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VIBRATIONS OF A BOX OF PACKAGES EXCITED BY NON-UNIFORMITIES OF THE ROAD PROFILE

KELIO PROFILIO NELYGUMŲ SUŽADINAMI PAKUOČIŲ DĖŽĖS VIRPESIAI

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The first eigenfrequencies of the packages in the non-deformable box have been determined as well as the forced frequencies excited by the non-uniformities of the road. In order to avoid big overloads it is recommended to choose the velocity of motion in such a way that the difference between the eigenfrequencies and the forced frequencies would be maxmin.

Eigenmodes of ten rows and ten columns of packages in a box are analyzed. A package is represented as a single plane strain element. Interconnection of packages is assumed by special elements which ensure continuity of the normal displacement by the penalty method.

Eigenmodes of ten long packages in a box are analyzed. A long package is represented as consisting from ten plane strain elements.

The influence of vibrations in the process of transportation of packages is analyzed by taking the non-uniformities of the road profile into account. The main structure of the performed investigation is presented here, while the detailed optimal synthesis and results of experimental investigations are the subjects of other papers.

Road, non-uniformity, forced frequencies, package, box, plane strain, eigenmodes, vibrations, finite elements, penalty method, interconnecting element, long package.

Introduction

The forced frequencies excited by the non-uniformities of the road are determined. In order to avoid big overloads of packages it is recommended to choose the velocity of motion in such a way that the difference between the eigenfrequencies and the forced frequencies would be maxmin.

Eigenmodes of ten rows and ten columns of packages in a box are analyzed. A package is represented as a single plane strain element.

Interconnection of packages is assumed by special elements ensuring approximate continuity of the normal displacement between the packages by the penalty method.

Eigenmodes of ten long packages in a box are analyzed. A long package is represented as consisting from ten plane strain elements.

The first eigenmodes are determined and analyzed.

The model for the analysis of vibrations of packages is proposed on the basis of the material described in [1, 2].

In the research presented in references [3-7] the problems of optimisation of breaking of a wheel of a car are analyzed by taking into account the non-uniformities of the road profile. There the variable representing the non-uniformity of the road is assumed as a variable random quantity in a stationary process with zero mean and the statistical dynamics of such a system is investigated.

In a number of references [8-10] the problems of comfort while driving are investigated. The possibilities of reduction of vibrations inside a vehicle are analyzed. The main source of excitation of such vibrations are the non-uniformities of the road profile [11].

In this paper the influence of vibrations in the process of transportation of packages is analyzed by taking the non-uniformities of the road profile into account. The main structure of the performed investigation is presented here, while the detailed optimal synthesis and results of experimental investigations are the subjects of other papers.

Vibrations excited by the non-uniformities of the road profile

In general non-uniformities of the road profile are represented in the following way:

$$\xi = \xi(x) = \sum_{n=1}^{s} A_n \cos\left(2\pi n \frac{x}{\lambda_n} + \alpha_n\right), \qquad (1)$$

where A_n are the amplitudes (n = 1, 2, …, s), x is the longitudinal coordinate, λ_n are the wavelengths and α_n are the phases.

When the box of packages is being displaced with a constant velocity experiencing point contact with the profile of the road, the equation (1) takes the following form:

$$\xi = \xi\left(\bar{\dot{x}}t\right) = \sum_{n=1}^{s} A_n \cos\left(2\pi\Omega_n t + \alpha_n\right), \qquad (2)$$

where:

$$\Omega_n = n\frac{\bar{\dot{x}}}{\lambda_n}, \qquad (3)$$

t is the time variable and $\bar{x}$ is the average velocity.

In order to avoid resonance vibrations and to minimize the level of vibrations it is recommended to choose the velocity of transportation of the box of packages in such a way that the minimum distance between the forced vibrations and the eigenfrequencies would be maximum, that is:

$$\max\min\sum_i\sum_n\left(\omega_i-\Omega_n\right), \tag{4}$$

where ω_i denotes the eigenfrequency with number i.

Model for the analysis of vibrations of packages

Further x and y denote the axes of the system of coordinates. The local coordinates (ξ, η) of the nodes of a plane strain element are (-1, -1), (1, -1), (-1, 1), (1, 1). The element has two nodal degrees of freedom: the displacement in the direction of the x axis denoted as u and the displacement in the direction of the y axis denoted as v.

The interconnecting element is considered as a one dimensional element with the local coordinate ξ in its longitudinal direction. The derivative of the longitudinal coordinate s with respect to the local coordinate is expressed as:

$$\frac{ds}{d\xi}=\sqrt{\left(\frac{dx}{d\xi}\right)^2+\left(\frac{dy}{d\xi}\right)^2}. \tag{5}$$

The interpolation of the difference of displacements du and dv for the interconnecting element is performed by:

$$\begin{Bmatrix} du \\ dv \end{Bmatrix}=\left[\bar{N}\right]\{\delta\}, \tag{6}$$

where $\{\delta\}$ is the vector of nodal displacements and for the horizontal interconnecting element:

$$\left[\bar{N}\right]=\begin{bmatrix} -N_1 & 0 & -N_2 & 0 & N_1 & 0 & N_2 & 0 \\ 0 & -N_1 & 0 & -N_2 & 0 & N_1 & 0 & N_2 \end{bmatrix}, \tag{7}$$

where N_i are the shape functions of the one dimensional linear finite element.

For the vertical interconnecting element:

$$\left[\bar{N}\right]=\begin{bmatrix} N_1 & 0 & -N_1 & 0 & N_2 & 0 & -N_2 & 0 \\ 0 & N_1 & 0 & -N_1 & 0 & N_2 & 0 & -N_2 \end{bmatrix}. \tag{8}$$

The difference of normal displacement du_n is expressed as:

$$du_n=\left[T\right]\begin{Bmatrix} du \\ dv \end{Bmatrix}=\left[T\right]\left[\bar{N}\right]\{\delta\}, \tag{9}$$

where the transformation matrix is introduced:

$$\left[T\right]=\begin{bmatrix} -\dfrac{dy}{d\xi}\Big/\dfrac{ds}{d\xi} & \dfrac{dx}{d\xi}\Big/\dfrac{ds}{d\xi} \end{bmatrix}. \tag{10}$$

The following notation is introduced:

$$\left[\bar{\bar{N}}\right]=\left[T\right]\left[\bar{N}\right]. \tag{11}$$

The stiffness matrix of the interconnecting element has the form:

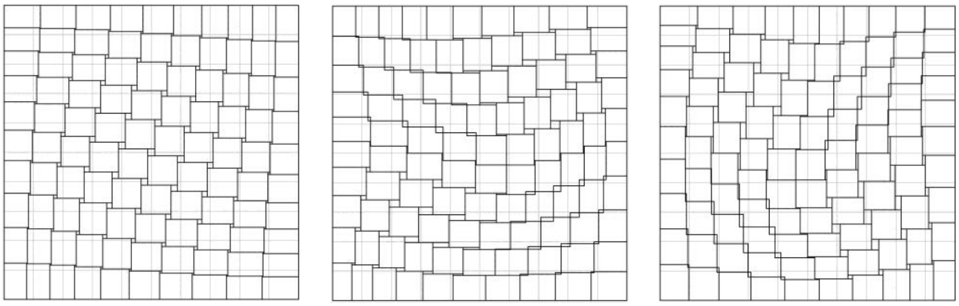
$$\left[K\right]=\int\left[\bar{\bar{N}}\right]^T\lambda\left[\bar{\bar{N}}\right]ds, \tag{12}$$

where λ is the penalty parameter.

Results of analysis of eigenmodes of packages

Length of the structure and width of the structure are equal to 2 m. On all the boundaries of the structure all the nodal displacements are assumed equal to zero. The following parameters of the packages are assumed: modulus of elasticity $E = 6000$ Pa, Poisson's ratio $\nu = 0.3$, density of the material ρ = 785 kg/m^3, while λ = 10^9 N/m^3. The first eigenmodes are presented in Fig. 1.

The first eigenvalues are $\omega_1^2 = 14.6263\left(\frac{\text{rad}}{\text{s}}\right)^2$, $\omega_2^2=\omega_3^2=19.801\left(\frac{\text{rad}}{\text{s}}\right)^2$. The second and the third eigenmodes correspond to the same eigenfrequency. This is the consequence of the symmetry of the analyzed structure: that is of assuming a square domain (box of packages). Thus any linear combination of those eigenmodes also is an eigenmode.



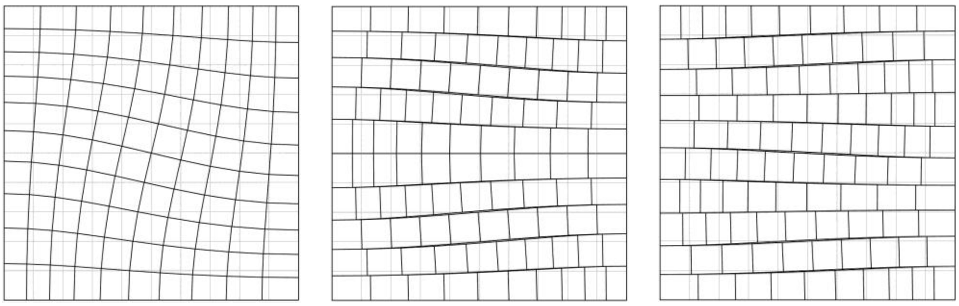
a) b) c)

Fig. 1. The first eigenmodes: a) the first eigenmode, b) the second eigenmode, c) the third eigenmode

1 pav. Pirmosios savos formos:a) pirma sava forma, b) antra sava forma, c) trečia sava forma

Results of analysis of eigenmodes of long packages

Eigenmodes of ten long packages in a box are analyzed. A long package is represented as consisting from ten plane strain elements. Other geometrical and physical parameters are assumed the same as for the previous problem. The first eigenmodes are presented in Fig. 2.



a) b) c)

Fig. 2. The first eigenmodes: a) the first eigenmode, b) the second eigenmode, c) the third eigenmode

2 pav. Pirmosios savos formos: a) pirma sava forma, b) antra sava forma, c) trečia sava forma

The first eigenvalues are $\omega_1^2 = 14.7755 \left(\frac{\text{rad}}{\text{s}}\right)^2$, $\omega_2^2 = 19.8687 \left(\frac{\text{rad}}{\text{s}}\right)^2$, $\omega_3^2 = 20.5246 \left(\frac{\text{rad}}{\text{s}}\right)^2$. The effect of slippage of packages with respect to one another is clearly seen from the graphical representations of the second and the third eigenmodes.

Conclusions

The first eigenfrequencies of the packages in the non-deformable box have been determined as well as the forced frequencies excited by the non-uniformities of the road. In order to avoid big overloads it is recommended to choose the velocity of motion in such a way that the difference between the eigenfrequencies and the forced frequencies would be maxmin.

Eigenmodes of ten rows and ten columns of packages in a box are calculated and analyzed. The applicability of special interconnecting elements ensuring approximate continuity of the normal displacement between the packages by the penalty method is investigated.

Eigenmodes of ten long packages in a box are calculated and analyzed.

This model is an idealized one, but the assumptions made enable to easily obtain the eigenmodes of packages.

In this paper the influence of vibrations in the process of transportation of packages is analyzed by taking the non-uniformities of the road profile into account. The main structure of the performed investigation is presented here, while the detailed optimal synthesis and results of experimental investigations are the subjects of other papers.

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KELIO PROFILIO NELYGUMŲ SUŽADINAMI PAKUOČIŲ DĖŽĖS VIRPESIAI

Reziumė

Nustatyti pirmieji pakuočių nedeformuojamoje dėžėje savi dažniai, o taip pat kelio nelygumų sužadinami priverstiniai dažniai. Tikslu išvengti per didelių perkrovų rekomenduojama parinkti tokį judesio greitį, kad skirtumas tarp savų dažnių ir priverstinių dažnių būtų maksmin.

Analizuojamos dešimties eilučių ir dešimties stulpelių pakuočių esančių dėžėje savos formos. Pakuotė vaizduojama vienu elementu esančiu plokščioje deformuotoje būsenoje. Pakuočių tarpusavio ryšys priimamas panaudojant specialius elementus, kurie užtikrina normalinio poslinkio tolydumą baudos metodu.

Analizuojamos dešimties ilgų pakuočių esančių dėžėje savos formos. Priimama, kad ilga pakuotė yra sudaryta iš dešimties elementų esančių plokščioje deformuotoje būsenoje.

Pakuočių transportavimo procese virpesių įtaka yra analizuojama įvertinant kelio profilio nelygumus. Pateikta pagrindinė atlikto tyrimo struktūra, o detali optimali sintezė ir eksperimentinių tyrimų rezultatai yra kitų straipsnių analizės objektais.

Kelias, nelygumas, priverstiniai dažniai, pakuotė, dėžė, plokščia deformuota būsena, savos formos, virpesiai, baigtiniai elementai, baudos metodas, jungiantis elementas, ilga pakuotė.

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КОЛЕБАНИЯ ЯЩИКА УПАКОВОК ВОЗБУЖДАЕМЫЕ НЕРОВНОСТЯМИ ПРОФИЛЯ ДОРОГИ

Резюме

Установлены первые собственные частоты упаковок в недеформируемом ящике, а также вынужденные частоты возбуждаемые неровностями дороги. Для избежания больших перегрузок рекомендуется выбрать такую скорость движения, при которой разница между собственными частотами и вынужденными частотами была бы максмин.

Анализируются собственные формы десяти строк и десяти столбцов упаковок в ящике. Упаковка представляется одним элементом в плоском деформированном состоянии. Взаимная связь упаковок принимается используя специальные элементы, которые обеспечивают непрерывность нормального перемещения штрафным методом.

Анализируются собственные формы десяти удлинённых упаковок в ящике. Принимается, что удлинённая упаковка состоит из десяти элементов в плоском деформированном состоянии.

В процессе транспортировки упаковок влияние вибраций анализируется с учётом неровностей профиля дороги. Приводится основная структура проведённого исследования, а детальный оптимальный синтез и результаты экспериментальных исследований являются объектом анализа других статьей.

Дорога, неровность, вынужденные частоты, упаковка, ящик, плоское деформированное состояние, собственные формы, колебания, конечные элементы, штрафной метод, соединяющий элемент, удлинённая упаковка.