Shock Wave Impact on Weak Concrete

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Abstract. A blast wave front possesses characteristics similar to a shock wave created in a shock tube and a reasonably realistic simulation of bomb blast loading on structures can be made using an equivalent shock simulator. A weak sand-cement mixture is tested in a blast wave simulator. The shock propagation and attenuation in the cylinder were correlated against quantity and distance of a TNT charge.

1 Introduction

The past decade has brought to the public attention terrorist bombings of civilian structures in many parts of the world. There is an urgent need to protect civilian structures from such blasts. The major effect of a terrorist-type bomb is from the blast, particularly from blast wave reflection when the pressure is amplified through multiple reflections in multiphase media or in confined geometries.

Protective strengthening and hardening are the two measures that can be taken to prevent or minimize damage to a structure from blast waves [1]. The best way to protect an existing structure is hardening like building a protective barrier built around it. In order to withstand the transient loads generated by bomb blasts, the elements of a structure need to be both massive and able to absorb large amounts of energy. For this reason, nearly all purpose-built protective structures are constructed of concrete or reinforced concrete.

This paper reports on the use of a shock wave to simulate the effect of a blast wave on weak concrete. A high-performance shock tube was modified to accept a standard concrete test cylinder in its test section. The concrete cylinder is exposed to a shock wave of varied strengths to provide the desired equivalent blast wave parameters. The development of the simulation facility is discussed in [2].

A weak concrete mix is used as it can disintegrate into small particles that can absorb a large amount of energy in the process. The small particles in the debris tend to disperse in different directions. Thus they cause less damage to the existing structure or its inhabitants and contents compared to the larger size shrapnel emanating from the disintegration of a stronger concrete mix (lower percentage of sand). The proposed mixture is also cost effective both in construction and cleanup after a blast.

2 Comparison between Shock wave and Blast wave

The Mach number of the shock wave in a shock tunnel can be obtained by

$$M_s = \frac{d}{t_{PT2} - t_{PT1}} (\gamma_1 R_1 T_1)^{-1/2} \tag{1}$$

where t_{PT2} and t_{PT1} are arrival times at the two transducers, d is the distance between them, γ_1 is the ratio of specific heats for air, R_1 is the gas constant for air, and T_1 is the temperature of air in the driven tube.

Smith and Hetherington [3] discuss wavefront parameters and scaling laws. Each simulation is equivalent to an explosion of a particular strength at a particular distance. The wavefront static pressure P_2 in kPa is given by

$$P_2 = 101.325 + \frac{1407.2}{Z} + \frac{554}{Z^2} - \frac{35.7}{Z^3} + \frac{0.625}{Z^4} \qquad (0.05 \leq Z \leq 0.3) \tag{2a}$$

$$= 101.325 + \frac{619.4}{Z} - \frac{32.6}{Z^2} + \frac{213.2}{Z^3} \qquad (0.3 \leq Z \leq 1) \tag{2b}$$

$$= 101.325 + \frac{66.2}{Z} + \frac{405}{Z^2} + \frac{328.8}{Z^3} \qquad (1 \leq Z \leq 10) \tag{2c}$$

The scaled distance parameter Z is given by

$$Z = R/W^{1/3} \tag{3}$$

where R is the distance from the charge center in meters and W is the charge mass in kilograms of TNT. With the Z parameter, an equivalent blast strength and range is determined for each test in the shock tube. The dynamic pressure q2 of the wavefront is given by [3]

$$q_2 = \frac{5P_2^2}{2(P_2 + 7p_{amb})} \tag{4}$$

where $p_{amb} = 101.325$ kPa is the ambient pressure. The total pressure of the blast wavefront can be obtained from the addition of the results of Eqns. (2a)–(2c) and (4) and compared with the total pressure [4] of the shock wave obtained from Mach number calculated in Eqn. (1).

3 Concrete Cylinder and Test Procedure

The test section accommodates a standard concrete cylinder with a length of 30.5 cm and a diameter of 15.2 cm. The cylinder is mounted with the flat ends facing an incoming shock wave. The concrete is composed of a very weak mix of cement i.e. high concentration of sand. The volume and mass compositions for casting five cylinders are found in Table 1. The mixture is subjected to a slump test and a 2.5 cm slump is noted. Two strain gauges are embedded in the cylinder while casting. The strain gauges are placed 101.6 mm apart, equidistant from the flat ends. The other two strain gauges are mounted on the two ends of the cylinder using epoxy. All the strain gauges are aligned with the axis of the cylinder. The gauges are used to measure the speed of the shock and provide an indication of the shock attenuation.

Twelve cylinders were tested over pressure ratios (the ratio between the high pressure in the driver tube and the vacuum in the driven tube) of approximately 200, 250, 350, 400, 450, 550 and 600, with a number of repeats. Variation of pressure ratios varied the Mach numbers and stagnation pressures of the shock wave, that is, the impact pressures of blast wave on the cylinders. The downstream was evacuated to around 6.9 kPa. The driver pressure was varied depending on the ratio required. Strain gauges placed on end faces of the concrete cylinder and embedded within the cylinder were used to determine the instants of shock propagation in the cylinder. Further description of the test procedure can be found in [2].

Fig. 1. Schematic side view and front view on the concrete cylinder mounted in the test section.

Table 1. Composition of the concrete.

Components	Volume	Mass
Water	13.5 L	13.5 kg
Cement (Type I/II Portland cement)	3 L	3.6 kg
Sand (Sakrete All-Purpose Sand)	45 L	73.3 kg

4 Test Results and Discussions

A sample plot of strain gauge outputs in shown in Fig. 2 Attenuation of wave strength as the wave passes through the cylinder is evident from the output.

The photographs in Fig. 3 show that the cylinder was pushed forward, out of the holder, at high pressures. Moreover, maximum damage occurred on the distal side of the cylinder. This shows that damage from the reflected wave is more severe than incident wave.

4.1 Wave Propagation

The wave propagation through the cylinder at various Mach numbers is show in Fig. 5. The distance between each gauge is 10.16 cm. The cylinder is divided into 3 different sectors of equal length for calculating the propagation speed through it. The general trend of the wave speeds is that of increasing with Mach number in all the three sectors. The speed varies the maximum with Mach number in sector 1. This can be attributed to the fact the wave possesses maximum amount of energy as soon as it enters the cylinder. The speed further reduces drastically as it exits the cylinder (end of sector 3) to around 1–3 m/s.

Figure 5 represents the variation between mass of TNT and distance from the center of blast for our maximum and minimum Z values, 1.83 and 1.16 respectively, based on

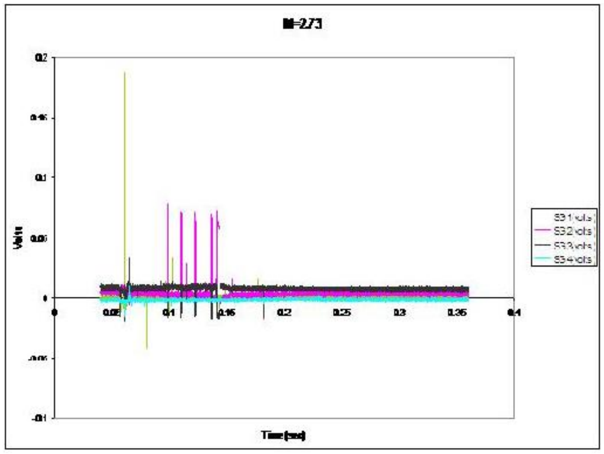

Fig. 2. Strain gauge output of a sample with $M = 2.7$.

Fig. 3. Cylindrical sample in the nozzle section after testing at $M = 2.82$.

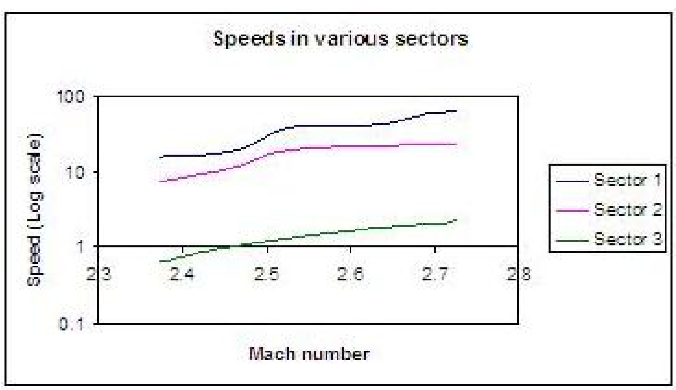

Fig. 4. Speeds (m/s) vs. Mach number in all three sectors (note logarithmic scale).

Eqns. (2a)–(2c) and (4). The figure shows a huge range of blast wave strengths ranging from 1 kg of TNT at a distance of 1 m to 5500 kg of TNT at a distance of 20 m.

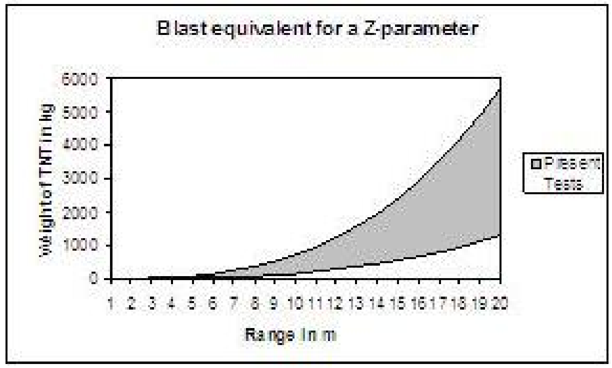

Fig. 5. Variation of mass of TNT and distance of center of blast.

5 Conclusions

Shock tube experiments of a weak concrete cylider shows that the wave speed is attenuated to only 1/5th of the incident wave speed in a distance of 10 cm. The experiments show that the reflected wave from the distal end can cause severe damage to the cylinder. The exit speed of the blast wave from the cylinder increases with increase of incident Mach number. Based on the characteristics revealed in the present tests, the weak concrete mix may be used to build a secondary wall to protect primary structures from a blast based on certain constraints. The mix is good for protecting buildings from low strength blasts, that is, blast wave speeds of Mach number less than 2.5. At higher blast strengths, the secondary wall will likely be blown off due to the strong reflecting blast wave. Walls of this material can be used to protect only isolated structures with vast spaces around it from blasts which have its center outside the wall.

Acknowledgements

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