Research article

Development of a Device for Measuring the Load Bearing Capacity of a Farm Road

KOJI WATANABE*
Graduated School of Agriculture, Tokyo University of Agriculture, Tokyo, Japan
Email: 45515008@nodai.ac.jp

FUTOSHI KAWANA
Faculty of Regional Environmental Science, Tokyo University of Agriculture, Tokyo, Japan

YASUSHI TAKEUCHI
Faculty of Regional Environmental Science, Tokyo University of Agriculture, Tokyo, Japan

Received 14 December 2016 Accepted 5 May 2017 (*Corresponding Author)

Abstract The maintenance of infrastructure for agricultural production is essential to sustainable agricultural productivity. Farm roads are particularly important infrastructure for transporting agricultural products. Load-bearing capacity is a performance index for evaluating the soundness of a road, and recently, falling weight deflectometer (FWD) tests have been used to measure such capacity. However, an FWD is a stationary device, so its use is time intensive. This study aims to develop a moving wheel deflectometer (MWD) device that determines the load-bearing capacity continuously and economically, for the efficient management of farm roads. For that reason, the development of the MWD involved fabrication, testing and the verification of its practicality on a public road. The MWD was used to estimate the load-bearing capacity of a public road at travel speeds of 10 to 60 km/h. The soundness evaluated based on the MWD measurements were shown to be comparable to that as evaluated by the FWD at all travel speeds. The results demonstrate that the MWD has the potential to be used for the comprehensive measurement of load-bearing capacity.

Keywords pavement management, soundness, load-bearing capacity, falling-weight deflectometer

INTRODUCTION

The maintenance of agricultural infrastructure is essential for sustainable agricultural productivity, and maintenance and repair should be implemented at times and scales that extend the service life. Therefore, a sustainable, recycling-oriented society can't be realized without preventive management system for infrastructure. To apply that system to farm road management, the soundness of infrastructure must be quantitatively evaluated. In general, a road's soundness is evaluated in terms of its surface condition and load-bearing capacity. Road surface measuring vehicles are able to obtain continuous data on road surface conditions, such as cracking, rutting and roughness, along a survey road, so such devices enables the efficient determination of road conditions. In contrast, load-bearing capacity is evaluated in terms of road surface deflection. The falling weight deflectometer (FWD) test has been used to obtain road surface deflection data. This non-destructive testing device accurately measures road surface deflection, however, its use is too time intensive for comprehensive road measurement. Also, the FWD is a stationary device, which means that there is the risk of overlooking localized damage between measurement points. Therefore, a method needs to be developed for determining the load-bearing capacity continuously at high travel speed.

Devices that continuously measure road surface deflection have been developed in other countries since 1990 (Kano, 2008). The rolling wheel deflectometer (USA), road deflection tester (Sweden) and high-speed deflectometer (Denmark) have been put into practical use (Maruyama, 2012; Flintsch et al., 2012). These devices determine load-bearing capacity by road surface deflection measured by Laser displacement sensors or assumed by deflection velocity measured by Doppler vibrometer (Van, 2009; Elseifi 2012; Diefenderfer et al., 2008; Ferne et al., 2009). The Laser displacement sensor measures directly the distance between the sensor and the road surface. This direct measurement enables to obtain road surface deflection easily without numerical calculation. Also, the deflection measurement results are independent of running speed. However, the measurement accuracy is closely related to road surface conditions, and measurement at curved sections is difficult. In contrast, the measurement results by Doppler vibrometer are not affected by road surface conditions because the device measures the deformation velocity of the road surface. In addition, deflection can be assumed by integration of deflection velocity. However, the deflection velocity is zero in the stationary condition. This means evaluation becomes difficult at slow running speed.

In general, Farm road has important roles of not only transporting products but also carrying in and out agricultural machines. Measurement at high travel speed makes ensuring safety difficult during running test. In addition, there are many curved sections and narrow sections in farm roads. Currently available moving devices for measuring load bearing capacity are used by heavy trailer vehicles that generate large deflection, for example RWD consisting of a 16.3 m long semitrailer. It means these devices are not necessarily suitable for farm road management. Therefore, a device to be used by smaller vehicles and which is capable of measuring load bearing capacity without effect on travel speed should be developed. For that reason we developed a moving wheel deflectometer (MWD) to determine which points of a deteriorating road sections require more detailed survey, such as FWD test (Terada, 2012; Matui, 2013). The MWD performes measurements by using a laser displacement sensor in combination with a Doppler vibrometer, and consists of 8.25 m vehicle. The Doppler vibrometer have been used to measure deflection velocity at high travel speed, and laser displacement sensors have been used at low travel speeds. In the present work, we propose a method for evaluating the pavement load-bearing capacity on farm roads by using an MWD equipped with a laser displacement sensor, and give the results of measurements on a public road.

METHODOLOGY

Outline of the MWD

Fig. 1 Installation state of deck for sensor

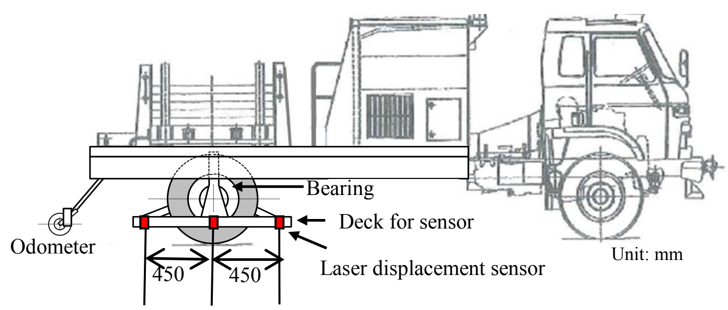


Fig. 2 Sensor configuration

In this study, load-bearing capacity is evaluated in terms of the deflection under the rear wheel as shown in Fig. 1. The deflection is measured by laser displacement sensor. Because of the vehicle's suspension, the axle and the body frame do not move in unison. Hence, as shown in Fig. 1, in order to make the sensor and axle move in unison, a sensor deck was attached to the wheel axle by the axle bearing. The sensor arrangement is shown in Fig. 2. One sensor is installed at the wheel axle, and other sensors are installed ±450 mm from the wheel axle. Additionally, running distance is measured by odometer installed in the rear body

Evaluation Method

The MWD test determines the load-bearing capacity based on road surface deflection generated by rear wheel load. Fig. 3 shows the concept of the determination method proposed in this study. In Fig. 3, the x-axis indicates the vehicle travel direction and the y-axis indicates the deflection direction. The origin of the x-axis is set at the wheel axle. Pavement deflection at the rear wheel is calculated by the following equation in the case of the ideal condition without vibration or torsion of the vehicle body.

$$w_0 = \Delta_0 - \Delta_d \tag{1}$$

Where,

w_0 : road deflection at the rear wheel ($x = 0$)

Δ_0 : distance between the wheel axle and the road surface at the rear wheel ($x = 0$)

Δ_d : distance between the wheel axle and the road surface without deflection ($x = d$)

The wheel radius and deformation are R and δ, respectively. If δ does not depend on pavement rigidity, then the difference between R and δ is always constant.

$$\Delta_0 = R - \delta = Const \tag{2}$$

As mentioned above, the deflection immediately below the rear wheel can be calculated by equation (1) under ideal conditions. However, measurement at the position $x = d$ is difficult, because measurement value in that position is influenced by vibration of sensor and the tilt of vehicle body in practical measurement. For that reason, as shown in Fig. 4, a deck for the sensors was attached to the wheel axle, and three sensors were attached so as to measure maximum deflection at the position $x = 0$ and deflection at the position $x = a, -a$; also, the deck is designed to tilt around the wheel axle. Therefore, in this study, the load bearing capacity was evaluated by the “deflection difference,” i.e., the difference between deflection generated just under the rear wheel and deflection generated at any other point ($x = a$). Assuming that the deflection curve is generated symmetrically with respect to the y-axis, the error of deflection measurement at the position $x = a$ due to the tilt of the sensor deck can be eliminated by averaging the measurement value at the position $x = a$ and measurement value at the position $x = -a$. Deflection difference is defined by following equation.

$$w = \Delta_0 - \Delta_a \tag{3a}$$

$$\Delta_a = \frac{1}{2}\left(\Delta_f + \Delta_b\right) \tag{3b}$$

Where,

w : deflection difference between deflection just under rear wheel and that at any other

Δ_f: distance between the sensor and the road surface at the position $x = a$

Δ_b: distance between the sensor and the road surface at the position $x = -a$

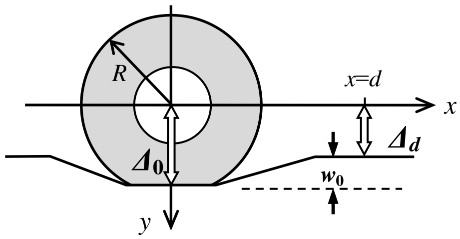


Fig. 3 Concept of deflection

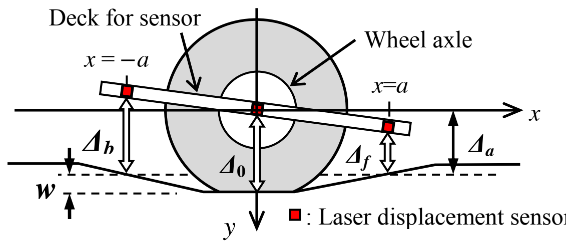


Fig. 4 Correction of displacement for the sensor deck tilt

MWD Testing

The MWD test was carried out at the testing course of the Public Works Research Institute in Tukuba, Japan (Fig. 5). The length of the testing section was approximately 1400 m. To assess repeatability and the effects of running speed, measurement was implemented three times for each with six running speed (10, 20, 30, 40, 50 and 60 km/h). Also, FWD test was conducted at the same test course to demonstrate accuracy of MWD. The pavement consists of an asphalt layer (14 cm) and a granulated subbase course (31 cm), and there are many cracks at several points. The sampling frequency was 2000 Hz. The wheel load in a static state was 46.5 kN.

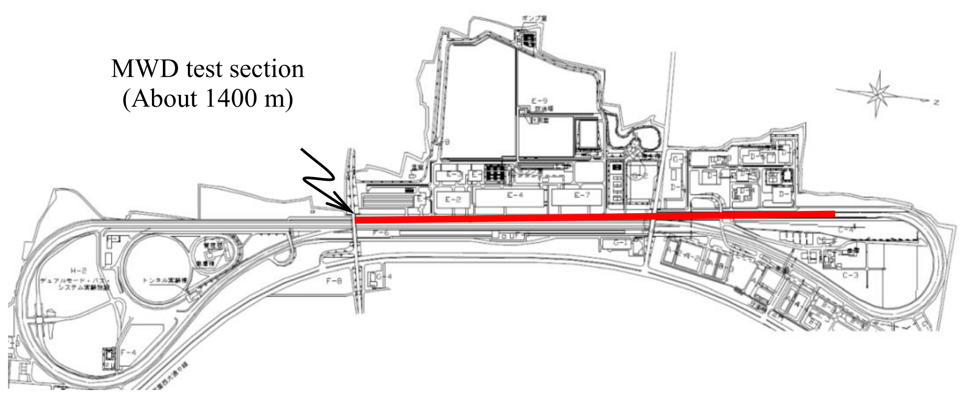
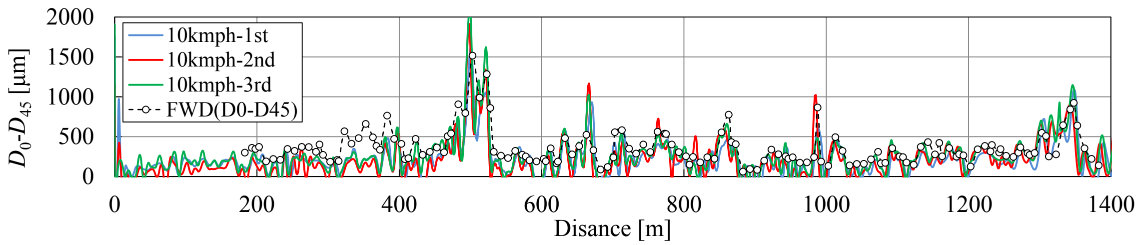


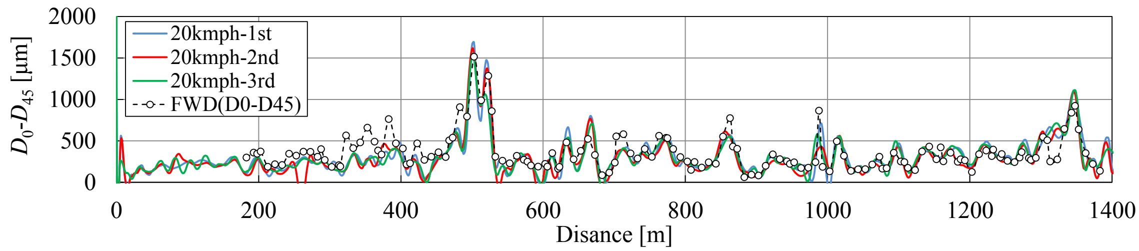
Fig. 5 Section for the MWD test

RESULTS AND DISCUSSION

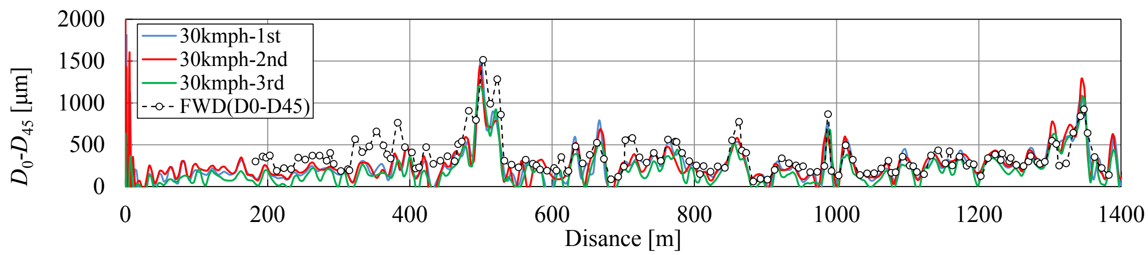
Fig. 6 illustrates the measured pavement surface deflection difference, i.e., the difference between deflection just under rear wheel ($x = 0$) and deflection at an arbitrary point ($e.g., x = 45\text{cm}$) (hereinafter referred to as ($D_0 - D_{45}$)) calculated by equation (3a). The MWD test was implemented three times for each running speed. As shown in Fig. 6, the results at each running speed were similar, which means that the measurements are repeatable. In addition, it is shown that the measurement accuracy is not closely dependent on the running speed. The results of FWD testing for a given measurement section is also presented in Fig. 6. In general, road surface deflection is affected by pavement temperature. Hence, temperature correction is necessary to get rid of effect of temperature on the measured deflection, and the MWD and FWD can measure pavement temperature during operation. The MWD and FWD tests were conducted in November and December respectively. As a result of temperature measurement, there was not almost difference of the temperature. For that reason, it was judged that there was no need for temperature correction. Also, the loads of MWD and FWD are different. Hence, the results of FWD testing are those after linear correction of load. As shown in Fig.6, it is showed that the results of MWD testing agree substantially with that of FWD. For example, the part and number of the biggest (D_0-D_{45}) obtained by MWD test are consistent with that of FWD test. It is possible that sensor deck designed to tilt around the wheel axle cleared measurement errors caused by tilt of sensor deck. In contrast, the results showed the scattering and uniformity of FWD and MWD data in approximately 350 m. It is possible that this is attributed to greater vibration and bouncing caused by road roughness during measurement. Also, these measurement results include effects on load change and impact load during measurement. Accordingly, the value of (D_0-D_{45}) does not always need to be accurate. However, in comparison with RWD that have been put into practical use, these results indicate that the MWD have enough accuracy as the device to specify deteriorating road sections which need detailed survey. Finally, the study determined from these results that the MWD has applicability as moving device for measuring load bearing capacity.



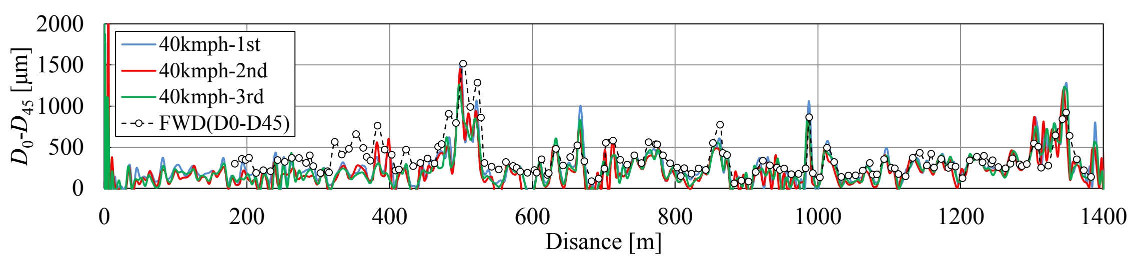
(a) Running Speed: 10 km/h



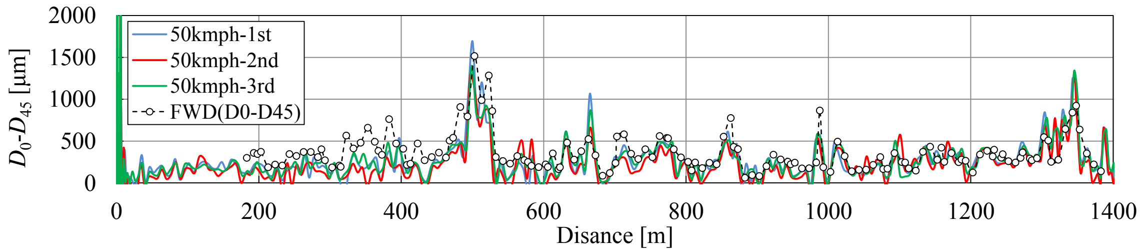
(b) Running Speed: 20 km/h



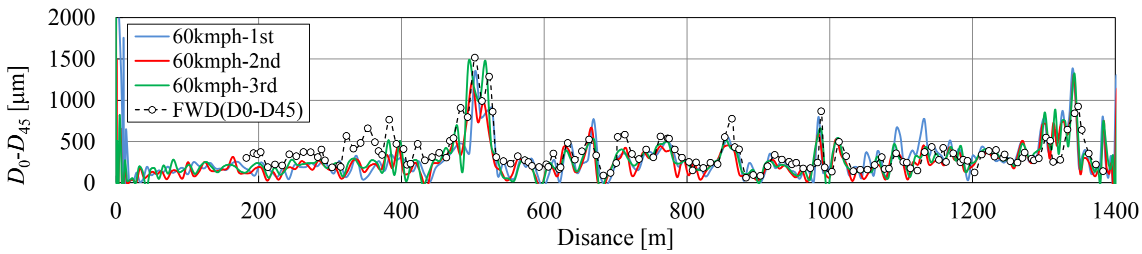
(c) Running Speed: 30 km/h



(d) Running Speed: 40 km/h



(e) Running Speed: 50 km/h



(f) Running Speed: 60 km/h

Fig. 6 The deflection difference (D_0-D_{45})

CONCLUSION

This study aims at developing a device for measuring the load bearing capacity and at establishing an efficient method for evaluating the soundness of farm roads. In this paper, we proposed a determination method that uses (D_0-D_{45}) obtained by MWD test. The results of MWD measurement showed that MWD deflection measurements are repeatable. Also, MWD measurement is not closely dependent on the running speed at travel speeds of 10 to 60 km/h. In addition, the results of MWD testing were agreement with that of FWD. Therefore, it is showed that the applicability of the MWD was demonstrated. A further direction of this study will be to accumulate test data under various conditions in order to improve the proposed method.

ACKNOWLEDGEMENTS

This study was done in collaboration with the National Institute for Land and Infrastructure Management. We are grateful to all those who provided assistance.

REFERENCES

Kano, T. 2008. Study on a moving deflectometer, The development of a moving deflectometer for pavement, Asphalt. 51, No. 224, 43-54.

Maruyama, T. 2012. High-speed moving deflectometer, Journal of Civil Engineering, 53 (5), 58-59.

Flintsch, G., Ferne, B., Diefenderfer, B., Katicha, S., Bryce, J., Nell, S. and Clark. T. 2012. Assessment of continuous pavement deflection measuring technologies, SHRP 2 Renewal Project R06F, Transportation Research Board.

Van, T. Rolling wheel deflectometer, Network-level pavement structural evaluation, Measuring Deflection at Highway Speeds, Asset Management, USA.

ERES Consultants. Rolling wheel deflectometer (RWD), Demonstration and comparison to other devices in Texas, Asset Management, US Department of Transportation, FHWA 2004.2

Brian, K. 2010. Diefenderfer, Investigation of the rolling wheel deflectometer, Virginia Transportation Research Council, Final Report, VTRC 10-R5.

Elseifi, M.A., Abdel-Khalek, A.M., Gaspard, K., Zhang, Z. and Ismail, S. 2012. Evaluation of continuous deflection testing using the rolling wheel deflectometer in Louisiana, Journal of Transportation Engineering, ASCE, 138 (4), 414-422.

Rasmussen, S., et al. 2008. A comparison of two years of network level measurements with the traffic speed deflectometer, Transport Research Arena Europe.

Ferne, B., Langdale, P. and Round, N. 2009. Development of the UK highways agency traffic speed deflectometer, Bearing capacity of roads, railways and airfields, Tutumluer & AI-Qadi, 409-418.

Terada, T., Kawana, H., Kubo, K., Takeshi, Y. and Matsui, K. 2012. A study on evaluation of pavement soundness using a mobile deflection measuring device. Journal of JSCE, 68 (3), 13-20.

Matui, H., Kubo, K., Terada, T. and Kawana, H. 2013. Development of moving weight deflectometer and application to pavement structural evaluation, Civil Engineering Journal, 55 (12), 10-13.