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Experimental Study on the Structural Safety of the Tractor Front-End Loader Against Impact Load

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Abstract

Purpose: This study was conducted to experimentally investigate the structural safety of and identify critical locations in a front-end loader under impact loads. **Methods:** Impact and static tests were conducted on a commonly used front-end loader mounted on a tractor. In the impact test, the bucket of the front-end loader with maximum live load was raised to its maximum lift height and was allowed to free fall to a height of 500 mm above the ground where it was stopped abruptly. For the static test, the bucket with maximum live load was raised and held at the maximum lift height, median height, and a height of 500 mm from the ground. Strain gages were attached at twenty-three main locations on the front-end loader, and the maximum stresses and strains were measured during respective impact and static tests. **Results:** Stresses and strains at the same location on the loader were higher in the impact test than in the static test, for most of measurement locations. This indicated that the front-end loader was put under a severe environment during impact loading. The safety factors for stresses were higher than 1.0 at all locations during impact and static tests. **Conclusions:** Since the lowest safety factor was higher than 1.0, the front-end loader was considered as structurally safe under impact loads. However, caution must be exercised at the locations having relatively low safety factors because failure may occur at these locations under high impact loads. These important design locations were identified to be the bucket link elements and the connection elements between the tractor frame and front-end loader. A robust design is required for these elements because of their high failure probability caused by excessive impact stress.

Keywords: Experimental study, Front-end loader, Impact test, Structural safety, Tractor

Introduction

A front-end loader is attached at the front of a tractor to facilitate the carry and transfer of loads. It comprises a bucket, which directly carries the load; a boom, which is the connecting frame for the bucket; hydraulic equipment, which forms the hydraulic system controlling the bucket and boom movement; and other connecting components and supporting structures. The loader operation takes up 19% of the nation's annual tractor usage time. With the rotary tillage and ploughing taking up 45% and 29%, respectively, of the annual tractor usage time, the loader operation is one of the major field operations that require a tractor (Kim et al., 2011).

Many obstacles are encountered during field operations employing a tractor; these operations are often carried out on uneven ground conditions. Therefore, impacts due to collisions may occur during loading, unloading, and driving operations, and this may result in extreme stresses

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leading to failure of the loader structure. The design of the front-end loader of a tractor must guarantee safety against these impact loads. Furthermore, it needs to include procedures for analyses and testing of the loader to verify the design.

Till date, not many studies on tractor front-end loaders have been conducted. Some experimental studies include reducing the driving shock using an accumulator (Ahn et al., 2014) and developing a measuring system for the forces and acceleration of the tractor and front-end loader under various working environments (Simion et al., 2005). Some analytical studies include deriving stresses and strains during impact loads using kinematic and finite element analysis (Lim and Lee, 2015) and developing mathematical models to investigate the dynamic stability of tractor front-end loader systems (Simion and Nastase, 2009). There was an analytical study verifying the structural safety of the front-end loader for impact loads (Lim and Lee, 2015); however, until now, there has been no experimental studies confirming the safety of the front-end loader against impact loads.

This research was aimed at experimentally verifying the structural safety of the tractor front-end loader against impact loads. The stresses and strains generated during impact loads were measured by strain gages attached at critical locations on the front-end loader. Then, the structural safety was evaluated using the measured results. This study could serve as reference material for present and future tractor front-end loader designs.

Materials and Methods

Front-end loader and tractor used

In this study, a front-end loader was mounted on a tractor to perform the impact load test. The tractor used was the 4110 model of Tongyang Moolsan with rated power of 29.1 kW, weight of 17.6 kN, and wheelbase and ground clearance values of 1813.6 mm and 330 mm, respectively. Moreover, the front-end loader used was the KTS-763 model of Taesung, a parallel type loader with two boom and bucket cylinders (Han, 2012). It had a weight of 5.8 kN, maximum allowable load of 4.9 kN and bucket capacity of 0.45 m^3.

Tables 1 and 2 list the specifications of the tractor and front-end loader, respectively. Figure 1 shows the illustration of the tractor. The specifications of the tractor are important because they determine the dimensions of the front-end loader attached system. Frames for attachment of the front-end loader were fixed on each front side of the tractor, and the front-end loader was mounted on these frames through bolted connections (Figure 2).

Table 1. Specifications of the tractor used in this study

Item	Specification
Model/Company/Nation	4110/Tongyang Moolsan/Korea
Engine: rated power (kW)/speed (rpm)	29.1/2700
Weight (kN)	17.6
Length × Width × Height (mm)	3220 × 1500 × 2410
Wheelbase (mm)	1813.6
Ground clearance (mm)	330

Table 2. Specifications of front-end loader used in this study

Item	Specification
Model/Company/Nation	KTS-763/Taesung/Korea
Bucket capacity (m^3)	0.45
Weight (kN)	5.8
Maximum allowable load (kN)	4.9

Figure 1. View of the tractor used in this study.

Figure 2. View of the front-end loader attached to the tractor.

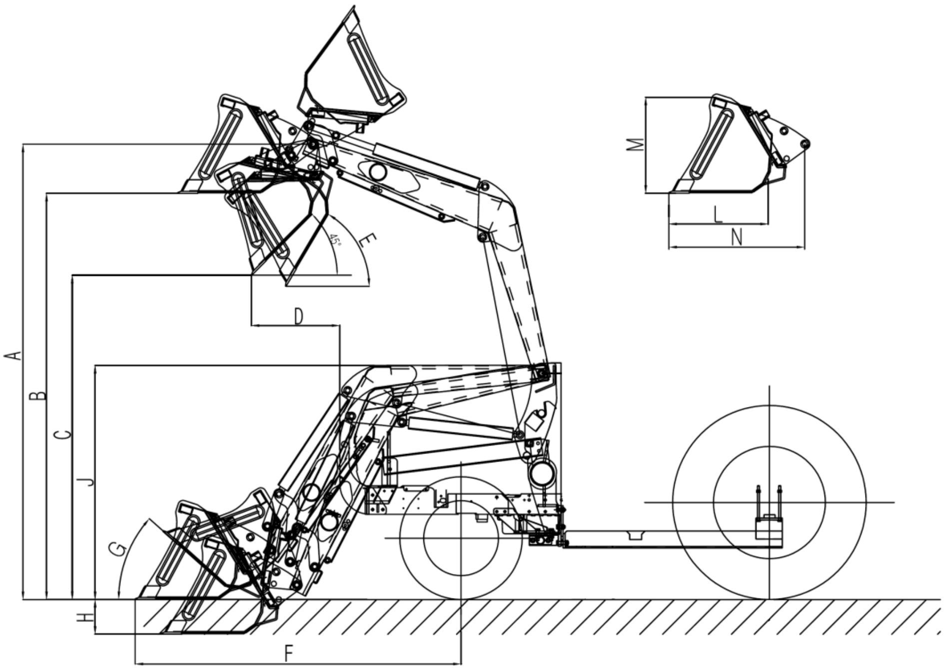


Figure 3. Schematic view of the front-end loader and tractor system.

Table 3. Main dimensions of the tractor front-end loader system shown in Fig. 3

Symbol	Item	Specification
A	Maximum lift height (mm)	2670
B	Clearance with attachment level (mm)	2382
C	Clearance with attachment dumped (mm)	1902
D	Reach at maximum height (mm)	521
E	Maximum dump angle (degrees)	59
F	Reach with attachment on ground (mm)	1910
G	Attachment rollback angle (degrees)	40
H	Digging depth below grade (mm)	195
J	Overall height in carry position (mm)	1373
L	Depth of attachment (inner shell) (mm)	584
M	Height of attachment (mm)	563
N	Depth of attachment (pivot pin) (mm)	798

Figure 3 and Table 3 show the schematic configuration of the front-end loader mounted on the tractor and list their main dimensions, respectively. Among the dimensions, lift height related variables are important in structural safety because they determine the stress levels acting on each component.

Test conditions

The front-end loader bucket was loaded to the maximum allowable limit of 4.9 kN using weights (Figure 4). For the impact test, the bucket loaded to the maximum allowable limit was raised to the maximum lift height. It was then allowed to free fall until a height of 500 mm off the ground, where it was stopped abruptly. This operation was repeated 20 times. During the test, the stresses and strains were measured at 23 locations on the front-end loader. Further, the static test was performed with the same bucket loaded with weights. In the static test, the bucket was raised to the maximum lift height (2670 mm), median height (1335 mm) and a height of 500 mm from the ground, and the stresses and strains were measured at the same locations as in the impact test.

Figure 4. Weight added on the bucket.

During the impact test, a large load acts on the front

Figure 5. Anchor to connect the tractor to the ground.

part of the tractor where the front-end loader is mounted. An anchor was thus used to maintain contact between the rear part of the tractor and the ground to prevent the tractor from overturning owing to moment imbalance between the front and the rear portions about its center of gravity (Figure 5).

Measurement platforms

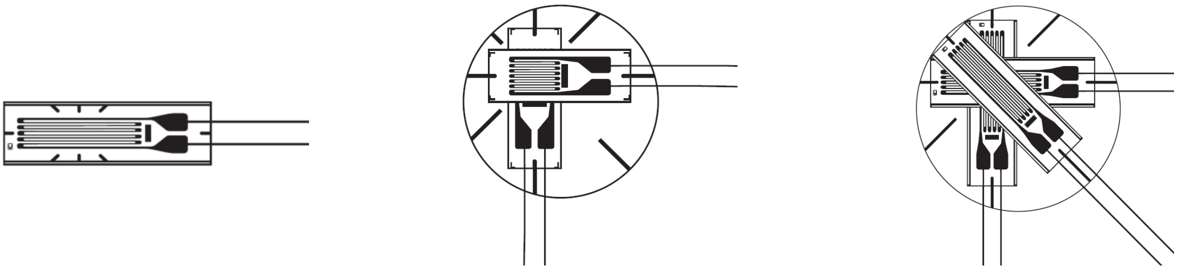
A strain gage was used to measure the stresses and strains during the impact and static tests. Three types of strain gages were used considering the structural layout of the locations and the directions of the applied external forces, as listed in Table 4. The type-1 strain gage measured strain in only 1 direction, while the type- 2 and 3 strain gages measured strains in 2 and 3 directions, respectively. For type- 2 and 3, the highest strain recorded was used in the results. The assembly pattern of each gage type is shown in Figure 6 (Kyowa).

Strain gage module of a data acquisition system (DEWE-3010) was used to measure and collect the strain gage signals. When the nominal resistance of a strain gage is given as input to the data acquisition system, the module automatically sets up the Wheatstone bridge circuit includ ing the strain gage, and the output to input voltage ratio of the Wheatstone bridge circuit is then generated corresponding to the strain gage signal. The strains and stresses at the measurement locations can be calculated by plugging in the values of the generated output to input voltage ratios in Eqs. (1) and (2) (Hannah and Reed, 1992) below.

The set up and specifications of the data collecting equipment are as shown in Figure 7 and Table 5. A low pass filter of 10 Hz was used to eliminate noise during measurements. For the impact test, the sampling rate was set to 2000 Hz, since a high peak strain occurs in a short

Table 4. Strain gages used in this study

Item	Specification		
	Type 1	Type 2	Type 3
Model	KFG-5-120-C1-11	KFG-2-350-D16-11	KFG-5-120-D17-11
Company/Nation	Kyowa/Japan	Kyowa/Japan	Kyowa/Japan
Gage pattern	Single element (uniaxial)	0°/90° rosette (biaxial)	0°/90°/45° rosette (triaxial)
Gage length (mm)	5	2	5
Gage factor	2.11	2.10	2.13
Maximum measuring strain (μm/m)	50000	50000	50000
Nominal resistance (Ohms)	120	350	120



(a) Type 1 (b) Type 2 (c) Type 3

Figure 6. Assembly patterns of the strain gages used.

Figure 7. Data acquisition system (DEWE-3010).

Table 5. Specifications of the data acquisition system

Item	Specification
Model	DEWE-3010
Company/Nation	Dewetron/Germany
Software	Dewesoft 6.4.1
Input voltage range (V)	10-32
Output voltage range (V)	-5-5 / -12-12
Operating temperature (°C)	-5-50

period.

$$\varepsilon = \frac{4}{GF} \times \frac{e_o}{e_i} \tag{1}$$

where ε = Strain (mm/mm)

GF = Gage factor

e_o/e_i = Output to input voltage ratio of the Wheatstone bridge circuit (V/V)

$$\sigma = E\varepsilon \tag{2}$$

where σ = Stress (Pa)

E = Modulus of elasticity (Pa)

Measurement spots

Twenty-three locations, including connecting parts and support structures of the front-end loader, were selected to measure the stresses and strains by attaching strain gages (Figure 8). These locations are ones at which large forces are likely to act. The measurement locations indicated in Figure 8 show that at locations L10 and L18, respectively, type-2 (biaxial) and type-3 (triaxial) strain gages were employed. At all other locations, the type-1 (uniaxial) strain gage was used. To ensure accuracy of measurements, the strain gages were attached only after the surface at each location was processed through a grinding technique to make it smooth (Figure 9).

Results and Discussion

Figure 10 shows the time history of the measured signal at location L3 during the impact test. This signal shows the pattern created during five rounds of repeated impact tests. In the beginning, while the front-end loader was being raised to the maximum lift height, the output to input voltage ratio, i.e., the measured stress and strain (the output to input voltage ratio is proportional to the strain, and the strain, in turn, is proportional to the stress as shown in Eqs. (1) and (2)) was seen to increase. However, once under free fall, this ratio started decreasing and demonstrated the peak stress value due to impact loading when the bucket was suddenly stopped at the 500 mm height above the ground. Similar signal trends were detected from measurement at other locations.

Figure 11 shows the signal time history at location L3 during the static test. The stress demonstrated a stair-step pattern as the front-end loader was held at a height of 500 mm from the ground, the median height, and the maximum lift height. The static stress value increased as the front-end loader was raised higher. Other measured locations showed similar signal patterns.

The largest stress was related to the ultimate stress for the front-end loader. Therefore, the peak stress during the impact test and the static stress at the highest lift height of the front-end loader during the static test were used to calculate the critical stress. Thence, the safety factors for stresses at each location were calculated using the critical stress (Table 6). The average value was used as the representative value during repeated tests. The front-end loader and tractor frame were manufactured with SS400 steel with yield strength of 400-500 MPa and modulus of elasticity of 200 GPa. The safety factor for stress was calculated based on the yield strength value of 400 MPa.

During the impact test, the interactions between several connecting components and support structures determine the dynamic effect acting on each subsystem. The impact load is shared by many subcomponents of the front-end loader, and the load magnitude is affected by the interactions. There are many factors influencing these interactions, such as shape, dimension, and connecting condition of each subcomponent. Owing to such complex interaction effects, there were some locations (L3, L7, L8, L9, and L13) demonstrating larger differences between the static and impact stresses than others. Further, the

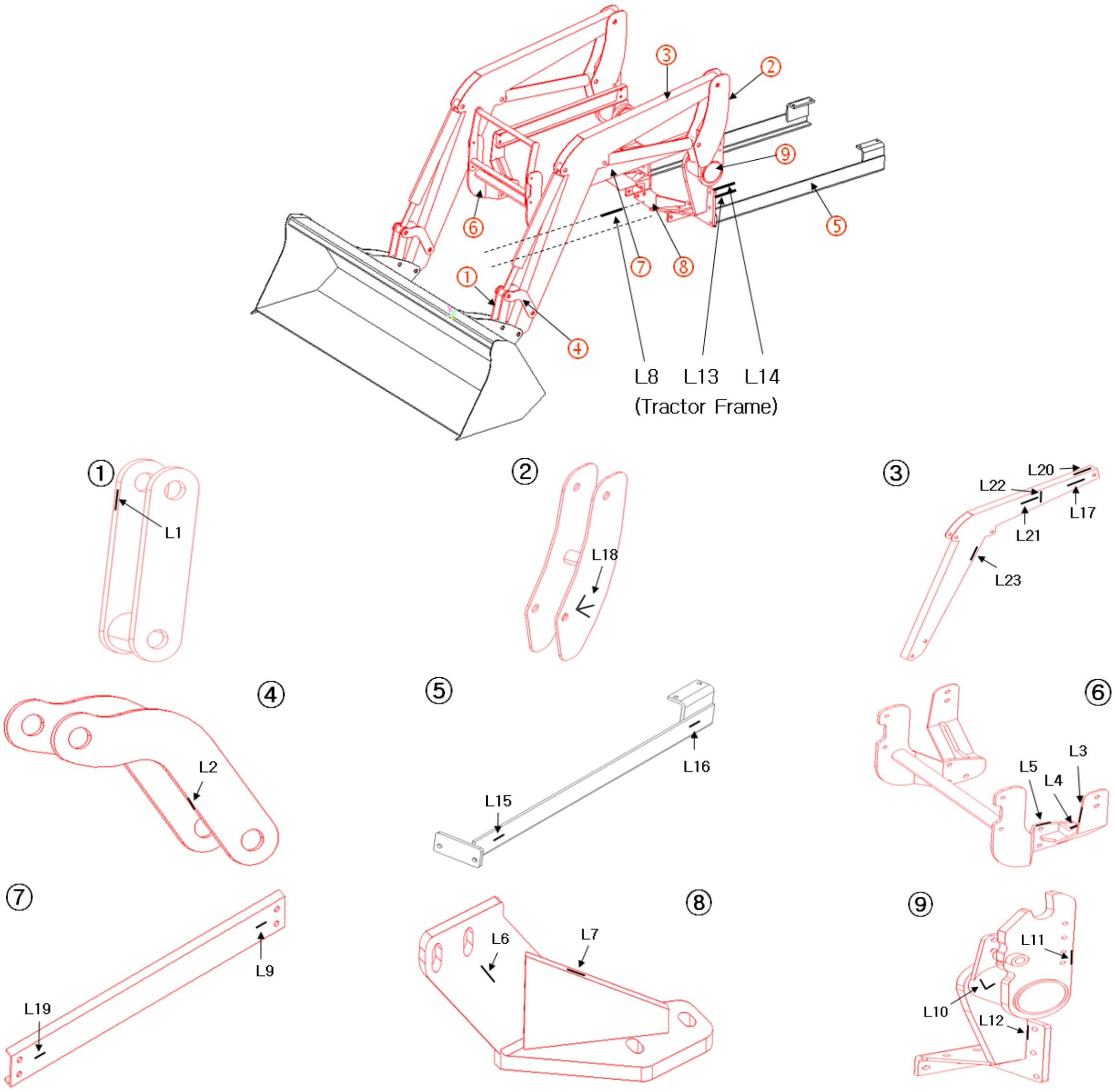


Figure 8. Strain and stress measuring locations.

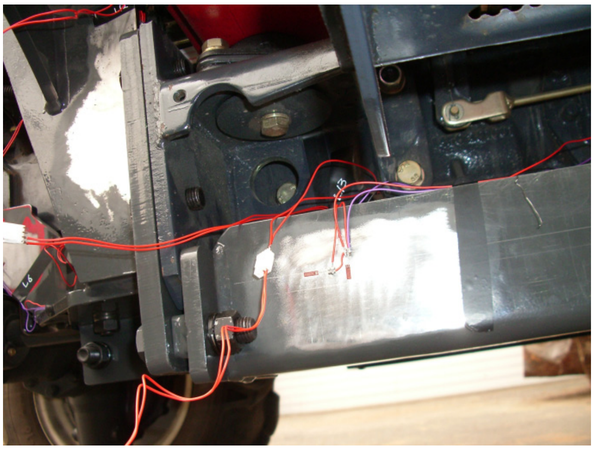


Figure 9. Strain gage attachment after grinding of the surface.

impact stress was less than the static stress in some locations (L2, L4, L10, and L11). In general, however, the safety factors during the impact test were comparatively lower than those during the static test at the same location. This means that the front-end loader was prone to greater damage when there was an impact, than when the maximum load was simply lifted to the maximum lift height. It can thus be concluded that the front-end loader is structurally safe from impact loads, applied in the same manner as shown in this study, because all the measured locations on the front-end loader had safety factors greater than 1.0 during the impact and static tests. However, the safety factors at L1, L2, L5, L12, and L13 locations had relatively low values of less than 2.0. These

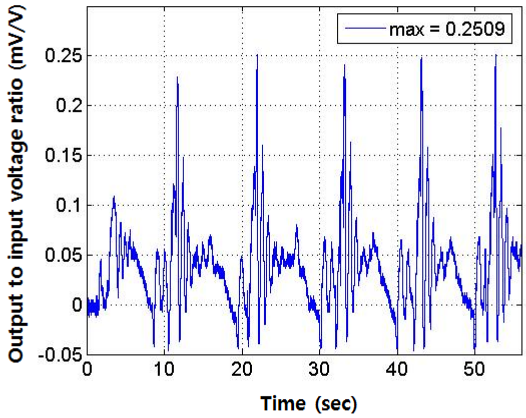


Figure 10. Measurement signal of L3 location during the impact test.

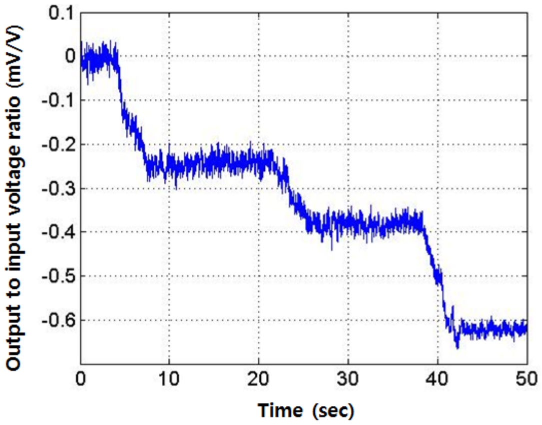


Figure 11. Measurement signal of L3 location during the static test.

Table 6. Measured strain and stress at each location

Gage location	Static test			Impact test		
	Strain (mm/m)	Stress (MPa)	Safety factor	Strain (mm/m)	Stress (MPa)	Safety factor
L1	-1.2499	-249.97	1.6	-1.6315	-326.29	1.2
L2	-1.6438	-328.76	1.2	-1.3892	-277.84	1.4
L3	0.0461	9.21	43.4	0.3839	76.78	5.2
L4	-0.1092	-21.84	18.3	-0.0320	-6.41	62.4
L5	-1.1929	-238.58	1.7	-1.5000	-300.00	1.3
L6	-0.3482	-69.65	5.7	-0.4297	-85.95	4.7
L7	-0.0131	-2.62	152.9	-0.1577	-31.55	12.7
L8	0.0053	1.06	376.8	0.3577	71.55	5.6
L9	0.0622	12.44	32.2	0.2914	58.27	6.9
L10	-0.3580	-71.61	5.6	0.3181	63.62	6.3
L11	-0.3105	-62.10	6.4	0.0936	18.73	21.4
L12	1.1046	220.93	1.8	1.6978	339.56	1.2
L13	0.0277	5.54	72.3	-1.1644	-232.87	1.7
L14	-0.3020	-60.40	6.6	-0.4040	-80.80	5.0
L15	0.0943	18.86	21.2	0.1451	29.02	13.8
L16	0.0820	16.39	24.4	0.1863	37.26	10.7
L17	-0.2154	-43.08	9.3	-0.3884	-77.67	5.1
L18	-0.6277	-125.54	3.2	-0.8000	-160.00	2.5
L19	0.0681	13.62	29.4	0.1506	30.11	13.3
L20	-0.1573	-31.47	12.7	-0.2114	-42.27	9.5
L21	0.0438	8.76	45.7	0.3027	60.55	6.6
L22	-0.0796	-15.92	25.1	-0.1132	-22.64	17.7
L23	-0.8034	-160.68	2.5	0.3873	77.46	5.2

locations were on the bucket link elements and the connection elements between tractor frame and front-end loader. Thus, caution must be exercised at these locations when working under severe conditions to avoid possible structural damage.

Conclusions

The structural safety of tractor front-end loader was experimentally verified against impact loads. A commonly used front-end loader with a bucket capacity of 0.45 m^3 and maximum allowable load of 4.9 kN was used. The impact test was performed by loading the bucket with the maximum load and raising it to the maximum lift height, then letting it free fall until it reached a height of 500 mm above the ground, where it was suddenly stopped to create an impact load. A static test was also performed for comparison, wherein the maximum loaded bucket was lifted and held at certain heights.

Twenty-three locations, where large loads are carried on the front-end loader, were selected and the maximum strain and hence, maximum stress were measured during the impact and static tests. The strain gage was used as a measuring sensor. The test results demonstrated a tendency that the impact test had larger strain and stress values compared to the static tests. All locations on the front-end loader had safety factors greater than 1.0 for stress, confirming the structural safety of the front-end loader used. The important design locations, which had relatively low safety factors, were on the bucket link elements and the connection elements between tractor frame and front-end loader. A careful design is required for these elements because they have a higher failure probability due to excessive impact stresses. In the future, supplementary research will be required to take more measurements at other locations.

Conflict of Interest

The authors have no conflicting financial or other interests.

References

Ahn, S. W., H. J. Kim, S. S. Lee and D. S. Choi. 2014. Study on driving shock reduction of a front end loader by accumulator. The Proceedings of the Korean Society for Agricultural Machinery 19(1):91-92 (In Korean, with English abstract).

Hannah, R. L and S. E. Reed. 1992. Strain gage user's handbook. London, UK: Chapman & Hall.

Han, Y. H. 2012. Development of the wheel loader front linkage retaining high breakout force and small angle change of an attachment. MS Thesis. Seoul National University, Department of Mechanical Engineering.

Kim, Y. J., S. O. Chung, S. J. Park and C. H. Choi. 2011. Analysis of power requirement of agricultural tractor by major field operation. Journal of Biosystems Engineering 36(2):79-88 (In Korean, with English abstract).

Kyowa. Strain gages. Available at: www.kyowa-ei.com.

Lim, G. S and B. Y. Lee. 2015. Study on the impact analysis of front loader for tractor. Journal of the Korea Academia-Industrial cooperation Society 16(8):5051-5059 (In Korean, with English abstract).

Simion, P., D. Ilie, B. Sorin and S. Stanislaw. 2005. Apparatus and method for experimental research on the dynamics of tractor-front loader systems. Teka-Commission of Motorization and Power Industry in Agriculture 5: 192-197.

Simion, P. and S. Nastase. 2009. Contributions to the study of the dynamics of agricultural tractors equipped with front-end loader and rear forklift loader. 8th International Scientific Conference. Engineering for Rural Development. Jelgava, Latvia.