CHAPTER – VI
SUMMARY AND CONCLUSIONS

Tractor overturns are one of the major causes of fatal accidents to agricultural workers each year. A United States report stated that at least 92 deaths per year were due to tractor overturn (Harris, 2008) while in India incidence rate of such deaths were about 5.7 per 100,000 workers per year (Gite, 2010). These deaths may have been prevented if the tractors had been equipped with a rollover protective structure (ROPS). It was, therefore, decided by various national authorities that the fitting of ROPS was the only tenable option, as this would eliminate both the judgment of the operator and the uncertainty of a safety device operating both quickly and correctly.

NIOSH estimated that about 50% of the 4.61 million tractors utilized in the United States are fitted with ROPS while in India, ROPS are still not standard on all tractors. Tractor manufacturers are not providing ROPS on domestic models but the same are offered on export models since it is mandatory in other countries. Manufacturers stated that Indian farmers are not familiar with advantage of ROPS and because of this, there is no demand in the market. Furthermore, they have opinion that designing of axle housing will have to be modified for incorporation of ROPS. Current tractors are less likely to incorporate ROPS due to variation of the axle housing top, fender location and the axle housing strength. Mostly, tractor axle housings are being made of grey cast iron which is responsible for strength particularly in torsional loading. Therefore, it is a challenge to retrofit ROPS on current tractors. The earlier findings suggested that there is need to target groups of popular tractors for retrofitting of ROPS, since common solution for each tractor is a complex task for retrofitting.

Therefore, it was understood that the current tractor models are not available with ROPS in India particularly, and if anyone wishes to install ROPS, there could be a problem of design variations of axle housings. Hence, with due consideration of these issues, the major objectives of this research was set to provide complete safety package for operator against tractor rollover. Accordingly, a Universal Mounting Fixture (UMF) has been
designed to accommodate different cross sections of ROPS on any design of tractor axle housing for ROPS retrofitting. Also, due to inadequate availability of ROPS design for Indian tractors, a low cost ROPS has also been designed and developed for retrofitting on current tractors. In order to achieve the goal of this investigation and come up with absolute safety package for operator safety against tractor rollover, the following objectives were set.

1. Categorization of axle housings of some popular models of tractors and assessment of their strength to support ROPS.
2. Development of a Test Rig for Static Testing of tractor ROPS as required for their Certification based on International Standards.
3. Design, development and performance evaluation of a Universal Mounting Fixture (UMF) for ROPS retrofitting.
4. Design of a Deployable Roll-Over Protective Structure (D-ROPS) for medium horsepower (20 - 35 kW) range of tractor models.

Earlier studies on this topic of study were reviewed. Design trend for ROPS has been continuing from several years for modern as well as older tractors. Johnson and Ayers (1994) found that many tractors do not have ROPS because they were not designed to structurally support tractor during an overturn and found that mounting techniques were one of the constraints in performance of ROPS. Anonymous (2003) points out that self-made roll-bar collapsed along with axle housing during field operations due to inappropriate mounting, resulting fatality. Myers and Synder (1995) and Liu et al. (1997) suggested that the agricultural tractor population should be prioritized and proper tractors should be targeted for ROPS retrofitting. The classification criterion of tractors could be based on axle housings. Zhifeng and Ayers (1997) predicted axle housing strength to assess their suitability for fitting ROPS in accordance with ASAE S519 Standard. Such experiments were related to crush testing whereas few researchers used finite element method to solve such problems. In this, axle housing was created in CATIA® V5 commercial software and predicted the reason for its premature failure (Topac et al., 2008). During test, tractor front end got elevated and the ROPS frame impacted the
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ground as intended, however, the axle housing of the tractor failed catastrophically (Job, 2008). Gillispie (2000) constructed a rigid block and attached to housing using grooves in the axle housing to prevent rotation and translation effect of mounting fixture. High strength bolts and nuts were used to clamp the rigid blocks of the axle housing. Baggerly (2004) investigated failure of axle housing castings due to welding and stated that minor changes in steel chemistry had a significant effect on the casting material. Further, the use of engineering plastic was explored as a mounting structure on pre-ROPS tractor (Comer et al., 2005). Harris (2008) designed and developed a Cost effective ROPS (CROPS). This techniques could facilitate development of future CROPS designs by identifying poor design choices before timely and costly prototype testing is conducted. Harris et al. (2000) compared ROPS deformation response from a simulated SAE J2194 static loading sequence in which Von-mises yield criterion was used.

Therefore, to sort-out major problem as intended above, a survey was planned which gives complete scenario of design constraints involved in ROPS retrofitting on agricultural tractors in India. For this purpose, a questionnaire was designed and communicated to leading tractor manufactures to assess the scenario of ROPS in the Indian market. Similarly, another survey was carried out to collect the information regarding variations in the design and shape of axle housings.

Since the investigation required the testing as per IS 11821 (Part 2), a dedicated test setup called ‘Test Rig’ was fabricated. It includes test bed, reaction frame, hydraulic power pack, hydraulic actuators, control panel, overhead crushing beam and instrumentation for measurement of force and deflection. Each actuator were designed at nominal force rating of about 45,000 N. Data Acquisition System running with ‘LabView’ software was used to record signals of sensors at 50 Hz sampling rate.

It was clear that an experimental program arranged for full scale testing and crush test would be a very expensive business and time consuming. Nowadays, finite element analysis with computer simulation is found to be the best technique for such type of problem. The results of FEM calculations were always on the safe side, providing a
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sufficiently accurate answer to the set loading and boundary conditions. Most manufactures and government test stations are now using some degree of computer data acquisition during all tests. It takes a little longer to get all the necessary capabilities to correctly evaluate, but it provides the all important data on single terminal. In view of this, CATIA_V5 (R19) commercial software with implication of finite element method was used. Axle housing was created in CATIA_V5 which was identical to testing setup and further analyzed with regards to longitudinal loading. Grey cast iron was the assigned material with specified mechanical properties like Young modulus, poisson ratio and yield strength etc. Maximum shear stress (Von-mises) and deflection were obtained during different loading condition.

Similarly, finite element model of Universal Mounting Fixture (UMF) was also developed in CATIA_V5. This model consisted of a number of beam elements and nodes connected to the tractor frame. For this simulation, fasteners between the ROPS and tractor axle housing were designed. The finite element model was developed parametrically to accommodate a range of tractors and ROPS sizes. The parametric design permits changes in the model dimensions without varying the number of nodes or elements. It was important to note that this research examined trends for various scenarios for one base-fixture finite element model. Some discrepancy may be expected from simulated results. So, final design of fixture was developed and tested accordance to IS 11821 (Part 2). With due consideration of part geometry, OCTREE Tetrahedron mesh was selected and parabolic displacement interpolation was used between the nodes and elements.

After getting the satisfactory result of UMF, the fixture was fabricated and validated through static testing of ROPS. The sequences for the loadings were as follows: rear longitudinal, vertical crush, transverse, and second longitudinal. Each testing except vertical loading, were carried out until the fulfillment of energy criterion. The vertical loading test required maintaining of the load for a specific period of time. The axle housing and mounting fixture combinations must pass the static testing criteria as per
standard for acceptability. To conduct this test, a set of ROPS and UMF were attached and tested in the Test Rig.

In order to design a low cost ROPS for Indian tractors, lateral dimensions were considered with due consideration to the anthropometric dimensions of Indian agricultural workers. The slope-deflection equations were utilized to design the ROPS cross section considering ROPS as portal frame whose base was rigidly fixed. The equation was applied to all columns and joints of the frame. Both symmetrical and non-symmetrical loading was considered. Further, equations were used for each joint to determine the moment at each location. During calculation the product of Young Modulus (E) and moment of inertia (I) was kept constant and then cross-sections of vertical post of ROPS were determined for its permissible deflection values.

The results of survey revealed that 60% of tractors manufacturers outsourced the protective structure while 20% were manufacturing. About 60% of the manufacturers provided ROPS on their export tractor models. About 60% manufacturers were against design modification while others were ready to accept that present axle housing may fail due to ROPS loading. Design variations were also found in available protective structures in term of used cross sections, width and height. It was found that Industries have different hp segment and each segment has several models with separate axle housings design. The variations observed in axle housing top, fender design and strength capacity. Therefore, the axle housings were categorized into different groups for the purpose of strength analysis using multivariate analysis in Minitab software.

UMF was theoretically analyzed and then a prototype of the modeled UMF was fabricated with two plate thickness of 12 mm and 15 mm for test in the Rig. Using the tractor reference mass about 2000 kg, the energy criterion for longitudinal loading was set at 2800 J. Displacement rate was limited to 3.5 mm/s for the static test. The combination of safety frame and UMF were tested for longitudinal, transverse and vertical crush loads. The testing was confirmed to the set energy criteria in each case.
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The Deployable Roll-Over Protective Structure (D-ROPS) was designed and modeled in CATIA and standard static testing was performed using FEM simulation. During testing, the maximum stress was found to be 298 MPa at the bottom of the lower post. The energy criterion was met at 18750 N and 215 mm of ROPS deflection. In Vertical crush loading, an energy criterion was fulfilled without deforming the ROPS. It was observed that during all loading condition the newly designed ROPS did not intrude into the Operator Clearance Zone and hence satisfied the set energy criteria.

The following major conclusions were drawn from the study,

1. Information obtained during survey of tractor manufacturers and their dealer points regarding Roll-Over Protective Structure (ROPS) indicates that none of the manufacturers is providing ROPS on Indian tractor models. Although ROPS were available with them (either their own product or outsourced) while they were providing the same on their export tractor models.

2. Manufacturers feel that in the case of a mandatory government regulation the ROPS could be installed on tractors at an additional cost varying between ₹10,000 – ₹20,000 to be borne by consumers since it is an optional unit at present. They were also felt that due to lack of awareness about tractor operator safety, the consumers are not prepared to purchase ROPS for their tractors.

3. Several designs of axle housing exist in the tractor models manufactured by different companies. They were found to vary in shape and size. The various cross sections include rectangular, square and circular. The rectangular cross section varied 150 mm × 170 mm to 180 mm × 200 mm, square 170 mm × 170 mm to 230 mm × 230 mm and circular 90 mm to 250 mm diameter whereas length of axle housings varied 460 mm to 520 mm in selected surveyed axle housing of different tractor models.

4. It was observed that some manufacturers have provided strong ‘canopy support’ for attaching hood particularly meant for operator protection from sun and rain. These ‘canopy supports’ may work as safety frame in the event of tractor overturn.

5. A new statistical technique of ‘Cluster analysis’ was employed to categorize different axle housings based on their level of similarity in their shapes, sizes, grooves, and
material of construction. Using Minitab (Version 5) software this cluster analysis was accomplished and three categories of axle housings were defined in the power range of 20-35 kW of tractors.

6. The “Single Linkage Cluster Analysis” resulted into three categories, namely, Category-I, which includes tractor models M1, M14 and M15, Category-II includes M2, M4, M5, M6, M10, M9 and M13 while Category-III comprised of tractor models M3, M7 and M11.

7. Torsional yield strength of a tractor axle housing (B4) was found to be 23,000 Nm using finite element method which was also validated experimentally. It was concluded that axle housing performed under elastic limit till 20,144 Nm applied torque and confirmed its suitability for ROPS retrofitting.

8. Axle housing strength index for ROPS supporting of tractor axle housing ‘B4’ has been worked out to be 1.57 which also justifies the axle housing suitability. Tractor axle housing B4 belongs to category-II therefore, it is expected that other axle housings belonging to this category would behave identically under similar given conditions and can be used for ROPS retrofitting.

9. A unique testing facility ‘Test Rig’ for ROPS static testing has been designed and developed. In this, ROPS could be tested for loading energy up to tractor reference mass of 3500 kg with safety factor 1.3.

10. A hydraulic loading system has been designed and fabricated for slow incremental loading. The system was designed for a loading rate below 5 mm/s. Three hydraulic actuators were employed for standard loading from different directions i.e. longitudinal, vertical and transverse. The hydraulic system could perform in the pressure range of 5 MPa to 15 MPa whereas relief valve was set at 18 MPa. For maintaining the load for a specific period of time, the system was equipped with four ports, three position, centre closed, spring centered, solenoid operated directional control valve of pressure rating 35 MPa.

11. Finite element analysis of UMF structure gave acceptable stress values throughout the designed load and mild steel was found the most suitable material. A 20,000 Nm applied moment on top plate of UMF produced maximum Von-mises stress of about 300 MPa (6.94% GPE) and 291 MPa (11.39% GPE) at the middle plate.
12. It was observed that bolt connection regions were highly stressed areas rather than plates of the fixture in all loading conditions. Therefore, high tensile bolt and nut were recommended to use for fastening the plates of UMF. The recommended bolt size was found to be 20 mm in diameter of class 8.8 grade (tensile strength 750 MPa).

13. Universal Mounting Fixture (UMF) was found capable of satisfying IS 11821 (Part 2): 1992 requirements and found suitable as mounting fixture for ROPS retrofitting on tractors. It could accommodate ROPS sizes of 40 mm × 40 mm to 70 mm × 70 mm in hollow square cross section, 40 mm × 60 mm to 70 mm × 90 mm of hollow rectangular cross-section and 40 mm to 90 mm diameter of hollow circular cross-sections.

14. The Deployable ROPS (D-ROPS) was designed and developed using hollow circular cross-section. The cross section of fixed post was found to be 88.9 × 7.62 mm whereas 73 mm × 5.16 mm was decided for deployable post. The high tensile nut and bolts of 20 mm size were recommended as lashing mechanism throughout for its connection and joints.

15. The D-ROPS was designed and developed with width adjustability option in the range of 725-875 mm. It measures a height of 1800 mm in full open condition while 1600 mm in full deployed condition.

16. Computer analyses of D-ROPS have indicated that it successfully absorbed the forces of the standard loading. The high stress levels were due to distorted geometry of an element in the mesh and occurred in very small areas resembling a stress concentration.

17. Static testing of D-ROPS indicated absorbed longitudinal energy criteria at 24,897 N with deflection of 206 mm. Similarly, a transverse energy criterion was satisfied at a load of 25,646 N and deflection of 180 mm and a vertical loading was absorbed till 48,902 N.