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Multi-link Suspension hotspot identification and Co-relation

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Abstract- The suspension system in an automobile plays a critical role in ensuring ride comfort, vehicle handling, and overall safety. It serves as the interface between the vehicle body and the wheels, absorbing road irregularities and maintaining tire contact with the road surface. Automotive suspension system durability refers to the ability of the suspension components to withstand operational stresses over time without failure or excessive degradation. In modern automotive suspension systems, the multi-link suspension offers superior ride and handling characteristics due to its geometric flexibility and precise wheel control. This paper presents a comprehensive methodology for simulating the behaviour of the longitudinal link, camber link, toe link, and upper link in a multi-link suspension architecture using finite element analysis (FEA). The study emphasises robust modelling strategies, realistic boundary condition definition, and accurate load-path representation under representative driving scenarios, including acceleration, braking, and road-induced excitations. Component-level FEA is employed to evaluate stress distribution and fatigue characteristics, which are subsequently correlated and validated through bench-level experimental testing. Further, the paper outlines a correlation methodology between simulated results and physical test data. The results demonstrate a high degree of correlation between the simulated and test data, affirming the robustness of the proposed methodology. The findings enable early-stage design optimization, reduce prototyping iterations, and enhance confidence in virtual validation processes for suspension systems.

Keywords: Multi-Link Rear Suspension, Fatigue Failure, Test-to-Analysis Correlation, Durability, Finite Element Analysis

I. INTRODUCTION

The rear suspension system plays a critical role in determining a vehicle's ride comfort, handling performance, durability, and overall safety. Modern passenger vehicles increasingly employ independent multi-link rear suspension architectures due to their superior ability to control wheel kinematics and force transmission under diverse driving conditions.

Unlike simpler suspension layouts, such as torsion beam or trailing arm systems, multi-link suspensions use multiple discrete links to decouple longitudinal, lateral, and vertical wheel motions. This architectural flexibility allows engineers to independently tune parameters such as camber gain, toe variation, roll Center height, and anti-squat characteristics.

Due to its function, the links are subjected to complex multi-axial loading conditions, including cyclic tensile and compressive forces, bending moments, and local stress concentrations at mounting interfaces and bushing regions. These load conditions often lead to fatigue-driven failures if not accurately predicted and validated during the design phase. As vehicle mass, powertrain torque, and customer durability expectations continue to increase, ensuring robust design and validation of multi-link suspension has become a critical engineering challenge.

Accurate correlation between analytical predictions and physical test results is therefore essential for reliable suspension development. Advanced simulation techniques—such as multi-body dynamics (MBD), finite element analysis (FEA), and fatigue life prediction—are widely used to evaluate multi-link suspension performance. However, discrepancies between simulated results and physical durability tests can arise due to simplified assumptions, material variability, bushing non-linearity, and incomplete representation of real-world load spectra.

This paper focuses on the role of the longitudinal link, camber link, upper link and toe link within a multi-link rear suspension system, with emphasis on its functional requirements, loading characteristics, and durability considerations. The study aims to highlight the importance of accurate test-to-analysis correlation in predicting failure modes and improving design robustness. By examining both experimental and analytical approaches, the paper contributes to a deeper understanding of multi-link behaviours and provides guidance for improving suspension durability validation processes.

II. ROLE OF DIFFERENT LINKS IN MULTI-LINK REAR SUSPENSION

Toe link primarily controls:

- Toe angle variation with suspension travel and lateral load
- Rear wheel steer behaviour, affecting vehicle handling and stability
- Compliance steer characteristics under braking and cornering forces

The toe link is generally connected to the wheel carrier through a ball joint and to the subframe via a compliant bushing. This configuration enables precise control of toe kinematics while isolating road-induced vibrations. Non-linear compliance effects arise due to bushing characteristics, leading to complex force transmission under combined longitudinal, lateral, and vertical loading conditions such as braking-in-corner and uneven road inputs

Upper link primarily controls:

- Spatial location of the wheel carrier, especially in the vertical and lateral directions
- Interaction between camber and toe kinematics
- Load distribution among suspension links, contributing to overall system stiffness and durability

The upper link is typically attached to the wheel carrier using a ball joint and to the vehicle body or subframe through a bushing or rigid mount, depending on design requirements. This link plays a key role in defining the three-dimensional position of the wheel carrier. Its joint configuration results in non-linear stiffness behaviour and multi-axial load transfer, especially under combined vertical, lateral, and longitudinal loads.

The camber link primarily controls:

- Camber angle variation during wheel travel (jounce and rebound)
- Tire contact patch optimisation by maintaining favourable camber under load
- Lateral compliance characteristics, influencing cornering stability and grip

The camber link is typically connected to the wheel carrier via a ball joint and to the vehicle body or subframe through a compliant bushing. This arrangement allows controlled camber variation while accommodating suspension travel. The presence of compliant joints introduces non-linear stiffness behaviour and complex load paths, particularly under combined lateral and vertical wheel loads experienced during cornering and road excitation.

Longitudinal link primarily controls:

- Traction and braking force transmission
- Longitudinal compliance characteristics
- Contribution to anti-squat and anti-dive behaviour

The link is typically connected to the wheel carrier through a bushing or ball joint and to the vehicle body or subframe through a compliant bushing. This configuration introduces non-linear stiffness characteristics and load path complexity, particularly under combined longitudinal and vertical wheel loads.

Figure 1: Typical multi-link rear suspension architecture.

III. FAILURE MODES OBSERVED IN LINKS OF MULTI-LINK SUSPENSION

Toe Link

- Permanent bending under extreme braking-in-corner loads
- Bushing degradation or ball-joint wear, causing toe compliance and instability
- Loss of toe control due to joint loosening

Upper Link

- Fatigue cracking near ball joint studs or mounting eyes
- Permanent deformation under combined vertical and lateral loads
- Ball-joint wear leading to increased kinematic variability
- Load redistribution–induced secondary failures in adjacent links

Camber Link

- Fatigue cracking at bushing housings or ball-joint seats
- Weld toe cracking in tube-to-bracket.
- Local plastic deformation under high lateral cornering loads
- Progressive increase in camber compliance due to bushing damage
- Occasional fracture at the wheel-carrier interface under overload conditions

Longitudinal Link

- High-cycle fatigue cracking near bushing sleeves
- Crack initiation at weld toes or heat-affected zones
- Plastic deformation under extreme load events
- Bushing housing ovalization leading to secondary failures

In the studied component, physical tests revealed fatigue crack initiation at the knuckle mounting due to combined axial and bending stresses.

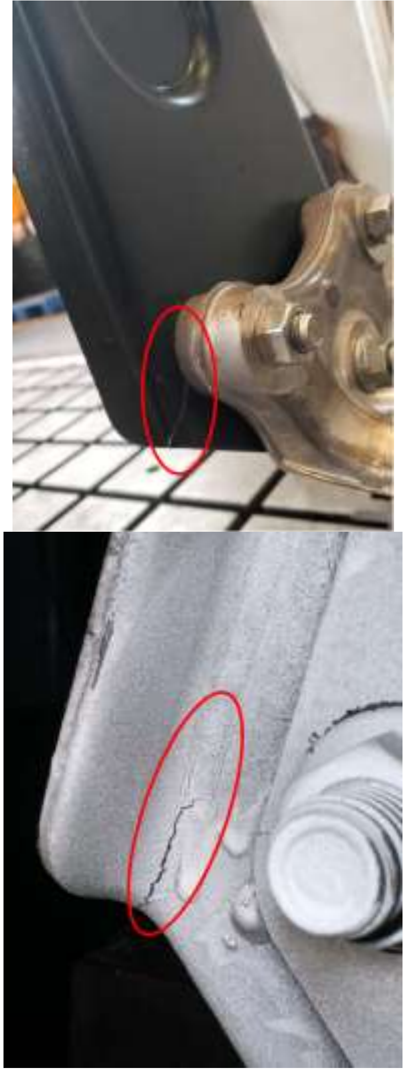
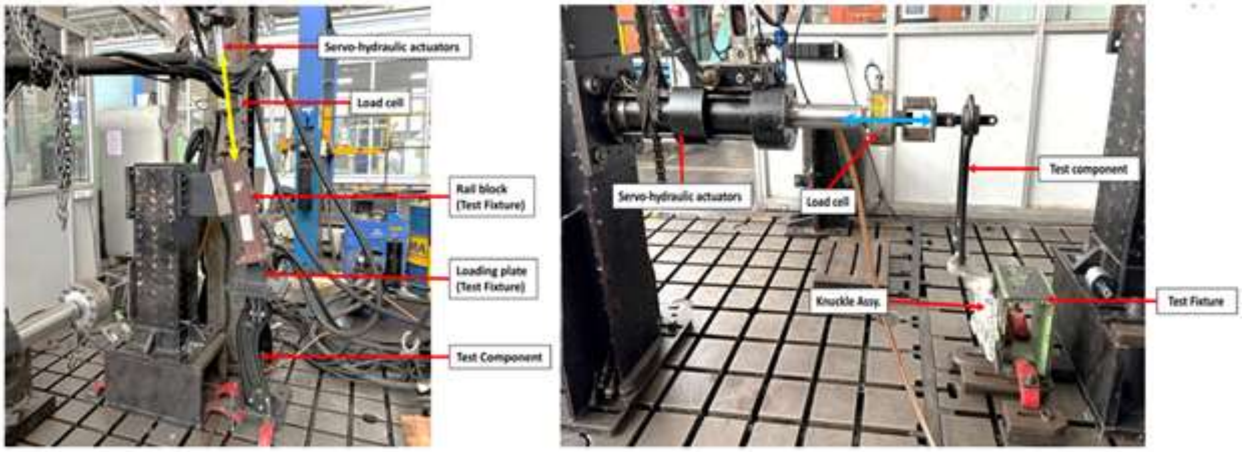


Figure 2: Physical test specimen showing fatigue crack initiation near the knuckle mounting of the longitudinal link.

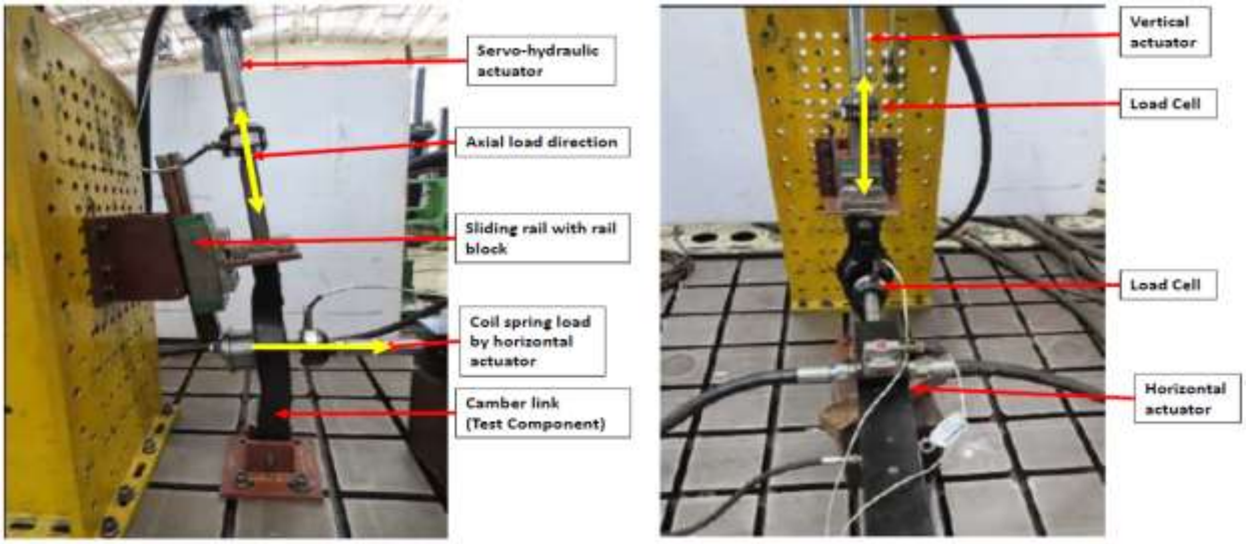
IV. TEST METHODOLOGY

Laboratory Durability Testing

The longitudinal link and camber link was subjected to accelerated durability testing on a servo-hydraulic test rig using measured load spectra. The test replicated multi-axis loading with combined longitudinal and lateral force inputs for longitudinal link and lateral force and spring force for camber link. Failure cycles and crack initiation locations were recorded for correlation.



a) Longitudinal Link



b) Camber link

Figure 3: Laboratory test setup for longitudinal link & Camber link durability evaluation with multi-axis loading capability.

Table 1: Representative Loading used for various link in durability testing.

Component Name	Test	Load (kN)		Angle		Cycles
		Compression	Tensile	X wrt Y (Deg.)	Z wrt Y (Deg.)	
Toe Link	Axial fatigue Test	-10	10	0	0	V
Upper Link	Axial fatigue Test	-13.3	4.7	0	0	W
Camber Link	Axial fatigue Test	-10	11	2.5	-8	X
	Note : Camber Link Coil Spring Seat Load – 14.70 kN					
Longitudinal Link	Axial fatigue Test	-12	12	1.8	-13	Y
	Lateral fatigue test	-1.0	1.0	0	0	Z

V. ANALYTICAL MODELLING AND FATIGUE PREDICTION

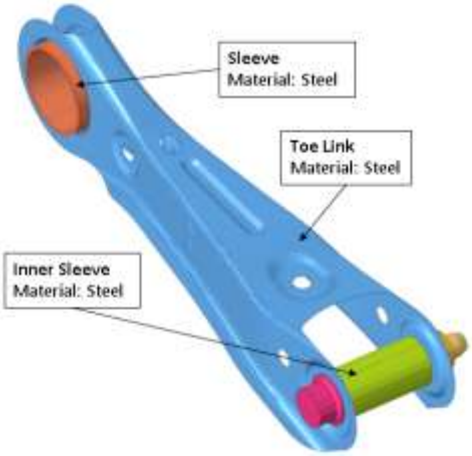
Finite Element Model

A detailed finite element model of the various links was developed, including:

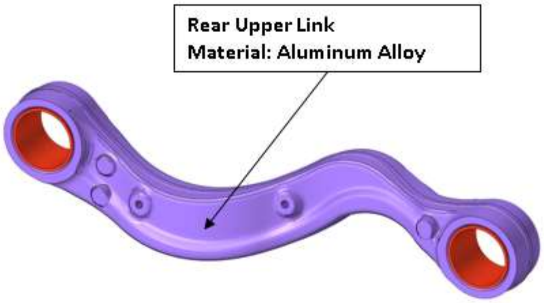
Accurate geometry and weld representations

Realistic boundary conditions derived from test setup

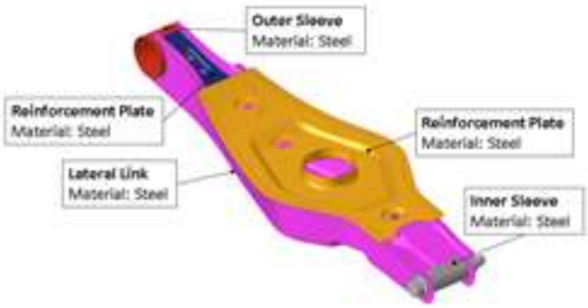
Mesh refinement was applied in high-stress regions to capture stress gradients accurately.



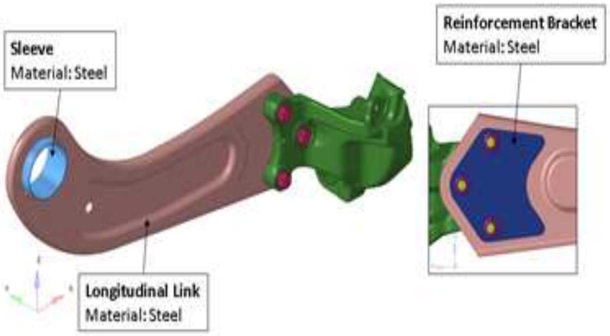
a) Toe link



b) Upper link



c) Camber link

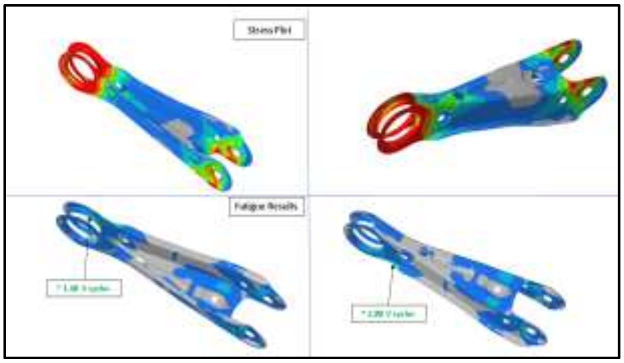


d. longitudinal link

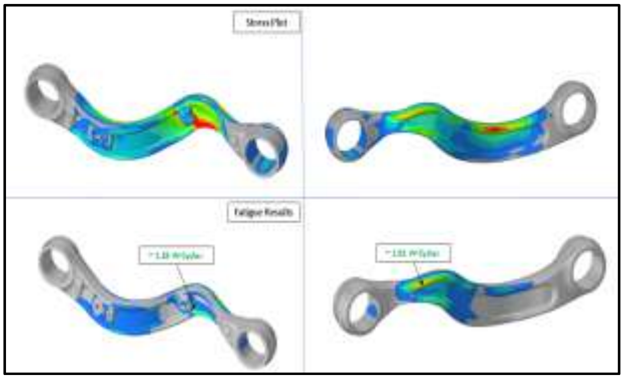
Figure 4: Finite element model of the various links showing mesh refinement at bushing housing and weld regions.

VI. FATIGUE LIFE ANALYSIS

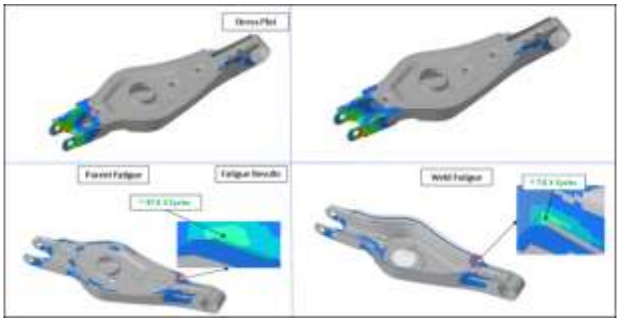
Fatigue analysis was performed using material fatigue properties. Fatigue life was calculated for the considered load cycles.



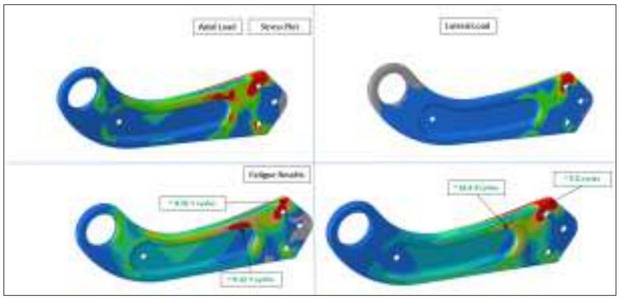
a) Toe Link



b) Upper Link



c) Camber Link



d) Longitudinal Link

Figure 5: Stress and Fatigue life plot for various links under peak longitudinal and lateral load.

VII. FAILURE CORRELATION METHODOLOGY

Failure correlation was performed using the following metrics:

- Comparison of predicted vs. tested fatigue life
- Alignment of crack initiation locations

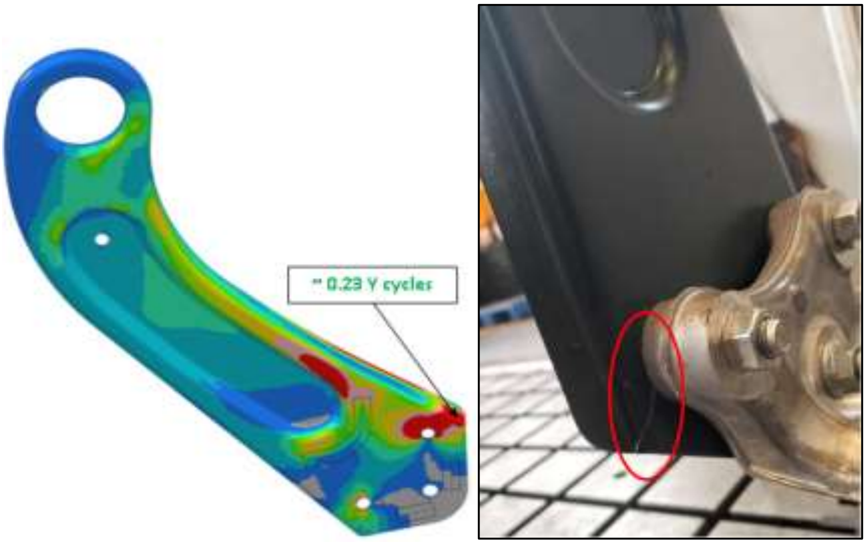


Figure 6: Comparison of predicted fatigue life from FEA with measured durability test results

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Table 2: Fatigue life correlation.

Fatigue Life Correlation Results

	FEA Simulation Results (Cycles)	Test Results (Cycles)	Co-relation Factor	Conclusion
Toe Link	1.46 V	V	1.46	Pass
Upper Link	1.19 W	W	1.19	
Camber Link	7.6 X	X	7.6	
Longitudinal Link (Axial)	0.23 Y	Y	0.23	Failure location co-related
Longitudinal Link (Lateral)	5 Z	Z	5	Failure location co-related

VIII. RESULTS AND DISCUSSION

Predicted fatigue life correlated within factor of ±3 with test results
Crack initiation locations matched physical failures
Stress trends across load cases showed strong agreement
The study highlighted that accurate representation of realistic load spectra are key contributors to successful failure correlation.

IX. CONCLUSIONS

This paper demonstrates a systematic approach to failure correlation for various links in a multi-link rear suspension. Key conclusions include:
Analysed four links experience complex multi-axial fatigue loading that must be accurately represented.
Realistic load spectra has a significant impact on stress and fatigue life prediction.
Improved test-to-analysis correlation enables robust design validation and reduced development risk.

Future Work

- **Future work will focus on:**
- Accounting for manufacturing variability in fatigue prediction
- Developing virtual durability test methodologies to reduce physical testing effort

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