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Design and Fabrication of an Alarm System to Prevent Tractor Overturning

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ABSTRACT

Serious agriculture - related accidents are increasing and tractor overturning is one of the most important factors leading to death in farms in Iran. In fact, the interplays between tractor operator and environment cause such damages. There are several reasons involved in tractors overturn that the recent method in tractor design is nearly to improve with using the electronics instrumentation that gives the operator key guides related to the tractor`s stability as it is operated. In this study a new system was developed. To measure a steep slope land electromagnetic gauge was constructed. The working principles of the slope gauge, based on the magnetic field were changed by changing the slope of the ground. The embedded inclinometer within the pendulum inclinometers with their period are used to altering the magnetic field. The output of inclinometer analog and the voltage range was (47/2-32/0) V. This information was then processed by a microprocessor, and an assessment of rollover potential was reported to the display device.

Keywords: Accident prevention, agricultural tractors, tractor overturn, safety

INTRODUCTION

According to the statistics from the National Safety Council (1983), the deaths caused by tractors overturn, are estimated around 49% (about 300 deaths). The main goal of this research is to know when and why tractors overturn. So if we can predict the possible over turn, a device or procedure can avoid it; otherwise we can control or cut off the factors that lead to overturn.

Tractors are involved in more than 45% of the farm victims and 13.7% of all confinements. According to Javadi and Rostami (2007), the widest percentage of vehicles injuries was reported to be roll overs and run overs and also tractor reversal

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was the prominent cause of agriculture machine-related deaths in the US (Sanderson et al., 2006). However, it is proven that the losses of rollover protective structure (ROPS) and seat belt play major roles in these fatalities.

A research in Finland proved that running around or walking around in the field are two important factors involved in tractors overturning (Rissanen & Taattola, 2003). In addition construction work and animal husbandry and forest work are the other factors that lead to deaths in the farms.

Two major etiologies for tractor overturn are habitual and unique. In habitual one, the operator makes the same mistakes repeatedly without knowing; then with a slight change in the land and position like having high speed or sharper turning radius an accident may happen. But if a driver knows and realizes about the danger of uphill and how to control it, the outcome may change. Thus learning is a useful Factor. However, driving badly in a steep slope or with wrong shutting the loads, the tractor becomes unstable and with a little shake or if the clutch works faster, then the tractor gets closer to reversal (Sommer et al., 2006).

Consequently minor terrain changes (erosion, rodent burrow), slightly faster ground speed or sharper turning radius can now lead to overturn. In particular, a sudden uphill turn to avoid an unforeseen obstacle on a marginally safe but familiar slope is a potential habituated overturn that could be avoided by learning that this slope is truly dangerous. Habituated rear overturns may be caused by repeatedly climbing very steep slopes or by repeated improper hitching of loads that create operating conditions very near instability. Consequently, if an attached implement encounters an obstacle or if the clutch is engaged faster than usual, tractor operation that was previously on the borderline of instability can now become a fatal incident.

On the other hand, unique overturn is very hard to forecast and usually happens when farmers try a new operation in the farm such as loading a large hay bale. Then for this type, operator education is more efficient than on-the-job learning by disabling the electronic clutch or releasing the throttle (gas valve); thus preventing the tractor from overturning doesn't seem impossible. Actually informed operator intervention is the most reliable way to safe guide the tractor.

Mechanical and operator intermediation while active intervention to prevent side overturns would require massive lateral actuators for outriggers or counterweights, electronic clutch deactivation and/or throttle release holds promise to prevent both rear overturn. Operator intervention addresses the root cause of habituated overturn by helping tractor operators learn to avoid hazard condition. To this end, one must be able to monitor tractor stability and detect how close the tractor is to an unstable condition or even to predict that an unseen future event might possibly cause an overturn. Then, the operator can predict and prevent overturn. Informed operator intervention is the most effective way to prevent tractor overturn events.

According to Nichol et al. (2005), studies and researchers claimed that by using cheap microelectronic machine system (MEMS) sensors and two axes accelerometer, they could manage and control tractors condition. In addition, they had designed a colour (LCD) visual display that helped the operator to be aware of the stability condition of the tractor.

A study has shown that a tractor may arrive in position in 3/4 of a second, but it takes more time for the operator to react and brake. However they are a lot of tractors operating condition in which the responding time is even less than 3/4 of a second to observe and react to the possible overturn (Agriculture Safety, Deere and Company, Inc., 2007). Imagine a tractor in a deep hole or travelling up a steep slope, in that case the space between tractors CG1 and back constant baseline will achieve the “point of no return”. Figure 1 discusses this situation.

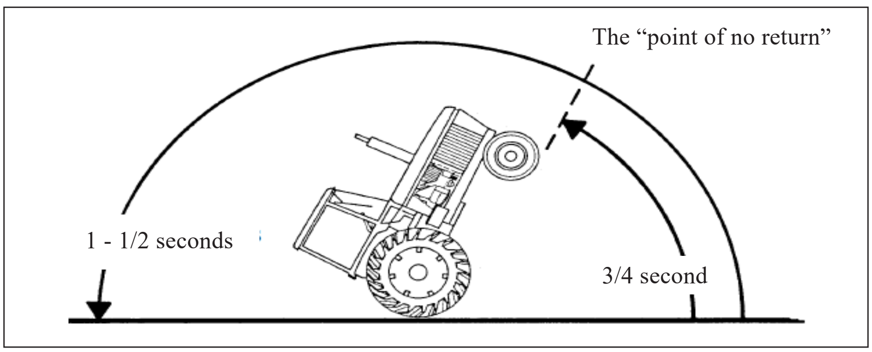

Figure 1. The "point of no return" during a rear turnover may be reached in 3/4 of a second.
Source: Agricultural Safety, Deere and Company, Inc.

In this paper the new inclinometer was developed to measure the slope of land and a new dynamometer was fabricated in order to measure the draft forces, because draft forces in a tractor were critical when a tractor was pulling an agricultural implement that might cause to tractor overturning. In this paper in order to predict side and overturning, two inclinometers were used. In order to record and analyse the input data, Micro controller AT Mega 32 and a LCD were used. This paper discusses the effective ways to warn tractor operators about possible hazards.

MATERIALS AND METHODS

In this study a 4WD Mitsubishi tractor with 25 hp was used. This tractor was a case study to this research. In order to sense the draft forces and slope of land, a micro electronic circuit was designed. Following diagram was used to sense the output of inclinometer and dynamometer. Because the outputs of these sensors were very low, two amplifiers were used. Microcontroller AT Mega 32 was used to analyse outputs of the sensors. Finally a monitor was used in order to show the slope and the draft force to the driver. With this monitor, a driver could see the critical operation of tractor and decided correct and safe operation (Figure 2).

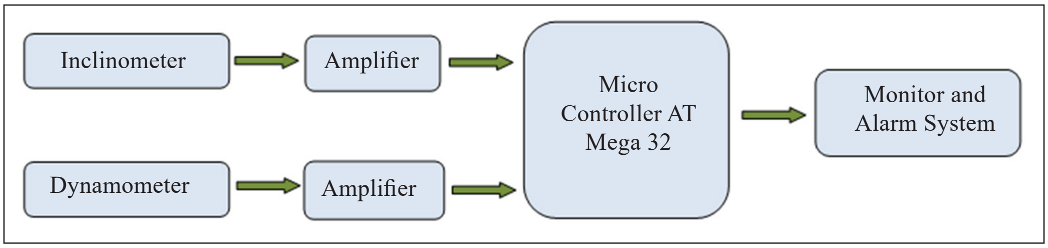

Figure 2. Block diagram of the sensing device

Center of Gravity

The center of gravity is a place where the total weights of tractor are located. Its position depends on the various types of tractor. In addition, we need to design the position of the center of gravity for analyzing the chassis of the tractor. Its common location is near to the rear axle (Point G in figure 3) (Macmillan, 2002).

Longitudinal Location. By measuring the weight of front (W_f) and rear (W_r) wheel, we are able to locate the center of gravity in linear (X) Direction. In the force equilibrium condition, the tractor weight W:

$$W = W_f + W_r \quad (1)$$

Also, consider the longitudinal axis (X_r) in the moment equilibrium condition as shown in Figure (3).

For the tractor take moments around point O:

$$W \cdot x_r = W_f \cdot x \quad (2)$$

$$X_{r_1} = \frac{W_f}{W} \cdot x \quad (3)$$

The wheel base (X) between the back and front axle is considered in the manufacturer's specification, if not, they can be calculated easily.

For most rear wheel drive tractors, (X_r) is nearly 30% of (x), also this is the percentage of the static tractor weight on the front wheel.

Vertical Location. Assigning the position of center of gravity in this type is very difficult. So by lifting the front or rear of tractor (as shown in Figure 3), we can measure the weight on the front wheel in the raised condition. Similarly the vertical position (Y_g) is achieved by moment balance (as shown in Figure 3, section c) (Barger et al., 1952). For the tractor take moments around point O:

$$X_r' = \frac{W_f'}{W} x'' \tag{4}$$

The geometry of the positions of the center of gravity (Figure 3(c)) gives:

$$Z = \frac{X_r'}{Cos\,\beta} \tag{5}$$

$$y_y = \frac{x_r - \dfrac{X_r'}{Cos\,\beta}}{tg\,\beta} \tag{6}$$

Substituting for (z) gives

$$y_y = \frac{x_r - \dfrac{X_r'}{Cos\,\beta}}{tg\,\beta} \tag{7}$$

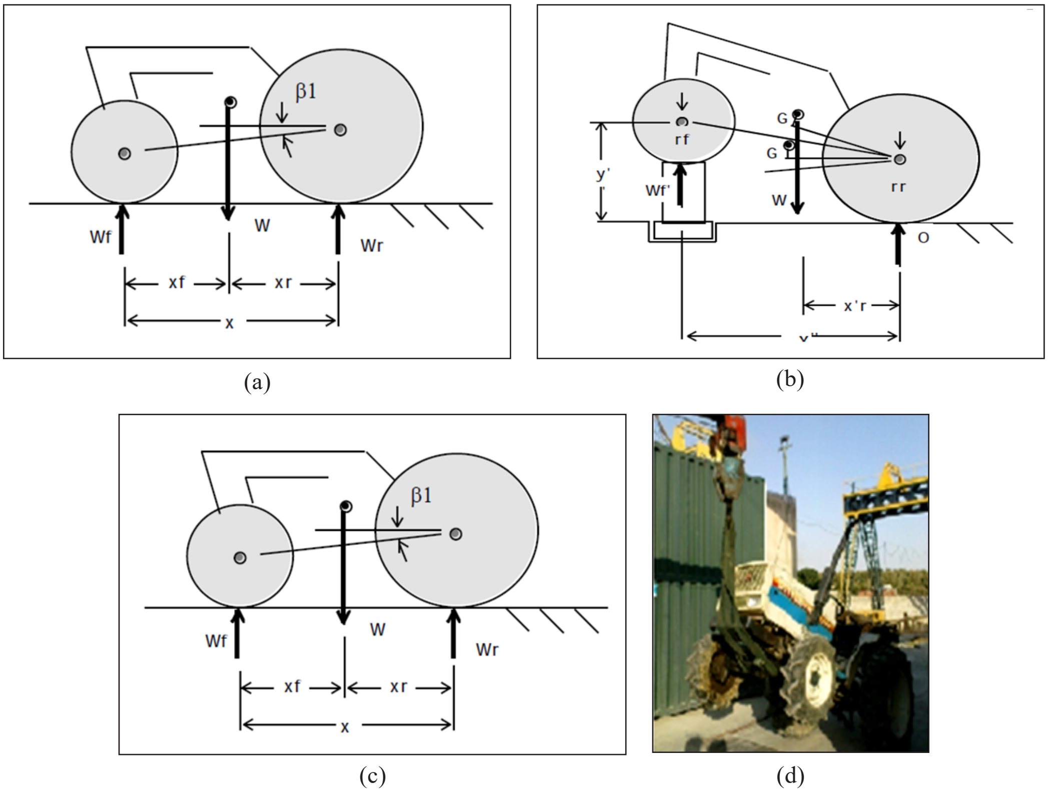

Figure 3. Center of gravity. (a) Distribution of tractor weight on front and rear tires; (b) Rise the front of tractor to measure the y_g; (c) Free diagram of section (b); and (d) real life photo

Where x'_r is as calculated from equation 4 above. And

$$\beta = \beta_1 + \beta_2 \tag{8}$$

$$= Arcxtg \frac{r_r - r_f}{x} + Arctg \frac{y' - r_r}{x''} \tag{9}$$

Examination of equation (7) proves that if the difference between $x_{r'}$ and $x_{r'}$ /cosβ calculated correct, β should be relatively large or accurately specified.

The angle of slope, αs, is the angle that causes the tractor to tip as a hard body on the ground. Contact points under static conditions for example, no drawbar pull condition are calculated from equation (10).

$$\frac{x_r}{r + y_g} = tg\,\alpha = tg\,\alpha_S \tag{10}$$

The critical angle for tractor that was used in this research was calculated as follows:

$$Tan\,\theta_{critical} = \frac{x_r}{r_r + y_g} = \frac{69}{55 + 25.55} = 0.88 \rightarrow \theta_{Critical} = 41 \tag{11}$$

This critical angle (θ critical= 41°) is inserted in microcontroller.

Inclinometer

In order to measure the slope, an electro- magnetic inclinometer was developed (Figure 4). The Inclinometer included a Mira pendulum that had been changed by changing the magnetic field when the slope of land changed. Pendulum consisted of a plastic page on both sides of it. The permanent magnets were installed under magnetic brass weights installed to cause centre of gravity of pendulum to be moved down. In order to measure the angle of slope the kmz41 and uzz9000 sensor were used (Figure 5). A capacitor with 470 nF was used to decrease the noise. The inclinometer was installed on the chassis of the tractor according to Figure 6.

Dynamometer

In this project a three point hitch dynamometer with the weight of 49 kg and U-shaped frame chassis from the class 0/I was made which could use the PTO simultaneously. The draft forces in each link were measurable beside the vertical forces on the lower link. The dynamometer system was made of 3 parts: The chassis, sensor element and recorder system. This dynamometer was built to measure the resistance pull of engaged soil and critical force that led to possible rear overturn. Note that the main purpose of this dynamometer was to

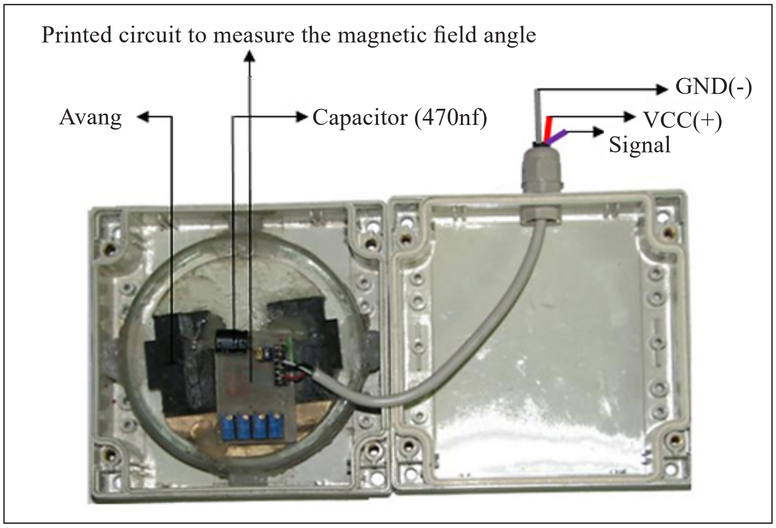

Figure 4. Inclinometer

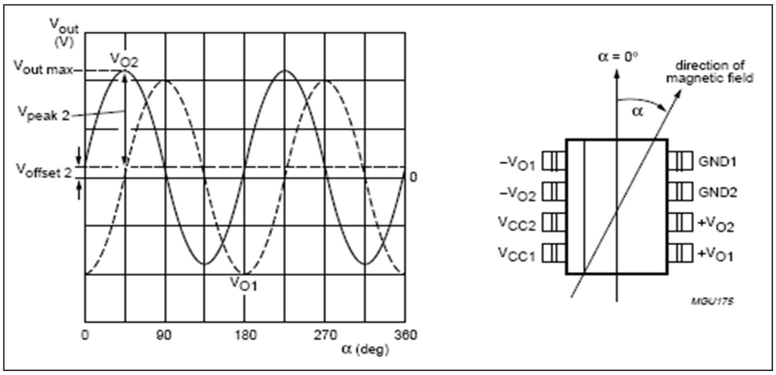

Figure 5. The output of KMZ41 versus the external magnet
Source: Data sheet of the kmz41 and uzz9000 sensor

Figure 6. Inclinometer installed on chassis calculate one or even more bottom tillage tools. The calculations related to dynamometer chassis were based on tractors design parameters and maximum horizontal force.

The resultant force P, which was applied by the tractor, was divided into 3 parts: Horizontal (F_x), vertical (F_y) and side (F_s). F_s was the element over the lower link arms and F_x and F_y were elements over the upper link arms. Among the elements of draft force, F_s was worthless, then it could be omitted from the calculations and just the horizontal force F_x, was measured in upper link arm. As a result, the only force led to the reverse is F_x. As mentioned, the chassis of the dynamometer was made in involved U – shaped frame that provided a condition to use the PTO at the same time. Because this dynamometer had been allocated to the small size tractors, then it should be as light as possible. The typical mast design was used instead of connecting clips. For measuring the impact and dynamic force the chassis was joined to the tractor by force converters sensing pins from one side and mast members from the other side.

Force Transducer

Converter is a device that changes mechanical to electrical signals (Niari, 2002). In this research three (3) force converters were used on the dynamometer; one of them was for measuring the force on the upper link and the other two were used to measure the forces on the lower links (Figure 7). Converters contain 2 parts: elastic member (called sensing pin) and Wheatstone bridge (called full bridge). This structure increased the converter's sensitivity as well as compensation for temperature. It should be noted that the strain caused by exerting the force on the elastic member must not exceed the allowable strain of the strain gauge. (Alimardani, 1997).

Equation (12) is used for calculating the elastic strain.

$$\varepsilon_{total} = \varepsilon_s + \varepsilon_p = \frac{F_s}{AE} + \frac{MC}{IE} \qquad (12)$$

Figure 7. The Dynamometer

Where
(ε_s) is side strains
(ε_p) is vertical strains
(F_s) is considered as the side force
(A) is the cross section of elastic member
(M) is bending moment (it is caused by vertical force)
(C & I) are radius and inertia moment of the elastic member.

Cross section and total (ε) in maximum tension resulted from vertical and side forces, which lead to the standard design for the elastic element.

Note that the strain yielded (compound of both vertical and side force) was considerably less than total (ε). If assigning the allowable strain of all strain gauges located on the elastic member is needed, so the following equation can be used:

$$\varepsilon_{SG} = \left(\frac{\Delta R}{R}\right) S_g \qquad (13)$$

Where (ε_{sg}) is the allowable strain caused by resistance change of strain gauge, S_g is the measurement factor and R is the tensile strength.

Rear Overturning

The function of stability of tractor in rear overturning is shown in Figure 8. When rear overturning occurs, the forces on front wheels are zero. When the tractor is driven on sloped land, if the slope increases and rises until critical angle, tractor will be close to rear overturning. Also the critical draft force can cause rear over turning.

The following equations are the stability function of tractor. N_f in this function is the reaction force on front tyres of the tractor.

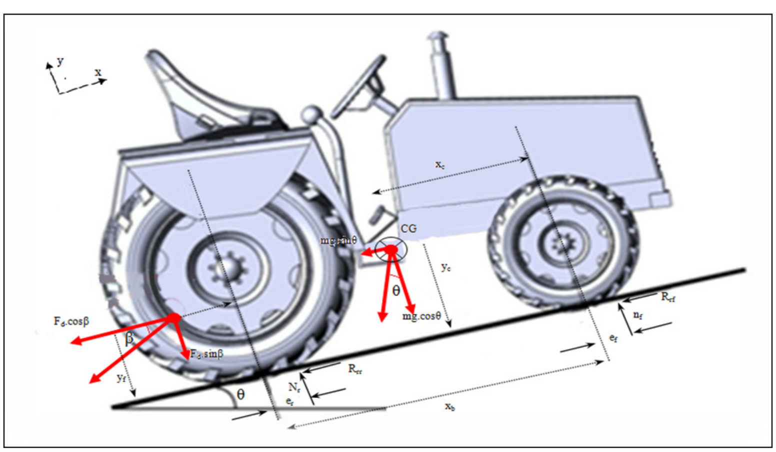

Figure 8. The Free Body Diagram of tractor in rear overturning

$$N_f = m_t g\ cos(\theta)\ +\ F\ sin(\theta)\ -\ \mathrm{N} \tag{14}$$

$$W = F_r - F_l \tag{15}$$

$$F_1 = W\left(\frac{a'}{a+b}\right) \tag{16}$$

$$a' = c.\cos(\alpha+\varphi) \tag{17}$$

$$F_r = W\left(1 - \frac{c}{a+b}\cos(\alpha+\varphi)\right) \tag{18}$$

$$N_f = \frac{1}{x_b + (e_f - e_r)}[m_t g(x_b - x_c - e_r)\cos(\theta) - y_c m_t g\sin(\theta) - y_f\ F\ cos(\beta)$$

$$-\left(x_f + e_r\right)F\ sin(\theta)] \tag{19}$$

When $N_{f=0}$

$$F = \frac{m_t g\left(x_b - x_c - e_r\right)\cos\left(\theta\right) - y_c m_t g\sin\left(\theta\right)}{y_f F\cos(\beta) - (x_f + e_r)F\sin(\theta)} \tag{20}$$

And,

$$\theta = tan^{-1}\left[\frac{x_f + e_r}{y_f}\right] \tag{21}$$

Therefore the critical draft force can calculated from equation (20). This force is measured with dynamometer and input into microcontroller. When the draft force increased up to a critical position the alarm system started and showed to operator that the tractor was close to critical operation. Alarm system includes two LED (yellow and red) and a loudspeaker. When the draft force increased up to 10000 N (for this type of tractor), the yellow LED turned on and showed that operation was next to critical situation and operator should be careful and when the draft force becomes 15000 N the red LED and loudspeaker turned on and in this position operator must stop the tractor.

Side Overturning

The equations for side overturning are shown below.

$$W = F_r + F_l \tag{22}$$

$$F_1 = W\left(\frac{a'}{a+b}\right) \tag{23}$$

$$a' = c.cos(\alpha+\varphi) \tag{24}$$

$$F_1 = W\left(\frac{c.\cos(\alpha+\varphi)}{a+b}\right) \qquad (25)$$

The angular φ was calculated with the dimension of tractor. The value of this parameter was 53 degrees. Therefore if α becomes 37 degrees the value of F_l becomes zero:

$$\cos(\alpha+\varphi) = 0 \Longrightarrow F_1 = 0 \qquad (26)$$

When the F_l becomes zero, side overturning accrues. In this study the side overturning had been predicted, too. Monitoring system and alarm system were developed the same way the rear overturning was developed. The Figure 9 shows the free diagram of side overturning.

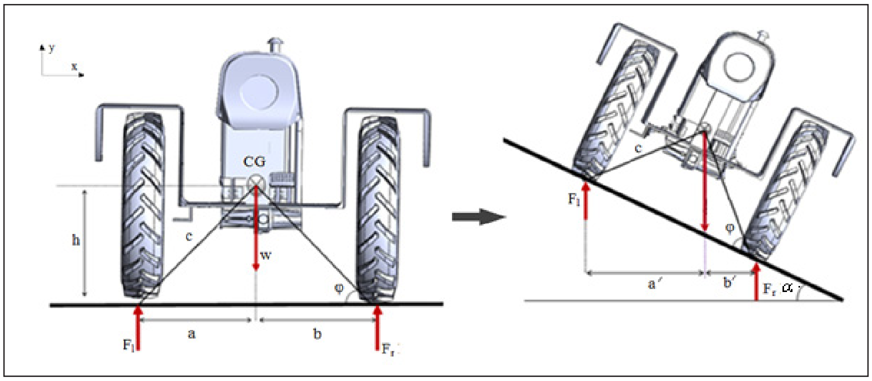

Figure 9. The free diagram of tractor in side overturning

RESULTS AND DISCUSSION

In thi research a new mechanism of tractor overturning alarm system was developed. 4WD Mitsubishi tractor with 25hp was used and according to experimental study and mathematical calculation the critical angle of this type of tractor (41 degrees) was obtained. The critical draft force of this tractor (15000N) was obtained. The experimental research of alarm system for tractor overturning was done in the laboratory in the University of Tehran. Results show that there is good relationship between output of inclinometer and dynamometer for measurement of the slope of land and draft force, respectively.

CONCLUSION

The following are suggestions in order to avoid tractor overturning and can be useful for operators:

1. Tractors should be equipped with rollover protective equipment such as ROPS (Roll over Protective Structure) and seat belts.

2. Reduce speed on rough ground, on slopes, when turning, or when driving onto roads
3. Avoid sudden turns, especially on sloping ground. Avoid uphill turns, and turning too fast with a load.
4. If the tractor has ROPS and the tractor starts to roll, do ***not*** jump off of the tractor. Stay with it until the machine comes to rest.
5. If the tractor is traversing a slope or travelling on the shoulder of the road with a sharp pavement incline, do not turn up slope. Always turn down slope.
6. When working on sloping land, add weight to the front and widen the wheel base of the tractor. This adds stability to the machine.
7. Do not "pop" the clutch or give a sudden jerk when pulling out stuck vehicles or stumps, or when pulling any machinery.

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