IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, May 2026
Impact Factor: 8.2

Dynamic Characteristics of Steering Column Collapse

Vikram Tukaram Khot[1], Mr. P. G. Sarasambi[2], Prof. Dr. A. D. Desai[3], Prof. Dr. S. D. Shinde[4]
P.G. Student, Department of Mechanical Engineering[1]
Professor, Department of Mechanical Engineering[2]
Assistant Professor, Department of Mechanical Engineering[3, 4]
Shree Ramchandra College of Engineering, Pune, India

Abstract: *Frontal collisions remain a leading cause of driver fatalities, with the steering column acting as a critical load path during impact. CAE crash simulations rely on quasi-static material data, which fail to capture true dynamic behavior, leading to poor correlation with physical crash tests. This study develops a drop-tower-based dynamic test methodology to replicate crash-level energy transfer on steering columns. Force–displacement and time-history data were recorded and integrated into LS-DYNA simulations. Results demonstrate improved correlation (≈80%) between CAE and physical crash outcomes, reducing prototype costs and enhancing occupant safety predictions. The methodology provides a foundation for standardizing dynamic component-level testing in future AIS/BNCAP protocols.*

Keywords: Road Safety, Frontal Collision, Steering column collapse, Dynamic Impact, Energy absorption, CAE Correlation

I. INTRODUCTION

Road safety continues to be a pressing challenge in India, where frontal collisions account for a significant proportion of driver fatalities. In such crashes, the steering column becomes a critical component influencing injury severity, as it directly interacts with the driver during impact. To mitigate these risks, automotive manufacturers have introduced advanced safety systems such as airbags, collapsible steering assemblies, and seatbelt pretensioners with load limiters. These mechanisms are designed to absorb energy and provide survival space for the occupant, but their effectiveness must be validated through rigorous testing and certification by agencies such as ARAI, ICAT, and CIRT. While full-vehicle crash tests remain the most reliable means of assessing safety performance, they are prohibitively expensive and can delay development timelines, especially when prototypes fail to meet regulatory requirements.

To overcome these challenges, the industry increasingly relies on Computer-Aided Engineering (CAE) simulations to predict crash behavior during the development phase. The accuracy of these simulations, however, depends heavily on the quality of input data, including material properties, geometry, thickness, and stress–strain characteristics. Metallic components, such as those used in steering columns, exhibit markedly different behavior under quasistatic and dynamic loading conditions. At elevated strain rates typical of real crash events, materials absorb energy differently, altering their load-bearing capacity. Unfortunately, suppliers generally provide only quasistatic stress–strain curves, which fail to capture these dynamic effects. This limitation often results in poor correlation between CAE predictions and actual crash outcomes, necessitating additional physical testing and increasing development costs.

The present study addresses this gap by developing a dynamic impact testing methodology for steering columns using a drop-tower rig. By replicating crash-level occupant impact energy under controlled laboratory conditions, the research captures precise force–displacement and ride-down data that more accurately reflect real-world behavior. These dynamic parameters are then integrated into CAE models to improve prediction fidelity. The approach not only enhances the reliability of virtual crash simulations but also reduces prototype iterations, accelerates product validation cycles, and contributes to improved occupant safety. Furthermore, the methodology has the potential to inform future

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, May 2026
Impact Factor: 8.2

updates to AIS and Bharat NCAP protocols by introducing dynamic component-level testing as a complementary standard to existing certification practices.

II. METHODOLOGY

To replicate crash-level occupant impact on the steering column, a dynamic drop-tower test rig was developed and calibrated.

Component	Description
Drop Tower Rig	Vertical impact rig designed to deliver controlled energy via dead weight
Dead weight Impactor	45 Kg mass droped from 1.36m height to simulate 600 J impact energy
Steering column Fixture	Rigid mount angled at 61°to replicate occupant - to- column interaction.
Load cell	Sensor placed at column tip to capture force during impact and strain gauge pasting on column body to capture post-breakdown deformation phase force.
Spacer Plate	Protective interface between tip impactor and loadcell to prevent damage.
Data Acquisition system	High- speed system to record force, displacement, and time data.
CAE software Stack	LS-DYNA (solver), HyperMesh/Primer (Pre), HyperView/ D3 plot (Post).

A 45 kg dead weight was released from a height of 1.36 m, imparting approximately 600 J of energy to the mounted steering column at an angle of 61°, chosen to represent real occupant-to-column interaction. The steering column was mounted at a 61° angle to simulate real occupant-to-column interaction, as shown in Photo 1 and Photo 2 of the test fixture.

High-speed load cells and strain gauges were employed to capture breakout and ride-down forces, while accelerometers and data acquisition systems ensured accurate time-history recording. Calibration procedures verified mass, height, velocity, and fixture alignment to guarantee test reliability.

Test Setup:

Photo 1: Fixture

Photo 2: Test Rig with fixture

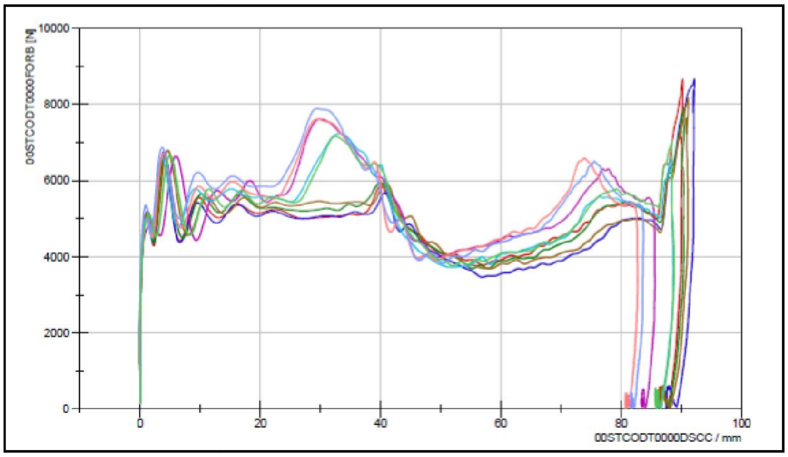
III. TEST RESULTS

Multiple drop tests (n=6) were performed on identical steering column samples to assess repeatability. Force vs. displacement curves were analysed for consistency in breakout force, ride-down behavior, and total collapse length.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, May 2026
Impact Factor: 8.2

Table: Test Results

Acceptance criterion	PartID								
	166	167	168	169	170	171	172	173	174
	20°		22°		25°		27°		25°
no slippage of tilt mechanism	passed	passed	passed	passed	passed	passed	passed	passed	passed
no fracture	passed	passed	passed	passed	passed	passed	passed	passed	passed



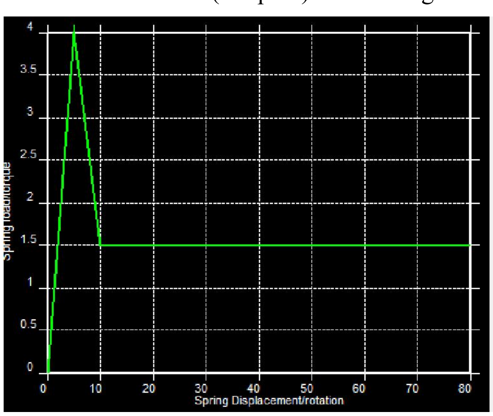
Graph: Force Vs Displacement

It can be clearly observed that the initial breakdown force varies from 4.2 kN to 5 kN. Additionally, the force during the ride-down phase also changes with the displacement (or stroke) of the column, ranging from 4.2 kN to 7.5 kN. This variation indicates the nonlinear behavior of the column collapse during the dynamic test.

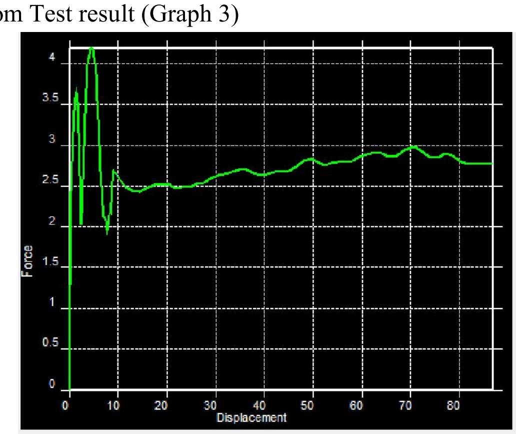
III. CAE CORRELATION & VALIDATION

Based on the above test results, a CAE material card for the column was developed in LS-DYNA. Subsequently, a full-vehicle simulation was performed to evaluate the improvements in the results compared to the test data. The key findings are summarized below:

Material load curve : Initial (Graph 2) Vs Loading curve from Test result (Graph 3)



Graph 2: Initial material load curve for collapse



Graph 3: Loading curve from Test result

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, May 2026
Impact Factor: 8.2

Force vs Displacement: CAE vs Physical Test:

CAE Simulation shows:

Initial peak force at **4 kN** (shear pin collapse)

Constant ride-down force of **~1.5 kN** until **70 mm**

Sharp increase post-collapse due to stack-up

Physical Test reveals:

Initial peak at **~4 kN**

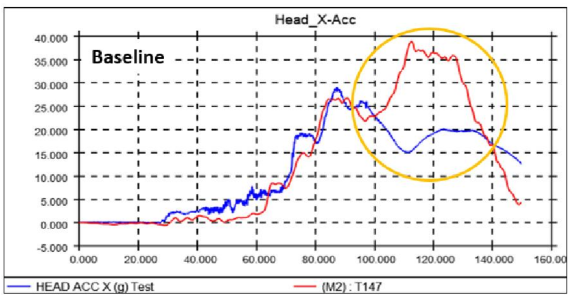
Non-linear ride-down force

Stack-up begins after **80 mm**, indicating more energy absorption

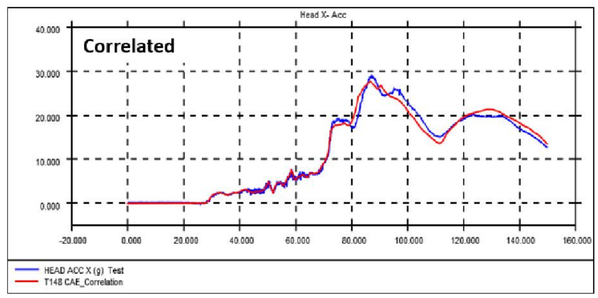
The obtained plots confirm that the experimentally measured dynamic collapse response diverges from the CAE, particularly during the ride-down segment where material damping becomes dominant.

Correlation (Full Vehicle):

Head X Acceleration vs Time:



Graph 4: Head Acceleration (With initial material)



Graph 5: Head Acceleration (After tested material)

Baseline simulation:

CAE Results: Show early collapse of the steering column and a secondary acceleration peak after collapse.

Physical Test Results: Exhibit a smoother deceleration curve with a delayed acceleration peak, indicating improved energy dissipation.

Observation: The mismatch between CAE and test results leads to poor correlation (approximately **65%**, as shown in the first graph

Correlation (Test data) simulation:

Updated CAE Model: Incorporating physical test data for the steering column results in improved alignment between CAE predictions and the full-vehicle physical test data of occupant head acceleration.

Observation: The correlation significantly improves to above 85%, demonstrating enhanced model accuracy and better physical behaviour representation.

IV. CONCLUSION

The experimental setup effectively reproduced steering column deformation under controlled dynamic loading. The correlation coefficient between simulation and experiment improved from 65% (using quasi-static data) to approximately 85% after integrating dynamic properties. This indicates the approach's capability to enhance simulation reliability and reduce dependency on physical prototypes.

REFERENCES

[1] S. Shaikh and S. Shakebuddin, "Analytical and optimization-based study on collapsible steering columns," 2021.

[2] China Society of Automotive Engineers, "Proceedings of China SAE Congress 2019: Selected Papers," 2019.

[3] E. Gotoh and Y. Satoh, "An investigation of steering column collapse behavior using finite element analysis," SAE Technical Paper Series, Nissan Motors Co. Ltd., 2019.

[4] T. Hee, L. Byung Ryul, H. Seong Oh, and H. Hong, "Study on steering column collapse analysis using detailed FE model," Advanced Safety CAE Team, Hyundai Motor Co., Korea, 2019.

[5] Bharat New Car Assessment Program (BNCAP), "Offset frontal crash test protocol," 2023.

[6] Automotive Research Association of India (ARAI), "Offset frontal crash test protocol AIS 098," 2023.

[7] Bharat New Car Assessment Program (BNCAP), "Official website," Available: https://www.bncap.in

[8] Automotive Research Association of India (ARAI), "Official website," Available: https://www.araiindia.com/