

SHOCK TUBE TESTING OF SAND AND ITS APPLICATION IN BLAST AND FRAGMENT ANALYSIS OF STRUCTURE

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**DEPARTMENT OF CIVIL ENGINEERING
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by

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DEPARTMENT OF CIVIL ENGINEERING

Submitted

*in fulfillment of the requirements of the degree of **Doctor of Philosophy***

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CERTIFICATE

This is to certify that thesis entitled “**SHOCK TUBE TESTING OF SAND AND ITS APPLICATION IN BLAST AND FRAGMENT ANALYSIS OF STRUCTURE**” submitted by **Ms. Rashmi (2017CEZ8531)** to the **Indian Institute of Technology (IIT) Delhi** for the award of the degree of **DOCTOR OF PHILOSOPHY** is record of the student’s bonafide research work carried out by her. She worked under my supervision for the submission of the thesis, which to my knowledge, has reached the requisite standard as demonstrated by excellent international publications in journals and conferences.

To the best of my knowledge and belief, the contents of her research work have not been submitted in full or in part to any other university or institute to confer a degree or diploma.

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Rashmi

Abstract

In the present day scenario, due to the increase in accidental or intentional detonations, there is a necessity to build blast and impact-resistant structures. Semi-buried box structures are important military protective structures of national and strategic importance and must withstand extreme loading threats from weapon detonations, which is usually in the form of combined blast and impact (fragment) loading. The stability of these structures is also greatly influenced by the behavior of soil under blast loading, therefore study of blast-induced ground shocks and its propagation in the soil media needs a detailed investigation.

Initially, the performance of the vertical shock tube (VST) is evaluated by characterizing the generated blast waves considering two different diaphragm types; Aluminium and Lexan, and two driver gases; Nitrogen and Helium. The properties of the blast waves generated in the VST are greatly influenced by the diaphragm type (material and thickness), and driver gas. The present VST can simulate blast waves with peak reflected overpressure ranging from, 0.59-2.04 MPa and 0.68-5.60 MPa upon using Nitrogen and Helium as driver gas, respectively. In addition, numerical simulations are also performed, and results are validated with the experimental results. The VST is then used to investigate the stress wave attenuation and vibrational characteristics of the four different sands each with two different relative densities (medium-dense and dense) under air-blast loading. A stress enhancement of about 1.01 - 2.76 times the peak over-pressure is observed at the top one-third layer of all the sand specimens. The amplitude of the peak particle acceleration is also observed to attenuate with the depth of all the sand specimens. In addition, the damages incurred in reinforced concrete (RC) walls subjected to combined loading of blast and fragment as a result of cased charge detonation is also studied using the finite element (FE) analysis method.

An increase in fragment penetration (5.4% - 23.1%), perforation, and excessive scabbing is noted under combined loading of blast and fragment, compared to fragment loading alone, considering different concrete strengths and thicknesses, which highlighted its severity. Based on the above study, the response of a semi-buried concrete box structure with a blast door (with and without protective sand layer) is studied under the two simultaneous cased charge explosions using the FE analysis software LS DYNA. A comparative study of semi-buried box structure is performed by varying the blast-scaled distances and point of fragment impact considering three cased explosive charges of 6, 9, and 12 kg TNT, each with a casing weight of 36 kg.

Keywords: Vertical shock tube, stress wave, peak particle acceleration, combined blast and fragment loading, semi-buried structure, diaphragm, driver gas, fragment penetration, scabbing.

सार

वर्तमान परिदृश्य में, आकस्मिक या जानबूझकर विस्फोटों में वृद्धि के कारण, विस्फोट और प्रभाव-प्रतिरोधी संरचनाओं के निर्माण की आवश्यकता है। अर्ध-दफन बॉक्स संरचनाएं राष्ट्रीय और सामरिक महत्व की महत्वपूर्ण सैन्य सुरक्षात्मक संरचनाएं हैं और इन्हें हथियार विस्फोटों से अत्यधिक लोडिंग खतरों का सामना करना पड़ता है, जो आमतौर पर संयुक्त विस्फोट और प्रभाव (टुकड़ा) लोडिंग के रूप में होता है। इन संरचनाओं की स्थिरता ब्लास्ट लोडिंग के तहत मिट्टी के व्यवहार से भी काफी प्रभावित होती है, इसलिए ब्लास्ट-प्रेरित जमीन के झटके और मिट्टी मीडिया में इसके प्रसार के अध्ययन की विस्तृत जांच की आवश्यकता है।

प्रारंभ में, ऊर्ध्वाधर शॉक ट्यूब (वीएसटी) के प्रदर्शन का मूल्यांकन दो अलग-अलग डायग्राम प्रकारों पर विचार करके उत्पन्न ब्लास्ट तरंगों को चिह्नित करके किया गया है; एल्यूमिनियम और लेक्सन, और दो चालक गैसों; नाइट्रोजन और हीलियम. वीएसटी में उत्पन्न विस्फोट तरंगों के गुण डायग्राम प्रकार (सामग्री और मोटाई), और ड्राइवर गैस से काफी प्रभावित होते हैं। वर्तमान वीएसटी नाइट्रोजन और हीलियम को ड्राइवर गैस के रूप में उपयोग करने पर क्रमशः 0.59 - 2.04 एमपीए और 0.68-5.60 एमपीए तक के चरम परावर्तित दबाव के साथ विस्फोट तरंगों का अनुकरण कर सकता है। इसके अलावा, संख्यात्मक सिमुलेशन भी किया गया है, और परिणामों को प्रयोगात्मक परिणामों के साथ मान्य किया गया है। इसके बाद वीएसटी का उपयोग एयर-ब्लास्ट लोडिंग के तहत दो अलग-अलग सापेक्ष घनत्व (मध्यम-घने और घने) के साथ चार अलग-अलग रेत की तनाव तरंग क्षीणन और कंपन विशेषताओं की जांच करने के लिए किया गया है। रेत के सभी नमूनों की शीर्ष एक-तिहाई परत पर अधिकतम दबाव में लगभग 1.01 - 2.76 गुना की तनाव वृद्धि देखी गई है। रेत के सभी नमूनों की गहराई के साथ शिखर कण त्वरण का आयाम भी क्षीण होता देखा गया है। इसके अलावा, केस चार्ज विस्फोट के परिणामस्वरूप विस्फोट और टुकड़े की संयुक्त लोडिंग के अधीन प्रबलित कंक्रीट (आरसी) दीवार में हुई क्षति का भी परिमित तत्व (एफई) विश्लेषण विधि का

उपयोग करके अध्ययन किया गया है। अकेले टुकड़े को लोड करने की तुलना में विस्फोट और टुकड़े के संयुक्त लोडिंग के तहत अलग-अलग कंक्रीट की ताकत और मोटाई पर विचार करते हुए, टुकड़े के प्रवेश में वृद्धि (5.4% - 23.1%), वेध, और अत्यधिक स्कैबिंग को नोट किया गया है, जिसने इसकी गंभीरता को उजागर किया है। उपरोक्त अध्ययन के आधार पर, ब्लास्ट डोर के साथ अर्ध-दबे हुए कंक्रीट बॉक्स संरचना (सुरक्षात्मक रेत परत के साथ और बिना) की प्रतिक्रिया का एक साथ दो आवरण वाले चार्ज विस्फोटों के तहत एफई विश्लेषण सॉफ्टवेयर एलएस डायना (LS DYNA) का उपयोग करके अध्ययन किया जाता है। अर्ध-दबे हुए बॉक्स संरचना का तुलनात्मक अध्ययन विस्फोट-स्केल की दूरी और टुकड़े के प्रभाव के बिंदु को अलग-अलग करके किया गया है, जिसमें 6, 9 और 12 किलोग्राम टीएनटी के तीन आवरण वाले विस्फोटक चार्ज हैं, जिनमें से प्रत्येक का आवरण वजन 36 किलोग्राम है।

कीवर्ड: ऊर्ध्वाधर शॉक ट्यूब, तनाव तरंग, चरम कण त्वरण, संयुक्त विस्फोट और टुकड़ा लोडिंग, अर्ध-दफन संरचना, डायनामाम, चालक गैस, टुकड़ा प्रवेश, स्कैबिंग।

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