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Experimental Study on the Drawbar Pull and Structural Safety of an Onion Harvester Attached to a Tractor

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트랙터 부착형 양파수확기의 작업 속도에 따른 견인 부하와 구조 안정성에 관한 실험적 연구

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ABSTRACT

Recently, due to labor shortages in rural areas within South Korea, the demand for upland-field machinery is growing. In addition, there is a lack of development of systematic performance testing of upland-field machinery. Thus, this study examined structural safety and drawbar pull based on soil properties, as a first step for systematic performance testing on the test bed. First, the properties of soil samples from 10 spots within the experimental site were examined. Second, the strain was measured and converted into stress on 8 points of an onion harvester that are likely to fail. More specifically, the chosen parts are linked to the power, along with the drawbar pull, using a 6-component load cell equipped between the tractor and the onion harvester. The water content of the soil ranged between 5.7%-7.5%, and the strength between 250-1171 kPa. The test soil was subsequently classified into loam soil based on the size distribution ratio of the sieved soil. The onion harvester can be considered as structurally safe based on the derived safety factor and the drawbar pull of 115-1194 kgf, according to the working speed based on agricultural fieldwork.

Key Words : Onion Harvester (양파 수확기), Soil Strength (토양 강도), Structural Safety (구조 안정성), Drawbar Pull (견인력), Tractor (트랙터)

1. Introduction

For decades in South Korea, labor shortage in rural area has facilitated the mechanization of agricultural work usually in paddy field area. Accordingly, the mechanization ratio for agricultural work conducted in paddy field became almost 97.9% in 2016. However, the mechanization ratio for agricultural work conducted in upland field is still low, 58.3% in 2016[1]. Thus, the needs for developing the machines to be used for planting and harvesting specifically on the upland field has been increased and many research for those has been reported[2-10].

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There are several test practice such as coast-down experiment test[2] being conducted for automotive. Recently, the study using the 6-component load cell to measure working load of the agricultural implement was reported[11]. Meanwhile, the soil property is important in agricultural machinery sector because the traction force is needed when agricultural work is done. However, there is no performance test conducted considering the conditions of soil and structural safety for most upland field machinery including onion harvesters yet.

In this study, the property of the soil on the test field including water content, soil strength, and the distribution of soil particle size was examined. And then, the performance such as the structural safety of the onion harvester along with drawbar pull was tested and evaluated experimentally as a first step of performance test for agricultural implement used on the upland field.

2. Experimental Setup

2.1 Equipment for soil sampling

Soil is a compound mixed with diverse particles in solid, liquid, gas phase and thus has diverse characteristics and properties. As one of the classification method of soil, there is the classification by the soil size. There are several types of soil such as sandy soil, sandy loam soil, clay, silty clay and silty clay loam according to the combination of the soil size. In order to check the type of the soil we tested on along with the moisture content and the soil strength, the tools are used as shown in Fig. 1. Using the auger and the sampling bottles shown in Fig. 1(b) and (c), soil was sampled at 10 spots which were located by 8 m distance on the one lane of the test field. Also, the soil strength was measured each at the same spots with the soil penetrometer (FieldScout SC 900, Spectrum technologies Inc.,) as shown in Fig. 1(a). And the moisture contents were

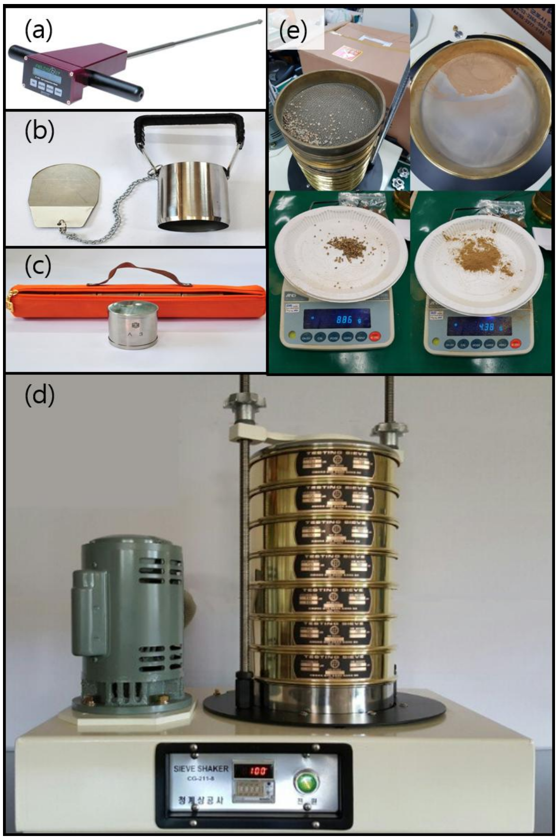

Fig. 1 Tools for soil sampling; (a) soil penetrometer; (b) soil auger; (c) soil sampling bottle; (d) shaker with sieves; (e) weight measurement by sieve after shaking

measured by measuring the weight before and after drying for 10 hours in the oven.

After drying soil samples, the soil samples in the sampling bottle were sieved for 2 hours using the shaker with sieves as shown in Fig. 1(d). And then the soil classified by the 8 kinds of sieves (0.02 mm, 0.053 mm, 0.106 mm, 0.25 mm, 0.5 mm, 1 mm, 2 mm, 4 mm of the sieve size from the bottom) were measured on the scale as shown in Fig. 1(e).

2.2 Stress and strain measurement

The onion harvester was linked to the tractor

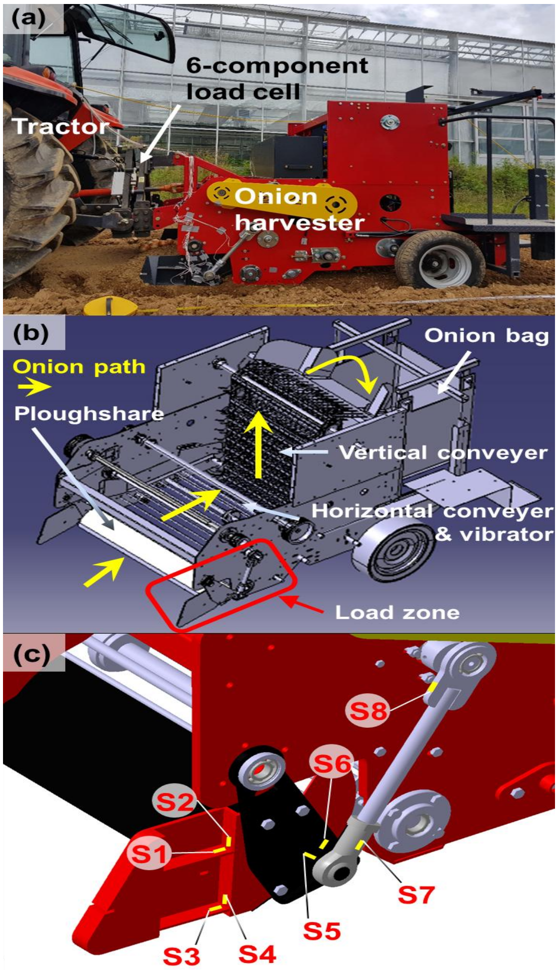

Fig. 2 Images for; (a) the onion harvester operated and pulled by a tractor; (b) working principle of onion harvester; (c) and the locations where strain gauges were placed around the load zone

(Tong Yang Moolsan, DX753C 56kW) as shown in Fig. 2(a) as a power source via power take off (PTO) along with 6-component load cell between the two. Also, the onion harvester moves the onions from the soil through the ploughshare, vibrating horizontal conveyer and vertical conveyer into the onion bag. as shown in Fig. 2(b). The ploughshare functions as a digger to get onions from the soil and is expected to get the biggest load among the parts of the onion harvester. And the vibrating horizontal conveyer is expected to take off the soil from the onions. Finally, the vertical conveyer deliver the onions into the onion bag without bruise. In order to ensure the safety of the onion harvester, the strain gages were attached on the 8 points of the linked part near to the ploughshare as shown in Fig. 2(c).

The strain and stress at each point can be obtained using Eqs. (1) and (2) (Hannah and Reed, 1992) by converting the measurement signals, the ratio of the output to input voltage,

$$\epsilon = \frac{4}{GF} \times \frac{e_0}{e_i} \tag{1}$$

where, ϵ = Strain, mm/mm
GF = Gage factor
ϵ_o/ϵ_i = Ratio of output to input voltage, V/V

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

where, σ = Stress, Pa
E = Young's modulus, Pa

And then, the safety factor at each point can be obtained by dividing the yield stress of the SS400 (400 MPa) by the stress obtained above.

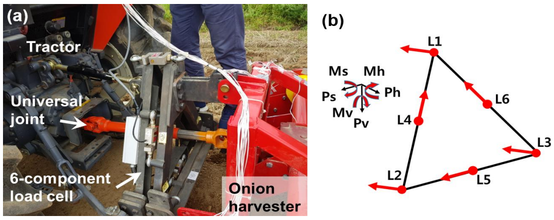

Fig. 3 An image of the 6-component load cell connected between a tractor and an onion harvester (a) and diagram of 3 way force and moment nomination for analysis of data collected using the 6-component load cell (b)

2.3 Drawbar pull measurement

Drawbar pull between a tractor and the agricultural implement can be measured using 6-component load cell as shown in Fig. 3(a).

The 6-component load cell is the sensor which can measure the 6 forces and moments (Fx, Fy, Fz, Mx, My, Mz). The drawbar pull (Ph) shown in Fig. 3(b) can be obtained by adding up Fx, Fy and Fz. The 6-component load cell is composed of front and rear frames connected to a tractor and an agricultural implement such as the onion harvester for each. The six load cells are positioned as shown in Fig. 3(b) and connect the front and rear frames.

Data measured on the 8 strain gages and 6-component load cell is stored in the laptop via data acquisition system (Gantner Instrument) which can get the signal of strain gages, torque, and acceleration.

3. Results and Discussion

3.1 Soil property

The property (strength, water content, passing ratio) of soil sampled on 10 spots of the experiment site is as shown in Fig. 4. Strength of the soil has the trend to increase as depth other than 5^{th} position. Water contents of soil ranged between 5.7 and 7.5 %. And passing ratio was similar between soil sampled on the 10 spots. In average, the ratio of the gravel was 15.4%, sand 54.4%, clay 30.2%. Thus, the soil can be classified into the loam soil because the ratio of clay is between 25% and 37.5% (USDA criterion).

3.2 Structural safety

According to the manufacturer of the onion harvester, the transmission position of a tractor for onion harvester is ranged between L3 (0.89 km/h), L4 (1.42 km/h), M1 (2.20 km/h).

The safety factors were between 1.57 and 36.0, beyond 1. Even when agricultural work could not be done for 70 seconds or so because of the stuck of the ploughshare of the onion harvester, the safety factor was 1.57 beyond 1. At that time, the tractor could not go forward and signals were weak as shown in Fig. 9 and Fig. 10. The tractor started to go forward again after lifting the ploughshare up a little bit. Thus, this onion harvester can be concluded to be designed and manufactured structurally safe.

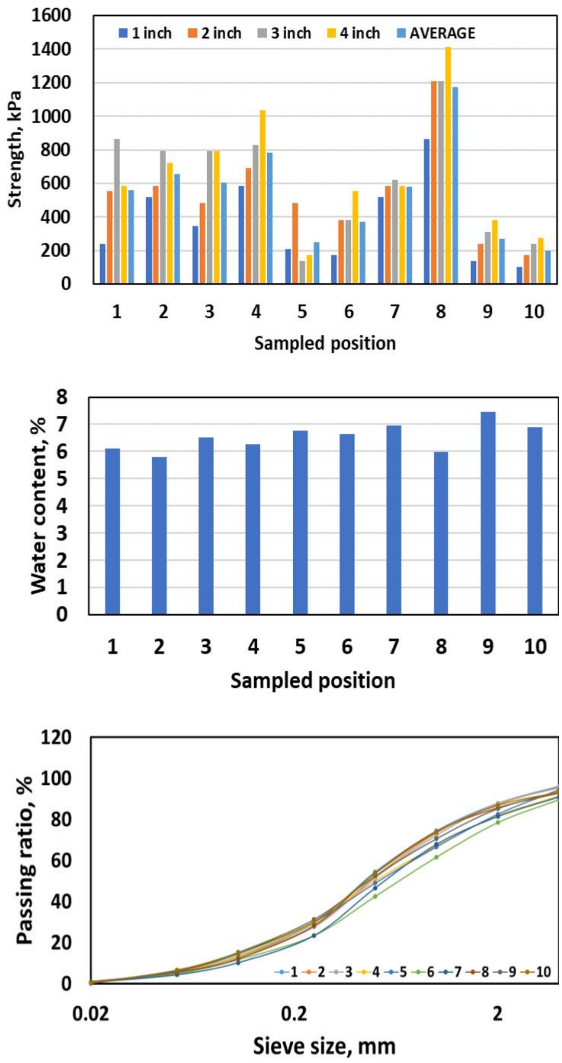

Fig. 4 Strength, Water content, and passing ratio of the soil sampled on 10 spots of the experiment site

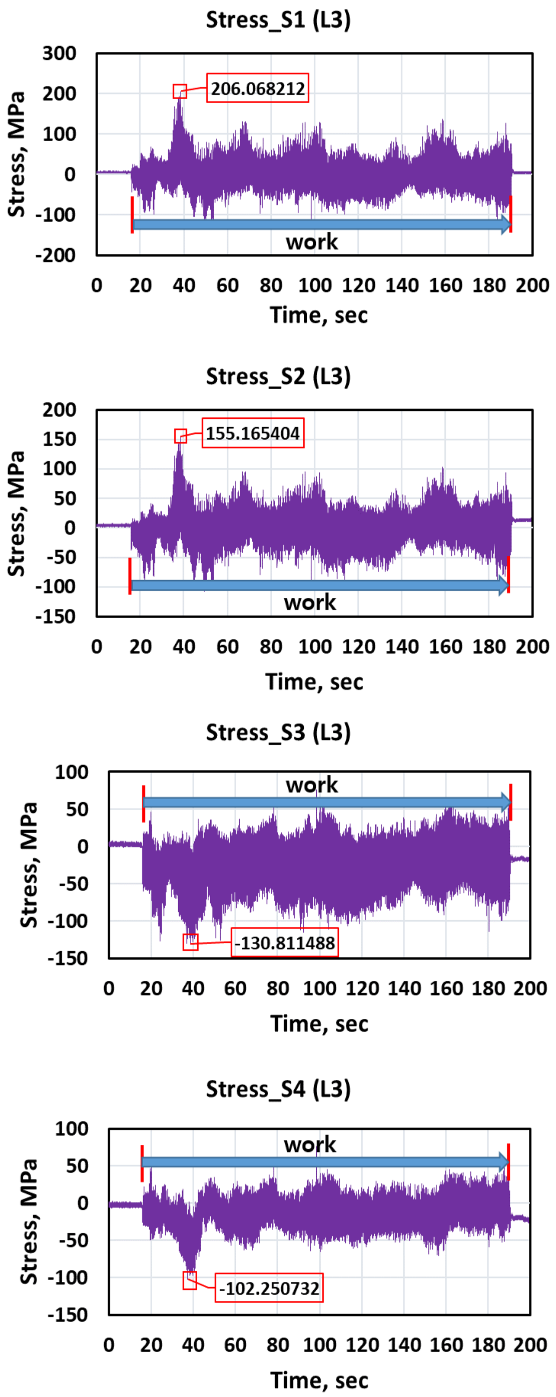

Fig. 5 Stress measured on S1, S2, S3 and S4 while transmission is L3

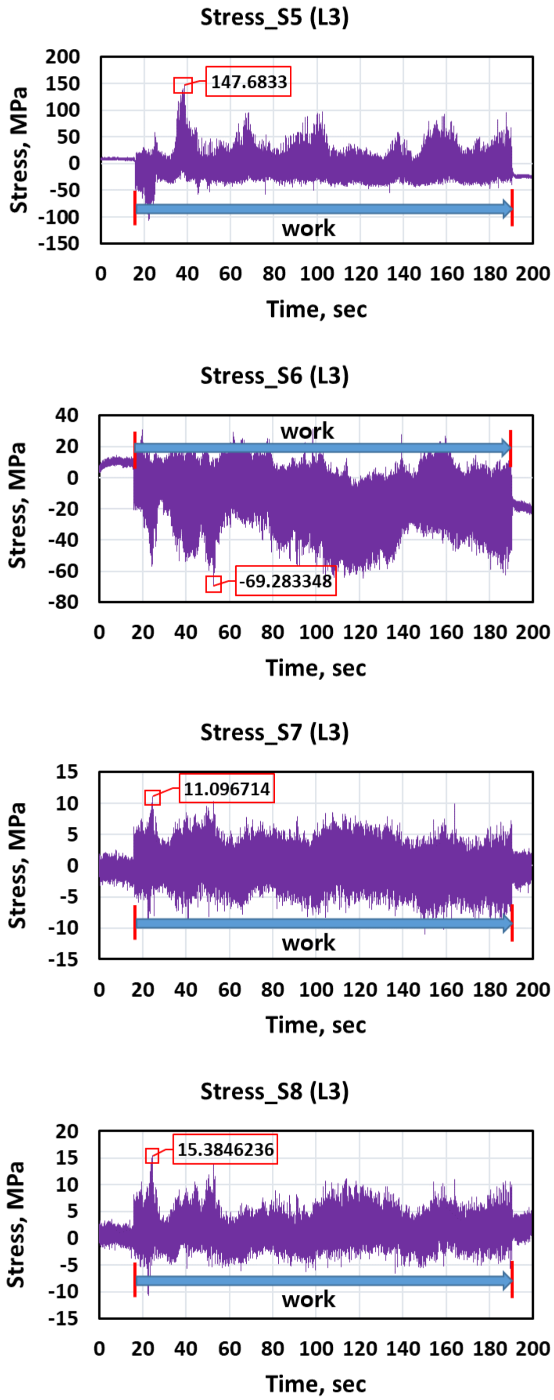

Fig. 6 Stress measured on S5, S6, S7 and S8 while transmission is L3

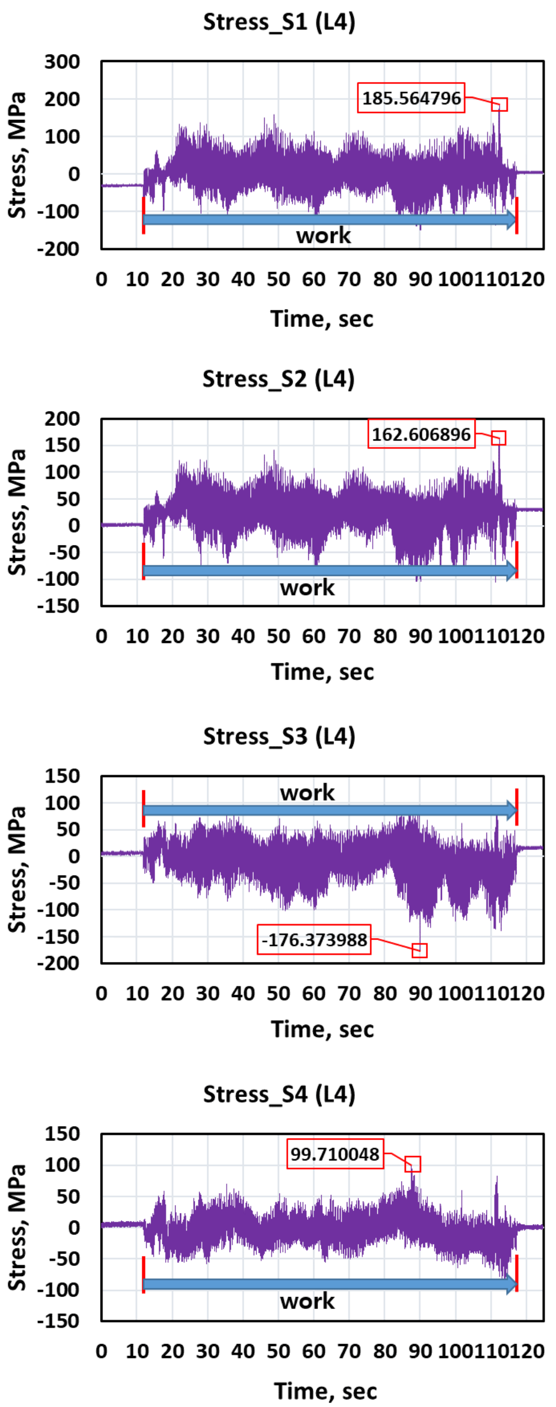

Fig. 7 Stress measured on S1, S2, S3 and S4 while transmission is L4

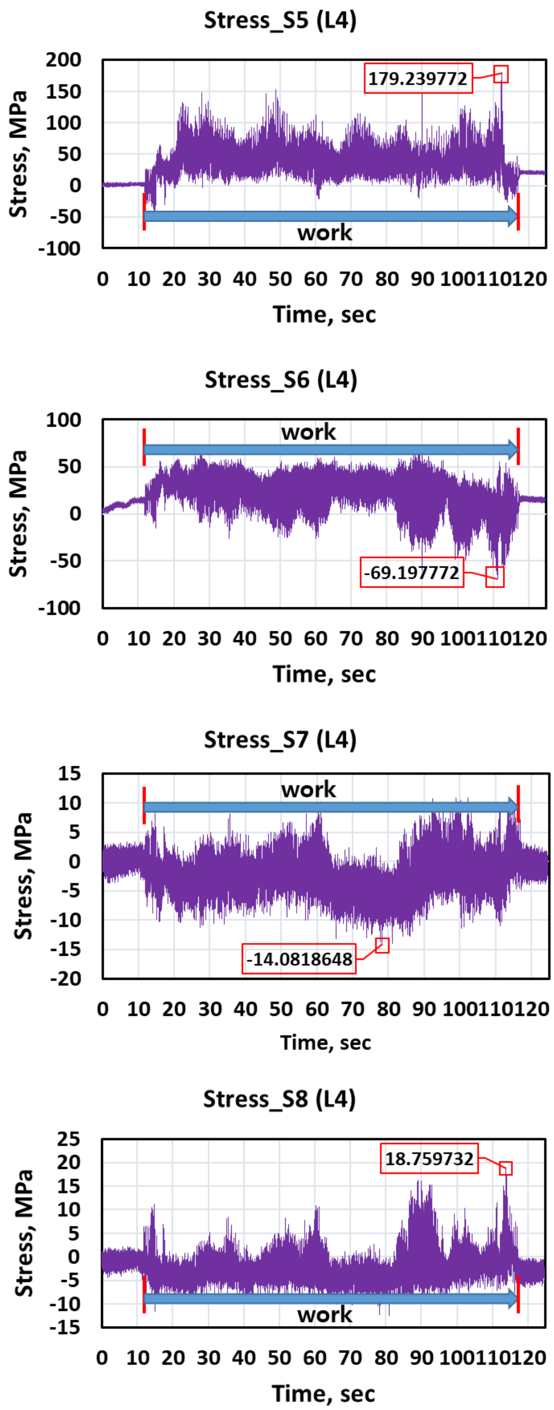

Fig. 8 Stress measured on S5, S6, S7 and S8 while transmission is L4

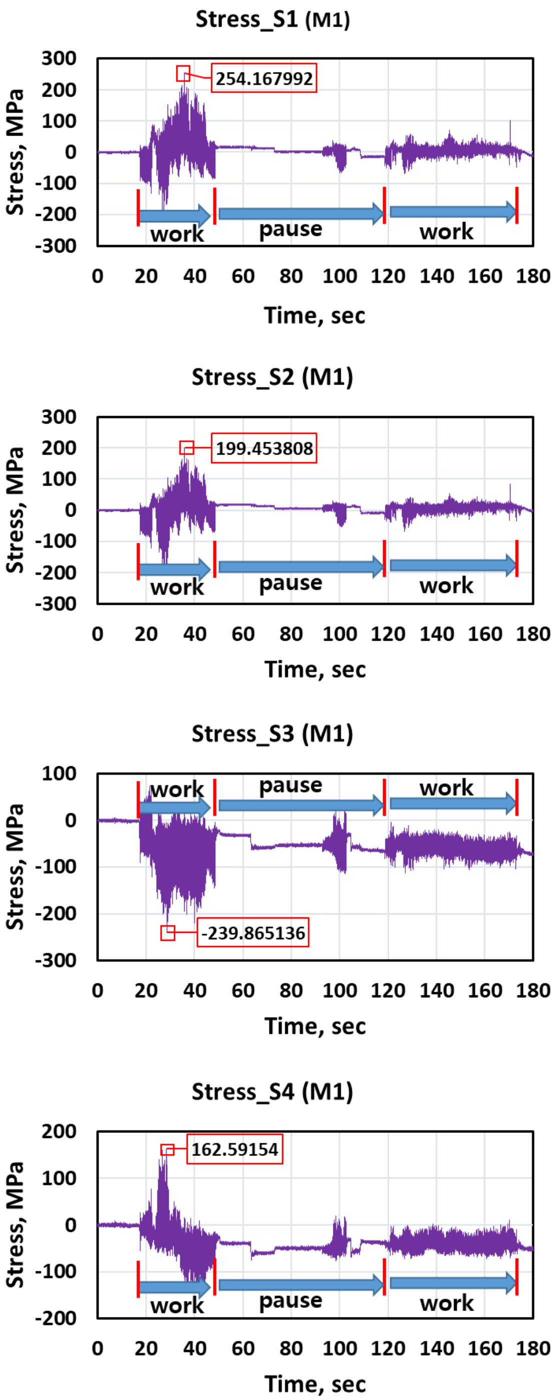

Fig. 9 Stress measured on S1, S2, S3 and S4 while transmission is M1

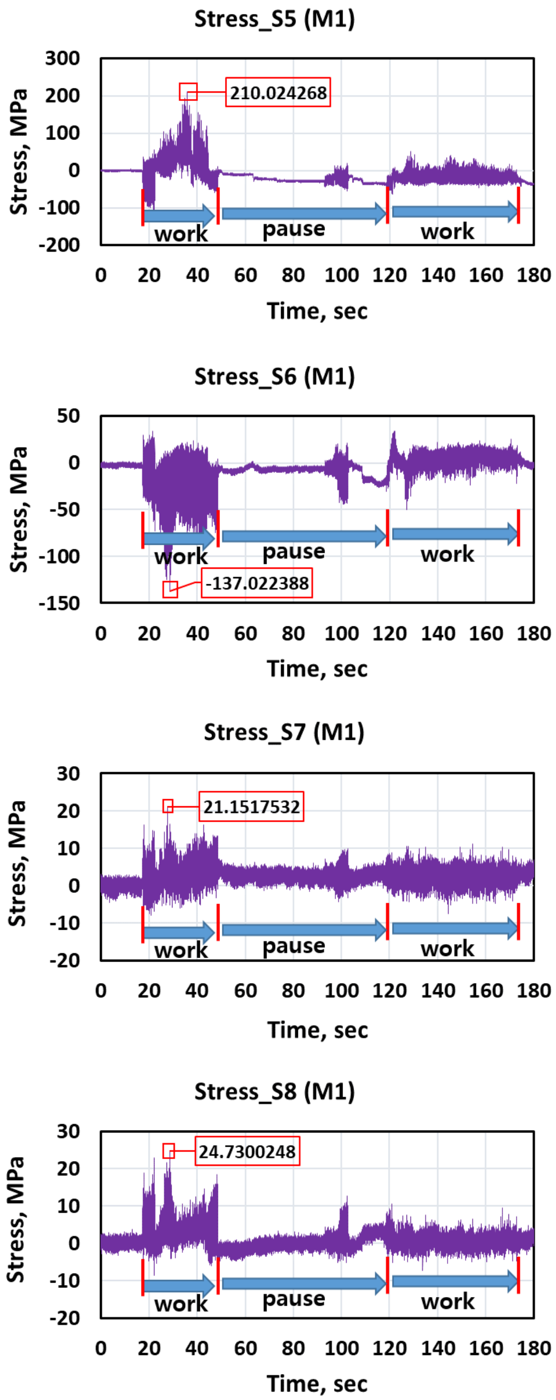

Fig. 10 Stress measured on S5, S6, S7 and S8 while transmission is M1

Table 4 Strain, stress and safety factor measured when transmission is L3 (0.89 km/h)

Gage	Strain, um/m	Stress, MPa	Safety factor
S1	1.03	206	1.94
S2	0.78	155	2.58
S3	0.65	131	3.06
S4	0.51	102	3.91
S5	0.74	148	2.71
S6	0.35	69.3	5.77
S7	0.06	11.1	36.0
S8	0.08	15.4	26.0

Table 5 Strain, stress and safety factor measured when transmission is L4 (1.42 km/h)

Gage	Strain, um/m	Stress, MPa	Safety factor
S1	0.93	186	2.16
S2	0.81	163	2.46
S3	0.88	176	2.27
S4	050	99.7	4.01
S5	0.90	179	2.23
S6	0.35	69.2	5.78
S7	0.07	14.1	28.4
S8	0.09	18.8	21.3

Table 6 Strain, stress and safety factor measured when transmission is M1 (2.20 km/h)

Gage	Strain, um/m	Stress, MPa	Safety factor
S1	1.27	254	1.57
S2	1.00	199	2.01
S3	1.20	240	1.67
S4	0.81	163	2.46
S5	1.05	210	1.90
S6	0.69	137	2.92
S7	0.11	21.2	18.9
S8	0.12	24.7	16.2

Table 7 ~Drawbar pull (Ph), vertical force (Pv), horizontal side force (Ps) and moments (Mh, Mv, Ms) at peak points when transmission is L3

Peak	Ph, kg	Pv, kg	Ps, kg	Mh, kg·m	Mv, kg·m	Ms, kg·m
S1	1026	948	97.4	-57.0	109	109
S2	1026	948	97.4	-57.0	109	109
S3	343	414	40.7	-23.8	42.0	42.0
S4	431	562	94.3	-55.3	40.0	40.0
S5	1027	770	60.9	-35.6	88.5	88.5
S6	135	-45.8	-140	82.0	-56.2	-56.2
S7	155	-524	-161	94.0	-174	-174
S8	155	-524	-161	94.0	-174	-174

Table 8 Drawbar pull (Ph), vertical force (Pv), horizontal side force (Ps) and moments (Mh, Mv, Ms) at peak points when transmission is L4

Peak	Ph, kg	Pv, kg	Ps, kg	Mh, kg·m	Mv, kg·m	Ms, kg·m
S1	1168	330	1.92	1.13	-225	-225
S2	1168	330	1.92	1.13	-225	-225
S3	-115	22.8	-15.6	9.14	-314	-314
S4	-43.3	255	116	-67.7	-350	-350
S5	1168	330	-1.92	1.13	-225	-225
S6	412	-410	-12.0	7.02	-221	-221
S7	430	230	0.13	0.08	-224	-224
S8	574	-820	100	-58.7	-281	-281

Table 9 Drawbar pull (Ph), vertical force (Pv), horizontal side force (Ps) and moments (Mh, Mv, Ms) at peak points when transmission is M1

Peak	Ph, kg	Pv, kg	Ps, kg	Mh, kg·m	Mv, kg·m	Ms, kg·m
S1	1194	619	98.4	-57.6	135	135
S2	1194	619	98.4	-57.6	135	135
S3	269	122	-181	106	-107	-107
S4	445	163	-144	84.5	-9.16	-9.16
S5	1194	619	98.4	-57.6	135	135
S6	358	13.8	-109	64.0	-133	-133
S7	751	84.4	-91.5	53.6	-64.5	-64.5
S8	269	122	-181	106	-107	-107

3.3 Drawbar pull

The drawbar pull was obtained at the moment when the peaks occurred at 8 strain gages each from table 7 to 9. In the case of L3, the drawbar pull ranged between 135 kgf and 1027 kgf. For L4, the drawbar pull ranged between -115 kgf and 1168 kgf at the same conditions as L3. The minus sign of drawbar pull in this study means that the compressive force occurred between the tractor and the onion harvester. At two peak points (S3, S4 for L4), the minus signal occurred. This might be because of the reactive force resulted from the low working speed and the vibrating ploughshare back and forth with any angle. For M1, the drawbar pull ranged between 269 kgf and 1194 kgf.

As the working speed increases, the maximum drawbar pull increased among 3 kinds of working speeds as expected.

4. Conclusion

We studied experimentally for making sure the structural safety of the onion harvester according to working speed (transmission) based on the usual working speed during agricultural work. Details of this study are as below.

1. The soil properties such as soil strength, water content, and soil size were examined using diverse measurement tools such as soil penetrometer, sampling bottles, a shaker with a sieve, and a scale.
2. The strain on the 8 spots which is likely to fail comparatively, specifically connection parts to the power were measured using strain gage and was converted into the stress and then the safety factor was obtained for 8 points. The onion harvester seems to be designed and manufactured enough to be safe structurally.
3. The drawbar pull was measured using 6-component load cell linked to the laptop via data acquisition system. The drawbar pull increased as working speed increased as expected.

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