Numerical Modeling of Stress Reducing Effects of Rigid Inclusions above Buried FRP Pipes

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ABSTRACT
Buried fibreglass reinforced-plastic (FRP) pipes are widely used in process industry, where, they are often subjected to large hauling loads. Few traditional protection approaches are in use. The inclusion of a reinforced concrete (RC) structural element above the crown of the pipe is a commonly adopted procedure. This paper presents a series of numerical analyses that parametrically study the interaction between the FRP Pipe-Soil-Rigid Inclusion system. Finite Element (FE) stress/deformation analyses of buried FRP pipes subjected to truck loads and protected by a rigid RC slab-on-grade are performed. The effect of using a RC slab-on-grade on the deformation of pipes is investigated considering different axle loading scenarios and different RC slab widths and thicknesses. The results show that the use of a RC slab-on-grade significantly reduces pipe deformation. Increasing the width of the slab yielded better practical benefits than increasing the slab thickness.

RÉSUMÉ
Tubes en la fibre de verre renforcée de plastique (FRP) enterrés sont largement utilisés dans l'industrie de transformation, où ils sont souvent soumis à de fortes charges de traction. Quelques approches de protection traditionnels sont utilisés. L'inclusion d'un béton armé (RC) élément structurel dessus de la couronne de la conduite est une procédure couramment adoptée. Ce document présente une série d'analyses numériques qui étudient paramétrique l'interaction entre le système de FRP Pipe-sol-rigide inclusion. Analyse par éléments finis (FE) le stress / déformation des tuyaux enterrés en FRP soumis à des charges de camions et protégés par un RC rigide dalle sur terre-plein sont effectuées. L'effet de l'utilisation d'une dalle sur terre-plein RC sur la déformation des tuyaux est enquêté envisage différents scénarios essieu de chargement et différentes largeurs de dalles de RC et épaisseurs. Les résultats montrent que l'utilisation d'un RC dalle sur sol réduit considérablement la déformation du tuyau. L'augmentation de la largeur de la dalle a abouti à de meilleurs avantages pratiques que d'augmenter l'épaisseur de la dalle

1 INTRODUCTION

Fiberglass reinforced-plastic (FRP) pipes have been replacing conventional steel, cast iron and concrete pipes because of the many attractions they offer. These include corrosion resistance and high strength-to-weight ratio. FRP pipes possess natural damping capabilities, and their fatigue endurance is much higher. FRP pipes offer significant energy savings; including energy consumed in manufacturing, transportation, installation, operation, maintenance and fuel value of the product itself. (Cheremisinoff and Cheremisinoff,1995; Turnipseed, 1995; Beckwith and Greenwood, 2006)

Many studies have been reported in the literature for the use of FRP pipes. Podivinsky et al. (1978) reported the use of FRP pipes for water mains in Edmonton, Alberta. Hille, and Romer (2004) highlighted design recommendations from their experience in the design and construction of the Owens Dry Lake project, the largest application of fiberglass pipe in the world at that time. LeBlanc and Palsson (2013) discussed the history and recent developments of large-diameter fiberglass pipes and reviewed a pressurized pipe project in which fiberglass pipe was utilized. Alawaji (2004) experimentally and numerically investigated the load deformation characteristics of fiberglass pipes (400-600 mm diameter). Bryden et al. (2014) investigated the behavior of very flexible large diameter FRP pipes with shallow soil cover with and without surface loading using centrifuge tests and 3D finite element analysis.

The current study investigates the use of buried flexible FRP pipes subjected to truck loading. The performance of buried pipes subjected to truck loads or vehicle loads has been studied using field tests (Trott and Gaunt, 1976; Watkins and Reeve, 1982; Faragher et. al., 2000; McGrath et al., 2002; Arockiasamy et al., 2006; Chaallal et al., 2014), laboratory tests (Rogers et al., 2005; Faragher, 1997; Moghadas Tafrishi and Khalaji, 2011) and numerical analyses (Kang et al., 2013; Chaallal et al., 2015).

The above noted literature does not however consider protection of the pipes from the heavy hauling loads and none used FRP pipes. The current research studies the performance of FRP pipes subjected to truck loading in the presence of a rigid inclusion used to protect the pipes and reduce stresses. Several methods of pipe protection have been used in practice and investigated for buried-pipe design. Methods of relieving stress and strain and reducing deflection include relieving slabs, casings, induced trenches and geosynthetics (Corey et al., 2014). The use of geogrid reinforcement above pipes was studied by many researchers (Rajkumar and Illamparuthi, 2008; Moghadas Tafrishi and Khalaji, 2008; Moghadas Tafrishi and Tavakoli Mehrjardi, 2008; Palmeire and Andrade, 2010; Corey et al., 2014) The use of geogrid layers was found to greatly reduce the deflections and strains of pipes. Hedge et al. (2014) studied the effectiveness of using a combination of geocells and geogrids to protect buried pipes subjected to static load using laboratory tests. Moghaddas Tafreshi et al. (2012) experimentally investigated the efficiency of using a layer of rubber-soil mixture in the trench above a buried pipe subjected to cyclic loading.

This paper investigates the efficiency of using a reinforced concrete (RC) slab-on-grade to protect FRP pipes subjected to truck loads. A series of numerical analyses that parametrically study the interaction between the FRP pipe-soil-rigid inclusion system is presented. Finite element (FE) stress/deformation analyses of the buried FRP pipes subjected to truck loads and protected by a rigid RC slab-on-grade are performed. The effect of using a RC slab-on-grade on the deformation of pipes is investigated. Different axle loading scenarios relative to the pipe location and different RC slab widths and thicknesses are considered.

2 METHODOLOGY

The methodology adopted in this paper is summarized as follows.

- Back-calculation of equivalent FRP pipe elastic modulus.
- Determination of design native soil/ backfill properties
- Identification of design traffic loads
- Finite Element (FE) stress/deformation analyses of buried FRP pipes subjected to AASHTO specified traffic loads assuming HS20 truck and protected by rigid RC slab.

2.1 Design Traffic Loads

HS20 design truck loads are assumed for the analyses outlined in this paper. AASHTO Standard Specifications for Highway Bridges requires the vehicular live loads to comprise the combination of:

- Design truck or design tandem, and
- Design lane load.

Each design lane under consideration is assumed to be occupied by either the design truck or tandem, coincident with the lane load. The live loads defined above are of static nature. Thus, the dynamic load allowance is calculated using the following expression:

$$IM = 33(1 - 4.1 * 10^{-4} * D_E) \qquad [1]$$

where, D_E is the minimum cover depth above pipe in mm. Table 1 summarizes the IM applicable to the pipe considered. Dynamic load allowance is not applicable to the design lane loads.

Table 1. Dynamic load allowance for buried components per AASHTO.

Pipe Diameter (mm)	**Min Depth of Earth Cover (mm)**	**IM (%)**
4064	1900	7.29

The weights and spacing of axles and wheels for the design truck are taken as per Figure 1. The spacing between the two 145000 N axles are varied between 4300mm and 9000mm to produce extreme force effects. This study assumes an average distance between the axles. The design tandem is considered as a pair of 110000 N axles spaced 1200mm apart. The transverse spacing of wheels is taken as 1800mm. The design lane load consisted of a load of 9.3 N/mm uniformly distributed in the longitudinal direction. Transversely, the design lane load is assumed to be uniformly distributed over a 3000mm width. The force effects from the design lane load are not subjected to a dynamic load allowance.

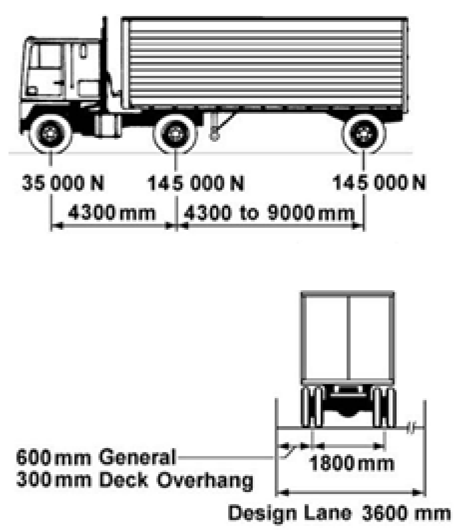


Figure 1. Characteristics of the design truck

The extreme force effects are taken as the larger of the following:

- The effect of one design truck with the variable axle spacing combined with the effect of the design lane load
- The effect of the design tandem combined with the effect of the design lane load

Different loading scenarios are simulated in search of most critical loading condition. Figure 2 depicts the axle loading positions considered in this paper relative to pipe location.

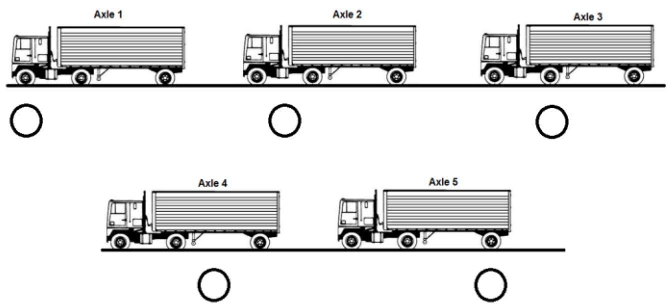


Figure 2. Axle loading positions

2.2 FRP Pipe Properties

The behavior of FRP pipes is very complicated as they are not only anisotropic but they also exhibit non-homogeneous behavior. This leads to a variety of failure mechanisms in these pipes. The FRP pipes are modeled using an elastic Timoshenko beam formulation in this study. Thus, the material properties assumed in this analysis for the FRP pipes were linear elastic as FRP pipes show a linear elastic behavior under longitudinal and hoop loading conditions until the near-failure stress states are reached. Thus, it is justified to model the FRP pipe using linear elastic beam elements, with elastic properties back calculated from the stress/strain behavior measured during the tangential stiffness testing of pipe.

The procedure for determining an equivalent modulus for a simplified beam included the FE simulation of pipe deformations based on an applied testing loads (see Figure 3) and determination of equivalent elastic modulus by adjusting the modulus value assigned to pipe material. The equivalent elastic modulus of the 47.5mm thick pipe section is determined as 24700 MPa.

Figure 3. Sample FE model used in pipe modulus simulations

2.3 Properties of Soils and Pavement

The subsurface conditions considered in the study are shown in Table 2. The ASTM Class I type soils are used for backfilling. ASTM D3839 provides the descriptions and stiffness properties of Class I soil type. Table 3 summarizes the mechanical properties of both native soils and engineered backfill. Flexible pavements are used for in-plant roads, thus the reduction of traffic load effects on the pipes due to the presence of pavement layer is negligible and ignored.

Table 2. Native ground stratigraphy

Layer	Depth (m)	Soil Description	SPT -N Value Range
Layer 1	0-2	Light brown, loose to medium dense, poorly graded fine to medium SAND (SP) to SAND with silt (SP-SM)	8-12
Layer 2	2-10.5	Light brown, medium dense to dense, poorly graded fine to medium SAND (SP) to SAND with silt (SP-SM)	17-48
Layer 3	10.5-12	Dark gray to yellowish gray, hard, lean CLAY with sand to sandy lean CLAY (CL)	>50
Layer 4	12-25	Light gray, very dense, poorly graded fine to medium cemented SAND (SP) to SAND with silt (SP-SM)	>50

Table 3. Soil mechanical properties

Material	Angle of Internal Friction (o)	Elastic Modulus (kPa)	Poisson's Ratio	Unit Weight (kN/m3)
Native Soil Layer 1	30	5000	0.3	16
Native Soil Layer 2	32	10000	0.3	18
Native Soil Layer 3	30	50000	0.35	20
Native Soil Layer 4	35	75000	0.3	19
SC1 Backfill	35	88000	0.3	18

2.4 Numerical Analyses:

The evaluation of the FRP pipe is carried out using 2D finite element analyses (PHASE 2 software). The design criterion is determined as maximum pipe deformation that is equal to 5% of pipe diameter. Figure 4 gives a view of FE soil-pipe interaction model.

3 RESULTS AND DISCUSSIONS

This section includes the results of analyses to determine the FRP pipe deformations considering the most critical combination of AASHTO truck loads and a single pipe arrangement.

The results of analyses are presented in Tables 4 to 7 for Cases 1 to 4, respectively. Cases 1 is with no slab, case 2 includes a 400mm slab with a width of 1D, case 3 includes a 400mm slab with a width of 2D while case 4 includes a 200mm slab with a width of 2D.The results indicate that the pipe deformation under axle loads were reduced significantly by the introduction of 1D wide RC slab. Increasing the width of RC slab resulted in further reduction in pipe diameter shortenings. The results of the analyses depicted in Table 7 show the pipe diameter changes for a case where slab was 200mm and 2D wide. The results of Table 7 indicated that a 200 mm slab provided almost the same benefit as a 400 mm slab. Thus, the width of the slab is more critical than its thickness.

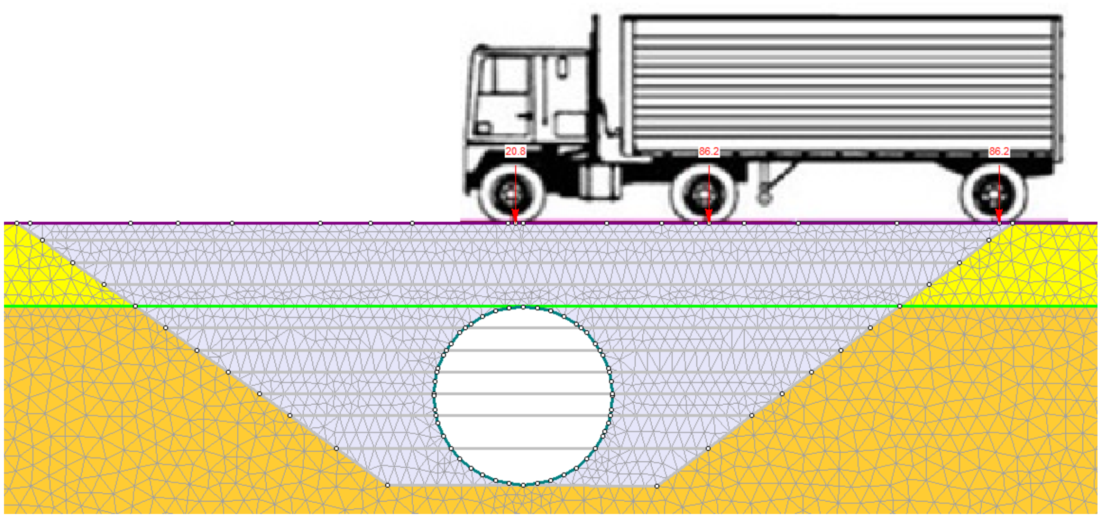


Figure 4. Sample FE model used in pipe modulus simulations

Table 4. Pipe deformations for Case 1 (no Slab)

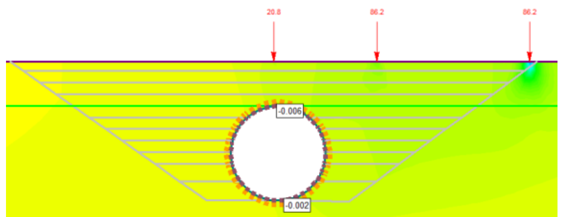
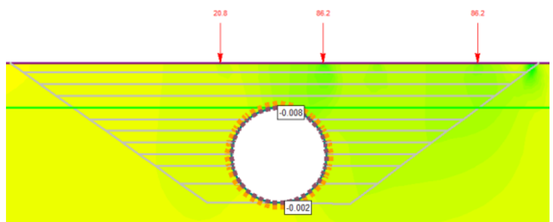
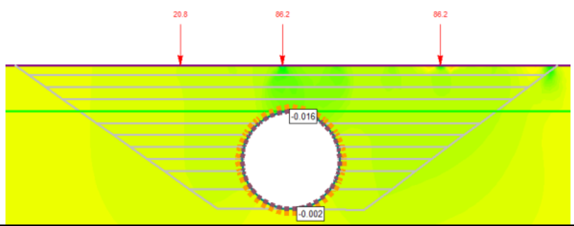
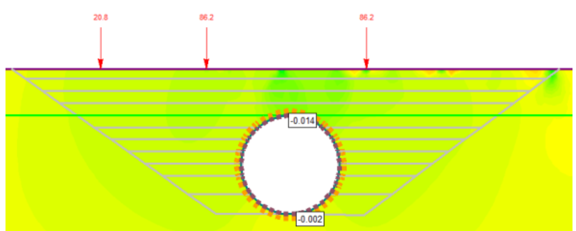
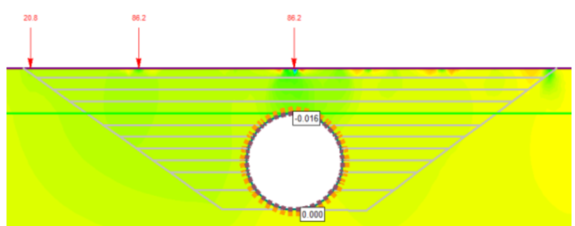
Load Position	**FE Model**	**Shortening of Pipe Dia. (mm)**
1		4
2		6
3		14
4		12
5		16

Table 5. Pipe deformations for Case 2 (400mm, 1D wide slab on the surface)

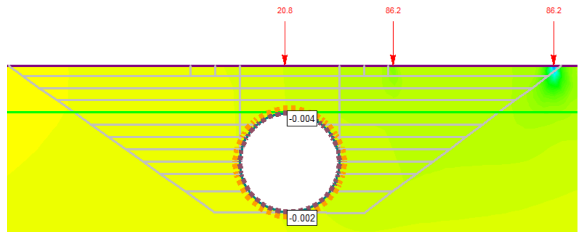
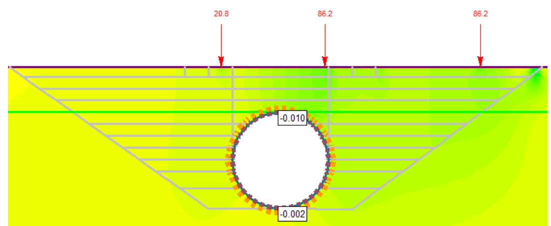
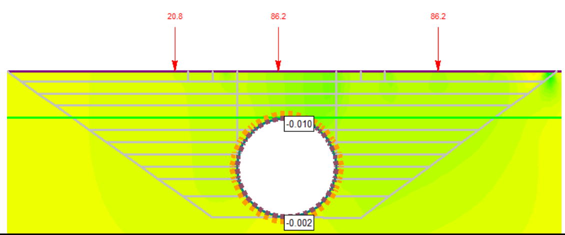
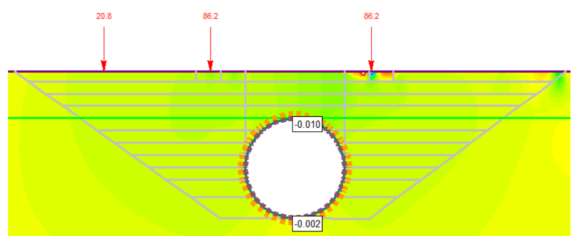
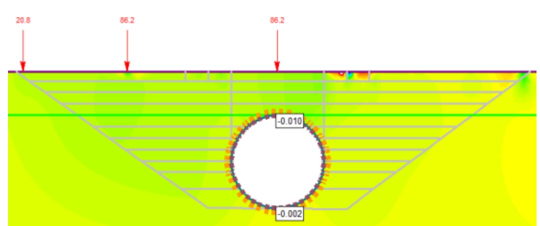
Load Position	**FE Model**	**Shortening of Pipe Dia. (mm)**
1		2
2		8
3		8
4		8
5		8

Table 6. Pipe deformations for Case 3 (400mm, 2D wide slab on the surface)

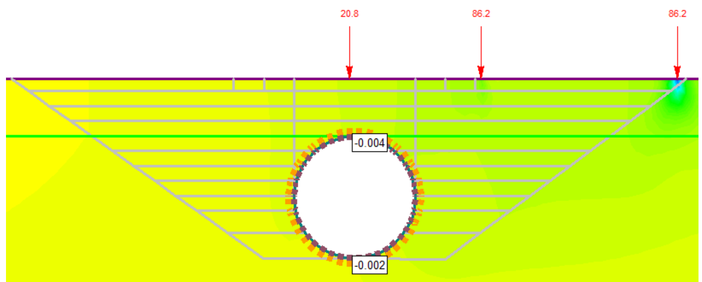
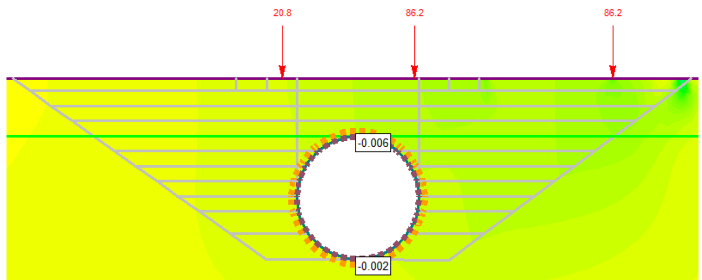
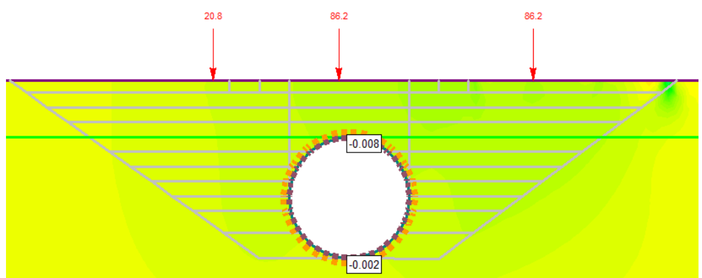
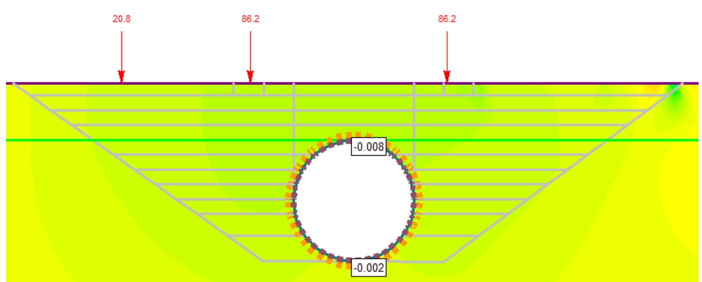
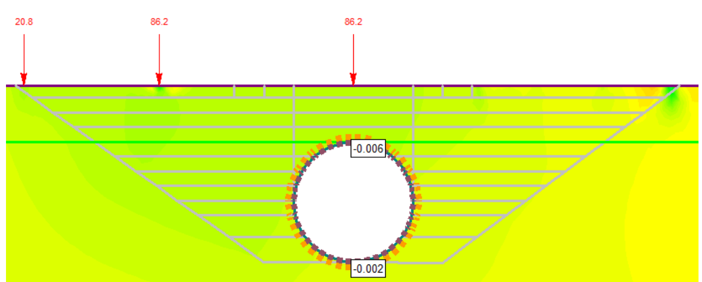
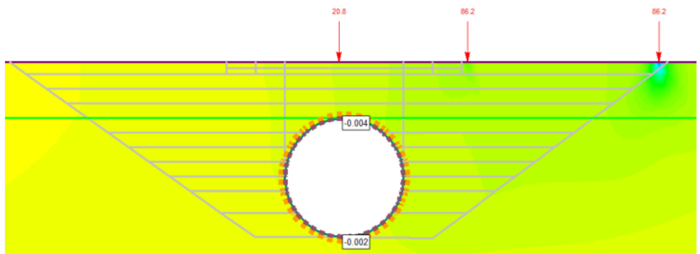
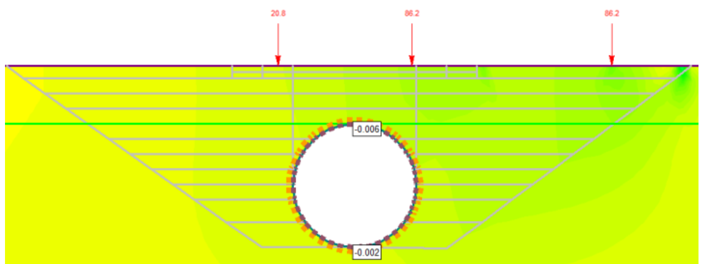
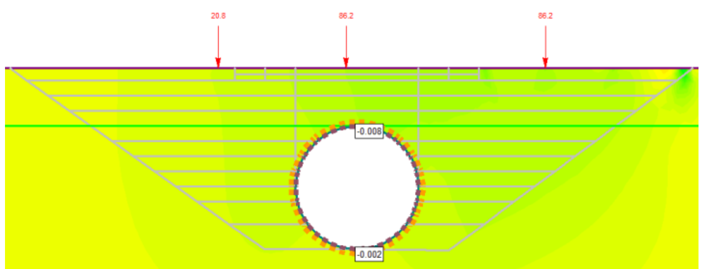
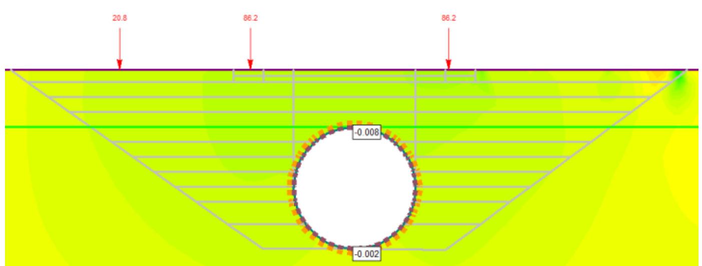
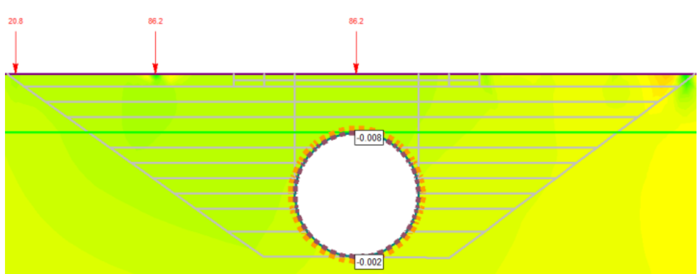
Load Position	**FE Model**	**Shortening of Pipe Dia. (mm)**
1		2
2		4
3		6
4		6
5		4

Table 7. Pipe deformations for Case 4 (200mm, 2D wide slab on the surface)

Load Position	FE Model	Shortening of Pipe Dia. (mm)
1		2
2		4
3		6
4		6
5		6

4 CONCLUSIONS

The paper investigated the efficiency of using a RC-slab on-grade as a protection for buried FRP pipes subjected to truck loading. Finite element stress/deformation analyses were conducted. Different axle loading scenarios were considered and the effect of the RC slab width and thickness were investigated. The following conclusions arose from this study:

- The selected buried FRP pipe case followed typical material used in backfilling and typical minimum embedment depth followed in practice. Thus, the percent pipe deformations were low (they were below 5% with compaction induced deformations) under standard AASHTO H20 truck loads. However, larger deformations can occur during heavy hauling operations.
- The results showed that the introduction of a RC slab-on-grade reduced the pipe deformations significantly.
- The 2D wide RC slab was seen to yield better results compared to 1D wide slab.
- The results indicated that reducing the slab thickness from 400mm to 200mm made no practical reduction in the benefits gained by the RC slab.
- The performance of load reduction capability of the RC slabs is expected to be larger for heavy loading and shallow embedment cases.
- The implementation of this approach should be accompanied by proper specifications covering sub-excavation, base preparation and slab placement along with installation tolerances as placement related issues may jeopardize the performance.

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