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A Study on the Stiffness Characteristics according to the Body Pressure on the Seat Cushion for Vehicle

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Abstract

Objectives: Since the riding comfort upon seating is determined according to the driving environment or the driver's preference, objective evaluations are accompanied by many constraints. **Methods/Statistical Analysis:** Variations in stiffness distribution of the seat cushion were analyzed by using body pressure distribution. First, to identify load-deflection characteristics of the seat cushion, static load tests were conducted and stiffness characteristics as a function of load were affirmed by application of quadratic spline interpolation method. And, body pressure distribution of the male subject produced upon seating in the cushion was measured under actual vehicle conditions. **Findings:** Variations in stiffness distribution of the seat cushion produced when a driver comes aboard a vehicle, and the following conclusions could be obtained. First, by conducting static load tests for the seat cushion to obtain load-deflection curves, deflection characteristics per load point were identified. Second, through quadratic function for the load-deflection curves derived from static load tests, stiffness distributions were derived. Stiffness characteristics were continuously varied as a function of load distribution applied to the seat cushion, which was analyzed to have an effect on stiffness distribution as a function of body pressure distribution for the driver. Third, based on body pressure distribution data for the male subject and load-deflection curves for the seat cushion, variations in stiffness of the seat cushion were analyzed as a function of body pressure distribution. As a result, the extent of hardness felt by the human body was greater for the right side even if body pressure of the male subject was shown to be larger in the left-side region. **Application/Improvements:** Characteristics of seat stiffness distribution as a function of body pressure distribution which were derived in the present study are considered to be utilized for pad development of car seat.

Keywords: Body Pressure Distribution, Deflection, Seat Cushion, Stiffness, Vehicle

1. Introduction

In the automotive industry today, not only development in technological aspects but also study for technology development of sensitivity quality is being actively implemented. Here, due to an increase in time which consumers spend inside a vehicle, importance of emotional quality is emerging further with vehicles surpassing the role as a mere transportation means to be ranked as a living space[1]. Among them, the seat is a module which comes into direct contact with the driver, playing not only the role of attenuating transmission of noise and vibration flown in from outside upon driving, but also that of providing riding comfort and convenience[2]. Particularly,

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since the riding comfort upon seating is determined according to the driving environment or the driver's preference, objective evaluations are accompanied by many constraints. Because of this, the recent automotive seat industry is studying a variety of seat evaluation methods of providing quantitative data[3]. In the case of advanced automotive businesses, not only ride comfort evaluation for the seat is considered to be reflected upon design from the past, but also test specs for quantitative evaluation are provided. Quantitative evaluation methods for automotive seats are largely divided into static evaluation and dynamic evaluation, and studies of analyzing correlations for comfort and discomfort have been already implemented in parallel with subjective evaluations[4–6]. When a driver is seated in the seat, more than 70% of human body weight is supported by the seat cushion, and considerable concentration of body pressure occurs particularly in ischial tuberosity[7,8]. This is a sufficient pressure to hamper blood circulation, resulting in induced pains and paralysis and becomes to act as a factor for degrading the sense of comfort. However, since the concentrated part of body pressure is changed by driver's seating posture and stiffness characteristics of the seat cushion, all of these should be considered for optimum design of the seat cushion. In the present study, therefore, variations in stiffness distribution of the seat cushion were analyzed by using body pressure distribution produced when a driver is seated in the seat, through which analysis methods and basic data could be secured for stiffness design of the cushion. First, to identify load-deflection characteristics of the seat cushion, static load tests were conducted and stiffness characteristics as a function of load were affirmed by application of quadratic spline interpolation method. And, body pressure distribution of the male subject produced upon seating in the cushion was measured under actual vehicle conditions. Based on the two experiments, variations in deflection and stiffness as a function of body pressure distribution could be identified.

2. Experiments method

2.1 Static Load Test

To obtain objective data on stiffness characteristics of the seat cushion pad for the driver's seat, static load tests were conducted. Static load test involves measurement of deflections by application of loads to the seat cushion using a load cell, as a test for derivation of elastic force and stiffness through hysteresis curve. In the present article, static load tests were conducted on the basis of Hardness profile test method of SAE J2896[9]. As shown in Figure 1, the tests were implemented with a pressing plate of 50mm in diameter, a total of 40 load points and an interval between points of 50mm. By considering correlations with data of body pressure distribution, the regions of seat cushion were divided into thigh, hip, bolster regions, as shown in Figure 2. Loads were vertically applied up to 200N, with the loading rate for pressing plate of 200mm/min. Since restoring force of the seat cushion was not the object of consideration in the present study, hysteresis curves were not used, and only pressurization data was obtained.

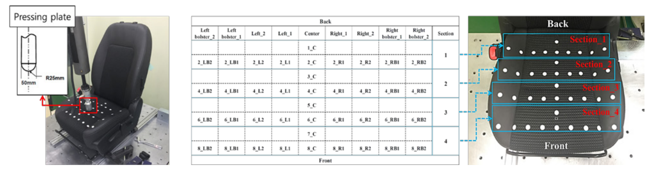
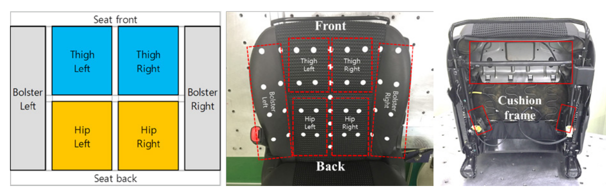


Figure 1. Static load test and loading points.



(a) (b)

Figure 2. The regions of the seat cushion. (a) Region segmentation of seat cushion (b) Seat cushion bottom.

2.2 Body Pressure Distribution Measurement

As the present experiment was intended to secure objective data for the driver's posture, the male subject was selected as a 25 year-old male of 172cm in height and 75kg in weight. Body pressure distribution measurement was conducted in an actual vehicle, where 2000cc-class SUV was employed for the type of the vehicle. As shown in Figure 3, seat back angle was set to be 100° as the design standard and the driver was allowed to freely take a driving posture usually preferred by him for the seating posture. As the equipment for body pressure distribution measurement, PX100 model of XSENSOR Technology Corporation was employed and body pressure data was collected from a matte composed of a total of 2,304 sensors.

Figure 3. Body pressure measurement in actual vehicle.

3. Result and Analysis

3.1 Stiffness Characterisis of Seat Cushion

To identify stiffness characteristics of the seat cushion from static load tests, stiffness values were derived by application of quadratic spline interpolation method to the load-deflection curves. Figure 4 shows a load-deflection curve measured in static load test and quadratic

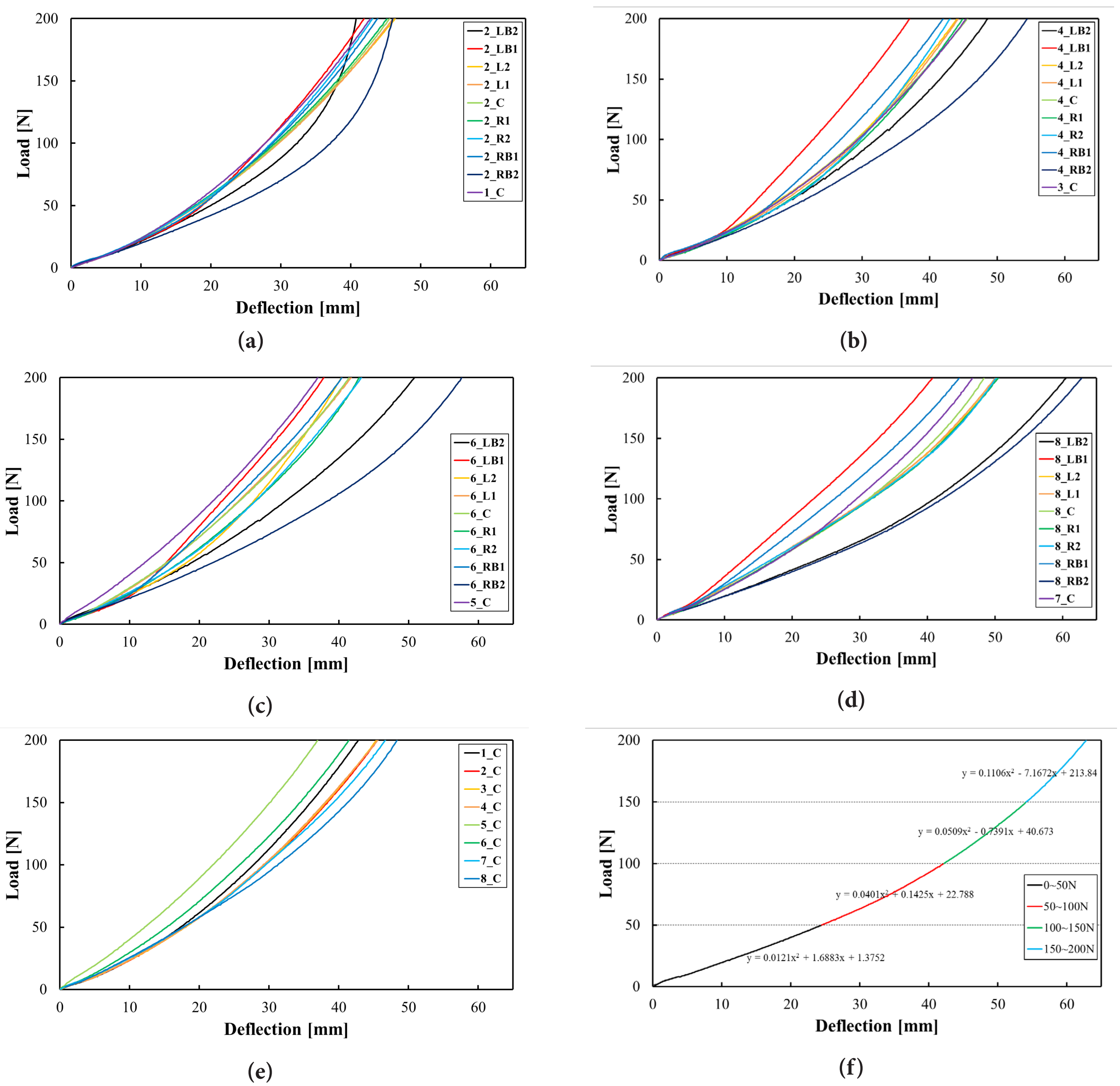
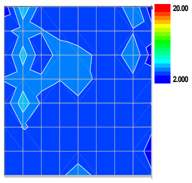
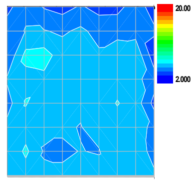
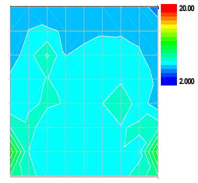
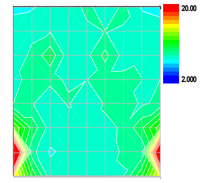


Figure 4. Load-deflction curve and quadratic spline interpolation (a) Section_1 (b) Section_2 (c) Section_3 (d) Section_4 (e) Center line (f) Quadratic spline interpolation(8_RB2 of Section_4)

Table 1. Stiffness distribution of seat cushion

50N	100N	150N	200N
			

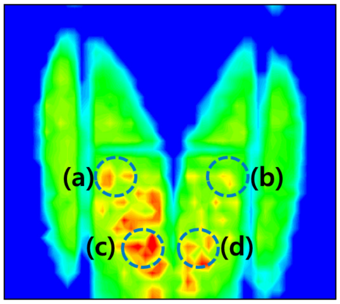
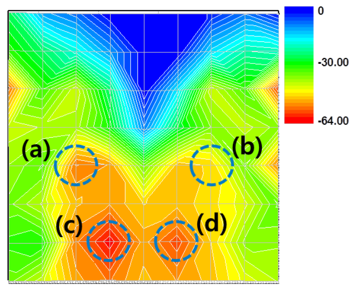
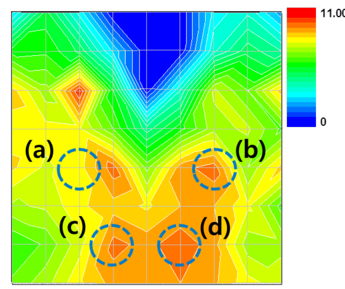
spline interpolation. For application sections of quadratic spline interpolation, 0~50N, 50~100N, 100~150N, and 150~200N were set, and stiffness values were derived by obtaining differentials for quadratic function at each load point. Table 1 shows 4 types of stiffness distribution corresponding to load conditions applied to the seat cushion based on static load test.

First, in the load-deflection curve of Section_1, a steep increase in the gradient of bolster_2 curve can be seen beginning with 100N, which was considered to indicate having a higher stiffness compared with other load points. And in Sections_2, 3, 4, the gradient of bolster_2 could be affirmed to be rather slow with an increase in deflection. Such occurrence was analyzed to suggest that the frame existing in the seat cushion bottom of Section_1 as shown in Figure 2 (b) directly supported the region of bolster_2. And in bolster_2 of Sections_2, 3, 4, curves with a rather low gradient were analyzed to be formed due to an increase in cushion pad thicknesses. In the case of Sections_3, 4, the effects of frame were small since cushion pad thicknesses were relatively larger than those of Sections_1, 2 although the frame supported the cushion. Because of this, the same steep gradient as with bolster_2 of Section_1 was not observed. Considering stiffness distribution as a function of seat cushion loads based on this, a high stiffness was observed in the left-side thigh region at 50N and 100N, while relatively low figures were exhibited in the right-side bolster region. At 150N and 200N, the highest stiffness was formed in the left and right bolsters, and somewhat high stiffness was also observed in the left and right thigh regions. Also, relatively low stiffness was commonly exhibited in the left hip region. Namely, stiffness characteristics were continuously varied as a function of load distribution applied to the seat cushion. Therefore stiffness distribution was analyzed to be affected by the driver's body pressure distribution.

3.2 Analysis on the Stiffness Characterics for Body Pressure

Based on data of load-deflection curves for the seat cushion and body pressure distribution for the male subject, characteristics of deflection and stiffness as a function of body pressure distribution were identified, and the results are presented as a figure in Table 2. First, we converted body pressure data of the male subject to load data, then stiffness and deflection distribution could be derived in the same way as chapter 3.1. In the case of deflection distribution, it was shown to be highest in (c) and (d) where body pressure was concentrated as shown in the figure of Table 2, followed by being next high in (a) and (b). As (c) and (d) correspond to ischial tuberosity, while (a) and (b) represent a hip region close to thigh, it could be affirmed that body pressure and deflection were shown to be higher in the left-side region. However, considering stiffness distribution, different characteristics were observed from the regions where body pressure and deflection were exhibited to be high. To analyze this, load, deflection and stiffness for each point were prepared in Table 3 for a comparative analysis. When (a) and (b) are compared, load 295.7N, deflection 56.2mm, stiffness 8.3N/mm were observed in (a), while load 261.4N, deflection 49.7mm, stiffness 9.8N/mm were observed in (b). Through this, it could be affirmed that (b) was shown to be higher by about 1.5N/mm in stiffness, whereas (a) was shown to be higher in load and deflection. Similarly, when (c) and (d) are compared, (c) showed load 347.6N, deflection 63.4mm, stiffness 9.7N/mm, while (d) showed load 324.6N, deflection 59.4mm, and stiffness 9.9N/mm. This is the same as the characteristics shown in (a) and

Table 2. Color map

Body pressure distribution	Deflection distribution	Stiffness distribution
		

(b), and stiffness of (d) was shown to be higher than that of (c) by about 0.3N/mm whereas load and deflection of (c) were shown to be higher than those of (d). Namely, it was learned that the right-side hip region had harder characteristics than the left-side hip region, due to which the human body receives a harder feeling on the right side even if a higher load was applied to the left-side hip region. This was identified to be similar to the stiffness distribution characteristics as a function of loads derived from load-deflection curves for the seat cushion which were analyzed in Section 3.1.

Table 3. Data comparison for each point

Section	Load [N]	Deflection [mm]	Stiffness [N/mm]
(a)	295.7	56.2	8.3
(b)	261.4	49.7	9.8
(c)	347.6	63.4	9.7
(d)	324.6	59.4	9.9

4. Conclusions

In the present study, variations in stiffness distribution of the seat cushion produced when a driver comes aboard a vehicle, and the following conclusions could be obtained.

1. By conducting static load tests for the seat cushion to obtain load-deflection curves, deflection characteristics per load point were identified. First, it could be affirmed that the steepest gradient in load-deflection curves was shown by bolster_2 of Section_1, which was analyzed to occur due to a support of the cushion pad by the frame at seat cushion bottom. Although a region supported by the frame also exists in Sections_3, 4, somewhat slower curves were analyzed to be formed as compared with the bolster_2 of Section_1 due to an effect of the cushion pad thicknesses.
2. Through quadratic function for the load-deflection curves derived from static load tests, stiffness distributions for 50N, 100N, 150N, 200N were derived. According to the results, relatively high stiffness characteristics were exhibited in the left-side thigh region of the seat cushion at 50N and 100N, and the highest stiffness was observed in bolster_2 at 150N and 200N. Meanwhile, relatively low stiffness characteristics were exhibited in the left-side hip region. Because of this, stiffness characteristics were continuously varied as a function of load distribution applied to the seat cushion, which was analyzed to have an effect on stiffness distribution as a function of body pressure distribution for the driver.
3. Based on body pressure distribution data for the male subject and load-deflection curves for the seat cushion, variations in stiffness of the seat cushion were analyzed as a function of body pressure distribution. According to the results, stiffness of (a) and (c) was shown to have relatively lower values as compared with that of (b) and (d), which was analyzed to contradict the results of body pressure distribution and deflection distribution. Through this observation, the right-side hip region of the seat cushion showed relatively hard characteristics in comparison the left-side hip region, which was analyzed to indicate that the extent of hardness felt by the human body was greater for the right side even if body pressure of the male subject was shown to be larger in the left-side region.
4. Characteristics of seat stiffness distribution as a function of body pressure distribution which were derived

in the present study are considered to be utilized for pad development of custom car seat. In the future, optimization of stiffness distribution for the seat cushion is planned to be implemented by additionally conducting subjective evaluation of riding comfort and restoring force evaluation for the seat cushion.

5. Acknowledgement

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6. References

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