FIELD INVESTIGATIONS OF THE INJURY PROTECTION OFFERED BY SOME "ENERGY ABSORBING" STEERING SYSTEMS

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ABSTRACT

A field study of accidents involving vehicles fitted with three designs of "energy absorbing" steering system is reported. Two of these systems, relying on axial collapse of the column, have been shown to provide no significant additional ride down, through column compression, in real life. A third system, involving a deformable can, directly behind a three spoke wheel, appears to provide good protection throughout the speed range of the present sample.

Laboratory testing has indicated that damage to steering systems produced under testing conditions specified in FMVSS 203 is completely different from that observed in the field. Reasons for these differences are suggested.

INTRODUCTION

Many steering systems fitted to current model British cars have been designed to meet the joint requirements of FMVSS 203 and 204. The intention of these standards was to devise simple test procedures which would limit both the chest loads developed between the driver and steering wheel to tolerable levels, and also control the intrusion of the whole system into the passenger compartment during frontal impacts.

The intention of the work reported here has been to investigate the field performance of three such systems, to see if the two standards mentioned above are achieving their goal of reducing steering wheel induced injuries.

EXISTING INFORMATION

A considerable amount of information about the design, development and initial field performance, of axial collapse "energy absorbing" columns has been published in the United States, where such devices have been installed since 1967 (1-9). These and other published works on the subject have been reviewed elsewhere (10) and will not be surveyed in detail here. However, much of the reported field work available before mid 1972, which concluded that axial collapse systems were working effectively in the field, has failed to discriminate between primary and secondary column damage. Conclusions drawn on the basis of total column collapse about both the 'correctness' of column compression loads and the functioning of the systems are misleading and not useful.

Little published work exists about the performance of "Capri" type systems in the field, although some testing and development work has been reported upon, (11,12,13).

Recent published work on axial collapse systems has continued to suggest that real benefits are provided for drivers (14,15,16,17). Relatively few problems with these systems have emerged from the literature although column bend has been cited as an occasional cause of failure (18,19). A recent analysis of police accident data in Britain has detected no statistically significant difference between driver injury in one model of car before or after the introduction of an axial collapse system (20).

The present study was, therefore, undertaken against a reported background of essentially satisfactory column performance.

METHODOLOGY OF STUDY

A 1-7 day retrospective field study was undertaken to assess the real life performance of three types of "energy absorbing" steering systems designed specifically to comply with current safety legislation. The three designs chosen were, the axial collapse systems fitted mainly to current Vauxhall models, the axial collapse system fitted to the Ford Mark III Cortina and Ford Granada/Consul range, and the deformable can behind the wheel, mounted on a 'rigid' column, which is fitted to the current Ford Escort range, and was fitted to the Ford Capri and the Ford Zephyr/Zodiac. The method of retrospective study used by the Accident Unit at Birmingham has been described elsewhere (10) and will not be detailed here.

FIELD EXPERIENCE

Sampling Procedure

The sample on which the following analysis is based is drawn from two separate sources. The police forces of West Mercia, Warwickshire and the City of Birmingham informed the Accident Unit of all accidents involving serious injury to at least one occupant of a current production car, occurring in their areas. From this large group of accidents, those involving frontal damage to the particular vehicle models of interest were selected. In addition, the police forces of Staffordshire, Cheshire, Northampton and County, Gloucestershire, Thames Valley, and West Midlands, informed the Unit of all frontal impacts involving the vehicle models of interest in which either, the driver was seriously injured or there was severe vehicle damage involving a probable insurance 'write off'.

It was intended that this sampling procedure would enable steering system performance to be studied throughout the energy range of frontal impacts.

FIELD RESULTS

Sample Structure

The structure of the sample to date with regard to make and model is shown in Table 1. All the axial collapse systems have been grouped together as there appears to be essentially no difference between their field performance. The main part of this analysis will deal with the protection offered by the two basic designs of steering system to unrestrained drivers, as it is this situation at which the legislation is mainly aimed. The field experience with lap diagonal seat belted drivers will be mentioned briefly later.

Table 2 describes the age and sex distributions of the unrestrained drivers in both groups. The time lag between initial inspection of the vehicle and full medical data becoming available explains the 'unknown' age category. As can be seen, the drivers in both groups are predominantly male. It is important to bear this in mind when assessing injury results as these reflect the performance of male drivers only. The age distribution within the two samples are essentially similar and show that the entire range of driver ages is represented in both groups.

The results quoted in this section will be described in terms of Equivalent Test Speed. This is a concept used for rating the severity of an impact. It is an attempt to relate the damage observed on a particular vehicle in the field, to the speed which that vehicle model would have to impact a rigid distributed barrier, in this case, to reproduce the actual damage. It is necessarily an approximate method and the errors increase as observed damage moves further away from that seen in the limited number of frontal test impacts carried out to date. However, with these reservations it is still considered the best method available, at present, for rating the relative severity of a group of accidents. In sections dealing with injury, a slightly modified AIS has been used in an attempt to differentiate between multiple fatal lesions to the chest and abdominal regions, causing instantaneous death, and rather less severe damage which may still result in death, although after a rather greater period.

Column performance is sometimes assessed in terms of shear capsule separation which is used as an indicator of column collapse due to driver impact.

It is a convenient and easy measure to take in the field but does not give an accurate assessment of "additional ride-down" in all cases. As the severity of the accident increases, the shear capsule separation is less and less a good reflection of extra ride-down, as the shear bracket support structure moves due to vehicle deformation. It is our experience that above an ETS of about 50 Km/h the supporting structure is normally severely distorted in the field. Table 3 records the measured shear capsule separations in our sample.

Categories of 2.5cms separation and above should be considered to be usually a combination of supporting structure movement and column collapse. The part played by column collapse in the larger measurements is small.

Of the eight cases recorded with capsule separation in excess of 2.5cms, six are known to involve fatal chest injuries from the steering system, whilst the injuries in other two cases are unknown at present.

Table 4(a) tabulates chest and abdominal injury severity against estimated Equivalent Test Speed, for unrestrained drivers impacting axial collapse systems. Table 4(b) indicates the relationship between the same parameters for "Capri" type steering systems.

The number of cases described in these tables is smaller than in the previous sections as complete medical data is only available on a proportion of the accidents at present.

Consideration of Tables 3 and 4(a) shows that axial collapse systems are not effectively limiting the loads on drivers' chests to below serious injury level. The sequence of events in real life, during impact, which leads to this failure, is thought to be as follows: frontal damage to the vehicle begins and the bottom of the column, adjacent to the toepan, undergoes some deformation which is non-axial with respect to the column. When the driver contacts the wheel, the telescoping sections in the column are already locked. A large load is developed between the steering wheel and the driver's chest which gives rise to a considerable bending moment on the column which, in turn, causes further bending and locking. As the loads rise the steering wheel begins to deform giving rise to load concentration, thus effectively lowering the load which can be tolerated by the chest without injury (See Figure 1).

Table 4(b) shows the performance of the 'deformable can' type system in the field. This system, absorbing energy by bending the can directly behind the wheel, and the column at its upper supporting bracket, is shown to be apparently highly effective in terms of preventing injury, even in the highest energy frontal impacts in the present sample. The sequence of events during impact with this system is thought to be as follows: the toepan is distorted by crush to the vehicle and the column increases its angle to the horizontal. The driver now moves on to the wheel which aligns itself with his chest under tolerable loads. The well padded spokes and the rim stay in the same plane thus spreading the load well over a large area, and allowing a high force to be tolerated on the chest without injury. Our laboratory work has shown that a peak load of around 2,500 lbs is generated when this wheel and column are struck under test conditions laid down in FMVSS 203 (See Figure 2).

It should be stressed at this point that both these basic designs of steering system comply with FMVSS 203, although one has been shown to be ineffective in the field whilst the other is apparently highly effective. The appropriateness of present standards testing procedures to reflect the true injury protection/hazard offered by steering systems must, therefore, be questioned.

However, before considering work carried out to investigate the standards testing procedures, a few other points should be made concerning the field results.

FMVSS 204 is designed to limit dynamic horizontal intrusion of the steering system into the passenger compartment during frontal impacts. Both groups of system in this study limited intrusion effectively until the severity of the accident caused the instrument panel to swing back towards the driver. In this situation all designs allowed considerable intrusion. The "Capri" type system with a solid column shows greater vertical movement of the centre of the steering wheel than do the axial collapse systems, but this elevation of the wheel does not seem to be associated with a high incidence of facial damage. It is thought that the relative timing of the driver and column movement is a very important factor in determining whether facial injury is a problem in this situation. It is felt that vertical deflection of the steering system due to vehicle crush may become more important in situations involving the lap/diagonal seat belted driver, where head contacts with the steering wheel are common (21).

Finally, an important point to emerge from this field study is the very severe hazard to the lower limbs, presented by the stiff supporting structures fitted in conjunction with axial collapse systems. This structure is placed in the knee impact area, in many current cars, and has been seen to be responsible for very severe injuries which have a high recovery time and have many associated long term problems.

THE STANDARDS TESTING PROCEDURE

The previous sections have shown that two basic designs of steering system, which under test conditions produce similar results, apparently provide very different protection to the unrestrained driver in real life. The whole ability of the standards testing procedure to reflect the injury potential of a system is, therefore, in doubt.

A series of tests is now under way, at Birmingham, designed to explore the correlation between accident performance of the systems and the results of tests carried out in accordance with FMVSS 203. This test programme is not yet completed but the following points can be made:

1) Damage to the two groups of systems, produced under test conditions as specified in FMVSS 203, is completely different to that observed in real accidents. The "Capri" type system experiences axial compression under test, whilst in the field the can and column bend. The axial collapse systems give considerable shear capsule separation under test, whereas they give no significant collapse, from the top, in the field. These differences are thought to indicate basic faults in the present standards testing procedures.

2) Field damage to the "Capri" type system can be accurately reproduced under test, by increasing the angle between the column and the horizontal. An increase of 10^{o} above the standard installation angle is sufficient to produce bending of the can, as opposed to axial compression (see Figure 2).

3) FMVSS 203 and 204 do not detect any interaction between primary damage to the system, caused by vehicle crush, and the ability of that system to control a subsequent driver's impact. The sequence of loading of the axial collapse columns, described earlier, shows that this interaction is of considerable importance.

4) Testing columns at their installation angle with an upright torso is unrealistic, as it does not take into account either the dynamic movement of the column or the fact that the driver's torso is usually not upright when he hits the wheel. The torso moves forward at approximately the seat back angle in the absence of any early knee impacts. These two factors combine to give a much steeper effective column angle at impact than is normally tested.

5) As accident severity increases, the dynamic movement of the column increases. It is therefore felt that if a system is to provide protection right through the range of accident severities, legislation should require a more or less uniform column performance from the system under test, mounted at its installation angle, and also, at any larger angle through to the installation angle plus, perhaps, 30^{o}. Also, to cater for the non-axial loading seen in the field, systems, when viewed in plan, should exhibit uniformity of performance with the column inclined at any angle within an arc, of perhaps, 20^{o} either side of its usual position.

6) It is felt that peak load is not a good criteria on which to assess injury. The distribution of this load appears to be at least as important as its peak value in determining injury in practice.

It should be noted that the speed distribution in the two samples are not significantly different at a 5% level of confidence, as determined by the Kolmogorov Smirnov test. However, no statistically significant difference in the injury levels can be demonstrated on present sample sizes. It is hoped that an increased number of cases in both groups will enable significant results to be produced, before too long. When such results are available, it is further hoped that definite modifications to the test procedures, and injury criterion can be suggested, to improve the very unrealistic test situation that exists at present.

CONCLUSIONS

Axial collapse steering systems, as fitted in British cars, have been shown not to provide any significant additional ride-down through column collapse, for the unrestrained driver, in real accidents. Systems utilizing a deformable can directly behind the wheel, appear to provide good protection against chest injury throughout the complete range of accident severities, seen in the present sample.

Accident damage to both groups of steering system has been shown to be completely different from that produced under normal test conditions, and the reasons for these differences have been explained. Some modification to present test procedures have been suggested and it is hoped that further improvements will be proposed when the study is completed.

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TABLE 1 SAMPLE STRUCTURE BY MAKE AND MODEL

Axial Collapse Systems

Vehicle Make and Model	Total Number	Number of unrestrained drivers
Ford Cortina Mk III	33	24
Vauxhall Victor FD	21	15
Vauxhall Viva HB	19	17
Vauxhall Viva HC + other 'mesh' columns	12	11
Total - all models	85	67

Three Spoke "Energy Absorbing" Wheel

Vehicle Make and Model	Total Number	Number of unrestrained drivers
Ford Capri	33	26
Ford Zodiac	3	3
Ford Escort	9	5
Total - all models	45	34

TABLE 2 SEX AND AGE DISTRIBUTIONS OF UNRESTRAINED DRIVERS IN SAMPLE

a) Drivers impacting axial collapse systems

		Age (Years)	Numbers of drivers
Male	65	17-25	9
Female	2	26-49	27
		50 +	9
Total	67	Unknown	22

b) Drivers impacting "Capri" type systems

		Age (Years)	Numbers of drivers
Male	33	17-25	4
Female	1	26-49	15
		50 +	4
Total	34	Unknown	11

TABLE 3 MEASURED SHEAR CAPSULE SEPARATION IN SAMPLE

Shear Capsule Separation (cms)	ETS Range Km/h 0-30	30-50	50-80	80-100	Total
0-0.5	41	6	2	0	49
0.5-2.5	6	2	1	1	10
2.5-5.0	1	1	1	1	4
5.0-7.5	0	0	3	0	3
Unknown	0	0	1	0	1

TABLE 4

a) CHEST AND ABDOMINAL INJURIES SUFFERED BY UNRESTRAINED DRIVERS IMPACTING AXIAL COLLAPSE STEERING SYSTEMS. 50 CASES.

MODIFIED AIS *	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-100
7			1		1	2	1	1	2
6						1	1		
5									
4			1						
3			1		1				
2		1		2	2				
1		2	7						
0	1	12	9	1					

ETS Km/h

b) CHEST AND ABDOMINAL INJURIES SUFFERED BY UNRESTRAINED DRIVERS IMPACTING "CAPRI" TYPE THREE SPOKE WHEELS. 33 CASES.

MODIFIED AIS *	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-100
7									
6									
5						1			
4									
3									
2			2					1	
1			7		1	1		1	
0	1	8	5	4	1				

ETS Km/h

* As for AIS except category 7 refers to "instantaneous" death, category 6 is death within 24 hours, 5 is survival uncertain, as before, and includes death after 24 hours or more.

FIGURE 1. A damaged axial collapse system removed from a Ford Mk III Cortina. The primary and secondary bends in the system are clear. Shear capsule separation in this case was 7 cms whereas the convoluted section was only shortened by 1.5 cms. The driver received fatal chest injuries (Severity 07 on modified AIS)

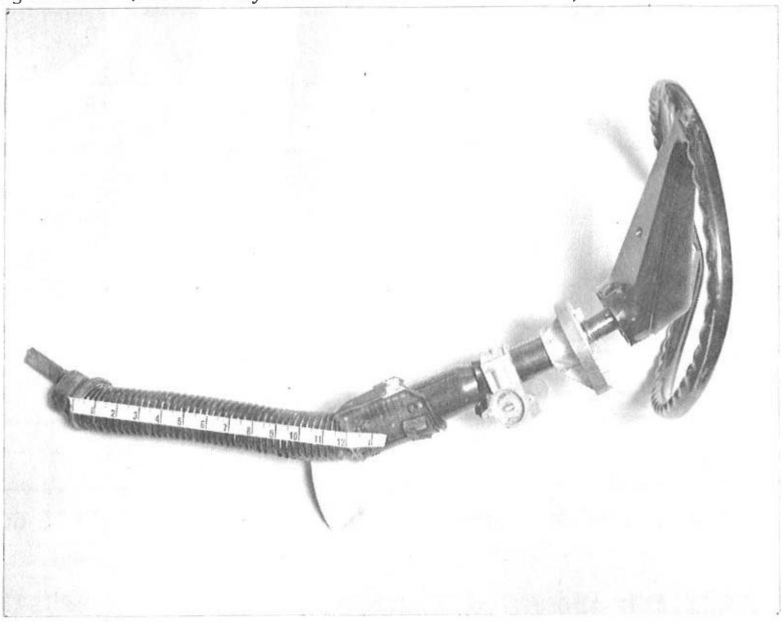

FIGURE 2. A damaged "deformable can" system, removed from a Ford Capri, showing bending of can and column with little damage to the wheel rim and spokes. (Background). Similar damage produced under modified test conditions. Column angle used was 10° more than normal installation angle (Foreground).