

# New dynamic analysis techniques for structural members subjected to blast loads

Jonathon Dragos

Bachelor of Engineering (Civil & Structural) (Hons)

Thesis submitted for the degree of Doctor of Philosophy at The University of Adelaide, Australia

The School of Civil, Environmental and Mining Engineering

May 2014

## Contents

Abstract.....	ii
Statement of Originality.....	iii
List of Publications .....	iv
Acknowledgements.....	v
Introduction and Background .....	1
Chapter 1 - Pressure Impulse Diagrams for Structural Members subjected to Confined Blasts4	
Introduction.....	4
List of Manuscripts .....	4
Simplification of Fully Confined Blasts for Structural Response Analysis .....	6
Pressure-Impulse Diagrams for an Elastic-Plastic Member under Confined Blasts.....	38
A New Approach to Derive Normalised Pressure Impulse Curves for Elastic Members ...	59
A New General Approach to Derive Normalised Pressure Impulse Curves .....	76
Application of Normalized Pressure Impulse Diagrams for Vented and Unvented Confined Blasts.....	106
Chapter 2 - Use of a Numerical Model for developing new Analysis Techniques for Blast Loaded Structural Members.....	130
Introduction.....	130
List of Manuscripts .....	130
A numerically efficient finite element analysis of reinforced concrete members subjected to blasts .....	132
A Single Degree of Freedom Approach to incorporate Axial Load Effects on Pressure Impulse Curves for Steel Columns .....	154
Interaction between Direct Shear and Flexural Responses for Blast Loaded Reinforced Concrete Slabs using a Finite Element Model.....	175
Chapter 3 - Conclusion & Future Research .....	196

## **Abstract**

This thesis contains a number of journal papers which aim to extend, or produce new, analyses techniques for determining the response of structural members subjected to blasts. Within the first portion of the thesis, a new approach is provided which extends upon the concept of the normalised, or non-dimensional, pressure impulse (PI) curve, allowing it to be applied to determine the response of structural members subjected to blasts occurring in vented and unvented confined environments. As a confined blast load is highly irregular, containing multiple peaks and long duration gas pressures, a method for simplifying the confined blast load is proposed. Then, an entirely new general approach for determining normalised PI curves is developed and presented. It is shown that, due to its generality, it can account for any pulse load shape. It is also shown that other curve-fitting techniques typically used to determine normalised PI curves, while being suitable for external blast loads, cannot be applied to the more abstract pulse load shapes associated with confined blast loads. Then, the newly proposed general approach is applied to, and validated for, vented confined blast loads. Furthermore, the entire concept of a PI curve is extended so that an infinitely long duration unvented confined blast load, having an infinite impulse, can be analysed using a PI diagram.

A one dimensional (1D) finite element model (FEM) is then adopted for further studies, due to its inherent accuracy and stability despite its numerical efficiency. As the 1D FEM can accurately model the global dynamic response of an entire structural member, it does not suffer from the limitations of more commonly used simplified analysis techniques, such as the single degree of freedom (SDOF) method. Firstly, a segmental moment-rotation model is incorporated into the 1D FEM to accurately analyse the response of reinforced concrete (RC) beams and slabs subjected to blasts. The model, as a whole, can accurately simulate important RC behaviour, such as slipping of steel reinforcement within concrete and softening of concrete in compression, despite being numerically efficient. Furthermore, the 1D FEM is used to determine PI curves for steel columns under various levels of axial loading. This study is then used to validate a newly developed simple SDOF approach for determining PI curves for steel columns under axial loading. Despite the simplicity of the approach, it is shown to accurately account for the new failure mechanism of global instability and  $P\Delta$  effects, all caused by the axial load. Finally, the 1D FEM is used to undertake a parametric study on RC slabs to determine the influence of the flexural behaviour and geometrical properties on the direct shear response. The results provided in this final study aim to be a starting point for determining more sophisticated simplified methods, such as a new SDOF method or normalised PI curves, for analysing the direct shear response of RC beams and slabs.

## Statement of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

.....

Jonathon Dragos

.....

Date

## List of Publications

Dragos, J., Wu, C., Oehlers, D.J. (2013). Simplification of fully confined blasts for structural response analysis. *Engineering Structures*, 56 (2013), 312–326.

Dragos, J., Wu, C., Vugts, K. (2013). Pressure-Impulse Diagrams for an Elastic-Plastic Member under Confined Blasts. *International Journal of Protective Structures*, 4 (2), 143-162.

Dragos, J., Wu, C. (2013). A New Approach to Derive Normalised Pressure Impulse Curves for Elastic Members. *Journal of Earthquake and Tsunami (Special Issue-IISE 2012)*, 7 (3), 1350016.

Dragos, J., Wu, C. (2013). A new general approach to derive normalised pressure impulse curves. *International Journal of Impact Engineering*, 62 (2013), 1-12.

Dragos, J., Wu, C. (2014). Application of normalised pressure impulse diagrams for vented and unvented confined blasts. *Journal of Engineering Mechanics - ASCE*, 140 (3), 593–603.

Dragos, J., Visintin, P., Wu, C., Oehlers, D. (2014). A numerically efficient finite element analysis of reinforced concrete members subjected to blasts. *International Journal of Protective Structures*, 5 (1), 65-82.

Dragos, J., Wu, C. (2013). A Single Degree of Freedom Approach to incorporate Axial Load Effects on Pressure Impulse Curves for Steel Columns. Tentatively accepted for publication in *Journal of Engineering Mechanics - ASCE*.

Dragos, J., Wu, C. (2014). Interaction between Direct Shear and Flexural Responses for Blast Loaded Reinforced Concrete Slabs using a Finite Element Model. Accepted for publication in *Engineering Structures*.

## **Acknowledgements**

My sincerest gratitude goes to Dr Chengqing Wu, whose knowledge in the field of structures response to blasts knows no bounds. For his willingness to provide guidance and assistance, no matter what day of the week it is, I am also extremely grateful for.

I would also like to thank Dr Phillip Visintin and Professor Deric Oehlers, who were always willing to provide their expertise when needed.

Also, my friends and family deserve my thanks and much more, for their patience and support.

Finally, I dedicate this thesis to my partner and soulmate, Stephanie, who has provided me with the confidence and support to complete this thesis to the best of my abilities.