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Comparative Analysis of Some Methods for Dynamic Behavior and the Structural Design of Multistory Structures

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Summary

This paper compared different calculation methods for the linear dynamic analysis of high multistory steel structures.

In order to exemplify the calculations, we choose a 26 levels structure which is up to be build now in Victoria Place, Bucharest.

Many tests were accomplished, on different ways, such as: modal analysis using vibrating eigenmodes; spectral acceleration using fundamental vibrating mode, two vibrating eigenmodes,…,12 vibrating eigenmodes – in order to relieve the contribution of eigenmodes; for the spectral analysis using 12 modes another set of tests was made for modal combination (SRSS, CQC, ABS, GMC, 10Pct, Dbl Sum); structural analysis using different combinations of the ground acceleration for Vrancea North-South and Vrancea East-West, the computations being realized in direct method and also using the vibrating eigenmodes.

The results of all the tests were registered in order to dignify the similitude of the results using more accessible methods with a more laborious calculation method.

KEYWORDS: eigenmodes, structural design, spectral analysis, dynamic analysis, multistory building, seismic.

1. MODAL ANALYSIS

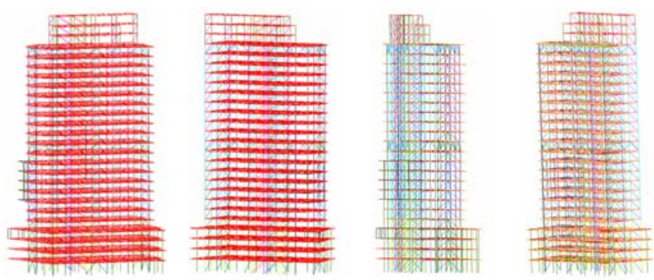

Figure 1. Model Discretisation

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After the modal analysis the following values were obtained:

Table 1. Periods

Mode	Period
Mode 1	3.033
Mode 2	2.473
Mode 3	2.055
Mode 4	1.487
Mode 5	1.306
Mode 6	1.126
Mode 7	1.044
Mode 8	0.969
Mode 9	0.969
Mode 10	0.879
Mode 11	0.866
Mode 12	0.815

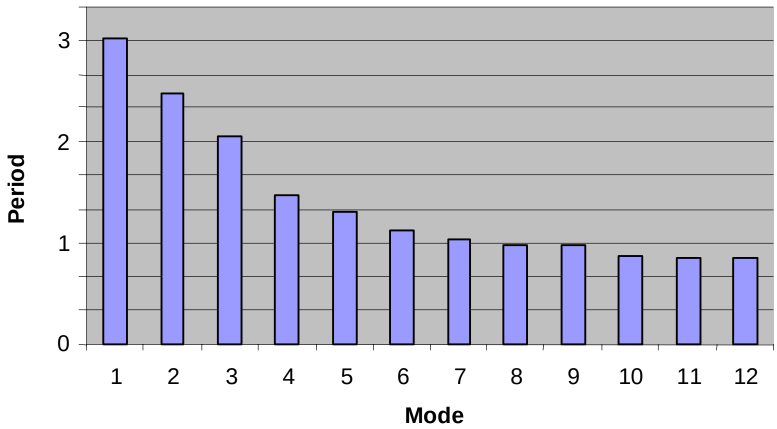

Figure 2. First 12 periods of vibration

The main vibrating eigenmodes are:

- mode 1: translation
- mode 2: torsion
- mode 3: torsion + translation

After the modal analysis, the deformed shape corresponding to the vibrating mode 1, mode 2, ….. mode 12 was obtained and we could educe the following: mode 1 is concordant with the translational effect on the oy direction, the mode 2 is concordant with the torsion effect, mode 3-correlated torsion with translational effect on the x direction and the rest of the modes are concordant with the individual vibrating modes.

2. SPECTRAL ANALYSIS

For this analysis a conventional statical load was used. It was considered a place in Bucharest with: K_s=0.2, T_c = 1.5sec., ψ=0.25, α = 1.

2.1 Eigenmodes Contribution

That design was made in many cases: with first eigenmode, with two eigenmodes, three eigenmodes…..12 eigenmodes, in order to relieve the eigenmodes contribution.

One could notice:

Table 2. Base Reactions

Mode	Global Fx [tf]	Global Fy [tf]
Mode 1	1747	3077
Mode 1 – Mode 2	2225	3116
Mode 1 – Mode 3	2998	3470
Mode 1 – Mode 4	2999	3471
Mode 1 – Mode 5	3000	3519
Mode 1 – Mode 6	3000	3519
Mode 1 – Mode 7	3009	3540
Mode 1 – Mode 8	3076	3540
Mode 1 – Mode 9	3186	3548
Mode 1 – Mode 10	3192	3556
Mode 1 – Mode 11	3194	3556
Mode 1 – Mode 12	3194	3629

The superposition of vibrating modes was made according to SRSS method, using the next formula:

$$SRSS = \sqrt{\Sigma y_i^2}$$

Although the main three parameters were followed (Shear Base Force, internal forces on elements, displacements) only the Shear Base Force was graphically represented:

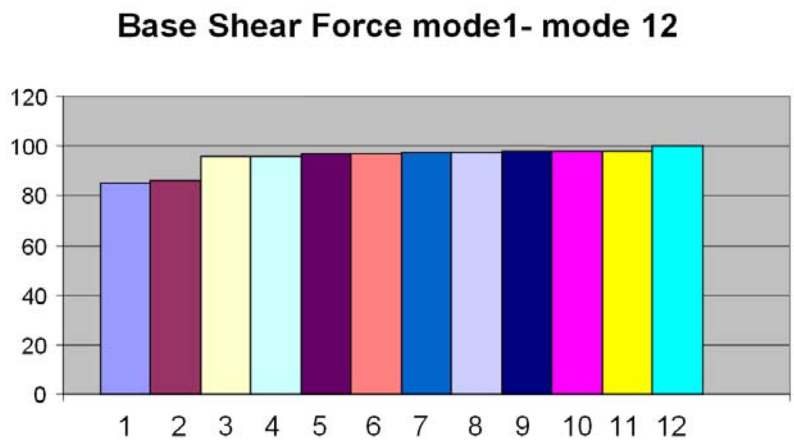

Figure 3. Base Shear Force

One can notice that the contribution of the first vibrating eigenmode was approximately 82% and for the first three modes the contribution was approximately 95%.

Although in many of the study cases it is marked the fact that on the flexible structures the first eigenmode is reduced, according to the previous analysis it was observed that of first eigenmode is important (80-82%).

3.2 The Different Methods for Superposition of Eigenmodes

The results of the spectral analysis (Base Shear Force) for the model with 12 eigenmodes and the main methods of superposition are presented in the next table:

Table 3. Base Reactions using different methods

Mode	Global Fx [tf]	Global Fy [tf]
CQC	3615	3770
ABS	6884	6977
GMC	3624	3779
10Pct	3416	3678
DblSum	3750	3831
SRSS	3194	3629

In the engineering literature the notions concerning the superposition of eigenmodes are different. For that reason the SAP engineers (from CSI Berkeley) gave the possibility to use many superposition methods.

In that paper all that possibilities were studied. Although the fundamental point of view of the methods are disparate in a practical point of view the results show close values between these methods (with an exception for the ABS method which gives different results but it is stated that this method is much too safe).

$$ABS = |y_1| + |y_2| + |y_i|$$

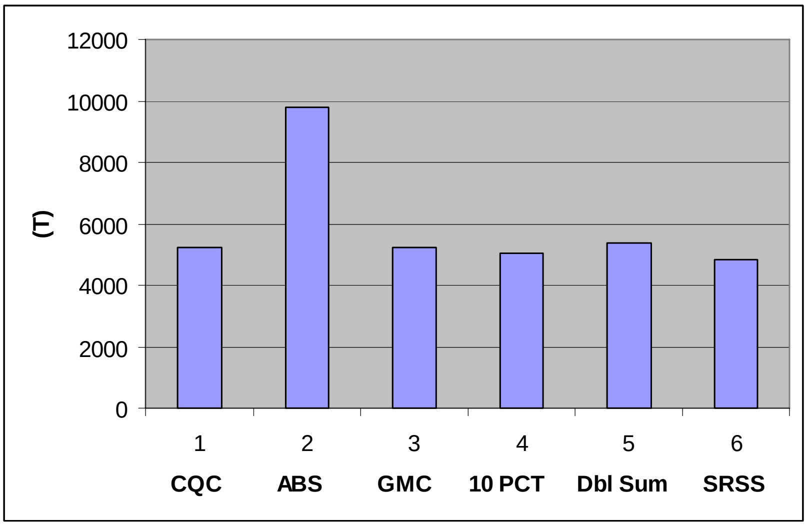

Figure 4. Base Reactions using different methods

For the 12 eigenmodes model we made the analysis with another 5 superposition methods: CQC, ABS, GMC, 10Pct, DblSum. The shear force values according to methods mentioned above is similar; the value is approximately 3800tf (for CQC method- 3770tf, for GMC method – 3779tf, 10 Pct methods– 3678tf, Dbl Sum Method – 3831tf, SRSS method – 3629tf) and approximately 6980tf for ABS method. The value of the member forces keeps the same similitude, approximately 30tf (for CQC method -26.7tf, for GMC method – 26.7tf, 10 Pct method– 30.7tf, Dbl Sum Method – 28.1tf and for ABS method – 67tf) and maximum displacement at the top of the structure for the ABS method is 375mm.

Table 4. Displacements using different methods

Mode	Displacement ox [mm]	Displacement oy [mm]	Displacement xy [mm]
CQC	161.45	251.50	295.68
ABS	255.07	375.00	438.60
GMC	162.28	251.20	295.33
10Pct	161.05	255.53	302.47
DblSum	160.94	247.11	285.03
SRSS	160.23	256.00	303.58

4. TIME HISTORY ANALISYS

4.1 Direct Integration Time History Analysis

For this analysis the Vrancea North-South Time History was considered and also Vrancea East-west Time History, each of them on ox direction and oy direction, and after that a combination was made for the both direction (North-South Time History on ox direction combined with oy direction, North-South Time History on oy direction combined with East-West Time History on ox direction).

Table 5. Base Reactions using different Time-History Accelerations

Case	Step type	Global Fx [tf]	Global Fy [tf]
vnsx	max	10691	5906
vnsx	min	-13136	-4088
vnsxewy	max	10836	5398
vnsxewy	min	-13040	-4489
vnsy	max	5906	10444
vnsy	min	-4088	-8230
vnsyewx	max	5340	10471
vnsyewx	min	-4430	-8280

- Time-History Acceleration “Vrancea North-South” on ox direction
- Time-History Acceleration “Vrancea North-South” on oy direction
- Time-History Acceleration “Vrancea North-South” on ox direction + Time-History Acceleration “Vrancea North-South” on oy direction
- Time-History Acceleration “Vrancea North-South” on oy direction + Time-History Acceleration “Vrancea North-South” on ox direction

One could notice that the shear force values concerning Vrancea North-South Time History on ox direction is approximately the same with the shear force value of the Vrancea North-South Time History on ox direction correlated with the Vrancea East-West Time History on oy direction.

From the picture above it can be noticed that the shear force value of the Vrancea North-South Time History on the oy direction is approximately 50% lower than the shear force value of the Vrancea North-South Time History on the ox direction. In the same time very close results appeared when only the Vrancea North-South Time History was used on the oy direction compared to the model where Vrancea North-South Time History was used on the oy direction and the Vrancea East-West Time History was used on the ox direction.

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$F_{eigenmodes\ SRSS}/\psi$ = 4834/0.25 = 19336 T (comparison with 13757 T the value for the base shear force in case of design with Time History Acceleration).

As at conclusion, the calculation based by eigenmodes (Spectral Analysis) and ψ=1 seems to be the worse case scenario in comparison with calculation based by Time History Acceleration (38%).

So a simplified design with elastic response of the structure using a value of ψ= 0.7 is enough for the design.

The maximum results are observed when Vrancea North-South Acceleration is applied for x direction (13136T).

Also it can be said that applying in the same time Vrancea East-West Acceleration and Vrancea North-South Acceleration brings insignificant increase of the results.

This fact is known in the case of Vrancea Acceleration that using simultaneous North-South and East-West doesn't bring important increase.

A particularity for this structure is that seismic action is more important in case of considering Vrancea North-South accelerogram for x direction instead of using Vrancea North-South accelerogram for y direction (15%).

This is due to the fact that the structure is more rigid on ox direction (the mode 1 is on oy direction). The period in mode 1 is 5.44sec (on oy direction) and 3.71sec (on ox direction). That means that for the typical Vrancea earthquake the seismic response is smaller if the structure is more flexible.

4.2 Eigenmodes Analysis

By using the Time History Acceleration VNSXEWY the value for Shear Base Force results 8839 tf.

Although in theory it is said that for linear calculations the results must correspond between Time History Analysis (laborious calculation) and Modal Analysis Method (much easier calculation) for the studied structure the differences are major (8839tf comparative with 13700tf).

5. CONCLUSIONS

The structure that we analysed has a self vibration period of 3.03 sec corresponding to a translation on y direction. The disposition of structural elements could not be done symmetrically in order to have identical vibration periods on x and y directions. Because of that more detailed dynamic analysis is needed. For that reason in this paper we used more calculation methods: the spectrum analysis method and the calculation with accelerograms.

Concerning the spectrum analysis method two conclusions can be mentioned:

Even if in the specific literature it is suggested that for flexible structures the influence of the 1st vibration mode is not the most important, from what we analysed the 1st vibration mode proved to be the most significant (as we mentioned 80-82%).

No matter what discrepancies can be in the academic environment concerning the different correct methods of composing for the vibration modes we did not find significant differences. For an exact calculation the use of the accelerograms method is recommended.

Concerning the analysis using accelerograms and the procedure of direct integration the conclusions are:

The calculation version using the vibration modes (spectrum analysis) and ψ= 1 is more on the safe side than the accelerograms calculation (38%).

It is noticed that the maximal results appear when the accelerogram s North-South Vrancea is used on x direction (13136 T).

We can also say that the simultaneous application of the accelerograms Vrancea Est-Vest and Vrancea Nord-Sud does not bring significant increase on the results (1%).

This is known that concerning the Vrancea accelerogram using N-S and E-W does not bring significant increase of the results.

The seismic action is more important when we introduce the North-South Vrancea accelerogram directly on x direction, instead of y direction. The difference is around (15%). This is due to the fact that the structure is more rigid on the x direction (1st vibration mode on y direction) . The 1st vibration mode has a period of 4.55 sec. on y and 3.71 sec. on x direction. The result is that for the seismic action type Vrancea the seismic action is smaller if the structure is more flexible.

Even if in theory it is said that in a linear calculation there should be no differences between the accelerogram calculation method using direct integration (elaborated calculation) and the vibration modes calculation (a more simple calculation) for the structure that we analysed the differences are significant 8839 instead of 13700 Tf.

Using the analysis described above it resulted that the consideration for the design of the wind forces is not necessary because the resultant of the wind forces is smaller than the seismic action (5400 instead of 13700 Tf).

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Using dynamic analysis of the structure in this paper it can be recommended that the analysis of the structure to be made in the elastic domain using the accelerogram method by direct integration without the danger of overdimensionning (the base shear force using accelerograms is estimated at 15.7% of the weight of the entire structure).

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