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Review Article

A Review of Farm Tractor Overturning Accidents and Safety

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ABSTRACT

Tractor rollover occurs when a tractor tips sideways or backwards and overturns, potentially crushing the operator. Rollovers are typically considered to occur more frequently during a sharp turn at a high speed on sloping terrains, although data show that rollovers do occur on flat land after hitting obstacles or through inappropriate use and hitching of implements. It is important to highlight that tractor overturns are the major cause of death in farm operations. The overturns are as a result of interactions between the tractor operator, the tractor and the environment. A review of the relevant literature reveals that more than 800 people are killed each year in tractor accidents, and for every person killed, at least 40 others are injured. This paper focuses on tractor overturns because they account for more than half of all the tractor-related deaths. In addition, farm tractor operational safety principles are also highlighted.

Keywords: Farm, tractor, overturning, accidents, safety

INTRODUCTION

Farm tractors are used for farm activities. However, there are serious risks of injuries involved while using tractors as they can either roll over sideways or backwards. At the same time, there is only little chance to prevent tractors from rolling over. Tractor rollover occurs when a tractor tips sideways or backwards and overturns, and it may potentially crush the operator. Rollovers are more frequently reported to have occurred on sloping terrains, often during a sharp turn at high speed, although data show that rollovers do occur on flat land after hitting obstacles or through inappropriate use and hitching of implements (Ashby and Day, 1995; Myers *et al*., 2006). Accident involving an overturning tractor always has serious consequences on the operator. For instance, the tractor driver/ operator may be killed or seriously injured and unable to return to work, perhaps for months. The tractor itself and other equipment may be severely damaged and need major repairs. Even when damage is slight, time is lost in repairing the tractor and making it serviceable again. Although the risk of death or injury has certainly been reduced by fitting safety cabs to most agricultural tractors, the safety measure has not eliminated the causes for overturning tractors due to several reasons such as the high centre of gravity and tractors are often used on sloping or uneven ground (Bureau of Labour Statistics, 2005; Owen and Hunter, 1977).

Meanwhile, studies have shown that farm tractors are involved in a high proportion of farm fatalities and severe injuries. Some of the potential hazards are difficult to be eliminated and they have in fact persisted over the years, despite the manufacturers' and engineering efforts to provide

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better designs (Cole *et al*., 2006; Melvin *et al*., 2009). In short, hazards related to farm tractors are related to stability, brakes, access to the workplaces, control, operators, as well as power transmission from the farm tractors, noise and the environment (Carlson *et al*., 2005; Hwang *et al*., 2001; Campbell, 1990).

In the United State of America, it is estimated that more than 800 people are killed each year in tractor accidents, and for every person killed at least 40 others are injured (Bureau of Labour Statistics, 2005). Overturns account for more than half of the tractor accidents that lead to death (Liljedahl *et al.*, 1979). According to a personnel at the National Safety Council (NSC, 1992), agriculture had a rate of 44 deaths per 100,000 workers in 1991, making agriculture relatively the most hazardous industry. Consequently, farm tractors have been categorized as the most hazardous of all farm machinery in the United States.

Accidents involving overturning farm tractors are issues of growing concern worldwide, particularly among the farm members' families, farm safety specialists, governments, and researchers. The reasons for concern are attributed to the increase in the occurrence of fatal injuries. In the light of these, this paper highlights the accidents involving overturned farm tractors and provides important information so as to create awareness on the efficient use of farm tractor.

FARM TRACTOR ACCIDENTS

Agriculture is one of the most hazardous industries in the United States, which is only surpassed by mining and construction. No other farm machine has been identified as with potential hazards in agricultural production as the tractor. Tractor-related injuries account for approximately 32% of the fatalities and 6% of the non-fatal injuries in agriculture. More importantly, over 50% of the accidents are attributed to tractor overturns. Farm tractor accidents are the major cause of farm work-related deaths. For example, more than 200 farmers' family members in Indiana died as a result of tractor accidents during the 70's (Carlson *et al*., 2005; Campbell and Field, 1979). The three major elements responsible for accidents involving farm tractors are:

1. the farm tractor operator,
2. the farm tractor, and
3. the environment (workstation)

The above elements might have control to some extent; among other, setting up fields with adequate turning room at the ends of rows is a safety factor entirely within human control. The speed at which the tractor is operated, as well as if a rollover protective structure (ROPS) and seat belt are used, is another important factor. However, there are some cases in which these elements are beyond humans' control. In such cases, operations must be modified in order to complete the job safely. A particular operator is probably safety-conscious and driving a tractor equipped with safety features, yet the operator may drive into a hazardous environment and because the environment is considered as "safe", the operator may work with an unsafe tractor. Either of these situations is likely to result in an incident. Preventing incidents means recognizing hazards and avoiding them, or at least, taking appropriate precautions if they must be encountered. Falls are also some causes of tractor accidents. Falls involve both tractor operators and extra riders who are often children. Another source of tractor-related injuries and death is entanglement (caught) in rotating power-take off shaft (Cole, 2003; Reynolds and Grovers, 2000; Aherin *et al*., 1992).

Farm tractor operation, like automobile driving, becomes hazardous with non-stop operation is extended without rest. According to Brauer (1990), drivers should limit themselves to 8-10 hours of automobile driving a day. Exceeding these suggested hours could lead to stress and tiredness, both of which have serious consequences on the operators' ability to function in a safe manner.

Modern tractors have rollover protection systems to prevent an operator from being crushed if the tractor overturns. It is important to remember that the ROPS does not prevent tractor overturns. Rather, it prevents the operator from being crushed during an overturn. This is especially important in open-air tractors, where the ROPS is a steel beam that extends above the operator's seat. For tractors with operator cabs, the ROPS is part of the frame of the cab. A ROPS with enclosed cab further reduces the likelihood of serious injury because the operator is protected by the sides and windows of the cab. In short, farm tractor accidents occur regularly from:

1. Rollovers
2. Power take offs
3. Falls from tractors
4. Hitching equipment
5. Tractor operations and
6. Towing

OVERTURNS/ROLLOVERS

Rollover is one of the main causes of fatalities in using farm tractors. No other machine is identified with hazards of farming more than the tractor. Tractors are often used on sloping or uneven ground as well as towing vehicles. Moreover, tractors have no suspension and this is one of the main reasons for overturning. In particular, it is very hazardous when a tractor is travelling downhill, changing direction, crossing the slope, and climbing uphill. Tractor turnover is by far the major cause of tractor-related deaths. Four reasons can be identified for tractor's overturning; these include tractor being operated on steep side slopes, tractor goes too fast for the sharpness of the turn, power applies to the rear wheels of the tractor too quickly and finally pulling pull a load that is not hitched to the drawbar of the tractor (Melvin *et al*., 2009). In a Johns Hopkins University, a study of tractor-related deaths between 1975 and 1981 revealed that 45 percent or 1,163 of the 2,566 total deaths were caused by roll-over accidents. Similarly, a 12-year study of Colorado agriculture-related deaths (1978 to 1990) revealed that 50 percent of the tractor-related deaths were due to roll-over (Carlson *et al*., 2005). Of the 175 tractor turnover accidents reported in Nebraska from January 1966 to January 1972, 78 involved fatal and 97 non-fatal injuries. According to Etherton *et al*. (1991), tractor overturns were the single most accident accounting for 52 percent of the reported tractor accidents. Rollover protective structure (ROPS) and seat belts were designed to provide overturn protection in the events of tractor rolls over. Tractors with ROPS were first used in New Zealand in the 1960s. The most effective form of protection in the event of a rollover is Rollover Protective Structures in combination with seat belt use. ROPS are structural components, either a roll bar device or crushproof cab, which provide an umbrella of safety in the event of a rollover. The effectiveness of ROPS in preventing tractor rollover deaths has been demonstrated in Sweden, Great Britain and Norway (Springfeldt *et al*., 1998). For example, the tractor rollover fatality rate decreased from 15 per 100,000 tractors to less than 1 per 100,000 tractors as the legal safety requirements moved from ROPS on all new tractors to safety cabins on all new and existing tractors in Sweden (Springfeldt *et al*., 1998).

Many farmers died when their tractors rolled on top of them before tractors with ROPS were introduced and used. Some farmers were killed by rollovers while operating tractors along steep slopes. Others were killed while attempting to pull an excessive load from above axle height, or when cold weather caused tyres of tractors to freeze down; in both cases, tractors were caused to pivot around the rear axle. Goering (1989) reported that early tractors had far fewer safety features than modern ones. Modern tractors are much safer than the ones used 20 or 30 years ago. In more specific, rollover protective structures, and seat belts of the modern tractors used at present prevent

many deaths and injuries during tractor overturns. In addition, these tractors are equipped with improved hitch designs and weight distribution which made them more stable. Moreover, wider wheel bases, better visibility, and other features such as running lights and adjustable seats have given these tractors more safety measures. Despite all these modern safety improvements in design, there are still risks involved while working with or operating a tractor. These risks can be reduced if the tractor operator understands operational safety precautions properly.

Tractors are quite safe when operated properly but they can cause serious injury and even deaths if they are used in improper manner. According to Murphy (1992), farm tractor operators frequently make physical changes to the safety features of the farm tractors. For example, some farmers cut the rollover protective structure (ROPS) off and remove the power take off (PTO) shaft master shield. On the contrary, a few modern features have actually increased the potential dangers. Such dangers include increased rear axle torque which increases the risk of rear overturns, while high speed tractors increase the danger of side overturns due to centrifugal force on curves or corners. High speed tractors increase the danger of losing control during road travel. Tractor upsets or overturns account for more than half of all tractor-related deaths. The side overturn is the most frequent type of overturn. Studies indicated that 75-85 percent of overturns are to the side. A tractor has a high centre of gravity, and this leads to sharp turns or high loads which can cause it to overturn quite easily at a relatively high speed. Meanwhile, centrifugal force can cause a tractor to overturn if the direction of travel is changed. For example, when the right front wheel of a tractor suddenly changes direction into the road ditch, the natural reaction of the operator is to steer it back onto the roadway. However, the forces will pull the tractor over on its side. Similarly, field slope, tractor speed, turning radius, rear axle torque, and centre of gravity are interrelated factors which determine the potential for tractor turnover (Myers *et al*., 2006).

FARM TRACTOR STABILITY

Generally, farm tractor overturn incidents are resulted from changes made to the limiting position of the vertical plane through the centre of gravity of the farm tractor to a position outside the points where any two wheels make contact with the ground. The main limitations of tractors are steep slope, high speed, rough ground, and loss of control. The stability loss on rough ground is more likely than on smooth ground because the wheels of a tractor follow the bumps and hollows of the rough ground which cause steep local slopes. The general ground slope may be small but its roughness can cause local slopes to become steep (Myers, 2008). Thus, it is very useful to design a system that is able to keep tractors stable in various situations. The location of the centre of gravity varies with the make and model of the tractors. It is ahead of the rear axle and midway between the rear wheels on wheel type tractors. As long as the tractor remains level enough (i.e. a vertical line drawn through the centre of gravity falls within the points where the wheels make contact with the ground), the tractor will not tip (Promersberger *et al*., 1979; Spencer, 1978; Spencer and Gilfillan, 1976; Spencer and Owen, 1981). Table 1 shows some classifications of farm tractor overturning accidents and their causes. When tractor stability is the main concern, then a slope of 15^{o} must be classified as steep and a slope of 30^{o} is extremely steep.

Slope and stability limits of some farm tractors are given in Table 2. It is important to realise that overturning tractors can occur on ground which is absolutely flat, such as when they are cornering and driven at a very speed. This is unlike most road vehicles, where skidding usually occurs instead of overturning.

TABLE 1
Classifications of farm tractor overturning accidents and their causes

Category	Cause	Description
Farm tractor related accidents	(1) Loss of stability (when tractor operational safety limit is exceeded) (i) Slope exceeds tip angle (ii) High speed (2) Loss of control	- Tractor overturning rearward - Mostly two wheel-drive tractor sliding downhill before overturning
Operator-related accidents (an operator misjudged width of a head land on which he/she intended to turn and drove into a ditch at low speed and on flat land)	(3) Operator's misjudgement	- Tractor side turning on a flat land

Source: Hunter and Owen, 1983

TABLE 2
Slope and stability limits of some farm tractors

Slope				Unstable tractor
Degree	Percentage	Gradient	Description	
0	0		Flat	Two wheel-drive tractor, turning at high speed
5	9	1 in 11	Gentle	Two wheel-drive tractor, with mounted implement turning at full breaking system lock
10	18	1 in 6	Medium	Two wheel-drive tractor, with heavy ballast on front loader (tipping side ways)
15	27	1 in 4	Steep	Two wheel-drive tractor, with heavy mounted implement
20	36	1 in 3	Very steep	Two wheel-drive tractor, with trailed equipment
25	47	1 in 2	Excessive	Two wheel-drive tractor, with standard wheel tract (1630 mm)
>30	58		Extreme	Four wheel-drive tractor, with wide wheel track (1840 mm)

Source: Murphy *et al*., 1985

TABLE 3
The number of farm tractors in use, the percentage of the farm tractors equipped with ROPS and the number of rollover fatalities per 100,000 farm tractors in some countries

Country	Number of farm tractors	Percentage of farm tractors with ROPS	Fatalities per 100,000 farm tractors per year
Sweden	324000	98	17
Norway	155000	83	24
Finland	240000	75	35
Great Britain	450000	99	14
West Germany	1600000	98	18
New Zealand	120000	65	37
Spain	500000	50	45
USA	4620000	55	60

Source: Bengt, 1996

Hunter and Owen (1983) studied 560 tractors overturning accidents on farms in the UK and found that there were three main conditions leading directly to loss of stability. These were exceeding the tip angle (i.e. exceeding the limit of static stability), travelling at too high a speed, and travelling over rough ground. Loss of stability also occurred indirectly after loss of control, which represented the fourth condition, in which case the tractor skidded downhill on sloping ground before overturning. The above four conditions, which accounted for 55% of total accidents, were seen as exceeding the limitations of the tractor (Myers, 2008). Skidding downhill occurs if the ground is too slippery for the tractor to remain under control, and this is also common on grass fields as well as loose surfaces. Skidding or overturning when cornering usually occurs at a high speed (Hard and Myers, 1999; Behrooz and Hanif, 2009). Sideways overturning often occurs on steep slopes and on rough ground. It is important to note that the manufacturers did not provide any guidelines on safe slope for any of the machines and therefore it was difficult for the tractor operators to prevent any of these accidents. In addition, the fact that a number of accidents caused by tractor operator's misjudgements have also been well accepted.

Table 3 shows the percentage of farm tractors equipped with ROPS and the number of rollover fatalities per 100,000 farm tractors in some countries. Based on the data, it was observed that as the percentage of tractors equipped with ROPS increased, the fatalities caused by farm tractor rollovers per 100,000 per year were decreased (*Fig. 1*).

CONCLUSIONS

Therefore, rollover prevention is an issue of major importance and the subject has become the main focus of several researchers. Rollover protective structure (ROPS) has been one of the most important advances in protecting drivers/operators from tractor overturn accidents. However, one of the most effective ways of minimising farm tractor accidents is through regulation of machinery design, manufacture, supply and operation. In conclusion, the following farm tractor operation safety tips (TOST) are highlighted:

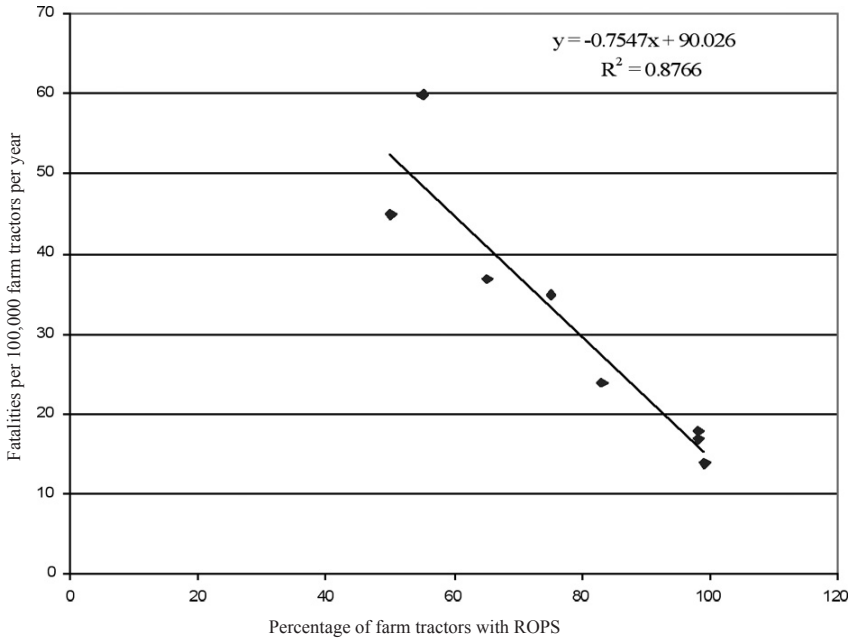

Fig. 1: Fatalities per 100,000 tractors per year against % of tractors with ROPS

1. When a tractor has adjustable wheel width, operate it with the widest wheel adjustment which is rather practical for the task at hand.
2. Add weights to the tractor to make it more stable.
3. Ensure that the shields for the power take off shaft and other moving parts are in place and in good condition.
4. Check the brakes individually and then make sure that the brakes are locked together with the tractor operating at a transport speed to ensure it will make a straight line stop.
5. The rollover protection structures (ROPS) and seat belts, when worn, are the two most important safety devices to protect operators from death during tractor overturns.
6. Slow down at turns and curves. The turning radius of a tractor is much smaller than that of an automobile. Thus, taking a curve too fast can cause an overturn or a jackknife, if machinery is attached.
7. If a tractor must be operated across the slope, use the widest possible wheel adjustment, very slow speeds and extra caution in watching for obstacles that the wheels may hit.
8. Lock break pedals together before driving at transport speed.
9. Four-wheel drive tractor is safer on slopes than two-wheel drive tractor because the former tractor has better front wheels grip.

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