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Design, Simulation and Fabrication of Load Cells for Commercial Vehicles

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Abstract: The aim of this project is to fabricate the weight bridge on moving vehicle. The recent survey suggests that weighing at places makes unwanted time and travel. The project is used to measure the weight of vehicle in the loading and unloading conditions by using the sensors while on running condition.
The work is carried out by using load cell based on the load. The load cell gives the value of the load that is carried, displayed through LED display to the driver. The load measured through load cell is proportional to the voltage displayed by the controller. This is mainly used in Lorries, trucks, and containers for measuring the weight before and after the load is applied on the vehicle. The project just works like a portable weight bridge. The dimensions of different parts of load cells and Truck chassis are calculated and used to make CAD models.
The CAD model of the Load cell and Truck chassis is designed using AUTODESK FUSION 360 and assembled by using ON SHAPE software. The material is chosen for load cell as stainless steel, Mild steel for steel channel and Alloy steel for Truck chassis.
The stress induced and deformation of the truck chassis is done computationally using ANSYS workbench. . The test results carried out in the fabricated truck chassis shows that the Load is distributed uniformly and analyzed with an equivalent stress and deformation statically and dynamically. This assembly would therefore contribute to keep uniform loading and prevention of rollover accidents in near future.
Keywords: Shear beam Loadcells, HX-711 Amplifier, Strain gauge, Wheatstone bridge, Wi-Fi Module, Arduino microcontroller.

I. INTRODUCTION

Road safety is one of the most significant issues in the world. Driving an overloaded vehicle causes various kinds of hazards such as mechanical failures and structural deformation of vehicles and roads, which lead to accidents, and it is an illegal and punishable offence in most countries.
According to the South African National Road Traffic Regulations, driving an overloaded vehicle leads to prosecution for an offence under regulations in the National Road Traffic Act, 1996.
According to the U.S. Department of Transportation, vehicle condition and road/environment conditions are the two factors which are collectively responsible for 5.2% of road accidents. Vehicles carrying more than the manufacturer's specified and permitted payload are considered overloaded.
In other words, a vehicle is overloaded if the total weight of a vehicle when fully loaded is more than the maximum allowed Gross Vehicle Weight (GVW), where the GVW is the sum of kerb weight and payload. A relatively large number of infringements is related to weights of heavy goods vehicles. On average, one in three vehicles checked is overloaded. These excess loads often exceed the maximum authorized weight by 10 or even 20%. Overweight vehicles lead to all sorts of negative issues, e.g., related to road safety, driver's safety, road degradation, environment and competition. There is some discussion about making on-board weighing (OBW) systems mandatory for new trucks. However, information from other sources suggests this cost range is unrealistically high. Transport & Environment would like to have better founded cost estimates as well as a solid analysis of what is technically feasible.

A. WIM

Weighing the weight of a moving vehicle on the road is known as weigh-in-motion (WIM). Fred Moses and George Globe introduced Bridge WIM (B-WIM) in the USA in the early 1970s. The successful B-WIM application took place in Australia in the mid-1980s. WIM has been used in the transport industry for more than a decade and for many reasons. Earlier, it was only used to plan and build the roads and bridges. In recent years, the legislation has been changed, and the WIM data is also used by traffic enforcement departments for the enforcement of overloading.

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B. Requirements on Weight Compliance

Different stakeholders have different perspectives and hence different requirements towards weight compliance,

1) *Public authorities* must consider how to improve the overall goals they want to achieve, e.g., reduced maintenance costs for road infrastructure, reduced environmental impact from road transport, and improved road safety, more efficient use of the road transport system.
2) *Transport companies* want to move goods in an efficient way, without being burdened by administration, paperwork and frequent stops for compliance checks by authorities. In general, transport companies are also interested in fair competition, which includes that regulatory requirements are enforced and prosecuted equally for all market actors.
3) *Vehicle manufacturers and suppliers* of (on-board) weighing systems want to make money by providing their customers with highly functional, productivity enhancing and distinctive products.
4) *Professional drivers* want to conduct their profession under safe and comfort conditions in their cabin and on the road.

II. LITERATURE SURVEY

From the literature review the following conclusions can be made:

A. Using strain gauge as load cell sensor. It is used because the load cell has resistance to extraneous forces, and it is protected against dust, moisture, and adverse environmental conditions

B. Using shear beam load cell as beam load cell type among various types. Shear beam load cell are relatively insensitive to the point of loading and offer a good resistance to side loads

C. Using Ladder frame chassis for mounting load cells .It is selected among various types of chassis because it has adaptability to accommodate large variety of body shapes exhibiting good bending strength and stiffness.

D. Using C-section frame member for steel channel provides additional stiffness, load bearing capacity, better handling characteristics and good performance of vehicles .

E. Using HX711 Load Amplifier Module amplifies and digitally converts the Load cell output. Then this amplified value is fed to the Arduino. Now Arduino calculates the output of HX711 and converts that into the weight values in grams and shows on LCD.

III. PROBLEM DEFINITION

Before the installation of load cells, the transportation companies face huge problems

A. Excessive wear and tear of tyres, wheel disc cracks

B. More fuel consumption due to uneven loading

C. Rollover accidents while travelling through hairpin bends

D. Theft of loaded goods and commodities while the vehicle is stationary

E. Instability of the vehicle

F. Tolerance occurs in payload when measuring through different weigh bridges.

There is a need to implement load cells in commercial vehicles to resolve all the mentioned issues. Also, installation of WIFI module in vehicle's cockpit helps to communicate with the drivers and to monitor the vehicle performance.

IV. SHEAR BEAM LOAD CELL

The (single ended) shear beam is designed for low profile scale and process applications. The shear beam capacities are from 100kg to 50t. One end of the shear beam contains the mounting holes while the opposite end is where the cell is loaded. The load cell should be mounted on a flat smooth surface with high strength hardened bolts. The larger shear beam cells have more than two mounting holes to accommodate extra bolts to keep the hardware from stretching under stress load.

Fig. 1 Shear beam load cell.

A. *Shear beam load cells features*

Shear beams are available of nickel-plated alloy steel or stainless steel for use in harsh environments.

1) Capacities 100kg- 50t.
2) 13 different types.
3) Hermetically sealed versions available (IP68).
4) Stainless steel and alloy steel.
5) Weighing accessories and modules available.

B. *The strength of the load cells*

$$L > \frac{(f_1 \times W_1 + W_2) \times f_2 \times f_3}{N}$$

1) L: Rated capacity
2) N: Number of load cells to be used
3) W1: Net measurement weight
4) W2: Weight of the hopper itself
5) f1: Dynamic factor (typically 1.3)
6) f2: Eccentricity factor (typically 1.2)
7) f3: Imbalance factor (1.0 when N = 3, and 1.2 when N = 4)

For example, when the net measurement weight is 150 kg, the weight of the hopper is 3 kg, and the number of load cells to be used is four,

$$L > \frac{(1.3 \times 150 + 3) \times 1.2 \times 1.2}{4} = 71.28\, kg \approx 71 kg$$

It is therefore desirable to use four load cells that each have a rated capacity of 71 kg.

V. SELECTION OF STEEL CHANNEL

There are four different kinds of sections available for selection of steel channel

1) C- section
2) I-section
3) Box section
4) Tubular section

C-section has good resistance of bending, which is used in long section of the frame. Though I-section has good resistance to both bending and torsion, it is not suggested for practical use because of clamping issues. Box sections are used in short frame members. Tubular sections are used in three wheelers and bicycles. For this project, C-section steel channel is selected. The present diagram shown below is a C-section steel channel of length 65 mm and breadth 125 mm having 8mm thickness along horizontal span and 6mm thickness along vertical span. The calculations for stress and deflection are performed below.

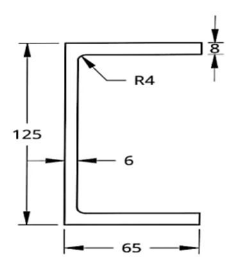

Fig. 2 C-Section steel channel

a) Radius of gyration R= $\frac{125}{2}$ =62.5mm
b) b=65mm h=125mm
c) b1=59 mm h1= 109 mm
d) Y=h/2=62.5 mm

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Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

Moment of inertia about X-X axis:

$$I_{XX} = \frac{bh^3 - b_1 {h_1}^3}{12}$$

$$= \frac{65*125^3 - 59*109^3}{12}$$

$$= 4212201.1 \text{ mm}^4$$

Section modulus along X-X axis

$z_{XX} = \frac{I_{XX}}{Y} = 67395.21\ mm^3$

$M_{max} = 6.729$ kNm

Stress produced on the steel channel

$$\sigma = \frac{M}{Z} = \frac{6.729}{67395.21} = 99.85\ {}^{N}/_{mm^2}$$

Maximum deflection produced on the steel channel

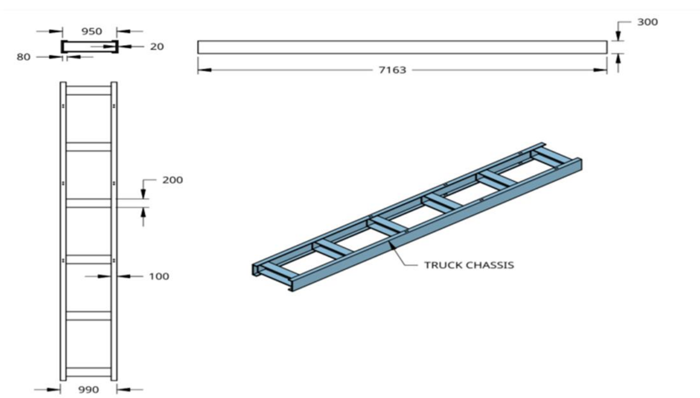
$$Y = \frac{1.4087*10^{13}}{E*I} = \frac{1.4087*10^{13}}{2.1*10^5*4.21*10^6} = 15.25 \text{ mm}$$

VI. SIMULATION WORK

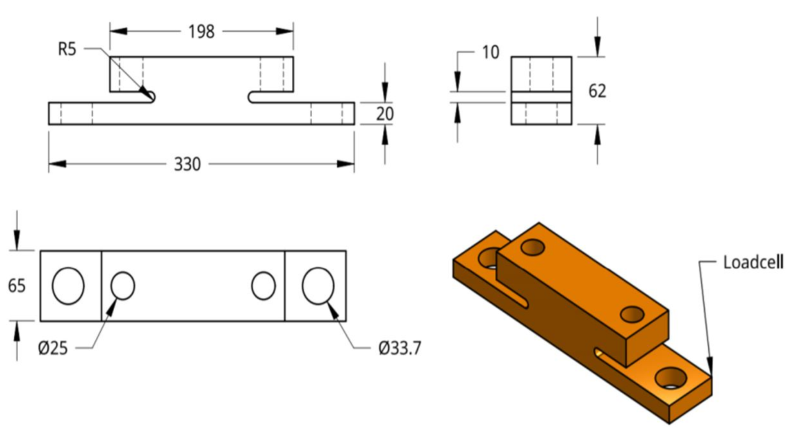
A. Cad Model

The CAD model of truck chassis assembled with loadcell and steel channel is discussed in this chapter. The design was made in on shape software.

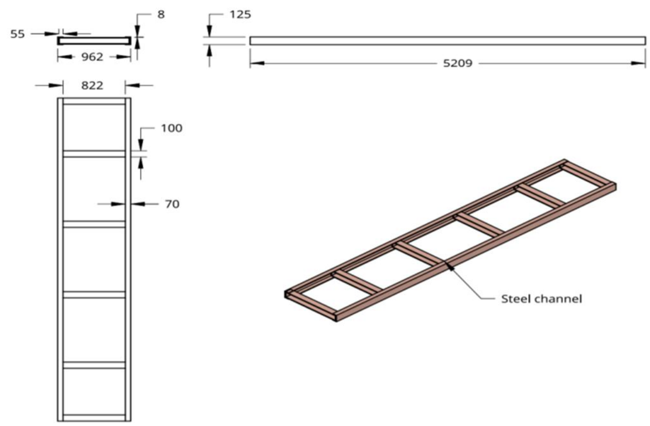
1) Truck Chassis



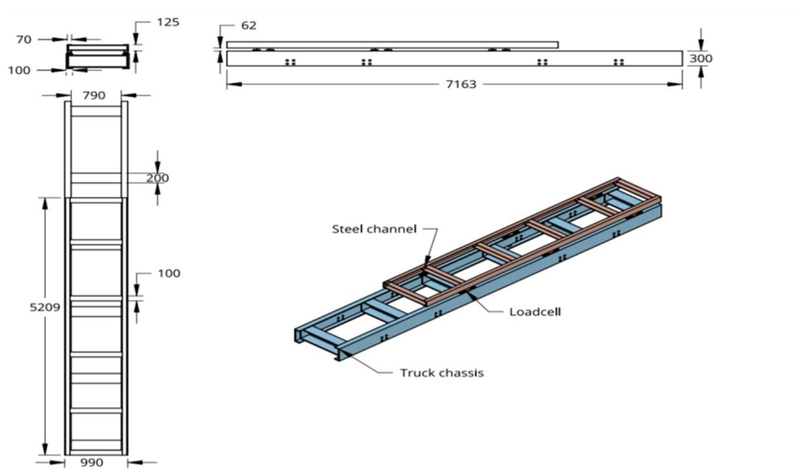
2) Load Cell



3) Steel Channel



4) Assembled View of the Model



B. Static Structural Analysis

The loadcell and steel channel design is analysed in ANSYS Workbench 20.0 to find the maximum stress induced and deformation in when the model is subjected to shear loads. AISI 4130 steel alloy is assigned to the truck chassis, stainless steel is assigned to loadcell and AISI 1018 mild steel is assigned to steel channel. The equivalent stress and deformation at the same time interval is analysed for 120000N.

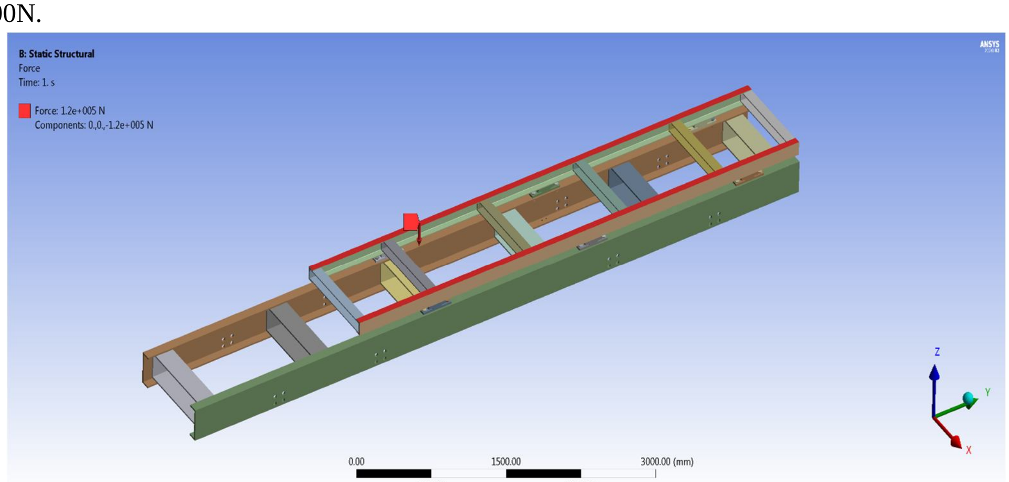


Fig. 3 Boundary conditions of payload

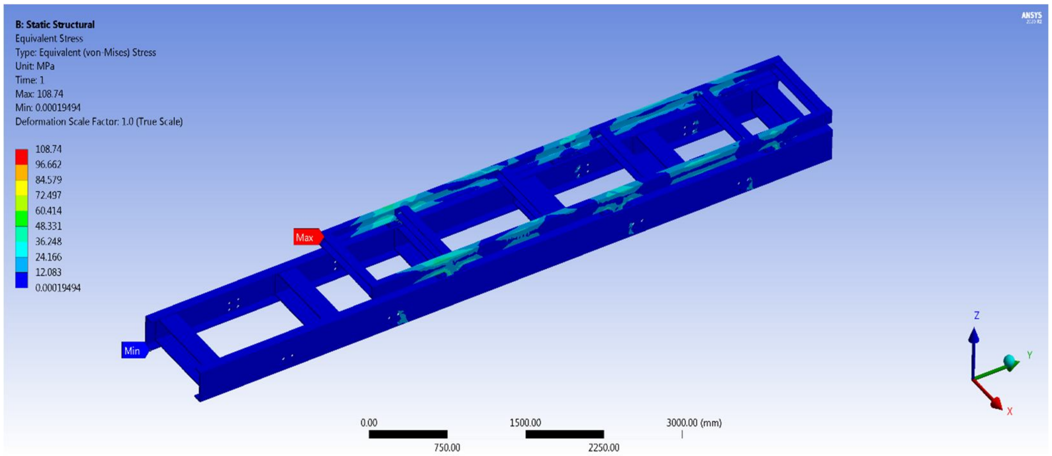


Fig. 4 Von mises stress

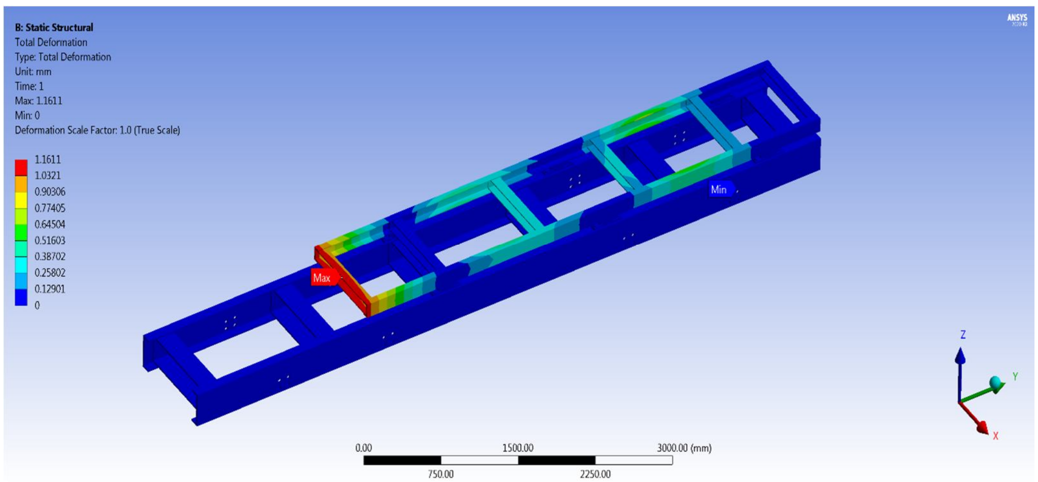


Fig.5 Total deformation

TABLE I
Payload observations

Load applied	120000N
Direction	-Z
Deformation	Maximum:1.16 mm
Stress	Maximum:108.74MPa

C. Dynamic Analysis

Dynamic analysis is used to evaluate the impact of transient loads or to design out potential noise and vibration problems.

1) *Modal Analysis:* Modal analysis is commonly used to reduce or avoid vibration in machine designs. A dynamic loading on a machine will introduce vibrations. Every structure has its own natural frequencies. When the excitation of a vibration on a machine coincides with a natural frequency of the system, the structure resonance with the excitation force which lead to excessive sometimes violent vibrations, which may lead to damage of the structure.

a) Boundary Conditions

Number of modes used = 6
Fixed support is given at the suspension mounting bracket holes
No. of nodes and elements = 109423 and 48824

TABLE II
Mode Frequencies

Mode Number	Frequency (Hz)	Eigen Deformation (mm)
1	56.22	2.92
2	63.17	2.93
3	67.69	3.8
4	73.91	6.63
5	92.91	2.43
6	104.52	2.97

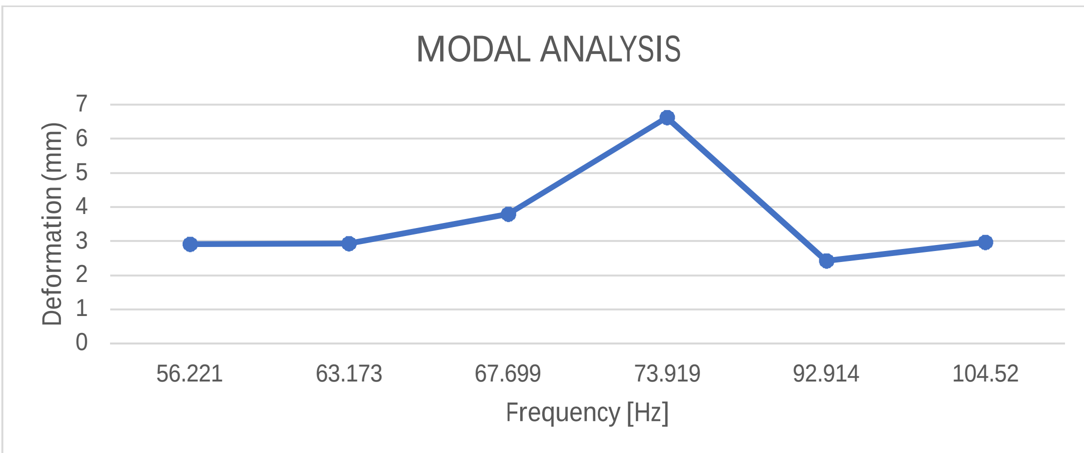


Fig.6 Modal analysis Frequency vs Deformation

2) *Harmonic Analysis:* A harmonic analysis is used to determine the response of the structure under a steady-state sinusoidal (harmonic) loading at a given frequency.

a) *Boundary Conditions*

Load applied: 120000N/ 12 Tons

Direction: -Z

No. of nodes and elements = 109423 and 48824

TABLE III
Mode Frequencies

Frequency [Hz]	Amplitude [mm]
56.122	0.89952
56.221	0.9083
63.173	1.8719
63.555	1.9693
67.699	4.4657
71.971	6.8484
73.919	2.801
81.503	0.39779
92.297	3.7257
92.914	3.196
104.52	0.93992

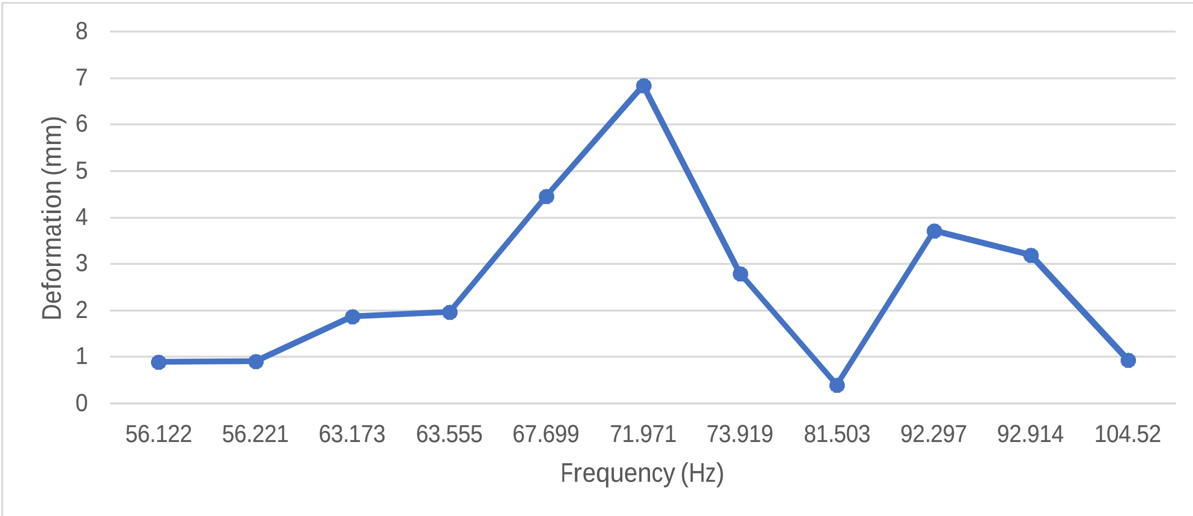


Fig.7 Harmonic response Frequency vs Deformation

3) *Random Vibration Analysis:* Random vibration analysis let us to find out the response of structures to random vibration loads. Typical applications of random vibration analysis are evaluation of the stress level of important devices mounted on vehicles (cars, trucks, railway vehicles etc.). The source of random vibrations is from the engine, road etc.

a) Boundary Conditions

Fixed support is given at the suspension mounting bracket holes

No. of nodes and elements = 109423 and 48824

Damping factor = 0.3

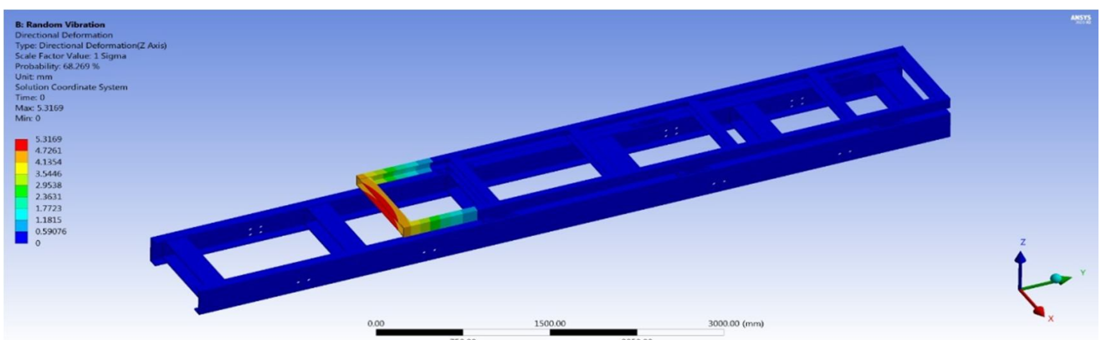


Fig. 8 Total deformation 1-Sigma

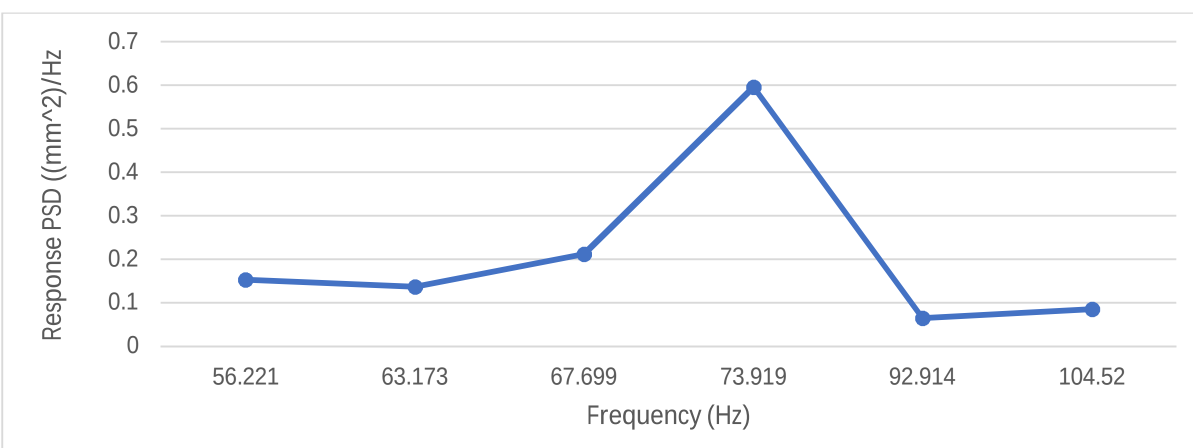


Fig. 9 Random vibration Frequency vs Response PSD

VII. EXPERIMENTATION

A. Under Load Conditions

The experimental setup is tested by using different loads where a 25kg rice sack is placed as load for the setup. The load values are viewed using I2C LCD display that is individual value of loadcells and total weight is observed. This value can be viewed remotely by using IoT module.

Fig. 10 Experimental setup under load condition

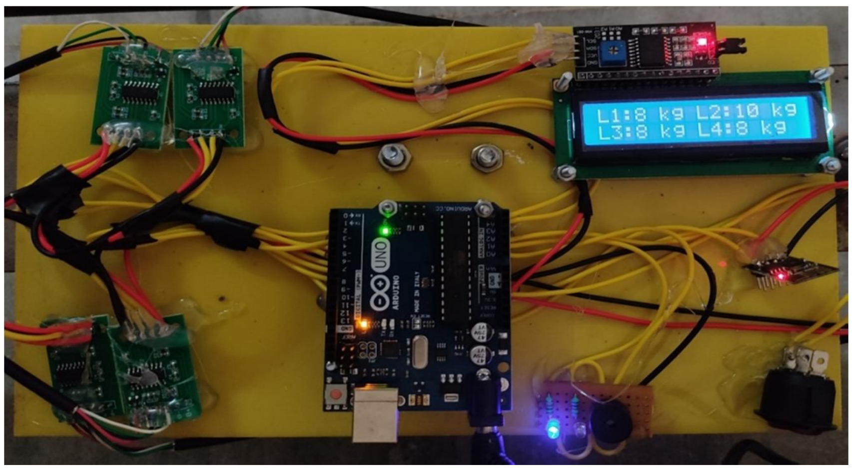


Fig.11 Individual loadcell values under load condition

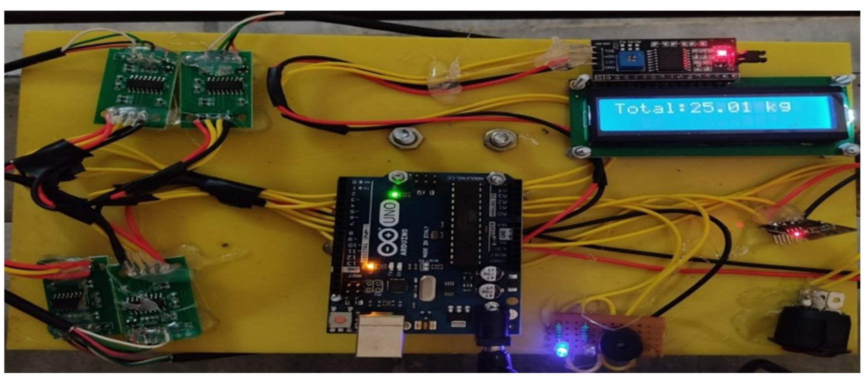


Fig. 12 Total weight under load condition

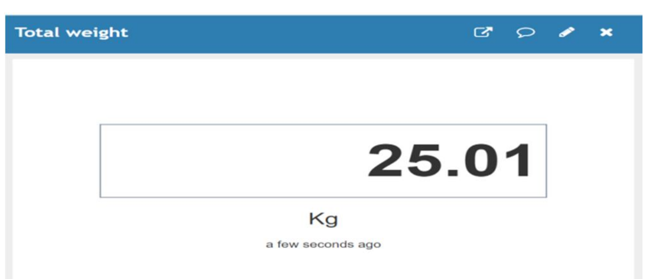


Fig. 13 Total load value displayed in Wi-Fi module under load condition

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Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

B. Under Overload Conditions

The experimental setup was loaded up to 75kgs by using three 25kgs rice sack the Arduino code is programmed in such a way that while exceeding 65kgs of weight the LCD shows the overloaded indication followingly buzzer and LED alert is given. These values can be viewed remotely by using IoT module

Fig. 14 Experimental setup under overload condition

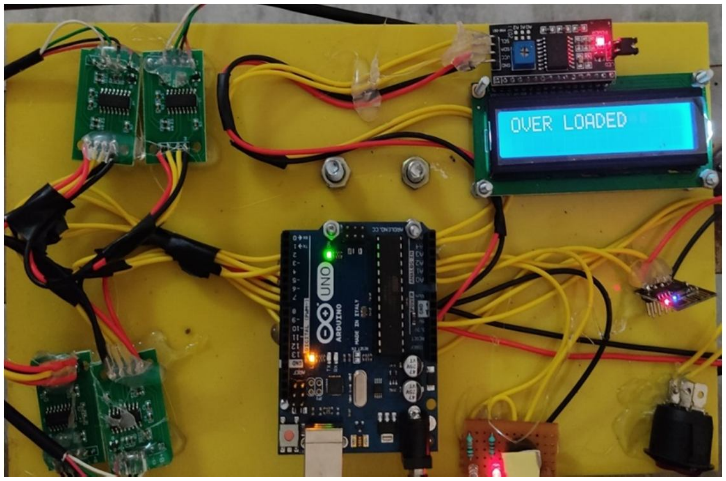

Fig. 15 Overload indication

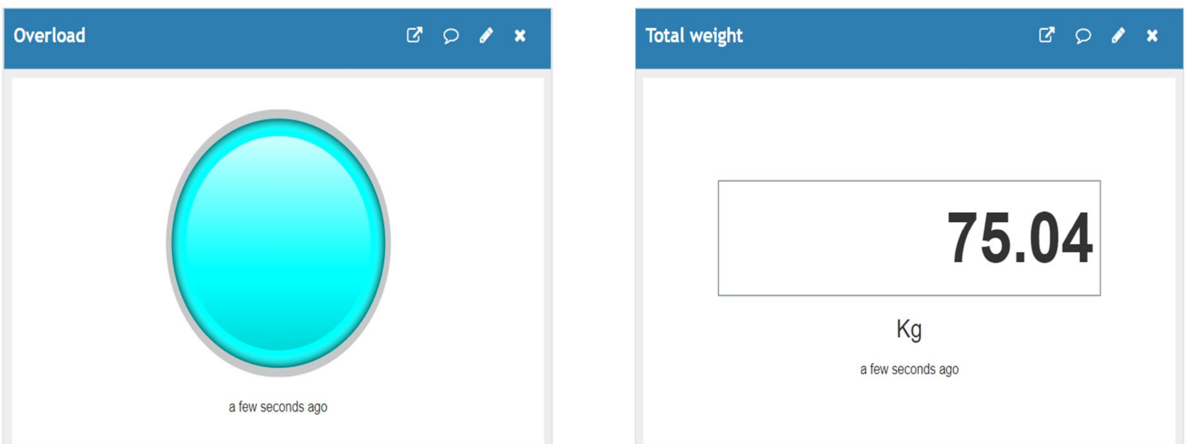

Fig. 16 Total load value displayed in Wi-Fi module under overload conditions

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Volume 9 Issue IV Apr 2021- Available at www.ijraset.com

C. Theft Detection

The experimental setup was loaded up to 75kgs by using three 25kgs rice sack. Once the weight is fixed the load value is set by using the switch by removing one rice sack the Arduino code is programmed in such a way that if a weight of 10 or more than 10kgs is removed there will be theft detection alert in the LCD display module followingly buzzer and LED alert is given. These values can be viewed remotely by using IoT module.

Fig. 17 Experimental setup under theft detection

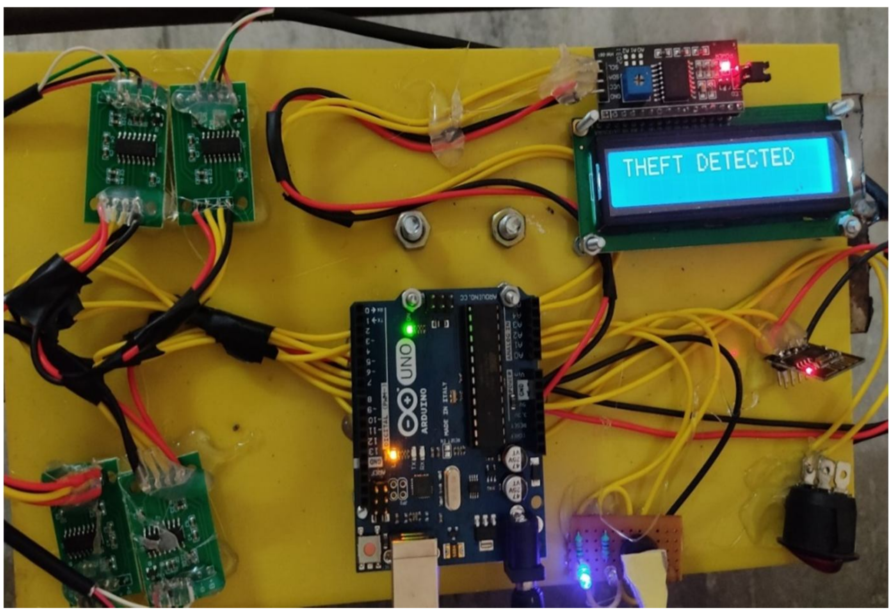

Fig. 18 Theft indication

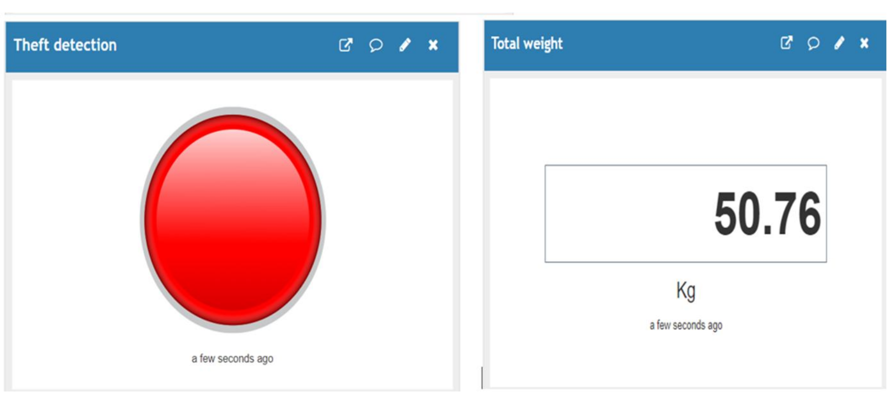

Fig. 19 Total load value displayed in Wi-Fi module under theft detection

VIII. CIRCUIT DIAGRAM

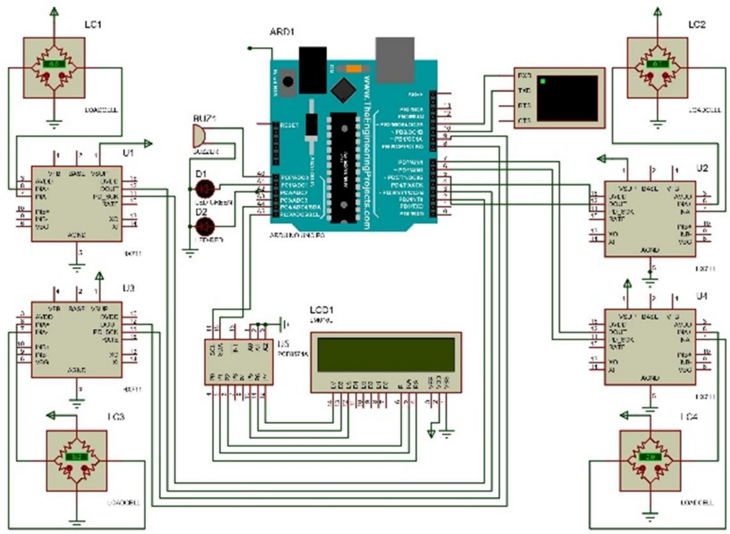

Fig. 20 Connection details by proteus software

IX. CONCLUSION

In these experimental studies, a weight measurement method based on load cell methodology in vehicle is studied and validated. It incorporates wi-fi module, weight measurement. Depending upon the weight the vehicle security is monitored and tracking of the vehicle is also possible for better accuracy and ensure the security, also prevent the accident due to overloading. It also helps us to control the pollution caused by the overloaded vehicle. The owner of the vehicle can also track if there is any loss of goods during travelling. Truck details can be shared with police for safety measurement and monitoring of truck. The load in truck can be displayed along with its live location in google maps which is user friendly mobile application. It also improves the overall efficiency of the vehicle by improving the tire life and life of the shock absorbers, etc.by avoiding the uneven loading and the over loading.

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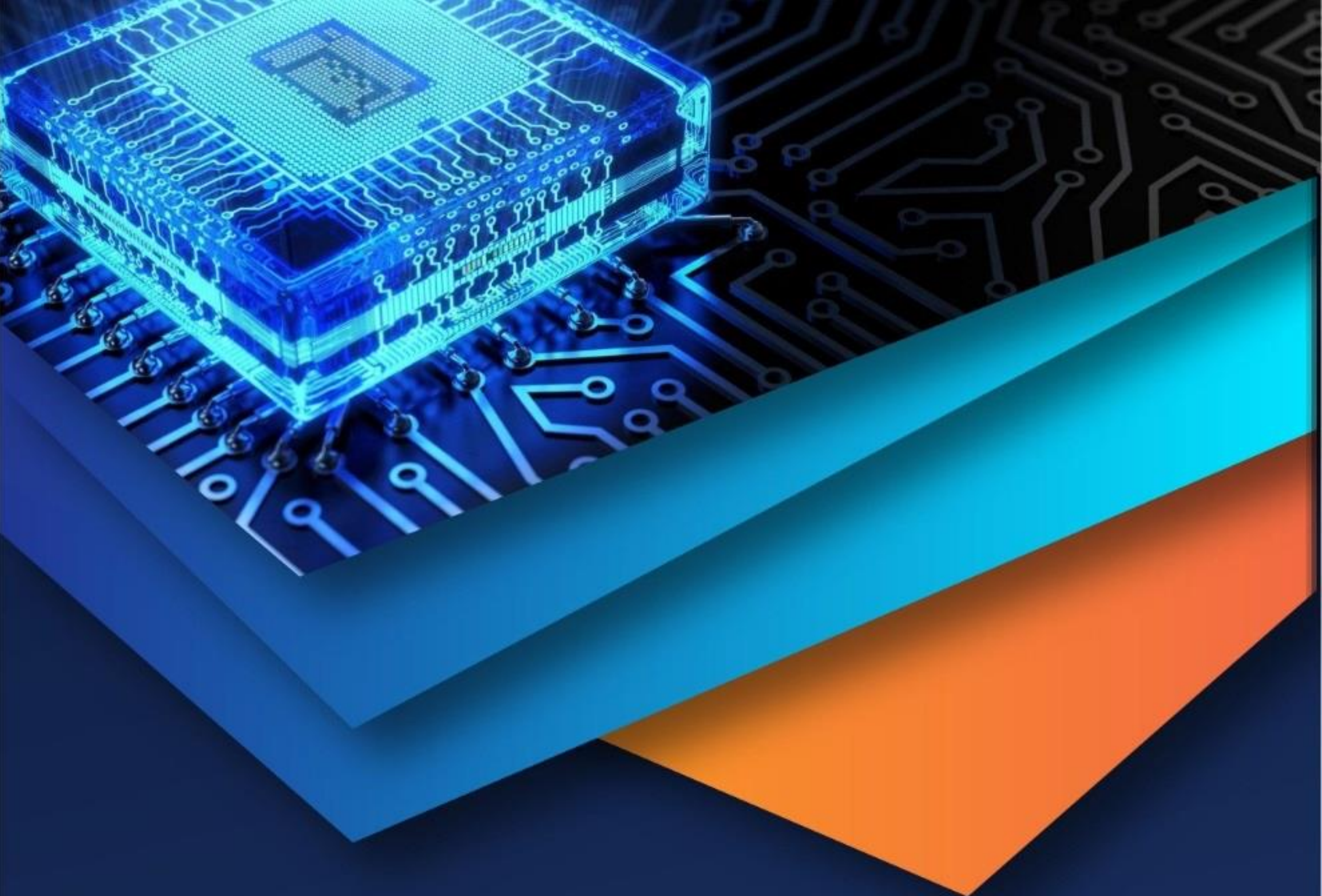

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