Response of the Residential Building Structure on Load Technical Seismicity due to Mining Activities

V. Salajka, Z. Kaláb, J. Kala and P. Hradil

Abstract**—**In the territories where high-intensity earthquakes are frequent is paid attention to the solving of the seismic problems. In the paper are described two computational model variants based on finite element method of the construction with different subsoil simulation (rigid or elastic subsoil) is used. For simulation and calculations program system based on method final elements ANSYS was used. Seismic responses calculations of residential building structure were effected on loading characterized by accelerogram for comparing with the responses spectra method.

Keywords**—**Accelerogram, ANSYS, mining induced seismic, residential building structure, spectra, subsoil.

I. Introduction

THE action invoked by shocks of the building objects subsoil is classified among the kinematics load and determined as seismic one. The source of the shaking may be natural (earthquake – tectonic processes, landslides etc.) or technical (mining operations, earthwork, explosion, fall of the massive object, effects of unbalanced machines or dynamics construction process in the surrounding, the transport influence in etc.). The seismic shocks character is always more or less accidental and description appropriate of the physical process is on principle very difficult. Set up of the corresponding and proper computational model of the seismic action for purposes of dynamic structure response represents therefore the challenge.

Mentioned this follows the meaning of the reliable prediction of seismic matters occurrence and credible description of the appropriate seismic load. These details are necessary for proper assembly of computational seismic load model as basic input for solving the seismic responses of the construction. Subsequently appropriate determined response determine the rational design of the structure, well - balanced solidity also stiffness usage of the bearing construction parts to assure require level of functionality during incidence of mentioned extraordinary loads and also after their quite down.

In the territories where high-intensity earthquakes are frequent is paid attention to the solving of the seismic problems. Worldwide meaning of this problem is evident from the range of special reports, conference contributions, workshops and scientific organization negotiations (e.g. EAEE - European Association for Earthquake Engineering, SECED - Society for Earthquake and Civil Engineering Dynamics, IASPEI - International Association of Seismology and Physics of the Earths Interior. ESC - European Seismological Commission) especially from USA and Japan. Is concerned the multidisciplinary problems, as evidenced by the group of universally bent organization (e.g. IAEG International Association of Engineering Geology, ESA - Experimental Stress Analysis, GS - Geotechnical Conference) which regularly arrange specialized workshops and other activities upon this subject.

In Czech Republic isn't necessary to take into account occurrence of the earthquake with high intensity, in limited regions aren't outcast phenomena with medium intensity (see [1], [2]). On the other hand loading of the building objects by the technical seismic is very frequent and in some industrial regions of the Czech Republic can be also enough high-intensity.

The mining operations are a specific source of technical seismic load in limited regions in Czech Republic. That source is long term active, no susceptive in practice, sometimes with high intensity, with efforts corresponding to the weak earthquake (see [3]). For example region in the surrounding of the Karviná is characteristic with significant technical seismic action induced by mining operations ([4], [5]). Technical seismic problems in mentioned areas are important with considering the reliability included in projects of new civil build up, on safeness estimation of a large number of current living home and on economy saving of older involved constructions.

Technical seismic loading of building objects estimation and assessment and appropriate responses appreciation objects located in Czech Republic is coming out from specification CSN 730040 [6], problems further detects in a set of the

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building codes and in hygienic recipes. Essential feature of the appropriate clauses of standards is endeavor to offer to the designers simple, easy applicable terms for seismic load construction description and for seismic responses structure assessment with the aim of complexity of structures limit state assessments.

Most of the technical seismic publications focuses on specification of empiric data based calculation of maximum amplitude response quantities in select referential points and global appreciation of damage level of the objects. Altogether very simplified computational models of the objects are used, which matches with more and more simplified description of seismic actuating and load from here derived. Sufficient and systematic attention is not paid to the improvement of the description of technical seismic actuating.

In the process of mentioned problems development with main aim in application in design and constructional practice there is possible a basic imperfection in insufficient range of combination of the experimental and computer based study of behavior of real objects at incidence of typical real technical seismic sources.

II. Analyzed Building Object Selection

Building objects of housing build up are ones of the mostly incident in Czech Republic thereby also in the area with undermine territory. These prefabbed houses structures were very often built up from second halve of the last century. Technical service life of these buildings isn't from far played out and is planned the reconstruction for increasing up-to-date facilities in using these constructions. Determination of constructions condition located in undermine regions is predominant at evaluation of their residual service life and for reconstruction costs evaluation.

Calculations have had be based on seismic subsoil movements data. Data were measured by analyzing the specific technical seismic sources induced by mining operations in the Karviná region.

For simulation and calculations program system based on method final elements ANSYS [7] was used.

III. Computational Model of Twelve Storey Prefab Bed Sectional Living House

Analyzed construction is twelve storey residential building - the representative construction from large panels (see fig. 1) with resistance class C (according to [8]) and with class of meaning II (according to [6]). Application of this type of structure is wide - spread and their number is considerable, as well in focused regions. The technical service life of most panel building structures is not yet far exhausted and reconstruction projects are planed with the aim to prolong the service life respecting both present and future requirements on comfortable dwelling. For their residual service life assessment have experiments based on constructions dynamic (or its parts) considerable meaning and over their demands it is possible to expect their usage. In spite of considerable number of these buildings is their variability very limited.

Fig. 1 Selected twelve storey residential building

Fig. 2 Computational model of structure – perspective view

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Two computational model variants of the construction were arranged differ in subsoil simulation (rigid or pliable subsoil).

Modeled panel building is in principle the type known as OP 1. Ground plan proportions are 23,25 m, (longitude) and 19,05 m (latitude). Building height is equal to 40,49 m. Structure of the construction is spatially complicatedly structured, with quantity of the wall openings and floor cuts, but inner section is relatively regular. Model is very fine structured. Buildings model is arranged from plate elements SHELL43 type and auxiliary elements for setting load SURF154 type. Additional (utility) materiality applied on the story can be in wide interval. Building is cellarage with foundation slab, fig. 2 to fig. 4. Materials characteristics are in view values mentioned in the project.

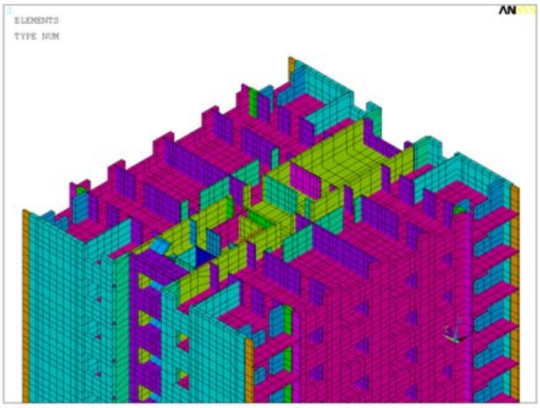

Fig. 3 Typical storey cut-elements mesh

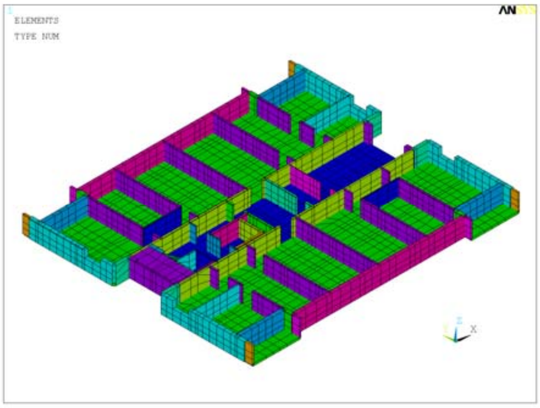

Fig. 4 Basement cut – elements mesh

For analyses purposes the standard characteristics of subsoil near the object is considering. Construction model with the intangible supple subsoil block can be seen in fig. 5 and 6. Soil block is described by SOLID45 elements. On lateral and bottom soil block surfaces are limitation in normal direction to these surfaces. Computational model contains from 74724 elements located by 56544 nodes with 279597 degrees of freedom.

Mechanical energy dissipation of structure vibration is approximated by using a corresponding standard value of modal damping 5%.

The real stiffness characteristic of subsoil for dynamic purposes estimates very hardly, the sensitivity of natural frequency and normal mode shape of vibration on changes of the soil stiffness characteristic values was analyzed.

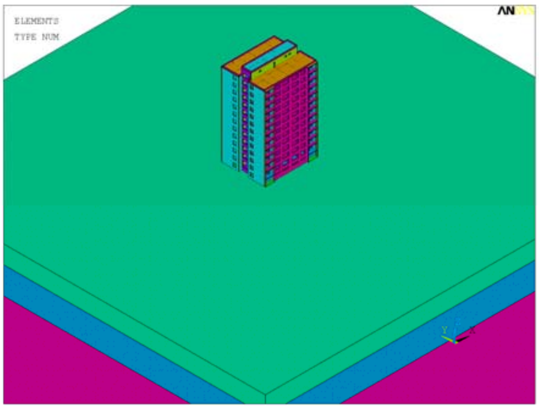

Fig. 5 Model with subsoil block

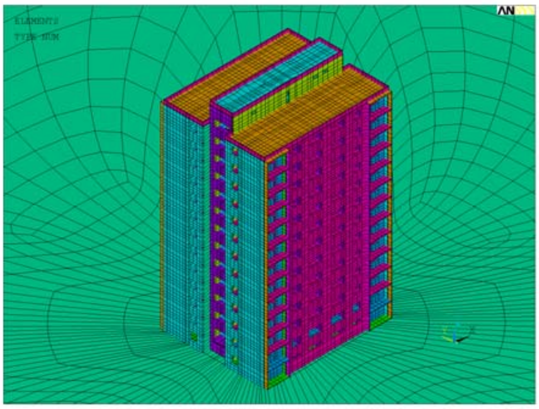

Fig. 6 Model with subsoil - elements mesh

IV. The Study of Natural Frequencies and Modes of Vibration

Block Lanczos method was used for calculation natural frequencies and normal modes of vibrations of both computational model variants.

For computational model in variant with stiff subsoil are in table 1 mentioned 7 lowest natural frequencies with description of corresponding modes of vibration. In the same way for variant with pliable subsoil, see tab. 2. Some modes of vibration for variant with stiff subsoil are depicted in fig. 7, 9 and 11. For variant with pliable bottom corresponding modes of vibration illustrate fig. 8, 10 and 12.

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TABLE I
NATURAL FREQUENCY – STIFF SUBSOIL BLOCK

No. frequency	(Hz)	Mode of vibration description
1	3.906	Bending about *x* axes
2	4.328	Bending about *y* axes
3	5.304	First torsional
4	12.685	Second bending about *x* axes
5	13.676	Second bending about *y* axes
6	16.212	Second torsional
7	16.872	Longitudal

TABLE II
NATURAL FREQUENCY – PLIABLE SUBSOIL BLOCK

No. frequency	(Hz)	Mode of vibration description
1	0.755	Bending about *x* axes
2	0.840	Bending about *y* axes
3	2.231	First torsional
4	2.316	Longitudal
5	3.295	Second bending about *x* axes
6	3.368	Second bending about *y* axes
7	9.926	Second torsional

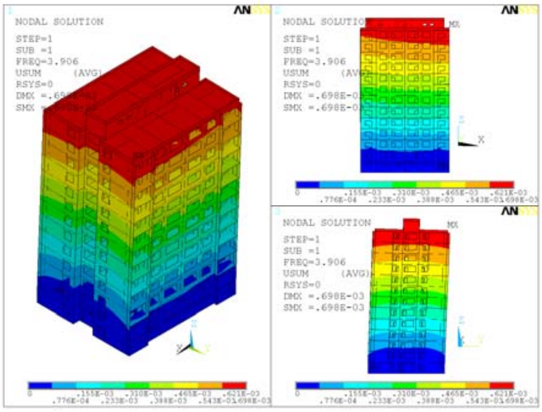

Fig. 7 The normal mode of vibration – f_1 = 3.906 (Hz)

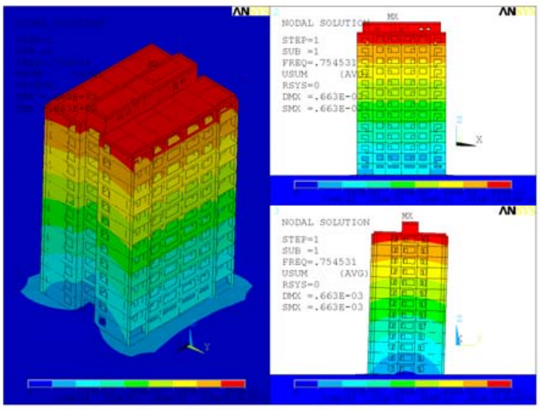

Fig. 8 The normal mode of vibration – f_1 = 0.755 (Hz)

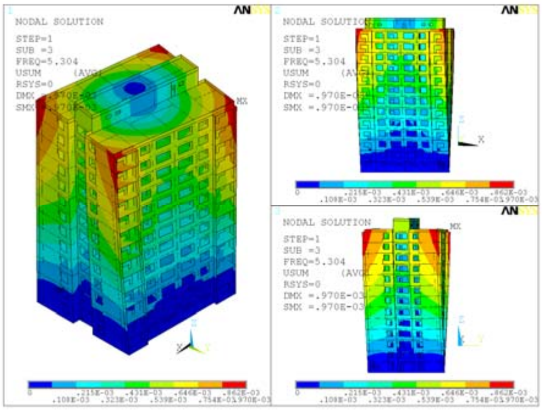

Fig. 9 The normal mode of vibration – f_3 = 5.304 (Hz)

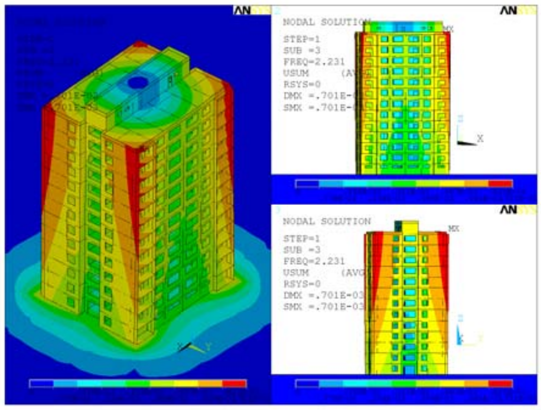

Fig. 10 The normal mode of vibration – f_3 = 2.231 (Hz)

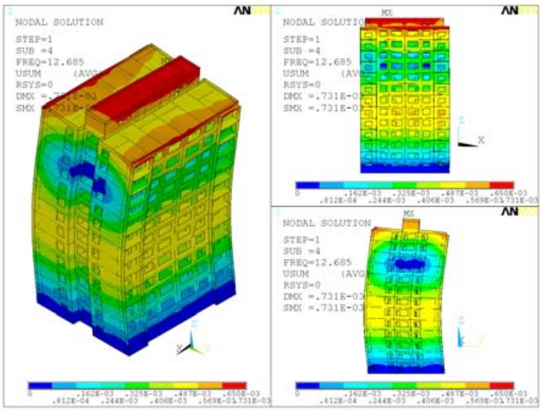

Fig. 11 The normal mode of vibration – f_4 = 12.685 (Hz)

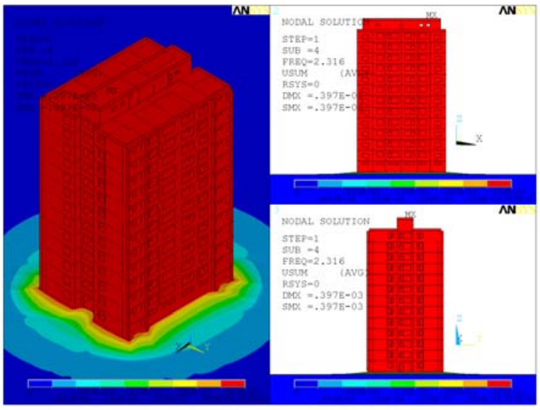

Fig. 12 The normal mode of vibration – $f_4 = 2.316$ (Hz)

In table 3 are the frequency ratios comparing variants with pliable and stiff subsoil block. On the basis of effected study it is possible to state that the influence of the soil block stiffness on natural frequency and shapes of oscillations is substantial.

TABLE III
RELATIVE FREQUENCY DROP

No. frequency	(Hz)	Mode of vibration description
1-1	0.1933	Bending about *x* axes
2-2	0.1940	Bending about *y* axes
3-3	0.4206	First torsional
4-7	0.1373	Longitudal
5-5	0.2409	Second bending about *x* axes
6-4	0.2655	Second bending about *y* axes
7-6	0.5883	Second torsional

Utility materiality on stories influences dynamic behavior of structure. Represents an element of the uncertainties, since their real values even in concrete cases it is impossible credibly determine. With the model was also advised sensitivity of natural frequencies and modes of vibration on changes of utility materiality values. On the basis of completed study it is possible state that the influence of utility materiality in common ranges for living house stories isn't substantial.

V. Seismic Actuating Computational Model Design

Computational model of subsoil seismic movement had be derived from the set of real seismologic data registered in the Karvina region along 32 (s) of seismic phenomenon of the day 11. 03. 2004. Maximum measured velocity value here was 2,83 (mm.s^{-1}). This entry was by contract termed as entry “mining induced phenomenon from 11. 03. 2004” [9]. Record of the phenomenon originates from measuring stand of Geonics dept. (UGN) situated nearby the analyzed building object, whose dynamic properties were computationally analyzed in detail. Responses of the object on seismic phenomena would have had be in the long term measured. Records were used for experimental and computer study combinations of behavior of typical real object at incidence of typical real sources of the technical seismic. At present aren't experimentation terminated.

Preliminary calculations proved altogether very weak effects of engaged seismic movement. Row of other metering (from on the whole c. 5000 seismic phenomenon records), proved the occurrence of phenomenon with essentially higher intensity. For example mining induced seismic phenomenon from 01. 09. 2005 (registered station UGN in Doubrava) exposed the maximum measured velocity variable of oscillating by 17,4 (mm.s^{-1}). It is presumption that is not the strongest phenomenon that was recorded (see [9]). On this account was resolved for purposes of calculations to multiple measured variable seismic actuating. Courses of the acceleration gained integration of the measured record are mentioned in fig. 13, 15 and 17. Using accelerogram was generated linear responses spectra in accelerations for standard levels of damping. Smoothed responses spectrum (see fig. 14, 15 and 18) is referred as “typical” one. Responses spectra are intended for routine seismic calculations.

VI. Responses Calculations Models on Variants Engaged Seismic Action

Seismic responses calculations of sectional house structure were effected on loading characterized by accelerogram for comparing with response spectrum method. Model response for estimated subsoil characteristics on seismic action given by time record acceleration derived from measured record of subsoil time velocity variable. Responses given by calculation for defined points on structure were compared with corresponding responses given by metering. Metering couldn't be realized on time. Next calculations were already effected by using created “typical” model of seismic action.

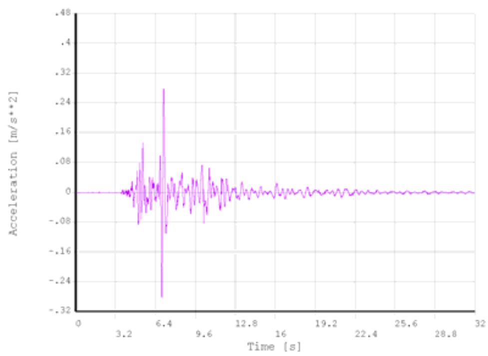

Fig. 13 Accelerogram – *x* direction

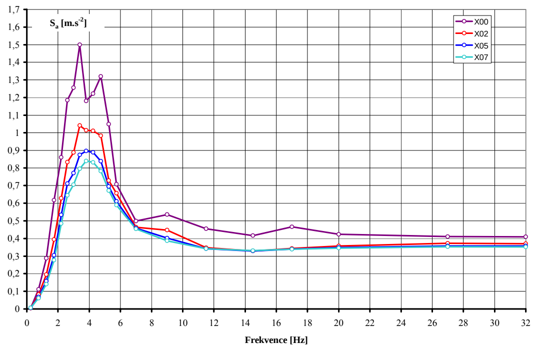

Fig. 14 Absolute acceleration modified spectra – *x* direction

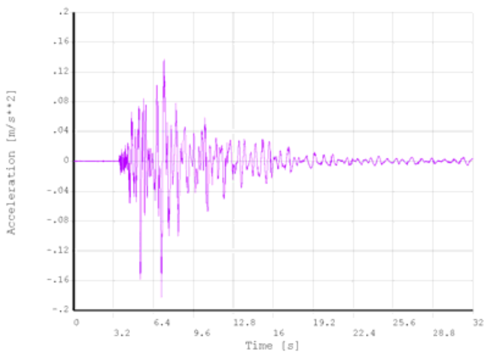

Fig. 15 Accelerogram – *y* direction

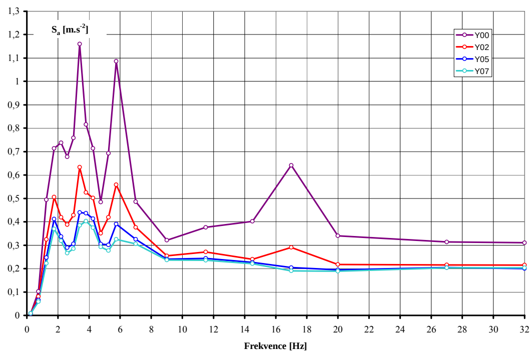

Fig. 16 Absolute acceleration modified spectra – *y* direction

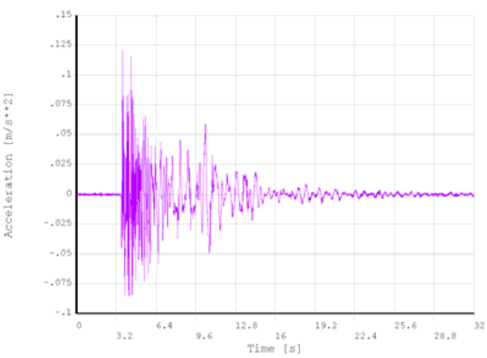

Fig. 15 Accelerogram – *z* direction

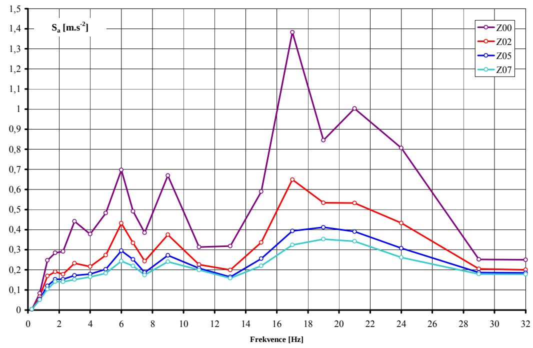

Fig. 16 Absolute acceleration modified spectra – *z* direction

Seismic analyses of the structure were carried out by using two variants of computational model structure differed by subsoil simulation (stiff or pliable subsoil). Response on the seismic subsoil movements corresponding to the typical “mining induced seismic phenomenon” was solved. Seismic responses calculations were pershapeed always for two models of seismic movement of subsoil block prescribed for its limits (“typical” foundation accelerograms and “typical” response spectra). In the event of description seismic movement subsoil by typical foundation accelerogram response is solved by equations computational model integrating. For any node in various storey levels it is possible to determine time behavior of displacement components and from here it is possible easily to determine appropriate response spectrum in acceleration (so - called component storey response spectrum). Storey response spectrum is derived from the set of response spectra given for set of nodes in storey level.

Calculation of responses of the construction on the seismic movement of subsoil described by typical foundation accelerograms $a_{sx}(t)$, $a_{sy}(t)$ and $a_{sz}(t)$ was solved for both variants of subsoil.

Response calculation can be seen in figs. 19 and 20. The fields of displacement components in models nodes are given by calculation for specific time moments during seismic phenomenon. Time courses of the displacement components u_x, u_y and u_z in corner node on the roof and in the base for the event of pliable subsoil block were mentioned can be seen in fig. 21 and 22. Extremes envelopes displacement components are in fig. 23 and 24.

In construction responses calculation on the seismic movement of subsoil prescribed by typical response spectra $S_{ax}(f)$, $S_{ay}(f)$, $S_{az}(f)$ was used 1000 natural modes of vibration. The condition of 90% efficient mass for all directions of vibration was fulfilled. General response was gained by summing using CQC rule. Records are illustrated in figs 26 and 27. Here are plotted appropriate fields of nodal displacement responses.

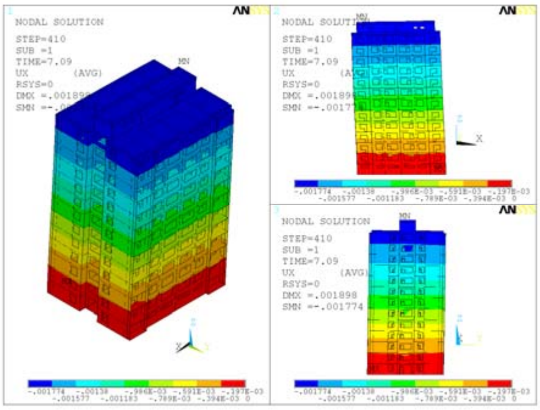

Fig. 19 Displacement u_x field at time 7.09 (s)

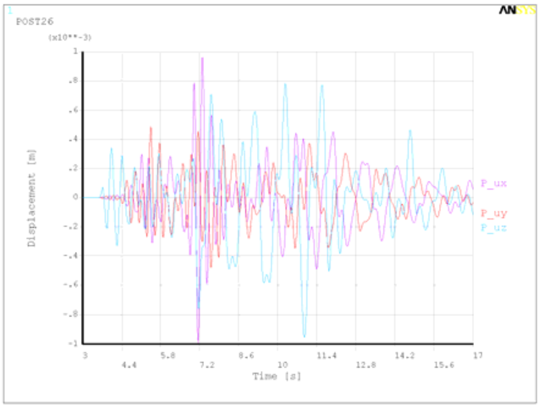

Fig. 22 Displacement behavior at basement level ±0.0 (m)

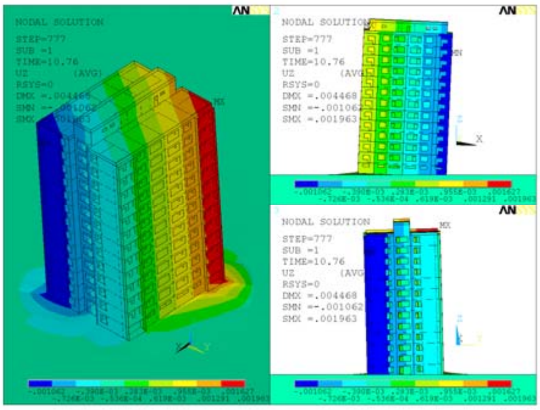

Fig. 20 Displacement u_z field at time 10.76 (s)

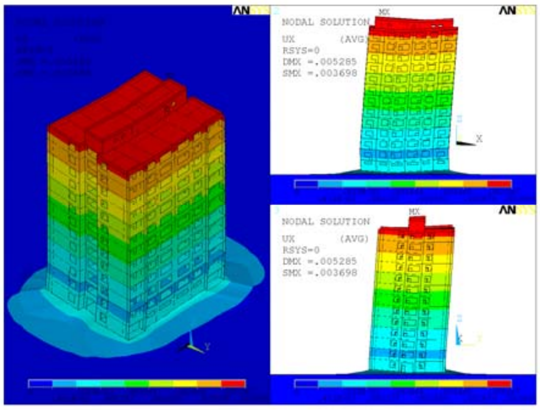

Fig. 23 Maximal displacement u_x envelope

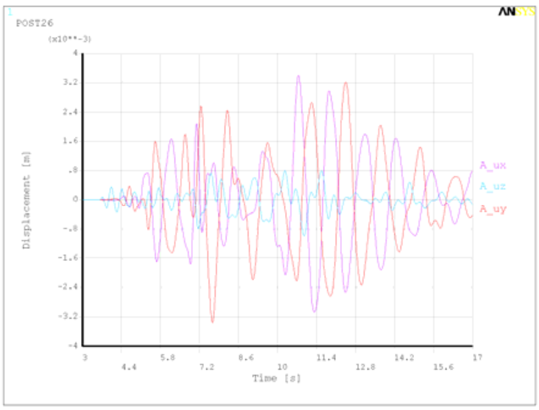

Fig. 21 Displacement behavior at roof level +36.4 (m)

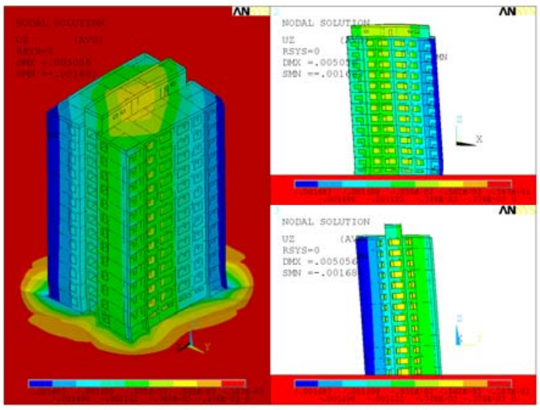

Fig. 24 Minimal displacement u_z envelope

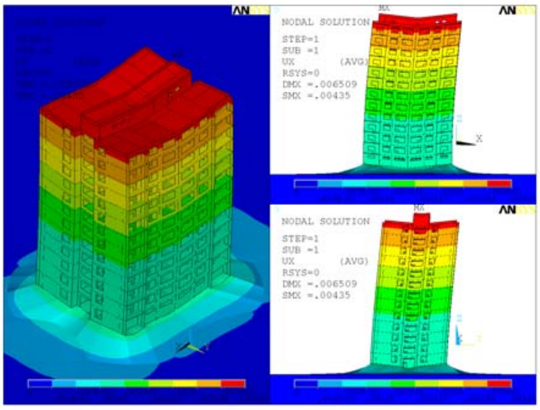

Fig. 26 Complete dynamic response – displacement u_x field

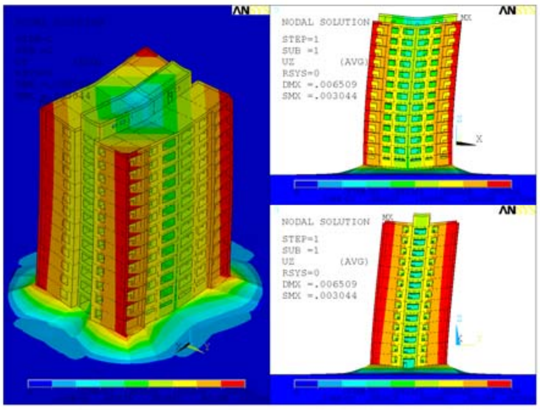

Fig. 27 Complete dynamic response – displacement u_z field

The main results of calculations responses are in tables 4 and 5. Here mentioned displacements extremes make possible to immediate compare responses given by using accelerogram and by using responses spectra.

TABLE IV
DISPLACEMENT EXTREME COMPARISON – STIFF SUBSOIL VARIANT

Displacement	Accelerogram excited seismic response		Spectra excited seismic response
	Maximal response (m)	Minimal response (m)	Maximal response (m)
u_x	+0.001500	-0.001774	0.001752
u_y	+0.000875	-0.000970	0.001119
u_z	+0.000402	-0.000401	0.000515

TABLE V
DISPLACEMENT EXTREME COMPARISON – PLIABLE SUBSOIL VARIANT

Displacement	Accelerogram excited seismic response		Spectra excited seismic response
	Maximal response (m)	Minimal response (m)	Maximal response (m)
u_x	+0.003698	-0.003328	0.004350
u_y	+0.003475	-0.003642	0.004373
u_z	+0.002038	-0.001683	0.003044

VII. CONCLUSIONS

Regarding to the calculation time demands only responses of the prefabbed house construction with stiff subsoil and massless elastic subsoil block in more detail were analyzed. Dynamic interaction of the construction with subsoil wasn't in view. It was demonstrate the principle influence of flexibility on the spectrum of natural frequency of the construction.

In the qualitatively way it was appreciate the influence of the subsoil simulation method on the character of spectrum of natural frequencies and appropriate modes of vibration.

The “typical” computational models of subsoil seismic movement of selected building objects lead out from the real seismologic data set registered for the typical “mining induced seismic phenomenon” in special - interest Karviná region. For seismic analysis construction exposed to the serious seismic loading cases the foundation accelerogram (corresponding time displacement and velocity distribution) were determined. For common seismic construction calculations appropriate linear response spectra were created.

The comparative seismic analyses for given set of construction were carried out and evaluated in case of subsoil block seismic movement prescribed for its boundaries using typical foundation accelerograms and response spectra. The response comparison was carried out for computational model with stiff and pliable subsoil. The obtained results of calculations responses in displacements variables denotes – in correspondence with general view – suitable agreement of the solution results according to the both computational progress. The results calculations responses in stresses evaluation was questionable, because in constructions are altogether an order differences among average, very low stress level and closely limited local stress extremes high dependent on time, size and position.

The results obtained from responses calculations in translations reflect the substantial differences in levels of responses given by using of both computational model types. It relates with big relative shift of spectrum of natural frequency with stiff and pliable subsoil and with typical response spectra character.

Except to prefabbed structure described in contribution in a similar way the masonry constructions, industrial hall with frame bearing construction system, high stacks and cooling towers were evaluated [10]. Obtained results are applicable at newly projected constructions calculations in special - interest Karviná region. Calculations of the responses contributed to increase of the knowledge of selected construction types behavior and constructions subject to the dynamic load induced by seismic.

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