x-like biaxial voided concrete slab

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Abstract In the modern world, progress and development is a constant process. In order to build buildings with extraordinary and complex geometric shapes, existing building materials are improved and new materials are invented constantly, construction technologies are improved, as well as daily reporting programs are being refined, all this gives us new opportunities to design buildings with complex architectural shapes and come up with out of ordinary construction solutions.

One of the main structural elements of modern frame buildings is considered to be a slab, which is in a difficult stress-deformed state under the influence of static and dynamic loads. There are several types of slabs: conventional, flat, with a capital, waffle and voided slabs [1, 2]. The present paper discusses a certain type of voided slabs, more precisely, voided box-like biaxial slab. The structural elements of this type of slab create a unified rigid system. The structure is examined as a stand-alone structure as well as a part of the building. The study takes into account static and dynamic loads as well as seismic impacts in the form of an accelerogram. The paper emphasizes the advantages of using this type of rigid slabs in large span structures.

Key words: Large span reinforced concrete slabs, Voided slab, U-Boot, Cobiax, FEM Ansys APDL.

Introduction

Reinforced concrete box-like biaxial slab is a complex structure consisting of 3 load-bearing elements. These elements are: main and auxiliary vertical stiffness ribs, bottom and top binding slabs (Figure 1, Figure 2).

Reinforced vertical stiffness ribs are placed in the plan perpendicular to each other, the gaps between which are filled with a special lightweight, construction foam, or similar type of material. The lower and upper planes of the ribs are bonded with thin reinforced slabs. Reinforced slabs distribute the load on the supporting thin, vertical ribs, which in turn transfer the load to the main thick vertical ribs, while the main ribs are directly connected to the vertical load-bearing elements of the building - columns and pylons.

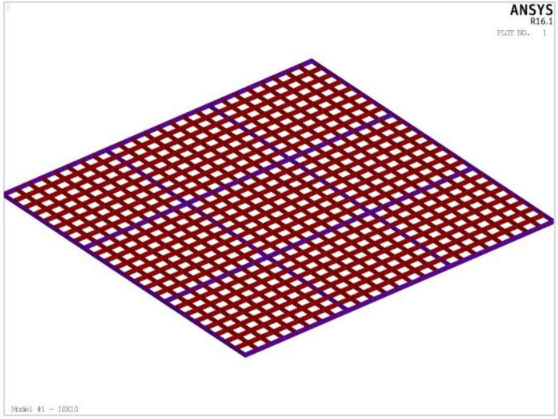


Fig. 1. Arrangement of main and auxiliary ribs

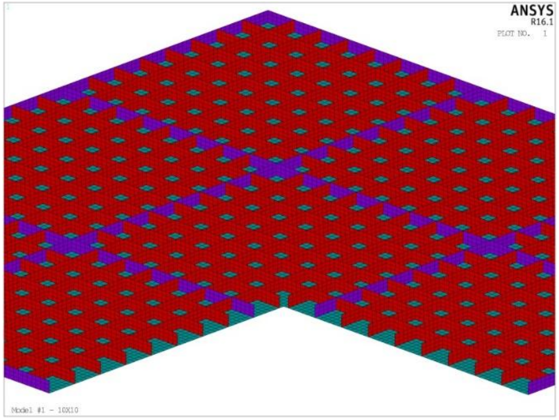


Fig. 2. Section of a box-like slab (only lower binding slab is visible)

The box-like structure allows us to get a rigid and light slab, as well as increase the size of the building span. The bottom surface of the box-like slab is also flat, giving architects and designers more opportunity for free planning.

In 2011, a patent was issued in Georgia for a similar type of slab, "Monolithic reinforced concrete skeleton" (patent number: U 2011 1651 Y) [3]. The author of the paper is also a co-author of the patent.

There are several systems of flat and light slabs in the world: U-BOOT BETON (Figure 3), U-BAHN BETON systems created by the Italian company DALIFORM GROUP [2, 4]

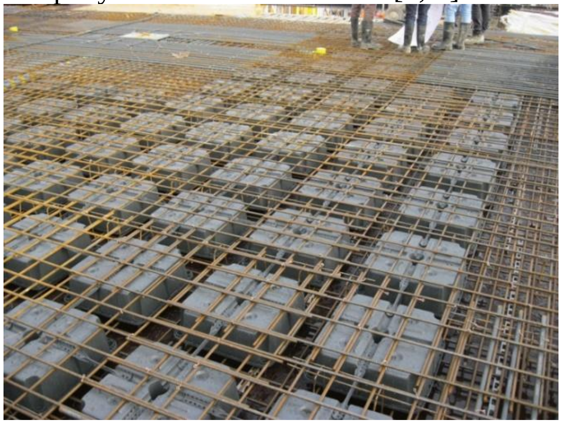


Fig. 3. U-BOOT BETON system

Also Cobiax SL (Figure 4), Cobiax EL systems created by the German company COBIAX. The main purpose of these systems is to lighten the structure of the slab [2, 5].

Fig. 4. Cobiax SL system

In the above-mentioned systems, the gaps are obtained from factory-made plastic products whose length and width or diameter do not exceed 52 cm, since these systems do not have an organized layout of load-bearing vertical ribs.

In contrast to these systems, our box-shaped slab ribs allow not only to alleviate the biaxial slab, but also to transfer the forces acting on them in an organized manner to the columns.

Main Part

Software complex Ansys Mechanical APDL. The Ansys finite element solvers enable a breadth and depth of capabilities unmatched by anyone in the world of computer-aided simulation. Thermal, Structural, Acoustic, Piezoelectric, Electrostatic and Circuit Coupled Electromagnetics are just an example of what can be simulated. Regardless of the type of simulation, each model is represented by a powerful scripting language the Ansys Parametric Design Language (APDL) [6, 7, 8].

APDL is like software; written on Fortran, in which we can enter thousands of commands of the analysis software Ansys (some commands represent an independent small algorithm). The software written using APDL allows us to calculate and investigate buildings of many shapes and sizes, where these types of slabs are used (different size and number of slabs, buildings of different heights and floors, different loads and their combination, different number of ribs in spans, different size of ribs, different materials, etc.). It is possible to obtain different types of solutions considering static, dynamic (including seismic) impacts, as well as to manage the inclusion of different methods in dynamics tasks (options for using spectral theory, different schemes of direct integration, use of different types of dimmers, etc.).

Using APDL we have created an analytical model of box-like biaxial slabs, therefore, with minimal intervention (modification) we can create and calculate models with different geometric shapes and sizes.

The structural elements of box-like biaxial slabs are approximated by the finite elements of the membrane represented in the program Ansys under the name Shell 181.

SHELL181 is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node (Figure 5). SHELL181 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. In the element domain, both full and reduced integration schemes are supported. SHELL181 accounts for follower (load stiffness) effects of distributed pressures. SHELL181 can be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory) [6, 7, 8, 9].

The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small.

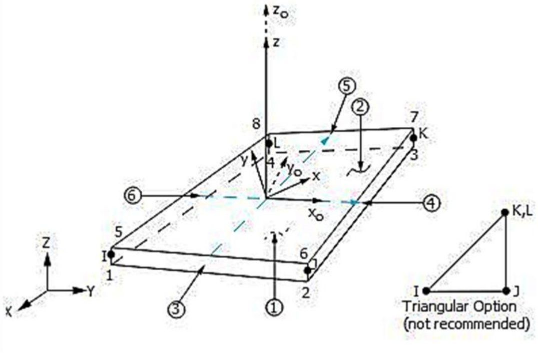


Fig. 5. Shell 181 Geometry

The element stress resultants (N11, M11, Q13, etc.) are parallel to the element coordinate system, as are the membrane strains and curvatures of the element. The program calculates moments (M11, M22, M12) with respect to the shell reference plane. By default, ANSYS adopts the shell midplane as the reference plane (Figure 6) [6, 7, 8].

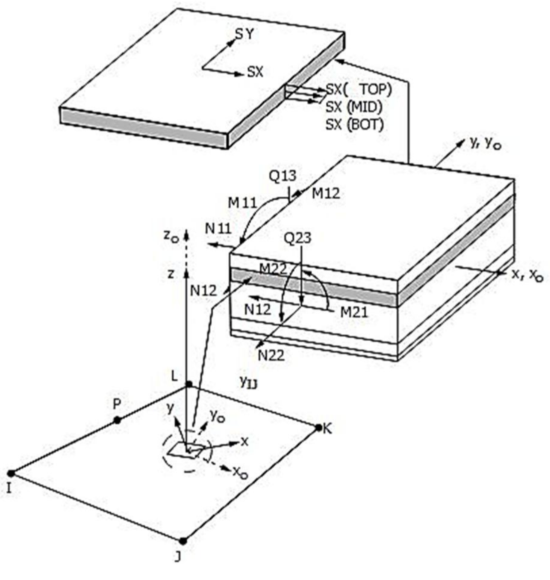
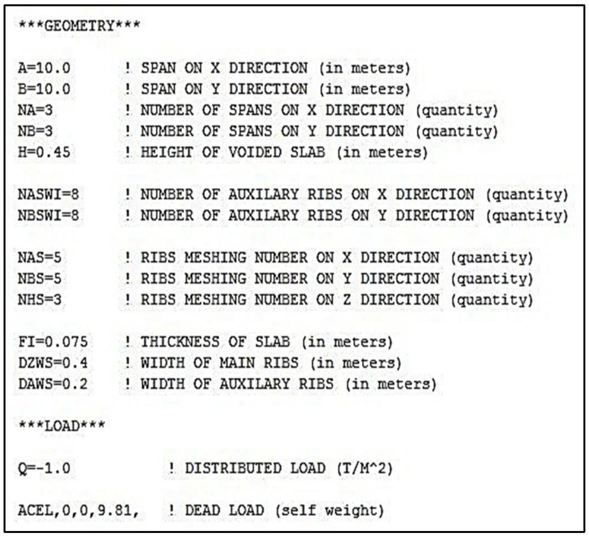


Fig. 6. Shell 181 Stress Output

The APDL model of box-like slab. Using APDL, we created an analytical model of box-like slabs. The model takes into account the geometric parameters of the structure (the size of the span, the number of ribs in both horizontal directions, the number of ribs, etc.), changing these parameters allows us to get a structure with various new geometric shapes.

The text file of the "software" written by us consists of more than 300 lines and dozens of different commands. Figure 7 shows a small fragment of a text file showing the initial variable parameters of the slab, the characteristics of the material used the creation of the joint's restraints and the modeling of an evenly distributed load on the surface of the box-like slab.



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***GEOMETRY***

A=10.0       ! SPAN ON X DIRECTION (in meters)
B=10.0       ! SPAN ON Y DIRECTION (in meters)
NA=3         ! NUMBER OF SPANS ON X DIRECTION (quantity)
NB=3         ! NUMBER OF SPANS ON Y DIRECTION (quantity)
H=0.45       ! HEIGHT OF VOIDED SLAB (in meters)

NASWI=8      ! NUMBER OF AUXILARY RIBS ON X DIRECTION (quantity)
NBSWI=8      ! NUMBER OF AUXILARY RIBS ON Y DIRECTION (quantity)

NAS=5        ! RIBS MESHING NUMBER ON X DIRECTION (quantity)
NBS=5        ! RIBS MESHING NUMBER ON Y DIRECTION (quantity)
NHS=3        ! RIBS MESHING NUMBER ON Z DIRECTION (quantity)

FI=0.075     ! THICKNESS OF SLAB (in meters)
DZWS=0.4     ! WIDTH OF MAIN RIBS (in meters)
DAWS=0.2     ! WIDTH OF AUXILARY RIBS (in meters)

***LOAD***

Q=-1.0            ! DISTRIBUTED LOAD (T/M^2)

ACEL,0,0,9.81,    ! DEAD LOAD (self weight)
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Fig. 7. Fragment from the APDL text file

We examined about 70 different models of box roofing. In this paper we discuss 3 models with different geometric shapes.

Model #1 is a 3-3 span box-like slab in the longitudinal and transverse directions, the length of each span is 10 meters, the height of the structure is 45 cm, the thicknesses of the main and auxiliary stiffness ribs are 40 and 20 cm, respectively, the thickness of the thin binding slabs is 7.5 cm. The pitch of the auxiliary stiffness ribs is 1.25 m. The material used is concrete grade B25, taking into account the model's own weight and evenly distributed static load on the surface – 1.0 t / m^2. The model rests freely on 16 supports.

Results obtained from the report: Maximum deformation of the structure - 8.5 mm in the edge spans of the structure (Figure 8); Figure 9 shows the distribution of the main tensile stresses (σ1)

the maximum value was generated at the support, in the upper part of the rib – 9.274 MPa (945.7 t / m^2); Figure 10 shows the distribution of the main compressive stresses (σ3) of the main stiffness rib, the maximum value was generated at the support, in the lower areas of the rib – 16.266 MPa (1658.6 t / m^2); Figure 11 shows the distribution of the main tensile stresses (σ1) of the auxiliary stiffness rib, the maximum value was generated at the support, at the top of the rib – 6.591 MPa (672.1 t / m^2); Figure 12 shows the distribution of the main compressive stresses (σ3) of the auxiliary stiffness rib, the maximum value was generated at the support, in the lower areas of the rib – 6.324 MPa (644.9 t / m^2).

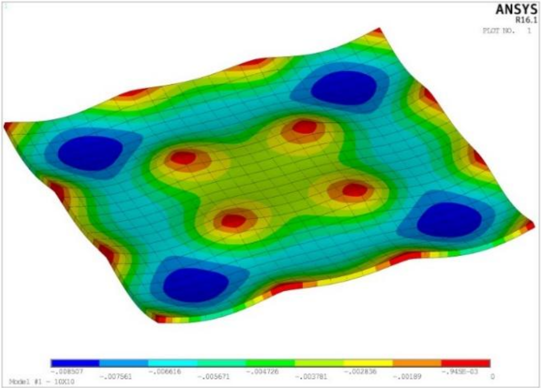

Fig. 8. Maximum deformation of the structure - 8.5 mm (scale is given in meters)

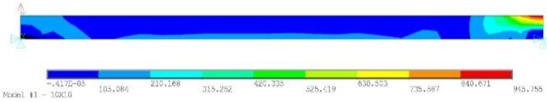

Fig. 9. Distribution of the main tensile stresses of the main stiffness rib (σ1 t / m^2). Maximum value – 9.274 MPa (945.7 t / m^2)

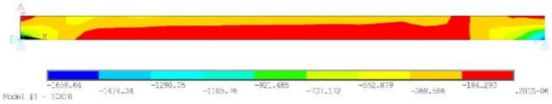

Fig. 10. Distribution of the main compressive stresses of the main stiffness rib (σ3 t / m^2). Maximum value – 16.266 MPa (1658.6 t / m^2)

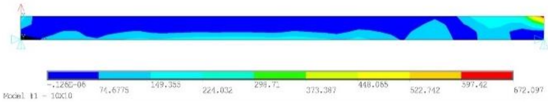

Fig. 11. Distribution of main tensile stresses of auxiliary stiffness rib (σ1 t / m^2). Maximum value – 6.591 MPa (672.1 t / m^2)

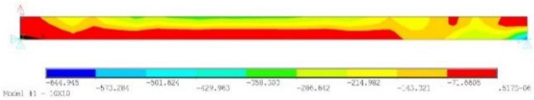

Fig. 12. Distribution of main compressive stresses of auxiliary stiffness rib (σ3 t / m^2). Maximum value – 6.324 MPa (644.9 t / m^2)

Forms and frequencies obtained by modal analysis of box-like slabs: Form I with a frequency of 9.15 Hz (Figure 13); II and III symmetric forms with frequencies – 9.479 Hz (Figure 13); Form IV with frequency – 9.553 Hz (Figure 14); Form V with frequency – 9.649 Hz (Figure 14).

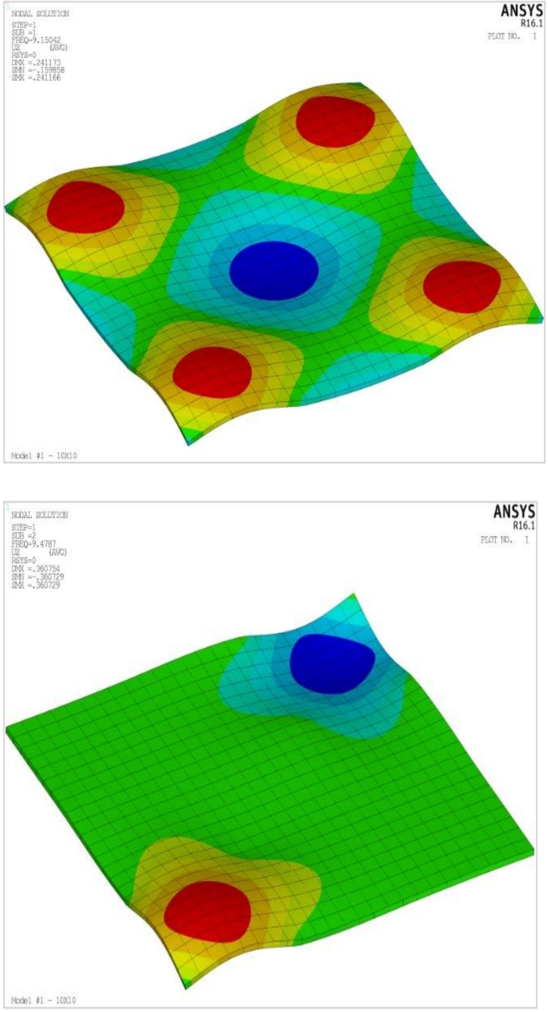

Fig. 13: I and II Forms and Frequencies of Model #1 slab (9.15 and 9.479 Hz)

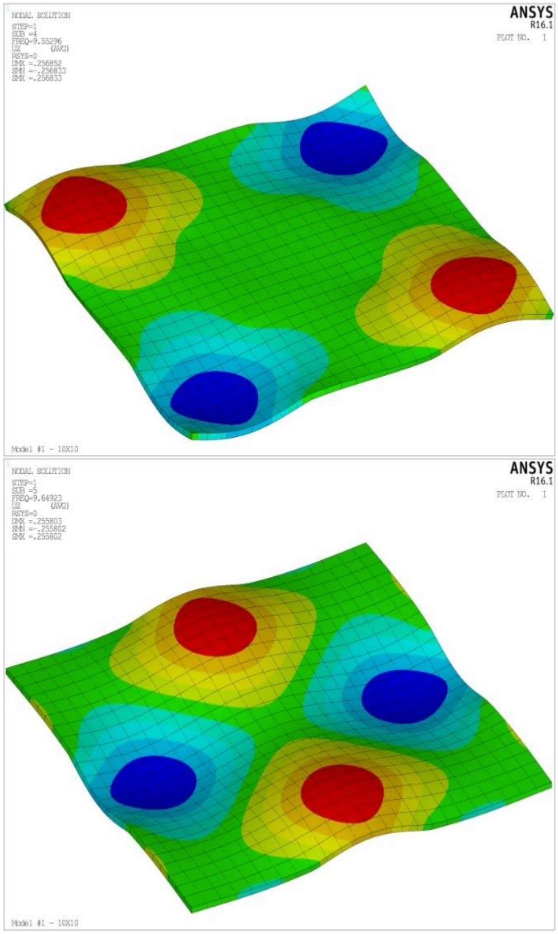

Fig. 14. IV and V Forms and frequencies of model #1 slab (9.553 and 9.649 Hz)

Model #2 is a 3-3 span box-like slab in the longitudinal and transverse directions, the length of each span is 12 meters, the height of the structure is 60 cm, the thicknesses of the main and auxiliary stiffness ribs are 40 and 20 cm, respectively, the thickness of the thin binding slabs is 7.5 cm. The pitch of the auxiliary stiffness ribs is 1.20 m. The material used is concrete grade B25, taking into account the model's own weight and evenly distributed static load on the surface – 1.0 t / m^2. The model rests freely on 16 supports.

Results obtained from the report: Maximum deformation of the structure – 10.2 mm in the edge spans of the structure. The distribution of the main tensile stresses (σ1) the maximum value was generated at the support, in the upper part of the rib – 10.116 MPa (1031.5 t / m^2); The distribution of the main compressive stresses (σ3) of the main stiffness rib, the maximum value was generated at the support, in the lower areas of the rib – 20.934 MPa (2134.7 t / m^2); The distribution of the main tensile stresses (σ1) of the auxiliary stiffness rib, the maximum value was generated at the support, at the top of the rib – 8.177 MPa (833.8 t / m^2); The distribution of the main compressive stresses (σ3) of the auxiliary stiffness rib, the maximum value was generated at the support, in the lower areas of the rib – 7.640 MPa (779.1 t / m^2).

Forms and frequencies obtained by modal analysis of box-like slabs: Form I with a frequency of 7.970 Hz; II and III symmetric forms with frequencies – 8.247 Hz; Form IV with frequency – 8.303 Hz; Form V with frequency – 8.340 Hz.

Model #3 is a 3-3 span box-like slab in the longitudinal and transverse directions, the length of each span is 14 meters, the height of the structure is 60 cm, the thicknesses of the main and auxiliary stiffness ribs are 40 and 20 cm, respectively, the thickness of the thin binding slabs is 7.5 cm. The pitch of the auxiliary stiffness ribs is 1.27 m. The material used is concrete grade B25, taking into account the model's own weight and evenly distributed static load on the surface – 1.0 t / m^2. The model rests freely on 16 supports.

Results obtained from the report: Maximum deformation of the structure – 18.5 mm in the edge spans of the structure. The distribution of the main tensile stresses (σ1) the maximum value was generated at the support, in the upper part of the rib – 14.342 MPa (1462.5 t / m^2); The distribution of the main compressive stresses (σ3) of the main stiffness rib, the maximum value was generated at the support, in the lower areas of the rib – 28.466 MPa (2902.7 t / m^2); The distribution of the main tensile stresses (σ1) of the auxiliary stiffness rib, the maximum value was generated at the support, at the top of the rib – 11.614 MPa (1184.3 t / m^2); The distribution of the main compressive stresses (σ3) of the auxiliary stiffness rib, the maximum value was generated at the support, in the lower areas of the rib – 10.769 MPa (1098.1 t / m^2).Forms and frequencies obtained by modal analysis of box-like slabs: Form I with a frequency of 5.938 Hz; II and III symmetric forms with frequencies – 6.162 Hz; Form IV with frequency – 6.210 Hz; Form V with frequency – 6.266 Hz.

Conclusions

The ratio of the maximum deformations obtained to the size of the span is 1/1150 for Model # 1, 1/1150 for Model # 2, and 1/760 for Model # 3. Frequencies for all three models exceed 6 Hz. Consequently, the box-like slab is a rigid structure. By increasing the concrete grade, the height of the structure and the thickness of the ribs it is possible to balance the main stresses induced in the ribs. Based on the above-mentioned results, it is interesting to see how box-like slab works in multi-story buildings.

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