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Tractor Controls Actuating Force Limits for Indian Operators

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Abstract: In four-wheel tractors, proper design of controls is important for comfortable and safe operation of the tractor. The design involves location and dimensions of controls as well as strength limits for operating these controls. The present study was aimed to quantify human strength for operation of tractor controls and to recommend the maximum control actuating forces for normal operation of tractors based on strength capability of 3,423 Indian male agricultural workers. The 5th percentile values of strength parameters i.e. leg strength sitting (left and right), foot strength sitting (right), torque strength (both hands) sitting, push strength (left hand and right hand) sitting and pull strength (left hand and right hand) sitting of agricultural workers collected using a strength measurement set-up were taken into consideration for the study. It was recommended that the maximum actuating forces for normal operation of frequently operated brake and clutch pedals of tractors should not exceed 260 N and 125 N based on 5th percentile values of right and left leg strength of male agricultural workers, respectively. The maximum actuating force required in steering wheel operation should not exceed 51 N based on 5th percentile value of torque strength (both hands) sitting of workers. The maximum actuating forces required for operating frequently operated levers viz. gear selection, speed selection, hydraulic control and hand throttle of Indian tractors should not exceed 46 N, 46 N, 25 N and 25 N, respectively. It may be concluded that the maximum actuating force limits as given in Bureau of Indian Standards IS 10703 are very high as compared to the findings of the study based on strength data of Indian male operators, which highlight the need to revise the standard.

Key words: Tractor, Strength limits, Controls, Indian operators, Actuating forces, IS 10703

Introduction

Operating a tractor imposes a lot of physical and mental stress upon the operator. If the operator seat and controls are not properly designed, his work performance may be poor and there is also a possibility of accidents in tractors. Hansson[1)] stated that safety, comfort and convenience should be considered in the design and construction of the operator's work place. Levers, pedals and instruments should be conveniently and logically located and work place should fit both tall and short operators. In addition, they recommended that the operator should be able to change his working position easily and the work area should be free of sharp edges and obstructions such as transmission cases. Matthew and Knight[2)] recommended the locations for optimum pedal area for British driver, when the controls were operated either by heel or toe. Some case studies on workplace layout of tractors were carried out for Indian operators[3–6)].

Tiwari[4)] ergonomically evaluated the tractor operator workplace and activities. He reported that all the locations of tractor controls met the requirements of Indian Standard IS 12343[7)]. But the range of dimensions given in Indian Standard were very large. He

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also observed that braking force increased with increase in forward speed during field operation. It was 746 N, which was above the recommended limits as per IS 10703[8]/ISO TR 3778[9]. Nag and Nag[10] reported that tractor operation often required a large braking force (600 N or more) to be exerted by an average Indian operator weighting 50 to 60 kg. Febo and Pessina[11] also observed that actuating forces for tractor controls were higher than 600 N for pedals and 300 N for levers on 20% of the surveyed 90 tractors in use in Nothern Italy. They also observed difficulty in operation of controls on these tractors. Fathallah *et al.*[12] estimated the activation forces required to operate the clutch, brakes and steering wheels of 40 tractors in common use in US. They concluded that the activation forces required to operate tractor controls exceeded the physical capabilities of most children aged 13–17 yr.

Jafry and Haslegrave[13] indicated that the operation of foot pedals required at least 143 N force, which was an important risk factor, associated with tractor driving. The flattening of the lumber spine could explain the increasing disc pressure when operating foot pedals. An increase in the activity of the illiopsous and the abdominal muscles each time the foot is lifted on to a pedal can also contribute to increase in disc pressure. The lumber disc pressure increased when the gears were shifted and increased even more when pedal was depressed.

Pheasant and Harris[14] optimised the pedal location for the British tractor operators and recommended that the pedal should be located at 47.5% stature in front of seat reference point (SRP) and 12.5% stature below SRP for a better driving posture. Mehta *et al.*[15] quantified human strength in the operation of tractor control pedals based on leg strength data of 20 male tractor operators and recommended that the limits for maximum actuating forces for brakes and clutch pedals should be 330 N and 280 N, respectively. They concluded that the optimum locations of clutch and brake pedals on Indian tractors should be at 40% stature in front and 19% stature below the SRP based on strength limits and postural comfort of operators.

Proper design of tractor controls is important for comfortable and safe operation of the tractor. The design involves location of control as well as strength limits for operating controls. An operator has to exert force using both hands and legs to operate tractor controls. Sometimes torque is also applied, such as when operating steering wheel. The capabilities of the operators have considerable effects on design features and control of tractor. However, very little data are available on capabilities of different population segments of Indian agricultural workers[16, 17].

Agarwal *et al.*[16] collected strength data on 100 subjects (52 male and 48 female) from Meghalaya state in the north eastern hill region of India. Mean leg strength (right) and foot strength (right) of female agricultural workers (334 N and 200 N) were found to be significantly lower ($p<0.01$) than their male counterparts (526 N and 343 N). They observed mean steering torque of 65.3 and 49.2 Nm for male and female agricultural workers, respectively. Tiwari *et al.*[17] collected strength data of 920 agricultural workers (male and female) from Madhya Pradesh state in central India. The 5th percentile push and pull strength values in standing posture were 167 N and 164 N, respectively for male subjects and 124 N and 134 N, respectively for female subjects. These studies indicated that the push/pull strengths in standing posture of male agricultural workers were higher than those of female workers[16, 17].

The Indian Standard IS 10703[8] and ASABE S 365.8[18] recommend the maximum actuating forces to operate controls of agricultural tractors equipped with normal controls and values are reported in Table 1. The forces specified in the IS 10703[8] standard are exactly same as given in ISO/TR 3778[9]. The annex A of ISO 15077[19] recommends that the maximum control actuating force for normal operation of tractor and self-propelled machinery in agriculture should not exceed the values given in Table 2. However, it mentions that emergency situations may require higher forces. Mehta *et al.*[15] observed that the actuating force limits as given in IS 10703[8]/ISO TR 3778[9] were very high as compared to leg strength of Indian operators. Similar results were reported by other investigators[4, 10, 16]. However, the Bureau of Indian Standards at present has adopted recommendations of ISO/ASABE standards due to non-availability of strength data of Indian male agricultural workers. These standards are primarily based on strength data of Western workers.

The maximum work tolerance on a working day can be indirectly obtained from the maximum isometric push/pull strength for a single exertion[20]. The risk of developing musculoskeletal disorders increases when exerted forces on a working day approximate the maximum strength and exceed the maximum acceptable forces. According to van Wely[21], dynamic effort of a repetitive nature should not exceed 30% of the maximum value, although it may rise to 50% as long as the effort is not prolonged for more than 5 min.

In order to achieve enhanced performance and efficiency of human-machine system along with better comfort and safety of operators, it is necessary to design various controls on tractors with due consideration to strength data of Indian male agricultural workers. Therefore, this paper presents the data on strength

Table 1. Maximum actuating forces required to operate tractor controls as per IS 10703[8] and ASABE S 365.8[18]

S. No.	Device to be operated	Type of control	Maximum actuating force to operate control (N)		Note
			IS 10703[8]	ASABE S365.8[18]	
1.	Service brake	Pedal	600	600	Push
		Hand lever	400	400	Pull
2.	Parking brake	Pedal	600	600	Push
		Hand lever	400	400	Pull
3.	Clutch	Pedal	350	—	Push
4.	Power take off coupling	Pedal	300	—	Push
		Hand lever	200	—	Pull
5.	Manual steering system	Steering wheel	250	—	For 12 m turning radius
6.	Hydraulic power lift system	Hand lever	70	—	Push and pull
7.	Differential lock	Pedal	600	—	Push
		Hand lever	400		Pull

Table 2. Maximum control actuating force for tractor and self-propelled machinery as per ISO 15077[19]

S. No	Type of control	Maximum force (N)
1.	Lever fore/aft	230
	Lever lateral	100
	Lever vertical upwards	400
2.	Pedal-leg/foot operation	450
3.	Pedal-ankle rotation	90
4.	Finger/wrist operation	20

parameters of Indian male agricultural workers and recommends the maximum control actuating forces for normal operation of tractors based on strength capability of Indian agricultural workers. The findings of the study will help the Bureau of Indian Standards to revise IS 10703[8] standard.

Subjects and Methods

A detailed action plan was worked out for collection of strength data on male agricultural workers of India by the All India Coordinated Research Project (AICRP) on Ergonomics and Safety in Agriculture (ESA) located at the Central Institute of Agricultural Engineering (CIAE), Bhopal[22]. It included identification of strength parameters useful in farm equipment design, finalization of methodology for data collection through cooperating centres of AICRP on ESA and Adhoc research schemes of State Agricultural Universities and compilation of data at CIAE, Bhopal. Keeping into consideration of the design requirements of hand tools, animal drawn equipment, tractors, power tillers, power operated machines, self propelled machines and workplaces, a total of 16 human strength parameters were identified for the survey. The calculation of sample size for the survey and experimental protocol and procedure used in the study to measure strength parameters for recommending the maximum control actuating forces for normal operation of tractors are as follows.

Sample size

It is generally considered that the strength is positively correlated to body weight. The representative sample size for strength survey of Indian male agricultural workers can be calculated from the following Roebuck *et al*.[23] equation which is based on body weight.

$$n = \left(\frac{K \times SD}{d} \right)^2 \quad (1)$$

where, n = sample size

SD = estimated standard deviation of the data

d = desired accuracy of the measurement (± d units), and

K = a value chosen for the statistics of interest (it is 4.14 for 5th and 95th percentile statistics).

The standard deviation (SD) can be estimated from the range by formula given by Raghavrao[24] as follows.

$$SD = \sqrt{\frac{(Range)^2}{36}} \quad (2)$$

The weight of Indian male agricultural workers varies from 45 to 85 kg. Thus, the range for the sample survey will be 40 kg. The calculated value of standard deviation (SD) using Eq (2) for weight range of 40 kg is 6.67 kg. The desired accuracy of measurement (d) in such a survey can be taken as 0.5 kg for measurement of weight. Substituting the values of K, SD and d

Table 3. Strength data collection of male agricultural workers under AICRP on ESA[25)]

Sl. No.	State	Centre	No. of subjects surveyed
1	Gujarat	GAU, Junagarh	75
2	Jammu & Kashmir	CAU, Sopore	485
3	Madhya Pradesh	CIAE, Bhopal	825
4	Maharashtra	KKV, Dapoli	649
		MAU, Parbhani	600
5	Orissa	OUAT, Bhubaneswar	171
6	Tamil Nadu	TNAU, Coimbatore	618
Total			3,423

in Eq (1), we get the sample size as 3,050. Thus, this will be the minimum sample size required for conducting strength survey.

Subjects

The strength data on 16 parameters were collected for 3,423 Indian male agricultural workers from different communities including tribal populations from 6 states of India (Table 3) by cooperating centres and centres of adhoc research schemes located in State Agricultural Universities/Research Organisations located all over the country[25)]. The subjects were randomly selected from the healthy agricultural workers in the age group of 17–65 yr. All the subjects were free from physical abnormalities and were in good health. The strength data were collected on 3,423 Indian male agricultural workers and survey sample size exceeded the minimum sample size required for representative data. Also, as the data collection centres were located in different states of the country, the data can be considered as representative data of Indian male agricultural workers.

Strength measurement set up

The strength measurement set-up (Fig. 1) developed at the Central Institute of Agricultural Engineering, Bhopal for measuring 14 human strength parameters useful for the design of agricultural machinery was used in the study. The setup for measurement of strength data mainly consisted of a wooden platform on which two vertical posts of mild steel pipes were bolted. Another vertical post made of mild steel box section and having the same height as the circular posts was erected between the posts. Two braces made of mild steel angle iron supported the vertical posts from the rear. A height adjustable horizontal bar made of box section was provided to slide over the circular posts with the help of two collars welded to the bar. A slot was provided on the front side of the horizontal bar to mount the load cell assembly with the help of two nuts and bolts. The load cell assembly could be shifted laterally by sliding the bolts in the slot. The load cell

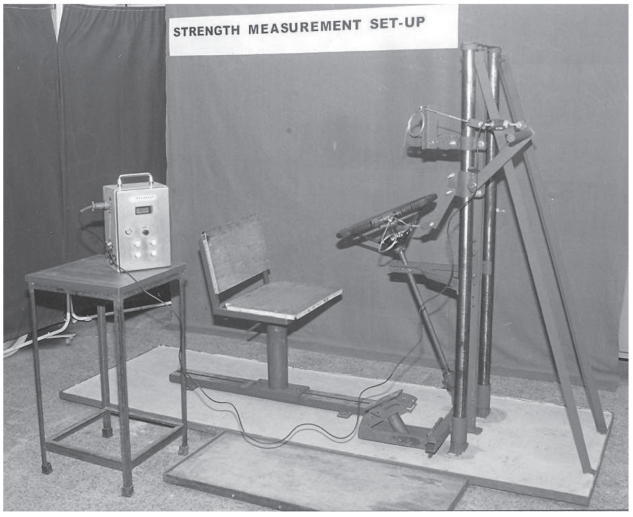


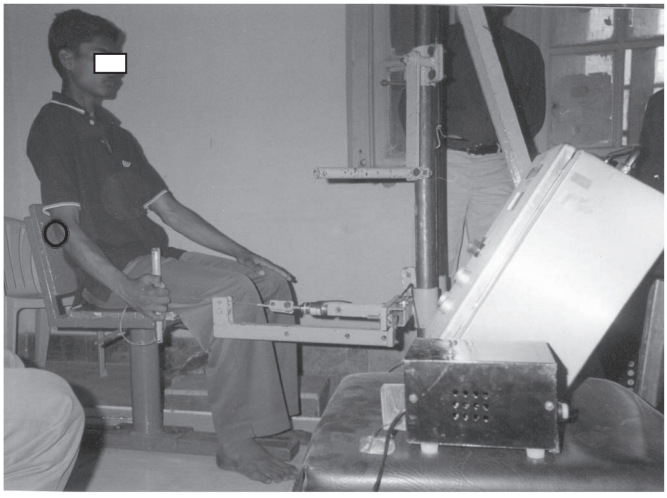
Fig. 1. Set up for measurement of strength parameters of agricultural workers.

assembly was provided with a pulley at its extreme end. The load cell was mounted between two wire ropes, the first of which had an end fixed to the horizontal bar, and the second was anchored to a handle at the other end. Turning the second wire rope around the end pulley could reverse the direction of force application to make it a push force. A Novatech load cell (1 kN) of the tension and compression type with a digital load indicator was used for measuring the strength data of the subjects. A wooden seat designed on the basis of anthropometric dimensions of Indian male agricultural workers was provided for strength measurement in sitting posture. This seat had provisions for its vertical and horizontal adjustments. The position of foot pedal in the set up could be adjusted up to 1,100 mm in front of seat reference point (SRP) and 570 mm below SRP. The set-up was portable and could be dismantled into different components for easy transport from place to place.

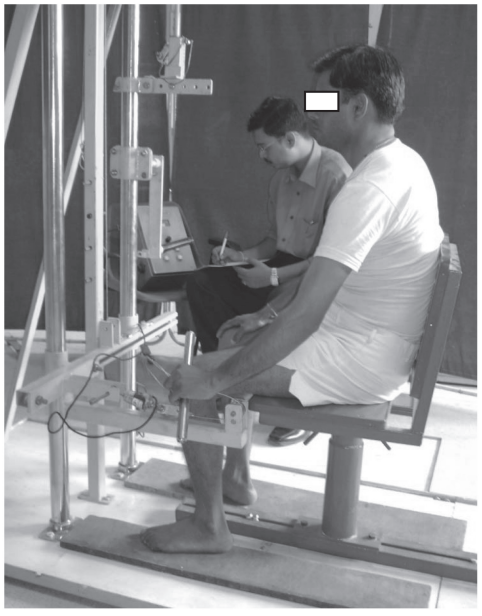
Experimental protocol and procedure

The strength parameters measured on the strength

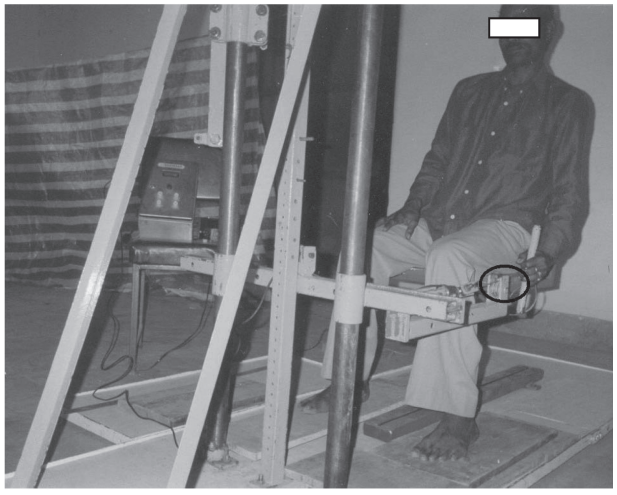
(a) Push strength (right hand)



(b) Pull strength (right hand)



(c) Push strength (left hand)

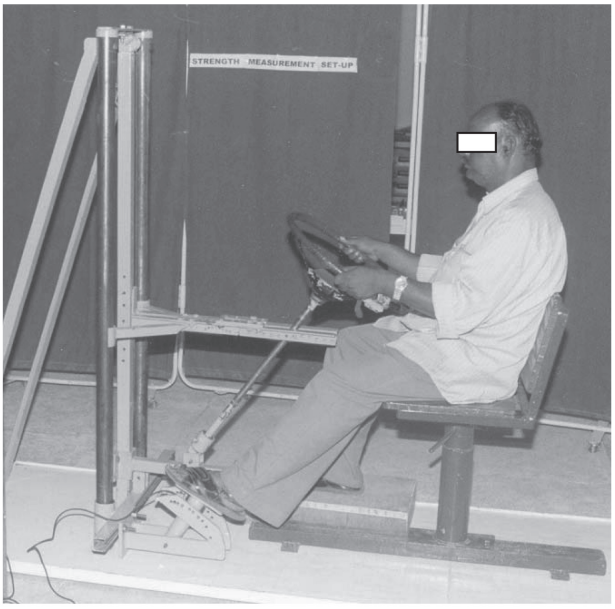


(d) Pull strength (left hand)

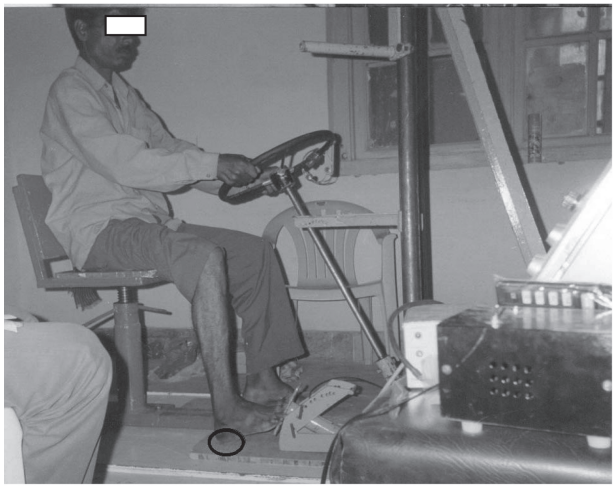
Fig. 2. Measurement of push/pull (left and right hand) strength parameters in sitting posture for deciding maximum control actuating force of tractor operators.

measurement set-up and used in the study were push and pull strengths by one hand (left and right) in sitting posture, leg strength (left and right) and foot strength in sitting posture and steering force which a seated operator can apply on a steering wheel of 420 mm diameter with both hands in clock-wise or anti clock-wise direction. Adequate training was given to field investigators for collection of strength data. The subjects were instructed to apply their maximum push/pull force with right/left hand on the load cell at seat height in the horizontal plane while sitting on an anthropometric seat without jerks to measure push/pull strength (right/left) sitting (Fig. 2). The leg strength (left/right) sitting was measured by application of the maximum force by the left/right leg on the load cell while the subject sat erect on an anthropometric seat with his knee flexed

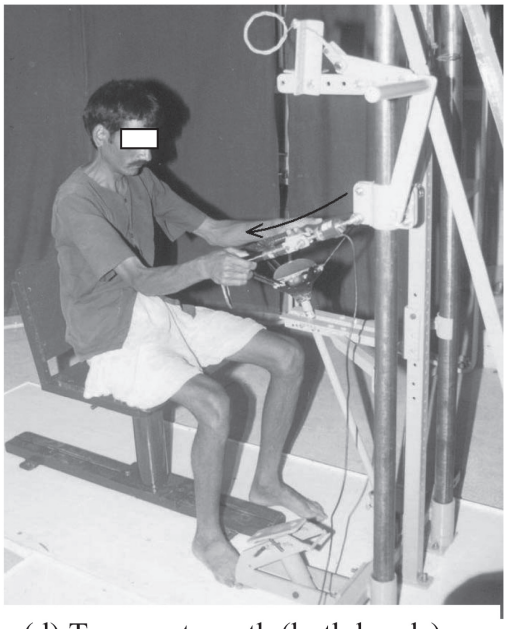
(a) Leg strength (right)



(b) Leg strength (left)



(c) Foot strength (right)



(d) Torque strength (both hands)

Fig. 3. Measurement of leg, foot and torque strength parameters in sitting posture for deciding maximum control actuating force of tractor operators.

at an angle between 90–110° (Figs. 3a, 3b). The foot strength (right) sitting was measured by application of the maximum force by the right foot on the load cell while keeping the heel as fulcrum and the subject sat straight on an anthropometric seat with his knee flexed at an angle between 90–110° (Fig. 3c). The torque strength (both hands) sitting was measured by application of maximum grip torque by both hands in inclined plane on steering wheel in sitting posture (Fig. 3d).

As per the protocol for strength data collection, each subject applied his maximum hand/foot/leg strength on the steering wheel/handle bar/foot pedal within first 2 s and then maintained it for next 3 s[26] while holding the steering wheel and getting support from the backrest. The average value of the strength parameter during the last three seconds of 5 s trial was taken for analysis. During a preliminary trial, it was observed that some stimulus in the form of sound was required to apply

Table 4. Strength data of Indian male agricultural workers used for recommending maximum tractor control actuating forces (N=3,423)[25)]

Sl. No.	Body Dimensions	Descriptive Statistics			
		Mean	SD	5th Percentile	95th Percentile
1	Age, yr	34.0	10.2	17.3	50.7
2	Weight, kg	54.7	8.7	40.4	68.9
3	Stature, mm	1,633	68	1,521	1,746
4	Push strength (right hand) sitting, N	77	17	49	106
5	Pull strength (right hand) sitting, N	92	19	60	123
6	Push strength (left hand) sitting, N	74	17	46	101
7	Pull strength (left hand) sitting, N	88	19	56	119
8	Foot strength (right) sitting, N	332	103	163	501
9	Leg strength (left) sitting, N	425	108	247	604
10	Leg strength (right) sitting, N	429	103	261	598
11	Torque strength* (both hands) sitting, Nm	60 (287)	15 (71)	36 (171)	85 (403)

*Data in parentheses are force values in N, lever arm length is 0.21 m.

the maximum leg/hand/foot strength for the desired time duration. Therefore, an electronic timer alarm of a 5 s duration was used to guide the subjects during force application. The subject was asked to release the applied force on the pedal as soon as the alarm stopped after 5 s. A rest of 2 min was given in between two successive trials and three such trials were done to get strength data for a particular treatment.

Results and Discussion

Indian tractors are mainly operated by male agricultural workers of the country. Therefore, strength data on eight parameters of 3,423 male agricultural workers were compiled and used to recommend maximum control actuating forces required for operating tractor controls. The strength data were analysed to calculate the mean, standard deviation (SD), and 5th (mean – 1.645 * SD) and 95th (mean + 1.645 * SD) percentile values and the values for the selected parameters useful for deciding maximum control actuating forces for tractors are reported in Table 4. The approach for recommending limits for maximum control actuating force for operation of tractor controls/levers for Indian operators is as follows.

Brake pedals

Operating a brake or clutch pedal of a tractor requires the driver to exert a force so as to move the pedal at prescribed distance along its axis of travel. In accordance with the generally accepted practice, tractor brake pedals are usually operated with the right leg and forces required in actuating these are quite high. The 5th percentile value of right leg strength (Fig. 3a) of Indian male agricultural workers is taken for design of brake pedals which is equal to 261 N (≈ 260 N). The Indian standard IS 10703[8)] and ASABE S365.8[18)] recommend that the maximum actuating force to operate tractor brake pedal should not exceed 600 N (Table 1). However, based on 5th percentile value of right leg strength of Indian male agricultural workers, the maximum actuating force for normal operation of brake pedals of Indian tractors should be less than 260 N. The majority of tractor accidents especially the collision happening on roadside is because of inability of the operator to generate the required pedal force for the operation of the brake pedal. Further, due to forward movement of brake pedal while being actuated, the operator loosens the support of backrest while trying to reach the brake pedal in compressed conditions. Under such circumstances it becomes difficult for the operator to generate the required actuating force.

Clutch pedal

The clutch pedal is used even more frequently than the brake pedals. This is a left leg operated control. The force necessary for the operation of clutch pedal on a tractor is usually lower than that required for brake pedals. The Indian standard IS 10703[8)] recommends that the maximum actuating force to operate tractor clutch pedal should not exceed 350 N. The ISO 15077[19)] recommends that maximum control actuating force for leg/foot operated pedal should not exceed 450 N. The 5th percentile value of left leg strength sitting (Fig. 3b) of Indian male agricultural workers is taken for design purpose which is equal to 247 N (Table 4). van Wely[21)] recommended that the dynamic effort of a repetitive nature should not exceed 30% of

the maximum value although it might increase to 50% as long as the effort was not prolonged for more than 5 min. Since the effort required during clutch operation on a tractor is not prolonged for more than 5 min, 50% of the 5th percentile value of left leg strength may be taken as limit for design purpose which is equal to 124 N (≈ 125 N). It may be concluded that the maximum actuating force for normal operation of clutch pedal should be less than 125 N.

Accelerator pedal

The accelerator pedal of a tractor moves in such a direction that the vibrations induced by driving over obstacles will not cause the foot and pedal to shake and vibrate. Otherwise, the engine speed will not remain steady. This can be completely prevented by allowing the heel of the foot to rest on a steady support. The accelerator pedal is a continuously operated control and has a great significance for accurate regulation of engine speed. If the pedal pressure is too high, the energy required to continuously operate the pedal will be excessive. The ISO 15077[19] recommends that maximum control actuating force for operating tractor pedal with ankle rotation should not exceed 90 N. van Wely[21] recommended that dynamic effort of a repetitive nature should not exceed 30% of the maximum value. Tiwari *et al.*[17] also recommended that force requirement should not exceed 30% of the 5th percentile strength value for agricultural activities of repetitive nature. The 5th percentile value of right foot strength (Fig. 3c) of Indian male agricultural worker is 163 N (Table 4). Since the accelerator pedal is continuously used on a tractor, we take 30% of the 5th percentile value of right foot strength for design purpose which is equal to 49 N (≈ 50 N). It may be concluded that the maximum actuating force for operation of accelerator pedal should not exceed 50 N. The weight of leg is about 9% of total body weight and 50% of this is supported at the heel. The remaining 50% of leg weight rests on accelerator pedal. For an Indian male agricultural worker with mean body weight of 54.7 kg, the weight supported by accelerator pedal comes to about 24 N. Therefore, the force required during accelerator pedal operation in a tractor should not be less than 24 N to avoid its undesired operation. Thus, the accelerator pedal of a tractor should be designed in such a way that the minimum force required for its operation is more than 24 N and less than 50 N.

Steering wheel

The steering wheel is a frequently operated hand control and used to transmit steering forces and to support the body of the operator. The Indian standard IS 10703[8] recommends that the maximum actuating force to operate tractor steering system should not exceed 250 N. Table 4 shows that the 5th percentile value of torque strength (both hands) sitting of Indian male agricultural worker is 36 Nm (force 171 N with lever arm length of 0.21 m) (Fig. 3d). The operation of tractor steering is of a repetitive nature, we take 30% of 5th percentile value of this strength as the limit of maximum actuating force based on the recommendation of van Wely[21] which is equal to 51 N. Therefore, the maximum actuating force required in steering wheel operation should be less than 51 N.

Gear selection/speed selection lever

According to Dupuis[27], the gearshift lever is the most frequently used tractor control lever. Therefore, the control should be located close to steering wheel in order to minimize the time for hand movements and prevent excessive movements of the body, as in all such functions energy is consumed. The ISO 15077[19] recommends that maximum control actuating force for operating tractor lever fore/aft and lateral should not exceed 230 and 100 N, respectively. The lowest 5th percentile value of push strength (right hand), push strength (left hand), pull strength (right hand) and pull strength (left hand) in sitting posture (Fig. 2) should be taken as the limiting force for operation of gear shift lever/speed selection lever on a tractor. The lowest 5th percentile hand strength value for male Indian agricultural workers is 46 N for push strength (left hand) sitting. Therefore, the desirable force required for operation of gear selection lever/speed selection lever on a tractor should not exceed 46 N.

Hydraulic control levers

The hydraulic control levers are frequently operated levers and are preferably placed to the right of the operator's seat. Therefore, these controls should be located in optimum area. As the effort required to operate hydraulic control levers is not prolonged for more than 5 min, the 50% of 5th percentile value of right hand push/pull strength sitting (Figs. 2a, 2b) may be taken as the limiting force for operation of hydraulic control levers on a tractor which is equal to 25 N. Therefore, the force required for operation of hydraulic control levers on a tractor should not exceed 25 N.

Hand throttle lever

It is usually fitted on right hand side of the steering column. The ISO 15077[19] recommends that maximum control actuating force for operating tractor lever fore/aft should not exceed 230 N. As the effort required to operate hand throttle lever is not prolonged for more

than 5 min, the 50% of 5th percentile value of right hand push/pull strength sitting (Figs. 2a, 2b) may be taken as the limiting force for operation of hand throttle lever on a tractor. The 5th percentile values of right hand push strength and left hand pull strength sitting of Indian male agricultural workers are 49 N and 60 N, respectively. Therefore, based on the lower 5th percentile value of 49 N for right hand push strength sitting, the force required for operation of hand throttle lever on a tractor should not exceed 25 N.

PTO lever

The PTO engaging lever is infrequently operated hand control. It is moved upward and/or forward to engage and downward or rearward to disengage. Therefore, it may be located either in optimum area or in limiting area. It is to be operated using power grip and pull force is applied for its operation. The Indian standard IS 10703[8] recommends that the maximum actuating force to operate tractor PTO coupling should not exceed 200 N. The ISO 15077[19] recommends that maximum control actuating force for operating tractor lever fore/aft and vertical should not exceed 230 and 400 N, respectively. The 5th percentile value of right hand pull strength sitting (Fig. 2b) may be taken as the limiting force for operation of infrequently operated PTO lever on a tractor which is equal to 60 N. Therefore, the force required for operation of this lever should not be more than 60 N.

Parking brake lever

The parking brake lever is infrequently operated arm activation control. Therefore, it may be located either in optimum area or in limiting area. The Indian standard IS 10703[8] and ASABE S 365.8[18] recommend that the maximum actuating force to operate tractor parking brake lever should not exceed 400 N (Table 1). The 5th percentile value of right hand pull strength sitting (Fig. 2b) may be taken as the limiting force for operation of parking brake lever on a tractor which is equal to 60 N. Therefore, the force required for operation of this lever should not be more than 60 N.

Differential lock lever

It is a heel operated control and shall be moved downward for engagement. The Indian standard IS 10703[8] recommends that the maximum actuating force to operate tractor differential lock should not exceed 600 N. The ISO 15077[19] recommends that maximum control actuating force for operating tractor pedal with ankle rotation should not exceed 90 N. The 5th percentile value of right leg strength sitting (Fig. 3a) of Indian male agricultural workers is 261 N. The 50% of this value is taken for design purpose which is equal to 130 N as the effort required to operate differential lock lever is not prolonged for more than 5 min. Therefore, force required to operate differential lock lever should not exceed 130 N.

The limits of maximum actuating forces for operating tractor controls based on strength data of 3,423 Indian male agricultural workers are compared with recommendation of Bureau of Indian Standards IS 10703[8] and are reported in Table 5. Table 5 shows that the maximum actuating force limits as given in IS 10703[8] are very high as compared to strength data of Indian operators. Similar findings were reported by Fathallah *et al.*[12]

Table 5. Recommendations on maximum actuating forces for tractor controls based on strength data of male agricultural workers

S No.	Controls	Type of control	Force applied	Maximum operating force, N	
				IS 10703[8]	Recommendations
1.	Clutch	Pedal	Push	350	125
2.	Service brakes	Combined pedal	Push	600	260
	L HS	Pedal	Push		
	R HS	Pedal	Push		
3.	Parking brake	Hand lever	Pull	400	50
4.	PTO coupling	Hand lever	Pull	200	60
5.	Steering	Wheel	Torque	250	51
6.	Hydraulic controls				
	Position	Hand lever	Pull	70	25
	Draft		Pull		
7.	Hand accelerator	Hand lever	Pull	—	25
8.	Foot accelerator	Pedal	Push	—	more than 24 N and less than 50 N
9.	Gear selection lever	Hand lever	Pull & Push	—	46
10.	Speed selection lever	Hand lever	Pull & Push	—	46
11.	Differential lock pedal	Pedal	Push	600	150

for US young tractor operators. It highlights the need to revise Bureau of Indian Standards IS 10703[8] on the basis of the findings of the study. The study will ultimately lead to better design of controls on tractors based on strength capabilities of operators.

Conclusions

The maximum control actuating forces for normal operation of tractor controls based on strength capability of 3,423 Indian male agricultural workers were recommended and compared with IS 10703[8], ASABE S 365.8[18] and ISO 15077[19] standards. It was observed that the maximum actuating forces for normal operation of frequently operated brake and clutch pedals of tractors should be less than 260 N and 125 N based on 5th percentile values of right and left leg strength of Indian male agricultural workers, respectively. It was also concluded that the accelerator pedal of a tractor should be designed in such a way that the minimum force required for its operation is more than 24 N and should not exceed 50 N. The maximum actuating force required in steering wheel operation should not exceed 51 N based on 5th percentile value of torque strength (both hands) sitting of Indian male agricultural workers. The maximum actuating force required for operating frequently operated levers viz. gear selection, speed selection, hydraulic control and hand throttle of Indian tractors should not exceed 46 N, 46 N, 25 N and 25 N, respectively. The 5th percentile value of right hand pull strength sitting was taken as the limiting force for operation of infrequently operated PTO lever and parking brake lever on a tractor and should not exceed 60 N. The findings of the study highlighted the need to revise the recommendations of Bureau of Indian Standards IS 10703[8] on maximum actuating force to operate tractor.

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