

CRASH ANALYSIS OF A RAINFOREST VEHICLE (RFV) UNDER FRONTAL
IMPACT LOADING

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DEDICATION

To my beloved wife, parents and family

To all my lecturers, for their guidance and encouragement

To all my friends, for their support and sincerity

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Praise to All Mighty Allah for giving the opportunity for me to complete my degree and final year project within a certain period of time. Praise also to our prophet Muhammad, peace be upon him and his followers for showing the right path in my entire life.

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ABSTRACT

Rainforest Vehicle (RFV) is defined as an outdoor vehicle that can be used in the rural, military area especially in the forest. This vehicle must have the capability to use in uneven terrain and sloping condition. This thesis presents the crash analysis of a (RFV) under frontal impact loading. A Finite Element (FE) nonlinear code, LSDYNA software was comprehensively employed to evaluate the crashworthiness performance of the space frame model of the RFV. Experimental testing was conducted on subcomponents to validate the FE model and the analytical analyses from the previous researchers were conducted to compare the results. In addition, the simplified model of the upper rails also validated throughout the quasi static experiment. The validated model was then used to examine three different crash scenarios; impacting rigid wall, 40% offset and rigid pole. The simulation results were used to identify the load path, deceleration and the energy absorption capacity of the main longitudinal component and available crush zone, thus facilitating crashworthiness requirement for future design improvements. The primary outcome of this research is to generate research and design information on the vehicle that will enable further modification and enhancement of the current design for optimizing crashworthiness performance and increasing the levels of safety.

ABSTAK

Kenderaan Rainforest (RFV) ditakrifkan sebagai kenderaan luar yang boleh digunakan di luar bandar, kawasan tentera terutama di dalam hutan. Kenderaan ini mesti mempunyai keupayaan untuk menggunakan di kawasan tidak sekata dan keadaan cerun. Tesis ini membentangkan analisa pelanggaran sebuah RFV berdasarkan pelanggaran hadapan. Perisian LSDYNA, yang menggunakan kaedah unsur tak terhingga yang tak linear digunakan secara menyeluruh untuk menilai kemampuan pelanggaran rangka kenderaan (RFV). Kaedah eksperimen dilakukan pada sebahagian tempat pada kenderaan untuk mengesahkan kaedah unsur tak terhingga (FE) dan kaedah analisa pengiraan daripada penyelidik yang lalu dilakukan untuk membandingkan hasil yang diperolehi. Di samping itu, sebuah model landasan atas yang dipermudahkan juga disahkan di seluruh eksperimen separa statik Model yang telah disahkan, digunakan untuk menganalisa tiga jenis pelanggaran yang berbeza iaitu; pelanggaran kekal, 40 peratus perubahan pelanggaran kekal dan tiang kekal. Keputusan simulasi digunakan bagi mengenal pasti laluan bebanan, nyah pecutan dan tenaga resapan pada sesetengah bahagian utama yang membujur dan zon kehancuran yang masih diperolehi sekaligus memudahkan keperluan untuk memberikan perlindungan pelanggaran bagi penambah baikkan reka bentuk pada masa akan datang. Hasil yang diharapkan daripada kajian ini adalah untuk menghasilkan penyelidikan dan reka bentuk maklumat mengenai kenderaan yang akan membolehkan pengubahsuaiaan dan peningkatan reka bentuk semasa untuk mengoptimumkan prestasi perlindungan pelanggaran dan meningkatkan tahap keselamatan.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF ABBREVIATIONS	xv
	LIST OF SYMBOLS	xvi
1	INTRODUCTION	1
	1.1 Rain Forest Vehicle	1
	1.2 Project Background	3
	1.3 Objectives of the study	5
	1.4 Scope of the study	5
2	LITERATURE REVIEW	6
	2.1 Introduction	6
	2.2 Crashworthiness	7
	2.3 Controlling the crush and energy	8
	2.3.1 Axial collapse	12

2.3.2 Bending collapse	13
2.4 Vehicle regulation	14
2.4.1 FMVSS 208	15
2.4.2 New Car Assessment Program (NCAP)	18
2.4.3 Rigid Pole	19
2.5 Collision Speed	20
2.6 Simulation of Finite Element Method (FEM)	21
3 RESEARCH METHODOLOGY	26
3.1 Tensile Test	28
3.2 Compression test by using FEA for a subcomponent of the RFV	30
3.3 Validation of the component test	33
3.4 Crash analysis of RFV by using FEA	35
3.4.1 Model Setup	35
3.4.2 Energy absorption of the main parts	37
3.4.3 Element definition	38
3.4.4 Material properties	38
3.4.5 Constraint	39
3.4.6 Output file	40
3.4.7 Test Setup	40
3.4.7.1 Full frontal	41
3.4.7.2 40 Percent offsets rigid	42
3.4.7.3 Rigid pole	43
3.5 Improvement of the crashworthiness	44
3.6 Resolutions	44
4 RESULTS AND DISCUSSIONS	45
4.1 Introduction	45
4.2 Compression test by using FEA for a subcomponent of the RFV supplement via experiment	46

4.3	Crash analysis of RFV by using FEA	52
4.3.1	Full frontal impact	52
4.3.1.1	The influences of mass and velocity in full frontal impact	58
4.3.1.2	Energy Absorption of Parts at Full Frontal	61
4.3.2	40 Percent offsets rigid impact	66
4.3.2.1	Energy Absorption of Parts at 40 percent offset	71
4.3.3	Rigid pole impact	73
4.3.3.1	Energy absorption of parts at rigid pole	78
4.3	Comparison of three different impacts	81
5	IMPROVEMENT OF CRASHWORTHINESS	87
5.1	Introduction	87
5.2	Part Improvement	88
5.3	Full frontal impact of reinforced structure	89
5.4	40% offset rigid impact of reinforced structure	93
5.5	Rigid poles impact of reinforced structure	96
5.6	Discussion of the reinforced structure	99
6	CONCLUSION AND FUTURE WORKS	100
6.1	Conclusions	100
6.2	Recommendation for future works	103
	REFERENCES	104
	APPENDIX	110

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Overview of the FMVSS 208	16
2.2	Overview of the EURO NCAP	18
2.3	Comparison between the current testing and the simulation of the Ford Taurus	21
3.1	True stress-plastic strain data points for carbon steel in the numerical simulation	30
3.2	Energy absorption part names	37
3.3	Mild Steel Elastic data	38
3.4	Mild Steel Plastic data	39
3.5	Keyword database	40
4.1	The comparison of average mean load, P_m (kN)	49
4.2	Comparison between original, simulation M and V	59
4.3	Energy absorption of different part of full frontal	62
4.4	Energy absorption of different parts on 40 percent offset	71
4.5	Energy absorption of different parts of rigid pole impact	79
4.6	Energy comparison for prescribed crash	85
5.1	Part improvement and description	89
5.2	Energy comparison for prescribed crash after reinforced	99

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Example of RFV	2
1.2	8 WD Vehicle	3
1.3	Prototype of Rain Forest Vehicle	4
2.1	Ideal crash of a square seamless steel tube	8
2.2	Dynamic is crushing mode for a thin-walled square tube	11
2.3	Bending Collapse	14
2.4	Full Frontal Fixed Barrier	15
2.5	Estimated energy absorption percentages in the frontal structure	17
2.6	40% offset impact	18
2.7	Three optimal deceleration curves in three phases	20
2.8	Comparison of real structure and simulation	22
2.9	Full Structure of OUV	23
3.1	Methodology Diagram of Overall Project	27
3.2	Specimen geometry according to the ASTM A370 standard	28
3.3	Specimen fracture	29
3.4	True stress versus plastic strain distribution of mild steel	29
3.5	Quasi static of single component by using FEA	30
3.6	Quasi static of frontal longitudinal section test by	32

	using FEA	
3.7	Quasi static test of a single component	33
3.8	Quasi static of frontal longitudinal section	34
3.9	RFV model	36
3.10	Centroid and element mass position	36
3.11	Main parts of energy absorption	37
3.12	Full frontal test setup	41
3.13	40 percent offset rigid test setup	42
3.14	Rigid pole test setup	43
4.1	Comparison between experiment and simulation	47
4.2	Graph force versus displacement between simulation and experiment of single component	48
4.3	Comparison between experiment and simulation of frontal longitudinal section	51
4.4	Graph force versus displacement between simulation and experiment of frontal longitudinal section	52
4.5	Sequence of full frontal impact	53
4.6	Von Misses Stress distribution after 60ms of full frontal impact	54
4.7	Bottom View of full frontal impact	54
4.8	Graph energy versus time of full frontal impact	56
4.9	Graph force versus displacement of full frontal impact	57
4.10	Full frontal deceleration curve	58
4.11	Simulation M	60
4.12	Simulation V	60
4.13	Simulation V at 75ms	61
4.14	Node identifying	62
4.15	Crush of part 451 at 30ms of full frontal impact	63
4.16	Crush of part 451 at 60ms of full frontal impact	63

4.17	Graph force of several nodes at right side of the vehicle during full frontal	65
4.18	Energy of several nodes at left side of the vehicle during full frontal	65
4.19	Sequence of 40 percent offset impact	66
4.20	Von Misses Stress distribution after 60 ms of 40 percent offset crash	67
4.21	Bottom view of 40 percent offset crash	68
4.22	Graph Energy versus time of 40 percent offset impact	69
4.23	Graph force versus displacement of 40 percent offset	70
4.24	Graph Acceleration versus Time	70
4.25	Energy versus time of 40 percent impact	72
4.26	Deformation of part 451 during 40 percent offset impact at 60ms	73
4.27	Graph force versus node during 40 percent offset on the left of part 451	73
4.28	Sequence of rigid pole impact	74
4.29	Von Misses stress at $t=60$ ms of rigid pole impact	75
4.30	Graph energy versus time of rigid pole impact	76
4.31	Graph force versus deformation of rigid pole	77
4.32	Graph Acceleration Versus Time	78
4.33	Graph Acceleration Versus Time	79
4.34	Deformation of part 451 at 60ms during rigid pole impact	80
4.35	Graph force versus node on left of part 451 on rigid pole impact	81
4.36	Deformation curves of three different impacts	82
4.37	The velocity difference in all crashes	83
4.38	Comparison Parts of Energy Absorption for	84

	Different Crash Situation	
5.1	Assembly of the reinforced structure	88
5.2	Von misses stress at t=60ms for full frontal impact	90
5.3	Bottom view of Von Misses stress at t=60ms for full frontal impact	91
5.4	Force versus displacement curve after reinforcing of the full frontal crash	92
5.5	Energy comparison of the reinforced structure for full frontal impact	93
5.6	Von misses stress at 60ms of 40 percent offset impact	94
5.7	Bottom view at 60ms of 40 percent offset impact	94
5.8	Force versus displacement curve after reinforcing of the 40 percent offset	95
5.9	Energy comparison of the reinforced structure for 40 percent impact test	96
5.10	Von misses stress at 60ms of rigid pole impact	97
5.11	Bottom view at 60ms of rigid pole impact	97
5.12	Force versus displacement curve after reinforcing of the rigid pole	98
5.13	Energy comparison of the reinforced structure of rigid pole impact tests	99

LIST OF ABBREVIATIONS

RFV	-	Rain Forest Vehicle
FEM	-	Finite Element Method
SUV	-	Sport Utilities Vehicle
OUV	-	Outdoor Utilities Vehicle
8WD	-	8 Wheel Drive
FEA	-	Finite Element Analysis
NHTSA	-	National Highway Traffic Safety Administration
CG	-	Centre of Gravity
NCAP	-	New Car Assessment Program
KE	-	Kinetic Energy
IE	-	Internal Energy

LIST OF SYMBOLS

L, l	-	Length
E	-	Modulus of Elasticity
A	-	Area
F	-	Force
K	-	Stiffnes
m	-	Mass
g	-	Constant due to Gravity
t	-	Time
σ	-	Stress
J	-	Joule
v	-	Velocity
a	-	acceleration

CHAPTER 1

INTRODUCTION

1.1 Rainforest Vehicle

Peninsular Malaysia consists about 5.87 million hectares or 45% of its total land area of tropical rainforest. The major rain forest types in Malaysia consist of dry inland forest which is the main forest cover, peat swamp forest and mangrove forest. 4.93 million hectares are Permanent Reserved (PRFs), 0.33 million hectares are State/Alienated Land Forest and 0.61 million hectares are National Park/Wildlife and Bird Sanctuary (Council, 2007). Regarding to this statistic, the use of transportation in the forest is very significant.

Based on the necessity in transportation, people need to travel and explore new areas, especially in the new rural areas. This demands the need of a vehicle that is equipped with relevant capabilities and able to restrain with the jungle road condition. In this era, automotive historians will remember 1990s as the Renaissance decade of automotive safety. During this decade, occupant safety has been established as a leading marketing characteristic of motor vehicles. In Malaysia, one company, Innopeak Sdn. Bhd with the association with scholars are developing a vehicle called Rainforest Vehicle (RFV).

RFV is defined as an outdoor vehicle that can be used in the rural, military area especially in the forest. This vehicle must have the capability to be driven in uneven terrain and sloping condition as well as on any paved or gravel surface.

Furthermore, ground clearance aspect has to be in account so that it will not get hung up on obstacles. Since the body is heavy, it needs to keep their wheels or tracks on the ground so as not to lose traction. As it goes through the sloping terrain, the centre of gravity must be maintained so will minimise the probability to turn over. This all are the advantages of this vehicle compared to normal transportation. Figure 1.1 shows the example of the RFV that is available in the market.



Figure 1.1: Example of RFV
(www.virtualmalaysia.com)

In the market, the well-established brand name like Toyota, Mitsubishi, Land Rover and Suzuki are multinational companies. However, this vehicle needs to be modified in order to have a great handling capability, especially while going through the Malaysian rainforest. Besides, it is a good opportunity to produce our own vehicle. In Australia, the use of 8 Wheel Drive (8WD) has been used in the Daintree rainforest as a means of transportation. This means, the utilisation of special vehicle in the forest is very significant throughout other country. Furthermore, the All-Terrain Vehicle (ATV) used in the off-road condition might be influential in designing this vehicle. By taking consideration of the rainforest condition, especially in Malaysia, this vehicle must implement the safety testing required by this vehicle during impact. In spite of these vehicles are not subjected to the safety standards of road cars, but it must be expected higher than the other category. The only regulation

that is available currently in the forest condition is ATV. However, this vehicle has the minimal regulation as it is only used for one or two people and the minimal weight that is less than 500kg and in fact, the safety regulation of ATVs is minimal compared with those road cars. As a result, the testing standard for the road safety is the best guideline for the safety requirement in testing the impact.



Figure 1.2: 8 WD Vehicle

(www.cairns.com.au)

1.2 Problem Statement

One company namely Innopeak (M) Sdn Bhd is on an upward spiral of increasing mass and stiffness for heavy duty vehicles. This company is developing one prototype vehicle called rainforest vehicle (RFV) which is used for the outdoor transportation. This design must fulfil the safety requirement before proceeding to another step; this RFV must be tested according to the road safety standard. Since the destructive testing is immensely expensive, time consuming and unsuitable for a developing company, another approach has been proposed to solve this issue. To address this, a comprehensive research will be undertaken to investigate the crash response of this vehicle using finite element techniques complimented by experiments.

This crash response must be guided using a world standard that has been used in the crashworthiness area. Validation of the model will be conducted by comparing finite element simulation with experimental result of individual frontal truck components and scale section of frontal parts. The effect of varying impact velocity and mass will be numerically examined using finite element models to manifest the impact and energy absorption response during a crash. Moreover, structural integrity and crashworthiness aspect will also be considered accordingly to optimise the design of the existing truck cabin during such an event. The expected outcome of this project is to generate research and design information on the design that will enable further modification and enhancement of the current design for optimising crashworthiness performance and enhancing level of safety.



Figure 1.3: Prototype of Rainforest Vehicle (RFV)

1.3 Objectives of the study

The objectives of the studies are as follows:

- a) To investigate the crashworthiness and energy absorption capability of a space frame rainforest vehicle when subjected to frontal impact.
- b) To generate research information and make design recommendation based on the numerical crash analysis performed.

1.4 Scope of the study

The scopes of this research were as follows:

- a) Development of preliminary model under impact loading.
- b) Crushing a quasi-static of the vehicle component
- c) Validation of FE results supplement by experiment
- d) Detailed impact cases of RFV; Full frontal, 40 % offset and rigid pole.
- e) Investigating energy absorption capability of frontal longitudinal members and the chassis.
- f) Recommendation of improvement in the critical vehicle component.

REFERENCES

- Abramowicz, W. and N. Jones (1984). *Dynamic Crushing of Square Tubes*. International Journal of Impact Engineering 2(2): 179-208.
- Ahmad, Z. and D. P. Thambiratnam (2009). *Crushing response of foam-filled conical tubes under quasi-static axial loading*. Materials and Design: 2293-2403.
- Ahmad, Z. and D. P. Thambiratnam (2009). *Dynamic computer simulation and energy absorption of foam-filled conical tubes under axial impact loading*. Computers and Structures(87): 186–197.
- Ahmad, Z., D. P. Thambiratnam and A. C. C. Tan (2010). *Dynamic energy absorption characteristics of foam-filled conical tubes under oblique impact loading*. International Journal of Impact Engineering(37): 475–488.
- Benhizia, A. and T. Outtas (2011) *Numerical Simulation of Frontal Offset Crash Test for the Vehicle Frame using Ls Dyna*. 56.
- Benson, D. J. (2007) *The History of LS-DYNA*.
- Brach, R. M., R. M. Brach and A. Louderback (2012). *Uncertainty of CRASH3 ΔV and Energy Loss for Frontal Collisions*. SAE 01.
- Cheng, Z. Q., J. G. Thacker, W. D. Pilkey, W. T. Hollowell, S. W. Reagan and E. M. Sieveka (2001). *Experiences in reverse-engineering of a finite element automobile crash model*. Finite Elements in Analysis and Design 37: 843–860.
- Choi, Won Mok, Kwon, Tae Su, Jung, Hyun Sung, Kim and J. Sung (2012). *Influence of impact velocity on energy absorption characteristics and friction coefficient of expansion tube*. International Journal of Crashworthiness: 1-9.
- Chou, C., *Mean Crush Load Prediction Technique - An Extension to MageeThornton Approach*, Ford Motor Company Vehicle Development Technology Report No. VDT-80-34, July (1980).

- Council, M. T. (2007). *Sustainable Forest Management*.
- Davis, S. C. and L. F. Truett (2000). *An analysis of the impact of sport utility vehicle in the United*.
- Devaraj, S. R., G. T. Kridli and R. C. Shulze (2005). *Design and Analysis of a Conceptual Modular Aluminum Spaceframe Platform*. SAE 2005(01): 61.
- Donald E. Malen, *Fundamental of Automobile Bdy Structure Design* (2011). SAE International, Warrendale, Pennsylvania USA
- Fan, Z., K. Liu and G. Lu (2011). *Quasi-static axial compression of thin-walled tubes with different cross-sectional shapes*.
- G. B. Gadekar, S. M. Athavale and P. R. Sajanpawa (1993). *Car Crash Simulation Studies using Explicit Nonlinear Finite Element Analysis*. SAE.
- Ghamarian, A., H. R. Zarei and M. T. Abadi (2011). *Experimental and numerical crashworthiness investigation of empty and foam-filled end-capped conical tubes*. Thin-WalledStructures(49): 1312–1319.
- Ghannam, M. Y., M. Niesluchowski and P. M. Culkeen (2002). *Analysis of a Frontal Rail Structure in a Frontal Collision*. SAE 01(0688).
- Gu, G., Y. Xia and Q. Zhou (2012). *On the fracture possibility of thin-walled tubes under axial crushing*. Journal of Thin-Walled Structures 55(0): 85-95.
- Gursel, K. T. , Nane and S. N. (2010). *Non-linear finite element analyses of automobiles and their elements in crashes*. International Journal of Crashworthiness 15(6): 667-692.
- Hollowell, W. T., H. C. Gabler, S. L. Stucki, S. Summers and J. R. H. NPS (1999) *Updated Review of Potential Test Procedures For FMVSS 208*.
- Hong, S.-W., C.-K. Park, Pradeep Mohan, R. M. Morgan, C.-D. Kan, K. Lee, S. Park and H. Bae (2008). *A Study of the IIHS Frontal Pole Impact Test*. SAE International 0507(01).
- Huiwen Hu, W.-J. Lu and Z. Lu (2011). *Impact crash analyses of an off-road utility vehicle – part II: simulation of frontal pole, pole side, rear barrier and rollover impact crashes*. International Journal of Crashworthiness 17(2): 163-172.
- Huiwen Hu, Z. L., Jieming Wang & Wei-Jun Lu (2011). *Impact crash analyses of an off-road utility vehicle – part I: validation of finite-element model for body structure*.

- International Journal of Crashworthiness 17(2): 153-162.
- Jenefeldt, F. and R. Thomson (2004). *A methodology to assess frontal stiffness to improve crash compatibility*. International Journal of Crashworthiness, 9:5: 475-482.
- Jones, S. S. H. a. N. (2004). *Dynamic axial crushing of aluminium alloy 6063 -T6 circular tubes*. Latin American Journal of Solids and Structures 1: 277-296.
- Jr., H. J. C. (1995). *A Front Rail Design For Efficient Crush Energy Absorption*. SAE 20(0016).
- Kerkhoff, J. F., S. E. Husher, M. S. Varat, A. M. Busenga and K. Hamilton (1993). *An Investigation into Vehicle Frontal Impact Stiffness, BEV and Repeated Testing for Reconstruction*. SAE(930899).
- Kim, B. S., K. Park and Y.-M. Song (2011) *Finite Element Frontal Crash Analysis of New Vehicles*.
- Kirkpatrick, S. W. (2000). *Development and Validation of High Fidelity Vehicle Crash Simulation Models*. SAE 01(0627).
- Krishanmurthy, V. (2005). *A CAE based study of reduction of crash aggressivity of pickup trucks*. Wichita State University: Master Thesis, Bangalore.
- Liu, Y. (2004). *Crashworthiness Analysis of Finite Element Truck Chassis Model Using LS-DYNA*. 11th International LS DYNA Users Conferences.
- Matsumoto, André Takashi, Driemeier, Larissa, Alves and Marcílio (2012). *Performance of polymeric reinforcements in vehicle structures submitted to frontal impact*. International Journal of Crashworthiness: 1-18.
- Mizuno, K., Y. Arai and C. A. Newland (2010). *Compartment strength and its evaluation in car crashes*. International Journal of Crashworthiness 9(5): 547.
- Mizuno, K., Y. Arai, K. Yamazaki, H. Kubota, H. Yonezawa and N. Hosokawa (2008). *Effectiveness and evaluation of SEAS of SUV in frontal impact*. International Journal of Crashworthiness 13(5): 533-541.
- Mogami, K., K. Fujiwara, H. Yamamoto, Y. Itho, M. Kubota and H. Ohmae (1998). *Frontal Crash Characteristics of Compact Car at a High Speed Collision*. SAE(980533).
- Motozawa, Y. and T. Kamei (2000). *A New Concept for Occupant Deceleration Control*

- in a Crash*. SAE 1(0881).
- Mustafa, M. N. (2006). "Overview of Current Road Safety in Malaysia.
- Nagel, G. M. and D. P. Thambiratnam (2006). *Dynamic simulation and energy absorption of tapered thin-walled tubes under oblique impact loading*. International Journal of Impact Engineering(32): 1595–1620.
- NCAP, E. N. C. A. P. (2011). *Frontal Impact Testing Protocol. V. 5.1*.
- Niknejad, A., G. H. Liaghat, A. H. Behraves and H. M. Naeini (2009). *Experimental investigation of the maximum axial force in the folding process of aluminum square columns*.
- Nolan, A. K. L. a. J. M. (2003). *Changes in Vehicle Designs from Frontal Offset and Side Impact Crash Testing*.
- Paul Du Bois, Clifford C. Chou, Bahig B. Fileta, Tawfik B. Khalil, Albert I. King, Hikmat F. Mahmood, Harold J. Mertz and J. Wisnans (2004). *Vehicle Crashworthiness and Occupant Protection*. Southfield, Michigan, Automotive Applications Committee American Iron and Steel Institute.
- Popa, V. and H. Beles (2011) *Sudy of Vehicle Adaptive Structures for Frontal Collisions*.
- Qi, C., S. Yang and F. Dong (2012). *Crushing analysis and multi objective crashworthiness optimization of tapered square tubes under oblique impact loading*. Thin-Walled Structures(59): 103–119.
- R, L. K. and V. K. Banthia (2009). *Numerical Simulation for Crashworthiness of Frontal Rail Structure Using Explicit Finite Element Code*. SAE 26(60).
- R.Mirzaamiri, M.Esfahanian and S. Ziaei-Rad3 (2012). *Crash Test Simulation and Structure Improvement of IKCO 2624 Truck According to ECE-R29 Regulation*. International Journal of Automotive Engineering 2(3): 180.
- Rahim, A. R. A., K. H. Lye and A. Richard (2011). *Forest Rehabilitation Initatives In Peninsular Malaysia*.
- Reza Mehryari Lima, Z.N. Ismarrubie, E. S. Zainudin and S. H. Tang (2012). *Effect of length on crashworthiness parameters and failure modes of steel and hybrid tube made by steel and GFRP under low velocity impact*. International Journal of Crashworthiness,.
- Said, M. R., Reddy and T. Y. (2002). *Quasi-static response of laterally simple*

- compressed hexagonal rings*. International Journal of Crashworthiness, Taylor & Francis. 7: 345-364.
- Samaan, M., A. Elmarakbi and K. Sennah (2009). *Crashworthiness: Numerical Simulation of Vehicle - Steel Pole Crash*. 7th International LS-DYNA Users Conference.
- Santosa, Sigit, Wierzbicki and Tomasz (1997). *Effect of an Ultralight Metal Filler on the Torsional Crushing Behaviour of Thin-Walled Prismatic Columns*. International Journal of Crashworthiness 2(4): 305-332.
- Schneider, F. and N. Jones (2004). *Impact of thin-walled high-strength steel structural sections*. Journal of Automobile Engineering 218(131).
- Shkolnikov, M. B. (2008). *Strain Rates in Crashworthiness*. 8th International LS-DYNA Conference. Detroit.
- Song, J. (2013). *Numerical simulation on windowed tubes subjected to oblique impact loading and a new method for the design of obliquely loaded tubes*. International Journal of Impact Engineering(54): 192 - 205.
- Sorg, A. (2008). *Crashworthiness Assessment of Automobile Front Ends using Explicit Finite Element Formulations*. Institute of Structural Mechanics, Universität Stuttgart. Master.
- Spinelli, D. M. and T. Adelman (1999). *Crash Simulation and Occupant Safety Analysis Using the Finite Element Method*. SAE 01.
- Stacy C. Davis and L. F. Truett (2000). *An Analysis of the Impact of Sport Utility Vehicles in the United States*.
- Subramaniam, K., M. Verma, R. Nagappala, R. Tedesco and L. Carlin (2006). *Evaluation of Stiffness Matching Concepts for Vehicle Safety Improvement* (07-0112).
- Thacker, J. G., S. W. Reagan, J.A. Pelletiere, W. D. Pilkey, J. R. Crandall and E. M. Sieveka (1998). *Experiences during development of a dynamic crash response automobile model*. Finite Elements in Analysis and Design 30: 279.
- Tracy, E. T. (2005). *Vehicle Crashworthiness- Identifying if Vehicle Defects Exist*.
- V. Tarigopula, M. Langseth, O.S. Hopperstad and A. H. Clausen (2005). *Axial crushing of thin-walled high-strength steel sections*. International Journal of Impact

- Engineering 32: 847–882.
- W.J. Witteman and R. F. C. Kriens (1998). *Modelling of an Innovative Frontal Car Structure: Similar Deceleration Curves at Full Overlap, 40 Per Cent Offset and 30 Degree Collisions*.
- Waseem Sarwar and N. Hayat (2007). *Crash Simulation and Analysis of a Car Body Using ANSYS LS- DYNA*.
- White, M. D., N. Jones and W. Abramowicz (1998). *A theoretical analysis for the quasi-static axial crushing of top-hat and double-hat thin-walled sections*.
- Wierzbicki, T. and W. Abramowicz (1983). *On The Crushing Mechanics of Thin-Walled Structures*. Journal of Applied Mechanics 50: 727-734.
- Witteman, W. J. (1999). *Improved Vehicle Crashworthiness Design by Control of the Energy Absorption for Different Collision Situations*, Technische Universiteit Eindhoven: Doctorate Thesis
- Wu, C.-H., C.-Y. Tung, J.-H. Lee and C. C. Tsai (2005). *Improvement Design of Vehicle's Front Rails for Dynamic Impact*. 5th European LS-DYNA Conference.
- Yang, C. C. (2003). *Dynamic Progressive Buckling of Square Tubes*. The 27th Conference on theoretical and Applied Mechanics. Taiwan.
- Zaouk, A. K., D. Marzougui and N. E. Bedewi (2010). *Development of a Detailed Vehicle Finite Element Model Part I: Methodology*. International Journal of Crashworthiness 5(1): 25-36.
- Zaouk, A. K., N. E. Bedewi, C.-D. Kan and D. Marzougui (1997) *Development and Evaluation of a C-1500 Pick-up Truck Model for Roadside Hardware Impact Simulation*.