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DYNAMICAL RESPONSE OF "SCALA" BUILDING BUCHAREST TO EARTHQUAKE MOTION WITH FINITE ELEMENT METHOD

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Abstract *The paper presents the comparatively analysis between the frame structure response to the horizontal excitation produced by an earthquake and the case of vertical earthquake appearance. The analysis has been effected for 2 variants of modeling. In the first variant the structure has been modeled at the ends of the columns with concentrated mass. In the second variant the mass has been considered as being uniform distributed on the floor. The distribution of masses allows the appearance of vertical vibrations of beams and floors. The paper points the necessity of taking into account the vertical components of earthquake and influences of the Rayleigh viscous damping in the dynamic response of the structure.*

Key words: mesh, earthquake, modal analysis, spectral analysis, damping

1. Introduction

The paper presents the modal and spectral dynamic analysis of the strength structure of "Scala" building.

The building is placed in the center oh Bucharest City, within a seismic zone of 8 degrees MSK; earthquake coefficient k_s=0.20.

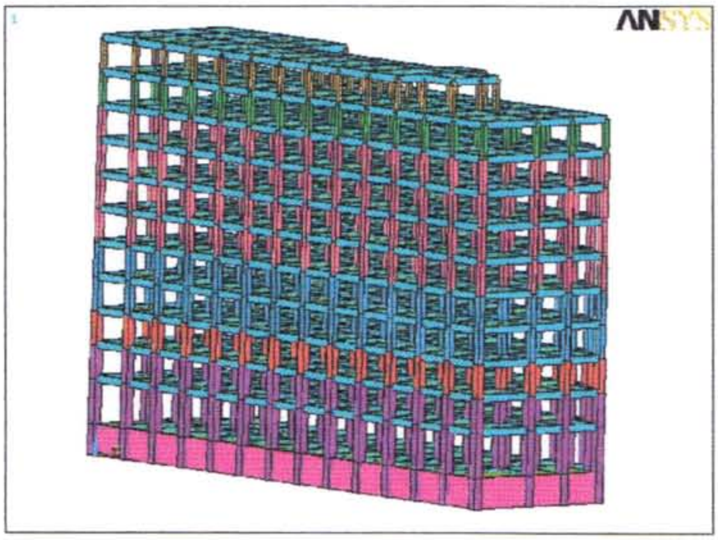

Figure 1. "Scala" building

The structure has a system with basement, ground floor and 10 floors. The height of floors 1-10 is 2.75m, and the height of the ground floor is: 3.61m. At the last two levels, the structure is presenting withdrawals. The destination of this building being flats, with the exception of the ground floor, where is functioning a market.

The strength structure of the building is made up of frames of monolithic reinforced concrete. The concrete floors are made up of 5 cm flagstone with connectors and monolithissing 8 cm breadth top concrete. The foundation of the building consists of a general foundation plate that together with the walls from basement and concrete ground floor make up a rigid box.

2. Consideration regarding the modeling

The structure has been analyzed from dynamic point of view, through the method of finite element, by means of the computational program ANSYS 5.4 produced by Swanson Analysis Systems, Inc.

The structure has been discrete made in two variants.

In the first variant have been generated the finite elements, type Beam and Shell, having the sizes of the elements whose demeanor are modeling between the geometrical crossing points of the columns with the beams.

It resulted: 788 nodes, 2167 elements type *Beam4* and 549 elements type *Shell63*.

In the second variant of modeling, each beam has been divided in two finite elements, type Beam, and each loop from concrete floor has been modeled by means of flour-finite elements, type Shell. In this case, the masses were considered as actioning in the junctions resulting in the field of the concrete floors. It resulted: 3147 elements type *Beam4*, 2305 elements type *Shell65* and 2888 nodes.

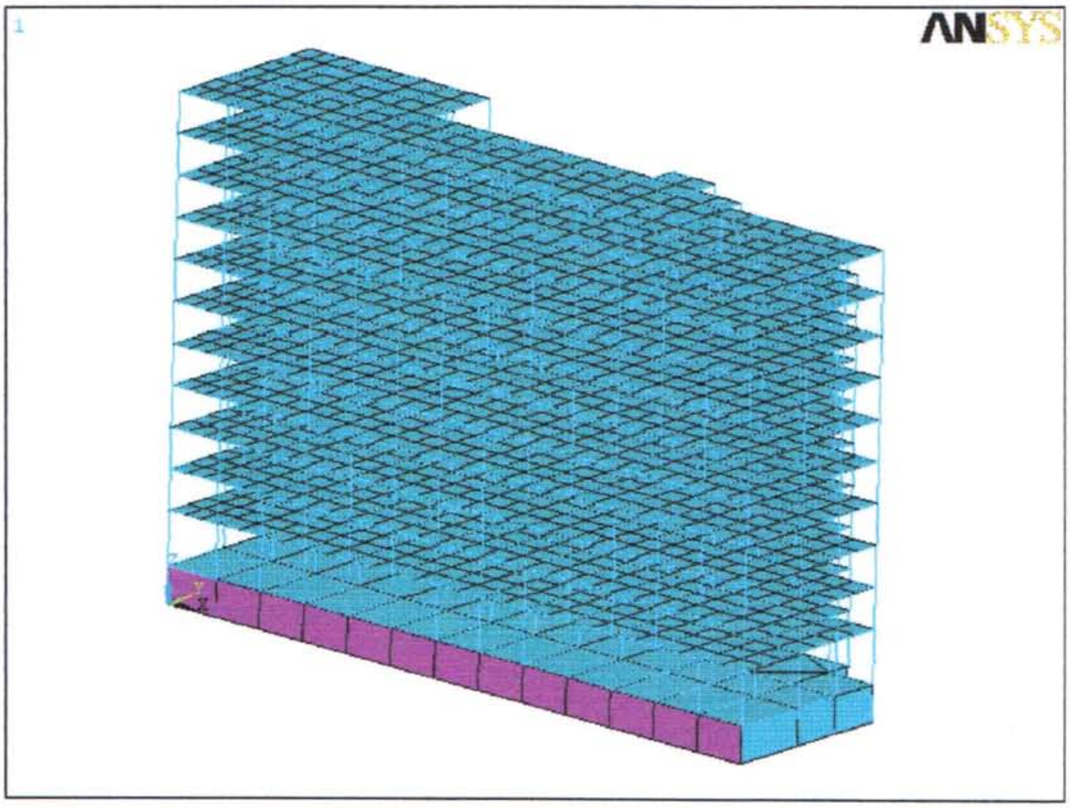

Figure 2 "Scala" structure. Dense mesh.

3. Considerations regarding the dynamic analysis

3.1. Undamped modal analysis

The moving equation for an undamped system, expressed in matrix notation, using the above assumptions, is:

$$[M]\{\ddot{u}\} + [K]\{u\} = \{0\} \qquad (1)$$

where: [M] - the structure mass matrix;

[K] - the structure stiffness matrix.

For a linear system, free vibrations will be harmonic of the form:

$$\{u\} = \{\phi\}_i \cos\omega_i t \qquad (2)$$

where: $\{\phi\}_i$ - eigenvector representing the mode shape of the i^{th} natural frequency.

Thus, equation (1) becomes:

$$\left(-\omega^2[M]+[K]\right)\{\phi\}_i = \{0\} \qquad (3)$$

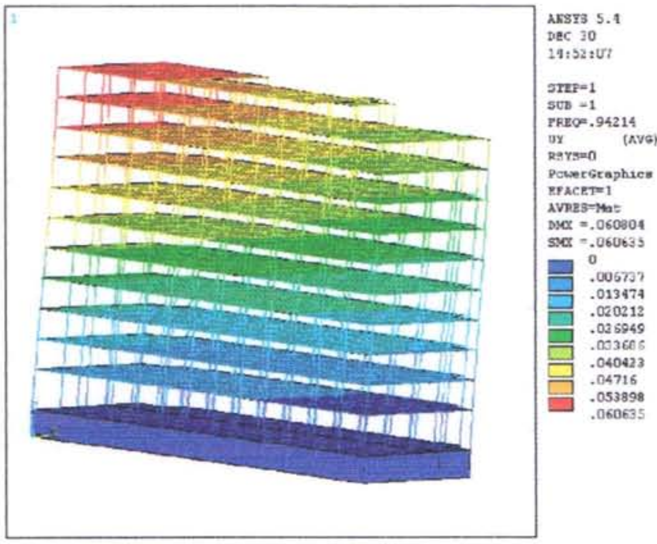

Figure 3 Mode shape 1 – transversal vibrations

This equality is satisfied if either $\{\phi\}_i = \{0\}$ or if the determinant of $\left([K]-\omega^2[M]\right)$ is zero. The first option is the trivial one and, is not of interest. Thus, the second one gives the solution:

This is an eigenvalue problem, which may be solved for up to n values of, ω^2 and n eigenvectors $\{\phi\}_i$, which satisfy equation (3) where "n" is the number of DOF's.

The eigenvalue and eigenvector problem needs to be solved for mode-frequency analyses. It has the form of:

$$[K]\{\phi_i\} = \lambda_i [M]\{\phi_i\} \qquad (4)$$

where: λ_i - the eigenvalue.

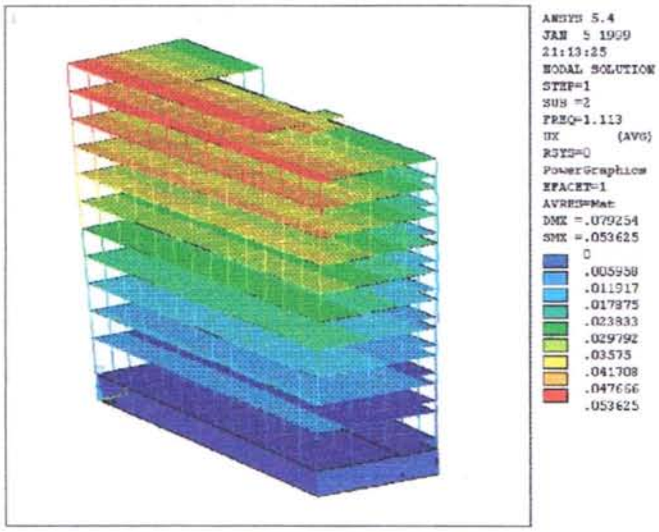

Figure 4 Mode shape 2 – longitudinal vibrations

Following the modal survey, we have been obtained the eigenmodes of vibration through the method of iterations on subspace, it reached in 20 mode shape up to 86% participating factors of masses on longitudinal "x"direction; up to 87% on transversal "y" direction and up to 60% on vertical gravitational "z" direction.

The fundamental period of vibration of the structure resulted $T_1 \cong 1.2s$. From the comparative survey of the modes shape of vibration of the structure within the two variants of modeling it can be observed that the horizontal vibrations of the structure are not influenced by the mash density and the situation of masses, while the vertical vibrations amplify, in case of modeling of structure, the second variant.

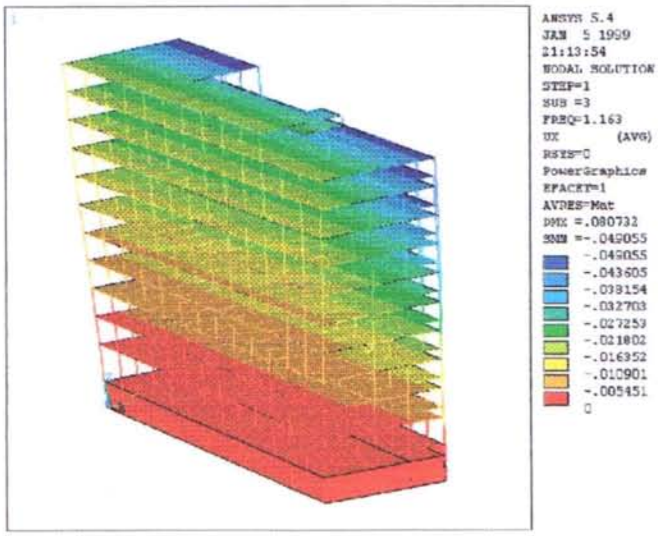

Figure 5 Mode shape 3 – longitudinal vibrations

Thus in the first variant of modeling, the meaningful vibrations on vertical line appear in the 14 mode shape of vibration, driving approximately 5000 KN, to which it corresponds a participating factor of 22%. In the second variant of modeling, the meaningful mode of vibration on vertical line is quicker obtained, on the 13 mode shape of vibration, the driven mass in vibration being 6760 KN, to which it corresponds a participating factor of 26%.

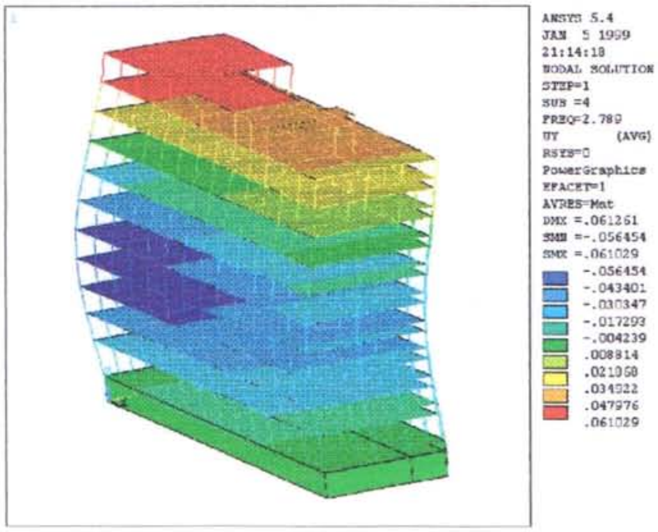

Figure 6 Mode shape 4 – transversal vibrations

On the whole of the 20 vibration modes which have been analyzed, the total sum of the driven mass on vertical line is approximately the same. In the case of dense variant of mesh, a trend of concentration of the vibrating mass in 3 modes of vibration (nr.13,14 and 15), while in rare variant of mesh, the meaningful vibrating mass can be found on 5 modes of vibrations (nr.13,14,16,17 and 18).

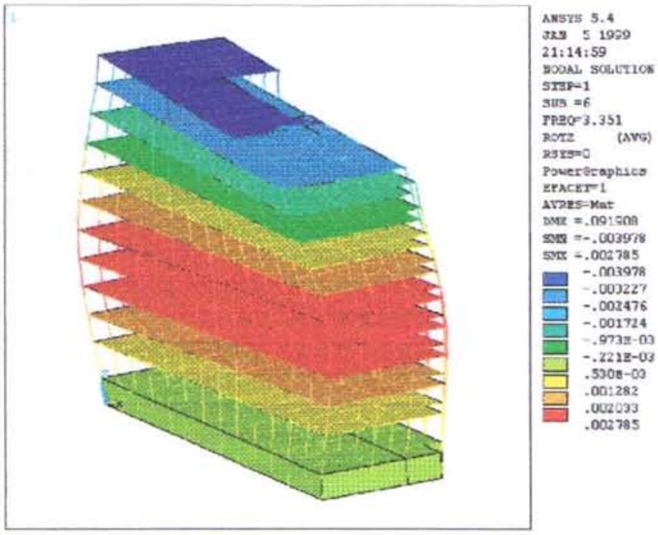

Figure 7 Mode shape 6 – torsional vibrations

3.2. Damped modal analysis

In the damped method the eigen problem becomes a quadratic eigenvalue problem given by:

$$[K]\{\phi_i\}+\bar{\lambda}_i[C]\{\phi_i\}=-\bar{\lambda}_i^{2}[M]\{\phi_i\} \qquad (5)$$

where: $\bar{\lambda}_i=\sqrt{-\lambda_i}$ - the complex eigenvalue;

[C] – the damping matrix.

The dynamic response of the system is given by:

$$\{u_i\}=\{\phi_i\}e^{(\sigma_i+j\omega_i)t} \qquad (6)$$

where: σ_i - real part of the eigenvalue; ω_i - imaginary part of the eigenvalue; j= $\sqrt{-1}$.

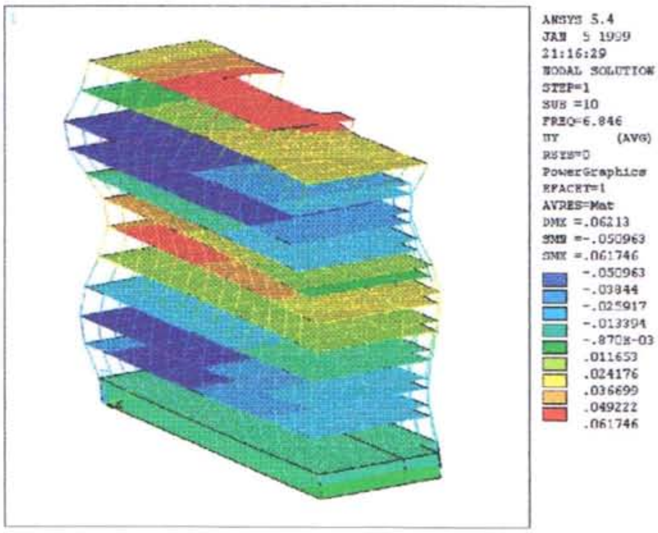

Figure 8 Mode shape 10 – transversal vibrations

The general damping matrix ([C]) may be used in damped modal analyses:

$$[C]=\alpha[M]+(\beta+\beta_c)[K]+\sum_{j=1}^{NMAT}\beta_j[K_j]+\sum_{k=1}^{NEL}[C_k]+[C_\xi] \qquad (7)$$

where: α - the constant mass matrix multiplier;

β - the constant stiffness matrix multiplier;

β_c - the variable stiffness matrix multiplier;

NMAT- the number of material;

β_j – the constant mass matrix multiplier for material j;

$[K_j]$ – the portion of structure stiffness matrix based on material j;

NEL – the number of elements with specified damping;

$[C_k]$ – the element damping matrix;

$[C_\xi]$ – the frequency-dependent damping matrix.

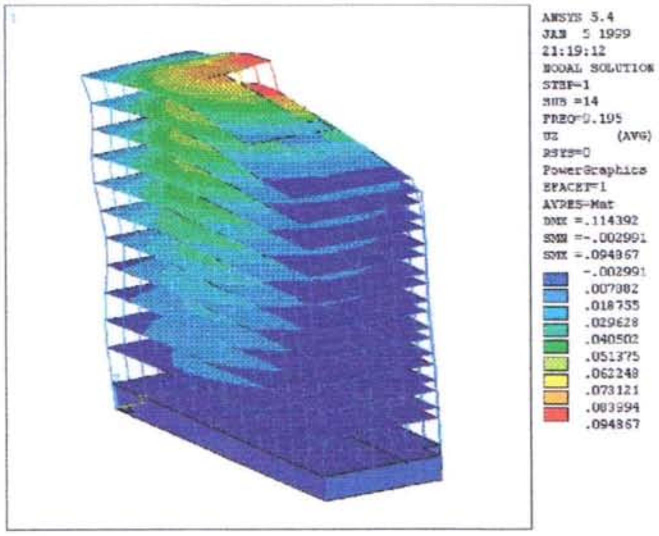

Figure 9 Mode shape 14 – vertical vibrations

In the Rayleigh model the damping matrix [C] is calculated by using these constants to multiply the mass matrix [M] and stiffness matrix [K]:

$$[C]=\alpha\,[M]+\beta\,[K] \qquad (8)$$

The values of α and β are not generally known directly, but are calculated from modal damping ratios, ξ_i. ξ_i is the ratio of actual damping for a particular mode of vibration, i. If ω_i is the natural circular frequency of mode i, α and β satisfy relation:

$$\xi_i = \frac{\alpha}{2\omega_i} + \frac{\beta\omega_i}{2} \qquad (9)$$

To specify both α and β forgiven damping ratio ξ, it is commonly assumed that the sum of the α and β terms is nearly constant over a range of frequencies (see figure 10). There forgiven ξ and a circular frequency range ω_i to ω_j, two simultaneous equations can be solved for α and β.

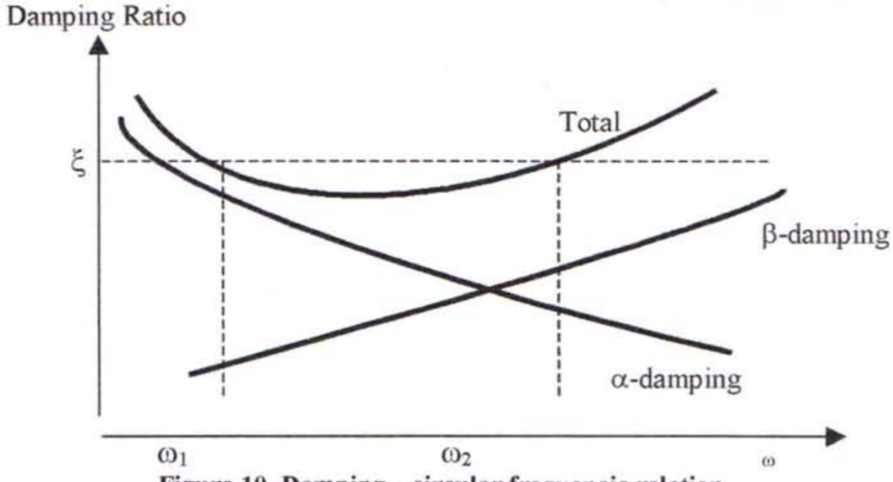

Figure 10 Damping – circular frequencie relation

In our computation we used the following values for the fraction of critical damping, corresponding to eigenmodes 1 and 2: ξ_1=2% and ξ_2=5%. Solving the equation system (9) we computed the values for the constants of proportionality, which are presented in table 2.

Table 2

T_1	ω_1	T_2	ω_2	α	β
1.19	5.24	1.01	6.15	-0.87	0.039

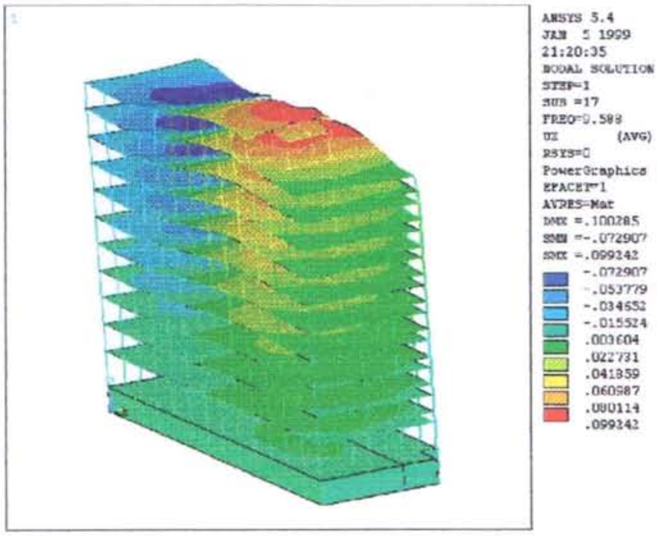

Figure 11 Mode shape 17 – vertical vibrations

The influence of damping decreases the dynamic response of the structure with 14%.

The first ten periods of vibration are presented in table 3.

Table 3

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
1.043	0.886	0.848	0.372	0.332	0.320	0.249	0.246	0.242	0.236

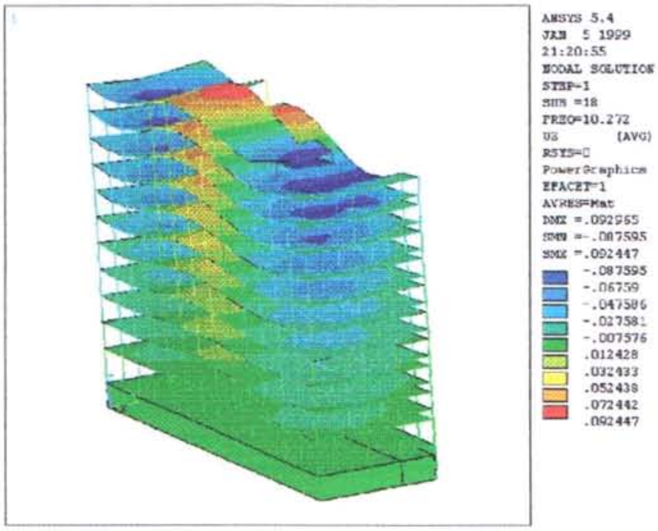

Figure 12 Mode shape 18 – vertical vibrations

3.3 Spectral analysis

The strength structure of "Scala" block of flats within the both variants of modeling was submitted to spectral analysis. Thus, it was established the maximum reply of the structure at horizontal and vertical action of an earthquake.

In case of on horizontal earthquake excitation the values of displacement of structure and of sectional efforts in the component elements (columns and beams) do not significantly differ in the two variants of modeling.

In case of vertical seismic excitation corresponding to a 0.6 ratio from the horizontal component part, the vertical oscillation of the beams can alter the answer of the structure. In this way, for the second variant of modeling with a large number of finite elements, it has been obtained tensile axial efforts in the central columns two times more rare than in the case of the first variant of discretisation. Although these axial efforts have not high values in comparison with the value of the compresion axial effort originated from the vertical loadings on the central columns, can decline the value of the efficient moment of columns.

For the opposite direction of action of the vertical component part of the earthquake, the axial efforts compress the columns. For the columns with reduced gravitational vertical loadings, the effect of the increasing of the compression is favorable, while for the central columns with important gravitational axial efforts, the increasing of the axial efforts of compression can lead to outrunning of the strengthening limit in compresion of concrete.

For what concerns the beams with important vertical stresses-leaning columns on beam at higher levels – from the vertical action of the earthquake, resulted maximum sectional bending effort M=57.4 KNm and shear effort T=46.7 KN, in case of the modeling with dense mesh, with 33% higher than in the case of the rare variant of modeling.

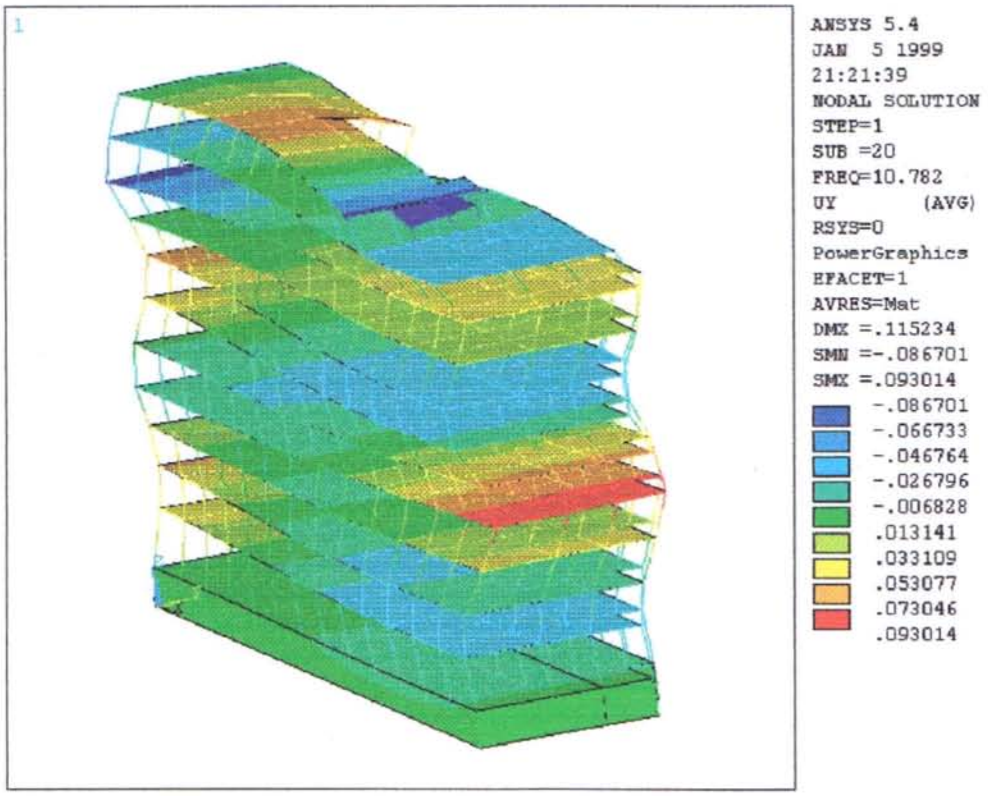

Figure 13 Mode shape 20 – vertical & transversal vibrations

4. Conclusions

The dynamic analysis of the strength structure of "Scala" building emphasizes the following aspects:

- The analyzed structure has a meaningful capacity of viscous damping of the vibrations (14%), taking into consideration that it takes part in the category of semi-flexible structure (T=1.2s).

- The type of mesh can distort the structural answer in case of an gravitational earthquake component. Talking into account that in the last years on registered earthquake with important vertical component, in comparison with the horizontal component (see 17.01.19994 Northridge: a_h=1.82g and a_v=1.18g), it becomes a necessity the introduction in the seismic dynamic analysis also towards the action of the vertical component part.

5. References

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