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External Works and Energies Generated in 10 mm and 20mm Thick Steel and Concrete Pipes Buried in Dense Sand at Different Embedment Ratio Due to Underground Blast

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ABSTRACT

The primary causes of explosions are military formation explosions, conflict, and other unintentional explosions. The purpose of this study is to simulate blast loads and ascertain how empty underground pipes would react. This will be done using the finite element approach. While the analytical method was utilized for the subsurface blast load of widely used explosives at various stand-off positions, the diverse responses are external work and energy. Soil and pipe materials were regarded as elastic, homogenous, and isotropic in this investigation. The material and geotechnical characteristics disclosed by several researchers and pipe makers were employed. With the use of the temporal integration technique, the responses of underground pipelines to an underground blast were examined using the finite element numerical code ABAQUS/Explicit. External work and energies generated in underground steel and concrete pipes buried at different embedment ratios in dense sand were observed.

Key Words: *Blast, Pipes, Concrete, Steel, Soil, Explicit, Numerical, Analysis*

I. INTRODUCTION

Pipes are underground installations that are used for a variety of purposes, including the transportation of petroleum products, the conveyance of sewage, the transportation of acid, liquid gas, gas in the petrol-chemical industries, and more. For example, the construction of the Canadian gas pipeline project in 1999 allowed natural gas to flow from Canada into the northeast market. Additional uses for pipes include caissons, buried and surface main lines for irrigation and drainage, atomic nuclear power plants, access points in the mining sector, storage facilities, piling for jetties docks and foundations, and underground transit, penstocks for hydroelectric work, and many more. This work is restricted to utilizing the finite element numerical code ABAQUS to determine the responses of modeled subsurface empty pipelines to blast loads. Only linear, elastic, homogenous, and isotropic materials can be used as the ground media, from the intervening medium, and pipes. This study only considers explosions that occur far underground pipelines in the case of an underground burst (Liu, 2009).

The constituents of blast, as applicable in this study, include the rock/soil media, structures, intervening medium, blast, and blast characteristics in the response study of buried structures caused by underground explosive loads. When analyzing how underground pipelines react to blast loads, these elements' qualities and traits are crucial. The rock media includes severely fractured rocks, average-quality rocks, poor-quality rocks, and intact rocks such schist (Liu, 2009; Adel-Aziz, 1987). Rocks are created by a variety of natural processes, including the magma's melting cooling, the inorganic mineral precipitation etc..

Rocks are divided into two categories: metamorphic rocks (such as slate and schist) and igneous rocks and sedimentary rocks. Soil is formed by geologic processes in rocks, such as deposition, erosion, and ground movement. A substance known as soil breaks down into individual grains using mechanical methods such as stirring in water, applying flow pressure, etc. Numerous techniques are used to identify soils, including the Bureau of Soils (1890–1895), Atterberg (1905), the Unified Soil Classification System (1952), and others. (Peck *et al.* 1974; US Department of the Interior, Bureau of Reclamation, 1979; Adel-Aziz, 1987; Arthur, 1974; Chen, 1995; Ola, 1983; Peter and David, 1987; Wagner, 1957).

There are three types of soils. They include frictional soils ($\emptyset \neq 0$, C= 0), cohesive soils ($\emptyset = 0$, C $\neq$ 0), and frictional-cohesive soils (C $\neq$ 0, $\emptyset \neq 0$) where C is cohesion while $\emptyset$ is angle of shearing resistance of the soil. A significant component of an Abaqus/Explicit analysis is frequently energy output. Analyses that provide suitable responses can be assessed using the use of comparisons between different energy components. The whole model's energy balance can be expressed as

$$E_I + E_V + E_{FD} + E_{KE} - E_W - E_{PW} - E_{CW} - E_{MW} = E_{total} = \text{constant},$$

where E_I, E_V, E_{FD}, E_{KE}, E_W are internal energy, viscous energy, frictional energy, kinetic energy, and work done by the loads applied externally respectively , and E_{PW}, E_{CW}, E_{MW} are the work done by contact penalties, by constraint penalties, and by propelling added mass, respectively. The summation of all the components of these energies is E_{total}. In the numerical model E_{total} is only approximately constant, generally with an error of less than 1%. The internal energy is the sum of the recoverable elastic strain energy, E_E; the energy dissipated through inelastic processes such as plasticity, E_P; the energy dissipated through visco-elasticity or creep, E_{CD}; and the artificial strain energy, E_A :

$$E_I = E_E + E_P + E_{CD} + E_A. \quad 2$$

The energy accumulated in hourglass resistances and transverse shear in shell and beam elements is included in the strain energy(artificial). High strain energy levels suggest that mesh needs to be refined or altered in some other way. The energy lost to damping mechanisms, such as material damping and bulk viscosity damping, is known as the viscous energy. Viscous energy, a key component of the global energy balance, is distinct from the energy lost as a result of inelastic or viscoelasticity processes. Nodal forces (moments) and displacements (rotations) are the only factors that define the external work of applied forces, which is continuously integrated forward.Specific boundary requirements also support the external work.

Each energy quantity in the energy balance can be requested as an output and displayed as the energy density of each element, individual elements, or particular element sets, as well as the total of the time histories for the entire model.

The variables named after the energy values added together for the whole model or sets of elements. Furthermore, energy output at the element level and energy density can be generated using Abaqus/Explicit.

II. METHODOLOGY

This study used dense sand as the ground media, and it examined how underground pipes responded to explosive loads below ground. The geotechnical characteristics of this ground media, as reported by a number of researchers (Das, 1994; FLAC, 2000; Coduto, 2001; Duncan, 2001; UFC, 2008; Kameswara, 1998, etc.), were taken into consideration. Material parameters such as the modulus of elasticity, E, Poisson's ratio, and density of the materials are used because the two elastic constants are sufficient to analyze the mechanics of an elastic body (Kameawara, 1998). With the sand-cone approach or the balloon-density method, one might determine the density of in-situ soil. Figure 1 displays a cross-section of an underground pipe as well as blast categories that apply to underground pipes.

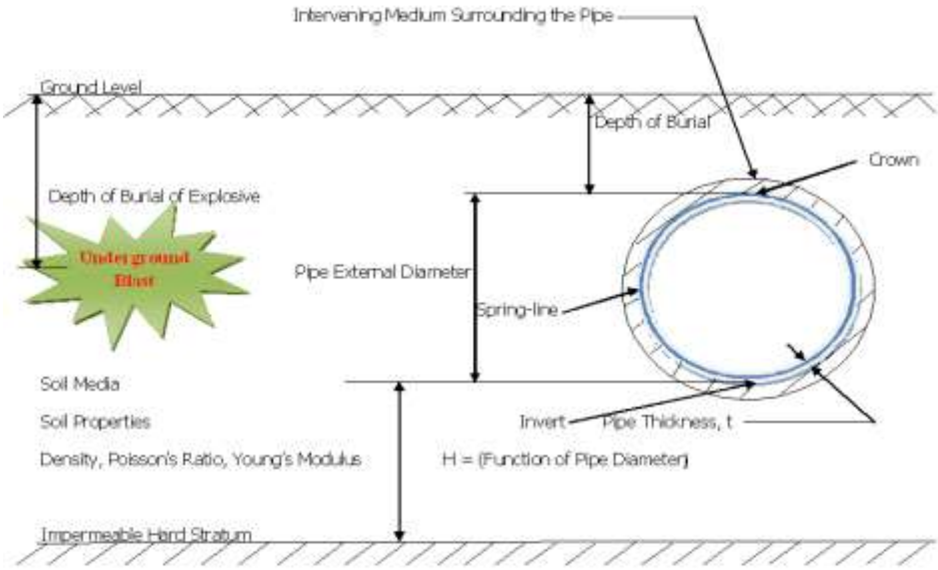


Figure 1: Underground blast

Table 1: Soil property

Material	Young’s Modulus E (MPa)	Poisson’ Ratio (υ)	Density (kg/m^3)
Undrained Clay	6.0	0.5	2060
Loose Sand	10	0.3	1733
Dense Sand	30	0.3	1833

Table 2: Pipes property

Material	Young's Modulus E (MPa)	Poisson' Ratio (υ)	Density (kg/m^3)
Steel Pipe	200 x 10^3	0.3	7951
Concrete Pipe	28 x 10^3	0.2	2400

ABAQUS/Explicit was utilized to analyze the reaction of simulated underground steel and concrete pipes buried in dense sand at various embedment ratios, using the calculated loading wave velocities. A dense sand soil medium with infinite length, width, and depth was modeled. 100-meter-long buried steel and concrete pipes with thicknesses of 10 and 20 mm and an external diameter of 1 m were buried at heights and depths of 1, 2, 3, 4, and 5 from the ground surface. An infinite intervening medium with an internal diameter of 1 m and a thickness of 0.15 m encircled the pipes. The pipe is elastic, round, and lengthy without joints.

It was believed that the pipe would be installed horizontally, with no soil slippage. After that, in order to permit slippage between the pipe and the dirt, contact was defined. The study used the values of material properties indicated in Tables 1 and 2 for the elastic, homogeneous, and isotropic soils and pipes under consideration. It was estimated that the underground blast load would occur more than 6 meters away from the buried pipe. Sand loading wave velocities of 300 m/s were used to approximate the blast load (Unified Facilities Criteria, 2009). As stated by the ABAQUS Analysis Users' Manual (2009), the governing equation of motion of the system represented by Equation 3 was solved in order to perform analysis on simulated models.

$$[m][\ddot{U}] + [c'][\dot{U}] + [k][U] = [P] \qquad 3$$

where dot denotes their time derivatives and m, c',k, U, and P stand for the global mass matrix, global stiffness matrix, global displacement vector, and global stiffness matrix, respectively (Kameswara, 1998; ABAQUS Analysis User's Manual, 2009).

The external work, energy, and viscous dissipation buried in the loose, dense, and undrained clay are the observable parameters.

III. DISCUSSION OF FINDINGS

The findings of the loading wave velocity(ldv) from an accidental underground explosion in 10 mm and 20 mm concrete and steel pipes buried in dense sand at different embedment ratios are shown in Figures 2 to 21, respectively. It was revealled that regardless of the material qualities, dense sand is crucial in reducing the impact of an underground unintentional explosion in buried pipelines, as seen by the nearly zero exterior work produced in all of the examples under investigation. The external works and energy generated in pipes are zero for 10 mm and 20 mm concrete and steel pipes (Figures 5, 6, 11, 15, 16, 19, and 21), irrespective of the H/D ratio. This is because buried pipes are protected from the effects of an underground explosion by the densely packed (high density material) sand. Only a very little portion of the energy used in underground blasts, also known as underground explosions, is transformed into seismic energy. The majority of the energy is used in the heating, melting, and vaporization of the surrounding rocks and soils (Bolt, 1976). The seismic efficiency of explosions is determined by the portion of the very small quantity of total energy that is converted into seismic energy. According to Bolt (1976) and Chi-Yuen et al. (2006), this efficiency varies from 10-3 to 10-2 for sediments (i.e., soils) and solid rocks, respectively. There is no explosion for an explosive charge that is buried far enough. Consequently, most subsurface explosives take place at very shallow depths. In that instance, explosions as tiny as 0.005 Kt have been shown to exhibit liquefaction (Inanov, 1967). Because of this, the cumulative ground-motion energy density decreases as distance increases in a proportionate to

$\frac{1}{R\max^3}$ where $R\max$ is the distance from the source of explosion, and this is consistent with strong-motion as recorded by Chi-Yuen et al. (2006)

The loads from underground blasts and the weight of the soil column above the buried pipelines are the basis for external works. As a result of elastic deformation brought on by these loads, the pipes accumulate strain and internal energy. The pipe moves because kinetic energy are released when it is distorted from its unstressed state. Dense sands, or those with closely spaced grains, have lower porosity and higher density due to the reduced amount of space between the grains. This characteristic of sand is crucial because loosely packed soil might eventually collapse due to the pressure of a construction. Uneven distribution of material might result in cracks or settlement in the foundation. The findings showed that as the H/D increases, the displacement for the 10 mm and 20 mm steel and concrete pipes decreases. This demonstrates that the vertical displacement and H/D ratio have an inverse connection. This suggests that when embedment depth increases and degree of embedment increases, the energy response of dense sand soil will decrease due to an increase in overburden pressure.

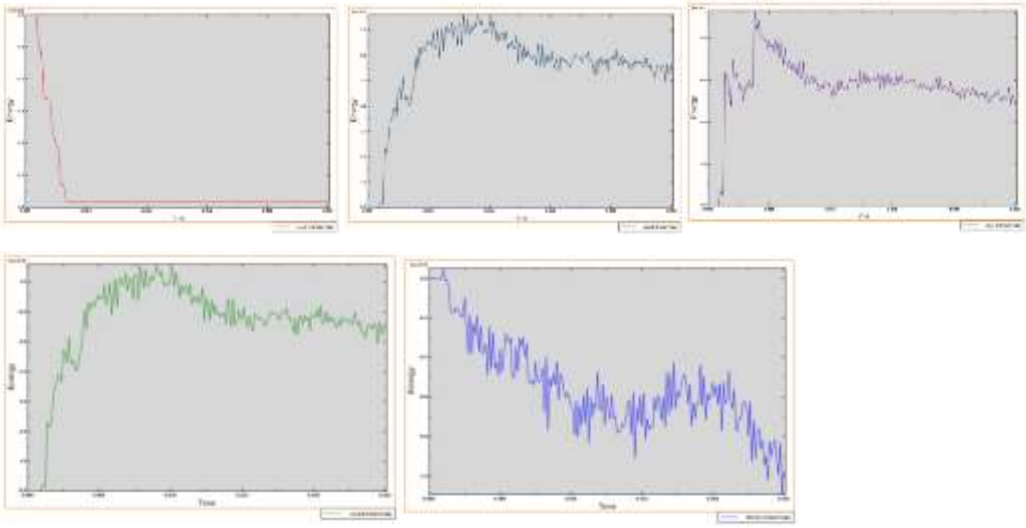


Figure 2: External work and energies generated in 20 mm concrete pipe buried in dense sand (H/D=1) due to ldv from underground accidental explosion

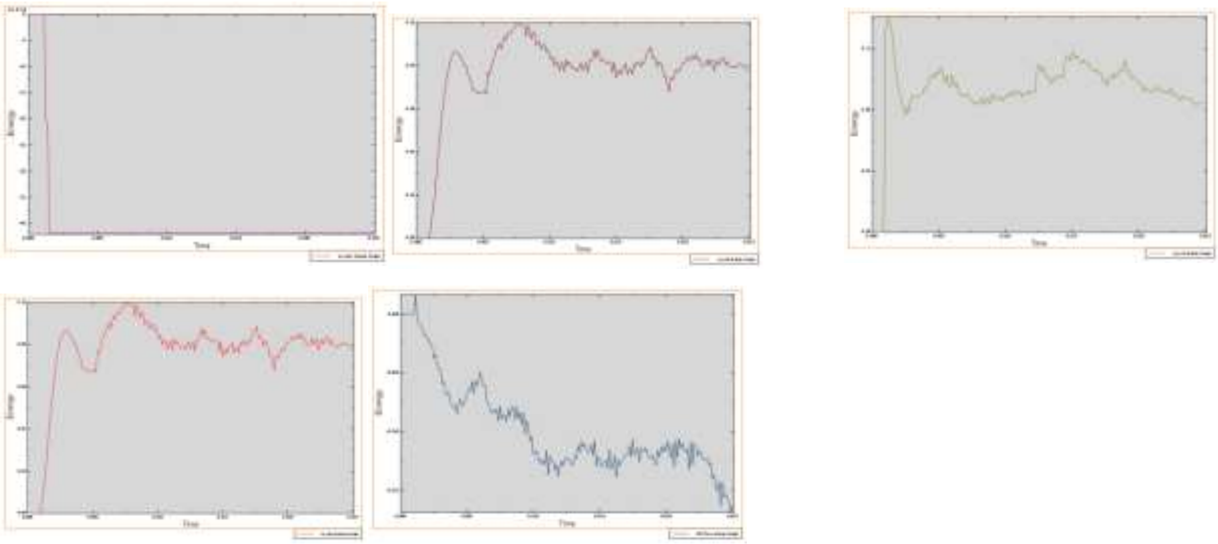


Figure 3: External work and energies generated in 20 mm concrete pipe buried in dense sand (H/D=2) due to ldv from underground accidental explosion

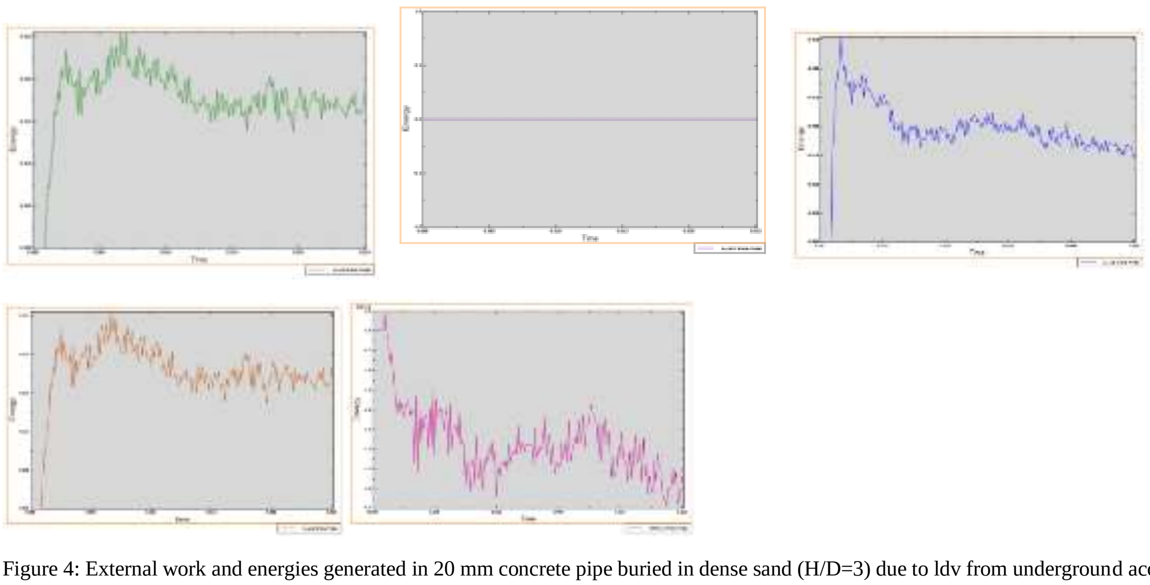


Figure 4: External work and energies generated in 20 mm concrete pipe buried in dense sand (H/D=3) due to ldv from underground accidental explosion

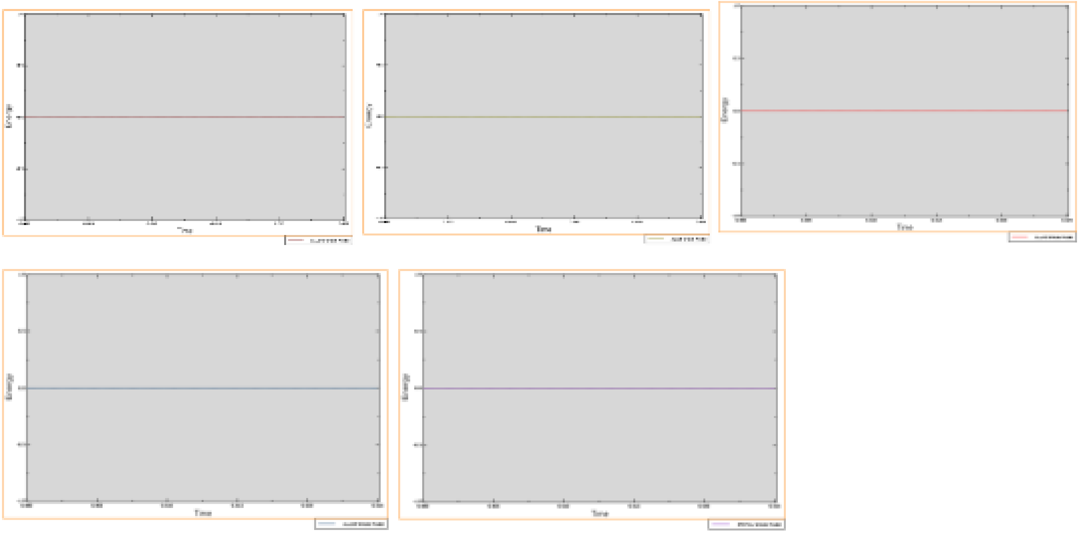


Figure 5: External work and energies generated in 20 mm concrete pipe buried in dense sand (H/D=4) due to ldv from underground accidental explosion

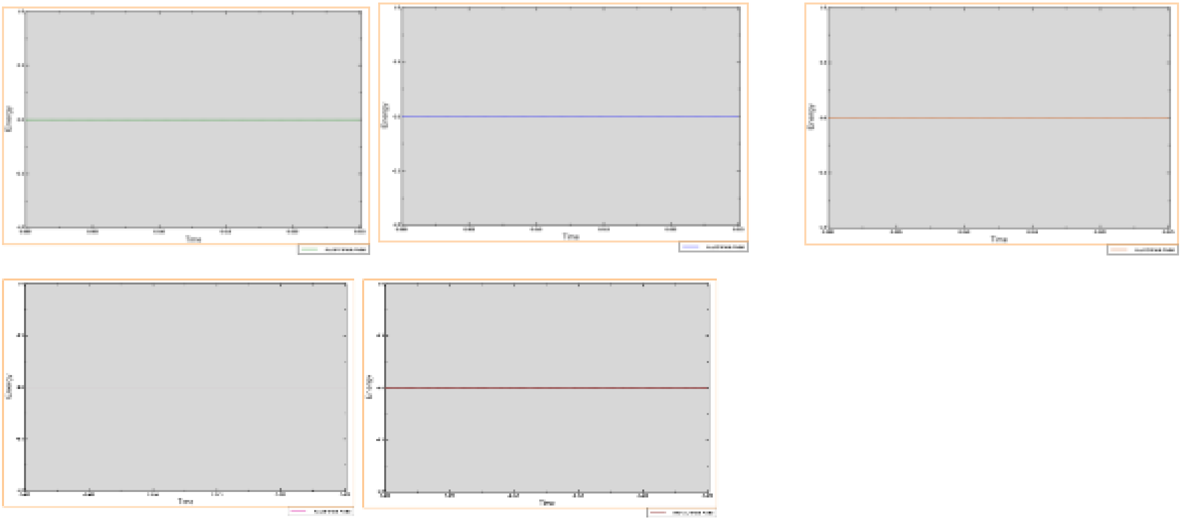


Figure 6: External work and energies generated in 20 mm concrete pipe buried in dense sand (H/D=5) due to ldv from underground accidental explosion

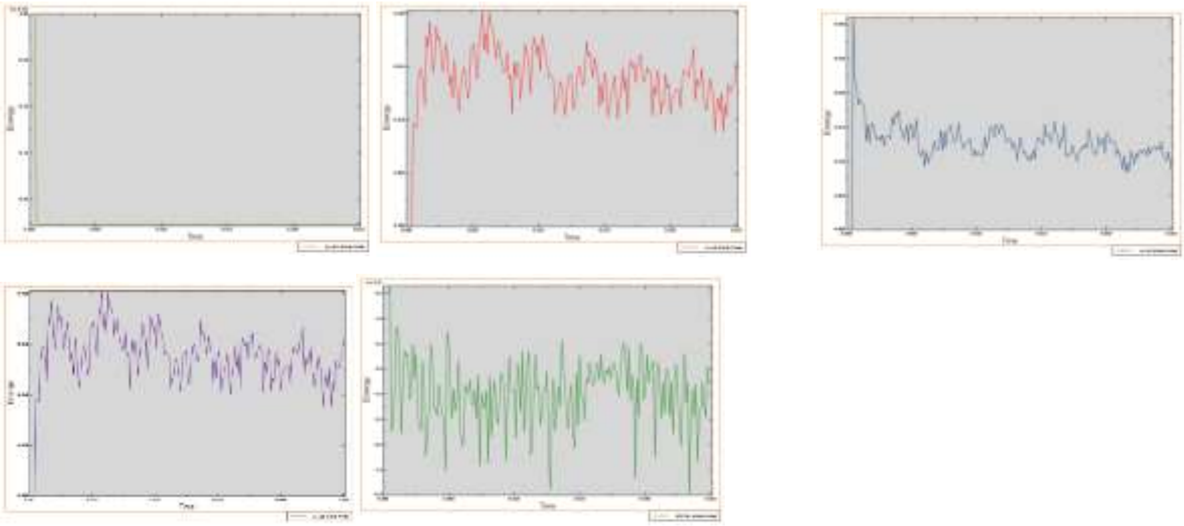


Figure 7: External work and energies generated in 10 mm concrete pipe buried in dense sand (H/D=1) due to ldv from underground accidental explosion

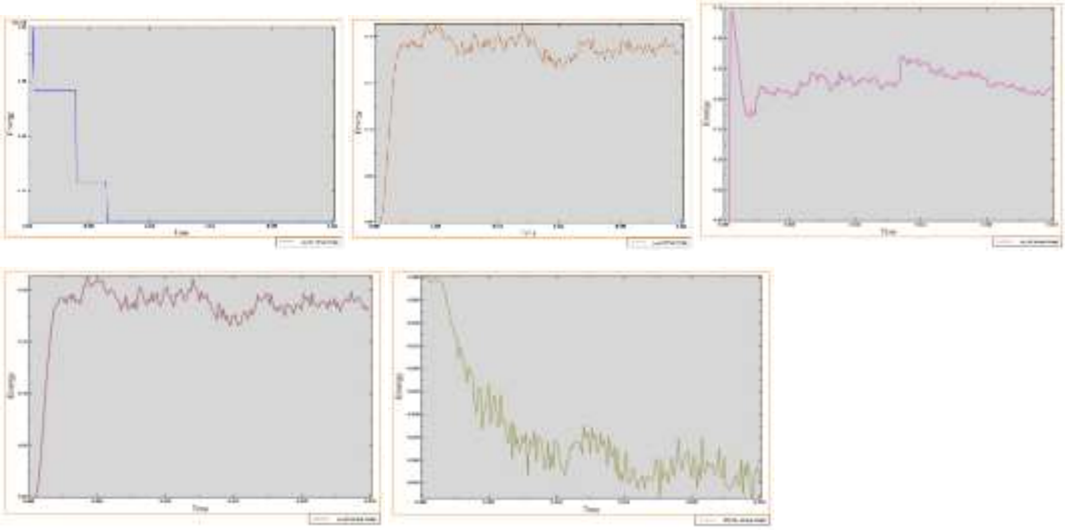


Figure 8: External work and energies generated in 10 mm concrete pipe buried in dense sand (H/D=2) due to ldv from underground accidental explosion

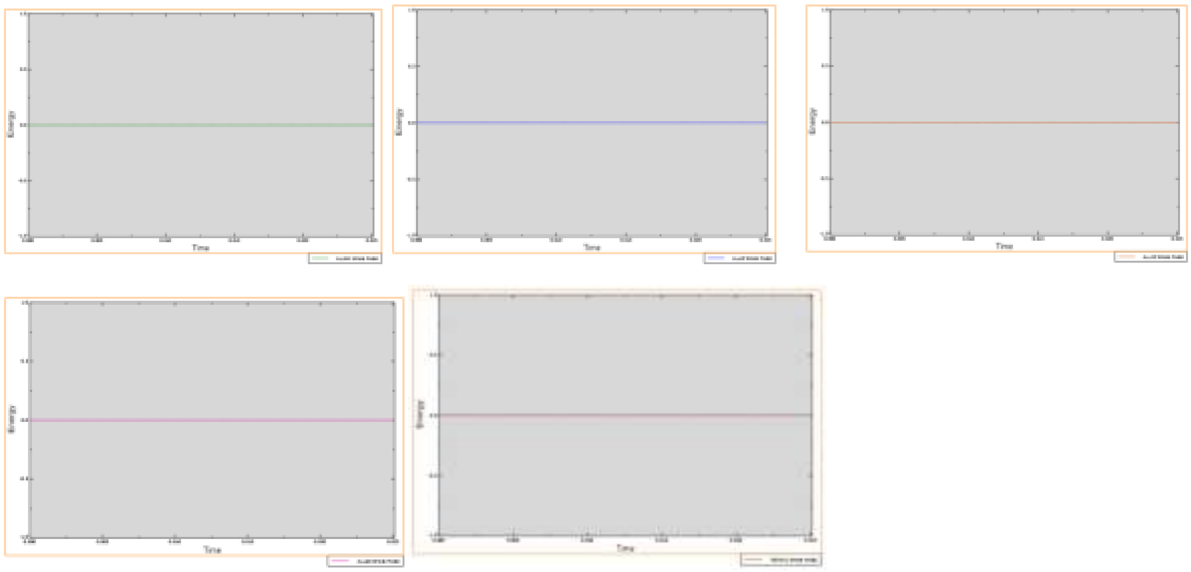


Figure 9: External work and energies generated in 10 mm concrete pipe buried in dense sand (H/D=3) due to ldv from underground accidental explosion

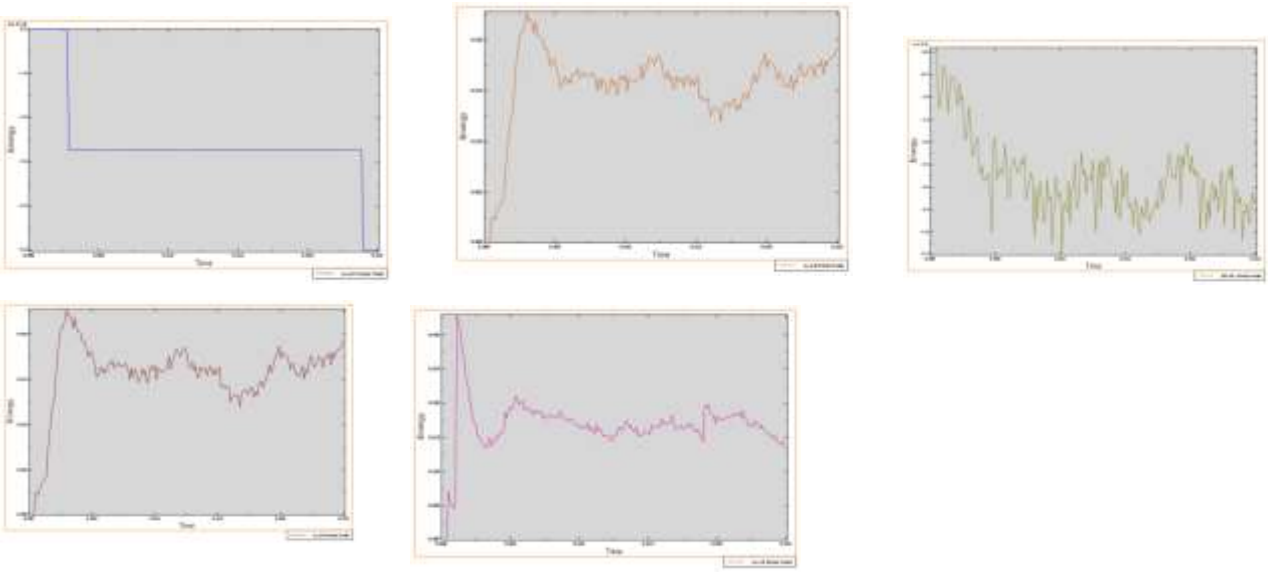


Figure 10: External work and energies generated in 10 mm concrete pipe buried in dense sand (H/D=4) due to ldv from underground accidental explosion

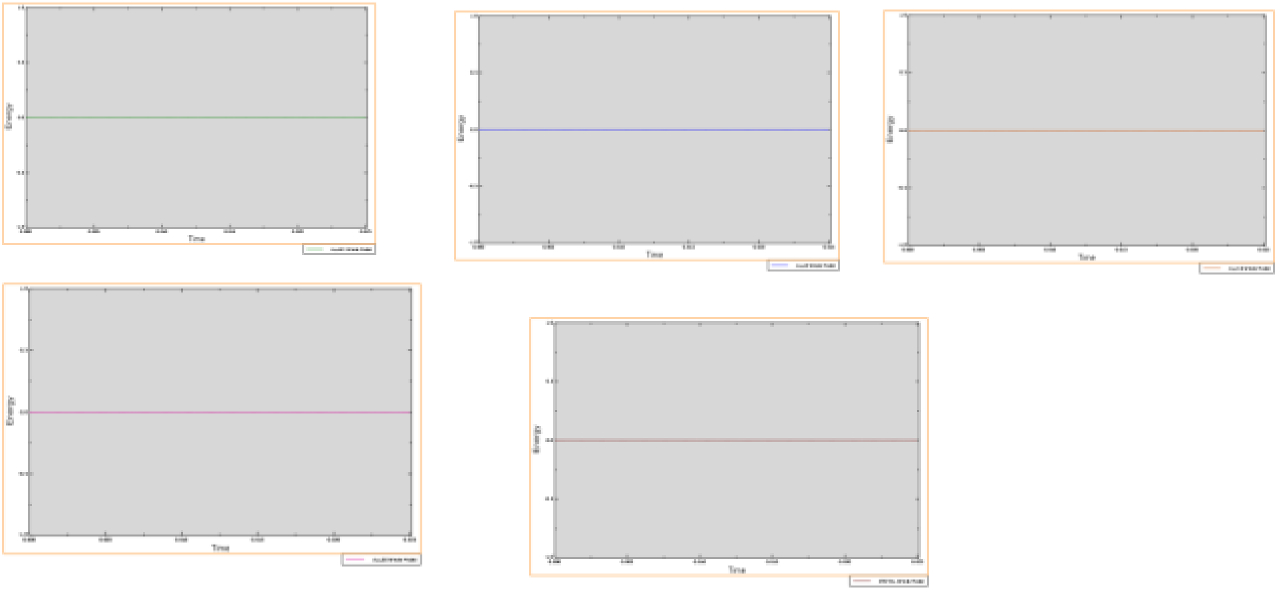


Figure 11: External work and energies generated in 10 mm concrete pipe buried in dense sand (H/D=5) due to ldv from underground accidental explosion

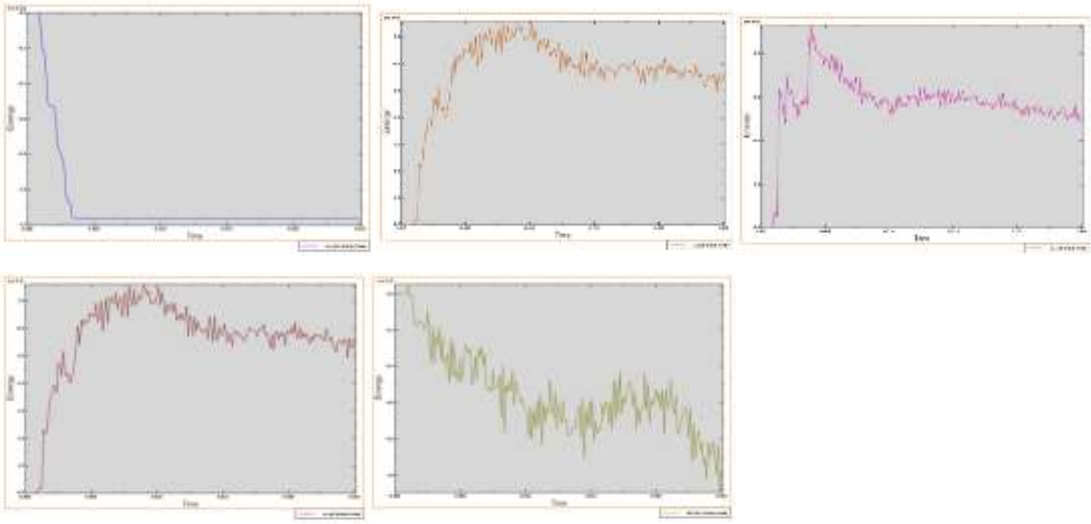
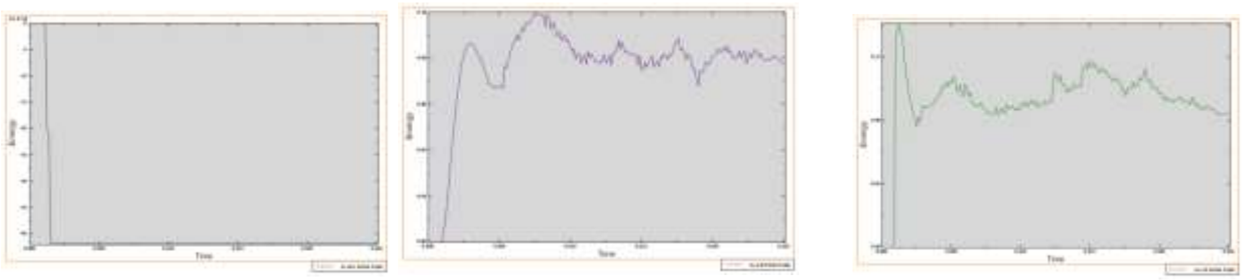


Figure 12: External work and energies generated in 20 mm steel pipe buried in dense sand (H/D=1) due to ldv from underground accidental explosion



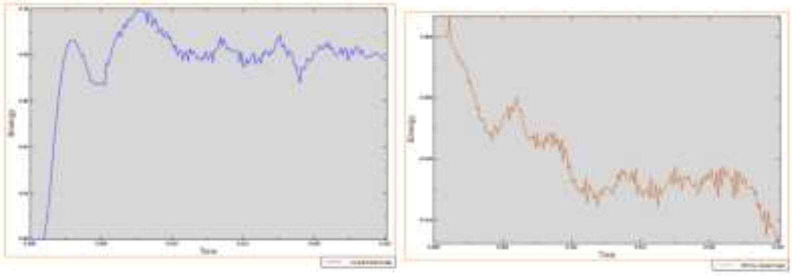


Figure 13: External work and energies generated in 20 mm steel pipe buried in dense sand (H/D=2) due to ldv from underground accidental explosion

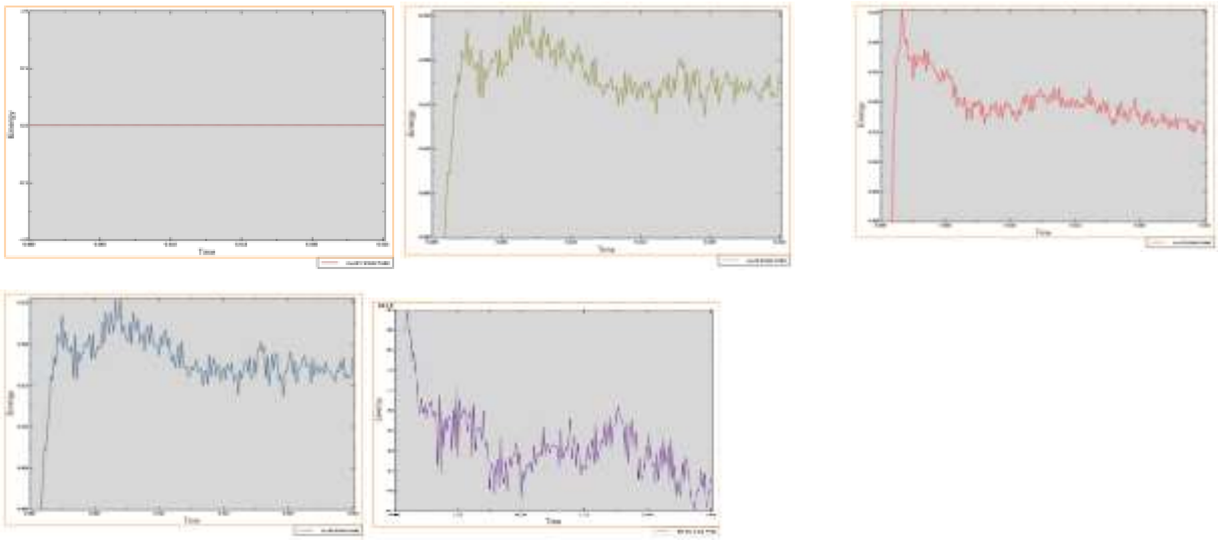


Figure 14: External work and energies generated in 20 mm steel pipe buried in dense sand (H/D=3) due to ldv from underground accidental explosion

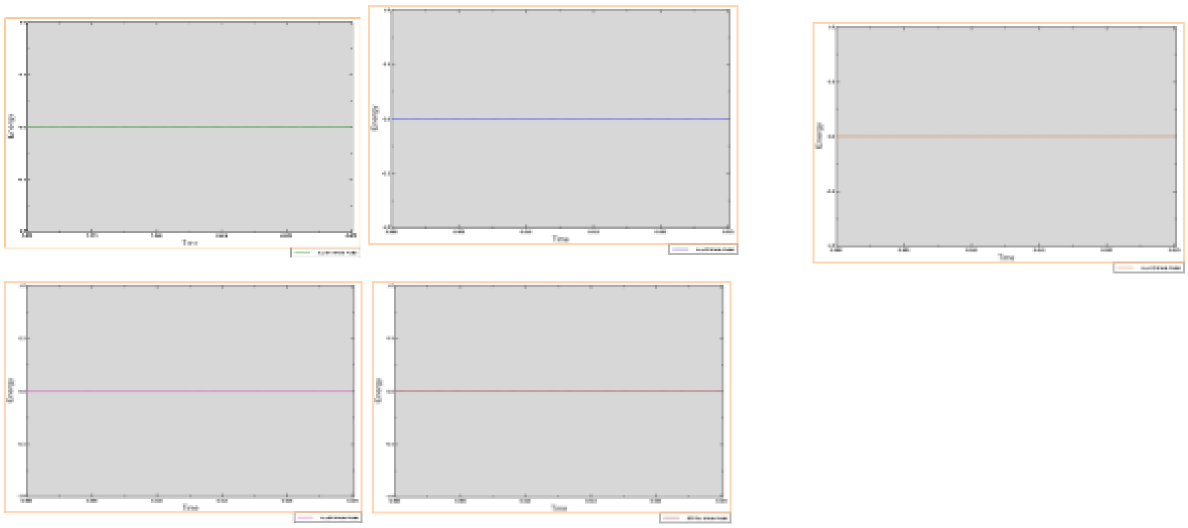
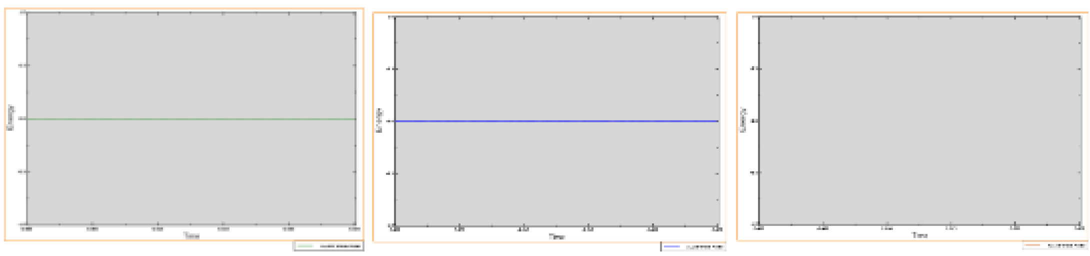


Figure 15: External work and energies generated in 20 mm steel pipe buried in dense sand (H/D=4) due to ldv from underground accidental explosion



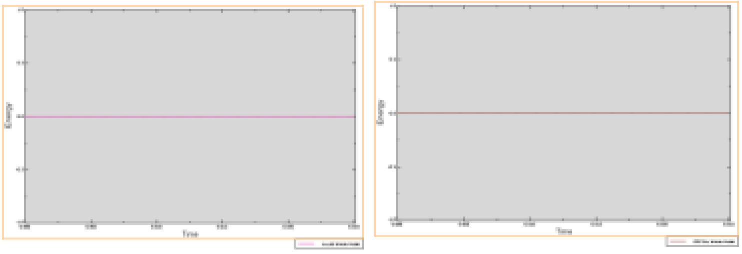


Figure 16: External work and energies generated in 20 mm steel pipe buried in dense sand (H/D=5) due to ldv from underground accidental explosion

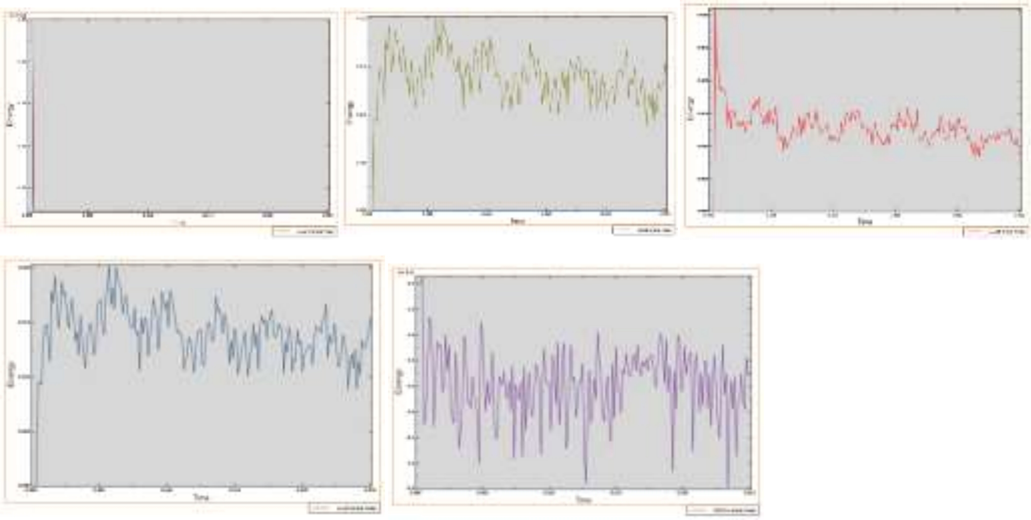


Figure 17: External work and energies generated in 10 mm steel pipe buried in dense sand (H/D=1) due to ldv from underground accidental explosion

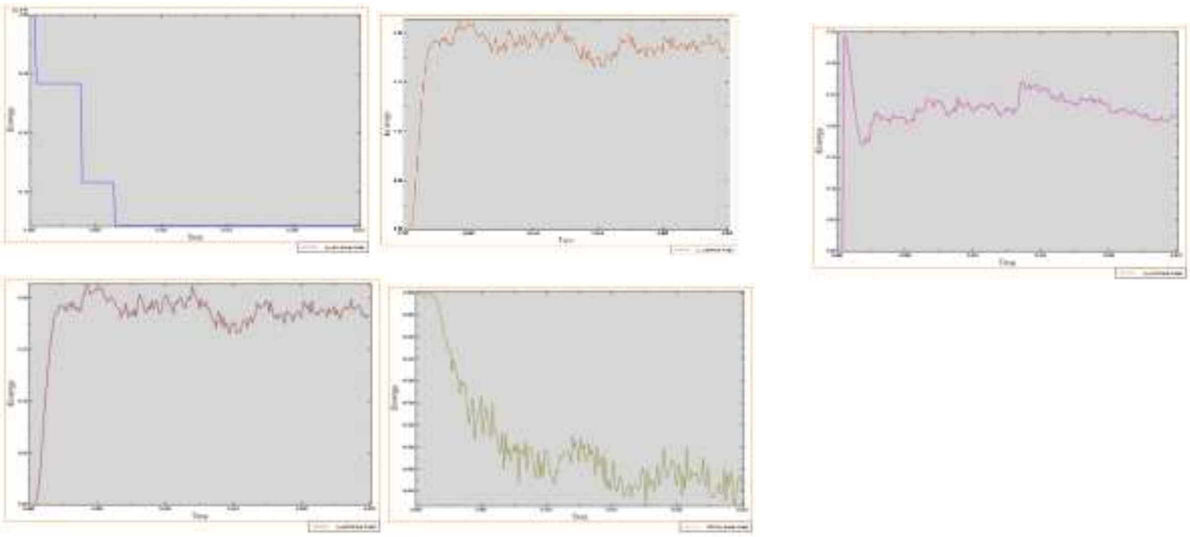
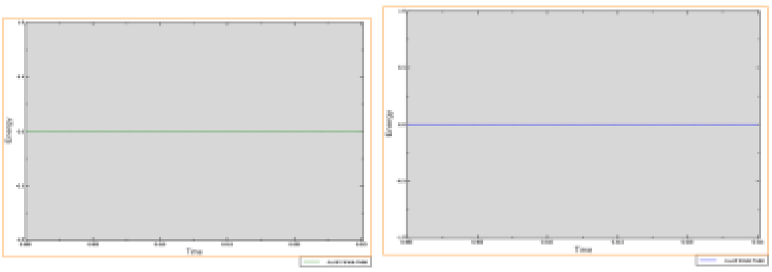


Figure 18: External work and energies generated in 10 mm steel pipe buried in dense sand (H/D=2) due to ldv from underground accidental explosion



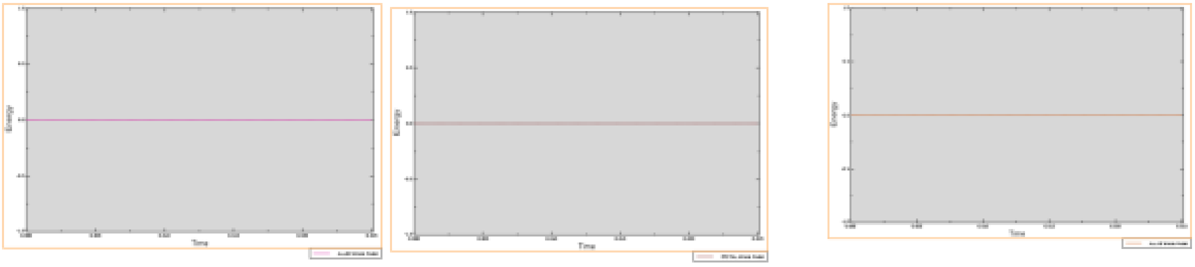


Figure 19: External work and energies generated in 10 mm steel pipe buried in dense sand (H/D=3) due to ldv from underground accidental explosion

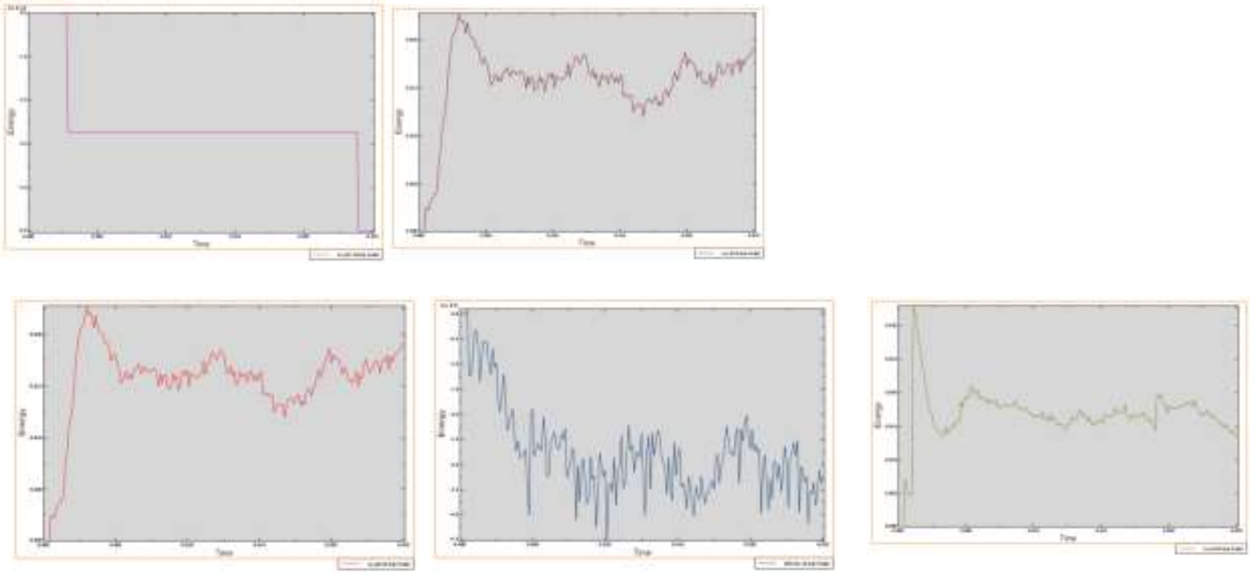


Figure 20: External work and energies generated in 10 mm steel pipe buried in dense sand (H/D=4) due to ldv from underground accidental explosion

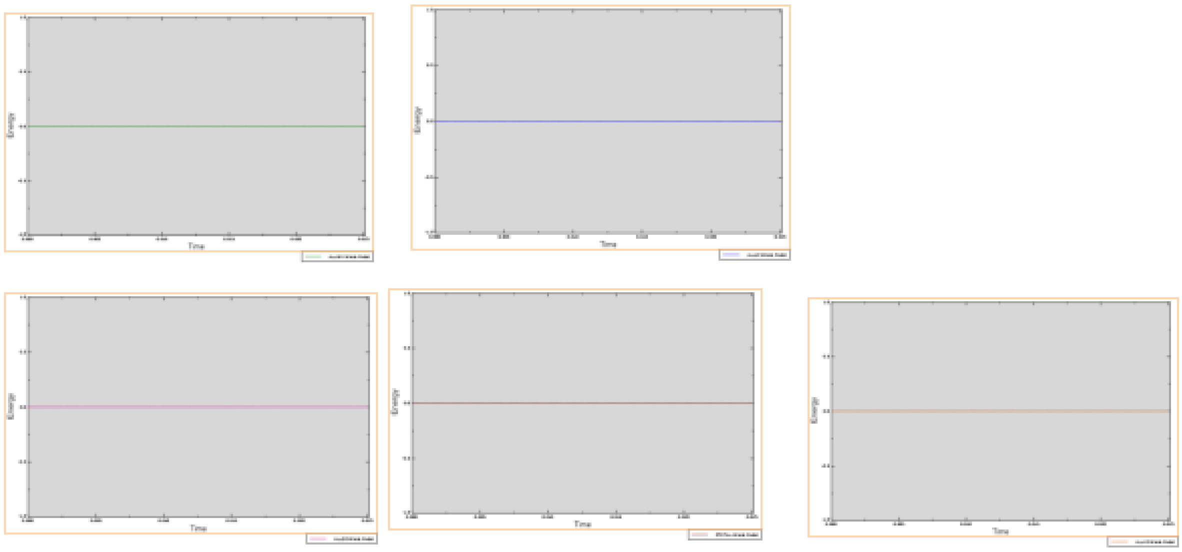


Figure 21: External work and energies generated in 10 mm steel pipe buried in dense sand (H/D=5) due to ldv from underground accidental explosion

IV. CONCLUSION

The ABAQUS Numerical code has been utilized to investigate and present the external works, internal energy, kinetic energy, strain energy, and total energy generated in 10 mm and 20 mm concrete and steel pipes buried in dense sand at different embedment ratios due to loading wave velocity from underground accidental explosion. Regardless of the material qualities, dense sand (high density material) also plays a significant role in preventing the impact of an underground unintentional explosion in buried pipelines, as seen by the nearly zero exterior work in all cases under investigation.

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