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Human centric operator seat of tractor and other self propelled agricultural machinery: A review

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Abstract

Anthropometry is of paramount importance in the design and development of Human Centric Workplace's (HCWs) for tractors and other self-propelled agricultural machinery, as these machines are operated by the human. In order to enhance the human-machine interface the concept of HCWs design and development involve creating a functional, efficient, and comfortable environment for the operator. The primary goal of the HCWs is to increase operator safety and productivity while reducing physical as well as psychological fatigue and the risk of accident. The HCWs design involves dimensions and location of different component at workplace, design and dimensions of operator's seat, provision of seat adjustability, placement of various controls, ease of operation, requirement of activation force etc. In this paper focuses on review of existing paper as well as suggested the design value of the operator's seat with gender neutral prospects based on the anthropometric data of the Indian user's population.

Keywords: Tractor operator workplace, operator seat, anthropometry

Introduction

The act of driving a tractor and other self propelled agricultural machinery places considerable physical and mental strain on the operator. In instances where the operator's seat lacks comfort, there is a decline in work performance, alongside an increased likelihood of accidents Potdar 2020 ^[30]; Mehta *et al.*, (2008) ^[23]. The operator's seat is a key component of the operator's workplace and it plays a crucial role in the operator's prolonged sitting. Therefore the operator seat should be such that it allows the operator to change his/her position from time to time to relieve pressure and to rotate muscle groups under tension. Tiwari and Prasad (2000) ^[36]; Shao and Zhou (1990) ^[33] Moreover, the seat position should be adjustable longitudinally as well as vertically, Because, adjustability is critical for operators to comfortably reach pedals and other controls, maintain a clear field of vision, and a neutral body posture. Mehta *et al.*, (2008) ^[23]; Bottoms (1978) ^[4] Moreover, adjusting the seat will prove to be more effective and easier than adjusting the controls to accommodate the physiology of tractor operators from the 5th to the 95th percentile Yadav *et al.*, (2000) ^[40]; Yadav and Tewari (1998) ^[38] and its adjustment provisions ought to be independent of each other. Such an adjustment ought to be possible without the use of any tools IS12343 (2021); ISO4253 (1993). It was felt that the seat should be designed in such a way that, in

both forward and backward sitting postures, it provides support to the upper edge of the pelvis Yadav *et al.*, (2000) ^[40]; Grandjean (1988) furthermore, the backrest angle is closely related to the lumbar support, The seat design should be such that it is easy for the operator to get on and off the tractor and allows easy and seamless access to all the controls Yadav and Tewari (1998) ^[39]. The seat pan concavity and operator's weight significantly affects the pressure distribution on the seat pan-subject interface. The back-rest concavity and inclination significantly affect pressure distribution on operator back-rest Dhingra *et al.*, (2003) ^[9]. The efficiency and comfort of operator can improved with properly design operator workplace Pheasant and Harris (1982) ^[27]; Huang and Suggs (1967); Bottoms (1973) ^[3] and Lehmann (1958) ^[19] If the operator's workplace is not properly adapted to his anthropometry, the performance demand for long-duration work may result in excessive discomfort, premature fatigue, locomotor system problems, and the possibility of events of accidents may increase Shukla *et al.*, (2021) ^[34]; Yadav *et al.*, (2017) ^[13]; Mehta *et al.*, (2007) ^[24] and Duppis (1959). Women are playing a significant role in development of agricultural and allied sectors. In India about 70% of female workers are employed in agriculture and they are responsible for 60-80% of food production (Chaturvedi *et al.*, 2023) ^[5]. The role of female workers is shifting from a source of power to

controller of various powered machines and self-propelled machinery (Potdar *et al.*, 2022; Shukla *et al.*, 2022) ^[30, 35] due to the migration of male workers to urban areas for better livelihood opportunities. Moreover, It is expected that many female workers will be operating tractors in the near future. Therefore, it is necessary to consider the limits and capacities of both genders during the design process of various farm machinery such as Tractor and self-propelled machinery as gender empowerment. Generally, tractors are designed based on factors important to male, but gendered design considerations can increase their use by female workers (ESCAP, U. 2022; Vemireddy, V. and Choudhary, A. 2021) ^[11, 1]. For instance, considering female's ergonomic needs and ensuring ease of use can lead to further adoption by female agricultural worker. This approach not only empowers women by making farm machinery more accessible but also enhances overall productivity in agricultural practices. By incorporating anthropometric data of female workers, it is required that better serve the diverse needs of all farmers.

Operator's seat is a key component of the operator's workplace and has a major impact on its long-duration work. The operator's seat is not only providing a seating space to the operator but also providing the bottom and back support to the operator. Seat adjustability play key role in comfort of operator so as to allow the operator to change his/her position in order to relieve pressure underside of the thigh and rotate muscle group under tension, generate a correct visibility at front and back for the operator to accomplish tasks, the various studies were conducted on operator seat with different aspects such as Matthew and Knight (1971); Zander, (1972) ^[41]; Grandjean, (1982); Donati *et al.*, (1984) ^[10]; Shao and Zhou., (1990) ^[33]; Tewari and Prasad, (2000) ^[36]; Pheasant and Huslegrave (2006) ^[28]; Mehta *et al.*, (2008) ^[23]; Jain *et al.*, (2008) ^[15]; Sander and McCormick (2013); Nag and Gite, (2020) ^[25]; Shukla (2021) ^[35]; Chandra *et al.*, (2022) ^[6]; and gets some important findings, and they were suggested and recommended the different technical requirement of operator seat of tractor and other self propelled agricultural machinery. In 1971 Matthew and Knight stated that seat height is the most important factor in seat design for determining the level of comfort. If the seat height and length are too high, smaller operators may not be able to reach the foot-operated controls and may lose support from the backrest. They concluded that effective support from the backrest, seat height, and seat length should correspond to the anthropometric dimensions of the user population. Zander, (1972) ^[41] concluded that the operator's seat is a key component of the operator's workplace and significantly impacts long-duration work. The seat not only provides a sitting space for the operator but also allows the use of both hands and feet for operating controls, while maintaining a comfortable seating posture. In 1982 Grandjean recommended that operator seats should be designed to provide proper support to the upper edge of the pelvis in both forward and backward sitting postures. To accommodate both larger and smaller tractor operators, suitable seat adjustments should be provided. It is easier to adjust the seat than to adjust the controls; however, some compromises between hand and foot controls may be necessary. He concluded that applying ergonomic principles

in machinery design helps improve operator productivity and quality of life by reducing both physical and psychological stress in the workplace.

In 1984 an experimental study conducted by (Donati, 1984) ^[10] on operator seats to measure postural comfort and other factors affecting operator comfort under both static and dynamic conditions. In this investigation, four tractors were used. Based on the results of various subjective analyses, he concluded that subjects can reliably differentiate between levels of seat comfort. He suggested that the height of the backrest appears to be the most important single factor contributing to overall comfort. Shao and Zhou (1990) ^[33] described the design principles of the operator's seat and static comfort from an ergonomic perspective. They emphasized that lumbar support plays a crucial role in ride comfort, and the backrest angle is closely related to lumbar support; therefore, this angle should be within the range of 105° to 115°. They concluded that the operator's seat position should be adjustable both vertically and longitudinally. It must allow the operator to shift positions from time to time to relieve pressure and rotate muscle groups under tension. In the year 2000 an experimental study was conducted by (Tewari and Prasad 2000) ^[36] on tractor seats to evaluate operator safety and comfort using a setup that measured the pressure distribution on the seat pan and backrest of the tractor seat. Anthropometric data of n=2,726 Indian males aged 17 to 45, collected by IIT Kharagpur, were used to represent the user population. These data closely matched the physical dimensions of the three subjects who participated in the study. Four different seat pans and backrests with radius of curvature were tested, along with three backrest inclination angles. The experimental results indicated that these parameters significantly affected pressure distribution. Pheasant and Huslegrave (2006) ^[28] emphasized the constraints and criteria of seat design. They stated that it is a common practice to use the 5th percentile female and the 95th percentile male values as the lower and upper design limits, respectively, for a mixed user population. However, in such cases, there is a high possibility that a 95th percentile male might feel uncomfortably cramped in a seat designed to accommodate a 5th percentile female. They provided seat design principles based on human-centric approaches, considering user diversity and task requirements. Mehta *et al.*, (2008) ^[23] emphasized the importance of considering the anthropometric data of the targeted user population in the design of the operator's seat. They provided seating dimensions for Indian male users based on the 5th and 95th percentile values of anthropometric data of (n=5434) male agricultural workers. In 2008 experimental tests were conducted on eight popular Indian tractors and five operator seats by (Jain *et al.*, 2008) ^[15]. They observed that, seat pan width and backrest width were found to be 10.9 percent and 20.4% less, respectively, while seat height was found to be 15.3 percent in excess compared to recommended values. The vertical seat adjustment was not provided in most of the seats. This lack of adjustability may affect hand and leg reach as well as the maximum actuating force required by tractor operators to operate frequently used controls like the clutch, brake, accelerator pedal, and steering wheel. Sander and McCormick (2013) used the 5th, 50th, and 95th percentile values of anthropometric data from the U.S.

civilian population, aged between 20 and 60 years. They recommended that the seat height should be lower than the 5th percentile value of popliteal height (sitting), and the seat width should be greater than the 95th percentile value of elbow-to-elbow breadth. They concluded that the backrest width should be wider in the lumbar region, and lumbar support should protrude about 50 mm forward from the back of the seat. They further emphasized that workplace design-including the work envelope, seating, and location of controls-must be based on anthropometric data to ensure comfort, safety, and efficiency. In 2016 a study was conducted by Daeijavad and Maleki, 2016^[7] on seat angles for achieving the correct posture of tractor operators. In this study, the Finite Element Method (FEM) was used to determine the appropriate angles of the operator's seat. Various backrest and seat-pan angles were simulated using ABAQUS software. Based on their analysis, they observed that the average effects of the backrest and seat-pan angles were significant at the 5 percent level. The optimal contact point for body-seat interaction should be considered during design. They also stated that improper or poorly designed tractor seats may lead to operator discomfort, thereby increasing operational difficulty and the risk of accidents. Nag and Gite (2020)^[25] stated that the operator's seat is a critical component that influences both the efficiency and well-being of the operator. They recommended that 5th and 95th percentile values should be used for determining seating dimensions such as seat length, width, height, seat pan tilt angle, backrest width, height, and inclination. They concluded that the seat height should be lower than the distance from the workplace platform to the underside of the thigh. Shukla (2021)^[35] concluded that the operator's seat is a crucial component of the operator's workplace and significantly affects performance during long-duration work. The seat not only provides a place for the operator to

sit but also enables the use of both hands and feet for operating controls, while ensuring a comfortable seating posture. He emphasized that special attention must be given to operator safety, comfort, and convenience during seat design. If the operator's seat is not properly integrated with his anthropometric dimensions, the physical demands of prolonged work may lead to excessive discomfort and reduced performance. Chandra *et al.*, (2022)^[6] conducted an ergonomic assessment of n = 55 male tractor operators from the Meerut division of Uttar Pradesh, aged between 26 and 50 years, to assist in the design of tractor seats based on the 5th and 95th percentile values of nine different anthropometric parameters. They concluded that proper consideration of anthropometric dimensions in seat design enables operators to perform tasks with greater efficiency, improved safety, and reduced fatigue.

The summary of operator seating dimensions given by various researchers are presented in the table.1 and these are compared with International Standard ISO 4253 (1993) and National standard IS 12343 (2021) standards. The table.1 shows that there is a variation in recommendations for seating dimensions by various researchers. This may be due to variation in anthropometric dimensions of the user population. However, the Bureau of Indian standard adopted International Standard as such. Moreover, The ISO standard is primarily based on the anthropometric data of Western/European countries workers. IS 12343(2021) the technical requirement of operator seat in agricultural tractors (second revision). In this second revision, all the dimensions related to the operator's seat except the functional mass for seat, have been taken from the International standard as such. However, the ISO standard is primarily based on the anthropometric data of Western countries' workers. Moreover, horizontal and vertical adjustability ranged have been taken based on male agricultural worker.

Table 1: Operator seat dimensions recommended by various researchers and scientists for operator comfort and safety. (All dimensions are in "mm" unless otherwise specified)

Particulars	C-I	C-II	C-III	C-IV	C-V	C-VI	C-VII	C-VIII
Seat Pan								
Length [#]	240	250-310	240-390	210-310	220-240	240	222	210-310
Width	450	≥ 450	≥ 400	> 450	420-450	430	456	> 450
Height [#]	490	--	470-490	450-520	520	470	490	450-520
Pan Tilt*	3-5	4.5-10	3-7	3-12	5-7	5-10	5-7	3-12
Seat Backrest								
Width (Top-Bottom)	(240-400)	(330-450)	400	450	(280-400)	(275-380)	(243-386)	450
Height [#]	150-310	333	--	> 260	260	310	310	> 260
Inclination**	93-95	>111	105-115	95-105	105-115	95-100	95-100	95-105
Seat Adjustability								
Horizontal	± 75	--	± 75	± 100	± 60	± 100	± 100	± 100
Vertical	± 50	--	± 30	± 50	± 50	± 50	± 50	± 50

Note: [#]dimensions w.r.t. Seat Index Point; T= Top; B= Bottom; *Seat pan tilt angle in degree w.r.t. horizontal plane; *Seat backrest inclination angle in degree w.r.t. horizontal plane; Seating dimensions given in Column; C-I= Zander, (1972)^[41]; C-II= Donati *et al.*, (1984)^[10]; C-III= Shao and Zhou., (1990)^[33]; C-IV=ISO4253(1993); C-V=Mehta *et al.*, (2008)^[23]; C-VI=Nag and Gite, (2020)^[25]; C-VII=Shukla (2021)^[35]; C-VIII=IS 12343 (2021) Seating dimensions recommended by Agricultural Machinery and Equipment Sectional Committee, Food and Agriculture Division 11.

Materials and Methods

Anthropometric data of Indian male and female agricultural workers

Anthropometry is the technology of measuring human traits such as size, mobility and strength, etc. Anthropometric data are initial data used in the design of Human centric

workplace. In India, numerous anthropometric studies have been carried out on Indian agricultural workers, by Sen *et al.*, 1977^[32]; Gupta *et al.*, 1983^[12]; Gite and Yadav, 1989; Dewangan *et al.*, 2005^[8]; Agrawal *et al.*, 2010^[1] and Gite *et al.*, (2020) compiled the anthropometric data on 79 body parameters of from Indian agricultural workers (n=14618)

from 15 states of India, under AICRP on ESAAS. They recommended that these 5th and 95th percentile values of anthropometric data could be used suitably for designing and developing agricultural tools, equipment, and operator workplaces for the Indian population involving ergonomic principles. Therefore, it is necessary to set the minimum, maximum and optimum dimensions as well as range of adjustment of operator seat w.r.t. SIP by application of anthropometric data of targeted population. Principally, the 5th percentile values of female worker represent the smaller operator or lower limit and 95th percentile values of male worker represent the large operator or upper limit, these limits were used to determine the dimensions of operator seat. The engineering anthropometry was applied to determine the dimension of seat pan, seat backrest seat handrest and seat headrest w.r.t. SIP, in the seated operator by using the some consideration from the methodology given by Mehta *et al.*, 2008^[23]; Tewari and Yadav 2000^[40], and the information available in various human factors literatures.

The relevant anthropometric data of Indian agricultural workers in sitting posture that were used for determine the dimensions of seat pan, seat backrest and seat handrest of operator seat are biacromial breadth sitting (BBS); Interscye breadth sitting (IBS); hip breadth sitting (HBS); buttock popliteal length (BPL); elbow-elbow breadth sitting (EEB); elbow rest height sitting (ERH); popliteal height sitting (PHS); interscye breadth (ISB); acromion height sitting (AHS); thigh circumference sitting (TCS); waist circumference sitting (WCS) and body weight, presented in table 2. The anthropometric data of Indian agricultural workers was collected by the 16 centres namely NERIST, Nirjuli (Arunachal Pradesh); GAU, Junagarh (Gujarat); CSKHPKV, Palampur (Himachal Pradesh); CAU, Sopore (Jammu and Kashmir); CIAE, Bhopal (Madhya Pradesh); KKV, Dapoli (Maharashtra); MAU, Parbhani (Maharashtra); ICAR Unit, Barapani (Meghalaya); NERIST Unit, (Mizoram); OUAT, Bhubaneswar (Odisha); PAU, Ludhiana (Punjab); MPUAT, Udaipur (Rajasthan); CAEPHT, Gangtok (Sikkim); TNAU, Coimbatore (Tamil Nadu); CAET, Etawah (Uttar Pradesh); IIT, Kharagpur (West Bengal) of all India coordinated research project (AICRP) on ergonomic and safety in agriculture and allied sectors (ESAAS) and the 5th, 50th and 95th percentile values of anthropometric data given by Nag and Gite, (2020)^[25] were used for the purpose of design of human centric operator seat. The different values of anthropometric

data were calculated by the following formulas.

Mean

It is the average of set of values, a central measure used in almost every field such as general body dimensions in engineering anthropometry, to represent typical values i.e. average body stature, or body weight and other anthropometric body dimensions

$$\mu = \frac{1}{n} \sum_{i=1}^n x_i$$

Where, μ = Mean, Σ = Summation, x_i = Observation, n = Total number of observations

Standard Deviation

It is a measure of how spreads out the values in a dataset are around the mean; it is used to quantify variability in the body dimensions. A high standard deviation indicates high variability.

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \mu)^2}$$

Where, σ = Standard deviation, μ = mean, Σ = summation, x_i = Observation, n= total number of observations

5th percentile

It is a measure that indicates the value of below which a fifth percentage of observations in the dataset fall. It means ninety fifth percentages of values are greater than or equal to this point.

$$5^{\text{th}}(P) = \text{Mean} - (1.645 \times SD)$$

95th percentile

It is a measure that indicates the value below which ninety fifth percentages of observations in the dataset fall. Only fifth percentages of values are greater than or equal to this value. It is a high end threshold, often used to identify unusually large values.

$$95^{\text{th}}(P) = \text{Mean} + (1.645 \times SD)$$

Table 2: Anthropometric data of Indian male and female agricultural workers prerequisite for operator seat design (Nag and Gite 2020)^[25]

Sl. No.	Particular	Male Agricultural Workers					Female Agricultural Workers				
	Body Dimensions	Mean	SD (±)	CV (%)	5 th (P)	95 th (P)	Mean	SD (±)	CV (%)	5 th (P)	95 th (P)
	Body weight, kg	55.1	9	0.163	42	71.5	47.8	8.9	0.186	35	65
	Biacromial breadth	332	45	0.136	273	420	296	36	0.122	246	360
	Interscye breadth	304	33	0.109	251	360	276	35	0.127	224	336
	Hip breadth sitting	303	29	0.096	259	352	291	32	0.110	240	342
	Elbow-elbow breadth sitting	379	49	0.129	305	465	358	45	0.126	288	440
	Elbow rest height sitting	216	34	0.157	167	276	211	30	0.142	161	261
	Acromion height sitting	569	46	0.081	500	641	532	41	0.077	470	599
	Popliteal height sitting	418	31	0.074	369	470	393	32	0.081	341	447
	Buttock-popliteal length	443	37	0.084	382	502	427	37	0.087	365	487
	Thigh circumference	443	49	0.111	362	520	416	58	0.139	325	510
	Waist circumference	772	88	0.114	650	940	736	95	0.129	605	911
	Shoulder grip length	720	58	0.081	625	814	667	54	0.081	570	750
	Functional leg length	977	63	0.064	880	1085	931	60	0.064	834	1027

Conclusion

Operator seat design for tractor and other self propelled agricultural machinery

Anthropometry is the initial data used to determine the geometric parameters of an operator seat. The anthropometric data of Indian male and female agricultural workers were used for design of operator seats based on anthropometric considerations. The seat characteristics that affect the operator's posture and static comfort are seat pan length (SPL); seat pan width (SPW); seat pan height (SPH); seat pan concavity (SPC); and seat pan tilt (SPT); seat backrest width (SBW); seat backrest height (SBH); seat backrest concavity (SBC); and seat backrest inclination (SBI); hand rest height (HRH); hand rest length (HRL); seat suspension system (SSS). The operator seat cushion and covering materials greatly affect the feeling of the operator and his well being in the seat. The relevant anthropometric parameters of Indian male and female agricultural workers compiled for operator seat design such as biacromial breadth sitting (BBS); hip breadth sitting (HBS), elbow-elbow breadth sitting (EEB); elbow rest height sitting (ERH); popliteal height sitting (PHS), buttock popliteal length (BPL), Interscye breadth (ISB) acromion height sitting (AHS); Thigh circumference sitting (TCS); Waist circumference sitting (WCS) and body weight. The geometric parameters of the operator seat for Indian user population were finalised based on anthropometric data compiled by the Gite *et al.* (2020), review of literature and by following relevant Indian standard IS 12343 (2021) and International Standard ISO 4253 (1993) standards. The seating dimension for Indian tractors and agricultural machinery are given in table 3. This accommodates maximum number of user population including female operators.

Seat Pan Length (SPL)

Seat pan length (SPL) refers to the horizontal distance parallel to the longitudinal plane of the tractor, measured from the front edge of the seat cushion to the vertical transverse plane. The SPL should neither be too long nor too short; it should allow the operator to use both hand- and foot-operated controls comfortably, with adequate thigh and backrest support. According to various researchers, the seat length should be less than the 5th percentile value of the buttock-popliteal length (BPL) of the user population. The 5th percentile BPL values for Indian female and male agricultural workers are 365 mm and 382 mm, respectively. Therefore, the recommended SPL is 375 ± 10 mm, which accommodates 95% of Indian agricultural workers.

Seat Pan Width (SPW)

Seat pan width (SPW) refers to the horizontal distance between the side edges of the seat cushion. To ensure operator comfort and allow convenient posture changes, it is recommended that the SPW be greater than the hip breadth. To design the SPW appropriately, the 95th percentile value of hip breadth while sitting (HBS) for the user population should be considered, along with an additional margin of ± 100 mm to accommodate posture changes. The 95th percentile HBS values for Indian female and male agricultural workers are 347 mm and 352 mm, respectively. Therefore, based on the anthropometric data of the user

population, the SPW should be ≥ 450 mm to accommodate 95% of Indian agricultural workers

Seat Pan Height (SPH)

Seat pan height (SPH) refers to the vertical distance from the upper edge of the seat cushion to the footrest. According to various researchers, The SPH should be less than the 5th percentile value of popliteal height while sitting (PHS) of the user population. The 5th percentile PHS values for Indian female and male agricultural workers are 342 mm and 369 mm, respectively. Therefore, based on the anthropometry of the user population, the minimum SPH for Indian tractors and other self-propelled agricultural machinery should be 355 ± 10 mm, including allowances for footwear. Additionally, the SPH should be adjustable to accommodate 95% of the Indian user population.

Seat pan concavity (SPC)

The seat pan concavity (SPC) refers to the inward curvature of seat surface where a operator sits, the function of SPC is improved weight distribution, pelvic stability, postural support as well as enhance the safety and comfort. It is recommended that the SPC be greater than the thigh circumference (TC). To design the SPC appropriately, the 95th percentile value of the TC for the user population should be considered, the 95th percentile TC values for Indian female and male agricultural workers are 510 mm and 520 mm, respectively. Therefore, based on the anthropometry of the user population and including a 100 mm margin for adequate support, the SPC should be 650 ± 50 mm for Indian user population

Seat Backrest Height (SBH)

Seat backrest height (SBH) refers to the vertical distance from the rear edge of the seat pan to the upper edge of the backrest. It is provided to support the upper part of the operator's body, allowing for better control and focus while operating tractors and other self-propelled agricultural machinery. According to various researchers, the SBH should be less than the 5th percentile value of acromion height while sitting (AHS) of the user population. The 5th percentile AHS values for Indian female and male agricultural workers are 470 mm and 500 mm, respectively. To allow free shoulder movement, approximately 100 mm should be subtracted from the AHS. Therefore, based on the anthropometry of the user population, the optimum SBH should be 380 ± 20 mm.

Seat Backrest Width (SBW)

Backrest width (SBW) refers to the horizontal distance between the outer edges of the seat backrest. It is provided to support the upper part of the operator's body, enhancing stability while operating tractors and other self-propelled agricultural machinery. According to various researchers, the BW should be greater than the 95th percentile value of hip breadth while sitting (HBS) of the user population. The 95th percentile HBS values for Indian female and male agricultural workers are 342 mm and 352 mm, respectively. Therefore, based on the anthropometry of the user population and including a 100 mm margin for adequate support, the optimum BW should be 450 ± 10 mm.

Seat backrest concavity (SBC)

The seat backrest concavity (SBC) refers to the rearward curvature of seat backrest where an operator takes back support while operation, the function of SBC is provided the lateral stability, postural alignment as well as it supports lumbar and thoracic region of spinal. It is recommended that the SBC be less than the waist circumference (WC). To design the SPC appropriately, the 5th percentile value of the WC for the user population should be considered, the 5th percentile WC values for Indian female and male agricultural workers are 605 mm and 650 mm, respectively. Therefore, the optimum range of SBC should be 625±25 mm for Indian user population.

Seat Adjustability-Vertically (SAV)

The vertical adjustability of the operator seat (SAV) is critical for enabling users to comfortably reach levers, pedals, and other controls, maintain a clear field of vision, and adopt a natural body posture. According to various researchers, the vertical adjustability should fall within the range of the 5th to the 95th percentile values of popliteal height while sitting (PHS) of the user population. For the Indian female and male user population, the 5th and 95th percentile PHS values are 341 mm and 470 mm, respectively, giving a total range of 129 mm. Therefore, the optimum vertical adjustability of the operator seat should be ±65 mm from its mid-position. This adjustment should be achievable without the use of tools. An adjustability range of ±65 mm will accommodate 95% of Indian tractor operators.

Seat Adjustability-Horizontally (SAH)

The horizontal adjustability of the operator seat (SAH) ensures proper reach to both hand- and foot-operated controls, enabling efficient and comfortable operation. This adjustability should fall within the range of the 5th to 95th percentile values of shoulder grip length (SGL) and functional leg length (FLL) of the user population while sitting. For Indian female and male agricultural workers, the 5th and 95th percentile values of SGL are 570 mm and 814 mm, respectively, and the 5th and 95th percentile values of FLL are 834 mm and 1085 mm, respectively. This results in an approximate difference of 250 mm in both dimensions. Therefore, the seat should be horizontally adjustable by ±125 mm from its mid-position. This adjustability should be achievable without the use of tools.

Seat Suspension Adjustability (SSA)

The seat suspension adjustability (SSA) is crucial in the design of operator seats for on/off-road vehicles. Its primary function is to reduce the transmission of vibration and shock from the vehicle to the operator's body. The SSA enhances safety and comfort while also minimizing the risk of lower back pain (LBP) and spinal disorder problems (SDP). Various types of suspension systems are used in on/off-road vehicles, including mechanical, pneumatic, hydraulic, and active suspensions. The range of adjustment, as a function of the operator's body mass, should be accordance to the 95th percentile values of the weight of user population along with an appropriate margin to account for population diversity. Moreover, the 5th and 95th percentile body weights of Indian female and male agricultural workers are 35 kg

and 71 kg respectively, the seat suspension system should therefore be adjustable within a range of 70 ± 30 kg. This adjustability must be achievable without the use of any tools.

Table 3: the seating dimensions recommended for India user population based on anthropometric data of n=14618 male and female agricultural workers.

Particulars	Abbreviation	Values
Seat pan (Bottom)		
Seat pan length	SPL	375 ± 10
Seat pan width	SPW	≥ 450
Seat pan height	SPH	355 ± 10
Seat pan tilt	SPT	7.5 ± 4.5
Seat pan concavity	SPC	650 ± 50
Seat Backrest		
Seat backrest width	SBW	450 ± 10
Seat backrest height	SBH	380 ± 20
Seat backrest inclination	SBI	10 ± 5
Seat backrest concavity	SBC	625 ± 25
Seat Adjustability		
Horizontal Adjustability	SAH	± 125
Vertical Adjustability	SAV	± 65
Suspension Adjustability, kg	SSA	70 ± 30

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