ANALYSIS OF ABOVEGROUND AND UNDERGROUND STRUCTURES SUBJECTED TO BLAST LOADING AND BLAST-INDUCED VIBRATIONS

by

HARSHADA SHARMA

SCHOOL OF INTERDISCIPLINARY RESEARCH

Under the Supervision of

Prof. Dr. VASANT MATSAGAR

(Professor, Dogra Chair, and Head)

and

Prof. Dr. SATINDER PAUL SINGH

(Professor)

submitted

in fulfilment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

DECEMBER 2024

ABSTRACT

Underground and aboveground structures are subjected to rising threats from intended and accidental explosions. Understanding the structure's response to blast loading has become essential in ensuring the safety and resilience of buildings, important infrastructure, military installations, and mankind. Although the need to understand various types of blast loading, their effects, and the measures for blast resistance is essentially required, limited research is available in this field. The uncertainty involved in the occurrence of blast load demands blast-resistant design of structures and implementation of blast load mitigation strategies. Aboveground structures require sophisticated lightweight materials and design methodologies to ensure high-intensity confined or unconfined blast loads. However, underground structures must confront issues associated with shockwave propagation due to controlled or accidental blasts, soil-structure interaction, and confinement. Therefore, this study aims to provide blast load mitigation techniques to protect aboveground and underground structures from undue blast loads using computational analysis with finite element methods, thus, providing in-depth and visual insights into the complex phenomena occurring during the explosion.

The blast-induced shock wave propagation and the influence of varied geo-medium on the prediction of ground motion parameters for accidental underground blast scenarios is investigated in the study. The accurate estimation of BIGM facilitates to design the underground facilities for blast resistance. The performance of underground facilities exposed to an underground accidental explosion is investigated. An accidental explosion in the explosive storage structure (ESS), could affect the important structure, known as the equipment and personnel structure (EPS) containing personnel and equipment. The performance of the EPS structure subjected to blast-induced ground vibrations is investigated by installing a blast mitigation barrier between the ESS and EPS structure. Flat and curved barrier types are investigated to mitigate the blast waves, and their effectiveness is assessed on EPS structure. Moreover, the efficacy of a rooftop barrier positioned above the ESS structure is investigated and found effective in reducing the ground signatures. The ground signature formed due to underground blasts in the form of ground acceleration proves disastrous for the aboveground structures. The precise estimation of ground acceleration can offer better blast mitigation strategies to reduce the adverse effects of blasts. The empirical and numerical approach-based estimation of ground acceleration is used as base excitation to a multistory structure above the ground. The response of the structure is measured for both approach estimation of ground acceleration and a conservative method of estimation is proposed in the study.

Safety of personnel and heavy machinery is a key requirement in the case of aboveground industrial facilities under accidental blast events. Moreover, the selection of materials, structural systems, and construction practices for such infrastructure are required to support faster construction, without compromising safety. Therefore, a modular industrial control room made of steel and aluminum foam composites fabricated and assembled suitably, along with pertinent connection details to serve the functional requirements is proposed in the study. The structural assembly is exposed to confined and unconfined blast loading scenarios, as applicable to the scenario-specific accidental blast events in typical industrial setups. Furthermore, the structures featuring three distinct central core lightweight materials such as polyurethane (PU) foam, aluminum (Al) foam, and saffil® foam (S) are investigated for confined blast loads. The structures can effectively sustain blast loads according to their material strengths. However, the overall strength is further enhanced by converting the structure to a prestressed composite structure. Thus, these structures can be effectively used in emergency shelters, defense facilities, and industrial rooms. The

modeling, analysis, design, and detailing strategies can be suitably adopted in designing facilities under the threat of blast-induced loading.

The confined blast-induced load becomes more critical when the explosives are enclosed in a casing. Steel is a commonly used explosive casing material and exhibits intricate and disastrous effects on the contained structure rupturing the casing material to develop fragments. The dynamic response of steel cubical structure and the influence of different lightweight explosive casing materials such as carbon fiber-reinforced polymer (CFRP), glass fiber-reinforced polymer (GFRP), and steel material on the response of the structure is assessed and compared. Furthermore, the response of the un-stiffened and stiffened cubical structure with different stiffener configurations i.e., cross, plus vertical, horizontal, and v-type is compared, and an effective configuration of the stiffener is proposed with the highest blast resistance of the structure. Thus, this doctoral research contributes to blast mitigation strategies and reliable composite structures with the use of lightweight materials.