

Finite Element–Based Optimization of Automotive Suspension Coil Springs for Enhanced Ride Comfort

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Abstract. This paper presents the finite element design and optimization of a front suspension coil spring for a 2017 Honda Civic with the objective of improving ride comfort while maintaining structural integrity. A parametric 3D spring model was developed and analysed in ANSYS under realistic loading conditions. Several materials high carbon steel, 54SiCr₆ high-tensile steel, structural steel, titanium alloy, and stainless steel 316 were evaluated for deformation behaviour, stress distribution, and strain energy. The optimized configuration, consisting of 54SiCr₆ steel combined with an increased coil count (from five to six), achieved superior compliance and reduced stress concentration relative to the stock design. Results show that the modified spring provides improved absorption of road irregularities without exceeding material limits. The study demonstrates how simulation-driven optimization can support affordable ride-comfort improvements in compact vehicles.

Keywords: Coil springs, Ride comfort, Suspension, ANSYS, Finite Element Analysis (FEA), Optimization.

1 Introduction

Ride comfort and vehicle stability depend heavily on the performance of the suspension system, which regulates vertical dynamics, vibration absorption, and tyre–road contact. In passenger vehicles, coil springs play a key role in moderating road-induced loads and determining the stiffness characteristics of the suspension. The 2017 Honda Civic, known for efficiency and handling, has been reported to deliver a relatively firm ride on uneven surfaces. This study focuses on re-engineering the front suspension coil spring to improve comfort without compromising safety.

Finite Element Analysis (FEA) enables the prediction of stress distribution, elastic deformation, and structural response before physical prototyping, making it an efficient approach for examining material and geometry variants. This work identifies an optimized material and spring configuration that enhances comfort while remaining compatible with the vehicle's existing suspension architecture.

2 Literature Review

2.1 Suspension Systems and Coil Springs

Vehicle suspension systems are designed to absorb shocks, maintain tyre contact, and ensure vehicle stability. Modern suspensions often adopt the MacPherson strut in the front axle and multi-link configurations in the rear due to their balance of comfort and control. Coil springs—typically helical compression springs store and release energy under vertical loads, thereby smoothing road irregularities. The stiffness, or spring rate, determines ride characteristics; a higher spring rate improves handling but reduces comfort, while a lower rate enhances comfort at the risk of excessive body movement. Figure 1 shows a typical front coil spring from the Honda Civic suspension assembly.

Historical development shows an evolution from leaf springs to helical springs and advanced electronically controlled suspension systems [1].

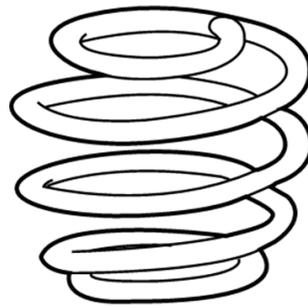


Fig. 1. typical front coil spring from the Honda Civic suspension assembly. [1]

2.2 Types of Helical Springs

Helical springs include extension, torsion, and compression types. Compression springs, which shorten under load, are the most common in automotive suspensions due to their high energy-storage efficiency [2]. Their geometry wire diameter, mean coil diameter, pitch, and number of active coils directly influences stiffness, stress behaviour, and fatigue life. Figures 2, 3, and 4 illustrate different spring types.



Fig. 2. Example of Torsion Spring. [2]



Fig. 3. Example of Leaf Spring. [2]

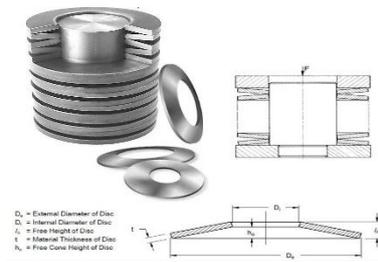


Fig. 4. Example of Disk Spring. [2]

2.3 Materials for Coil Springs

Material selection affects elasticity, fatigue resistance, and corrosion performance. Common spring materials include:

- High-carbon steel: widely used, economical, moderate fatigue resistance.
- Chrome–silicon and chrome–vanadium steels: preferred for high-stress applications due to superior fatigue strength [3].
- Stainless steel: excellent corrosion resistance but lower stiffness.
- Titanium alloys: lightweight but costly and overly compliant for many automotive uses.

54SiCr₆ high-tensile steel has gained attention for its strength, resilience, and fatigue behaviour, making it suitable for heavy-load and dynamic applications [4].

2.4 Fatigue Behaviour of Coil Springs

Springs undergo millions of load cycles, making fatigue a critical design parameter. Microstructural imperfections, surface roughness, and corrosion pits significantly reduce fatigue life [5]. Shot peening and surface treatments are frequently used to enhance durability.

High-cycle fatigue analyses have shown that stress concentration at the inner coil radius governs failure initiation [6].

2.5 Finite Element Method for Spring Analysis

The FEA process includes discretising the model, selecting element types, applying boundary conditions, and evaluating stresses and deflection [7]. ANSYS tools enable nonlinear stress–strain analysis and allow engineers to simulate real-world loading scenarios accurately. Studies indicate that geometry refinement and material improvements offer significant increases in fatigue life and comfort [8].

2.6 Spring Optimization Strategies

Optimization can involve:

- Geometry optimization (pitch, coil diameter, active coils)
- Material optimization
- Topological and structural optimization
- Fatigue and stress distribution optimization

Geometry-based methods, such as increasing the number of coils, reduce stiffness and improve comfort by distributing load across more coils [9].

3 Methodology

3.1 Data Collection

Stock spring dimensions were extracted from manufacturer technical documentation. The model represents a front suspension coil spring with:

- Wire diameter: 12.3 mm
- Mean coil diameter: 152.8 mm
- Total coils: 5
- Active coils: 3
- Pitch: 63.5 mm

3.2 Spring Modelling and Meshing

A 3D helical spring model was created in ANSYS shown in Figure 5. The mesh size of 6 mm provided a balance between precision and computational efficiency. Both ends of the spring were modelled as boundary conditions: one fixed support and one subjected to vertical loading representative of vehicle weight.

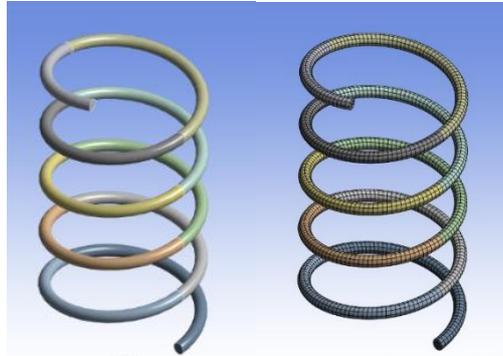


Fig. 5. Coil Spring Model and Mesh in ANSYS

3.3 Material Analysis and Load Application

Five materials were evaluated:

1. High-carbon steel
2. Structural steel
3. Stainless steel 316
4. Titanium alloy
5. 54SiCr6 high-tensile steel

The analysis examined:

- Total deformation
- Von-Mises stress
- Shear stress
- Equivalent elastic strain and Strain energy

3.4 Geometry Optimization

Two additional designs were evaluated:

- 6-coil spring (one extra turn)
- 7-coil spring

The goal was to determine the configuration offering the best improvement in comfort while keeping stresses below yield thresholds. Figures 6 and 7 show the sample simulated deformation and stress fields for these variants for different materials.

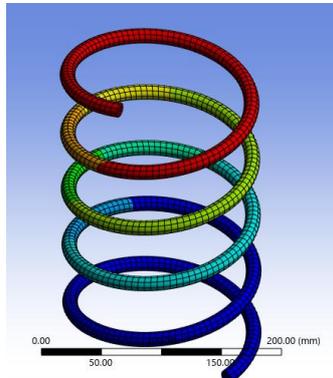


Fig. 6. Total Deformation simulation in ANSYS

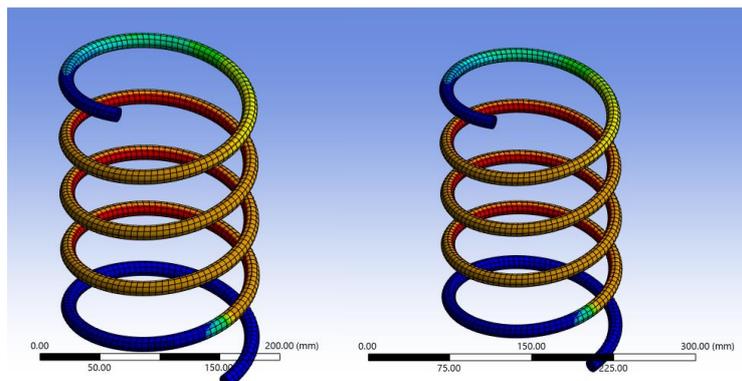


Fig. 7. Von-Mises and Max Shear Stress simulations in ANSYS

4 Results and Discussion

4.1 Material Comparison

High-carbon steel exhibited high stress concentrations and limited deformation. Stainless steel 316 and titanium alloy produced excessive deformation, indicating a risk of bottoming out. However, 54SiCr₆ demonstrated:

- Lower equivalent stress
- Reduced shear stress concentration
- More uniform stress distribution
- Improved deformation characteristics

This confirms findings from prior studies indicating that chrome–silicon steels outperform baseline materials in dynamic applications [3], [4].

4.2 Geometry Optimization Results

The 6-coil spring provided:

- Increased deformation (≈ 267 mm)
- Lower peak stresses
- Improved energy absorption

The 7-coil spring, however, showed:

- Excessive total deformation (≈ 336 mm)
- Reduced stability

Thus, the 6-coil design offers the best comfort–stability balance.

5 Conclusion

This study demonstrates how finite element modelling can guide the optimization of suspension coil springs. Among the analysed materials, 54SiCr₆ high-tensile steel provided the best structural performance and comfort characteristics. Geometry optimization confirmed that adding one additional coil improves compliance without compromising safety. The resulting 6-coil, 54SiCr₆ spring represents a feasible enhancement for passenger-vehicle ride comfort. Future work should include physical fatigue testing, environmental exposure evaluation, and integration with damper tuning to further refine ride comfort and vehicle dynamics.

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