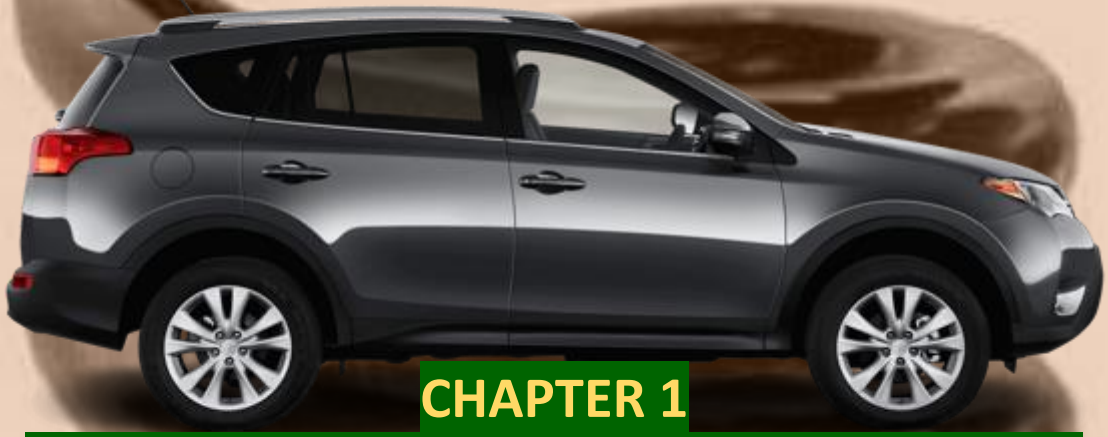
PROJECT 2
FATIGUE ANALYSIS OF HELICAL COIL COMPRESSION SPRING FROM TOYOTA RAV4 XLE 2015



CHAPTER 1
PROJECT DEFINITION, GOALS, VEHICLE AND COMPONENT

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Chapter 1: Project Definition, Goals, Vehicle and Component

Section 1.1: Section 1.1: Project Definition, Goals

Springs are everywhere. It is an elastic object that stores mechanical energy and releases it when forces are not acting on it. Almost every material acts like a spring. When it is stretched, it stretches until yield stress and reaches a maximum ultimate stress. Similar to traditional materials, a wire can be coiled helically to form a spring. Every spring has a spring constant which relates the amount of force applied on the compression or expansion of the spring. This is explained through the Hooke's law.[i]

Springs can be of two types – expansion or compression. Expansion springs typically are very compact and when a force is applied on them, the spring expands or stretches outwards. On the opposite is the compression spring, when the force acts on it, the spring compresses. The compression springs have numerous applications, but one major area where this is applied is in suspensions in vehicles. These springs absorb energy and mitigate shocks. In doing this, the spring has to deflect by a considerable amount.[ii] Energy is just transferred from kinetic to elastic potential energy of the spring. These springs help in reducing the shocks when the user in a car is going through an uneven surface – an application absolutely necessary in today's cars.

The one particular we are interested in is a helical coil compression springs. These are present in almost every car available on market today. They have become a necessity is every car, especially in some developing countries where there are uneven roads. These springs also compress when a car takes a turn. A car goes through numerous of these in its lifetime and a comprehensive study in terms of fatigue analysis is required to predict the life of these springs. Through some assumptions, mentioned in the later chapters, we will be able to provide a method for conducting this fatigue analysis for any helical coil compression spring in any car.

There is a lot of value in conducting this study. Using this book, a mechanic or engineer or even a layman should be able to follow the steps to predict the life of a helical coil compression spring. This is the anticipation of the author. Using this study, a user can know how frequently should they change the spring for proper safety of the passengers. The instructions in this book can also be used by the designers to find the most appropriate parameters to design the spring, while at the same time considering the economic factors also. In order to do this, a satisfactory life along with size are important factors to consider. The fatigue analysis presented in the book will facilitate that to the user.

Section 1.2: Vehicle Information

In order to test this helical coil spring, we need a dummy car where we can gain the information for different parameters. For convenience, we will choose the car that is readily available to the author. However, the method described is applicable for any available car. As suggested in the title, the car we will be analyzing is a Toyota RAV4 XLE 2015, shown in the Figure 1.2-1Figure 1.2-1 below.

Toyota RAV4 2015 is a 5 seater SUV having a unique sporty look and is black in colour (Figure 1.2-1). It has a superb mileage of 38.6 kilometres per gallon and has an automatic shift. Its curb weight is 3445 lbs or 1563kg as given in the Toyota website.[iii] The full capacity weight with passenger is not available, therefore, we will have to approximate it and use that for the rest of the book. The average weight of a person is 137 lbs[iv] and the average baggage that a person carries is 48 lbs.[v] Using these assumptions that there are 5 people in the car at all times, we can calculate the total weight of the car using the Equation 1.2-1.

$$W\_full = 3445\text{lbs} + 137 * 5\text{lbs} + 48 * 5\text{lbs} = 4370\text{lbs} \qquad \text{Equation 1.2-1}$$

Figure 1.2-1: Side view of Toyota RAV4 XLE 2015

Therefore, the full capacity weight (W_{full}) of the car is 4370 lbm (pounds mass) or 1982 kg. This is under the assumption that the car consists of 5 people sitting with their 48 pound baggage along with them.

Majority of the weight of the car is resting on these springs. However, some weight is not being cushioned/suspension the spring. The weight that is not being supported by these suspension springs is known as the unsprung weight ($W_{unsprung}$). This weight includes the following categories[vi]:–

a. Brake rotors or drums + shoes, wheel cylinders, backing plates, calipers, pads, caliper brackets, flex hoses, return springs, wheel bearings, etc.
b. Wheels, tires, tubes & valves
c. Steering knuckles
d. Rear axle housing, ring & pinion, differential, axles, etc.
e. Pinion snubber
f. Sway bar linkage (but not the arms or center beam)

All of the above categories have been labelled in the unsprung Figure 1.2-2**Figure *1.2-2*** below. Basically, as it is visible form the figure below, the unsprung weight consists of objects that are below the spring.

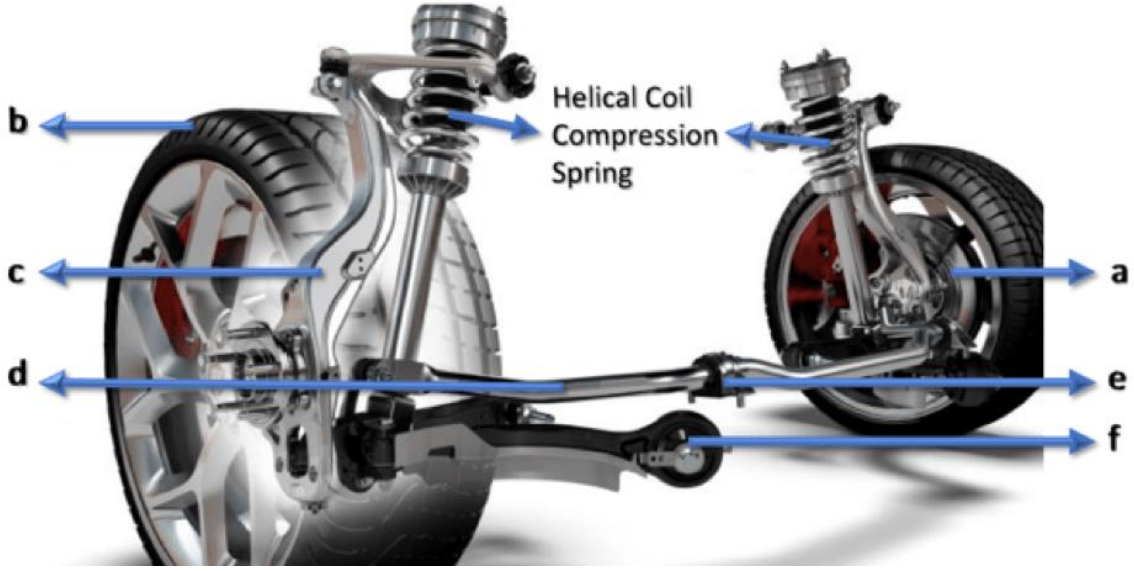

Figure 1.2-2: Unsprung weights in a car - labelled

Chapter 1: Project Definition, Goals, Vehicle and Component

The goal of the designers is to reduce the amount of unsprung weight as much as possible to increase the traction of the tyres. Lower unsprings weight is also beneficial for longevity of the cars. However, decreasing this weight is not easy since every part is essential in the safety mechanism of the car.[vii]

After a thorough literature search, we were not able to find the unsprung weight of the Toyota RAV4 XLE 2015. The unsprung components weight is generally between 13 and 15% of the W_{curb}. For best practise, we are going to assume that it is 15%. This calculation has been found in the Equation 1.2-2.

$$W_{unsprung} = 15\% \text{ of } W_{curb} = \frac{15}{100} \times 3445\text{lbm} = 517\text{lbm} \qquad \text{Equation 1.2-2}$$

Therefore, the unsprung weight of Toyota RAV4 XLE 2015 is 517lbm or 235kg. in order to carry out further calculations, it is important that we find the other dimensions of the car as well. Its height is 65.4 in, length is 179.9 in and width is 72.6 in without the side-view mirrors.[viii] The exact weight distribution is not known; however, it is mentioned that they have built the car with quite low centre of gravity for extra stability.[ix] For the ease of our calculation, we will assume the centre of gravity is at half distance of all the dimensions of the car. Therefore, the centre of gravity of the car is at:

- Height = 32.7 in
- Length = 90.0 in
- Width = 36.3 in

As mentioned earlier, springs are present in almost every cars these days. And not just one spring but in total, 4 suspension springs are installed in all the cars, shown in the Figure ***1.2-3***.

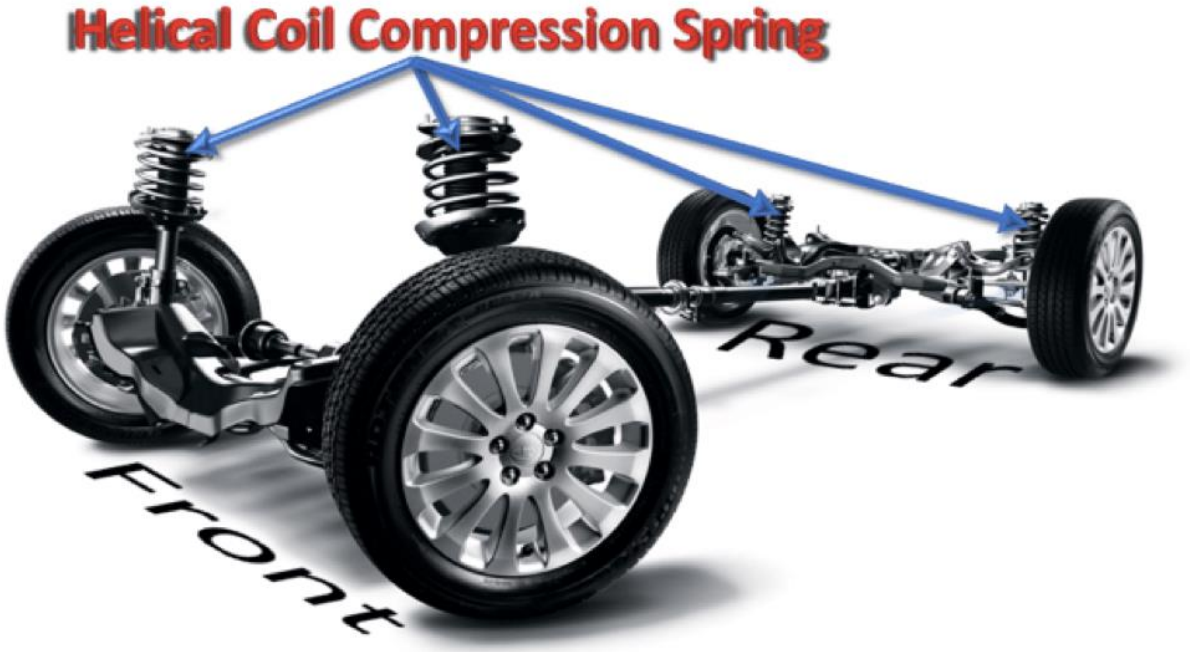

Figure 1.2-3: Four Springs in the chassis design

The mechanical component we are analysing is in all four corners of the chassis as shown above. The spring, as shown in Figure 1.2-2 and Figure 1.2-3, is placed right next to the wheel on the inside of the car. This is exactly the case in RAV4 also, where there are suspensions on all four wheel of the car. This has been shown in the Figure 1.2-4 below.

Figure 1.2-4: Helical Coil Compression Spring behind the wheel, a – close up and b – distant view

As it will be mentioned, there are a total of 6 turns of the spring, however, only three are visible in the Figure 1.2-4 above. The fourth coil is barely visible. The rest are covered. This picture is taken of the front right wheel of the car. There are suspensions on each tyres, but the springs are only visible in the front tyres. At the back they are covered for unknown reasons.

Section 1.3: Mechanical Component

As it has been mentioned earlier, the mechanical component we are interested in analysing is a helical coil compression spring. This is the most readily available product in market. The Figure 1.3-1 below provides a picture of a similar spring used in the car.

Figure 1.3-1: Helical Coil Compression Spring

For safety purposes, we are not extracting the actual spring from the car to analyse. **The instructor for this book requires us to use a generic spring**. Therefore, the Figure 1.3-1 is a spring provided by the instructor. We are making an assumption that the spring is coming from RAV4 as shown in the Figure 1.3-2.

Figure 1.3-2: Helical Coil Compression Spring behind the wheel, a – close up and b – distant view

In order to carry out a fatigue analysis in the later chapters, we must find out the various parameters of the spring and the car and these will be found in the following chapter 2.

The spring plays a crucial role in the safety of the car. The mechanism of suspension is based on damping. Out of different types of damping, critical damping takes place in a car suspension system, shown in the Figure 1.3-3 below.[x]

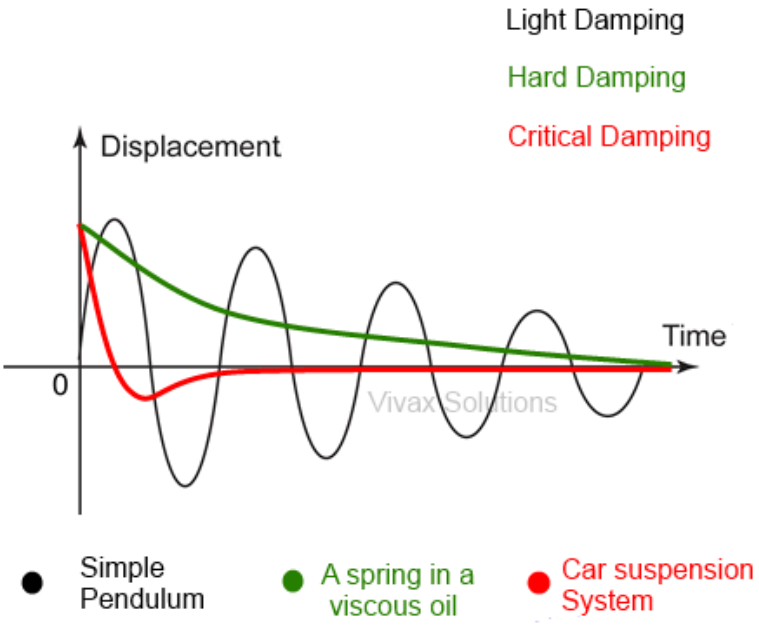

Figure 1.3-3: Different types of damping systems

When the weight of the car pushes the spring down, the elastic energy of the spring pushes the weight up and decreases the amount of displacement that would have happened if the spring was not present. The springs used in the suspension system are especially good at doing that since they stop the vibrations in just one oscillation.[xi] This is only possible if the spring constant of the spring is really high, and that is the design constraint that the suspension spring manufacturers have to keep in mind. Along with this, we will find that the dimensions, materials and the environmental conditions also play a strong role in the manufacturing of the suspension springs. This will be discussed in chapter 2 and the following.

Section 1.4: Table of Data

Table 1.4-1: Chapter 1 table of Data

Parameter	Description	English Units		Metric Units	
		Value	Units	Value	Units
W_{curb}	Curb Weight	3445	lbm	1563	kg
W_full	Full Capacity Weight	4370	lbm	1982	kg
$W_{unsprung}$	Unspring Weight	517	lbm	235	kg
Height	Height of the car	65.4	in	1.66	m
Length	Length of the car	179.9	in	4.57	m
Width	Width of the car	72.6	in	1.84	m
COG-H	Centre of Gravity Height	32.7	in	0.82	m
COG-L	Centre of Gravity of Length	90.0	in	2.29	m
COG-W	Centre of Gravity Width	36.3	in	0.92	m
N	Number of coils	6	None	6	None

Section 1.5: References

[i] “Spring (Device).” Wikipedia, Wikimedia Foundation, 28 Feb. 2018, en.wikipedia.org/wiki/Spring_(device).
[ii] Wahl, A. M. Mechanical Springs. University Microfilms, 1980.
[iii] “2018 Toyota RAV4 Weight & Cargo Volume.” Toyota, www.toyota.com/rav4/features/weights_capacities/4430/4440/4444.
[iv] Quilty-Harper, Conrad. “The World's Fattest Countries: How Do You Compare?” *The Telegraph*, Telegraph Media Group, 21 June 2012, www.telegraph.co.uk/news/earth/earthnews/9345086/The-worlds-fattest-countries-how-do-you-compare.html.
[v] "Wheel Stud 1/2 Ton, Each." *Wheel Stud 1/2 Ton, Each-Broncograveyard.com*. N.p., n.d. Web. 21 Jan. 2018.
[vi] Pejit, Jeffrey Diamond panic kitabel. “Sprung Vs. Unsprung Weight.” Victory Library, victorylibrary.com/mopar/sprung-c.htm.
[vii] “Understanding Unsprung Weight and Its Effects on Your Daily Driving.” PakWheels Blog, 1 Nov. 2017, www.pakwheels.com/blog/understanding-unsprung-weight-effects-daily-driving/.
[viii] “2015 Toyota RAV4 FWD 4-Door LE Specs.” *The Car Connection*, www.thecarconnection.com/specifications/toyota_rav4_2015_fwd-4dr-le-se.
[ix] Allen, Author Markus. "29 Tips, Secrets and Surprises about the New Toyota RAV4." *TruthIn7Minutes.com*. N.p., n.d. Web. 21 Jan. 2018.
[x] Solutions.com, Vivax. “Physics.” Simple Harmonic Motion Tutorial for A-Level: SHM, Damping, Pendulum, Springs | Vivax Solutions, www.vivaxsolutions.com/physics/alsmplhrmncmotion.aspx.
[xi] “Learn About Compression Springs.” Compression Springs | Metal Coil Springs | Helical Compression Springs, www.leespring.com/int_learn_compression.asp.

Section 1.6: Level of Effort

I wanted to get all the formatting right from the very first chapter. That is why I spent a lot of time researching a lot of Word formatting techniques. I would have spent about 15 hours working on this chapter.