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PARAMETRIC STUDY ON DYNAMIC BEHAVIOUR OF A MULTI-STOREY BUILDING INCLUDING SOIL-STRUCTURE INTERACTION

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Abstract: *The paper deals of a with the parametric study of the dynamic behavior multistorey panel building applying an advanced computation model developed using finite element library of the ANSYS program package. Variations of parameters determining dynamic behavior of both building and subsoil motion have been considered. Response of the building to seismic motion of the subsoil has been analyzed. The method of elastic response spectra has been used for computing the building response. The decisive input data have been parameterized. Subsequently, a deterministic type sensitivity analysis has been carried out, applying the LHS (Latin Hypercube Sampling) method. Computations have been performed using the program "optiSlang", designed for optimization and probabilistic analyses.*

Keywords: ***Seismic analysis, dynamic response, response spectra, deterministic sensitivity analysis, parametric study, multi-story panel building, Latin Hypercube Sampling, ANSYS, OptiSlang.***

1. Introduction

Calculation of maximum possible building structure response to given seismic motion of object foundations (e.g. record of measured velocities by geotechnical station), has been applied on numerical finite element method. Subsequently the solution of dynamic response has been solved by direct integration of the equation of motion or mode superposition method and spectral analysis consequently. In both cases resultant maximum response (in time domain) depends on frequency characteristics of computational model.

In the case, that a natural frequency of the model occurs close to a sharp local peak or concavity in the response spectrum curve, the response can vary considerably even due to small changes of structure input parameters. Then the resultant response can vary at small change of input parameters. Due to seismic excitation calculated by response spectra method dynamic response strongly depends on natural frequency of computational model. For example, if a natural frequency of a model is about 3.5 Hz (Fig. 1, Čada et al., 2010), than small change of model frequency can cause for significant change of dynamic response. In practice, small change of frequency can be caused by different modelling techniques depended on individual engineering approach.

2. Description of mathematical model and analysis of parameters

Dynamic behaviour of panel structure (Fig. 2) depending on input parameter has been analysed using computational model assembled in system ANSYS (ANSYS Release 13.0, 2010). Superstructure has been modelled using finite element SHELL43 and subsoil has been modelled using SOLID187 elements.

2.1. Modulus of elasticity, mass distribution, thickness of panels

Modulus of elasticity of concrete has been considered with high variation. Value of modulus of elasticity is generally influenced by many factors (such as age of concrete, range of micro-cracks ...) with different probability distribution. Value of modulus of elasticity represents the stiffness of entire

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construction (finishing of panel joints, weak stiffness of minor not-modelled construction parts, viscous behaviour of concrete …)

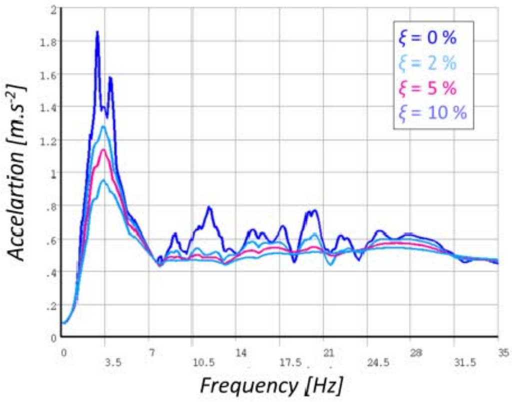

Fig. 1: Ground response spectra of a seismic action.

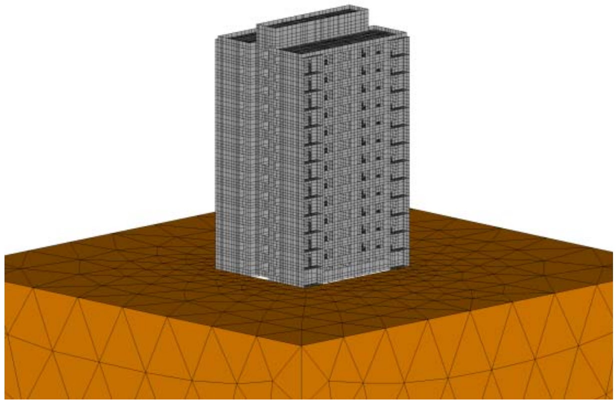

Fig. 2: Computational model.

Total mass of building structure is determined as a sum of self-weight (load bearing and non-bearing construction members) and mass of persons and accessories that varies in time of building structure utilization. Total mass of the building structure is determined as the sum of the proper mass of the structure (including both load bearing and non-bearing parts) and the mass that varies within the building utilization time (e.g. mass of accessories, persons, etc.). The mass of the load bearing structural parts is derived from the panel thickness and the concrete density. Time varying component of object mass has been modelled as added mass uniformly distributed over the ceilings. Variances of concrete density takes into account its uncertainty which changes due to the moisture and the reinforcement ratio etc. Uncertainty of non-bearing construction members is further taken into account.

Manufacturing tolerances of a panel thickness are expected small. Despite this fact formerly mentioned property variation has been included in computation in order to model the change of wall and bending stiffness ratio. Panels have been divided into 4 groups: ceiling panels, transverse wall panels, lateral wall panels, roofing construction. For each of this groups have been prescribed one parameter of thickness ratio. This includes the presumption of soft change of transverse, lateral and vertical stiffness ratio.

2.2. Model of subsoil

Within this case study the spatial computational model of subsoil consisting of solid elements has been implemented. Region of solid elements models elastic massless subsoil. Size of modelled subsoil and elements has been parameterized. In case of modelling massless subsoil the mass of soil moving with the subsoil zone during the dynamic action is neglected. This simplification facilitates the computation (necessary amount of calculated mode shapes) and evaluation (searching for dominant mode shapes). Dynamic modulus of elasticity of soil has been set as a linear function of the depth. Input parameters are the modulus of elasticity at the ground surface and the gradient of elasticity modulus (change corresponding to 1 m depth). Used range of soil modulus of elasticity has been stated with assumption of considerable uncertainty during the soil profile determination in situ.

2.3. Computation of natural frequencies and mode shapes

Natural frequencies and mode shapes have been obtained using Block Lanczos method. Ten lowest frequencies have been investigated.

2.4. Output parameters

Output parameters correspond to response characteristics of the model. It concerns three natural frequencies at which the participation factor takes the maximum value in directions *x*, *y* and *z*. These participation factors are recorded too. The response to the unit spectrum of acceleration for three directions of excitation ($S_{a,x}$ = 1 m.s^{-2}, $S_{a,y}$ = 1 m.s^{-2}, $S_{a,z}$ = 1 m.s^{-2}) has been solved. SRSS method has been used for calculating only for internal forces at different floors and displacement of the top floor. Then the formula for single internal force (direction x) evaluation is:

$$F_{x,SRSS}(z) = \sqrt{\sum_N \left(\frac{F_{x,i}(z) p_x S_{a,x}}{(2\pi f_i)^2}\right)^2 + \sum_N \left(\frac{F_{x,i}(z) p_y S_{a,y}}{(2\pi f_i)^2}\right)^2 + \sum_N \left(\frac{F_{x,i}(z) p_z S_{a,z}}{(2\pi f_i)^2}\right)^2} \quad (1)$$

Internal forces (e.g. $F_{x,i}$) at different floors have been obtained as a sum of node forces at horizontal section of building structure model. Displacement of the top floor has been obtained as an average value of four displacement values at roof corners. Resulting parameter of internal forces is then the extreme value of internal forces distribution.

Tab. 1: Input and output parameters.

	Variable	**Unit**	**Limits**		**Description**
			Bot.	**Top**	
a r	*sirka_m*	[m]	2	40	Size of subsoil region surrounding building.
	hloubka_m	[m]	3	80	Depth of subsoil
	es_1_m	[m]	1	5	Size of finite elements bellow the building
	es_2_m	[m]	2	15	Size of finite elements at the interface of building and subsoil
	E0_MPa	[MPa]	35	75	Modulus of elasticity of subsoil at level 0
	E1_MPa	[MPa.m^{-1}]	10	25	Linear part elasticity modulus of subsoil raises with depth
	DENS_beton_kgm3	[kg.m^{-3}]	2100	2500	Density of concrete structure components
	r_pricne	[-]	0.95	1.05	Thickness ration of transverse panels to designed thickness
	r_podelne	[-]	0.95	1.05	Thickness ration of lateral panels to designed thickness
	r_stropy	[-]	0.95	1.05	Thickness ration of floor panels to designed thickness
	r_strecha	[-]	0.95	1.05	Thickness ration of roof panels to designed thickness
	prid_hmota_kgm2	[kg.m^{-2}]	25	100	Additional mass in floors
	r_EX	[-]	0.80	1.30	Ratio of concrete modulus of elasticity to designed modulus
r a	*px_max*	[m$^{0.5}$]	1994	2449	Maximal participation factor in *x* direction
	py_max	[m$^{0.5}$]	1992	2462	Maximal participation factor in *y* direction
	pz_max	[m$^{0.5}$]	1836	2660	Maximal participation factor in *z* direction
	Fx_max_MN	[MN]	3.997	5.804	Maximal shear force (SRSS) over building cross-section
	Fy_max_MN	[MN]	4.000	5.696	Maximal shear force (SRSS) over building cross-section
	Fz_max_MN	[MN]	4.100	6.341	Maximal normal force (SRSS) over building cross-section
	Mx_max_MNm	[MNm]	91.71	124.43	Maximal bending moment (SRSS) over building cross-section
	My_max_MNm	[MNm]	93.26	126.38	Maximal bending moment (SRSS) over building cross-section
	Mz_max_MNm	[MNm]	2.518	3.994	Maximal torsional moment (SRSS) over building cross-section
	ux_mm	[mm]	7.469	25.428	Maximum displacement of roof (SRSS) in *x* direction
	uy_mm	[mm]	7.854	21.570	Maximum displacement of roof (SRSS) in *y* direction
	uz_mm	[mm]	0.322	1.697	Maximum displacement of roof (SRSS) in *z* direction
	usum_mm	[mm]	9.842	32.937	Maximum total displacement of roof (SRSS)
	mass_t	[10^3 t]	5.323	7.101	Total mass of structure and additional load
	fx_Hz	[Hz]	1.276	2.316	Frequency at maximum participation factor in *x* direction
	fy_Hz	[Hz]	1.169	2.167	Frequency at maximum participation factor in *y* direction
	fz_Hz	[Hz]	3.890	9.191	Frequency at maximum participation factor in *z* direction

3. Deterministic sensitivity analysis

Deterministic sensitivity analysis of parametric model has been carried out using LHS method (Latin Hypercube Sampling) which is included in software optiSlang (optiSlang 3.1.4, 2010). In case of deterministic sensitivity analysis the individual parameters are defined by equal distribution. Adopting deterministic approach compared to stochastic there is no need to know the statistic distribution of each parameter. Input parameters and equal distribution intervals are stated in Tab. 1. Total count of simulation has been one thousand which overreaches recommendation given by the sum multiplied by two of input and output parameters.

Sensitivity of chosen input parameters to input parameters are shown in Fig. 3. Sensitivity has been calculated based on the linear correlation coefficient of two parameters. Output parameters represent the response magnitude. Behaviour is similar for the other directions.

4. Conclusions

Dependence between input and output parameters is proved by the study carried out on the numerical model of the panel building interacting with subsoil.

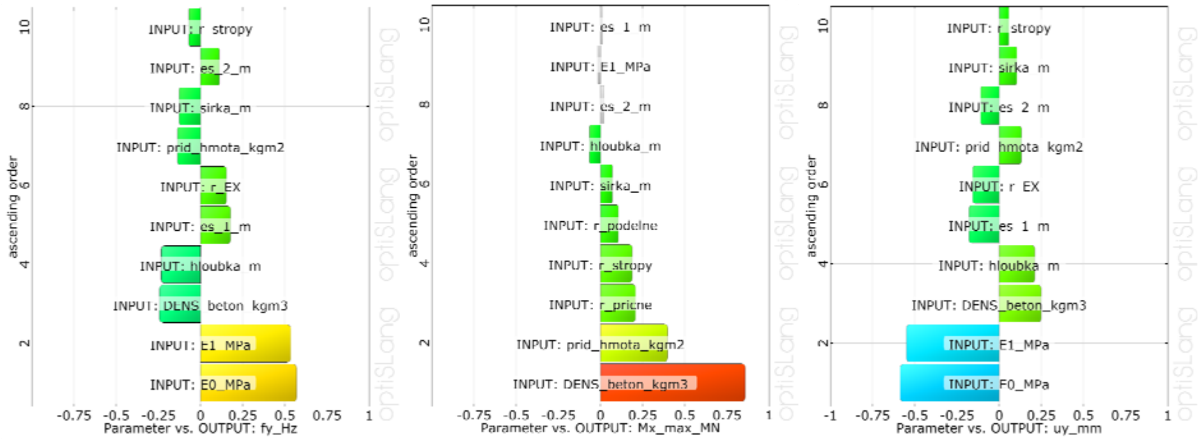

Fig. 3: Linear correlation coefficient fy_Hz, Mx_max_MN and uy_mm parameters.

Deterministically unfavourable values of parameters are probably supposed to be chosen by the engineer. Decreasing the subsoil stiffness and increasing the mass of construction can result in lower dominant natural frequency and increase of bending moment and shear force. On condition of approximately constant spectrum of acceleration such choice of parameters results in conservative results. In other cases the inaccuracy of the response strongly depends on spectral values so that the resulting response can be undervalued (non-conservative).

Resulting response spectra determined by the measurements or calculated as floor response spectra should be modified so that the user obtain conservative results without the need of performing model parametric studies. Modification of response spectra is deal with in ASCE 4-98 (2000) and Regulatory Guide 1.122 (1978). Modification reduces values peaks by 15% and extends frequency zone about 15%. Modification of response spectra must depend on probabilistic distribution of parameters with respect to ultimate limit states according (Eurocode 8, 2008).

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