

**SIMULATION AND EXPERIMENTAL STRESS ANALYSIS OF
THE WASTE COMPRESSION ASSEMBLY IN UTILITY
VEHICLES FOR THE REMOVAL OF THE COMMUNAL WASTE
"NORBA" TYPE WITH TWO ACTUATORS**

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Abstract. *The paper deals with the accuracy problem of applying the finite element of tetrahedron type. The variable quality of modeling a solid continuum with a finite element tetrahedron and hexahedron is presented by using several examples. The analysis is directed towards the dependence of the basic finite elements accuracy on the character of the external construction load. The results of numerous comparative FEM and control experimental analyses are given. The presented examples show where the precision of discrete models is compromised and warn against the possibility of presence of large errors in analyses.*

Key Words: *Utility Vehicles for the Removal of Communal waste, FEM Analysis, Experimental Stress Analysis*

1. INTRODUCTION

Utility vehicles for communal waste transport are motor vehicles from regular production programs of motor vehicle manufacturers, upon whose chassis (using special pre-torqued bolts) a specific upgrade adjusted to particular use is mounted, in this case for compression and transport of communal waste. Due to frequent failures of certain parts of the waste compression system also known as sweep-and-slide, the need arose to determine whether the examined system was designed badly or some other factors caused failures. Therefore, the analysis of stress states in the part that was subjected to the highest load of the waste compression process was conducted. The analysis included only the examination of the vehicle upgrade, that is, the part for compressing communal waste into the main waist container on the system entitled "NORBA" – Fig. 1.



Fig. 1 "Norba" utility vehicle for communal waste transport

The compaction mechanism for waste compression of the "NORBA" system may have one (in vehicles with lesser waste capacity) or two hydraulic cylinders (in vehicles with greater waste capacity). Regardless of the number of cylinders, the "NORBA" system possesses two rotational elements: a) the compactor plate or compactor knife, b) waste receiver. These elements rotate around the axis perpendicular to the vehicle movement direction.

2. WORKING PRINCIPLE OF THE "NORBA" SYSTEM FOR WASTE COMPRESSION

On the examined vehicle the communal waste content is manually deposited from waste bins and cans into the waste receiver – Fig. 2. When the waste receiver is full enough, it is lifted from the lower position by the hydraulic system into the working position where the compactor plate compacts and compresses waste towards the main waste container – Fig. 3. Each new bin load takes up new volume inside the main waste container, before which it is compressed by the compactor plate to a volume defined by waste deformability and strength of hydraulic cylinders that push the plate. The photographs in Fig. 4 illustrate the working cycle in real conditions.

From the standpoint of kinematics, the waste compression system is an inverted slider crank mechanism driven by hydraulic cylinders, which consequently leads to the rotary movement of the compactor plate for a certain angle. The driving angle between the hydraulic cylinders and the compactor plate is most inadequate in the initial position of compression operation, thus the loading of the mechanism parts is highest at that position.

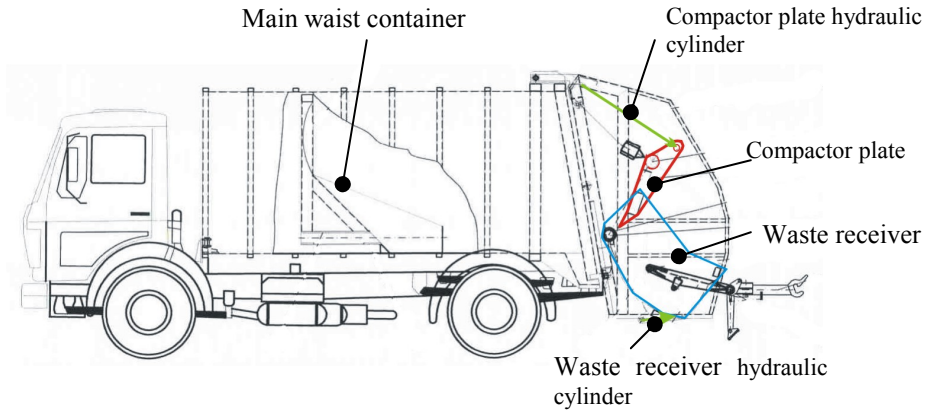


Fig. 2 The configuration of the waste compression system in the position of loading the waste receiver

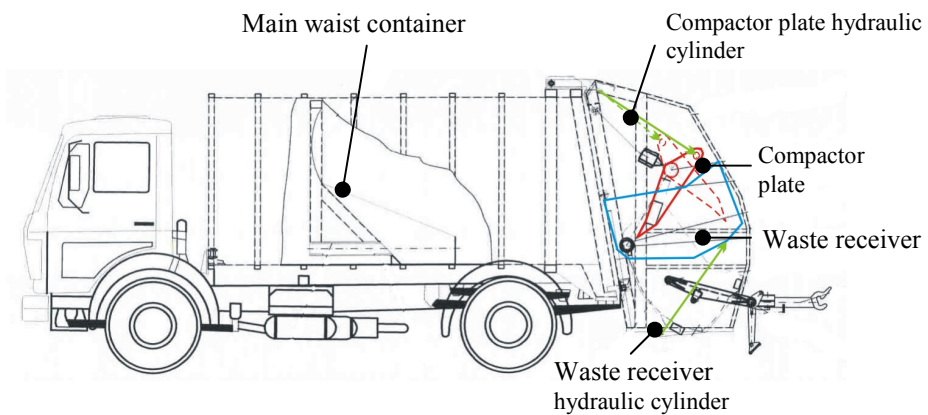


Fig. 3 The configuration of the waste compression system at the movement of the compactor plate



Fig. 4 The waste compression working cycle on a "Norba" system vehicle

3. MODELING OF THE STRESS STATE OF THE COMPACTOR PLATE

The mathematical model of the stress state of the compactor plate would be almost impossible to calculate without the existence of software solutions that offer the possibility of obtaining the stress state of a particular part using the finite element method (FEM method). The software package "SolidWorks" with its stress state modeling section "SolidWorks Simulation" was used for the analysis of stress state by applying the finite element method. Firstly, a three-dimensional model of the compactor plate was made using the received documentation, and it was selected as the most loaded part of the construction where failures occur during exploitation.

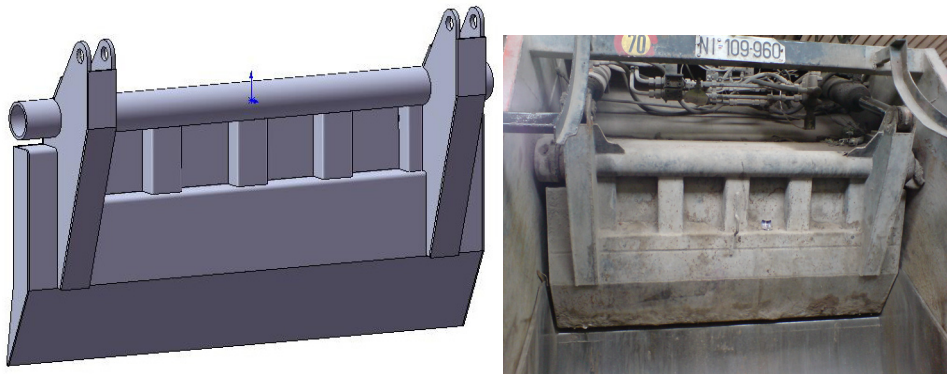


Fig. 5 The three-dimensional model and the actual look of the compactor plate

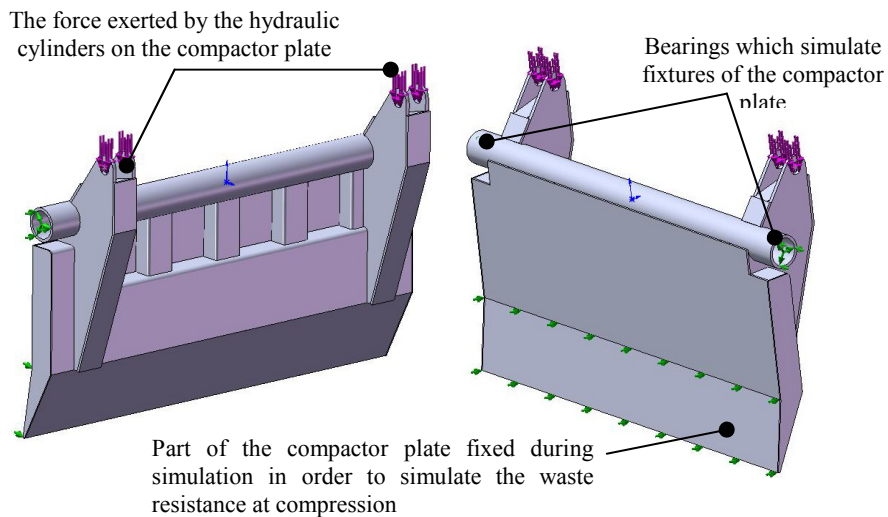


Fig. 6 Setting the boundary conditions in the analysis using the finite element method

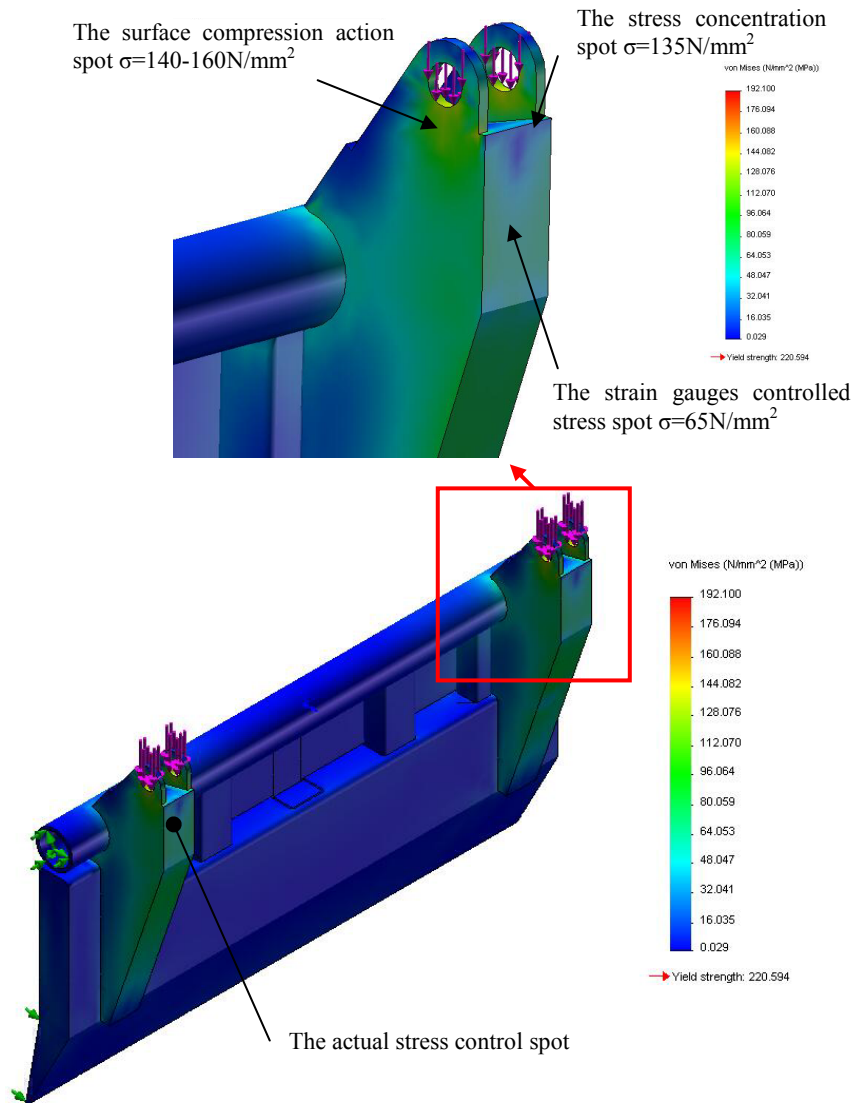


Fig. 7 The stress state obtained using the finite element method

The stress state modeling was conducted by setting the boundary conditions, which define the leaning spots of the compactor plate and the forces which are exerted upon it. According to the technical documentation data of the waste compression system manufacturer, the maximum force generated by the hydraulic cylinders at working compression ranges from 300 to 320 kN per cylinder. The force is conveyed to the compactor plate in the leaning spots – mounting brackets of the compactor plate. The compactor plate leans over its bearing groups at the edges of the plate which allow the plate to rotate around its

axis. The simulation of waste which resists the movement of the compactor plate is done by setting the boundaries on the front side of the plate as an immovable support, since the highest loading occurs exactly at the moment when waste can no longer be compressed – Fig. 6.

The obtained results show that stresses do not exceed the elasticity boundary, even at the spots of concentration of stress and surface compression action. Since the exact material out of which the compactor plate was manufactured was not known, the weakest material with characteristics similar to S.0361 steel was selected. The spot where stress would be experimentally set, that is, the spot where strain gauges would be positioned, was conditioned by the state of the examined compactor plate.

4. EXPERIMENTAL TESTING OF THE STRESS STATE OF THE COMPACTOR PLATE

On the located spots, the bending stress state measurements were conducted using a measurement-acquisition system with strain gauges. The measurements were conducted by strain gauges LY 10 – HBM ("Hotinger Baldwin Messtechnik"), and the signals were transmitted using cables to the digital measuring amplifier DMC 9012A of the same manufacturer, and processed by software BEAM, ver. 3.1, also by the same manufacturer. The measurement equipment is of laboratory class accuracy (Fig. 8).

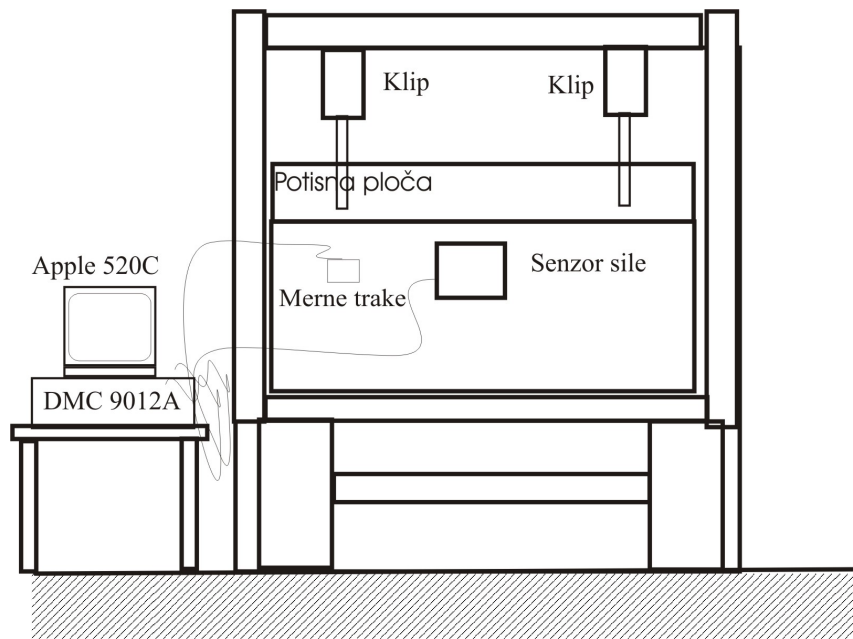


Fig. 8 A schematic representation of the measuring equipment and positioning spots of strain gauges and force sensors

Fig. 9 shows the spots and manner in which strain gauges were positioned. Strain gauges were secured by metallic filler in case of further use and due to the specificity of the waste transport vehicle line of work.

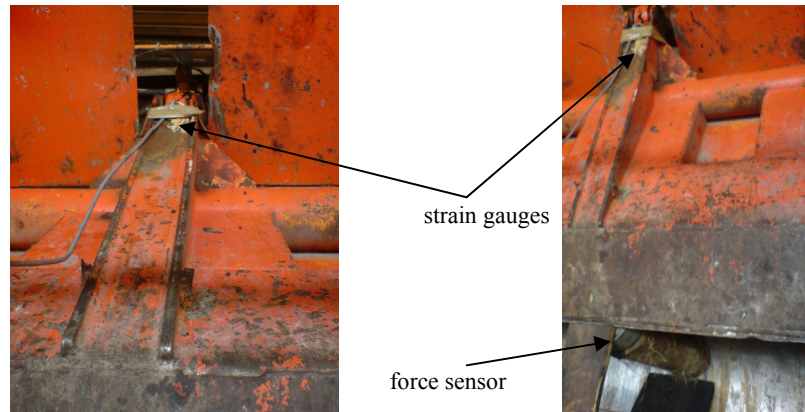


Fig. 9 Positioning spots of strain gauges and force sensors on the compactor plate

In order to determine the correlation between the force that compacts waste and the measured stresses, it is necessary to measure the force exerted upon waste by the compactor plate, and that is done by positioning the force sensor C6-200t. The sensor is secured from local overload by a wooden log, and the test results are shown in Fig. 10.

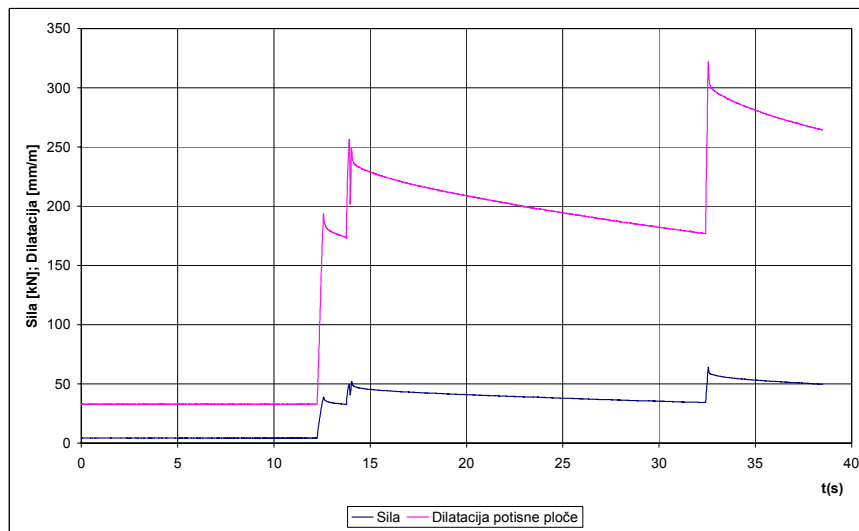


Fig. 10 Diagram of dilatation and force on the compactor plate when exerted in the middle of the plate

If we take a look at the test results, we can see that the largest dilatation on the compactor plate for waste compression does not exceed the value of $\varepsilon=330 \mu\text{m}/\text{m}$. This practically means that the stress is in the region of Hook's law, and within a correct boundary at that, i.e. $\sigma=\varepsilon \cdot E$, where E is the elasticity modulus (Young modulus), that amounts to $E=2,1 \times 10^5 \text{ N}/\text{mm}^2$ for steel, which means that the highest measured stress is $\sigma=330 \mu\text{m}/\text{m} \cdot 10^{-6} \text{ m}/\mu\text{m} \cdot 2,1 \times 10^5 \text{ N}/\text{mm}^2=69,5 \text{ N}/\text{mm}^2$, which is within the region of allowed stresses for steel sheets from which the waste compactor plate structure is made. These elements are usually made of S.0361 and S.0561, that have the allowed bending stress at direct-alternating loading of $\sigma_{\text{doz sav}}=225-270 \text{ N}/\text{mm}^2$.

After having determined the magnitude of the stress-causing force at the measurement points, the measurement with actual waste was done, that is, in the real working conditions. The vehicle was loaded with regular waste in the field, and a single working waste compression cycle was done. The cycle was repeated several times and the test results are shown in Fig. 11. The obtained dilatation is smaller in comparison to the previous measurement – $\varepsilon=155 \mu\text{m}/\text{m}$, that is: $\sigma=\varepsilon \cdot E=155 \mu\text{m}/\text{m} \cdot 10^{-6} \text{ m}/\mu\text{m} \cdot 2,1 \times 10^5 \text{ N}/\text{mm}^2=32,5 \text{ N}/\text{mm}^2$. The cause of the reduced stress lies in the fact that waste is still being compressed even when the compactor plate is in its final position. This means that the stresses of real waste compression are smaller in comparison to the most unfavorable case when the wooden log, which has a much smaller degree of deformability than waste, was used to simulate waste resistance.

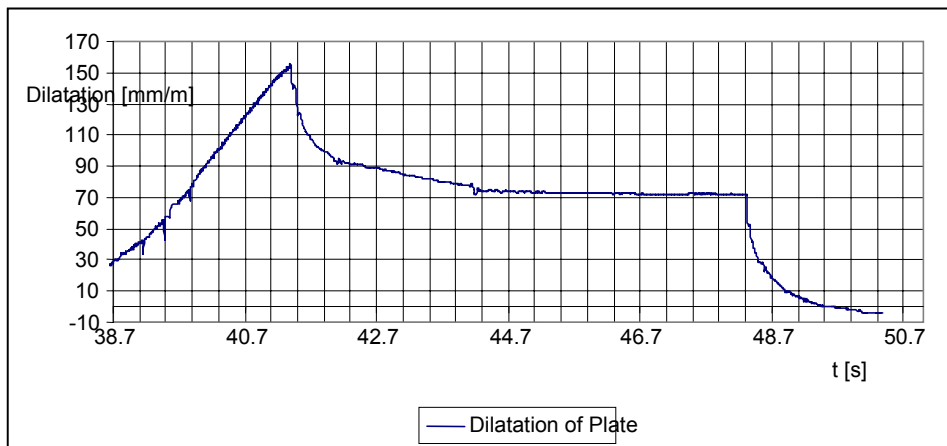


Fig. 11 Measured stresses on the compactor plate at compression of real waste

5. CONCLUSION

The application of the finite element method and software which enables it in the phase of design of new products can be considered as a modern approach to designing, and can usually be found in the engineering practice. However, this paper shows a new approach to the analysis of the problems of exploitation of mechanical systems by applying the stress state modeling. The modeling of a system for communal waste compression

with a compactor plate and two cylinders was done using the SolidWorks Simulation software, which includes the analysis of the stress state using the FEM analysis (Finite Element Method). Experimental verification showed that the measured stresses in a controlled section were $\sigma=69.5 \text{ N/mm}^2$, and the value of $\sigma=65 \text{ N/mm}^2$ was obtained through modeling which presented a very good agreement of model and reality. On the basis of the conducted experimental verification of the model, an opportunity arises for the analysis of exploitation problems by using the modern software package simulations, apart from expensive experimental methods, as it was done in this case.

The experimental tests proved that the compactor plate system is designed well in the view of predicted loading from the standpoint of designing, and that failures of waste compression system, that is, the compactor plate, most probably occur due to the functional breakdown in geometry, caused by the increased clearance in the control arm bearings, cylinder brackets. Also, they can occur due to the bearing design and the compactor plate for waste compression, including their path toward the waste receiver, which leads to additional loading that is not taken into consideration in the design. This practically means that more attention should be paid to geometry control, wear of mobile parts of waste compression mechanism, and integrity of their connections. The occurrence of exploitation failures should be prevented by an early discovery of worn-out parts and mechanism geometry errors caused by them.

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**MODELIRANJE I EKSPERIMENTALNA VERIFIKACIJA
NAPONSKOG STANJA POTISNE PLOČE KOMUNALNIH
VOZILA ZA PREVOZ SMEĆA TIPA "NORBA" SA DVA
PRITISNA CILINDRA**

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Komunalna vozila za odnošenje smeća koriste nadogradnju za sabijanje i prevoz komunalnog otpada. Najopterećeniji sklop tog sistema je sklop za sabijanje otpada koji u eksploataciji često strada. Modeliranjem i eksperimentalnom verifikacijom naponskog stanja potisne ploče za sabijanje otpada pokušao se naći uzrok čestim havarijama potisnog sklopa. Modeliranje je izvršeno korišćenjem modernih software-a za analizu konačnim elementima, čime je dobijen uvid u naponsko stanje potisne ploče pri delovanju pogonskih cilindara. Eksperimentalnim ispitivanjem naponskog stanja merno-akvizicionim sistemom sa mernim trakama za merenje napona u realnim uslovima i pri stvarnom opterećenju proveravani su rezultati dobijeni modelima.

Ključne reči: komunalna vozila za odnošenje smeća, analiza napona konačnim elementima, eksperimentalna verifikacija modeliranog naponskog stanja