https://dx.doi.org/10.22161/ijaers.74.19 ISSN: 2349-6495(P) | 2456-1908(O)

Dynamic analysis of curved plate - columns system subjected to moving load

Le Xuan Thuy

Department of Solid Mechanics, Le Quy Don Technical University, Viet Nam

***Abstract*— When calculating and designing a bridge structure, the guarantee of usability, structural durability, aesthetic is important requirements. There are many types of bridge structures proposed when constructed in different locations, including the type of bridge with the curved surface. Approaching this problem, the structure consists of curved plates associated with columns resistant subjected to moving load is solved in this paper. The numerical results are references for calculating and designing bridges and other structures which are subject to moving load.*

***Keywords*— Dynamic analysis, plate, curve, moving load.**

I. INTRODUCTION

In the transportation and construction fields, many types of plate, shell structure subjected to the moving load can be seen, such as bridge and road models. Depending on the level of accuracy required and the ability to calculate, the face of the bridge can be described in the form of a plate, shell or beams in the calculation model. These types of structural calculation is influenced by moving load that many scientists are interested in, such as: C. Johansson et al. [1], Ladislav Frysba [2], Nguyen Thai Chung et al. [3, 4], Qinghua Song et al. [5], Nguyen Van Khang et al. [6], Nguyen Van Chinh et al. [7], T.O.Awodola et al. [8], Volkan Kahya et al. [9], Bui Manh Cuong [10]. The publication is quite varied. However, the shape of structures is simple in most studies. Study subjects mentioned are ordinary beams and plates, or plates on elastic foundation.

In this paper, the problem curved plate – columns system subjected to the moving load is solved (Fig. 2). In which, the results of the free vibration and the forced oscillation problem are shown. The structure depicts the curved part of the bridge. The term curved plate here refers to the curved profile of a plate. The calculation program is built on the programming language APDL run on ANSYS software.

The article focuses on the types of elements used in the program and the algorithm using the element "Birth and Death" to describe the moving load. With the program set up, Users can easily change the dimension structures as well as the load, customized to solve many different problems. The results of this paper are the basis to solve more complex problems in the future.

Fig 1. The Bridge with curved surface

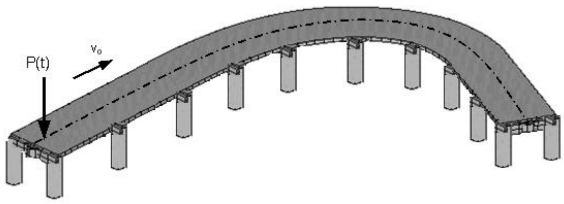


Fig 2. The curved plate – columns system model

The system consists of a reinforced plate with a curved profile in the horizontal plane attached to the pillars, clamped supported at the end of columns and simply supports at two short edges of the plate. The load acting on the system is the moving force has rules P(t) run curved orbit along the center line of the plate with velocity v_0.

II. FINITE ELEMENT MODELING

To describe the bending plate, the SHELL99 element is used. SHELL99 may be used for layered applications of a structural shell model. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. SHELL99 allows up to 250 layers. If more than 250 layers are required, a user-input constitutive matrix is available.

Supported beams and columns described by BEAM188 element. BEAM188 is suitable for analyzing slender to moderately stubby/thick beam structures. This element is based on Timoshenko beam theory. Shear deformation effects are included.

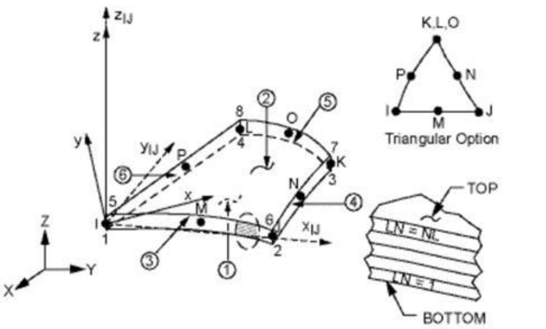


Fig 3. SHELL99 Geometry [12]

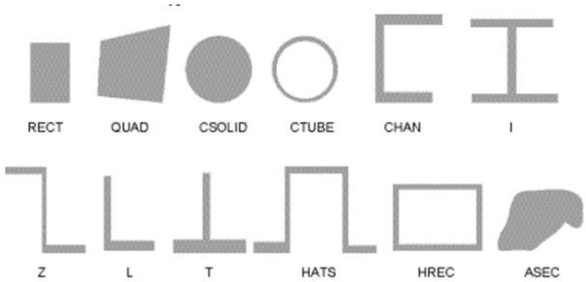


Fig 4. Cross-sectional shapes can be described when use Beam188 element [11,12]

BEAM188 is a linear (2-node) or a quadratic beam element in 3-D. BEAM188 has six or seven degrees of freedom at each node, with the number of degrees of freedom depending on the value of KEYOPT(1). BEAM188 can be used with any beam cross-section defined via SECTYPE, SECDATA, SECOFFSET, SECWRITE, and SECREAD. The cross-section associated with the beam may be linearly tapered.

Elasticity, creep, and plasticity models are supported (irrespective of cross-section subtype). A cross-section associated with this element type can be a built-up section referencing more than one material.

III. ELEMENT BIRTH AND DEATH DESCRIBE THE MOVING MASS

In the trajectory of moving mass M, the node of the plate element can be added to the M volume or not. M is described by the MASS21 element (MASS21 is a point element having up to six degrees of freedom: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes).

If material is added to or removed from a system, certain elements in model may become "existent" or "nonexistent." In such cases, we can employ element birth and death options to deactivate or reactivate selected elements, respectively [11].

To achieve the "element death" effect, the ANSYS program does not actually remove "killed" elements. Instead, it deactivates them by multiplying their stiffness (or conductivity, or other analogous quantity) by a severe reduction factor (ESTIF). This factor is set to 1E-6 by default, but can be given other values.

Element loads associated with deactivated elements are zeroed out of the load vector, however, they still appear in element-load lists. Similarly, mass, damping, specific heat, and other such effects are set to zero for deactivated elements. The mass and energy of deactivated elements are not included in the summations over the model. An element's strain is also set to zero as soon as that element is killed. In like manner, when elements are "born" they are not actually added to the model; they are simply reactivated. We must create all elements, including those to be born in later stages of your analysis, while in PREP7. We cannot create new elements in the SOLUTION. To "add" an element, we first deactivate it, then reactivate it at the proper load step.

The algorithm consists of two steps:

Step 1: All the moving masses are attached to all the nodes along the trajectory of motion, and then they are deactivated.

Step 2: Depending on the velocity and the time taken, whenever a moving object reaches a certain node, the corresponding mass at that node is activated. When volume passes, MASS21 element at that node is deactivated again.

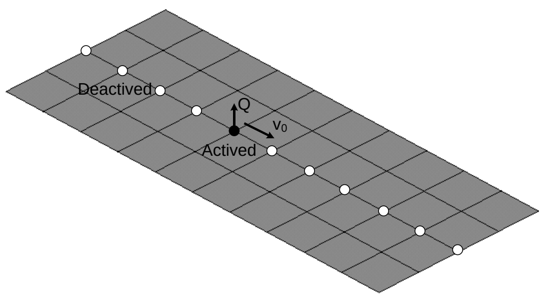


Fig. 5. Element Birth and Death

https://dx.doi.org/10.22161/ijaers.74.19 *ISSN: 2349-6495(P) | 2456-1908(O)*

IV. GOVERNING EQUATIONS AND SOLUTION METHOD

After assembling the matrices, element vector of elements describing beams, plate, pillar support and moving mass, the governing equations of the system is [11, 12]:

$$[M]\{\ddot{q}\}+[C]\{\dot{q}\}+[K]\{q\}=\{R\}, \quad (1)$$

in which $\{q\},\{\dot{q}\},\{\ddot{q}\}$ are global displacement vector, global velocity vector, and global acceleration vector, respectively;

$$[M]=\sum_e\left(\left[M^e\right]+\left[M_Q^e\right]\right),[K]=\sum_e\left(\left[K^e\right]+\left[K_Q^e\right]\right),$$

$$[C]=\sum_e\left(\left[C^e\right]+\left[C_Q^e\right]\right),\{R\}=\sum_e\{P(t)\}_e \quad (2)$$

are the global mass matrix, the global stiff matrix, the global resistance matrix and the global load matrix, respectively.

The global resistance matrix $\left[C^e\right]=\alpha[M]_e+\beta[K]_e$ (3) in which Rayleigh coefficients α, β defined by resistance score ξ and the first two natural frequencies of the system. $\left[M_Q^e\right]$, $\left[C_Q^e\right]$, $\left[K_Q^e\right]$ are matrices related to moving mass.

During the resolution, matrices related to moving load are recalculated after each time step. The equations (1) are solved, we have a set of displacement parameters of the node of the system on each time step, from that calculates the stress, internal force, etc.

Flow diagram of the program [11, 12]:

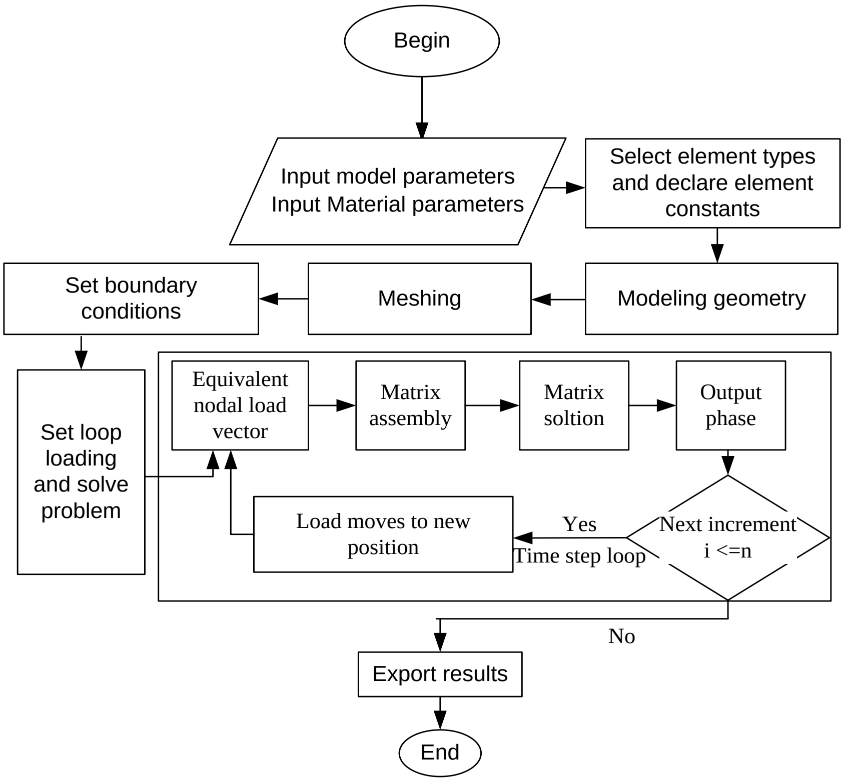


Fig. 6. Flow diagram

V. CHECK THE RELIABILITY OF THE SIMULATION PROGRAM

To evaluate the reliability of the solving algorithm, plate subjected to moving mass is applied [5]. In ref. [5], the authors used numerical methods to solve the problem. The geometrical and material properties of plate are as follows: L = 1 m, W = 0.5 m, h = 0.01 m, ρ = 7820 kg/m^3, E = 206.8 Gpa, μ = 0.29. A mass M = 2.3 kg moves at a speed v_M = 10 m/s along the centerline of the plate y = W /2 in x direction (Fig. 7).

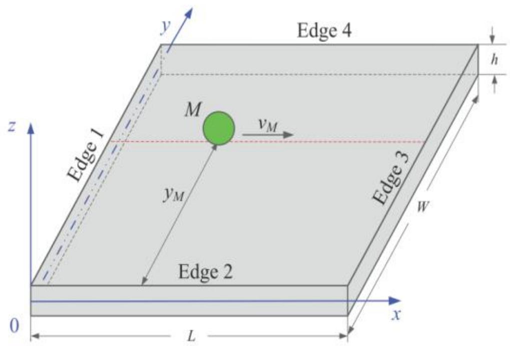


Fig 7. The geometry of the plate [5]

https://dx.doi.org/10.22161/ijaers.74.19 ISSN: 2349-6495(P) | 2456-1908(O)

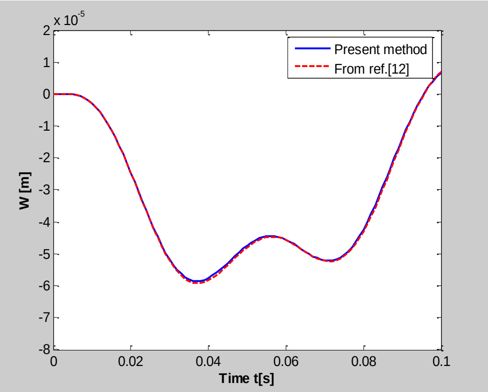


Fig. 8. Displacement at center points of the plate

The difference of the max value of the displacement at the midpoint of the plate is 0.8%, indicating that the algorithms and calculation programs established by the authors are reliable.

VI. NUMERICAL ANALYSIS

Consider the curved plate with stiffeners put on the pillar supports. Plates with curved shapes with dimension as Figure 9, thickness w = 20cm; 10 stiffeners in the position as shown, width of stiffener B_b = 0.2m, height of stiffener H_b = 0.4m; at the end of the support beams have columns have diameter D_c = 0.6m, height H_c = 4.0m. There is a curved stiffener along the center line, at the bottom of the plate that has the same dimension with the transverse ones. End of columns is clamped. Two short edges of the plate are simply supported. The moving load effect perpendicular to the surface of the plate with the law P(t) = $P_0 \sin\omega t$ ($P_0 = 2.4\times10^3$ N, $\omega = 30\pi$ rad/s), move from right to left along the center line of plate with speed v_0 = 10 m/s.

The plate is made of composite material with: E_1=161.9 GPa, E_2=9.5 GPa, μ_{12}=0.33, $G_{12}=G_{13}=G_{23}$=7.47 GPa, ρ_1=1600 kg/m^3. Material properties of stiffeners and columns: Young modulus E = 210 GPa, Poisson coefficient μ = 0.29, density ρ = 7800 kg/m^3.

The finite element model of the system is shown in Figure 10. Use the program that was set up, free vibration problem of the curved plate – columns system subjected to moving mass is solved. The natural frequencies of model are shown in Figure 11.

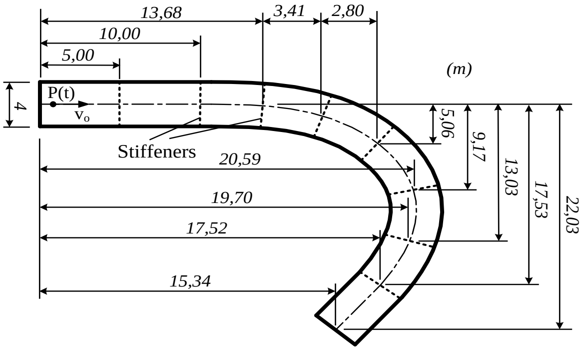


Fig 9. Curved plate dimension

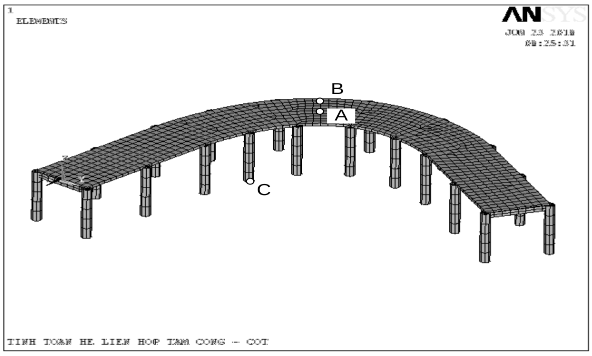
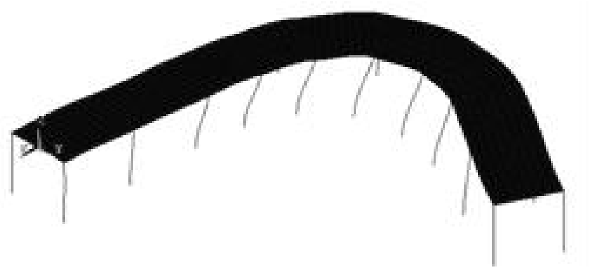
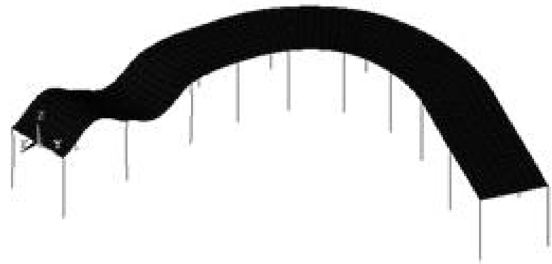
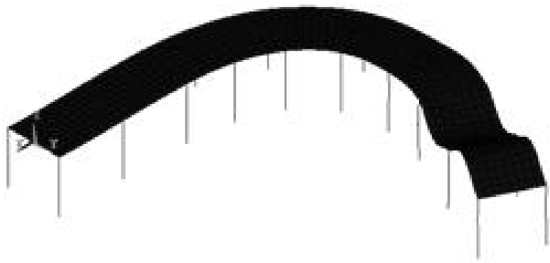


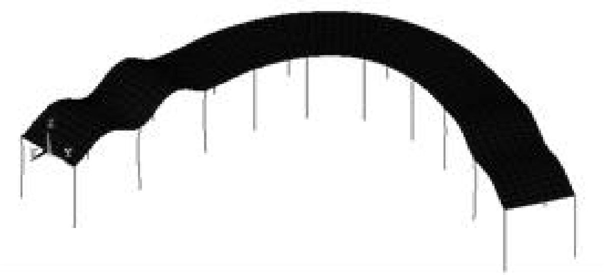
Fig 10. Finite element model of the system


a) Mode 1 (f_1 = 25.05Hz)


b) Mode 2 (f_2 = 34.24Hz)


c) Mode 3 (f_3 = 34.47Hz)

https://dx.doi.org/10.22161/ijaers.74.19 ISSN: 2349-6495(P) | 2456-1908(O)



d) Mode 4 (f_4 = 36.17Hz)

Fig 11. Mode shapes of the system

Solving the forced oscillation problem with moving load P(t) action, time calculation is the time moving load go to the end of the way. Some representative results are retrieved at A, B, C as shown in Figures 12, 13, 14, 15, 16, 17 and Table 1.

Table 1. The extreme value is at the point A, B, C

	W_A^{max} [cm]	W_B^{max} [cm]	ε_A^{max}	ε_B^{max}	F_{zC}^{max} [N]	M_{xC}^{max} Nm]
Value	$3.152.10^{-3}$	$3.833.10^{-3}$	$5.126.10^{-5}$	$2.371.10^{-6}$	9222.06	2723.62

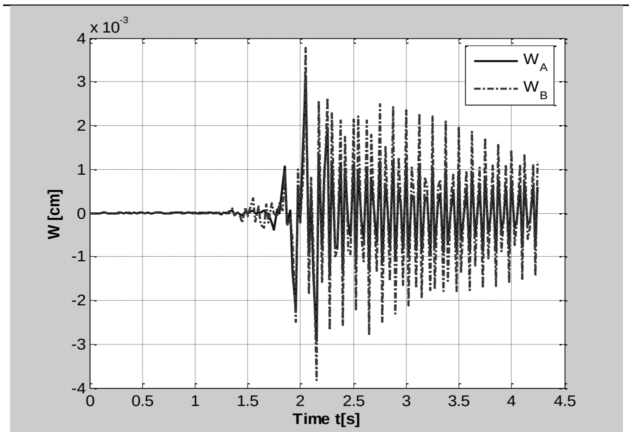


Fig. 12. Vertical displacement W at point A, B

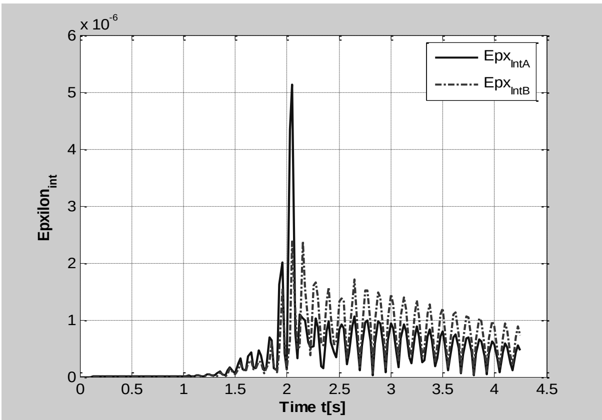


Fig. 13: Elastic strain intensity at point A, B

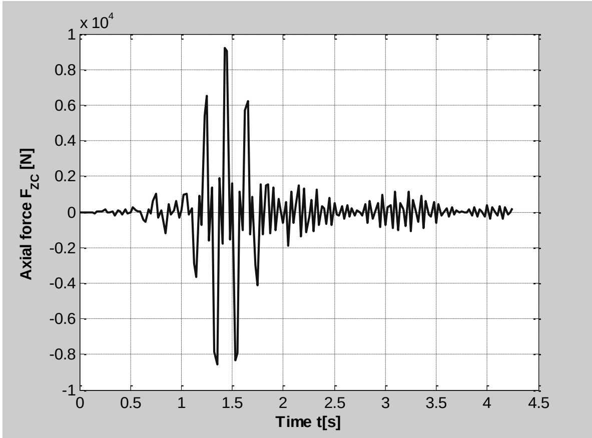


Fig. 14. Axial force F_{ZC}

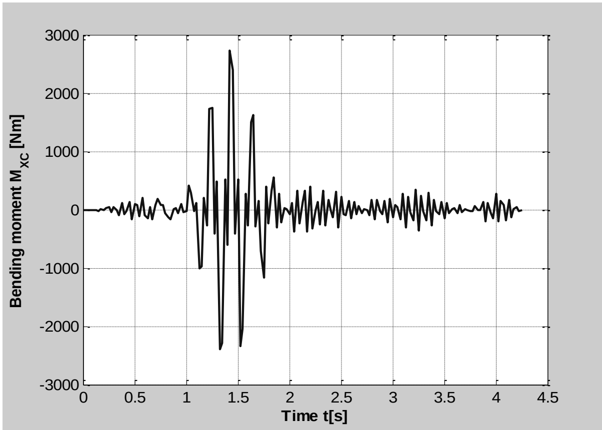


Fig. 15. Bending moment M_{XC}

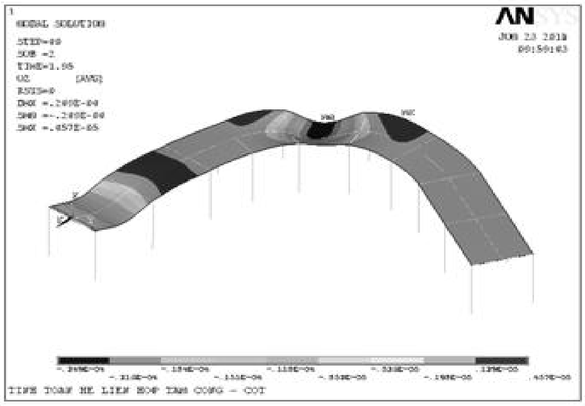


Fig. 16. The displacement field W at time t = 2s

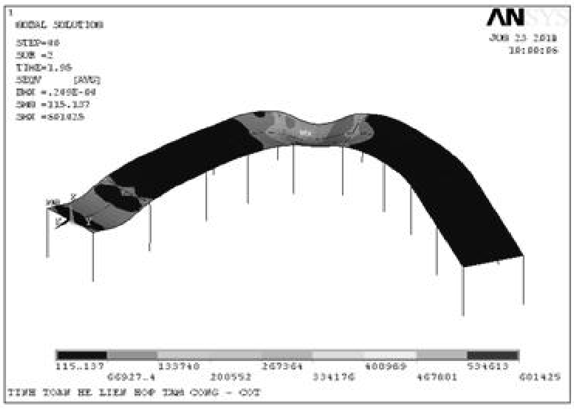


Fig. 17. The Von mises stress at time t = 2s

Comment: Along the backbone of the plate, when the moving load has not arrived, the oscillating of the review point is quite small, almost equal zero. When the load come near and pass, oscillate of the calculated point increase (Figs. 12,13, 14, 15). The strain at point A is much larger than the one at point B due to the load going pass A and without passing B.

VII. CONCLUSION

In this paper, the simulation program of the curved plate – columns system subjected to the moving load is built based on APDL programming language. Results show the reliability of the algorithm that employs the "Element Birth and Death" technique developed. Deep interference in ANSYS software simulation program allows to solve complex problems.

The program that was set up, is capable of solving many different problems with the change of texture and load parameters, allow to evaluate the effect of these parameters on the oscillation of the system. Research results are the first step to develop calculations with complex structural problems (the system subjected to multi moving load, the system subjected to moving oscillators, and so on).

REFERENCES

[1] C. Johansson, C. Pacoste, R. Karoumi (2013), Closed-form solution for the mode superposition analysis of the vibration in multi-span beam bridges caused by concentrated moving loads, Computers and Structures 119 (2013) 85–94.
[2] Ladislav Frysba, Vibration of solid and structures under moving loads, Thomas Telford, ISBN 0-7277-2741-9 (1999).
[3] Nguyen Thai Chung, Le Pham Binh, Nonlinear Dynamic Analysis of Cracked Beam on Elastic Foundation Subjected to Moving Mass, International Journal of Advanced Engineering Research and Science (IJAERS), Vol 4, Issue-9, Sep- 2017, pp.73-81.
[4] Nguyễn Thái Chung, Nguyễn Thị Cẩm Nhung, Lê Xuân Thùy, Phân tích động lực học hệ liên hợp dầm cong – dây – tấm chịu tác dụng của tải trọng di động, Tuyển tập Hội nghị Cơ học toàn quốc lần thứ X, Tập 3 Q1 (2017), 155-162.
[5] Qinghua Song, Jiahao Shi, Zhanqiang Liu, Vibration analysis of functionally graded plate with a moving mass, Applied Mathematical Modelling 46 (2017) 141–160.
[6] Nguyen Van Khang, Nguyen Minh Phuong, Transverse vibration of orthotropic rectangular plates under moving bodies, Vietnam Journal of Mechanics, VAST, Vol.31, No.1 (2009), 47-56.
[7] Nguyễn Văn Chình, Trần Hữu Quốc, Nghiên cứu đáp ứng động của tấm mỏng FGM chịu tác dụng của tải trọng di động với quỹ đạo chuyển động phức tạp, Tuyển tập Hội nghị Cơ học toàn quốc lần thứ X, Tập 3 Q1 (2017), 139-146.
[8] T.O.Awodola, S.T.Oni, Dynamic response to moving masses of rectangular plates with general boundary and resting on variable winkler foundation, Latin American Journal of Solids and Structures, 10 (2013), 301-322.
[9] Volkan Kahya, Ayman S. Mosallam, Dynamic Analysis Of Composite Sandwich Beams Under Moving Mass, KSU. Journal of Engineering Sciences, 14(1), (2011), 18-25.
[10] Bùi Mạnh Cường, Phân tích dao động của dầm FGM dưới tác dụng của nhiều vật di động trên cơ sở kỹ thuật phần tử sinh, diệt, Tuyển tập Hội nghị Cơ học toàn quốc lần thứ X, Tập 3 Q1 (2017), 179-185.
[11] Erdogan Madenci, Ibrahim Guven, The finite element method and applications in engineering using ANSYS, Springer International Publishing, (2015).
[12] Release 11.0 Documentation for ANSYS.