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NUMERICAL SIMULATION WITH THE EFFECT OF DISSIPATION IN DYNAMIC HETEROGENEOUS "SOIL-STRUCTURE" SYSTEMS

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Abstract: *Dynamic loads influence directly on structure (wind, loads from rotating mechanisms, shock effects) or transmitted to system through a soil massif (earthquakes, loads from transport motion). Usually dynamic interaction of a structure and soil (ground) is considered as a factor that has a favorable effect on the dynamic operation of the structure (higher damping).*

This leads to the wrong conclusion that this phenomenon can be neglected. Directly contrary is the well-known example of the collapse of flyover on the Hanshin (Japan) highway during the earthquake in Kobe. The true nature of the process of dynamic interaction of structures and a ground has a complex origin and the results of calculation, which are beyond the intuitive representation, can often validate difficulty to predict, even for an experienced designer.

Based on Hamilton-Ostrogradski variational principle a discrete model of the finite-element problem of hereditarily deformed systems is constructed in this paper. The method and algorithm for calculating of viscoelastic infinite semi-plane area with the standard viscous boundary condition for the absorption of elastic waves is developed. The method is realized by carrying out specific numerical examples.

Аннотация: *Динамические нагрузки (ветер, нагрузки от вращающихся механизмов, ударные эффекты) влияют непосредственно на строительные конструкции или передаются в систему через грунтовый массив (землетрясения, нагрузки от движения транспорта). Обычно динамическое взаимодействие конструкции и грунта (основание) рассматривается как фактор, который благоприятно влияет на динамическую работу конструкции (более высокое затухание).*

Это приводит к неверному выводу, что этим явлением можно пренебречь. Напротив, имеется хорошо известный пример крушение пролета моста на шоссе Хансин (Япония) во время землетрясения в Кобе. Истинный характер процесса динамического взаимодействия конструкции и грунта имеет сложное происхождение, и результаты расчета, выходящие за пределы интуитивного представления, часто могут утверждать трудности для прогнозирования даже для опытного проектировщика.

В статье на основе вариационного принципа Гамильтона-Остроградского, построена дискретная модель конечных элементов наследственно деформированных систем. Разработана методика и алгоритм расчета вязкоупругой бесконечной полуплоскости со стандартным вязким граничным условием для поглощения упругих волн. Метод реализуется путем выполнения конкретных численных примеров.

Аннотация: *Динамикалык оорчулуктар (шамал, айлануучу механизмден келген оорчулуктар, сокку эффектилери) курулуш консрукцияларына түздөн-түз таасир этет же кыртыштык массив аркылуу берилет (жер титирөө, транспорттун кыймылынан келген оорчулуктар). Конструкциянын жана кыртыштын (негиздин) динамикалык өз ара аракеттенүүсү дайыма конструкциянын динамикалык иштөөсүнө жагымдуу таасир берүүчү фактор катары каралат.*

Бул өз кезегинде туура эмес жыйынтыкка алып келет, бул кубулушка тоготпой койсо болот. Тескерисинче, Кобедеги жер титирөө мезгилинде Хансин (Япония) шоссесиндеги көпүрөнүн тирөөчтөрүнүн кыйрашы сыяктуу белгилүү мисалы бар. Конструкциянын жана

кыртыштын динамикалык өз ара аракеттенүүсүнүн чыныгы мүнөзү татаал келип чыгышка ээ, интуитивдик элестетүүлөрдүн чегинен чыгуучу эсептөөлөрдүн жыйынтыгы тажрыйбалуу долбоорлоочу үчүн да божомолдоо үчүн кыйынчылыктарды алып келет деп бекемдеши мүмкүн.

Макалада Гамильтон-Остроградскийдин вариационндук принцибинин негизинде мураскор бузулган тутумдардын, түпкү элементтеринин дискреттик модели түзүлгөн. Серпилгич толкундарды жоюу үчүн стандарттуу илешкек кырдуу шарттары менен илешкек-серпилгич чексиз жарым тегиздиктин эсебинин методикасы жана алгоритми иштелип чыккан. Ыкма конкреттүү сандык мисалдарды аткаруу жолу менен ишке ашырылат.

The consideration of interaction of soil and structure is illustrated by the example of a building or bridge, depicted in fig. 1. Various dynamic loads can act on these structures. In particular, the propagation of seismic waves in a soil massif causes oscillations, the intensity of which changes with the presence of buildings and foundations. This is the first feature of the interaction of structure and soil. The seismic front, reaching the basement, causes the structure to vibrate.

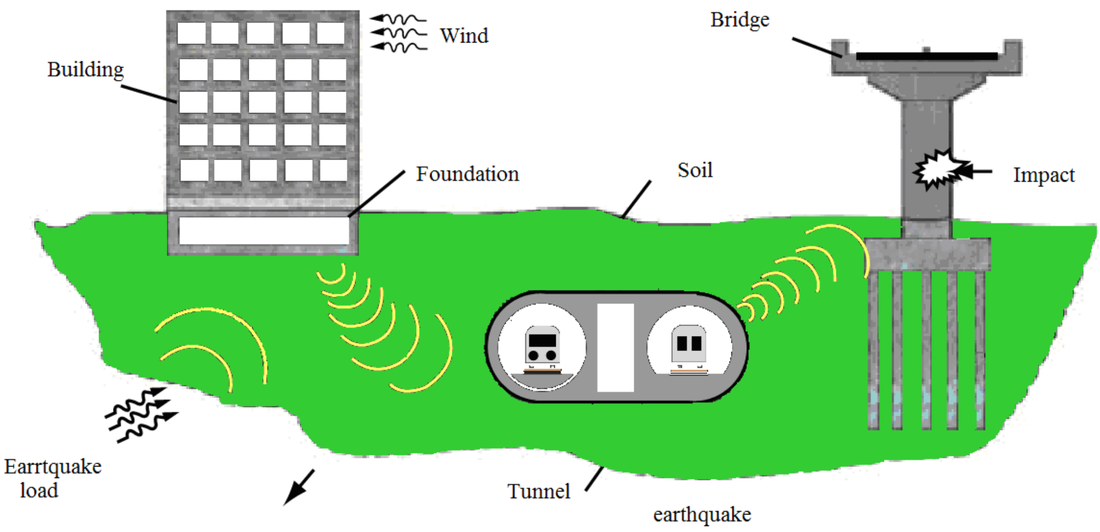

Fig. 1. Dynamic system of "soil-structure" media

Investigation of the stress-strain state under the influence of dynamic and seismic loads on the system should be carried out taking into account internal friction in the structures and especially in the soil massif. With the course of time, damping occurs due to the presence of viscous properties in materials and with outgoing of dynamic waves in the soil to infinity.

The main difficulty in solving such problems is that it is necessary to take a limited area and this leads to the reflection of the wave from the borders. This brings in inaccuracy to the results of the solution. Therefore, there are several approaches to solving this problem. But we use a special boundary conditions providing damping of the waves, so such conditions are called the standard viscous boundary [1, 4].

Let’s write the main dynamic equations [1, 2] for the system with the corresponding boundary and initial conditions:

$$\begin{aligned} &A\vec{\sigma} + \vec{J} = 0 \\ &\vec{\varepsilon} = A^T \vec{U} \\ &\vec{\sigma} = D\vec{\varepsilon} \end{aligned} \qquad (1)$$

Here, according to the principle of d'Alembert

$$\vec{J} = -\rho \frac{\partial^2 \vec{U}}{\partial t^2} \qquad (2)$$

The formulas (1-2) constitute a complete direct formulation of the problem of the dynamic theory of elasticity in displacements. Now we write the third equation of Hooke's law from (1) according to the hereditary Boltzmann-Volterra theory [3]:

$$\vec{\sigma} = D(1 - R^*)\vec{\varepsilon} \qquad (3)$$

where $R^* = \int_0^t R(t-\tau)d\tau$ - integral Volterra operator. Then for a heredity kernel having a weakly singular feature we can write

$$R(t-\tau) = \bar{\varepsilon} e^{-\beta(t-\tau)}(t-\tau)^{\alpha-1} \qquad (4)$$

For the transition from continuum model to discrete one we use the Hamilton-Ostrogradski variational principle on the base of the of the finite-element method. So the system of equations for problem of hereditarily deformed systems can be written

$$M\ddot{\vec{Z}}(t) + K(1 - R^*)\vec{Z}(t) = \vec{P}(t) - \Gamma\dot{\vec{Z}}(t) \qquad (5)$$

The obtained equation are the system of ordinary integro-differential equations (IDE). In the case of $\vec{\varepsilon}^*$ = 0 they become a system of differential equations. To solve these equations we use the stepped direct integration method (Wilson method) [2].

Let’s consider a real example of effect of high-speed action to character of wave propagation in soil. In work [5] in-situ is studied of vibrational process of the earthen structure (embankment) erected from loess-like sandy loam located on the Tashkent-Samarkand highway (fig. 2). At this time speed range of passenger rolling stock was 85-180 km / h with a gauge width of 1520 mm. The measurements were carried out on the section of the long-welded rails with a ballast thickness of 40 cm and on subgrade filled by loess-like sandy loam. Table 1 shows the characteristics of the materials of model.

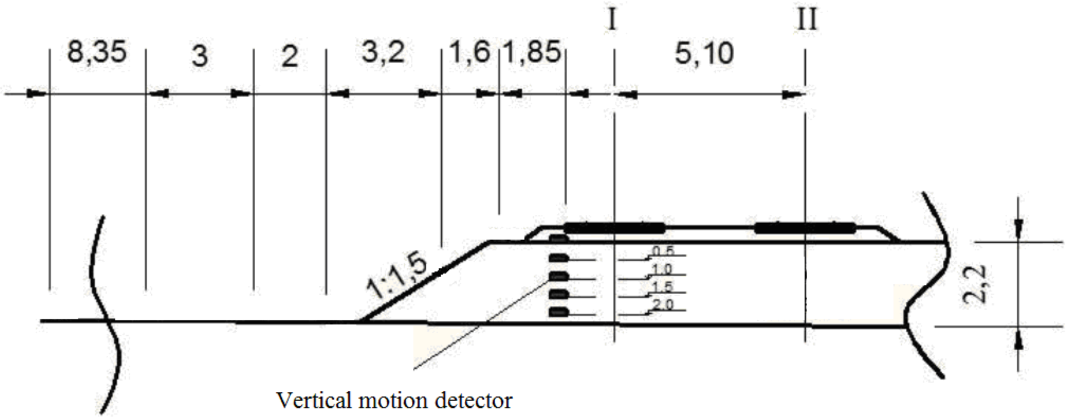

Fig. 2. Cross section of experimental plot

Table 1

Material characteristics of model

Material	Properties					
	E, кPa	***ν***	***ρ***, t/m^3	$\bar{\varepsilon}$	β	α
Crushed ballast (I)	$1 \cdot 10^5$	0,27	1,85	0,01373	$13 \cdot 10^{-6}$	0,20
Subgrade soil)	$6 \cdot 10^4$	0,35	1,8	0,0674	$2{,}43 \cdot 10^{-3}$	0,25
Base soil (III)	$4 \cdot 10^4$	0,3	1,71	0,0333	$3{,}6 \cdot 10^{-4}$	0,25

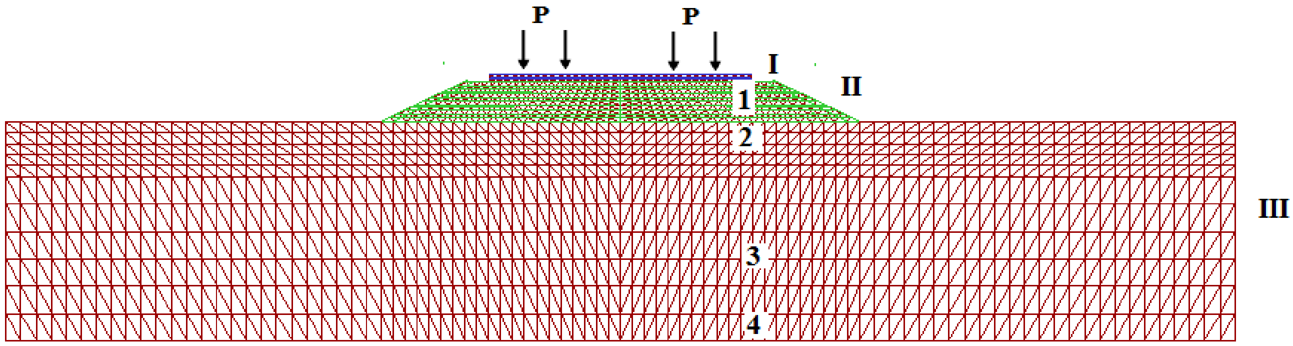

Fig. 3. The calculation scheme: I-III - materials, 1,2,3,4 - points

The installation of the vibration sensors are shown in fig. 2, 3.

According to the developed technique it is necessary to determine the dynamic stress-strain state of area under action of rolling stock. If we assume that speed of rolling stock is constant (Vn), and it consists a periodically repeated impulse waves, which occurs under the train wheels (distances between them equal to L = 2.8 m) then we can write the following

$$P(t) = \frac{1}{2}, P_0(1 - \cos\theta t)\,, \quad \frac{2\pi V_n}{L} = \theta,$$

In calculation the pressure is taken as the load from rail-grating lattice exciting by normal load equal to 18,000 kg. The number of axes for the entire train is 10 pieces.

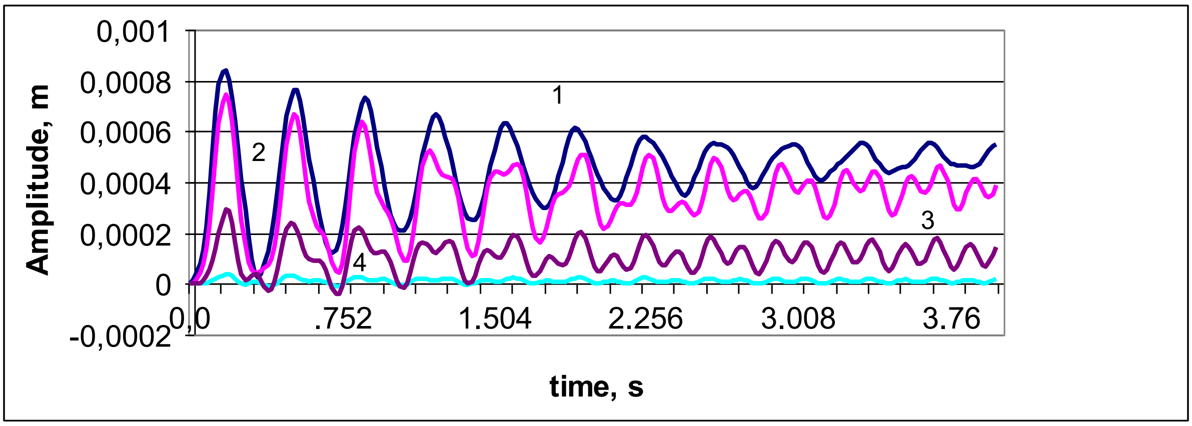

Fig. 4. Defined vertical displacements at points 1, 2, 3, 4

Dynamic stress state of the ballast layer and subgrade in the developed model is realized by introducing inertial components in the horizontal and vertical directions, arising from the weight of the finite elements (according to the D'Alembert principle). In the calculation, we have taken into account the loss factors with the introduction of values of rheological coefficients, which are given in table 1. The fig.4, 5 show the change in vertical displacement at depths of 0,5 m, 1,0 m, 1,5 m and 2,2 m which obtained from the experiment and calculating by FEM program at Vn = 160 km/h.

a) б)

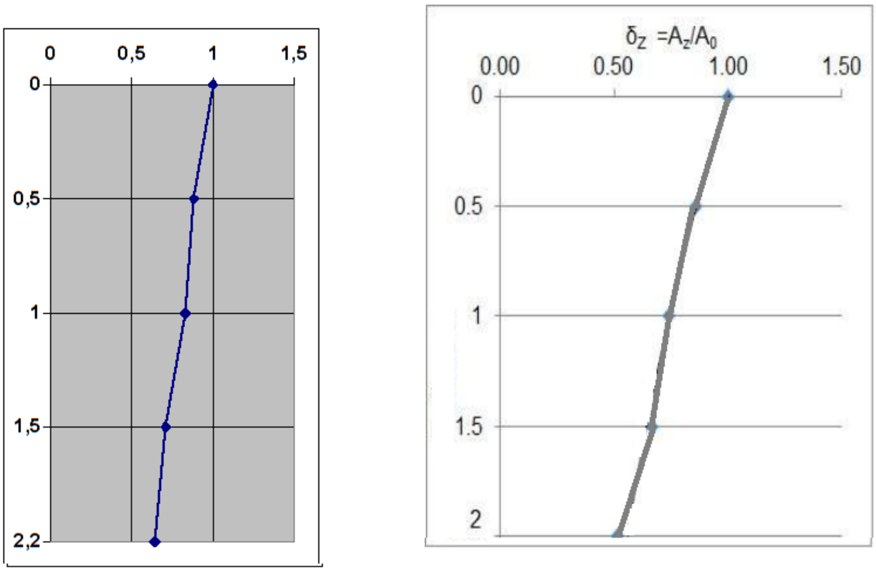

Fig. 5. Changing of vertical displacements in depth: a) theoretical, b) experimental

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