Effective reinforced concrete structures of monolithic frame buildings and structures

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Abstract. The purpose of the research is to analyze various types and kinds of building supporting frame structures, taking into account the construction conditions of Mexico, as well as a calculated assessment of structural solutions for the buildings and structures’ frame for various purposes with the determination of effective solutions.

Introduction
Construction efficiency improvement is largely related to the issues of reducing the building frame construction cost.
Currently, the main task of construction companies is to erect the high-quality buildings at the lowest cost, satisfying all the people’s needs.
Reinforced concrete slabs make the most significant contribution to the building frame construction cost.
There are several types of slabs used in construction - the monolithic single-layer, cellular-lattice, ribbed and precast-monolithic slabs.
The simplest design is a monolithic single-layer slab.
The materials of which this system consists of are concrete and reinforcing steel. Usually double steel reinforcement is used, one mesh at the bottom and another mesh at the top. This distribution is due to the moments, both positive and negative, in both directions.

Lightweight slabs
This type of slab has the main advantage that a part of its volume is occupied by lighter materials, heavy concrete does not occupy the entire thickness of the slab. Filling is performed with inserts such as pumice or polyurethane elements, as well as the elements that serve as a temporary formwork.

Cellular lattice plate
This system consists of ribbed beams that connect the supports and provide greater rigidity. The materials that make up this system are: steel reinforcement, lightweight core and concrete shell.
Monolithic slab systems, depending on their aspect ratio, determine the load transfer and they are classified as unidirectional or bi-directional:
- Unidirectional plate.
When the spans ratio, long side to short side is larger 2>x (L / S> 2), the plate will work in the short direction [1]. In this system, it is easy to visualize the loads distribution from the slab to the secondary beams, from them to the main beams and then to the columns.
- Bi-directional plate.

Bi-directional slabs are known as the slabs in which, due to their geometry and support type, bending stresses are created in two orthogonal directions, that is, when the slab is supported on four sides and bending stresses are developed in both directions. To resist these bending forces, the slab must be reinforced in both directions.

Currently, there are several floor systems, however, with such a wide variety, it is difficult to choose the most suitable system [2]. This article discusses the main characteristics, properties, and advantages of several types of slabs: the most common is a homogeneous monolithic slab, as well as the types of slabs offered by the authors - wafer slabs and precast monolithic slabs with shaped holes.

**Wafer plates**

This slab type is made on the basis of the crossbeams’ network that form a mesh, leaving gaps that can be filled with blocks of materials, the density of which does not exceed 900 kg/m$^3$.

The design of these slabs is reminiscent of a simple concrete prefabricated elements’ combination in the form of boxes with reinforced concrete ribs, which form a mesh surrounding the precast blocks on all four sides. They can also be temporarily placed as formwork for the manufacture of beams, prefabricated plastic boxes, which, after the concrete has gained strength, should be removed and rinsed for later use. The result is a lightweight slab of uniform thickness.

The advantages of such structures are: bending and shear stresses are relatively small and spread over large areas. This makes possible the partitions’ free placement. Good resistance to strong concentrated loads, as very large stripes are distributed over adjacent ribs in both directions. Wafer boards are lighter and more rigid than the solid boards, concrete consumption is reduced. In addition, the formwork service life is longer, since it only adjoins the ribs and can be used a large number of times. This cellular lattice system gives structures a pleasing lightness appearance.

The flat covering on both sides gives the structure a cleaner look and allows the floor-to-ceiling height to be used for natural light.

The surface of the slab has optimal characteristics, due to which, when finishing, the materials have good adhesion, leaving a smooth surface without cracking.

Design with an increase in spans is allowed, which means the possibility of a significant reduction in the columns’ number.

The construction of this slab type provides sound and heat insulation. They are distinguished by higher rigidity, greater stability of the dynamic loads’ perception.

These plates can be used both in low-rise buildings and in rather large ones: public buildings, schools, shopping centers, hospitals, offices, apartment buildings, warehouses, as well as industrial buildings. Reinforcement or strengthening the plates with composite materials is possible [3,4].

The main characteristics of the plate are:

- The distance between the ribs should not exceed 75 cm. The ribs’ width should not exceed 10 cm.
- The transverse reinforcement time step interval should not exceed the rib width by more than three times. The distribution footplate must be at least 3.5 cm thick and at least 1/12 of the distance between the supports [5].

![Figure 1. Longitudinal section of a wafer plate](image-url)

**Precast monolithic slabs with shaped holes**
Such structures consist of precast beams, which are made of prestressed concrete and include voids of various configurations, within which the lighting elements can be placed.

Various parameters of voids for different design modifications are proposed. They can also be manufactured with a plug to prevent concrete from entering the holes.

It is a lightweight structure that reduces stress on the underlying structure.

In accordance with this technique the beams, which are combined with other structures and constitute a common prefabricated floor system, are produced.

These beams are lightweight, resulting in significant savings in transport and handling costs. They can have different widths and lengths, depending on the conditions of their operation, as well as on the occupied areas [6].

![Figure 2. Longitudinal section of a precast-monolithic slab with figured voids](image)

**Columns** - these are the vertical elements that absorb compressive and bending forces and are responsible for transferring all loads from the structures to the foundation. They are one of the most important elements of frame buildings, therefore, the improvement of their structures requires special attention.

Columns can be divided into two categories: short (rigid) columns, for which the strength is determined by the materials’ strength and the cross-section geometry; and flexible columns, for which strength can be significantly reduced due to lateral deflections.

Flexible columns are more common today as due to the wider use of high-strength materials; it is possible to reduce the elements’ cross-sections dimensions.

The following column types are offered: Composite Columns, High Strength Concrete Columns, Prestressed Concrete Columns.

**Composite Columns**

The axial compressive strength of a reinforced concrete element is generally derived from the contribution of four factors: the concrete core, the longitudinal reinforcement, the higher strength concrete shell and the spiral reinforcement. The last two factors cannot exist simultaneously, since the spiral reinforcement is noticeable only when the concrete of the shell has low strength indicators. The contribution of both the core and the shell to the resistance provided by concrete can be roughly estimated as the product of 85% of the control cylinder resistance with the corresponding area and the contribution of longitudinal steel as the product of the yield strength with area.

If we take into account the concrete core and column shell strengths, we can make the columns work more efficiently.
Figure 3. Column section with a weaker core

With the help of concrete with low resistance in the core and concrete with high resistance in the outer zone, which prevents the transverse deformations’ development, the resistance of the concrete located in the core increases by 1.5 times. This type of column offers great savings.

Figure 4. Column section with a weaker core

$H$ – height between plates
$S$ – time step interval of structural reinforcement
High-strength concrete columns
Currently, there are high-strength concretes of class B100 and more. Although today there is no exact definition of high-strength concrete, so if the concrete class is more than B40, then we can assume that it already has increased strength [7,8].

![Stress-deformation curve](image)

**Figure 5.** Relationship between stresses and strains of different concrete types

The shape of the stress-strain curve changes with the concrete resistance. It can be seen that with an increase in resistance, the graphs become closer to a straight line in the initial part and their descending branches become more pronounced, the descending section of the diagram decreases significantly, while the deformation corresponding to the maximum stress, the greater, the greater the resistance. Concrete becomes more brittle and breaks down quickly. This reduces such structures’ reliability and requires the appropriate reduction factors’ introduction.

The studies have shown the cost-effectiveness that high-strength concrete provides in high-rise buildings. In buildings of low to medium height, in addition to reducing the size of the columns and obtaining a stronger material, the use of high-strength concrete has been shown to be beneficial in terms of lateral stiffness.

![Cross-section](image)

**Figure 6.** Cross-section of high-strength column
High strength concrete columns are classified into:
- high strength concrete columns under axial loads;
- high-strength concrete columns under the combined action of axial load and bending moment.

In the columns experiencing axial loads, the effect of concrete is of great importance. The low permeability of high strength concrete leads to shrinkage deformations in the concrete of the outer shell, while the core remains relatively moist. As a result, tensile stresses arise in the concrete shell.

**Prestressed concrete columns**

Prestressed concrete columns are very effective because they have high strength, high load resistance and are able to withstand significant tensile stresses. Prestressed columns are not as widely used today as prestressed beams and slabs, which are the flexural elements. It may seem irrational to cause pre-compression of an element that will subsequently work in compression under operational loads in columns. However, with a sufficiently high flexibility of the elements, prestressed columns become effective due to their high buckling resistance [8]. The ratio of load and moment makes it possible to determine the so-called interaction diagram, which is very important, since it indicates the failure of the column section at any ratio of the load moment [9]. The following hypotheses are proposed to define this diagram:
- strain distribution in concrete varies linearly within the compression zone.
- stress strain diagrams for concrete and steel are known.
- the section destruction does not occur until the relative deformations in concrete in the extreme fiber reaches 0.003.

![Figure 7. Columns with local prestressing of reinforcement: a) monolithic middle part; b) prefabricated middle part](image-url)

In compression with a small eccentricity, fracture occurs as a result of the materials strength exhaustion [9]. A flexible column is an element subjected to combined loads and stresses (compression and bending), which can be deformed not only in the longitudinal but also in the transverse direction and creates additional moments. Consequently, such columns are more likely to fail due to instability after reaching the maximum load before concrete failure, that is, the behavior of the structure is no longer controlled by the material failure. In accordance with the above-mentioned, it is expected that the relative deformations caused by the breaking load on the most compressed surface of concrete are less than 0.003.
The procedure for calculating columns is as follows:
1. To determine the axial load and maximum moment and calculate the total eccentricity.
2. To accept the cross-section (type and dimensions).
3. To take the number of prestressed reinforcements.
4. We assume that the deformations in the most stretched fibers are equal to the deformations during the repayment of the prestress forces.
5. To accept the service loading condition in the following parameters: net compression, compression plus bending, net bending and buckling condition.
6. To find the corresponding values of axial load and bending moment for the intended section.

Summary
Bi-axial - Corner columns of buildings are the structural elements subjected to axial loading around the X-axis and Y-axis. In addition, non-axial loading occurs due to the unbalanced loads in the adjacent spans and almost always in the bridge supports. This leads to the fact that the specified elements are affected by the moment MXX and the moment MYY. In addition, the neutral axis of the section is inclined with respect to the cross section and the inclination angle depends on the failure moments interaction and the total load.

The proposed solutions for the structures of frame buildings will significantly increase efficiency and reduce construction costs.

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