Sideways Overturning Experiment for the Safety of Small-Sized Tractor

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Abstract. The main design for a commercial tractor is safety and a rollover protection structure has gradually been equipped on tractor. The purpose of this study is to experiment the sideways overturning behaviour of a commercially available tractor in China with rollover protection structure. The object vehicle is a small-size tractor which weights near 1200 kg and was widely used in Chinese farm work. The cases of sideways overturning accident with no travelling speed and with idling speed with first gear were considered. Two gyroscopes were attached to the left and right fender on the rear wheels to measure the dynamic of this tractor. The rollover protection structure for the object tractor has been assembled to laterally contact the ground ahead of any side parts on this tractor, and a weight sensor was assembled at the lateral contact point of the rollover protection structure. The result shows that the sideways overturning behaviour of no traveling speed case was similar to that of idling speed case. Moreover, the result of measured impact force is significant while the rollover protection structure for a small-size commercially available tractor in China was designed.

1. Introduction

Small-size agricultural tractors have become popular for work in orchards and in fields to reduce physical burdens on elderly farmers when transporting farm products and implements. Even though a roll-over protective structure which is designed to absorb the impact energy of an overturning tractor in the form of a frame or cab surrounding the operator has been applied gradually to farm tractor since the 1960s (Scarlett et al., 2006), this safety structure is not widely equipped on a small-size agricultural tractor such as the under 40 horsepower serious of Dongfanghong tractor.

One of the evaluation criterions for a rollover protection structure is the capability to stop the tractor from continuous sideways overturning. Chisholm (1979) overturned a full-size tractor on a bank slope and Nichol (2005) drove a mid-size tractor over a mound to recording the sideways overturning dynamic. Those previous researches portray that the overturning dynamic of tractors contribute to the protective efficiency of the rollover protection structure.

To quantify the overturning dynamic of the small-size tractor and the impact of the rollover protection structure, the linear acceleration, the angular velocity and the rotating angle of tractor along with the impact force on rollover protection structure were measured. To minimize the inaccuracy, the rollover protection structure was redesigned to be wider than any vertical side components of the tractor, so that the primarily impacting point of the tractor during sideways overturning could be the rollover protection structure.
The purpose of this study was to investigate the relationship between the dynamic of tractor with the impact of rollover protection structure during an overturning experiment. Moreover, the dynamic of a tractor which is vertically towed to overturn was compared to the dynamic of a tractor which is longitudinally along a bank slope at idling speed and overturned itself.

2. Method

2.1. Main body of tractor
The small-size tractor (1100kg) manufactured by Dongfanghong Industry did not equip with rollover protection structure originally. So that the geometry of the rollover protection structure was redesigned to be wider than any vertical side components of the tractor and the bottom of the rollover protection structure was fixed on the rear part of the transmission.

Dongfanghong SA-250 small-size tractor is of simple structure. The main components of this tractor are wheels, transmission, engine, bonnet and rollover protection structure, which are regular shapes. On the assumption that the whole tractor kept lateral symmetry and the center of gravity of each component was their geometrical center, the weight of each component could be easily calculated as shown in Table 1 after the weight distribution on front and rear wheels (39% on front and 61% on rear) and weight of each wheel had been measured.

After the weights of all components had been determined as presented in Table 1, the height of center of gravity of the tractor was calculated as 0.64 m off the ground.

| Parameter       | Length [m] | Width [m] | Height [m] | Weight [kg] |
|-----------------|------------|-----------|------------|-------------|
| Front wheel     | 1.0\(^a\)  | 0.11      | 0.62       | 15          |
| Rear wheel      | 1.02\(^a\) | 0.22      | 1.04       | 55          |
| Bonnet          | 1.01       | 0.75      | 0.83       | 10          |
| Engine          | 0.65       | 0.40      | 0.80       | 260         |
| Transmission    | 1.30       | 0.24      | 0.31       | 676         |
| Frame           | 0.08       | 1.19      | 1.90       | 56          |

\(^a\) Length of axle between center of left and right wheels.

2.2. Measuring device
Two JY-901 gyroscopes from MIT Motion were attached on the left and right fender of rear wheels as shown in Fig. 1, which can record the acceleration including gravity, angular velocity and rotating angle every 1/10 second.

An electronic force sensor (MEACON, MIK-LCLY-G) was assembled between the main frame of rollover protection structure and the widen impact bar as shown in Fig. 1. The widen impact bar on the right side of the main frame would laterally impact the electronic force sensor so that only lateral impact force would be measured. The instant value would be displayed and only extreme value could be recorded, so the only maximum impact force during overturning and the instant impact force after all the motion of tractor stopped would be collected. The electronic force sensor measures the lateral impact force 10 times per second.
2.3. Overturning setting

Figure 2 shows the coordinate of the gyroscope, the longitudinal axis follows the forward direction of the tractor, the lateral is toward the left side of the tractor, and the vertical axis points to the up direction of the tractor. The coordinate rotates along with the overturning of the tractor.

In the case of the overturning experiment without traveling speed, the rollover protection structure was laterally towed to overturn the tractor on the level ground. In the case of the overturning experiment with traveling speed, the tractor traveled at 0.77 m/s as an idling speed, and was downhill along the 4.4 deg bank slope until the tractor overturned.

3. Results and discussion

3.1. Results of overturning dynamics without traveling speed

Figure 3 is the observed angular velocity along three directions for the cases that tractor was laterally towed to overturn. The timing when the tractor overturned by gravity acceleration was regard as the origin. The obvious overturning tendency of the tractor stopped after 2 s. The overturning experiments with no traveling speed were repeated 5 times.

The maximum values in Fig. 3 (b) at 0.6 s reached a close range to 2 rad/s when the rollover protection structure was going to impact the level ground. The changes of 5 experiment groups after 0.7 s in Fig. 3 (b) became different from each other, which might because the main body of the tractor liberated irregularly after the impact of the rollover protection structure.

The dynamics along pitch direction from 0.6 to 0.9 s in Fig. 3 (a) were similar in all 5 experiment groups, which caused by the fact that the front pivot axle returned to its default pivot angle 0 deg after the impact of the rollover protection structure. The vibrations after 1 s were insignificant.

The results in Fig. 3 (c) show that the dynamic along yaw direction might cause by irregular liberations and were insignificant.
Figure 3. Result of angular velocity on left fender with no traveling speed.

Figure 4 is the results of angular velocities along all three directions observed on the right fender. The results along roll direction and pitch on right fender in Fig. 4 (a) and (b) resembled that on left fender in Fig 3 (a) and (b). The liberations along yaw direction in Fig 4 (c) were also irregular and insignificant.

Figure 5 portrays the results of rotating angles along roll directions observed on the left and right fender. The results show that the rotating angles which represent the lateral instant posture of the tractor during overturning converge to coherence. Moreover, the curves became smooth after 0.8 s in Fig. 5, which also means that the tractor body did not liberated obviously even their angular velocities reported relatively large as shown in Fig. 3 (b) and Fig 4 (b).
3.2. Results of overturning dynamics with traveling speed

Figure 7 is the observed angular velocity along three directions for the cases that tractor was traveling forward at 0.77 m/s along a bank slope with idling speed. The timing when the tractor overturned by gravity acceleration was regard as the origin. The obvious overturning tendency of the tractor stopped after 2.5 s, which is slightly longer than that of the cases with no traveling speed. The overturning experiments with traveling speed were repeated 3 times.

The curves in Fig. 7(b) are similar to the cases with no traveling speed in Fig. 3(b) and Fig. 4(b). But the curves in Fig. 6(a) are different to that in Fig. 3(a) and Fig. 4(a), because the right front wheel slipped toward the bottom side of the bank slope from 0.6 to 1.1 s. The results along yaw direction as shown in Fig. 7(c) are irregular as those in Fig. 3(c) and Fig. 4(c).
Figure 7 portrays the observed angular velocity along three directions for the cases that tractor overturned with traveling speed. The results on right fender in Fig. 8 along pitch, roll, and yaw direction resemble that in Fig. 7.

Figure 9 shows the similarity in rotating angles along roll directions on the left and right fender.
Figure 10 portrays the results of lateral acceleration observed on the left and right fender. The accelerations along lateral direction result in the same tendency as the cases with no traveling speed in Fig. 6 that the left fender reach the opposite extreme to the right fender.

![Figure 10](image)

Fig. 10. Result of lateral acceleration with traveling speed.

### 3.3. Results of lateral impact force

Table 2 shows the result of the measured lateral impact force on rollover protection structure including the maximum value during overturning and the steady value after all the motion of tractor stopped. The contact point of rollover protection structure in experiment #4 with no traveling speed happened to rotate into a hole on the level ground which is filled with soft sand and differs the observed data.

| Roll [rad/s] | Maximum impact force [N] | Steady force [N] |
|-------------|--------------------------|-----------------|
| No traveling speed |
| #1          | 3,949                    | 2,577           |
| #2          | 4,165                    | 2,489           |
| #3          | 5,135, cable out         |                 |
| #4          | contact bar stuck into a hole, data not useful |
| #5          | 3,685                    | 2,264           |
| With traveling speed |
| #1          | 5,125                    | 2,587           |
| #2          | 5,125                    | 2,783           |
| #3          | 4,096                    | 2,293           |

The maximum impact forces of the cases with no traveling speed in Table 2 result in the same range as the that of the cases with traveling speed. According to those dynamic data specially the angular velocities, the overturning dynamics of the tractor in both cases with and without traveling speed tend to be a stable performance every time. Since there have lots of vibrations along yaw direction, which changes the weight distribution between front right wheel and rollover protection structure, the impact force shared by the front right wheel might cause the differences in maximum impact force.

The steady forces of the cases with and without traveling speed in Table 2 converge to coherence because the final postures after the motion of the tractor stopped are much similar. The differences in observed results might be induced by that the pivoted angles of the front axle are irregular during experiments.
3.4. Discussion
The observed dynamic data along pitch and roll direction show that the overturning performances with no traveling speed resemble that with traveling speed at 0.77 m/s. The vibrations in angular velocities along yaw direction portray that the pivot front angle has effect on stability of the tractor when the rollover protection structure impacts the level ground, which might also influence the maximum impact force on rollover protection structure. The lateral accelerations on left fender have the opposite extreme value to that on right fender, which means that right fender might contact the level ground during the overturning of the tractor.

4. Conclusion
The experiment of measuring the overturning dynamic of the small-size commercially available tractor and the impact force of rollover protection structure as the primarily impacting point has been conducted. The overturning performances in both the cases without and with 0.77 m/s traveling speed are similar. The maximum impact force on rollover protection structure to stop the continuous overturning might contribute to the design for rear mounted safety frame.

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