Characterization of the Honda S2000 Original Equipment Suspension Springs

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ABSTRACT

Combining publicly available manufacturer data with new measurements of original equipment (OE) springs and stabilizer bars, new results are derived which characterize the suspension springs of the Honda S2000 for all U.S. model years, including the Club Racer (CR) trim. It is shown that a total of six different OE configurations were released in the U.S., with significant variations in coil spring rates and stabilizer stiffness.

INTRODUCTION

More than a year after the end of its decade-long production run, and despite the existence of an ownership community that is unusually active in online communities, motorsport, and vehicle customization, the Honda S2000's original equipment (OE) suspension characteristics remain sparsely documented and poorly understood. This paper attempts to partially remedy that situation by applying well-known suspension spring relations to new measurements of the S2000 OE suspension components.

The principal result of this paper is the development of new estimates of the "designed" spring rates of the OE coil springs and stabilizer bars of U.S. model S2000s. For reasons outlined below, our estimates are indirect, i.e. based on measurements of the size and shape of the OE components, rather than of actual force versus deflection. Nevertheless, we demonstrate our measurements' exceptional agreement with (and partial incorporation of) relevant publicly available data from Honda Motor Company. Our results identify a total of six known OE configurations and characterize the spring rates of each.

DESIGN PARAMETERS OF THE HONDA S2000 SUSPENSION SPRINGS

In this paper we are concerned with estimating the spring rates of the Honda S2000 OE suspension springs (i.e. coil springs and stabilizer bars). We wish to do so in a way that allows comparison of the OE components to aftermarket parts or even across platforms; this will ultimately require accounting for the unique physical shapes and/or configurations of the OE components. To begin, however, we examine idealized cases.

For any spring, the rate *S*, or stiffness, is the amount of force *W* required to produce a given deflection *X*, and is defined as *S* = *W*/*X*. For an ideal helical (i.e. coil) spring, the spring rate is determined by the physical properties of the coil as follows (see [1], for example):

$$S_{\mathrm{coil}} = \frac{Gd^4}{8ND^3}$$

where *G* is the shear modulus of elasticity of the spring material, *N* is the number of "active" coils (discussed further below), and as shown in Figure 1, *d* is the wire diameter and *D* is the mean coil diameter.

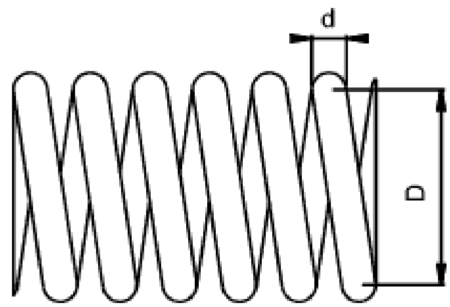

Figure 1. Parameters of a helical spring.

Since *G* is a constant, we wish to estimate S_{coil} by determining *d*, *D*, and *N* for each OE S2000 coil spring.

Turning to stabilizer bars, we observe that in vehicle suspensions, a stabilizer bar acts as a torsion spring. The spring rate of an ideal torsion spring is the force *W* required to deflect one lever arm a distance *X*, when the rest of the bar is held stationary. For this type of spring we have (from [1] again)

$$S_{\mathrm{bar}} = \frac{\pi Gd^4}{32R^2L}$$

where a bar with circular cross-section is assumed, *G* is as above, and as shown in Figure 2, *d* is the bar diameter, *R* is the lever arm length, and L is the overall torsion bar length. For the common case of a hollow bar with thickness *t*, we substitute the quantity d^4 with $d_{\mathrm{eff}}^4 = d^4 - (d-2t)^4$.

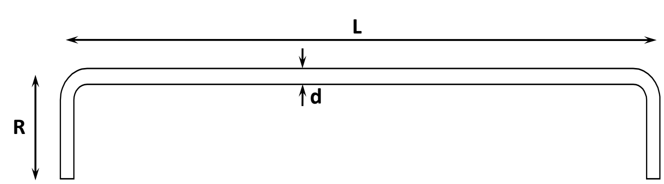

Figure 2. Parameters of an ideal torsion bar

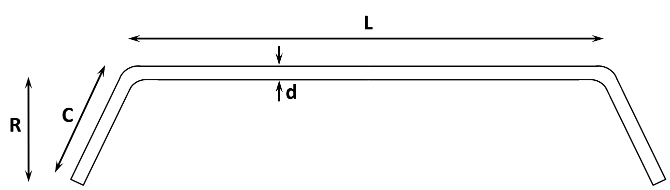

Figure 3. Parameters of a torsion bar with splayed arms

For cases in which the lever arms are not perpendicular to the torsion bar, as diagrammed in Figure 3, Puhn [2] has proposed the following phenomenological relation:

$$S_{\text{Puhn}} = \frac{\pi G d^4}{30R^2 L + 16C^3}.$$

Here C is the total length of the lever arms, and R is the perpendicular length. On the S2000, both stabilizer bars' arms depart significantly from the perpendicular (more so for the front bar). Therefore we utilize Puhn's modified relation in our calculations.

Finally, we address a specific case of an irregularly-shaped torsion bar, as in Figure 4. This shape is representative of the S2000 OE rear stabilizer bar.

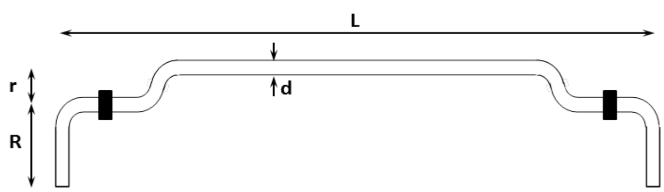

Figure 4. Parameters of a torsion bar with central offset

Here, for reasons of chassis clearance, the torsion section is formed with an "offset" portion at an additional distance r from the lever arm ends. However, since this portion of the bar is contained entirely inboard of the bushings, the additional distance does not act as an extension of the lever arms. Instead, the effect of the offset (to first order) is to increase the effective length L of the torsion bar; we therefore replace L in the above formulas with $L_{\text{eff}} = L + 2r.$

Combining the modifications of Figures 3 and 4, our task will be to determine the quantities d, t, L, R, and C for both the front and rear OE stabilizer bars, plus the quantity r for the rear bar.

MEASUREMENT AND ANALYSIS APPROACH

For this paper, direct measurements of applied force and spring deflection were not undertaken; instead, we have attempted to determine the physical parameters of the OE spring components and use the above relations to estimate spring rates. This approach was taken for several reasons:

- Equipment was not available to produce and/or measure up to several hundred pounds of force with a level of accuracy, precision, and repeatability comparable to the methods used here;
- Equipment was not available which would fix an OE component during measurement in the same configuration as it would be in the S2000 chassis while simultaneously isolating the measurement to the spring force alone;
- Determination and documentation of the physical parameters of the OE components provides insight into both the component and overall suspension design, by capturing models that are likely similar (at least to first order) to ones that might have been used by the vehicle's suspension engineers; and
- Determination and documentation of the physical parameters of the OE components facilitates fair comparisons to aftermarket S2000 parts, and even to other vehicles.

HONDA S2000 OE COIL SPRING ANALYSIS

Approach and Parts Summary

Since the primary goal of this research is a self-consistent, unbiased assessment of the OE suspension components, it was felt that all springs should be subject to the same physical measuring tools (including the same human tool operator), and should be measured in a single session. Further, since determining the relative stiffness of the components was central to the analysis, having all parts available simultaneously would facilitate back-to-back comparison if a case arose in which two different springs appeared to have similar or identical parameters.

Therefore, we acquired one complete sample set of OE coil springs (i.e. front and rear axle pairs), representing each different U.S. model of the Honda S2000. The springs obtained were used components, purchased for a nominal price from vehicle owners who had no knowledge of this study. (The author's own vehicle served as donor for the model year 2000-2001 springs.) The mileage of the springs, as reported by the owners, varied from less than 5,000 up to approximately 50,000 miles.

Once obtained, correct identification of the different springs is crucial; fortunately this task is assisted by the color-code system employed by Honda. Three paint dots are applied to each spring (one on each of three successive coils) according to the specific application of the part. Thus, even after removal from the donor vehicles and separation from the OE damper assemblies, each spring was readily identifiable.

For the S2000, there are six distinct OE configurations for springs and dampers, with a total of eleven distinct spring designs. These are summarized in Table 1, while Figure 5 provides an annotated photograph of the actual components measured for this analysis.

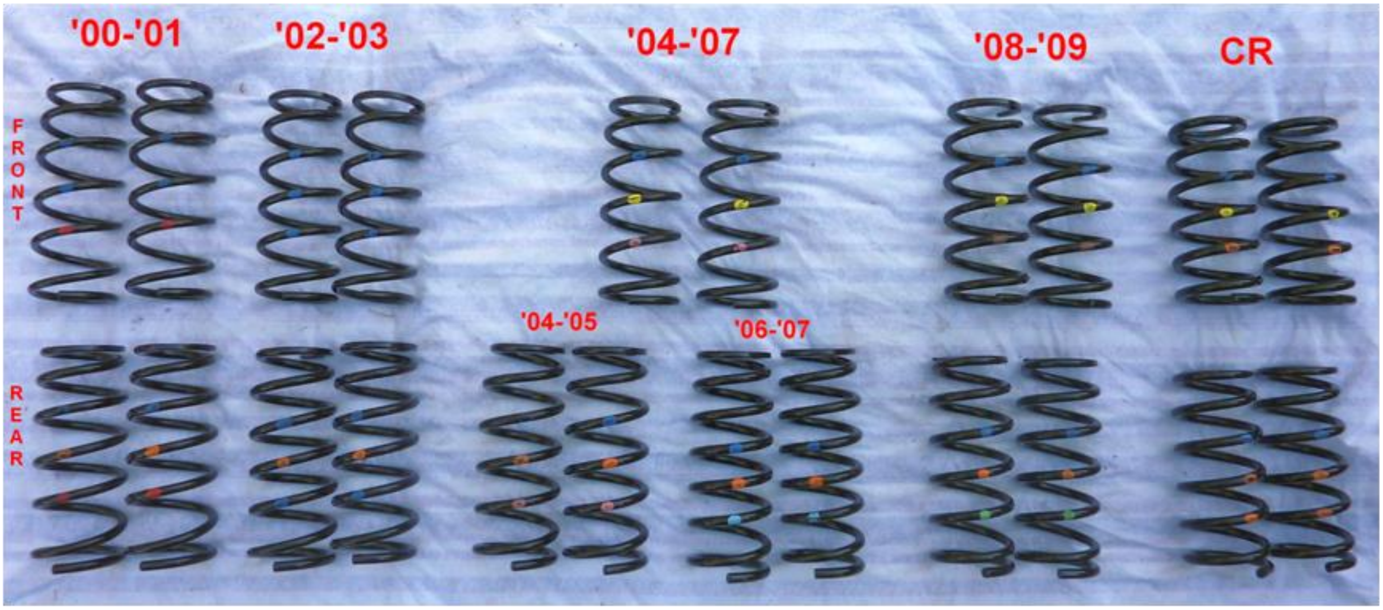

Figure 5. Photograph of the Honda S2000 OE coil spring components used for measurement.

Table 1. Honda S2000 OE Coil Spring Codes

FRONT COIL SPRINGS				
Model Year	**Part Number**	**Color 1**	**Color 2**	**Color 3**
2000-2001	51401-S2A-014	**Blue**	**Blue**	**Red**
2002-2003	51401-S2A-901	**Blue**	**Blue**	**Blue**
2004-2005 2006-2007	51401-S2A-903	**Blue**	**Yellow**	**Pink**
2008-2009	51401-S2A-024	**Blue**	**Yellow**	**Brown**
2008-2009 CR	51401-S2A-S21	**Blue**	**Yellow**	**Orange**
REAR COIL SPRINGS				
2000-2001	52441-S2A-014	**Blue**	**Orange**	**Red**
2002-2003	52441-S2A-901	**Blue**	**Orange**	**Blue**
2004-2005	52441-S2A-902	**Blue**	**Orange**	**Pink**
2006-2007	52441-S2A-902	**Blue**	**Orange**	**Lt Blue**
2008-2009	52441-S2A-S11	**Blue**	**Orange**	**Green**
2008-2009 CR	52441-S2A-S21	**Blue**	**Orange**	**Orange**

As is evident from Table 1, the first color (topmost, when installed onto the damper assembly) of all S2000 OE springs is blue, while the middle color can be used to distinguish front from rear, and (for front springs) AP1 from AP2. The final color is unique to the particular spring design.

One peculiarity in Table 1 is notable: As we will see, the rear springs for the 2004-2005 model years are distinctly different (in terms of both color codes and physical properties) from those of the 2006-2007 model years; however, current Honda parts databases show a common part number. It is not known if this is simply a database error or perhaps a case of parts supersession. If it is supersession, it is a remarkable case since the two parts are certainly not equivalent, and in fact the rear damper part numbers are different for 2004-2005 vs. 2006-2007. Regardless of the underlying cause, the shared spring part numbers have contributed to a common misperception in the S2000 owner community that all 2004-2007 suspensions are identical. (Note: this is actually true for the front springs and dampers, as well as the front and rear stabilizer bars).

We now turn to our measurements and results.

Coil Spring Measurements

Once the full sample set of OE springs was obtained, each spring was carefully cleaned to remove accumulated road dirt and debris. Each pair was inspected and gross measurements were taken of free length (total unloaded length) and total number of coils. Next, precision measurements were performed with a vernier caliper to characterize wire diameter d and coil diameter D.

We note that extra care was taken in assessing wire diameter. Since spring rate varies as d^4, this is a particularly dominant parameter, and measurement variations on the order of the vernier caliper's precision limit (0.1mm) can result in significantly different calculated spring rates. To reduce the statistical uncertainty of the wire diameter measurements, the following procedure was used: one measurement was taken on each full coil of each spring, and the caliper was removed, reset, and refitted for each measurement. For each pair of springs, this resulted in two sets of measurements: five measurements per spring, or ten total measurements (except for the 2006-2007 rear springs, which have an extra coil, giving twelve data points). The average of these measurements was used as the initial estimate of d. Basic estimation theory (e.g., [3]) states that averaging n independent measurements reduces statistical variance by about a factor of n; in this case, the raw precision obtained is roughly 0.01mm.

To assess coil diameter, the vernier caliper was used in conjunction with a simple workbench vise. The spring was placed in the vise, which was carefully closed until the plates just touched the spring. The caliper was then used to measure the plate separation.

Finally, the springs and the OE damper body were examined to determine the total number of active coils *N*. A coil in a spring is "active" if it deflects when a force is applied to the spring. The topmost coil of each OE spring is "closed and ground" (see [1]), sitting flush against the top hat of the damper assembly; therefore it does not deform under load and is inactive. The bottom-most coil of each OE spring is not ground, and appears to be (at least partially) "open". However, the OE spring perch mounted on each damper assembly is specially formed so that nearly the entire bottom coil is supported. Once installed in the vehicle, the preload on the spring is such that essentially the entire coil is prevented from deflecting, and is therefore inactive. Thus, in our calculations of spring rate, the total number of coils is reduced by two to arrive at the number of active coils.

An important observation here is that the topmost coil of each OE spring is slightly narrower than the remaining coils. The amount of diameter reduction varies from spring to spring, and can result in a significant (3-5 percent) difference in the estimated spring rate. As shown in [1], this narrow coil can be treated as a second spring in series with the "main" coil spring (whose coil count *N* must, of course, be reduced by 1). The overall spring rate is

$$S_{\text{total}} = \frac{S_{\text{main}} S_{\text{top}}}{S_{\text{main}} + S_{\text{top}}}.$$

where S_{main} represents a spring with $N-1$ coils of the larger diameter, and S_{top} represents a spring with a single coil of the smaller diameter. The actual measurement of the smaller-diameter coil was performed in the same way as for the larger-diameter coils.

Adjustments for Measurement Accuracy and Consistency with Published Data

In addition to measurement precision, two correction factors affecting overall measurement accuracy were addressed. The first is the calibration of the vernier caliper itself: careful study of the tool and use of known reference objects revealed a bias of about +0.10mm, which was removed from the measured data. The second factor accounts for the protective powder-coat finish on each OE spring, which does not contribute to spring rate. Observing that each vernier caliper measurement includes two layers of powder-coat, and assuming a nominal coating thickness of 5 mils (0.127mm, typical of industrial applications), we applied a further correction of -0.25mm to each caliper measurement. The total correction, therefore, was -0.35mm.

We also note here that our calculations rely on an assumption of the value *G*, the shear modulus of elasticity of steel. A great variety of steel alloys exists, but it is reasonable to assume that the OE suspension springs are made of a class of steels known simply as "spring steel". In [1], the authors recommend the value *G* = 1.1E7 psi for spring steel, while Puhn, in [2], uses *G* = 1.125E7 psi. A rudimentary internet search reveals that the most common value for general steels is *G* = 1.15E7 psi, while *G* = 1.16E7 psi is also common. Thus the mere choice of this constant has the potential to affect our computed results by over 5%. For our calculations, we have elected to use the single value of *G* recommended by the American Institute of Steel Construction (AISC) [4] for use as a design parameter characterizing all quality steels: *G* = 1.12E7 psi.

Finally, we reiterate the overarching goal of this paper: estimating the "designed" rates of the OE suspension springs. If our present measurements of the particular set of OE springs were the only reliable data available, we would accept the resulting calculations without question. However, there exists relevant, reliable "side information" directly from Honda in the form of published press releases and spec data. We take it as given that this data contains valuable clues as to the "true" values of the OE spring rates, and therefore we wish to use them to rationalize our raw measurements. In this way, we hope to arrive at a set of estimates that are in agreement with known data from Honda, but which also reflect a self-consistent and scientifically sound engineering model.

Our approach to rationalizing our measured data was to simply adjust certain parameter values within their known measurement uncertainties in order to obtain the best overall agreement between Honda's published data and our calculations. Every effort was made to minimize the magnitude of adjustment of any one parameter away from its "raw" measured value. Fortunately, our careful measurement techniques meant that we needed very few adjustments to obtain excellent agreement with Honda's published data: of some 55 measured parameters, only 12 were altered in any way. Moreover, of those 12 items, the largest magnitude of adjustment amounted to less than 1% of the measured value.

Summary of Coil Spring Rate Measurements and Calculations

In Table 2, we provide our best estimates of the designed spring rates of the OE S2000 coil springs. As described above, our estimates represent the calibrated/corrected measurements of the coil spring set, rationalized to obtain the best possible agreement with published Honda data. Table 3 summarizes the key S2000 coil spring data published by Honda Motor Co. during the vehicle's production (see [5], [6], and [7]), and the corresponding data as implied by our rationalized estimates. As is evident from the table, there is excellent agreement between our results and the published data from Honda.

The results in Table 2 demonstrate a significant variation in spring rates across model years. Excluding the CR model, front spring rates increased steadily from 219 to 280 lb/in

Table 2. New Estimates of Honda S2000 OE Coil Spring Parameters*

Model Year		'00-'01	'00-'01	'02-'03	'02-'03	'04-'07	'04-'05	'06-'07	'08-'09	'08-'09	'08-'09 CR	'08-'09 CR
Front/Rear		Front	Rear	Front	Rear	Front	Rear	Rear	Front	Rear	Front	Rear
Color 1		Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Color 2		Blue	Orange	Blue	Orange	Yellow	Orange	Orange	Yellow	Orange	Yellow	Orange
Color 3		Red	Red	Blue	Blue	Pink	Pink	Lt Blue	Brown	Green	Orange	Orange
Total coils	coils	6.5	6.4	6.4	6.5	6.4	6.5	7.4	6.4	6.7	6.6	6.5
Wire diameter, *d*	mm	11.18	11.94	11.40	12.15	11.65	11.95	12.22	11.85	12.01	12.83	12.41
'Main' coil diam., *Dmain*	mm	96.5	96.7	96.3	96.2	97.1	97.2	95.0	97.3	95.2	96.3	95.5
No. active 'main' coils	coils	3.5	3.4	3.4	3.5	3.4	3.5	4.4	3.4	3.7	3.6	3.5
'Top' coil diam., *Dtop*	mm	92.5	92.7	91.8	91.5	92.0	93.7	91.4	91.3	90.1	87.8	91.2
Total active coils, *N*	coils	4.5	4.4	4.4	4.5	4.4	4.5	5.4	4.4	4.7	4.6	4.5
Spring rate – 'main' coils	lb/in	274	366	309	385	328	349	324	349	362	466	429
Spring rate – 'top' coil	lb/in	1088	1404	1204	1566	1302	1364	1606	1426	1564	2202	1719
Calculated spring rate	**lb/in**	**219**	**291**	**246**	**309**	**262**	**278**	**269**	**280**	**294**	**384**	**343**
Free length	**in.**	**11.39**	**10.95**	**11.03**	**10.83**	**10.70**	**10.86**	**11.06**	**10.55**	**10.73**	**9.89**	**10.13**

*Revised 17 November 2010.

(+27%), while rear spring rates increased, decreased, and then returned to essentially their original value. The CR model, meanwhile, was fitted with the two overall stiffest OE coil springs; indeed, the fronts are fully 75% stiffer than the '00-'01 front springs (which are the softest overall).

Table 3. Comparison of New S2000 Coil Spring Rate Estimates to Honda Published Data

S2000 Coil Spring Rate Item		Published Value	New Estimate
2000-2001 Spring Rates [5]	Front	219 lb/in	219 lb/in
	Rear	291 lb/in	291 lb/in
Spec Change: 2004 vs. 2003 [6]	Front	+6.7%	+6.6%
	Rear	-10%	-10.0%
Spec Change: 2008 vs. 2007 [7]	Front	+7%	+7.0%
	Rear	+9%	+9.0%
Spec Difference: CR vs. 2008 [7]	Front	+37%	+37.1%
	Rear	+17%	+16.9%

Before leaving the topic of coil springs, we note that Table 3 provides further evidence of a change in the rear spring rate from model year 2005 to 2006 (i.e. MY05 to MY06), despite the identical part numbers. Honda's press releases ([6] and [7]) outlining the MY03-to-MY04 and MY07-to-MY08 spec changes are both in excellent agreement with our measurements, a fact which would not be possible if the MY06-MY07 rear springs were designed to have rates identical to those of MY04-MY05.

HONDA S2000 OE STABILIZER BAR ANALYSIS

Our analysis of the OE S2000 stabilizer bars was assisted greatly by the fact that their gross physical dimensions have remained unchanged for all models and years; the only differences are in the diameter and thickness of the steel bar material. Moreover, both of these critical parameters have been published by Honda for all model years. Therefore, our only remaining task was to obtain an accurate measurement of the bars' geometries. In Table 4, we provide values of the stabilizer bar model parameters (as diagrammed in Figures 2, 3, and 4) for the OE S2000 components. The parameters *L*, *R*, *C*, and *r* are from our new measurements, while *d* and *t* are reproduced from Honda's published specifications ([5], [6], and [7]). Combining the effects of the splayed arms, hollow torsion tubes, and offset central torsion sections, the final form of the stabilizer bar equation used to calculate the spring rates shown in Table 4 is

$$S = \frac{\pi G(d^4 - (d-2t)^4)}{30R^2(L+2r) + 16C^3}.$$

A final note regarding Table 4 concerns another part number peculiarity. In this case, the MY02-MY03 front stabilizer part number differs from the MY04-MY07 part number; however, it is clear from Honda's published data ([6] and [7]) that the diameter and thickness remained unchanged during this time. Unlike the MY04-MY07 rear spring anomaly, this is precisely what one would expect in a case of parts obsolescence: the performance parameters remain the same, but the part number is updated and the old part number is phased out. The peculiarity here is that the MY02-MY03 part number remains a distinct and valid item in the current Honda parts catalog.

SUMMARY RESULTS

For ease of reference, Table 5 provides a combined summary of our spring rate estimates by model year, including both coil springs and stabilizer bars. As is evident from the table, Honda's engineers specified six distinct configurations of spring rates for the U.S. model S2000 over the course of the car's 10-year production run.

Table 4. New Estimates of OE S2000 Stabilizer Bar Characteristics

Model Year	Honda Part Number	Diam *d* (mm)*	Thickness *t* (mm)*	Bar Length *L* (in.)	Lever Arm *R* (in.)	Lever Length *C* (in.)	Offset *r* (in.)	Spring Rate *S* (lb/in.)
FRONT STABILIZER BARS								
'00-'01	51300-S2A-003	28.2	5.0	34.0	9.6	10.5	0	393
'02-'03	51300-S2A-013	26.5	4.5					300
'04-'05 '06-'07	51300-S2A-033	26.5	4.5					300
'08-'09	51300-S2A-S01	27.2	5.3					354
'08-'09 CR	51300-S2A-S11	28.6	4.5					392
REAR STABILIZER BARS								
'00-'01	52300-S2A-013	27.2	5.3	35.4	8.5	8.9	1.25	427
'02-'03	52300-S2A-J01	27.2	4.5					396
'04-'05 '06-'07 '08-'09	52300-S2A-J02	25.4	4.5					311
'08-'09 CR	52300-S2A-S01	26.5	4.5					362

*Honda published data ([5], [6], [7])

Table 5. New Estimates of S2000 OE Spring Rates* – Summary Results

Model Year	Coil Springs		Stabilizer Bars	
	Front	Rear	Front	Rear
'00-'01	219	291	393	427
'02-'03	246	309	300	396
'04-'05	262	278	300	311
'06-'07	262	269	300	311
'08-'09	280	294	354	311
'08-'09 CR	384	343	392	362

*All values in lb/in.

CONCLUSIONS

We have undertaken a comprehensive analysis of the Honda S2000 OE suspension springs (coil springs and stabilizer bars), in order to characterize both their absolute and relative stiffness across all models and production years. Our analysis relied on our own independent measurements of OE components as well as publicly-available data from Honda Motor Company, with which our data exhibits strong agreement. Moreover, our results are derived in terms of engineering model parameters, allowing insight into the design features of the suspension springs as well as permitting fair comparison to aftermarket components. Finally, the results of our analysis make it clear that Honda made significant changes to the OE S2000 spring specifications every two years during the vehicle's production run.

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ABOUT THE AUTHOR

John McCanless purchased a 2000 Honda S2000 (VIN #0814 in New Formula Red) on September 17, 1999—the first day the vehicle was available for sale in the U.S.—after eight months on the waiting lists of three local dealers. His first track day with the car was in the summer of 2001. He won the 2002 and 2003 Speed Ventures S2000 Challenge (MOD class), and administered the Speed Ventures S2000 Challenge series in 2005 and 2006. To date he has logged some 6,000 track miles in his S2000, using a variety of different springs, dampers, and stabilizer bars. He holds a B.S. and M.S. in Electrical Engineering, both from the University of Virginia.

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