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Behavior of box culvert with geofoam as a backfill material in Highway

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Abstract

Box culverts are generally required to provide a passage for drainage and small vehicle and act as a stable base for a road embankment. Box culverts are subjected to traffic load and overburden pressure due to the cushion. Mostly box culverts are subjected to the lateral earth pressure and overburden pressure. The quantities of reinforced concrete in box culvert depends upon the anticipated lateral earth pressure which may be larger than overburden pressure. The magnitude of earth pressure due to a large quantity of backfill generates stresses and deformations on the face of box culvert. For counteracting this large pressure, either more thickness of reinforced concrete in box culvert is provided or light weight material is used as a backfill. EPS geofoam is a light weight backfill material which reduces the dead and lateral load on box culvert. The objective of this paper is to optimize the thickness of box culvert with the use of EPS geofoam as backfill material. For achieving this objective, finite element analysis has been done using PLAXIS 3D. The results of finite element analysis shows that the inclusion of geofoam as backfill material helps in reducing lateral deformation at the face of box culvert as compared to conventional backfill material. The use of geofoam makes it possible to reduce the thickness of box culvert which is beneficial in minimizing concrete requirement therefore reducing total cost of project.

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Keywords: EPS geofoam; Box culvert; Finite element analysis; Lateral deformation

1. Introduction

Various types of box culvert are available in engineering applications. Box culvert of reinforced concrete are used in roads and railways. A box culvert is subjected to various loads, which gives rise to a complex interaction problem between soil and structure.

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Several researchers have studied the effect of earth pressure on box culvert under embankment installations. (Spangler (1950), Russ (1975), Katona, and Vittes (1982), James et al. (1986), Tadros (1986), Dasgupta and Sengupta (1991), Yang, M. Z. (2000), Bennett et al. (2005), Pimentel et al. (2009), Abuhajar et al (2016)). Orton et al (2015) have carried out studies to understand the effect of live load on reinforced concrete box culvert. However, the studies focusing on reducing the earth pressure are very scant. The large horizontal pressure acts on the culvert due to the backfill and the surcharge loads. This large earth pressure can be reduced by providing lightweight materials in the backfill. Expanded polystyrene geofoam is a light weight material which can help in reducing the earth pressure. Kandolkar and Mandal (2015) have found that the inclusion of geofoam in the face of a reinforced wall helps in reducing the wall facia displacement.

The use of geofoam helps in reducing the thickness of box culvert due to which the land requirement is reduced as the culvert can be constructed in small area. The EPS geofoam is also effective in controlling noise and vibration. Thus it acts as a sustainable solution. It also reduces the maintenance cost of the structure.

In this study an effort has been made to reduce the earth pressure by inclusion of geofoam in the soil. Finite element modelling tool PLAXIS 3D had been used to modelling. For this study, the backfill material of natural soil, geofoam and combination of soil and geofoam was used and its effect on the deformation of walls of culvert was

Nomenclature

EPS	Expanded Polystyrene
u_x	Lateral Displacement
γ_{unsat}	Unsaturated unit weight
γ_{sat}	Saturated unit weight
E’	Modulus of Elasticity
ν’	Poisson’s ratio
c’	Cohesion
ϕ’	Angle of Internal friction

2. Materials Used

The box culvert was made of reinforced concrete. The backfill materials used are natural soil and geofoam. The properties of material used for finite element modelling are given in Table 1.

Table 1. Properties of Material

Properties	Backfill		Culvert
	Natural Soil	Geofoam	Reinforced concrete
Material Model	Mohr- coulomb	Mohr- coulomb	Linear Elastic
Drainage type	undrained	Non-Porous	Non-Porous
γ_{unsat} (kN/m^3)	18	0.3	24
γ_{sat} (kN/m^3)	19	-	-
E’ (kPa)	10000	7550	3.1×107
ν’	0.3	0.12	0.15
C’ (kPa)	24	45	-
Φ’ (°)	14	3	-

3. Finite Element Model

A box culvert of 3 m × 3 m opening was used. The thickness of the box culvert and friction slab was 0.32 m and 0.15 m respectively. Backfill of 2.8 m length was placed symmetrically to either sides of box culvert. A uniformly distributed load of 10.59 kN/m^2 was applied on the top of the culvert. Fig. 1 shows the box culvert model.

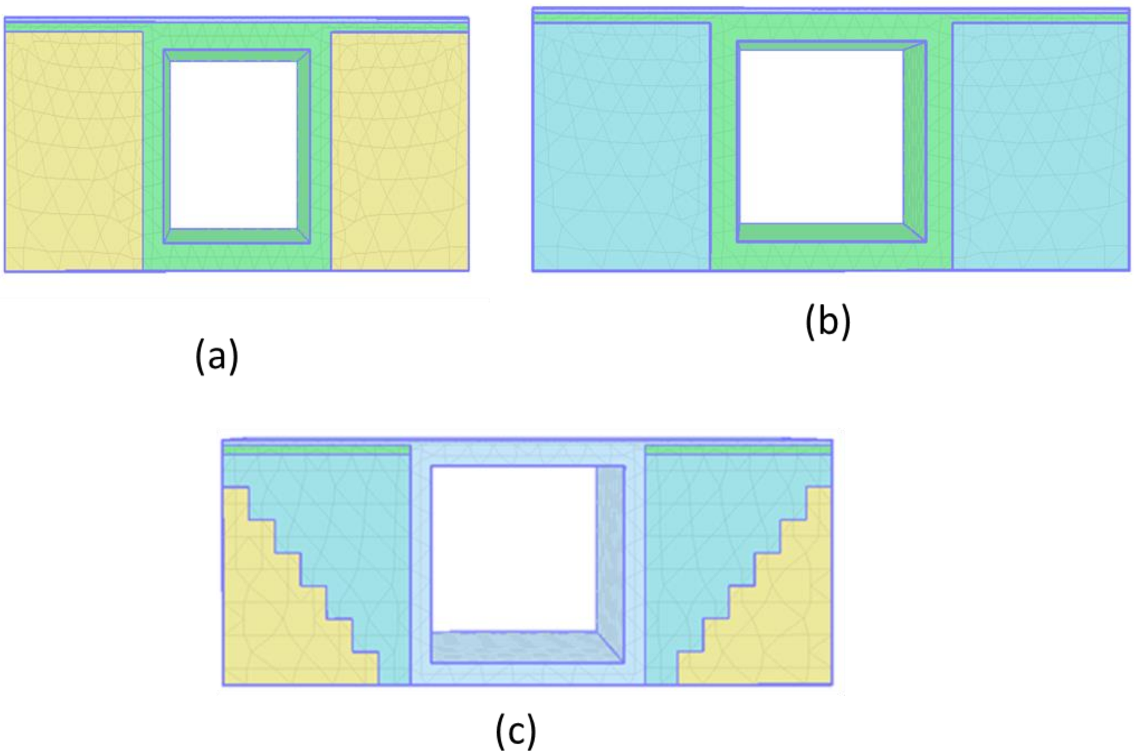

Fig. 1. (a) Finite Element Model of Box Culvert with (a) Soil backfill; (b) Geofoam Backfill; (c) Combination of soil geofoam Backfill.

4. Results and Discussions

Fig. 2 and Fig. 3 shows the total displacement diagram and the lateral displacement diagram of finite element models under the uniformly distributed load respectively. From the figures it is evident that the maximum total displacement of natural fill soil is observed towards the walls of culvert. This movement of the soil is responsible high lateral earth pressure on the walls of culvert. However in case of geofoam backfill and soil-geofoam combination backfill, the displacements were considerably reduced near the walls of culvert.

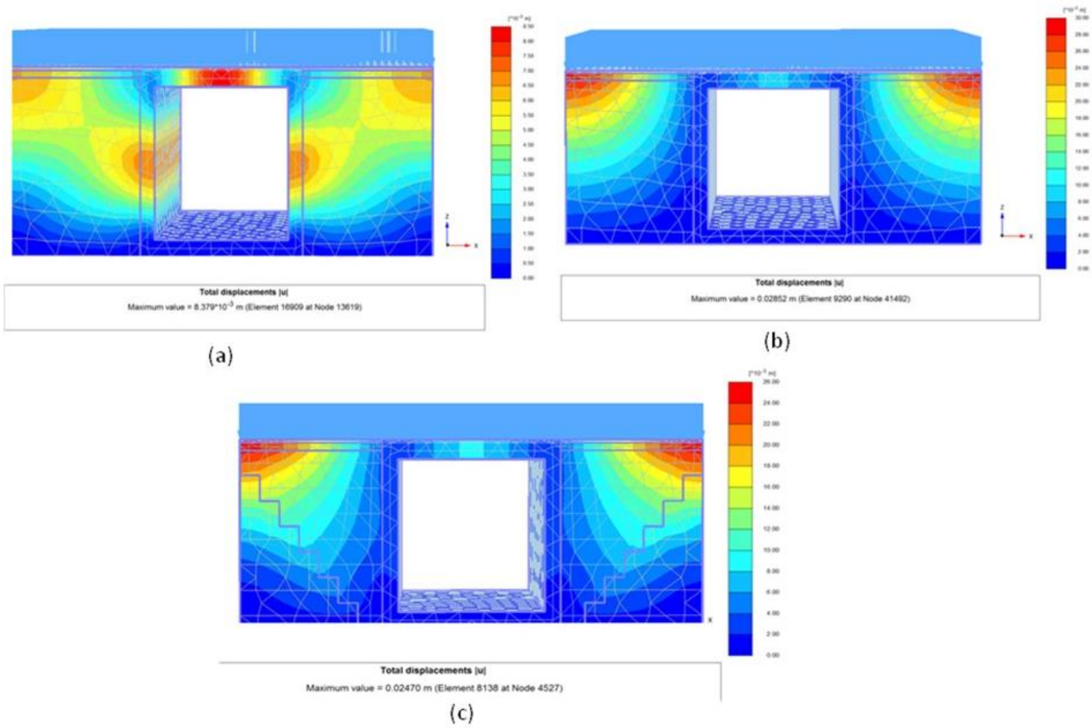

Fig. 2. Total Displacement of Finite Element Model of Box Culvert of 0.32 m thickness with (a) Soil backfill, (b) Geofoam Backfill and (c) Combination of soil geofoam Backfill

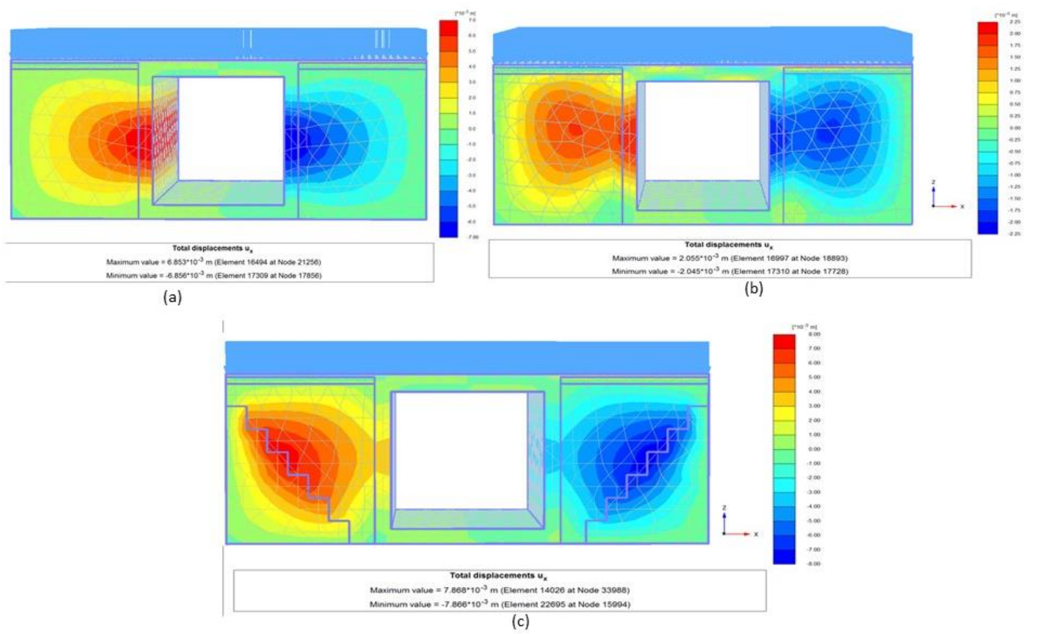

Fig. 3. Lateral Displacement of Finite Element Model of Box Culvert of 0.32 m thickness with (a) Soil backfill, (b) Geofoam Backfill and (c) Combination of soil geofoam Backfill

Fig. 4 shows the vector diagram of finite element models. It is evident that all the stresses are acting towards the walls of culvert when subjecting walls of the culvert to high lateral earth pressure, however inclusion of the geofoam reduces the lateral earth pressure on the culvert. The reduction in total displacements and lateral displacements acting on the walls of box culvert are summarized in Table 2. It was observed that geofoam is efficient in reducing displacements acting on walls of box culvert.

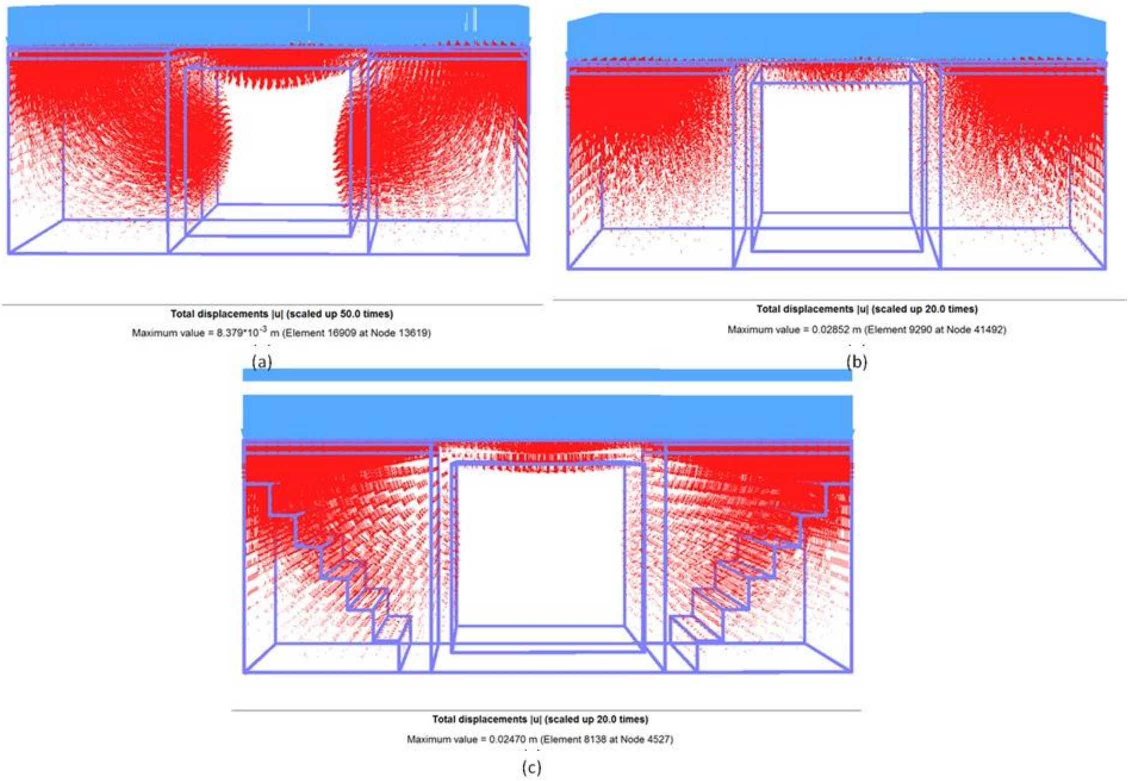

Fig. 4. Vector Diagram of Finite Element Model of Box Culvert of 0.32 m thickness with (a) Soil backfill, (b) Geofoam Backfill and (c) Combination of soil geofoam Backfill

Table 2. Comparison of Total and lateral deformation on the side of wall

Backfill material	Thickness of box culvert (m)	Thickness of friction slab(m)	Total deformation on the side wall (mm)	Reduction in deformation (%)	Lateral deformation on the side wall (mm)	Reduction in deformation (%)
Soil	0.32	0.15	7.5	-	6.83	-
Geofoam	0.32	0.15	2.0	73.3	2.05	63.3
Soil+Geofoam	0.32	0.15	4.0	46.6	4.0	41.4

5. Conclusion

In the present study, effect of displacements on the walls of box culvert was studied. Based on finite element analysis from PLAXIS 3D following conclusions are as follows:

1. High total and lateral displacements were observed on the walls of box culvert with soil as backfill. Reduction in total and lateral deformation on the wall facia was 73.3% and 63.3% respectively in case of geofoam backfill and 46.6% and 41.4% respectively in case of soil-geofoam combination backfill. This reduction was observed due to the compressibility of geofoam.

2. The lateral earth pressure acting on the wall facia considerably reduces due to the inclusion of geofoam.

3. The vector diagrams were obtained to understand the direction of the displacements. From the vector diagrams, it was observed that the displacements act towards the walls of box culvert when natural fill was used. However, direction of displacements was vertical in case of geofoam. Thus, the direction of displacements is affected by the type of backfill.

4. Inclusion of geofoam is a sustainable solution to reduce the lateral pressure acting on the culvert.

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