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Comparative Study of Bending Loads at Wheel Centres of Heavy Commercial Vehicles

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***Abstract:** In commercial vehicles, leaf springs play a major role in designing the suspension system. Leaf springs are the most popular designs having multiple leaves in contact with each other and show hysteresis behaviour when loaded and unloaded. The leaf spring acts as a linkage for holding the axle in position and thus separate linkages are not necessary. It makes the construction of the suspension simple and strong. Because the positioning of the axle is carried out by the leaf springs, it is disadvantageous to use soft springs i.e. springs with low spring constant. Leaf springs are excellent in suspending large loads, since they are designed using 'bending beam' equations. The stiffness of the leaf spring assembly can be altered as desired, by changing the number of leaves. The objective of this paper is to compare the bending loads coming at the rear wheel centres of the vehicle when it runs in torture track and over a single bump. Bending loads were compared for the same rear suspension but two different leaf springs (7 leaf suspension system and 11 leaf suspension system).*

***Keywords:** Suspension, Leaf spring, Bending loads, Torture Track, Single bump, Wheel centre, Calibration, Strain gauge, Data acquisition, Sample rate, Gross Vehicle Weight (GVW).*

I. INTRODUCTION

A. Suspension System

The automobile chassis is mounted on the axles, not directly but with the help of some form of springs. This is done to isolate the vehicle body from the road shocks which may be in the form of bounce, pitch, roll or sway. These tendencies give rise to an uncomfortable ride and also cause additional stress in the automobile frame and body. The main parts which perform the function of isolating the automobile from the road shocks are collectively called the suspension system. Leaf spring is one such device which is used in suspension system to safeguard the vehicle and the occupants. These systems are also responsible for ride comfort. The suspension system consists of a spring and a damper. The energy of the road shock causes the spring to oscillate. These oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber. The objective of the suspension system is

To prevent the road shocks from being transmitted to the vehicle components.

To safeguard the occupants from road shocks.

To preserve the stability of the vehicle in rolling while in motion.

B. Leaf Springs

Semi elliptical springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also these are widely used in rear suspension. The spring consists of number of leaves called blades. The blades are varying in length. The blades are usually given an initial curvature or cambered so that they will tend to straighten under the load. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining leaves are called graduated leaves. All the leaves are bound together by means of steel straps. The spring is mounted on the axle of the vehicle. The entire load of the vehicle rests on the leaf spring. The front end of the spring is connected to the frame with a simple pin joint while the rear end is connected with a shackle. When the vehicle comes across a projection on the road surface, the wheel moves up and leads in the deflection of the spring.

When the rear wheel comes across a bump or pit on the road, it is subjected to vertical (bending) forces, tensile or compressive forces depending on the nature of the road irregularity. These are absorbed by the elastic compression, shear bending or twisting of the spring. When the front wheel strikes a bump, it starts vibrating. These vibrations are die down exponentially due to damping present in the system. The rear wheel, however, reaches the same bump after certain time depending on the speed of the vehicle. When the rear wheel reaches the bump, it experiences similar vibrations as experienced by the front wheel some time ago.

To reduce the pitching tendency of the vehicle, the frequency of the front springing system be less than that of the rear springing system. From human comfort point also it is seen that it is desirable to have low vibration frequencies. Maximum amplitude which may be allowed for a certain level of discomfort decreases with the increase of vibration frequency.

C. Rolling

The centre of gravity of the vehicle is considerably above the ground. Due to this reason, while taking a turn, the centrifugal force acts outwards on the centre of gravity of the vehicle, while the road resistance acts inward at the wheels. This gives rise to a couple turning the vehicle about a longitudinal axis. This is called rolling. The way the vehicle is sprung determines the axis about which the vehicle will roll. The tendency to roll is checked by means of a stabilizer.

II. VEHICLE INSTRUMENTATION

The experiments were conducted on a heavy commercial twin rear axle vehicle in 30% over laden condition. The Gross Vehicle Wight (GVW) was around 32600Kg. Initially the two rear axles were strain gauged as shown below.

Fig. 1 Strain gauge pasted on axle top

Fig.1 represents Strain gauges pasted on the rear axle top face close to wheel center.

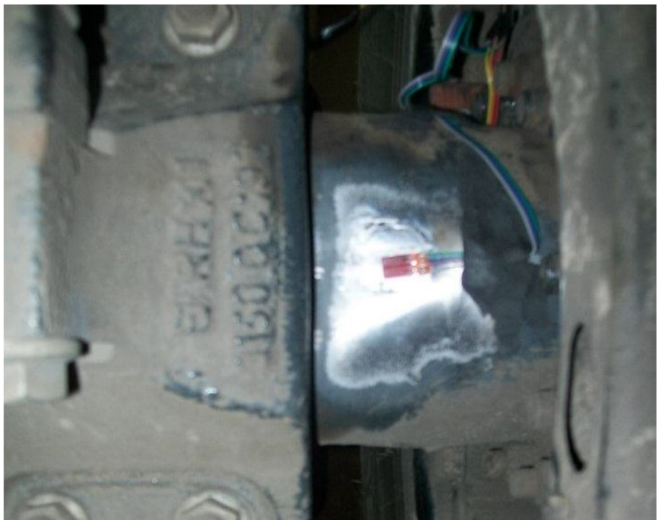

Fig. 2 Strain gauge pasted on axle bottom

Fig. 2 represents Strain gauges pasted on the rear axle bottom surface close to wheel center.

Strain gauges on the axle top and bottom together form bending full bridge. Fig. 1 and 2 show full bridge on the one side of the axle. The same was put on the other side of the axle.

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A. Full Bridge Strain Gauge

Strain gauges are configured in Wheatstone bridge circuits to detect small change in resistance.

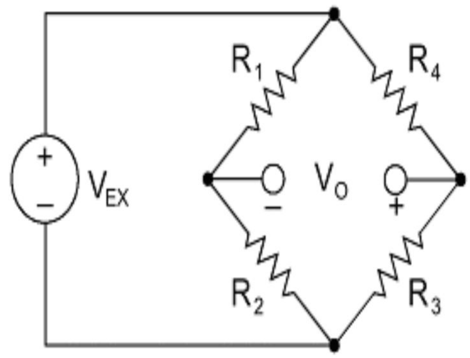

Fig. 3 Wheatstone bridge circuit

The Wheatstone bridge is the electrical equivalent of two parallel voltage divider circuits. R_1 and R_2 compose one voltage divider circuit, and R_4 and R_3 compose the second voltage divider circuit.
The output of a Wheatstone bridge, Vo, is measured between the middle nodes of the two voltage dividers.

$$Vo = [\ (R_3/R_4) - (R_2/R_1)\ ] * V_{EX} \text{ - - - - - - - - - - - - - } (1)$$

Where R_1, R_2, R_3 and R_4 are resistors
Vo = Output Voltage
V_{EX} = Excitation Voltage

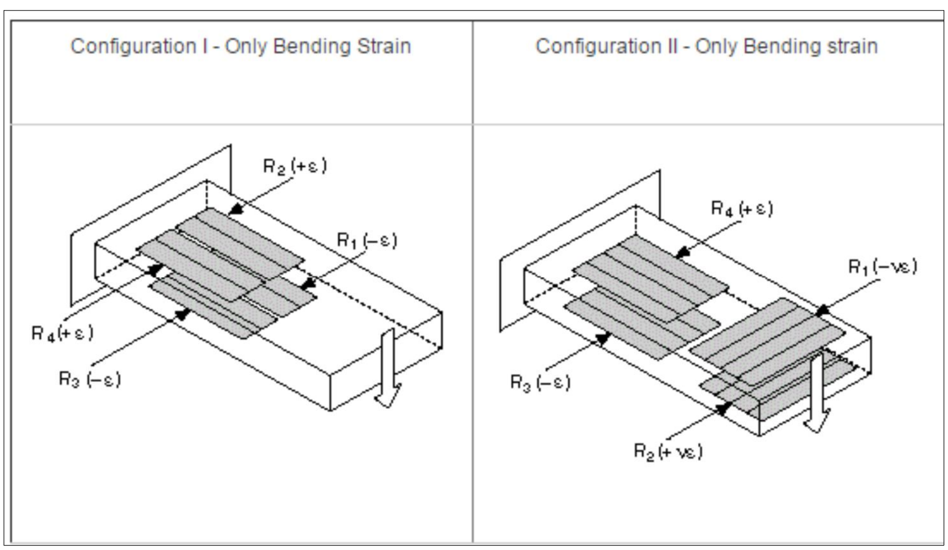

Figure-4 Bending full bridge configuration

A full-bridge strain gauge configuration has four active strain gauges. R_1 and R_3 are active strain gauges measuring compressive strain (-ε). R_2 and R_4 are active strain gauges measuring tensile strain (+ε).Once the strain gauging part was completed, the vehicle was placed on the weighing pads and the strain on both the axles was set to zero in unladen condition of the vehicle. It has been taken care of by the constant term appearing in the calibration equation. After that, the strain gauges were calibrated by placing known load blocks and recording the microstrain versus axle reaction data. Data acquisition system with a sample rate of 512Hz was used to collect the strain and axle reaction data.

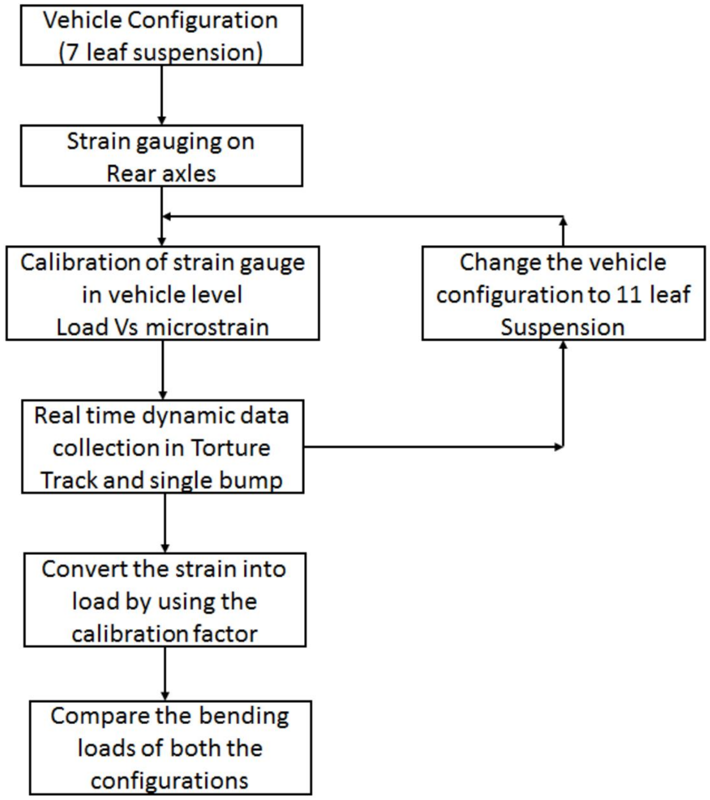

Figure-5 Layout to Compare the bending loads coming at wheel centers during the dynamic condition

Fig.5 shows the process to compute and compare the bending loads coming at wheel centers.

B. Load Vs Microstrain Calibration

Vehicle Front Axle Weight (FAW) = 5110kg
Vehicle Rear Axle weight (RAW) = 27,550kg
Gross Vehicle Weight (GVW) = 32,660kg

Load Vs microstrain calibration plots are as shown in Fig.6 to Fig. 9

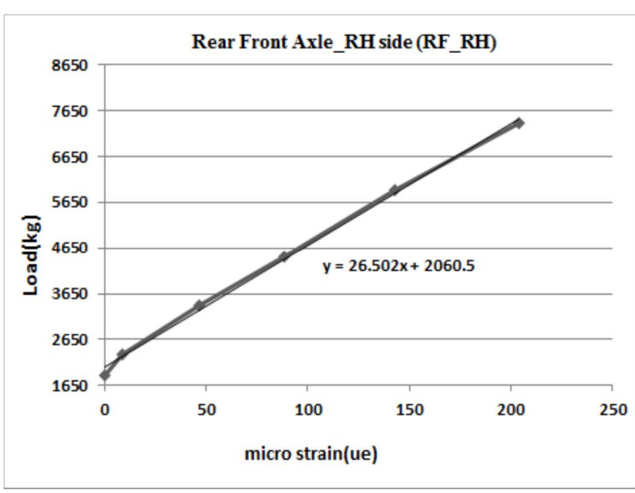

Fig. 6 Calibration plot of Rear Front Axle _LH side (RF_LH)

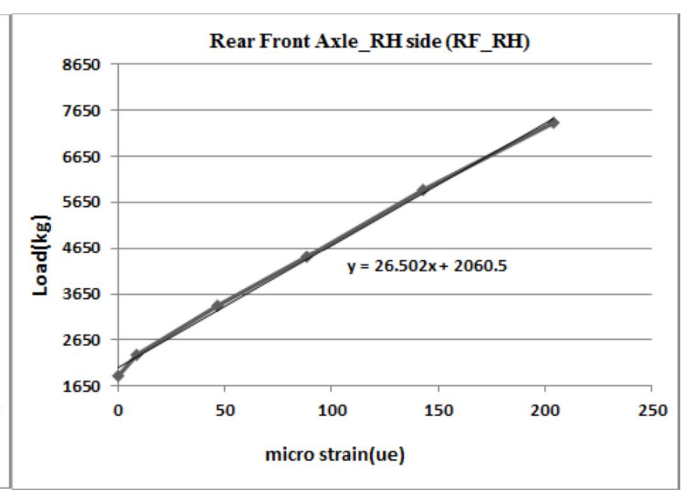

Fig.7 Calibration plot of Rear Front Axle _RH side (RF_RH)

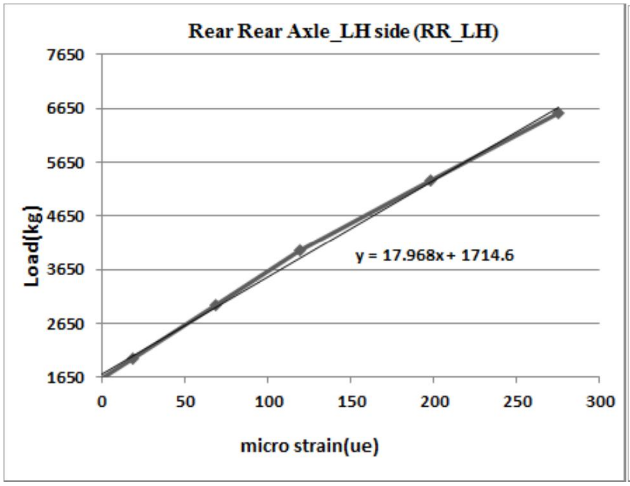

Fig. 8 Calibration plot of Rear Front Axle _LH side (RR_LH)

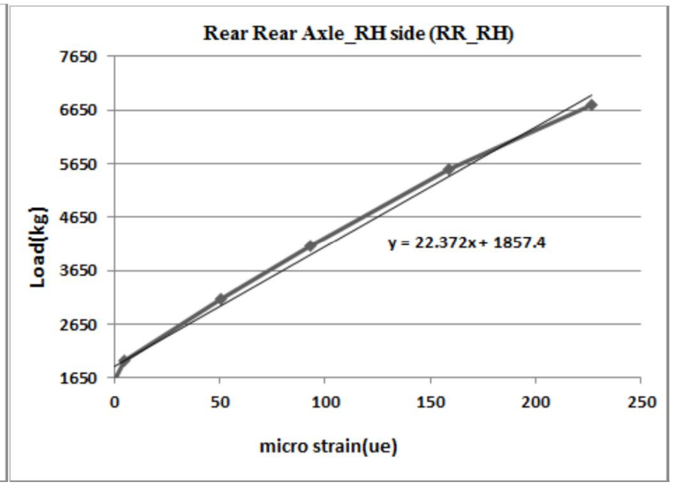

Fig. 9 Calibration plot of Rear Front Axle _RH side (RR_RH)

C. Data Acquisition

After the calibration of the strain gauges, Road Load Data (RLD) on 7 leaf suspension vehicle has been collected at torture track which includes Twist, Belgium, Pebbles, Potholes and Corrugated Tracks. The same exercise has been repeated for the 11 leaf suspension vehicle and the results were compared.

In addition to this, the data has been collected on a single bump when the vehicle moves over it to get the better understanding and comparison of the bending loads coming at the wheel centres.

III.RESULTS

A. Static Load Comparison

The circuit is implemented using pass transistor logic and with the help of the logic first constructed the Ex-or gate circuit. And observed the output without any glitches. Tested by applying 1.8v and 2v voltages and obtained simulations are verified through truth table.

Strain gauge location	7 leaf suspension		11 leaf suspension	
	microstrain	Load (kg)	microstrain	Load (kg)
RF_LH	238	6857	271	7579
RF_RH	204	7457	200	7352
RR _LH	275	6644	265	6464
RR _RH	226	6912	240	7225

Table-1 Comparison of static loads in 7 leaf and 11 leaf suspension configurations

Table-1 shows the comparison of bending loads in static condition of the vehicle. Static loads on both the suspension configurations are in similar order. The small change in loads at the wheel centres is due to switching from one configuration to another configuration. Since we are going to measure the percentage difference in the loads expected in terms of “g” which is the ratio of dynamic and static loads, the dynamic loads on each wheel centre will be divided by the static load on the corresponding wheel centre, so shift in the static load in 11 leaf configurations will not impact our test results.

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B. Single Bump Load Comparison

Strain gauge location	Maximum Load (kg)		RMS Load (kg)	
	7 Leaf Config.	11 Leaf Config.	7 Leaf Config.	11 Leaf Config.
RF_LH	8513	10398	6909	7977
RF_RH	10183	10588	7790	7513
RR_LH	7800	8544	6116	6175
RR_RH	10235	10762	7209	7299

Table-2 Single bump load comparison results

Table-2 shows the comparison of dynamic loads of both 7 leaf and 11 leaf suspension configurations when the vehicle moves over a single bump with 30% overload. It is observed that the dynamic loads on 11 suspensions is more as compared to the 7 leaf suspension due to stiffness of the spring.

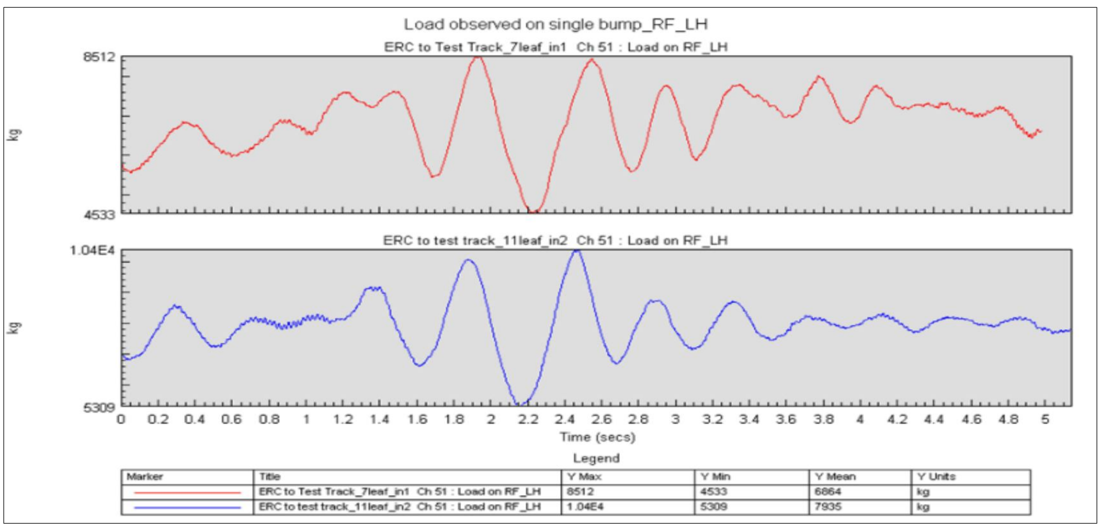

Fig. 10 Single bump load comparison at RF_LH location

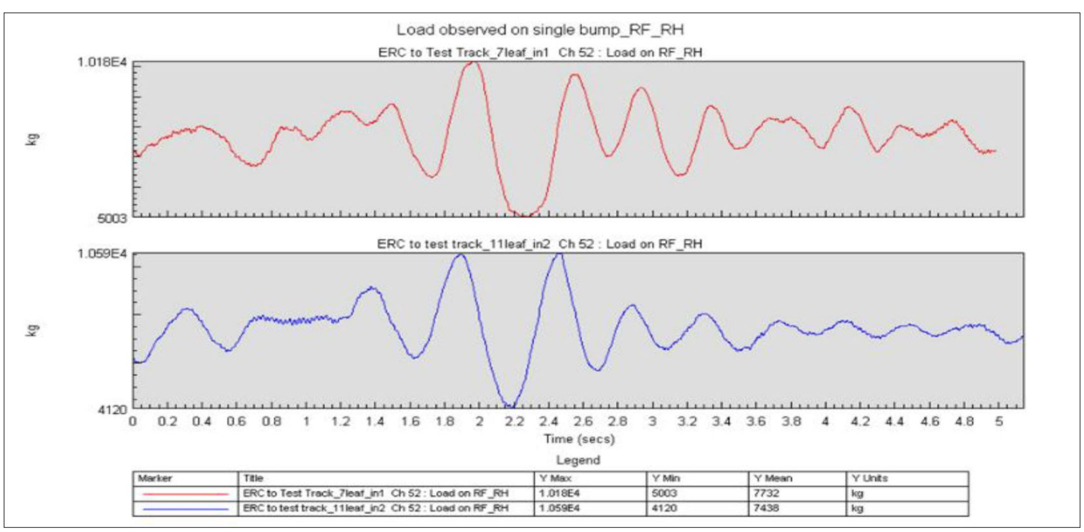

Fig. 11 Single bump load comparison at RF_RH location

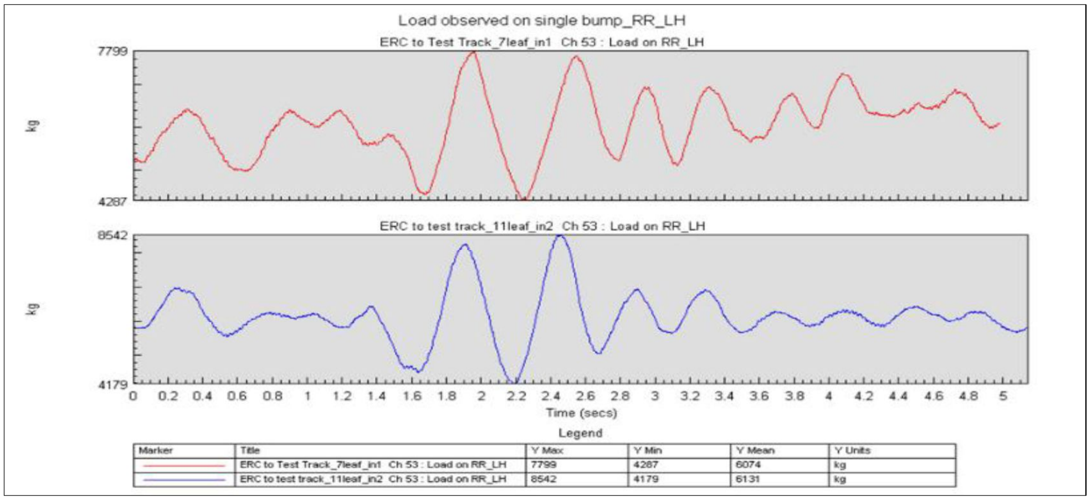

Fig. 12 Single bump load comparison at RR_LH location

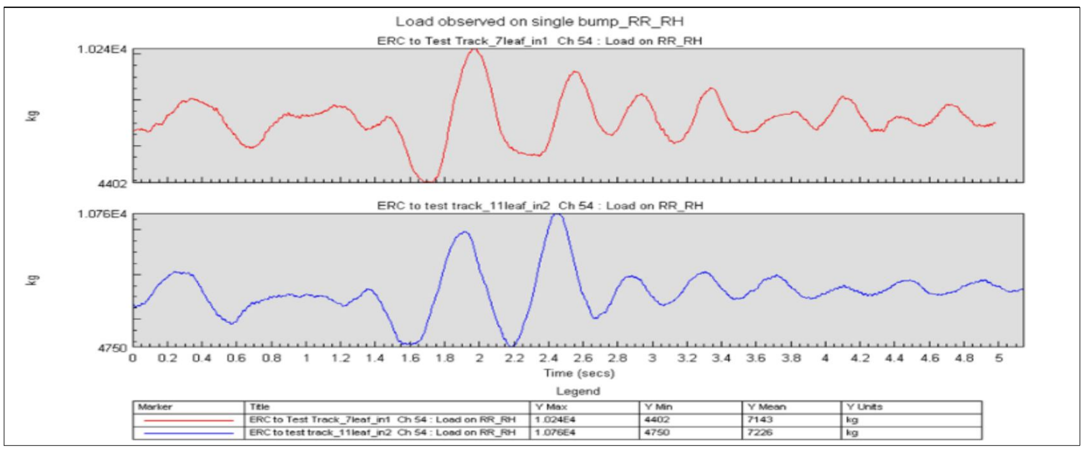

Fig. 13 Single bump load comparison at RR_RH location

Fig. 10 to Fig. 13 show the comparison plots of 7 leaf and 11 leaf suspension configurations when the vehicle moves over a single bump with 30% overload. The red curve shows the dynamic load of 7 leaf suspension and the blue curve shows the dynamic load of 11 leaf suspension.

C. Percentage Difference in Max Loads

Location	Max load in single bump (kg		Wheel reactions in 30% over laden (kg)		g = (Dynamic load) ÷ (Static load)		% difference in "g"
	7 leaf	11 leaf	7 leaf	11 leaf	7 leaf	11 leaf	
RF_LH	8513	10398	6857	7579	1.24	1.37	10.5
RF_RH	10183	10588	7457	7352	1.37	1.44	5.5
RR_LH	7800	8544	6644	6464	1.17	1.32	12.6
RR_RH	10235	10762	6912	7225	1.48	1.49	0.6

Table-3 Percentage difference in max loads normalized to wheel reactions when the vehicle moves over a single bump

Table-3 shows the percentage difference in max loads when the dynamic loads are normalized to wheel reactions at static load. Maximum 'g' value coming in 7 leaf suspension and 11 leaf suspensions are is 1.48 and 1.49 respectively, which means the dynamic loads are almost 1.5 times more than the static loads when the vehicle runs over a single bump with 30% over load. Also it has been observed that the average of percentage change in 'g' value for all four locations is around 8%. In the other words it can be stated that when the 7 leaf spring is replaced with a 11 leaf spring in the same suspension, the percentage change in the 'g' value is below 10% if the vehicle moves over a single bump. This percentage may be altered when the vehicle moves in torture track especially during the durability trials.

D. Torture Track Load Comparison

The same vehicle with the two different configurations (7 leaf and 11 leaf suspension) ran on the torture track which consists of Twist, Belgium, Pebbles, Potholes and Corrugated patches of length approximately 200m. The data has been collected in 30% over laden condition. Dynamic load values are compared between 7 leaf and 11 leaf suspension configurations.

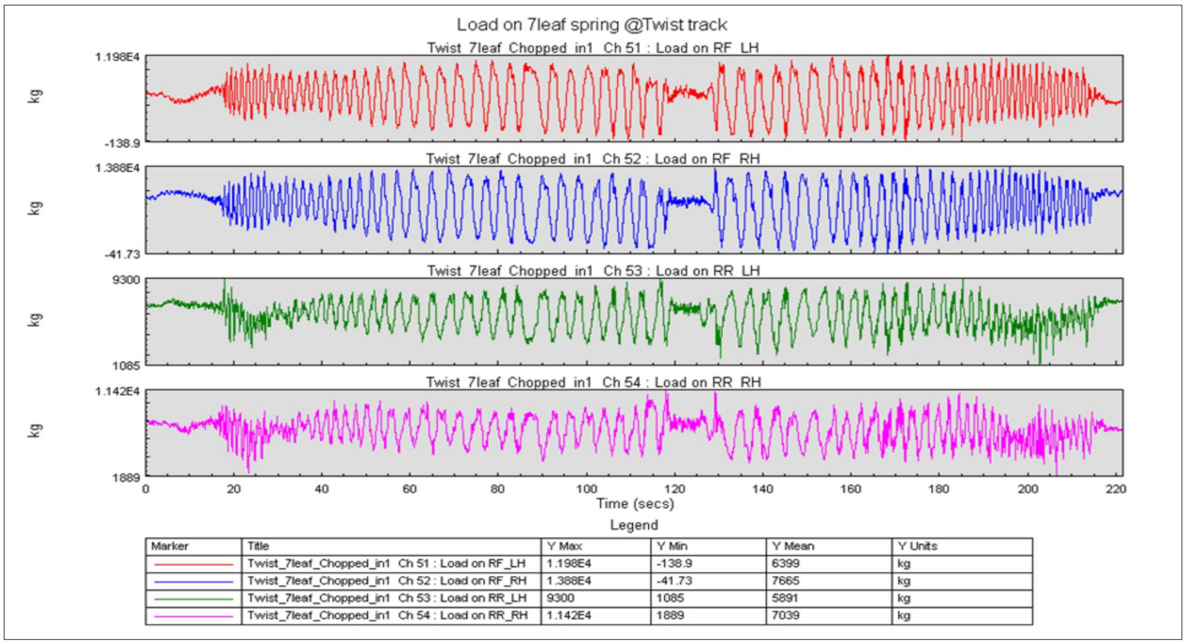

Fig. 14 Dynamic loads of 7 leaf suspension in Twist Track

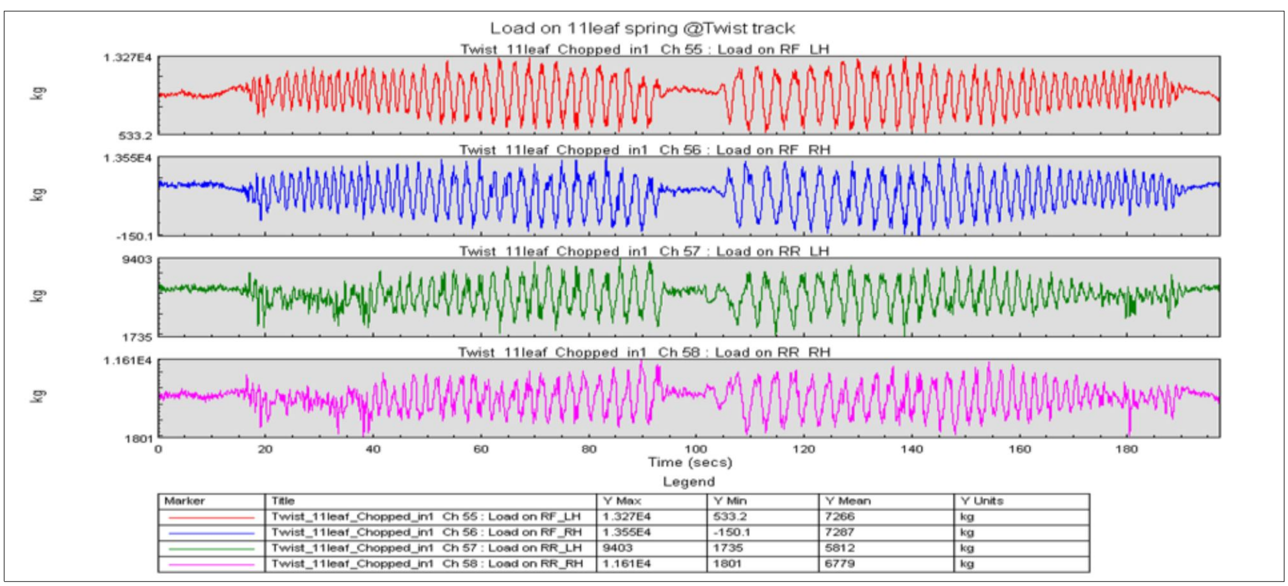

Fig. 15 Dynamic loads of 11 leaf suspension in Twist Track

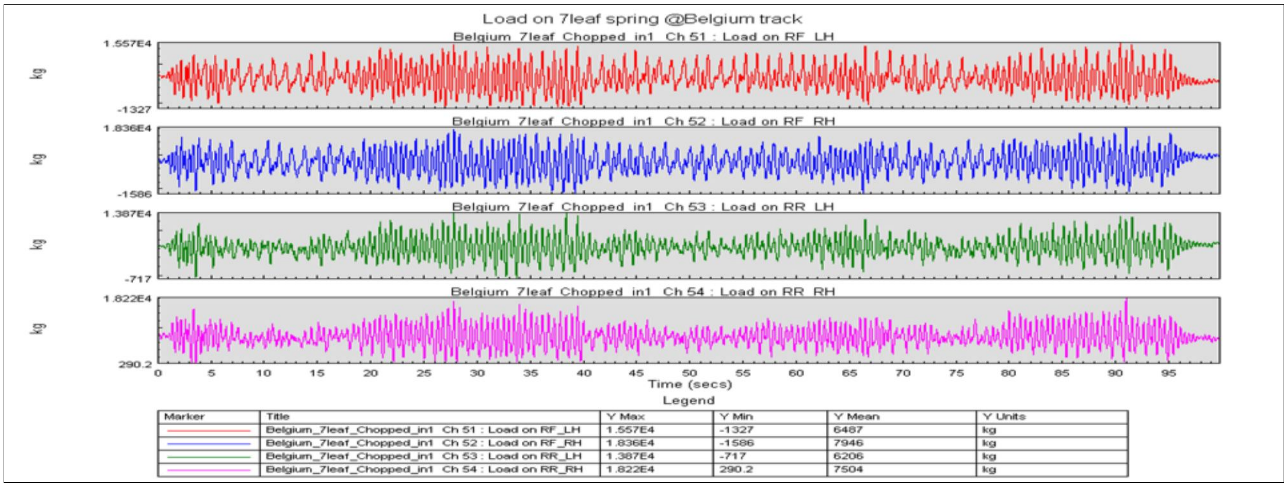

Fig. 16 Dynamic loads of 7 leaf suspension in BelgiumTrack

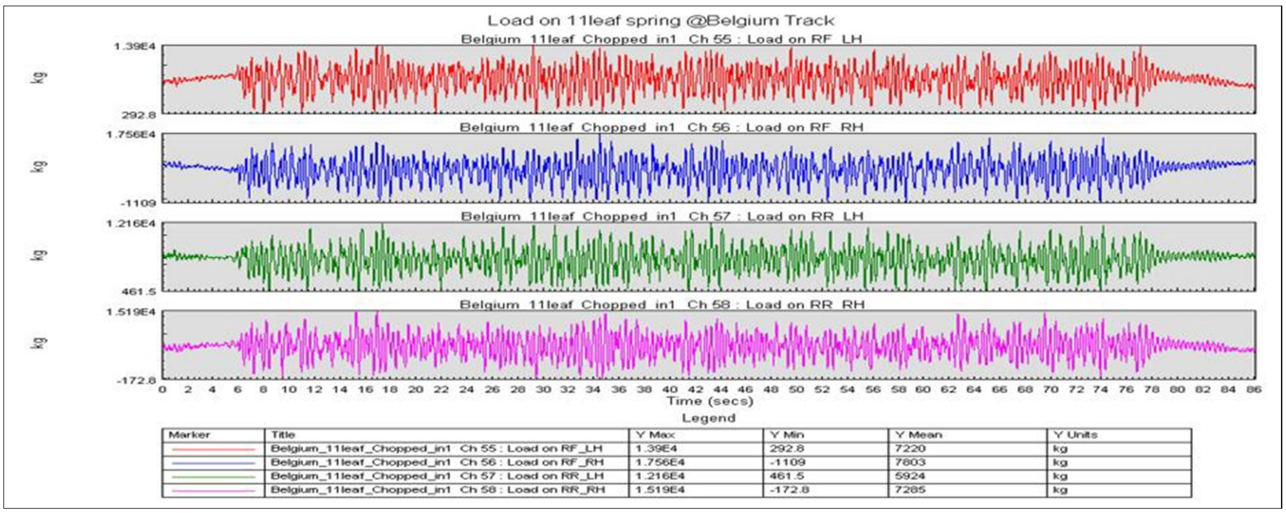

Fig. 17 Dynamic loads of 11 leaf suspension in BelgiumTrack

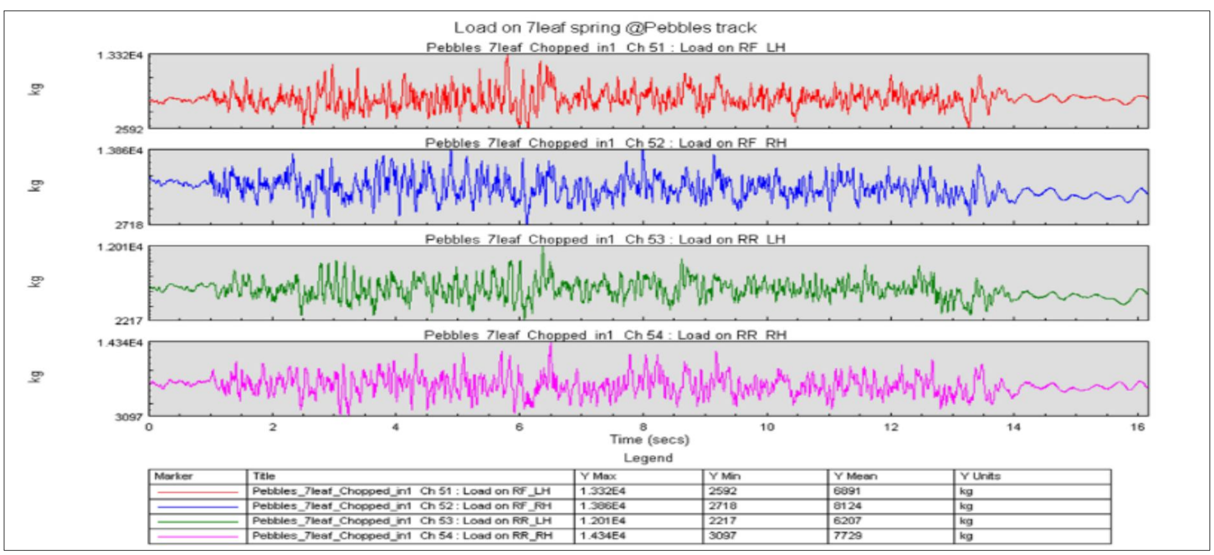

Fig. 18 Dynamic loads of 7 leaf suspension in Pebbles Track

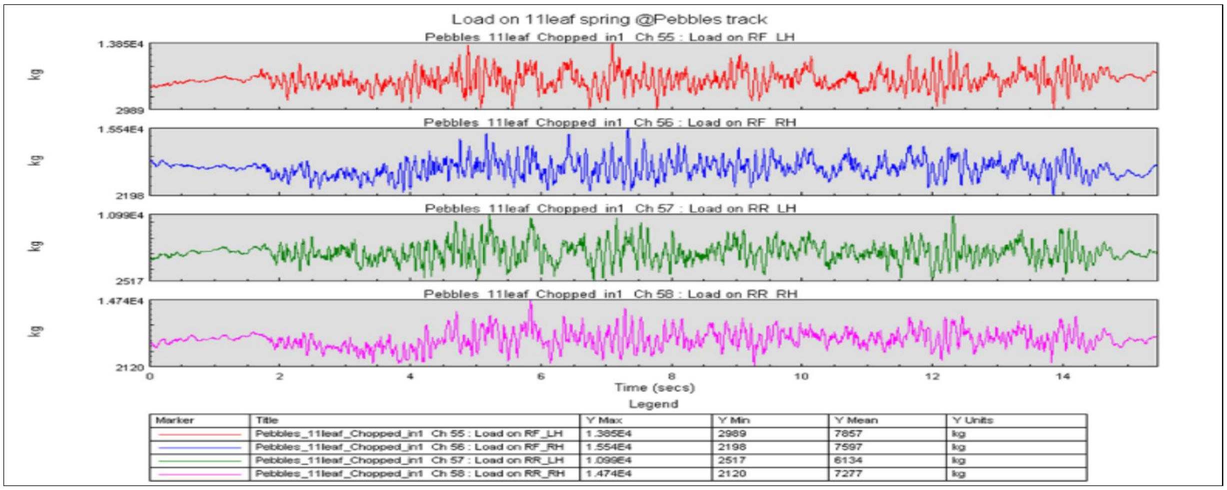

Fig. 19 Dynamic loads of 11 leaf suspension in Pebbles Track

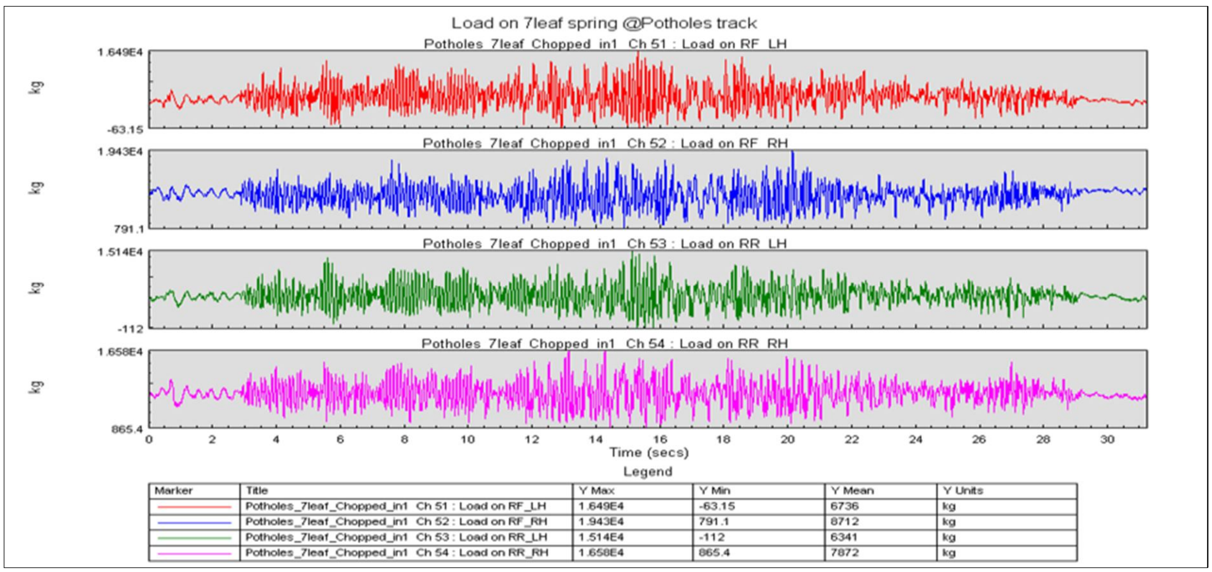

Fig. 20 Dynamic loads of 7 leaf suspension in Potholes Track

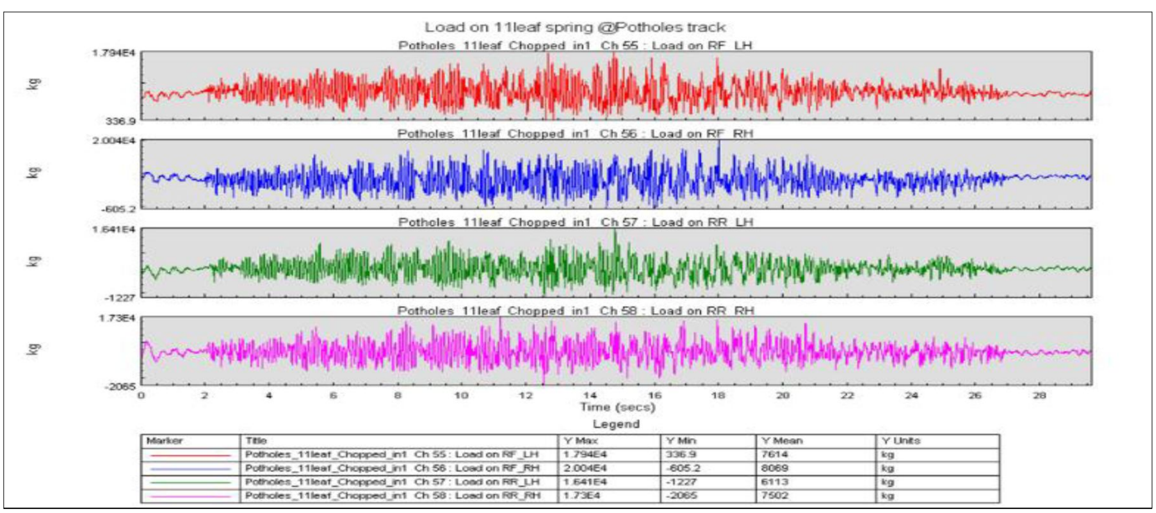

Fig. 21 Dynamic loads of 11 leaf suspension in Potholes Track

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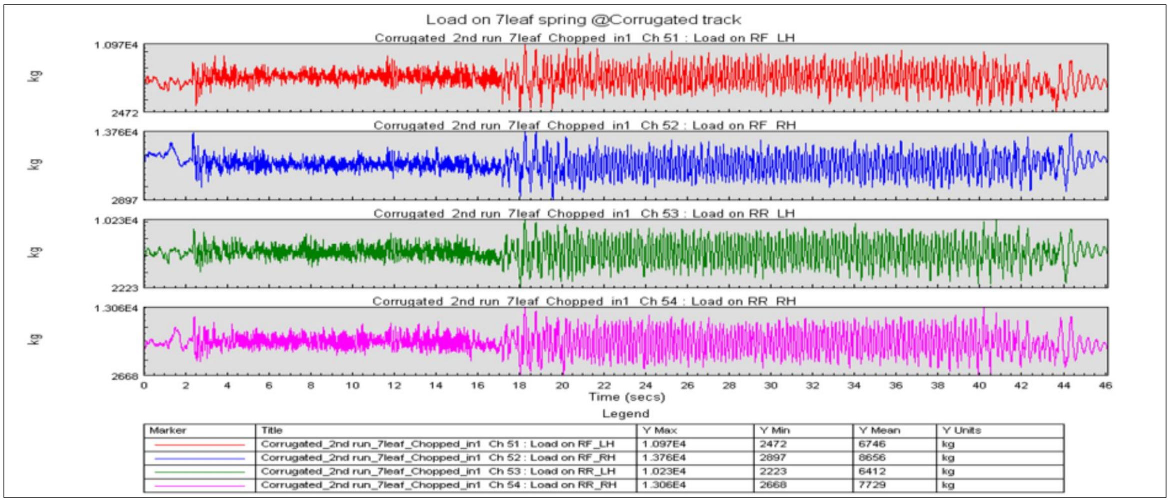

Fig. 22 Dynamic loads of 7 leaf suspension in Corrugated Track

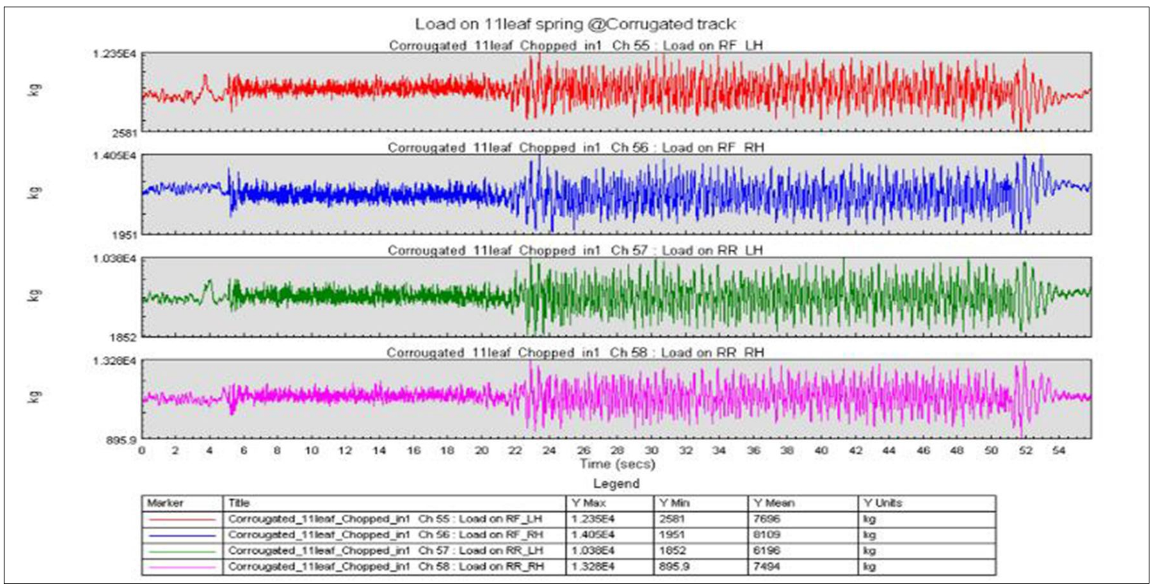

Fig. 23 Dynamic loads of 11 leaf suspension in Corrugated Track

Fig. 14 to Fig. 23 show the dynamic loads coming on four-wheel centres for 7 leaf and 11 leaf suspension configurations in Twist, Belgium, Pebbles, Potholes and Corrugated Tracks respectively. Data has been collected as per the standard torture track recipe of the organization.

Location	Max load in single bump (kg		Wheel reactions in 30% over laden (kg)		g = (Dynamic load) ÷ (Static load)		% difference in "g"
	7 leaf	11 leaf	7 leaf	11 leaf	7 leaf	11 leaf	
RF_LH	11981	13271	6399	7266	1.87	1.83	-2.4
RF_RH	13879	13547	7665	7287	1.81	1.86	2.7
RR_LH	9300	9403	5891	5812	1.58	1.62	2.5
RR_RH	11423	11607	7039	6779	1.62	1.71	5.5

Table-4 Percentage difference in max loads normalized to wheel reactions when the vehicle runs in Twist Track

Location	Max load in single bump (kg		Wheel reactions in 30% over laden (kg)		g = (Dynamic load) ÷ (Static load)		% difference in "g"
	7 leaf	11 leaf	7 leaf	11 leaf	7 leaf	11 leaf	
RF_LH	15573	13904	6487	7220	2.40	1.93	-19.8
RF_RH	18362	17556	7946	7803	2.31	2.25	-2.6
RR_LH	13872	12162	6206	5924	2.24	2.05	-8.2
RR_RH	18219	15188	7504	7285	2.43	2.08	-14.1

Table-5 Percentage difference in max loads normalized to wheel reactions when the vehicle runs in Belgium Track

Location	Max load in single bump (kg		Wheel reactions in 30% over laden (kg)		g = (Dynamic load) ÷ (Static load)		% difference in "g"
	7 leaf	11 leaf	7 leaf	11 leaf	7 leaf	11 leaf	
RF_LH	13320	13852	6891	7857	1.93	1.76	-8.8
RF_RH	13864	15537	8124	7597	1.71	2.05	19.8
RR_LH	12008	10990	6207	6134	1.93	1.79	-7.4
RR_RH	14339	14740	7729	7277	1.86	2.03	9.2

Table-6 Percentage difference in max loads normalized to wheel reactions when the vehicle runs in Pebbles Track

Location	Max load in single bump (kg		Wheel reactions in 30% over laden (kg)		g = (Dynamic load) ÷ (Static load)		% difference in "g"
	7 leaf	11 leaf	7 leaf	11 leaf	7 leaf	11 leaf	
RF_LH	16490	17938	6736	7616	2.45	2.36	-3.8
RF_RH	19427	20035	8712	8069	2.23	2.48	11.3
RR_LH	15138	16406	6341	6113	2.39	2.68	12.4
RR_RH	16583	17301	7872	7502	2.11	2.31	9.5

Table-7 Percentage difference in max loads normalized to wheel reactions when the vehicle runs in Potholes Track

Location	Max load in single bump (kg		Wheel reactions in 30% over laden (kg)		g = (Dynamic load) ÷ (Static load)		% difference in "g"
	7 leaf	11 leaf	7 leaf	11 leaf	7 leaf	11 leaf	
RF_LH	10972	12349	6746	7696	1.63	1.60	-1.3
RF_RH	13762	14051	8656	8109	1.59	1.73	9.0
RR_LH	10229	10381	6412	6196	1.60	1.68	5.0
RR_RH	13058	13279	7729	7494	1.69	1.77	4.9

Table-8 Percentage difference in max loads normalized to wheel reactions when the vehicle runs in Corrugated Track

Tables-4 to 8 show the percentage change in max loads between 7 leaf and 11 leaf suspensions when the vehicle ran on different patches in torture track. Mixed trend has been observed in the percentage change in ‘g’ values between 7 leaf and 11 leaf suspensions. In a low-speed track like Belgium, the average percentage change in the bending loads coming on 7 leaf suspension are in the higher side, where as in the other tracks average percentage change in the bending loads on 11 leaf spring are in the higher side. Though Twist track is a low speed and high displacement track, due to the high straight and cross articulations on the rear axles, the bending loads are coming more in 11 leaf suspension than 7 leaf suspension.

IV. CONCLUSION

Comparative study of bending loads coming at wheel centres of heavy commercial vehicles for the same rear suspension system connected with two different leaf springs has been discussed in this paper. The change in loads expected on the rear axles have been evaluated using appropriate strain gauging on the rear axles. Due to the increase in the stiffness of the spring, the 11 leaf suspension is giving better performance as compared to the 7 leaf suspension in most of the terrains like Twist, Pebbles, Potholes and Corrugated tracks. To get the better understanding of the quasi-static loads on the suspension the vehicle ran over a single bump and proved that the better performance is observed in the 11 leaf suspension. In the present exercise we have focused on the bending or vertical loads coming on the axles. But the vehicle runs on severe terrains like torture tracks and country roads, complex loads will come in all 6 degrees of freedom and will affect the durability of the suspension followed by the chassis. To get the better accuracy and completeness covering forces and moments in all 6 degrees of freedom, Wheel Force Transducers need to be used.

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