

Coil Springs in Automotive Suspensions

Spring rate, shear stress, ride frequency, materials and failure modes

Design Equations

Spring rate	$k = G d^4 / (8 D^3 n)$	Wire diameter enters to the 4th power: the most sensitive design parameter.
Max shear stress	$\tau = 8 F D W / (\pi d^3)$	Must stay below the material's fatigue limit. F = spring force at curb mass.
Wahl factor	$W = (4C - 1)/(4C - 4) + 0.615/C$	Corrects for coil-curvature stress concentration.
Spring index	$C = D / d$	Ratio of mean coil diameter to wire diameter.
Ride frequency (simplified)	$f = (1/2\pi) \sqrt{k / m}$	Ignores unsprung mass and tire stiffness; the dual-mass model includes both.
Hooke's law	$F = k \cdot x$	e.g. 100 lb compresses 1 in → 200 lb compresses 2 in.

Symbols & Key Terms

G, d, D, n	Shear modulus · wire diameter · mean coil diameter · number of active coils.
Sprung mass	Mass carried by the springs: body, frame, engine, transmission.
Unsprung mass	Mass not carried by the springs: tires, wheels, brake assemblies. Lower is better for ride and traction.
Ride frequency	Target that sets how soft or firm a car feels. Lower for comfort cars, higher for sports cars.
Jounce limit	At full compression the spring must avoid coil bind. Drives d, D, n and free length.
Variable rate	Varying wire thickness or coil spacing so coils progressively bottom out: soft when light, stiff when loaded.
Coil-over vs torsion bar	A coil wrapped around the damper side-loads it and adds friction; a torsion bar avoids that but costs more packaging.

Higher vs Lower Spring Rate

	Higher (stiffer)	Lower (softer)
Feel	Firmer ride	Softer ride
Body control	Less roll and lean; steadier ride height under downforce	More pitch, roll and squat
Grip on bumpy roads	Tires can hop and lose contact	Better tire contact over bumps and curbs
Best for	Smooth tracks, low ride height	Rough roads, comfort-focused vehicles

Newey example: ~1,600 / 1,500 lb/in (≈280 / 263 N/mm) front/rear softened by 200 lb/in (≈35 N/mm) for a bumpy street circuit. 1 lb/in ≈ 0.175 N/mm.

Materials & Manufacturing

SAE 9254

Typical high-strength martensitic spring steel

~500 → 1200+ MPa

Design stress: early springs vs modern springs

Shot peening

Adds beneficial compressive residual stress

Heat treat

Controlled quench and temper for fatigue life

Failure Modes & Root Causes

- **Sag** (most common): spring settles below design ride height, altering geometry, wearing tires and other parts. Check ride height at service.
- **Material defects**: non-metallic inclusions or abnormal microstructure start cracks.
- **Surface imperfections**: poor shot peening or tool marks shorten fatigue life.
- **Heat treatment errors**: brittle phases or decarburized layers.
- **Corrosion**: coating damage allows pitting, accelerating fatigue.
- **Forging defects**: improper radial forging leaves helical marks that act as stress risers. FEA helps model these.