Seat Design and the Estimation Problem

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(1.1) If we say that furniture designing is a field into which scholars of many sciences have stepped during the last two decades, it is not to scare the Indian furniture designer (if there be many in our country). Ours is an age when sciencc should not be scary to the pursuers of applied art. In fact scientific knowledge makes the art of designing a greater art. (Verma, 1960 a).

(1.2) Recently, we came across a three-page appreciationof a lady who is said to be at alented furniture designer of our country. The magazine gaves pictures of items designed by her and referred to her modern ideas in the fields· Frankly speaking, we doubt very much whether she has contributed anything really useful to the art of designing furniture. She has contributed only to the art of decoration and ornamentation applied to furniture. It would be wrong to call her a furniture designer. This is the time for us to understand the difference between decoration and design, between a 'new style' and an 'improved design'.

(1·3) The fact that the scientific principles can revolutionize the design of furniture, garments and other articles of daily use, has not yet caught the attention of designers, manufacturers and applied scientists of this country. The reason has been mainly the static conditions through which India has passed during the last few centuries and resulting frozen minds of most of its people. Progress is bound to be slow and halting when we have been in the habit of holding fast to the traditions, good or bad. Technologically we are growing, and occasionally tend to grow very fast, but certain other things of no less value to life almost refuse to change with the times e.g., our habits, our social set up, our too much adherence to religious beliefs and practices.

(1·4) Of course our problems are great and we do not have the Alladin lamp to change our whole life overnight. It will take time to get out of the clutches of the past. Questions of food, shelter and clothing have to be given top priority, and other problems will take their own time to meet solutions. Education is fast spreading but we neither have a really good plan for imparting the right type of education nor an adequate number of schools to accomodate all students. Under the circumstances, it does not look quite nice to suggest that schools should be spacious, beautiful, rightly furnished and homely. When the buses plying in Calcutta city go crowded to the bursting point, with an extra dozen of passengers hanging at the doors, our minds tend to think more of the problem of crowded buses and surging populaiion than about the design and arrangement of seats in them. But then, sometimes I feel that 'one thing that India requires in so many fields is to be hit on the head' so that we atleast start thinking in the right direction.

(1.5) However, before the readers get the impression that good design, e.g., in seats, is a luxury for India, they must realise that a close correlation exists between health and good posture. If a seat maintains body in a poor posture, it is likely to result in disabilities involving skeletal, muscular, circulatory and digestive system. It has been observed that corrections in posture increase alertness, vigour and endurance, and improve circulation and respiration of most people

(1.6) The question of good design, by which we always mean a scientific design, comes up when we start using a seat. What about situations where workers are not using, or not allowed to use any kind of seat? For centuries, it has been a belief with most of the people that seats are inclined to encourage laziness, that better work is possible while keeping standing. For this reason, in certain working situations the provision of seats was considered unnecessary and undesirable. This was particularly true in factories, manufacturing concerns and jobs of armed forces where the general practice was to keep operators standing at work. In Calcutta, not to talk of conditions in factories, even drivers of tram-cars have been standing at their work for the last several decades. Is it impossible to provide them with seats? No. But who cares?

(1.7) It has not been realised fully in India that prolonged standing at work causes avoidable discomfort and early onset of fatigue. In keeping body upright, the muscles of thighs and calves do not find opportunity to relax, resulting in consumption of body energy which can be better utilized for work. The use of seats reduces fatigue, increases output by increasing efficiency and accuracy. Therefore, operators should sit at their work wherever practicable. When we say this, it must be emphasized that the seats should be really useful and healthy for the user. This is not possible unless the design is scientific.

(1.8) In Britain, the Factories Act, 1948, requires that 'where any employed persons have in the course of their employment reasonable opportunities for sitting without detriment to their work, suitable and sufficient facilities for sitting must be provided and maintained for their use to enable them to take advantage of those opportunities'. The seat provided should be of a 'design, construction and dimensions suitable for him and the work together with a footrest on which he can readily and comfortably support his feet if he cannot do so without the footrest'. These requirements affected all workers irrespective of sex or age (Ministry of Labour and National Service, Welfare Pamphlet No. 6, 1951).

(1.9) The science of seating, as many other branches of science, got impetus as a result of urgency with which scores of war-problems were solved to provide greater convenience, efficiency and safety in the operation of aircrafts, naval warweapons and in a variety of other working situations. Solutions for the problems were generally found for rather special situations and so the principles formulated for guiding the design and construction of seats were most useful in those particular situations. But many of those principles can also be fruitfully applied to numerous industrial situations and in buses, tram-cars, trains, cinema-halls and homes. The final design of a seat in a particular situation should however always be treated as an individual problem.

(1.10) The scientific principles in furniture designing, particularly seat designing, have already been disscussed by Verma (1960 b). Some of those conclusions are repeated here to provide the necessary background for further consideration of the problem and the manner in which it can be solved.

(1.11) A seat of proper size and correct design makes sitting a comfortable job and provides an efficient working position. This is a position in which the different segements of the body are balanced vertically upon one another, so that the weight is borne mainly by the bony framework with a minimum of efforts and strain on muscles and ligaments (Bowen, 1928), and no arteries or nerves are subjected to excessive pressure. By permitting several restful positions to the body it allows the user to change his posture from time to time and during rest-pauses, thus promoting blood circulation through fatigued muscles (Vernon, 1922). In a suitably constructed chair, one is able to slide forward and lean against a back-rest thus disturbing some of the body-weight to the back and relieving the pressure on the skin over the buttocks (Darcus and Weddell, 1947). A reclining position provides more rest than small changes in the upright position (Gilbreth and Gilbreth, 1919). Christensen (1951) also points out that 'a sitting position with the legs close to horizontal level will favour the return flow of blood to the heart and diminish the blood accumulation, in the legs, arising from the hydrostatic effects'.

(1.12) Akerblom has briefed the chief characteristics of an ideal chair as follows : 'It is so low that even those with short legs can sit on it without discomfort to the legs. The seat slopes somswhat backwards. These characteristics combine one to make full use of the backrest. The backrest slopes backwards and has a forward convexity which give restful support to the small of the back. A particularly important characteristic of the chair is the good opportunity which it offers for changing one's position'.

(1.13) In Britain, standard specifications for school tables and chairs are available. These specifications are based on results of anthropometric surveys (B.S. 2639:1955; see particularly B.S. 3030 and Hammond 1960). One such survey is known as Birmingham Anthropometric Survey, planned in 1946, whose first report appeared in 1947, and the second report, based on more adequate samples, was released in 1956 by the Department of Anatomy, University of Birmingham. The report is based on forty measurements taken on 5,000 children of the age-group 5 to 18 years, taken from 138 schools. In U.S.A., the size and design of most of the school furniture and equipments now in the market, is based on Bennett's (1928) measurements, and the recently undertaken survey, directed by Martin (1953), Specialist for School Furniture and Equipment, U.S. Department of Health Education and Welfare. The last report has proved valuable to design engineers, manufacturers of school furniture, architects, school administrators, school business officials and class room teachers.

(1.14) Body-measurements in characteristic working positions can improve the design of school equipments and thus contribute to the efficiency, health, comfort and safety of the students. A sound knowledge of man's proportions, anatomy (especially bone structure), and possible movements is a great asset to the designer (Kape, 1956). 'Investigations show that discomfort and bad posture may result from unsatisfactory table and chair heights, which generally in the past tended to be too high '(B.S. 2639: 1955). Akerblom (1948, 1951) points out that sufferers from back-ache and people with weak backs are benefited by scientificaly designed chairs and tables. He suggests that it may also help in the prevention of weakness of the back. Prevention of weakness of the back (in growing children, and the promotion of efficiency and safety of factory-workers should draw the immediate attention of India's anthropologists, the Education Ministry, the Health Ministry and the Indian Standards Institution. The accelerated body-development, as has been observed in Britain, U.S.A., New-Zealand and some other countries, emphasizes the importance of continued research. Americans have been wise enough to have increased the width of, say, standard theatre-chairs from 18 inches, in early 1900's to 20 inches around

1930's and finally to 22 inches, in keeping with the increasing size of the people. If they do not do so, and a theatre gets fire, customers would find it difficult to get out of their seats !

(1.15) Modern furniture designers must have a thorough knowledge about the materials they handle, the construction process and factory requirements. What about basic facts and figures about the human requirements with regard to furniture? Who will tell them about physiological requirements of man, if physiologists don't do it ? Who will tell them about the size and shape of men, women and children living in different regions, if anthropometricians don't help them ? In this age of science, scientists should help designers in refusing to rely on guess work and rough methods.

(1.16) Indian scientists, therefore, must feel the urgent need for anthropological, anatomical and physiological researches which will guide the manufacturers in producing furniture in correct sizes and shapes, and thus contribute to the efficiency, health, comfort and safety of the people in homes and in numerous working situations (Verma, 1959).

2. An Experimental Survey

(2.1) A few years back we decided to conduct a large scale anthropometric survey for solving seating problem in schools. We were to deal with a new set of measurements, other than the so-called classical ones which we had customarily used in previous surveys. We also needed special instruments and equipments for the survey and as they were not manufactured anywhere, they were to be designed by us. To get used to the new type of measurements and to design new equipments suited to our work, we held some experiments. It was during the period of experimentation that some measurements were taken on 66 boys of a small school in Calcutta. All the students measured were in the age-group 16 to 25 years.

Measurements

(2.2) Ten measurements were taken on each individual. They were Stature, Sitting Height, Seat Length, Buttock-knee Length, Elbow-seat Height, Back Height, Shoulder Breadth, Hip Breadth and Weight. The definitions followed for these measurements are given below.

(2.3) Stature : The subject in bare feet stands on a foot-plate as erect as possible, with heels in contact, shoulders erect, arms pendant at the sides with palms facing inwards, and looking straight ahead with the head in the eye-bar plane so that the axis of vision is horizontal (an approximation to the Frankfurt Horizontal plane). The height of the vertex (the highest point on the top of the head in the mid-sagittal plane) above the surface on the footplate is measured by an anthropometer clamped to a stand that keeps the instrument vertical.

(2.4) Sitting Height : The subject sits on a horizontal seat in the most erect position possible. The spine is held in the erect standing position and the lumbar curve is maintained. The thighs are horizontal, the knees flexed, the legs vertical and the feet resting on the foot-board. The gluteal and extensor muscles of the thigh are relaxed and the body weight falls on the ischial tuberosities. The head is in the eye-ear plane. The height of the vertex above the surface of the seat is measured by an anthropometer.

(2.5) Seat Height : The clothed individual sits on a horizontal seat in a normal erect position. The thighs are kept horizontal; the legs vertical and the feet allowed to rest on the top of the foot-boards placed upon each other. The front edge of the seat touches the hollow of the knee. The shoulders and buttocks are in contact with the vertical back rest attached to the seat. The upper arm is pendant, the elbow fixed, the forearm and hand lying on a horizontal axis and the palms facing inwards. This position is maintained for all the subsequent measurements except weight. The height of the seat above the surface of the foot-rest is measured. (Note : With the use of foot-boards of fixed thickness, in place of an adjustable footrest, it could not be possible to take correct measurement of seat height in the case of every individual, These measurements are therefore approximations but they are equally useful for our purpose here.)

(2.6) Seat Length : Subject's position as in (2.5). The distance between the back of the buttocks and the uppermost part of the lower leg behind the knee is measured. In other words, it is the length of the seat from its front edge to the back rest.

(2.7) Buttock-knee Length : Subject's position as in (2.5). The horizontal distance between the back of the buttocks (or the front surface of the back rest) and the skin over patella (knee cap) is measured.

(2.8) Elbow-seat Heigth : Subject's position as in (2.5). The vertical distance between the lower surface of the forearm and the surface of the seat is measured.

(2.9) Back Height : Subject's position as in (2.5). The back height, as measured here, is the vertical distance between the point cervicale (the extremity of the long and prominent spinous process of the seventh cervical vertebra, known as vertebra prominens) and the surface of the seat. This measurement is a little different from the back height used by Hooton for the survey in railway coach seating. Instead of the cervicale, he chose the point of junction between the head and neck, roughly called the 'nape of the neck'. His measurement was therefore a little larger than what has been obtaind in the present survey.

(2.10) Shoulder Breadth : Subject's postion as (2.5). It is the maximum contact dimension across deltoid muscles around the shoulders.

(2.11) Hip Breadth : Subject's position as in (2.5). It is the maximum lateral diameter of buttocks (upper thighs).

(2.12) Weight : The subject in ordinary clothes, without shoes and heavy pocket contents, stands still on the platform of the weighing machine. Weight is recorded to the nearest pound.

(2.13) The measurements taken have been given in Table 1. Ranges and means are also given in the same table. Measurements for seat height, seat length, elbow-seat height, shoulder breadth and hip breadth have been arranged in order of increasing value, separately for each character, in Table 2.

"Key-Measurements"

(2,14) Of the above ten measurements, stature, sitting height, buttock-knee length and weight are not useful for sizing a seat. Stature is important because body-dimensions considered as proportions of stature prove to be of great value (Barkla, 1961), particularly in situations when an idea is to be formed of body-dimensions of a population which has been measured for one or two characters only.

(2.15) The information we usually have in abundance is only about the height and weight of different people. Fortunately, this pair of measurements is most useful in predicting distributions of other body-measurements since it has been found that some body-dimensions are closely related even in individuals of different body-build. Thus, by statistical manipulation the lengths of trunk, arms and legs can be accurately predicted from stature and body girths can be determined from weight. Such measurements greatly simplify the task. If distribution of "key-measurements", like height and weight, is known for whole of the Indian population, it is only necessary that a few groups may be measured for other useful body-dimensions and such "dependent measurements" for the remaining population may be determined by calculations. A lot of labour and money can be saved in this way.

Buttock-knee length

(2.16) Travel in the private buses of Calcutta and you will find that leg-space between to seats, one behind the other, is not sufficient. About half of Calcutta's adult male population is inconvenienced in this way (and of course, in many other ways). Buttock-knee length is the measurement of highest importance in determining the amount of leg-space to be left between to seats. The recommended knee-space will have to be more than the actual buttock-knee length because people generally slide a little forward instead of keeping an upright position, in which measurements are generally taken. Along with sefficient knee-space, there should also be sufficient room for legs to stretch a little forward in order to help in blood circulation through fatigued muscles.

(2.17) Before we proceed further to analyse the measurements given in Table 1, it must be pointed out that the present survey is useful only in so far as it draws the attention of Indian students of physical anthropology towards such studies that can do a great service to the people and our country. It would be improper to recommend the dimensions of seats obtained above for use in any school, in any region, and for any age-group of students because the sample is small and not representative of reasonably definite ages or population of any definite region that can be adequately defined. The statistical methodology involved is precented in rection 4 in a general set up and is applicable to any estimation problem in seating survey.

3. Principles

(3.1) Seat Height. The height of the seat should be such to allow small movements of leg muscles which have a favourable effect on blood circulation (Chrisensen, 1951). Clement (1951) points out that 'it is apparently possible to sit with ease on a chair less than the optimnm height but uncomfortable to sit on one above it'. 'Here the critical consideration is to fit the short people satisfactorily because there will be considerable tolerance with the tall people'. The longer-legged people can comfortably adjust to a lower seat height by placing the feet forward of the vertical from the front edge of the seat to floor (Hooton, 1945). In situations where the same seats are used by men and women both, it must be remembered that a seat height well suited to males will be generally too high for females.

(3.2) A pamphlet issued by Ministry of Labour and National Service (1941) recommends that the seat should be about half an inch lower than the length of the lower leg so as to give moderate support to the thighs. Hooton (1945) suggests that a relief of pressure on popilteal area can be brought about by lowering the seat height at least one inch. We think that the seat height recommended should be, in general, 3 cms lower than the seat height measured.

(3.3) Seat Depth : The depth (length) of the seat should be sufficient to afford a light support for the thighs almost to the hollow of the knee (Hebestreit, 1930). But the thighs must not press heavily against the front edge of the cushion for it may prevent free movement of legs and may possibly lead to interference with the blood-supply to the legs (Darcus and Weddell, 1947).

(3.4) The back rest will be of no use if the person cannot make contact with it. To make this contract possible, the depth of the seat should not be more than the length of the thigh from the fold of the knee to the back in the sacral region.

(3.5) Seat Breadth : For the determination of the seat breadth, two measurements need be considered—maximum hip breadth and maximum shoulder breadth. In the case of males the shoulder breadth is generally more than the hip breadth and so the former measurement is of greater importance for our purpose, particularly because in many situations. e. g.. buses, tram-cars and trains, sufficient space has to be left between individuals sitting side by side. The problem is not only of accomodating the buttocks but also the greatest width of the body represented by shoulder breadth. Even in case of females, it has been observed that the shoulder breadth is generally larger than the hip breadth, though the difference is not so much as in males (look at Hooton's 1955 figures : Hip breadth-Boston females 17.3, Chicago females 16.7, Total females 17.2; Shoulder breadth-Boston females 17.8, Chicago females 16.9, Total females 17.6).

(3.6) If the measurements have been taken on light summer clothes, the maximum body-width will increase in winter due to woollen cloths and shoulder pads. This must be kept in mind. Some allowance must also be made for slight movements of the body towards sides.

(3.7) Back Rest : While shoulder breadth cannot be ignored in determining the seat breadth, it directly determines the width of the back rest. The ideal is to give a complete support to the back, with special consideration to curves in the lumbar region (for a detailed discussion, see Verma, 1960b). If, in a working situation, a full support to the back restricts the movements of back rest due to limitations of space or weight, a support should at least be given to the lumbar region, and more specially to the lumbar hollow. Dealing with the problem of railway coach seating, Hooton has suggested that a support should be given (also) at the base of the skull.

(3.8) Elbow Rest : If a person is seatad on a chair with shoulders level, upper arm pendant, forearm horizontal, and an angle of approximately 90° between the upper arm and forearm, the height of the elbow rest should in no case be more than the height of the elbow from the rest. In fact the height of elbow rest should be less than the elbow height measured because of several resons listed by Hooton. The reasons are : (1) the habit of many persons to slump to a varying extent, (2) the habit of many persons to throw most of the body weight on one elbow, (3) the undesireability of extending the arms laterally which has to be done if the armrest is too high (even this cannot be done unless there is extra lateral space on the seat), and (4) the need to prevent the shoulders from hitching up which forms an uncomfortable position.

(3.9) For a discussion of the problem of seat cushion, slope of the seat and footrest, ree Verma, 1960.

4. Statistical Methodology

(4.1) Suppose $x_{(1)} < x_{(2)} < \dots < x_{(n)}$ are n ordered measurements of a certain characteristic on a random sample of size n selected from a population. Consider the problem of estimating the p-th percentile, ξ_p, of the population [i.e., a value] ξ_p below which there are 100p percent individuals in the population] on the basis of the sample. Since there is always some amount of uncertainty while estimating ξ_p from the sample we settle an arbitrary $\alpha = .95$ and require that the inference we derive about ξ_p from sample holds with probability .95 or better. In the sequel this probability will be called the confidence probability.

(4.2) In seating problem the most suited method of estimation of ξ_p is that of confidence intervals. Here we are interested in two types of confidence intervals : (i) the upper confidence interval for ξ_p, and (ii) the lower confidence interval for p.

(4.3) *Upper confidence interval for* p : We want to have an upper estimate x_u for ξ_p such that there is high probabilty that p will be less than or equal to x_u, i.e., we want an estimate x_u from sample such that.

$$P [\varepsilon p \xi x_u] \varepsilon .95 \qquad \ldots \qquad \ldots \qquad (1)$$

(4.4) As for instance, when we want to specify the seat breadth, we should have estimate x_u of the 90th percentile of hip breadth (or shoulder breadth as the case may be) which satisfies (1). This will insure that with probability greater than ·95 more than 90 percent of individuals will have breadth less than x_u and therefore a chair with seat breadth x_u will satisfy more than 90 percent population.

(4·5) Using the order-statistics $x_{(1)}, x_{(2)}, \dots, x_{(n)}$ the solution of (1) is

$$P [\ p \varepsilon x_u] \ .95 \qquad \ldots \qquad \ldots \qquad (2)$$

where $x_{(u)}$ is the u-th order-statistic and u is to be determined from the following equation

$$\sum_{r=0}^{n-1} \binom{n}{r} p^r (1-p)^{n-r} \varepsilon .95 \qquad (3)$$

(4.6) For given n and p, this equation can be solved for u numerically. Tables for the cumulated sum of $\binom{n}{r} p^r (1-p)^{n-r}$ are available and can be utilized for this purpose. It is to be seen that the sample size n should be greater than or equal to $\left[\frac{\log .95}{\log (1-p)} \right]$ in order to have such an x_u .

(4.7) When n is large, say 25. normal distribution can be used to solve (3). The solution is given by

$$u \quad z_{.95} / [\overline{np (1-p)} \,] + np + \frac{1}{2} \qquad .. \qquad .. \qquad (4)$$

where $z_{.95} = 1.6.45$ is the 95-th percetile of the standard normal distribution.

(4.8) *Lower confidence interval for* ξ p : There are other situations where we want to have lower estimate x_l of ξ p such that there is high probability that ξ p will be greater than x_l . For sample, while specifying the seat height, if we have a lower estimate x_l of ihe 10-th percentile of the seat height measured, a chair with seat x_l will satisfy more than 90 percent of population. For the confidence probability $\alpha = .95$, the estimate in given by the following equation.

$$P \; [\; \xi p > x_l \;] \quad .95 \qquad .. \qquad .. \qquad (5)$$

where x_l is the l-th order statstic and l is determined from the following equation—

$$\sum_{r=l}^{n-1} \binom{n}{r} p^r (1-p)^{n-r} \quad .95 \qquad .. \qquad .. \qquad (6)$$

(4.9) The equation can also be solved numerically for l in a manner similar to that suggested above. The sample size n should be greater than or equal to $\frac{\log .95}{\log .95}$ in order to have such an l.

(4.10) The use of normal appoximation for large n given the following solution of l.

$$l \quad z_{.05} / \overline{np (1-p) + np} + \frac{1}{2} \qquad .. \qquad (7)$$

where $z_{.05} = - 1{\cdot}045$ is the 5-th percentile of the standard normol distribution.

(4.11) *Determination of optium sample size* : We take for illustration the sa e of upper estimate of p, the other case can be treated similarly. Eqt at ons (2) and (3) provide us with and estimate of $x_{(u)}$ which insures that a high probably $\xi p < x_{(u)}$. For any n $\left[\frac{\log .95}{\log (1-p)} \right]$, $x_{(u)}$ can be determined so as to statisfy (1), but this does not tell us how close $x_{(u)}$ is an estimate of ξ p. As the sample size increases, $x_{(u)}$ approaches ξ p. In order to be sure that $x_{(u)}$ is not far away from ξ p, we determine n such that

$$P \left[x_u < \xi p_1 \right] \quad .95 \qquad (8)$$

for a preassigned p_1 (> p) and close to p.

(4.12) This mean that we reject persons beyond ξp_1 for the estimation. We do not have any special perference for persons between ξp and ξp_1 bnt we have strong perference to statisfy person below ξp.

(4.14) Approximate solution that determines n which satisfies the above equation is given by

$$n \xi \frac{\left[z_{.95} / p(1-p) - z_{.05} / p_1 (1-p_1) \right]^2}{(p_1 - p)^2}$$

For instanee, if $p_1 = .95$ and $p = .90$, the minimum n should be nearly equal to 290.

(4.14) In case of several measurements, the least maximum n that is optimum for all measurements can be chosen.

5 The Numerical Example

(5.1) For illustration we consider the measurements of 66 boys described in section 2. As already pointed out in para (2.17), these measurements are not useful for making any recommendation about the size of seats in any school; they are used here only to explain the methodology for finding a solution to the problem in general.

(5.2) Seat Height : It is found from equation (VII) that lower estimate of the 10-the percentile of seat height measured from the above sample (n=66, p=.10) is given by the 3rd order-statistic which is equal to 36.1 cms. This means that more than 90 percent of the students have the measured seat height greater than 36.1. It follows from paras (3.1) and (3.2) that the appropriate seat height to be reeommended which will satisfy 90 percent of the population with probability. 95 or better is 36.1-3. 00=33.1 cms.

(5.3) Seat Depth : The upper estimate of the 90th percentile of seat depth is given as the 64-th order-statistic which is equal to 50.1 cms. Thus the recommended seat length should be 50.1 cms. As the people generally do not put their buttocks in touch with the back rest but keep them several cms from it, the recommended seat length can therefore be increased. The short legged people can slide a little forward of the back rest so as to avoid undue pressure of edge at the hollow of the knee.

(5.4) Seat Breadth : As shoulder breadth is generally larger than hip breadth, the former should be utilized in determining the seat breadth. The upper estimate of the 90th percentile of shoulder breadth is equal to 47.2 cms. The recommended seat breadth can be increased further but consideration must be given to the position of the upper arm and the position of the arm rest along which the lower arm is placed.

(5.5) Back Rest : The width of the back rest should be determined on the basis of shoulder breadth, as we have to give support to maximum possible area of the back of human body. Hence the recommended back rest should be at least 47.2 cms broad.

(5.6) Elbow Rest : The lower estimate of the elbow height should be used to recommend the height of the elbow rest as it should in no case be more than the elbow height measured. The lower estimate of the 10-th percentile is given by 3rd order-statistic which is equal to 16.3 cms. Thus the recommended height is 16.3 cms.

(5.7) When we design seats for schools and colleges, we are designing for boys and girls of growing age. A seat meant for students of one class will not suit students of higher or lower class. Therefore, seats should be sized according to the age-group represented in a particular class.

(5.8) We remark finally that extreme people of the population must be measured very critically as they are the persons who determine the measurement of seat. Any error in their measurments may completely alter the true picture of the population.

Table 1

FUNCTIONAL MEASUREMENTS OF SCHOOL BOYS

Arranged in order of increasing stature. Measurements are in cms. Weight is in lbs.

Sl.	Stature	Sitting height	Seat height	Seat length	Buttock knee length	Elbow seat height	Back heigth	Shoulder breadth	Hip breadth	Weight
1	139·1	72.4	35.1	40.5	47.4	17.6	49.3	32·4	25.6	65
2	140.7	72.2	34.9	40.8	48.2	19.0	50.3	43.0	26.2	68
3	141.0	70.9	35.1	40.0	47.1	15.3	48.4	31.0	25.3	61
4	143.7	72.4	43.8	41.9	49.3	18.3	51.4	44.0	27.0	69
5	146.9	71.3	38.5	44.8	53.3	17.4	50.1	32.0	25.2	71
6	148.7	77.2	39.0	41.3	50.5	18.6	54.2	43.6	26.5	77
7	149.1	77.2	39.0	43.9	52.0	19.2	56.3	49.2	28.5	88
8	149.7	79.9	39.0	43.3	51.9	19.5	58.2	38.0	29.5	92
9	151.2	78.1	38.5	43.9	52.1	19.1	55.2	45.0	27.2	76
10	151.6	80.2	38.5	42.3	50.5	21.6	57.8	38.7	29.7	92
11	151.7	80.6	38.0	42.7	50.7	22.5	58.1	40.1	28.6	87
12	151·9	79.7	39.0	42.5	52.9	19.2	57.9	39.5	28.0	91
13	152.7	78.5	36.5	42.5	52.3	21.4	57.1	38.4	29.8	91
14	153.5	77.5	40.0	46.1	55.6	15.3	56.8	37.1	29.1	78
15	154.5	74.8	39.5	47.5	57.2	18.4	54.1	39.8	28.8	99
16	154.2	79.2	39.5	42.7	51.3	23.4	56.7	39.1	31.4	101
17	154.7	84.6	40.5	42.0	49.4	25.4	59.4	46.0	29.1	84
18	155.1	82.2	37.8	43.4	52.3	25.0	59.3	46.0	28.7	85
19	155.4	81.0	40.5	46.5	55.7	20.8	60.4	40.2	30.5	97
20	155.6	80.6	40.5	42.3	52.2	21.3	58.6	37.5	29.5	87
21	155.7	79.6	40.5	43.7	53.2	21.3	55.6	41.2	28.7	98
22	155.8	81.7	40.5	44.3	52.2	22.8	57.4	34.3	27.4	77
23	155.9	82.0	40.5	44.3	52.7	23.1	58.6	36.9	29.1	87
24	156.2	81.0	42.3	49.1	58.3	19.1	59.8	37.1	31.2	95
25	156.4	81.2	42.3	45.9	55.6	21.5	57.4	37.3	31.9	93
26	156.9	81.3	42.3	42.9	51.1	22.3	58.4	38.5	28.9	88

Sl.	Stature	Sitting height	Seat height	Seat length	Buttock knee lenght	Elbow seat height	Back height	Shoulder breadth	Hip breadth	Weight
27	157.2	81.0	42.3	46.0	54.5	20.4	59.2	40.3	31.0	108
28	157.2	81.4	42.3	48.9	57.8	19.1	57.4	40.3	29.9	94
29	157.3	75.6	39.0	47.7	56.9	16.3	55.8	36.5	28.6	85
30	157.3	82.9	42.3	45.1	54.6	25.3	59.6	39.3	28.6	95
31	157.6	82.9	42.3	44.2	52.6	23.5	60.3	39.1	29.8	98
32	158.3	82.1	39.5	48.0	56.7	24.0	59.0	37.5	27.9	99
33	158.3	79.9	39.5	44.5	53.2	21.8	58.6	37.3	30.0	98
34	159.0	82.8	40.5	44.3	52.4	23.6	60.4	38.8	29.4	95
35	159.1	81.9	39.5	44.4	53.4	21.4	59.1	37.1	30.1	94
36	159.2	81.2	39.5	51.6	61.1	16.7	57.7	47.2	40.1	95
37	159.3	83.6	40.5	44.8	53.5	23.7	61.5	41.3	29.9	85
38	159.6	79.3	40.5	48.0	56.4	19.0	56.2	38.8	30.6	98
39	159.8	82.2	40.5	46.3	55.2	23.8	59.0	36.9	30.0	85
40	159.9	81.9	42.5	44.5	53.7	20.8	59.4	39.4	32.1	115
41	160.5	81.3	42.3	46.7	56.1	19.8	58.8	27.8	29.0	91
42	160.8	80.2	42.3	45.4	54.5	21.3	58.5	40.7	30.1	103
43	161.7	81.5	43.3	44.7	53.7	23.9	58.2	37.6	29.6	90
44	162.0	83.6	42.3	44.6	53.1	21.9	61.5	38.5	29.1	92
45	162.5	79.7	42.8	49.1	57.8	18.6	56.2	37.0	27.4	86
46	153.3	86.3	42.3	43.6	53.2	26.3	61.7	40.9	29.1	100
47	163.4	85.5	42.3	47.6	56.3	24.1	61.2	40.3	29.4	91
48	163.5	89.2	43.8	46.5	54.7	26.9	64.8	40.0	43.5	114
49	164.4	84.1	42.3	49.3	58.6	24.0	51.2	40.7	43.6	119
50	164.6	84.1	42.9	44,6	56.8	21.6	59.6	35.6	29.4	86
51	165.1	83.0	39·5	37.8	56.3	19.8	58.7	47.2	28.8	92
52	165.3	86.7	42.3	46.7	54.3	21.9	61.5	36.5	29.7	94
53	165.7	83.6	39.5	46.1	57.5	23.3	59.8	41.7	32.0	121
54	165.8	81.8	42.3	48.3	59.0	21.4	58.4	43.6	32.4	131
55	165.9	87.4	42.3	44.6	54.9	27.0	63.6	43.3	44.5	133
56	166.1	85.8	42.3	45.8	55.9	19.3	64.1	41.9	41.4	109
57	166.9	86.3	42.3	46.5	55.6	23.8	60.8	38.0	28.6	86
58	167.1	86.7	42.3	45.1	54.9	26.5	63.5	44.0	32.0	125
59	167.7	85.9	22.3	48.2	57.7	22.5	65.8	41.7	41.6	102
60	166.5	87.6	42.3	46.9	55.8	22.3	62.2	41.6	30.5	103
61	168.7	87.2	42.3	49.1	58.2	25.4	64.4	40.6	41.7	118
62	169.1	90.0	42.3	45.8	64.1	25.3	64.7	40.5	31.6	104
63	170.3	85.4	42.3	50.1	60.1	23.6	62.9	41.0	42.3	112
64	171.5	87.5	43.1	47.2	57.6	25.3	55.1	42,9	31.6	117
65	172.5	85.8	43.5	49.5	59.7	23.5	62 5	40.1	41.1	100
66	173.2	90.7	42.3	50.3	59.7	26.5	67.5	42.7	34.5	120
range	139-173	70-91	34-44	40-52	47-61	15-27	48-68	27-49	25-44	61-133
mean	158.6	8.71	40.8	45.5	54.4	21.7	58.7	39.8	31.1	95.2

Table 2

FUNCTIONAL MEASUREMENTS OF SCHOOL BOYS

Arranged in increasing order of magnitude, separately for each character.

Si.	Seat height	Seat length	Elbow seat height	Shoulder breadth	Hip breadth
1	34.9	40.0	15.3	27.8	25.2
2	35.1	40.5	15.3	31.0	25.3
3	36.1	40.8	16,3	32.0	25.6
4	36.5	41.3	16.7	32.4	26.2
5	37.8	40.9	17.4	34.3	26.5
6	38.5	42.0	17.6	36.5	27.0
7	38.5	42.3	18.3	36.9	27.2
8	38.5	42.3	18.4	36.9	27.4
9	39.0	42.5	18.6	36.9	27.4
10	39.0	42.5	18.6	37.0	27.9
11	29.0	42.7	19.0	37.1	28.0
12	39.0	42.7	19.0	37.1	28.5
13	39.0	42.9	19.1	37.1	28.6
14	39.0	43.3	19.1	37.3	28.6
15	39.5	43.4	19.1	37.3	28.6
16	39.5	43.6	19.2	37.5	28.6
17	39.5	43.7	19.2	37.5	28.7
18	39.5	43.9	19.3	37.6	28.7
19	39.5	43.9	19.5	38.0	28.8
20	39.5	44.2	19.8	38.4	28.9
21	39.5	44.3	19.8	38.5	28.9
22	39.5	44.3	20.4	38.5	29.0
23	40.0	44.3	20.8	38.7	29.1
24	40,5	44.4	20.8	38.8	29.1
25	40.5	44.5	21.3	38.8	29.1
26	40.5	44.5	21.3	38.8	29.1
27	40.5	54·6	21.3	39.1	29.1
28	40.5	44.6	21.4	39.1	29.4
29	40.5	44.7	21.4	39.3	29.4
30	40.5	44.8	21.4	39.4	29.4
31	40.5	44.8	21.5	39.5	29.5
32	40.5	45.1	21.6	39.5	29.5
33	40.5	45.1	21.6	39.8	29.6
34	40.5	45.4	21.8	40.0	29.7
35	42.5	45.6	21.9	40.1	29.7
36	42.3	45.8	21.9	40.1	29.8
37	42.3	45.8	22.3	40.2	29.8
38	42.3	45.9	22.3	40.3	29.9
39	42.3	46.0	22.5	40.3	29.9
40	42.3	46.1	22.8	40.5	30.0
41	42.3	46.1	21.8	40.5	30.0

Contd. Table 2

Sl.	Seat height	Seat length	Elbow seat height	Shoulder breadth	Hip bradth
42	42.3	46.3	23.1	40.6	30.1
43	42.3	46.5	22.3	40.7	30.1
44	42.3	46.5	23.4	40.7	30.5
45	42.3	46.5	23.5	40.9	30.5
46	42.3	46.7	23.5	41.0	30.6
47	42.3	46.7	23.6	41.2	31.0
48	42.3	46.9	23.6	41.3	31.2
49	42.3	47,2	23.7	42.6	31.4
50	42.3	47.5	23.8	41.7	31.6
51	42.3	47.6	23.8	41.7	31.6
52	42 3	47.7	23.9	41.9	31.9
53	42.3	47.8	24.0	42.7	32.0
54	42.3	48.0	24.0	42.9	32.0
65	42.3	48.0	24.1	43.0	32.1
56	42.3	48.2	25.0	43.3	32.4
57	42.3	48.3	25.3	43.6	34.5
58	42.3	48.9	25.3	43.6	40.1
59	42.4	49.1	25 3	44.0	41.1
60	42.3	49.1	25.4	44.0	41,4
61	42.3	49.1	25.4	45.0	41.6
62	43.1	49.3	26.3	46.0	41.7
63	43.3	49.5	26.5	47.2	42.3
	43.5	50.1	26.5	47.2	43.5
	43.8	50.3	26.9	49.2	43.6
	43.8	51.6	27.0		44.5

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