Tall buildings subjected to horizontal loading: Structural analysis by an *in-house* numerical code

Giuseppe Nitti, Giuseppe Lacidogna, Alberto Carpinteri

Department of Structural, Geotechnical and Building Engineering,
Politecnico di Torino, Torino, Italy
e-mail: giuseppe.nitti@polito.it, giuseppe.lacidogna@polito.it, alberto.carpinteri@polito.it

Targets of the research

Tall building structures are usually calculated by finite element models since the early design stages. This approach, although giving detailed information, is time-consuming and often leads to lose sight of parameters and variables that govern the general problem. In the context of design of High-rise buildings, numerical codes based on simplified analytical formulations could be useful for preliminary calculations.

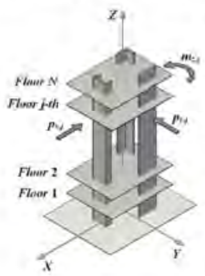
In this contribution, an original analytical methodology, called General Algorithm, has been implemented in a software which can be used in the preliminary design.

The proposed model provides a simple and clear explanation of the various parameters effects which characterize the tall buildings behavior. The analytical formulation, based on the original work by A. Carpinteri [1], was extended and implemented in a numerical code that, according to the Timoshenko-Vlasov's theory and to the Capurso's approach, encompasses any type of bracings, including closed and open thin-walled shearwalls [2]. Then, the cases of interaction between bracings of different height and variable section elements, like twisted and tapered structures, were introduced [3].

The main advantage of this approach is that it requires a shorter computation time if compared to FEM software programs, obtaining results which are quite close to those achieved by the commercial software programs.

Lateral loading Distribution: Analytical Formulation

A building with M vertical bracings and N-storeys is considered.



Each floor of the structure is subjected to external load $\{F\}$

$$\{F\} = \begin{Bmatrix} p_x \\ p_y \\ m_z \end{Bmatrix}$$

The global displacement of the are:

$$\{\delta\} = \begin{Bmatrix} \xi \\ \eta \\ \vartheta \end{Bmatrix}$$

The horizontal forces acting on each vertical bracing are:

$$\{F_i\} = \begin{Bmatrix} p_{x,i} \\ p_{y,i} \\ m_{z,i} \end{Bmatrix}$$

The relation between $\{F_i\}$ and $\{\delta\}$ is condensed by a stiffness matrix

$$\{F_i\} = [\bar{K}_i]\{\delta\}$$

Considering M vertical bracings, the conditions of equilibrium provide:

$$\{F\} = \sum_{i=1}^{M}\{F_i\} = \left(\sum_{i=1}^{M}[\bar{K}_i]\right)\{\delta\} = [\bar{K}]\{\delta\}$$

Connecting the vectors $\{F\}$ and $\{F_i\}$ we obtain:

$$\{F_i\} = [\bar{K}_i][\bar{K}]^{-1}\{F\} = [R_i]\{F\}$$

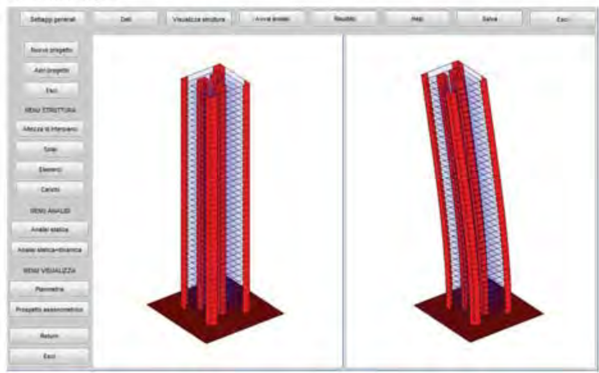
The load distribution matrix $[R_i]$, shows that each bracing is subjected to a load $\{F_i\}$ given by the product of the external load $\{F\}$ premultiplied by its own stiffness matrix and the inverse of the global stiffness matrix.

Numerical Code

The analytical formulation has been implemented in a numerical code by using Matlab program.

The main advantages of this approach are:

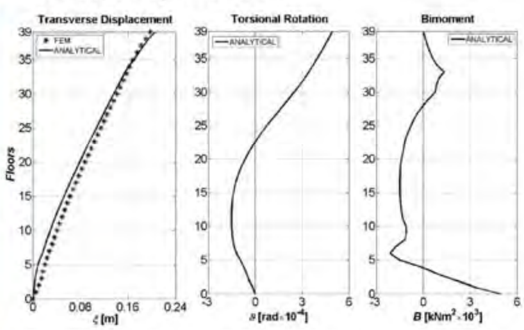
- Only three degrees of freedom for each storey are considered
- Shorter computation time if compared to commercial FEM softwares
- No mesh is defined
- Simple and fast input



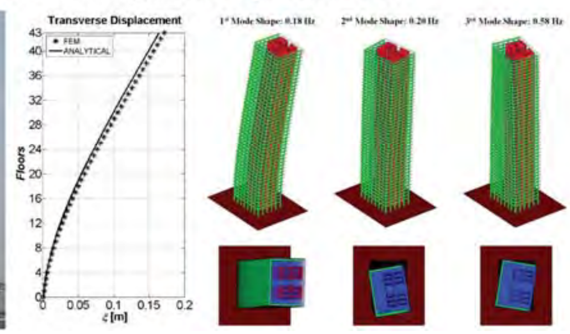
Results

The approach effectiveness is demonstrated by two examples on real structures [4]. In particular, the studies are focused on two tall buildings recently built in the City of Turin: the Intesa Sanpaolo Tower, inaugurated in 2015, and the Piedmont Region Headquarters, still under construction. The first building, 167 meters tall, consists of reinforced concrete cores composed by thin-wall open-sections and six large steel columns. The peculiarity of this structure is the great eccentricity of the cores with respect to the floors' centroid. The second building, 209 meters tall, is composed by four cores and three frames placed along the perimeter, all made in reinforced concrete. The particularity of this structure is that the cores are connected in pairs, to further reduce the transverse displacements of the whole building.

Intesa Sanpaolo Tower



Piedmont Region Headquarters Tower



Conclusions

Nowadays, the use of finite element calculation software programs allows us to analyze with extreme accuracy any High-rise structures shape, but the complex structural analysis of such buildings involves very long computational times. In addition, the results provided by these programs are difficult to understand because it is not easy to synthesize from the obtained results the overall behavior, especially in terms of elementary and combined internal forces belonging to every structural element.

Therefore, in the preliminary design stage, the use of algorithms based on simplified hypotheses can solve certain problems delivering reliable results. In this respect the proposed numerical code, provide reliable results in very short computational times, giving to the designer the key parameters to handle the structural behavior. The following elaboration by Finite Elements programs can then be used to analyze the finer buildings' details.

References

[1] A. Carpinteri, An. Carpinteri, Lateral loading distribution between the elements of a three-dimensional civil structure, *Computers & Structures*, 21, 563-580, 1985.

[2] A. Carpinteri, G. Lacidogna, G. Nitti, Open and closed shear-walls in high-rise structural systems: Static and dynamic analysis, *Curved and Layered Structures*, 3, 154-171, 2016.

[3] G. Lacidogna, Tall buildings: Secondary effects on the structural behaviour, *Proceedings of the Institution of Civil Engineers. Structures and Buildings*, 6, 391-405, 2017.

[4] G. Nitti, G. Lacidogna, A. Carpinteri, Tall buildings subjected to horizontal loading: Analysis of two case studies by an in-house numerical code, *Proceedings of the XXIII Conference of the Italian Association of Theoretical and Applied Mechanics,* 1, 292-300, 2017.