Comparison of jumping process between small-sized and large-sized tractors

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Abstract: Fatal farm accidents are a serious problem in agriculture. In particular, tractor-related accidents are frequent. Overturning brackets and rollover protection structures have been developed for reducing the fatal tractor-related accidents. However, the mechanism by which tractors overturn has not yet been completely clarified. Tractors, especially small-sized ones commonly used in paddy fields in Japan, jump under certain conditions. This jumping is considered to lead to abnormal behaviors and could cause fatal accidents. Jumping process has been studied in small-sized tractors. However, it is controversial as to whether the jumping process can occur in large-sized tractors which are used in Germany. In the present study, we demonstrate how tractor size effects jumping. Based on the modeling of the jumping process, we conducted simulations for a small-sized tractor typical of those used in Japan and a large-sized tractor typical of those used in Germany. The results of simulations indicate that jumping process is a serious safety issue even for large-sized tractors.

Keywords: tractors, fatal farm accidents, computer simulation, jumping process, nonlinear dynamics

1 Introduction

In 2016, employees in agriculture are 1922.0 and 940.1 thousand in Japan and Germany respectively. In 2014, there were 350 fatal farm accidents in Japan [MA 14] and 166 in Germany [SV 14]. In Japan, nearly half of all fatal farm accidents involve agricultural vehicles, such as tractors and trucks. Tractor-related accidents are a severe safety issue for agriculture. In Germany, fatal tractor-related accidents were massively reduced by overrunning brackets and safety cabins. Due to this safety appliance which was mandatory introduced in West Germany in 1970, deadly accidents in this country decreased from more than 150 in 1970 to less than 50 in 1977 [Sö 13]. However, mechanisms of tractor overturning accidents have not yet been clarified. Thus, it is an urgent issue to clarify mechanisms of tractor-related accidents in order to prevent them. Tractors have been shown to jump under certain conditions. Jumping has been investigated in small-sized tractors (approximately 1000 kg) designed for paddy field use in Japan [Sa 99; Sa 00; Wa

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17]. [Ga 05] conducted an experimental investigation using medium-sized tractors (approximately 4000 kg). It is controversial as to whether the jumping process could cause a fatal accident with large-sized tractors (approximately 7000 kg) such as those used in Germany. It is important to investigate effects of tractor size on jumping. For the present study conducted numerical simulations for two different sized tractors: a small-sized tractor typical of those used in Japan, and a large-sized tractor typical of those used in Germany. Aims of the present paper are to investigate how jumping process occur on different sized tractors.

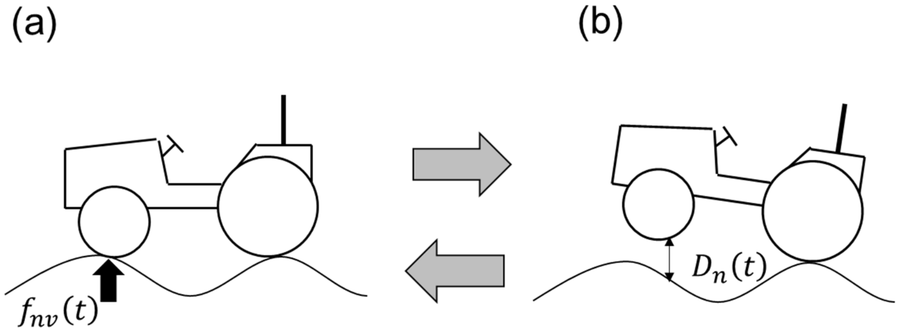

Fig. 1 Schematic diagram of the modeling of tractor jumping in the (a) grounded and (b) jumping states

2 Simulation model

2.1 Modeling the tractor jumping process

In the tractor jumping model, the tractor can be in one of two states, either grounded or jumping (Fig. 1). The tractor jumps when the dynamic load on the front tires f_{nv} (t) becomes zero. At this time, the spring constant k_{nv} and damping coefficient c_{nv} are set to zero. After jumping, the tractor freefalls and the front tires impact the ground. The moment of the collision is defined when the relative displacement D_n(t) between the tire and the ground becomes zero in the jumping state. At this time, k_{nv} and c_{nv} are reset to their original values. Numerical simulations were conducted for the small-sized tractor and the large-sized tractor. The input road is a sinusoidal function, the amplitude of the road was set to 0.05 m and the wavelength of the road was set to the half of the wheel base in both simulations. Travel velocity was 4.020 m/s (14.4 km/h) for the small-sized tractor and 2.355 m/s (8.48 km/h) for the large-sized tractor. Table 1 shows the specifications of both tractors.

Parameters	**Small-sized (Japanese)**	**Large-sized (German)**
Mass of tractor	1000 kg	7600 kg
Pitch axis inertia of moment	700 kg m^2	6473 kg m^2
Roll axis inertia of moment	240 kgm^2	2829 kg m^2
Wheel base	1.340 m	2.770 m
Tread	1.035 m	1.940 m

Tab. 1 Specification of the small-sized tractor and the large-sized tractor used in the simulations

3 Results and discussion

Figure 2 shows simulation results for the front- and rear-tire dynamic load, front- and rear-tire relative displacement, and vertical acceleration at the center of gravity (CG). As shown in Figure 2(a), the front and rear vertical dynamic load become zero; thus, the front and rear tires of the small-sized tractor leave the ground at certain points.

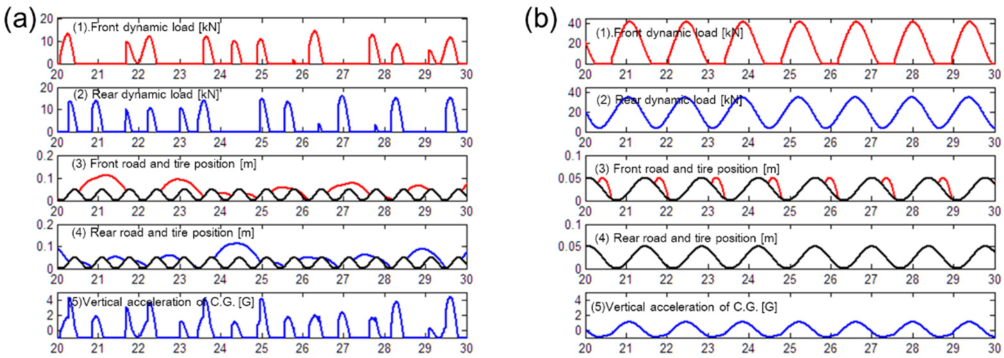

Fig. 2 Simulation results for (a) the small-sized tractor (travel velocity 4.020 m/s) and (b) the large-sized tractor (travel velocity 2.355 m/s). (1) Front-tire dynamic load; (2) rear-tire dynamic load; (3) front-tire relative displacement; (4) rear-tire relative displacement; (5) vertical acceleration at the center of gravity (CG)acceleration at the center of gravity (CG)

The maximum vertical acceleration at the CG is 5.34 g. The minimum vertical acceleration is −1 g, indicating that the tractor is in freefall at that point. Jumping can cause very severe vibration occur in the small-sized tractor. As shown in Figure 2(b), the front dynamic load becomes zero whereas the rear dynamic load does not. Thus, only the front tire jumps from the ground in the large-sized tractor. This causes a reduction in steering performance and can lead to accidents. The results show that large-sized tractors jump as well as small-sized tractors for a road amplitude less than 0.05 m. Nonlinearity arising from jumping is omnipresent in tractor dynamics. Jumping may cause safety issues for both small-sized and large-sized tractors.

4 Conclusion

The effects of tractor size on jumping phenomenon were investigated in the present study. Simulations of a small-sized tractor and a large-sized tractor were conducted. Both large-sized and small-sized tractors were found to jump at certain travel velocities. The results indicate that the jumping is a safety issue for both small-sized and large-sized tractors. Therefore, modeling jumping and nonlinear analysis are important for both small-sized tractors and large-sized tractors.

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