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ANALIZA DINAMIČKE INTERAKCIJA TLA I RAMOVSKIH KONSTRUKCIJA PRIMENOM SPEKTRALNIH ELEMENATA DEO II

Rezime

U radu je prikazani rezultati dinamičke analize jedne konzolne grede i dimnjaka modeliranih spektralnim elementima. Greda je izložena dejstvu harmonijske sile na vrhu, dok je dinamička analiza dimnjaka sprovedena za slučaj pomeranja osnove usled Razleigh-evih talasa. Analiziran je uticaj deformacije smicanja, interakcije tla i objekta i mase fundamenta na deformaciju, kao i na prigušenje sistema.

Ključne riječi

Interakcija tla i objekta, spektralni elementi, Timošenkova greda, dinamička krutost.

DYNAMIC SOIL-STRUCTURE INTERACTION OF FRAME STRUCTURES WITH SPECTRAL ELEMENTS – PART II

Summary

The dynamic response of a single cantilever beam and a tower-like structure modeled with spectral elements is investigated. A beam is subjected to a harmonic point load at the top of the structure while a harmonic free field Rayleigh wave is selected as excitation of the tower-like structure. The influence of shear deformation, soil-structure interaction and foundation mass as a function of the excitation frequency on deformation and damping are shown.

Key words

Soil-structure interaction, spectral element, Timoshenko beam, dynamic stiffness

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1. INTRODUCTION

With simple models insight can be gained about the factors influencing the response of soil-structure systems. Our structural model is one spectral beam element founded on half-space. Firstly, a harmonic point load at the top of the beam, secondly a harmonic Rayleigh wave is selected as excitation. Theory, basic equations and definitions related to the applications are presented in the first part of this paper 0, also presented at this conference.

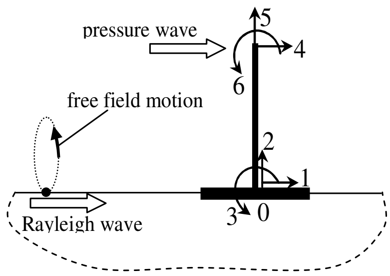


Figure 1: Mechanical model

1.1. CANTILVER-BEAM SUBJECTED TO HARMONIC FORCE

A computer program in MatLab for dynamic analysis of the frame structures using spectral elements was made. The investigations of the dynamic response of the cantilever-beam subjected to a harmonic force at the top of the beam were performed for a beam including shear deformation (Timoshenko beam) and for a beam neglecting shear deformation (Bernouli beam); without soil-structure interaction (SSI), i.e. fix base, and with SSI included; with foundation mass and without foundation mass. All material damping wass neglected in oder to show the effects of radiation damping.

The beam has the lenght of 3.5 m and a Young's modulus of E=2 x 10^7 kN/m^2. In order to show the effects of shear deformation beams with different cross sections were investigated using Euler-Bernouli and Timoshenko beam spectral elements 0. The results for the beam with cross section *A=30/100 cm* are presented.

Table 1. Eigen frequencies for the fixed beam

	Euler-Bernoul beam		*Timoshenko beam*	
n	ω *[rad]*	*f [Hz]*	ω *[rad]*	*f [Hz]*
1	*239.04*	*38.04*	*219.84*	*34.99*
2	*1498.01*	*238.42*	*1091.00*	*173.64*
3	*4194.47*	*667.57*	*2401.00*	*382.13*

In SSI analysis the dynamic stiffness of the rectangular footing (BxLxD=0.5x1.0x0.8 m, ρ=2.403 t/m^3) is represented by an equivalent circular footing on the surface of the soil (embedment neglected). The characteristics of the soil are ν =0.25, G=24138 kN/m^2, ρ=1.90 t/m^3. The impedance functions of a circular foundation are obtained from [5], in the form

$$K_j = K_{s,j}\left[K_{jo}(a_o) + i a_o C_{jo}(a_o)\right] \quad , \quad a_o = \omega r / v_s \quad j = v,\ h,\ r,\ hr$$

where $K_{s,j}$ is the static stiffnes, $K_j(a_o)$ and $C_j(a_o)$ are the dimensionless functions of stiffness and damping in *j*-direction, respectively, a_o is the dimensionless frequency, *r* is the radius of equivalent footing, v_s is the velocity of the shear wave in the soil.

The horizontal displacements at the top for Euler-Bernouli and Timoshenko beam are calculated for three cases: fixed beam, beam with SSI, beam with SSI and mass of the footing as a function of the excitation frequencies, and presented in Fig. 2, 3, 4.

The eigen frequency obtained for Bernoulli and Timoshenko beam using spectral elements Figure 2, are equal to the eigen frequencies given in *Table 1* which are obtained analyticaly.

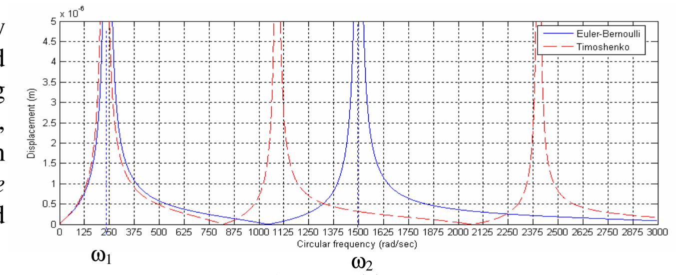
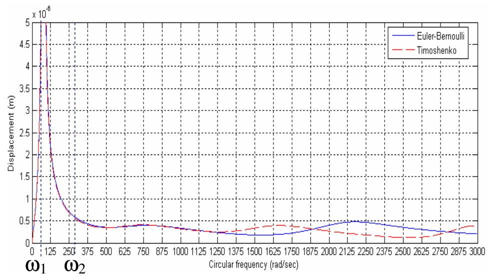


Figure 2. Fixed beam



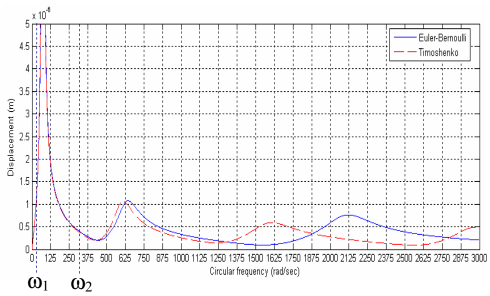


Figure 3. Beam with SSI *Figure 4. Beam with SSI and foundation mass*

The amplitudes at higher frequencies are damped if SSI is included, but less damped if the foundation mass is taken into account, see Figure 3, 4.

Snapshots of the displacements along the Timoshenko beam for selected frequencies are presented in Figures 5, 6 and 7. For the beam without SSI the beam deformations show fixed vibration nodes in time. For the beam with SSI the beam deformations the vaibration nodes disappear due to radiation damping, see Figures 5, 6.

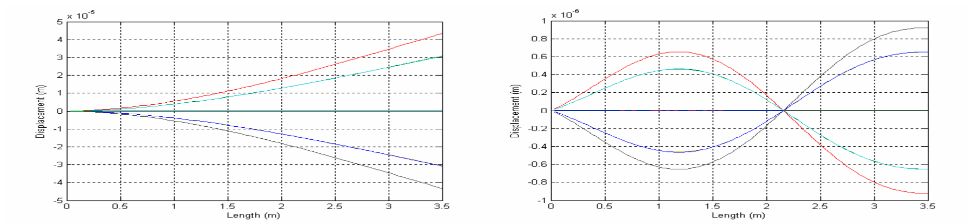


Figure 6. Timoshenko fixed beam; frequencies 20 and 259 Hz

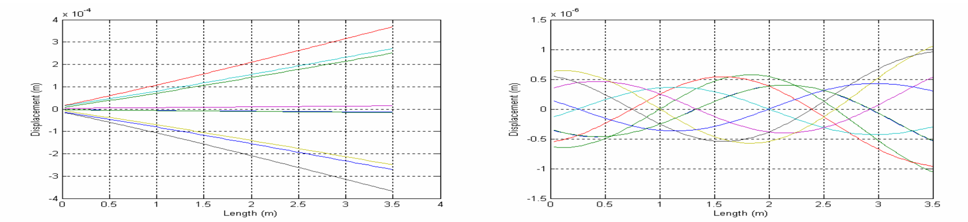


Figure 7. Timoshenko beam with SSI; frequencies 8 and 298 Hz

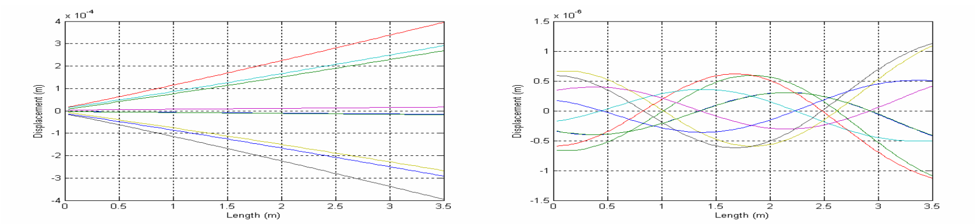


Figure 8. Timoshenko beam, SSI, foundation mass; frequencies 8 and 298 Hz

1.2. STRUCTURE EXCITED WITH HARMONIC RAYLEIGH WAVE

A tower-like structure is repesented as Bernouli beam with a rigid circulare foundation block resting on a homogeneous half-space. The properties of the beam and of the soil are given in Figure 9. The structure is excited through a harmonic Rayleigh wave. Material damping is neglected in the beam and in the soil.

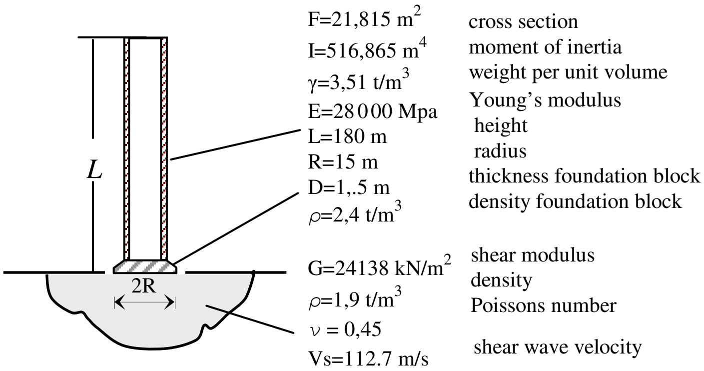


Figure 9. Properties of structure and soil

The retrograde motion of the Rayleigh wave traveling in the positive x-direction at the surface of a half space with Poisson's number equal ν = 0.45 is expressed with horizontal and vertical components

$$v_h(t) = |\tilde{v}_h| \cos \omega t \,; \qquad v_v(t) = 2.5|\tilde{v}_h| \sin \omega t \,; \qquad \omega = \frac{2\pi}{T}\,.$$

For a very stiff sub-grade the motion of the structure due to the elliptical free field motion of the base is calculated. The frequency response of the amplitudes in horizontal and vertical motion on top of the structure is shown in Figure 10. Since damping is neglected the resonances show singularities at the eigenfrequencies. In the chosen example the third resonance in bending (represented by $|\tilde{v}_4|$), is very close with the first resonance in elongation (represented by $|\tilde{v}_5|$) .

Figure 11 shows maximal bending displacements along the beam at times $t = (n\text{-}1)T$, n = *1,2,3, ...* for those 5 frequencies which are marked in Figure 10. The deformations change the shape when the frequency of excitation crosses the resonance frequencies. Ten snapshots taken in the first half period show in Figure 12 the motion of the beam for an excitation frequency of ω=*8 rad/s*.

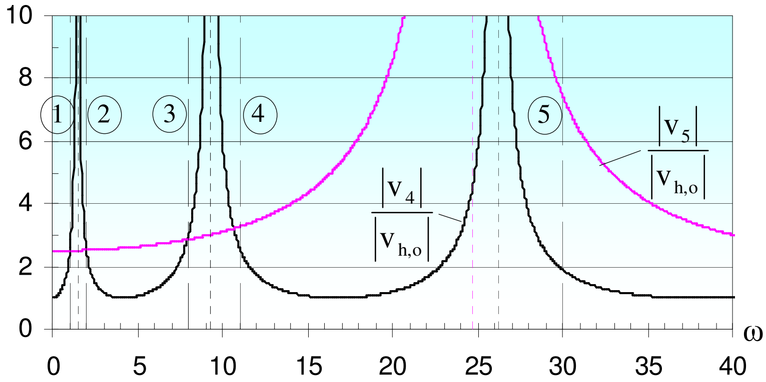


Figure 10: Frequency response of horizontal, $|\tilde{v}_4|$ *,and vertical displacement,* $|\tilde{v}_5|$*,*
at the top of the structure. at selected frequencies: ω = *1,2,8,11,30 rad/s.*

In Figure 13 effects of SSI is shown. Due to radiation damping the singularities for the situation in Figure 10 disappear. Due to the 2 additional DOFs at the base new resonances occur in swaying and rocking motion.

These motions are influenced by the foundation mass, as can be seen in Figure 13. Also of interest is, that only the first resonance frequency in bending is considerably damped while the 2[nd] and 3[rd] show still high amplification. This shows that the different foundation motions radiate different energy away from the foundation.

Unfortunately the effect of vertical excitation with SSI could not be include in the written version of our contribution.

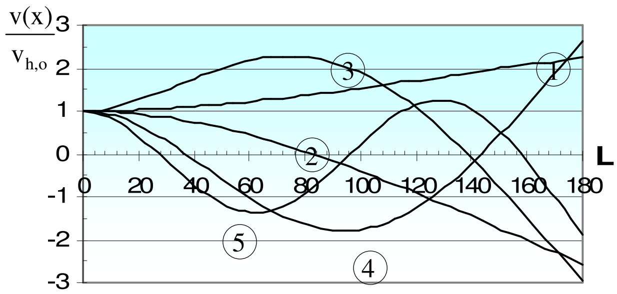


Figure 11. Snapshots of the displacements along the beam in bending at selected excitation frequencies (rad/s): 1, 2, 8, 11, 30

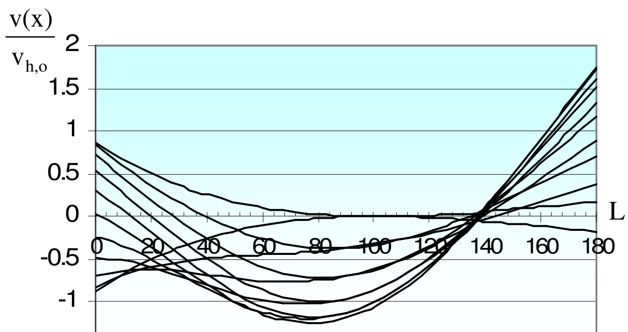


Figure 12. Snapshots of the beam deformation in bending at the frequencies of 8 rad/s

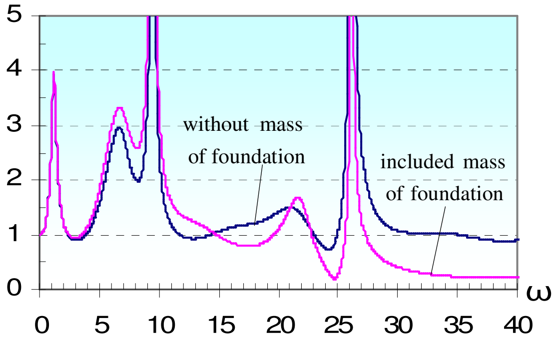


Figure 13. Influence of foundation mass on horizontal displacement, $\left|\tilde{v}_4\right|$, *on top of beam*

2. CONCLUSION

The results show that it is of advantage to use spectral elements together with dynamic stiffneses of the soil in soil-structure analysis. This methods enable the engineers to understand better the phenomena of soil structure interaction. More research and teaching is needed to make this method powerfull for practical applications. If such an impuls is given the paper fulfiled its purpose.

3. ACKNOLEDGEMLENT

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LITERATURE

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