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WEIGHING SYSTEMS IN TRAFFIC

Summary. This article presents a brief overview of weighing systems and devices designed to facilitate fluent and safe road traffic. The number of vehicles on roads is perpetually on the rise, resulting in increased wear of road surfaces. This is why weight check gates have widely been implemented to check the speed and weight of a vehicle against what is permitted by law. A cheaper, albeit more time-consuming, traffic weighing alternative would involve weighing points using weighbridges or mobile axle scales. The second part of this article examines the development of an axle scale. The design and calculation works were performed with the use of the Creo Parametric CAD system and the ANSYS Workbench FEM system.
Keywords: dynamic weighing system axle scale; load cell vehicle

1. INTRODUCTION

The primary expectation of transport infrastructure is the assurance of traffic safety and fluency [10,11,12]. To be able to meet this requirement, motorways, roads, bridges and other traffic structures must have their pavement in an appropriate technical condition. The growing

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number of vehicles increases the load on roads and their speed of their deterioration, resulting in an impaired road pavement quality. In order to maintain roads in a good condition, in addition to ensuring regular road maintenance and repair, it is necessary to exclude, or impose limitations on, the traffic of unfit categories of vehicles. Such vehicle categories could include those failing to meet technical requirements (in terms of dimensions, weight etc.), as well as overloaded trucks exceeding the permitted total mass.

To achieve this, statutory weight limits have been established by law for each vehicle category. The implementation of the new legislation has been accompanied by the development of technical devices to check compliance with the limits. Since it is not feasible to have all vehicles stopped and weighed at a single point, it has been necessary to develop a system that will be able to determine the weight of a vehicle, within a reasonable range of accuracy, while the vehicle is in motion. Vehicles suspected of non-compliance with the weight limitation regulations will thus be identified and can be safely stopped, with their mass checked by means of a mobile axle weighing system or a weighbridge in a suitable place.

2. VEHICLE WEIGHING SYSTEMS AND DEVICES

Two weighing methods are recognized: dynamic weighing and static weighing.

Static method

The static method requires the vehicle to be in a static state on the scale; more specifically, where a weighbridge or a small mobile scale is employed, either the whole vehicle or the measured wheel, respectively, must be motionless. What is measured is the total mass transmitted from all axles to the wheels over a 15-s time span. The measured impulse is then processed and evaluated by the control electronics. The weight reading is visible on a display or an external monitor.

Dynamic method

This method is used in high-speed weight-in-motion (HS-WIM) systems and low-speed weight-in-motion (LS-WIM) systems (more often referred to as axle weighing systems). With a HS-WIM system, the vehicle is weighed as it passes over two or three sensors sunk in the road pavement; the weighing is performed at speeds up to 250 km/h (intervals of 1 s) without the driver noticing what happens. The measured signal is processed within 0.5 s and the result that is obtained is either the total mass or the load on each axle of the vehicle.

In the latter case, a number of axle scales corresponding to the number of vehicle axles is set on a firm floor. The measurement is performed as the wheels of each axle of the vehicle pass over the axle scales at a speed of 10 to 15 km/h at intervals of 30 or 60 s. The resulting weight of the vehicle (or weight per wheel or per axle) is calculated from the acquired time course records.

2.1. High-speed weight-in-motion system

The system is used on motorways and expressways for the purposes of control monitoring the vehicle traffic flow. The system checks compliance with the statutory speed and weight limits.

A WIM system is composed of a gate with ANPR cameras, laser scanners and, possibly, other electronics to improve the accuracy of the control cycle.

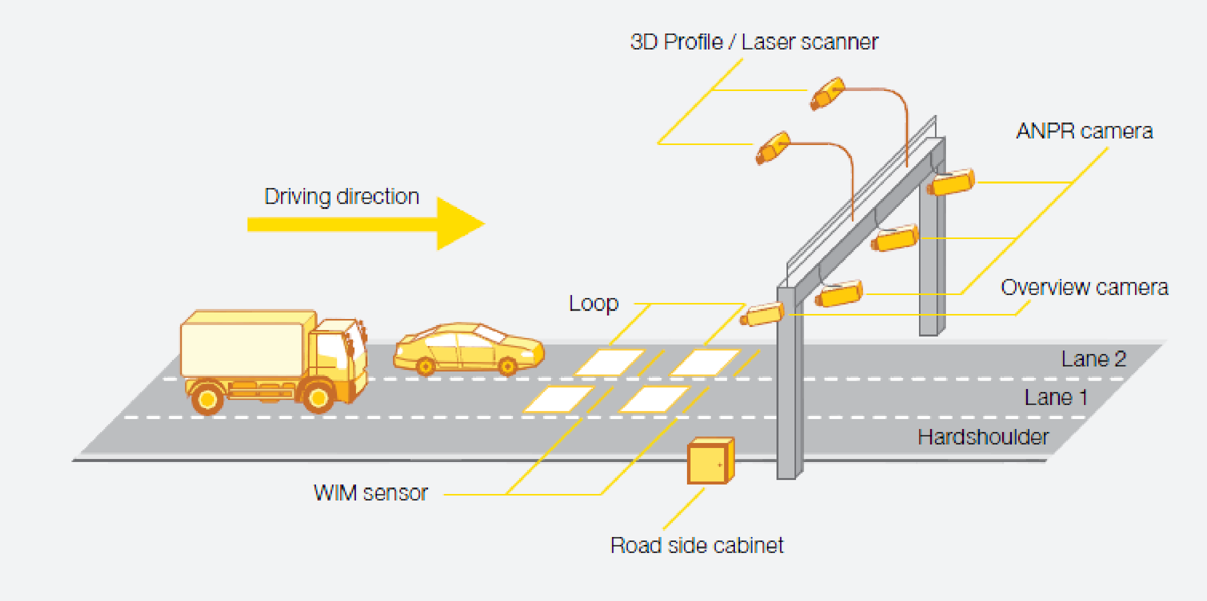

Fig. 1. High-speed weight-in-motion system

Two to three piezoelectric sensors (of the Kistler Lineas quartz type) are installed in the pavement to weigh, with a high accuracy, a vehicle in motion at up to 250 km/h. The control unit with evaluation electronics is installed in a cabinet in a safeguarded location near to the check gate.

Kistler Lineas quartz sensor

The sensor consists of a weighbridge mounted onto an aluminium alloy section. Two quartz plates are placed in the middle of the section to generate an electric impulse when loaded (based on the piezoelectric principle), with the signal directly proportional to the gravitational force of the wheel. The sensor is isolated from lateral forces by means of a special flexible material.

The load measurement accuracy is neither influenced by the tyre type, tread pattern or pressure, nor the number of tyres. In the case of dual tyres, the sensor generates a single signal, which is expressed as a single-wheel load, equivalent to the sum of the two-wheel loads.

The sensor is inserted in a slot in the pavement and fixed by a grouting compound (supplied by the manufacturer) made of an epoxy material and sand. The surface is then ground to a level [3,5].

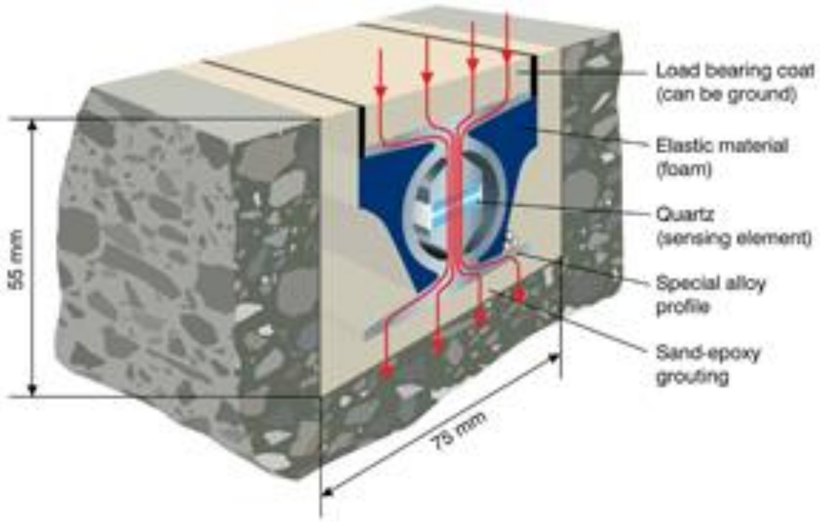

Fig. 2. Kistler Lineas quartz sensor design

Tab. 1

Technical parameters of the Kistler Lineas 9195E sensor

Technical parameter	**Value**
Accuracy class [%]	2
Range wheel load [kN]	0-150
Load-bearing capacity on the sensor surface [N/mm^2]	6
Operating temperature range [ºC]	-40÷70
Temperature coefficient (sensitivity) [%/ºC]	-0.02
Sensor length [m]	1.5/1.75/2.00
Sensor length [m]	40/100
Degree of protection	IP 68
Position	Stationary

2.2. Weighbridge

A weighbridge is a device designed to measure the weight of a passenger car, a truck, or a truck and trailer combination. There are two basic design types: an above-ground version and a pit version.

An above-ground weighbridge comprises load cells, evaluation electronics, a weighbridge, an approach ramp and a departure ramp. It is usually designed as a steel structure with a weighing capacity between 1 and 80 t and a length ranging between 5 and 20 m. The scale may be positioned on either a paved ground or a concrete road surface that has a sufficient load-bearing capacity and is appropriately level. Where the device is to be installed on a concrete road, concrete bases are usually provided for the load cells. The design must reasonably provide for the approach of a vehicle.

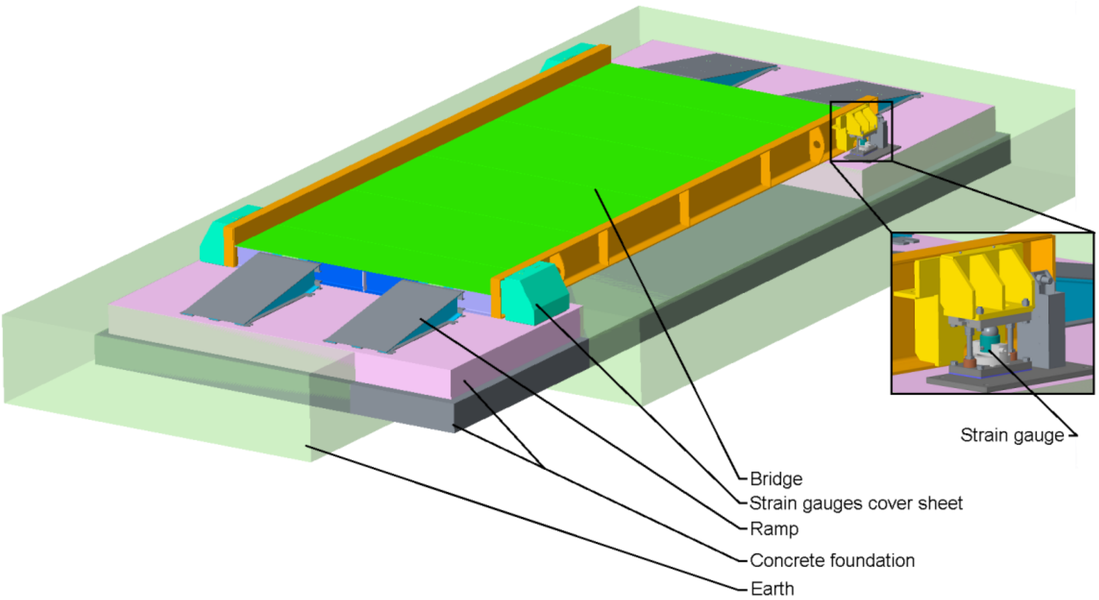

Fig. 3. Above-ground weighbridge

A pit-mounted road weighbridge does not pose any obstacle and is, therefore, usually installed in locations where the available space is limited by adjacent structures. The installation depends on the prefabricated pit, the location layout and the slope of the road. Lengths vary within the range of 8 to 24 m. The bridge may be designed as either a steel structure with a load-bearing capacity of 60 t or a steel shell filled with high-performance concrete with a load-bearing capacity of up to 120 t.

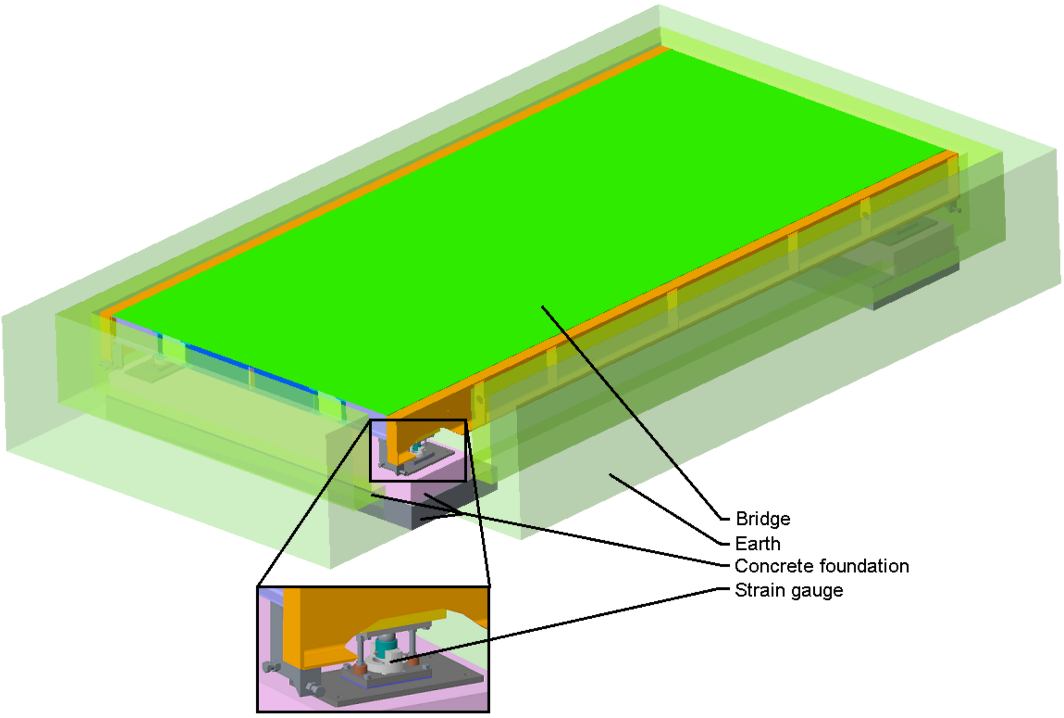

Fig. 4. Pit weighbridge

2.3. Axle measurement system

An axle measurement system comprises a control and evaluation unit and an even number of axle scales (two scales for each vehicle axle to be weighed).

An axle scale is made of an aluminium weighbridge, which is set on four, six or eight load cells. The measurement range is up to 3, 6, 10, 12 or 20 t. Smooth passage over the bridge is facilitated by approach and departure ramps with a structure made of steel or a hardened material [1].

The evaluation unit is enclosed in a protective case made of a strong, but flexible, impact resistant copolymer to ensure safety. During the measurement (using a static method, or a dynamic method for LS-WIM systems), the unit processes the electric signal generated by the scales, which is transmitted via 15-m cables or Wi-Fi. The resulting weight reading is shown on the display or printed in a paper-based measurement report.

Fig. 5. Axle measurement system

3. AXLE SCALE DEVELOPMENT

The customer who initiated the project requested six mobile scales to be developed for an existing control and evaluation unit. The system was required to be able to weigh any vehicle with a mass of up to 40 t and no more than three axles in any place with a paved surface.

3.1. Requirements for the axle scale development

Requirements for the axle scale development are:

- Axle scale measuring range: up to 10 t/wheel
- Maximum dimensions of a scale with ramps: (WxLxH): 500x11,000x60 [mm]
- Scale capacity: vehicles with two or three axles up to 40 t in weight
- Manufacturability within the company's own capacities
- Mobility and simple handling
- Reasonable project costs

3.2. Design of the chosen axle scale alternative

The axle scale system incorporates a weighbridge and load cell units. The weighbridge is designed as an aluminium alloy plate deck with weight reduction slots, two handles and sliding locks to secure the passage ramps against movement. Two wheels are provided on the right-hand side to facilitate the handling. The scale electronics is mounted on the bottom side of the deck in a steel enclosure. The enclosure partially enhances the rigidity of the deck. Four load cell units are screw-mounted to the deck.

A load cell unit contains a HBM C9C load cell, which is mounted in a slot of the unit base. Three screws are provided on the base, turned by 120º to secure the sensor against movement in the x-axis and y-axis directions (offset). A steel roller is fitted between the top cover and the measurement surface of a tension meter to provide the single-point force transmission. The top cover is fixed to the base by two screw rods, each with two nuts [4,6].

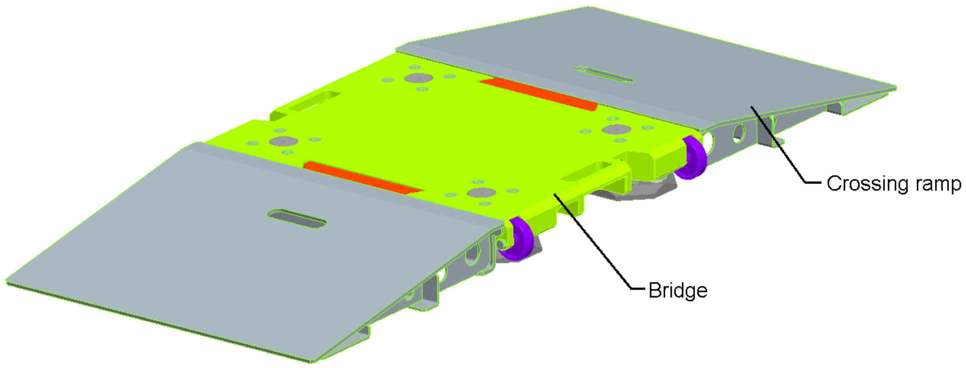

Fig. 6. Axle scale

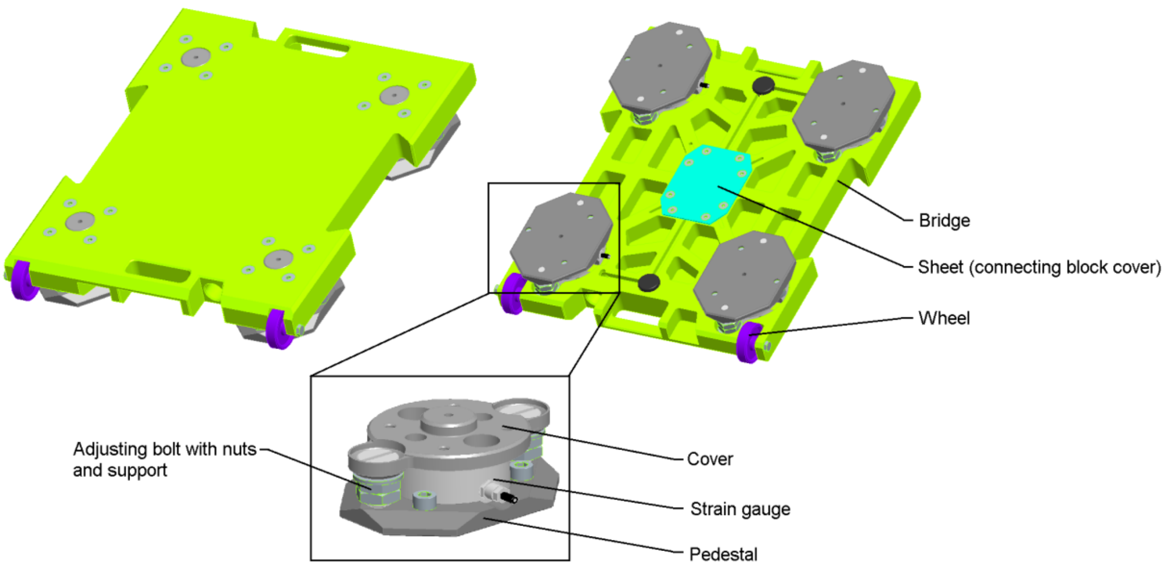

Fig. 7. Axle scale with a load cell unit

Tab. 2

Technical parameters of the designed axle scale

Description	**Unit/characteristics**
Weighing capacity [kg]	10,000
Readability - scale division [kg]	5
Nominal sensitivity [mV/ V]	2±0.2%
Function	Weighing (static/dynamic)
Weighing speed [s]	≤10
Deck dimensions (WxL) [mm]	500x400
Dimensions of the scale with ramps: (Wx LxH) [mm]	500x1,100x60
Scale weight [kg]	35
Structure material	Steel/aluminium
Standard operating temperature [°C]	-10÷40
Operating temperature limit [°C]	-40÷70
Data transmission	Cable
Position	Mobile
Protection class	IP 68

3.3. Simulation

The proposed axle scale design was subjected to an FEM-based strength analysis in the Static Structural module of the Ansys Workbench software. The static weighing of a truck was simulated. The simplified simulation model incorporated a weighbridge (material: aluminium alloy) and a cabling enclosure (material: steel). The contact surface between the deck and the truck wheel was modelled using an FEM mesh of 23,278 elements with 43,209 nods. The contact surface was loaded with a force (F) of 100,000 N (the gravity transmitted by a wheel from the axle). The seats of the load cell units were fitted by means of a fixed support and a frictionless support. The model also provides for the gravity of the weighbridge itself (gravitational acceleration (g) of 9.8066 m/s; see Fig. 8).

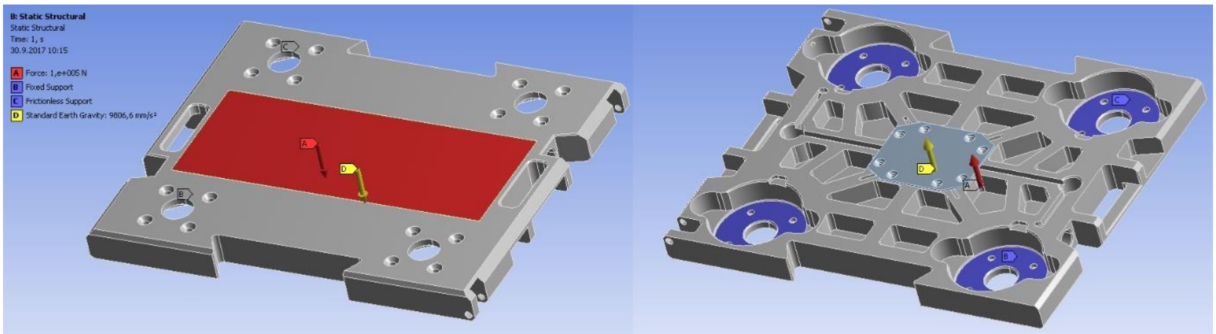

Fig. 8. Scale simulation model

3.4. Results

The outcome of the FEM simulation is the maximum plate deflection of 0.221 mm and tensions ranging from 25 to 100 MPa, which occur in the centre of the bottom side of the scale (Figs. 9-10). The agreed yield strength of the chosen aluminium alloy material is Re_{min}=260 MPa and ultimate tensile strength is R_m=675 MPa. The agreed yield strength of the chosen steel material is Re_{min}=180 MPa and ultimate tensile strength is R_m=380 MPa. The former implies that the proposed axle scale design meets the strength requirements.

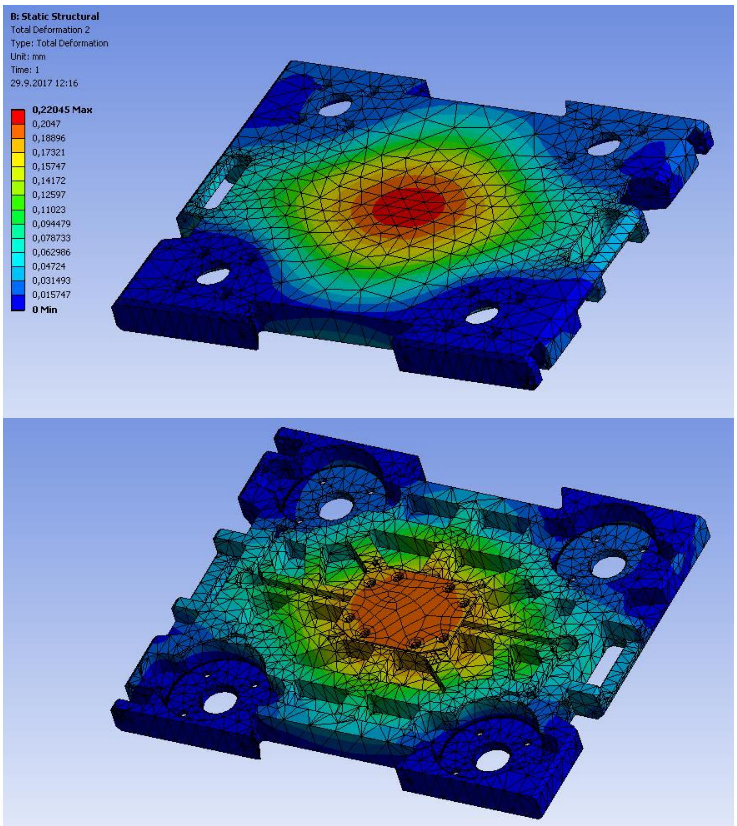

Fig. 9. FEM simulation result

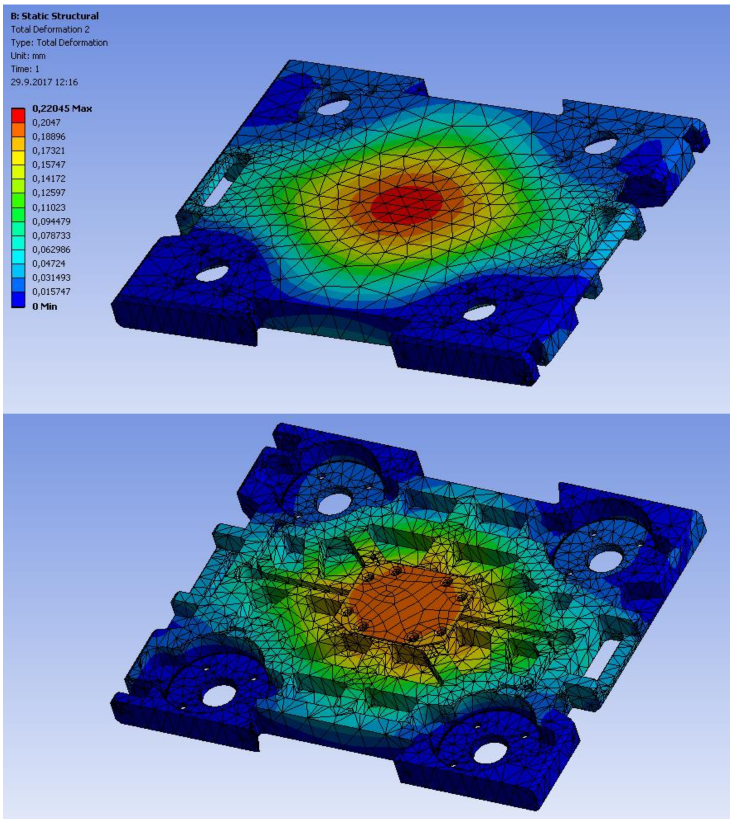

Fig. 10. FEM simulation result

4. DISCUSSION

The FEM simulation in ANSYS Workbench demonstrated that the proposed axle scale design meets the strength requirements based on the anticipated loads. The FEM analysis results are consistent with the strength calculations performed at the device development stage. Hence, one pair of test prototypes was fabricated and tested in practice. The test prototypes passed the tests successfully [2].

5. CONCLUSION

The first part of this article provided a brief overview and description of weighing systems and devices currently used in traffic applications. The second part of the article described the development of an axle scale that meets all the requirements of the customer. As a particular advantage, the scale features a mobile design, easy installation and a favourable cost. The scale is able to weigh trucks with two or three axles and a total mass of up to 40 t.

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