1. Influence of k_b and c_b to Comfort of the Patient

From the previous study we can see that difference values of k_b and c_b have a great influence on vertical displacement and acceleration of the patient on the stretcher. We can make a plot of a indicator of comfort performance of patient varying k_b and c_b, showing the influence of k_b and c_b on $\ddot{z}_b$ more clearly and find the optimum value of k_b and c_b more accurately.

1.1 RMS value of the signal

One good indicator of the comfort performance of the patients is the plot of $\ddot{z}_b$. But it is more convenient to use just one value to represent the comfort of the patients in a defined condition. The mean value of $\ddot{z}_b$ is equal to zero. The mean square value of $\ddot{z}_b$ can be a good indicator, but in this case the unit of the indicator will be different from $\ddot{z}_b$. To not change the unit, the RMS (Root Mean Square) value of $\ddot{z}_b$ can be used as the indicator of comfort performance of the patient.

The RMS value of a signal f(t) can be expressed as the equation below:

$$RMS = \sqrt{\frac{1}{T}\int_{t-T}^{t} f(t)^2\,dt}$$

Where f(t) is the function of the signal in time domain. T is the total time of the signal. For example if we have a plot of $\ddot{z}_b$ like in figure 1.1, the RMS value of the signal can be seen as the root of the area between the signal and the horizontal axis. So, lower the RMS of $\ddot{z}_b$, better the comfort performance of the patient.

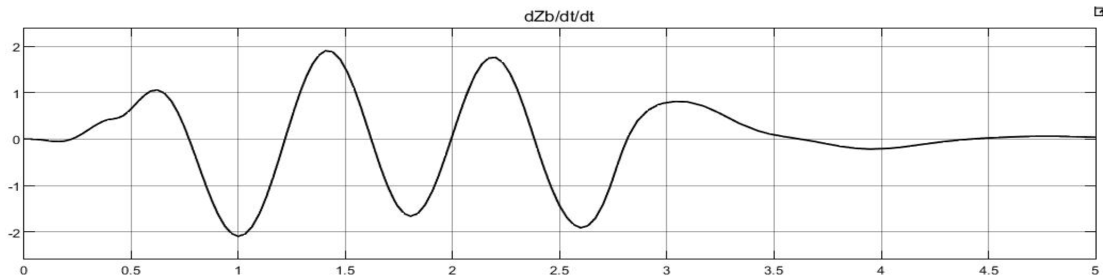

Figure 1.1 Plot of f(t)

Based on the grade C random road as input, fixing the k_b and c_b value, using the ambulance model we obtained before, we can plot $\ddot{z}_b$ in time domain in Matlab/Simulink. Then using the block "To workplace" in Simulink, all of the data in this plot can be output to Matlab workplace. In this way, using some Matlab code the RMS value of these data can be calculated. For example, if k_b=2000, c_b=350, the RMS value of $\ddot{z}_b$ is 4.3963.

1.2 RMS value of $\ddot{z}_b$ varying k_b

To analyse the influence of k_b on the RMS value of $\ddot{z}_b$, we fix the damping value c_b=200, the velocity of the ambulance V=30 km/h and varying the k_b from 2000 to

10000 at the distance of 250. With each value of k_b corresponding to one value of RMS, all of the value of RMS of $\ddot{z}_b$ can be plotted. As a comparison, the RMS of $\ddot{z}_s$ can also be plotted. The results shows in Figure 1.2.

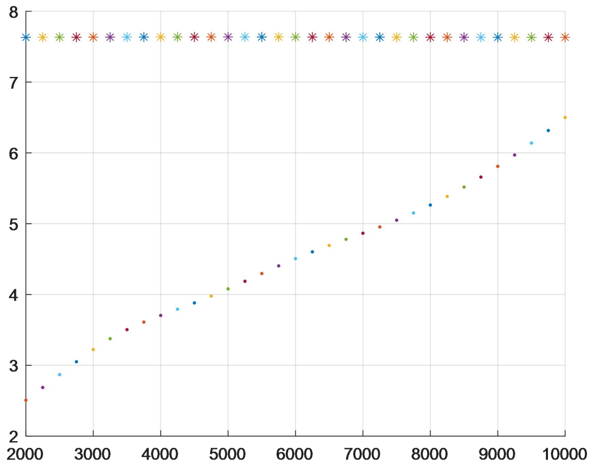

Figure 1.2 RMS of $\ddot{z}_b$ and $\ddot{z}_s$ varying k_b

In this figure, "." represent the RMS values of $\ddot{z}_b$; "*" represent the RMS values of $\ddot{z}_s$. From the Figure, the relation between RMS and k_b is clear: lower the k_b, lower the RMS of $\ddot{z}_b$, better the comfort of the patients. In addition, the RMS of $\ddot{z}_s$ is much higher than the RMS value of $\ddot{z}_b$, meaning that the comfort performance of the patients is much better than the comfort of sprung mass (ex. the driver). RMS values of $\ddot{z}_s$ can also represent the comfort performance in the case that the connection between the stretcher and the sprung mass is rigid. In this case, we can find that the use of stretcher suspension greatly improve the comfort of the patients. Furthermore, it is clear that the RMS of $\ddot{z}_s$ are almost not influenced by the changing of k_b.

1.3 RMS value of $\ddot{z}_b$ varying c_b

In the same way, we fix the k_b at its optimum value 2000. Then, varying the value of c_b from 50 to 1000, at the distance of 25. With each c_b value corresponding to one RMS value of $\ddot{z}_b$ and one of the $\ddot{z}_s$. The results shown in Figure 1.3.

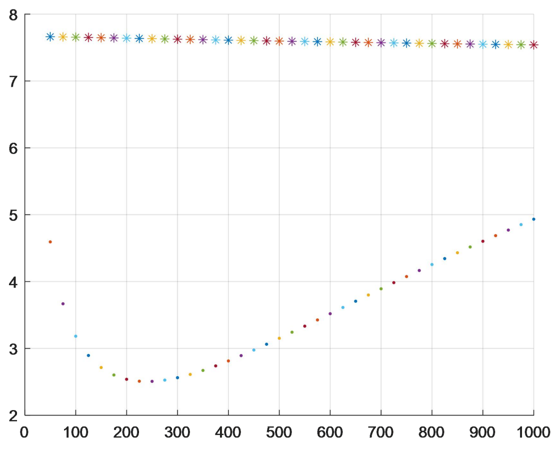

Figure 1.3 RMS of $\ddot{z}_b$ and $\ddot{z}_s$ varying c_b

In this figure, "." represent the RMS values of $\ddot{z}_b$; "*" represent the RMS values of $\ddot{z}_s$. From the Figure, the relation between RMS and c_b is not like in varying k_b. In this case, there is a c_b that corresponding to the minimum value of RMS of $\ddot{z}_b$, which is c_b equal to 250. In addition, the RMS value of $\ddot{z}_s$ approximately not influenced by different values of c_b.

1.4 Responses of the system based on optimum value of k_b and c_b

In this way, we obtain the accurate optimum values of k_b and c_b corresponding to the best comfort performance of the patients when ambulance is riding on the random road. The optimum values are: k_b=2000 N/m, c_b=250 Ns/m.

Based on this optimum value of k_b and c_b, the responses of roll motion, pitch motion and vertical motion of the sprung mass and vertical motion of stretcher are shown in Figure 1.4 to 1.7.

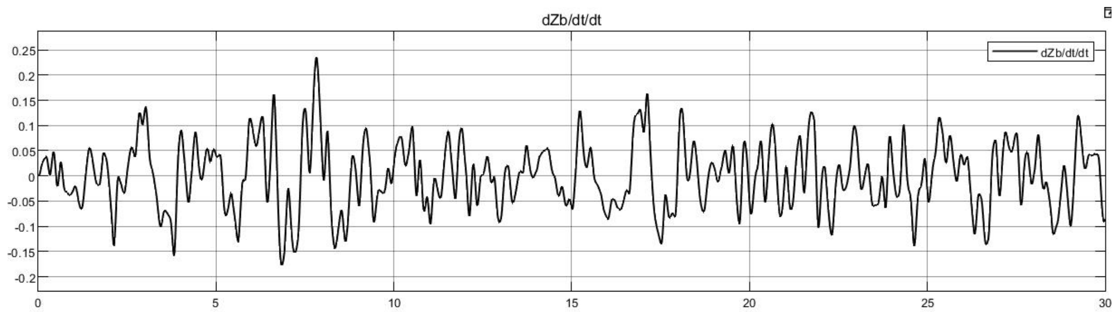

Figure 1.4 Vertical acceleration of the stretcher

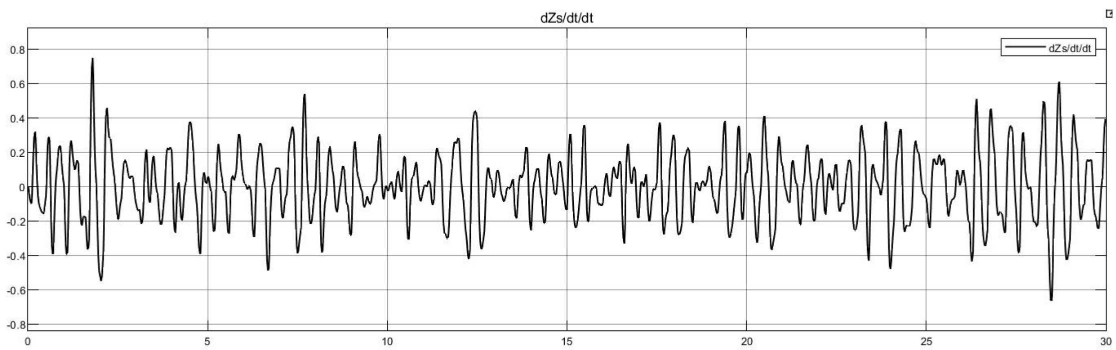

Figure 1.5 Vertical acceleration of the sprung mass

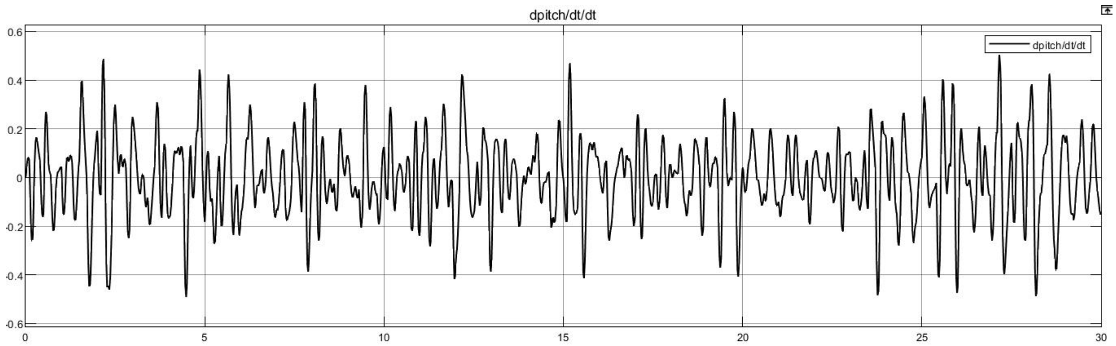

Figure 1.6 Acceleration of pitch motion of the sprung mass

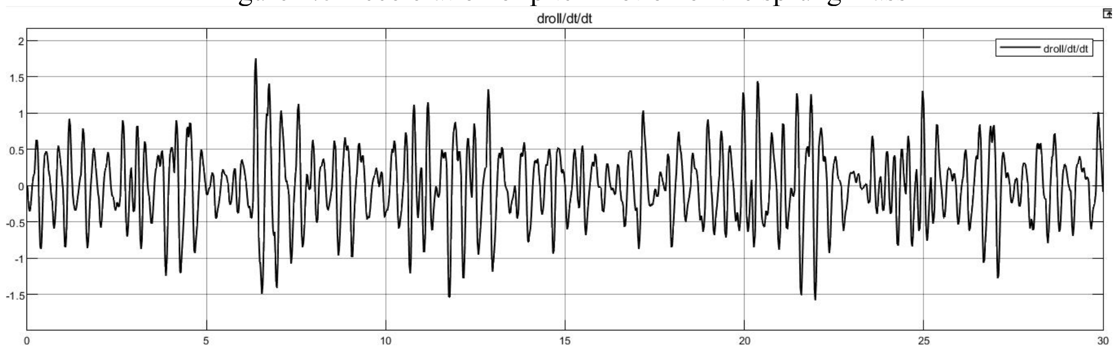

Figure 1.7 Acceleration of roll motion of the sprung mass

2. Influence of Speed of Ambulance to the Results

In real case, when ambulance is riding on the road, the speed of the ambulance is certainly not constant, and often much higher than 30 km/h, and the comfort performance of the patients is certainly not the same as the results obtained in 30 km/h. In this case, the influence of different speed on choosing optimum value of c_b and on comfort performance of the patients and will be analyzed.

2.1 Influence of different speed on comfort of the patients

In this chapter, k_b and c_b will be fixed (k_b=2000, c_b=250) and the RMS of $\ddot{z}_b$ is still be used as the indicator of the comfort of the patients. To analyse the influence of different speeds on RMS value of $\ddot{z}_b$, instead of varying k_b and c_b, we vary the speed of the ambulance from 10 km/h to 120 km/h, and output all the values of RMS corresponding to each values of the speed. The results is shown in Figure 2.1.

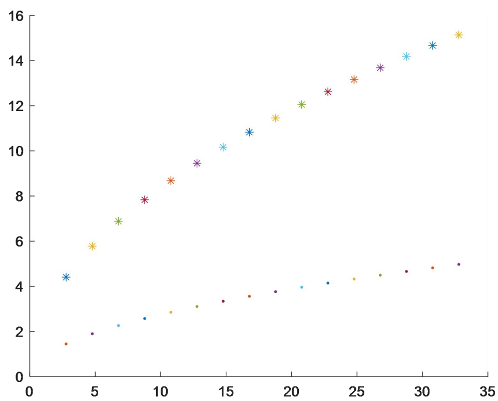

Figure 2.1 RMS of $\ddot{z}_b$ and $\ddot{z}_s$ from 10km/h to 120 km/h

In this figure, "." represent the RMS values of $\ddot{z}_b$; "*" represent the RMS values of $\ddot{z}_b$. The figure tells us that higher the speed, higher the values of the RMS, worse the comfort performance of the patients. In addition, comparing to the comfort of the patients, the comfort of the sprung mass is much more sensitive to the change of the speed.

To further verify the results, we build the model in Matlab Simulink with a defined profile of the speed as input, and the time domain responses of vertical acceleration of patients and sprung mass, acceleration of pitch motion and roll motion of sprung mass as output. The Simulink diagram is shown in Figure 2.2.

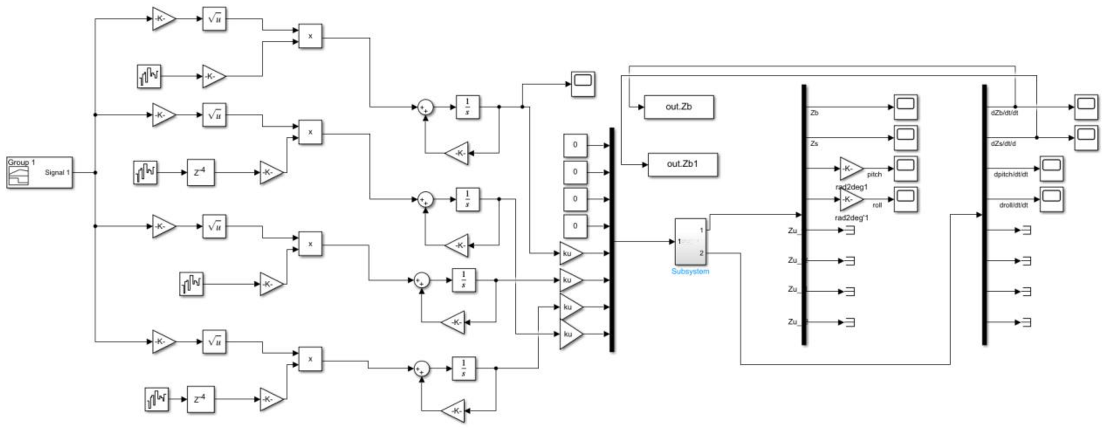

Figure 2.2 Random road profile Simulink diagram as input of a defined speed profile

Taking front right wheel as an example, the plot of defined speed profile is shown in Figure 2.3.

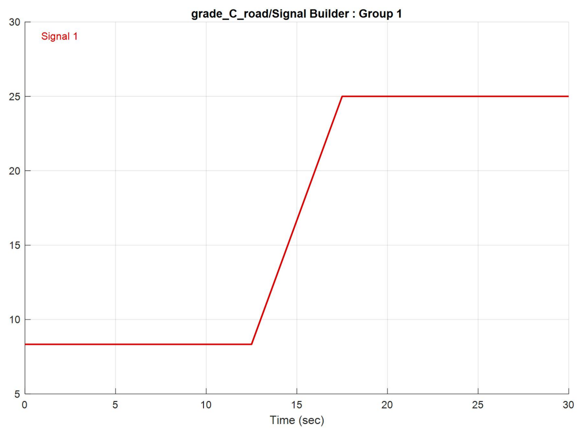

Figure 2.3 Defined profile of the speed

The ambulance is riding at constant speed of 30 km/h for 12.5 seconds and accelerate to 90 km/h by 5 seconds and keep the speed at 90 km/h for 12.5 second (30 seconds in total). The outputs is shown from Figure 2.3 to 2.6.

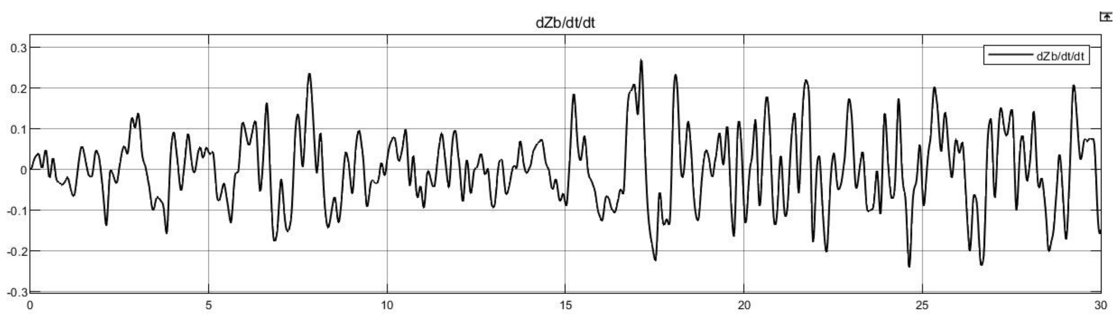

Figure 2.3 Output of $\ddot{z}_b$

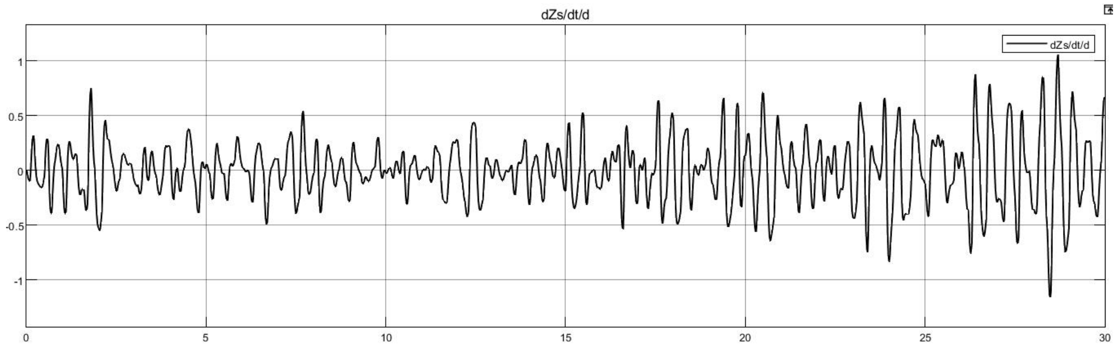

Figure 2.4 Output of $\ddot{z}_s$

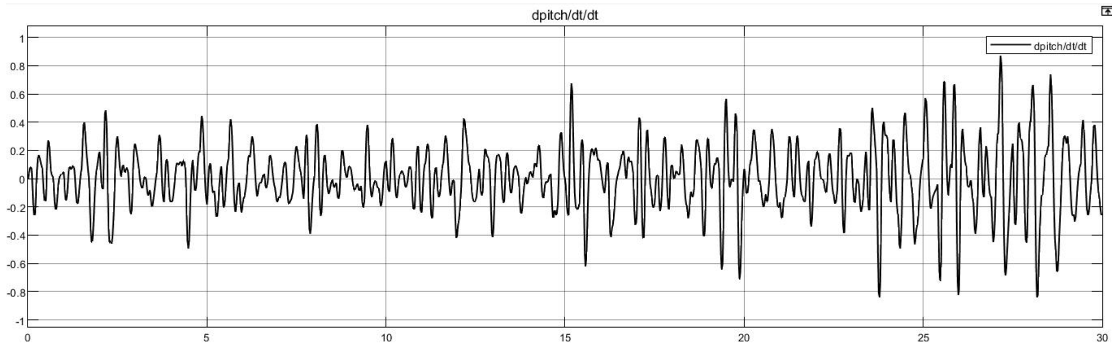

Figure 2.5 Output of acceleration of pitch motion of sprung mass

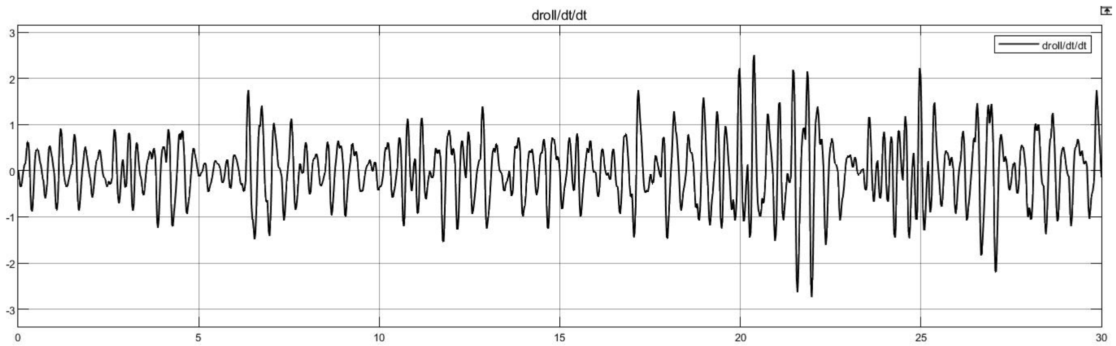

Figure 2.6 Output of acceleration of roll motion of sprung mass

In those four plots, the amplitude of first 12.5 seconds of the responses is lower than last 12.5 seconds of the responses.

2.2 Influence of different speed on choosing optimum and c_b

In this chapter, four different values of the speed is tested and at the same time varying c_b. The values of RMS of $\ddot{z}_b$ in each different values of speed and c_b is shown in Figure 2.1.

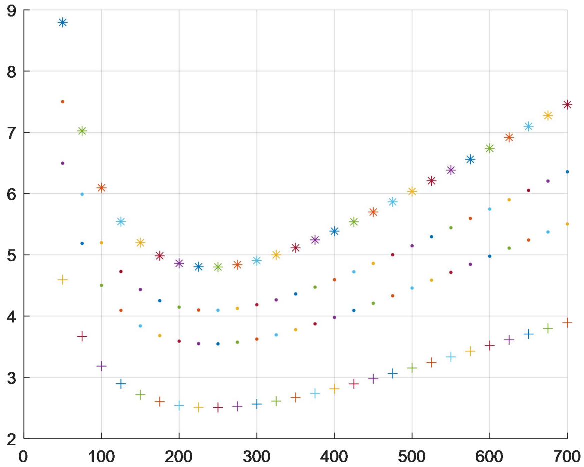

Figure 2.7 RMS of $\ddot{z}_b$ varying speed and c_b

In this figure there are approximately four curves, corresponding to four different speeds: V=30 km/h, V=45 km/h, V=60 km/h, V=90 km/h. We can find that no matter what the speed is, the lowest value of RMS all at the same value of c_b=250. Changing the speed does not influence the optimum value of c_b.

3. Comparison Between Sinusoidal and Random Road Profile

In this chapter, the road excitation is changed to see if the optimum value of c_b is affected or not. The results of RMS values of $\ddot{z}_b$ varying c_b from 50 to 1000, at the distance of 20, is shown in Figure 3.1. The results are obtained from sinusoidal and random road profile respectively.

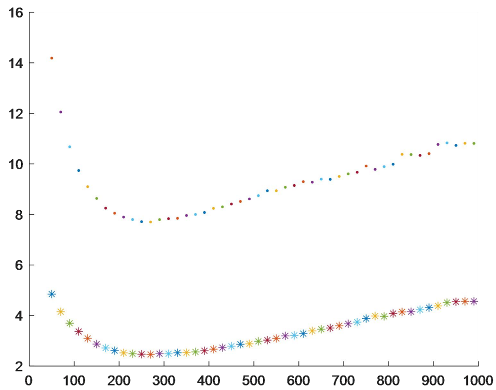

Figure 3.1 RMS of $\ddot{z}_b$ varying c_b in sinusoidal and random road profile

From the figure, it is clear that different road profile does not influence the optimum value of c_b. So the same optimum value of c_b can be applied to the cases of different road profiles.