PhD Dissertation Proposal

Seismic Behavior Analysis of Buried Lightweight Concrete Box Culvert

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Abstract

Due to rapidly urbanization development, the infrastructure projects increased for connecting sewage networks to many areas. At the beginning, cast iron pipes were used in these networks. However, they are fragile and need to be treated carefully during installation under the ground. Moreover, they may cause soil and groundwater contamination due to steel corrosion and rust. Reinforced concrete box culverts are considered to be a good and economic choice for sewage since they are less expensive, locally produced, and environmentally safe.

The shortcoming of box culverts is that they do not bear large overburden loads of soil hence cannot be embedded at large depths underground as it is sometimes required in sewage network. They may also crack from ground seismic movements such as earthquakes. The aim of this study is to investigate the seismic behavior of lightweight concrete buried box culvert. Both experimental and numerical analyses will be carried out to improve the performance of these types of conduits. The performance of box culverts under high overburden pressure will

be tested using a thin layer of EPS-geofoam. The hypothesis is that the use of EPS-geofoam layer forms an arch action which would reduce the vertical and lateral stress. The performance of the culvert will also be tested by changing the material of conduit such as lightweight concrete. Numerical study will be carried out through finite element modeling to investigate the effect of several factors on the culvert performance under vertical and lateral loads. The results of the proposed research would substantially improve the performance of this type of conduit and can be applied in the construction and infrastructure projects throughout Canada as well as other regions.

***Key words*:** box culvert, EPS geofoam, lightweight concrete, earthquakes, numerical modeling, centrifuge modeling.

Introduction

In recent years, engineers started to use new materials for sewage pipes such as plastic, reinforced concrete, and fiberglass. Reinforced concrete (RC) pipes are considered an economic and environmentally safe. Concrete conduits are a crucial component of the sustainability of contemporary life as they provide the appropriate means for transporting drinking water, sewage, and storm-water. The consequences of pipeline damage have a direct impact on the economic, social, and environmental sectors (Alzabeebee 2019). Compared wither other types such as steel, composite, or plastic pipes, concrete pipes are built using locally produced, less expensive, and less harmful to environment materials. The disadvantage of reinforced concrete pipes is that they do not bear large overburden loads of soil to avoid their breakage and they may crack from ground seismic movements. Load reduction measures must be observed to reduce backfill pressure on and around conduits. These measures must take into account the mechanisms for transporting and reducing the load.

Expanded polystyrene, EPS-Geofoam is a lightweight material that has been used in engineering applications around the world since at least the 1950s. EPS geofoam reduces the loads on underlying soils and structures under the surface (Puppala et al., 2019). Also, the addition of the geocell just above the conduit reduced the vertical pipe diameter deflection, settlement of the soil surface, and pressure on the pipe crown, respectively, by about 27%, 43%, and 25%. Using the EPS block over the conduit increased the settlement of the soil surface, but reduced the pressure transferred to the pipe. The use of geo-cell reinforced backfill with EPS block with h = 0.3D and w = 1.5D over culverts will provide a practical and beneficial solution for protecting pipe and surface soil under heavy traffic loads (Tafreshi et al., 2020).

Furthermore, centrifuge test models and parametric study will be performed to investigate the effect of several factors on the culvert performance under vertical and lateral loads. Factors such as concrete type, wall thickness, soil-culvert interaction, EPS geofoam layer thickness, ground seismic loads, and embedment depth will be considered in the parametric study.

Objectives of the Research

1. To investigate the stress profile on buried box culverts as embedment depth increase, concrete type changed and with different soil types.
2. To investigate techniques to reduce the stress utilizing compressible EPS geofoam.
3. To investigate some techniques to reduce the cracks due to seismic loads by using lightweight concrete for box culvert.
4. To perform a parametric study on the effect of selected parameters on the stress of box culverts; such as:
    a- Concrete type.
    b- Wall thickness.
    c- Soil type (soil-culvert interaction).
    d- Seismic load values.
    e- Thickness of the compressible inclusion.
    f- Embedment depth.

5. To develop a scientific research and access to the market, taking into account the needs to be economically and is harmful to the environment and this one that concerns the university and its mission.

Literature Review

Conduits are important structure elements, which are used for transferring materials from one point to another. Rigid conduits have a long history of excellent performance as a durable product for stormwater drainage and sewer applications throughout the world. There are many types of these conduits like rectangular box culverts, tongue and groove pipes, O-ring pipes, and arch pipes. It is a rigid pipe system that depends mostly on the strength of the pipe and slightly dependent on the strength derived from the soil envelope. Steel bars that are included in the concrete pipe adds significantly to its inherent strength (Vrabie et al., 2019). There are many advantages to use reinforced concrete conduits like easy to install with flexible joints and suitable for conveying all types of water. It also has a high compressive strength which can withstand the backfill pressure, and there are small friction losses because of the smooth inner surface. However, these types of pipes require a special care in their manufacturing, transportation, and installation. Also, it has a low tensile strength that causes cracks under loading (UNEP 2001).

Another type of conduits used in the same field is steel pipe which has some advantages like resistance to high pressures, easy to connect, install, operate, maintain, and it can withstand shocks and traffic vibrations. But these pipes are susceptible to wear and corrosion in sub-surface lines that reducing their lifespan compared to other types of pipes and they have a low resistance to acidic or highly-salinity soils (UNEP 2001). The analysis, design, and installation of buried structures thus require a comprehensive understanding of soil-structure interactions (Kim et al., 2018). Therefore, reinforced concrete conduits are widely used worldwide as open channels for sewage and stormwater transfer (Mohamed 2015). These conduits can be designed and tested at the plant to resist any type of load like live and dead load required. Reinforced concrete conduits are the most durable and long-lasting pipe that can exceed more than 100 years. However, increasing the embedment depth exposes them to high overburden soil pressure which would reduce their service life expectancy.

Reinforced concrete box culvert consists of a top slab, bottom slab, and vertical walls monolithically constructed to form closed single, multiple, or square cells (Hussien 2020). The box culvert with four corners are connected uniformly. Cushioning is very important in every box culvert which is determined by the profile of the road and the bearing capacity of the soil available in the site. The total deformation, normal stress, maximum principle stress, and equivalent stress of a box which is full without cushion condition are more than box full with cushion conditions (Patel and Jamle 2019). It was found that the contact pressure distribution on the walls of the buried box culvert is not uniform with a noticeable high stress at the corners, especially for positive projection installation without EPS geofoam. These stresses concentration decreased significantly after adding the EPS block over the structure. It has been found that adding two EPS blocks against the sidewalls reduces significantly the contact pressure acting on the side and bottom walls. However, this resulted in a slight increase in the pressure at the top wall of the culvert (Meguid et al., 2017).

The main factors affecting the load on the underground culverts depend on the relative settlement between the soil column directly above the conduit and the adjacent soil that controls the magnitude and orientation of friction, which affects the resulting load on the structure. An area of compressible material can be placed over the culvert to reduce the load on concrete conduits and induce positive arch action. Also, geogrids that shown in Figure 1 can be used to protect and reduce loads on buried conduits (Li et al., 2020). Hussien's study (2020) shows that the stresses on the culvert decreased when the thickness of the section increased. Also, the proportional between stresses and the dimension of the haunch is an inversed relationship and this choice is more economical than the thickness. Meguid and Youssef (2018) found that the average earth pressure measured above the pipe crown be as low as 30% of the overburden pressure for installations with granular backfill materials.

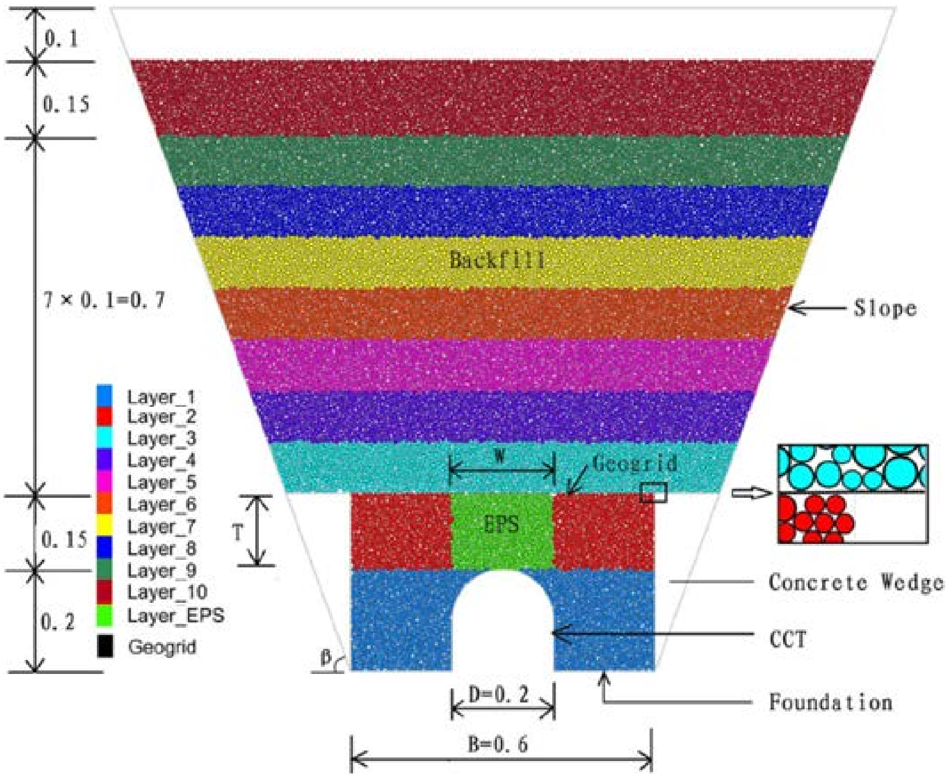

Figure1 : Discrete-element model of load reduction for a high-filled cut-and-cover tunnel (Li et al., 2019)

The displacement of the conduit, the negative soil arching on the conduit, and the stresses of the conduit wall are increase due to soil saturation increased. Also, the maximum bending moment in the wall of a buried concrete conduit is increased by 9% when the backfill soil changed from an unsaturated to a saturated state (Alzabeebee 2020). The basic concept of soil arching is to transfer a portion of the soil weight and any additional surface loads between the soil prism over the buried culvert and the adjacent soil. In addition, the burial depth is directly proportional to the positive soil arching (Allard and El Naggar 2016). In addition, it was found that the ground loads in induced trench installation are strongly affected by soil properties. Well-graded sand with a compaction level of 90% is more effective in reducing the earth's pressure and shear forces than silty sand or sand with a lower compaction level (Kang 2019). The induced trench installation method is a viable option for buried box culverts under high backfill, regardless of the increased underlying stress from the drag forces developed on the outer walls of the box culvert (Oshati et al., 2012). This type of installation was successful in reducing the vertical loads on the buried conduits (Meguid and Youssef 2018).

The vertical earth pressure (VEP) on the top central axis of the cut-and-cover tunnel with a rectangular cross-section is less than that with an arched cross-section. Otherwise, the arched section is more favorable for soil arching than the rectangular one. There is a significant difference for the earth pressure at the center and at the edges of the cut-and-cover tunnel, especially when it is wide and the backfill is high. (Li et al., 2020). However, the lateral earth pressure (LEP) on the sides of the box culvert is affected by the soil-relative movement, shape of conduit cross-section, mechanical properties of the backfill soil, and the width of the conduit (Ma et al., 2020).

Expanded polystyrene (EPS) geofoam is an ultra-light used in transportation infrastructure projects to reduce vertical and horizontal stresses subjected to buried pipeline and culvert systems (Bartlett et al., 2015). It is manufactured by pre-expanding polystyrene beads which are molded and fused in block-molds using dry saturated steam. Generally, three main stages exist in the manufacturing process of EPS geofoam: pre-foaming, maturation, and molding blocks before cutting into specific dimensions (Khajeh et al., 2020).

There are many applications of using EPS geofoam below the ground in civil engineering projects including road embankments, bridges, retaining walls, protection of pipelines and buried structures, slope stabilization, airports, and road construction over poor soils. It is used to reduce settlement below embankments and also to reduce lateral pressure on sub-structures. Further, it is utilized to reduce stresses on rigid buried conduits and related applications (Puppala et al., 2019). Morever, EPS geofoam blocks are used for vertical load reduction on buried pipes and culverts under highway fills. The earth pressure imposed on deeply buried pipelines and culverts is safely effected by soil arching. The magnitude and distribution of earth pressure on buried pipelines and culverts depend on the relative stiffness and the depth of burial of the pipe or culvert, compressible inclusion, and surrounding soil (Bartlett et al., 2015). The EPS geofoam can be used to reduce the overburden stresses on the main substrates and thus produce a transportation infrastructure free from distress conditions. It is not only reducing vertical pressure on foundation soil but, also, alleviated the soil erosion problem that usually occurs in the overhead bridge structure from moisture seepage and runoff events due to precipitation (Puppala et al., 2019). For the case of putting a strip of EPS geofoam at a distance a top of buried reinforced concrete pipe, the soft zone caused by the compressible inclusion compresses more than the surrounding fill. Thus, inducing positive arching above the conduit. The deformation in the compressible inclusion provides mobilization of the shear strength of the soil above the pipe. EPS applied in geotechnical engineering as lightweight fill (Liu and Negussey 2019). As a result, the vertical earth pressure remains lower than the overburden pressure caused by the weight of the soil (Bartlett et al., 2015). The density of EPS has a major influence on the performance of the geofoam system. Furthermore, the use of a higher EPS density significantly reduced deformations in the system compared to a lighter geofoam block (Abdollahi et al., 2019). Increasing the EPS density by 20% increases the material's properties by 50%. The use of EPS modulation with shallow tunnels creates preferential movement between the wedge above the tunnel and the adjacent fill, resulting in positive arching of the soil (AbdelSalam 2019). The amount of displacement achieved with a compressible geofoam depends on the properties of it, including the effects of strength, stiffness, and creep. These properties are closely related to the EPS density (Witthoeft and Kim 2016).

There are two important material properties of geofoam that make it beneficial for protecting buried pipelines: (1) its ultra-light unit weight when compared to other earthen materials, (2) it allows for controlled compression and yielding while keeping its original shape and size (Siabil et al., 2019). The best location for EPS block installation above the pipe is at the distance that less than or equal to 20% of pipe diameter (Beju and Mandal 2017). The closed-cell structure of EPS results in excellent insulating characteristics that remain stable over the life of the material (Khajeh et al., 2020). Poisson’s ratio for EPS is approximately a value between 0.14 and 0.2 within the elastic range (AbdelSalam et al., 2019). If the blocks are installed in a submerged application, an increase in the density of EPS geofoam can be expected over time due to water absorption (Puppala et al., 2019). EPS is resistant to fungi and mold and no nutritional value to insects. Based on these tests, the friction angle between sand and geofoam is approximately 31°. The friction angle between geofoam and another geofoam is around 42° (Newman 2006).

Geofoam technology has been used elsewhere in Europe, Asia, and the United States for roadway and rail construction (Bartlett et al., 2015). Due to its lightweight properties, this material has been used as a partial or total replacement fill in embankments on soft compressible soils to minimize settlements and avoid stability problems (Ossa and Romo 2011; Tafreshi 2020). Properties of EPS geofoam can solve many significant geotechnical engineering problems like settlement, slope stability, and bearing capacity problems (Elragi 2000). EPS geofoam is not affected by weather conditions. So, it retains its physical properties in service (Liu 2015).

In 1994, EPS geofoam was used in the construction of 21m embankment for an emergency truck escape ramp in Hawaii. Also, a 648 cubic meters of EPS geofoam was utilized in a 61m section of US highway 160 that failed in Colorado as fill in the crest of the slope to increase the factor of safety of the road (Elragi 2000). An explosion on the ground surface may cause significant damage to an underground structure, such as a tunnel or a pipeline. The compacted backfill and upper pavement imposed excessive pressure (Negussey et al., 2019). The extent of damage would depend on the intensity of the blast, the material, and configuration of the structure, as well as the nature and geometry of the intervening material. An underground structure may be protected by means of a protective barrier, installed directly above the structure. The effectiveness of using a compressible barrier, made of polyurethane geofoam, to mitigate the effects of the surface explosion was investigated (Anirban et al., 2016). The cost has been reduced up to 30% by using the compressible inclusion above rigid culverts in Norway and has made possible the use of reinforced concrete conduits under high fills (Mohsen 2014).

Conduits that are manufactured from steel and composite materials are tested with only 130 mm thick sand protecting layer without any geofoam structure, and then with two different geofoams with different thicknesses. The results are presented in a comparative form and the effect of geofoam on the impact behavior of the sand layer is investigated. Impact load and accelerations on the pipes are measured concerning time during experiments. The best result of these tests is obtained from a 50 mm thick geofoam with a sand layer (Anil 2015). Vaslestad, (1993) reported the results of three tests for reinforced concrete culverts with EPS geofoam placed above them. In the first test, the instrumented culvert was a 1.95m diameter pipe under a 14m high rock fill embankment. In the second test, a 1.71m diameter pipe was used under a 15m high rock fill. In the third test, a 2 m width box culvert was used under 11m of silty clay. The effect of soil arching decreases as the soil fill height to culvert width ratio increases for the thick culvert. However, soil arching increases for the case of a thin culvert (Abuhajar et al., 2015). Soil is stiffer than the flexible conduit, so it settles less than the pipe displaces, then permitting the development of soil abutments that a necessary condition for the formation of a soil arch. This technique will happen if we put a layer of EPS geofoam at some distance above the rigid conduit. In some cases, it was demonstrated that the load on a pipe in a trench was lower than the weight of the soil prism above the pipe. They demonstrated that through arching action. It was also showed that rigid pipes buried in embankment conditions showed negative arching, or additional load, over the pipe caused by the down drag of the soil prism directly over the pipe by the surrounding embankment (Corey 2015).

An increase in the thickness of EPS geo-foam on the crown of the buried conduit can play a significant role in reducing the vertical load as shown in Figure 3. Therefore, the effect of reducing the load from two compressible layers on the crown of the buried pipe is better than that of a single-layer with the same total thickness. Flexible pipes can play an important role in load reduction when the filling height is low (Ma et al., 2019). Recently, the use of foam geotextiles effectively reduces vertical earth pressure, and long-term observations show that the earth pressure drops to less than 30% of the calculated overburden in the case of granular fill and less than 50% in the case of silty clay fill. It is well known that both the magnitude and the distribution of earth pressure on buried culverts depend on the relative stiffness of the buried conduit and the soil Figure 2 shows the effect of EPS geofoam as a compressible inclusion by creating a positive curvature above the buried culvert, which shifts parts of the vertical soil pressure sideways. The type of fill material is the main factor in creating positive curvature (Vaslestad and Sayd 2019). Interactions between EPS geofoam blocks of different densities resulted in increased stress and localized creep deformations (Negussey et al., 2019). Also, Geocells can reduce settlement of the ground surface by up to 41% compared to an unsupported case. Using EPS geofoam as a fill material reduces both dead and seismic loads. As the thickness of the soil decreases, the effectiveness of geocells increases greatly as shown in Figure 4 (Siabil et al., 2020). Geo-composite compressible layer has sufficient compressibility to replace EPS geofoam. The reduction in vertical soil pressures over the crown of shallow pipelines ranged from 60% to 90% using it. It was found that geo-composite width and its distance from the crown of the buried conduit significantly affect the stress reduction at the crown. In addition, the best for earth pressure reduction when the geo-composite layer is located closer to the crown of the buried pipe (Plácido and Portelinha 2019).

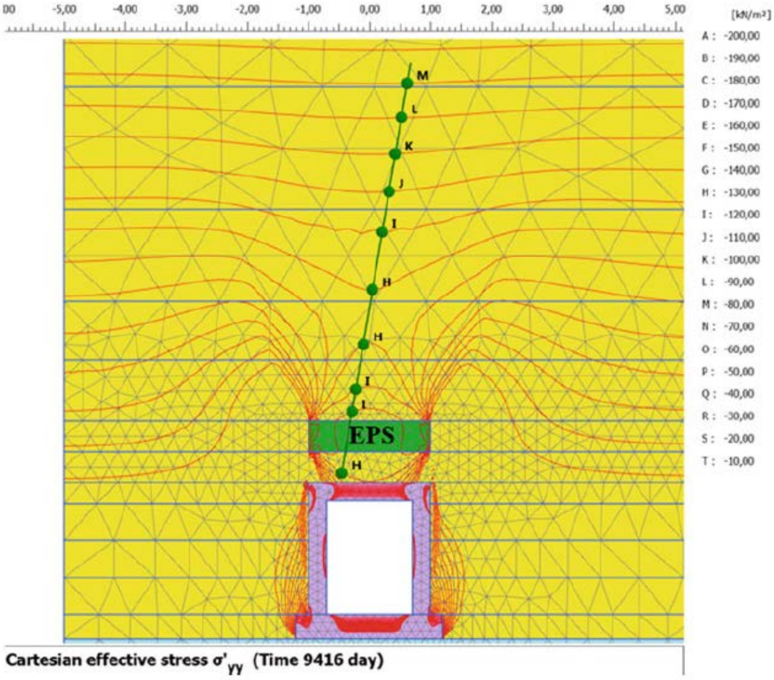

Figure2 : Vertical overburden pressure distribution over culvert using EPS geofoam (Vaslestad and Sayd 2019)

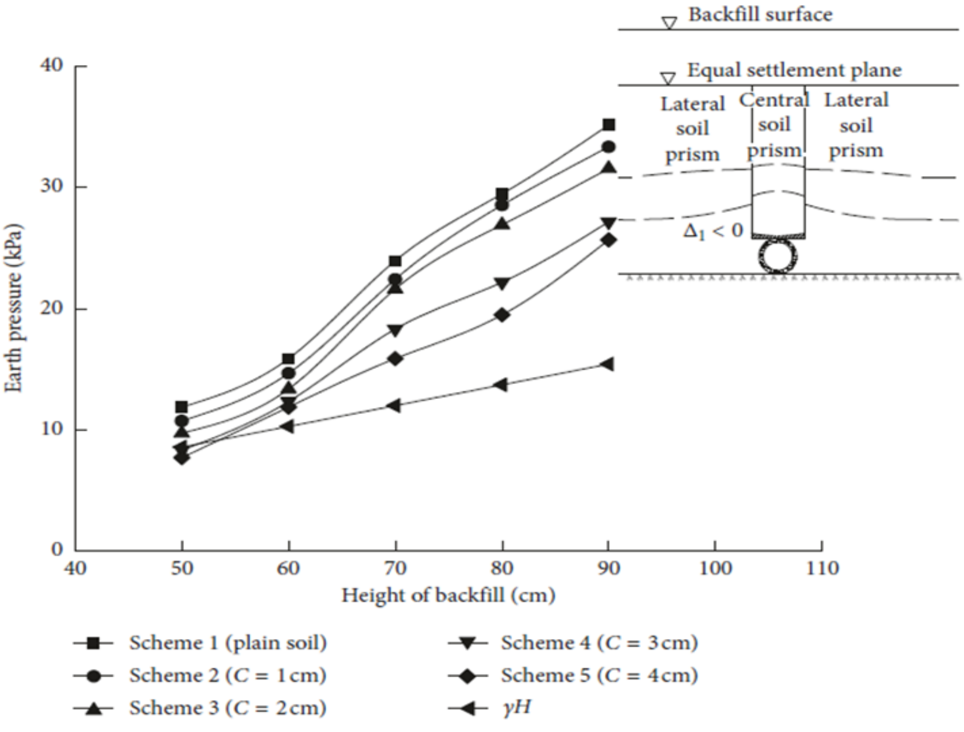

Figure3 : Pressure on crown of pipe vs. height change of filling soil with different thicknesses of EPS (Ma et al., 2019)

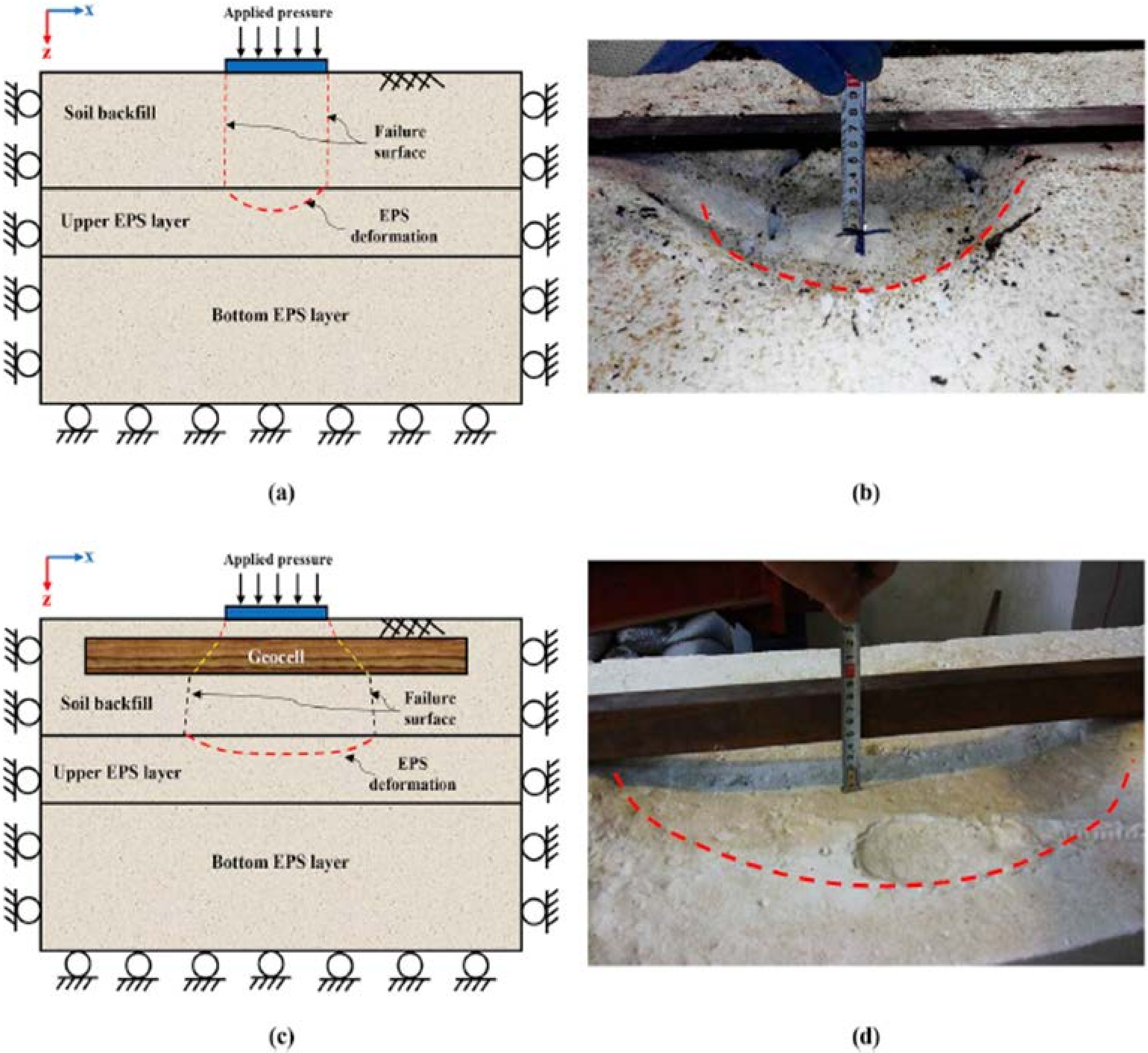

Figure4 : The effectiveness of geocells on reducing settlement of the ground surface

Buried conduits may be subjected to significant additional stresses from seismic activities if the structure is buried in active seismic areas. Figure 5 shows that stresses on buried structures increased due to increase in the backfill height and maximum absolute acceleration. A comparison of the maximum bending moment of the static and seismic state showed that the seismic vibration does not change the location of the maximum bending moment. Seismic vibration significantly increases the maximum bending moment of the buried concrete pipe. Although the percentage of rise depends on the diameter of the pipe and the height of the backfill, the rate of rise ranged between 39% and 63%. It is suggested for the researchers to use the evolutionary polynomial regression analysis method (EPR) to develop design equations involving the effect of seismic vibration. EPR is a newly developed intelligent regression analysis technology that overcomes the limitations of simple regression with intelligent research methodology that uses artificial intelligence (Alzabeebee 2019). It was found that the seismic response of the shallow circular tunnels is related to the terrestrial layers. The results of the dynamic centrifugal test by Chen and Shen (2014) indicated that the insulation layer improved the seismic behavior of the tunnel. Tunnel depth and incident wavelength are effects on the seismic activities that cause tunnel damage. Figure 6 that gave by Owen and Scholl (1981) shows the forms of deformation of tunnel lining structure due to seismic waves. The transverse displacements within the seismic action-exposed ground layer decrease when the buried depth or modulus of elasticity of the ground stratum material increased (Wang et al., 2019).

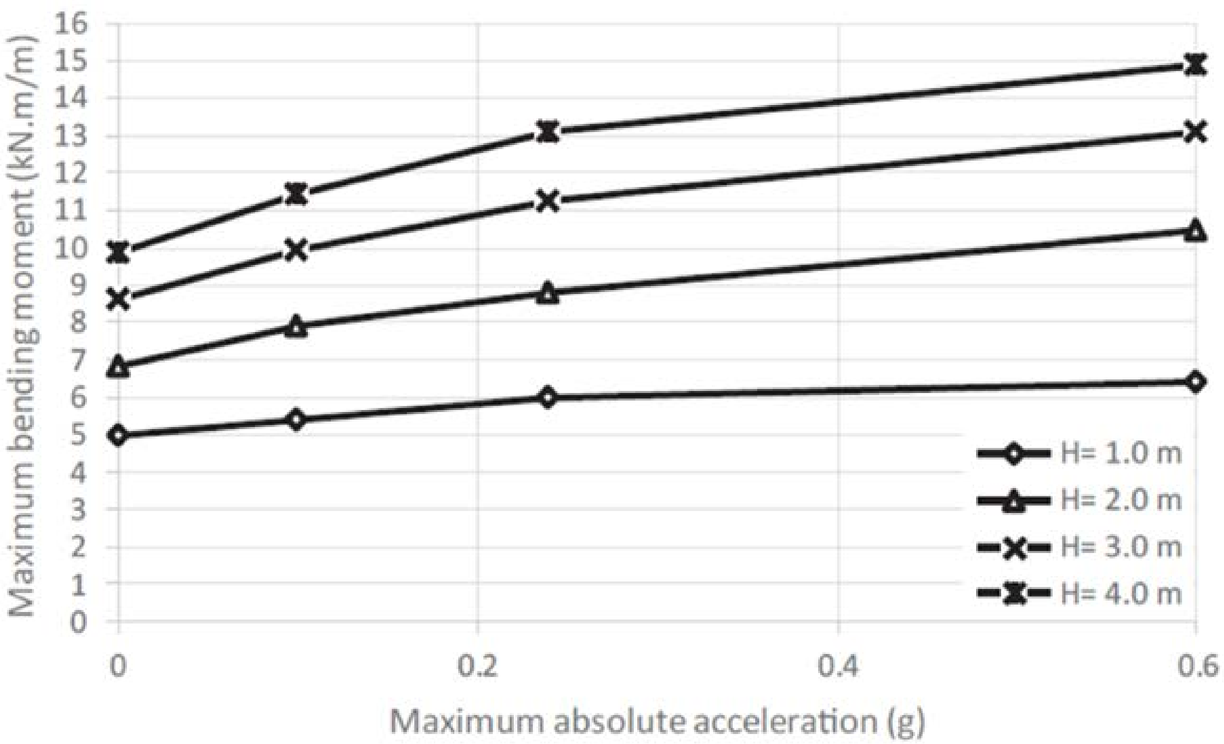

Figure 5: Stresses on buried structures with different backfill height and maximum absolute acceleration (Alzabeebee 2019)

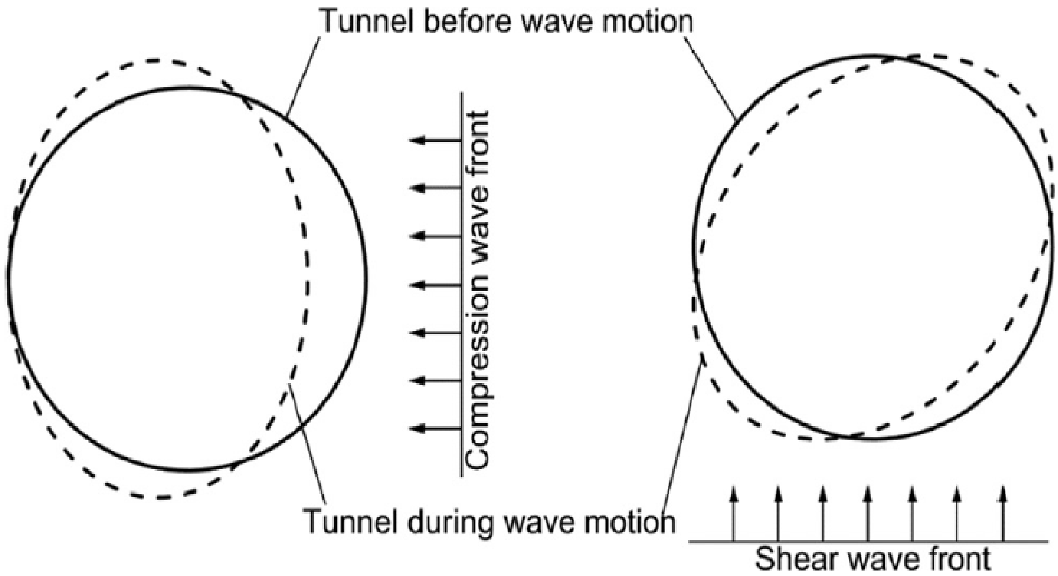

Figure 6: The effect of waves on buried pipes (Wang et al., 2019)

Buried flexible conduits are remarkably affected by a seismic shake that results in significant increases in the pipe wall thrust, pipe wall bending moment, and vertical diameter change. The influence of the earthquake shaking on the seismic response of buried flexible pipes increases due to the backfill height raise and decrease in the soil stiffness. The weight of the backfill soil has no noticeable effect on the response of the buried flexible conduits exposed to earthquake shake. Also, Increasing the predominant frequency of earthquake shake reduces the seismic response of the buried flexible conduit (Alzabeebee 2019). Variation in soil density affects the spread of ground shaking of a higher density resulting in less bending moments in an existing nearby structure. In addition, higher Poisson ratios reduced vibration attenuation (Liyanapathirana and Ekanayake 2016). During a seismic shake, the flexibility ratio of the box tunnel has a pronounced influence on its acceleration and it is positively correlated to the racking ratio. The increased elasticity ratio leads to a corresponding increase in the shear stress around the tunnel lining (Sadiq et al., 2019). Buried pipe displacement due to dynamic loads is always less than pipe displacement due to static loads. Also, it was found that the ratio of static to dynamic displacement decreases with increasing conduit stiffness and increases to a lesser extent with increasing truck speed as illustrated shown in Figure 7 (Alzabeebee et al., 2018). The dynamic lateral pressures acting on the sidewalls of box culverts decrease with the increase in the wall flexibility ratio. Also, the dynamic force on the sidewalls may be up to 2.8 times the static ground load of the rigid prototype and 1.6 times the static ground load of the flexible prototype (Ertugrul 2015). Therefore, the effect of kinematic interaction appears to be more significant when the backfill soil height over the buried conduit is less than three times the buried culvert width (Abuhajar et al., 2015).

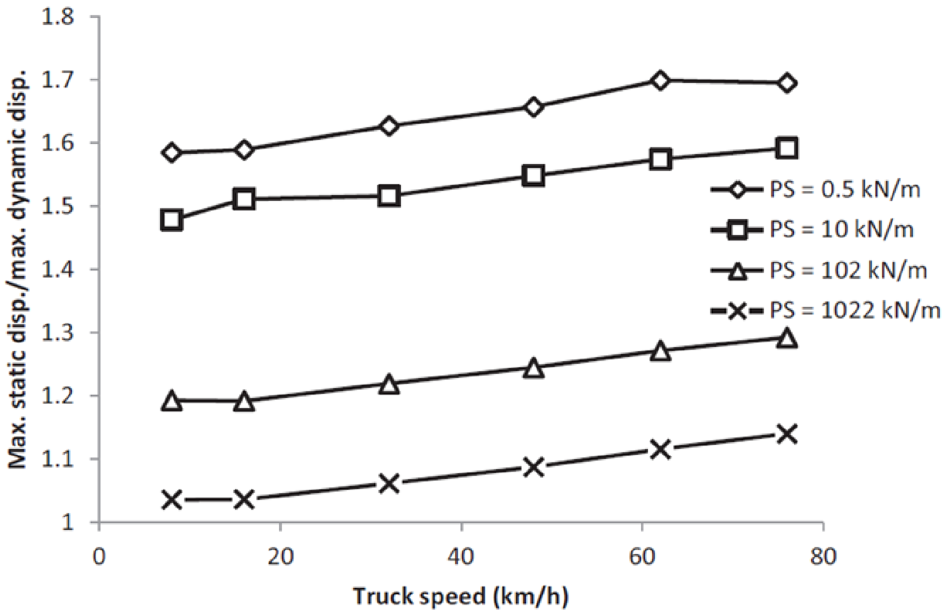

Figure 7: Relation between truck speed and maximum static to dynamic displacement with different conduit stiffness

Abu Hajar et al. (2016) made a series of centrifuge tests to examine the response of the box culverts to the loads from the surface foundation. Generally, the effect of foundation pressure on the distribution of the bending moment on the upper slab of the box culvert is large for the case of the shallow culvert and significant of the sidewall. However, it is less than the effect of the overburden pressure of the deep culverts. Only a few design guidelines are included in the general provisions for seismic design of box culverts. For instance, American Association of State and Highway Transportation Officials (AASHTO) doesn't contain any design criteria related to the calculation of earth shake loads on box culverts. However, the Canadian Highway Bridge Design Code (CHBDC) takes into account seismic loads calculations on concrete box culverts by multiplying the effects of the force produced by the self-weight and the ground load by the ratio of the vertical acceleration (Abuhajar et al., 2015). Different models of centrifuge tests used to examine soil culvert interaction under static loadings. Also, they used a numerical model to perform a static parametric study to investigate the effect of change in box culvert dimension on soil culvert interaction factors. As given Figure 8, it was observed that the values of the soil culvert interaction factor (*Fe*) obtained from the width of the box culvert (*Bc*) to the ratio of soil height (*H*) increased at the edges of the upper slab as the thickness of box culvert decreased while it decreased at the center as the thickness decreased (Abuhajar et al., 2017). In addition, the result of a complex interaction between soil and buried conduit due to the relative stiffness between the buried culvert and the surrounding soil is soil arching (Abuhajar et al., 2015). Yatsumoto et al. (2019) used also centrifuge model tests and numerical analysis to verify the seismic behavior of the buried road box culverts and establish a method for evaluating their seismic behavior. It confirms that dynamic analysis can be used to assess the seismic behavior of RBCs. On another hand, the main exterior force on buried pipes is due to the vertical pressure of the backfill and also may be caused by the traffic (Vrabie et al., 2019).

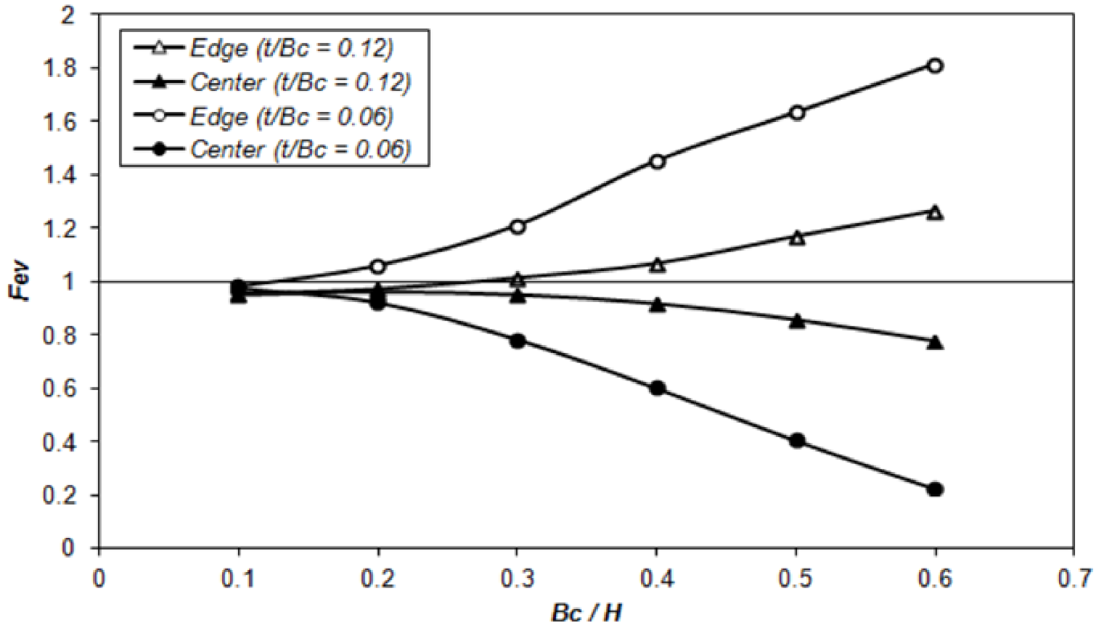

Figure8 : Effect of the thickness and the ratio *Bc/H* on the soil culvert interaction factors *Fe* on the top slab

Proposed Methodology

The following, represents the main steps of the proposed research plan:

1. Experimental work: using small scale centrifuge physical model tests to investigate the following;
    a. The effect of seismic waves on buried box culvert.
    b. The effect of placing a compressible EPS geofoam to reduce stress.
    c. Soil-culvert interaction due to the relative stiffness between the culvert and the surrounding soil.
    d. To calibrate and verify a numerical model that will be used for a parametric study.
2. Numerical analysis: parametric study will be performed to investigate the effect of several factors on the culvert performance under vertical and lateral loads. Finite element modeling will be carried out using finite element software. Plaxis 2D, is a useful tool for optimizing and analyzing earth pressure distribution over buried conduits.

Expected Results

The results of the study are expected to show improvement in the performance of box culverts under high overburden pressure. Using a thin layer of EPS-geofoam due to the development of arch action which reduces the vertical backfill weight and lateral seismic shake stresses on it, or by changing the material of conduit by using lightweight concrete. Also, wall thicknesses and reinforcement could be reduced. The results of the proposed research would substantially improve the performance of this type of conduit and can be applied in the construction and infrastructure projects throughout Canada as well as other regions.

References

Alzabeebee, S. (2020). “Influence of Backfill Soil Saturation on the Structural Response of Buried Pipes” *Transportation Infrastructure Geotechnology, 7, no.2, pp.156-174*.

Hussien, O. (2020). “Effect of Haunch on the Stresses of Box Culvert” *Research article, AIMS Environmental Science, 7, no.1, pp.31–45.*

Khajeh, A., Chenari, R. J., and Payan, M. (2020). “A Review of the Studies on Soil-EPS Composites: Beads and Blocks” *Geotechnical and Geological Engineering, pp.1-21*.

Li, S., Jianie, Y., Ho, I. H., Ma, L., Wang, Q., and Yu, B. (2020). “Experimental and Numerical Analyses for Earth Pressure Distribution on High-Filled Cut-and-Cover Tunnels” *KSCE Journal of Civil Engineering, pp.1-11.*

Li, S., Yao, Y., Ho, I. H., Ma, L., Wang, Q., and Wang, C. (2020). “Coupled Effect of Expanded Polystyrene and Geogrid on Load Reduction for High-Filled Cut-and-Cover Tunnels Using the Discrete-Element Method” *International Journal of Geomechanics, 20, no.6, 04020052*.

Ma, L., Li, S., Ho, I. H., Wang, Q., and Yu, B. (2020). “Method to Estimate Lateral Earth Pressure on High-Filled Cut-and-Cover Tunnels” *KSCE Journal of Civil Engineering, 24, no.3, pp.975-987*.

Siabil, S. G., Tafreshi, S. M., and Dawson, A. R. (2020). “Response of Pavement Foundations Incorporating Both Geocells and Expanded Polystyrene (EPS) Geofoam” *Geotextiles and Geomembranes, 48, no.1, pp.1-23.*

Tafreshi, S. M., Darabi, N. J., and Dawson, A. R. (2020). “Combining EPS Geo-foam with Geo-cell to Reduce Buried Pipe Loads and Trench Surface Rutting” *Geotextiles and Geomembranes, 48, no.3, pp.400-418.*

AbdelSalam, S. S., Jama, R. A., and Salah, M. A. (2019). “EPS inclusion to reduce vertical stresses on shallow tunnels” *Geosynthetics International, 26, no. 2, pp.121-135*.

Abdollahi, M., Moghaddas Tafreshi, S. N., and Leshchinsky, B. (2019). “Experimental-Numerical Assessment of Geogrid-EPS Systems for Protecting Buried Utilities” *Geosynthetics International, 26, no.4, pp.333-353.*

Alzabeebee, S. (2019). “Response of Buried uPVC Pipes Subjected to Earthquake Shake” *Innovative Infrastructure Solutions, 4, no.1, p.52.*

Alzabeebee, S. (2019). “Seismic Response and Design of Buried Concrete Pipes Subjected to Soil Loads” *Tunnelling and Underground Space Technology, 93, 103084.*

Kang, J. (2019). “Finite Element Analysis for Deeply Buried Concrete Pipes in Proposed Imperfect Trench Installations with Expanded Polystyrene (EPS) Foams” *Engineering Structures, 189, pp.286-295.*

Li, S., Ho, I. H., Ma, L., Yao, Y., and Wang, C. (2019). “Load Reduction on High-Filled Cut-and-Cover Tunnel Using Discrete Element Method” *Computers and Geotechnics, 114, p.103149.*

Liu, C., and Negussey, D. (2019). “Effects of Installation of Different Density Geofoam and Continuous Vertical Gaps” *In 5th International Conference on Geofoam Blocks in Construction Applications (pp. 239-250), Springer, Cham*.

Ma, Q., Ku, Z., and Xiao, H. (2019). “Model Tests of Earth Pressure on Buried Rigid Pipes and Flexible Pipes underneath Expanded Polystyrene (EPS)” *Research Article, Advances in Civil Engineering*.

Negussey, D., Andrews, L., Singh, S., and Liu, C. (2019). “Forensic Investigation of a Wide Culvert Reconstruction Failure” *Journal of Pipeline Systems Engineering and Practice, 10, no.3, p.05019001.*

Patel, R., and Jamle, S. (2019). “Analysis and Design of Box Culvert: A Manual Approach” *International Journal of Advanced Engineering Research and Science, 6, no.3.*

Plácido, R., and Portelinha, F. H. M. (2019). “Evaluation of Geocomposite Compressible Layers as Induced Trench Method Applied to Shallow Buried Pipelines” *Geotextiles and Geomembranes, 47, no.5, pp.662-670.*

Puppala, A. J., Ruttanaporamakul, P., and Congress, S. S. C. (2019). “Design and Construction of Lightweight EPS Geofoam Embedded Geomaterial Embankment System for Control of Settlements” *Geotextiles and Geomembranes, 47, no. 3, pp.295-305*.

Sadiq, S., Van Nguyen, Q., Jung, H., and Park, D. (2019). “Effect of Flexibility Ratio on Seismic Response of Cut-and-Cover Box Tunnel” *Research Article, Advances in Civil Engineering.*

Vaslestad, J., and Sayd, M. S. (2019). “Load Reduction on Buried Rigid Culverts, Instrumented Case Histories and Numerical Modeling” *In 5th International Conference on Geofoam Blocks in Construction Applications, Springer, Cham, pp. 115-128.*

Vrabie, M., Băetu, S. A., and Toma, A. (2019). “On the Calculation of the Vertical Soil Pressure on Rigid Pipes Installed in Embankment Conditions” *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura, 65, no.1, pp.87-101.*

Wang, Y. X., Shan, S. B., Zhang, C., and Guo, P. P. (2019). “Seismic Response of Tunnel Lining Structure in a Thick Expansive Soil Stratum” *Tunnelling and Underground Space Technology, 88, pp.250-259.*

Yatsumoto, H., Mitsuyoshi, Y., Sawamura, Y., and Kimura, M. (2019). "Evaluation of Seismic Behavior of Box Culvert Buried in the Ground Through Centrifuge Model Tests and Numerical Analysis" *Underground space, 4, no.2, pp.147-167.*

Alzabeebee, S., Chapman, D. N., and Faramarzi, A. (2018). "A Comparative Study of the Response of Buried Pipes Under Static and Moving Loads" *Transportation Geotechnics, 15, pp.39-46.*

Kim, S. H., Park, J. S., and Kang, J. S. (2018). "Numerical Analysis of Load Reduction for Underground Arch Structures with Soft Zone Using Expanded PolyStyrene Geofoam" *Journal of the Korea Academia-Industrial cooperation Society, 19, no. 10, pp.24-30.*

Meguid, M. A., and Youssef, T. A. (2018). "Experimental Investigation of the Earth Pressure Distribution on Buried Pipes Backfilled with Tire-Derived Aggregate" *Transportation Geotechnics, 14, pp.117-125.*

Abuhajar, O., Newson, T., and El Naggar, H. (2017). "The Effect of Soil Depth and Box Culvert Geometry on the Static Soil-Culvert Interaction" *In Geotechnical Frontiers 2017, pp. 202-211.*

Beju, Y. Z., and Mandal, J. N. (2017). "Combined Use of Jute Geotextile-EPS Geofoam to Protect Flexible Buried Pipes: Experimental and Numerical Studies" *International Journal of Geosynthetics and Ground Engineering, 3, no.4, p.32.*

Meguid, M. A., Hussein, M. G., Ahmed, M. R., Omeman, Z., and Whalen, J. (2017). "Investigation of Soil-Geosynthetic-Structure Interaction Associated with Induced Trench Installation" *Geotextiles and Geomembranes, 45, no.4, pp.320-330.*

Abuhajar, O., El Naggar, H., and Newson, T. (2016). "Numerical Modeling of Soil and Surface Foundation Pressure Effects on Buried Box Culvert Behavior" *Journal of Geotechnical and Geoenvironmental Engineering, 142, no.12, p.04016072.*

Allard, E., and El Naggar, H. (2016). "Pressure Distribution Around Rigid Culverts Considering Soil–Structure Interaction Effects" *International Journal of Geomechanics, 16, no.2, p.04015056.*

Anirban, D., Morgante, A. N., and Zimmie, T. F. (2016). "Numerical and Physical Modeling of Geofoam Barriers as Protection Against Effects of Surface Blast on Underground Tunnels" *Geotextiles and Geomembranes, 44, no. 1, pp.1-12.*

Liyanapathirana, D. S., and Ekanayake, S. D. (2016). "Application of EPS Geofoam in Attenuating Ground Vibrations During Vibratory Pile Driving" *Geotextiles and Geomembranes, 44, no.1, pp.59-69.*

Witthoeft, A. F., and Kim, H. (2016). "Numerical Investigation of Earth Pressure Reduction on Buried Pipes Using EPS Geofoam Compressible Inclusions" *Geosynthetics International, 23, no.4, pp.287-300.*

Abuhajar, O., El Naggar, H., and Newson, T. (2015). “Experimental and Numerical Investigations of the Effect of Buried Box Culverts on Earthquake Excitation” *Soil Dynamics and Earthquake Engineering, 79, pp.130-148.*

Abuhajar, O., El Naggar, H., and Newson, T. (2015). “Seismic Soil–Culvert Interaction” *Canadian Geotechnical Journal, 52, no.11, pp.1649-1667.*

Abuhajar, O., El Naggar, H., and Newson, T. (2015). “Static Soil Culvert Interaction the Effect of Box Culvert Geometric Configurations and Soil Properties” *Computers and Geotechnics, 69, pp.219-235.*

Anil, Ö., Erdem, R. T., and Kantar, E. (2015). “Improving the Impact Behavior of Pipes Using Geofoam Layer for Protection” *International Journal of Pressure Vessels and Piping, 132, pp.52-64.*

Bartlett, S. F., Lingwall, B. N., and Vaslestad, J. (2015). “Methods of Protecting Buried Pipelines and Culverts in Transportation Infrastructure Using EPS Geofoam” *Geotextiles and Geomembranes 43, no. 5, pp.450-461.*

Corey, R. A. (2015). “Protection of Buried Flexible Pipes with a Geosynthetic: Experimental and Numerical Studies” *Doctoral dissertation, University of Kansas.*

Ertugrul, O. L. (2015). “Numerical Modeling of the Seismic Racking Behavior of Box Culverts in Dry Cohesionless Soils” *KSCE Journal of Civil Engineering, 20, no.5, pp.1737-1746.*

Liu, C., (2015). "Stress Strain Behavior by Image Analysis, Mix Density and Pre-Strain Effects of EPS Geofoam" *Thesis, Syracuse University.*

Mohamed, N. (2015). “Experimental and Numerical Study on Full-Scale Precast Steel Fibre-Reinforced Concrete Pipes” *Electronic Thesis and Dissertation Repository, The University of Western Ontario.*

Mohsen, R. A., (2014). “Investigation of Reinforced Polystyrene Foam Waste with Natural or Synthetic Fibers” *Doctoral dissertation, The American University in Cairo.*

Oshati, O. S., Valsangkar, A. J., and Schriver, A. B. (2012). “Earth Pressures Exerted on An Induced Trench Cast-in-Place Double-Cell Rectangular Box Culvert” *Canadian Geotechnical Journal, 49, no.11, pp.1267-1284.*

Ossa, A., and Romo, M.P., (2011). "Dynamic Characterization of EPS Geofoam” *Geotextiles and Geomembranes journal, 29, no. 1, pp.40-50.*

Newman, M.P., (2006). "Numerical Modeling of Geofoam Embankments" *Doctoral dissertation, University of Utah.*

UNEP. (2001). “Sourcebook of Alternative Technologies for Freshwater Augmentation in West Asia”

Elragi, A.F., (2000). "Selected Engineering Properties and Applications of EPS Geofoam" *Doctoral dissertation, State University of New York, NY, USA.*