Study of seismic control systems on the behaviour of industrial storage racks

by

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Certificate of authorship/originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

Steel storage racks are structures which are used in factories and warehouses to store goods and merchandises. They consist of uprights, beams and braces made of cold-formed steel, and although they are very light in comparison with conventional structures, they are designed to carry very heavy loads. Storage racks are designed to resist horizontal loads in orthogonal directions using two different frame systems: moment resisting frames in down aisle direction and braced frames in cross aisle direction. The design of racks is different from typical buildings because they are made of slender thin walled members, hence, making them sensitive to global, local, and distortional buckling if overloaded. Moreover; the connections demonstrate highly nonlinear behaviours under loading. Due to the aforementioned reasons, the design of racks poses major challenges for engineers especially in seismic regions where mitigating the vulnerability of racks is important.

The objective of this numerical and experimental research was to investigate the seismic behaviour of storage racks and to establish the effectiveness of two alternative control systems to improve the performance of the racks under seismic loads. The control systems studied are new generation passive dampers: (i) a pounding tuned mass damper (PTMD) and (ii) a base isolation system. Full scaled shake table testing was performed at the University of Technology, Sydney (UTS) to study the dynamic behaviour of storage racks and to verify the numerical models. As part of the research, numerical models based on the Finite Element Method (FEM) were developed and applied to conduct parametric analyses of the racks in order to compare the seismic response of cross aisle braced frames of different heights with and without control devices. The FEM results showed that PTMD dampers enhance by up to 40% the seismic behaviour of racks under 5 meters height while the base isolation system was more effective for tall racks. Financial support for this research was provided by Dexion.

Key words: Rack storages, down aisle, cross aisle, Base isolation, PTMD

CONTENTS

List of Figures

List of Tables

NOTATIONS

The symbols used in this thesis, including their definitions, are listed below.

A	Cross-sectional area
a_g	Design horizontal ground acceleration
c	Impact damping
C_1	Damping of mass
C_0	Damping of structure
d	Distance between the centroidal axes of uprights
E	Modulus of elasticity of steel
F	Applied action
f_u	Specified ultimate strength of steel
f_y	Specified yield strength of steel
G	Shear modulus of rubber
h	Total height of upright frame
I	Moment inertia
K	Bulk modulus of rubber
K_0	Equivalent stiffness of structure
K_1	Equivalent stiffness of damper
Se(T)	Ordinate of the elastic spectrum (normalized by g)
T_B	Lower limit of the constant spectral acceleration branch
T_C	Upper limit of the constant spectral acceleration branch
T_D	Period value defining the beginning of the spectrum constant displacement range
ε_y	Steel Yield tensile strain
ε_p	Steel tensile plastic strain
ε_u	Steel maximum tensile strain
η	Damping spectrum correction factor
η_d	Reduction ratio of displacement
η_f	Reduction ratio of shear force
σ_y	Steel yielding stress
σ_u	Steel ultimate stress

β	Impact stiffness parameter
δ	Horizontal deflection of the frame
Δ	Deflection of base plate at base of shear frame