Computer-Aided Structural Analysis of the Lift Car – Frame System Under Emergency Arrest Operational Conditions

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Abstract. The paper presents Computer-Aided Analysis (CAA) model of a lift car - frame system. Structural analysis is carried out by the application of the Finite Element Method (FEM) to predict the responses and stresses arising in the system arising under the emergency conditions. The emergency scenario presented in the paper involves a buffer strike event which occurs during the car overtravel. The model can then be used to optimise the design to ensure safe operation of the system.

1 INTRODUCTION

Vertical transportation systems (VTS) such as lifts (elevators) are key elements in the built environment, especially in the high-rise building environment. It is important that the design of VTS provides efficient and safe service to building occupants and users [1].

Various dynamic loads act upon components of the lift system during the normal operation and the emergency conditions. High levels of dynamic stresses in the lift car-frame structure might then occur. In order to satisfy the requirements of safety standards and to meet the criteria for acceptable service, thorough understanding of engineering principles and models applied is of paramount importance in conducting the system calculations [2].

The aim of this work is to demonstrate a computer aided solution and analysis of the dynamic responses that arise during an emergency scenario. The emergency arrest is initiated when the car overtravels the designated terminal floor at the bottom of the hoistway. The dynamic loads that arise during the event are determined and applied in the FEM structural analysis of the car frame structural components.

2 CAR OVERTRAVEL AND EMERGENCY ARREST

The overtravel arrest mechanism consists of buffers beneath the car (and often beneath the counterweight) [2]. Three types of buffer are permitted by safety codes [3]: linear, energy accumulation type buffers, non-linear energy accumulation buffers, and energy dissipation buffers. Consider a scenario when the car is striking an energy dissipation buffer (see Fig. 1).

The equation of motion describing the dynamics of the system when the car travelling at speed V has engaged an energy dissipation buffer (buffering event) is given as

$$M\ddot{x} + c\dot{x} + kx = Mg \tag{1}$$

where g is the acceleration of gravity, x is the displacement, M is the mass of the car-frame assembly, c represents the coefficient of damping and k denotes the coefficient of stiffness of the buffer. The buffer acting at the buffer striking plate is determined as

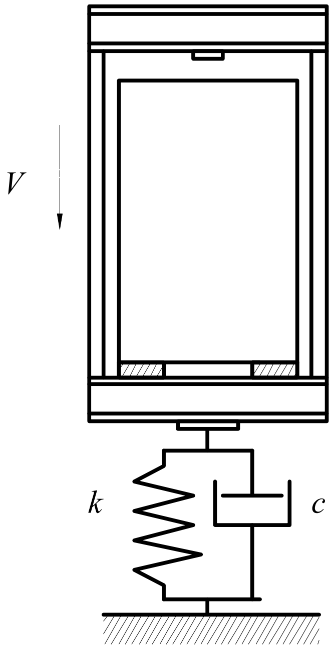

Figure 1 Descending car striking a buffer of energy dissipation type.

$$F_b = c\dot{x} + kx \tag{2}$$

In this model of the car-frame – buffer dynamics is represented by the fundamental mode with the car-frame treated as a rigid body. By solving the equation of motion (1) the buffer force can then be readily evaluated from equation (2).

3 STRUCTURAL ANALYSIS OF THE CAR-FRAME ASSEMBLY

To determine the dynamic deformations and stress levels of the car-frame assembly, the system can be analyzed by the application of Finite Element Method (FEM). The behaviour of the structure is then represented by the following equation [4]

$$[M]\ddot{\bar{x}} + [C]\dot{\bar{x}} + [K]\bar{x} = \bar{F} \tag{3}$$

where [*M*] is the mass matrix, [*C*] is the damping matrix, [*K*] is the stiffness matrix, $\bar{F}$ is the load vector and $\bar{x}$ denotes the displacement vector.

3.1 CAD model

The lift car-frame assembly is a combination of three distinct components: car bodywork (enclosure), sling (frame) and car platform. A CAD model used in the study is shown in Fig. 3.

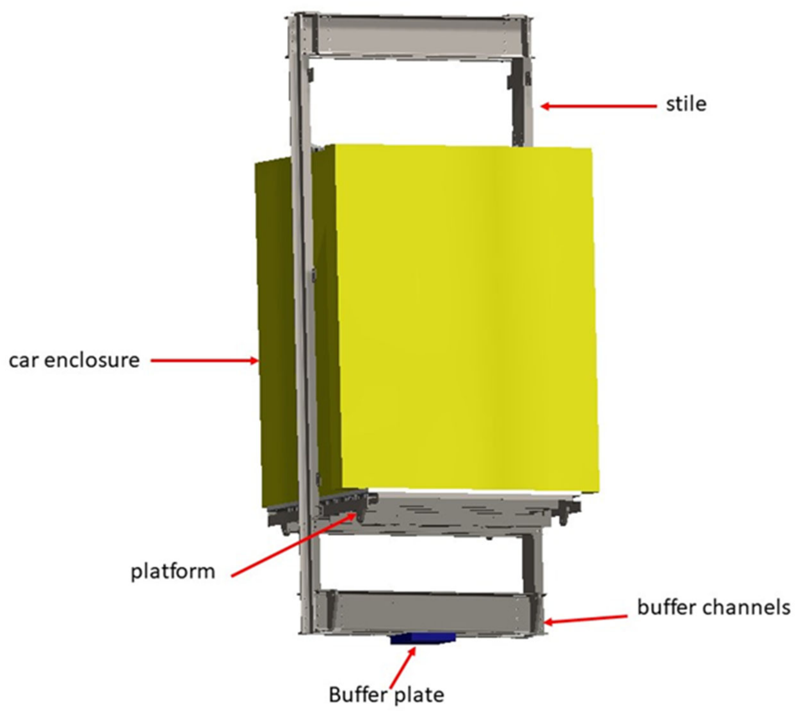

Figure 2 CAD model of the car-frame assembly

3.2 Fundamental mode analysis of the car-frame - buffer system

Equation (1) can be re-formulated in terms of the fundamental mode parameters as

$$\ddot{x} + 2\zeta\omega\dot{x} + \omega^2 x = g \tag{4}$$

where ζ is the damping ratio and ω represents the fundamental frequency of the car-frame - buffer system.

Equation (4) is then solved by considering the car speed of 2 m/s, the damping ratio ζ = 0.25, 0.75, and the fundamental frequency assumed as 1.63 Hz, respectively. The results are shown in Fig. 3.

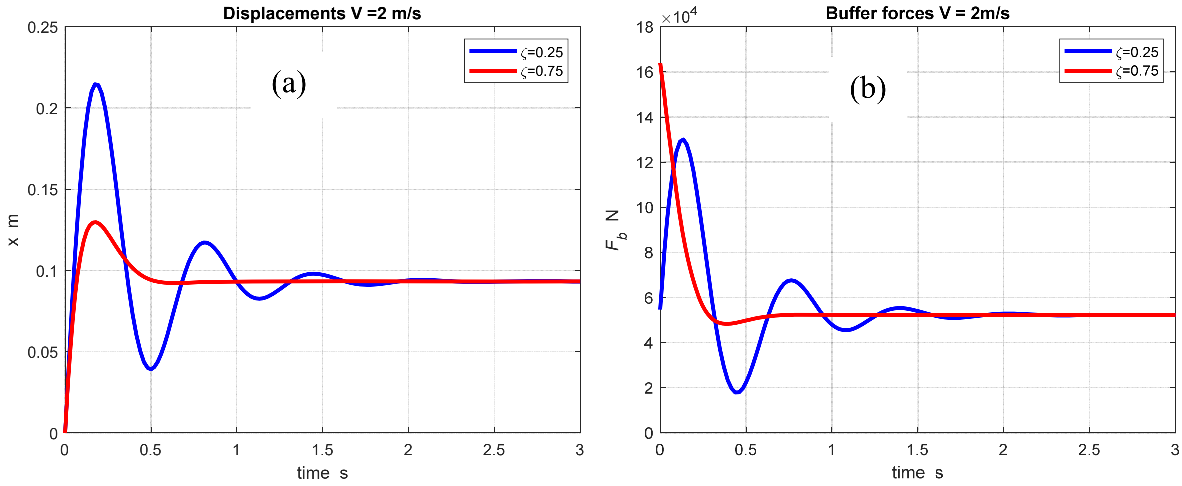

Figure 3 Fundamental mode displacements and the corresponding buffer forces

The dynamic deflections are shown in Fig. 3(a) and the buffer forces are illustrated in Fig. 3(b), respectively.

The rating of buffers is based on arresting the car from 115% rated speed (the overspeed governor electrical trip speed). Safety codes [4] stipulate that the total possible stroke of energy dissipation buffers shall be at least equal to the gravity stopping. Considering that the car strikes the buffer at rated speed and the gravity stopping distance, for the rated speed of V = 2 m/s, is calculated as $\frac{(1.15\times V)^2}{2g} = 0.2696$ m it is evident that the maximum deflections of the buffer are smaller than the minimum buffer stroke.

3.3 FEM Simulation and results

In the FEM simulation of the car-frame assembly the buffer channel beam structure is selected. The bending stresses (see Fig. 4) and the deflection levels (see Fig. 5) are determined under the maximum load conditions as illustrated in Fig. 3b.

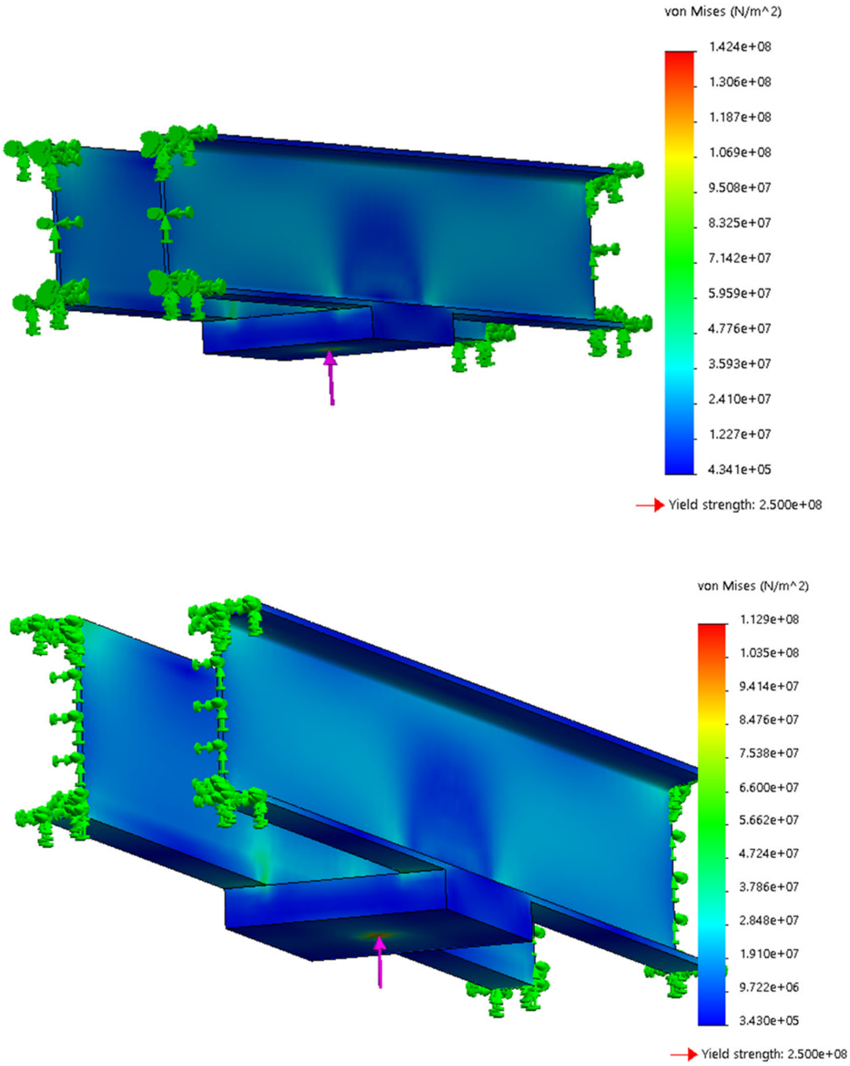

Figure 4 FEM simulation results: bending stresses

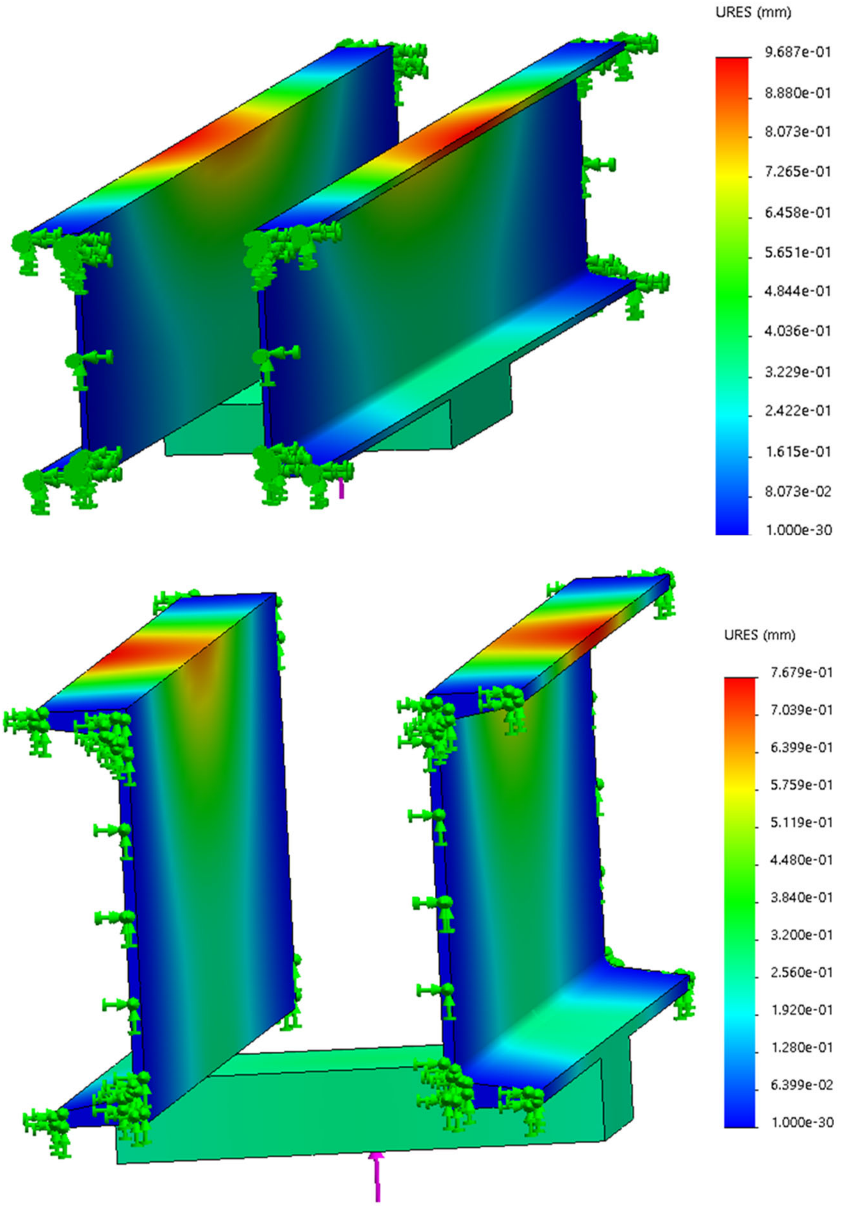

Figure 5 FEM simulation results: bending deflections

Maximum permissible stresses in car frame buffer plank under buffering conditions specified in ASME A17.1 are given as 189.6 MPa (27,500 psi). It is evident that under the loading conditions considered the maximum stress levels (determined as 142.4 MPa and 112.9 MPa, respectively) do not exceed the permissible value. Normal practice for dealing with loads that act at the buffer channel beam (safety plank) structure is to ensure that the deflections shall be no more than $\frac{1}{1000}$th of the channels' span. Considering the span length of 2350.7 mm the maximum deflections (determined as 0.9687 mm and 0.7679 mm, respectively) are within the acceptable range.

4 CONCLUSIONS

The analysis and results presented in this paper demonstrate that large deformations and stress levels may occur in a lift system during an emergency arrest event triggered by car overtravel. The stresses and deflections in the buffer channels need to be assessed for the worst case of operation. This should be carried out for the buffering events, as demonstrated in the paper.

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BIOGRAPHICAL DETAILS

Mohammad Ghaleeh is Senior Lecturer in Engineering at the University of Northampton. He received his PhD in the durability of solder joints under thermo-mechanical loading: application to Sn-37Pb and Sn-3.8Ag-0.7Cu lead-free replacement alloy from Heriot-Watt University. He is an expert in Finite Element Analysis as applied to problems in structural mechanics, multiple Experience in material design engineering, materials and structural analyst in Oil & Gas, Automotive industries, etc. Research interests related to the project include the durability of structural joints under thermo-mechanical loading; with design engineering, engineering materials and structural analysis/ FEM modelling.

Stefan Kaczmarczyk is Professor of Applied Mechanics and Postgraduate Programme Leader for Lift Engineering at the University of Northampton. His expertise is in the area of applied dynamics with particular applications to vertical transportation and material handling systems. Professor Kaczmarczyk is a Chartered Engineer, a Fellow of the Institution of Mechanical Engineers and a Fellow of the Higher Education Academy.

Shafqat Rasool is Lecturer in Engineering (Mechanical Engineering and Design) at the University of Northampton. He received his PhD from Delft University of Technology for his research in durability of thermoplastic composites under fatigue loading. He has also worked as post doc researcher on projects focusing on powder resin processing and structural health monitoring of thick composites. His research interests are durability and structural integrity of composites materials and structures. He has border experience in the context of experimental investigation, design and development of testing fixture, testing and measurements, and failure analysis.

Jonathan Adams graduated from the University of Bradford in 1990 with a B.Eng. degree in Electrical and Electronic Engineering. He holds a Certificate in Education from the University of Leicester, and an M.A. in Continuing Education from the University of Warwick. He also holds a PhD in Engineering Education. His industrial background is in the lift-making industry where he spent nearly 10 years. He has been employed at The University of Northampton for over 20 years specialising in distance education for the lift industry. He is currently Head of Department of Engineering & Technology. His research interests include teaching and learning strategies used in continuing and engineering education, and in the use of electronic methods for delivery, assessment and support. He is a Teaching Fellow of The University of Northampton.