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Investigations into Dynamic Response of Automobile Components during Crash Simulation

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Abstract

Crash simulation is a virtual recreation of a destructive crash test of a vehicle and its components using a computer aided analysis software in order to examine the level of safety of the vehicle and its occupants by analysing the level and nature of impact stresses occurring in the component and the magnitude and nature of the deformation happening in the component. Computer aided parametric design software are generally used for modelling of the vehicle components, to define all the coordinate values and geometrical details and then this CAD data is generally transferred to an FEM software for pre-processing and solution followed by generation and interpretation of results related to energies, acceleration and displacements with different loads & boundary conditions possible in various accidental situations. This major accomplishment is possible due to advent of advanced FE software system and computers offered within the last few years. Simulating the crashworthiness of the vehicle is a significant step to design automobiles of present age and automotive industry has probably the widest application of such simulation. Nowadays software such as LSDYNA, RADIOSS, ABASUS and others have very wide practical aspects to perform crash simulations.

In the present work, Finite element modelling practices used for crash analysis are studied and after effects of the different parameters on the vehicle have been reviewed. The aim of this work is to study the effects of such crash parameters on the dynamic response of automobile component through finite element approach path. This paper presents an investigations of development done in the crash simulation of automobile components and the related process parameters through finite element approach.

Keywords: Crash analysis; Finite Element Analysis; Simulation; Crashworthiness; Automotive; Occupant protection; Fullscale test

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1. Introduction

A crash simulation is a virtual recreation of a destructive crash test of a vehicle using a computer simulation in order to examine the level of safety of the vehicle and its occupants. Data obtained from a crash simulation indicate the capability of the vehicle body to protect the vehicle occupants during a collision against injury. This simulation technology have greatly increased the protection, dependability and producing potency in today's vehicles. The advantage of the simulation are numerous and important. Computer aided parametric design software will be used for modelling of the problem to define all the coordinate values and geometrical details, then this CAD data would be transferred to an FEM software for pre-processing, solution and post-processing followed by generation and interpretation of results related to energies, acceleration and displacements with different loads & boundary conditions possible in various accidental situations. Automotive [16] industry has probably the widest application of crash simulation. Simulating the crashworthiness of the vehicle in terms of very simple models based on the spring mass damper systems was the focus when the computers were very slow and the breakthrough occurred when LSTC was formed. Nowadays software such as LSDYNA and others have very wide practical aspects by incorporating special seat belt elements and passenger dummies for simulating precisely the occupant safety under various crash situations. Several standards have been originated in various countries related to automobile crashing. Although developed mainly for automotive applications, crash simulation software's have also found application in train, ship and aircraft crashworthiness. The two main standards associated with FAA (Federal Aviation Administration) requirements are those of bird strike impact and engine blade containment. Other applications in defence sector are simulating the explosive detonation process and design of weapons. Computational Biomechanics also is continuously evolving with the development of finite element models closely following the actual physics models.

2. Finite Element Analysis

Simulation using finite element method [19] comprises of three major phases: (1) pre-processing, in which the analyst develops a finite element mesh to divide the subject geometry into sub-domains for mathematical analysis, and applies material properties and boundary conditions, (2) solution, during which the program derives the governing matrix equations from the model and solves for the primary quantities, and (3) post-processing, in which the analyst checks the validity of the solution, examines the values of primary quantities (such as displacements and stresses), and derives and examines additional quantities (such as specialized stresses and error indicators).

3. Various Crash Test

A crash test is a form of destructive testing usually performed in order to ensure safe design standards in crashworthiness and crash compatibility for various types of vehicle like small, medium and heavy duty and its related systems and components for the sake of getting the performance of the vehicle under the different conditions of crash at different angles with taking certain object like rigid wall, cables specially three-strand cable, concrete barriers, guardrail systems etc. It will be performed either by numerical simulations or experimentally. Figure 1 depicts different types of crash test generally used.

- Frontal Impact test- In this test a fully front structure of the vehicle collides with another object like another vehicle, rigid wall etc. at a given speed.

- Offset Test- In this test only a part of front portion of the vehicle strikes on some barrier usually a vehicle at a given speed.

- Small Overlap Test- In this only a small portions of the vehicle strikes an object like tree, pole or if a car were to clip another. This situation loads a maximum value of force into the vehicle structure at a particular given speed. This test usually comprises of 15% to 20% of the front structure.
- Side Impact Test- In this test sometimes the vehicle is in static condition or in dynamic and another vehicle or an object collide at the side surface having some speed.

- Roll-Over Test- In this test a vehicle is in rollover condition having certain angle by which they tests ability (specifically the pillars holding the roof) to support itself in a dynamic impact. It is also done for the static crash testing condition.

- Roadside Hardware- These are performed to ensure that the crash barriers and crash cushions will protect vehicle occupants from roadside hazards.

- Old Versus New- In this an impact is done between old car against a new car and the big car against a small car; it is performed to show the advancements in crashworthiness.

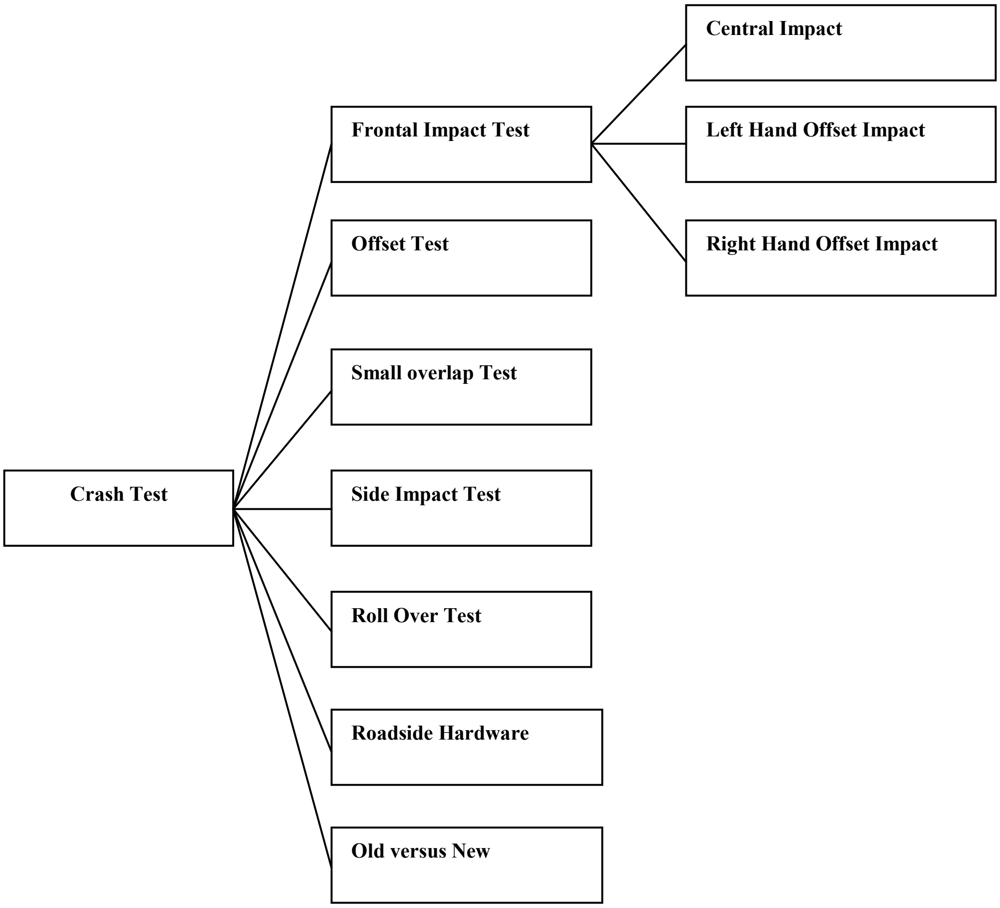

Fig. 1. Classification of various crash test used in testing

4. Software used for Crash Analysis

In the below Table 1 shows the common features and the capabilities of the different software's available for the analysis in the various field like dynamic and static analysis.

Table 1. Software used for Crash Finite Element analysis

Software	Elements library	Material Library	Facilities	Advantages	Applications
LS-DYNA	Shell element, Beam element, Brick element etc.	Metals, Plastics, Glass, Foams, Fabrics, Honeycombs, steel, aluminum, rubbers, foams, composites etc.	Full 2D & 3D capabilities, Nonlinear dynamics, Rigid body dynamics, Quasi-static simulations etc.	Analysis of different situations or patterns of accidents.	Crashworthiness, Occupant Protection, Metal Forming, Product Testing, Drop Testing, High velocity impacts etc.
PAMCRASH	Shell elements Quadrilateral (Belytchko-Tsay, Hughes-Tezduyar), Triangle (Belytchko-Tsay) etc.	Corus, Posco, Nippon Steel etc.	Simulate the performance of a proposed vehicle design and evaluate the potential for injury to occupants in multiple crash scenarios.	Reduces design cycle, Shortens time to market, Optimizes costs, Decreases the number of prototype phases, Allows the testing of more crash scenarios.	Aerospace application,Nuclear application etc
RADIOSS	Solid Elements (Hexahedron, Tetrahedron), Shell element, Truss element, Beam element etc.	Concrete, Foam, Rubber, Steel, Composites, Biomaterials etc.	Non-linear explicit dynamic structural analysis, Non-linear implicit structural analysis, Explicit Computational Fluid Dynamics (CFD).	Handling linear and non-linear finite element analysis, Sheet metalstamping, Multi-body dynamics and Highly vectorized implementation.	Solving highly non-linear problems under dynamic loadings etc
MSC.DYTRAN	Solid element, shell and Membrane element, Beam element, Spring element, Damper element etc.	Metals, Foam materials, Rubber, and Elastomers; Flow of fluid, Gases and Viscous Materials etc.	Simulating and analyzing extreme, Short-duration events involving the deformation of structural materials and interaction of fluids and structures	Handling high degree of material nonlinearity, Large geometric nonlinearity, Extreme boundary nonlinearity.	Aerospace applications, Automotive applications , Military and defense applications, Other commercial and industrial applications etc.
MADYMO	Rigid bodies, Ellipsoids, Cylinders, Planes,Facet surfaces etc.	Form, Honeycomb, sandwich material etc.	Simulates the dynamic behavior of physical system emphasizing the analysis of vehicle collision and assessing injuries sustained by passengers.	Provides Solution to problems in crash engineering applications.	Airbag Modeling, Frontal Impact Application, Side Impact Application, FMVSS 208 Out-of-Position (OOP) Analyses, Rollover application, Airbag using Initial Metric Method 2, MADYMO/Simulink application etc.

ABAQUS	Cylindrical elements Solid elements, Structural elements Shell elements Beam elements etc.	Metals, Rubbers, Concrete Fabrics etc.	Solves advanced computational electromagnetic problems, computational fluid dynamics capabilities, piezoelectric, etc.	Explicit integration scheme to solve highly nonlinear systems with many complex contacts under transient loads.	Automotive, Aerospace, and Industrial products industries etc.
ANSYS	Link, Plane, Beam, Solid, Pipe, Surf etc.	Metals, Rubber, Plastics, Glass, Foam, etc.	Structural analysis, including linear, non-linear etc.	Good for static and transient analysis	Structural Analysis,Thermal Analysis etc.

5. Implicit and Explicit Philosophy

Most software's would normally solve the dynamic equilibrium equation in an implicit approach however the foremost widespread approach that ought to be used for highly non-linear issues is to use explicit(specific) time integration scheme like a central difference scheme. There are several benefits of such a procedure and therefore the most significant is that it results in an algorithmic programmed which may be simplified programmed, does not need any matrix operation procedure and more is very appropriate for a quick parallel computing methodology [16]. In the below Table 2 shows the common difference between the implicit and explicit philosophy.

Table 2. Implicit and Explicit philosophy

Criteria	Explicit	Implicit
Common Software	In this philosophy software used such as LS-DYNA, MSC-DYTRAN, MADYMO, ABAQUS Explicit, PAMCRASH, RADIOSS	In this philosophy software used such as LS-DYNA-Implicit, ABAQUS-Standard, RADIOSS-Implicit
Support non-linearity	Its capability to solve highly non-linear problems without numerous iterations.	Its capability to solve highly non-linear problems without numerous iterations.
Maximum size of computational problem	To avoid large amount of CPU time, the explicit method is usually used for non-linear dynamic problems with a short period of simulation duration.	To avoid large amount of CPU time, the explicit method is usually used for non-linear dynamic problems with a short period of simulation duration.
Speed of calculation	Computational speed is very fast as there is no matrix operation.	Computational speed is very fast as there is no matrix operation.

6. Governing Equations

The equilibrium equations of transient dynamics [14] are written below as follows:

$$[M]\left\{\frac{d^2u}{dt^2}\right\}+c\left\{\frac{du}{dt}\right\}+k\{U\}=\{F_{ext}(t)\}..............(1)$$

Where M= Mass matrix,

C= Damping matrix, K= Stiffness matrix, F_{ext} = External force, t = Time

In Explicit time integration schemes above equation can be written as:

$$[M]\left\{\frac{d^2u}{dt^2}\right\}_n+c\left\{\frac{du}{dt}\right\}_n+k\{U\}_n=\{F_{ext}\}_n..............(2)$$

Where 'n' represents a time level index.

Physically it refers to
Inertial force + Damping force + Stiffness force = External force.................. (3)
Using second order accurate Explicit Central Difference Operator $\left\{\frac{du}{dt}\right\}_n$ and $\left\{\frac{d^2u}{dt^2}\right\}_n$ can be expressed as

$$\left\{\frac{du}{dt}\right\}_n = \frac{\{U\}_{n+1} - \{U\}_{n-1}}{2\Delta t} \quad (4)$$

$$\left\{\frac{d^2u}{dt^2}\right\}_n = \frac{\{U\}_{n+1} - 2\{U\}_n + \{U\}_{n-1}}{\Delta t^2} \quad (5)$$

Substituting the above equations into equation (2), we get

$$\frac{1}{\Delta t^2}[M] + \frac{1}{2\Delta t}[C]\{U\}_{n+1} = \{F_{ext}\}_n - \{F_{\text{int}}\}_n + \frac{1}{\Delta t^2}[M]\left[2\{U\}_n - \{U\}_{n+1}\right] + \frac{1}{2\Delta t}[C]\{U\}_{n-1} \quad (6)$$

Where F_{int} = Internal force
This is the final governing equation for crash analysis.

7. Standards and Regulation

There are some of the important standards/regulations shown in Table 3 related to crash situations which are referred for the modelling and testing purpose. Most common standards in US are FMVSS (Federal Motor Vehicle Safety Standards) regulations, ECE (Economic Commission of Europe) regulations in Europe, ARAI (Automotive Research Association of India) testing standards are used in our country.

Table 3. Regulations/Standards [16, 17, 18]

FMVSS Standard number	Description	ECE Regulation number	Description	ARAI Standard number	Description
201	Occupant Protection in Interior Impact	ECE R-11	Occupant Protection in Interior Impact	AIS-002	Occupant Protection in Interior Impact.
202	Head Restraints	ECE R-12	Head Restraints	AIS-009 / 2001	Head Restraints.
203	Impact Protection for the Driver from the Steering Control System	ECE R-14	Impact Protection for the Driver from the Steering Control System	AIS-011 / 2001 and Amd. No.1	Impact Protection for the Driver from the Steering Control System.
204	Steering Control Rearward Displacement	ECE R-16	Steering Control Rearward Displacement	AIS-012	Steering Control Rearward Displacement.
205	Glazing Materials	ECE R-17	Glazing Materials	AIS-015 / 2000	Glazing Materials.
206	Door locks and Door Retention Components	ECE R-21	Door locks and Door Retention Components	AIS-016 / 2000	Door locks and Door Retention Components.
207	Seating System	ECE R-25	Seating System	AIS-018 / 2001 and Amd.No.1/ June 2002 & Amd. 2	Seating System.

208	Occupant Crash protection	ECE R-32	Occupant Crash protection	AIS-020	Occupant Crash protection.
209	Seat Belt Assemblies	ECE R-33	Seat Belt Assemblies	AIS - 023	Seat Belt Assemblies.
210	Seat Belt Anchorage System	ECE R-42	Seat Belt Anchorage System	AIS-029 and Amd. No. 1 & Amd. No. 2	Seat Belt Anchorage System.
212	Windshield Mounting	ECE R-44	Windshield Mounting	AIS-031 & Amd. No.1	Windshield Mounting
214	Side Impact protection	ECE R-94	Child Restraint System	AIS-058 (Part1) and Amd. No. 1	Child Restraint System
218	Motorcycle Helmets	ECE R-95	Side Impact protection		

8. Existing Research Efforts

In the literature survey it is found that various researchers had studied different models related to the FE crash simulation with various boundary conditions as depicted through Table 4.

Table 4. Different model studied in literature review

Name Of Researchers	Year	Author Model	Case	Impact Object	Nodes	Other Units and Joints	Element Used	Software/Crash Code Used	Crash Speed
Jorge A. C.[1]	1990	Roll bar cage	Roll over	_	12	_	13 Beam element	_	25mph
Dhafer Marzougui et.al.[2]	1996	1993 Ford Taurus (Weight of the Body Crashed:1725 Kg)	Frontal Impact	Rigid Flat Wall	26,741	_	Shell element(27,874),Beam element(341), Brick element(140)	LS-DYNA3D	30mph (48.3 km/hr)
Abdullatif K. Zaouk et. al.[3]	1996	1994 Chevrolet C-1500 pick-up truck	Frontal Impact, Corner Impact	Rigid wall, 42inch vertical concrete median barrier	61,776		52,541 Shell elements, 109 Beam elements,1716 Hexahedron elements.	AutoCAD, PATRAN, L-S DYNA, LS-INGRID	35mph(56kph), 62.5mph (100 kph)
T. Omar et. al.[4]	1998	Box-beam with an attached rigid mass	Frontal Impact	Rigid wall	_	_	5064 Quadrilateral shell elements, Belytschko-Tsay shell element	LS-DYNA 3 D.	7m/s(20 ms).
N. Bedewi et. al.[5]	1998	midsize sedan vehicle based on 1991 ford Taurus	Frontal Impact	Rigid wall	_	_	28,000 Shell elements, 140 Beam elements, and 350 Solid elements.	LS-DYNA 3 D.	26,30, 34, and 40 mph

S.Mukherjee et. al.[6]	2001	Toyota Corolla	Side Impact	Motorcycle (Kawasaki GPZ)	_	Car (4 Kinematic joints and 4 Spherical Joints). Motorcycle(2 kinematic joints and 9 spherical joints.)	For Car (14828 Shellelements, 432 Brick elements, 465 Beam elements). For Motorcycle (96 Solid elements, 850 Shell elements, 102 Beam elements, 1 Bar element)	PAMCRASH	Car- 6.7m/s, Motorcycle- 13.4m/s
Motoaki Deguchi[7]	2005	Motorcycle	Side impact	Car	_	21 joints	21 Rigid bodies ,many surfaces etc.	MADYMO	_
Zhida Shen et. al[8]	2012	Car (Weight of the Body Crashed:1145 Kg)	Frontal Impact	Rigid Barrier	1,183, 754	(1,292,149) Units, (3,698) Body Welding points	_	HYPERMESH, LS-DYNA	Velocity of the Car is 50km/h
Guangyo Zhao et.al. [9]	2012	Car(Weight of the Body Crashed:1115 Kg)	Side Impact	Side barrier	99426	1091149 units, 3549 solder joints	_	HYPERMESH, LS- DYNA	Velocity of the barrier is 50km/h
Tejasagar Ambati et. al. [10]	2012	Chevrolet C-1500	Frontal Impact	Wall	11060	65 Parts, 61 Material.	Include Solid element, Hughes-Liu Beam element, Belytschko-Lin-Tsay shell element	L-S DYNA	35 mph (approx. 56 km/h)
Bastian Bohn et. al. [11]	2013	Chevrolet C2500 pick-up truck	Frontal	_	66,000	251 physical parts	_	L-S DYNA	_

9. Common Element used in Crash FE Analysis

- Shell element- Quadrilateral, Triangular, Belytschko-Lin-Tsay shell element
- Beam element- Hughes-Liu beam element
- Hexahedron element
- Solid element

10. Common Material used in Crash FE Analysis

These are some material found in the literature survey [10] & [12] which is generally used in crash analysis of automobile components which is shown through Table 5.

Table 5. Material used in crash analysis

Material and their specification		Components
Aluminium	AA 3005	Radiator
	AA5182	Door, Hood, Fonder, Wheel housing
	AA5454	Tire rim
	A 319	Engine
Steel	ASTM A514	Rail
Fabrics		Airbag
Rubber and composites		Design especially for energy absorption
Honeycomb and foam material		Used in bumper design
Laminated glass		Window modelling
Other materials like Piecewise linear isotropic plastic, glass, rubber (Blatz-Ko rubber), stamped sheet metal.		

11. Typical Issues in Contact Analysis

Some contact conditions which are given at the time of crash analysis are given below:-

- Contact with rigid walls
- Contact with two bodies
- Folding of some shell parts of the car body on itself.
- Other multiple contact

Contact between [14] the two components occurs when they try to come towards each other during the deformation process. But at the time of contact some of the issues are playing major roles which are given below:-

- Improper surface normal
- Compatible elements
- Boundary conditions
- Extending the rigid surface
- Mesh density of slave surface
- Proper selection of master & slave
- No initial penetration
- Avoid sharp corner

Fig.2 shows the flow chart of a typical algorithm [14] used for contact analysis. It examines the states of all contact pairs at the start of each increment to establish whether slave nodes are open or closed. If a node is closed, it determines whether it is sliding or sticking. A constraint is applied for each closed node and removes the constraints from anywhere contact stage changes from closed to open. The procedure is repeated until the iteration is completed with no change in contacts states and this iteration becomes the first equilibrium iteration. The algorithm then checks for normal equilibrium convergence checks. If the convergence check fails, another iteration is performed.

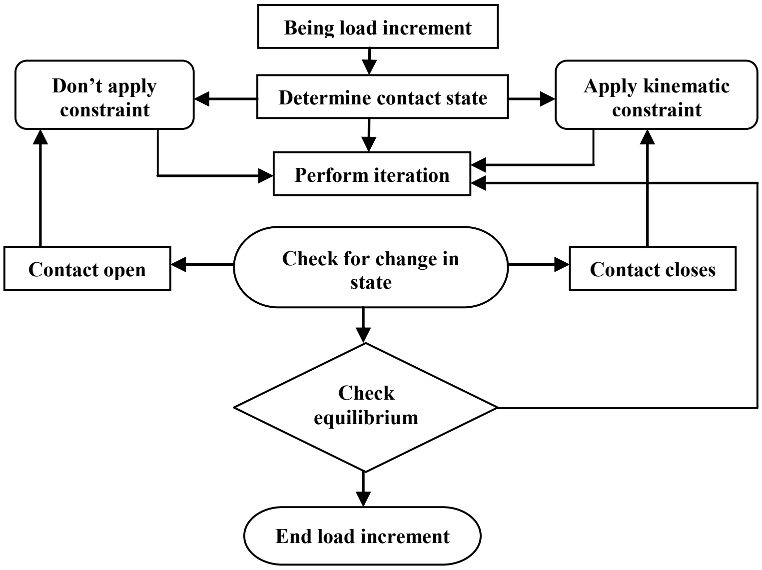

Fig. 2. Algorithm for contact analysis [14]

12. Impact Objects and Conditions

The conditions and object which are used at the time of impact are given below:-

- Rigid wall
- Flexible walls
- Barriers
- Arbitrary impact angles
- Head-to-Head collision
- Rollover impact
- Multiple vehicle collision (car-to-car, car-to-motorcycle) and so forth.

13. Conclusion

In the present work, Finite element modelling practices used for crash analysis are studied and after effects of the different parameters on the vehicle have been reviewed. The aim of this work is to study the effects of such crash parameters on the dynamic response of automobile component through finite element approach path. These analyses mainly focus on software selected, crash type, vehicle/components considered for crashing, material used, type of element used, boundary conditions adopted tool used for post processing the results etc. A considerable amount of work has been reported by the researchers on the finite element crash analysis of various automobile components and several approaches are proposed in the literature to model various crash situations, hence it is felt that a review of the various approaches developed would help to compare their main features and their relative advantages or limitations to allow choose the most suitable approach for a particular application and also throw light on aspects that needs further attention.

References

[1] Jorge A.C. Ambrosio, parviz E. Nikravesh, "Crashworthiness Analysis of a Truck", Mathematical and Computer Modelling, 1990, vol.14, pp.959-964.

[2] Dhafer Marzougui, Cing-Dao Kan, Nabih E. Bedewi, "Development and Validation of an NCAP Simulation using LS-DYNA3D",Fourth International LS-DYNA3D conference, Cray Research, pp.319-332, Minneapolis, MN, September 5-6, 1996.

[3] Abdullatif K. Zaouk, Nabih E. Bedewi, Cing-Dao Kan, Dhafer Marzougui., “Validation of a NON-LINEAR Finite Element Vehicle model using multiple impact data” Proceedings of the 1996 ASME International Mechanical Engineering Congress and Exposition, Atlanta, GA, 1996, pp. 91-106.
[4] T. Omar, A. Eskandarian ,N. Bedewi, “Vehicle Crash Modelling Using Recurrent Neural Networks” Mathematical and computer Modelling , Vol. 28, No. 9, 1998, pp. 31-42.
[5] T. Omar, A. Eskandarian ,N. Bedewi, “Vehicle Crash Modelling Using Recurrent Neural Networks” Mathematical and computer Modelling , Vol. 28, No. 9, 1998, pp. 31-42.
[6] S. Mukherjee, A. Chawla, D. Mohan, M. Singh,M. Sakurai, Y. Tamura, “Motorcycle-Car side impact simulation” International Research Council on the Biomechanics of Injury Proceedings, October 2001, pp. 133-141.
[7] Motoaki Deguchi, “ Simulation of a Motorcycle-Car Collision”, 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Yamaha Motor CO., LTD. Japan,2005, pp. 05-0041.
[8] Zhida Shen, Xin Qiao, Haishu Chen, “BIW Safety Performance Research Based on Vehicle Frontal Crash” Proceedings of the FISITA 2012 World Automotive Congress, 2012, Lecture Notes in Electrical Engineering 197.
[9] Guangyo Zhao, Yifeng Zhao, Xuejia Li, “Whole Car Side Impact Mode and Response Evaluation” Procedia Engineering 29:2667-2671, 2012.
[10] Tejsagar Ambati, K.V.N.S. Shrikant, P. Veeraraju, “Simulation of Vehicular Frontal Crash-Test”, International Journal of Applied Research in Mechanical Engineering ,2012, Vol.-2,Issue-1.
[11] Bastian Bohn, Jochen Garcke, Rodrigo Iza-Teran, Alexander Paprotny, Benjamin Peherstorfer, Ulf Schepsmeier, Clemens-August Thole , “Analysis of Car Crash Simulation Data with Nonlinear Machine Learning Methods” International Conference on Computational Science, ICCS 2013, Procedia Computer Science 00 (2013) 000–000
[12] K. Schweizerhoof , L. Nilsson, J.O. Hallquist, “Crashworthiness analysis in the automotive industry”, International Journal of Computer Application in Technology, special issue on the industrial use of Finite-element analysis, 1996, vol. 5, Nos. 2/3/4, pp. 134-156.
[13] John o Hallquist, “LS-DYNA Theoretical Manual”, Livermore Software Technology Corporation, 1998.
[14] Nitin S Gokhale et. al. “Practical Finite Element Analysis” Finite To Infinite Publication .
[15] Paul Du Bois et. al. “Vehicle Crashworthiness and Occupant Protection” Sponsored by: Automotive Applications Committee American Iron and Steel Institute Southfield, Michigan copyright c 2004 American Iron and Steel Institute 2000 Town Center Southfield, Michigan 48075.
[16] http://www.nhtsa.gov/cars/rules/import/fmvss/
[17] http://www.crash-network.com/Regulations/ECE_Regulations/ece_regulations.html
[18] https://araiindia.com/hmr/Control/AIS
[19] http://www.academia.edu/4629337/FINITE_ELEMENT_ANALYSIS_1