IJMRSETM

e-ISSN: 2395 - 7639

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING, TECHNOLOGY AND MANAGEMENT

Volume 10, Issue 10, October 2023

INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.580

+91 99405 72462 +9163819 07438 ijmrsetm@gmail.com www.ijmrsetm.com

Comparing the Speed of Traveling Waves in Soils, Generated By Train Traffic

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ABSTRACT. The paper considers a three-dimensional problem of vibration propagation in soils created by a freight train. The load created by the train is represented as a dynamic force. The problem is solved by the finite element method. Finite elements in the form of an irregular tetrahedron are used. Fragments of research results on determining the degree of influence of physical parameters of the ground on the level of vibrations propagated in the ground are given. The displacements of ground vibrations at various points remote from the railroad tracks were checked.
KEYWORDS: railroad train, vibration waves, finite element method, soil, elasticity theory, elastic waves, vibration, boundary conditions, infinite plane, velocity.

I. INTRODUCTION.

Nowadays, as a result of population increase, construction of buildings and structures, development of production processes in industry, the demand for vehicles transporting people and cargo is growing.

Cargo transport is a convenient means of transport for the service of people and transportation of various types of goods. Therefore, the need for it is growing, the number of cargo vehicles increases from year to year, its modern types appear, i.e. capacity and speed increase.

II. LITERATURE REVIEW

The study [1] analyzes the displacement velocity of vibrations emanating from railway tracks during train movement. The vibration measurements were carried out at 31 different locations. The dynamic load is measured for railroad trains. As a result of the measurements and comparative analysis, it has been established to what extent the type of the subgrade, its technical condition, and the different dynamic loads generated by the vehicle affect the level of vibration propagating in the environment.

The level of impact of noise and vibrations created by the movement of vehicles exceeds sanitary norms several times, there are many complaints about the need to reduce it. As a result of experimental surveys of the population, the problem of this kind is confirmed, and therefore, this topic remains relevant [2].

Since the ground is a carrier that transmits vibrations from the source to the building or structure, it is necessary to determine the properties of the ground that contribute to the transmission of vibrations through the ground [1, 2].

Vibrations occurring in the ground in close proximity to transportation structures result in the occurrence of changes in the building structure and soil structure. These negative changes are more common in buildings subjected to vibrations caused by continuous vehicle traffic. Taking this into account, the paper studied the vibrations created by cargo vehicles in nearby buildings and soil [3].

III. PROBLEM STATEMENT

The main feature of the methodology under consideration is its ability to efficiently solve problems taking into account ground properties, i.e. it allows modeling large areas in a short time. In dynamic response estimation for an observation point located from 10m to 100m from the railway tracks for the analyzed case study, a reduction in calculation time of almost 50% was achieved.

This research work is aimed at determining the level of vibration generated in the ground when a freight train moves along the railroad track.

The results of the study show that a large number of works have been carried out to determine the vibrations generated by the movement of a freight train, in most of which satisfactory results have been obtained. In this study, the results obtained for two types of soil bases were compared.

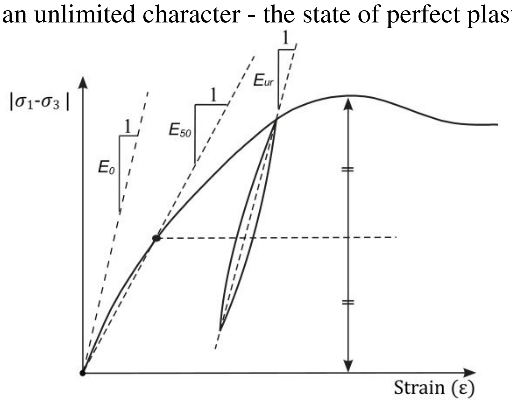
The models of soil medium behavior that have been relatively widely used include the elastic-ideal-plastic Coulomb-Mohr model. This model is the most common model in use in modern engineering practice. Its main advantage is the simplicity of obtaining the initial data, which are always contained in standard engineering-geological reports:

$\boldsymbol{E}$ - strain modulus, MPa;
$\boldsymbol{\nu}$ - transverse deformation coefficient (Poisson's ratio);
$\boldsymbol{\varphi}$ - angle of internal friction, deg;
$\boldsymbol{C}$ - specific adhesion, kPa;
$\boldsymbol{\psi}$ - angle of dilatancy, deg.

The Coulomb-Mohr model is utilized to describe soil dynamics and has various applications. The deformation shows a linear pattern, and the soil strains are proportionate to the stress level $\boldsymbol{\sigma}$ and change with a specific modulus of deformation $\boldsymbol{E}$ of the soil. When dealing with triaxial stress, it is represented as (1).

$$d\varepsilon_{ij} = C^{e}{}_{ijkl} d\sigma^{e} kl \quad (1)$$

The strain modulus $\boldsymbol{E}$ has a constant value over the entire stress range. When the limit state σ = ***E is*** reached, the material behavior is characterized by zero stiffness $\boldsymbol{E = 0}$, i.e. the strain growth does not depend on the stress growth and has an unlimited character - the state of perfect plasticity (Fig. 1).



Graphical representation of the Coulomb-Mohr behavioral model

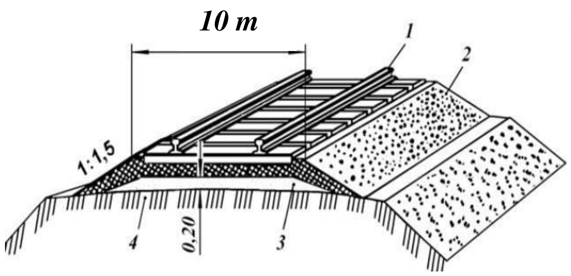


Figure 1: Drawing of the construction of the base for a railroad train

When studying the behavior of soils and buildings under dynamic activity, authors often utilize elastic-plastic models. Viscoplastic models yield more accurate results, but are more complex to work with. The nonlinear ground expansion model helps address issues concerning wave propagation in the ground and its interaction with building and structure components. This model can also generate wave parameters that are distinct from those obtained through ideal elastic and nonlinear-elastic media models.

In the problem under consideration, the vibration levels in the ground due to the movement of a freight train are determined. A soil foundation with a section of 200 m wide, 100 m long and 50 m deep was taken as a model. The effect of groundwater was not considered in the question. The soil characteristics given in Tables 1 and 2 were selected as an example.

The drawing shown in Figure 1 was used to form the railroad track, based on the railroad track construction standards. In accordance with the drawing, 1 m of protective layer and 50 cm of balancing base are laid on the ground from the 0 meter mark above the surface, on which the railway track (sleepers and rails) is designed. The movement of a freight train with a mass of 120 tons together with cargo is investigated. The freight train is moving at a speed of 100 km/h. Since the selected limiting area has a length of 100 m, the vibration time acting on the ground base lasts until the freight transport passes completely.

To solve the problem, we will use the finite element method. The investigated area is divided into **7875 finite elements**. The finite element shapes are chosen in the form of irregular tetrahedron.

The dynamic loads through the train tracks are considered to affect the subgrade. Here we consider the action of eight **axially** concentrated z loads moving at a certain speed along the axis. y. Let us determine the displacements and velocities of the resulting nodes in the soils, taking into account the physical and mechanical characteristics of the material. In this problem, we replace the infinite half-space by a finite parallelepiped [3, 4, 5, 6] In this case, on the faces of the parallelepiped, where the continuation of the medium is discarded, the conditions are set:

$$\left.\begin{aligned}\sigma_x &= a\rho V_p\dot{u}\\ \tau_{yz} &= b\rho V_s\dot{u}\\ \tau_{zy} &= b\rho V_s\dot{w}\end{aligned}\right\} \quad \left.\begin{aligned}\sigma_y &= a\rho V_p\dot{v}\\ \tau_{xz} &= b\rho V_s\dot{w}\\ \tau_{zx} &= b\rho V_s\dot{u}\end{aligned}\right\} \quad \left.\begin{aligned}\sigma_z &= a\rho V_p\dot{w}\\ \tau_{xy} &= b\rho V_s\dot{u}\\ \tau_{yx} &= b\rho V_s\dot{v}\end{aligned}\right\} \qquad (1)$$

The kinematic relation can be formulated as follows:

$$\varepsilon = Lu \qquad (2)$$

L^T - is the transpose of the differential operator, which is defined as

$$\mathrm{L}^{\mathrm{T}} = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix} \qquad (3)$$

The dynamic model of the problem solving field is presented in Fig. 2.

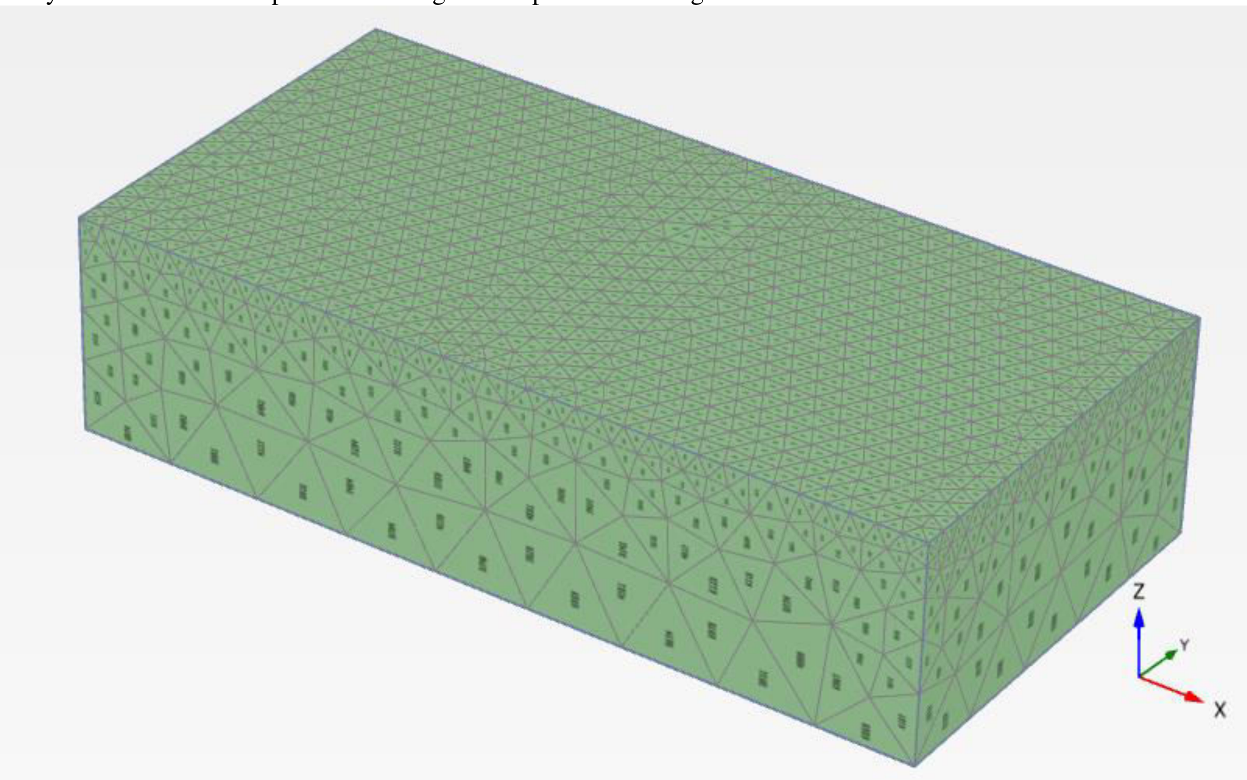


Fig.2 . Model in which the domain is partitioned into finite elements

The basic equation for the time-dependent motion of the volume under dynamic load is expressed as follows:

$$M\ddot{u} + C\dot{u} + Ku = F\,, \qquad (4)$$

where $M -$ mass matrix, $u -$ displacement vector, $C -$ damping matrix, which also takes into account the boundary conditions, $K -$ stiffness matrix, $F -$ load vector. Displacement u, velocity $\dot{u}$ and acceleration $\ddot{u}$ can change with time.

In general, the material inside the element may have initial deformations due to temperature effects, shrinkage, crystallization, etc. If we denote these deformations by $\{\varepsilon_0\}$ then the stresses will be determined by the difference between the existing and initial deformations.

In addition, it is convenient to propose that at a given point in time there are some residual stresses in the body $\{\sigma_0\}$ which, for example, can be measured but cannot be predicted without knowing the complete loading history of the material. These stresses can simply be added to the general expression. Thus, under the assumption of elastic behavior, the relationship between stresses and strains will be linear:

$$\{\sigma\} = [D](\{\varepsilon\} - \{\varepsilon_0\}) + \{\sigma_0\} \quad (5)$$

Where $[D]$ - is the elasticity matrix containing the material characteristics.

For the special case of plane stress state, it is necessary to consider three stress components corresponding to the introduced deformations. In the adopted notations they are written in the form:

$$\{\sigma\} = \{\sigma_x\ \sigma_y\ \tau_{xy}\}$$

Matrix $[D]$ is easily obtained from the usual relations between stresses and strains for an isotropic material:

$$\varepsilon_x - (\varepsilon_x)_0 = \frac{1}{E}\sigma_x - \frac{v}{E}\sigma_y;$$

$$\varepsilon_y - (\varepsilon_y)_0 = -\frac{v}{E}\sigma_x + \frac{1}{E}\sigma_y;$$

$$\gamma_{xy} - (\gamma_{xy})_0 = \frac{2 + (1+v)}{E}\tau_{xy;}$$

Hence:

$$[D] = \frac{E}{1-v^2}\left[1\ v\ 0\ v\ 1\ 0\ 0\ 0\ \frac{1-v}{2}\right] \qquad (6)$$

In principle, all models can be used for dynamic analysis. Soil conditions can be either dried or undrained. (There may be water table or no water table present in the study areas to obtain data). The **Plaxis 3D program can be used to solve problems with or without water table**. Matrix **M** considers the mass of materials (soil+water+any structure).

Formation of time integration in the numerical representation of dynamics is an important factor in the stability and accuracy of the computational process. The Newmark scheme of numerical integration is used. Soil and material properties are summarized in Tables 1, 2, and 3.

Table 1.

Physical and mechanical properties of materials

Parameter	Unit of measurement	Designation	loam	Loess-like loams
General properties				
Soil model	-	-	Mor-Coulon	Mor-Coulon
Type of material behavior	-	-	Drained	Drained
Specific gravity of soil above the water table	$\frac{кН}{м^3}$	γ_{unsat}	16	14,70
Specific gravity of soil below the water table	$\frac{кН}{м^3}$	γ_{sat}	18	16,80
Mechanical parameters				
Young's modulus (constant value)	$\frac{кН}{м^2}$	E'_{ref}	60000	95000
Poisson's ratio	-	$v/\ v_{ur}$	0.32	0,35
Clutch (permanent)	$\frac{кН}{м^2}$	c'_{ref}	6	5,6
Angle of internal friction	°	φ'	22	25
Dilatancy angle	°	ψ	1	0

Table 2.

Features of the ballast layer

Ballast layer / Features stacking	Protective layer	Balast
№	1	2
Soil model	Mor-Coulon	Mor-Coulon
Type of material behavior	Drained	Drained
Specific gravity of soil above the water table - γ_{unsat} [kN/m]^3	22	19
Specific gravity of soil below the water table - γ_{sat} [kN/m]^3	23	21
Angle of internal friction - φ [°]	40	35
Dilatancy angle - ψ [°]	15	5

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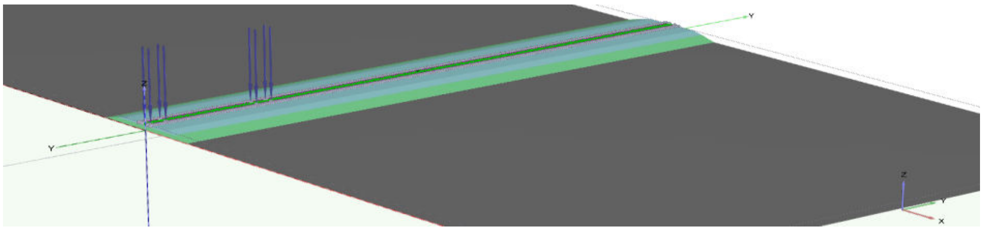
Clutch (constant) - c_{ref} [kN/m]^2	30	30
Young's modulus - E [kN/m]^2	55000	50000
Poisson's ratio - ν	0.25	0,3

Table 3.

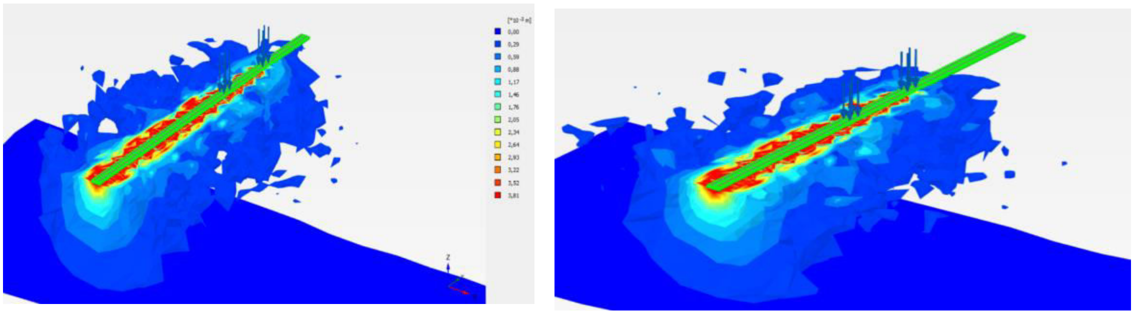
Physical and mechanical properties of rail and sleepers

			Rail	Sleeper
Specific weight		[kN/m]^3	78	25
Section type			User - defined	Defined
Cross-sectional area		m^2	0,0077	0,0513
Moment of inertia	I_2	m^4	0,00000513	0,000245
	I_3	m^4	0,00003005	0,02530
Young's modulus		ν	200 000 000	360 000

IV. EXPERIMENTAL RESULTS



a) Location of the railroad track, and load movements on the selected bounded area



b) Moving the points along the axis direction z

Figure 3. Vibration levels in each node of the tested model

The graphs in Figs. 4-6 were detailed, comparing the vibrations resulting from the train movement in the ground located at different distances from the railway track. In order to analyze the difference in the levels of propagation of vibrations in two cases, the displacement of vibrations at several points, i.e., at distances ranging from 10 m to 100 m from the railway track, were analyzed.

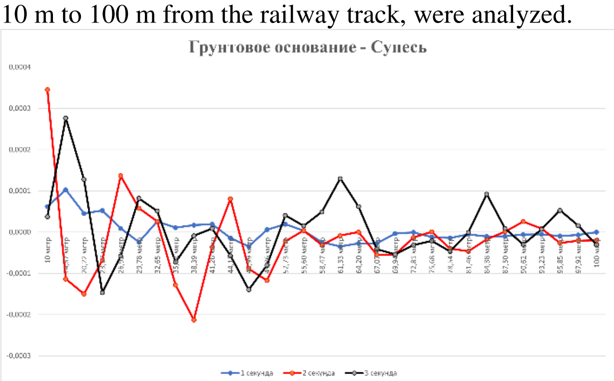


Fig.4. Graph of time-dependent displacement of oscillations occurring in sandy loam soil foundation

Fig.5. Graph of time-dependent displacement of oscillations occurring in loess-like loam at different distances

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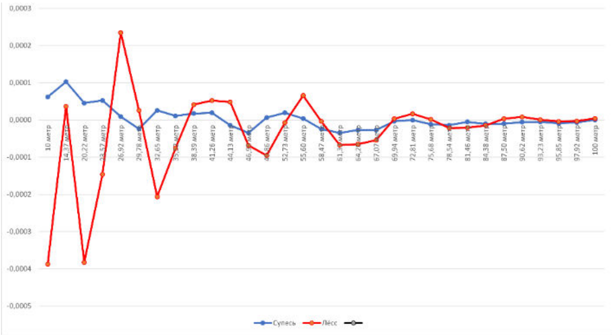

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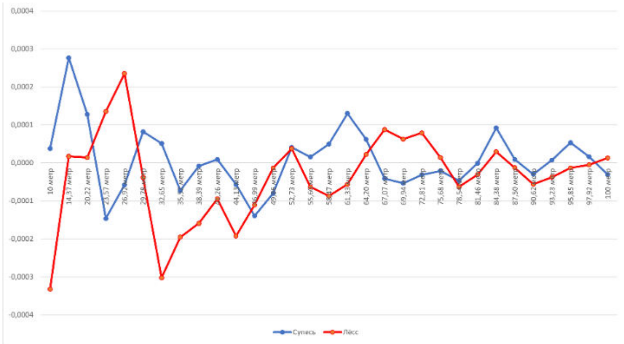

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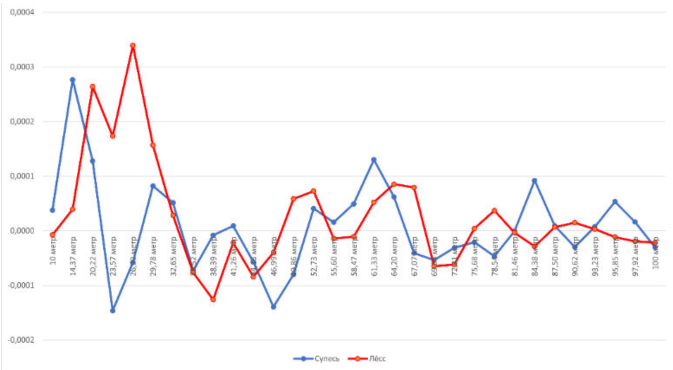

c)

Fig.6. Graph of time-dependent displacement of oscillations, comparing loamy sandy loam and loess loamy loamy soil substrate

V. CONCLUSION

The comparison of the results obtained when solving problems on vibration propagation for two cases (sandy loam and loess loam) of soil foundations has been carried out. It is revealed that propagation of vibrations in soils and structures depends on their properties (modulus of elasticity, Poisson's ratio, density). By comparing the results for different soils it was determined that the velocity of wave propagation. The data were obtained at t=1,2,and 3 second propagation velocity. Comparison relative to the results obtained for loam (subgrade soil) showed the following differences at t= 1 s (loess loamy soil) the displacement at x=25.22m will be greater by 18.95%; at t= 1 s x=59.86m will be greater by 29.29%; at t= 1 s x=75.68m will be greater by 22.69%. At t= 2 with x=25.22m will be greater by 71.73%; at t= 2 with x=59.86m will be greater by 12.38%; at t= 2 with x=75.68m will be greater by 48.37%. At t= 3 with x=25.22m will be more by 60.64%; at t= 3 with x=59.86m will be more by 5.45%; at t= 3 with x=75.68m will be less by 17.20%.

Based on this, it can be said that it is necessary to consider the real physical parameters when studying the process of vibration propagation in soils. Thus, based on the results obtained, it can be said that the degree of vibration resulting from the movement of vehicles depends largely on the properties of soils. Consequently, it is necessary to take into account physical and mechanical properties of soils concerning the considered area during calculations.

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