A Survey on Working under Trees with an Agricultural Narrow Tractor in Italy

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Abstract: To protect the driver in case of a tractor overturn, narrow-track tractors, mainly used for working under trees or in vineyards, can be equipped with a foldable roll-over protective structure (FROPS) generally consisting of a two-pillar front-mounted foldable rollbar. FROPSs have been mainly developed to offer greater mobility when working in low overhead clearance zones (CZs) and more storage options. However, many fatalities and serious injuries in Italy are due to overturn of narrow tractors with FROPS not in safety configuration. The reason lies on that lowering and raising a conventional FROPS is a time-consuming and strenuous process. After operators fold down FROPS to pass a low overhead CZ, some prefer to leave it in the folded or inoperative position, increasing the risk of a roll-over fatality. Italian Workers Compensation Authority (Inail) collects injury reports of workers covered by compulsory accident insurance. However, for agricultural sector Inail set up in 2008 a national observatory to add data and information on fatalities in agriculture covering workers, even those not Inail insured. From these data it appears that about 10 fatalities per year occur in Italy involving folded ROPS. The aim of the analysis in this article is to make a survey on the FROPS issue considering both what is required by Mother Regulation (Regulation (EU) 167/2013) for new tractors and the achievable technical solutions to be applied on old tractors for reducing the misuse of FROPS.

Key words: foldable roll-over protective structure (FROPS), compact ROPS (CROPS), finite element method (FEM), low profile tractor.

1. Introduction

The roll-over risk is the main risk related to the use of agricultural tractors. This is mainly because of tractors’ high center of gravity, exposure to considerable external loads, large torque outputs, sloping or uneven ground [1]. For this reason the presence and the use of roll-over protective structure (ROPS) and seat belt are compulsory, even for old manufactured tractors. Nowadays, many narrow-track wheeled and crawler agricultural and forestry tractors are equipped with two posts front mounted ROPSs. These kinds of ROPSs are mainly of two different types: fixed or completely foldable. In Italy many agricultural and forestry tractors are equipped with foldable ROPS (FROPS). The main reason lies on the necessity to work under trees (e.g. vineyards) or in greenhouses or in similar environments. A completely foldable ROPS fulfils this necessity. However, the time spent on folding the ROPS many times each day and the physical load required lead to maintaining FROPS in horizontal configuration [2]. In Italy, this situation leads to an important number of accidents per year, and most of them are fatal, which involves tractors used with a folded ROPS. Considering the analyses of the accident scenario [3] and of the data acquired by Italian Workers Compensation Authority (Inail) observatory on accidents in agricultural sector, it is possible to say that a mean of 10 fatalities per year occurring in Italy for tractor roll-over is determined by ROPS in folded position. Many research activities focused on this issue, both for verifying the capability of protection of FROPS in folded configuration [4] and for defining technical solutions in order to improve the use of FROPS in upright configuration [5, 6] or automatically deploy...
FOPS in case of roll-over [7].

For what concern new tractors, with the introduction of Regulation (EU) 167/2013 [8], the Delegated Regulation (EU) 1322/2014 [9] in its Annex XXII requires that operator’s manuals of tractors with FOPS contains specific information. In particular:

- information about safe use of FOPS (e.g. erecting/lowering operations and locking in the erected position);
- warning of consequences in the event of roll-over with the ROPS folded;
- description of the situations which might need to be folded (e.g. work within a building, orchard, hop or vineyard) and a reminder that the ROPS should be re-deployed on completion of the aforementioned tasks.

Moreover, Delegated Regulation (EU) 1322/2014 according to the provisions of OECD Code 6 [10] defines a specific grasping area and a maximum value of actuation force for hand-operated FOPS.

On the other hand, old narrow tractors still in use and fitted with FOPS have no specific requirements for reducing the aforementioned actuation force or improving the possibility of working with FOPS in safe configuration. Considering that in Italy there are many old tractors still in use but not equipped with ROPS, Inail in the past developed specific guidelines to make it possible to conform old tractors to the requirement of fitting a ROPS [11]. FOPSs were and still are included among the possible structures used as retrofitting ROPS on old tractors. Thus, Inail in the recent years starts a specific research activity to reduce the risk of roll-over while working with narrow tractors in case of low overhead clearance environment (e.g. under trees, in greenhouses, etc.) [12]. The main topics can be summarized as follow:

1. systems for reducing the activation force for unfolding FOPS;
2. not deployable compact roll-over protective structures (CROPSS);
3. design of an innovative low profile agricultural tractor.

2. Materials and Methods

2.1 Device for Reducing the Activation Force for Unfolding FOPS

Since 2007 Italy has adopted Inail national guidelines for retro-fitting ROPSs on old agricultural and forestry tractors [11]. The guidelines present the technical info for realizing and installing ROPS on a great variety of old tractors. Among them there are also narrow tyred tractors and tracklying tractors for which it is possible to install a FOPS. In order to reduce the effort of the operator during unfolding operation, Inail developed a specific study finalized to define the main parameters necessary to integrate onto FOPS a gas spring.

With reference to Fig. 1, for each FOPS described in the guidelines, information about the technical
features of the gas spring and about the location of the anchorages points has been introduced. In particular, in order to define the correct location of the gas spring with respect to its minimum amount of force to be generated during unfolding operation, a kinematic synthesis has been developed.

As depicted in Fig. 2, knowing the FROPS range of motion, the minimum ($r$) and maximum ($R$) elongations of gas spring according to the necessary force to be developed by the gas spring and choosing the location of the mobile anchorage point (A), it is possible to define the correct location of the fixed anchorage point (B) accordingly.

2.2 CROPS

Even though several studies on the improvement of ROPSS have been proposed in literature (e.g. in Refs. [13-15]), the study of protective solutions for narrow track tractors that reduce the intervention of users, allowing them a permanent protection, has not been investigated sufficiently. On these considerations, a reverse engineering approach was used to develop a proper methodology for re-designing ROPS. Starting from the general principles proposed by Otto and Wood [16], main issues were implemented in a design methodology, as shown in Fig. 3 [17].

Such a framework was further augmented integrating the methodical approach developed by Eder and Hosnedl [18] for reverse engineering of technical systems. Specific attention was paid to the following phases:

- establish list of requirements;
- amend design specification for new requirements;
- establish the transformation process;
- establish the existing technical system-function structure;
- establish the new function structure;
- establish the new constructional structure.

The goal of the study consisted in the development of a ROPS for narrow track tyred or tracklying tractors, which can not be folded by the user. This type of technical solution, named CROPS, was developed as a step by step design activity, which can be summarized in the following main phases.

2.2.1 Preliminary Analysis

A detailed investigation on the use of tractors in narrow environments was carried out in collaboration with a focus group of both professional and non-professional users. Thus, the design task that emerged from this investigation consisted in finding a technical solution able to guarantee at the same time:

- the presence of a protection against the roll-over risk;
- the possibility of using the tractor in very narrow spaces;
- the presence of a proper clearance zone (CZ) to provide enough operating space for the operator, as well as an adequate field of vision.

As reference for the development of this task, the OECD Code 4 [10] was taken into account.
### 2.2.2 Concrete Experience

The use of CROPS allows avoiding or reducing the misuse of the protective structure, even when the operator neglects to apply safety use instructions. Different technical solutions were implemented and tested in collaboration with a manufacturer in order to better understand the limits of the clearance space without neglecting ergonomics issues for the driver. This phase of the study allowed defining technical requirements of CROPS, which were tested through the development of modelling and prototyping.

### 2.2.3 Prototyping

More in details, in this phase the CROPS design was based on the following steps:

1. CAD virtual prototyping of the CROPS;
2. Finite element analysis (FEA) of the CROPS according to OECD Code 4;
3. Optimization of shape and dimensions to define the new constructional structure;

![Fig. 3 Scheme of the research approach.](image)
(4) development of physical prototypes for static test (crushing) in laboratory.

In order to virtually reproduce the position and the relative disposition of the anchorage points suitable for the CROPS, virtual models were developed. This allowed faithfully reproducing the operator CZ on the tractor, as well as avoiding interferences between the protective structure and the tractor itself. Then, the CROPS was shaped in its upper portion according to the profile of the CZ (Fig. 4) and in its lower portion with the goal of making the connection points ease-to-fix.

The further step consisted of performing FEA in order to verify:
- the strength of the protective structure according to the sequence of test defined in the OECD Code 4;
- the effectiveness of the internal protection of the CROPS (i.e. no parts of the tractor should enter inside the CZ around the driving seat during each sequence of load applied);
- the effectiveness of external protection of the CROPS (i.e. verify that the CZ is not outside the protection of the protective structure during and after each sequence of load applied).

2.2.4 Redesign Validation

Once verified the aforementioned requirements, the CROPS’s shape was optimized. It is important to note that any modification of CROPS’s shape or dimensions at this stage might affect its structural strength. Thus, it was necessary to perform another FEA to recursively verify the compliance with the above issues. As an example, the initial CAD prototype of CROPS for Fiat 605 was meshed in order to perform the FEA. In Fig. 5 results of the contour diagrams obtained during the FEA are shown. As a consequence of the results obtained, in order to strengthen the CROPS structure with respect to side loading, the tubular shape was changed from circular $\phi 60$ mm to square $50 \times 50$ mm and some trusts have been added. Thus, another finite element method (FEM) test has been performed and then a physical prototype has been realized in order to test it by means of an experimental test rig.

2.2.5 Physical Prototype

The last step of the design process concerned the development of a physical prototype. The CROPS structure was realized by means of tubular steel bars, in S235-J0 steel, having a square shape of 50 mm and a thickness of 5 mm (Fig. 6).

The model of tractor chosen for mounting the prototype was a 40 years old Fiat 605. This model of tractor was selected since it is a very widespread model in Italy, and in its original configuration it was not equipped with a ROPS.

Fig. 4 Clearance zone (CZ) and ROPS shaping: (a) 3D-view; (b) main dimensions.
Fig. 5 Example of FEA according to OECD Code 4.

Fig. 6 Physical prototype of CROPS installed on Fiat 605.

2.3 Design of an Innovative Low Profile Agricultural Tractor

In order to improve the safety level when tractors work on slope under canopy, Inail funded a research project, named Traclas, devoted to developing a prototype of low-profile tractor (see Fig. 7), not exceeding 1.52 m in height, equipped with a fixed ROPS integrated into the chassis and with innovative features, as hybrid propulsion, hydrostatic transmission.

Thanks to these technical features, the operator platform was lowered very close to the ground, about 25 cm (see Fig. 7), while the operator is protected by a compact four-post structure in case of roll-over. As mentioned earlier, the ROPS elements are fixed and part of the chassis. The protection capability of these elements has been evaluated by means of FEA, mimicking the application of static loads as prescribed by the OECD Code 4 (see Table 1).

This analysis approach is a reliable one since it is applied to study the structural behaviour of ROPS [19, 20], or to validate retrofitted ROPS [21].

As already mentioned for the design of CROPS, according to the flow chart in Fig. 3, during the prototyping phase a FEA on the innovative ROPS structure has been developed according to the requirements of the OECD Code 4.
3. Results and Discussion

3.1 Device for Reducing the Activation Force for Unfolding FROPS

Considering the device for reducing the activation force for bringing the FROPS in safety configuration, based on the kinematic synthesis previously presented, some prototypes have been realized and tested. With reference to Fig. 8, the movable part of FROPS herein depicted is made up of square steel tubular $70 \times 70 \times 5$ mm having a mass of about 65 kg. Considering a grasping area near the FROPS bend corner, at the beginning of the motion the operator has to exert a force of about 40 N in upright direction. After 10° of rotation of FROPS, the gas springs start to apply a moment on the structure greater than the one due to the weight of the FROPS. Thus, the FROPS continues to move until it reaches the safe configuration without any other action of the operator. When FROPS reached the upright configuration the operator has just to lock FROPS in that configuration. The results achieved allowed defining the minimum parameters necessary to properly apply these systems to FROPS realized in compliance with the information of Inail national guidelines. With these updates, the national guidelines are also in line with the recent requirements concerning activation forces introduced by Regulation (EU) 167/2013 and allow the operator to reduce his effort for repositioning FROPS in safe configuration.

3.2 CROPS

The physical prototype of CROPS has been experimentally tested according to OECD Code 4 by means of Inail test rig in the research center of Monte Porzio Catone (Rome). The reference mass ($M_{rif}$) used for the test was 3,500 kg. The forces and energies required by the sequence of load defined in OECD Code 4 are summarized in Table 2.

For what concerns longitudinal load from the rear, the energy attained by the CROPS was 5,012 J in correspondence to a force applied of 89,370 N and a maximum deformation (elastic + plastic) of 104 mm (Fig. 9).

During crushing at rear CROPS sustained 70,100 N for more than 5 s with a maximum deformation downward of 13 mm (Fig. 10).

The energy absorbed by the CROPS during loading from the side was 6,391 J attained at a force of 84,120 N and a maximum deformation (elastic + plastic) of 132 mm (Fig. 11).

<table>
<thead>
<tr>
<th>Loading sequence</th>
<th>Required energy and force</th>
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<tr>
<td>Longitudinal loading</td>
<td>1.4 M = 4,200 J</td>
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<tr>
<td>First crushing test</td>
<td>20 M = 60,000 N</td>
</tr>
<tr>
<td>Side loading</td>
<td>1.75 M = 5,250 J</td>
</tr>
<tr>
<td>Second crushing test</td>
<td>20 M = 60,000 N</td>
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<td>Reference mass $m = 3,000$ kg</td>
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The operator applies less than 40 N to start the upright motion of the FROPS. After 10° the gas springs alone are able to maintain FROPS motion. FROPS reaches the safe configuration without any other intervention of the operator.

Fig. 8  Experimental test of the device for reducing the activation force.

Fig. 9  Longitudinal load from the rear.

Fig. 10  Crushing at rear.
During crushing at front, CROPS sustained 73,130 N for more than 5 s with a maximum deformation downward of 19 mm (Fig. 12).

According to the results achieved, CROPS installed on Fiat 605 passed OECD Code 4 test without infringing or unprotecting the CZ. Thus, the use of CROPS reached the goal of protecting the operator while working under low overhead clearance environments reducing the overall height of tractor equipped by an Inail FROPS of about 350 mm.
3.3 Design of an Innovative Low Profile Agricultural Tractor

According to the acceptance criteria of OECD Code 4, applying the loading sequence of the operator’s CZ shall not be infringed or unprotected. In particular, during crushing tests (at rear and at front) the deflection of the four posts is very limited and the maximum level of stress is under the ultimate stress limit of the material (see Fig. 13).

The longitudinal and side loadings show the high stiffness of the structure, since significantly high loads have been attained to reach the required energy: 120,000 N at the rear for the longitudinal loading and 61,000 N on the left side for the horizontal transversal loading.

The effects of longitudinal loading on ROPS are shown in Fig. 14. In correspondence of the required energy, the maximum deflection happens at the top of the structure and it is equal to 49 mm inwards (see Fig. 14b). The CZ is neither infringed nor unprotected. The tensile strength remains under the ultimate stress limit of the material for 99.8% of the elements.

The side loading results are reported in Fig. 15. In correspondence of the required energy, the maximum deflection happens at the rear—top of the structure and it is equal to 101 mm inwards (see Fig. 15a). The CZ is neither infringed nor unprotected. The tensile strength remains under the ultimate stress limit of the material for 99.5 % of the elements.

![Fig. 13](image1)
![Fig. 14](image2)
4. Conclusion

Considering the relevant number of accidents occurring in Italy due to roll-over of tractors equipped with FROPS not in safe configuration and the significant number of old tractors still in use, Inail developed specific research activities in order to face this issue. In particular, technical analysis and experimental tests were performed in order to define and characterize main parameters of devices for reducing the effort during the unfolding operation of FROPS designed in Inail national guidelines. Moreover, specific ROPSs of reduced height (CROPS) were designed for the most widespread tractors already in use in Italy. Finally, an innovative design of a low profile tractor with an integrated fixed ROPS and hybrid/electric propulsion has been developed.

On the basis of the research activity’s results, nowadays operators could upgrade FROPS in line with Inail guidelines with specific gas spring, which allow reducing the actuation force during repositioning in upright configuration. This solution is an upgrade, but it continues to rely on the attitude of the operator.

On the other hand, the CROPS solution is actually ideal for operators who have to work with old tractors in low clearance environments without the duty of repositioning FROPS. CROPSs are already applied in Italy for conforming old tractors, more than 1,000 units per year, with positive results for some specific kind of cultivation (e.g. vineyards, hazelnuts). Finally, the design of an innovative low profile tractor is not a conventional solution which may be particularly useful for reducing in a significant manner the overall height of the tractor. Actually the prototyping and virtual testing phases are continuing. The first results achieved seem to be positive encouraging to proceed in its development.

Contemporary, other research activities are ongoing for reducing the misuse of FROPS by means of active technical solutions and they may represent other possibilities to face and decrease the number of accidents related to this issue.

References

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