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# SIMULATION OF 3D MODELED BOX CULVERT AND SEARCH THE MAXIMUM AND MINIMUM VALUES OF THE PRINCIPAL STRESSES

*This article describes the results of finite element analysis of concrete box culvert. The principal stress state of the culvert was studied before and after backfilling, as well as in cases of water-filled and empty, and indicated the value and location of the maximum and minimum principal stresses in the 3D body of the culvert. In this work we tried to find the critical stressed elements and critical load combination for box culvert from point of view of principal stresses.*

***Keyword:*** *Box culvert, 3D modeling, principal stress.*

## Introduction

The structures to accomplish water flow across the road are called culverts, depending on their span, which in turn depends on discharge is divided into two categories: small and large. It is well known that box culverts are generally constructed under roads which come in the way of natural flow of storm water[1]. The culvert covers can mainly be of two types, namely, box or slab. The box is one which has its top and bottom slabs monolithically connected to the vertical walls. In case of a slab culvert the top slab is supported over the vertical walls (abutments/piers) but has no monolithic connection between them.

As known, the culverts are an integral part of infrastructure of any modern city, at the same time play an important role in the construction of roads and highways. [2]

In the last decade, box culverts were extensively used in waterways in Kurdistan as very important part of infrastructure of cities.

In the 2010s there was a significant boom in box culvert bridge construction in many cities, and roads. These culverts have different configurations and their analysis and design procedure are given from previous Iraqi typically structures, with the average age of 30-40 years.

There is many manuals and guide for analysis and design of underground structures, in general, and box culvert, in particular [3, 4], but purpose of this work is more detailed and comprehensive study of the stress state of these structures.

Based on the above it was decided in this article investigate the most vulnerable places in terms of principal stresses in the box culvert.

The study aim is investigation of the feasibility and effectiveness of placement of reinforcement to reduce cracking in the stress concentrated zones from point of view of principal stresses, thus increasing the service life of box culvert.

The visually observation of many box culverts across roads in different geographic zones in Kurdistan have become a good stimulus and the scientific basis for this article Fig.1.

Fig.1.Existing box culvert.

Box culverts are economical due to their rigidity and monolithic action and separate foundations are not required since the bottom slab resting directly on the soil, serves as raft foundation. For small discharges, single celled box culvert is used and for large discharges, multi-celled box culverts can be employed.

 

One of the conditions for ensuring the durability of concrete box culverts is the high crack resistance of the material [5] which can be achieved by the full study of the stress state of the entire body of culvert. During the analysis of engineering structures do not need to define the stresses in all planes, passing through a given point or particle, it is sufficient to know the extreme (i.e. the maximum and minimum) values.

## 3D Box Culvert Modeling

Proceeding from the above and for a more realistic approach of the computer modeling of structure, it was decided to create three-dimensional model of box culverts and study their stress state.

3D modeling helps to comprehensively study the location of the maximum and minimum principal stresses which will develop the concepts of the kinetics of fracture of box culvert operated under different loading conditions.

The concept of principal stress is extremely important for understanding how and where cracks occur in the body of 3D model of box culverts by maximum normal stresses.

We emphasize that it is possible to find the principal stresses on the basis of the geometries, Mohr's circle, tensors, as well as lots of algebra.

We propose in this paper to create a three-dimensional model of the box culvert and applied the all actual loads, then find all post analysis parameters, including required values of the principal stresses.

In each point of the stressed body there is a system of global axes x, y, z and other three axes along which shear stresses are zero. These axes are called the principal axes, corresponding mutually perpendicular plane called the principal planes and normal stress on them reaches the maximum and minimum values, called principal stresses Fig.2.

In ascending order, these stresses represent $\sigma_1 \geq \sigma_2 \geq \sigma_3$. Then $\sigma_1$ is called the maximum principal stress (first), $\sigma_3$ the minimum principal stress (third), and $\sigma_2$ the intermediate principal stress (second). The principal stresses in 3D are the eigenvalues of the 3D stress matrix.

Research tasks and the aim of this article are to achieve the following goals:

1. Location of the maximum principal stress.
2. Location of the minimum principal stress.
3. Comparison the value and location of principal stresses between three loading conditions of analyzed box culvert.

Based on consideration of hydraulic requirements and site characteristics, the dimensions of the box culvert units were selected to be 3.6x3.6m with a wall thickness of 300mm. The model consists of a three-dimensional mesh of horizontal and vertical 8 nodes elements with thickness equal to the thickness of the box walls (300mm) Fig.3.

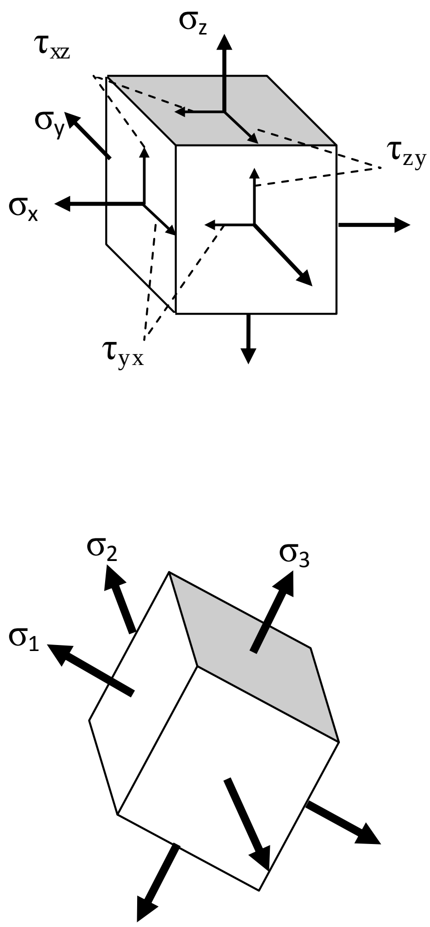


Fig.2. General and principal stress state of the 3D finite element of the box culvert.

In this work simulation of the three loading cases of the box culvert is carried out by the Commercial Simulation Package COMSOL Multiphysics.

The simulation is done in the SMM (Structural Mechanics Module), which based on the COMSOL program, as shown in Fig.3, the configuration of box culvert consists two verticals walls, and bottom and top slabs.

Our model has dimensions as shown in Fig.3, and Table-1 provides detailed information about the geometry and configuration of the model created in COMSOL.

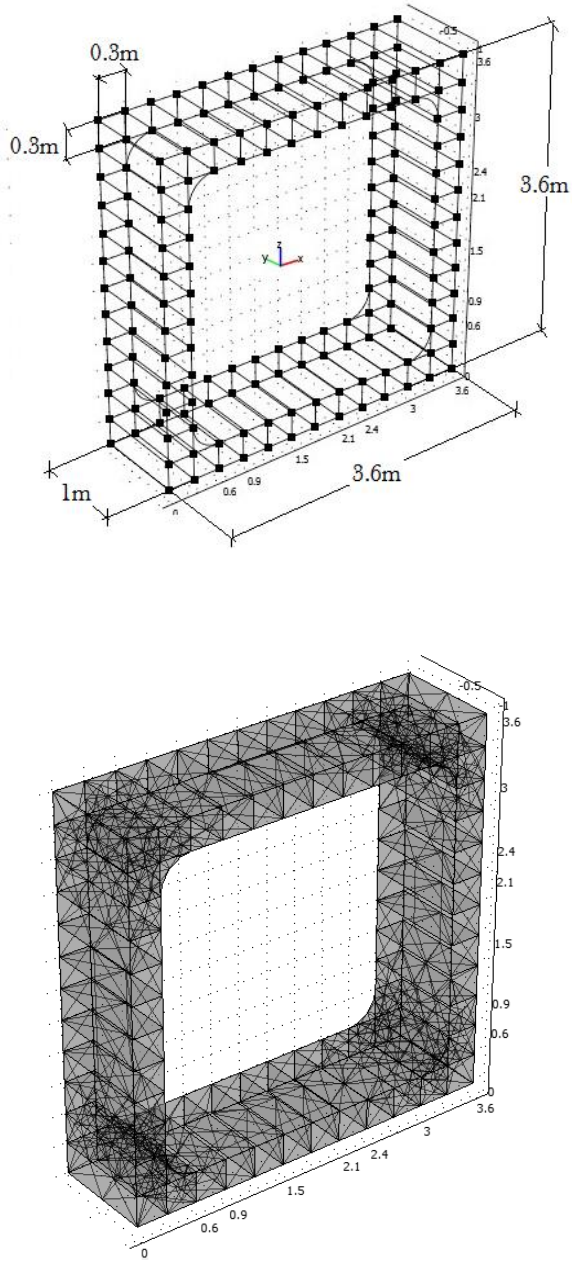


Fig.3. Dimensions of 3D modeled box culvert and meshing.

Table1- Characteristics of computer model.

| Name | Q-ty | Equation |
|---|---|---|
| Subdom. | 48 | $\nabla\cdot(-c\nabla u-\alpha u+\Upsilon)+au+\beta\cdot\nabla u=f$ |
| Boundary | 232 | $n\cdot(c\nabla u+\alpha u-\Upsilon)+qu=g-h^T\mu$<br>$hu=r$ |
| Edge | 360 | |
| Nodes | 176 | |
| Number of nodes of each element | 8 | |

This study will be based on finite element modeling and analysis of box culvert, based on the COMSOL program. The objective of finite element model is to achieve an insight on how to approach the modeling of structural mechanics of box culvert.

The structural design of the concrete box culvert comprises the detailed analysis of rigid frame for moments, shear forces and thrusts due to various types of loading conditions outlined below :

1. Uniformly distributed vertical load, represented the live load.

2. Inside pressure represented the water pressure in culvert.

3. Earth Pressure on vertical side walls.

4. Self weight of the box culvert.

An important aspect of box culvert analysis is the formulation of the loads applied to the finite element modeled structure.

Using COMSOL program we can apply loads on subdomain, boundary, edge, or point of each 3D finite element. Considering the use of box culverts we decided to apply all kinds of loads to the boundary of elements as shown in Figs.4-6.

In this paper we investigated three different types of loading. It was found that load cases the culvert may be three types: empty, full water, and full water without lateral backfill pressure.

The loading applied to the top of the box culvert, also is uniformly distributed over the entire it's bottom. This load distribution is used for dead load and live loads.

The box culvert self-weight is automatically considered by COMSOL program based on the walls and slabs thicknesses.

Figures 4-6 illustrate the load application on the boundary of the finite elements of the box culvert. The water load is applied to the model in increments at top to the bottom slab, and the backfill soil pressure is in inverse direction and increments. The backfill is the worst combination of load from zero fill to maximum height of fill as shown in Figs.4 and 5.

In order to best simulate the following three load combinations are considered [6]:

1. Self weight + live load + backfill earth pressure Fig.4.

2. Self weight + live load + backfill earth pressure + inside water pressure Fig.5.

3. Self weight + live load + inside water pressure Fig.6.

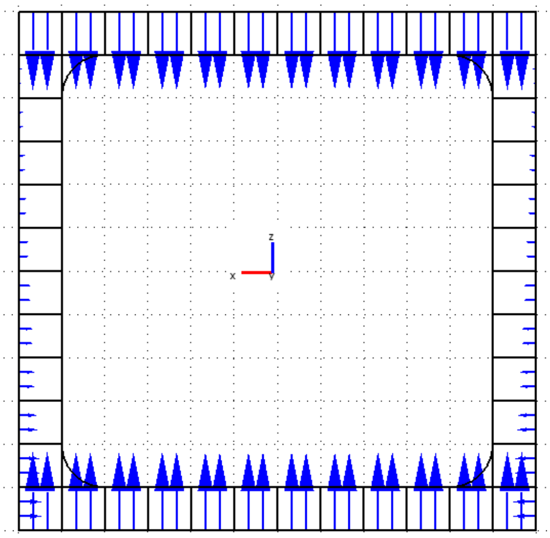


Fig.4. 2D of 1st load combination.

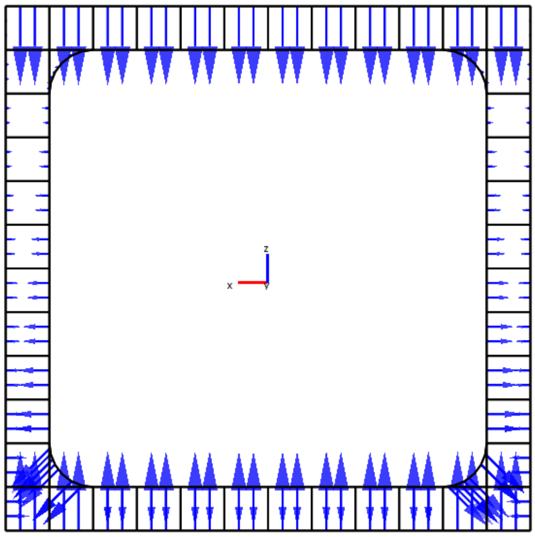


Fig.5. 2D view of 2nd load combination.

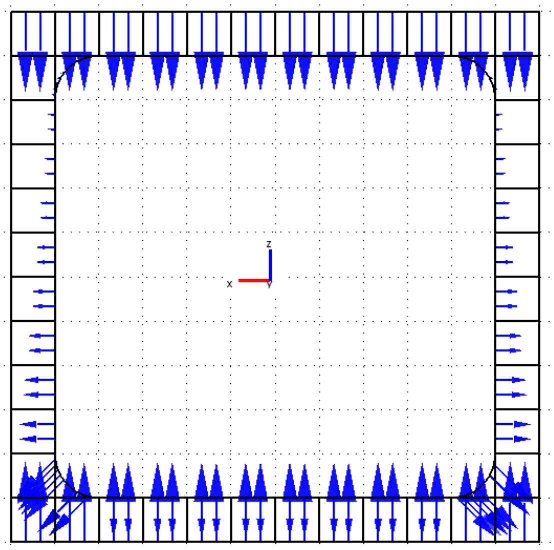


Fig.6. 2D view of 3rd load combination.

## Results and Discussion

After running the all three models the geometrically identical culverts, with the same type of finite elements as shown in Figs. 4-6, we began to study the post analyze results. The complete illustration of the distribution of principal stresses is shown in Figs. 7-9.

After looking at the calculated results, it is easy to observe a significant qualitative and quantitative discrepancy during the operation of culvert in three different phases (under different load combinations).

It is necessary to note the location of maximum and minimum principal stresses in the body of culvert during first load combination mainly is on the top slab (except $\sigma_3^{min}$), Fig.7, when the second for the second load combination the location of the all maximum and minimum principal stresses is observed on the bottom slab of the culvert Fig.8, and for the third load combination location of these stresses is the corners of culvert (except $\sigma_3^{min}$).

On the other hand, it is interesting to look at the quantitative value of these stresses that are shown in Fig.10. As seen from the diagrams (Fig.10), the values of the maximum principal stress during all load combinations are positive, when the values of minimum principal stresses for the second load combination changes the sign from negative to positive. And we note that for the third load combination $\sigma_1^{max}$, $\sigma_2^{max}$, and $\sigma_3^{min}$ reach their peak value, 5.717, 2.084, and -5.407MPa respectively.

For the first loading $\sigma_3^{min}$ has the maximum value of -2.927, whereas when second load combination is acting the value of maximum and minimum principal stresses, and also the value of $\sigma_1$, $\sigma_2$, and $\sigma_3$ are not much different. And the third principal stress $\sigma_3^{min}$ increases rapidly and reaches a value of -5.407 during third load combination.

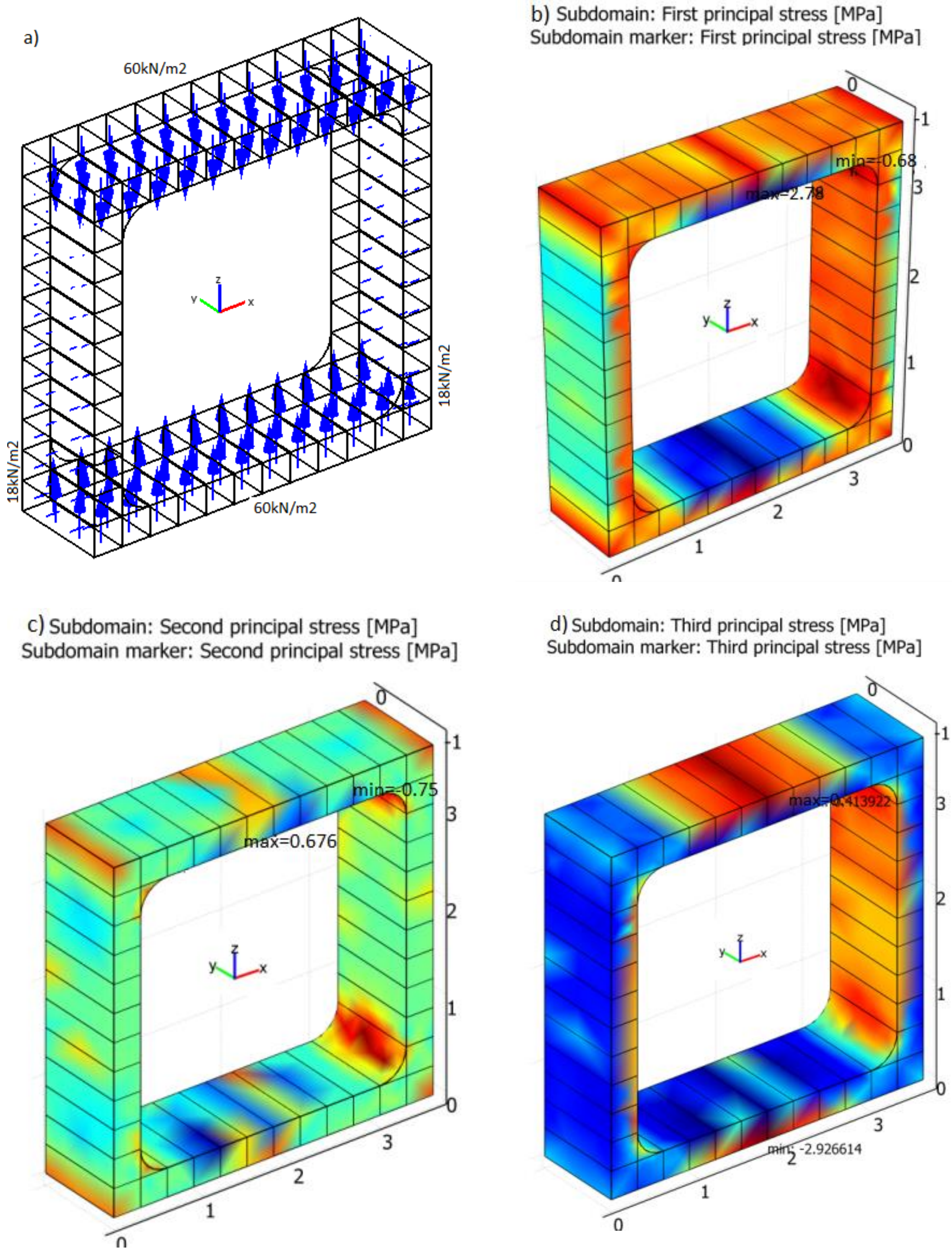


Fig.7.First load combination, value and location of the subdomain principal stresses.

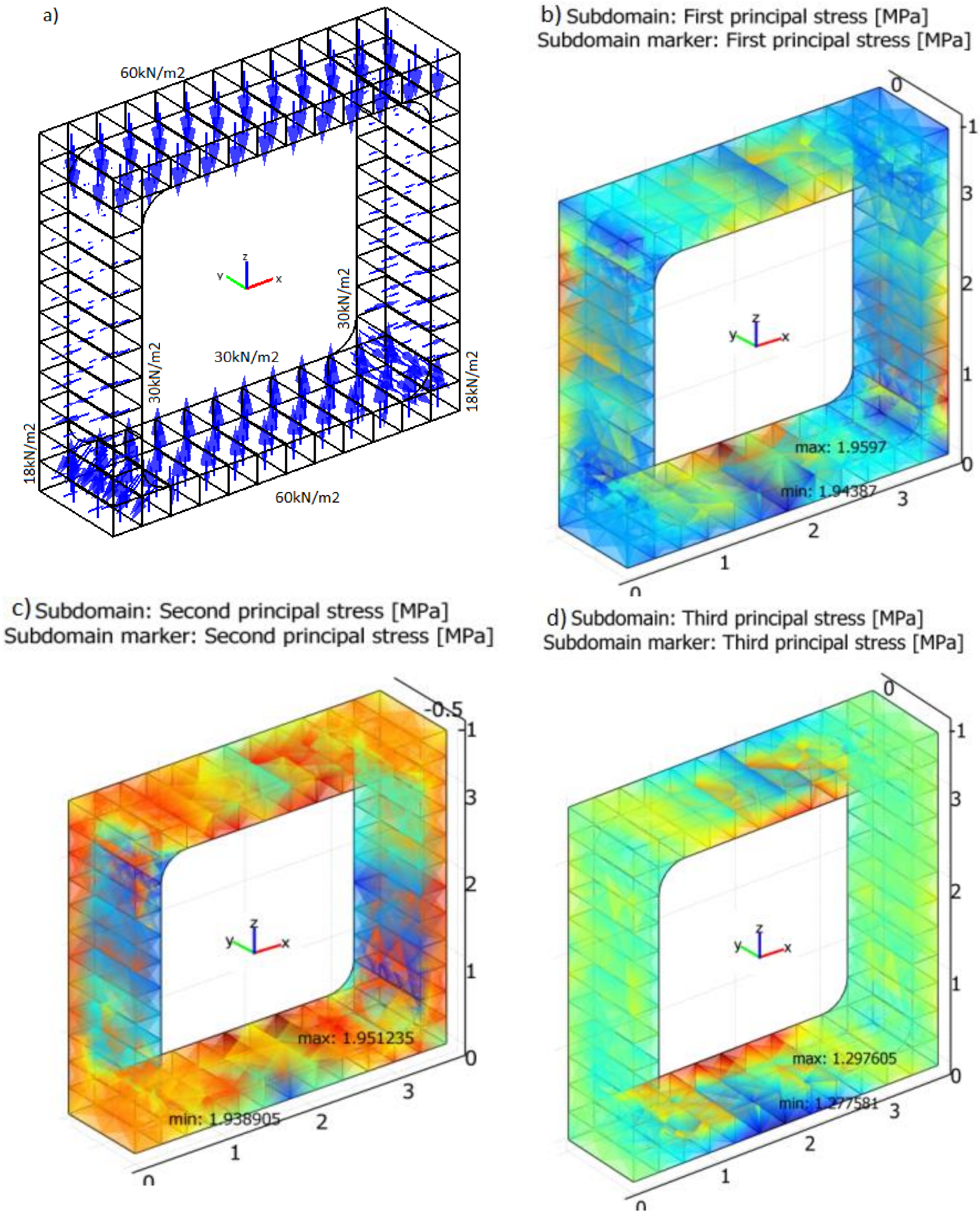


Fig.8.Second load combination, value and location of the subdomain principal stresses.

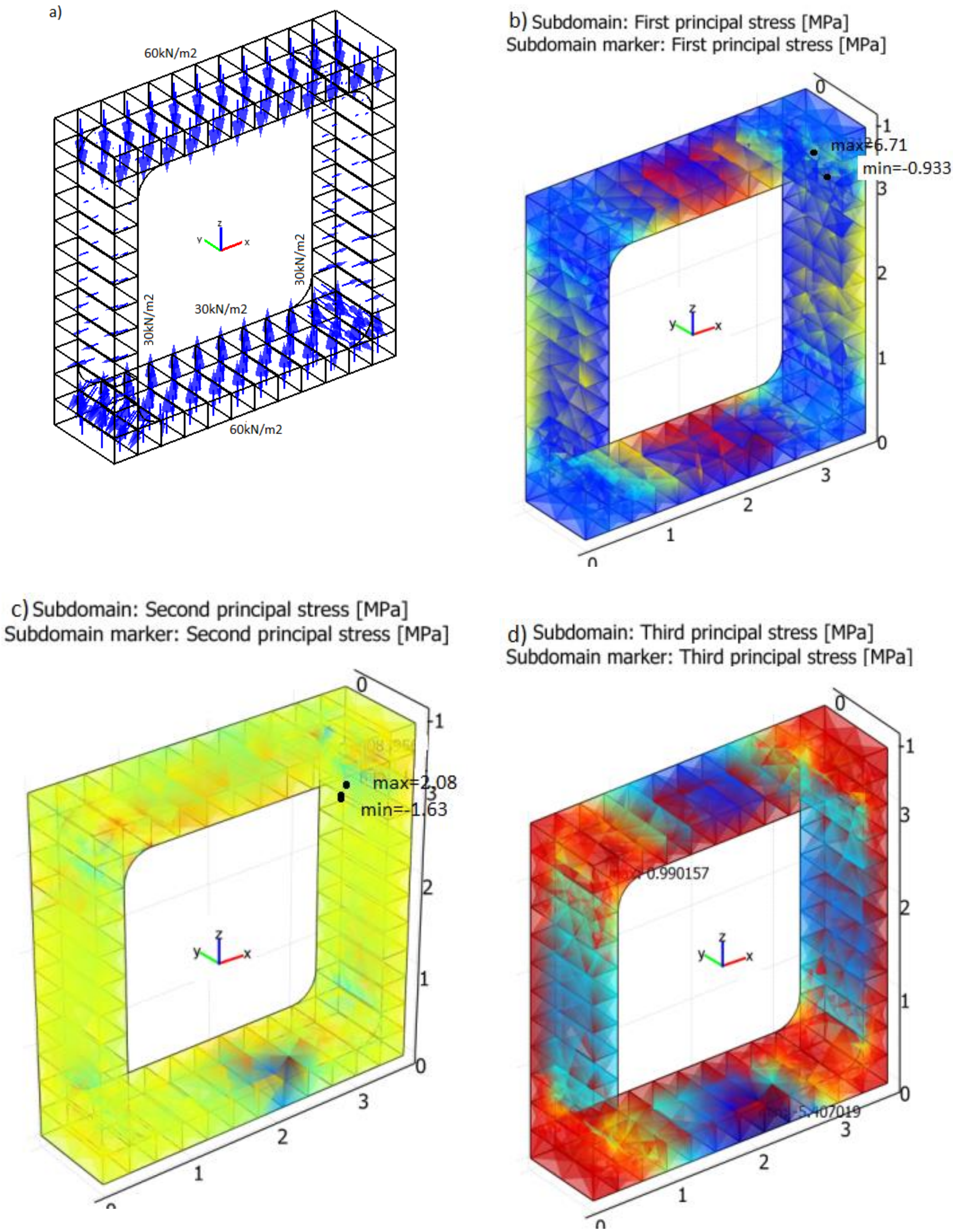


Fig.9. Third load combination, value and location of the subdomain principal stresses.

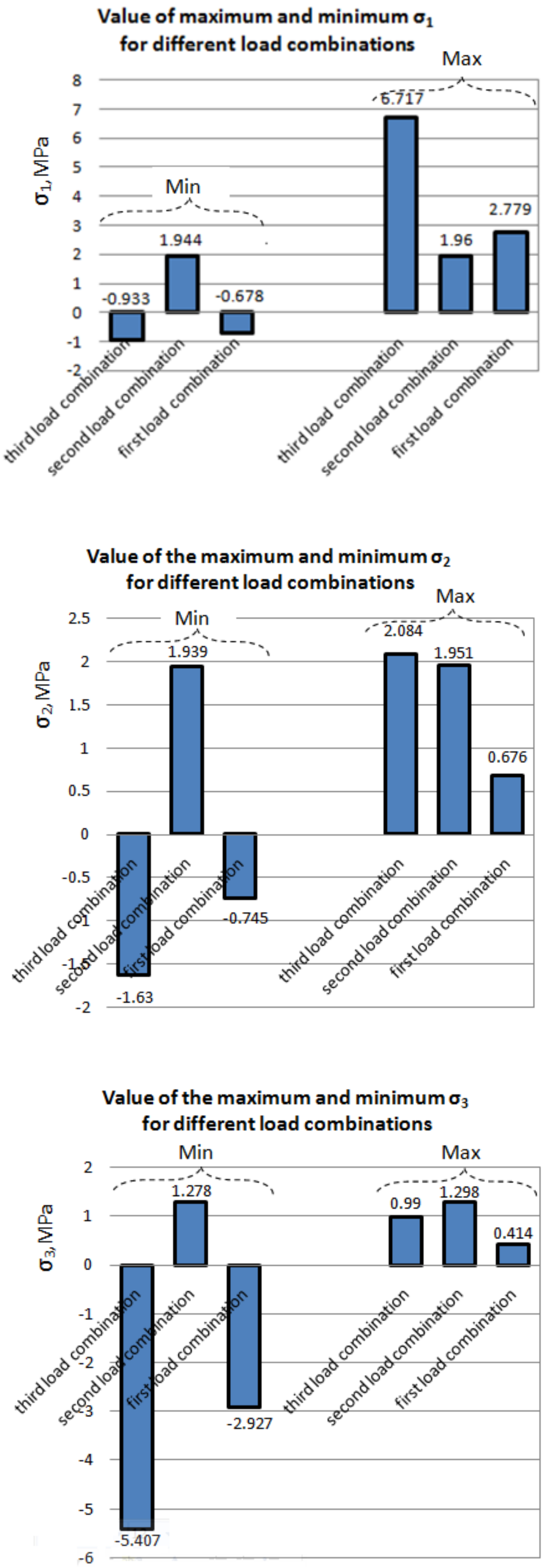


Fig.10. Value of the maximum and minimum principal stresses for three load combinations.

## Conclusion

As seen from the presented results of this article, the most convenient form of loadings for box culvert is the second load combination, i.e., when the load of water pressure is applied and at the same time present the backfill soil pressure. In this case the location of maximum and minimum principal stresses is on the base plate, which in itself is a plus.

The third type of loading, which is especially possible when the culvert is laid not across, but along the road, when a part of it comes out from backfill soil, which is often found in urban areas, is most critical combination for box culverts. In this case the different between maximum principal stresses reaches more than 100% for $\sigma_1$, and more than 80% for $\sigma_3$, which is very important for the further design of such facilities.

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### МОДЕЛИРОВАНИЕ ТРЕХМЕРНОГО *КОРОБЧАТОГО* КОЛЛЕКТОРА И ПОИСК МАКСИМАЛЬНОГО И МИНИМАЛЬНОГО ЗНАЧЕНИЙ ГЛАВНЫХ НАПРЯЖЕНИЙ

**Feirusha S. H. (Kakshar)**

*Данная статья описывает результаты анализа железобетонного коллектора методом конечных элементов. Изучено главное напряженное состояние водопропускного коробчатого коллектора до и после засыпки, а также в случаях заполненой водой и в пустом состоянии, и найдены значение и место расположение максимальных и минимальных главных напряжений в трехмерном моделе коллектора. В этой работе мы попытались найти критическое сочетание нагрузки и критические элементы в теле коллектора с точки зрения главных напряжений.*

***Ключевые слова:*** *водопропускной коробчатый коллектор, трехмерная модель, главные напряжения*