Damping of high rise buildings

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Abstract. High-rise construction acquires demand in Russia and abroad. New features are practiced in order to ensure the rigidity and stability of the building frame, to withstand wind and snow loads. It is about architectural and design features. The article discusses the variations of skyscrapers damping, which are used in the design and construction of high-rise buildings in recent decades. Existing examples from around the world are also provided for clarity.

Introduction
High-rise buildings and structures in the modern construction industry are in great demand, arouse professional interest and are the foremost direction of construction around the world. In connection with the growth and prospects of scientific and technological progress, today attention is also focused on unique buildings and structures. In the case of high-rise buildings and structures, unique ones are those which height exceeds 100 meters. Ensuring the structure rigidity and stability of the object, as well as opposition to loads, impacts and collapses are the main objectives that should be pursued by designers-engineers.

Material and technique
What is the damping? Translated from the German language Dämpfer is a muffler, shock absorber, dämpfen is to muffle. Damping is the suppression or prevention of building vibrations. The dampers are designed in conjunction with the building frame and foundation, whereby they contribute to the reduction of seismic effects due to the dissipation of seismic energy penetrating the structures. Dampers can be configured and act as various structural elements.

Despite many advantages of such buildings, it is worth noting a number of factors that complicate the design and construction:

- first of all, it is the development of the optimal framework and foundation as in the construction case of high-rise buildings and structures, careful approach is needed to choose either the framework and foundation elements already used in practice (dampers, outriggers, cable stays, vertical and horizontal bracings, rigidity cores, trusses), or to the application of new technologies. These new technologies will provide the building or structure with the necessary rigidity and stability as well as counteract external loads and impacts;
- it is required to check and identify the most reliable and at the same time economical frame scheme of a high-rise building, correct sections selection of the structure’s skeleton, reinforcement of reinforced concrete elements, structural junctions, check deformations of structures and building as a whole (with foundations and soil conditions) using calculations. Then it is necessary to compare them...
with permissible for this type of buildings and structures in regulatory documents (CR, Building codes and regulations, GOST, etc.). Modern computational software systems use, such as PC Lira CAD, SCAD Office PC, Base, etc., has also become topical. They allow performing analysis, design and calculation of building and engineering structures for a particular purpose. Calculations can be performed on static (force and deformation) and dynamic effects. Selection of steel sections and/or reinforced concrete structures can be also performed. Sketches of KM working drawings and individual reinforced concrete elements are being developed. Calculation programs allow simulating the building or structure behavior under various influences on them and show a calculated-deformable scheme. This is a very convenient and modern way to predict the behavior of structural elements or the entire building as a whole, without resorting to practical tests;

- it is necessary to correctly and efficiently use building materials in the construction of high-rise buildings or structures. Grades of concrete, reinforcement and steel grades must meet the requirements of reliability and durability during the construction and operation of a high-rise building, and correspond to the climatic conditions of the construction area;

-when designing high-rise buildings particular attention is paid to the urban environment where such a building will be located. The concept of a future skyscraper should be carried out without prejudice to the cultural and historical appearance and harmoniously fit into the general panorama of the city, especially when it comes to compaction of urban development.

**About constructive systems.**

Designing and building of high-rise and unique buildings requires careful preparation and analysis of a large amount of material, studying foreign and domestic experience, especially design schemes and techniques that allow sustainability and low deformability of such buildings and structures. It is necessary to consider various options for design schemes, perform calculations and come to the most rational and economically optimal option among all. The most applicable design solutions are listed below:

1. Frameless system is a system with bearing walls. The wall system was the main design for a long time. However, its use is more relevant in residential construction.

   The tallest constructed wall system is the residential building “Colonia-Haus” with a height of 147 meters (42 floors) in Germany. The building is made of monolithic reinforced concrete and has a scheme with transverse load-bearing walls.

2. Braced frame structural diagram – is a frame diagram with stiffening diaphragms. High-rise construction is directly related to the light steel frame use, which use implies that the designers attention should focus on horizontal loads. Therefore, there was a need for new structures and materials that should ensure the buildings rigidity and stability. The principle of such a system is that the wall-diaphragm is made in the form of a monolithic reinforced concrete or steel-reinforced concrete stiffening trunk; the framework is made of monolithic reinforced concrete; improving the frame efficiency with the use of horizontal stiffness belts and outriggers.

   The Evolution Tower in Moscow is an example of the frame-bond scheme application. The structural tower system is a frame-barrel system with a stiffness core and a grid of monolithic reinforced concrete columns. The tower rigidity is provided only by the barrel stiffness.

3. Frame-skeleton system - with the advent of welded attach structures in the 1940s the structural scheme with stiff frames gained widespread use. The advantage of the frame scheme is a relatively free layout. However, due to the significant consumption of steel for building frames, the economic feasibility of such a variant of the structural system will be questionable. Therefore, in buildings with a height of more than 30 floors, channel frames are rarely used. Using the frame scheme, the building of the Ministry of Foreign Affairs of the Russian Federation was built on Smolenskaya Sennaya square, the frame height was 125 m.

4. Barrel - stiffness trunks, which are an integral part of communication systems, can be used to create frames with cantilever and suspended floors. Distinctive feature of such a system is that the buildings facades are as open as possible and the rooms are well lighted. Example of a building with
cantilevered floors is the 36-storey Aspire Tower, 300 meters high in the State of Qatar. Suspended systems are complex from a constructive point of view and from the erection point of view.

5. Box-shaped (shell) - stem systems are simple in terms of static calculation, but with high altitude (approximately 80 m) or with great cores flexibility these systems are not a rational solution especially in terms of ensuring sufficient rigidity in the horizontal direction. Therefore in the world practice a box-shaped (shell) structural system was developed. Classic example of such a system is the Sears (Willis) Tower, 442 meters high, USA. The shell system in its "pure" form is practically not used since the design of vertical communications and floors determines the use of internal supporting vertical structures.

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The outer shell of these buildings is a lattice structure of diagonal mesh elements. The system frame-shell is used when the internal trunks use is unacceptable for planning reasons and the rigidity is provided only by the outer shell. According to this system, the World Trade Center towers were built in New York, USA and have heights of 417 m - the north and 415 m - the south; building "30 St Mary Ax" height 180 m (London, UK). The shell stiffness is so great that it works under horizontal loads like a cantilever beam.

6. Systems with megacolumns. One of the modern directions of world high-rise construction is the use of combined steel-reinforced concrete structures. The combination of rolled steel and high-strength reinforced concrete allows modifying the existing structural systems and as a consequence the construction of ultra-high buildings. Among such systems can be identified frame-barrel with megacolons. The features of this system will be considered on the example of the “Shanghai World Financial Center” building with a height of 492 m (Shanghai, China). The bearing framework is a system consisting of hard core; four megacolumns (two of which in the level of the third technical floor branch into a couple of columns each); seven outriggers in the level of each technical floor; diagonals, providing the spatial rigidity of the building. Outriggers are an important element of the system and consist of a shingling truss and vertical ties. With the help of the outriggers, the reinforced concrete core is connected to megacolumns in order to increase the total inertia moment of the building cross-section to perceive the horizontal load. It can be said that megacolumns are a combined steel-reinforced concrete structure, reinforced with separate rods and rigid reinforcement (welded box-shaped profiles). In fact, megacolumns ensure the operation of the entire system as a whole. According to this system, the following buildings were also erected: the Commerzbank Tower building with a height of 300 m (Frankfurt am Main, Germany); Lotte World Tower building, 555 m high (Seoul, South Korea); 600 meters high Ping An Finance Center (Shenzhen, PRC); Tower "Shanghai Tower" height of 632 m (Shanghai, China).

7. System "HexaGrid". This is an innovative constructive system, which is called "Honeycomb" or "Hexagonal grid." The system consists of a network of diagonal links located along the building perimeter formed as a result of the intersection of its diagonal and horizontal components. The elements of the hexagon configuration constructive due to its shape can carry both vertical and horizontal loads redistributing them most evenly. The honeycomb structure provides both elasticity during deflections and stiffness against the action of transverse forces and does not need a high stiffness of the central trunk. At the same time, transverse deformations are minimized more efficiently, distributing transverse forces by means of the axial action of diagonal elements, while other schemes perceive transverse forces with bending of vertical columns and horizontal bridges. The angle degree between the diagonal elements forming the nodes of the HexaGrid network is an essential design parameter that determines the stresses distribution of internal forces in elements of the building system. The HexaGrid system is a relatively new idea and requires further research.

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When choosing a structural system for a high-rise and unique building or structure, it is necessary to proceed from the results of the calculations in one or another case to select individual approaches to
the rigidity solution. Stability and geometrical immutability as structures in particular and the building as a whole. For this purpose in practice, the following constructive "techniques" are used:

1. Dampers (in translation from German - "to muffle") is a system consisting of load and its special fastenings, absorbing wind or seismic vibrations of a high-rise building, which works on the principle of counterweight. Dampers have their subspecies, the most used - inertial and induction. Inertia is a system consisting of load and hydraulic fastenings (cables), which allow the load-damper to swing freely in such a way that its inertia resists the movement of the building from external actions. The entire hydraulic system protects the pendulum from too sharp deviations and too large amplitudes. To stabilize the "tops" of a building with an induction damper, electromagnets are used, which serve as energy absorbers. Calculations determine the height where it is necessary to arrange a damper, as a rule, these are the upper floors of a skyscraper.

The Taipei 101 building in the Republic of China is 509.2 m high is an example. Since the skyscraper location is a zone of strong winds and earthquakes, its design had a high degree of innovation and the use of impeccable technology. The result: the world's largest damper is an 800-ton monolithic ball-pendulum on the 92nd floor and 8 damping hydraulic shock absorbers, which during oscillations produce a viscous fluid, which absorbs wind loads.

2. Cable stays and ropes. Devices that are often used in high-rise buildings are the towers, masts, etc. They represent steel or metal tensioned cables. The ropes principle will be considered using an example of the Ostankino television tower in Moscow. The tower height is 540 meters, weight is 55 thousand tons. The construction of enormous parameters caused many contradictions and doubts during construction, mainly due to the doubtfully shallow bedding of the foundation (from 3.5 to 4.6 meters). That is why the chief designer Nikolai Nikitin first applied an innovative method - the balanced tension of steel ropes. He explained this by the fact that the building should rest on the ground, acquiring stability, due to the multiple excess of the base mass over the the structuremass, namely in a ratio of 1: 3. 149 steel ropes, with a total tension of about 10 thousand tons, were located inside the structural frame and created a reliable system consisting of a foundation and a frame that can withstand even eight earthquakes on the Richter scale. The principle is that the ropes take on all the tensile forces of the tower, by "tightening" the body of the tower, in consequence the normalized crack resistance of concrete and anti-corrosion reinforcement is ensured.

3. Outriggers. The outrigger device is a stiffness belt consisting of trusses that connect the columns of a high-altitude object with a central stiffness core, thus forming an inseparable structure. Outriggers act, as a rule, in the form of bracing (outrigger) floors, which are located in one or several parts of the building, and are accepted for the calculation. Designing outrigger floors makes it possible to distribute the load between the core and the columns, increase the flexural rigidity of a high-rise building, reduce longitudinal deformations, and, more importantly, counteract the progressive collapse. Therefore, in the building of the multifunctional complex Lakhta Center (St. Petersburg) five outriggers were designed, four of which are double floors, and the fifth is in the form of a reinforced concrete "washer". Outriggers consist of diagonal trusses that run from the perimeter columns to the core.

4. Additional elements of the high-rise building frame of a can be used in addition to the above, or, in the case of low lateral loads, separately from them, are stiffening cores, stiffening diaphragms, horizontal and vertical connections, etc. There are horizontal and vertical communication systems. It is about the perception of horizontal loads on the building, which are crucial in the design. It is the connection that takes the whole blow from wind or seismic loads. Accordingly, the use of rigid bracing structural elements that will exclude possible strains of the building is required.

Factors affecting the choice of design solutions for high-rise buildings.
What to apply in a particular project of a high-rise building? How to design a skeleton frame? These are the main issues facing designers - architects and engineers. The choice of the optimal variant of the constructive solution for the future high-rise depends on many factors:
- height and size in the building plan;
- space-planning decisions to be applied in a high-rise building;
- the functional purpose of the building;
- climatic and seismic conditions of the construction area;
- integrated security of high-rise buildings;
- urban situation;
- architectural and compositional requirements;
- engineering systems and equipment necessary for the operation of the building;
- space-planning decisions to be applied in a high-rise building.

It is important to note that in advance, when developing layouts and frameworks, it is necessary to proceed from the symmetry of the stiffness arrangement (stiffness diaphragms, connections, etc.). The more symmetrical they are, the less there will be moments twisting the building, causing rolls, uneven deformations of structures, bases and foundations and also the building as a whole will be more economical.

**Summary**

The modern designer has a number of advantages associated with scientific and technological progress. Certainly, this is the presence of accurate CAD programs that allow simulating different variations of building structure schemes and predict the behavior of its constituent elements. Consequently it is possible to compare various models of the frame, bases and foundations of a high-rise building and stop at a more reliable and cost-effective option.

When choosing the location for a high-rise and unique building, it is necessary to take into account the surrounding urban environment. When designing, use variation solutions, check their calculations, conduct comparative monitoring. To apply modern advanced programs for calculations and modeling of adopted design schemes and other solutions. To study the experience of designed and constructed high-rise and unique buildings in the country and abroad. In addition, strive to improve and find new ideas and techniques to ensure reliability, minimize deformability and totally eliminate the collapse.

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