GDAŃSK UNIVERSITY OF TECHNOLOGY

Journal of POLISH CIMAC

Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

# STRAIN GAUGE VERIFICATION OF NUMERICAL CALCULATIONS OF FRAME STRUCTURE OF SINGLE AXIS MANURE SPREADER

**Artur Cichański, Dariusz Skibicki, Zbigniew Lis, Michał Burak, Michał Stopel**

*University of Technology and Live Sciences in Bydgoszcz*
*ul. Kaliskiego 7, 85-789 Bydgoszcz, Poland*
*tel.: +48 52 3408235, fax: +48 52 3408245*
*e-mail:artur.cichanski@utp.edu.pl*

***Abstract***

*The study presents a manner of experimental testing of frame structure of single axis manure spreader. The work aimed at verification of strains determined by FEM in two areas. The first area was the manure box floor, which operated in harshest conditions. The other issue involved verification of correctness of maximum strains determined for the entire structure. Significant issue was to consider of variability of distribution and values of loads. The work suggests reflecting of the variable values through a set of manure box load variants describing stages of the manure spreader loading, unevenness of loading as well as unloading. Obtained by experiment values of stresses have been compared with results of numerical calculations by finite elements method which has proven their high compliance. Maximum stresses have been determined with accuracy of ca. 7%. A load variant affects determined strain values. Strains determined in variants reflecting loading and unevenness of load are characterised by a smaller error than in the case of variants reflecting unloading. This indicates to a greater accuracy of determination of strains with higher values.*

***Keywords:*** *agricultural machinery, manure spreader, strain gauge measurements, numerical analyses*

## 1. Introduction

Numerical analyses of construction resistance conducted with finite elements method allow for determination of stress condition in construction of complex geometrical form. Conditions for performance of such analyses require adaptation of a series of assumptions the most important of which is the continuum and isotropic characteristics of material mechanical properties [8]. Real constructional elements include defects resulting from technological process. The effects as well as inaccuracies of evaluation of boundary conditions and differences between nominal and real geometrical dimensions result in the fact that stresses determined numerically can differ from stresses present in real constructional elements during operation. In order to estimate values of such differences experimental tests of constructions are conducted.

One of the more commonly used methods of measurements of deformation in structural elements include resistance strain gauge measurements [7]. Deformations measured with the use of this method are compared to results of numerical analyses as averaged in a given cross-section [6] or reduced to a point selected on the surface of the considered object [3]. The difference between results of analyses and resistance strain gauge measurements made as part of the work [6] did not exceed 1%. In case of small-sized objects, where it is not possible to use a resistance strain gauge, experimental measurements are made with the use of laser methods [5]. The difference between results of analyses and laser measurements performed as part of the work [6] was approx.

9%. In case of large-sized objects with subassemblies creating various spatial configurations, the verification is done in various measurement points separately for each configuration [4]. In such conditions, each of the configurations can be characterized by a different error. An example of the error for a given measurement point presented in this work [4] and all considered configurations changed from -17.4% to 17.7%. Another method of verification of accuracy of FEM analyses is a verification done on the basis of analytical results [1]. Due to a different character of both modelling methods, an error resulting from comparison of the results may change with the change of boundary conditions.

In this work, we made verification tests of numerical analyses of the structure of a manure spreader bearing frame as described in the work [2]. Numerical analyses of strain of relatively long structures may give reliable results only for a certain range of work of the tested object [1]. Therefore, during experimental verification it is significant to consider variability of distribution and values of loads. The work suggests reflecting of the variable values through a set of manure box load variants describing stages of the manure spreader loading, unevenness of loading as well as unloading. The work aimed at verification of strains determined by FEM in two areas. The first area was the manure box floor, which operated in harshest conditions. The other issue involved verification of correctness of maximum strains determined for the entire structure.

## 2. The tested object

The tested object was frame construction of single axis manure spreader of carrying capacity of 14t (Fig. 1). Geometrical form of the tested frame structure was described in detail in the study [2]. Main frame beams are made of closed profiles 100x200. Frame is made of steel S235JR. On the one side the spreader is supported on both sides of rear axis. On the other side the spreader is supported at the end of tow bar in joint for single axis trailers. The load is distributed evenly across manure box floor, fixed with lateral ribs. Manure applicators frame is mounted in rear part of the box.

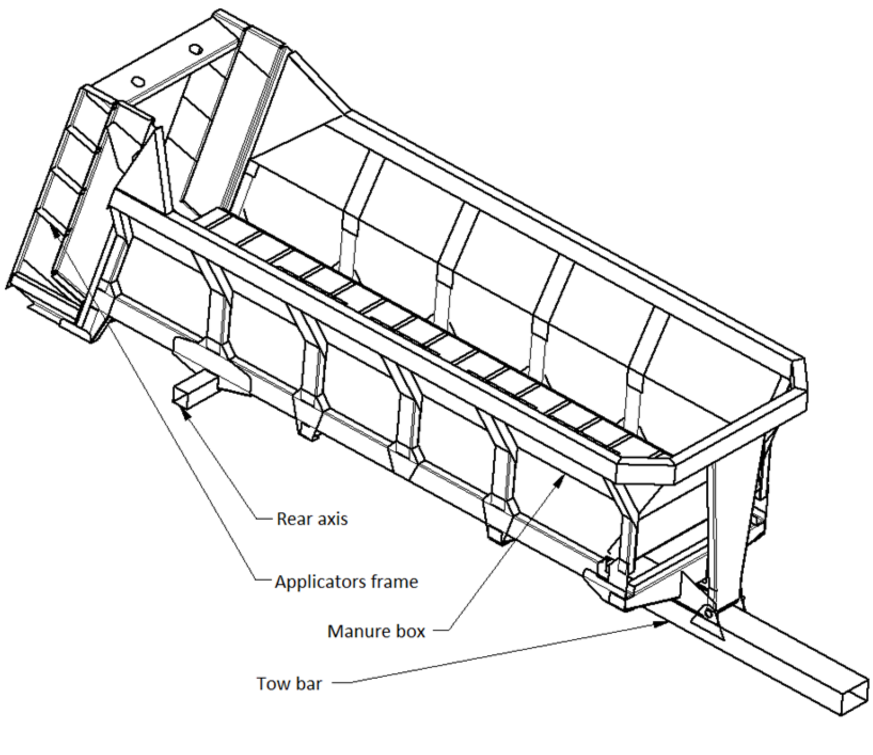


*Fig. 1. The tested object.*

## 3. Conditions for research performance

The analysis of the method of operation of the manure spreader indicates that the manure box floor is the part, which operates in harshest conditions. In the course of operation the floor is subject to greatest deformations. Its behaviour as a whole is determined, above all, by rigidity of the system of ribs. The results of numerical analyses [2] served as a reference for determination of most loaded ribs. In places, where extreme strains appeared, they indicated characteristic points on the surface the rib No. 7, 8 and 15. In order to verify the symmetry of load distribution, they indicated an ancillary point found on the surface of the rib No. 7 symmetrically to the axis of the manure spreader. Moreover, FEM analyses constituted a basis for determination of the third transverse beam as a place, where maximum strains for the tested structure can be found. Strain gauge measurements were conducted at these points. The diagram of numbering of strain gauges is presented on Fig. 2.

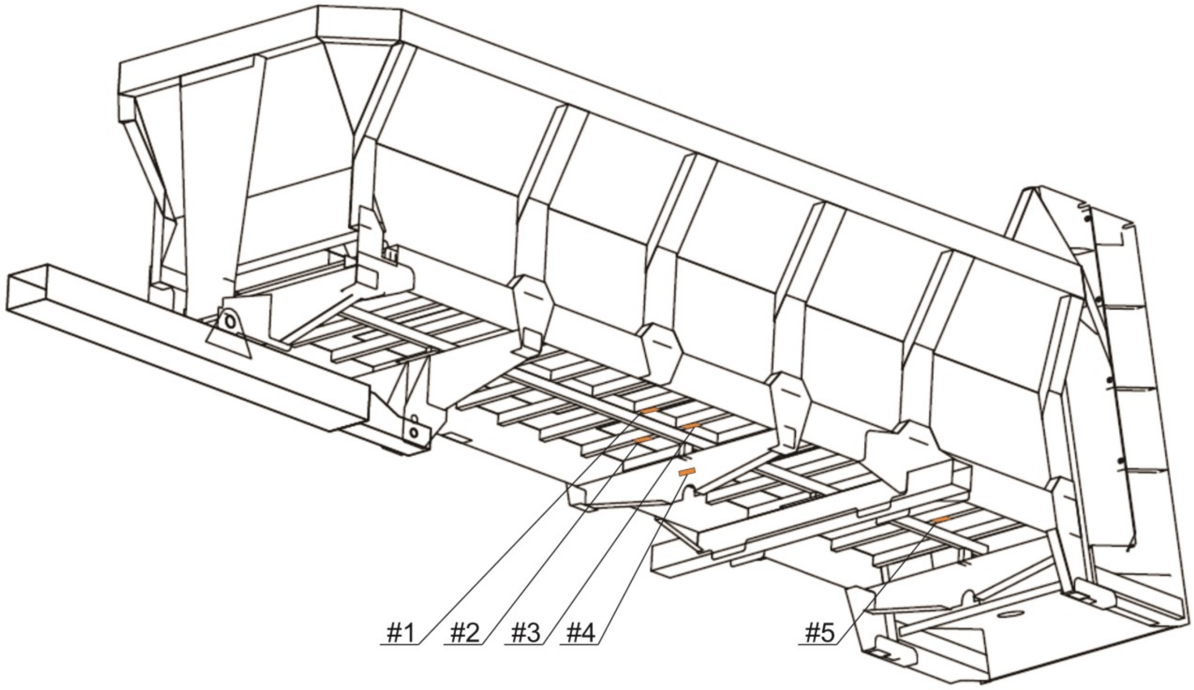


*Fig. 2. Diagram of numbering of strain gauges.*

Strain gauge No. 4 was located over recess in third transverse beam counting from tow bar side (Fig. 3). Other strain gauges were located in beams reinforcing the floor ribbed structure. Strain gauges No. 1 and No. 2 were located on rib No. 7 symmetrically along the spreader axis (Fig. 3). Strain gauge No. 3 was located on rib No. 8, and strain gauge No. 5 on rib No. 15 (Fig. 3).

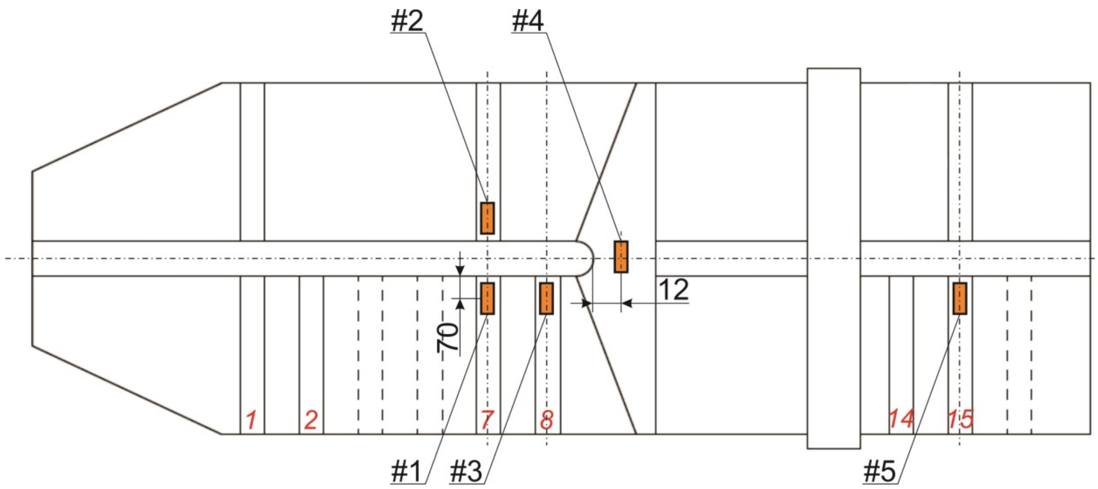


*Fig. 3. Diagram of location of strain gauges.*

Strain gauge measurements were conducted for the spreader loaded with various sets of forces applied to five areas specified on floor surface. Diagram of identification of the areas is presented on Fig. 4, and their location on Fig. 5. Measurements were conducted on the complete manure spreader. Load was applied at selected areas by locating one – three boxes of mass 540 kg each. Values of loads realized in subsequent variants are presented in table 1. During operation of the manure spreader, variability of loads results from the change of manure distribution along the length of the manure box. In the course of the tests they reflected load increase during the box loading in variant 1 to 4 (table 1). Unevenness of load distribution is reflected in variant 5 to 9. The load decrease during the box unloading is reflected in variant 10 to 14 (table 1).

For reading of values measured with tensometric sensors, 8-channel universal strain gauge bridge made by National Instruments – NI SCXI-1520 and USB module for acquisition of data of 16bits resolution and sampling frequency 200 kS/s – NI SCXI-1600 were used. For data recording NI LabVIEW SignalExpress software was used. During tests strain gauges made by HBM – 1-LY11-6/120-3-3m, of measuring base 6mm and fast drying glue 1-Z70 were used.

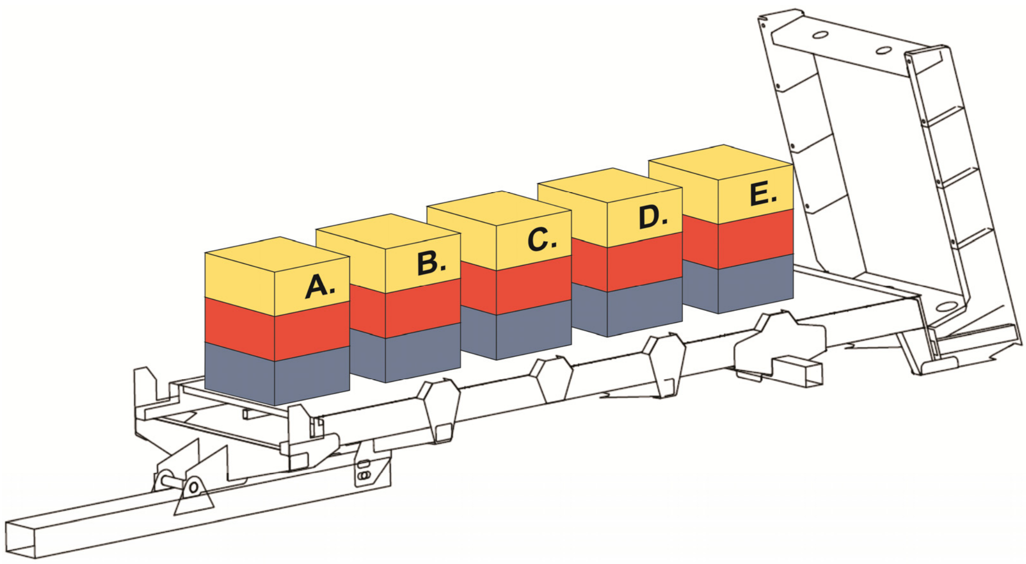


*Fig. 4. Diagram of identification of the areas for load application.*

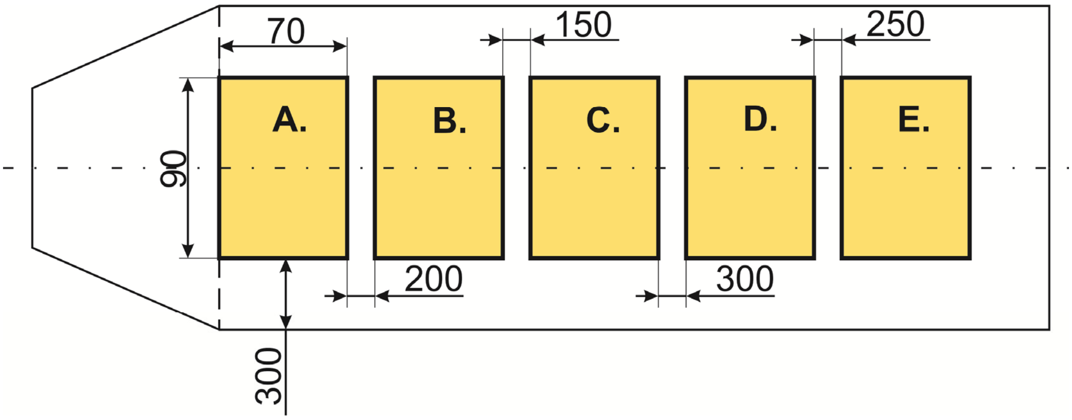


*Fig. 5. Diagram of location and size of the areas for load application.*

*Table. 1. Variants of load realized in subsequent measurements.*

| Variant | Load in the area [kN] | | | | |
|---|---|---|---|---|---|
| | A. | B. | C. | D. | E. |
| 1. | 16.2 | 16.2 | 10.8 | 0 | 0 |
| 2. | 16.2 | 16.2 | 10.8 | 5.4 | 0 |
| 3. | 16.2 | 16.2 | 16.2 | 5.4 | 0 |
| 4. | 16.2 | 16.2 | 10.8 | 10.8 | 0 |
| 5. | 16.2 | 10.8 | 10.8 | 10.8 | 5.4 |
| 6. | 10.8 | 10.8 | 10.8 | 10.8 | 10.8 |
| 7. | 5.4 | 10.8 | 10.8 | 16.2 | 10.8 |
| 8. | 5.4 | 10.8 | 16.2 | 10.8 | 10.8 |
| 9. | 5.4 | 16.2 | 10.8 | 10.8 | 10.8 |
| 10. | 5.4 | 10.8 | 10.8 | 10.8 | 10.8 |
| 11. | 5.4 | 10.8 | 10.8 | 10.8 | 5.4 |
| 12. | 5.4 | 10.8 | 10.8 | 5.4 | 5.4 |
| 13. | 5.4 | 10.8 | 10.8 | 5.4 | 0 |
| 14. | 5.4 | 10.8 | 10.8 | 0 | 0 |


*Fig. 6. Manner of loading of the tested frame structure*

## 4. Results of strain gauge measurements

Results of strain gauge measurements measured with strain gauge No. 1 for subsequent variants of load are presented on Fig. 7 with values of stresses read from FEM analyses at the location of strain gauge application. Results of measurements and numerical analyses for strain gauges No. 2 – No. 4 are presented subsequently on Fig. 8 to Fig. 10. Due to location of strain gauge No. 5 at edge area of manure box, for this strain gauge the reading was performed starting from load variant No. 7 from which load in rear part of manure box significantly increased (Table. 1).

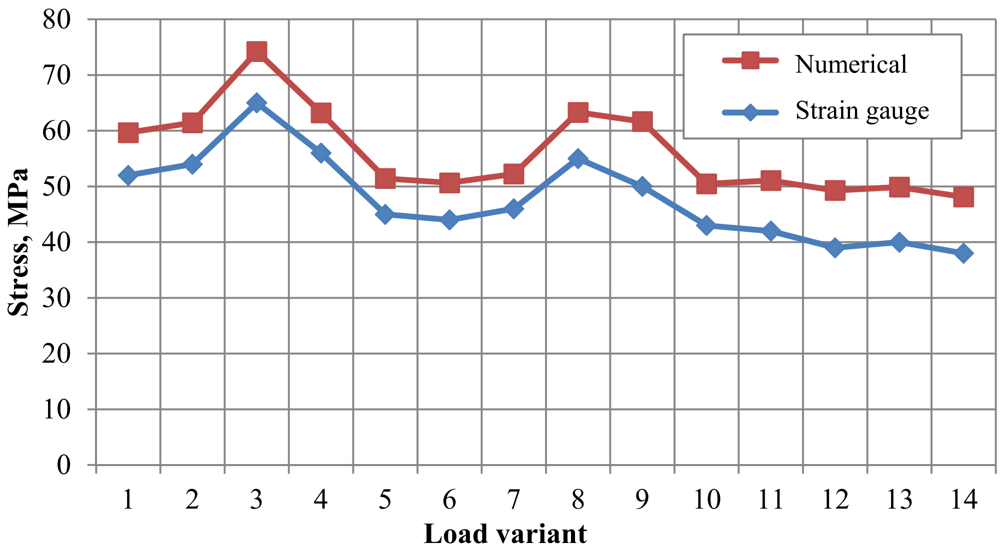


*Fig. 7. Results of experimental measurements and numerical calculations for strain gauge #1.*

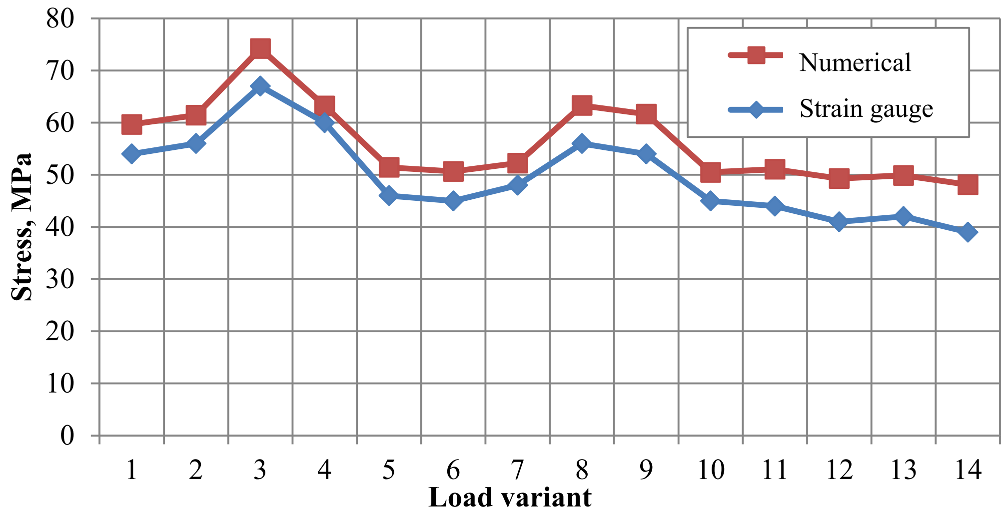


*Fig. 8. Results of experimental measurements and numerical calculations for strain gauge #2.*

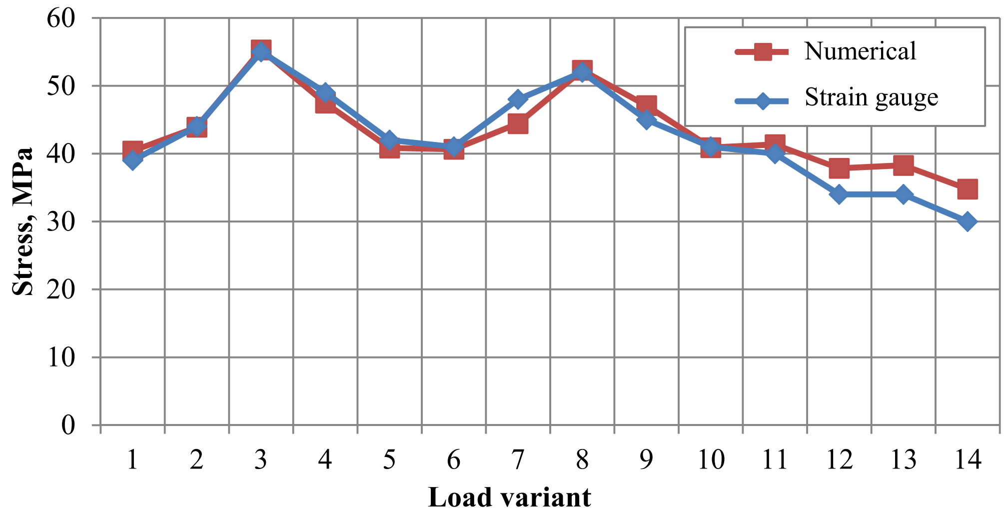


*Fig. 9. Results of experimental measurements and numerical calculations for strain gauge #3.*

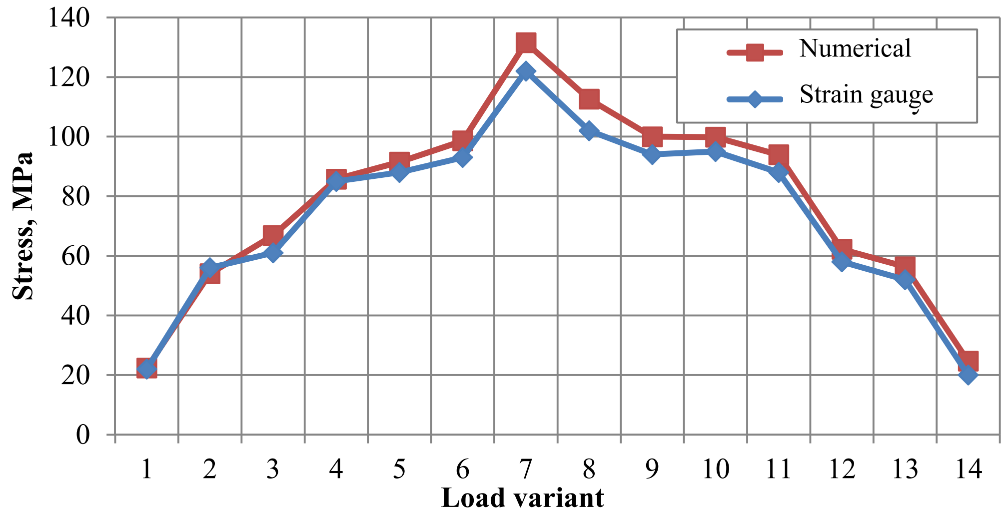


*Fig. 10. Results of experimental measurements and numerical calculations for strain gauge #4.*

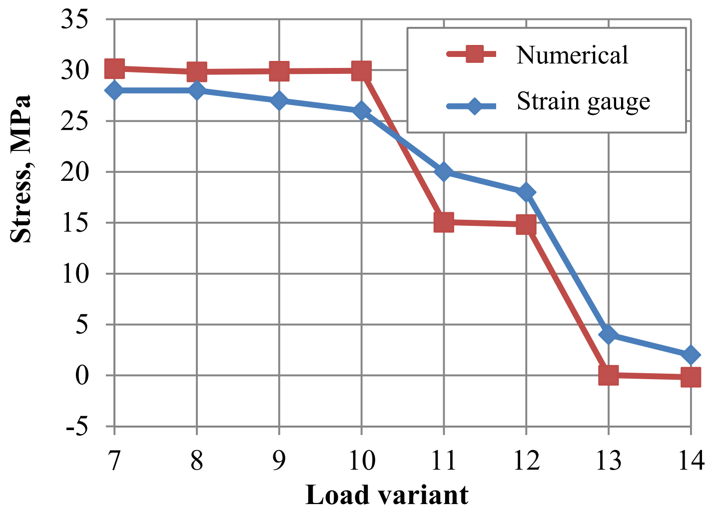


*Fig. 11. Results of experimental measurements and numerical calculations for strain gauge #5.*

For stresses obtained as a result of strain gauge measurements percentage error was determined from dependencies (1):

$$\delta = \left|\frac{\sigma_{FEM} - \sigma_{meas}}{\sigma_{MES}}\right| * 100\% \qquad (1)$$

Values of percentage error for each load variant calculated for individual strain gauges are presented in the form of a plot on Fig. 12. Due to the plot legibility readings of strain gauge No. 5, for which in case of stresses of several MPa significant error values were obtained, were omitted.

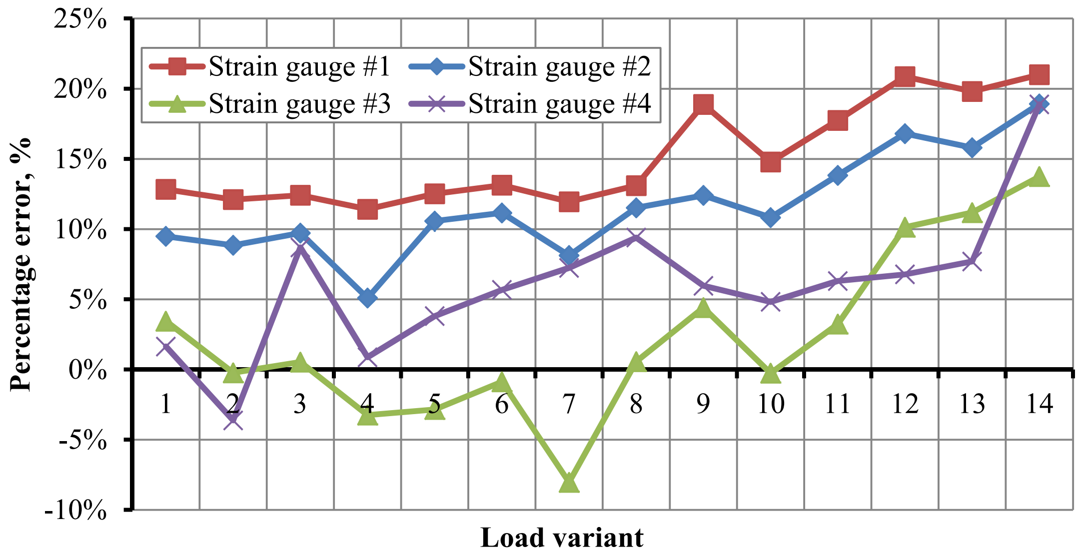


*Fig. 12. Strain gauge measurements errors*

Comparison of measurement error for strain gauges No. 1 and No. 2 indicates that the stresses determined at selected points located at right side of frame (Fig. 7) reach higher values than analogical stresses at left frame side (Fig. 8). Maximum stress value for the tested frame structure amounting to ca. 130 MPa was determined by strain gauge No. 4 for 7 variant of load with error not exceeding 10%. Maximum error for the whole analysis reached the value of ca. 20%. For strain gauges No. 1 to No. 3 starting from 8 load variant relative error increases as the stress value decreases.

## 5. Summary

The study presents the conditions for performance of strain gauge measurements of frame structure of manure spreader and values of stresses determined at selected frame structure points. Experimental measurement results were compared with FEM numerical calculation results. Good compliance between values of stresses specified by both methods was achieved which confirmed correctness of performance of numerical analyses. In the vast scope of comparison of results of calculations and measurements overestimation of values of stresses specified numerically was noted which locates measurement results on safe side. Increase of values of determined stresses was accompanied by increase of accuracy of calculations.

A load variant affects determined strain values. Strains determined in variants reflecting loading and unevenness of load are characterized by a smaller error than in the case of variants reflecting unloading. This indicates to a greater accuracy of determination of strains with higher values.

In the course of measurements they also found that strains in the manure box floor ribs and maximum strains for the structure had been determined correctly. They also found a slight asymmetry of distribution in the course of the manure box load during tests.

## References


[1] Chłus K., Krasoń W., Analiza wytrzymałości mostu składanego z uwzględnieniem luzów montażowych, Modelowanie Inżynierskie, 41, Gliwice, 2011, s.19-26

[2] Cichański A., Burak M., Stopel M., *Numerical analysis of frame structure of single axis manure spreader*, Journal of Polish CIMAC, Gdańsk, 2013.

[3] Dobrot O-M, Tocu F., Mocanu C.I, Numerical and experimental method to align 2500 TF press columns, Journal of Engineering Studies and Research, 18, 2012, s. 29-34

[4] Kosmol J., Wilk P. Doświadczalna weryfikacja numerycznego modelu pionowego centrum obróbkowego. Modelowanie Inżynierskie, 41, Gliwice, 2011, s. 187-195.

[5] Pilch Z., Trawiński T., Pomiarowa weryfikacja odkształceń ramienia aktuatora dysku HDD określonych metodą analityczną i MES, Modelowanie Inżynierskie, 42, Gliwice, 2011, s.342-350

[6] Ryś J., Malara P., Barski N., Analiza numeryczna wpływu sztywności uszczelki na obciążenie śrub w połączeniu kołnierzowym, Mechanika. Czasopismo Techniczne, Wydawnictwo Politechniki Krakowskiej, Zeszyt 5, Rok 108, Kraków, 2011, s.93-112.

[7] Roliński Z., *Tensometria oporowa: podstawy teoretyczne i przykłady zastosowań*, Warszawa, WNT, 1981

[8] Ugural A.C., *Mechanics of materials*, John Wiley&Sons, 2008.