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Full Length Research Paper

Simulation comparison of the dispersion behaviour of dry sand subjected to explosion

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This research simulated the dispersion behavior of sand subjected to explosion on the surface of a sand layer. The simulation was conducted using AUTODYN. Explosion effects from an explosive were achieved by using the computer program, Conventional Weapon Effects Backfill (CONWEB), which was based on field data compiled by the U.S. Army (US Army, 1986). Three different governing equations were used for air, sand and explosive. Ideal gas equation was used to equate the movement of air and the dry sand was based on the compaction effort. For the explosion, the JWL (Jones-Wilkins-Lee) equation was used. This paper presents the effect of explosion on the crater depth, crater diameter and overpressure exerted on sand and the surrounding air. The results have shown that crater depth and diameter increase with time during explosion. The experimental data on crater depth, however, were initially lower than the numerical simulation, but after 30 ms, it increased more than the numerical simulation. The overpressure showed a reducing trend with time. The numerical simulation, based on AUTODYN, predicted higher crater depth and overpressure at the initial stage, but showed a good agreement with the experimental data with time.

Key words: Numerical simulation, AUTODYN®, dry sand, electro-optical system (EOS), Jones-Wilkins-Lee (JWL), explosive, Euler, conventional weapon effects backfill (CONWEB).

INTRODUCTION

Previous researchers have done some researches on the effect of explosion on/into the soil, which was conducted to influence the design of underground structures and support military vehicles. In the recent decades, several experimental and numerical investigations have been carried out to determine the overpressure and crater depth of explosive materials into/on different soil types (Polyak and Sher, 1978; Rodionov and Terent'ev, 1985; Absil et al., 1997; Dorn et al., 1999; Williams and Poon, 2000; Laine and Sandvik, 2001; Niekerk, 2001; Wang, 2001; Cheng et al., 2002; Fairlie and Bergeron, 2002; Gupta, 2002; Jacko et al., 2002; Persson et al., 2003; Rhijnsburger, 2003; Fiserova et al., 2004; Olofsson, 2007; Niroumand and Kassim, 2009). The previous researches are shown in Table 1.

Simulation of the performance of soil subjected to close-in explosion, using explosives materials, is a challenge for the research. It is important to study the interaction between the explosion and soil response because different structures are affected differently, causing deformation due to detonations. The experimental cases and simulation analysis are very important in this research, due to the fact that the numerical simulations can minimize the number of experimental cases, saving considerable amounts of cost and time. Simulation of detonations is complex where the explosion may cause a shock wave on the soil and air that will interact with different materials. AUTODYN 2D software is a good program for this application.

FIELD DATA

An explosion effect, from an explosive material, was achieved by using the computer program, Conventional Weapon Effects Backfill (CONWEB), which was based on the field data compiled by the U. S. Army (US Army, 1986). Input to the CONWEB software involves dry sand properties and explosive types, to include their mass. The dry sand properties were chosen from results of tests in

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Table 1. Analytical and numerical studies on explosion into/on cohesion less soils.

Researcher	Code/software	Cell size (mm)	Explosive	Soil
Polyak and Sher (1978)	Mathematical model	-	Solid - liquid model	Rigid surface
Rodionov and Terent'ev (1985)	Mathematical model	-	Solid - liquid model	Rigid surface
Absil et al. (1997)	AUTODYN	2	475 g composition B	-
Dorn et al. (1999)	FLUENT and LS-DYNA	-	-	-
Williams and Poon (2000)	LS-DYNA	-	7.5 kg C4	Cohesion less soil
Laine and Sandvik (2001)	AUTODYN	8	10.4 kg composition B	Cohesion less soil
Niekerk (2001)	MSC. Dytran	-	800 g Pentolite	-
Wang (2001)	LS-DYNA	-	100 g C4	Cohesion less soil
Cheng et al. (2002)	AUTODYN and MSC. Dytran	10	5 kg TNT	Rigid surface
Fairlie and Bergeron, (2002)	AUTODYN	25	1 kg C4	Cohesion less soil
Gupta (2002)	LS-DYNA	-	907.2 g Pentolite	-
Jacko et al. (2002)	AUTODYN	-	500 gr TNT	-
Persson et al. (2003)	AUTODYN	-	0.125/0.5/1/4 kg PETN	-
Rhijnsburger (2003)	LS-DYNA	-	10 kg TNT	Rigid surface
Fiserova et al. (2004)	AUTODYN	-	100 g TNT	Cohesion less soil
Olofsson (2007)	FLAC	-	-	-
Niroumand and Kassim (2009)	AUTODYN	10	100 g TNT	Cohesion less soil

geotechnical laboratory of Universiti Teknologi Malaysia. The explosive used was Tri Nitro Tulane (TNT) with 100 g and a density of 1641 kg/m^3 . The dry unit weight of sand (1690 kg/m^3) was achieved in the dry sand of Malaysia.

SIMULATION METHOD USING AUTODYN 2D

Basic ideas of AUTODYN 2D

The foundation of AUTODYN 2D is fully integrated in the analysis codes that are specifically designed for non-linear dynamic deformations and, especially, for large strain deformations. Precisely, it is the explicit numerical analysis codes, sometimes referred to as hydro codes, where the equations of mass, momentum and energy conservation, coupled with materials descriptions, are solved. The differential function is solved in AUTODYN using a combination of finite volume, finite element and mesh free solver technologies. The application implemented an Eulerian mesh with the 2D multi-material option. So, the Euler capability was extended for multi-materials flows, to include materials strength. The solvers that were implemented, included the Lagrange Euler, Arbitrary Lagrange Euler, Smoothed Particle Hydro dynamics, Shell and Beam in AUTODYN. Lagrange is a coordinate system, where the coordinates move with the material ideally, in regions of relatively low distortion and possibly large displacement. Its moderate pressure gradients can be simulated, due to the fact that the material boundaries are well defined and the pressure peaks are accurately predicted. The Eulerian representation allows materials to flow from cell to cell, while the structured IJK numerical mesh is spatially fixed. The treatment is suitable for modeling fluids, gases and large deformation of structural materials.

AUTODYN 2D model for explosion on the dry sand of Malaysia

The model size for AUTODYN 2D is 1000 and 1500 mm in length and height for sand, respectively, while it is 1000 and 700 mm in length and height for air, respectively. However, its explosive material is 50 mm in diameter. The dry sand-explosion interaction makes a significant contribution to the total loading, in which the first step undertaken was to simulate the explosion wave propagation in the surrounding air, in order to gain familiarity with the AUTODYN 2D software and ascertain the numerical simulation procedures in AUTODYN 2D. However, the numerical analysis findings were compared with the experimental data obtained from CONWEB.

A two-dimensional axi-symmetric model was developed, using the multi-material solver (Euler), in AUTODYN 2D. The explosive material was laid on the dry sand surface. The model includes the properties of soil and explosive materials that are shown, respectively in Table 2.

The explosive material is represented by 100 g TNT charge which is described by the Jones-Wilkins-Lee state equation. The Jones-Wilkins-Lee (JWL) state equation is widely used in explosion calculations, although the mesh size is 10 mm. The model setup is shown in Figure 1, whereas the origin of the co-ordinates (0, 0) is located in

Table 2. Model properties for explosion on the dry sand of Malaysia**.**

Model	2D axi-symmetrical model
Solver	Euler
Units	mm, g, ms
Boundary conditions	Flow out
Model sizes	Air: 1000 mm length, 700 mm height; dry sand: 1000 mm length,1500 mm height
Explosive	TNT: 100 g
Size	Radius: 25 mm
EOS	JWL (Jones-Wilkins-Lee)
Surrounding material	Air
EOS	Ideal gas
Soil	Dry sand of Malaysia
EOS	Compaction
Strength model	Granular
Failure model	-1 kPa

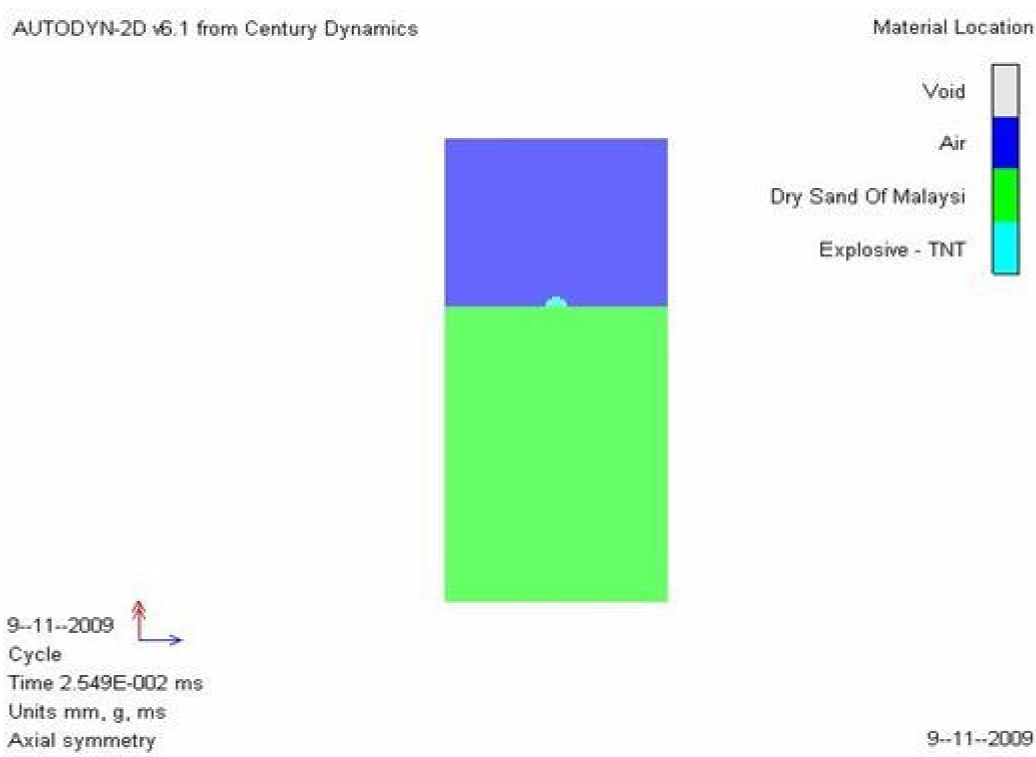

Figure 1. The model setup.

the inter section of the dry sand surface. Moreover, the dry sand is modeled as a porous material (Laine and Sandvik, 2001). The dry sand model includes an EOS that describes the compaction and granular strength model, expresses the yield surface dependence on pressure and assumes the negligible tensile strength. The model is derived by dry sand using 1690 kg/m^3 in dry density.

The explosion steps are shown for dry Malaysian sand in Figures 2 to 5. It is clearly shown that the influence of

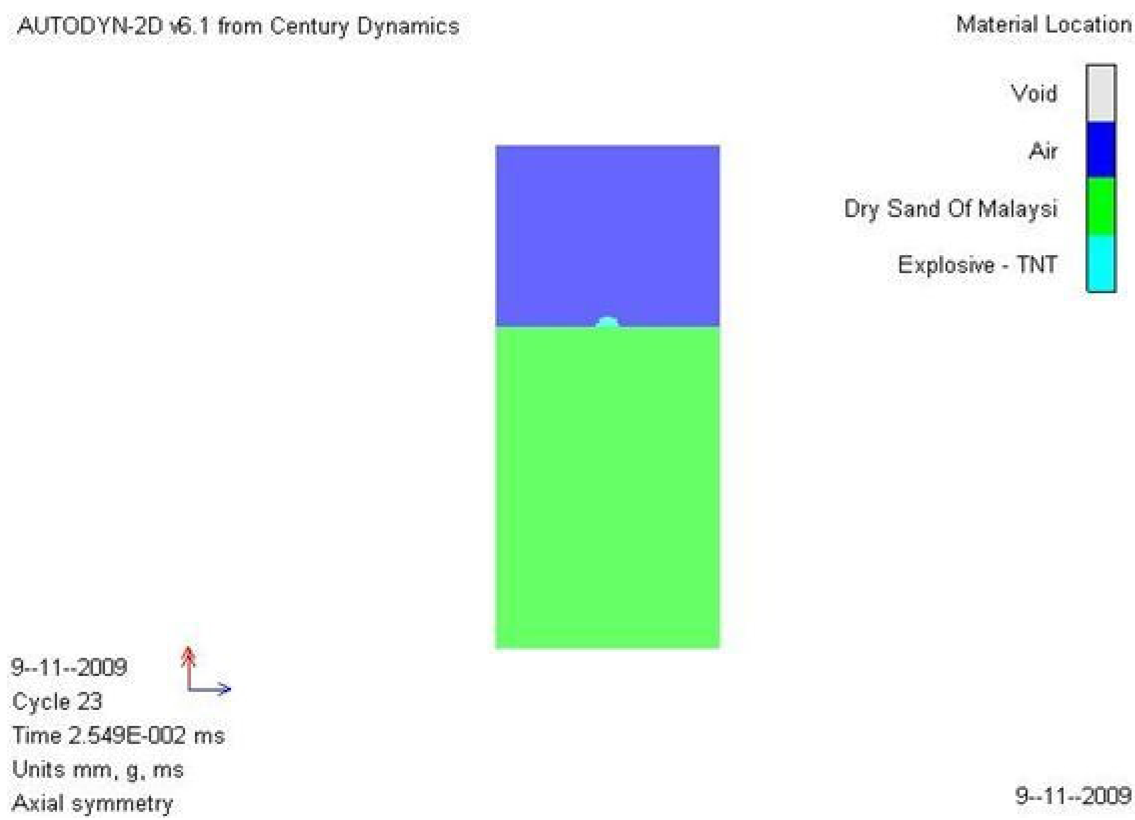

Figure 2. The material variation in 1.36 ms.

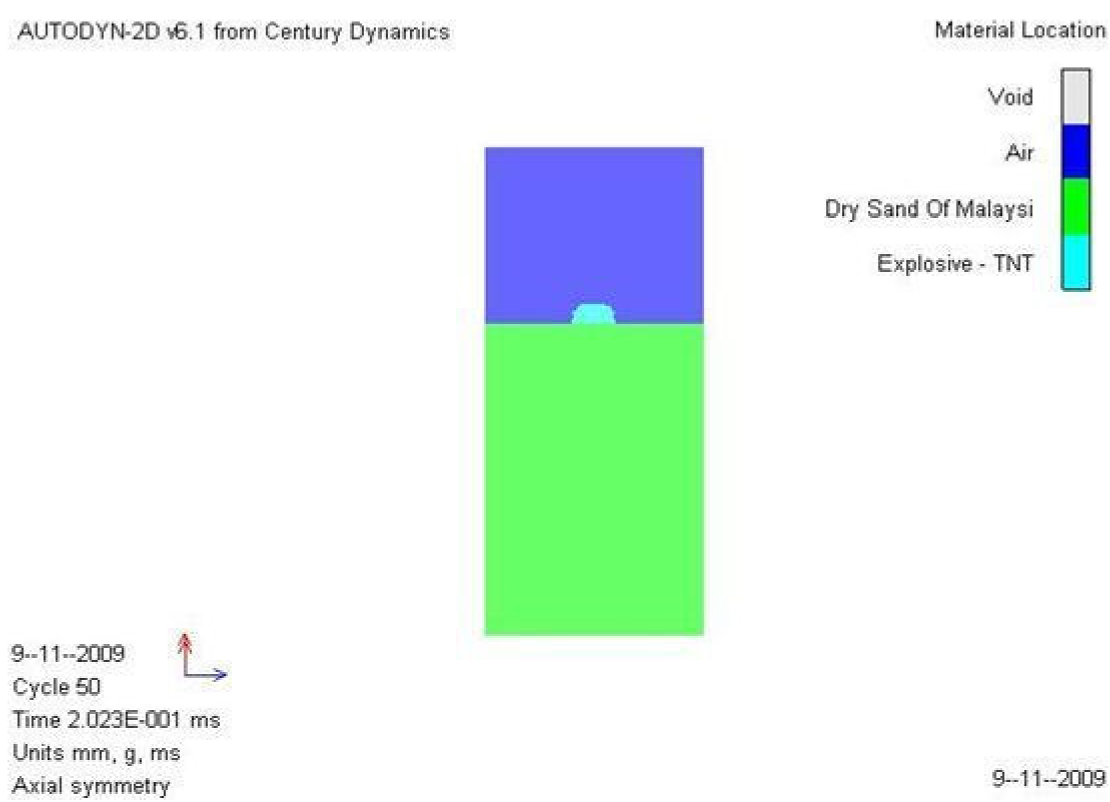

Figure 3. The material variation in 2.02 ms.

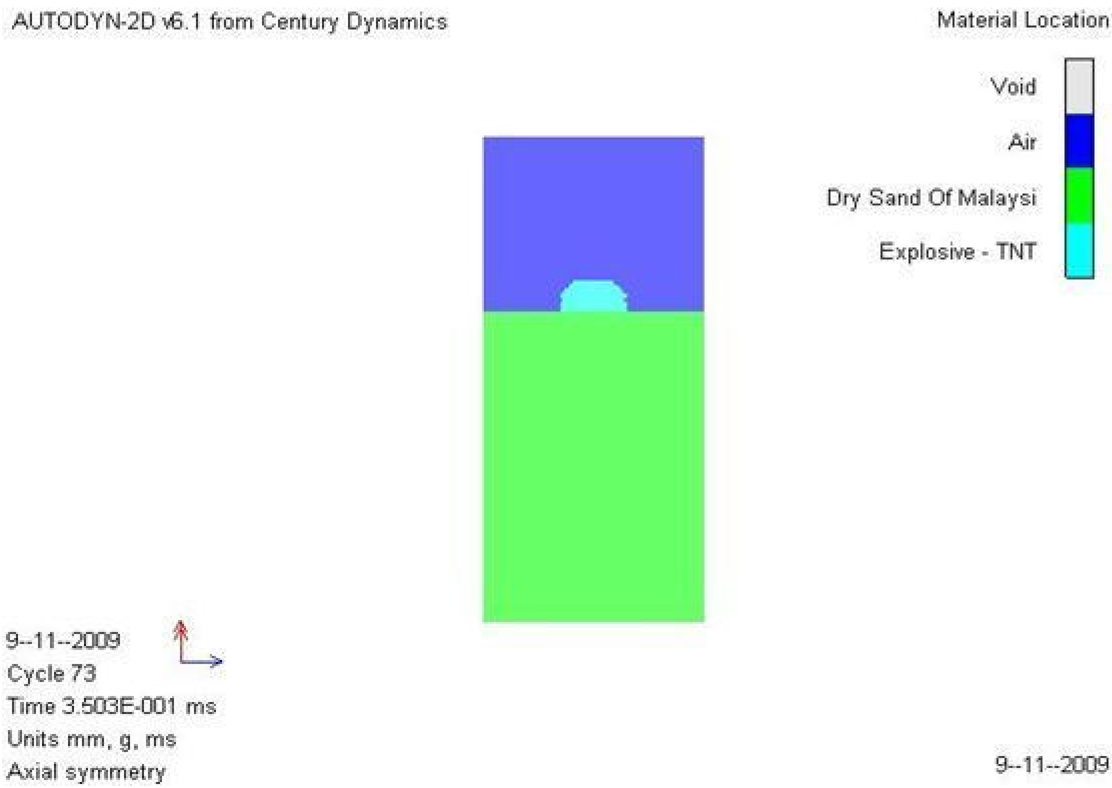

Figure 4. The material variation in 3.50 ms.

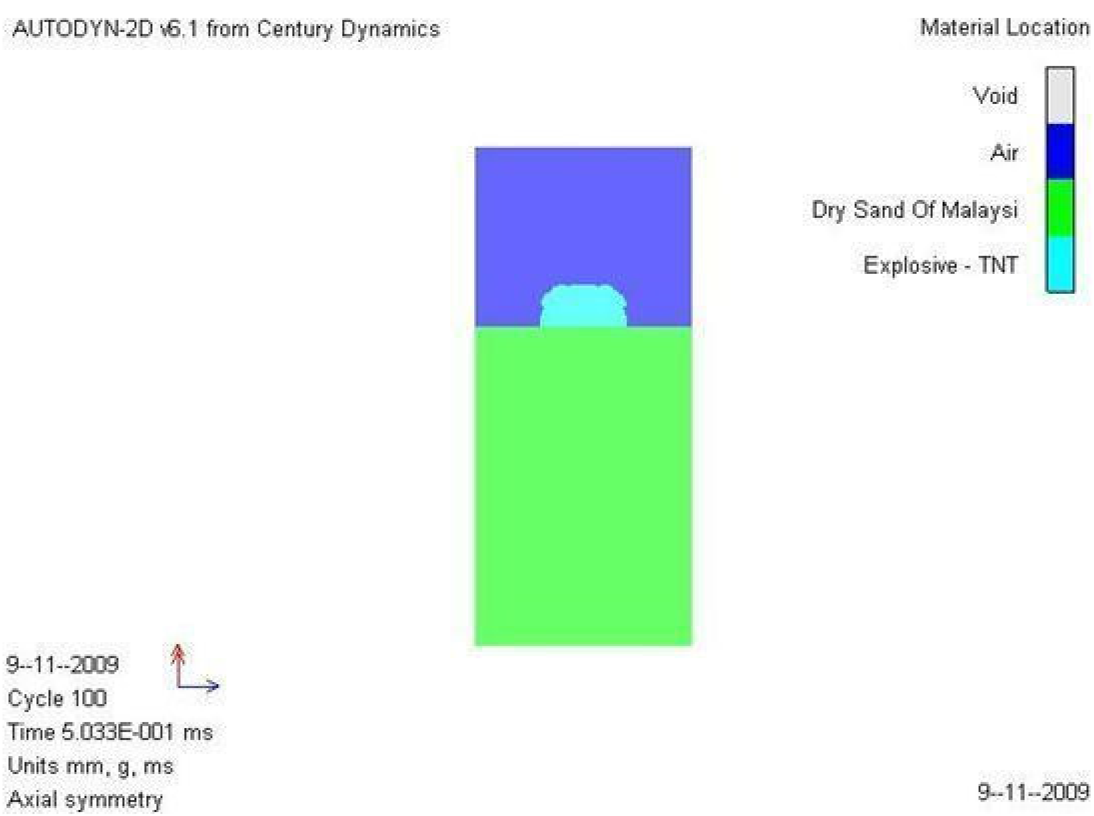

Figure 5. The material variation in 5.03 ms.

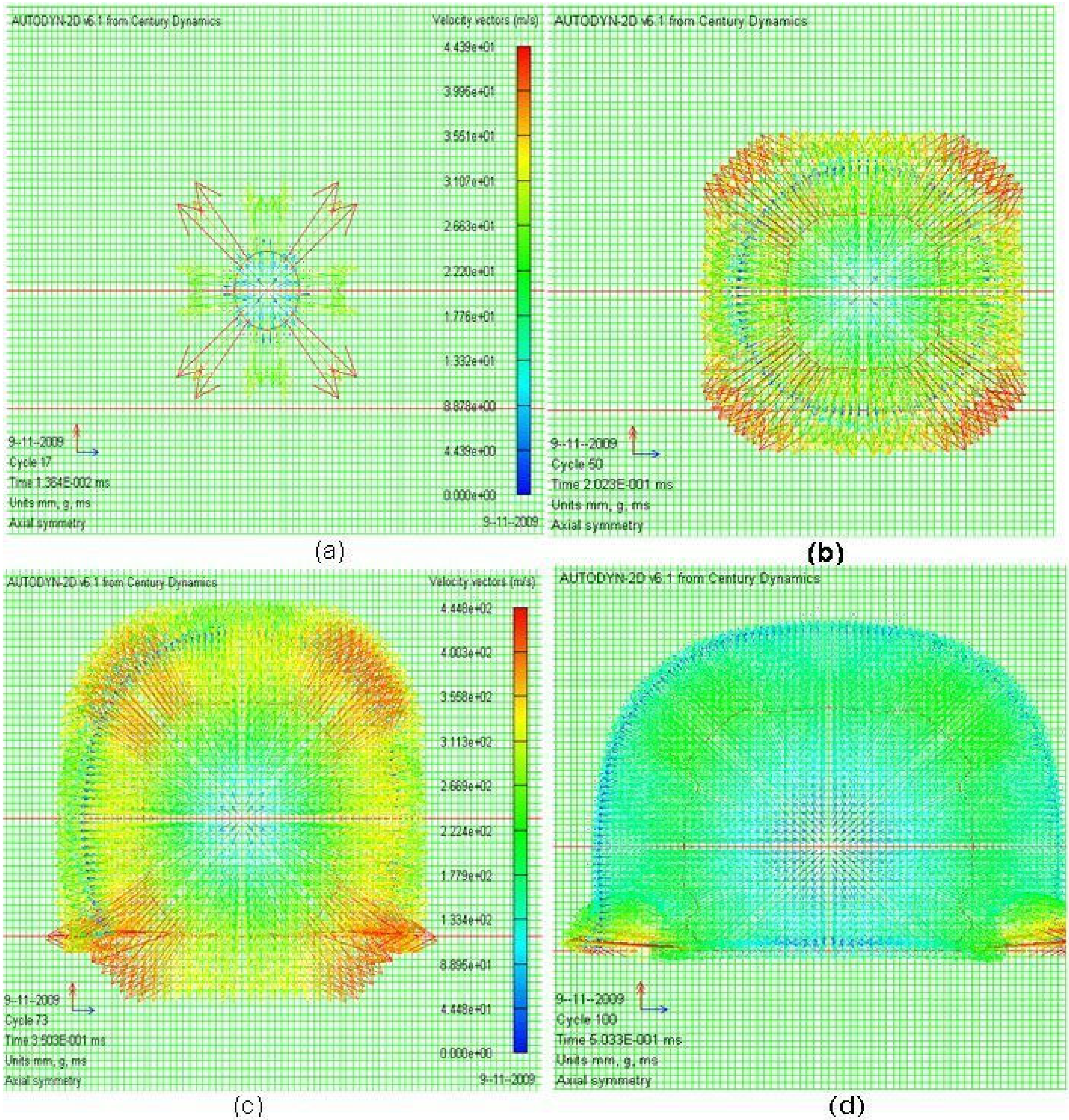

Figure 6. Velocity vector lines and displacements in (a) 1.36 ms, (b) 2.02 ms, (c) 3.50 ms, and (d) 5.03 ms.

explosion results in Figures 4 and 5 is more than that in Figures 2 and 3. The maximum pressure based on numerical simulation and experimental results is shown in Figure 6, respectively. The model that used the ideal gas EOS was not included, because it was not in good agreement with the explosion wave parameters of CONWEB at the initial distance. Therefore, the ideal gas representation will not be considered in future studies.

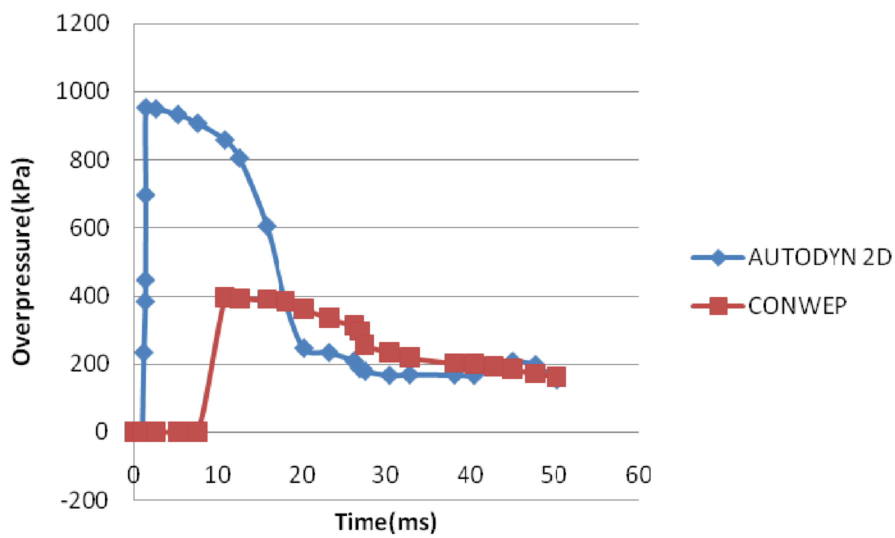

Figure 7. Comparison of overpressure and time between numerical simulation and experimental (CONWEB).

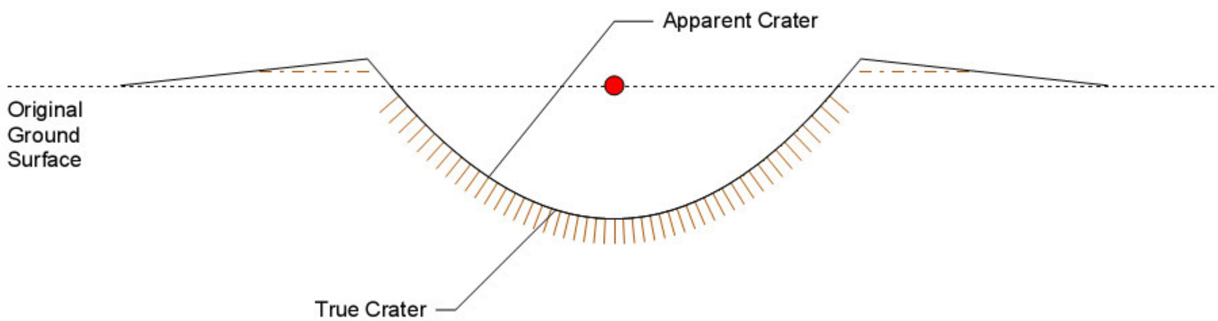

Figure 8. View of a crater in explosion.

The results based on the JWL, EOS model are not included in the entire region observed.

The displacement variations are described by the displacement of materials, based on time variation, in terms of height of ejecta, crater diameter, height and width of detonation products cloud. Expansion of the explosion products, after breaking through the dry sand, is characterized in the conditions of height and width, using the explosion products cloud.

The overpressure vs time variations, based on numerical simulation and experimental findings, are shown in Figure 7. In the case of explosion on dry sand, the explosion was made with a crater, amid true radius. However, Figure 8 shows the view of a crater.

Crater deformation vs time variation, for the explosive materials on dry sand in numerical simulation and experimental (CONWEB) findings, is shown in Figure 9. According to Figure 9, the crater formation, based on the experimental (CONWEB) and numerical simulation findings, includes a good conformity.

At 1.36 ms, dry sand ejecta reaches the maximum height of 90 mm. Moreover, displacement variations are obtained "by hand" through the velocity vector plots.

Conclusions

The experiment was conducted based on Malaysian dry sand parameters, which were imported in CONWEB for the experimented result. The simulation was conducted using AUTODYN 2D, based on the soil parameters, explosive properties, experiment condition and embedment ratio for explosive materials. More so, the feasibility of the proposed modeling methodology was demonstrated. Sensitivity analysis of the model set up was conducted to show the capability of the simulation analysis. However, the experimental data on crater depth were initially lower than the numerical simulation, but later increased after 30 ms. Overall, the numerical results, using AUTODYN 2D, has always been in good

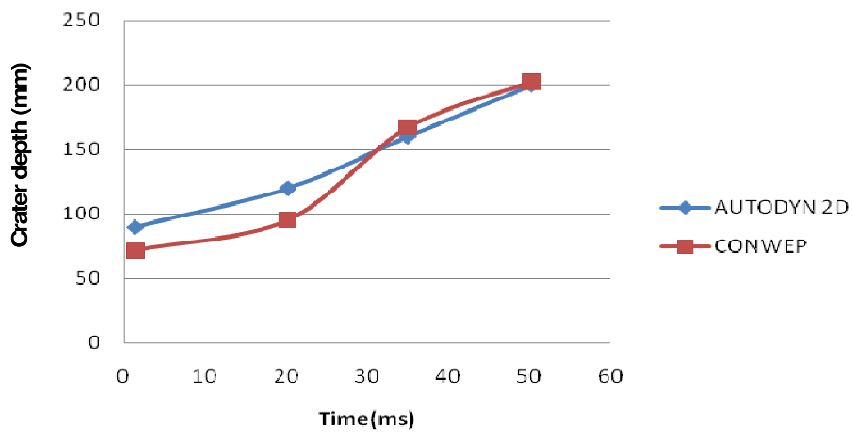

Figure 9. Comparison of crater depth and time variations between numerical simulation and experimental findings.

agreement with the experimental data based on CONWEB findings.

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