Definition of Unambiguous Criteria to Evaluate Tractor Rops Equivalence

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Abstract
The Roll Over Protective Structure (ROPS) is the most diffused means to reduce the operator's risk in case of agricultural and forestry tractor overturning. Many tractor models are nowadays available on the market; as a consequence, manufacturers are compelled to fit and submit for testing and approval a high number of ROPS very similar one another, in order to comply the relevant Regulations. The most popular dedicated Standards often do not provide clear and unambiguous criteria for evaluating the real strength equivalence of ROPS revealing only slight differences among old and new versions, frequently modified for a higher manufacturing uniformity. It could be useful to establish one maximum tolerance value(s), within a structural modification could be considered admissible without carrying out a new validation test. The probably most applied ROPS standard, issued by the OECD, the Code 4, provided for standard agricultural and forestry tractors, was taken into account. At the point 3.9.2.1 "*Extension of the structural test results to other models of tractors*", is written "…The required energy shall not exceed the energy calculated for the original test by more than 5 %...". Some cases of protective structures for which a test was been repeated due to the introduction of slight structural modifications were examined, by comparing the rear and side loading curves, in order to correlate the structural modifications characteristics and the differences found. On the basis of the obtained data, a series of unambiguous criteria could so defined, to evaluate various ROPS modifications and their need to carry out (or not) a new validation test.

Keywords: ROPS, criteria, strength, equivalence

Introduction
Operators safety is one of the most important items to be considered in agriculture: despite the overall risk level has been recently decreased, the agricultural sector still suffers at present several serious and even fatal injuries. Agricultural machinery, especially tractors, represent important occupational hazard factors, causing very serious injuries. Statistics show that tractor drivers are exposed to grip and dragging from motion transmission elements, falls to the ground getting on or off from the driving place, crushing while hooking up or disconnecting tools, inhalation of exhaust gases, burns for hot surface contact, high levels of noise and vibrations and incongruous postures. But the most serious hazard is the **tractor overturning** (lateral, longitudinal or both, combined) due to vehicle overload and/or very high pull force and/or excessive ground slope.
ROPS (Roll Over Protective Structure) is still now the most diffused device to reduce the operator's risk in case of agricultural and forestry tractor overturning. ROPS became popular in the 50's, starting their application in Scandinavian Countries, where dedicated studies established the energy levels to be applied in order to simulate the mechanical stress produced in case of a rollover accident occurred in well-defined conditions. This information represented later the basis

for the most popular International Standard (issued by OECD, EU, ISO and other international Organisations) currently in force to test ROPS strength. The first official Standard Code for the official testing of protective structures on agricultural tractors was approved on 21th April 1959 by the OEEC Council, then turned in OECD (Organisation for Economic Co-operation Development). Since then, the various OECD codes were also applied to forestry tractors, to determine other performance characteristics of safety and noise. All ROPS testing methods are based on a rollover simulation through blows (with a mass equipped with pendular motion) or horizontal loadings (applied with a hydraulic cylinder) and crushing tests, to be quantified vs the mass of the tractor on which the protective structure is to be fitted.
In Italy, since 1st January 1974 each new standard wheeled tractor must be fitted with a ROPS (front or rear roll-bar, frame or cab), being it a structure of welded and bolted steel tubes, plates and sheets of various dimensions and thickness, fitted around the driving place, tested according to dedicated international Standards. In the following years, further specific standards were issued for specialized tractors (i.e. those narrow tracked, mainly used in vineyard and orchards); at a later time, also tracklaying tractors were equipped with tested ROPS. To comply with the technical legislation, ROPS manufacturers have to check their prototypes through strength to be carried out in officially qualified Testing Stations. To be considered positively, ROPS must ensure a safety volume (clearance zone) fitted around the seat in case of overturning.
The main purpose of the present study is:

- to determine clear and unambiguous criteria about the strength equivalence of two or more different versions of ROPS showing, due to homologation requirements, very slight differences among them;
- to study how ROPS minimum modifications affect their performances.

Materials and methods

Since 1973 the Dipartimento di Ingegneria Agraria of University of Milan - Italy (DIA-Unimi, formerly IIA-Unimi) is acting as a Testing Station officially recognized by the OECD for the assessment of the agricultural tractors performance and their components (particularly ROPS). For this purpose, from 1991 DIA-Unimi operates on its static test bench, and since 1994 an automatic data processing and arrangement of certificates has been activated, together with a file archive, for managing and sending approval reports.
Thanks to this file archive, 6 ROPS cases were found in which the tests were repeated twice or more, due to the introduction of slight structural modifications in respect to the first version. These structural modifications were then correlated to the rear and side loading curves, in terms of their trends and of the maximum force and deflection values obtained.

Results

The details of the 6 ROPS cases for which the tests were repeated due to the introduction of slight structural modifications are shown in **table 1**.

Table 1. Specifications of ROPS cases for which the test were repeated due to the introduction of slight structural modifications.

Case No.	DIA-Unimi ref.	ROPS make and model	Modifications detail
1	IIA 441 MI 1987	Landini TS 19	No spacer on rear mountings; M=3000 kg
	IIA 443 MI 1987	Landini TS 19/1	1 spacer th.30 mm on rear mountings; M=3000 kg
	IIA 444 MI 1987	Landini TS 19/2	2 spacers th.30 mm on rear mountings; M=3000 kg
	IIA 682 MI 1999	Landini TS 19/3	3 spacers th.30 mm on rear mountings; M=3400 kg
2	IIA 682 MI 1999 IIA 733 MI 2002	Landini TS 19/3 Landini TS 19/3 ext	Different spacers on the rear axle and reinforcement plates on the mudguards
3	IIA 744 MI 2004 IIA 758 MI 2004	Same Deutz-Fahr Italia AP 43A & AP 43A ext	Different bolts fitting direction; different length of some sections; M=4900 kg
4	IIA 602 MI 1994 IIA 759 MI 2004	Same Deutz-Fahr Italia C 36 & C 36 ext	Reference mass increase (3200 kg instead of 3000 kg); small shape modification of the front mounting; different length of some sections
5	IIA 611 MI 1995 IIA 772 MI 2005	Same Deutz-Fahr Italia T 69 & T 69 ext	Reference mass increase (3100 kg instead of 2850 kg); small shape modification of the front mounting
6	DIA 838 MI2010	Same Deutz-Fahr Italia C 56 & C 56 ext	Alternative rear mountings with different length

M = reference tractor mass; ext = extension

The differences of maximum force and deflection values recorded during the side and rear loadings of tests carried out on similar ROPS are shown in **tables 2 and 3**.

Table 2. Difference of the maximum force and deflection values recorded during the *rear* loading of tests carried out on similar ROPS.

Case No.	ROPS versions involved	Rear loading		Notes
		max deflection diff., %	max force diff., %	
1	TS 19 vs TS 19/1	0	-6,87	TS 19, TS 19/1: M=3000 kg
	TS 19 vs TS 19/2	5	4,61	TS 19, TS 19/2: M=3000 kg
	TS 19 vs TS 19/3	15	-4,46	TS 19: M=3000 kg TS 19/3: M=3400 kg
2	TS 19/3 vs TS 19/3 ext	-8,70	7,73	TS 19/3, TS 19/3 ext : M=3400 kg
3	AP43A vs AP43A ext	not applicable	not applicable	AP 43A, AP 43A ext: M=4900 kg
4	C36 vs C36 ext	6,90	10,66	C 36: M=3000 kg C 36 ext: M=3200 kg
5	T 69 vs T 69 ext	29,40	-24,60	T 69: M=2850 kg T 69 ext: M=3100 kg
6	C 56 vs C 56 ext	-0,53	-1,74	C 56, C 56 ext: M=4800 kg

Table 3. Difference of the maximum force and deflection values recorded during the *side* loading of tests carried out on similar ROPS.

Case No.	ROPS versions involved	Side loading		Notes
		max deflection diff., %	max force diff., %	
1	TS 19 vs TS 19/1	-1,25	-7,06	TS 19, TS 19/1: M=3000 kg
	TS 19 vs TS 19/2	-3,13	0,73	TS 19, TS 19/2: M=3000 kg
	TS 19 vs TS 19/3	6,25	2,41	TS 19: M=3000 kg TS 19/3: M=3400 kg
2	TS 19/3 vs TS 19/3 ext	-8,82	3,69	TS 19/3, TS 19/3 ext : M=3400 kg
3	AP43A vs AP43A ext	2,38	-7,83	AP 43A, AP 43A ext: M=4900 kg
4	C36 vs C36 ext	-6,53	37,74	C 36: M=3000 kg C 36 ext: M=3200 kg
5	T 69 vs T 69 ext	16	21,71	T 69: M=2850 kg T 69 ext: M=3100 kg
6	C 56 vs C 56 ext	-1,5	-2,75	C 56, C 56 ext: M=4800 kg

In general, if slight structural modifications are introduced, the differences for both rear and side loadings are not greater than 7-8 %. On the contrary, when also the reference mass is changed, logically the maximum force and deflection values variation become higher (as for example in Same Deutz-Fahr Italia C 36 and T 69 cases). In these last two cases (*Nos. 4 and 5*) the differences recorded were much greater than that of the reference mass: this is probably due also to not negligible structural modifications introduced. On the contrary, the *case No. 1* (Landini TS 19 and derived versions TS 19/1, TS 19/2, TS 19/3) is particularly interesting, because the reference mass remained constant (apart in one sub-case, see **Table 4**) and the structural modifications introduced were really very slight (**fig. 1**). The comparison among the relevant 4 force/deflection rear and side loading curves is shown in **fig. 2 and 3**.

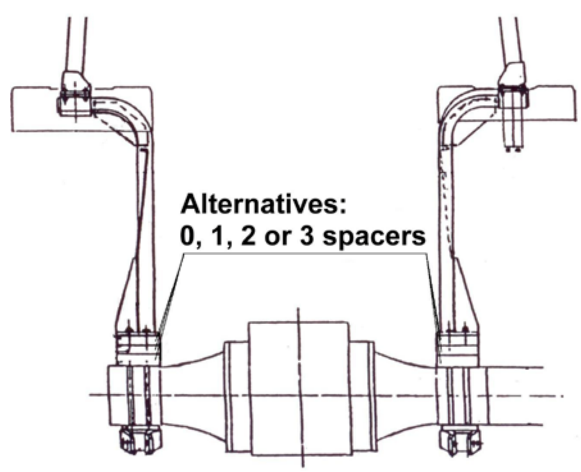

Figure 1. TS 19, TS19/1, TS 19/2 and TS 19/3 alternative spacers combinations.

If the reference mass is not changing, for Landini TS 19 ROPS series the difference in maximum force and deflection values remains within 6-7 %, evidencing higher figures for the force in respect to the deflection; on the other hand, considering a reference mass increase of 13.3 % (from 3000 to 3400 kg, sub-case TS 19 vs TS 19/3) and the relevant increase of energy to be absorbed, the max force and deflection values varied less, as an average.

Table 4. Energies to be absorbed and forces to be applied in the strength tests of the 4-posts frames Landini TS 19, and derived versions TS 19/1, TS 19/2, TS 19/3.

Tests sequence	Formulae for required energies E (J) and forces F (N)	Energies E and forces F applied (M_{ref} = *3000 kg*)	Energies E and forces F applied (M_{ref} = *3400 kg*)
1. Rear longitudinal loading	E = 1.4 M	E = 4.20 kJ	E = 4.76 kJ
2. 1st vertical loading	F = 20 M	F = 60.0 kN	F = 68.0 kN
3. Side longitudinal loading	E = 1.75 M	E = 5.25 kJ	E = 5.95 kJ
4. 2nd vertical loading	F = 20 M	F = 60.0 kN	F = 68.0 kN

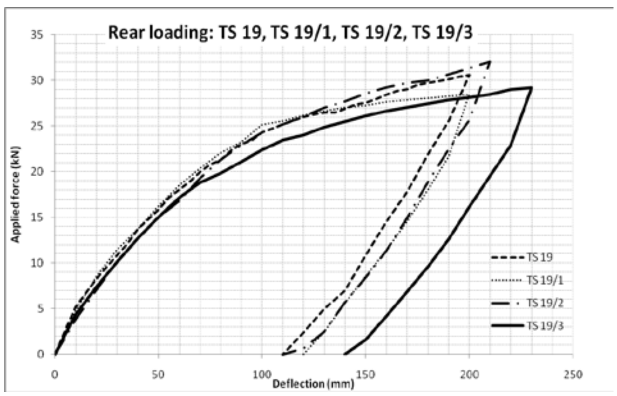

Figure 2. Comparison among the 4 *rear* loading curves of the protective structure Landini TS 19 and its slight modified versions TS 19/1, 19/2 and 19/3.

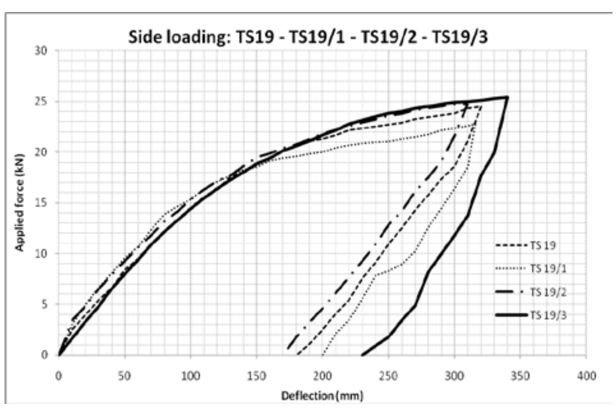

Figure 3. Comparison among the 4 *side* loading curves of the protective structure Landini TS 19 and its slight modified versions TS 19/1, 19/2 and 19/3.

In **fig. 4** the comparison between the 2 force/deflection rear and side loading curves of the protective structure TS 19/3 and its modified version TS 19/3 ext. is shown. The same reference mass was considered in this case. To evaluate the behaviour of the two ROPS versions, the "elasticity ratio" could be calculated, being it the elastic/plastic deflections ratio, a useful indicator of the elasticity of the structure (**fig. 5**).
The frame TS 19/3 was characterized by a rear elasticity ratio of 100 mm/130 mm = 0.77, while for the TS 19/3 ext resulted a ratio of 0.91 (+ 18 %). TS 19/3 ext evidenced a lower stiffness, not depending on the spacers of different shape fitted on the rear axle, but probably due to the reinforcing plates fitted on the mudguards: The reinforcements compelled the upper part of the frame to absorb a greater amount of the applied energy. The side loading confirmed this trend, evidencing an elasticity ratio of 0.48 for the TS19/3 frame and a value of 0.55 (+15 %) for the TS 19/3 ext.

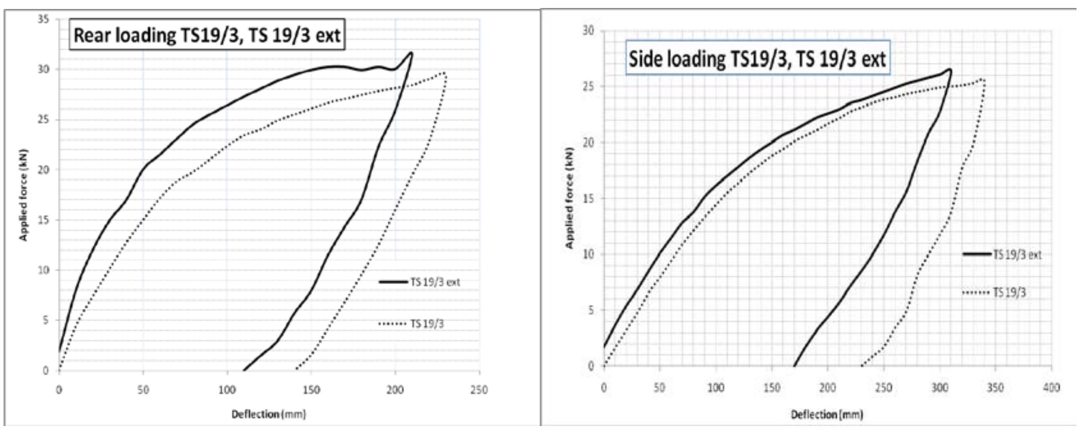

Figure 4. Comparison among the rear and side loading curves of the protective structures TS 19/3 and TS 19/3 ext.

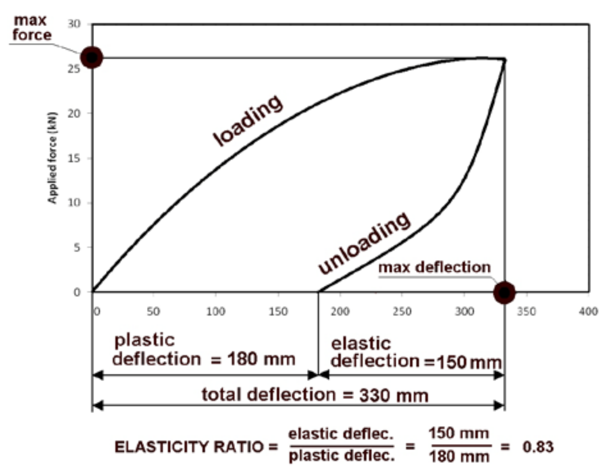

Figure 5. The "elasticity ratio" (elastic/plastic deflection values) is a useful indicator of the elasticity of a ROPS.

The *case No. 3* was relevant to the Same Deutz-Fahr Italia AP 43A frame, fitted on track-laying tractors, and therefore subjected to what prescribed by OECD Code 8. In this case, only the side loading is provided, and therefore no enough information was collected to draw a significant evaluation about the behaviour of the two ROPS versions.

The 2 force/deflection rear and side loading curves of the protective structures Same Deutz-Fahr Italia C 56 and C 56 ext are shown in **fig. 6 and 7** (*case No. 6*). These two ROPS versions were identical, apart the rear mountings that were showing a very slight different length. The trend of the rear loading curves are practically the same, and also the side loading curves are very similar. The differences of the maximum force and deflection values never exceed 3 %. This confirms that the structural modification introduced practically does not affect the ROPS strength.

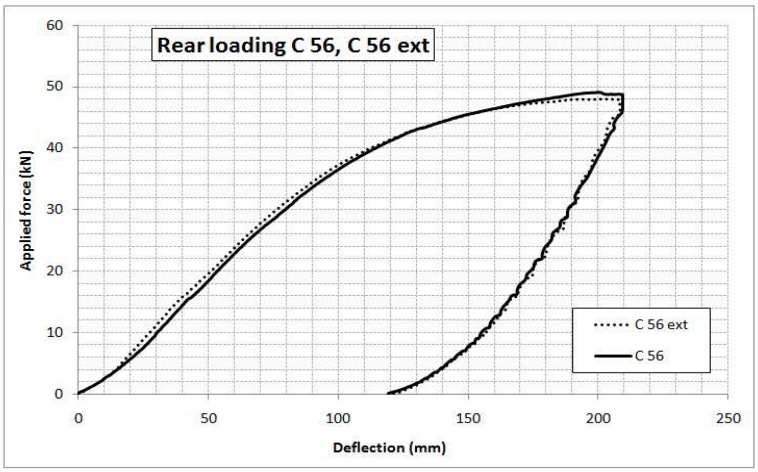

Figure 6. Comparison between the *rear* loading curves of the protective structures C 56 and C 56 ext.

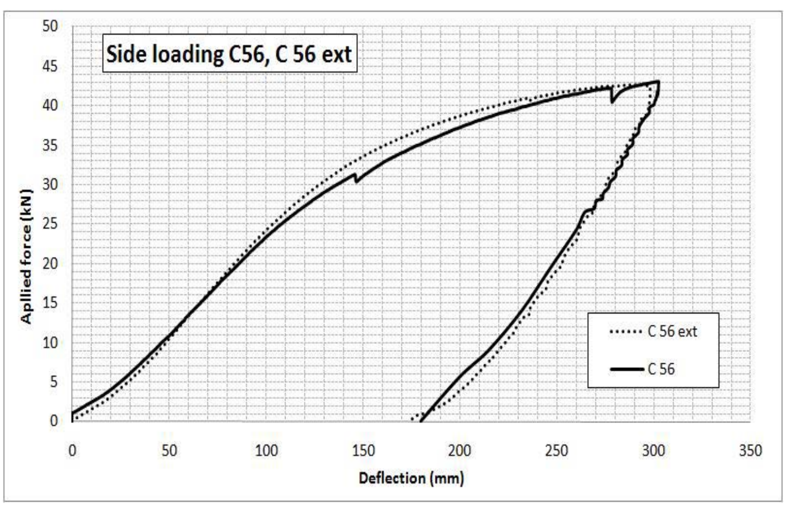

Figure 7. Comparison between the *side* loading curves of the protective structures C 56 and C 56 ext.

Conclusions

The technical updating of the models included in a tractor series could lead to a mass slight increase, i.e. for the fitting of a new gearbox, or new larger tyres, or the air conditioner, and so on. If the cab already fitted has been tested for an insufficient reference mass to include these modifications, OECD Code 4, in paragraph 3.9.2.1, named "*Extension of the structural test results to other models of tractors*", says: "The loading and crushing tests need not be carried out on each model of tractor, provided that the protective structure and tractor comply (…omissis…) the required energy shall not exceed the energy calculated for the original test by more than 5 %." On the other hand, in recent years tractor manufacturers establish their production on the basis of "families", being them series or groups of models on which the same cab is to be fitted, adapting it through little structural modifications. In these cases, OECD Code 4 provides that when technical modifications occur on the tractor, the protective structure or the method of attachment of the protective structure to the tractor, the Testing Station that has carried out the original test can issue a "technical extension report" based on the execution of a new test. As a consequence, manufacturer are compelled to submit for testing all the ROPS including at least one slight structural modification. This situation is much time and money consuming.

Taking as a reference the figure of 5 % admitted for increased energy due to the increase of reference mass, it could be taken into account a similar limit in order to evaluate the possibility to avoid the execution of a new test in case of slightly structural modifications, such as the height of mountings, or their shape and thickness.

The tests repetition of the 6 cases analysed in this paper show encouraging possibilities for a positive consideration. In several situations, light structural modifications lead to little differences in maximum forces and deflection figures; in many cases they do not exceed 5 %. On the contrary the increase of reference mass caused a higher variance.

To evaluate the possible impact of structural modifications on the strength of a ROPS, and therefore their role in changing the rear and side force/deflection curves trends, the Finite Element analysis (FEA) technique can now profitably adopted, using as a reference the most popular software tools, such as Ansys, Nastran, Msc Pal 2, etc.

References

OECD Code 4, "OECD Standard Code for the official testing of protective structures on agricultural and forestry tractors (static test). OECD, Paris.

OECD Code 8, "OECD Standard Code for the official testing of protective structures on agricultural and forestry tracklaying tractors". OECD, Paris.