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Stress Analysis of Tractor Front-End Loader against Impact Load Using Flexible Multi-Body Dynamic Simulation

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유연 다물체 동역학 해석을 이용한 충격 하중에 따른 트랙터 프론트 로더의 응력 분석

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ABSTRACT

This study was conducted to analyze the stresses by impact loads on front-end loaders attached to tractors using flexible multi-body dynamics. The model was designed and validated by comparing previous experimental data with the simulation data obtained in this study. Nine sets of conditions were designed using three weights (500, 300, and 100 kg) loaded inside a bucket and three heights (1700, 1350, and 1000 mm) of the bucket from ground level. A parametric study was carried out at five locations for two types of parts of a front-end loader. All the safety factors for the five locations under all conditions were calculated and were greater than 1. Thus, the designs of the front-end loaders were structurally safe. Based on this study, front-end loaders attached to tractors can be designed effectively in terms of cost and safety.

Key Words : Front-end Loader(프론트 로더), Flexible Multi-Body Dynamics Simulation(유연 다물체 동역학 시뮬레이션), Parametric Study(매개변수 연구), Tractor(트랙터), Validation(검증)

1. Introduction

Although there are self-propelled agricultural machines, such as combine harvesters, most agricultural machinery is attached to the rear end of tractors through a power take-off (PTO) shaft. In addition, front-end loaders are attached to the front ends of tractors and use hydraulic cylinders as power sources.

Based on annual operation times, rotary tillage (45%), plow tillage (29%) and loader work (19%) constitute the majority of farm work involving tractors[1]. As heavy soil is moved up and down by

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a loader, free fall occurs and creates an impact load on the loader while loading and unloading soil. Accordingly, it is necessary to analyse the stresses on the front-end loader, which is subjected to various impact loads from different heights.

Park et al.[2] conducted an experimental study to measure the stresses on tractor front-end loaders and analysed the structural safety. However, the analysis was limited to impact loads of uniform magnitudes falling from the same height. Thus, variable load and height conditions were not considered.

In one study, a flexible multi-body dynamics analysis program for wheel loaders was developed[3]. In another study, the safety of the seat and belt of a two-wheeler was examined using Recurdyn, which is commercial software[4]. In addition, the development of a dynamic model of a wheel-loader using the transmission, hydraulic, and vehicle dynamic modules of Recurdyn was reported[5]. Flexible multi-body dynamics simulations have been applied to ships[6-9] and in other fields. However, this method has not been applied to front-end loaders for tractors.

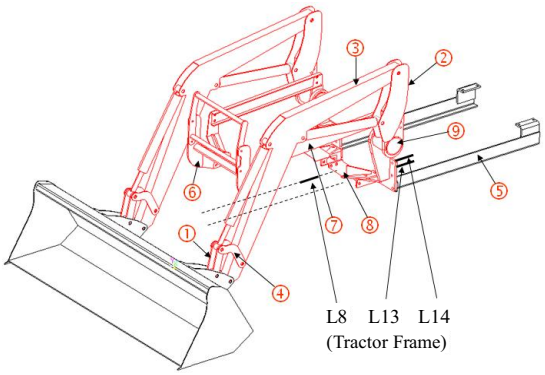
Based on existing experimental data for impact loads acting on front-end loaders for agricultural tractors, a multi-body dynamic simulation was conducted in this study to identify the stresses and strains at five points under three different load magnitudes at three different heights. After validating the simulations, a parametric study was performed.

2. Impact load test

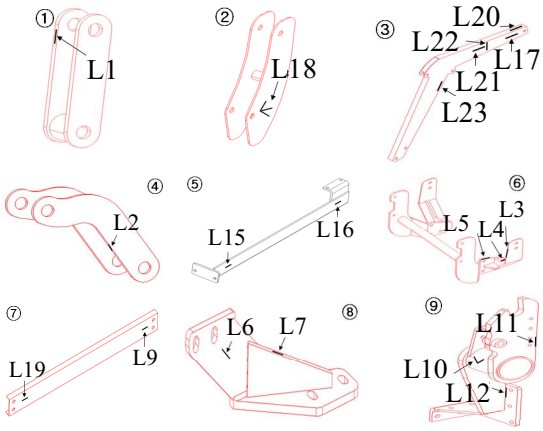
The work in this section was based on the study by Park et al.[2].

2.1 Equipment for test

For the impact load test conducted by Park et al.[2], a steel structure was loaded to a total load of 500 kg in the tractor front-end loader bucket.



(a) Parts for measuring strain



(b) Strain measurement locations

Fig. 1 Equipment for impact test

The front-end loader used in the test was the Taesung KTS-763 model, which is a parallel-type loader with two booms and bucket cylinders. The loader was mounted on a TYM 4100 tractor manufactured by Tongyang Moolsan. Fig. 1 shows the shape of the front-end loader, parts for measuring the strain, and strain measurement locations of each part. Three types of strain gauges (Kyowa's uni-, bi-, and triaxial strain gauges) were used. Data were acquired using a data collector from Dewetron.

2.2 Impact load test

A 500 kg steel structure, which corresponds to the maximum permissible load, was loaded in the front-end loader bucket. The bucket was lifted 20 times to a height of 1350 mm and was subsequently subjected to free fall to a height of 500 mm above the ground, where measured strains at 23 locations on the front-end loader (Fig. 1(b)).

3. Modeling and Validation

Before the parametric study, the Von-Mises stress values of the flexible multi-body dynamic simulations of this study were compared with the stress data obtained from existing experiments to validate the simulation model.

3.1 Tractor Model

Based on the ratio of the two weight loads applied to the front and rear wheels of the tractor (0.44:0.56), as illustrated in Fig. 2 below, the center of mass (CM) for modelling the tractor body with a loader was determined at a point 1015.62 mm horizontally from the center of the front wheel and 450 mm vertically from the ground. The tire was modeled as a bushing element with stiffness and damping coefficients only in the y-direction.

3.2 Loader Model

The hydraulic cylinder of the loader was modelled as a spring-damper. The wheels and the body were connected through a dummy element of the tractor chassis.

As shown in Fig. 3, rigid body modeling was conducted for most components, including the bucket and load. Flexible body modeling was performed to form meshes for Arm LH, which was necessary for the stress analysis, and PIN was connected to it as shown in Fig. 4.

3.3 Simulation Condition

After 4 s stabilizing process, the bushing element, which restrained the rotation between the tractor body and the arm, was deactivated to allow the arm to fall due to gravity.

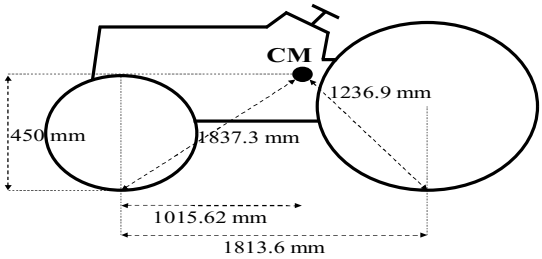


Fig. 2 Modelling of tractor body with tire

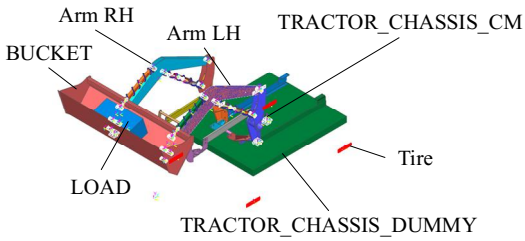
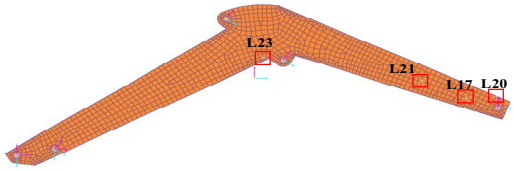
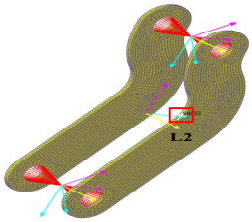


Fig. 3 Modelling of loader attached to the tractor



(a) part 3 in figure 1



(b) part 4 in figure 1

Fig. 4 Mesh of 5 points for stress analysis

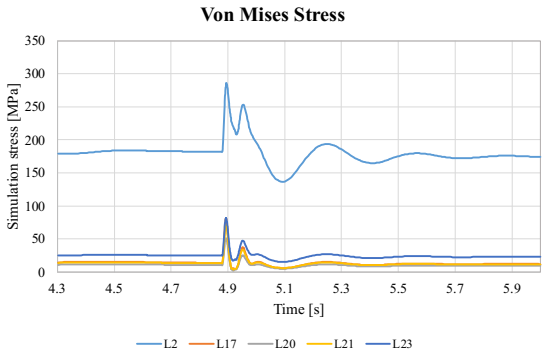


Fig. 5 Stresses on 5 locations after free fall

Table 1 Error between test and simulation results

Gage	Test, MPa	Simulation, MPa	Error, %
L2	277.84	285.89	2.90
L17	77.67	80.818	4.05
L20	42.27	50.732	20.02
L21	60.55	69.779	15.24
L23	77.46	81.544	5.27

3.4 Von-Mises Stress

As shown in Fig. 5, the Von Mises stress values at five locations obtained from the simulation ranged from 50.732 (L20) to 285.89 (L2). As presented in Table 1, the stresses of the simulation were similar to those of the existing experiments, with a lowest difference of 2.9% (L2).

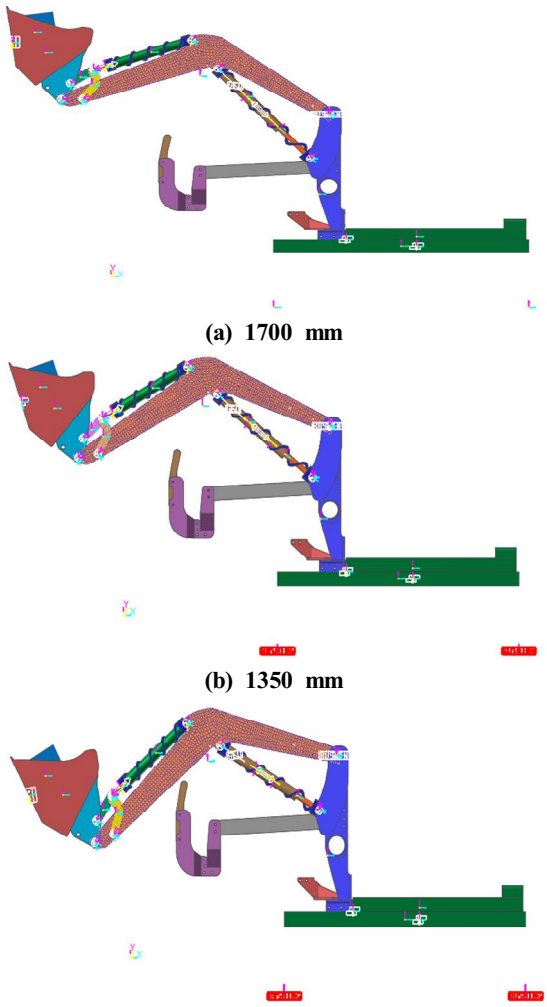
4. Parametric study

4.1 Parameter conditions

As illustrated in Fig. 6, the height conditions of the loader bucket wer 1700, 1350, and 1000 mm. For the load in the bucket, weight conditions of 500, 300, and 100 kg were applied. The nine analysis conditions used in the study are presented in Table 2.

4.2 Stresses by 9 conditions

Fig. 7 shows the results obtained for the nine conditions. The safety factors at each location were calculated by dividing the yield strength of SS400, which was used as the material, by the peak stress obtained by the analysis.



(a) 1700 mm

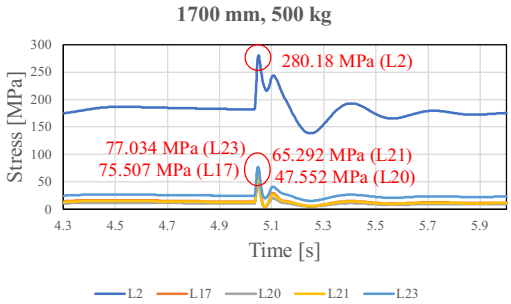
(b) 1350 mm

(c) 1000 mm

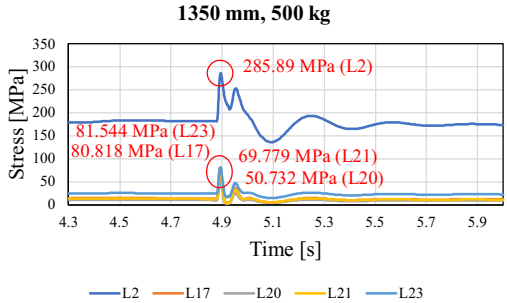
Fig. 6 Height Conditions for parametric study

Table 2 9 Cases for analysis by weight and height

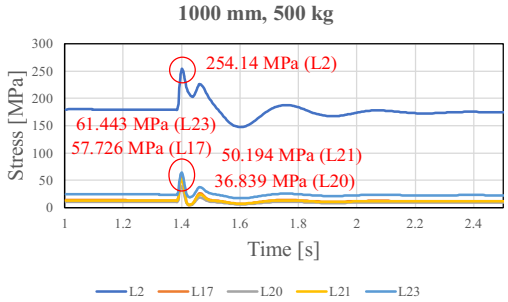
Weight, kg	500	300	100
H, mm	1700 (case 1)	1700 (case 4)	1700 (case 7)
	1350 (case 2)	1350 (case 5)	1350 (case 8)
	1000 (case 3)	1000 (case 6)	1000 (case 9)



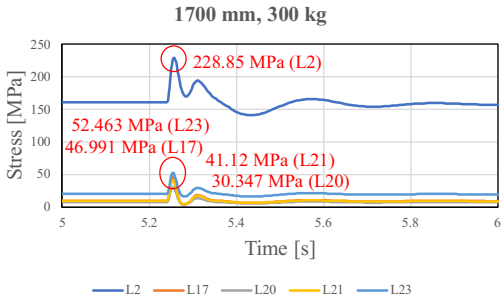
(a) Case 1 : 1700 mm & 500 kg



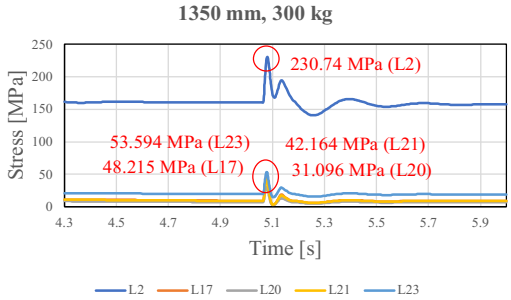
(b) Case 2 : 1350 mm & 500 kg



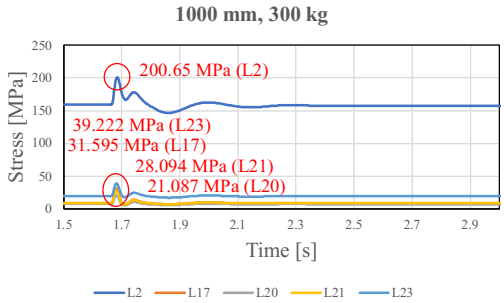
(c) Case 3 : 1000 mm & 500 kg



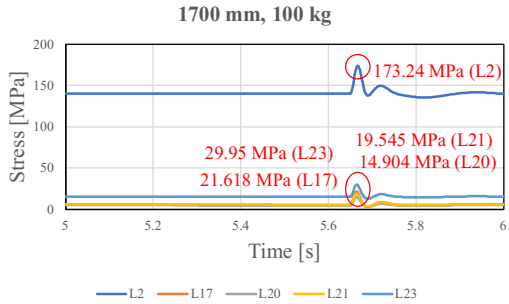
(d) Case 4 : 1700 mm & 300 kg



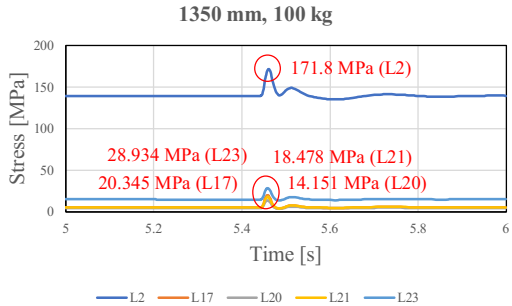
(e) Case 5 : 1350 mm & 300 kg



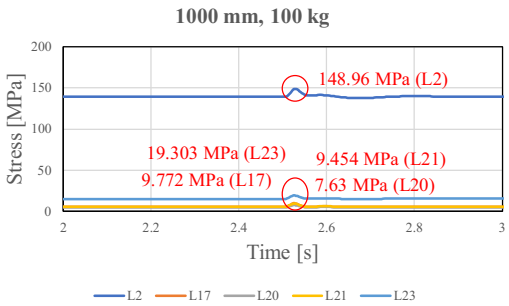
(f) Case 6 : 1000 mm & 300 kg



(g) Case 7 : 1700 mm & 100 kg



(h) Case 8 : 1350 mm & 100 kg



(i) Case 9 : 1000 mm & 100 kg

Fig. 7 Stresses by study conditions

As presented at Table 3-7, the minimum value of the stresses and safety factors was 1.4. Accordingly, all the cases were safe, with safety factors over 1. The loader underwent larger loads when bucket loads of 500 or 300 kg fell from a height of 1350 mm than when they fell from 1700 mm. However, there was not a significant difference between the two cases. Accordingly, free fall from any heights between 1700 and 1350 mm did not cause significantly differently loads on the loader.

Table 3 Stresses (MPa) and safety factor for 9 cases on L2 location

Height	500 kg	300 kg	100 kg
1700 mm	280.2 (1.4)	228.9 (1.7)	173.7 (2.3)
1350 mm	285.9 (1.4)	230.7 (1.7)	171.8 (2.3)
1000 mm	254.1 (1.6)	200.7 (2.0)	149.0 (2.7)

Table 4 Stresses (MPa) for 9 cases on L17 location

Height	500 kg	300 kg	100 kg
1700 mm	75.5 (5.3)	47.0 (8.5)	21.6 (18.5)
1350 mm	80.8 (4.9)	48.2 (8.3)	20.3 (19.7)
1000 mm	57.7 (6.9)	31.6 (12.7)	9.8 (40.9)

Table 5 Stresses (MPa) for 9 cases on L20 location

Height	500 kg	300 kg	100 kg
1700 mm	47.6 (8.4)	30.3 (13.2)	14.9 (26.8)
1350 mm	50.7 (7.9)	31.1 (12.9)	14.2 (28.3)
1000 mm	36.8 (10.9)	21.1 (19.0)	7.6 (52.4)

Table 6 Stresses (MPa) for 9 cases on L21 location

Height	500 kg	300 kg	100 kg
1700 mm	65.3 (6.1)	41.1 (9.7)	19.5 (20.5)
1350 mm	69.8 (5.7)	42.2 (9.5)	18.5 (21.6)
1000 mm	50.2 (8.0)	28.1 (14.2)	9.5 (42.3)

Table 7 Stresses (MPa) for 9 cases on L23 location

Height	500 kg	300 kg	100 kg
1700 mm	77.0 (5.2)	52.5 (7,6)	30.0 (13.4)
1350 mm	81.5 (4.9)	53.6 (7.5)	28.9 (13.8)
1000 mm	61.4 (6.5)	39.2 (10.2)	19.3 (20.7)

5. Summary and Conclusions

To determine the structural safety for each component of the tractor-mounted loader, a parametric study was conducted by using a commercial flexible multi-body dynamics simulation program. The findings of this study can be summarized as follows.

1. When the simulation results were compared with the existing experimental data, the error rates were 2.9% (L2), 4.05% (L17), 20.02% (L20), 15.24% (L21), and 5.27% (L23), demonstrating the high accuracy of the model.
2. When the bucket was loaded with 500 or 300 kg, the free fall from a height of 1350 mm caused a larger stress than that from a height of 1700 mm.
3. Safety factors were calculated based on stresses generated by free falls from heights of 1700, 1350, and 1000 mm, and weights of 100, 300, 500 kg were used, where 500 kg was the maximum permissible load. All the safety factors obtained exceeded 1. The results of these flexible multi-body dynamics simulations will be useful for the design of tractor-mounted loaders.

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