Evaluation of Testing Procedures for ROPS Fitted on Self-propelled Agricultural Machinery

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Abstract

Fatalities and serious injuries resulting from rollover accidents involving tractors and self-propelled agricultural machinery often occur in the field. Since 1974 tractors have been fitted with Roll-Over Protective Structure (ROPS) according to the requirements of the EC directive 74/150 EEC. On the contrary rollover protection of the driver was not required for self-propelled agricultural machinery until recently. The recognized potential risk of rollover for these machines, currently considered by the EC Directive 2006/42/EC, has led to manufactures implementing ROPS on new or existing self-propelled agricultural machinery, such as grape harvesters and sprayers. Consequently there is a need to develop standard strength tests for these applications. Nowadays ROPS tests involving agricultural machinery are carried out according to the ROPS testing procedure studied for tractors and/or earth-moving machinery.

An evaluation of the applicability of the tractor OECD ROPS Codes 4 and 8 to rollover protective structures retrofitted on in-use grape harvester was performed and the strength test results are presented and discussed.

The results showed that the Code 8 procedure was more suitable for evaluating the strength performance of the ROPS retrofitted on the tested grape harvesters. However the results demonstrated also some points where the testing procedures need to be modified in order to match the specific characteristics of the machinery considered.

Keywords: rollover, safety, OECD ROPS codes, energy, force

Introduction

The safety and health of the workers are considered in many official documents of the European Community (EC).

The Directive 2006/42/EC, often identified as "Machinery Directive", foresees requirements for the manufactures in order to reduce the potential risks for the machinery users. In particular for the case of self-propelled machinery with a ride-on driver, if the potential risk of rollover in the normal operation of the vehicle is recognised, the manufacturer has to minimise the risk by fitting a roll-over protective structure (ROPS) which has to provide and guarantee a survival volume for the operator in case of the machine overturning.

The first agricultural vehicle considered at risk of rollover was the tractor. Indeed tractor rollover has been a major issue since 1930, as stated by many international researches (Devis e Rehkuger, 1974; Myers, 2000), and at the end of the fifties it reached a strategic role for the high number of fatal accidents documented (Arndt, 1971; Myers, 2002).

The introduction of the ROPS, typically a passive means of operator protection in respect to alternative approaches, was supported by the research carried out firstly in Sweden (Moberg, 1973) and the efficacy has been documented by the decrease of the number of fatalities observed in Europe in the following years (Thelin, 1998). Nonetheless, recent analyses in US have pointed out that tractor rollover is still the first cause of fatalities, with an average number of 120 events per years (Reynolds e Groves, 2000, Harris et al, 2010) and relevant economic and social effects (Myers, 2002).

Tractors ROPSs need to be submitted by the manufacturers to official strength tests carried out according to international standard procedures for the particular tractor (Directive 2003/37/EC, which replaced the previous Directive 74/150/EEC). The normalised tests comprise a series of energy (force-displacement) and force requirements whilst ensuring that the survival volume has not been encroached. ROPS tests are performed within Europe according to the Codes of the Organisation for Economic and Co-operation Development (OECD) or the equivalent EC Directives. In the late 1970s the Code 4, based on a static testing procedure was introduced and it is still used (OECD Code 4, 2008). Other codes have since been added as Code 8 for track-laying tractors (OECD Code 8, 2008), with a testing procedure derived from the testing strength requirements originally studied for the ROPS fitted on earth-moving machinery (ISO 3471:2008).

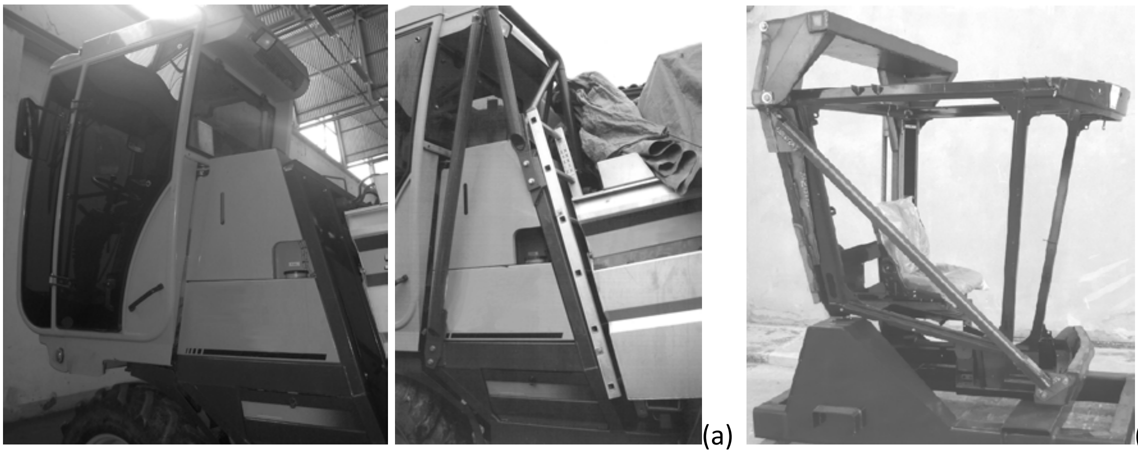
According to the requirements of the Directive 2006/42/EC, if manufacturers of agricultural machinery, such as combines, grape harvesters, sprayers, provide a ROPS on the machine they have to give evidence of the ROPS strength performance. Performing appropriate tests or using a computer simulation of the machine rollover behaviour are the possible options. The first approach, the most common, has a crucial issue: the lack of dedicated standardised procedures for the specific type of agricultural machinery considered.

However standards for earth-moving machines and agricultural tractors are in use and could be adopted to give an answer to the need of self-propelled machines whilst the proper standards are developed. The subject concerns the new model of machines but also the "in-use" machines. In the United States for the in-use tractor models the usefulness in developing retrofitted ROPS was studied together with the need for increasing the acceptance and the use of protective structures among farmers. (Reynolds, 2000). A similar approach should be adopted for the in-use self-propelled machines, mainly when these are used on slopes, typical of the Italian environment, where a high risk of a rollover event exists. The occurrence of accidents involving the agricultural operators in Italy requires the fitting of ROPS structures to all machines at risk of rollover, both the new and the old models.

Protective structures retrofitted on in use grape harvester were tested according to the requirements of the OECD ROPS Codes. The purpose was to assess the behaviour of these structures during the tests so as to evaluate criticisms of the normalised procedures in testing rollover protective structures fitted on machinery differing from the tractors.

Materials and methods

Strength tests on two ROPS protective structures (CASES 1 and 2), fitted on two different in-use grape harvesters, were carried out at the laboratory of the Department of Agricultural Economics and Engineering (DEIAgra) of the University of Bologna, according to the provisions of the OECD Codes 4 and 8. Originally the two machines were marketed with cabs aimed at protecting the driver from environmental conditions. The manufacturers, so as to prevent injury to the driver during a rollover, designed dual pillar ROPS retrofitted behind the cab originally mounted (Figure 1).



(a) (b)

Figure 1. Tested ROPSs. (a) CASE 1 (b) CASE 2

The ROPS structures were subjected to the sequence of strength tests foreseen by the normalised procedures.

<u>Normalised testing procedures</u>

Codes 4 and 8 foresee loadings based on energy and/or force requirements, calculated on the basis of the reference mass (M [kg]) of the machine. Both standardised procedures indeed are based on a linear relationship between the test energy/force and the machine mass (Table 1).

The reference mass is defined by the manufacturer with the only limitation to be at least equal to the mass of the tractor in running order, without driver, ballasts and implements.

<u>OECD ROPS Code4</u>

The OECD ROPS Code 4 is applicable to wheeled or track-laying tractors, with an unballasted mass not less than 600 kg and a minimum track width of the rear wheels generally greater than 1150 mm.

The sequence of loadings are: Longitudinal loading; First crushing (vertical loading); Side loading; Second crushing (vertical loading); Second longitudinal loading (only applied in case of folding or tiltable protective structures).

<u>OECD ROPS Code 8</u>

The OECD ROPS Code 8 is applicable to track-laying tractors with an unballasted mass not less than 600 kg and a ground clearance not more than 600 mm beneath the lowest point of the front and rear axles.

The horizontal and vertical loading are foreseen in the following order: Side loading; Crushing test; Longitudinal loading test.

The code procedure in case of the tractors fitted with a rollbar ROPS placed in front of the driver considers the rear hard point as a component of the protective system.

<u>Arrangements of the tests</u>

Longitudinal and side loads were applied to the tested structures by means of a hydraulic cylinder fitted with a load cell and a linear displacement transducer to measure the loading force and the ROPS deflection under loading. The vertical loadings were carried out using a rigid beam linked to two hydraulic cylinders fitted with load cells. The loading tests were stopped when the energy and/or the force absorbed by the protective structure was equal to or greater than that required (Table 2). The crushing tests were stopped when the force applied to the structures was equal or greater than the required force, shown in Table 1, and the force was maintained for 5 seconds after cessation of any visually detectable movement of the ROPS. The tests were accepted if the ROPS during the test did not infringe or leave the driver's survival volume unprotected. The clearance zone represents for Code 4 the safety volume for the driver in case of a rollover event while Code 8 refers to the Deflection Limit Volume (DLV). The DLV is a volume related to the operator and it is an orthogonal approximation of the dimensions of a large seated operator (ISO 3164:1995).

Table 1. OECD Codes 4 and 8 - Energy and Force equations

OECD CODE 4	Required Energy and Force	OECD CODE 8	Required Energy and Force
Longitudinal loading	1,4·M [J]	Side loading (Force)	$70000 \cdot (M/10^4)^{1.2}$ [N]
First crushing test	20·M [N]	Side loading (Energy)	$13000 \cdot (M/10^4)^{1.25}$ [J]
Side loading	1,75·M [J]	Crushing test	20·M [N]
Second crushing test	20·M [N]	Longitudinal loading (Force)	$56000 \cdot (M/10^4)^{1.2}$ [N]
Note M [kg]		Rear hard fixture test	15·M [N]

The reference mass (M) used to define the test energies and forces was 8000 kg for the CASE 1 and 8160 kg for CASE 2. These masses were defined considering the machines in running order, with all tools and equipment fitted when in its traditional agricultural tasks.

The tests for CASE 1 were carried out according to the OECD ROPS Code 4. The original cab fitted on the grape harvester was submitted to an additional longitudinal loading applied in front of the cab, according to the provisions of the Code 4 (Table 2).

CASE 2 was tested according to the procedure of Code 8 (Table 2). The front-bottom part of the original cab was regarded as a protective point in the event of a sideway or rear overturning. In accordance with Code 8 this fixture was tested applying a downward force equal to 15M, extending the same testing procedure foreseen in Code 8 for the rear hard fixture in tractors fitted with a rollbar ROPS in front of the driver.

Table 2. Energy [J] and Force [N] values required by OECD Codes 4 and 8

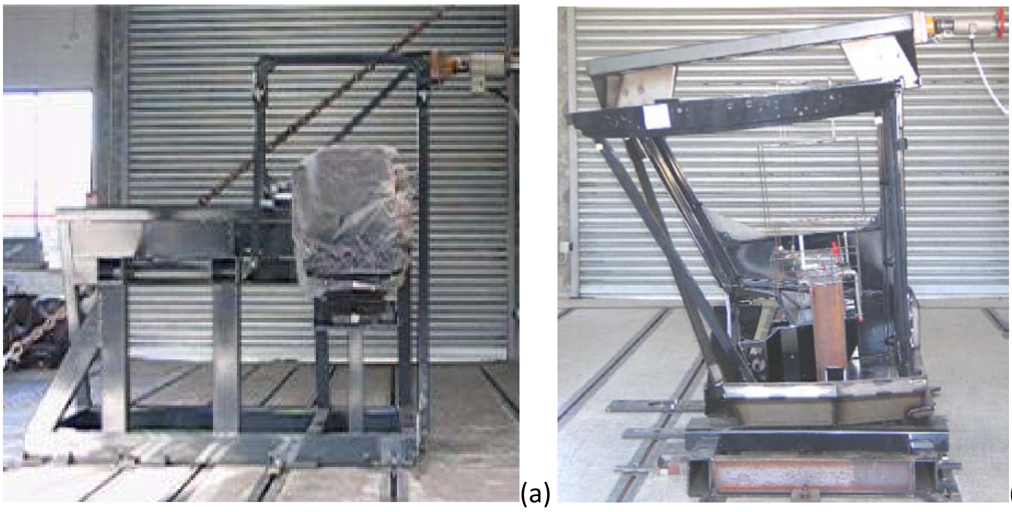
OECD CODE 4	CASE 1	CASE 2	OECD CODE 8	CASE 1	CASE 2
Longitudinal loading	11200 J	11424 J	Side loading	9458 J 48000 N	10082 J 54844 N
First crushing test	160000 N	163200 N	Crushing test	156880 N	163200 N
Side loading	14000 J	14280 J	Longitudinal loading	38400 N	43875 N
Second crushing test	160000 N	163200 N	Front hard fixture loading	--	122400 N

Results and considerations

Results CASE 1

The longitudinal loading test according to Code 4 was carried out successfully. The roll-bar structure absorbed the energy foreseen by Code 4 and reached the force required by the Code 8. The total energy absorbed during the longitudinal loading was 11249 J, corresponding to a force of 136299 N. In the following crushing test the force reached the value of 163901 N.

Problems were raised during the side loading (Figure 2a). The structure was designed extremely rigid, due to the need of a retrofitting to an existing cab, and the absorption of the required energy involved elevated force. Figure 3 shows force versus displacement during the test.



(a) (b)

Figure 2. Protective structures subjected to the side loading (a) CASE 1 (b) CASE 2

The side loading test was stopped when the force reached 178084 N, due to the unsuitability of the testing equipment to so high force values. The corresponding absorbed energy was 9517 J, too low for the Code 4, with an energy required of 14000 J, but in line with the requirements of Code 8 in the side loading.

The absorbed energy in the longitudinal loading carried over the original cab fulfils the requirement of Code 4. In this test, the force measured was 36563 N when the energy absorbed was 11277 J. During all tests neither the original cab nor the roll-bar retrofitted infringed the safety volume.

Results CASE 2

The roll-bar structure fulfilled the energy and force required by Code 8 (Figure 2b). The total energy absorbed during side loading was 10330 J in correspondence of a force equal to 69904 N (Figure 3). During the crushing test the force reached 173000 N. The longitudinal loading was stopped when the force was 45523 N. The front hard fixture test showed the strong behaviour of the bottom front part of the original cab, properly reinforced and linked to the retrofitted rollbar. The force reached was 124082 N, with a displacement less than 60 mm.

Tests were carried out without breakages and the safety volume was not infringed.

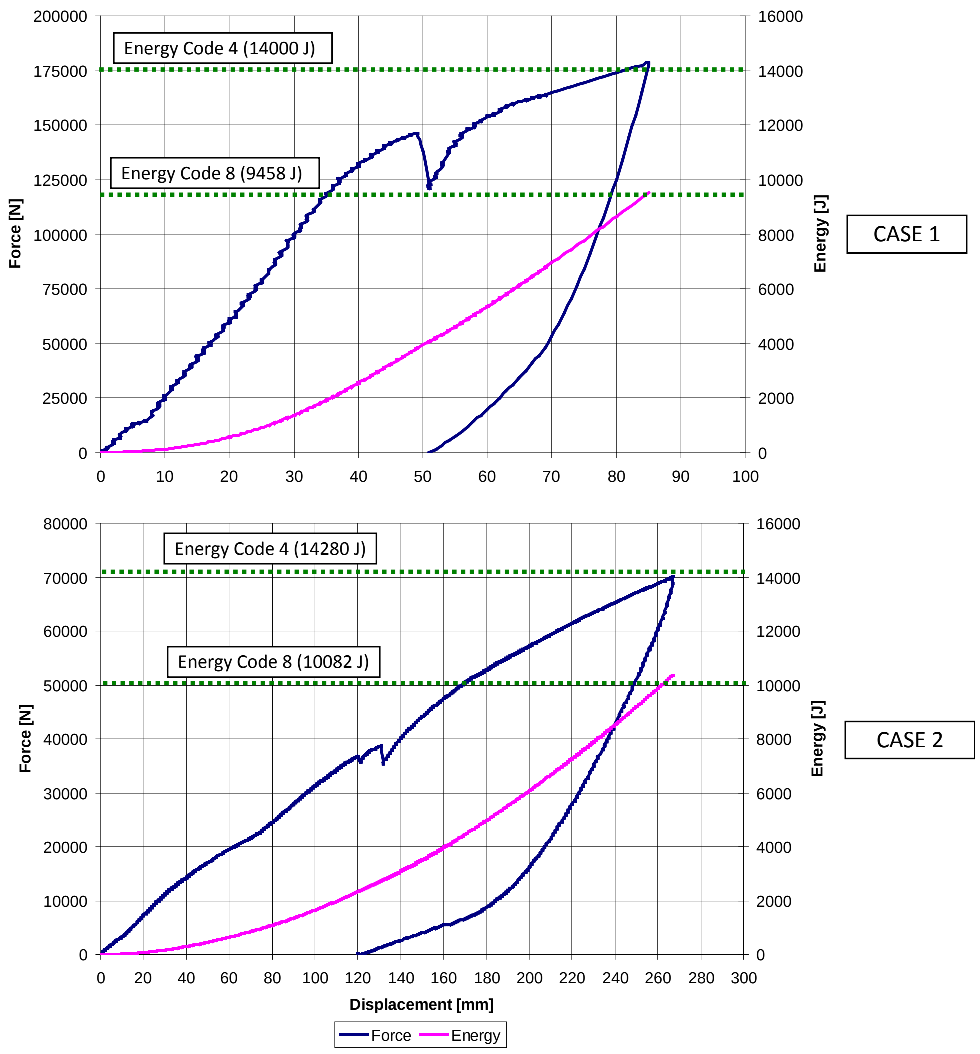


Figure 3. Force and Energy measured during the side loading tests

<u>*Considerations*</u>

The testing procedures considered in the tests present clear differences in the criteria adopted. Indeed Code 4 is essentially based on an energy to be reached in the horizontal loadings, while a force has to be sustained by the protective structure during the vertical loadings. Code 8 has the same approach in the vertical loading, but in both horizontal loadings a force requirement is introduced; only the side loading considers an additional energy to be reached. That means Code 8 deals mainly with a ROPS designed to be robust (i.e., rigid). The force requirement foreseen in Code 8 is the consequence of its derivation from a testing procedure originally studied for the ROPS fitted on earth-moving machinery.

The sequence of horizontal loadings applied to the tested CASE 1 demonstrated that the use of a procedure based on an energy criterion was not suitable due to the high rigidity of the structure. The ROPS was designed to be highly stiff because it had to be fitted behind an existing cab and in the intention of the manufacturer a high rigidity contributed to preserve the cab in case of rollover of the machine increasing the driver's safety level. The additional test applied frontally on the cab showed a certain strength of the cab itself, but this did not guarantee its behavior in case of hitting onto the ground.

On the basis of the results of the CASE 1 tests, the CASE 2 was subjected directly to the sequence of loadings foreseen by Code 8 with a general positive result.

The additional test on the front hard fixture was carried out in order to verify the strength of a portion of the machine that could be considered as a component of the protective structure. Indeed in the general arrangement of the grape harvester quite often the driver's position is suspended laterally on a platform and in front of the driver there is not a real hard point, as for example the outer portion of the bonnet in the case of the agricultural tractor, able to sustain the machine when overturned. Therefore, in order to complete the protection of the driver, the basis of the original cab in the CASE 2 was properly reinforced and tested extending the same procedure foreseen by Code 8 for the strength requirement of the rear hard point when the tractor is fitted with front ROPS.

An additional consideration is related to the definition of the reference mass to be used for the test, both Codes did not consider the equipment fitted on the vehicle but simply refer to the empty tractor in running order. It could be appropriate to refer to the requirement of the ISO 3471:2008 procedure in selecting the reference mass of the vehicle including all attachment in operating condition, tools and ROPS, and excluding the material carried or handled.

Conclusions

The results of the tests carried out on the two dual pillar ROPS fitted behind the cabs originally designed for the two in-use grape harvesters demonstrated the difficulties in adapting standardized testing procedures originally studied for ROPS fitted on the tractors. The CASE 1 tested appeared extremely rigid and it did not fulfill the provisions of a testing procedure based on an energy requirement criterion, as specified by Code 4. CASE 2 showed a higher deflection but generally the ROPS designed to be retrofitted on the in-use machine has to be rigid enough to avoid a large displacement that could involve the original cab and cause possible injury to the driver during the vehicle rollover.

The Code 8 procedure was more suitable for evaluating the strength performance of the ROPS retrofitted on the tested grape harvesters. However the results demonstrated also some points where the testing procedures need to be modified in order to match the specific characteristics of the considered machine.

In a more general context it seems advisable to study an ad hoc standardised procedure for such machines as the grape harvesters, providing strength criteria based on an energy or a force requirement depending on the characteristics of the ROPS designed and fitted on the machinery.

Another point to be solved is the clear indication of the reference mass to be considered for the strength tests.

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