

Tractor stability parameters as affected by ROPS type

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Abstract

Tractor overturns are a major cause of death in agriculture. Many variables are involved. To minimise the risks of driver injuries in an overturn a Roll-Over Protective Structure (ROPS) has been invented. Narrow-track tractors for orchard and vineyard operations are mainly available with two different ROPS types: an enclosed cab frequently fitted with filters and air-conditioning system or a simple front two post ROPS designed to be folded down allowing the tractor to operate in a reduced space. Concerning stability, the tractor unstable equilibrium angles are the result of the tractor configuration and position with respect to the ground slope. The aim of the paper was to study the effect of ROPS type on tractor stability performance.

The tractor stability parameters were evaluated on 18 modern narrow-track tractors measuring the mass, track width, wheelbase, Centre of Gravity (CoG) and Moments of Inertia (MoI). The evaluation considered pairs of tractors equipped with cab ROPS and two post ROPS.

The cab fitment keeps the wheelbase and track width of the tractor unchanged with respect to the front foldable ROPS but affects the mass, position of the CoG and longitudinal and transversal MoI. Data show an increase of tractor mass and higher CoG and MoI for the cab fitment with respect to the two post ROPS.

The recent debate on the safety performance of two post ROPS is consequent to the incorrect use of the foldable ROPS and the cab is often claimed to provide better driver protection. The investigation conducted denotes that on sloping fields narrow-track tractors fitted with a cab ROPS reach the unstable state at lower angle than two post ROPS tractors.

Keywords: Front foldable ROPS, Enclosed cab, Rollover, Moment of inertia, Unstable equilibrium angle

1. Introduction

Roll-Over Protective structures (ROPS) were conceived in Europe in the 1950s in Europe as a passive approach for driver protection in the case of tractor overturning (Moberg, 1964). Data of fatal accidents for tractor rollover in Sweden showed a sharp decrease in twenty years and confirmed the efficacy of the device (Springfeldt, 1996; Thelin, 1998). The good performance of the ROPS in driver protection was the result of an accurate design by the tractor manufacturer combined with standardized tests for evaluating the strength behaviour of the structure during a load sequence where the ROPS had to sustain and absorb normalised forces and energies (Organisation for the Economic Co-operation and Development, OECD Standard Codes, 2016). Over the years ROPS continued to be adopted for tractor rollover driver protection. Currently ROPS mounted on agricultural tractors are currently designed as two post protective structures, fixed to the rear or in front of the driver, and enclosed cabs with windows and doors. The ROPS structures mounted on narrow-track tractors specifically designed for operating in orchards and vineyards are commonly front foldable two post ROPS and enclosed cabs (Fig. 1), recently designed also in a configuration type with a very rounded shape and a reduced height to better match with the lower overhead clearance in vine and fruit tree inter-rows (Rondelli et al., 2012).

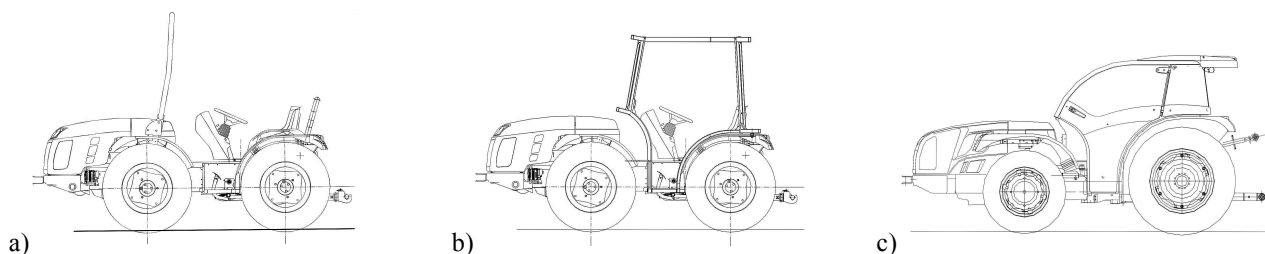


Figure 1. ROPS types currently mounted on specialised narrow-track tractors for orchards and vineyards:

a) front foldable two post ROPS, b) square cab ROPS, c) round cab ROPS.

Enclosed cab ROPS have added advantages for the driver with respect to the front ROPS because, when pressurized and fitted with filters, they also provide protection from high or low temperatures, rain, dust and chemicals and normally allow a greater comfort when tractors are in normal field operation. Front ROPS have advantages when the tractor needs to operate in reduced overhead clearance conditions such as orchards and vineyards because if strictly necessary the ROPS can be folded by turning the upper part down on the supports fixed to the tractor chassis. A recent international

debate was related to the incorrect use of front foldable ROPS, potentially due to the difficulty in raising the structure because of its heavy mass and the uncomfortable position of the operator for the manual handling. Increased rollover fatalities and serious injuries were recently reported as deriving from front ROPS in the folded-down position (Hoy, 2009; Pessina et al., 2015). An approach selected at the standardization level was to complement the sequence of ROPS loadings with a limit in the force to be manually sustained in the ROPS actuation combined with a clear identification of the point from which to carry out the handling operation. At present, due to a predictable incorrect use of the front ROPS, enclosed cabs are considered as the safer option because of the clearance zone always surrounding the driver. Considering the high tractor rollover risk as a consequence of its configuration and position with respect to the ground slope, the aim of this paper was to study the effect of ROPS types on tractor stability performance. Front two post ROPS and enclosed cabs fitted on narrow-track tractors were compared.

2. Materials and Methods

The evaluation of the effect of the ROPS type on tractor stability performance was performed at the University of Bologna, Laboratorio di Meccanica Agraria, which is an official OECD Test Station. Eighteen tractors specifically designed for use in orchards and vineyards were analysed. Mass, wheelbase, track-width, height of gravity centre and moments of inertia were considered the parameters affecting the tractor stability and so were all measured.

2.1. Tractor configurations

Nine pairs of narrow-track tractor types were considered for a total of eighteen tractors submitted to the tests, each tractor type being mounted with two different ROPS: front foldable two post ROPS and cab ROPS. Seven tractor types were equipped with equal-sized wheels, five had the steering wheel acting on the front wheels while two were articulated tractor types with the steering wheel acting on the central articulation joint. Seven tractor types were fitted with square-shaped cabs allowing a wide field of vision because they were designed for normal and reversible driving positions. The other two types were provided with standard wheels, one had the steering wheel acting on the front wheels and the second one was equipped with a dual steering system acting on the front wheels and central articulation joint. The cab ROPS fitted had a rounded shape and reduced height and were specifically designed for normal driving standard wheeled narrow-track tractors operating in low overhead clearance conditions, such as in modern orchards and vineyards. The main characteristics of the tractor types are summarized in Table 1, defining the Equal-Sized Wheels type as ESW and the Standard Wheels type as SW.

Table 1. Tractor configurations considered in the tests.

Tractor type	ROPS type	Wheels type	Steering type
Tractor 1	Front two post square cab	ESW	Front wheels
Tractor 2	Front two post square cab	ESW	Front wheels
Tractor 3	Front two post square cab	ESW	Front wheels
Tractor 4	Front two post round cab	SW	Dual Steering
Tractor 5	Front two post square cab	ESW	Front wheels
Tractor 6	Front two post round cab	SW	Front wheels
Tractor 7	Front two post square cab	ESW	Front wheels
Tractor 8	Front two post square cab	ESW	Articulation joint
Tractor 9	Front two post square cab	ESW	Articulation joint

2.2. Tractor stability parameters

Mass, track width and wheelbase were directly measured on the tested tractors while the tractor’s inertia and centre of gravity (CoG) height were calculated.

Tractor’s inertia and CoG height were measured from the period of oscillation when the tractor was secured on an oscillating platform for two different pivot heights, according to the parallel axis theorem (Casini-Ropa, 1976). Two tractor positions on the platform were tested allowing calculating the longitudinal (M_oI_l) and the transversal (M_oI_t) moments of inertia to be calculated (Figure 2).



Figure 2. Tractor positions on the oscillating platform for longitudinal and transversal moments of inertia calculation.
 a) front foldable two post ROPS, b) square Cab ROPS, c) round Cab ROPS

3. Results and Discussion

The results obtained from the measurements performed on the eighteen tractors evidenced the effect of the replacement of a two post ROPS with a cab ROPS in terms of repartition of the total mass and its consequence on the stability performance of the machine. The comparison between tractor type configurations fitted with a two post ROPS and a Cab ROPS is depicted in Figure 3; cab mounted tractors show a higher total mass with respect to the two post ROPS ones. The averaged mass increase was 170 kg.

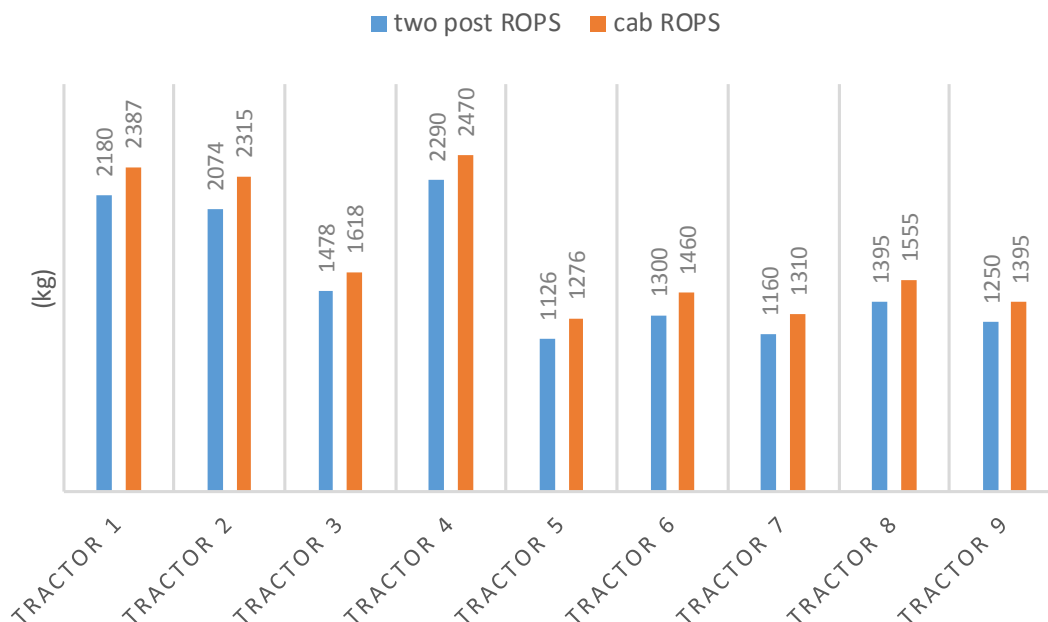


Figure 3. Tractor masses: front two post and cab ROPS configurations.

These results clearly evidence that the cab is heavier than the two post ROPS but this does not affect the tractor track width and wheelbase (Table 2). On the contrary mounting a cab ROPS instead of a two post ROPS caused an increment in the tractor’s inertia and CoG height due to the location of the cab. This trend is common for all tractors; the averaged data are depicted in Figure 4. Tractor mass ranged from 1584 to 1754 kg, CoG height was from 588 to 654, M_oI_l from 239 to 372 and M_oI_t from 1092 to 1481.

Table 2. Track width and Wheelbase of the tested tractor configurations.

Tractor type	Track width*	Wheelbase
Tractor 1	910-1140	1495
Tractor 2	853-1245	1495
Tractor 3	984-1325	1390
Tractor 4	1007-1605	1495
Tractor 5	886-1182	1200
Tractor 6	900-1250	1240
Tractor 7	938-1286	1280
Tractor 8	827-1120	1390
Tractor 9	762-1078	1362

*track width adjustment by changing position of rims with respect to discs.

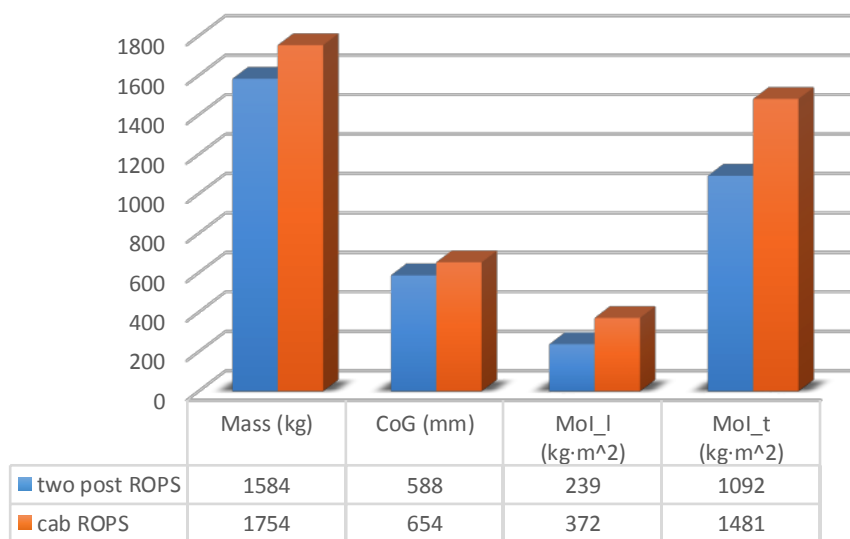


Figure 4. Mass, CoG height, MoI_l and MoI_t: averaged data comparison for front two post and cab ROPS tractor configurations.

Results in Figure 5 comparing the stability data of the two tractor ROPS configurations show a 10.8% increment of the tractor mass and consequently a CoG height 11.2%, a MoI_l 55.9% and a MoI_t 35.6% higher.

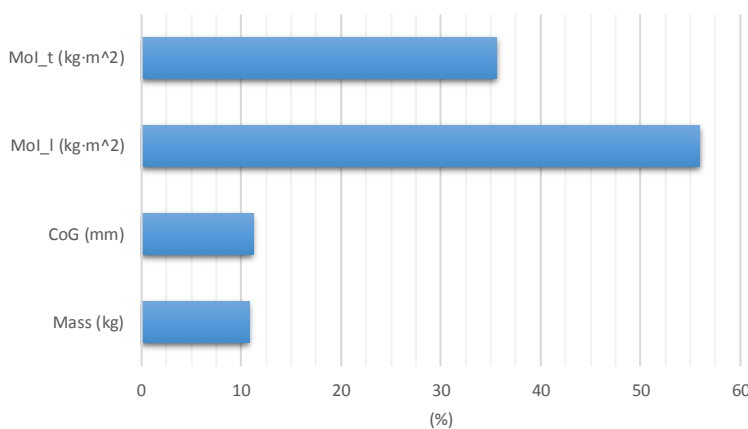


Figure 5. Mass, CoG height, MoI_l and MoI_t: % data increase of cab ROPS with respect to two post ROPS tractors.

The comparison of the two ROPS types, as currently mounted on tractors specialised for operations in orchards and

vineyards, shows a clear effect of the cab with respect to the two post ROPS on the tractor stability, as previously evidenced in studies analysing tractor rollover behaviour (Guzzomi et al., 2009; Liu and Ayers, 1998; Murphy et al., 1985). Increasing all stability parameters, it is demonstrated that a cab mounted tractor reaches the unstable state at a lower angle with respect to the equivalent two post ROPS tractor type because of the higher CoG height. Moreover, by increasing the mass and moments of inertia, a higher tractor energy is involved in the rollover event.

4. Conclusions

The study considered narrow-track tractors specialized for operating in orchards and vineyards with the purpose of comparing the contribution of the ROPS type to the stability performance. Two post and cab ROPS mounted tractors were evaluated by measuring the mass, track width, wheelbase and longitudinal and transversal moments of inertia, defined as the parameters affecting the behaviour of the tractor in a rollover event. The results obtained reveal that, mounted on the same narrow-track tractor, a cab ROPS negatively affects the stability of the machine with respect to the two post ROPS. Fitting a cab ROPS, due to the tractor shape and position of the driver's seat, influenced the CoG position and the tractor consequently had a decreased stability limit angle. The cab mounting was also associated to a higher tractor mass and inertia, so a higher energy was involved in the rollover event.

A recent debate at international level on the safety performance of the two post ROPS, consequent to an increase in the number of fatal accidents involving tractors with foldable ROPS in the folded-down position, led to claims that the cab ROPS provide a better driver protection in a rollover event because the clearance zone is always surrounding the driver. However, the investigation conducted denoted that on sloping areas, typical of many orchards and vineyards, narrow-track tractors fitted with a cab ROPS reach the unstable state at a lower slope than the two post ROPS tractors. As the ROPS types are currently tested according to normalised procedures, none of them could be defined as providing a higher level of safety for the driver in terms of strength behaviour. The results obtained demonstrated that if the two post ROPS is correctly mounted and used in the upright position during normal operations, the driver safety is higher as the tractor stability is higher. It is therefore essential to properly train tractor drivers on the correct use of foldable ROPS and to improve the ease of ROPS manual handling.

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