AIRPORTS AND THEIR INFRASTRUCTURE

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STRUCTURAL DESIGNS OF MULTI-STOREY BUILDINGS

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Abstract

The article is devoted to topical issues of researching structural designs of multi-story buildings. Designing high-rise buildings of any purpose begins with solution of the main task - choosing a structural system based on functional and technological requirements. The choice of the structural system determines the role of each load-bearing structural element in the three-dimensional structure of the building. Conditionally, all structural systems can be divided into four main types: I – framework type; type II - framework with stiffening diaphragms; type III – tube system; IV - box (shell) type. Combined designs have greater structural flexibility due to the possibility of distributing parts of the loads by varying the rigidity of the load-bearing elements. In accordance with load distribution, high-rise building braces are divided into horizontal and vertical. Horizontal braces provide formation of hard discs in high-rise buildings, which distribute external forces among their elements, reduce bending moments, and prevent the frame from torsion and coming out of the plane of the elements. Vertical braces give rigidity under the action of horizontal loads on the vertical building elements connecting the floor discs.

Keywords: structural designs; multi-storey buildings; frames of high-rise structures; frameworks; frame systems

1. Introduction

Over the past two decades, the construction of high-rise buildings has been developing significantly due to the introduction of modern construction materials and enclosing structures with high heat-insulating properties.

Designing of any type of high-rise building begins with their main task solution - the choice of its structural system based on certain functional and technological requirements. The choice of a structural system predetermines the role of each bearing structural element in the spatial structure of the building.

In 1969, Fazlur Khan proposed to classify the high-rise building's structural design effectiveness depending on the building height. Khan deduced that the rigid framework dominating at that time in high-rise construction, was not the only possible structural design variant suitable for high-rise buildings. With the development of computer simulation it became possible to analyze the behaviour of a high-rise building as a single spatial structure. The increase of high-rise buildings` height through their design system improvement during the time period of 1900-2010 years is represented in Fig.1 [1].

In modern high-rise construction there are different structural systems and structural designs with various variants and their arrangement (Fig. 2). The number of possible variants of combined systems is wide enough. It is worth noting that the terminology of structural design hasn't been defined normatively yet and has ambiguous interpretation in various publications.

2. Development and modern concepts of multy-storey buildings structural design

Conditionally, all structural systems can be divided into four main types:

— Type I – framework system;

— Type II – framework system with stiffening diaphragms;

— Type III – tube system;

— Type IV – box (shell) system.

Combined structural designs have greater structural flexibility due to the possibility of distributing parts of loads by varying the bearing elements stiffness.

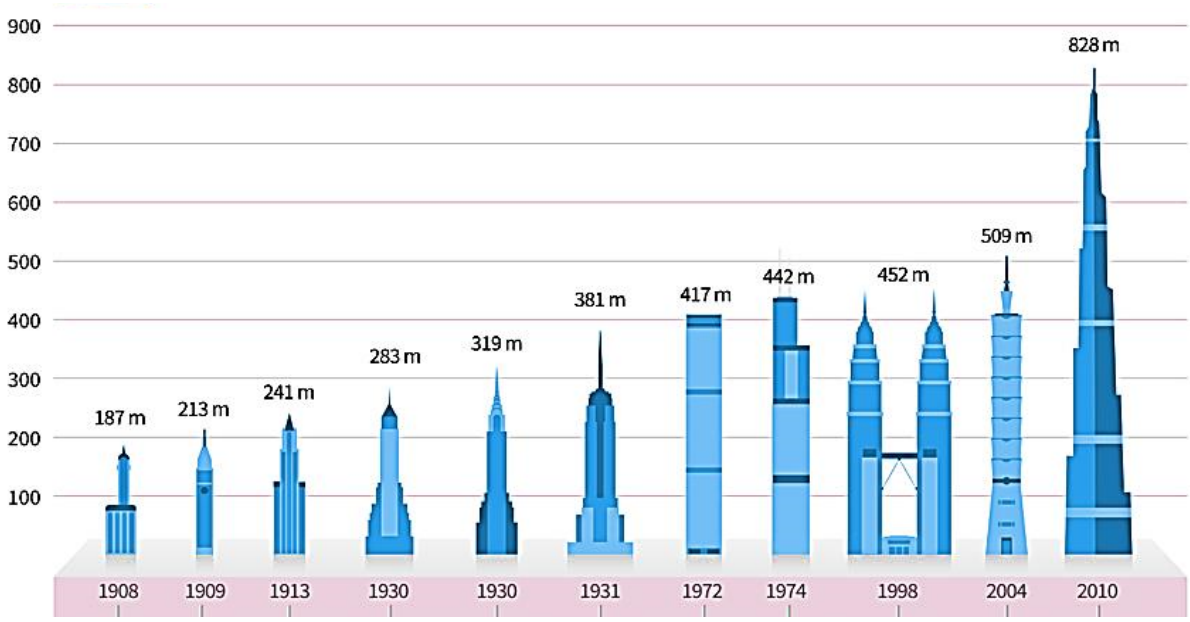


Fig. 1. Structural design of high-rise building's framework

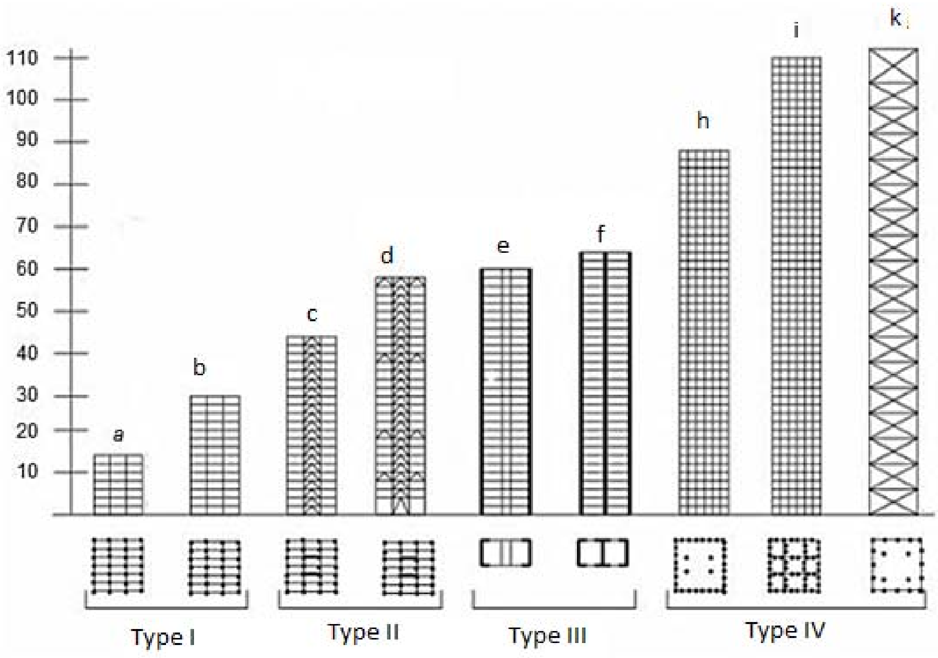


Fig. 2. Structural designs of high-rise building's framework:
a – semi-rigid; b – hard; c – with flat; d – with rigidity girts; e – pipe system with edge channels and internal trusses; f – pipe system with edge channels and middle I-beam; g – external genderless shell; h – frame skeleton with shells; i – external girder shell

In the tube structural system, the stiffness of a high-rise building is provided by a staircase-lifting unit located usually in the central part of the house and made of monolithic reinforced concrete, steel structures or their combination. The stiffness of the tube structural system, its stability and the ability to suppress the horizontal oscillations is ensured by immersing its central tube into the foundation. The tube structural system has varieties: the cantilevered support of the intermediate floors on the tube, the upper bearing cantilever (outrigger) carries the outer part of the floor, the intermediate location of the load bearing cantilevers of the floor height that carry loads from the part of the floors.

Frame and mixed structural systems, depending on the distribution of functions between the frame elements to provide their spatial rigidity and stability, are divided into: frame (Fig. 4, a); brace (Fig. 4, b); frame-brace (Fig. 4, c).

Fig. 3. The frame structural designs of high-rise buildings:
a – semi-rigid (BMA Tower, Kansas City); b – rigid (Nishi-Shimbashi Square, Tokyo); c – with rigidity girts (Strarata SE1, London); d – with external diagonal web shell (One Maritime Plaza, San Francisco); e – frame skeleton with shells (Hearst Tower, New York); f – tube with external

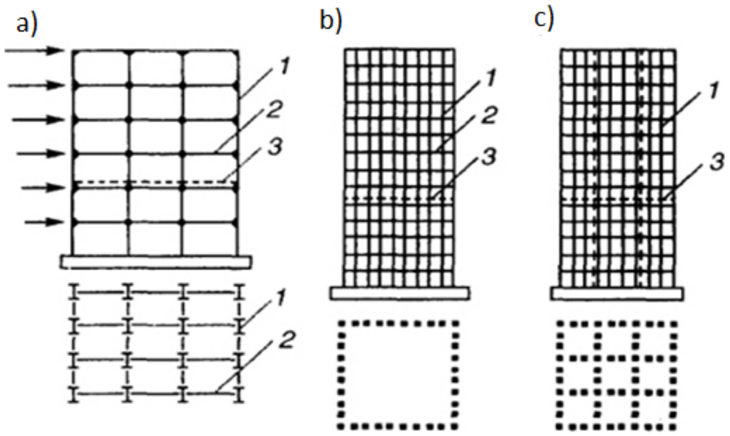


Fig. 4. Frame and mixed structural systems:
a – frame; *b* – brace ; *c*– frame-brace;1 – column; *2* – frame girder; *3* – intermediate floor plane

The increase in the bearing skeleton rigidity of high-rise buildings with the tube structural systems and their resistance to the dynamic horizontal loads are achieved by using the outrigger structures carrying part of loads from intermediate floors. As a rule, they are fairly strong flat or spatial structures, located at the top of a building with a certain step and connected by vertical rod elements, providing the tube's vertical rotation in case of its deformation.

The box type structural system is the most rigid of the systems owing to the external bearing shell, which can be in the form of a steel diagonal girder frame or simple steel girder frame.

When the stiffness of the frame or tube system is not enough, the combined solutions of the structural systems are used. To increase the resistance of the bearing structures to horizontal loads, a combination of the tube wall system is used. In this case, the horizontal loads are taken up not only by the outer shell and the central tube, but also by the internal bearing walls. Combined structural systems have greater structural flexibility due to the possibility of distributing a part of loads by varying the stiffness of the bearing elements. The design diagram of high-rise building's bar framework must be geometrically invariable system and work together as a single object (Fig. 5).

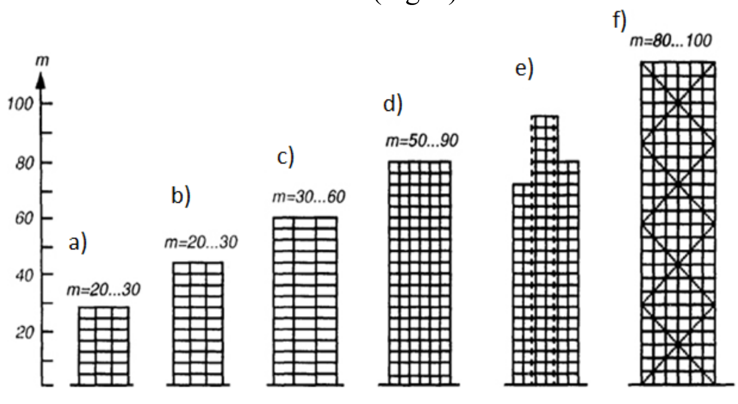


Fig. 5 Rod frames of high-rise buildings of various structural systems:
a - the usual frame system; b - brace or frame-brace system with rigid diaphragms or internal tube; *c* – the same with crib ; *d* - frame system with outer space frame; *e* – sectional frame system; *f* – brace system with external tube in the form of a spatial truss

In regular systems, this can be achieved in two ways: by creation of rigid joints or by proper braces arrangement. Depending on the method ensuring the invariability, the frames are divided into fixed and not fixed against skewness (Fig. 6).

The frameworks fixed to avoid skewness are decomposed into separate subsystems and elements, while the unfixed frameworks should be considered as a single system.

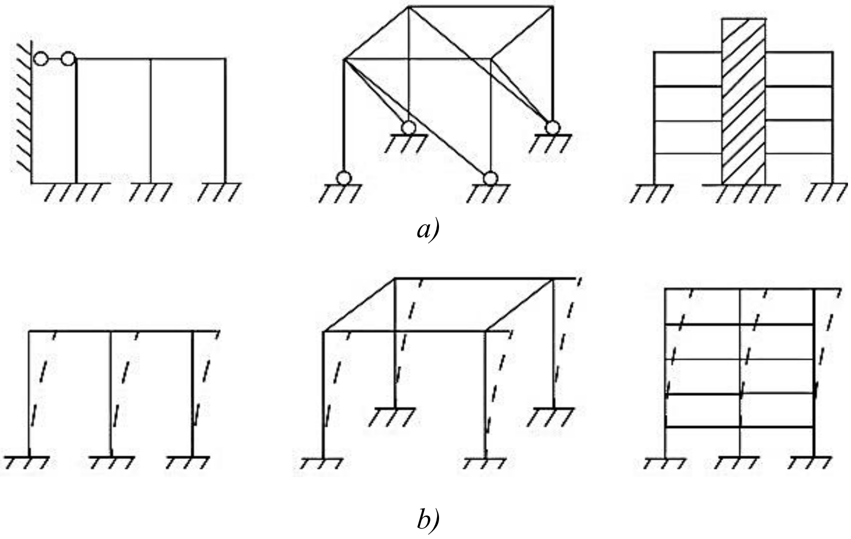


Fig. 6. High-rise building frames:

a – fixed; b – not fixed from skewness

Thus, it is possible to identify the basic functions of the frame's braces:

- providing the geometric invariability of the main bearing structure;
- providing spatial work of all elements and subsystems of the bearing structure as a single unit;
- taking up and distribution of horizontal loads between elements of the main bearing structure;
- reduction of the calculated lengths of elements of the main bearing structure;
- facilitation of erection through temporary fixing the bearing structure elements during construction process.

3. Analysis of high-rise buildings braces

By the way of taking up and distribution of loads, there are horizontal and vertical braces. The horizontal ones provide the formation of hard disks in high-rise buildings to distribute external forces among their elements, reduce bending moments and prevent both the torsion of the frame and coming out of the plane of the elements. The vertical braces provide stiffness under the action of horizontal loads on the building's vertical elements connecting the floor discs.

By the design peculiarities, the braces can be either concentric or eccentric. By the geometrical form, braces can be divided into four groups (Fig. 7).

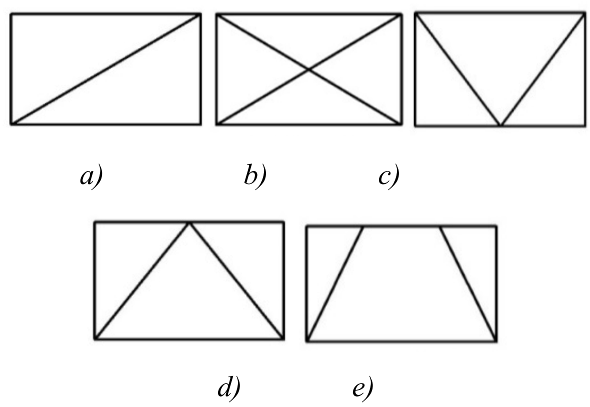
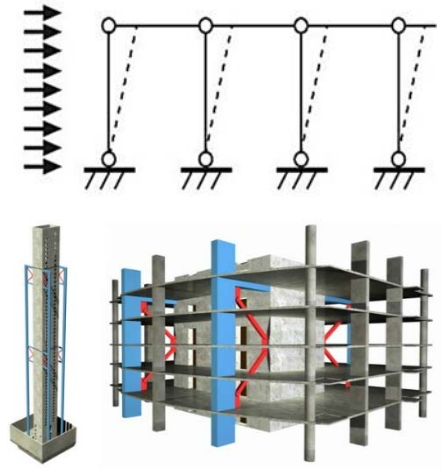


Fig. 7. Types of vertical braces:

a – diagonal; b – X-shaped; c,d – V-shaped;

e – K-shaped or portal

By the structural design, the braces are divided into rigid and flexible. Rigid braces are able to take up compressive forces, transmitting undesirable action to the support while the flexible ones take up only the tensile forces (Fig. 8).



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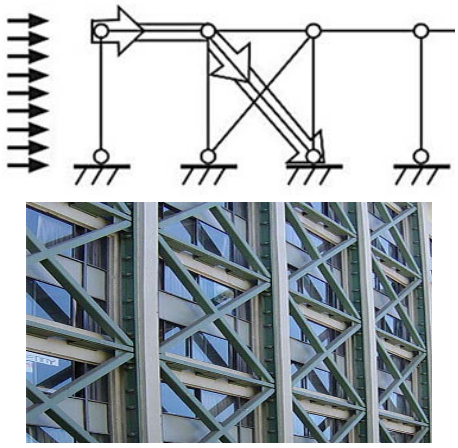

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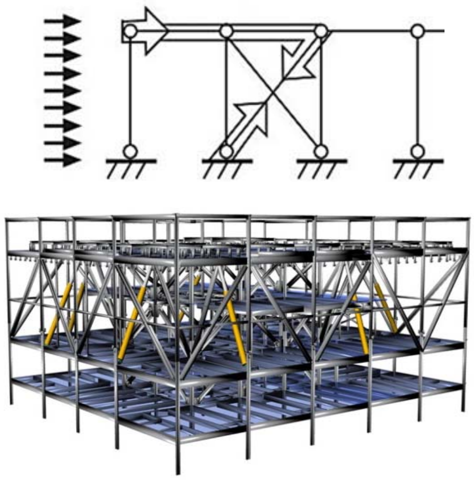
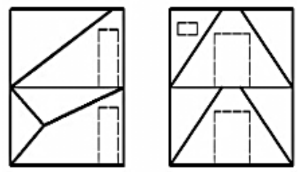


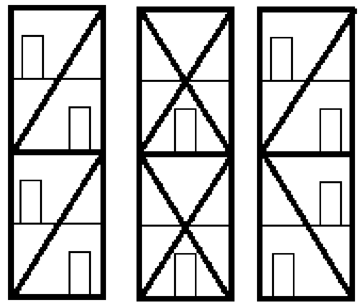
c)

Fig. 8. The work of vertical braces:
a – unfixed framework; *b* – rigid braces; *c* – flexible braces

The braces are the simplest and lowest in cost for their erection, but from an architectural point of view, they reduce to zero the possibility of designing openings. For walls with openings, the braces are designed in several stores or individually for each story (Fig. 9).



a)



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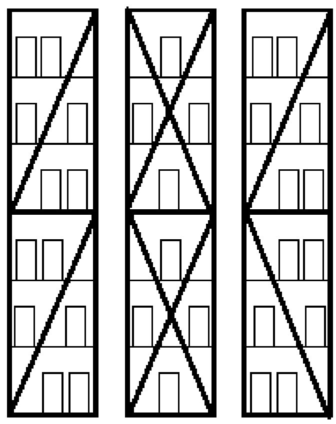
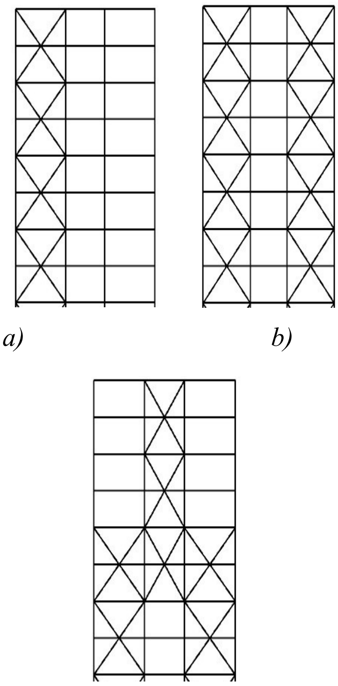


c)

Fig. 9. Braces for walls with openings:
a – one storey; b – two storeys; *c* – three storeys

The static and design requirements become decisive for the walls without openings (Fig. 10).

Design features of braces. Diagonal braces are the simplest and lowest in cost in the erection process, but they create asymmetrical fastenings and therefore must be strictly rigid.



a) *b)*

c)

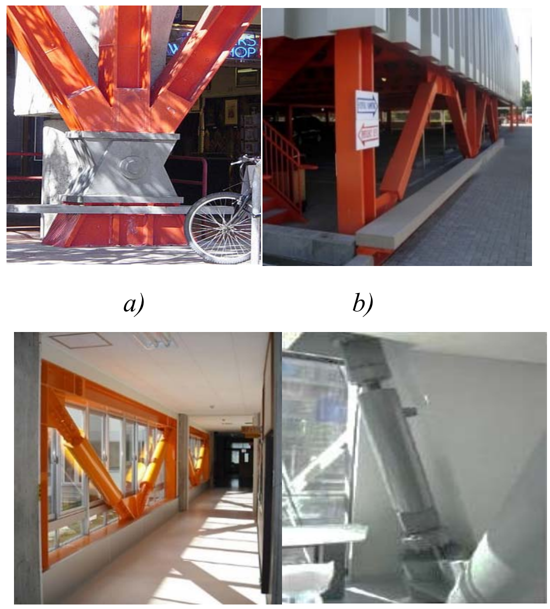
Fig. 10. Vertical braces in three spans:
a – simple X-brace; b – simple X-brace in two spans;
c – frame type arrangement of braces

The fixed frameworks fastened against skewness with brace systems or monolithic diaphragms can be divided, during their analysis, into separate subsystems and elements, while unfixed frameworks should be considered as single structures. Thus, the following basic functions of braces are distinguished:

- providing the geometric invariability of the main bearing structure;
- providing spatial work of all elements and subsystems of the bearing structure as a single unit;
- taking up and distribution of horizontal loads among elements of the main bearing structure;
- reduction of the calculated lengths of elements of the main bearing structure;
- facilitation of erection through temporary fixing the bearing structure elements during construction process.

The diagonal elements between columns of the rigid frame form a framing in which the columns are the chords of the truss. Braces take up the horizontal loads while columns take up the vertical loads. Columns, beams and braces are usually made of steel, sometimes steel-reinforced concrete and occasionally of reinforced concrete.

The vertical elements connecting the floors of the building together with vertical braces form a rigid system under the action of horizontal forces. The axes of the braces must pass through the central axis of the main vertical elements – posts and columns. The horizontal braces provide the formation of hard disks in buildings, which distribute external forces among the elements, reduce bending moments, and prevent both the framework torsion and deplanation of the structural elements.



a) *b)*

c) *d)*

Fig. 11. Vertical braces of high-rise building's frameworks: a – external; b – external combined; c – internal combined; d – internal hydraulic

Usually the diagonal braces have a small cross-section area and can be placed within the partition structure or behind the facing (Fig. 11).

Since horizontal loads are cyclic by their nature, the vertical braces are under either the tensile or the compressive stresses. The reinforced concrete braces have a low bearing capacity under the tensile stresses. Therefore, steel and composite braces are used most commonly in construction. On the other hand, buckling of steel braces is a critical factor for the whole structure stability. So, the cross-section of steel braces must be increased to avoid the buckling collapse.

Usual steel reinforcing rods under the action of cyclic loads behave asymmetrically: on one hand, under the action of tensile stresses, they have high elongation due to the steel plasticity, and, on the other hand, their efficiency is limited by their buckling under the action of compressive stresses. The crippling phenomenon affects the cyclic reaction of the element causing the cyclic degradation of its bearing capacity.

The hydraulic braces characterized by a very high tensile property and energy absorption, can be used to reduce horizontal loads. Such braces are ideal for reinforcing the frame structures. The bolted or friction joints are used predominantly in erection joints (Fig. 12).

a) *b)* *c)*

Fig. 12. Types of brace joints:
a - welded; b - bolted; c - a pin-eye

A special advantage of hinged and welded joints is that they can be connected with existing beams, columns and joint straps without any problems. The bolted joint begins to take up loads after installing several bolts enabling you in such a manner to control the correctness of the joint geometry during its assembling.

Welded joints become more effective in case bolted joints are complicated with a great variety of components (many bolts, large joint straps). A recently introduced practice in the high-rise housebuilding is to use buckling restrained braces. Such braces represent a steel plate treated by specialized coating to reduce friction. This steel plate is placed inside a steel closed casing filled with concrete (Fig. 13).

Fig. 13. Buckling restrained brace

In such braces the longitudinal tensile forces are taken up by steel plate only. The longitudinal compressive forces are taken by steel casing to avoid the brace's buckling. Such design feature enables to ensure the similar strength and plasticity characteristics under both the tensile and compressive forces. The stiffness and increased cross-sectional area of the extreme sections provide elastic work of braces, while the central part provides their plasticity.

The frameworks with buckling restrained braces increase significantly the building's seismic stability. However, the assembly joints of increased stiffness (Fig. 14, a) may fail caused by buckling of the connecting plates and lead to the brace's failure as well. (Fig. 14, b).

a) b) c)

Fig. 14. The brace joints:
a – rigid joint; *b* – buckling of rigid joint; *c* – flexible joint of "*Scorpion*" type

To solve this problem the flexible joint of "*Scorpion*" type is used. The CAST CONNEX® Scorpion joint was developed at Toronto University to increase the seismic efficiency of the concentric frame-braces skeletons.

The design of "Scorpio" type joint (Fig. 14, c) consists of two cast steel connectors. Each connector consists of a bracket and a series of fingers of plastic and viscous steel grades. The fingers of both connectors are fastened with bolts to the steel plate at the intersection of the column and beams. The energy dissipation occurs due to bending plasticity of connecting fingers.

4. Conclusions

Summarizing the structural systems development of high-rise buildings in recent years, it is possible to note their main features:

- application of three main structural systems: tube, box, tube-box and variants of their combination;
- creation of new structural system - a mega-space frame;
- use of a diagonal lattice as a bearing element of the outer shell;
- introduction of systems: active, resonant, and frictional oscillation suppression;
- introduction of design techniques for effective taking up of wind loads by structural system of buildings - outrigger structures;
- use of double ventilated facade.

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Конструктивні схеми багатоповерхових будівель

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Стаття присвячена актуальним питанням дослідження конструктивних схем багатоповерхових будівель. Проектування висотних будівель будь-якого призначення починається з вирішення основного завдання – вибору конструктивної системи виходячи з функціонально-технологічних вимог. Вибір конструктивної системи визначає роль кожного несучого конструктивного елемента в об'ємно-просторовій структурі будівлі. Умовно всі конструктивні системи можна поділити на основні чотири типи: тип I – каркасна; тип II – каркасна з діафрагмами жорсткості; тип III – стовбурна; тип IV – коробчаста (оболонкова). Комбіновані схеми мають більшу конструктивну гнучкість завдяки можливості розподілу частин зусиль за рахунок змінної жорсткості несучих елементів. Відповідно до розподілу навантажень, в'язі висотних будівель. поділяють на горизонтальні та вертикальні. Горизонтальні забезпечують утворення в висотних будівлях жорстких дисків, які розподіляють зовнішні силові дії між елементами, перешкоджають закручуванню каркаса, виходу із площини елементів і зменшують згинальні моменти. Вертикальні в'язі надають жорсткість при дії горизонтальних навантажень вертикальним елементам будівлі, які з'єднують диски перекриттів.

Ключові слова: конструктивні схеми, багатоповерхові будівлі, каркаси висотних споруд, рамні системи

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Конструктивные схемы многоэтажных зданий

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Статья посвящена актуальным вопросам исследования конструктивних схем многоэтажных зданий. Проектирование высотных зданий начинается с решения основной задачи – выбору конструктивной системы исходя из функционально-технологическихт ребований. Выбор конструктивной системы означает роль каждого несущего конструктивного элемента в объемно-пространственной структурездания. Условно все конструктивные системы можно разделить на основные 4типы: тип I – каркасная; тип II – каркасная с диафрагмами жёсткости; тип III – столбчастая; тип IV – коробчастая (оболочка). Комбинированные схемы имеют большую конструктивную гибкость за счет возможности распределени частей усилий за счет изменяемой жёсткости несущих элементов. В соответствиис распределением нагрузок, связи высотных зданийподразделяются на горизонтальные и вертикальные. Горизонтальные связи обеспечуют создание в высотных зданиях жёстких дисков, которые распределяют внешние силовые воздействия между элементами, препятствуют закручуванню каркаса, выходу из плоскости элементов и уменьшают изгибающие моменты. Вертикальные связи дают жёсткость при действии горизонтальных нагрузок вертикальным элементам зданий, которые соединяют диски перекритий.

Ключевые слова: конструктивные схемы, многоэтажные здания, каркасы высотных сооружений, рамные системы

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