UNIVERSITI PUTRA MALAYSIA

THE STRUCTURAL RESPONSE OF A BUNKER SUBJECTED TO BLAST LOADING

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APPROVAL SHEET

This project attached here, entitled **"THE STRUCTURAL RESPONSE OF A BUNKER SUBJECTED TO BLAST LOADING"** prepared and submitted by **MOHD NORDIN BIN MOHD PILUS (GS 15617)** in partial fulfillment of the requirements for the Degree in Master of Science in Structural Engineering and Construction is hereby approved.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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ABSTRACT

In recent years there is an increasing incidence of bomb attacks on civil engineering structures which frequently caused substantial damage or even collapse of structures. Such incidence always results in economic loss and more seriously loss if life. This clearly indicates that it is timely for structural engineers to consider blast loads in their design.

There are substantial costs incurred in designing structures against blast loads. Therefore there are only a certain category of structures which require such design in accordance to the level of protection required. In this paper a reinforced concrete bunker was used to represent such structure, whereby its structural response to an external explosion of a surface charge was investigated.

The blast load was theoretically generated based on the explosion of 300 kg of TNT at a distance of 50 meters from the structure. Both linear and non-linear analyses were conducted using a computer program considering the dead load alone as well as the combination of dead and blast loads. The program utilizes the finite element method which provides results in the form of nodal displacements and stress resultants.

As expected, the linear analysis gave lower results than the non-linear analysis. Linear analysis is only applicable in the linear elastic range and is unreliable when extreme loadings are involved. Since the blast loads caused severe effect on structures, non-linear analysis is more appropriate for the purpose.

Blast load causes a tremendous increase of stress levels in structures, indicating the severity of the loading. This is due to the fact that such load acts as moving pulses loading only a small part of the structure at a time. Therefore the structure must be design to resist the high stress levels.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 2 – LITERATURE VIEW

APPENDIX B – Blast Load Computation

APPENDIX C – Manual Calculation

LIST OF FIGURES

CHAPTER 2 – LITERATURE VIEW

CHAPTER 3 - METHODOLOGY

CHAPTER 4 – ANALYSIS AND RESULT

CHAPTER 1

INTRODUCTION

1.0 Introductory Remarks

There is growing interest nowadays in designing civil engineering structures to withstand dynamic loads. Dynamic loads refer to any load whose magnitude, direction and position vary with time. Similarly, the responses of a structure (the resulting displacements and stresses) to such loads are also time-varying. Examples of dynamic loads are impact, explosion, earthquake, wind, waves and loads due to unbalanced mass in a rotating machine. All loads in nature are time-dependent, but in most cases the variation is slow compared to the natural period of vibration of the structure which implies that static conditions can be assumed. Thus, whether a load varies slowly or fast is only in relation to the time required for the structure to complete a full cycle of vibration.

Dynamic loads can be further categorized as periodic or non-periodic loadings. Periodic loadings are repetitive loads which exhibit the same time-variation successively for a large number of cycles. Non-periodic loadings may be either short-duration (impulsive) or long-duration general forms of loads. A blast or explosion is a typical source of impulsive load. For such short-duration loads, special simplified forms of analysis may be employed. For long-duration load such as earthquake, it can be treated only by general dynamic analysis procedure.

Dynamic analyses essentially focus on evaluation of time dependent displacements, from which the stress state of the structure under consideration can be computed. In these analyses the dynamic properties of the structure are required, primarily the natural period of vibration which is a function of the structure's mass and stiffness and the amount of damping.

In modeling of structures for structural dynamic problems, the structures are regarded as distributed or continuous mass or discrete or lumped mass. The distributed mass concept is realistic but difficult and involves lengthy process. The lumped-mass concept provides a simple means of limiting the number of degrees of freedom that must be considered and leads to an approximate solution to the problem. It is most effective in treating systems in which a large proportion of the total mass is concentrated at a few discrete points such as frame structures.

1.1 Blast Loads

The need to consider blast load in the design of certain important structures has increased significantly in the recent years, due to the enhanced use of explosives for security as well as terrorist attacks. The origin of the blast can either be within or outside the structure, thus giving rise to the terms internal and external blasts. This paper attempts to analyze the structural response of a reinforced concrete bunker which is an arch structure when subjected to an external blast of a charge placed on the ground (surface burst).

The basic difference between blast loads and other dynamic loads is that the blast loads are moving pulse loads, loading different part of the structure at different times, with varying magnitudes and durations, depending on the distance and angle of incidence. The shock front due to a surface burst is hemispherical in shape with its parameters such as side-on overpressure ($\mathbf{p_{so}}$), positive phase duration ($\mathbf{T_s}$) and arrival time ($\mathbf{t}$) being functions of the stand-off distance (radial distance) of the target.

The pressure pulses generated by detonations on the ground are transmitted through the air and soil. When a shock front reaches an obstacle such as a building, there is an abrupt pressure rise to a maximum (shock-like) followed by decay to below atmospheric pressure which is generally neglected except when a rebound analysis of a roof is required.

The transient, impulsive dynamic loading of external blasts may act locally over building parts or over the entire structure, depending on the duration of loading. When the blast loading is of short duration (or blast source is very near to the structure) only the closest structural parts to the detonation source will be acted on by the blast loading. On the contrary, if the blast duration is long such as large nuclear weapons or other extremely large explosions, it can be considered to act over the entire building at the same time with the same time history.

The blast loads on arch surfaces are functions of time as well as space, since the incident angle which fixes the reflection coefficient continuously changes with the traverse of the shock front. Dynamic analysis using the lumped mass concept is very complicated since the mass is continuous over the structure. A simplified method of evaluating the blast response is to represent the blast load as an equivalent static load. A more rigorous approach is to treat the blast pressure as a moving triangular pulse traversing the curved surface. In this paper the equivalent static load method is adopted.

1.2 Nature of the Problem

In the last decade, there has been an increasing incidence of bomb attack on modern societies. Therefore it is becoming more evident that structural engineers need to consider blast loadings in their design in order to protect the societies from such attacks.

An explosion generates extreme loads which in most cases result in severe damage or even collapse of structures. As a consequence, it always causes economic loss and usually loss of life and unavoidable psychological impact on societies. In order to reduce the consequences of such threat, a clear understanding of structural response and damage characteristics due to explosive loads is essential.

The requirement for protection against blast loadings depend on the likelihood of a particular building will be subjected to such loadings, established by means of a threat analysis. This indicates that only certain critical and important buildings require such protection. Furthermore there is a cost associated with each level of protection provided. In this study, a reinforced concrete bunker is used to represent such buildings for the purpose to demonstrate the effect of blast loading on structures. Furthermore the arch structure is among the leading structural forms employed for protection from weapon effects.

1.3 Objectives of Study

The primary objectives of this study are:

(a) To propose a computational model to simulate geometry and constitutive non-linearity.
(b) To investigate the structural response of a reinforced concrete bunker when subjected to the explosion of a surface charge.
(c) To suggest procedures and factors to be considered for design purposes.

1.4 Scope of Study

In the investigation of the structural response of a reinforced concrete bunker subjected to a blast load, the study was conducted within the following scope:

(a) Reviewing the literature to establish the current state of knowledge on the nature and characteristics of loads generated by detonation of high explosives.

(b) Establishing the loads to be applied to the structure which comprise of the dead load of materials and the blast loads generated by detonation of a surface charge.

(c) Using the Finite Element Method through shell elements with the features of material non-linearity and crack analysis capability.

1.5 Organization of Report

In order to achieve the objectives of the study, this report was written and organized in the following manner:

(a) Chapter 1 - Introduce the subject matter and provides general description of the problem of interest.

(b) Chapter 2 - Presents a general view of blast loads with the aim to keep abreast with the current state of knowledge with regards to the nature and characteristics of blast loads.

(c) Chapter 3 - This chapter presents in detail the methodology adopted in the study. The problem was approached through the classical method as well as the numerical method which involved the finite element formulation of the problem. This chapter also provides the detail procedure in calculating the blast loads which serve as data for the analyses.

(d) Chapter 4 - In this chapter the analyses both linear and non-linear were carried out and the results presented, compared and discussed.

(e) Chapter 5 - The last chapter provides conclusions drawn from the study. Recommendations for future studies and research are also provided.

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