vibration velocity increase with the load at a constant frequency. The peak point in both loading cases was at point D, which is located on FPL layer. This increasing trend continues to point E, which is the intersection of FPL and sub-grade layer, and then declines. Therefore, most vibrations primarily occur at point D and then point E, which are located on FPL and the contact point of this layer with sub-grade. These points were considered as critical points of the system in these studies. Then, the most optimum trough dimensions and the most suitable elasticity will be recommended for the surrounding rail materials with the aim of minimizing the vibrations at these points and limiting them to maximum allowable values.

4. Introduction of the design method of experiment for vibration optimization of pavement system

Design experiment method is a useful method by which key variables affecting the intended quality specifications could be identified. By using this method, one can change the controllable input factors systematically and evaluate their effect on the parameters of output product. Experiments that are designed by statistics may significantly reduce variations in the quality specifications. They also determine the level of controllable variables which optimize the process performances. Design of experiments is one of the main quality control methods prior to production, which is often used in the development activities and initial production stages. Design technique of experiments was developed by Ronald A. Fisher at Rothamasted experimental station, which is an agricultural research station located north of London, during 1920–1930 [10].

The algorithm used in this section is based on the design of experiments (DOE) method and uses the response surface method (RSM), which is an effective tool for determining the response of multiple variables simultaneously and optimizing vibrations, utilizing limited resources and data along with a suitable design of experiments. In fact, this algorithm is aimed at determining the best response for resolving a problem with minimum number of trial and error. Scientists often perform tests to explore facts relating to a system or process in order to recognize phenomena. Performing tests would always involve time and costs. Hence, performing effective tests which leads to maximum data and information with minimum costs and at the shortest time is the goal of every scientist or researcher [11].

Some other studies have also been undertaken using the design experiment in civil engineering such as concrete strength analysis using this method and the neural network [12]. In 2000, researchers designed an experiment for evaluation of the interaction reducing the water content and anti-wash mixture for a high-performance cement grout [13]. In 2002, the role of temperature and the ending level in prediction of tool wear was evaluated using neural networks and design experiment [14]. In 2007, key parameters affecting the reinforcement of ballast geogrids for railways were identified [15]. Design experiment was used for thermal spraying [16] in 2008, in which year the critical effective factors affecting on shrinkage porosity of permanent mold casting were evaluated using numerical simulation [17]. Design experiment was also used in 2010 for developing a neural network model for prediction of the chromium layer thickness in chromium plating process [18], whereas alkaline cement with a high lime stone content was developed by researchers using the design experiments in 2011 [19].

In the present research, response surface method (RSM) was used for optimization, which includes the following four steps:
Step 1. Design and performing experiments for obtaining sufficient and reliable criteria for the intended response
Step 2. Developing mathematical models for first order and quadratic response surface with the best correlation
Step 3. Finding an optimized set of parameters which produce maximum or minimum response values
Step 4. Evaluation of the direct and interactive effects of process parameters using analysis of variance table (ANOVA)[20]. Figure 6 shows the optimization process.

4.1. Vibration optimization constraints and objective functions of the embedded rail system (ERS)

As shown in Figure 6, three parameters are considered for optimization. These parameters are elasticity modulus A, width B and height C. Suitable range of geometrical variations are set in accordance with CROW (2001) guidelines. The minimum and maximum values of elasticity modulus A are 1 and 10, respectively which are selected in accordance with the reference [6] Given that the objective is to minimize vibrations, vibration value (decibel) was taken as the objective function, and elasticity modulus, width and height are constraints. Thus, constraints are defined as below:

\[
\begin{align*}
1 & \leq A \leq 10 & (2) \\
160 & \leq B \leq 220 & (3) \\
110 & \leq C \leq 200 & (4)
\end{align*}
\]

The objective is to achieve the minimum vibration of 65 decibel, which is the allowable value set by FTA [22] as shown in Table 3. Thus, the objective function will be as below. In accordance with FTA code of the United States, the vibration value at point D up to point G (the surrounding environment of embedded rail system) is 69 decibel which is 6 percent more than allowable value of 65 decibel defined by FTA. Here, the objective is to minimize vibrations in accordance with FTA standard. Thus, as it may be noted, vibration value should reduce to 65 decibel.

\[
dB (X) \leq 65 VdB \quad (5)
\]

In Equation 5, dB is the vibration decibel. X represents the intended point. i.e. the vibration decibel at point X should be equal or less than 65 VdB.

5. Vibration optimization results of the embedded rail system (ERS)

Based on the limits specified for constraints as per CCD method, 20 primary experiments were defined, which equals the number of models required for numerical vibration analysis in ABAQUS. Experiments were designed and the vibration values obtained from the sensitivity analysis aimed at optimization under 1.5 ton loading and frequencies of 35 Hz are shown in Table 4.

Considering the selected values for rail surrounding compound elasticity modulus, width and height of the rail (i.e. each row of the Table 4), a specific dynamic analysis was carried out by ABAQUS and the values of vertical vibration velocities were recorded at points D and E (in
Figure 3) in decibel and consequently these values were considered as objective functions. Finally, the optimization results were obtained.

5.1 Formulating a mathematical function with effective parameters for calculation of vibration at critical points

There are some standard design methods for design experiment with the aid of RSM. In this research, Central Composite Design (CCD) method was used for second-order correlation with a very good accuracy. This equation was formulated using CCD method. In this method, one can calculate the vibration value (decibel) at points D and E, once elasticity modulus, width and height are known. The equation below shows the general form, and Table 5 shows the coefficients used at two critical points of the system.

\[
dB(\text{In target point}) = A + B \times X_1 + C \times X_2 + D \times X_3 + E \times X_1 \times X_2 + F \times X_1 \times X_3 + G \times X_2 \times X_3 + H \times X_1^2 + I \times X_2^2 + J \times X_3^2
\]  

Where, \(X_1, X_2\) and \(X_3\) are elasticity module, width and height of rail, respectively and the target point is E or D. As it can be seen, vibrations (decibel) variation with respect to the width, height and elasticity module as design parameters has quadratic form.

5.2. Variance Analysis (ANNOVA)

Table 6 shows variance analysis of model parameters in the order of their importance. The significance threshold is assumed 0.05 (5%) in here. This coefficient determines the error probability in the model. In other words, the probability of error is 5 percent in this mode. p-value should be less than the significance coefficient so that the intended factor equals a significant value. A p-value less than 0.0001 in ANOVA makes it significant, which may be seen in the first row of table below. BC and \(B^2\) parameters are significant only.

5.3 Checking the optimization results for 1.5 ton loading at a frequency of 35 Hz

Given that the objective is to minimize the system vibrations produced in the surrounding environment, a vibration value of 65 decibel was considered as the maximum vibration transferred to the environment in accordance with FTA(2006) code. An optimization result for a 1.5 ton loading at a frequency of 35 Hz is given in Table 7.

As it can be seen in Table 7, the optimization results for a 1.5 ton wheel load at a frequency of 35 Hz are shown in Table 7. Ten optimum cases are presented in the table, and the selected model by the software is shown in the first row of the table.

5.3.1. Optimization results

Optimization results are shown in various ways in figures below. Figures 7, 8 show the anticipated vibration lines of the model.

In figures above, the predicted response values are shown for the abovementioned loading conditions in case 1 of Table 4. Dark blue zones show the predicted value of optimization, and other zones show higher values. In fact, we can see the vibration values (in decibel) at these points, which are obtained as the result of optimization. These values correspond to the lowest vibration values produced by the system.

As it can be seen in Figure 9, changes in the width do not affect the suitability of responses at low height values. However, the suitability of responses increases with the height. The peak
point of this diagram corresponds to higher heights and increased widths. Hence, at constant, high heights, the suitability of responses increases with the width. ANOVA table shows the importance of height/width ratio.

According to Figure 10, it may be noted that suitability level does not change with an increase in elasticity modulus. However, for elasticity modulus below 2MPa, the suitability level increases significantly. Therefore, the importance of elasticity modulus versus height may be clearly seen as shown in ANOVA table. In fact, system desirability tends to increase with a reduction of elasticity modulus and increase of height. However, for higher parameter values, the system desirability is a factor or height and values of elasticity modulus.

Similar to Figure 10, we can see in Figure 11 that for modulus of elasticity values less than 2 MPa, the desirability increases with the width. However, at higher values of elasticity modulus, variations in the width do not affect system desirability. In fact, elasticity modulus is a more important parameter in design than the width of elastic compound, which can be seen in ANOVA Table.

5.4 Optimization results for all loadings
Optimization for 1.5 Ton load at a frequency of 35 Hz using Design Expert software was described in the previous sections. Given the excessive results and various loading conditions and frequencies of these models, optimization of other models is given briefly in Table 8.

Consider the table above, vibration may not be reduced to 65 decibel in all loading conditions. “Minimize Column” shows the vibration (decibel) of the system under various loading and frequencies. As it can be seen, frequency increase produces better results when a 1.5 ton wheel load was applied. Thus, vibrations could be reduced to 65 decibel for higher frequencies. However, these conditions change with an increase in loadings as they produce different results under higher loads. For instance, under a 5 ton load and 5 Hz frequency conditions, maximum vibration is significantly higher than the vibration produced at this frequency with a 9 ton wheel load.

6. Summary and Conclusion
In this paper, embedded rail system (ERS) was modeled statically using the finite element software ABAQUS, and then compared with the research undertaken by Esveld et al. It was noted that the results had a negligible difference. Then, this numerical model was developed for a vibration analysis. Vertical dynamic loads were applied to the model and results of vibration results (decibel) were obtained for various loadings using the design experiment method with the aid of DESIGN EXPERT (DE) software. This research is aimed at minimizing the environmental vibrations by optimizing the trough geometry of the rail and properties of surrounding elastic compounds. Considering the experiments designed for the width, height and elasticity modulus of compound, the following optimization results were obtained:

- Considering the investigations made in the optimization process, it was revealed that elasticity modulus is the most effective parameter in producing vibration. Increases in this parameter will result in more vibrations, and lower values of this parameter will lead to more system desirability. When the elasticity modulus value is high (approx. in excess of 7 MPa), increasing or decreasing the height of elastic compound will not have a significant effect on reduction of vibrations.
After elasticity modulus, the effect of elastic compound height on the vibration level is significant. Increasing the height will decrease vibrations. When the elasticity modulus of elastic compound is low (2MPa or less), increasing the height of elastic compound will reduce vibrations.

The width parameter like the height parameter has fewer effects on the vibrations. At a low elasticity modulus value, an increase in width will not produce high vibration values. At lower heights, changes in the width will not affect the system desirability. However, the system desirability increases with the height. At higher heights, model desirability decreases with the width. Also, at low elasticity modulus values, the vibrations tend to decrease with an increase or decrease of the width.

As shown in ANOVA, the interaction of elasticity modulus with the height is the most effective parameter in the level of vibrations (decibel). According to the results, we can see that when the height parameter changes in the range of 110-220 mm, an increase in elasticity modulus will increase the vibration level. At lower heights, the increase in elasticity modulus will produce more vibrations than higher heights. For elasticity modulus equivalent to 10 MPa, the vibration values in the upper and lower limits are the same.

There are no interactions between the width and height parameters. As it can be noted in ANOVA, the interaction between these two parameters has the lowest importance with the least effects in the optimization process. In fact, for elasticity modulus of 2 or less than 2 MPa, increasing the width and height of elastic compounds will not have any significant effects on the level of vibrations.

7. REFERENCES


Figure 1. Finite element discretization of embedded rail system
Figure 2. SA42 rail and elastic compound in ABAQUS
Figure 3. Lay-out of embedded rail system in ABAQUS
Figure 4. Vertical loading in ABAQUS software
Figure 5. Evaluation of the sensitivity analysis results at point A to J
Figure 6. Procedures of optimization process
Figure 7. Vibration (decibel) at point D, width to elasticity modulus at the constant height of 189.62 mm
Figure 8. Vibration diagram at point E, width to elasticity modulus at constant height 189.62 mm
Figure 9. 3D level-suitability of responses-constant elasticity modulus

Figure 10. 3D level-suitability of responses-constant width

Figure 11. 3D level-suitability of responses-constant height

Table 1. Comparison of the results of numerical analysis with the reference [6]

Table 2. The specifications of the system components [6]

Table 3. FRA criteria for vibrations transferred from the ground [21]

Table 4. Primary experiments designed for optimization of embedded rail system

Table 5. Coefficients of design parameters in equation 1

Table 6. ANOVA for Response Surface Quadratic Model

Table 7. Optimization results for a 1.5 ton loading at a frequency of 35 Hz

Table 8. Optimization results for various loadings- lowest vibration (decibel) for various loads and frequencies
Definition of design parameters A, B and C in DE

Modeling in ABAQUS using the new measurements of design experiments

Sensitivity analysis of new models with changing loading amplitudes and frequencies using ABAQUS software

Calculation of vibrations (decibel) resulting from particle velocity

Entering the vibration values (response) into DE software

Optimization

Figure 6.
Figure 7.

Figure 8.
Figure 9.

Figure 10.
Figure 11.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reference numerical model[6]</th>
<th>Current research model</th>
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<tr>
<td>σ (Pa)</td>
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<tr>
<td>P_{buckl} (MN )</td>
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### Frost protection layer (FPL)

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### Land Use Category

<table>
<thead>
<tr>
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<th>Ground-Borne Vibration Impact Criteria (VdB relative to 1 micro inch/second)</th>
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<tbody>
<tr>
<td></td>
<td>Frequent Events</td>
</tr>
<tr>
<td>Category 1: Buildings where vibration would interfere with interior operations.</td>
<td>65 VdB</td>
</tr>
<tr>
<td>Category 2: Residences and buildings where people normally sleep.</td>
<td>72 VdB</td>
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<tr>
<td>Category 3: Institutional land uses with primarily daytime use.</td>
<td>72 VdB</td>
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</tbody>
</table>

*Frequent Events is defined as more than 70 vibration events per day.

Infrequent Events is defined as fewer than 70 vibration events per day.

This criterion limit is based on levels that are acceptable for most moderately sensitive equipment, such as optical microscopes.

Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels.

Ensuring lower vibration levels in a building often requires special design of the heating, ventilating and air conditioning systems, and stiffened floors.


<table>
<thead>
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<th>Factor 1</th>
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<th>Factor 3</th>
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<th>Response 2</th>
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<td>Height (mm)</td>
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<td>dB(E)</td>
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Coefficients of design parameters

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<tr>
<td>B-Width</td>
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<td>C-Height</td>
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<td>&lt; 0.0001</td>
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Biographies

**Morteza Esmaeili** obtained his BS degree from the Department of Civil Engineering at Iran University of Science and Technology (IUST), Tehran, Iran, and MS and PhD degrees in Geotechnical Engineering from the University of Tehran (UT), Iran. He is currently Associate Professor at the School of Railway Engineering at Iran University of Science and Technology (IUST). His key research interests and areas of expertise include track geo-technology, mechanics of porous media, train induced vibration and design of ballast-less tracks. He has also published five books in different fields consisting of bridge substructure design, TBM tunneling, railway track geo-technology, soil steel bridges and ballast-less tracks.

**Masoud Yaghini** received the Ph.D. degree in Rail Transportation Planning and Engineering from the Beijing Jiaotong University of China, in 2002. He joined the School of Railway Engineering of Iran University of Science and technology as an Assistant Professor and became an Associate Professor in 2014. His current research interests include rail transportation planning, optimization techniques, and data mining techniques.

**Shila Moslemipour** received her BS degree in Civil Engineering from Iran University of science and culture, Tehran, Iran, in 2010, and MS degree in Railway Engineering from Iran University of Science and Technology (IUST), Tehran, Iran, in 2013. Her research interests include optimization of embedded rail slab track with respect to the environmental vibrations using ABAQUS and Design Of Experiment (DOE).