1. Introduction

Most ambulances are customized or adapted from cargo transport vehicles like trucks, and these vehicles are usually heavier and less comfortable than passenger cars. In this case, the passenger on ambulance will subject to severe acceleration during braking, curves or running on a uneven road. But the patients in ambulances are usually exposed to serious illness or injury, any severe acceleration can cause damage to the body of patients. Particularly, patients in lying down position are more sensitive to vertical acceleration when comparing to a passenger in standing or seated position. In this case, to improve the comfort performance of the patients, we can either focus on properly designing the suspension of the ambulance or the suspension of the stretch.

But since the ambulance is driving at relatively higher speed than regular trucks, the ambulance is likely to rollover during cornering at this high speed. So the handling requirement of ambulance is higher than regular trucks. But to give the ambulance good handling we need to make the suspension stiffer. So, to make the patients more comfortable and at the same time not affecting the handling performance of the ambulance, we focus on properly designing the suspension of the stretch.

There are many ways of designing the suspension of the stretch. In this thesis, we focus on properly choosing the stiffness are damping value of the suspension to achieve the minimum vertical displacement and acceleration of the stretch. To do this, a mathematical model is built and a sinusoidal shape of the road profile is used as the input signal of the system. Then different set of stiffness and damping value (k_b and c_b) is tested to find the optimum k_b and c_b. With this optimum value, we output the vertical displacement, roll angle, pitch angle and acceleration of the ambulance during the riding on the sinusoidal road. In the end, we used the grade C road profile to verify the optimum k_b and c_b also applied to the real case.

2. Mathematical Model

2.1 Ambulance Model

Including the stretcher, the 8 DOF dynamic model is built shown in Figure 2.1(a). The 8 DOF are vertical motion of the stretcher (z_b), roll motion, pitch motion and vertical motion of the sprung mass (ϕ, θ and z_s), and vertical motions of four unsprung mass (z_{fl}, z_{fr}, z_{rr}, z_{rl}). The compliance between stretcher and sprung mass is modeled by spring stiffness k_b and damping value c_b. The compliance between sprung and unsprung mass is modeled as spring stiffness k_{fr}, k_{fl}, k_{rr}, k_{rl} and damping value c_{fr}, c_{fl}, c_{rr}, c_{rl}. The compliance of each tire is modeled as k_{tfl}, k_{tfr}, k_{trr}, k_{trl} and c_{tfl}, c_{tfr}, c_{trr}, c_{trl}. The most critical region of the patient are head and stomach shown as point 2 and point 1 in figure 2.1(b). These two points will be analyse respectively which define the position of m_b (x_b and y_b).

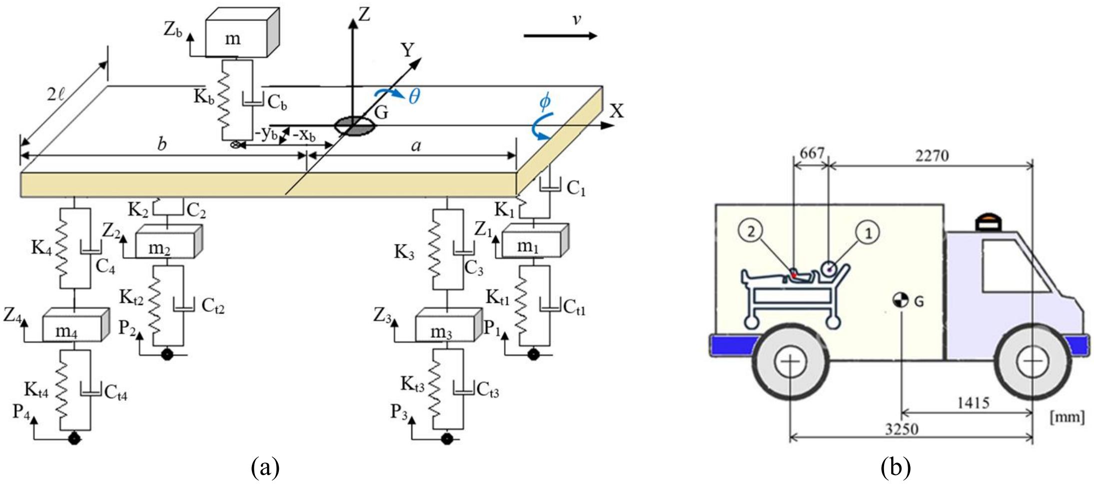

Figure 2.1 (a)8 DOF ambulance model (b)Locations of point 1 and 2

2.2 Sinusoidal Road Profile

The sinusoidal shape of road profile consists of three successive bumps of height equal to 0.1m with the total length of 19.5m shown in Figure 2.2. The velocity of the ambulance is 30 km/h.

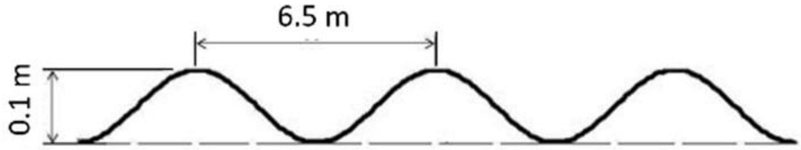

Figure 2.2 Sinusoidal road profile

2.3 Dynamic Equations of Each Degrees of Freedom

The equations of motion for this system can be derived according to Newton Law.

The vertical acceleration of m_b is caused by relative vertical motion between m_b and m_s, roll motion and pitch motion of sprung mass:

$$m_b\ddot{z}_b = -(z_b - z_s)k_b - (\dot{z}_b - \dot{z}_s)c_b - k_b\phi \cdot y_b + k_b\theta \cdot x_b - c_b\dot{\phi} \cdot y_b + c_b\dot{\theta} \cdot x_b$$

The vertical acceleration of m_s is caused by relative vertical motion between m_b and m_s, vertical motion of four unsprung masses. In addition, it can be also affected by roll motion and pitch motion of sprung mass:

$$\begin{aligned} m_s\ddot{z}_s = &-(z_s - z_{fl})k_{fl} - (\dot{z}_s - \dot{z}_{fl})c_{fl} - (z_s - z_{fr})k_{fr} - (\dot{z}_s - \dot{z}_{fr})c_{fr} - (z_s - z_{rl})k_{rl} - (\dot{z}_s - \dot{z}_{rl})c_{rl} \\ &- (z_s - z_{rr})k_{rr} - (\dot{z}_s - \dot{z}_{rr})c_{rr} + (bk_{fl} + bk_{fr} - ak_{rl} - ak_{rr})\theta - k_b\theta \cdot y_b + (bc_{fl} + bc_{fr} - ac_{rl} - ac_{rr})\dot{\theta} \\ &- c_b\dot{\theta} \cdot y_b + (lk_{fl} + lk_{rl} - lk_{rr} - lk_{fr})\phi + k_b x_b \phi + (lc_{fl} + lc_{rl} - lc_{rr} - lc_{fr})\dot{\phi} + c_b x_b \dot{\phi} \end{aligned}$$

The acceleration of pitch motion of sprung mass is caused by relative vertical motion between sprung mass and unsprung masses, relative motion between sprung mass and stretcher, and the pitch motion itself. In addition, because of the presence of the asymmetry stretcher, roll motion of sprung mass can also affect the acceleration of pitch motion:

$$J_y\ddot{\theta} = ak_{fl}(z_s - z_{fl}) + ac_{fl}(\dot{z}_s - \dot{z}_{fl}) + ak_{fr}(z_s - z_{fr}) + ac_{fr}(\dot{z}_s - \dot{z}_{fr}) - bk_{rl}(z_s - z_{rl}) - bc_{rl}(\dot{z}_s - \dot{z}_{rl})$$
$$-bk_{rr}(z_s - z_{rr}) - bc_{rr}(\dot{z}_s - \dot{z}_{rr}) + x_b k_b(z_b - z_s) + x_b c_b(\dot{z}_b - \dot{z}_s) - k_{fr}\theta\cdot a^2 - k_{fl}\theta\cdot a^2 - k_{rr}\theta\cdot b^2$$
$$-k_{rl}\theta\cdot b^2 - k_b\theta\cdot {x_b}^2 + k_b\phi\cdot y_b x_b - c_{fr}\dot{\theta}\cdot a^2 - c_{fl}\dot{\theta}\cdot a^2 - c_{rr}\dot{\theta}\cdot b^2 - c_{rl}\dot{\theta}\cdot b^2 - c_b\dot{\theta}\cdot {x_b}^2 + c_b\dot{\phi}\cdot y_b x_b$$

In the same way we can calculate the acceleration of roll motion of the sprung mass:

$$J_x\ddot{\phi} = -lk_{fl}(z_s - z_{fl}) - lc_{fl}(\dot{z}_s - \dot{z}_{fl}) - lk_{rl}(z_s - z_{rl}) - lc_{rl}(\dot{z}_s - \dot{z}_{rl}) + lk_{fr}(z_s - z_{fr}) + lc_{fr}(\dot{z}_s - \dot{z}_{fr})$$
$$+lk_{rr}(z_s - z_{rr}) + lc_{rr}(\dot{z}_s - \dot{z}_{rr}) - y_b k_b(z_b - z_s) + y_b c_b(\dot{z}_b - \dot{z}_s) - k_{fr}\phi\cdot l^2 - k_{fl}\phi\cdot l^2 - k_{rr}\phi\cdot l^2$$
$$-k_{rl}\phi\cdot l^2 - k_b\phi\cdot {y_b}^2 + k_b\theta\cdot x_b y_b - c_{fr}\dot{\phi}\cdot l^2 - c_{fl}\dot{\phi}\cdot l^2 - c_{rr}\dot{\phi}\cdot l^2 - c_{rl}\dot{\phi}\cdot l^2 - c_b\dot{\phi}\cdot {y_b}^2 + c_b\dot{\theta}\cdot x_b y_b$$

The vertical acceleration of unsprung mass is caused by relative motion between sprung and unsprung mass, roll and pitch motion of sprung mass and the road excitation:

$$m_{fl}\ddot{z}_{fl} = k_{fl}z_s + c_{fl}\dot{z}_s + (-k_{fl} - k_{tfl})z_{fl} + (-c_{fl} - c_{tfl})\dot{z}_{fl} + k_{tfl}h_{fl} + c_{tfl}\dot{h}_{fl} + k_{tfl}\phi\cdot l - k_{tfl}\theta\cdot a$$
$$+c_{tfl}\dot{\phi}\cdot l - c_{tfl}\dot{\theta}\cdot a$$
$$m_{fr}\ddot{z}_{fr} = k_{fr}z_s + c_{fr}\dot{z}_s + (-k_{fr} - k_{tfr})z_{fr} + (-c_{fr} - c_{tfr})\dot{z}_{fr} + k_{tfr}h_{fr} + c_{tfr}\dot{h}_{fr} + k_{tfr}\phi\cdot l - k_{tfr}\theta\cdot a$$
$$+c_{tfr}\dot{\phi}\cdot l - c_{tfr}\dot{\theta}\cdot a$$
$$m_{rr}\ddot{z}_{fl} = k_{rr}z_s + c_{rr}\dot{z}_s + (-k_{rr} - k_{trr})z_{rr} + (-c_{rr} - c_{trr})\dot{z}_{rr} + k_{trr}h_{rr} + c_{trr}\dot{h}_{rr} + k_{trr}\phi\cdot l - k_{trr}\theta\cdot a$$
$$+c_{trr}\dot{\phi}\cdot l - c_{trr}\dot{\theta}\cdot a$$
$$m_{rl}\ddot{z}_{rl} = k_{rl}z_s + c_{rl}\dot{z}_s + (-k_{rl} - k_{trl})z_{rl} + (-c_{rl} - c_{trl})\dot{z}_{rl} + k_{trl}h_{rl} + c_{trl}\dot{h}_{rl} + k_{trl}\phi\cdot l - k_{trl}\theta\cdot a$$
$$+c_{trl}\dot{\phi}\cdot l - c_{trl}\dot{\theta}\cdot a$$

Rearranging all of these eight equations, the second order differential equations of this 8 DOF model can be given as (Where $X = [z_b \quad z_s \quad \theta \quad \phi \quad z_{fr} \quad z_{fl} \quad z_{rl} \quad z_{rr}]^T$):

$$M\cdot\ddot{X} + C\cdot\dot{X} + K\cdot X = F$$

In the equation, the details of each matrices are (the stiffness between sprung and unsprung mass: $k_{fl} = k_{fr} = k_f$, $k_{rl} = k_{rr} = k_r$; the damping value between sprung and unsprung mass: $c_{fl} = c_{fr} = c_f$, $c_{rl} = c_{rr} = c_r$; the stiffness of the tire: $k_{ufl} = k_{ufr} = k_{url} = k_{urr} = k_u$; the damping value of the tire: $c_{ufl} = c_{ufr} = c_{url} = c_{urr} = c_u$):

$$M=\begin{bmatrix} m_b & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_s & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & J_{xx} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & J_{yy} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_{fr} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_{fl} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & m_{rl} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{rr} \end{bmatrix}$$

$$K=\begin{bmatrix} k_b & -k_b & -k_b x_b & k_b y_b & 0 & 0 & 0 & 0 \\ -k_b & k_b+2k_f+2k_r & k_b x_b-2k_f a+2k_r b & -k_b y_b & -k_f & -k_f & -k_r & -k_r \\ -k_b x_b & k_b x_b-2k_f a+2k_r b & k_b x_b^2-2k_f a^2+2k_r b^2 & -k_b x_b y_b & k_f a & k_f a & -k_r b & -k_r b \\ k_b y_b & -k_b y_b & -k_b x_b y_b & k_b y_b^2+2k_f l^2+2k_r l^2 & -k_f l & k_f l & k_r l & -k_r l \\ 0 & -k_f & k_f a & -k_f l & k_f+k_u & 0 & 0 & 0 \\ 0 & -k_f & k_f a & k_f l & 0 & k_f+k_u & 0 & 0 \\ 0 & -k_r & -k_r b & k_r l & 0 & 0 & k_r+k_u & 0 \\ 0 & -k_r & -k_r b & -k_r l & 0 & 0 & 0 & k_r+k_u \end{bmatrix}$$

$$C=\begin{bmatrix} c_b & -c_b & -c_b x_b & c_b y_b & 0 & 0 & 0 & 0 \\ -c_b & c_b+2c_f+2c_r & c_b x_b-2c_f a+2c_r b & -c_b y_b & -c_f & -c_f & -c_r & -c_r \\ -c_b x_b & c_b x_b-2c_f a+2c_r b & c_b x_b^2-2c_f a^2+2c_r b^2 & -c_b x_b y_b & c_f a & c_f a & -c_r b & -c_r b \\ c_b y_b & -c_b y_b & -c_b x_b y_b & c_b y_b^2+2c_f l^2+2c_r l^2 & -c_f l & c_f l & c_r l & -c_r l \\ 0 & -c_f & c_f a & -c_f l & c_f+c_u & 0 & 0 & 0 \\ 0 & -c_f & c_f a & c_f l & 0 & c_f+c_u & 0 & 0 \\ 0 & -c_r & -c_r b & c_r l & 0 & 0 & c_r+c_u & 0 \\ 0 & -c_r & -c_r b & -c_r l & 0 & 0 & 0 & c_r+c_u \end{bmatrix}$$

$$F=\begin{bmatrix} 0 & 0 & 0 & 0 & c_f\dot{h}_{fr}+k_u h_{fr} & c_f\dot{h}_{fl}+k_u h_{fl} & c_r\dot{h}_{rl}+k_u h_{rl} & c_r\dot{h}_{rr}+k_u h_{rr} \end{bmatrix}^T$$

2.4 Ambulance Parameters

The ambulance parameters applied to the simulations are compatible with Mercedes-Benz's Sprinter 415 CDI 7.5 m3 vehicle adapted to the ICU model, while Figure 2.1(b) illustrates the corresponding ambulance parameters. The value of all of the other parameters are summarized in the Table 2.1.

Table 2.1 Ambulance parameters

Parameters	Values	Parameters	Values
Sprung mass[kg]	2600	Front suspension stiffness [N/m]	198000
Roll inertia [kgm^2]	658	Rear suspension stiffness [N/m]	130000
Pitch inertia [kgm^2]	4174	Front suspension damping [Ns/m]	12500
Wheel centers [mm] (front & rear)	1550	Rear suspension damping [Ns/m]	12500
Front unsprung mass [kg] (both sides)	150	Tire stiffness [N/m] (front & rear)	250000
Rear unsprung mass [kg] (both sides)	100	Tire damping [Ns/m] (front & rear)	null

2.5 Parameter Optimization and Analysis

In this study, Matlab/Simulink software is used to simulate the dynamic behavior of this 8 DOF ambulance model. Four sinusoidal signals acting on each of the four wheels are used as inputs to this full car model and different damping and stiffness coefficients (k_b and c_b) of stretcher suspension is applied and tested in the simulation to find the optimum k_b and c_b that could minimize the vertical acceleration of the stretcher.

Since ride comfort is improved when the magnitude of vertical acceleration is reduced. So, the displacement and the acceleration of the stretcher (z_b and $\ddot{z}_b$) are the good indicator of comfort performance of the patients. The points chosen to calculate the acceleration, denoted as point “1” and “2” in Figure 2.1(b), will be tested respectively.

As constraints to the optimization problem, the maximum allowable jerk experienced by the patient is 18 m/s^3 (max $\dddot{z}_b$ =18 m/s^3). In addition, if the relative displacement of the spring of the stretcher suspension is too large, the connection between stretcher and sprung mass will become rigid. Assuming the flexible length of the spring is 80 mm, the displacement of the spring during riding should less than 80 mm($|z_b - z + \theta \cdot x_b| \le 0.08$, neglect the displacement caused by rolling of the sprung mass). In conclusion, the system should be limited according to the following inequality:

$$\begin{cases} 2000 \le k_b \le 30000 \\ 5 \le c_b \le 500 \\ |z_b - z + \theta \cdot x_b| \le 0.08 \\ \dddot{z}_b \le 18 m/s^3 \end{cases}$$

3. Simulation and Results

3.1 Simulation of the sinusoidal road profile

In order to input the sinusoidal signals in Matlab/Simulink, we calculate the signal in time domain. Based on the ambulance speed of 30 km/h, the frequency of the signal: $w = 2\pi/(6.5/(30/3.6)) = 8.0554$; the amplitude is 0.05; the bias is 0.05. The phase of the front wheels is $\varphi_f = -w \cdot (6.5/4/(30/3.6)) = -1.5708$. The phase of the rear wheel is $\varphi_r = w\cdot(-6.5/4/(30/3.6)+3.25/(30/3.6)) = 1.5708$. so the expression of the front and rear inputs in time domain are:

$$\begin{cases} h_f = 0.05\sin(8.0554t - 1.5708) + 0.05 \\ h_r = 0.05\sin(8.0554t + 1.5708) + 0.05 \end{cases}$$

The plots of the signals in time domain are shown in Figure 3.1:

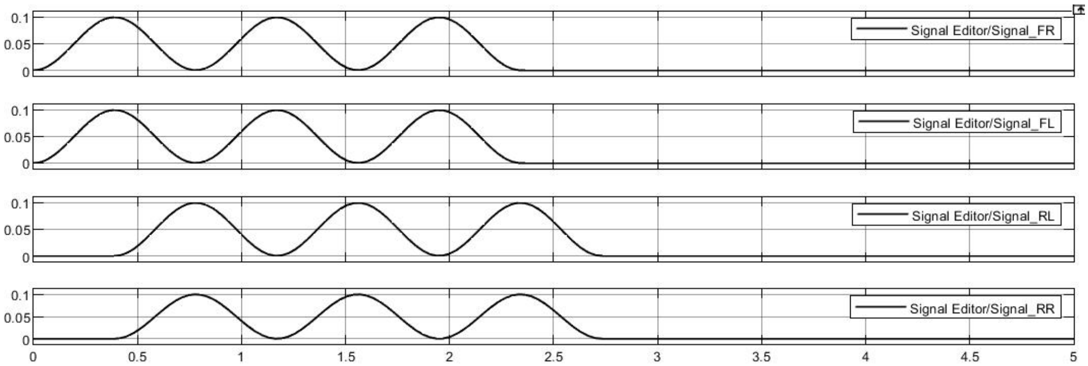

Figure 3.1 Input signals of four wheels

3.2 8-DOF Simulink model

In Matlab/Simulink, Based on the sets of second order differential equations in 2.3, the Simulink block diagram model can be built shown in Figure 3.2. The paths of the inequality described in 2.5 also included in this Simulink model.

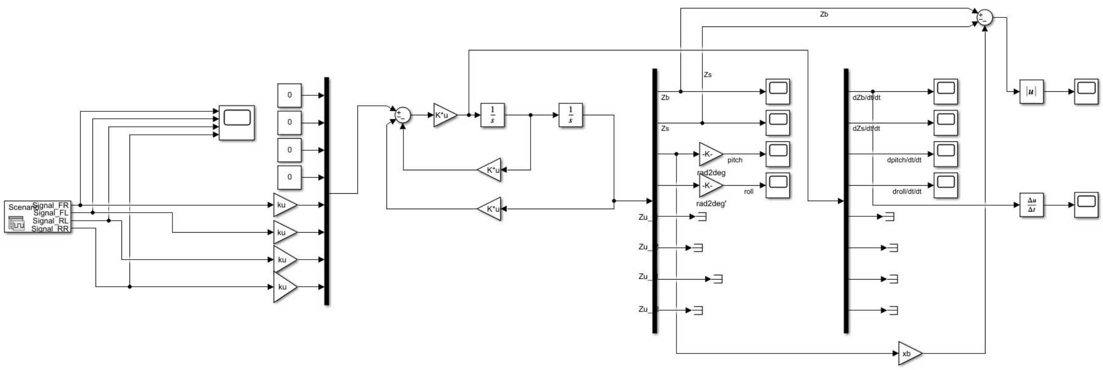

Figure 3.2 8-DOF Simulink model

3.3 Choosing the Optimum k_b and c_b (point "2")

Firstly, the point "2" is analyzed. Then the same procedures are done in point "1".

(1) Fix c_b, find the optimum k_b
The value of c_b is fixed at 300 Ns/m. Then varying k_b from 2000 to 10000. The responses of displacement and acceleration of stretcher is shown in Figure 3.3. Table 3.1 shows the comfort performance of stretcher numerically varying k_b. From the plots of the responses, we can find that the lower the k_b (softer the stretcher suspension), better the comfort responses, which matches the real case. But if the k_b is

too small, the relative displacement of the spring will be larger than 80 mm, which against the requirement of the inequality in 2.5.

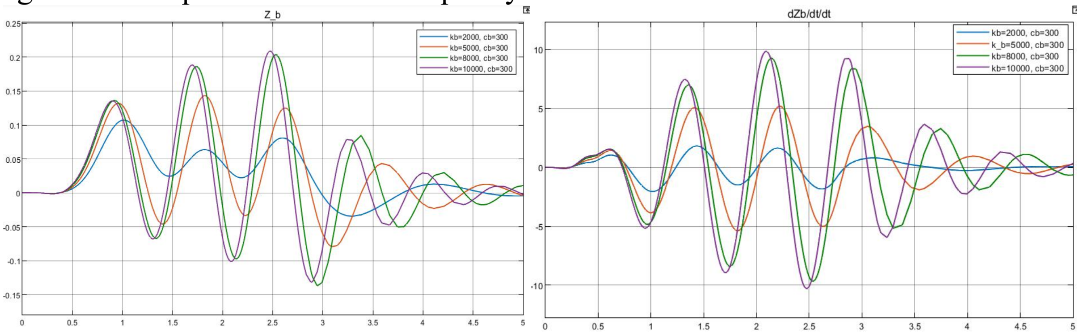

Figure 3.3 Displacement and acceleration of stretcher varying k_b of point "2"

Table 3.1 Displacement and acceleration of stretcher varying k_b of point "2"

K_b (N/m)	Vertical acceleration (m/s^2)		Vertical displacement (m)	
	Max	Min	Max	Min
2000	2.645	-2.365	0.116	-0.034
5000	5.153	-5.233	0.141	-0.075
8000	9.126	-9.837	0.200	-0.134
10000	9.935	-10.062	0.207	-0.126

(2) Fix the optimum k_b=2000 N/s, varying c_b.
The value of k_b is fixed at 2000 N/m. Then varying c_b from 250 to 500. The responds of displacement and acceleration of stretcher is shown in Figure 3.4. Table 3.2 shows the comfort performance of stretcher numerically varying c_b. From the plots of the responses, we can find that the best comfort performance is obtained when c_b=350 Ns/m.

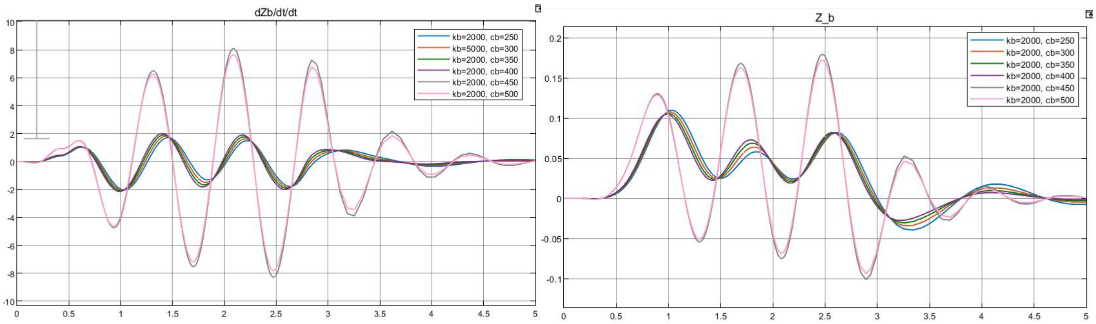

Figure 3.3 Displacement and acceleration of stretcher varying k_b of point "2"

Table 3.2 Displacement and acceleration of stretcher varying c_b of point "2"

C_b (N/m)	Vertical displacement (m)		Vertical acceleration (m/s^2)	
	Max	Min	Max	Min
250	0.117	-0.041	1.935	-1.973
300	0.114	-0.038	1.903	-1.917
350	0.109	-0.214	1.897	-1.913
400	0.109	-0.233	1.993	-2.072
450	0.174	-0.103	8.051	-8.227
500	0.168	-0.092	7.634	-7.956

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 are shown in Figure 3.5 to 3.12.

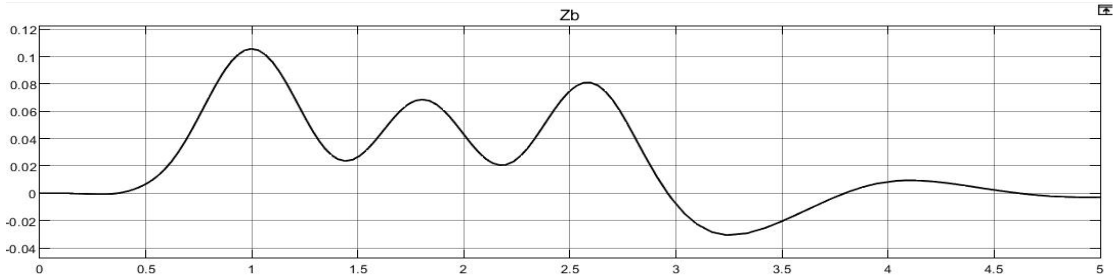

Figure 3.5 vertical displacement of stretcher of point “2”

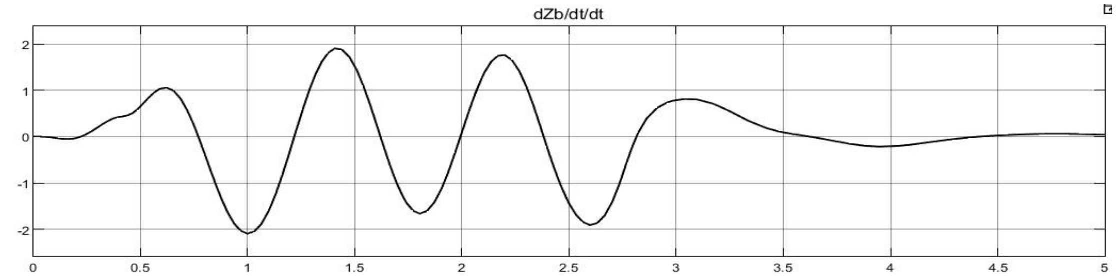

Figure 3.6 vertical acceleration of stretcher of point “2”

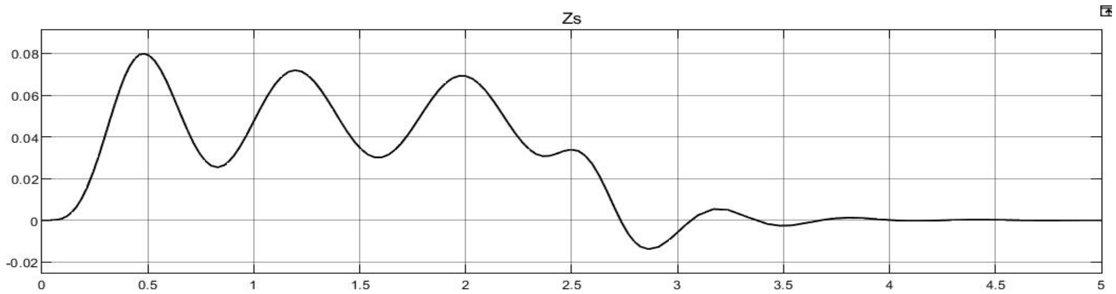

Figure 3.7 vertical displacement of sprung mass of point “2”

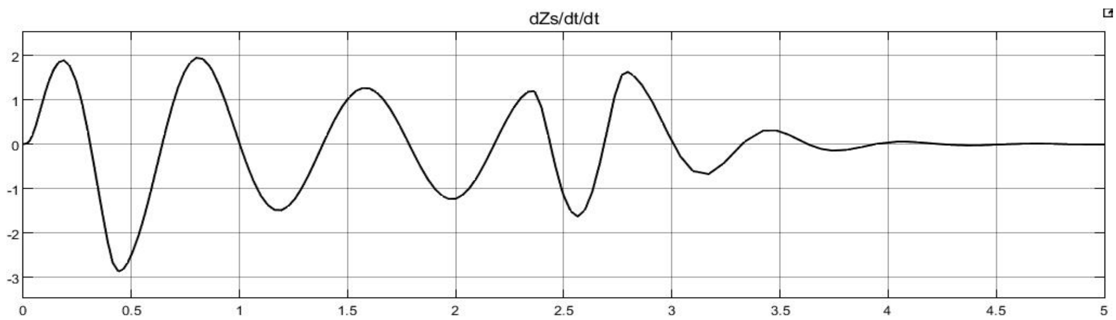

Figure 3.8 vertical acceleration of sprung mass of point “2”

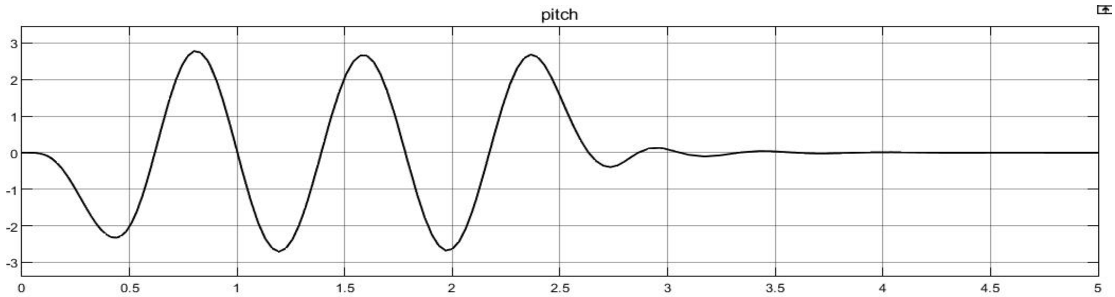

Figure 3.9 pitch of sprung mass of point “2”

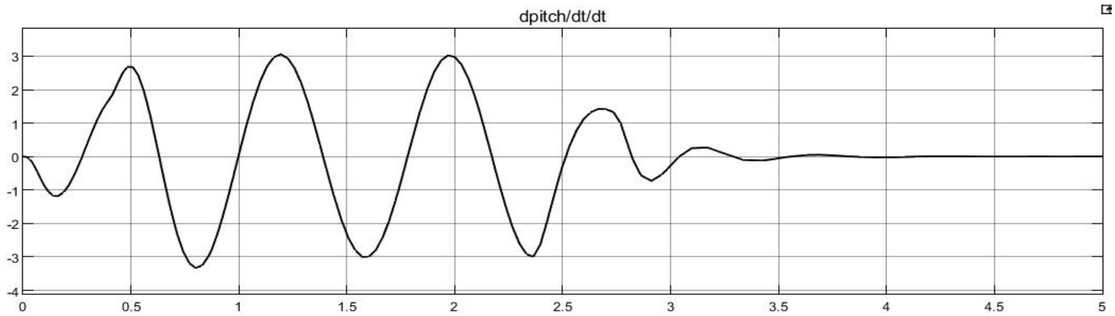

Figure 3.10 pitch acceleration of sprung mass of point “2”

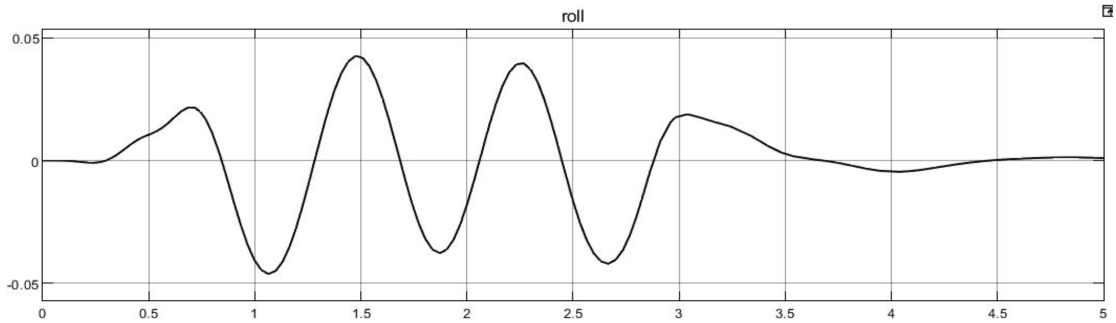

Figure 3.11 roll of sprung mass of point “2”

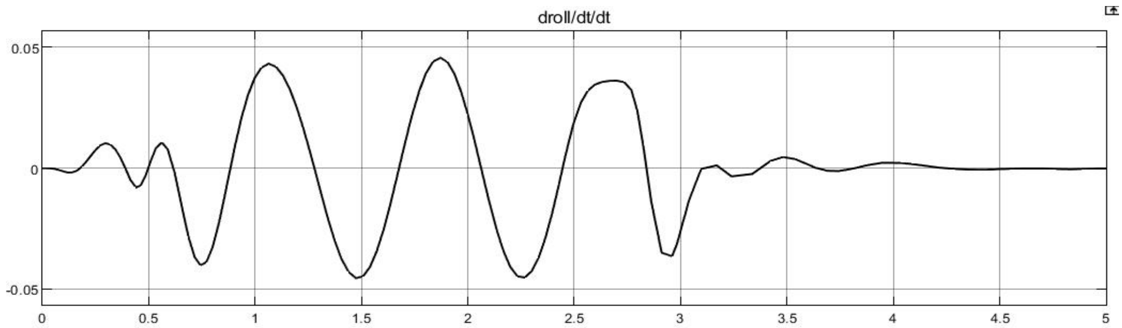

Figure 3.12 roll acceleration of sprung mass of point “2”

In addition, at this optimum value of k_b and c_b, the plots of inequality $\ddot{z}_b$ and $\left|z_b - z + \theta \cdot x_b\right|$ are shown in Figure 3.13 and Figure 3.14. From the plots we can say that the requirements of inequality are satisfied.

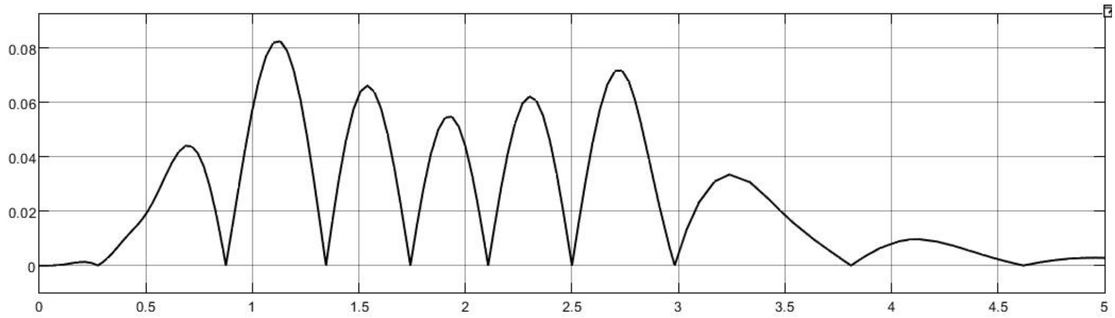

Figure 3.13 Plot of $\left| z_b - z + \theta \cdot x_b \right|$

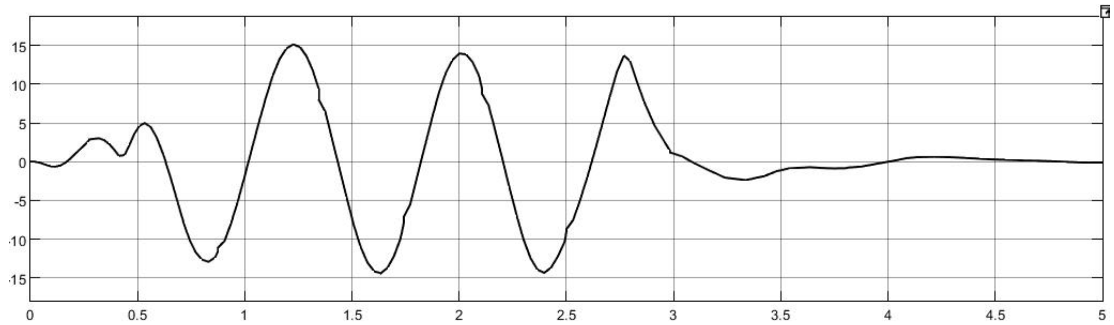

Figure 3.14 Plot of $\dddot{z}_b$

3.3 Choosing the Optimum k_b and c_b (point "1")

In the same way of point "2", we can simulate the vertical displacement and acceleration of point "1" varying different value of k_b and c_b. The responses of different value of kb and cb are shown in Figure 3.15 and 3.16. Table 3.3 and 3.4 shows the comfort performance of stretcher numerically varying k_b amd c_b. From the plots, we can say that the results are exactly like what we find in point "2". The point "1" and "2" share the same optimum k_b and c_b.

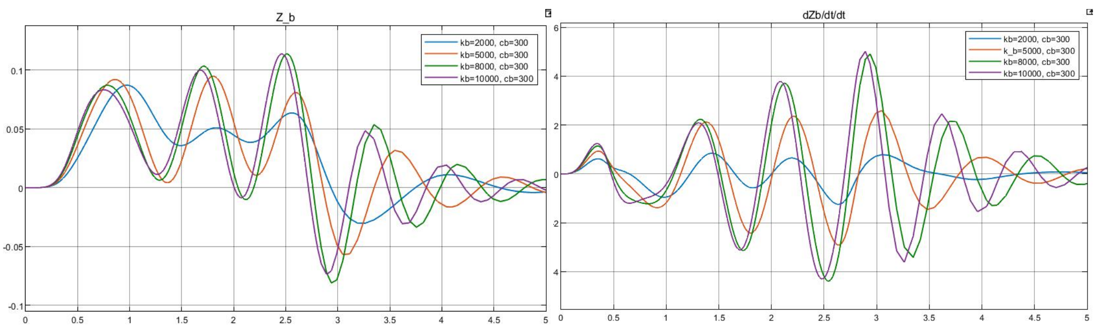

Figure 3.15 Displacement and acceleration of stretcher varying k_b of point "1"

Table 3.3 Displacement and acceleration of stretcher varying k_b of point "1"

K_b (N/m)	Vertical acceleration (m/s^2)		Vertical displacement (m)	
	Max	Min	Max	Min
2000	1.028	-1.674	0.076	-0.038
5000	2.574	-2.976	0.081	-0.068
8000	4.467	-4.453	0.127	-0.073
10000	4.253	-4.432	0.125	-0.072

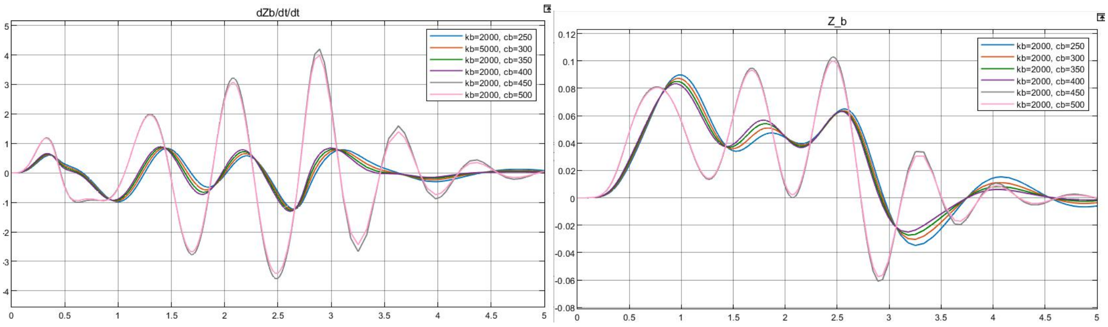

Figure 3.16 Displacement and acceleration of stretcher varying c_b of point “1”

Table 3.4 Displacement and acceleration of stretcher varying c_b of point “1”

C_b (N/m)	Vertical acceleration (m/s^2)		Vertical displacement (m)	
	Max	Min	Max	Min
250	0.717	-1.441	0.090	-0.029
300	0.613	-1.338	0.086	-0.034
350	0.502	-1.214	0.084	-0.025
400	0.563	-1.333	0.090	-0.023
450	4.074	-3.532	0.092	-0.057
500	4.148	-3.094	0.107	-0.063

Based on this optimum value of k_b and c_b, the responses of vertical motion of the stretcher are shown in Figure 3.17 to 3.12.

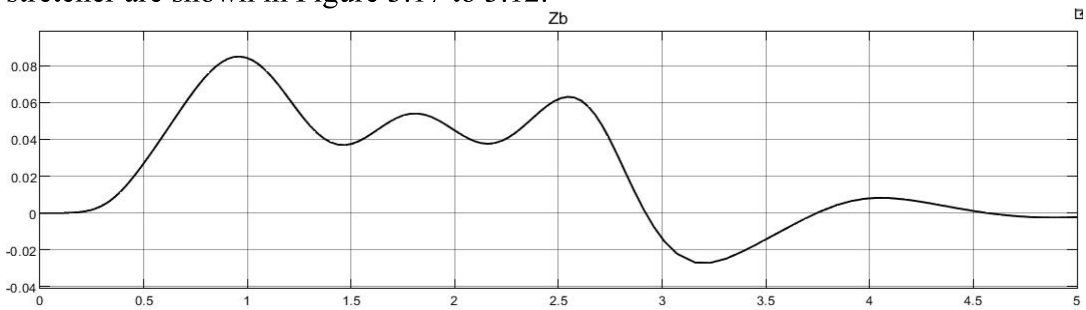

Figure 3.17 vertical displacement of stretcher of point “1”

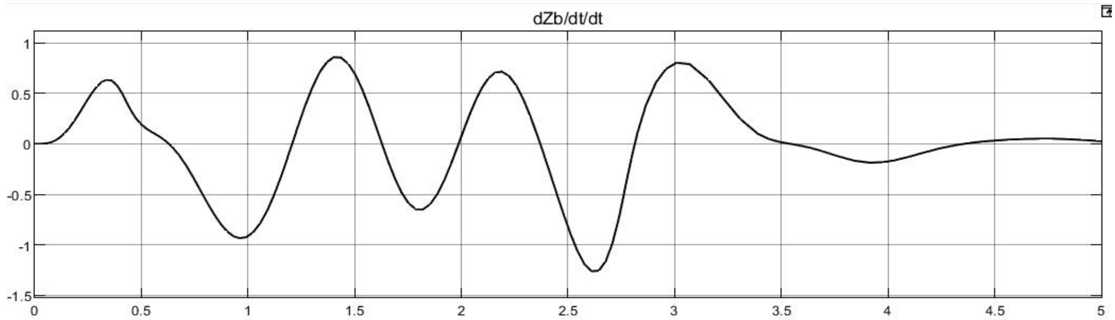

Figure 3.18 vertical acceleration of stretcher of point “1”

From the Figure 3.19 and 3.20, we can also say that this optimum value of k_b and c_b satisfy the requirement of inequality mentioned in 3.25.

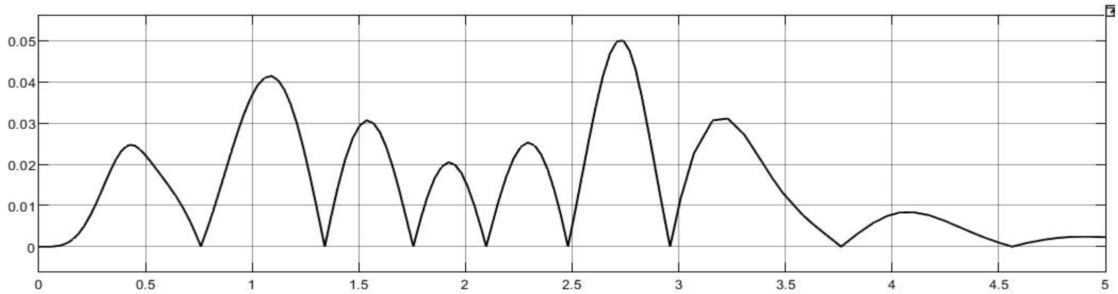

Figure 3.19 Plot of $\left|z_b - z + \theta \cdot x_b\right|$ of point "1"

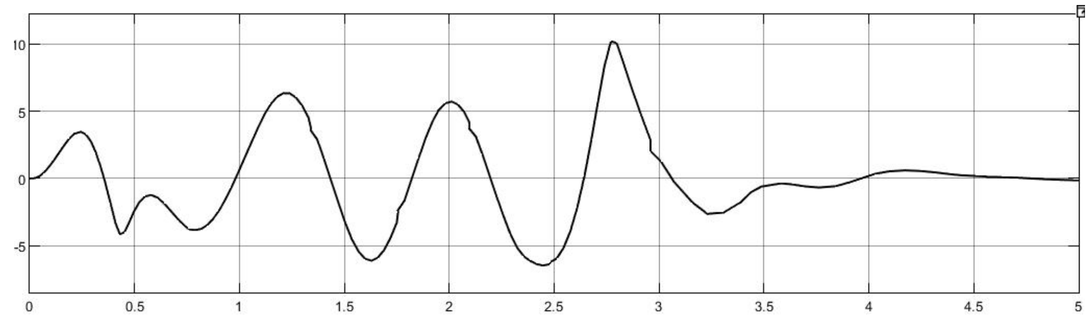

Figure 3.20 Plot of $\ddot{z}_b$ of point "1"

4. Simulation of Grade C Road Profile

Uneven road is normally used to evaluate the vehicle roll stability in terms of comfort performance. According to the ISO/TC108/SC2N67 standard, random roads can be simulated in terms of the roughness coefficient $G_q(n_0)$. In this case, random road profile is simulated in equation below.

$$\dot{h}_0(t) = -2\pi f_0 \cdot h_0(t) + 2\pi n_0 \cdot \sqrt{G_q(n_0)u(t)}w(t)$$

In the equation, n_0 is a spatial reference frequency of 0.1, f_0 is a minimal boundary frequency of 0.0628 Hz, u(t) is the speed in m/s, and w(t) is a white noise signal. Based on this equation the block diagram of road profile on four wheels in Simulink is shown in Figure 4.1.

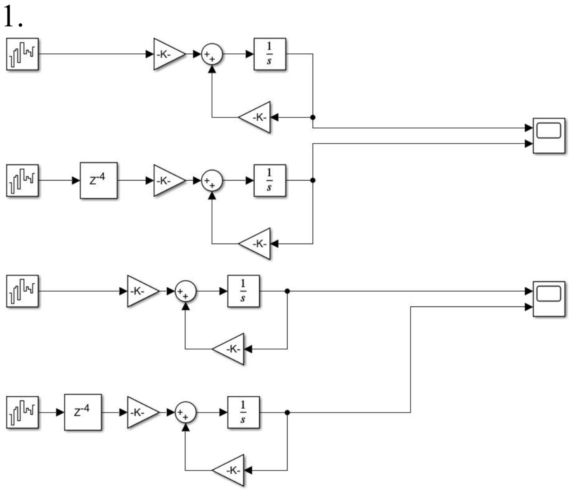

Figure 4.1 Block diagram of random road profile

The road class is ISO grade C road with a roughness coefficient of $256*10^{-6}$. In Figure 4.2, the road excitation for each tire considering the delay between the front and rear axles, which is a significant factor for the vehicle roll motion.

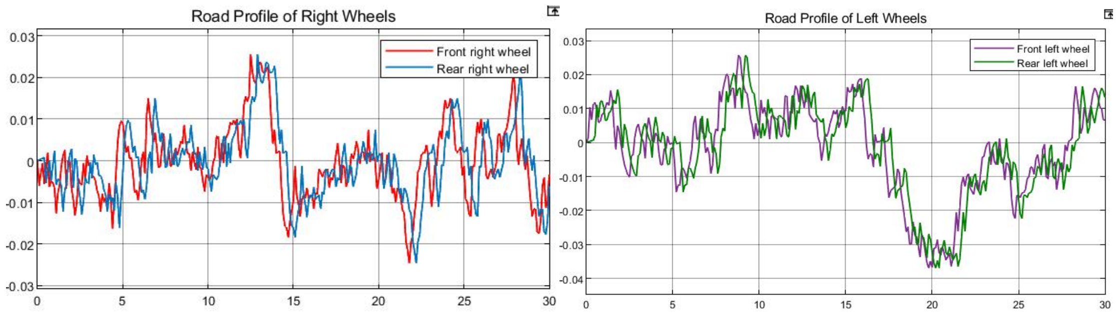

Figure 4.2 Grade C road profile of four wheels

The responses of vertical displacement and acceleration of stretcher varying different values of k_b and c_b are shown in Figure 4.3. From the plots we can verify that the optimum values of k_b and c_b (k_b=2000 N/m, c_b=350 Ns/m) also valid in random road profile.

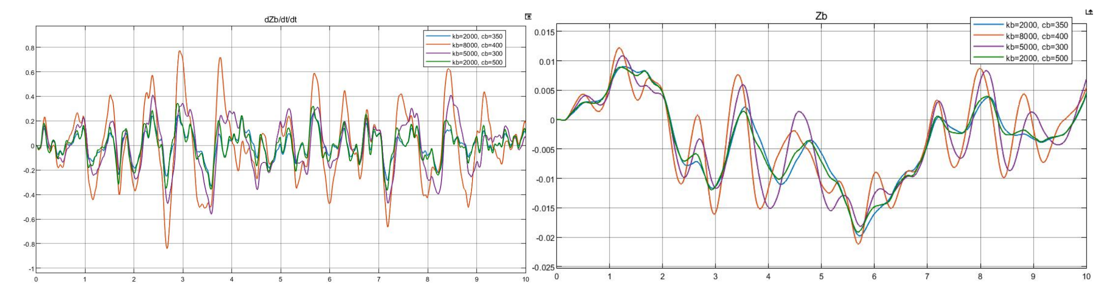

Figure 4.3 vertical displacement and acceleration of stretcher on random road profile