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Development of a Contact Type Height Sensor to Measure Ground Clearance of an Agricultural Tractor

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Abstract

The tillage depth control system is one of the most salient control system of tractor implements. A contact-type height sensor was developed to measure ground clearance for the tillage depth control. The height sensor was fabricated in this study, and its efficacy in a tillage depth control system was evaluated. Experiments were conducted in order to determine both static and dynamic detection characteristics of the height sensor using soil bin system on the sampled soil (sandy loam, sand, clay loam). The results of the static detection characteristics showed that in the case, sandy loam soil despite and clay loam soil at a wet basis moisture content of 30%, large measurement errors were observed a due to penetration of a plastic puck into the sampled soil. The results of the dynamic detection characteristics showed that the height sensor detected the distance from the ground of sandy loam soil despite the uneven nature of the ground surface and the changes in traveling speed 1 km/h~5 km/h at a wet basis moisture content of 10%.

Keywords : Height sensor, Contact type, Ground clearance, Agricultural tractor, Tillage depth control

1. INTRODUCTION

Tillage operations using agricultural tractors are conducted primarily using plows and rotary implements. In the case of rotary implements, implement attitude and tillage depth control systems are considered to be particularly relevant. The attitude control system for the maintenance of a horizontal implement attitude, even on an uneven field, has been utilized extensively in tillage operations worldwide. Tillage depth control systems and implement attitude control systems have been developed for agricultural tractors in a host of studies, most of which have been conducted in Japan and Korea.

Satow et al. (1985) reported on a plow depth control system predicated on the distance measured from the ground surface, as determined by an ultrasonic sensor. Jiang et al. (1992) conducted a study regarding a mixed control system which included tillage depth control. Using potentiometer, these investigators detected the angle of the lift arm and the proper pitching for the tillage depth control system. Lee et al. (1996, 1998, 2000) conducted a study concerning the use of a tillage depth control system for rotary implements. They detected the lift arm angle, pitching, and ground clearance characteristics based on the readings of non-contact

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optical and ultrasonic sensors. Recently, investigators in Korea and Japan attempted to employ the swing angle of the leveling plate hinged on the cover of the rotary implements as a feedback signal for the developed tillage depth control system. This system is regulated by the control system under normal operational ground conditions. However, when an agricultural tractor experiences excessive pitching due to both the uneven nature of the ground surfaces and wheel sinkage, a constant tillage depth cannot be attained due to the developed sensor comprising the control system. In order to solve this problem, the ground clearance should be detected via a more accurate system.

Therefore, the primary objectives of this study were: 1) to design and fabricate a contact-type height sensor for the detection of the distance between a height sensor reference position and the soil surface about uneven ground surfaces, 2) to determine the detection data of the height sensor via indoor experiments, and 3) to evaluate the possible efficacy of the height sensor in applications as a ground clearance detector for a tillage depth control system.

2. MATERIALS AND METHODS

A. Materials

1) The height sensor

The height sensor is comprised of two primary units; a driving unit and a controller, as shown in Fig. 1. The dimensions are 350×100×100 mm (height × length × width). The dimension of plastic punk are 15×15×10 mm (x × y × height). The driving unit consists of a bar for the detection of the ground surface, a DC motor (Model: RS-755SH, Mabuchi Co. Ltd., Japan) to drive the detection bar, and a 2kΩ potentiometer for measurements of the displacement of the detection bar. The potentiometer is connected to the detection bar in two places, an upper link and a lower link. The detection bar is linked to the pulley, which is fixed to the axle of the DC motor by a string and a spring. The controller consists of a host of electronic circuits for the control of the DC motor.

The motor lifts the detection bar, and is turned off when the detection bar achieves the reference position. Then the

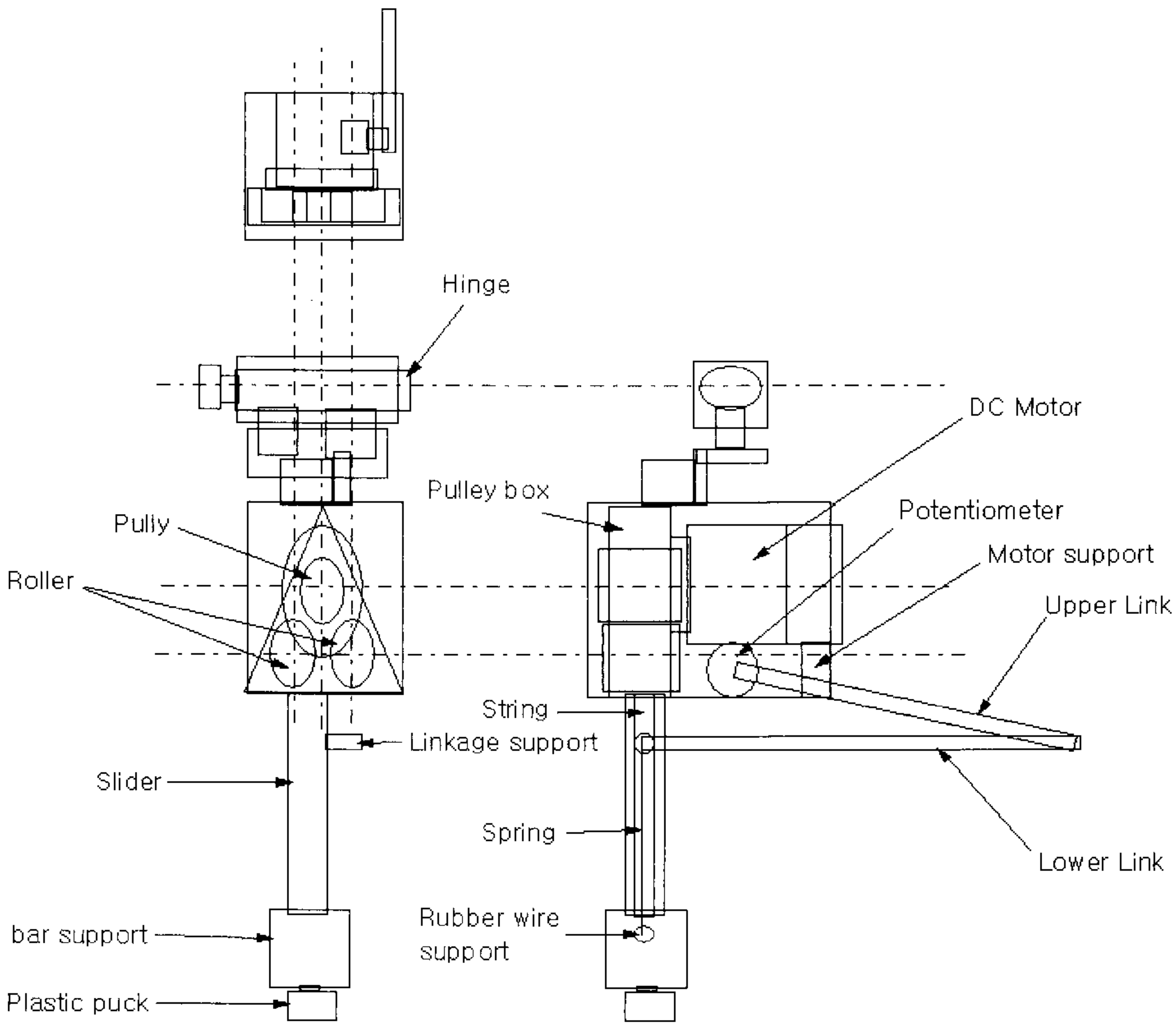


Fig. 1 Schematic diagram of the height sensor.

bar descends along a slider by a self-weight and a spring, which is fixed between the bar and the slider, descents. The height sensor outputs the voltage of the potentiometer when the bar reaches the ground surface. Simultaneously, the motor is turned on and lifts the detection bar. The height sensor operates at a velocity of 10 cycles/s.

2) Experimental apparatus

Fig. 2 depicts the experimental apparatus. It is comprised of a soil bin, a carrier, an AC motor (Model: 261PA, Mabuchi Co. Ltd., Japan) for moving the carrier, and a small soil bin for constructing the configuration of the ground surface. The soil bin is equipped with rails and pulleys, which are attached at both ends, and move the carrier. Both ends of the carrier are linked by strings, which run through pulleys. The pulley is connected to the axles of the AC motors by chains. The carrier is moved by the motor, and the speed of movement is adjusted by the rotation speed of the AC motor. The height sensor is attached to a supporting frame, which is fixed to the carrier. The fifth wheel, which is equipped with a tacho-generator, is attached to the carrier, in order to measure the traveling speed of the carrier during the experiments.

B. Methods

1) Static experiments

Static experiments were conducted in order to determine the effects of factors including soil type, moisture content (wet basis), and distance, according to the detection characteristics of the height sensor.

Four types of soil samples were employed in the experiments. The composition, classification and condition of the soils are shown in Table 1. The moisture contents of the soil samples (wet basis) were 0%, 10%, 20%, and 30%.

The experiments were conducted at different vertical positions of the height sensor from the ground surface: 40 mm, 90 mm, 140 mm, and 190 mm, and different wet basis moisture contents: 0%, 10%, 20% and 30%, for soil samples A (SL), B (SL), C (S), and D (CL) of USDA Classification. The output voltage of the height sensor was measured under the above conditions.

Table 1 The composition and classification of the soils

Soil (USDA classification)		A(SL)	B(SL)	C(S)	D(CL)
Particle size dist, %	Sand	76	65	96	32
	Silt	16	21	2	39
	Clay	8	14	2	29
Cone index (CI), kPa		220	250	90	410

2) Dynamic experiments

In order to characterize the effects of an uneven ground surface and traveling speed on the detection characteristics of the height sensor, we conducted dynamic experiments indoors.

Soil sample B (wet basis moisture contents: 10%) was typically used for the experiments. Two types of configurations of the ground surface, step and sine waves, were constructed in the small soil bin, the dimensions of which were 3,000 mm in length, 300 mm in width, and 260 mm in height.

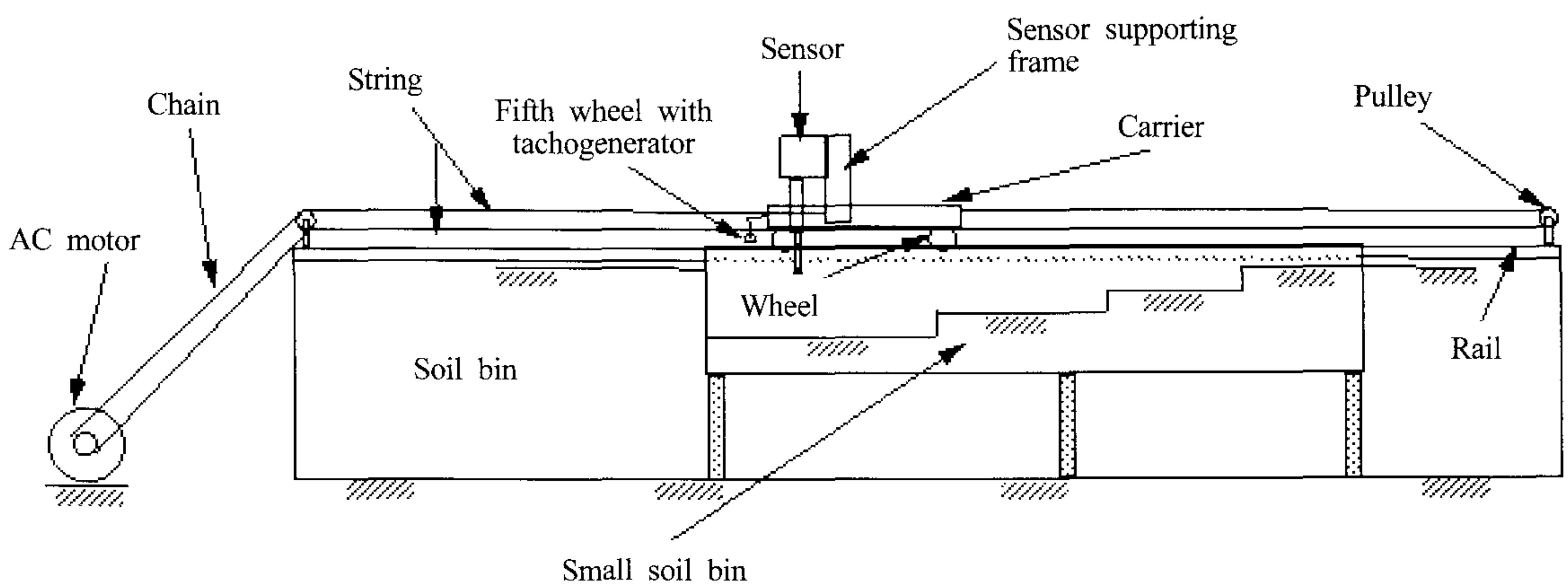


Fig. 2 Schematic diagram of the experimental soil-bin system apparatus.

In the step configuration experiments, four steps were constructed within the small soil bin, as is shown in Fig. 3. For these experiments, the height sensor was moved 180 mm, 140 mm, 110 mm, and 60 mm from each step of the ground surface.

Fig. 3 Shape view of soil-bin for the step configuration experiments.

In the sine wave configuration experiments, the amplitude of the ground surface was ±80 mm, and the distance of the height sensor from the reference surface was 110 mm, as is shown in Fig. 4.

Both experiments were conducted at five traveling speeds, 1 km/h, 2 km/h, 3 km/h, 4 km/h, and 5 km/h. During these experiments, all output signals from the height sensor were recorded on an analog data recorder. The data was then processed by a computer after the completion of the experiments.

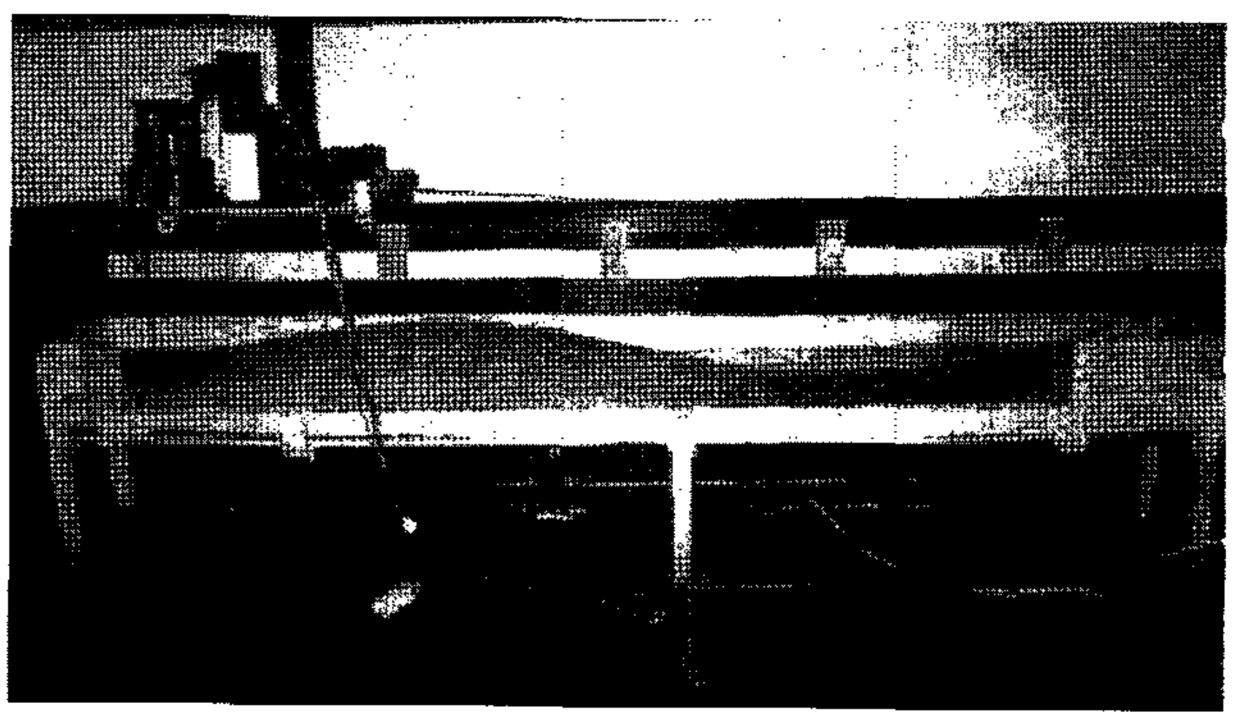


Fig. 4 Shape view of soil-bin for the sine wave experiments.

3. RESULTS AND DISCUSSION

A. Static experiments

The calibration results of the height sensor are plotted in Fig. 5. A highly linear relationship ($R^2 = 0.996$) was detected between the detection distance from the ground surface and the output voltage. The output of the height sensor is proportional to the displacement of the detection bar.

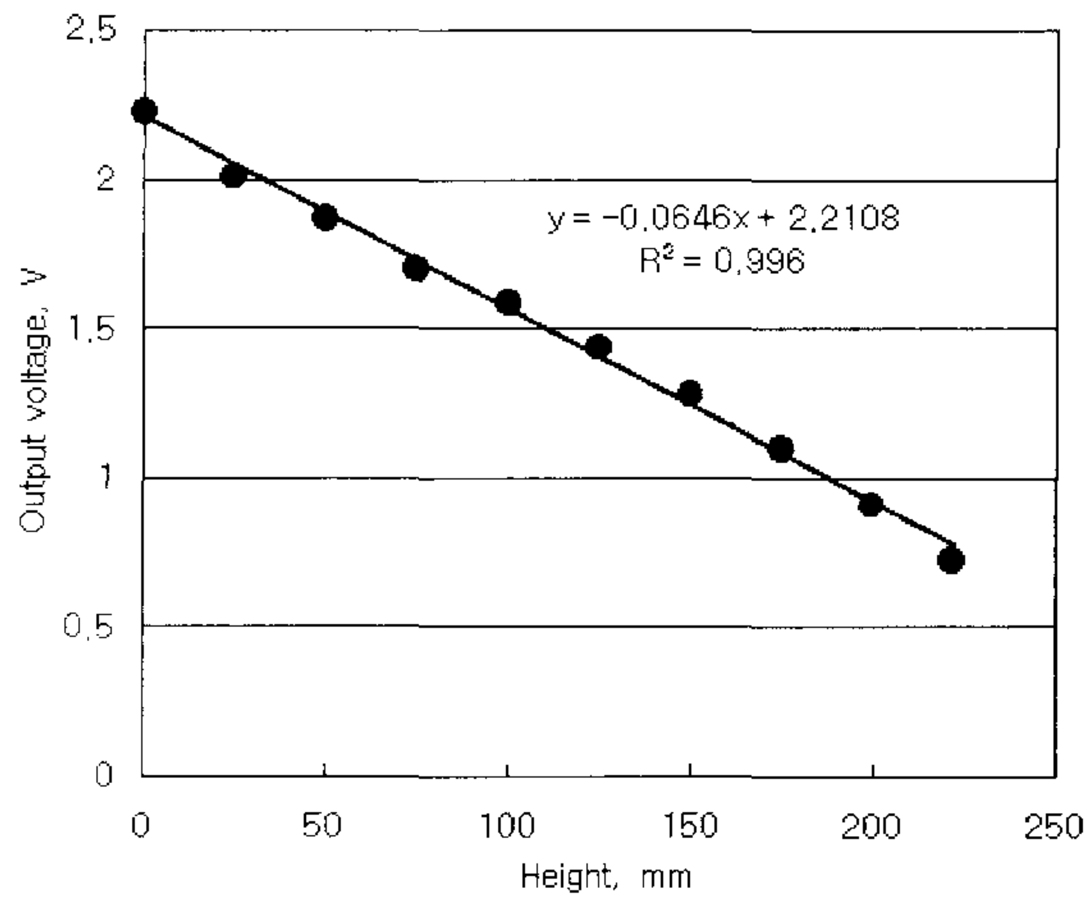
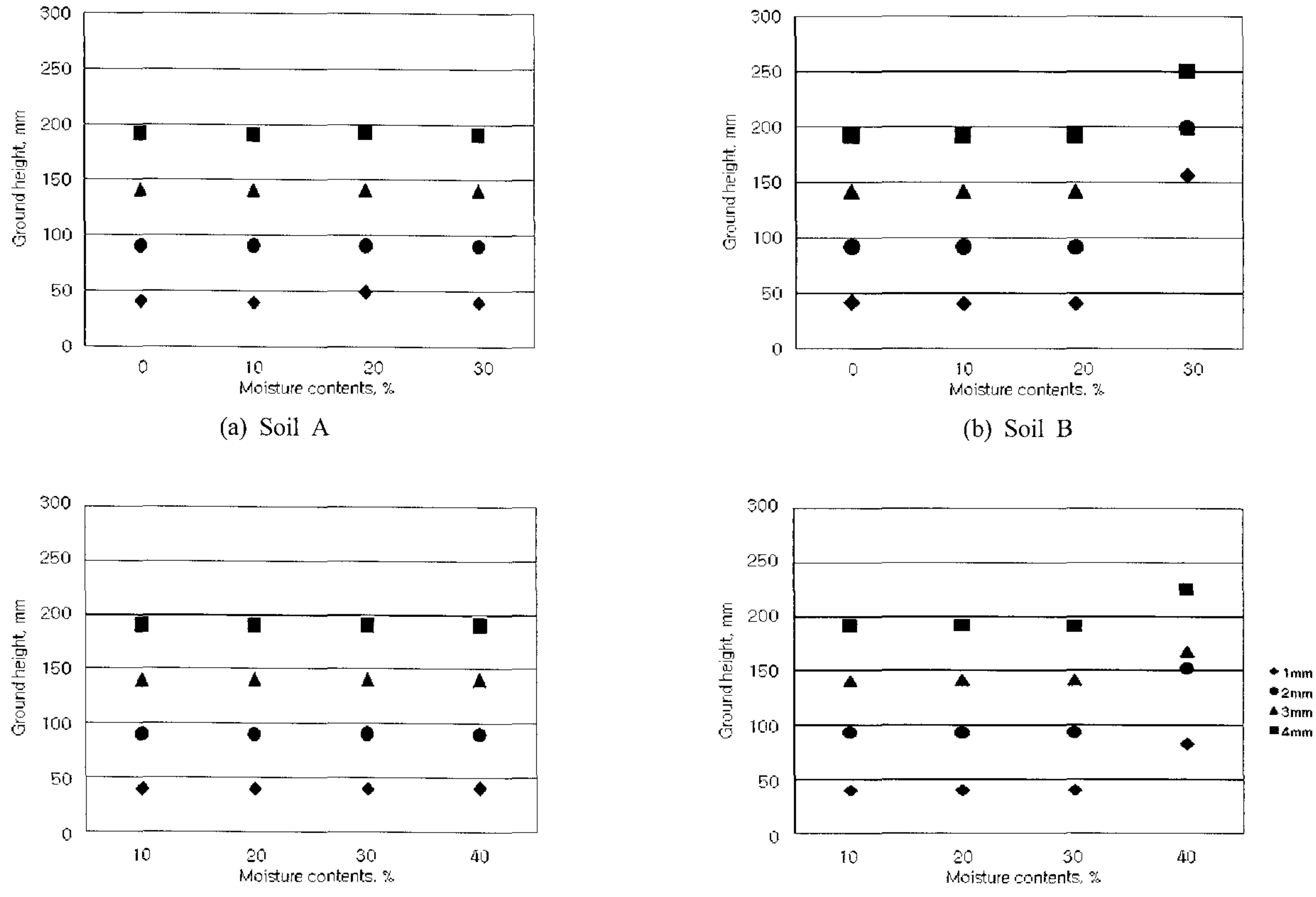


Fig. 5 Calibration of the height sensor.

Fig. 6 shows the experimental results of the height sensor at different vertical positions (40 mm, 90 mm, 140 mm, and 190 mm), and different wet basis moisture contents (0%, 10%, 20%, and 30%) for the four types of soil samples. As is shown in Fig. 6, in the case of soils A and C, minimal measurement errors were observed despite the different ground types, moisture contents of the soil, and the vertical positioning of the height sensor. However, substantial errors were observed in the measurement of soils B and D at a wet basis moisture content of 30. Soils B and D achieved a state of saturation at 30%, at which the soil became soft. Therefore, it is believed that these errors were induced by the penetration of the plastic puck, which was attached to the bottom of the detection bar, into the sampled soils.

B. Dynamic experiments

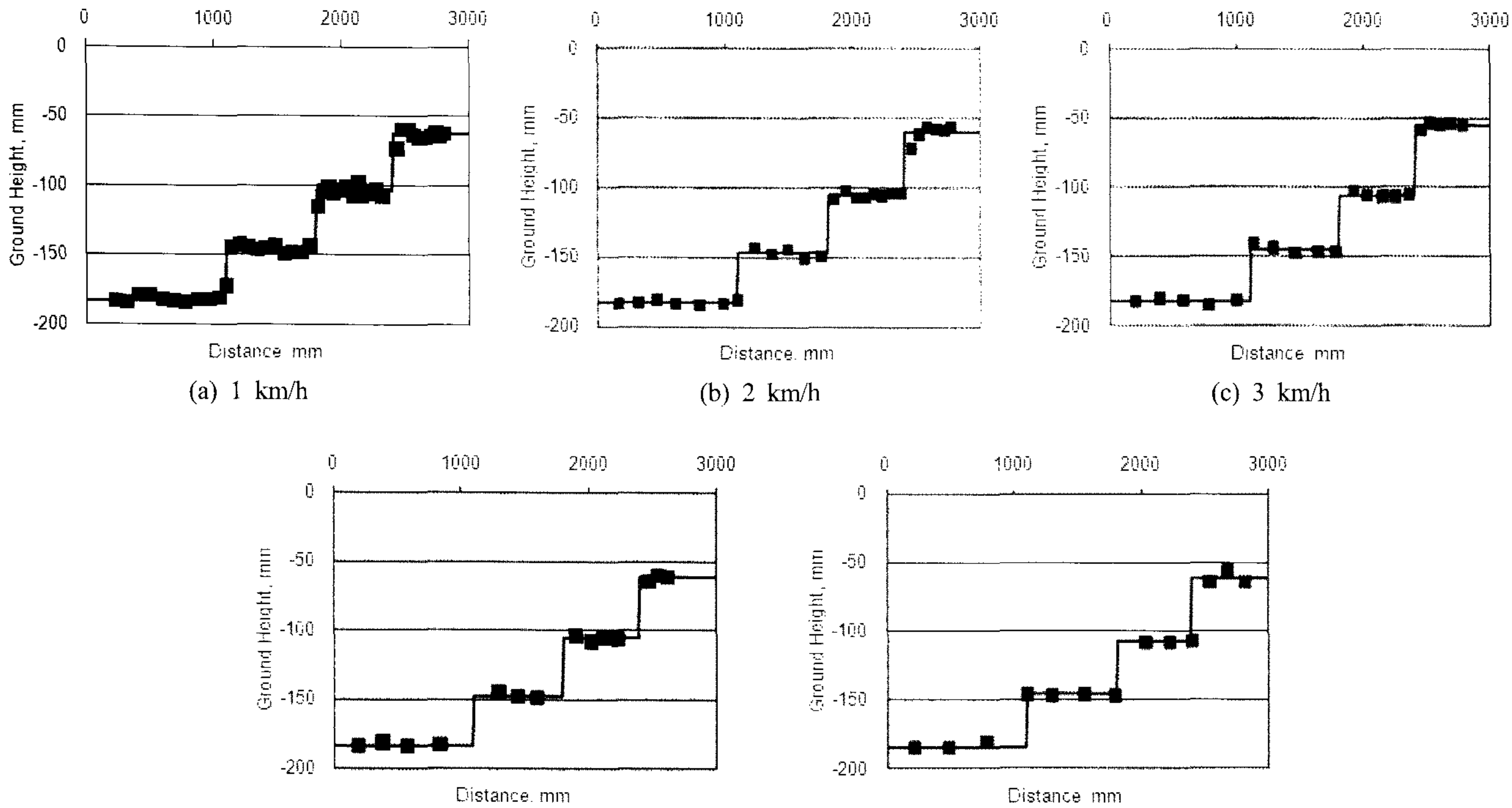
Fig. 7 shows the experimental results for the step configurations of the ground surface at five carrier travel speeds; 1 km/h, 2 km/h, 3 km/h, 4 km/h, and 5 km/h. The height sensor detected the distance from the ground surface along the configuration of the ground surface constructed for the experiments in the small soil bin. The standard deviation for the step experiments is shown in Table 2. It ranged around an average of 2.24 mm.



(a) Soil A (b) Soil B

(c) Soil C (d) Soil D

Fig. 6 Effect of different ground types at different wet basis moisture contents and vertical positions on the detection characteristics of the height sensor: square: 190 mm, triangle: 140 mm, circle: 90 mm, diamond: 40 mm.



(a) 1 km/h (b) 2 km/h (c) 3 km/h

(d) 4 km/h (e) 5 km/h

Fig. 7 Results for the step configuration experiments (dot: detected distance, line: reference surface).

Table 2 Standard deviation in the step configuration experiments

Speed, km/h	Ground clearance, mm			
	60	100	140	180
1	2.2	2.3	1.5	1.5
2	3.2	2.2	2.0	2.6
3	2.1	4.1	3.3	2.2
4	1.1	0.9	1.5	0.7
5	2.7	5.0	1.2	2.5

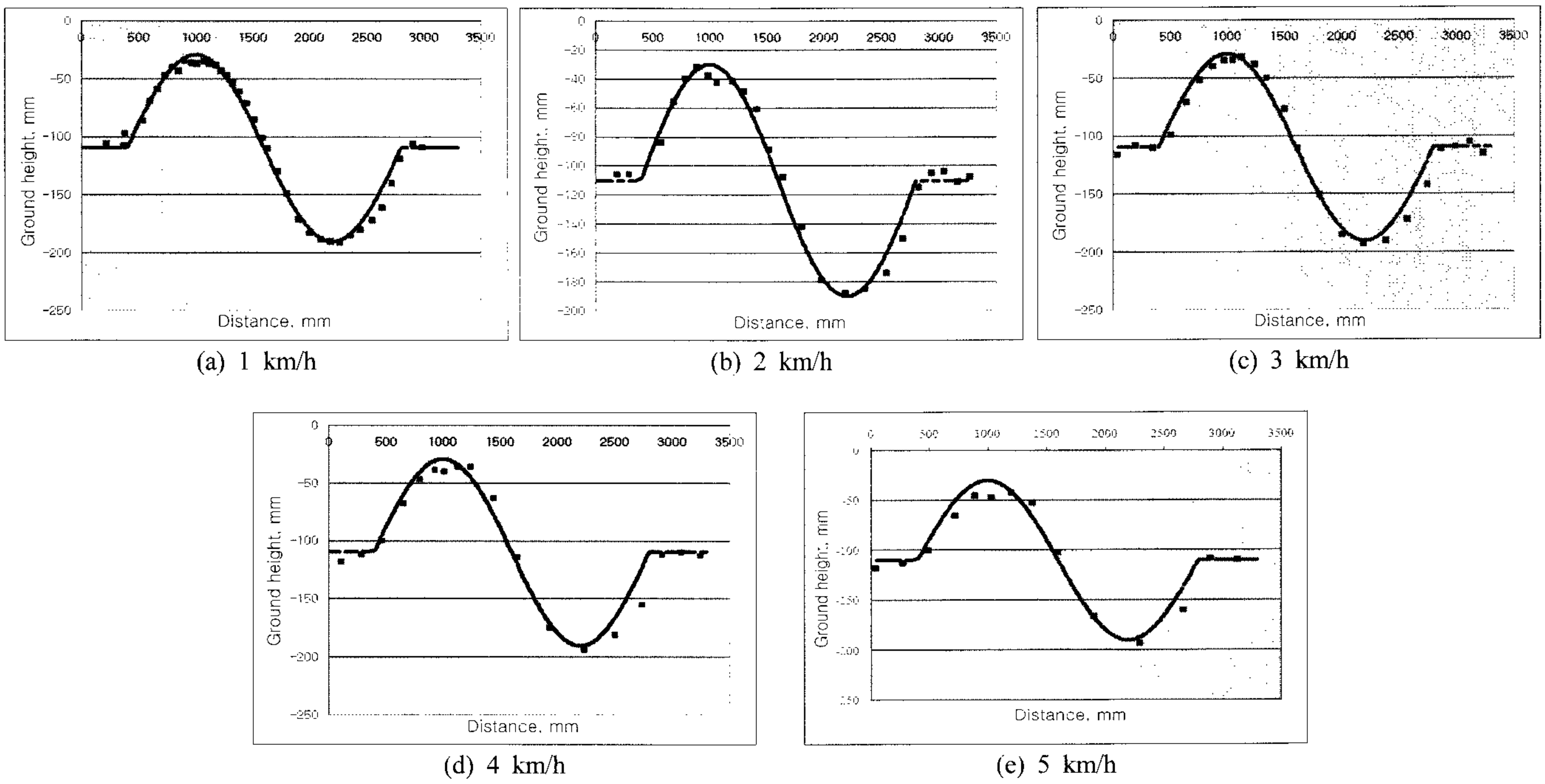


Fig. 8 Result for the sine wave configuration experiments at a reference distance of 110 mm, amplitude is ±80 mm (dot: detected distance, line: reference surface).

The results for the sine wave experiments are shown in Fig. 8. It shows the experimental results for the sine wave configurations of the ground surface at a carrier travel speeds; 1 km/h, 2 km/h, 3 km/h, 4 km/h, and 5 km/h. The vertical positioning was detected by the height sensor despite the uneven nature of the ground surfaces, as well as the changes in traveling speed. The standard deviation ranged around an average of 2.53 mm.

4. CONCLUSIONS

In this study, a contact-type height sensor for the agricultural tractor on soil was designed and fabricated, and indoor experiments were conducted under various conditions to assess the detection ability of the height sensor. The various characteristics tested and included: distance from the ground surface, soil type, moisture content (wet basis), ground surface configuration, and carrier traveling speed. The results can be summarized as follows;

(1) The static detection characteristics of the height sensor were unaffected by vertical positioning and soil type. However, in the case of the soils B (SL) and D (CL), substantial measurement errors were observed, due to the penetration of the plastic puck into the sampled soil, under conditions in which the soils reached a state of saturation at a wet basis moisture content of 30%.

(2) The results of the dynamic detection characteristics showed that the height sensor detected the distance from the ground of soil B (SL) despite the uneven nature of the ground surface and the changes in

traveling speed 1 km/h ~ 5 km/h at a wet basis moisture content of 10%.

(3) The experimental results indicated the potential for the application of the height sensor as a ground clearance detector in a tillage depth control system. The problem detected in the loam-type soils under saturation conditions and the compensation method for static experiments according to the moisture contents should be considered in future investigations.

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