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DEVELOPMENT OF AN AUTOMOTIVE SEAT FOR RIDE COMFORT

(PEMBANGUNAN TEMPAT DUDUK KENDERAAN UNTUK KESELESAAN)

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ABSTRACT

Seat is one of the main aspects to be considered when defining comfort in a moving vehicle. Experience shows that a seat produces different levels of comfort in different conditions. Comfort on automotive seats is dictated by a combination of static and dynamic factors. This project attempts to study the static and dynamic characteristics of a bus passenger seat for comfort through subjective and objective evaluation. Two surveys including pilot test were carried out to study the subjective evaluation responded directly by local users on seat comfort during their journey on road. For objective evaluation, two tests were conducted; SEAT (Seat Effective Amplitude Transmissibility) test and pressure distribution test. Both tests had been carried out under controlled and uncontrolled conditions. Experimental works in laboratory were considered as controllable. Uncontrolled condition refers to the road trials or field tests carried out in a moving vehicle which produced random vibration. Results have shown that, besides the postures and size of the passenger, the road conditions have effects on the pressure distribution and SEAT data. An improved seat structure with spring and damper properties was proven to be more effective in achieving seat vibration comfort. By improving the seat parameters according to those methods mentioned, the vehicle seats, such as buses' seats, could be developed in term of ride comfort for local purposes.

ABSTRAK

Tempat duduk merupakan salah satu aspek yang perlu dipertimbangkan untuk mendefinasikan keselesaan dalam suatu kenderaan yang sedang bergerak. Pengalaman menunjukkan bahawa suatu tempat duduk memberikan tahap keselesaan yang berlainan dalam keadaan yang berbeza. Keselesaan tempat duduk kenderaan terbentuk daripada gabungan factor-faktor statik dan dinamik. Penyelidikan ini bertujuan untuk mengkaji sifat-sifat statik dan dinamik pada suatu tempat duduk penumpang bas untuk keselesaan melalui penilaian secara subjektif dan objektif. Dua kajian soal selidik termasuk *pilot test* telah diadakan untuk mengkaji penilaian subjektif secara langsung daripada pengguna tempatan terhadap keselesaan tempat duduk semasa perjalanan mereka. Dua ujian sebagai penilaian objektif telah dijalankan, iaitu ujian *SEAT (Seat Effective Amplitude Transmissibility)* dan ujian taburan tekanan. *SAE Sit-pad Accelerometer* digunakan untuk mengukur getaran pada tempat duduk. Manakala, taburan tekanan pada permukaan antara manusia dan tempat duduk diukur dengan menggunakan sistem *pressure mapping*. Kedua-dua jenis ujian telah dijalankan dalam keadaan terkawal dan tidak terkawal. Keputusan menunjukkan bahawa keadaan jalan mempengaruh data taburan tekanan dan data SEAT, selain postur dan saiz penumpang. Suatu struktur tempat duduk yang telah diubahsuai dengan fungsi pegas dan perendam telah dibuktikan bahawa lebih berkesan dalam mencapai keselesaan tempat duduk. Dengan memperbaik parameter-parameter tempat duduk berdasarkan kaedah yang tersebut di atas, keselesaan tempat duduk kenderaan seperti tempat duduk bas dapat ditingkatkan untuk kegunaan tempatan.

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7.3 First sketch or drawing was made on (Date) : 13 / 5 / 2004 disclosed to and understood by (Name) : ______ on (Date) : ___ / ___ / ___

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10.2What is potential market ?

The major customers will be the bus manufacturers and bus companies. If the bus companies are interested, they can replace the current seat bases in their buses with the product from this invention. Joint venture together with bus manufacturer is also possible.

10.3Estimate commercial market in RM and USD : RM _______ USD _______

11. List independent referees with expertise in the area of the invention with whom we may communicate for additional information (with your approval) :

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12.1 Drawings, diagrams, figures, flowcharts, sketches etc. which illustrate the invention.
12.2 Chemical structural form (if the invention is a new chemical compound).
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12.5 Describe why your product or process is sufficiently novel compared to those already available to warrant patentability.

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

Comfort on automotive seats is dictated by a combination of static and dynamic factors (Ebe and Griffin, 2000). A seat that is comfortable in a showroom may have poor dynamic characteristics that make it uncomfortable in a vehicle on road. When considering the quality of the in-vehicle experience, it is therefore important to consider both static and dynamic comfort. Research on the project "Development of an Automotive Seat for Ride Comfort" is to serve those purposes of considering both static and dynamic conditions for automotive seat comfort.

This project had been granted RM253,000 under IRPA to conduct research towards the "Development of an Automotive Seat for Ride Comfort". Time duration of 2 years and six months was needed to conclude and build a solid ground on such development. Headed by Associate Professor Mustafa Yusof, this research has produced significant results in term of developing guidelines on the evaluation of seat comfort for both static and dynamic conditions, information database on the existing commercial vehicle seat designs and design guidelines towards producing an automotive seat which can provide maximum comfort to the user.

Both lab tests and field trials had been conducted to evaluate the existing commercial vehicle seat by acquiring sample from the industry of commercial vehicle. An attempt to correlate subjective assessment based on public opinions and test subjects with objective measurement were carried out. With focus on developing the right methods of testing and evaluation, results from this project are basically more on developing the guidelines for further study in this area.

1.1 Problem Statement

Trade liberalization of AFTA will require a world class standard cars and automotive components from local automotive manufacturers and components vendors. Various type and design of vehicles have been manufactured to fulfill the characteristic needs of user. However, the vehicle seat characteristics have not been studied fully in depth even though various vehicle models have been introduced. This project has emphasized the development of automotive seat to ensure maximum comfort to the passenger. Disturbance such as shock and vibration need to be reduced in order to produce a seat design which is comfortable and safe to users.

1.2 Objectives

The objectives of this project are:

1. To characterize automotive seat for ride comfort on existing vehicle through laboratory tests and road trials,
2. To develop new seat design for better ride comfort, and
3. To develop data base on vibration and pressure distribution to passenger.

These objectives will carry out evaluation methods for automotive seat and guidelines of automotive seat design.

1.3 Scope of Work

Scope of work for this project includes:

I. <u>Study on existing automotive seat</u>

A study on existing automotive seats will assist the development of new seat design for optimum comfort. Test sample was acquired to be tested and analyzed to understand the related theories and weaknesses of the existing design.

II. Purchasing and commissioning of test equipments

During this project, several equipments had been purchased and commissioned for testing purpose. Pressure mapping system has been commissioned to evaluate seat comfort based on pressure distribution. Transducer specifically for measuring vibration on seat based on International Standard and British Standard was also purchased to equip the existing system for vibration test on ride comfort.

III. Test Rig Development

A test rig for laboratory tests had been constructed to cope with the Universal Testing Machine for vibration test on the sample. Rigid load dummy was used to replace human subject due to safety purpose.

IV. Measurement Exercises

Subjective assessment was conducted to gather information on existing commercial vehicle seats from public and to evaluate perceived comfort.

For objective methods, both static and dynamic tests were conducted on seat sample. Types of test are:

1. Pressure mapping test for static evaluation
2. Vibration test for dynamic evaluation of test sample in laboratory environment using dummy.
3. Pressure mapping test for dynamic evaluation of test sample in laboratory environment using dummy.
4. Road trials; vibration and pressure mapping tests on existing commercial vehicle i.e. bus conducted on two male subjects.
5. Road trials; vibration and pressure mapping tests on seat sample from laboratory conducted on five subjects.
6. Road trials; vibration and pressure mapping tests on improved seat sample from laboratory conducted on five subjects.

V. Analyzing and evaluating of test results

Correlation on subjective and objective assessments was attempted. Results from laboratory tests and road trials were analyzed. Ride value was measured from vibration test.

1.4 Literature Review

1.4.1 Defining Comfort in Automotive Seating

Term “comfort” is used to define the short-term effect of a seat on a human body; that is, the sensation that commonly occurs from sitting on a seat for a short period of time. In contrast, the term “fatigue” defines the physical effect caused by exposure to the seat dynamics for a long period of time. Formal definition of comfort is different but according to dictionary, comfort is “State or feeling of having relief, encouragement and enjoyment”, or in scientific manner, “a pleasant harmony between physiological, psychological and physical harmony between a human being and the environment”. It has also been referred as “absence of discomfort”. Many research studies indicate that “discomfort is primarily associated with the physiological and biomechanical factors”. Being comfortable has a very broad definition. Comfort is subjective and it is difficult to define this term objectively in order to determine design specification of seat that will provide this attribute to an occupant (Pywell, 1993). Some comfort definitions based on literature review are listed as below:

i. Comfort is some state of well-being or being at ease (Oborne and Clarke, 1973). Comfort implies a conscious well being and perception of being at ease. This definition is very general and does not represent any means of measuring comfort.

ii. Comfort is the absence of discomfort (Branton, 1969, Cortlett, 1973, Herzberg, 1958). For testing purpose, only discomfort will exist and comfort is only the absence of discomfort. Thus, according to this definition, comfort cannot be provided in seat design but sources of discomfort can be eliminated. Comfort exists when physical discomfort is reducing.

1.4.1.1 Three Modes of Ride Comfort Process (Sitting Comfort)

Seating comfort is strongly related to physical comfort of an occupant. Physical comfort can be defined as the physiological and psychological state perceived during the autonomic process of relieving physical discomfort and achieving corporeal homeostasis. There are three modes of comfort identified; static, transient and dynamic comfort (Shen and Vértiz, 1997). Comfort is experienced during a dynamic process rather than static. Discomfort can be static and exist for as long as the bodily balance is not assumed. However, comfort only exists when some positive changes are being made. When discomfort is not present, comfort does not necessarily exist, and it is only “indifference” (Branton, 1969). Feelings of comfort may gradually saturate or even disappear some time after discomfort is eliminated and homeostasis is reached. Homeostasis is a state of equilibrium between different but interrelated functions or elements, as in organism or group (Webster Dictionary, 1984).

However, human beings are stimulus seekers and human sensory functions work as cycles of excitation and adaptation, meaning that when homeostasis is reached or body is in ease for a period of time, the excitation which induces sensation is gone. Thus, the sensation of comfort is also gone. Therefore, seat comfort is a temporal process rather than a static condition. Comfort should be treated as the relieving process of discomfort rather than being simply as the absence of discomfort (Shen and Vértiz, 1997).

Therefore, perceived comfort relates both the level of discomfort and the elimination process of discomfort. Both excitation and adaptation level of comfort are described as time courses of changing discomfort and comfort.

According to Shen and Vértiz (1997), there are three modes of ride comfort process; initial comfort, transient comfort and dynamic comfort, as shown in Figure 1.1. The explanation will be based on the hypothetical load-deflection curve of a seat cushion assembly.

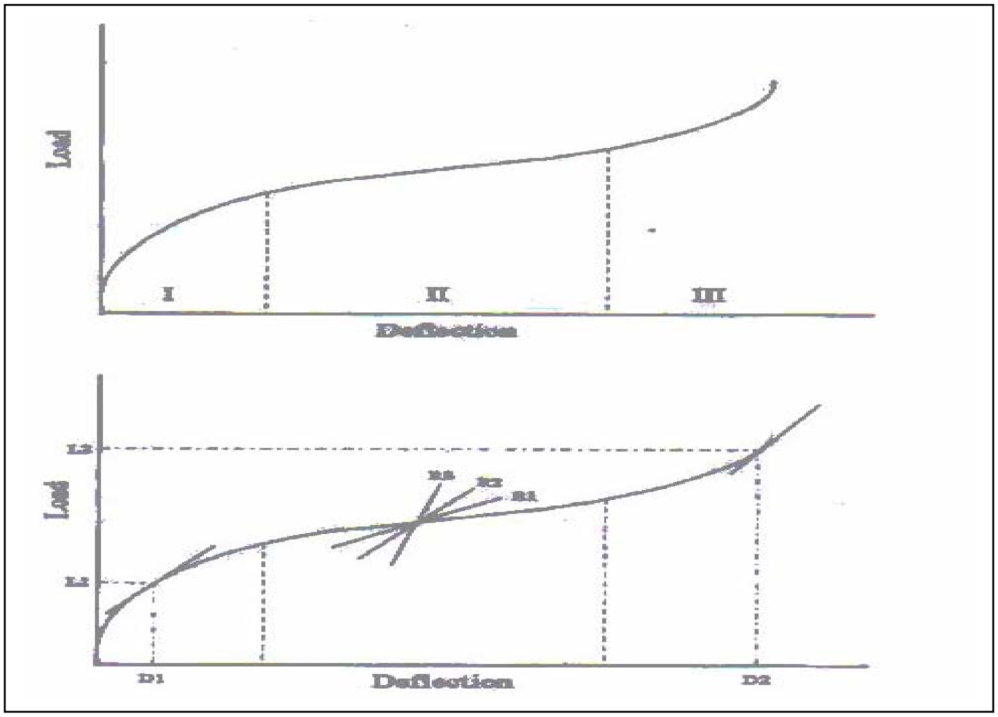


Figure 1.1: Seat force-deflection curves

1.4.1.2 Evaluation of Seat Comfort (Static and Dynamic)

Good test and measurement methods for seat comfort evaluation can be important tools in the development of an automotive seat to fulfill the criteria of ride comfort. Static comfort can be evaluated using postural assessment, interface pressure and other standard ergonomic techniques. Dynamic comfort is usually assessed by making vibration measurement on the surface of passenger seats using method based on standards such as ISO2631, BS6841 etc., or through on-road trials. Subjective assessment is as important as objective measurement. A correlation from both assessments will practically ensure ride comfort of the automotive seat users. This project focused on two types of objective measurements; vibration and pressure distribution tests, as well as subjective assessment by gathering public's and selected subjects' opinions.

1.4.2 Pressure Distribution

Interface pressure measurement systems have been developed to provide information on the interaction of forces between persons and a surface such as a bed or a seat. They are designed to provide information on forces axial or perpendicular to the interface and, if in an array or matrix, can provide information on patterns of pressure distribution between sensors.

1.4.2.1 Previous Studies on Pressure Distribution

The technique of interface pressure measurement has generated a considerable interest as a method used to predict automotive seat discomfort. Automotive seat is partially similar in function as our home furniture such as sofa or chair. In addition to support a sitting person, automotive seat needs extra design criteria in order to enable the seat functioning well in a wide range of mobile operating conditions. Since surface pressure can cause discomfort while sitting, the seat comfort on a journey is critical and needs attention. When designing for comfort, with regard to interface pressure distribution, there are two pressure distribution conditions applied. The averaging pressure is evenly distributed on the seat surface and concentrated pressure is more on rigid parts of the body such as ischial tuberosities (Seigler, 2002).

Several studies were conducted to relate the seat discomfort or driver comfort with interface pressure. Kamijo et al. (1982) evaluated 43 car seats as comfort or discomfort with no time indication. The results stated that static pressure distribution approximately correlated with the difference between comfortable and uncomfortable seats. However, the analyses were based on the patterns of pressure readings of only one subject being matched with the subjective evaluations of each seat by 15 subjects. Lee and Ferraiuolo (1993) used a large number of subjects (100 individuals) to evaluate 16 similarly visualized car seats. The seat parameters were varied; foam thickness and hardness, back contour and angle, cushion angle, spring suspension rates and side support. Each subject is to sit for 2 minutes on each seat and evaluate the seat. Despite the large number of subjects, the author concluded that there were not enough correlation between pressure and subjective comfort to form the basis of design decisions.

Gross et al. (1994) recorded the perceived comfort of 12 aspects of the seat for each of 50 car seats. Each seat lasted for 5 to 10 minutes. The authors concluded that the pressure data statistics were strongly related to perceived comfort and therefore perceived comfort can be predicted. Shen and Galer (1993) attempted to build a multifactor model of sitting discomfort using interface pressure measurements. The force applied to the body, the sitting postures, the move ability of the body on the seat and time sitting in a posture was considered as factors involved. In the pilot experiment, 11 subjects sat on the experimental seat for a 40 minutes session. 2 seat angles (10° and 20°) and 3 seat cushion backrest angles. It was revealed that general ratings of discomfort were not found to be sensitive to postural differences but pressure measurements did significantly reflect these changes.

There were also researches conducted on dynamic analyses of pressure distribution. However, researches performed in this area of study are quite limited. Since pressure distribution is one of the aspects of comfort analyses, deformation of soft tissues due to seat loading during dynamic condition will be particularly relevant for comfort. Knowing the exact pressure distribution profiles between cushion and subject show more about the effect of the seat cushion, the posture of the driver, and the way the pressure points are distributed over both ischial tuberosities points.

An experiment was conducted to investigate the dynamic pressure distribution on visco-elastic seat measured under sinusoidal vibration. A group of subject weighing from 470N to 931N was selected to investigate the variations in the contact force, pressure and area caused by vibration. Each subject was required to sit on the seat while adapting to two seated postures; erect with back not supported and erect with back supported. The distribution of contact pressure and forces between the seated human subjects and visco-elastic seat was experimentally studied under vertical vibration of different magnitudes in the 1-10Hz frequency range and compared between soft seat and rigid seat. The results showed that the maximum variations in the ischium pressure and effective contact area on a soft seat occur near the resonant frequency of the coupled human-seat system in the frequency range of 2.5-3.0 Hz. The pressure distribution on the soft seat was distributed more evenly on a larger effective contact area than on rigid seats (Wu et al, 1997). An extended road trial study also had been conducted to further investigate the potential value of pressure distribution data in the prediction of reported discomfort (Gyi et al, 1999). Road trial data were collected from three cars and then interface pressure data were recorded for each of the three seats. However, the study revealed that there was no clear relationship found between reported discomfort and pressure distribution data.

1.4.2.2 The main types of sensors used in pressure distribution measurement

Generally, the main types of sensors used to measure the interface pressure distribution are electronic (capacitive, resistive, strain gauge), pneumatic and electro-pneumatic.

Electronic transducer consists of deformable component to which a sensing element is attached. The applied force results in variations in resistance or capacitance which can be measured electrically. Few of the pressure distribution systems available in market are Xsensor with capacitive-based sensors and Tekscan with resistive-based sensors.

The pneumatic sensor is an air cell connected to an air reservoir. In order to inflate the sensor, the pressure in the air reservoir must slightly exceed that applied to the sensor. As inflation pressure rises above applied pressure, the volume of air in the sensor increases suddenly, causing an abrupt drop in the rate of pressure increase. The pressure in the air reservoir which changes the rate of pressure increase is recorded as applied interface pressure. One of the commercially available sensors of this type is the Talley Pressure Monitor (TPM) sensor.

Electro-pneumatic sensors have electrical contacts on the inner surface of a flexible, inflatable sac. Air is pumped into the sac. When both internal and external pressure are in equilibrium, the electrical contact breaks and pressure at this point is recorded as interface pressure.

Table 1.1 below compares different sensor type used in pressure measurement system.

Table 1.1: Characteristics of different pressure measurement systems

Sources: Reference 5; (Cardi M, personal communication)

Sensor type/ Transducer	**Advantages**	**Disadvantages**	**Description**
Dye-releasing capsules; chemically impregnated sheets	• simple • easy to use • inexpensive	• sensitive to temperature and humidity • values obtained unreliable and of limited use.	Reaction at a rate modified by the applied pressure
Simple electropneumatic closed system	• simple • commercially available • useful for routine measurements	• cannot differentiate between normal pressure and shear • possible breakage of electric conductors	Sensor is inflated until the electrical contact on the opposing internal surface of the thin, flexible walled capsule are separated. Capsule is allowed to slowly deflate until the indicator shows that the walls are in contact again - this is the interface pressure.
Pneumatic, strained-gauge diaphragm continuous output	• sensors available in small sizes and diameters (less than 3 mm) • thickness less than 1 mm • useful for pressure-time history	• sensors rigid • expensive • cannot differentiate between normal pressure and shear	Measurement of displaced volume of air as the interface pressure increases. Pneumatic sensor arrays consisting of more than 90 elements have been developed for dynamic pressure measurements.
Resistance or capacitance	• portable, self-contained units are commercially available • relatively inexpensive • versatile, can be configured into various shapes and sizes - clinically useful • thin • can withstand large overloads	• hysteresis • creep • sensitive to shear, temperature, moisture and curvature • depends not only on the load but also the previous load history • difficult to obtain an unambiguous measurement	Transducer responds to increased pressure with increased capacitance. When the capacitance of the transducer varies, the current flow varies. The magnitude of the current is related to the magnitude of the pressure exerted on the transducer.

1.4.2.3 Previous studies using pressure measurement system

There are several types of pressure measurement system available in market which has been used in several studies to analyze the seat comfort and interface pressure relationship. Those studies are:

1. Buttock and back pressure distribution tests on seat of mobile agricultural machinery (Hostens et al., 2001):
   - The study was conducted to compare the static buttock and back support pressure of four combine foam seats and a new air-based seat. These seats were tested for static pressure distribution characteristics.
   - This study compared and evaluated existing solution of foam based combine seating systems and the new air based cushion designed especially to minimize sitting discomfort during prolonged sitting and driving.
   - The study used Xsensor pressure measurement system.
   - The technical specifications of Xsensor system:
     - Capacitive sensor system
     - Able to detect the areas of extreme pressure
     - Cushion pad size : 46cm x 46cm
     - Number of sensors : 1296 capacitive sensors
     - The sensor's thickness : 0.64mm (compressed)
     - The sampling rate : up to 5000 sensors per second
     - The pressure range : 0-220mmHg (0-29.33kPa)
   - Pressure distribution profile from each seat was compared. Each pressure profile of the back or the buttock is called a frame. From each frame the maximum and mean value of pressure was calculated.

2. Distribution of human-seat interface pressure on a soft automotive seat under vertical vibration (Wu et al., 1999):
   - This research conducted experiment to study distribution of contact pressure and forces between seated occupant and soft seat (visco-elastic) under vertical vibration in the 1-10Hz frequency range.

- The experiment used a flexible grid of pressure sensors because accurate measurement of pressure distribution in the area of ischial tuberosities (occupant body part) requires a closely spaced measurement grid of thin, miniature and flexible sensors.
- Due to large hysteresis problem associated with the force sensing resistors, capacitive sensors were used in the study. Thus, PLIANCE System developed by NOVEL Inc. using capacitive type of sensor for their pressure measurement system was used in this study.
- PLIANCE pressure measurement system comprises of:
  - Pressure sensing mat of 16 x 16 flexible capacitive sensors
  - Analyzer with analog amplifier
  - A control / interface module
  - Data acquisition system
- Description of the PLIANCE System
  - The sensing matrix (16 x 16) comprises of 256 sensors molded within a mat of flexible material with thickness less than 2mm
  - Surface area of each sensor is 1 cm^2
  - Distance between the centers of successive sensors in row or column is 2.45 cm
  - Spacing between sensors (row or column) is 1.45 cm
  - Total surface area of the sensing mat is 1536 cm^2
  - Note: more sensors in the sensor matrix would increase the spatial resolution at the price of reducing the sampling rate (reducing the highest vibration frequency that can be studied)
  - The analyzer samples data from the sensor matrix during a measurement and transfers it to computer through the serial interface
  - Sampling rate of the entire PLIANCE System is limited to 21.2 Hz

3. Seat pressure measurement technologies: considerations for their evaluation (Gyi et al., 1999):

- The study evaluated one of the commercially available pressure measurement systems to understand the strengths and weaknesses of the system. Thus, the sensor matrix was redesigned to improve its performance.
- The Talley Pressure Monitor Mark 3 (TPM) was evaluated against several criteria as following:
  - Repeatability and calibration
  - Partial sensor coverage and TPM accuracy
  - Sensor curvature and TPM accuracy
  - Sensor stretch and TPM accuracy
  - Literature (Ferguson-Pell and Cardi,1991)
    - TPM produced the most accurate and repeatable measurements but limited by scan rate and ease of use.
    - Could only be used for static measurement.
- TPM3 is a pneumatic system.
- Technical Specifications of the existing TPM3
  - Diameter of the individual sensor is 20mm
  - Pressure range of 0-100mmHg
  - Only 48 sensors to cover an area of 330 x 330mm
  - Distance between centers of successive sensors (row and column) is 100mm. Thus, this system has a poor resolution.
  - Sensor thickness is 0.05mm.
  - Graphical display before redesign was inadequate.
- The redesign of the TPM system:
  - The sensor diameter is 20mm
  - Number of sensors is 144 for seat pan and seat back. Thus, there are 72 cells for each part.
  - Design only half of matrix sensor for measuring right side of seated body. Asymmetry in seated pressure maps of normal individuals was noted to make such decision.

1.4.3 Vibration Analysis

There has been strong body of opinion that vibration and shock cause significant disturbance on human comfort and health. This opinion has been recognized by International Standard on human-body vibration (ISO 2631) and other standards i.e. British Standard (BS 6841). Seating comfort in all vehicles is affected by the interactions of the vehicles with the rough terrain and power source. A comfortable seat should be able to isolate the automotive seat occupant from road and vehicle vibrations.

Experimental methods that consider human body behaviour under random vibration can be both objective and subjective. Objective methods consider and evaluate changes in blood pressure, fluid levels in the human body, etc (Simić, 1970), which are medical methods and also human-seat pressure distribution. Subjective methods are based on subjective assessments of human exposed to vibration. For this purpose, equal comfort curves are usually in use (Simić, 1970).

Beside cars and buses, several agricultural machinery-seating systems have been tested for the effects of seat suspension on exposure to whole body vibration of professional driver (Burdorf and Swuste, 1993). Sharing same theory with agricultural machinery seats, more comparative studies need to be produced with regards to pressure related information of different passenger seats (Hostens et al, 2001).

It is important to consider the vehicle and human as a coupled dynamic system when considering the vibration that will be experienced by a passenger in a bus. In addition, there are usually a number of possible sources of vibration that can reduce the perceived comfort of the occupants. Two possible vibration sources are the road input at the tyre contact patches as well as the induced vibration from the power train and engine. The vibration from these sources is filtered by the structure dynamic transmission paths from the points of excitation to the seat tracks, which are usually attached to the floor-pan of vehicle. The resultant vibration may be amplified in some frequency regions and attenuated in others, depending on structural resonance occurring in the transmission path. As a seat is constructed by combining a metal frame with spring and foam it will also result in additional modification of the vibration. Moreover, since the human body can be modelled as a mechanical system consisting of masses connected by spring and dampers, the resultant transmissibility will also depend on the build, height and weight of the occupant as well as the dynamic of the seat (Ebe and Griffin, 2000).

Contours of equivalent comfort are similar for x-axis and y-axis vibration of seated subjects when there's no backrest (Griffin, 1982). Horizontal seat motion is most easily transmitted to the upper part in the region of 1-2 Hz. Presence of a backrest may greatly alter the situation.

Researchers looked at road roughness as the primary source of vibration in vehicles and tried to measure and correlate the human response to these vibrations. For instance, vibration at 4 Hz was found to cause severe discomfort in humans due to the fact that the spine, shoulders, and the head resonate near this frequency (Seigler, 2002).

It was then realized that other important vibration sources existed from the tyres, driveline, and engine. Subsequent studies were performed that evaluated human exposure to whole-body vibration from a vehicle and how it affected human discomfort. Afterward, researchers understood that vibration and acceleration were only part of the discomfort for the driver.

In order to obtain the SEAT value of a seat, there are two sensors to be used to measure the vibration of a seat during vehicle drive; one for the seat base vibration and another for seat pan vibration. The sensor for seat base is a normal type low-frequency (50Hz) accelerometer whereas the sensor for seat base is a SAE seat pad accelerometer.

1.4.3.1 SEAT Calculation

Seat Effective Amplitude Transmissibility (SEAT) is a non-dimensional measure of the efficiency of a seat in isolating the body from vibration or shock. SEAT values have been widely used to determine the vibration isolation efficiency of a seat. SEAT value is defined as:

$$\text{SEAT\%} = \frac{\text{Vibration on the seat}}{\text{Vibration on the floor}} \times 100 \quad (1)$$

Vibration on the seat and vibration on the floor can be represented by the root mean square (RMS) or vibration dose value (VDV) of the measured signals. This can be expressed graphically in Figure 1.2.

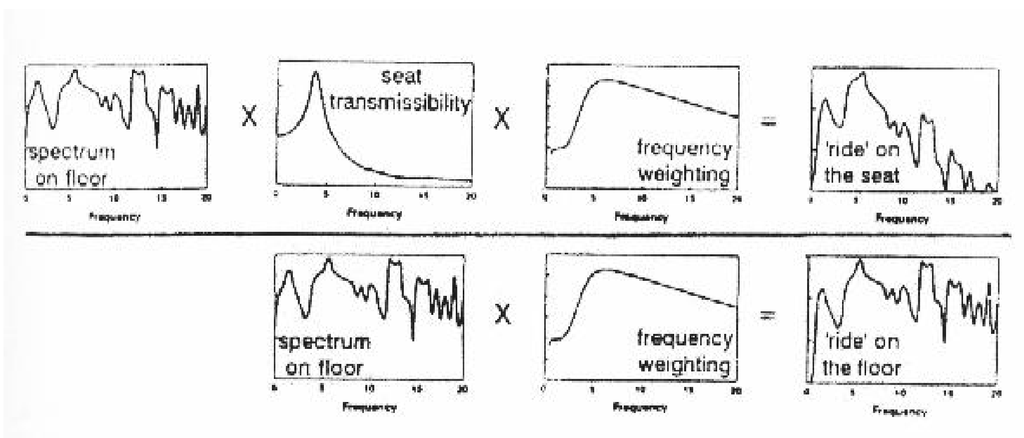


Figure 1.2: SEAT calculation

If a seat with low crest factor motions is assessed, the SEAT value is given by:

$$SEAT(\%) = \left[\frac{\int G_{ss}(f) W_i^2(f) df}{\int G_{ff}(f) W_i^2(f) df} \right]^{\frac{1}{2}} \times 100, \quad (2)$$

$G_{ss}(f)$ and $G_{ff}(f)$ are the seat and floor acceleration power spectra and $W_i(f)$ is the frequency weighting for the human response to vibration which occurs on the seat.

If the transfer function, H(f) is known, the SEAT value may be calculated from the floor vibration spectrum, $G_{ff}(f)$:

$$SEAT(\%) = \left[\frac{\int G_{ff}(f) |H(f)|^2 W_i^2(f) df}{\int G_{ff}(f) W_i^2(f) df} \right]^{\frac{1}{2}} \times 100 \tag{3}$$

This expression is useful as the SEAT value can be obtained without having to test the seat vibration. For example, it may be used to predict the change in SEAT value that will occur when a vehicle is used on a different road surface giving a different spectrum of floor vibration. Besides, it could also be used to predict the improvements in ride comfort obtained in a vehicle by fitting a seat from another vehicle.

Crest factor, in this case, is defined as the ratio of the peak value to the RMS value of the acceleration:

$$\text{Crest factor} = \frac{\text{Peak acceleration}}{\text{RMS acceleration}} \tag{4}$$

The crest factor is usually calculated from the acceleration after it has been frequency weighted according to human sensitivity to different frequencies. Crest factor for typical vibration in vehicle during a good road condition is in the range 3-6. However, the crest factor will increase with the increase of peak value (shock). If there is a high crest factor for the motion either on the floor or on the seat, the SEAT value should be obtained using vibration dose value (VDV):

$$\text{SEAT}(\%) = \frac{\text{VDV on the seat}}{\text{VDV on the floor}} \times 100 \tag{5}$$

The VDV on the floor is calculated using the same frequency weighting applied to the vibration occurring on the seat.

$$\text{VDV} = \left[\int_{t=0}^{t=T} a_w^4(t)\,dt \right]^{\frac{1}{4}} \qquad (6)$$

$a_w(t)$ is the frequency weighted acceleration time history and T is the period of time over which vibration may occur. Frequency weighting is applied to the signals before calculations to account for human vibration perception. This is the method of assessing the cumulative effect of vibration which is defined in BS6841.

In order to obtain the SEAT value of a seat, there are two sensors to be used to measure the vibration of a seat during vehicle ride; one for the seat base vibration and another for seat pan vibration. The sensor for seat base is a normal type low frequency accelerometer whereas the other sensor for seat base is a SAE sit-pad accelerometer.

The isolation efficiency of a seat depends on the vibration input spectrum, the seat transfer function and the relative sensitivity of the body to different vibration frequencies. Maximum attenuation is required at frequencies when there is a maximum floor vibration and the body is most sensitive.

1.4.3.2 Frequency Weightings

The most frequently used standards for frequency weighting are ISO 2631-1, BS 6841 (Figure 1.3). The frequency weighting used in this research is the BS6841 straight-line approximations as shown in Figure 1.4.

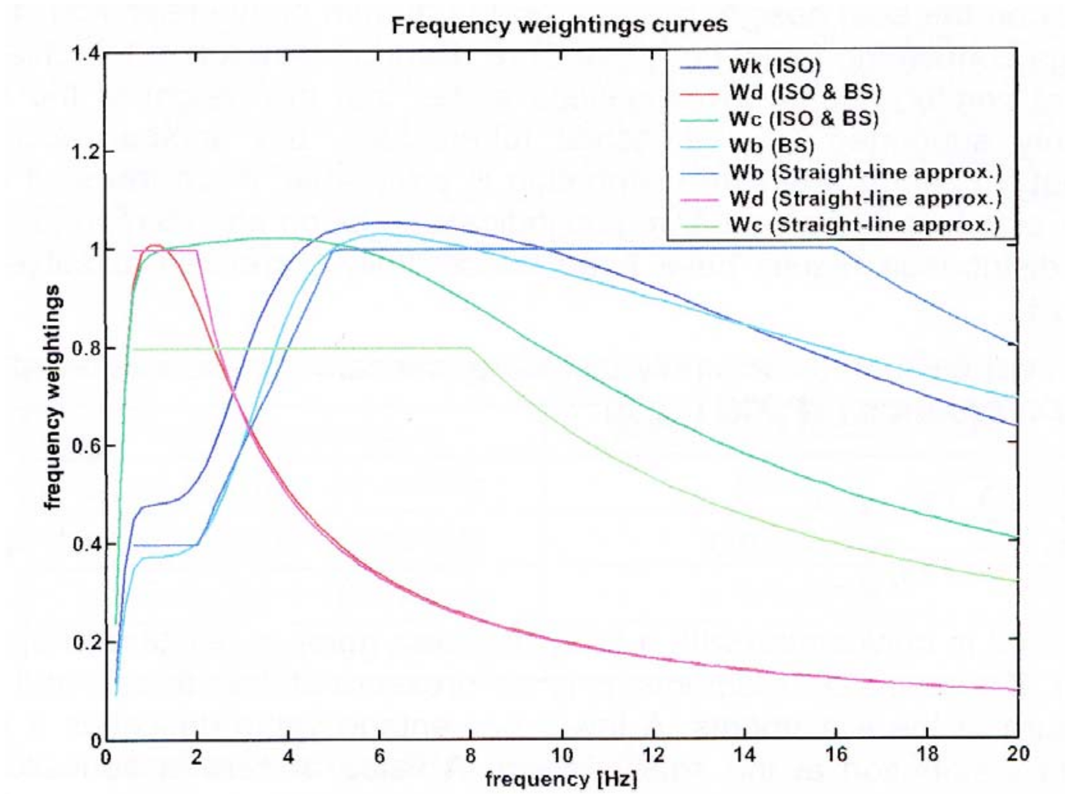


Figure 1.3: Frequency weighting curves.

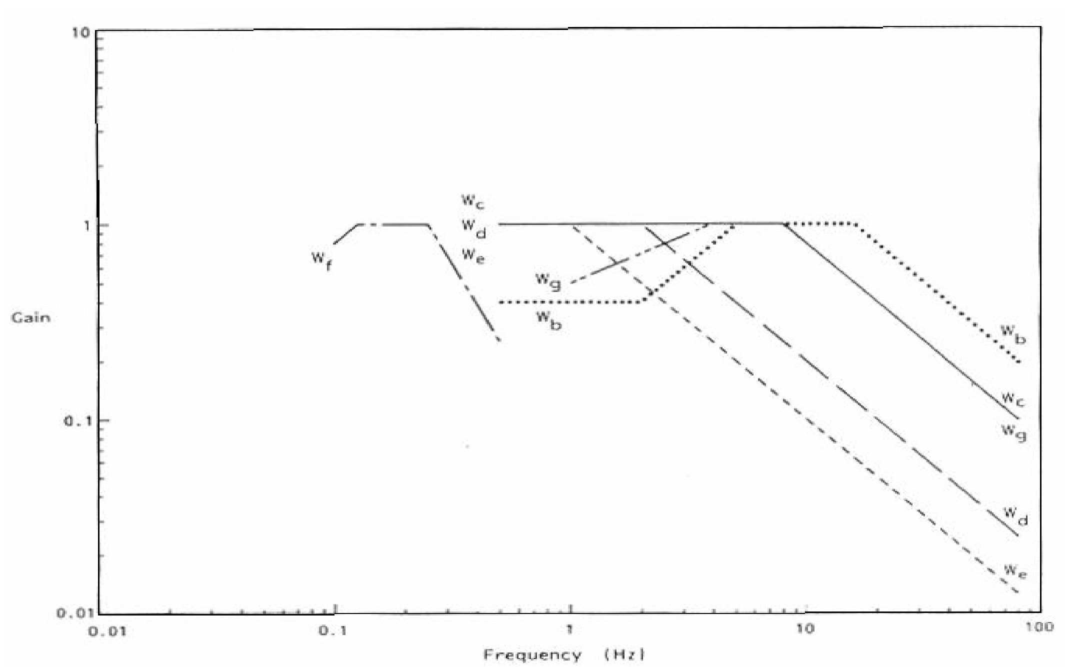


Figure 1.4: Asymtotic approximations to frequency weightings W_b, W_c, W_d, W_e, W_f, and W_g for whole body vibration as defined in BS 6841 (British Standards Institution, 1987a)

CHAPTER 2

SUBJECTIVE ASSESSMENT

This method is to gather public's opinion towards the seat comfort of commercial vehicles. From this method, the questionnaire design, data collection process and initial responds from public would be tested. Besides, the survey's results also report the assessment of public evaluation on existing seat features of local commercial buses and identify the most experienced ailments during long journey traveling. This would assist in the investigation on correlation between parameters that might exist.

During this research, the survey had been carried out to gain insights of ride discomfort for long distance journey at the rest area near the highway where most buses would stop for about half an hour. It is an interview-based method. Interviewers approached the public and asked for some of their time to answer the questions. It is necessary to explain any terms and questions that public might not be familiar with. The interview was conducted in a day; responses were collected as many as possible. Respondents evaluated the questionnaires based on their journey. They were asked to rate the seat features and body part discomfort (BPD) scale using scale of 1 to 5. The target population for the study is adult respondents ageing from 18 to 50, traveling to anywhere in Peninsular Malaysia covering all regions; center, north and east coast to south, and vice versa.

The type of buses targeted for the survey study was long journey buses which cruised on the highway. For such buses, there are two main seat arrangements: single and double seats. The features of both types of seat are almost the same, except the size. The questionnaire (APPENDIX A) was designed in such a way that the participants would respond for general questions first then move toward those more specific questions. People prefer responding to the questions by selecting the suitable rating scale. The survey also included questions seeking for participants' opinion about the seat and sources of discomfort. Participants would have to respond to the body part checklist (body part discomfort) at the later part, to identify discomfort experienced on certain body parts. Most of the questions are close-ended questions and there are also some open-ended questions to seek for participant's opinion. Such responses are useful and valuable to develop an automotive seat which will reduce or minimize discomfort even during long-hour sitting. Therefore users' point of view is very important. The questionnaire contains the following aspects:

(a) Demographic questions – Participants would have to give the rough measurement of their body size: weight and height, besides gender, age and back or neck pain history.

(b) Seat characteristics - height, width, depth, cushion, stability, surface, armrest height, backrest inclination, personal acceptance for the seat and overall discomfort. Participants would be asked to assess each characteristic in five rating scale (Drury and Coury, 1982).

(c) Body part discomfort (BPD) - Participants were to evaluate the discomfort of certain body part which will be faced during the journey. There are 12 parts - neck, shoulder, upper arms, lower arms, hands, upper back, mid back, lower back, buttock, thighs, legs and feet. They would be evaluated using 5 rating scales from 1 to 5: 1 for 'comfortable/no pain', 3 for 'less comfortable', and 5 for 'very painful/ uncomfortable'.

(d) Overall evaluation - Participants would be asked to tick the overall comfort rating.

Two surveys were carried out; one as the pilot survey and another one as the actual survey. The findings from the pilot test would be used to modify the instruments, correct the procedures and the type of analysis to be conducted. Analysis was based on descriptive statistics, where information of parameters involved was reported based on frequencies, averages, measures of dispersion and correlation involved. Based on the pilot test result, a regression model on an overall seat comfort had been attempted. Questionnaire had been studied and restructured for the actual survey. Therefore there were 2 sets of questionnaires (APPENDIX A1 - Pilot Survey, APPENDIX A2 - Actual Survey) and also 2 sets of results. Following are the analysis results of both the pilot test and the actual survey.

2.1 Subjective Evaluation of Ride Comfort (Pilot Study)

2.1.1 Objectives

1. To test the questionnaire design, data collection process and initial responds from public.
2. The findings from the pilot test will be used to modify the instruments, and correct procedures, and type of analyses to be conducted.
3. To report the assessment of public evaluation on existing seat features of commercial buses in Malaysia and identify most experienced ailments during journey.
4. To investigate any correlation between parameters that might exist and build a model of ride comfort.

2.1.2 Methodology

1. Date: 13 August 2004

2. Location: Lucky Garden Sdn. Bhd., Yong Peng

3. Target Group

   The target group is the adult population consisting of male and female who travel by bus (19-50 yrs old).

4. Method of collecting data
   - Interview-based method. It is necessary to explain any terms and questions that public might not be familiar with.
   - Location of interview: Rest area near the highway where most buses stop for about half an hour. Interviewer approached the public and asked for some of their time to answer the questions. A token of

appreciation was distributed to respondent for his or her willingness to participate.

- The interview was conducted in a day; responses were collected as many as possible.

5. Questionnaire Structure

There are 5 sections in the questionnaire set to be answered; Demographic, general questions on journey, seat features evaluation, Body Part Discomfort (BPD) scale and sources of discomfort. The set consists of 6 pages. (A sample of questionnaire is available)

i. Demographic Questions

To retrieve personal information such as respondent's age, medical history and physical statue.

ii. General question on journey

To identify the destination, seat type, location and sitting period before the bus stops for rest. Respondent will also be asked about their frequency of traveling by bus and preference of seat type and seat location.

iii. Seat Features Evaluation

Respondent will be asked to rate his or her seat based on rating scale given (5 points rating scale) and seat features that are listed. Respondent will also be also asked to select an overall value of seat comfort given a group of range value.

iv. Body Part Discomfort (BPD) Scale

Scale used:

1	2	3	4	5
No pain / discomfort		Moderate pain / discomfort		Extreme pain / discomfort

To assess most experienced ailments during journey on bus. A human figure labeled with human parts was provided to ease the rating process.

v. Sources of Discomfort

To identify sources of discomfort based on list of sources possibly causes discomfort during ride on bus. Other comment on seat will also be acquired if exist.

6. Method of analyzing result

Analysis will be based on descriptive statistics; where information of parameters involved will be reported based on frequencies, averages, measures of dispersion and correlation involved. Based on this pilot test result, a regression model on an overall seat comfort will also be attempted. Questionnaire will be studied and restructure if necessary before actual survey takes place.

2.1.3 Results

2.1.3.1 Descriptive Results

Statistical Summary of Respondents

	AGE(YEARS)	WEIGHT(KG)	HEIGHT(CM)
MINIMUM	19	39	145
MAXIMUM	50	110	180
MEAN	28	67.3	163.82
STD. DEVIATION	10.56	20.7	10.07

There were 23 respondents involved in this study; 43.5% female respondents and 56.5% male respondents involved in this pilot test study and willing to spend some times to be interviewed. This group of respondents comes from multi-racial background; 62.5% were Malays, 17.4% were Chinese, 8.7% were Indians and the rests were from other races. The summary of demographic characteristics of the inquired populations is depicted in table as shown above.

Based on the number of respondents participated during the campaign, age of participations were ranging from 19 – 50 years old. Minimum age was 19 and maximum age was 50 with mean of 28 years old and standard deviation was 10.56 years. Weight and height was varied from 39 to 110 kg and 145 to 180 cm respectively. It is also reported that based on respondents' medical history, 80% never experienced any ailments related to back and neck, 13.0% experienced neck pain, 4.3% experienced back pain and 4.3% experienced both.

General Information regarding respondents' journey

There were 3 different regions classified to each respondent based on his or her destination. Geographically, destinations in Peninsular Malaysia has been divided into 3 regions; center (from southern state (Johor) to central states (up to Selangor) and vice versa), North (from southern state to northern states (up to Perlis) and vice versa) and East Coast (from southern state (Johor) to east coast of Peninsular Malaysia (up to Kelantan) and vice versa). 87% of the respondents were heading towards south to central or vice versa. 8.7% were going to east coast or from east coast to south and only 4.3% were heading to north or vice versa. However, geographic bias is not expected to be a significant factor in this study.

Since there are two main seat arrangements seen in most local buses, single and double seat type; 56.5% respondents in the study, sat on double seat and 43.5% sat on single seat. However when asked of their opinion which type of seat they do prefer, 78.3% preferred to sit on single sit, and the rest were being not selective. Respondents were also asked about their seat location during journey. 26.1% of the respondents sat in front row seat, 47.8% of the respondents sat in the middle row and 26.1% sat at the back. While when they were asked on their location preference; 47.8% preferred to sit in the middle, 26.1% preferred to sit in the front, 13.0% preferred to sit in the back row and the rest were being not selective. We asked them this type of questions in order to investigate more if seat type and its location had influenced their judgment on ride and seat comfort. Given three range of sitting period before the bus stops for rest, only two group of sitting period were reported; 69.6% were reported to sit about 1 to 2 hours and 30.6% reported to sit more than 2 hours but less than 4 hours. Respondents were also asked on their frequency ride by bus in a year. 43.5% claimed to ride a bus for long journey once in a month, 30.4% claimed going for long journey few times in 3 months and 26.1% claimed experienced ride only once in 6 months or less.

Respondents were also asked to check if their seat has seat parts listed; armrest, backrest mechanism and footrest. All respondents have confirmed that armrest was available on their seat, while one respondent reported that his backrest adjuster was broken and 2 respondents did not have footrest on their seat.

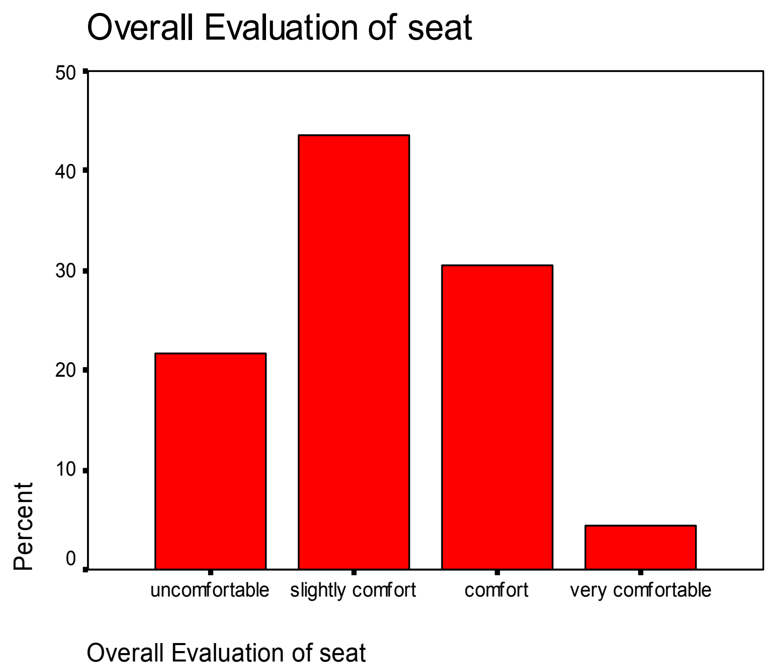
Evaluation of Seat Features

Seat features were evaluated using a rating scale of 5 points numbered as 1 to 5; value of 3 represents neutral value i.e. 'just nice' value. Treating the scale as if continuous scale (ordinal data treated as interval), mean and standard deviation value for each seat feature evaluation was depicted as in the table below

Table1

		Seat Height	Seat Width	Seat Depth	Seat Cushion	Seat Structure	Seatpan Shape	Armrest Height	Backrest Width	backrest inclination	Backrest shape	Personal Acceptanc e	Overall Evaluation of seat
N	Valid	23	23	23	23	23	23	23	23	22	23	23	23
	Missing	0	0	0	0	0	0	0	0	1	0	0	0
Mean		3.09	2.87	2.87	3.17	3.48	2.91	3.22	2.96	2.91	2.78	3.13	3.17
Std. Deviation		.417	.757	.626	.717	1.275	.596	.600	.638	.526	.600	.458	.834

As shown in the table, mean value of evaluation on each seat feature was ranging from 2.78 (backrest shape) to 3.48 (seat structure). Overall, no extreme mean value or large value of standard deviation was shown in this evaluation, showing that the probability of 5 point scale was not fully used by most of the respondents.



Body Part Discomfort (BPD) Evaluation

Body part discomfort scale is a 5 point scale with lowest value (1) represents no pain or no discomfort and highest value (5) represents painful or very discomfort on respondent's body parts. There were 12 body parts to be evaluated by respondents. When the data was treated as continuous rating data, result was depicted as below,

Table 2

		Neck	Shoulder	Upper Arm	Lower Arm	Hand	Upper Back	Middle Back	Lower Back	buttock	Thigh	Leg	Fee t
N	Valid	23	23	23	23	23	23	23	23	23	23	23	23
	Missing	0	0	0	0	0	0	0	0	0	0	0	0
Mean		2.57	1.87	1.52	1.43	1.43	2.13	2.04	2.13	2.04	1.74	1.48	1.43
Std. Deviation		1.037	.920	.790	.788	.896	1.058	.928	1.100	1.065	.915	.846	.896

Mean value for BPD rating on 12 body parts was ranging from 2.57 to 1.43 which indicated a slightly inflated use of the scale. Most respondents' complaint of discomfort or pain was on neck, upper, middle and lower back, buttock and some were on shoulder. While feet, leg, hand and arms were reported not experiencing any ailments. No extreme value of 5 was reported on any body part. Complaint ailments on neck, lower back and buttocks were also highly reported in survey on heavy duty trucks operators reported by The Heavy Duty Truck Seating Task Force of the S4 Cab & Controls Study Group of The Maintenance Council (TMC) of The American Trucking Association in paper entitled 'User Perspectives on Seat Design'.

Table 3: Frequencies (%) of BPD Scale Result

No Pain/ No discomfort ↔ Painful/ very discomfort

No	Body Part	1	2	3	4	5
1	Neck	26.1	4.3	56.5	13.0	-
2	Shoulder	43.5	30.4	21.7	4.3	-
3	Upper Arm	65.2	17.4	17.4	-	-
4	Lower Arm	73.9	8.7	17.4	-	-
5	Hand	78.3	4.3	13.0	4.3	-
6	Upper Back	39.1	17.4	34.8	8.7	-
7	Middle Back	39.1	17.4	43.5	-	-
8	Lower Back	43.5	8.7	39.1	8.7	-
9	Buttock	43.5	17.4	30.4	8.7	-
10	Thigh	56.5	13.0	30.4	-	-
11	Leg	73.9	4.3	21.7		
12	Feet	78.3	4.3	13.0	4.3	-

2.1.3.2 Correlation and Regression Analysis

Correlation or the Pearson product-moment correlation designated a simple correlation between two variables in study. The relationships between paired variables among many variables in study were analyzed before relationship of more than 2 variables was analyzed by developing a regression model.

Correlation on respondents' destination, seat type, location, upholstery, sitting period and journey frequency with their evaluation on seat features were analyzed and shown in table 4 below. Based on the result, there were variables that have strong correlation between them and needed to be investigated more. Treating the data as interval data (the differences between the categories on the scale are meaningful), *Pearson correlation* was chosen to obtain the constant value of correlation. As the table below illustrated the matrix result of the variables, our interest was to study is there any correlation exist between respondents' judgment of seat features with destination, seat type, location, upholstery, sitting period and journey frequency.

Based on the result, there is a positive correlation between seat type and respondents perception on their seat cushion, seat location and seat depth, seat upholstery and backrest shape and also correlation on subjective evaluation of backrest width with how long they have been sitting on the seat. According to Guildford (1956), the value of correlation coefficient (r) which is in range 0.40 – 0.70 is considered as not very strong in relationship. This result was significance either at the 0.01 or 0.05 level.

Based on responses from subjects on the seat features evaluation, a regression model was attempted. Using a stepwise regression method, a model to predict overall evaluation based on evaluation of seat features by respondents was developed. Result has shown that only 2 parameters in seat features influenced overall comfort on seat; personal acceptance and seat depth. Personal Acceptance has more influence on respondent's perception of overall comfort and seat feature; seat depth has less influence in this equation. The direction of all influence for both is positive. The equation of predicted overall comfort on seat generated as below:

$$\text{Overall Comfort}_{(predicted)} = -\,0.184 + 0.694\ \text{Personal Acceptance} + 0.383\ \text{Seat depth}$$

$R^2 = 0.358$ → It is shown that approximately 35.8% of the variance in overall evaluation is accounted for by personal acceptance and seat depth. Based on this result, it is shown that this regression model has no strong influence against overall evaluation of seat comfort. Detail on regression result is as below:

Variables Entered / Removed (a)

Model	Variables Entered	Variables Removed	Method
1	Personal Acceptance	.	Stepwise (Criteria: Probability-of-F-to-enter <= .100, Probability-of-F-to-remove >= .200).
2	Seat Depth	.	Stepwise (Criteria: Probability-of-F-to-enter <= .100, Probability-of-F-to-remove >= .200).

a Dependent Variable: Overall Evaluation of seat

Model Summary(c)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.506(a)	.256	.219	.663
2	.598(b)	.358	.290	.632

a Predictors: (Constant), Personal Acceptance
b Predictors: (Constant), Personal Acceptance, Seat Depth
c Dependent Variable: Overall Evaluation of seat.

ANOVA(c)

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	3.026	1	3.026	6.884	.016(a)
	Residual	8.792	20	.440		
	Total	11.818	21			
2	Regression	4.226	2	2.113	5.288	.015(b)
	Residual	7.592	19	.400		
	Total	11.818	21			

a Predictors: (Constant), Personal Acceptance
b Predictors: (Constant), Personal Acceptance, Seat Depth
c Dependent Variable: Overall Evaluation of seat

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.545	.981		.555	.585
	Personal Acceptance	.812	.309	.506	2.624	.016
2	(Constant)	-.184	1.025		-.180	.859
	Personal Acceptance	.694	.303	.433	2.293	.033
	Seat Depth	.383	.221	.327	1.733	.099

a Dependent Variable: Overall Evaluation of seat

2.1.3.3 Mean Comparison Analysis

Mean comparison analysis allows the exploration of certain characteristics of continuous variables within certain categories. In this pilot test study, seat features evaluation and BPD evaluation were compared within categories of respondents' seat type, seat location and sitting period.

<u>Independent-samples t test</u>

The independent-samples t test compares the means of two different samples. The two samples share some variable of interest in common, but there is no overlap between memberships of the two groups. T tests in this pilot test study were then used to determine if two distributions differ significantly from each other, the test that measures the probability associated with the difference between groups was a two-tailed test of significance. The two-tailed test examines whether the mean of one distribution differs significantly from the mean of the other distribution, regardless of the direction (positive or negative) of the difference.

The means of two different type of seat; single seat and double seat were compared for the evaluation of seat features and body part discomfort rating. The 'null hypothesis' of this study is to assume that there is no difference between single and double seat evaluation on each seat feature and body part discomfort by respondents. The independent samples t-test utilizes the Levene's Test for Equality of Variances and the alpha level chosen for statistical significance was 0.05. There were few cases on seat features evaluation which has significant mean distribution difference within seat type categories. While for body part discomfort evaluation, there was no significant difference between means of two distributions of seat type. Detail report on each case and result tables are available in the appendix A.

Case 2:

H_2 – There is a difference between single and double seat type sitters' evaluation of seat width.

Hypothesis 2: "There is a difference between single and double seat type sitters' evaluation of seat width." The mean evaluation score for single seat was 3.20, with a standard deviation of .422 and for double seat it was 2.62, with a standard deviation of .870. The significance level for the assumption of equal variances was less than alpha level, so equal variance was not assumed. At an alpha of .05, there was a significant difference in seat width evaluation between single seat and double seat respondents (t18.189 = 2.121; p = .048); therefore the null hypothesis is rejected.

Case 4 :

H_4 – There is a difference between single and double seat type sitters' evaluation of seat cushion.

Hypothesis 4: "There is a difference between single and double seat type sitters' evaluation of seat cushion." The mean evaluation score for single seat was 2.80, with a standard deviation of .422 and for double seat it was 3.46, with a standard deviation of .776. The significance level for the assumption of equal variances was less than alpha level, so equal variance was not assumed. At an alpha of .05, there was a significant difference in seat cushion evaluation between single seat and double seat respondents (t19.204 = -2.612; p = .017); therefore the null hypothesis is rejected.

One - way ANOVA

Based on one-way ANOVA analyses, both seat features evaluation and BPD evaluation illustrated almost no significance difference in mean comparison based on seat location, except for evaluation on seat depth.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Seat Height	Between Groups	.159	2	.080	.435	.653
	Within Groups	3.667	20	.183		
	Total	3.826	22			
Seat Width	Between Groups	2.366	2	1.183	2.310	.125
	Within Groups	10.242	20	.512		
	Total	12.609	22			
Seat Depth	Between Groups	2.442	2	1.221	3.960	.036
	Within Groups	6.167	20	.308		
	Total	8.609	22			
Seat Cushion	Between Groups	2.229	2	1.114	2.456	.111
	Within Groups	9.076	20	.454		
	Total	11.304	22			
Seat Structure	Between Groups	1.027	2	.514	.296	.747
	Within Groups	34.712	20	1.736		
	Total	35.739	22			
Seatpan Shape	Between Groups	1.493	2	.746	2.357	.120
	Within Groups	6.333	20	.317		
	Total	7.826	22			
Armrest Height	Between Groups	.337	2	.169	.445	.647
	Within Groups	7.576	20	.379		
	Total	7.913	22			
Backrest Width	Between Groups	.714	2	.357	.866	.436
	Within Groups	8.242	20	.412		
	Total	8.957	22			
backrest inclination	Between Groups	.776	2	.388	1.462	.257
	Within Groups	5.042	19	.265		
	Total	5.818	21			
Backrest shape	Between Groups	.671	2	.335	.926	.412
	Within Groups	7.242	20	.362		
	Total	7.913	22			
Personal Acceptance	Between Groups	.760	2	.380	1.975	.165
	Within Groups	3.848	20	.192		
	Total	4.609	22			
Overall Evaluation of seat	Between Groups	2.092	2	1.046	1.584	.230
	Within Groups	13.212	20	.661		
	Total	15.304	22			

Post Hoc Test

Multiple Comparisons (for seat depth)

LSD

Dependent Variable	(I) Seat Loc	(J) Seat Loc	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Seat Depth	Front	Middle	0.17	0.282	0.561	-0.42	0.75
		Back	0.83*	0.321	0.017	0.16	1.50
	Middle	Front	-0.17	0.282	0.561	-0.75	0.42
		Back	0.67*	0.282	0.028	0.08	1.25
	Back	Front	-0.83*	0.321	0.017	-1.50	-0.16
		Middle	-0.67*	0.282	0.028	-1.25	-0.08

* The mean difference is significant at the 0.05 level

2.1.3.4 Conclusion

Three type of statistical analysis were conducted on the gathered data from pilot test study on the 13th August, 2004 at Yong Peng, Batu Pahat. Based on the result, further study with refined and edited questionnaire will be conducted as the final stage of public assessment on ride comfort. Evaluation on seat features and body part discomfort was analyzed based on simple statistics, mean comparison analyses and correlation and regression analysis. It was found that several frequently reported body part discomfort complaints were similar relatively with study conducted on highway truck operators in one of the literature reviews. While mean comparison analyses revealed that there were significant difference exist in certain seat features evaluation within seat type and seat location. Further analysis needed to be conducted to investigate more relationship based on this evaluation. Regression model had been attempted; however the result was not strong enough to convince that such relationship will influence overall perception of seat comfort to a great extend. It was believed that insufficient data is a major cause of this problem. More data needed to be collected in order to develop a better regression model.

2.1.3.5 Suggestion

Problems identified during pilot test campaign:

1. Lengthy questions – respondents' interest were quite low. More time needed to explain and to answer the questions
2. Lack of manpower – two interviewers was not enough to collect sufficient data.
3. Unnecessary questions – need to be omitted

Suggestions:

1. Restructure the question order and minimize pages.
2. Survey structure: Questionnaire will be divided into three parts; demographic and general, Seat features evaluation And BPD scale.
3. Several seat features and body parts which had shown no significance relationship were omitted from the evaluation sheet to reduce number of questions. Repetitive questions were also omitted.
4. Extra manpower needed to conduct and gather more data. Remittance for extra manpower is required. 1 person is required to interview at least 10 people (at least 5 extras are required).

2.2 Subjective Evaluation of Ride Comfort (Actual Study)

2.2.1 Objectives

1. The findings from the survey will identify important seat features criteria that will lead towards a good seat design for ride comfort.
2. To report the assessment of public evaluation on existing seat features of commercial buses in Malaysia and identify most experienced ailments. To investigate any correlation between parameters that might exist related to evaluation of ride comfort and compare results with the established studies.

2.2.2 Methodology

1. Date: 10 October 2004

2. Location: Lucky Garden Sdn. Bhd., Yong Peng

3. Target Group:

   The target group is the adult population consisting of male and female who travel by bus (19-50 yrs old).

4. Method of collecting data:
   - Interview-based method. It is necessary to explain any terms and questions that public might not be familiar with.
   - Location of interview: Rest area near the highway where most buses stop for about half an hour. Interviewer approached the public and asked for some of their time to answer the questions. A token of appreciation was distributed to respondent for his or her willingness to participate.
   - The interview was conducted in a day; responses were collected as many as possible.

5. Questionnaire Structure

Based on the result gathered from pilot study, number of questions was reduced. Several seat features and body parts which had shown no significance relationship were omitted from the evaluation sheet to reduce the number. Repetitive questions were also omitted. Previously, there were 5 sections in the questionnaire set to be answered; Demographic, general questions on journey, seat features evaluation, Body Part Discomfort (BPD) scale and sources of discomfort. The sections were reduced to three; demographic and general, Seat features evaluation And BPD scale.

i. <u>Demographic Questions</u>

To retrieve personal information such as respondent's age, medical history and physical statue.

ii. <u>General question on journey</u>

To identify the destination and seat location. Based on this data, sitting period will be determined.

iii. <u>Seat Features Evaluation</u>

Respondent will be asked to rate his or her seat based on rating scale given (5 points rating scale) and seat features that are listed. Respondent will also be asked to select an overall value of seat comfort given a group of range value.

iv. <u>Body Part Discomfort (BPD) Scale</u>

Scale used:

1	2	3	4	5
No pain / discomfort		Moderate pain / discomfort		Extreme pain / discomfort

To asses most experienced ailments during journey on bus. A human figure labeled with human parts was provided to ease the rating process.

6. Method of analyzing result

Analysis will be based on descriptive statistics; where information of parameters involved will be reported based on frequencies, averages, measures of dispersion and correlation involved. The results will be compared with available studies by others regarding seat or ride comfort.

2.2.3 Results

2.2.3.1 Descriptive Results

Statistical Summary of Respondents

	AGE (Years)	WEIGHT (kg)	HEIGHT (cm)
MIN	16	35	140
MAX	60	98	184
MEAN	30.81	58.77	163.78
STD. DEVIATION	11.469	11.608	8.689

There were 51.2 % male and 48.8% female involved in this survey. The summary of demographic characteristics of the inquired populations is depicted in table as shown above. Based on the number of respondents participated during the campaign, age of participations were ranging from 16 to 60 years old. Minimum age was 16 and maximum age was 60 with mean of 30.81 years old and standard deviation was 11.469 years. Weight and height was varied from 35 to 98 kg and 140 to 184 cm respectively. It is also reported that based on respondents' medical history, 65% never experienced any ailments related to back and neck while 34.1% have medical history on back pain or neck pain.

General Information regarding respondents' journey

There were 3 different regions classified to each respondent based on his or her destination. Geographically, destinations in Peninsular Malaysia has been divided into 3 regions; center (from southern state (Johor) to central states (up to Selangor) and vice versa), North (from southern state to northern states (up to Perlis) and vice versa) and East Coast (from southern state (Johor) to east coast of Peninsular Malaysia (up to Kelantan) and vice versa).

84.8% of the respondents were from the center region going to the south region. This group had been sitting for more than two hours before their bus made a stop. 12 % of the respondents were from east coast region going to the south. This group had spent their time in the bus for more than 4 hours similar to the time spent in the bus by 3.2% of the respondents from the north region. While geographic bias is not expected to be a significant factor in this study, information on respondents' destination will be considered as sitting duration factor in this analysis.

Respondents were also asked about their seat location during journey. 20.0% of the respondents sat in front row seat, 47.2% of the respondents sat in the middle row and 32.8% sat at the back. This question was asked to see whether seat location influence respondents' evaluation judgment.

Evaluation of Seat Features

Seat features were evaluated using a rating scale of 5 points numbered as 1 to 5; value of 3 represents neutral value i.e. 'just nice' value. Treating the scale as if continuous scale (ordinal data treated as interval), mean and standard deviation value for each seat feature evaluation was depicted as in the table below:

Table 1

	Seat Height	**Seatpan width**	**Seatpan depth**	**Cushion Softness**	**Stability**	**Armrest height**	**Buttock comfort**
Mean	2.94	2.81	2.68	3.12	3.10	2.95	2.90
Std. Deviation	0.681	0.631	0.716	0.703	0.983	0.612	0.770
	Thigh comfort	**Footrest comfort**	**Backrest width**	**Lateral support**	**Lumbar Support**	**Neck support**	**Personal acceptance**
Mean	2.79	2.40	2.98	2.91	2.67	2.34	2.88
Std. Deviation	0.779	0.998	0.624	0.722	1.022	1.071	0.984

As shown in the table, mean value of evaluation on each seat feature was ranging from 2.34 (Neck support) to 3.12 (cushion softness). Overall, no extreme mean value or large value of standard deviation was shown in this evaluation, showing that the probability of 5 point scale was not fully used by most of the respondents.

As each seat feature has its own independent value representation, mean value as depicted above corresponds to this independent value. For example, evaluation of seat height; value 1 represents the seat to be too low and value 5 represents the seat to be too high for respondent, while evaluation of seat width; value 1 represents the seat to be too narrow and value 5 represents the seat to be too wide for respondent. However, it has been justified that respondent's judgment of seat feature will be better as the value increase.

It was found that most respondents did not have much complaint on their seat features; many seat features were rated as 'just nice' or 'comfortable' such as seat height (75.2% rated their seat height as 'just nice), seat pan width (73.6% agreed that their seat height was 'just nice'), seat pan depth (72% rated their seat height as 'just nice'), armrest height (77.2% of the respondents rated their armrest height as 'just nice'), backrest width (73.4% agreed that the backrest width was 'just nice'). However, when respondents were asked to rate their seat features based on their function and comfort as body support, it was found that their evaluation was mostly distributed ranging from 'very uncomfortable' to 'just nice'. 35% to 50% respondents complaint their neck support, lumbar support and footrest comfort were either very uncomfortable or uncomfortable with high uncomfortable rating went to neck support. Summary of respondents' rating on each seat features is depicted in table 2 below.

Table 2: Frequencies (%) of Seat Features Evaluation Result

No	**Seat Features**	**1**	**2**	**3**	**4**	**5**
		very low	*Low*	*Just nice*	*High*	*very high*
1	**Seat Height**	4.8	9.6	75.2	8.0	2.4
		Too narrow	*Narrow*	*Just nice*	*Wide*	*Very wide*
2	**Seat pan Width**	4.8	16.0	73.6	4.8	0.8
		Too short	*Short*	*Just nice*	*Long*	*Too long*
3	**Seat pan Depth**	11.2	12.8	72.0	3.2	-
		Too soft	*Soft*	*Just nice*	*Hard*	*Very hard*
4	**Cushion Softness**	2.4	8.0	68.8	16.8	4.0
		Too shaky	Shaky	Ok	Stable	Very stable
5	**Stability**	5.6	15.2	53.6	13.6	11.2
		Very low	Low	Just nice	High	Very high

6	**Armrest height**	3.2	9.6	76.0	8.0	1.6
		Very uncomfortable	*uncomfortable*	*Just nice*	*comfortable*	*Very comfortable*
7	**Buttock comfort**	5.6	15.2	64.0	12.0	2.4
		Very uncomfortable	*uncomfortable*	*Just nice*	*comfortable*	*Very comfortable*
8	**Thigh Comfort**	6.5	21.8	59.7	10.5	1.6
		Very uncomfortable	*uncomfortable*	*Just nice*	*comfortable*	*Very comfortable*
9	**Footrest Comfort**	23.6	24.4	43.1	6.5	2.4
		Too narrow	*Narrow*	*Just nice*	*Wide*	*Very wide*
10	**Backrest Width**	3.2	9.7	73.4	12.9	0.8
		Very uncomfortable	*uncomfortable*	*Just nice*	*comfortable*	*Very comfortable*
11	**Lateral Support**	3.3	18.3	65.0	10.8	2.5
		Very uncomfortable	*uncomfortable*	*Just nice*	*comfortable*	*Very comfortable*
12	**Lumbar Support**	17.6	16.8	50.4	11.2	4.0
		Very uncomfortable	*uncomfortable*	*Just nice*	*comfortable*	*Very comfortable*
13	**Neck Support**	28.0	24.0	36.8	8.0	3.2
		Strongly dislike	*dislike*	*ok*	*like*	*Strongly like*
14	**Personal Acceptance**	10.5	18.5	48.4	17.7	4.8

Evaluation of Body Part Discomfort (BPD)

Body part discomfort scale is a 5 point scale with lowest value (1) represents no pain or no discomfort and highest value (5) represents painful or very discomfort on respondent's body parts. There were 12 body parts to be evaluated by respondents. When the data was treated as continuous rating data, result was depicted as below:

Table 3

	Neck	**Shoulder**	**Upper Back**	**Middle Back**	**Lower Back**	**Buttock**	**Thigh**
Mean	2.54	1.81	2.01	2.09	2.29	1.90	1.95
Std. Deviation	1.273	1.090	1.267	1.251	1.396	1.192	1.224

Mean value for BPD rating on 12 body parts was ranging from 2.54 to 1.81 which indicated a slightly inflated use of the scale. Most respondents' complaint of discomfort or pain was on neck, upper, middle and lower back, buttock and some were on shoulder. The result was correlated with responses of seat features evaluation regarding their functions and comfort as body support. Complaint ailments on neck, middle back, lower back and buttocks were also highly reported in survey on heavy duty trucks operators reported by The Heavy Duty Truck Seating Task Force of the S4 Cab & Controls Study Group of The Maintenance Council (TMC) of The American Trucking Association in paper entitled 'User Perspectives on Seat Design'.

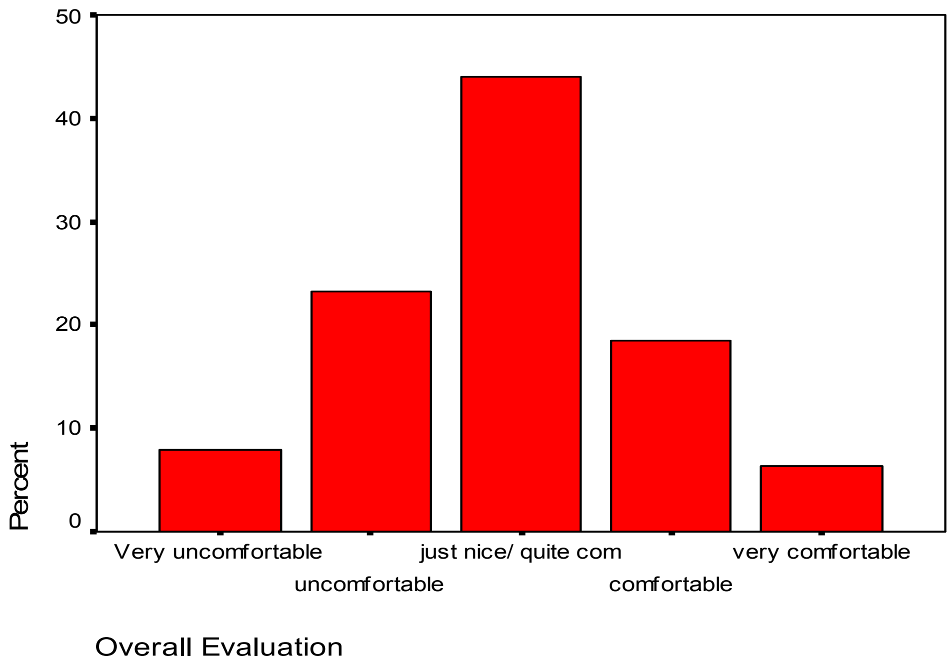
Table 4: Frequencies (%) of BPD Scale Result

No Pain/ No discomfort ⟷ Painful/ very discomfort

No	Body Part	1	2	3	4	5
1	**Neck**	31.2	13.6	32.8	15.2	7.2
2	**Shoulder**	58.4	13.6	17.6	9.6	0.8
3	**Upper Back**	53.6	12.0	20.0	8.8	5.6
4	**Middle Back**	49.6	11.2	24.8	9.6	4.8
5	**Lower Back**	46.4	8.8	24.0	11.2	9.6
6	**Buttock**	55.6	15.3	15.3	10.5	3.2
7	**Thigh**	54.4	13.6	19.2	8.0	4.8

Overall Evaluation

Based on the graph shown below, it was clearly revealed that 44% of the respondents rated overall evaluation of their ride comfort as 'quite comfortable'. 18.4% rated their ride comfort as 'comfortable' and only 6.4% rated their ride comfort as 'very comfortable'. On the other hand, 8.0% of the respondents did not satisfied with their ride comfort quality and rated it as 'very uncomfortable' and 23.2% rated their ride comfort as 'uncomfortable'.



2.2.3.2 Correlation Analysis

Correlation or the Pearson product –moment correlation designated a simple correlation between two variables in this study. The relationships between paired variables among many variables in study were analyzed before further relationship of the variables was analyzed in depth. Correlations on respondents' gender, physical characteristics, sitting period, seat location and overall evaluation on their ride comfort with their evaluation on seat features were analyzed.

Based on the result, there were variables that have strong correlation and needed to be investigated more. Treating the data as interval data (the differences between the categories on the scale are meaningful), *Pearson correlation* was chosen to obtain the constant value of correlation. As shown in table 5, there was positive correlation between overall evaluations of ride comfort with seat pan width, seat stability, buttock comfort, footrest comfort, backrest width, lateral support, lumbar support, neck support and personal acceptability. There is also correlation between seat location and seat stability in a negative direction. Further study on this result will help to clarify the matter._ A significant test such as t test will be helpful. It was also found that there was a positive correlation between age and neck support evaluation and physical characteristics i.e. weight and height was correlated with seat height. As we can see, the correlation coefficient values are ranging from 0.178 to 0.568. According to Guildford (1956), the value of correlation coefficient (r) which is in range 0.40 – 0.70 is considered as not very strong in relationship. There was also a positive correlation between seat height and lumbar support, seat pan depth with seat pan width, seat pan width with buttock comfort, backrest width, lumbar support and personal acceptance. These seat features were positively correlated with value ranging from 0.198 to 0.471. Seat pan depth had shown a positive correlation with thigh comfort, lumbar support and personal acceptability. This result revealed that improper seat depth will affect respondents' thigh and lumbar comfort and also personal acceptance towards the seat. Nevertheless, in depth study is needed to validate this hypothesis.

Cushion softness feature has some influence on many of other seat features such as seat stability, buttock comfort, footrest comfort, backrest width, lateral support, lumbar support, neck support and personal acceptance. However, these seat features are negatively correlated with cushion softness features.

Based on the correlation result, a model will be attempted and several other tests will be conducted to clarify type and strength of relationship for all parameters of ride comfort. While, several parameters had shown correlation at 0.01 or 0.05 significance level, the correlation coefficient measures only the degree of linear association between two variables only. Any conclusions regarding cause-and-effect relationship of these parameters must not be made without any further findings.

CORRELATIONS

	Age	Wt	Ht	Dest	Sloc	Oeva	Sht	Spwd	SPD	CS	S	Ah	BC	TC	FC	BW	LaS	LuS	NS	Pa
Age	1	0.334**	0.003	-0.106	-0.168	0.082	0.145	-0.083	-0.093	-0.041	0.169	-0.054	0.061	-0.018	0.069	-0.118	-0.007	0.006	0.21*	0.013
Wt	0.334**	1	0.471**	-0.242**	0.143	0.00	-0.213*	-0.040	-0.104	-0.075	-0.029	-0.101	0.054	-0.061	-0.039	-0.107	-0.143	-0.054	0.028	-0.032
Ht	0.003	0.471**	1	-0.204*	0.110	-0.044	-0.285**	-0.040	-0.014	-0.031	-0.044	-0.015	-0.056	-0.105	-0.014	-0.09	-0.016	0.016	0.105	-0.079
Dest	-0.106	-0.242**	-0.204*	1	-0.023	0.015	0.012	0.039	0.035	0.129	0.085	0.175	0.050	0.175	-0.056	0.038	0.003	0.111	0.034	0.085
Sloc	-0.168	0.143	0.110	-0.023	1	-0.132	-0.082	0.019	0.071	0.001	-0.213*	0.05	0.023	0.049	0.12	0.059	-0.074	-0.019	0.005	-0.069
Oeva	0.082	0.00	-0.044	0.015	-0.132	1	0.123	0.180*	0.163	-0.251**	0.178*	-0.035	0.296**	0.137	0.341**	0.219**	0.302**	0.346**	0.366**	0.568**
Sht	0.145	-0.213*	-0.285**	0.012	-0.082	0.123	1	0.140	0.065	0.050	0.155	-0.026	0.096	0.066	0.074	0.112	0.164	0.178*	0.11	-0.048
Spwd	-0.083	-0.040	-0.040	0.039	0.019	0.180*	0.140	1	0.471**	-0.002	-0.048	0.081	0.198*	0.169	0.2	0.199*	0.177	0.214*	0.11	0.353**
SPD	-0.093	-0.104	-0.014	0.035	0.071	0.163	0.065	0.471**	1	0.03	0.022	-0.037	-0.043	0.185*	0.148	0.007	0.037	0.186*	0.133	0.313**
CS	-0.041	-0.075	-0.031	0.129	0.001	-0.251**	0.050	-0.002	0.03	1	0.23*	0.127	-0.263**	-0.057	-0.392**	-0.309**	-0.208*	-0.259**	-0.184*	-0.178*
S	0.169	-0.029	-0.044	0.085	-0.213*	0.178*	0.155	-0.048	0.022	0.23*	1	0.089	0.023	0.069	-0.028	-0.05	0.051	0.072	0.138	0.106
Ah	-0.054	-0.101	-0.015	0.175	0.05	-0.035	-0.026	0.081	-0.037	0.127	0.089	1	-0.009	0.047	0.04	0.112	0.029	0.104	-0.013	-0.025
BC	0.061	0.054	-0.056	0.050	0.023	0.296**	0.096	0.198*	-0.043	-0.263**	0.023	-0.009	1	0.435**	0.293**	0.2*	0.258**	0.404**	0.218*	0.318**
TC	-0.018	-0.061	-0.105	0.175	0.049	0.137	0.066	0.169	0.185*	-0.057	0.069	0.047	0.435**	1	0.383**	0.098	0.239**	0.271**	0.185*	0.299**
FC	0.069	-0.039	-0.014	-0.056	0.12	0.341**	0.074	0.2	0.148	-0.392**	-0.028	0.04	0.293**	0.383**	1	0.239**	0.258**	0.383**	0.249**	0.298**
BW	-0.118	-0.107	-0.09	0.038	0.059	0.219**	0.112	0.199*	0.007	-0.309**	-0.05	0.112	0.2*	0.098	0.239**	1	0.266**	0.246**	0.154	0.252**
LaS	-0.007	-0.143	-0.016	0.003	-0.074	0.302**	0.164	0.177	0.037	-0.208*	0.051	0.029	0.258**	0.239**	0.258**	0.266**	1	0.532**	0.26**	0.236**
LuS	0.006	-0.054	0.016	0.111	-0.019	0.346**	0.178*	0.214*	0.186*	-0.259**	0.072	0.104	0.404**	0.271**	0.383**	0.246**	0.532**	1	0.413**	0.33**
NS	0.21*	0.028	0.105	0.034	0.005	0.366**	0.11	0.11	0.133	-0.184*	0.138	-0.013	0.218*	0.185*	0.249**	0.154	0.26**	0.413**	1	0.462**
Pa	0.013	-0.032	-0.079	0.085	-0.069	0.568**	-0.048	0.353**	0.313**	-0.178*	0.106	-0.025	0.318**	0.299**	0.298**	0.252**	0.236**	0.33**	0.462**	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

CORRELATIONS

	N	Sh	Ub	Mb	Lb	B	Th	Sht	Spwd	SPD	CS	S	Ah	BC	TC	FC	BW	LaS	LuS	NS
N	1	0.33**	0.317**	0.244**	0.33**	0.232**	0.229*	-0.062	-0.082	-0.148	0.063	-0.061	0.108	-0.145	-0.024	-0.114	-0.071	-0.1	-0.143	-0.349**
Sh	0.33**	1	0.55**	0.557**	0.492**	0.347**	0.319**	-0.082	-0.007	-0.077	0.041	-0.066	-0.074	-0.147	-0.204*	-0.317**	-0.1	-0.229*	-0.274**	-0.268**
Ub	0.317**	0.55**	1	0.793**	0.655**	0.49**	0.494**	-0.13	-0.079	-0.057	-0.001	-0.105	-0.136	-0.373**	-0.334**	-0.415**	-0.092	-0.202*	-0.347**	-0.246**
Mb	0.244**	0.557**	0.793**	1	0.655**	0.513**	0.551**	-0.088	-0.081	-0.083	0.135	-0.086	-0.123	-0.243**	-0.261**	-0.44**	-0.05	-0.229*	-0.349**	-0.233**
Lb	0.33**	0.492**	0.655**	0.655**	1	0.53**	0.381**	-0.193*	-0.12	-0.057	0.104	-0.015	-0.098	-0.2**	-0.351**	-0.362**	-0.125	-0.249**	-0.414**	-0.212*
B	0.232**	0.347**	0.49**	0.513**	0.53**	1	0.535**	-0.11	-0.23	-0.034	0.032	-0.132	-0.098	-0.321**	-0.248**	-0.214*	-0.067	-0.361**	-0.306**	-0.216*
Th	0.229*	0.319**	0.494**	0.551**	0.381**	0.535**	1	-0.13	-0.148	-0.117	0.063	-0.151	0.074	-0.202*	-0.328**	-0.264**	-0.011	-0.236**	-0.109	-0.153
Sht	-0.062	-0.082	-0.13	-0.088	-0.193*	-0.11	-0.13	1	0.14	0.065	0.05	0.155	-0.026	0.096	0.066	0.074	0.112	0.164	0.178*	0.064
Spwd	-0.082	-0.007	-0.079	-0.081	-0.12	-0.23	-0.148	0.14	1	0.471**	-0.002	-0.048	0.081	0.198*	0.169	0.02	0.199*	0.177	0.214*	0.11
SPD	-0.148	-0.077	-0.057	-0.083	-0.057	-0.034	-0.117	0.065	0.471**	1	0.03	0.022	-0.037	-0.043	0.185*	0.148	0.007	0.037	0.186*	0.133
CS	0.063	0.041	-0.001	0.135	0.104	0.032	0.063	0.05	-0.002	0.03	1	0.23*	0.127	-0.263**	-0.057	-0.392**	-0.309**	-0.208*	-0.259**	-0.184*
S	-0.061	-0.066	-0.105	-0.086	-0.015	-0.132	-0.151	0.155	-0.048	0.022	0.23*	1	0.089	0.023	0.069	-0.028	-0.05	0.051	0.072	0.138
Ah	0.108	-0.074	-0.136	-0.123	-0.098	-0.098	0.074	-0.026	0.081	-0.037	0.127	0.089	1	-0.009	0.047	0.004	0.112	0.029	0.104	-0.013
BC	-0.145	-0.147	-0.373**	-0.243**	-0.2**	-0.321**	-0.202*	0.096	0.198*	-0.043	-0.263**	0.023	-0.009	1	0.435**	0.293**	0.2*	0.258**	0.404**	0.218*
TC	-0.024	-0.204*	-0.334**	-0.261**	-0.351**	-0.248**	-0.328**	0.066	0.169	0.185*	-0.057	0.069	0.047	0.435**	1	0.383**	0.098	0.239**	0.271**	0.185*
FC	-0.114	-0.317**	-0.415**	-0.44**	-0.362**	-0.214*	-0.264**	0.074	0.02	0.148	-0.392**	-0.028	0.004	0.293**	0.383**	1	0.239**	0.258**	0.383**	0.249**
BW	-0.071	-0.1	-0.092	-0.05	-0.125	-0.067	-0.011	0.112	0.199*	0.007	-0.309**	-0.05	0.112	0.2*	0.098	0.239**	1	0.266**	0.246**	0.154
LaS	-0.1	-0.229*	-0.202*	-0.229*	-0.249**	-0.361**	-0.236**	0.164	0.177	0.037	-0.208*	0.051	0.029	0.258**	0.239**	0.258**	0.266**	1	0.532**	0.26**
LuS	-0.143	-0.274**	-0.347**	-0.349**	-0.414**	-0.306**	-0.109	0.178*	0.214*	0.186*	-0.259**	0.072	0.104	0.404**	0.271**	0.383**	0.246**	0.532**	1	0.413**
NS	-0.349**	-0.268**	-0.246**	-0.233**	-0.212*	-0.216*	-0.153	0.064	0.11	0.133	-0.184*	0.138	-0.013	0.218*	0.185*	0.249**	0.154	0.26**	0.413**	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Keywords:

Wt	*Weight*	*S*	*Seat Stability*
Ht	*Height*	*Ah*	*Armrest Height*
Dest	*Destination*	*BC*	*Buttock Comfort*
Sloc	*Seat Location*	*TC*	*Thigh Comfort*
Oeva	*Overall Evaluation*	*FC*	*Footrest Comfort*
Sht	*Seat Height*	*BW*	*Backrest Width*
Spwd	*Seat pan Width*	*LaS*	*Lateral Support*
SPD	*Seat pan Depth*	*LuS*	*Lumbar Support*
CS	*Cushion Softness*	*NS*	*Neck Support*
Pa	*Personal Acceptance*		

Correlation analysis was also run between respondents' gender, physical characteristics, sitting period, seat location and overall evaluation on their ride comfort and their evaluation on body part discomfort. However, no significant relationship was identified between any paired parameters.

Due to quite a number of complaints on several aspects of seat features and high uncomfortable response on several body parts, correlation analysis was run between evaluation on seat features and body part discomfort rating. Based on this analysis, seat features that have a significant effect on ride comfort will perhaps be identified and further investigated in lab environment and road trial using several measurement methods.

2.3 Conclusion

From the survey, it is known that certain seat features were evaluated by respondents as the contributors to ride discomfort during their journey. However, survey statistic had revealed that more than half of the survey respondents (68.8%) were satisfied with the current existing bus passenger seat. This figure shows that the current existing passenger seat has a good level of comfort except for the smaller group who might have experienced discomfort at certain body parts during their long journey, such as shoulder, mid back, thigh and buttock. This comfort level rated by public was later correlated to the objective methods to produce the comfort values for same type of seat through laboratory and field tests. Following is the paper written for the Asia Pacific Vibration Conference (APVC), Langkawi, Malaysia, 23rd-25th November, 2005. This paper is about the pre-survey held at a different location before both the pilot and actual survey.

SUBJECTIVE EVALUATION OF SEAT DISCOMFORT ON DYNAMIC STUDY

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This paper attempts to study subjective evaluation of buses' seat responded by Malaysian users during their journey on road. Two hundred sets of questionnaire had been distributed and were evaluated by respondents on their journey Respondents were asked to rate the seat features and body part discomfort (BPD) scale using scale of 1 to 5. The results show significant difference in some seat feature evaluation between male and female respondents. Independent sample t statistic and one sample t statistic were used to analyze both males and females' responses. Most users experienced discomfort or some pain in several body parts on their body. Neck, backside and lower part including buttock and thigh experienced discomfort over time.

Keywords: Subjective assessment; Ride Discomfort; Bus seat; Statistical analysis; Ergonomics

1. Introduction

Comfort on automotive seats is dictated by a combination of static and dynamic factors. (Ebe K and Griffin, 2000) A seat that is comfortable in a showroom may have poor dynamic characteristics that make it uncomfortable whilst on road. When considering the quality of the in-vehiele experience, it is therefore important to consider both static and dynamic comfort.

Term "comfort" is used to define the short-term effect of a seat on a human body; that is, the sensation that commonly occurs from sitting on a seat for a short period of time. In contrast, the term "fatigue" defines the physical effect that results from exposure to the seat dynamics for a long period of time. Many research studies indicate that "discomfort is primarily associated with the physiological and biomechanical factors".

Viano and Andrzejak (1992) stated that the sources of discomfort such as transmission of vehicle vibration to the occupant, body pressure distributed under and supporting both the buttock, thighs and back of an operator, control of posture either statically or dynamically through differing loading paths, clothing and seat covering material, perceptions and interior ergonomic characteristics need to be quantified in terms of mechanical requirements for seat design and its behavior. A lot of studies reported on measuring discomfort objectively to evaluate parameters such as body pressure distribution, posture control and ride vibration. For example, by evaluating pressure discomfort on seat it was found that compression or shear forces, or both, that develop at the human-seat interface are the main causes of discomfort. (Kiosak, 1976; Brienza et al., 1996)

Previously, subjective evaluation regarding comfort usually assessed in the controlled environment and road trial to correlate objective evaluation with subject's responses. Several subjective assessments had been done to study seating discomfort on off-highway vehicle and truck seats specifically for the driver seats. One of the reported studies dictated that, the truck drivers ranked the forward-backward and backrest inclination adjustments as most important features for ride comfort. (Donati and Patel, 1999).

While in car, the driver's posture is more relaxed with larger seat having better body seat contact as compared to an off-highway or truck driver. Ng et al. (1995) used a questionnaire to 20 healthy subjects to determine the important features of a car seat. They concluded that 70% of the car drivers felt that lumbar support and seat pan tilt are very important while only 35% felt that the seat height is very important. Subjects also indicated that their perception of seat comfort was influenced by thigh support (75%), thoracic support (70%) and lumbar support (65%).

A study of comfort in public transportation buses conducted by the University of Coimbra collected the responses of the occupants and correlated the subjective responses to physical parameters such as thermal comfort, air quality, vibration and noise (Alcobia and Silva, 1999). It was found that noise was the main annoyance cause with percentages of dissatisfied between 25% (1^{st} test) and 47% (4^{th} test).

This paper is an initial effort to identify perceived discomfort amongst local Malaysian users on seat during long journey. From the research, the data might be useful in providing important guidelines from real world to develop a better seat design features in terms of ride comfort.

2. Research Methodology

2.1 Bus Seat

The type of buses selected for the survey study was long journey buses which cruised on the highway. There are two main seat arrangements seen in most local buses, single and double seat type (Figure 1 and Figure 2). The features of both types are basically the same; however, the size of different parts of the seat is different. As visualized in figures the single seat is larger than the double seat and takes much more space. Respondents then were expected to rated the seat features before their journey ended.

Figure 1. Example of single

Figure 2. Example of seat double seat

2.2 Survey Respondents

Adult population consisting of male and female between 18 to 50 years old that travel by bus was the target for this subjective assessment. However, the responds from young adults from age 18 to 30 years old were mostly available. Questionnaires were distributed to about 200 individuals who travel by bus. Mainly the area covered is for buses traveling on the highway in Peninsular Malaysia namely three regions; North, East Coast and South to Center region. The survey forms were distributed mostly at the main bus stations and university students were also the main target for the sample.

2.3 Questionnaire

The questionnaire was designed in such a way that participants would respond for general questions then move toward more specific questions. People will mostly respond to the questions by selecting the appropriate rating scale. The survey also included questions seeking for participants' opinion about the seat and sources of discomfort. Participants would have to respond to the body part checklist (Body part discomfort) at the later part, to identify discomfort experienced on certain parts of body. Such responds are useful and valuable to develop an automotive seat which will reduce or minimize discomfort even during long-time sitting. The questionnaire covered the following areas:

(a) Ten seat characteristics - height, width, depth, cushion, stability, surface, armrest height, backrest inclination, personal acceptance for the seat and overall discomfort. Participants were asked to assess each characteristic in five rating scale. (Adapted from Drury and Coury. 1982)

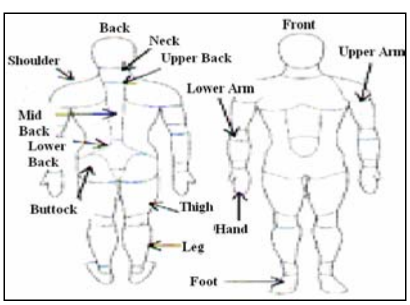

Figure 3. Bodv Parts to be rated

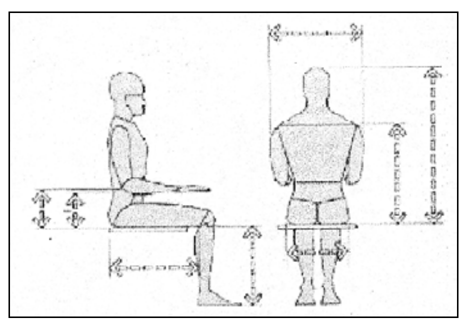

Figure 4. Rough measurements of physical parts(Adapted from Galloway et. Al. 1991)

(b) Six sources of discomfort - long journey, bad road condition, vibration on the seat or the floor, seat problem, temperature problem (too hot or too cold) and noise. Participants were asked to choose any of these sources

(c) Common evaluation - participants were asked to tick any comfort statements given and give their own opinion.

(d) Body part discomfort (BPD) - Participants were to evaluate the discomfort of certain body part (Figure 3) which will be faced during the journey. There were 12 parts – neck, shoulder, upper arms, lower arms, hands, upper back, mid back, lower back, buttock, thighs, legs and foot. They will be evaluated using 5 rating scales from 1 to 5: 1 for 'comfortable/no pain', 3 for 'less comfortable' and 5 for 'very painful / uncomfortable'.

(e) Physical measurement - Participants had to give the rough measurement for their body parts while sitting. Those measurements included buttock popliteal length, popliteal height, hip breadth, shoulder height, sitting height normal, shoulder width and armrest height. (Figure 4)

2.4 Administration Technique

All the responds for the survey were delivered by mail from the participants. The questionnaire is designed in a way that could be self-administered by participants. Most of the questions were close-ended questions and there were also some open-ended questions to seek for participant's opinion. The questionnaires were distributed together with an envelope each, with address and stamp, to ensure and make it easy for participants to deliver back their responds.

The survey was conducted in the middle of October until November 2003 because most of the students were going home for holiday. The proposed time frame of data collection was 7 weeks, a time tolerance to receive maximum responds from participants.

3. Results

As has been expected, the total response rate for analysis purpose was quite low as it represented only 20% of the total questionnaire distributed. However, the profile responses received have covered all three regions required in the survey as shown in Figure 5. Respondents who travel north, east coast and center were 43.5%, 19.6% and 37% respectively. Thus, the data were used to analyze the comfort rating given by the respondents.

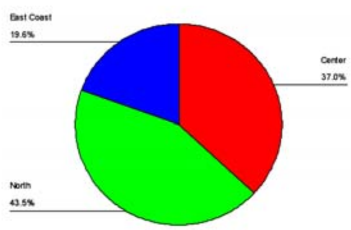

Figure 5. Pie chart showing percentage of respondents based on destination categories

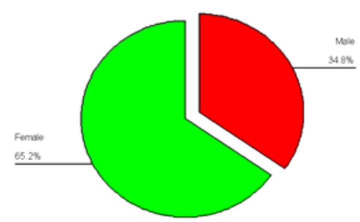

Figure 6. Percentage of respondents based on gender

3.1 Demographic results

Respondents who sent back the questionnaire for analysis purpose were mostly female, 65.2% and male were represented by 34.8% of total replied survey. (Figure 6)

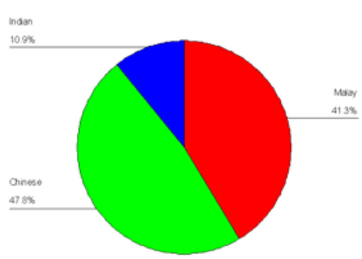

Figure 7. Percentage of respondents based on race

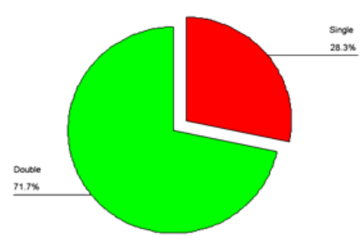

Figure 8. Seat type percentage

The summary of demographic characteristics of the inquired populations is depicted in Table 1.

From Table 1, the average weight and height for male were 61.9 kg and 171.1 cm and female were 48.6 kg and 159.4 cm.

Malaysian users are diverse in population; three main groups identified in the study were Malay (41.3%), Chinese (47.8%) and Indians (10.9%). This survey also represents the groups accordingly as shown in chart below. (Figure 7) The analysis also covered the frequency of respondents' preference of single or double seat.(Figure 8). Table 2 represented the percentage of seat type preference based on respondents' destination during survey campaign.

Table1
Statistical summary of Respondents

	Gender					
	Male			Female		
	Age	W (kg)	H (cm)	Age	W (kg)	H (cm)
Min	18	52	158	18	22	149
Max	29	79	180	26	60	172
Mean	21	61.9	171.1	20.6	48.6	159.4
Std. Dev.	2.5	9.3	5.38	1.6	7.76	5.91

Table 2
Percentage of Seat type based on destination

Destination	Seat Type	Percentage (%)
North	Single	23.5
	Double	76.5
Center	Single	45.0
	Double	55.0
East Coast	Double	100.0

It was shown that during the survey campaign, respondents who went to East Coast of Peninsular Malaysia did not occupy single seat during their journey. Percentage of respondents whose journey to Center and North East occupied single seat was 23.5% and 45.0%. Further analysis would show which seat type and respondents destination does affect respondents' point of view on ride discomfort.

4.0 Statistical Analysis

4.1 Seat Features Evaluation

There were eight seat features evaluated by respondents to determine which features are to be improved and studied in depth to develop a better seat design for local Malaysian needs. Based on the frequency response gained, it was noted that; seat width, seat depth, seat cushioning, stability and backrest inclination affected users perceived discomfort in quite a great length. Our research is interested to find if there's any significance difference existed on each seat feature evaluation between genders. This kind of hypothesis is useful to measure the importance of body size (which is different between male and female) in each seat feature improvement and new design. Correlation matrix was developed to study significance correlation of seat features to be considered in gender differences, seat type and destination. Correlation existed between gender and backrest inclination; gender and seat stability. Therefore, further investigation on these seat features will clarify the relationship. There were also correlations between seat type and seat width and also seat type with respondents' personal acceptance.

Independent sample T Test was conducted (Table 3 and 4) to identify significance relationship between gender and seat features evaluation. This test utilizes the Levene's Test for equality variances. The alpha level chosen for statistical significance was .05 and for all seat features equality variance was assumed due to the significance level was greater than alpha level for each case. The hypothesis associated with the analysis of each seat feature case was "There is a difference between males' and females' evaluation on each seat features." When the hypotheses are validated for some seat features, suggestion to develop and design of particular seat features will be based on gender anthropometric measurements

The analysis for each seat feature evaluation of independent sample T test also depicted significant relationship existed between gender and backrest inclination and also gender and seat stability. Seat stability evaluation showed that the mean "Likert' scale value for males was 3.06 with a standard deviation of .574 while females was 2.53 with standard deviation of -629. At an alpha of .05, there was a significant difference in seat stability evaluation between males and females (t44 = 2.8, p = 0.008); therefore the null hypothesis was rejected. While backrest inclination showed that the mean "Likert" scale value for male respondents was 3.06 with a standard deviation of .929 and mean value for female respondents was 2.43 with standard deviation of .774. At the same alpha level like other cases (.05), there was a significant difference in backrest inclination evaluation between males and females (t44 = 2.449, p = 0.018); therefore the null hypothesis was rejected. The same seat feature; backrest inclination also ranked as the most important feature by fork-lift truck drivers in the study conducted by Donati and Patel (1999).

4.2 Sources of Discomfort

The survey enquired respondents to tick the sources of discomfort which they think contributed to discomfort experienced during their journey. From the data, there were 5 significant sources identified by users. The sources and their contributing percentage based on yes or no responses were listed as below:

1. Length of journey - 58.7%
2. Vibration-43.5%
3. Temperature (cold/ hot) - 50 %
4. Space for legrest - 47.8 %
5. Discomfort on Backrest - 45.7 %

Respondents were having problem sitting too long due to long journey experienced. It was known that sitting too long without fidgeting position will induce fatigue.

4.3 Body Part Discomfort Evaluation

Several distinct parts on the body were identified to experience most discomfort feeling during the journey. "Likert" scale was used to identify which body part experienced discomfort or extreme pain; labeled with number 5 and which body part experience less discomfort or no pain at all; labeled with number 1. Neck and backside; upper,

Table 3
T Test Group Statistics

	Gender	N	Mean	Std Deviation	Std Error Mean
Seat Height	Male	16	3.13	.619	.155
	Female	30	2.87	.571	.104
Seat Width	Male	15	2.73	.799	.206
	Female	30	2.63	.669	.122
Seat Depth	Male	16	3.19	.655	.164
	Female	30	3.17	.699	.128
Seat Cushioning	Male	15	2.73	.704	.182
	Female	30	2.57	.626	.114
Seat Stability	Male	16	3.06	.574	.143
	Female	30	2.53	.629	.115
Seat Surface	Male	16	2.81	1.109	.277
	Female	30	2.43	.858	.157
Armrest Height	Male	16	3.00	.632	.158
	Female	30	3.30	.750	.137
Backrest Inclination	Male	16	3.06	.929	.232
	Female	30	2.43	.774	.141
Personal Acceptability	Male	16	3.00	.730	.183
	Female	30	2.90	.759	.139

Table 4
T-Test Equal Variances assumed

	Levene's Test for Equality of Variances		t-test for equality of means					95% confidence interval of the difference	
	F	Sig.	t	df	Sig (2-tailed)	Mean Difference	Std. error Difference	Lower	Upper
Seat Height	.007	.935	1.419	44	.163	.26	.182	-.109	.625
Seat Width	1.059	.309	.443	43	.660	.10	.226	-.355	.555
Seat Depth	.145	.705	.098	44	.922	.02	.212	-.406	.448
Seat Cushioning	.050	.824	.808	43	.424	.17	.206	-.249	.583
Seat Stability	3.975	.052	2.80	44	.008	.53	.189	.148	.910
Seat Surface	.041	.840	1.288	44	.205	.38	.294	-.214	.973
Armrest Height	1.773	.190	-1.361	44	.180	-.30	.220	-.744	.144
Backrest Inclination	.187	.667	2.449	44	.018	.63	.257	.111	1.147
Personal Acceptability	.085	.772	.431	44	.668	.10	.232	-.367	.567
Overall Discomfort	.170	.682	.774	44	.443	.22	.285	-.354	.796

mid and lower back experienced some pain or discomfort probably related to backrest inclination feature which was rated as being too straight by some of the respondents. Buttock and thigh experience some pain and discomfort. However, these results were solely depicted from visualizing the frequency raw data into chart form (bar graph). To verify these results, one sample T test (Table 5 and 6) was conducted for each body part evaluated by respondents. The confidence interval percentage was chosen as 95% and the results were compared between males and females.

Based on Table 5, mean values of body part discomfort (BPD) Likert scale for both males and females were clearly below test value of 3 with quite large variation. Overall evaluation of BPD for each body part was concluded to be not in significant discomfort or pain situation. Several body parts such as neck and backside however have larger mean value compared to other body parts. Other body parts did not experienced any major discomfort or pain. These observations were verified using one sample t test, where the confidence intervals lie entirely below 0.0 with large mean difference in values; body parts such as upper arm, forearm, hands and feet were identified did not experience extreme discomfort for both male and female respondents.

While body part such as shoulder, which had smaller mean difference value and confidence interval lay entirely below zero experienced some pain for both males and females. There was more body part discomfort experienced by female respondents. Apart from experiencing some pain on shoulder, they also experienced some pain or discomfort on their mid back, buttock and thigh (smaller value of mean difference). Since, most discomfort or pain was experienced at the back of body; the result confirmed the seat feature evaluated that state the backrest inclination was the most important feature to be considered.

5. Conclusion

It can be concluded that seat stability and backrest inclination were evaluated differently by males and females. With concern more on female respondents' side to improve seat stability and backrest inclination, these seat features would be suggested to be designed and improved differently for male and female. Other seat features are to be treated with no difference for both genders. It was also agreed that discomfort increased with time when respondents

Table 5
One-Sample Statistics and T-test

Gender	Body Parts	N	Mean	Std. Deviation	Std. Error Mean	Test Value - 3 t	df	Sig.(2-tailed)	Mean Difference	95° o Confidence Interval of the Difference Lower	Upper
Male	Neck	16	2.94	1.181	0.295	-0.212	15	0.835	-0.06	-0.69	-0.212
	Shoulder	16	2.31	1.138	0.285	-2.416	15	0.029	-0.69	-1.29	-2.416
	Upper arm	16	1.63	0.5	125	- 11.000	15	0	-1.38	-1.64	- 11.000
	Forearm	16	1.69	0.602	151	-8.72	15	0	-1.31	-1.63	-8.72
	Hands	16	1.88	0.719	0.18	-6.26	15	0	-1 13	-1.51	-6.26
	Upper back	16	2.88	1.36	0.34	-0.368	15	0.718	-0.13	-0.85	-0.368
	Mid back	16	2.63	1.258	0.315	-1.192	15	0.252	-0.38	-1.05	-1.192
	Lower back	16	2.88	1.258	0.315	-0.397	15	0.697	-13	-0.8	-0.397
	Buttock	16	2.44	1.209	0.302	-1.861	15	0.083	-0.56	-1.21	-1.861
	Thigh	16	2.69	1.078	0.27	-1.159	15	0.264	-31	-0.89	-1.159
	Leg	16	2.5	1.03.1	0.258	-1.936	15	0.072	-0.5	-1.05	-1.936
	Feet	16	1.88	0.885	0.221	-5.084	15	0	-1 13	-1.6	-5.084
Female	Neck	30	2.9	0.845	0.154	-0.648	29	0.522	-0.1	-0.42	-0.648
	Shoulder	30	2.27	1.015	0.185	-3.958	29	0	-0.73	-1.11	-3.958
	Upper arm	30	2.07	1.015	0.185	-5.037	29	0	-0.93	-1.31	-5.037
	Forearm	30	1.7	0.877	0.16	-8.12	29	0	-1.3	-1.63	-8.12
	Hands	30	1.6	0.814	0.149	-9.424	29	0	-1.4	-1.7	-9.424
	Upper back	30	2.73	1.172	0.214	-1.246	29	0.223	-0.27	-0.7	-1.246
	Mid back	30	2.53	1.196	0.218	-2.138	29	0.041	-0.47	-0.91	-2.138
	Lower back	30	2.77	1.135	0.207	-1.126	29	0.269	-0.23	-0.66	-1.126
	Buttock	30	2.5	0.974	0.178	-2.812	29	0.009	-0.5	-0.86	-2.812
	Thigh	30	2.3	0.988	0.18	-3.881	29	0.001	-0.7	-1.07	-3.881
	Leg	30	2.67	0.959	0.175	-1.904	29	0.067	-0.33	-0.69	-1.904
	Feet	30	2	1.017	0.186	-5.385	29	0	-1	-1.38	-5.385

voted length of journey as one of the major causes to discomfort. The survey also identified parts of body that might experience discomfort during journey, such as, shoulder for both males and females and mid back, thigh and buttock for female respondent only. The survey complied with several past studies stating these parts as the parts that would experience pain or discomfort when the time of seating was increased. This study would become the first step guideline for seat design and development to determine and developed a better seat design based on the most important aspects pointed out by users in real life situations.

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CHAPTER 3

STATIC TEST

3.1 Introduction

This chapter is divided into two parts; details on the main seat sample geometry and pressure mapping test on static condition. The first part is mainly to acknowledge the seat sample used in this research study, as one of the outcomes from this research will introduce a new design of seat structure that will replace the existing structure. Therefore acknowledgement of the existing seat sample should be noted. The later part of this chapter analyzes static pressure distribution on seat. This test was conducted to study the pressure distribution of the new seat sample and the old seat sample available. The objectives are to analyze the contributing factors towards good pressure distribution which is claimed to be one of the seat comfort factors and compare the result with the existing study on static pressure testing of seat comfort.

3.2 Details on Test Sample (Seat Geometry)

A bus seat from local manufacturer had been acquired in order to conduct testing on the existing bus seat design. Specifications of the seat are available from the manufacturer and by measuring the sample in laboratory.

3.2.1 Bus Seat Specifications

Material:

Cushion	:	Resilient Polyurethane Foam (PUF), Fireproof fabrics
Seat Structure	:	Aluminium Steel

Manufacturer : Sin Wah Seng Cushion Sdn Bhd.

Bus Seat Components : Seat Pan
Backrest
Arm rest
Leg rest
Backrest Recliner

3.2.2 Bus Seat Design

Detail measurements on seat structure were taken and contour shape of the seat cushion was recorded using Coordinate Measuring Machine (CMM), as shown in APPENDIX A, in order to redraw the seat design in CAD for analysis purpose in the future. However, information on the arm rest and leg rest were not included due to the study focused only on the seat pan and backrest. The design will be analyzed together with experimental data taken by conducting pressure mapping test on the seat in laboratory and road trial. The design of existing bus seat structure is shown in Figure 3.1.

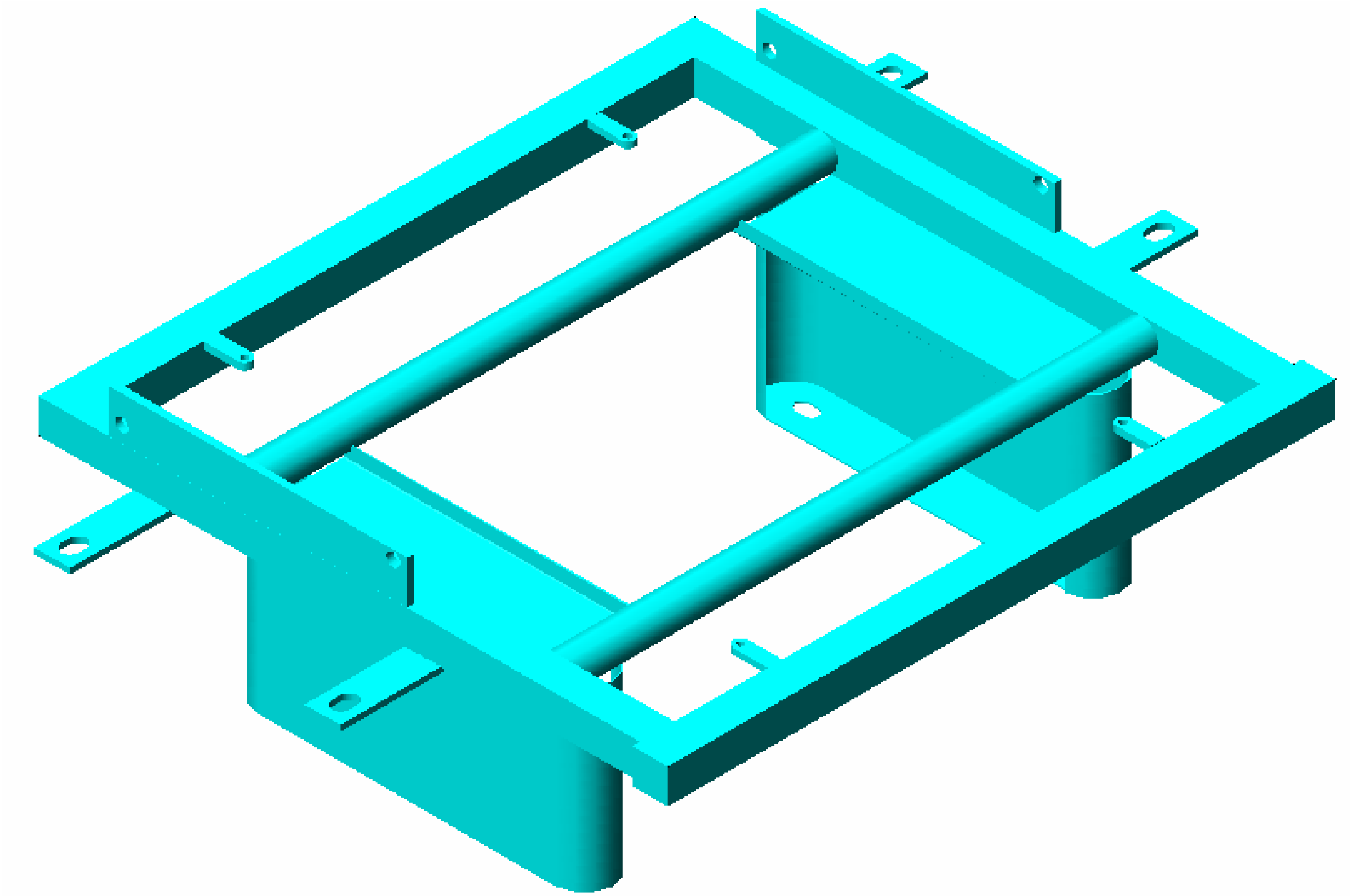


Figure 3.1: The design of the existing bus seat structure

3.3 Pressure Distribution on Seat

Surface pressure on seat can cause discomfort during sitting. It has been found that surface pressure causes blood vessel constriction in underlying tissues (Grandjean et al., 1973). Although people of different body and weight display similar pattern of pressure distribution, the intensity and distribution area are highly dependent on the physical criteria of the individual. However, as a guideline for seat designer, good pressure distribution in a seat focuses peak under ischial tuberosities and lumbar area. Good body pressure distribution should indicate sufficient and balanced support to body areas in contact with the seat.

<u>Pressure Mapping System Description</u>

System : XSensor Pressure Mapping System (Figure C)

Specifications :

a) Capacitive sensor system
b) Able to detect the areas of extreme pressure to show the area of pressure related problems more likely to occur.
c) Cushion pad size : 46cm x 46cm
d) Number of sensors : 1296 capacitive sensors
e) The sensor's thickness : 0.64mm (compressed)
f) The sampling rate : up to 5000 sensors per second
g) The pressure range : 0-220mmHg (0-29.33kPa)

3.3.1 Methodology

3.3.1.1 Static Pressure Distribution Measurement

A closely spaced measurement grid of thin, miniature and flexible sensors is needed to produce an accurate measurement of pressure distribution in the vicinity of ischial tuberosities. Therefore development has been made from a number of flexible, thin-film resistive and capacitive pressure sensors to perform measurements on flexible curved seating and lying surfaces. In this research, the measuring system used is Xsensor pressure mapping system developed by Xsensor Technology Corporation. The Xsensor system comprises of two pressure mapping pads, electronic unit, power supply and cord, battery pack, smart media card and Xsensor software. Each sensing pad consists of 1296 sensors arranged in 36 rows and 36 columns, molded within a mat of flexible material less than 2mm in thickness. The measured data is displayed in colour contoured graphics and can be stored for further analysis.

Static test was carried out to measure the buttock-seat pressure distribution. The purpose is to show if there were variances of data with different subjects' weight, height and build and also between different types of seat contours. The sample consists of 5 males and 5 females with a wide range of body sizes. In this test, Xsensor pressure mapping system was used and the seat remained static. Each subject would have to sit with different postures; erect with backrest supported (EBS) and erect without backrest supported (ENS). They also would have to sit with different positions during EBS; normal straight ($\approx 110^0$), 1st inclination ($\approx 120^0$), 2nd inclination ($\approx 130^0$), and normal straight with cushion added. Each angle took about 2 minutes to achieve data stability. The measured pressure distribution is evaluated in terms of static pressure distribution contours, maximum (peak) ischium pressure and contact area. Two seats were used as the specimen in this test: an improved seat (Figure 3.2) and an older seat (Figure 3.3). The laboratory test was carried out with the seat mounted on a static platform.

TEST SAMPLE

Figure 3.2: Main sample used for static and vibration test

Figure 3.3: Another sample used for static test

3.3.1.2 Results and Discussion

During static environment, the measured pressure distribution under different postures was evaluated for each subject in terms of static pressure distribution contours, maximum (peak) ischium pressure and contact area.

Figures 3.4 and Figure 3.5 show the 3-dimensional typical surface plots and contour maps of the interface pressure measured by Xsensor pressure mapping system at the surface of the same passenger seat under static seating conditions for 1 male subject and 1 female subject. This data is derived from measurements performed with subjects assuming an erect with back supported (EBS) posture. Both subjects sat with the seat adjusted to identical height and backrest inclination (angle). The results show that more peak pressure occurred in the vicinity of the male's ischial tuberosities than the female's. The high interface pressure peaks observed are expected to cause fatigue and discomfort over prolonged sitting. Whereas, the human-seat contact area is slightly larger for the male subject compared to the female subject. Results further reveal relatively low-pressure distribution under subjects' thighs. For the backrest pressure distribution, the maximum pressure is considered low for both subjects. Therefore, there is not much fatigue occurred at the back due to pressure distribution.

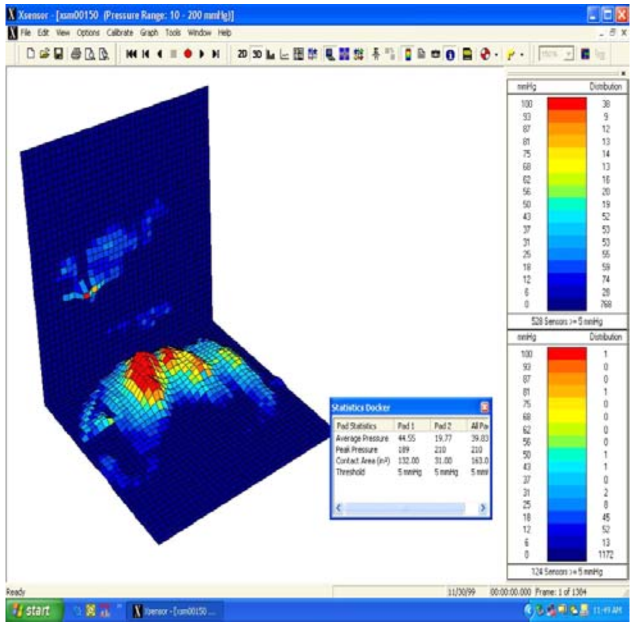


Figure 3.4: 3-D static pressure distribution: male subject

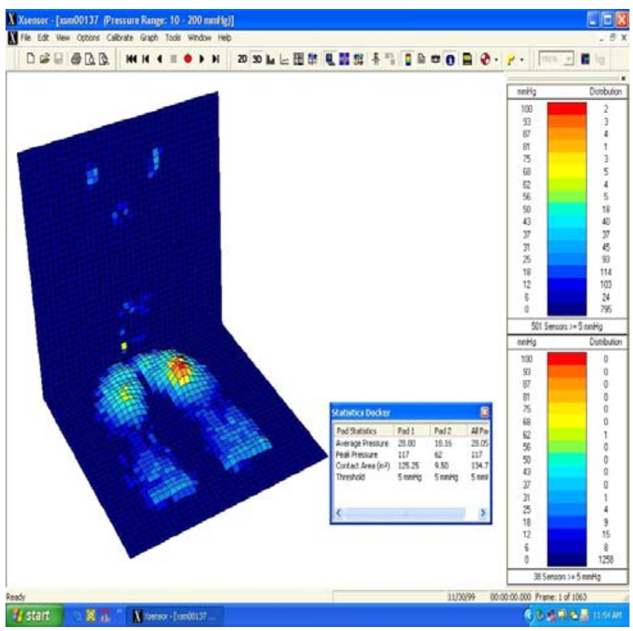


Figure 3.5: 3-D static pressure distribution: female subject

The magnitude and coordinates of the peak ischium pressure are sensitive to seated posture and the sitting position of the subject with respect to the pressure pad. Although the subjects were advised to assume a balanced posture, while maintaining similar patterns of pressure distribution in the right and left sides of the sitting surface, test data revealed that there were still variations between the right and left tuberosities. This may be due to the difficulties faced by subjects in maintaining a balanced posture during measurement. Besides, variations in coordinates of the peak pressure were caused by difficulties seating the subjects at identical position on pressure pad during different tests.

Table 3.1 shows the anthropometry for the 10 subjects involved in the static pressure test; subjects 1-5 are males and subjects 6-10 are females. Table 3.2, 3.3 and 3.4 show the pressure distribution test results for the 10 subjects for normal, 1st inclination and 2nd inclination sitting position as illustrated in Figure 3.6, respectively. Pressure mapping contour of these 10 subjects for different postures are shown in Table 3.5.

Table 3.1: Anthropometry of 10 subjects

Subject	**Height(cm)**	**Weight(kg)**
1	170	68
2	169	63
3	170	75
4	178	73
5	170	75
6	165	50
7	156	47
8	158	42
9	154	46
10	167	50

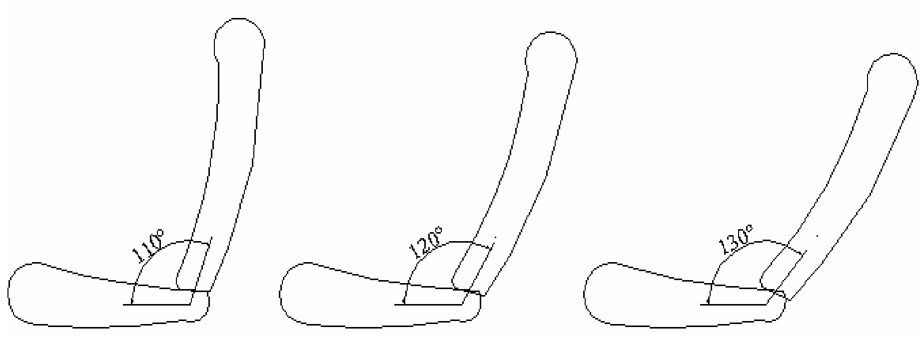


Figure 3.6: Normal, 1st and 2nd inclination of the sitting position

Table 3.2: Pressure distribution test results for 10 subjects during sitting with normal straight posture.

Subject	Seat-pan			Backrest			No. of Red Sensor
	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	
1	54.98	175	1116.13	30.91	63	511.2	17
2	57.45	293	717.74	23.82	59	275.81	80
3	42.78	153	888.71	25.3	51	441.93	23
4	55.44	193	853.22	26.84	57	448.39	68
5	54.41	284	1096.77	25.88	48	393.55	76
6	47.61	124	1045.16	25.88	55	316.1	19
7	33.69	92	948.39	28.63	60	346.77	0
8	38.54	117	772.58	20.67	35	143.55	3
9	42.83	152	867.74	23.74	64	148.39	24
10	43.47	108	1017.74	19.91	59	224.19	4

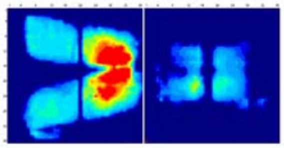
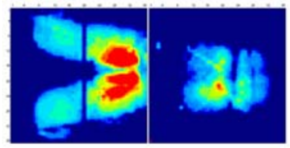
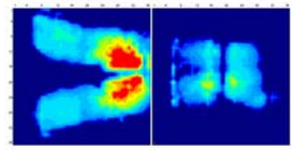
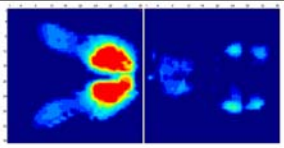
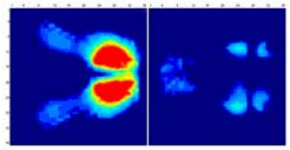
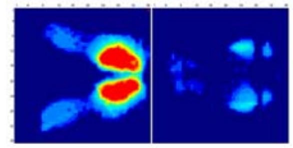
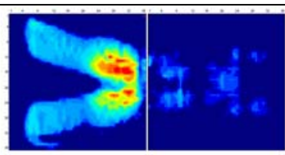
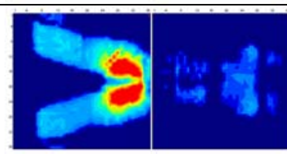
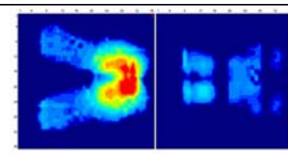
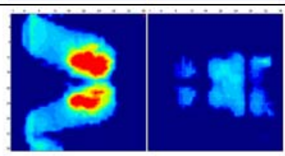
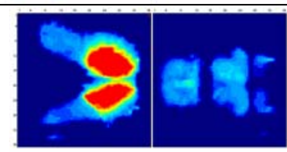
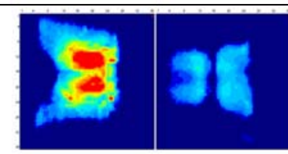
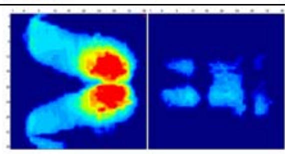
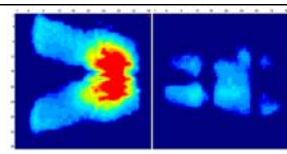
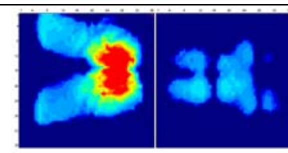
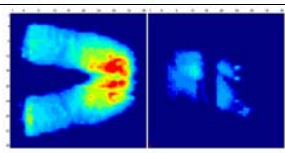
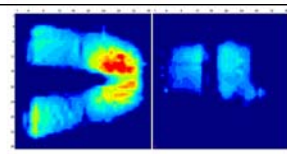
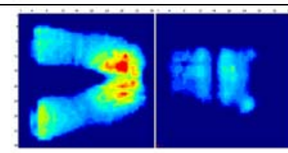
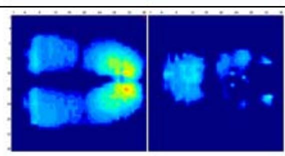
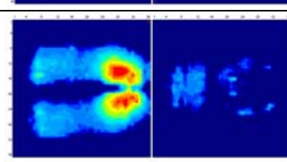
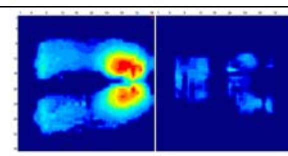
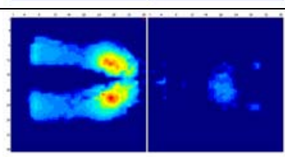
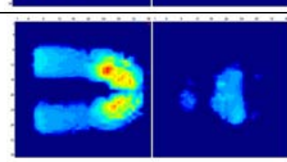
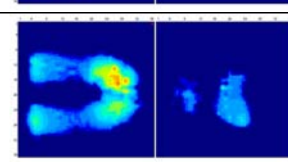
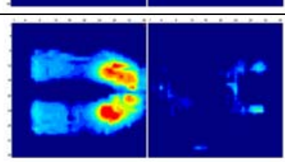
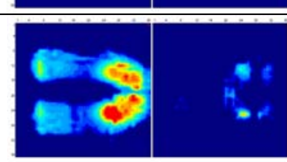
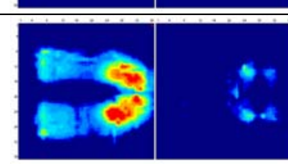
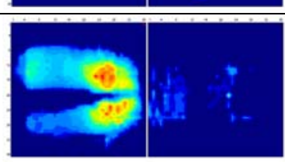
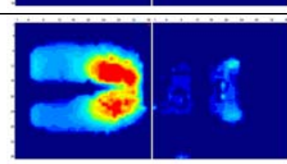
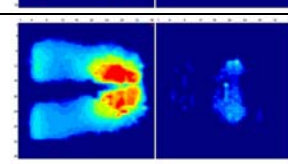
Table 3.2: Pressure distribution test results for 10 subjects during sitting with 1st inclination posture.

Subject	Seat-pan			Backrest			No. of Red Sensor
	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	
1	55	177	1098.38	37.29	112	579	22
2	57.88	267	716.13	24.68	55	275.81	85
3	43.61	119	1048.39	19.46	44	372.58	14
4	61.21	239	809.68	28	57	569.35	111
5	52.64	213	1035.48	28.01	53	482.26	81
6	45.91	129	1035.48	30.17	55	438.7	19
7	40.94	115	972.58	23.5	55	1241.94	16
8	40.93	104	819.35	27.51	51	243.55	2
9	43.27	128	883.87	23.68	61	154.84	19
10	50.19	152	983.87	21.02	59	275.81	57

Table 3.4: Pressure distribution test results for 10 subjects during sitting with 2nd inclination posture.

Subject	Seat-pan			Backrest			No. of Red Sensor
	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	
1	51.26	159	1087.09	35.13	67	616.1	8
2	53.72	275	729.03	24.8	55	272.58	73
3	48.02	164	1020.97	20.8	35	425.81	60
4	53.29	161	806.45	31.86	53	519.35	52
5	53.42	216	1030.64	29.72	51	530.64	75
6	45.61	124	1024.19	28.9	61	488.7	14
7	40.87	128	969.35	22.71	55	1290.32	16
8	36.72	97	745.16	27.12	60	229.03	0
9	44.01	125	935.48	24.03	63	158.06	21
10	46.38	127	1062.9	21.7	61	200	32

Table 3.5: Pressure mapping contour of 10 subjects for different postures; subject 1-5: male, subject 6-10: female

Subject	Normal Straight Posture	1st Inclination	2nd Inclination
1 H=170cm W=68kg			
2 H=169cm W=63kg			
3 H=170cm W=75kg			
4 H=178cm W=73kg			
5 H=170cm W=75kg			
6 H=165cm W=50kg			
7 H=156cm W=47kg			
8 H=158cm W=42kg			
9 H=154cm W=46kg			
10 H=167cm W=50kg			

For subject 1, a pressure test onto a rigid (wooden) surface had been conducted. The result shown in Figure 3.7 shows that the average pressure and peak pressure is the highest whereas the contact area is the lowest because the pressure is more concentrated on a rigid surface compared to a soft surface (cushion). The contact area is higher on a cushion because the human body is easier to sink into a softer surface than a harder surface. Hence, human body pressure is more evenly distributed on a cushion than a wooden surface.

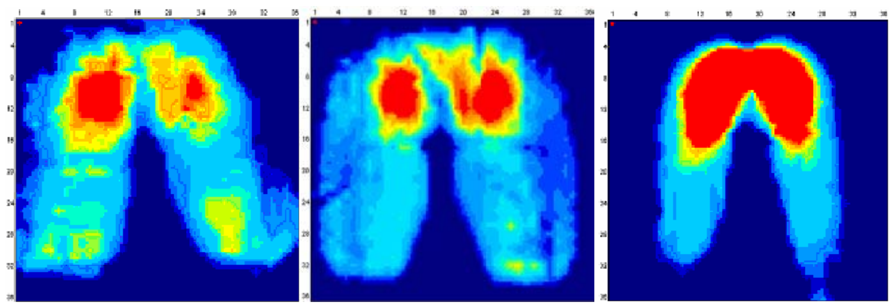


Figure 3.7: Comparison of ENS pressure distribution between current existing cushion surface, old cushion surface and wooden surface (from left to right)

Both the static and dynamic characteristics of the human-seat interface pressure are strongly related to the weight, height and build of the seated body. As the subject is heavier, the average pressure, peak pressure and contact area are also higher. The contact area at the human buttock-seat interface is strongly related to the pressure distribution. Effective contact area under static condition is defined as the area represented by sensors with a pressure reading greater than 5mmHg, which is the threshold value of measurement system preset to reduce signal noise. Based on the data contours in Table 3.5, between male and female subjects, heavier subject (mostly male) exhibits relatively larger effective contact area. The contact area increases with the increase in subject weight. Most of the female subjects tend to have small contact areas at their human-backrest interface, compared to the male subjects. This might be due to the gender differences in both weight and body build.

For the EBS (erect with back supported) postures, about 30-40% of the total sitting pressure was transmitted to the backrest. From Table 3.6, the average pressure transmitted to the backrest ranges from 31.41-45.94%, 29.52-40.41% and

30.22-42.48%, for normal sitting posture, 1st and 2nd inclination, respectively. From the same table, it is shown that most of the percentage of pressure transmitted was increasing with the increase of backrest inclination.

Table 3.6: Percentage of pressure transmitted to the backrest

Subject	Inclination		
	Normal	**1st**	**2nd**
1	35.99	40.41	40.66
2	29.31	29.89	31.58
3	37.16	30.85	30.22
4	32.62	31.39	37.42
5	32.23	34.73	35.75
6	35.22	39.66	38.79
7	45.94	36.47	35.72
8	34.91	40.20	42.48
9	35.66	35.37	35.32
10	31.41	29.52	31.87

Table 3.7 and Table 3.8 show the examples of the pressure distribution test results on the new seat for subject 1 (male) and subject 6 (female), respectively. From the tables, the pressure transmitted to backrest is 30-35% for the postures with cushion (form) added to the seat backrest. Test with cushion added 1 was conducted by adding a form at the lumbar support of the seat whereas test with cushion added 2 was conducted by adding the form along the backrest, from the upper back area to the lower back area, as shown in Figure 3.8. The average pressure for subject 6 at the seat-pan with added cushion was slightly higher than the normal EBS sitting but for subject 1, the average pressure for seat-pan was lower than normal sitting posture when cushion was added. For both subjects, the average pressure onto the backrest with cushion added was lower than the average pressure during normal sitting. However, the numbers of red sensors for the cushion-added postures for the subjects in Table 3.7 and Table 3.8 are the least. Less red sensors means smaller peak pressure area. All ENS (erect with back not supported) posture data have shown that the average pressure, peak pressure and contact area at the human buttock-seat interface were the highest. Zero reading was shown for the backrest because subjects were not leaning against the backrest during ENS sitting.

Table 3.7: Example of the pressure distribution test results for subject 1(male) on the current existing seat

Posture	Seat-pan			Backrest			No. of Red Sensor
	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	
Normal	54.98	175	1116.13	30.91	63	511.2	17
1st Inclination	55	177	1098.38	37.29	112	579	22
2nd Inclination	51.26	159	1087.09	35.13	67	616.1	8
Cushion-added 1	52.08	141	1022.58	25.15	55	556.4	8
Cushion-added2	52.01	157	1166.13	21.06	45	401.6	5
ENS	64.04	223	1367.74	0	0	0	38
Rigid surface(ENS)	108.99	293	880.64	0	0	0	141

Table 3.8: Example of the pressure distribution test results for subject 6(female) on the current existing seat

Posture	Seat-pan			Backrest			No. of Red Sensor
	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	
Normal	47.61	124	1045.16	25.88	55	316.1	19
1st Inclination	45.91	129	1035.48	30.17	55	438.7	19
2nd Inclination	45.61	124	1024.19	28.9	61	488.7	14
Cushion-added1	51.93	139	1008.06	27.23	64	417.7	1
Cushion-added2	51.45	159	1001.61	23.26	47	440.3	5
ENS	63	232	1140.32	0	0	0	43

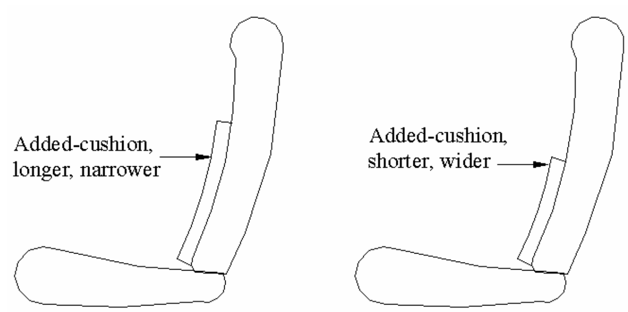


Figure 3.8: Seat position with cushion-added 1 (longer, narrower) and cushion-added 2 (shorter, wider)

During an EBS posture, when the inclination angle of the backrest was increased from normal position to first and then to second inclination, the pressure will be more distributed from the human-seatpan interface to human-backrest interface. The changes are small if referred to the data contours in Table 3.5. Therefore the data would be better analyzed in graph form as shown in Figure 3.9, 3.10, 3.11, and 3.12. As shown in Figure 3.9 and 3.10 below, with the increase of inclination angle, the peak pressure at the buttock-seat interface was reduced. This is because more pressure was transmitted from the seat pan to the backrest when the angle between both surfaces increased. Thus, inclination of the backrest also affects the human-seat pressure distribution. It is also noted from the graphs of contact area against height or weight in Figure 3.11 and 3.12, that the backrest inclination would not have effect onto the contact area at human-seatpan interface. The contact area onto seat pan would remain almost the same no matter how the angle increased.

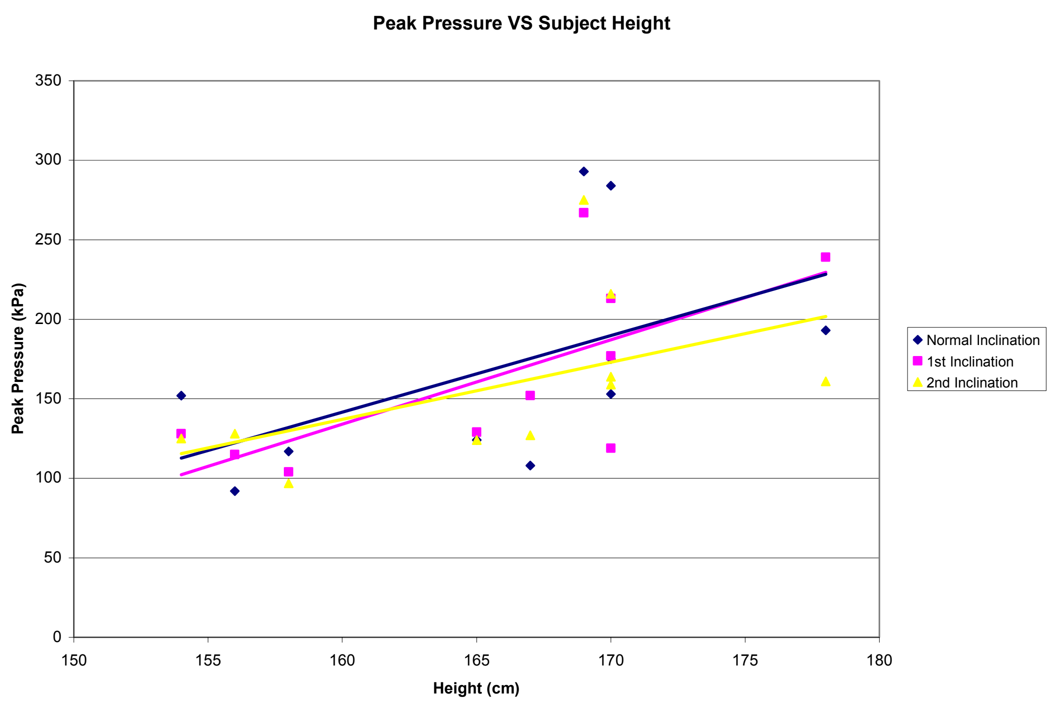


Figure 3.9: Effect of subjects' height onto peak pressure at buttock-seat interface

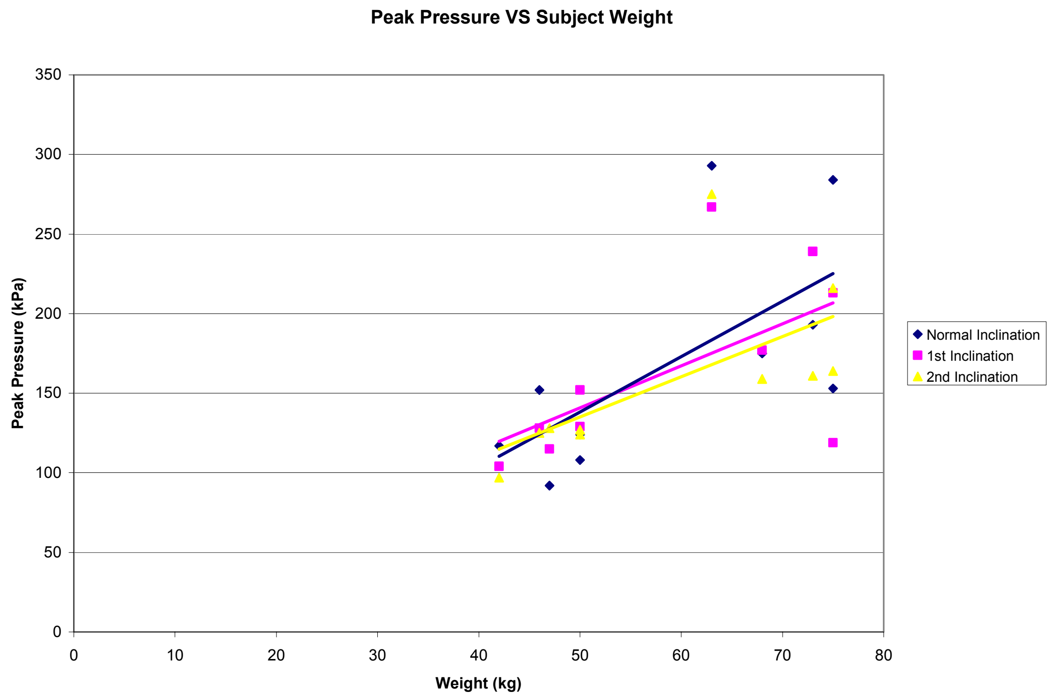


Figure 3.10: Effect of subjects' weight onto peak pressure at buttock-seat interface

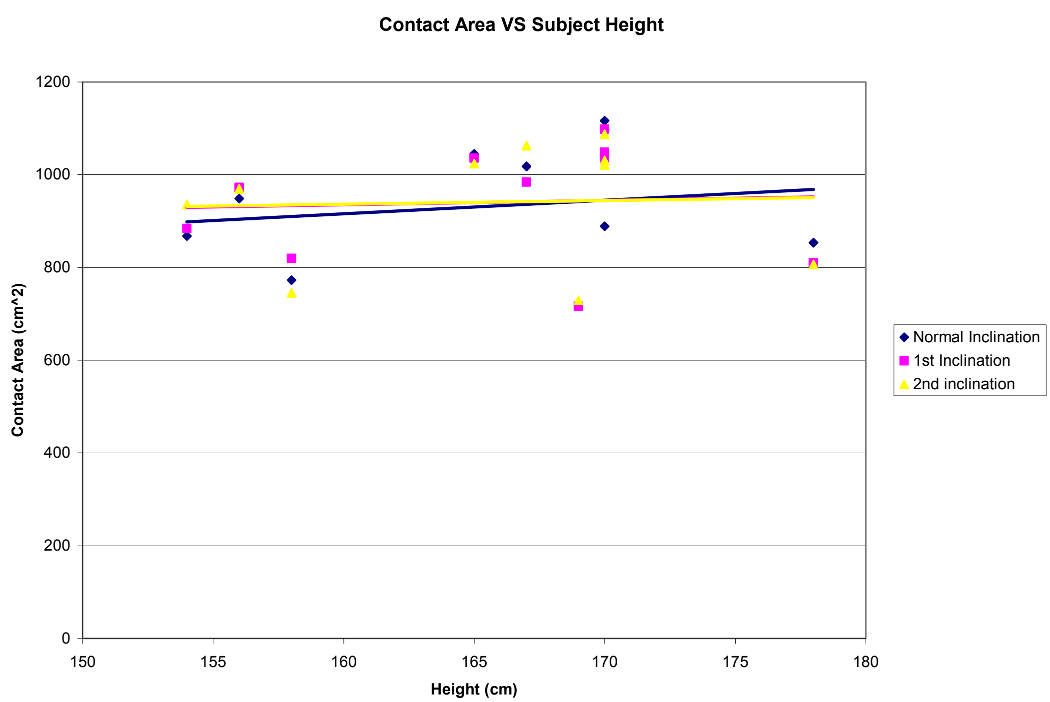


Figure 3.11: Effect of subjects' height onto contact area at buttock-seat interface

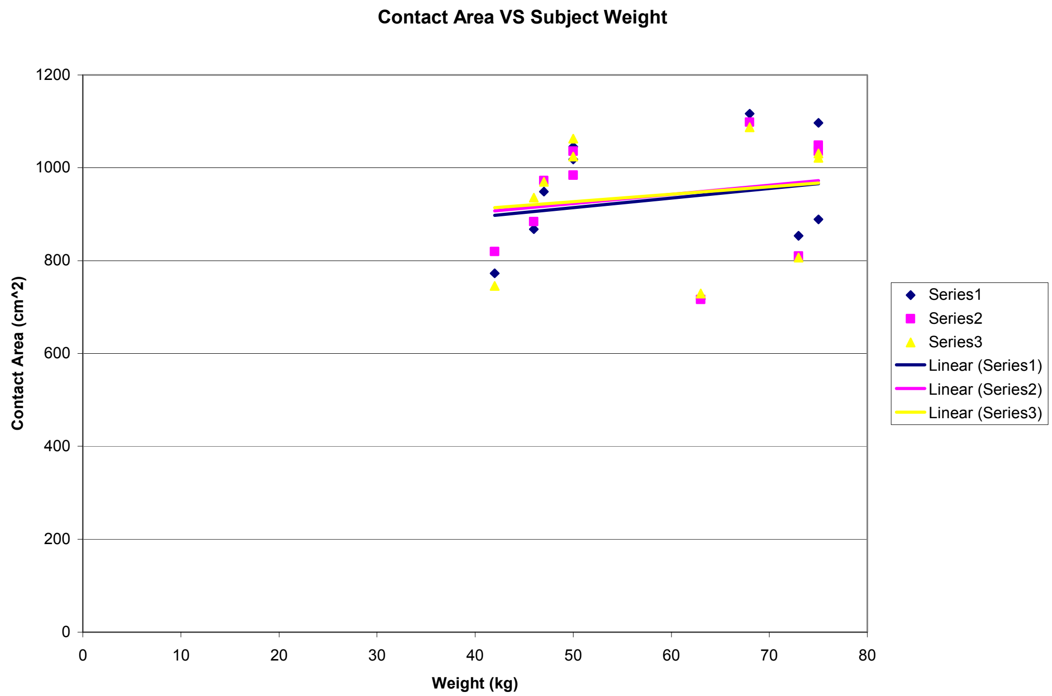


Figure 3.12: Effect of subjects' weight onto contact area at buttock-seat interface

Table 3.9 shows the static pressure distribution test results for subject 1 by using the older passenger seat as illustrated in Figure B6. From the table, comparison can be made between the older seat and the current existing passenger seat. For normal EBS sitting, the peak pressure and contact area of the subject onto the older seat pan is higher, although the average pressure is lower. All the data for the backrest pressure is also lower than the data for the current existing seat backrest. Not much of the pressure at the buttock was transferred to the backrest of the old seat. As predicted, the data for the ENS posture is higher than the data for normal EBS posture. When compared with the ENS data for the current existing seat (as shown in Table 3.7), the peak pressure and contact area are much higher although the average pressure is slightly lower. Subject 1 has the sitting weight which is the nearest to the sample's weight in example for subchapter 3.2. By using the ENS data in Table 3.7, the average pressure is 64.04 kPa/cm^2(/10) = 6.404kPa, compared to the 3.141kPa in the static pressure analysis.

Table 3.9: Example of the pressure distribution test results for subject 1(male) on the older seat

Posture	Seat-pan			Backrest			No. of Red Sensor
	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	Average (kPa/10)	Peak (kPa/10)	Contact Area (cm^2)	
Normal	53.00	187	1174.19	25.96	59	253.23	24
ENS	60.06	285	890	0	0	0	47

3.4 Paper

Following is the paper written for the 9th International Research/Expert Conference, "Trends in the Development of Machinery and Associated Technology", TMT 2005, Antalya, Turkey, 26th-30th September, 2005.

9th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
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PASSENGER SEAT FOR RIDE COMFORT

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ABSTRACT
Seat is the main aspect to be considered when defining comfort in a moving vehicle. This paper attempts to study the static characteristics of an existing bus passenger seat through objective evaluation. The discomfort factors to be concentrated on are the seat contour and pressure distribution at the human-seat interface under static condition. The pressure distribution at the human-seat interface was measured by using the pressure mapping system. By improving the seat parameter, the outcome of this study will become the guidelines for designing and developing the vehicle seat (i.e. buses' seats) for local purposes in term of ride comfort.
Keywords: comfort, static and dynamic, pressure distribution, pressure mapping, human-seat interface

1. INTRODUCTION
Comfort was first operationally defined as "the absence of discomfort" [1]. In recent years, development of a seat with low fatigue during long distance journey is demanded. The "fit" feeling (defined as the body pressure dispersion is good, after sitting postures are ensured) and "soft" feeling (defined as there is the deflection feeling and the body dispersion is good) of the sitting position were converted to points of simulation that the human body receives [2].

Biomedical causes like pressure distribution at passenger-seat interface and body posture are the main factors leading to discomfort of the passenger [3]. The comfort of passenger is strongly related to various seat design factors, such as posture, range and ease of adjustments, and ride vibration environment. Seat temperature and humidity may also increase the discomfort. This is potential for seated pressure distribution to be used as a predictor of discomfort [4].

The development of advanced sensing and evaluation techniques has made it possible to begin to understand the relationship between seating comfort and objective measurements of the human body-seat interface. These studies have relied on pressure sensors positioned between the passenger and the seat along with other custom modifications to the seat itself in order to obtain quantitative measurements [5].The pressure relief effect that was resulted from user movement and repositioning evaluation of the shifting of pressure distribution from the buttock to the back support while increasing the inclination angle has been attempted [6]. Pressure measurements at the seat showed higher-pressure concentrations for the foam cushion at the bony prominence of the seat profile—namely, the ischial tuberosities [7].

The effects of magnitude and frequency of vibration on the pressure distribution has been investigated in terms of ischium pressure, effective contact area and contact force distribution. It was found that heavy subjects tend to induce low ischium pressure as a result of increased effective contact area [8]. There are high hopes in the automotive industry that seat interface pressure measurement can be used to predict areas of subjective discomfort. The objective of the paper is to determine the pressure distribution at the human-seat interface of commercial vehicle passenger seat.

2. METHODOLOGY

2.1 Static Pressure Distribution Measurement at the Human-seat Interface

In this research, the measuring system used is Xsensor pressure mapping system developed by Xsensor Technology Corporation. The system consists of two pressure mapping pads, each sensing pad consisting of 1296 sensors arranged in 36 rows and 36 columns, molded within a mat of flexible material less than 2mm in thickness. The measured data is displayed in colour contoured graphics.

Static test was carried out to measure the buttock-seat pressure distribution. The purpose is to show if there were variances of data with different subjects' weight, height and build and also between different types of seat contours. The sample consists of 5 males and 5 females with a wide range of body sizes. In this test, Xsensor pressure mapping system was used and the seat remained static. Each subject would have to sit with different postures: erect with backrest supported (EBS) and erect without backrest supported (ENS). They also have to sit with different positions during EBS: normal straight ($\approx 110^0$), 1st inclination ($\approx 120^0$), 2nd inclination ($\approx 130^0$), and normal straight with cushion added. Each angle took about 2 minutes to achieve data stability. The measured pressure distribution is evaluated in terms of static pressure distribution contours, maximum (peak) ischium pressure and contact area. Two seats were used as the specimen in this test: an older seat (Figure 1) and an improved seat (Figure 2). The laboratory test was carried out with the seat mounted on a static platform.

Figure 1: Old bus passenger seat

Figure 2: New bus passenger seat

3. RESULTS AND DISCUSSION

Figures 3 and 4 show the 3-dimensional typical surface plots and contour maps of the interface pressure measured by Xsensor pressure mapping system at the surface of the same passenger seat under static seating conditions. These data were derived from measurements performed with subjects erect with back supported (EBS) posture. The results show that more peak pressure occurring in the vicinity of the male's ischial tuberosities than the female's. The high interface pressure peaks (red area) observed are expected to cause fatigue and discomfort over prolonged sitting. Whereas, the human-seat contact area is slightly larger for the male subject compared to the female subject. Results further reveal relatively low-pressure distribution under subjects' thighs. For the backrest pressure distribution, minimum fatigue occurred for both subjects.

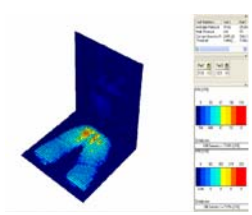


Figure 3: Pressure distribution: female subject

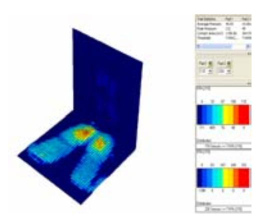


Figure 4: Pressure distribution: male subject

The static characteristics of the human-seat interface pressure are strongly related to the weight, height and build of the seated body. Table 1 and 2 show the static pressure distribution test results of 2 among 10 subjects, which include average pressure, peak pressure and contact area after 2 minutes sitting on the passenger seat. Average pressure, peak pressure and contact area are all higher for male subject. The contact area is strongly related to the pressure distribution. Effective contact area under static condition is defined as area represented by sensors with a pressure reading greater than 5mmHg, which is the threshold value of measurement system to reduce signal noise. Based on the data contour figures between male and female subjects, a heavier subject (male) exhibits relatively larger effective contact area. The contact area increases linearly with the increase in subject weight.

The magnitudes and coordinates of the peak ischium pressure are sensitive to seated posture and the sitting position of the subject with respect to the pressure pad. Although the subjects were advised to assume a balanced posture, test data revealed that there are still variations between the right and left tuberosities, due to the difficulties faced by subjects in maintaining a balanced posture during measurement. Whereas, variations in coordinates of the peak pressure are caused by difficulties seating the subjects at identical position on pressure pad during different tests.

Table 1: Example of the pressure distribution test results for subject 1(female) on the new seat

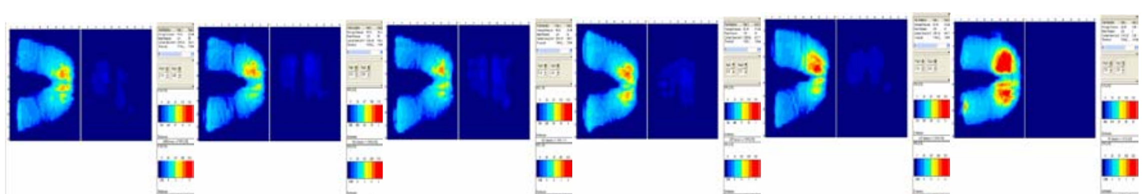
Posture	Seat-pan			Backrest			No. of Red Sensor
	Average (Kpi/10)	Peak (Kpi/10)	Contact Area (cm^2)	Average (Kpi/10)	Peak (Kpi/10)	Contact Area (cm^2)	
Normal	47.61	124	1045.16	25.88	55	316.1	19
1st Inclination	45.91	129	1035.48	30.17	55	438.7	19
2nd Inclination	45.61	124	1024.19	28.9	61	488.7	14
Cushion-added1	51.93	139	1008.06	27.23	64	417.7	1
Cushion-added2	51.45	159	1001.61	23.26	47	440.3	5
ENS	63	232	1140.32	0	0	0	43

Table 2: Example of the pressure distribution test results for subject 2(male) on the new seat

Posture	Seat-pan			Backrest			No. of Red Sensor
	Average (Kpi/10)	Peak (Kpi/10)	Contact Area (cm^2)	Average (Kpi/10)	Peak (Kpi/10)	Contact Area (cm^2)	
Normal	54.98	175	1116.13	30.91	63	511.2	17
1st Inclination	55	177	1098.38	37.29	112	579	22
2nd Inclination	51.26	159	1087.09	35.13	67	616.1	8
Cushion-added 1	52.08	141	1022.58	25.15	55	556.4	8
Cushion-added2	52.01	157	1166.13	21.06	45	401.6	5
ENS	64.04	223	1367.74	0	0	0	38
Rigid surface(ENS)	108.99	293	880.64	0	0	0	141

Table 3: Example of the pressure distribution test results for subject 2(male) on the older seat

Posture	Seat-pan			Backrest			No. of Red Sensor
	Average (Kpi/10)	Peak (Kpi/10)	Contact Area (cm^2)	Average (Kpi/10)	Peak (Kpi/10)	Contact Area (cm^2)	
Normal	53.00	187	1174.19	25.96	59	253.23	24
ENS	60.06	285	1435.48	0	0	0	47



Normal angle 1st inclination 2nd inclination Add-cushion 1 Add-cushion 2 Without backrest

Figure 5: Lab test: Static pressure distribution onto the new passenger seat for subject 1

Figure 5 shows the static pressure distribution onto the new passenger seat for subject 1 with different postures. In Table 1 and 2, when the inclination angle of the backrest was increased from normal position to second inclination, the average pressure at the buttock-seat interface reduced while the average pressure at the backrest increased. This shows that the inclination of the backrest affects the human-seat pressure distribution. During an EBS posture, when the angle of backrest-seatpan is increased, the pressure will be more evenly distributed. Therefore, the contact area will increase on the backrest and the peak pressure of seat pan will reduce.

For the EBS (erect with backrest supported) postures, about 30-40% of the total sitting pressure was transmitted to the backrest. About 35-36% was transmitted to the backrest for normal sitting posture, about 40% for 1st and 2nd inclination, and 30-35% for the postures with cushion thickness added with form to the seat backrest. For subject 1, the average pressure at the seat-pan with added cushion was slightly higher than the normal EBS sitting but for subject 2, the average pressure for seat-pan was lower than normal sitting posture when cushion was added. For both subjects, the average pressure onto the backrest with cushion added was mostly lower than the average pressure during normal sitting. For all subjects, with the increase of inclination angle, the contact area at the buttock-seat interface was reduced whereas the contact area at the backrest was increased. All ENS (erect with backrest not supported) posture data have shown that the average pressure, peak pressure and contact area at the human buttock-seat interface were the highest. Zero reading was shown for the backrest because subjects were not leaning against the backrest during ENS sitting. For subject 2, a pressure test onto a rigid (wooden) surface was conducted. The result shown in Figure 6 shows that the average pressure and peak pressure is the highest whereas the contact area is the lowest because the pressure is more concentrated on a rigid surface compared to a soft surface (cushion). The contact area is higher on a cushion because human body is more easily sink into a softer surface than a harder surface. Hence, human body pressure is more evenly distributed on a cushion than a wooden surface.

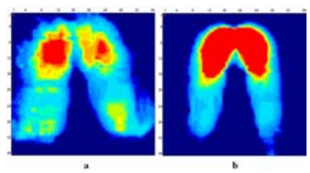


*Figure 6: Comparison of pressure distribution between **a.** cushion surface and **b.** wooden surface*

Table 3 shows the static pressure distribution test results for subject 2 by using the older passenger seat as illustrated in Figure 3. From the table, comparison can be made between the older seat and the new passenger seat. For normal EBS sitting, the peak pressure and contact area of the subject onto the older seat pan is higher, although the average pressure is lower. All the data for the backrest pressure is also lower than the data for the new seat backrest. Not much of the pressure at the buttock was transferred to the backrest of the old seat. The data for the ENS posture is higher than the data for normal EBS posture. When compared with the ENS data for the new seat, the peak pressure and contact area are much higher although the average pressure is lower a little.

4. CONCLUSION

The seat conditions, i.e. backrest-seatpan angle and cushion contour (thickness) have effects onto the average pressure, peak pressure and contact area of the human-seat interface. Differences of ischium pressure, contact area and subject weight between an erect posture with backrest not supported (ENS) and an erect posture with backrest supported (EBS) can be discovered through those objective methods. The study showed that the interface pressure on a softer seat is more evenly distributed compared to a more rigid seat.

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CHAPTER 4

LABORATORY DYNAMIC TEST

Laboratory tests were conducted to determine the human-seat interface pressure distribution under static and dynamic seating environment. Therefore, the laboratory test was carried out in 2 conditions; static and dynamic. Dynamic test was conducted to obtain the seat transmissibility. The dynamic tests procedures are shown in APPENDIX C.

4.1 Measurement of Seat Vibration Transmission Characteristics

To measure the vibration transmission characteristics of the passenger seat loaded with a subject of certain weight, an additional sensor known as seat-accelerometer would be installed at the human-seat interface. The sensor used in this research to measure the vibration on the seat is SAE Sit-pad Accelerometer (Figure C5). The method to do this measurement are more or less same with the method used during dynamic pressure distribution tests, except the pressure map be replaced by the Sit-pad Accelerometer.

4.2 Pressure Distribution Measurement at the Human-seat Interface

Measured data was analyzed to determine the human-seat interface pressure distribution under dynamic seating environment. Dynamic tests were carried out under two conditions; laboratory and road trial. During laboratory tests, sinusoidal signal was generated by a machine named Dartec Universal Testing Machine. Due to safety factor, a mass system with dead load weighted about 44kg (which is about the weight of an average-size person sitting on a seat) was used in the laboratory dynamic test. Whereas, random vibration could be obtained in a moving bus during road trials, which will be discussed in the following chapter. Before dynamic tests were carried out, static test should be done to measure the buttock-seat pressure distribution among the sample of 10 passengers to show if there are variances of data with different subjects' weight, height and build and also between different types of seat contours. This static test has been discussed in the previous chapter.

4.3 Rigid Load Dummy

Since using human as test subject in vibration test using universal testing machine is quite dangerous, the rigid load dummy, or rather mass system which had similar weight to the sitting weight of a person, was used. It consists of a layer of thin neoprene (Figure 4.1), cushion load indenter (Figure 4.2), buttock model (Figure 4.3) and rigid load up to 55 kg (Figure 4.4). This system was used for vibration test; transmissibility and pressure distribution test (as shown in Figure 4.5).

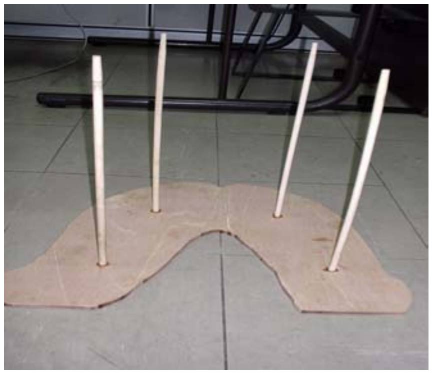


Figure 4.1: A thin layer of neoprene

Figure 4.2: Cushion Load Indenter

Figure 4.3: Buttock Model

Figure 4.4: Rigid Load

Figure 4.5: Rigid Load Dummy to determine the correct pressure distribution for vibration test

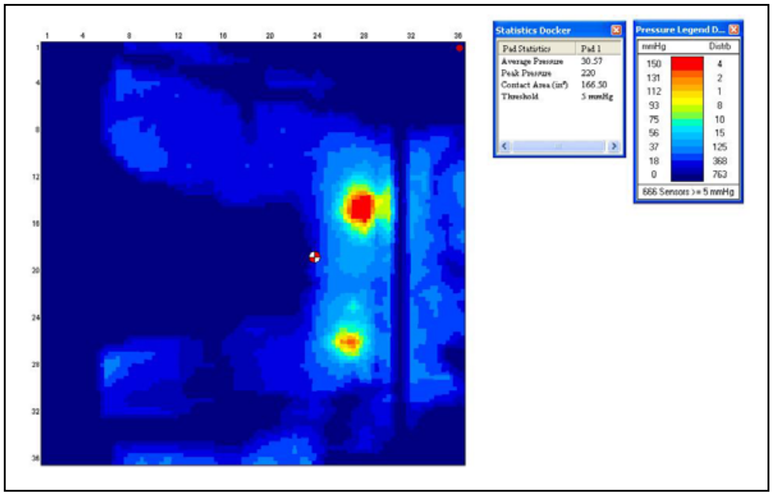
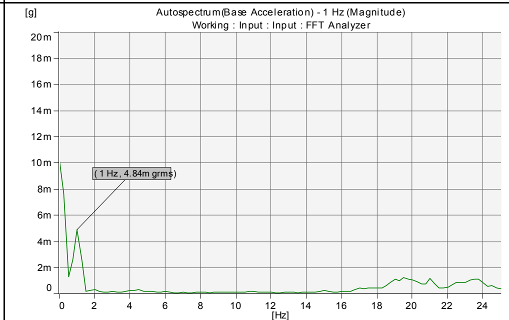
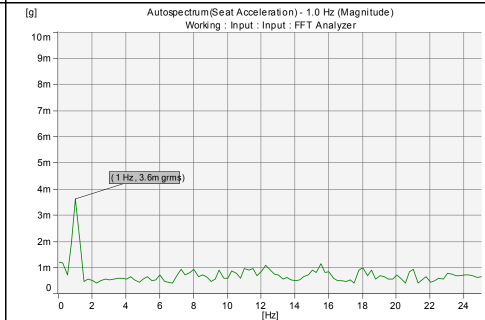
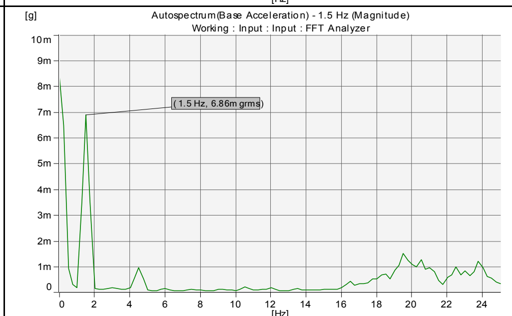
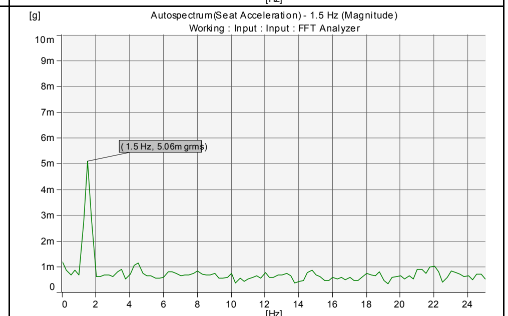
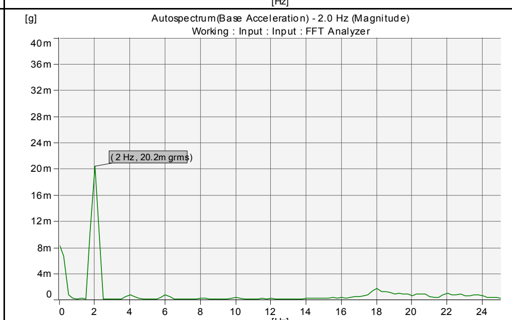
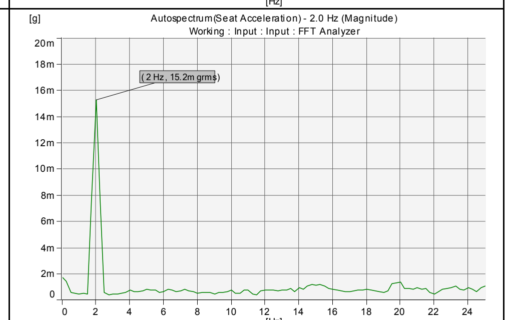
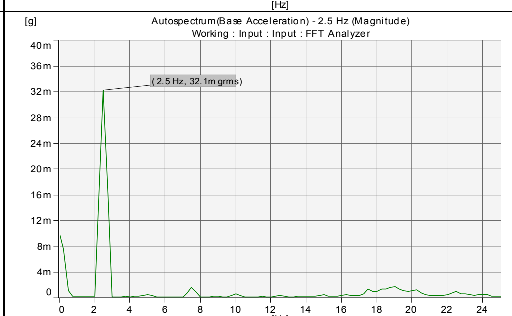
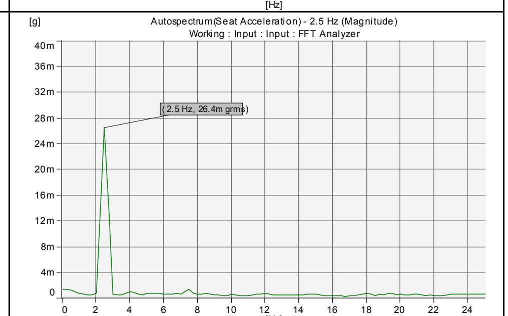
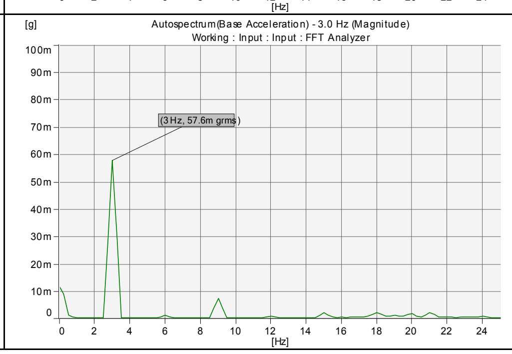
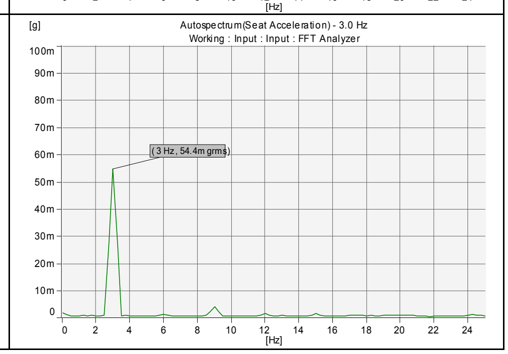


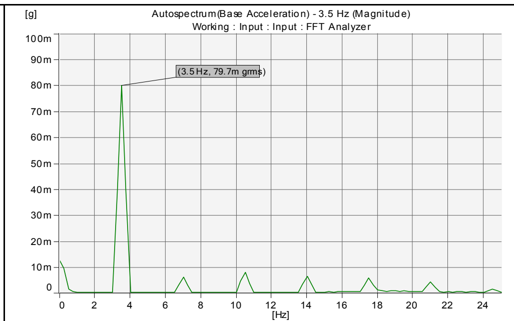
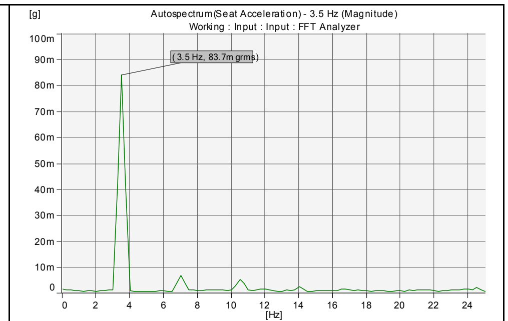
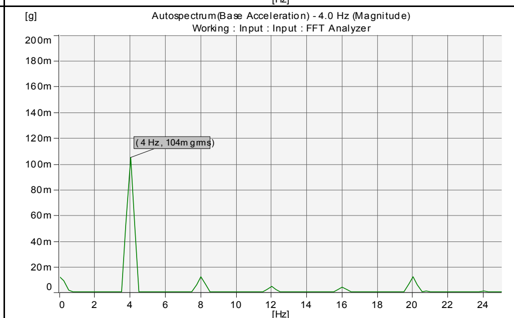
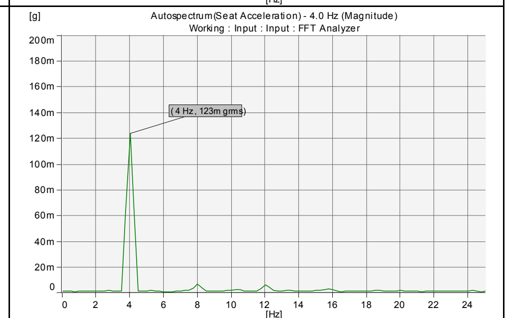
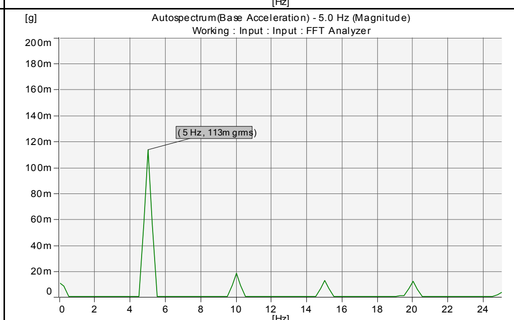
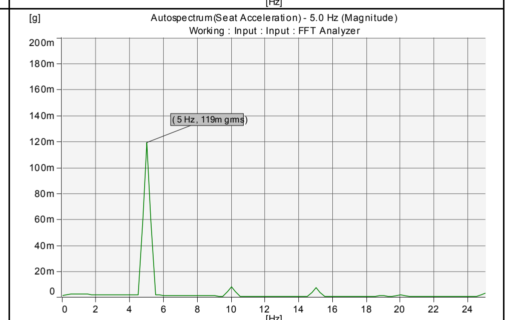
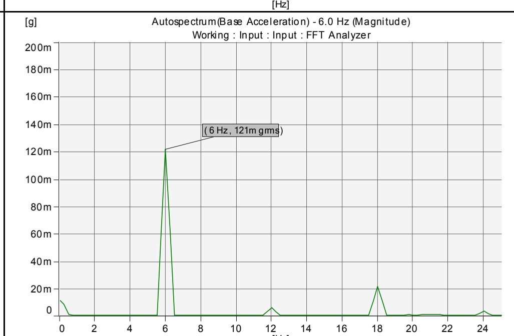
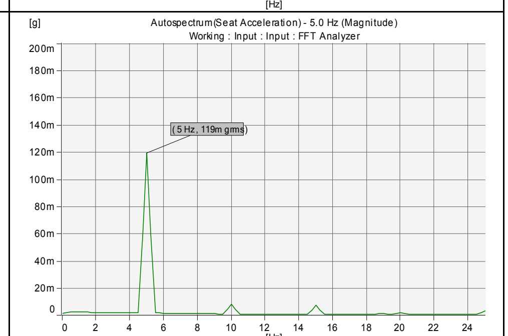
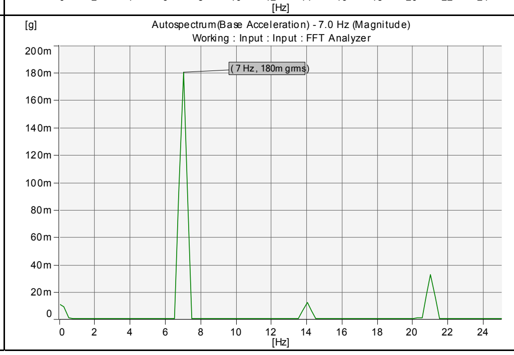
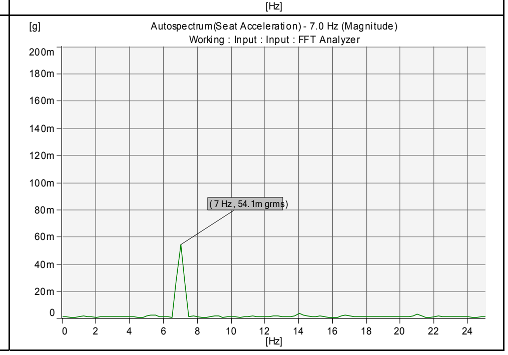
Figure 4.6: Approximate pressure distribution used for vibration test in laboratory.

4.4 Results

This test was carried out by increasing the frequency, from 1 Hz until 10 Hz. There were 2 kinds of data in the test; input data and output data. Input data was obtained from the accelerometer installed at the base of the seat, whereas output data would be obtained from the seat pad accelerometer put on the seat pan. The acceleration results are shown in Figure 4.7. The test was done with the dummy weight on the seat. From these figures, it can be seen that the acceleration values are increasing with the frequency increase.

The vibration test was followed by pressure distribution test, in which the seat pad accelerometer was replaced by the Xsensor pressure map as the output transducer, with the same input as in the vibration test. The results are shown in Figure 4.7.

	Seat Base	Seat Pan
1Hz		
1.5Hz		
2.0Hz		
2.5Hz		
3.0Hz		

3.5Hz		
4.0Hz		
5.0Hz		
6.0Hz		
7.0Hz		

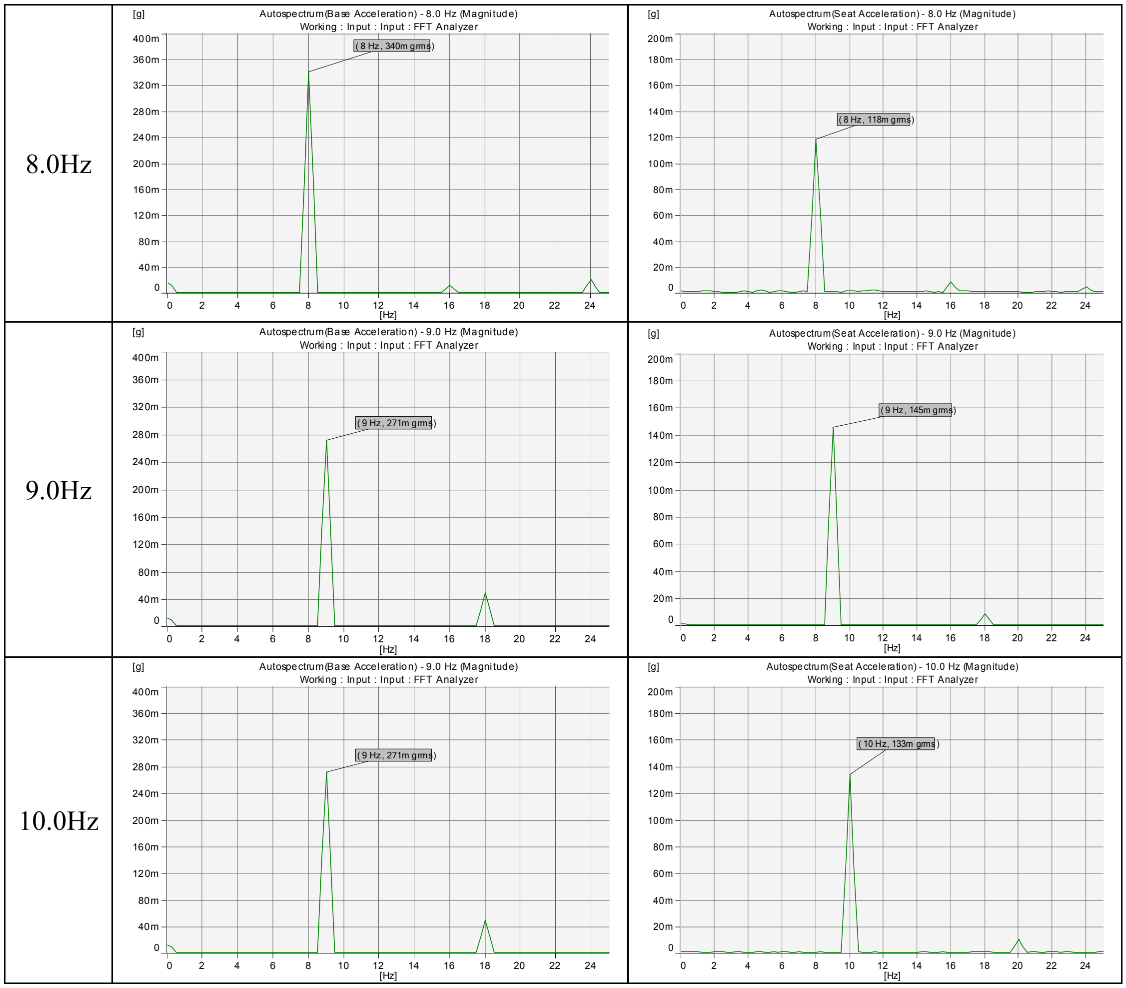


Figure 4.7: Graphs (g RMS vs. Hz) showing seat base and seat pan acceleration according to frequencies (from 1Hz until 10 Hz)

From Figure 4.7, it can be seen that the acceleration values are increasing with the frequency increase. A transmissibility graph that shows the vertical (z-axis) seat transmissibility for the seat is plotted as in Figure 4.8. From the transmissibility test, the SEAT value obtained was 75.18%.

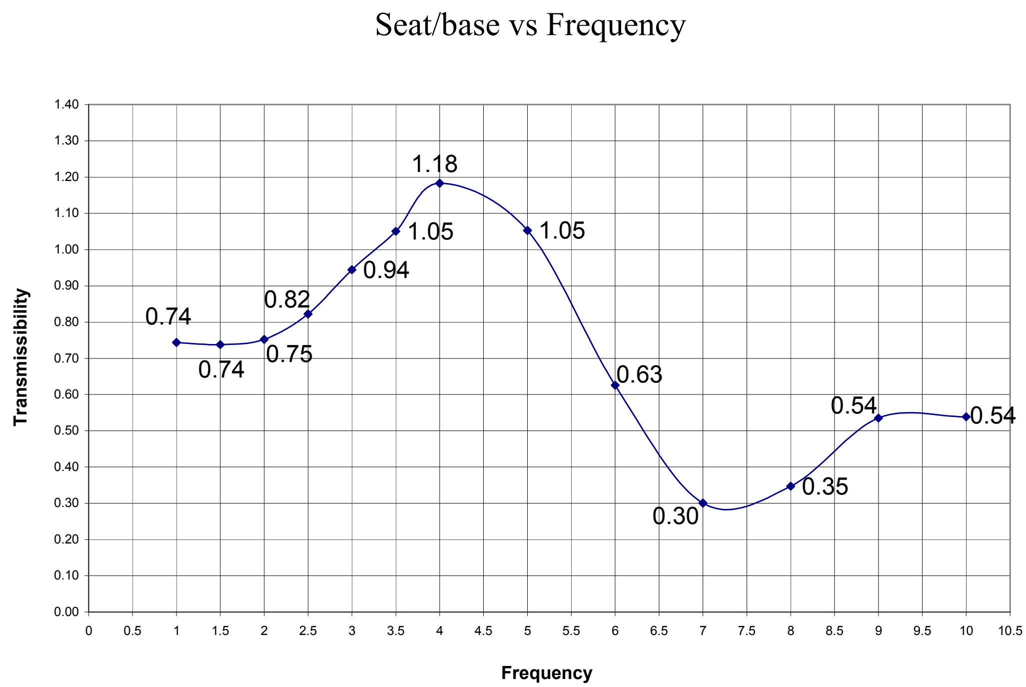
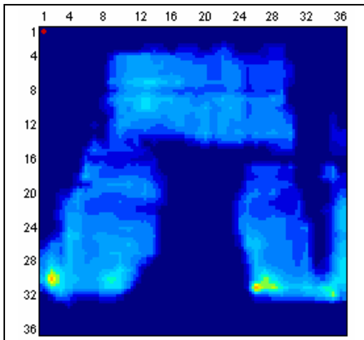
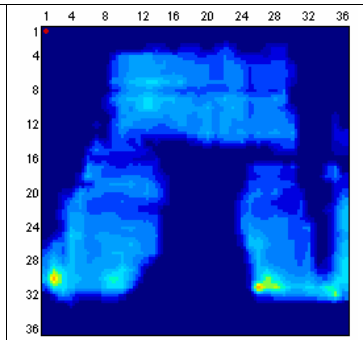
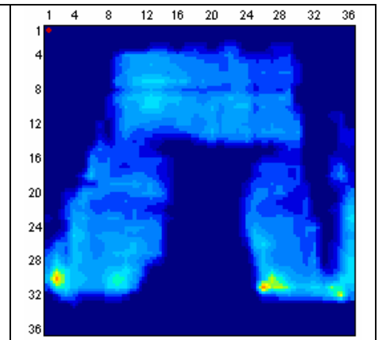
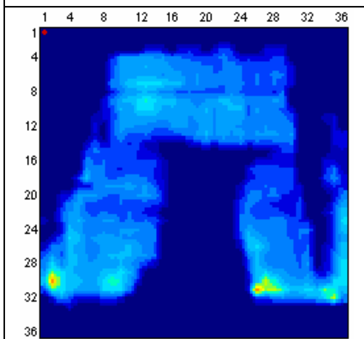
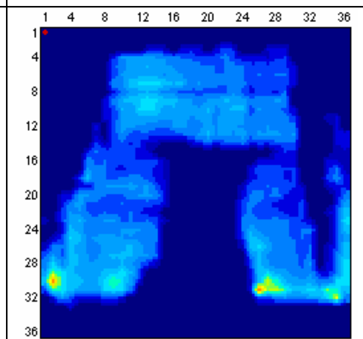
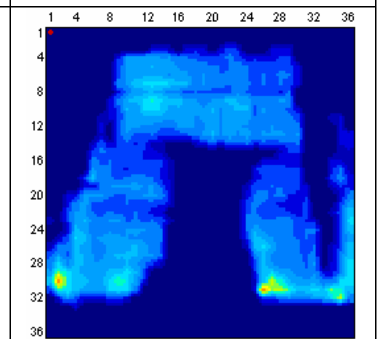
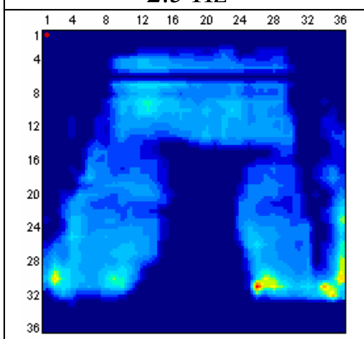
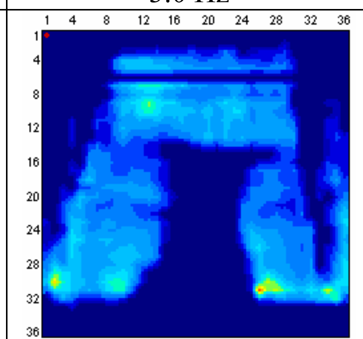
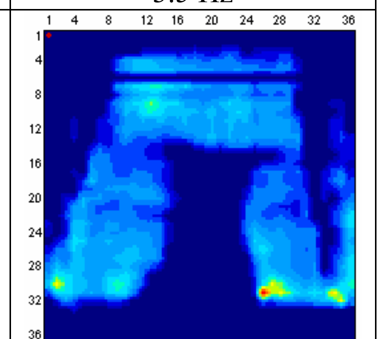
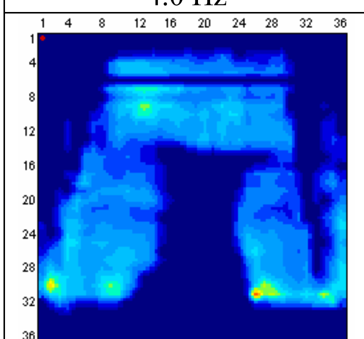
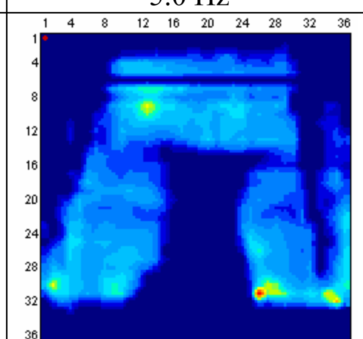
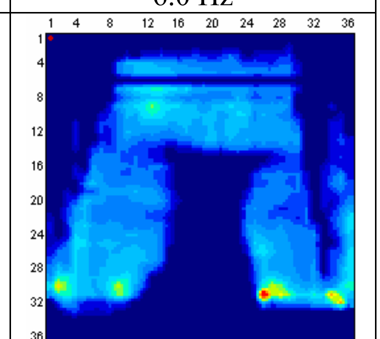
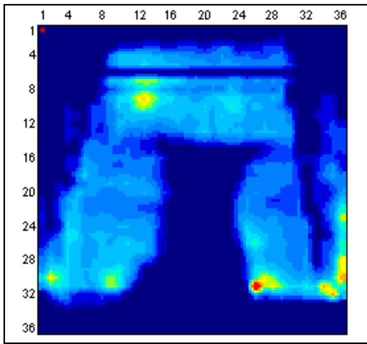


Figure 4.8: Vertical (z-axis) seat transmissibility for the existing seat.

From the graph in Figure 4.8, it can be seen that the maximum transmissibility is at the frequency of 4 Hz. This can be explained by the statement from M. J. Griffin (1990) that a vertical resonance frequency close to 4 Hz will occur for many current conventional seats. Starting from 1 Hz, the transmissibility was lower than 1, then was slowly amplified to exceed 1. After the peak transmissibility at 4 Hz, attenuation occurred and at frequency 7-7.5 Hz there was a small increase in transmissibility until 0.54 at 10 Hz.

The vibration test was followed by pressure distribution test, in which the seat pad accelerometer was replaced by the Xsensor pressure map as the output transducer. The results are shown as in Figure 4.9.

		
1.0 Hz	1.5 Hz	2.0 Hz
		
2.5 Hz	3.0 Hz	3.5 Hz
		
4.0 Hz	5.0 Hz	6.0 Hz
		
7.0 Hz	8.0 Hz	9.0 Hz



10.0 Hz

Figure 4.9: Contour maps of the dynamic pressure interface between mass system which simulated human buttock and cushion for different frequencies from 1-10 Hz

From Figure 4.9, it can be seen that, with the increase in frequency, the red area at the edge of the thigh part would become clearer. Red area represents high pressure. Such results differ very much from the expected results. For a real human subject, it is the ischial tuberosities that should produce the highest peak pressure along the test but not the thigh part, as shown in this test. This might be due to the system material used where the edge of the plywood at the thigh part had resulted in concentration to the seat cushion. Apart from that, not much difference can be seen from the figure above despite of the increase of frequency. When the data is observed in detail through the pressure system software, the differences can be detected as shown in Figure 4.10.

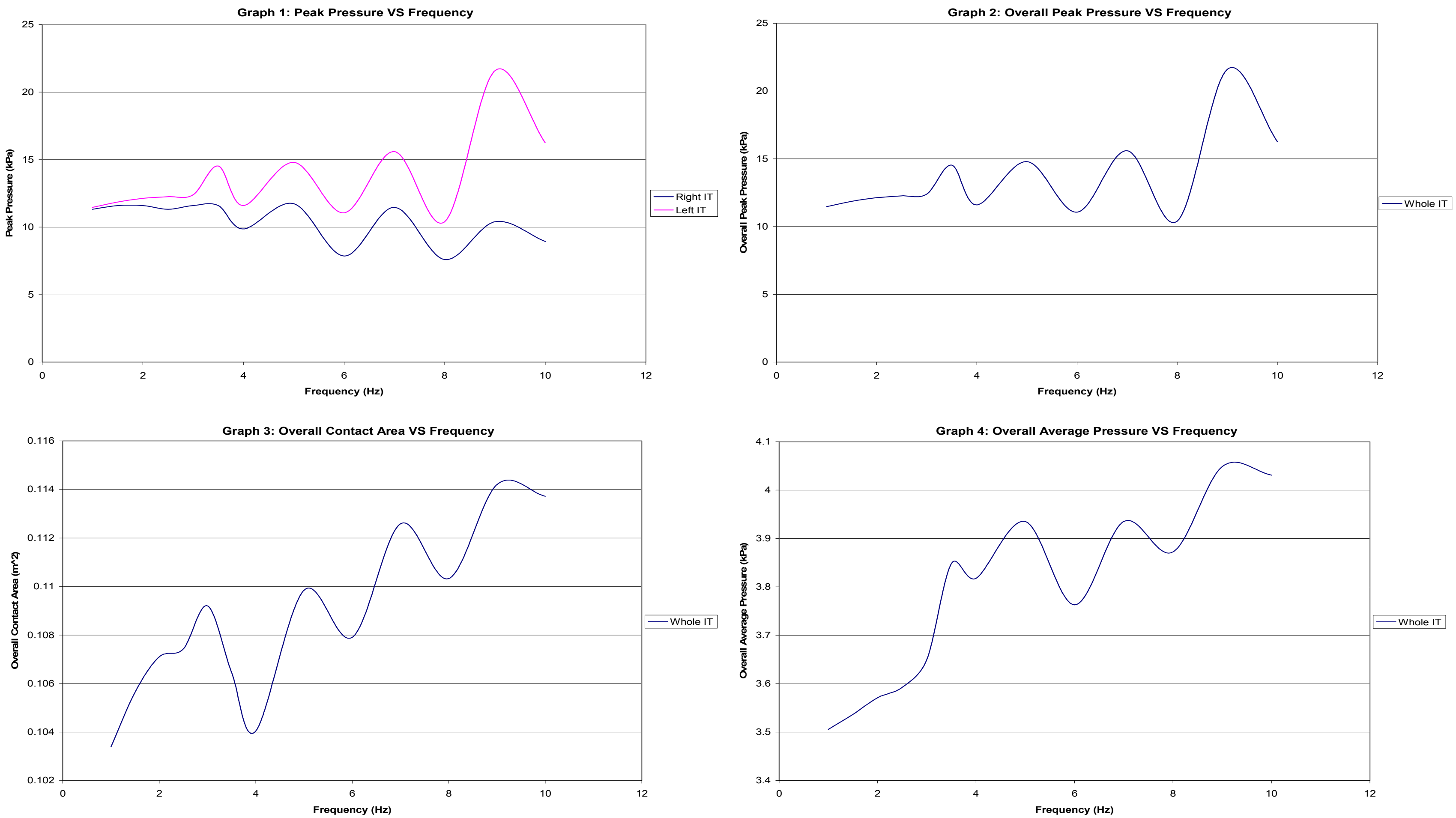


Figure 4.10: Characteristics of pressure distribution shown by pressure sensors during laboratory dynamic test

The graphs in Figure 4.10 show how the data changed against frequency during the dynamic pressure test on the mass system representing human load. From Graph 1, we can see that both the right ischial tuberosity and the left ischial tuberosity have different values of peak pressure against frequency. Peak pressure on left ichial tuberosity is higher than the right ichial tuberoisity. This might be due to the difficulties faced when maintaining the mass system in a balanced posture during measurement. Such situation also happens to human subjects, where data variation often exists between left and right ischial tuberosities. However, both parts share a similar polar where the sinusoidal pattern can be seen in both graphs after 3 Hz.

Graph 2, 3, and 4 show the overall peak pressure, contact area and average pressure, respectively, against the frequency. All these graphs show the similarity with Graph 1, where the data goes up and down in sinusoidal form after 3 Hz. The data seems increasing until the peak frequency, as a sinusoidal wave. This shows that the force of the mass system onto the cushion increased when the seat vibrated with higher frequencies, causing the rise in contact area and pressure. Sinusoidal waves occurred because the vibration (after 3 Hz) caused the whole mass system to rebound. The other reason is that resonance occurred at 4 Hz (refer to Figure 4.8) when the system moved almost with the same or higher frequency with the vibrating seat.

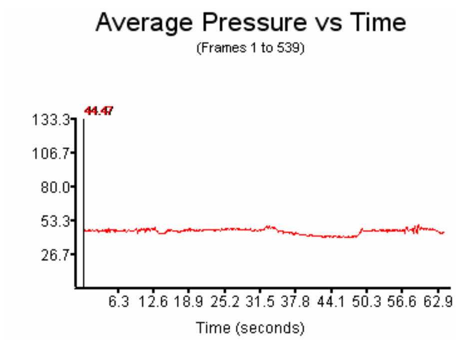
CHAPTER 5

FIELD TRIAL

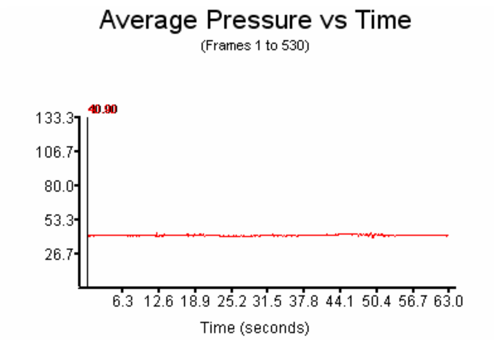
Random vibration can be obtained in a moving bus, during road trials. Before dynamic tests are carried out, static test should be done to measure the buttock-seat pressure distribution among the sample of 10 passengers to show if there are variances of data with different subjects' weight, height and build and also between different types of seat contours. This had been done in static test as in Chapter 3.

5.1 Pressure Distribution Test

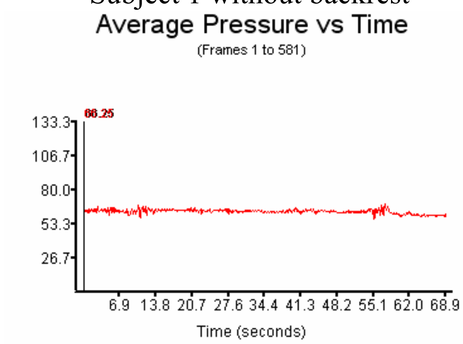
The first test (as a pretest) was done on a university bus. The bus was a normal VIP bus with 4 seats in a row. Therefore the type of seat used was different and smaller than the super VIP seat used in laboratory test. However, the cushion material for both the seats was almost the same. The type of vibration produced during the field trial was random vibration because the bus was moving on the road where the frequency could not be set or predicted. There were 2 subjects assisting in this test. The bus would be driven through 2 conditions of road; bumpy and smooth-surfaced roads. For each condition, each subject was required to sit with 2 positions; EBS (erect with back supported) and ENS (erect without back supported). Therefore there were all 8 data recorded for this test, as shown in both Figure 5.1 and Figure 5.2.



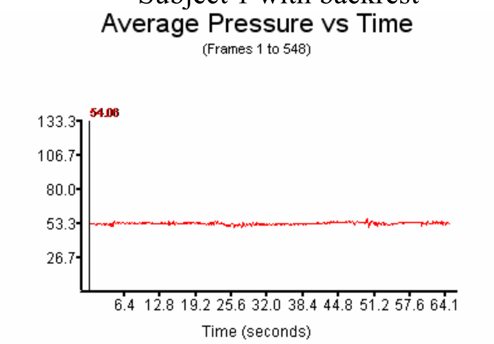
Subject 1 without backrest



Subject 1 with backrest

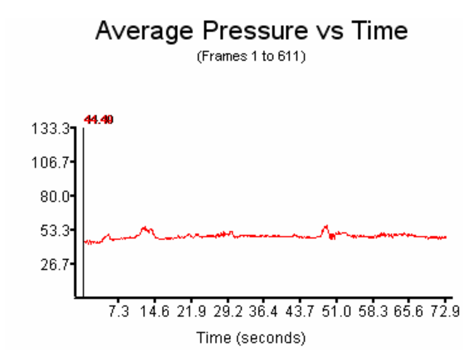


Subject 2 without backrest

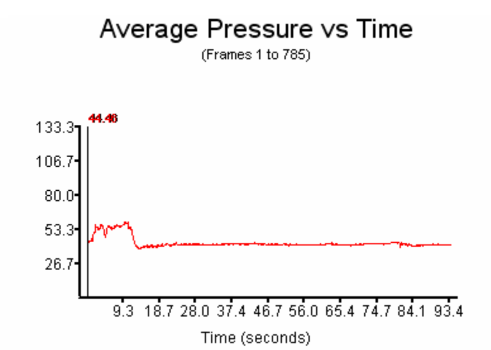


Subject 2 with backrest

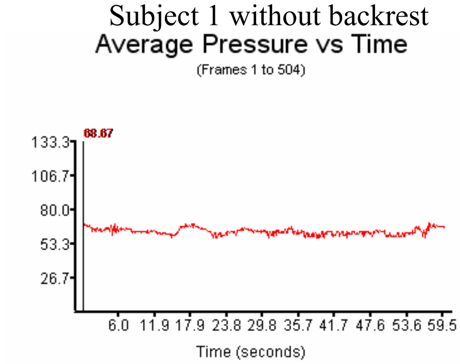
Figure 5.1: Average pressure against time for the field test on the bumpy road: 2 subjects with 2 positions each



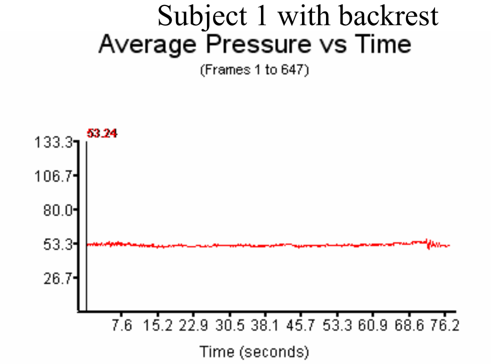
Subject 1 without backrest



Subject 1 with backrest



Subject 2 without backrest



Subject 2 with backrest

Figure 5.2: Average pressure against time for the field test on the smooth-surfaced road: 2 subjects with 2 positions each

From the graphs in both Figure 5.1 and Figure 5.2, it can be seen that for both subjects, the data of average pressure during sitting without backrest is higher than the data range of sitting with backrest. This is similar with the static pressure test. Besides, the EBS reading is more constant than the ENS reading showing that the position without backrest is unstable as there is nothing for the subjects to lean against. To compare both the 'bumpy' and 'smooth' road data, the data of sitting with back supported (EBS) is taken to be considered (the data of sitting without back supported is abandoned because the subjects' bodies were unstable without backrest, no matter how the road condition is during vehicle ride). If zoomed in more detail, it is discovered that the data of the even road is more constant than the data of bumpy road.

Second test was carried out in a moving van with the same super VIP seat (current existing bus passenger seat) which was used in the laboratory tests earlier. Van was used for the actual field trial due to its vibration condition which was critical than the bus. The seat was mounted onto the floor of the van. 5 subjects (who were among the 10 subjects in the static pressure test) assisted in this test. The size of subjects is shown in Table 5.1. The van was driven through the same route used by the first test. The results for every test were recorded for 1 minute each and are shown in Figure 5.3 and Figure 5.4.

Table 5.1: Anthropometry of the field trial subjects

Subject	**Height(cm)**	**Weight(kg)**
A	178	73
B	170	68
C	154	46
D	169	63
E	158	42

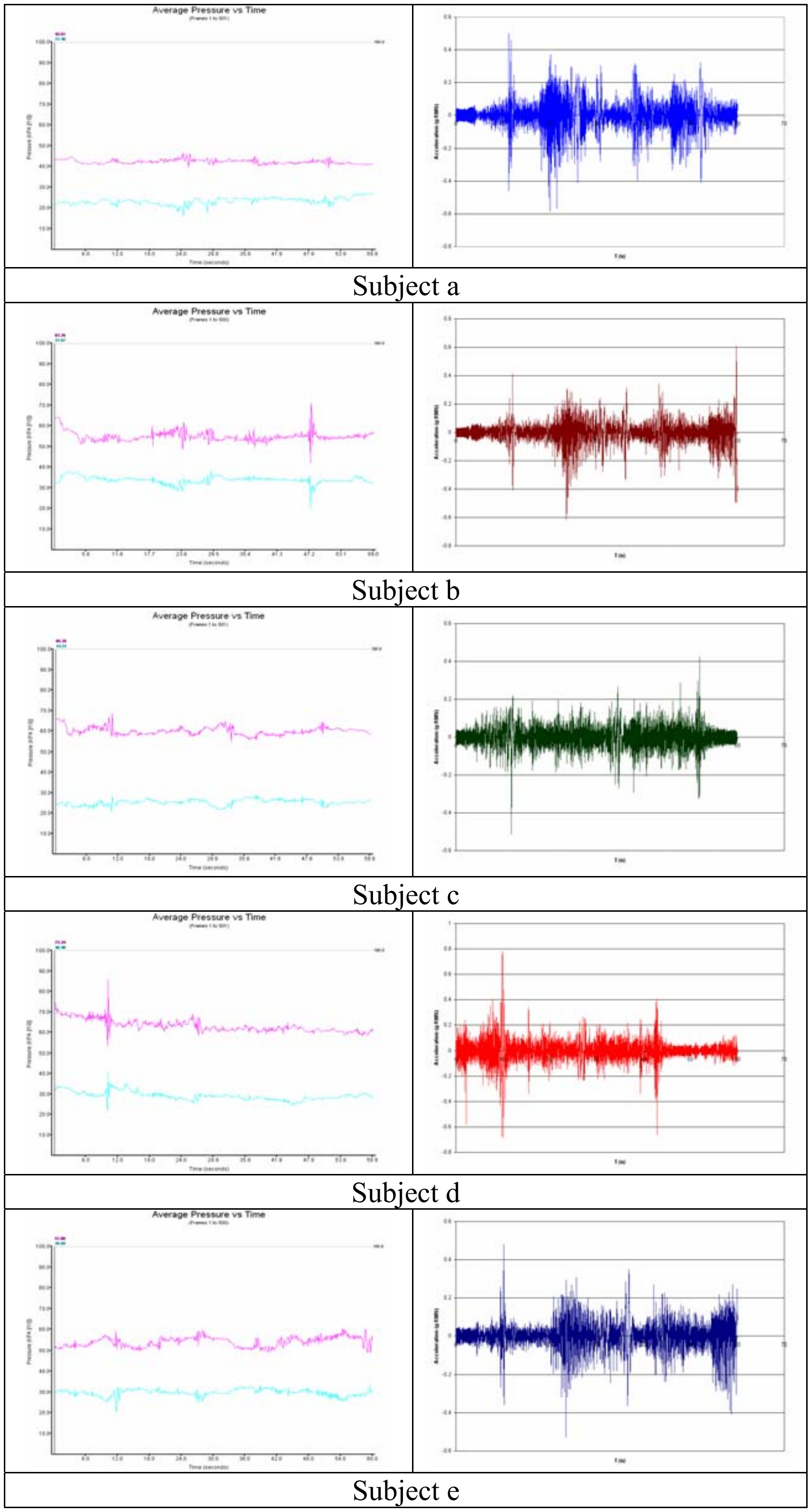


Figure 5.3: Average pressure with the synchronized vibration for 1 minute each for 5 subjects on bumpy road

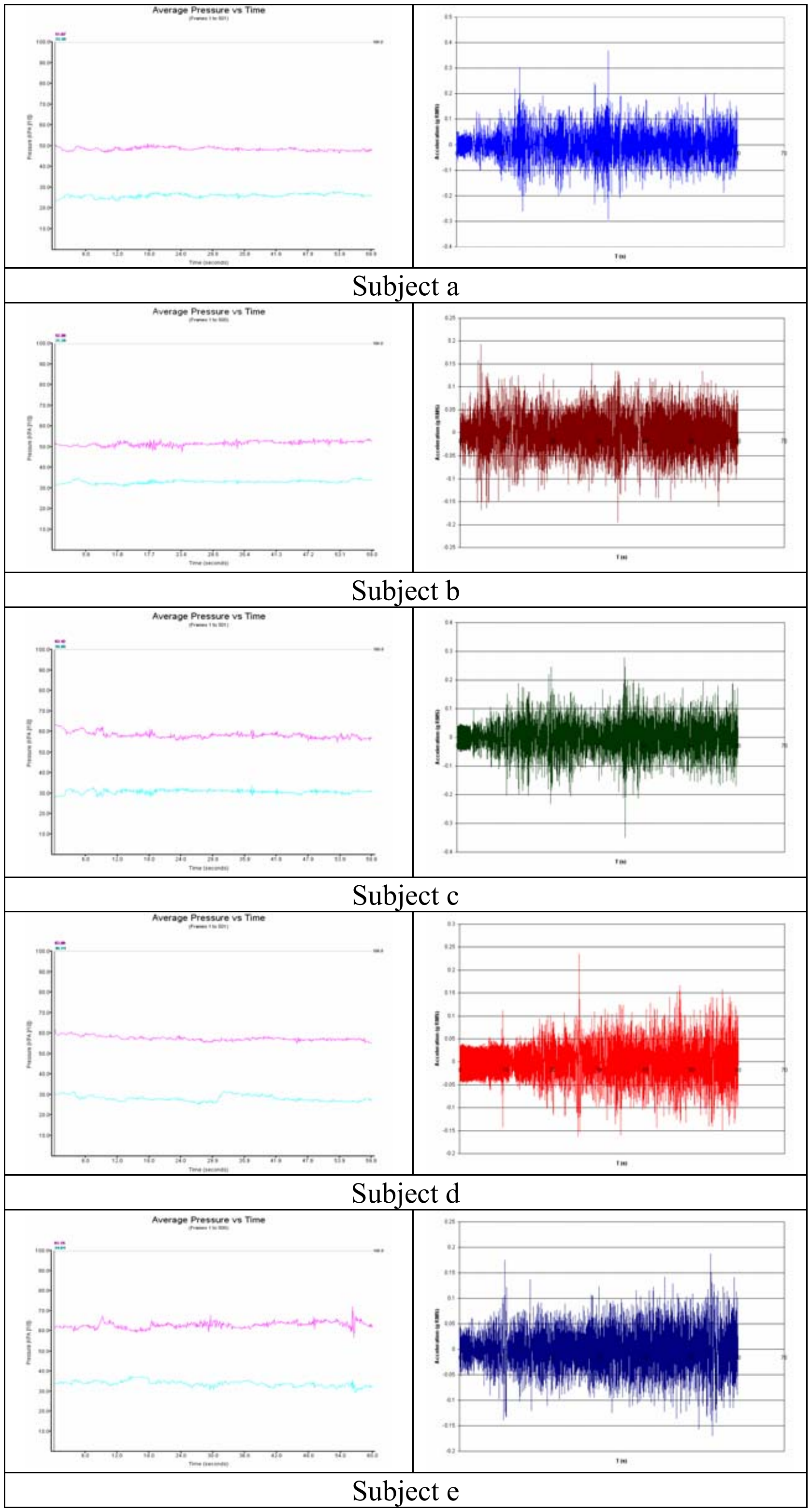
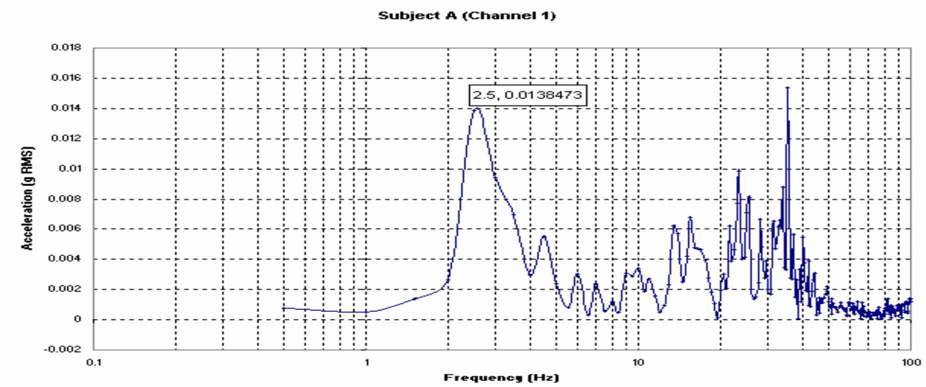


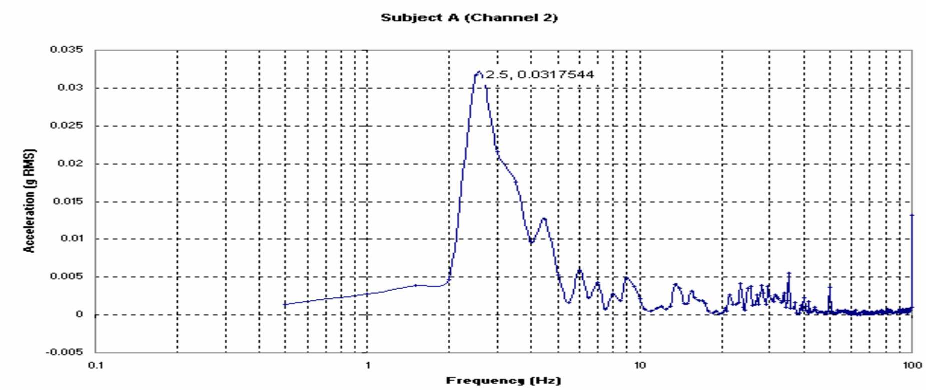
Figure 5.4: Average pressure with the synchronized vibration for 1 minute each for 5 subjects on straight road

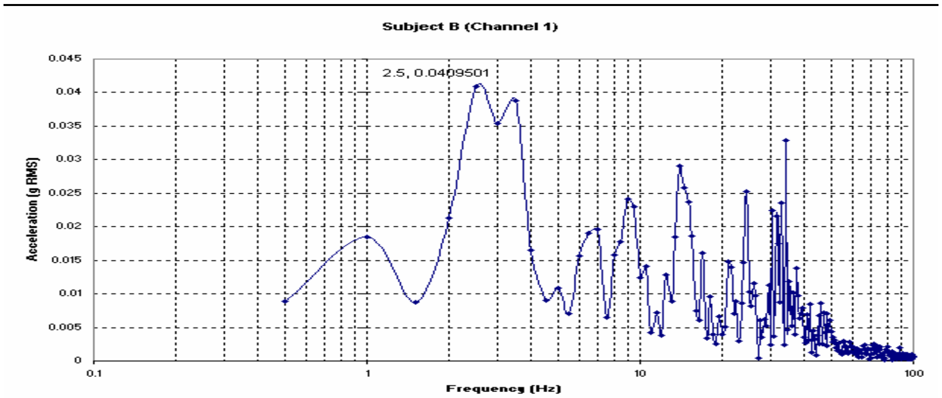
From both the Figures 5.3 and 5.4, it is known that the average pressure during bumpy road trial was unstable compared with the average pressure during smooth surfaced road trial which was more constant, in the range of 0.2-0.4Hz. The highest and lowest peaks of the graph for average pressure during bumpy road are clearly shown. The acceleration was measured in unit ms^{-2} RMS as the reading had been frequency-weighted to quantify the severity of human vibration exposures according to BS 6841.

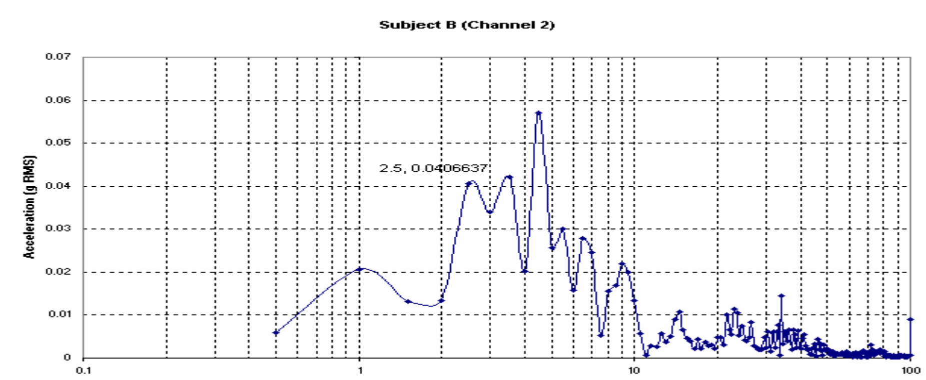
5.2 SEAT Test

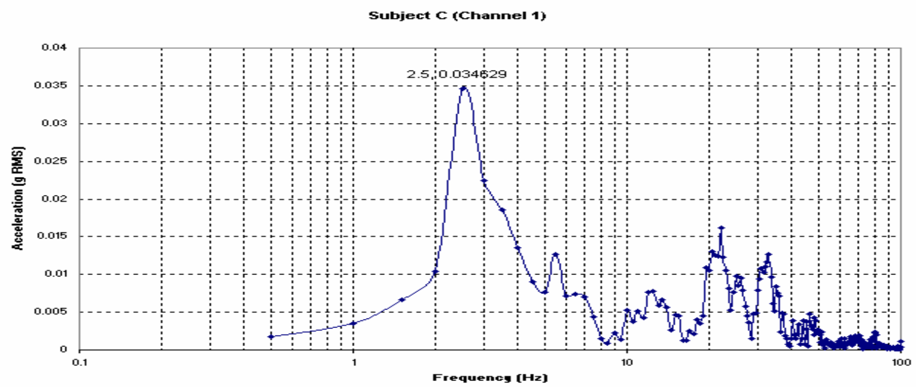
SEAT (Seat Effective Amplitude Transmissibility) tests were carried out by replacing the pressure pads with the seat pad accelerometer on the seat pan. The seat-based low frequency accelerometer was remained at the same point. Input data (Channel 1) was obtained from the low frequency accelerometer installed at the base of the seat, whereas output data (Channel 2) was obtained from the seat pad accelerometer positioned on the seat pan. During the pretest, vibration data for the subject 1 had also been analyzed to produce the SEAT value. The actual test was done with subject sitting comfortably on the seat which had been attached to the floor of the van. There were 5 subjects and for every subject, the van would be driven through two routes; bumpy road and smooth-surfaced road. Graphs in Figure 5.5 and Figure 5.6 below show the power spectrums of Channel 1 and Channel 2 for the 5 subjects during the ride on bumpy and smooth-surfaced road, respectively. All the graphs show that the power spectrums of both the Channel 1 and Channel 2 have a peak RMS value around 2 to 4 Hz. After these frequencies, the output signals become lower.

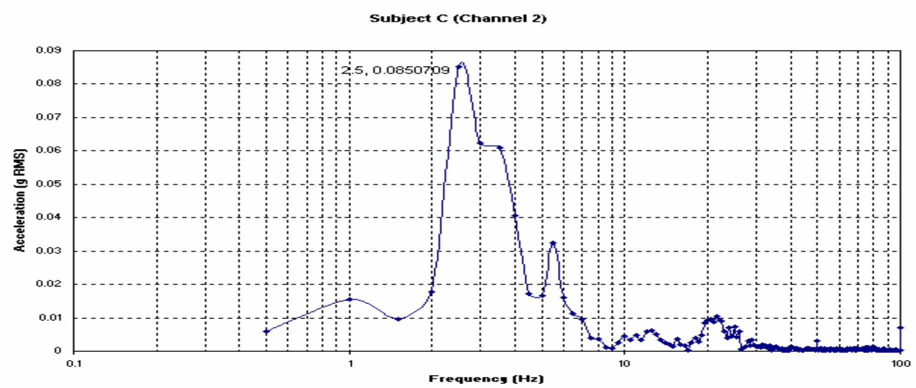

Subject A (Channel 1)
2.5, 0.0138473
Acceleration (g RMS)
Frequency (Hz)

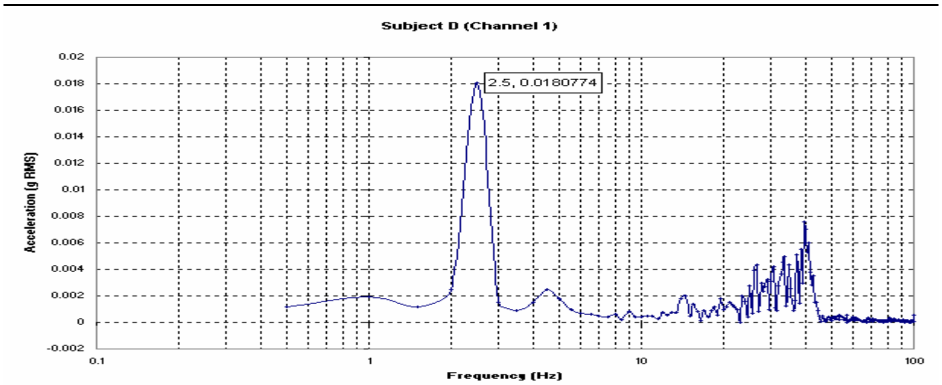

Subject A (Channel 2)
2.5, 0.0317544
Acceleration (g RMS)
Frequency (Hz)


Subject B (Channel 1)
2.5, 0.0409501
Acceleration (g RMS)
Frequency (Hz)


Subject B (Channel 2)
2.5, 0.0406637
Acceleration (g RMS)
Frequency (Hz)


Subject C (Channel 1)
Acceleration (g RMS)
Frequency (Hz)
2.5, 0.034629
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.1
1
10
100


Subject C (Channel 2)
Acceleration (g RMS)
Frequency (Hz)
2.5, 0.0850709
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.1
1
10
100


Subject D (Channel 1)
Acceleration (g RMS)
Frequency (Hz)
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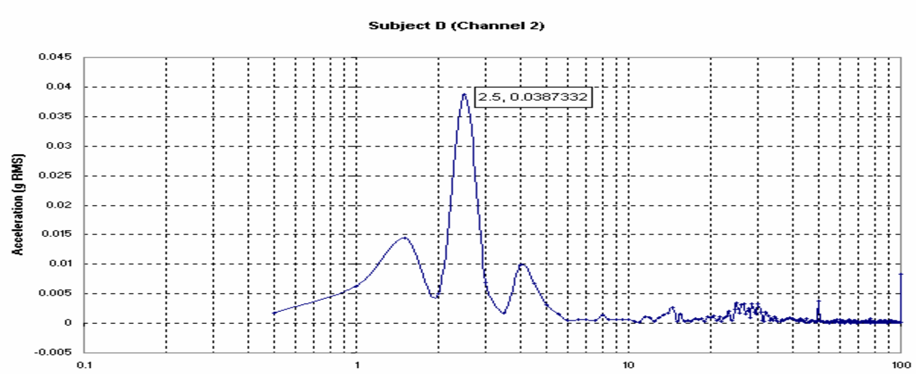
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
0.1
1
10
100


Subject D (Channel 2)
Acceleration (g RMS)
Frequency (Hz)
2.5, 0.0387332
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
0.1
1
10
100

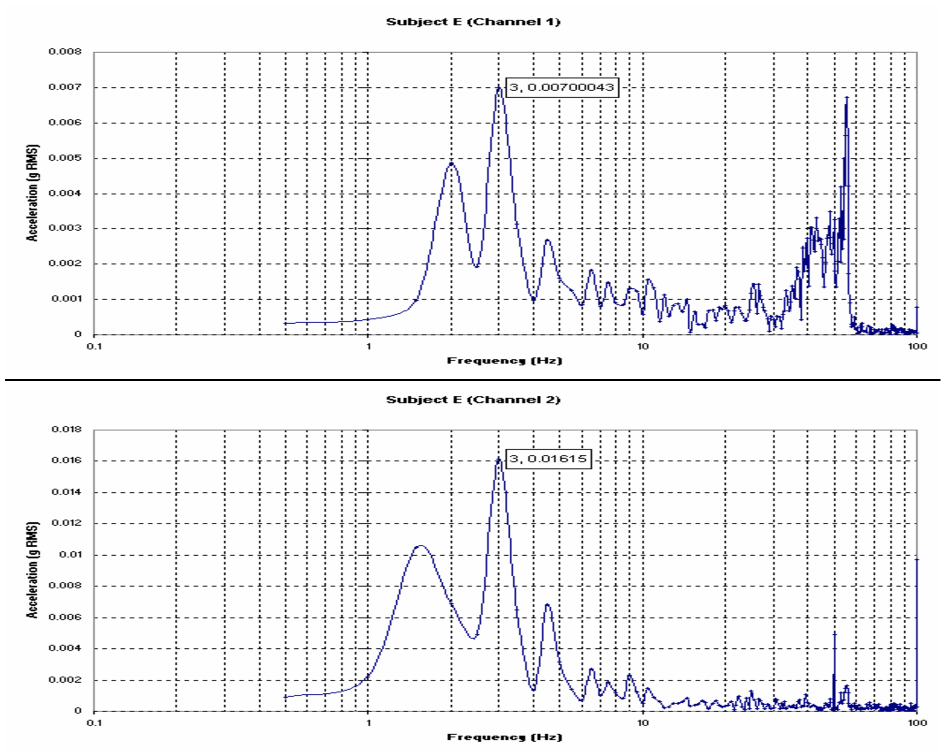
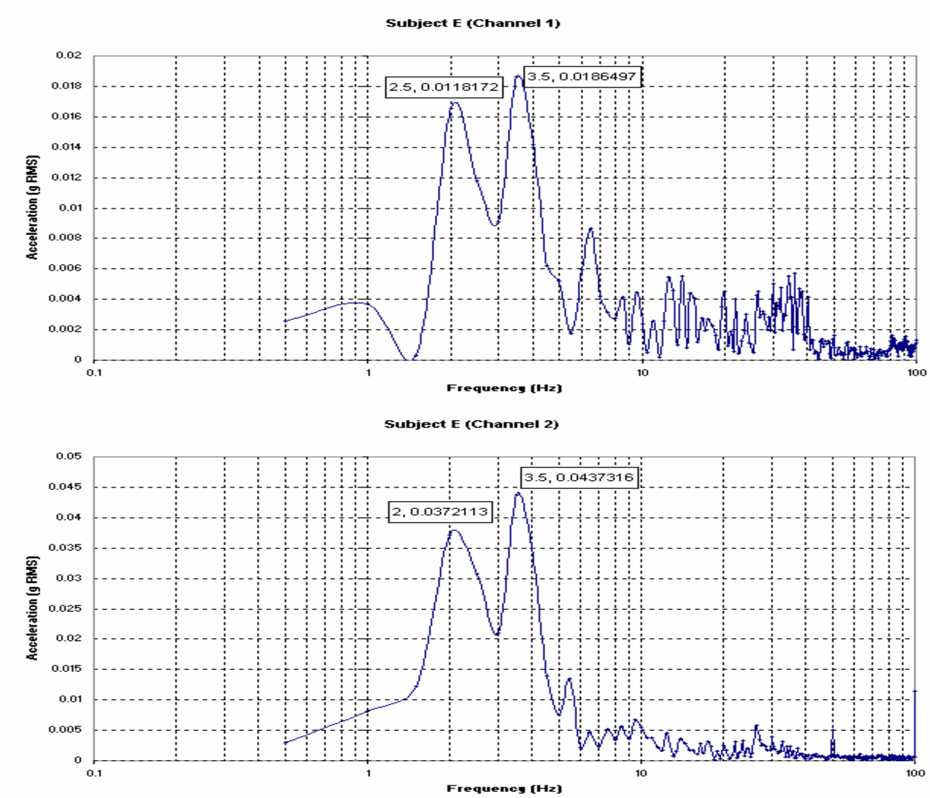
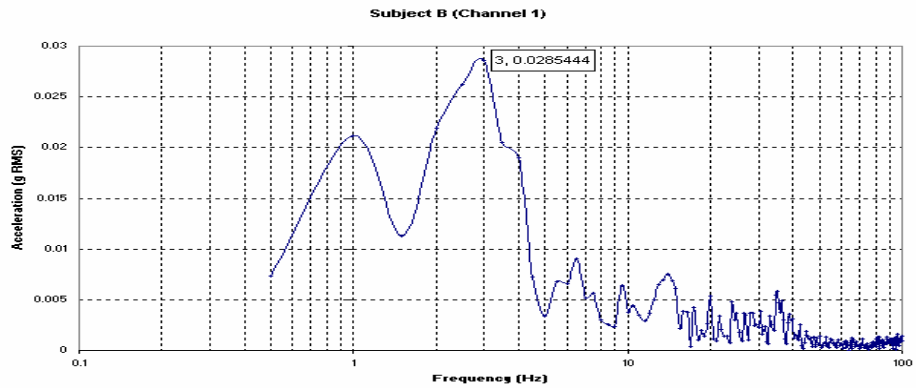
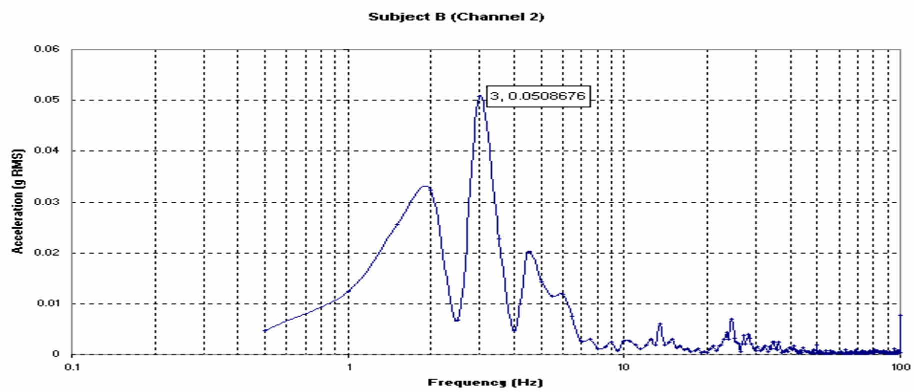
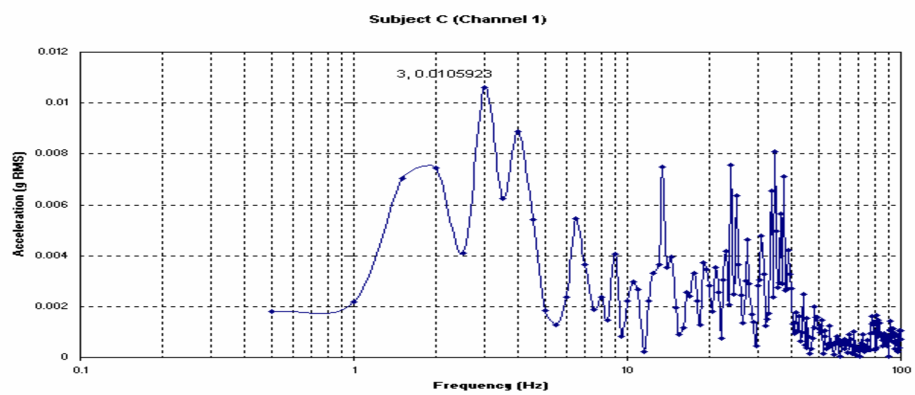


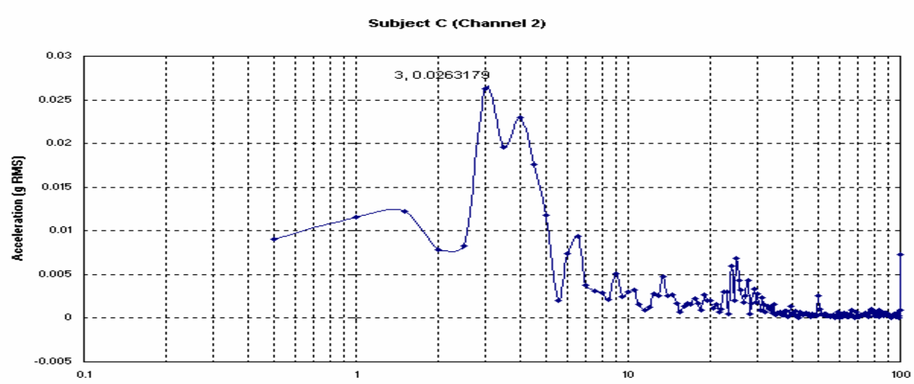
Figure 5.5: Power spectrum of Channel 1 and Channel 2 for the 5 subjects during bumpy road ride




Subject B (Channel 1)
3, 0.0285444
Acceleration (g RMS)
Frequency (Hz)


Subject B (Channel 2)
3, 0.0508676
Acceleration (g RMS)
Frequency (Hz)


Subject C (Channel 1)
3, 0.0105923
Acceleration (g RMS)
Frequency (Hz)


Subject C (Channel 2)
3, 0.0263179
Acceleration (g RMS)
Frequency (Hz)

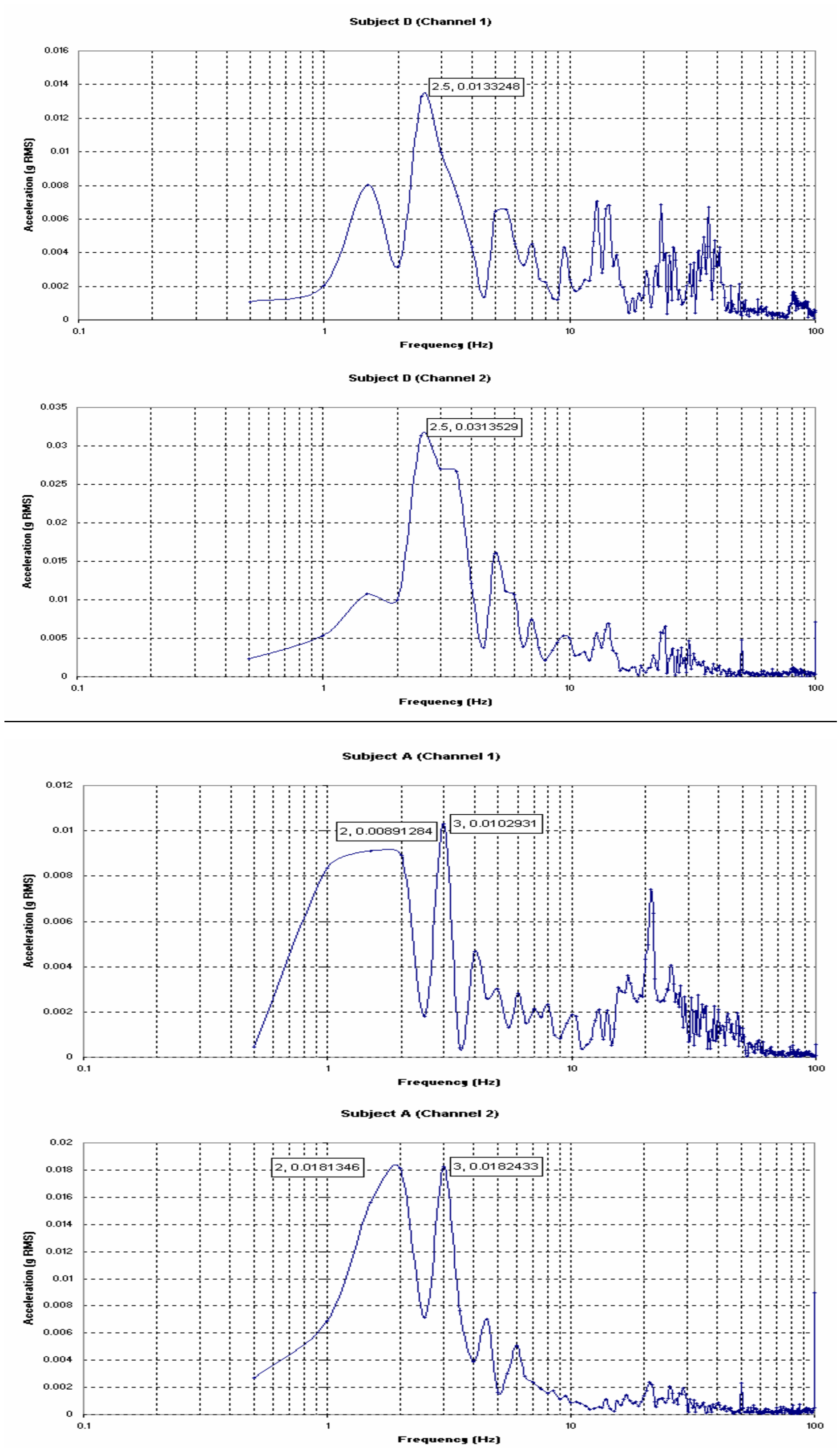


Figure 5.6: Power spectrum of Channel 1 and Channel 2 for the 5 subjects during smooth-surfaced road ride

SEAT values were obtained by importing the post-processed (power spectrum) data from the analyzer into the Microsoft Excel program. From Equation (2), the "ride on the seat" is the integral of frequency-weighted experienced on the seat, whereas the "ride on the floor" is the integral of frequency-weighted experienced on the floor. From the basic knowledge of integral, this equation can be stated as the ratio of the area under the graph of "ride on the seat" to the area under the graph of "ride on the floor", as below:

$$SEAT(\%) = \left[\frac{\sum G_{ss}(f) W_b^2(f)_{\min}}{\sum G_{ff}(f) W_b^2(f)_{\min}} \right]^{\frac{1}{2}} \times 100 \quad (7)$$

$W_b(f)$ is the frequency weighting applied to whole-body.

From the data analysis, the SEAT values obtained for each subject and for each condition of road are different, ranging in between 80% to 120%, as shown in Table 5.2:

Table 5.2: SEAT values for 5 subjects

Road \ Subject	SEAT(%)				
	A	B	C	D	E
Bumpy	91.02	89.91	106.59	107.58	100.45
Smooth-surfaced	86.08	91.23	109.98	116.23	80.34

These percentage values explain the comfort level felt by every subject on the seat. If the SEAT value is less than 100%, then there is vibration or discomfort absorption by the seat. If the SEAT value is more than 100%, then the vibration or discomfort has been amplified by the seat. For example, SEAT value for subject A is 91.02% during bumpy road trial. This means that the discomfort had been reduced by 8.98%. Therefore, the smaller the SEAT value is, the more comfort a subject could feel, and vice versa. The SEAT value for a more comfortable seat is expected to be as low as possible. From the data in Table 5.2, it is proven that a seat which is comfortable for a person may not be comfortable for others because some of the SEAT values are less than 100% but others exceed 100%, although same seat was used. SEAT value more than 100% is similar with those values from heavy vehicle such as truck and train (Figure D1). From all the graphs below, it is very clear that all the peaks are at around 2.5-3.5 Hz. This shows that that resonance frequency occurs at that range for almost every subject. Significant attenuation is provided at frequencies above 4 Hz. With comparison with both the data from pretest and the data obtained by M. J. Griffin (1978), which was 85% for the SEAT value of the seat on a bus (Figure D1), average SEAT data of the bus seat on the van from this test is far more critical.

5.2.1 Repeatability

It is important that data collected by accelerometers is repeatable, so that an actual change in the system does not disappear in differences between different measurement conditions. During some of the tests, the subject was shaken so badly that it is impossible to maintain a consistent sitting position. The subject is tossed around and therefore the repeatability gets poor.

Figure 5.7 shows that the repeatability for Channel 1 among 5 subjects is poor despite of going through the same route. This might be caused by certain circumstances such as the speed of the vehicle, situation when braking is necessary, unstable road condition, etc. Figure 5.8 shows that most of the seat base vibrations had been absorbed except at frequency 3-4 Hz.

Figure 5.9 and Figure 5.10 show better repeatability where all the graphs are more closely plotted. This might be due to the seat stability when the vehicle is moving on a smooth surface. The figures also show that the seat base vibrations had been reduced while being transferred to the human-seat interface except during frequency 3Hz when the vibration is amplified.

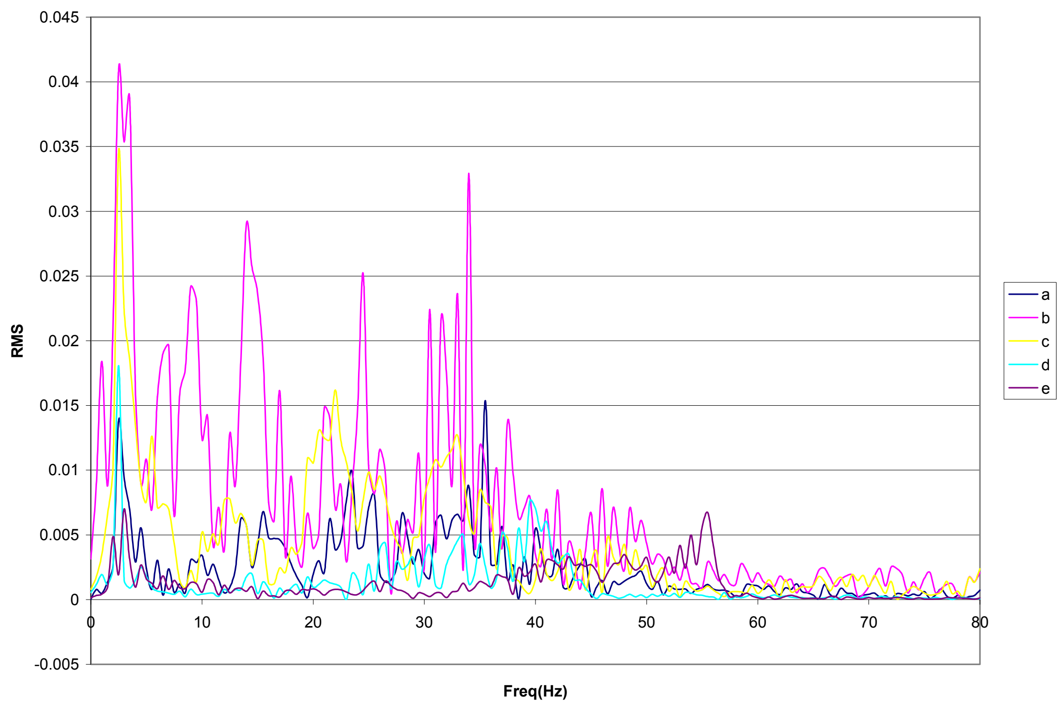


Figure 5.7: Effect of random vibration onto the seat base (Channel 1) measured with five subjects a, b, c, d, e through the bumpy roads.

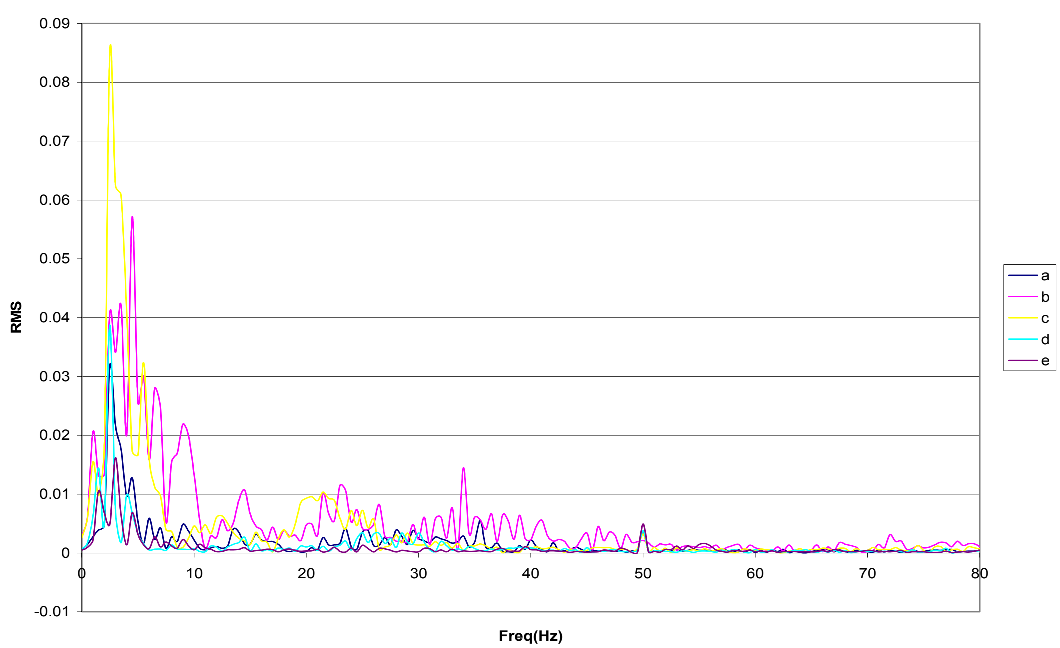


Figure 5.8: Effect of random vibration onto the seat pan (channel 2) measured with five subjects a, b, c, d, e through the bumpy roads.

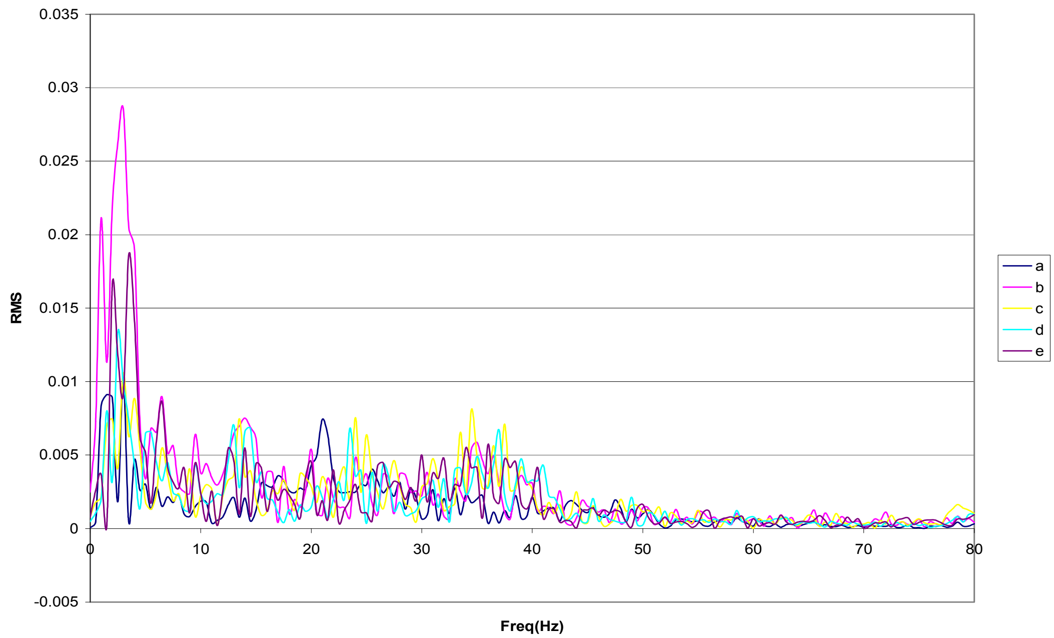


Figure 5.9: Effect of random vibration onto the seat base (channel 1) measured with five subjects a, b, c, d, e through the smooth-surfaced roads.

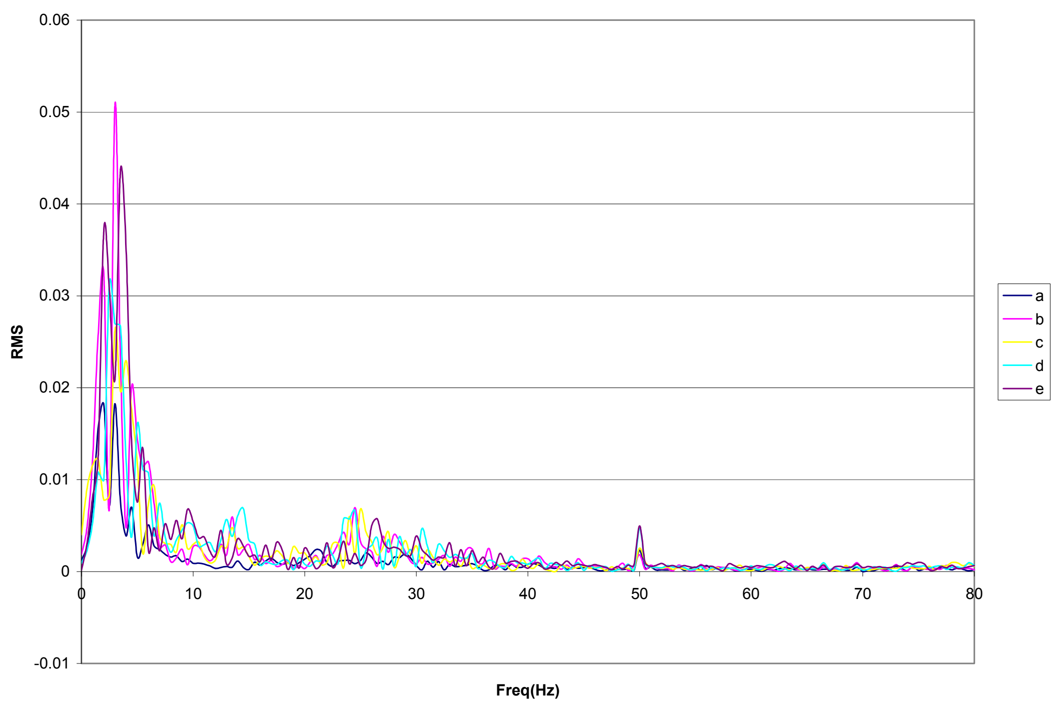


Figure 5.10: Effect of random vibration onto the seat pan (channel 2) measured with five subjects a, b, c, d, e through the smooth-surfaced roads.

5.3 Improved Seat

From the current conventional seat, improvement had been made to optimize the passenger ride comfort. For most of the current existing passenger seat, the common way to achieve comfort is through the cushion. Cushion properties such as material, thickness, softness, contour etc., will affect the comfort satisfactory of a passenger. However, improvements made in this research focused on the seat structure (without cushion). Spring and absorber properties were added to the structure. Therefore, beside cushion, the seat structure itself would also play an important role in reducing the transmissibility of shock and vibration from the vehicle floor to the passenger to minimum. With several modifications to the original seat structure, this design of the new seat structure was finally produced. The structure was designed as a spring itself so that it would attenuate the vibration more effectively, even during shocks. Two absorbers were added to the structure to absorb the shock and vibration from the vehicle floor. This function is usually found on the seat cushion. The height of the new structure remains the same as the previous model as it fits the size of average occupants. The design of the improved seat structure is shown in Figure 5.11 and Figure 5.12. Road trials were carried out to verify that the new seat structure is efficient in improving (optimizing) seat comfort.

Besides improving the seat vibration comfort, there are other advantages of the improved seat structure:

a. Simple design – The seat structure consists of only a few components. The structure itself acts as a spring with two replaceable absorbers attached to it. Thus, it is less complex compared to those suspension seats which consist of many complicated parts and small components.

b. Low costing – The simple design will result in the low cost of producing the seat, especially for a mass production. Furthermore, the cost of maintenance is low compared to those seats with hydraulic or air suspension. The absorbers are easy to install.

c. Controlled movement – Besides allowing the movement in up and down direction (z-axis), both the absorbers; one controlling the movement of the seat's front part , another controlling the movement of the seat's rear part, will prevent the movement to left and right. The front and rear movements are allowed in a small distance so that the seat comfort would not be affected while the absorbers is functioning at the same time.

d. Adjustability – The stiffness of the spring part of the structure can be adjusted by putting a stopper at the connected part between the spring part and the upper or lower part of the structure. The absorbers can also be adjusted according to individual needs.

e. Safety – During emergency (collision or sudden braking), the seat structure would be able to absorb the impact transmitted from the vehicle to the passenger.

f. Convenience – The spacious room in the seat structure would allow the passenger to put their things or luggage under the seat.

g. Stability – Although the passenger load concentrates more on the rear part of the seat cushion (Fakir, M. N., 2000), about 1 / 4 of the structure length (front to rear) from the center, stability would not be a problem as both the absorbers has been installed with the center of movement at the rear part (about 10 mm from the center) of the structure.

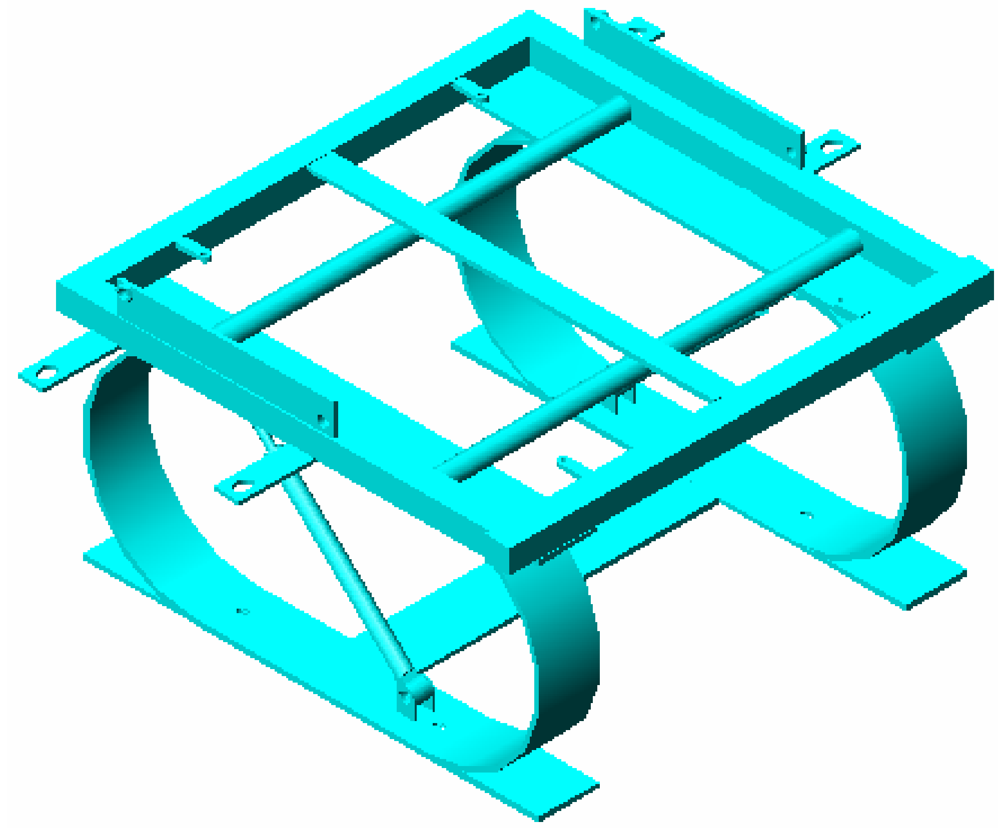


Figure 5.11: New seat structure

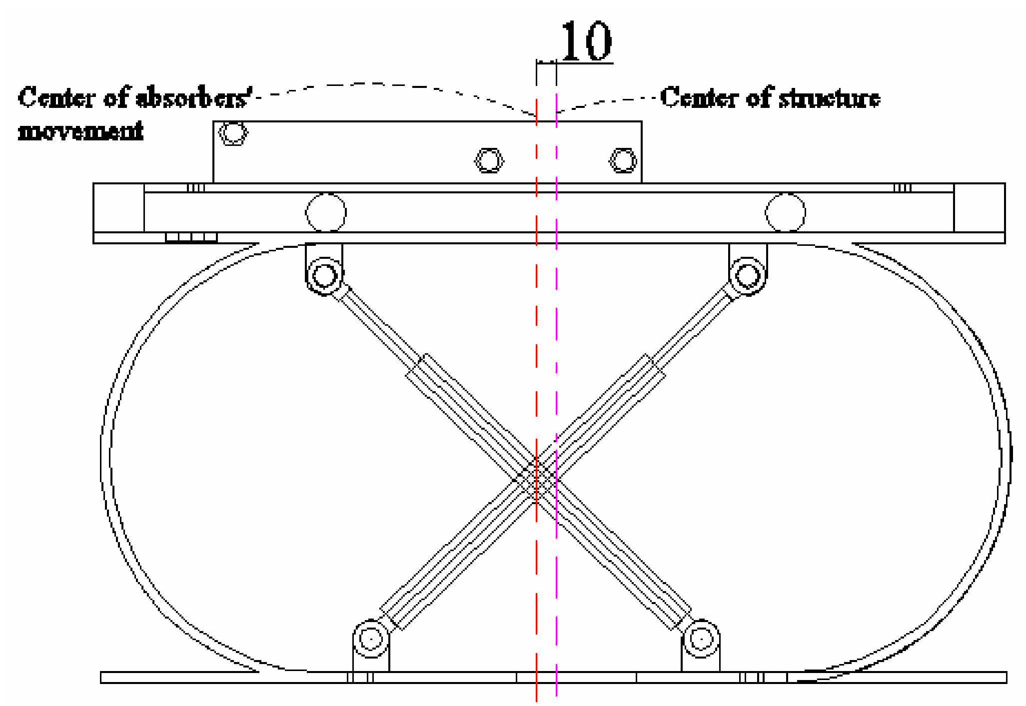


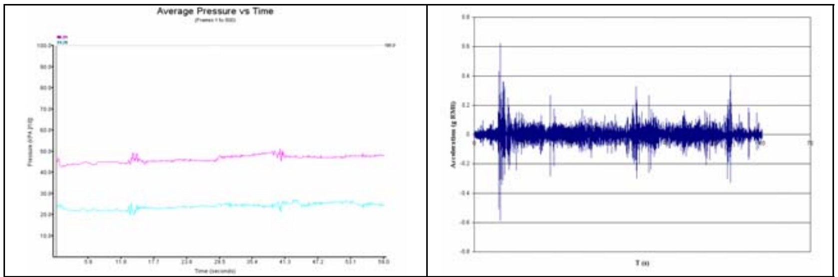
Figure 5.12: New seat structure (with the center of structure and center of movement)

5.3.1 Pressure Distribution Test

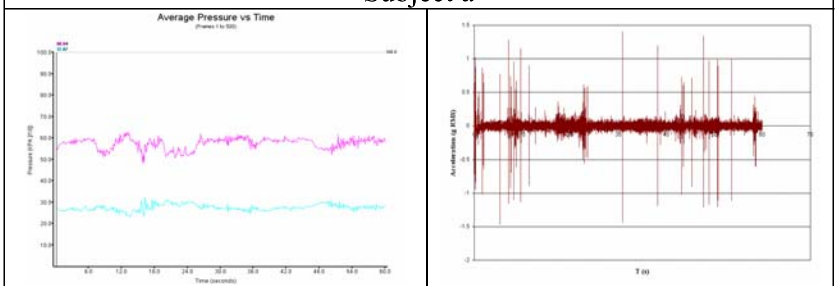
To prove the effectiveness of the improved parameters of the new seat structure, road trials were carried out to obtain the pressure and vibration values. Similar with the tests on previous passenger seat (current existing seat), the improved seat was mounted on the floor of the same vehicle (van). The procedures, routes and subjects in these road trials remained the same.

From both the Figures 5.13 and 5.14, the average pressure during bumpy road trial was unstable compared with the average pressure during smooth-surfaced road trial which was more constant. This is almost similar with the results of the test onto the previous model (current existing seat) without any modification. The maximum and minimum peaks of the graph for average pressure during bumpy road are clearly shown. For some of the tests on smooth-surfaced road, some peaks can be obviously seen from the time history graphs due to the shocks the vehicle might have faced during certain circumstances, such as small and sharp bumps, stones, etc.

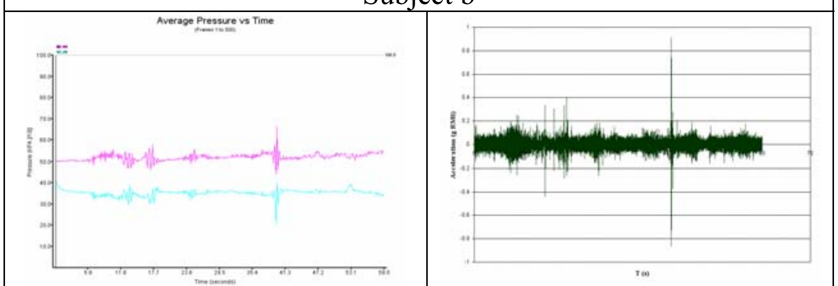
From the comparison made for the pressure test between both the current existing seat and the improved seat, the differences are more obvious for the tests on the bumpy road. For most of the subjects (a,b,c,d,e), the average pressure onto the seat pan for the improved seat was reduced, while the average pressure onto the backrest was not much different. As expected, the results for the tests on the smooth-surfaced road for both the current existing seat and the improved seat are almost the same. The graphs show that the average pressure is more constant on the smooth-surfaced roads than on the bumpy (uneven) roads.



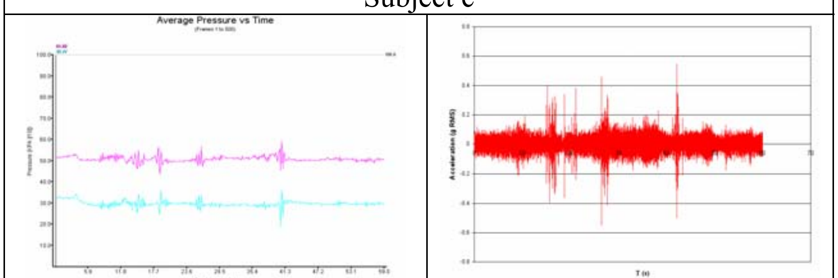
Subject a



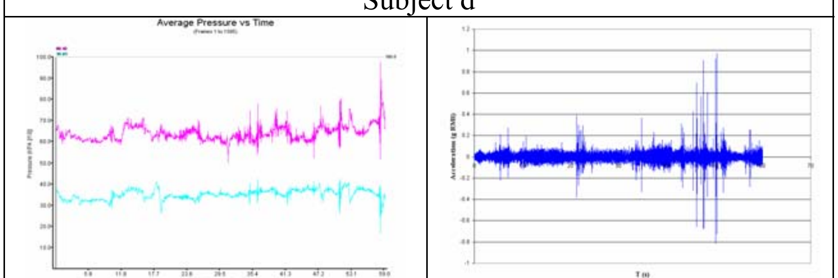
Subject b



Subject c



Subject d



Subject e

Figure 5.13: Average pressure onto the improved seat with the synchronized vibration for 1 minute each for 5 subjects on bumpy road

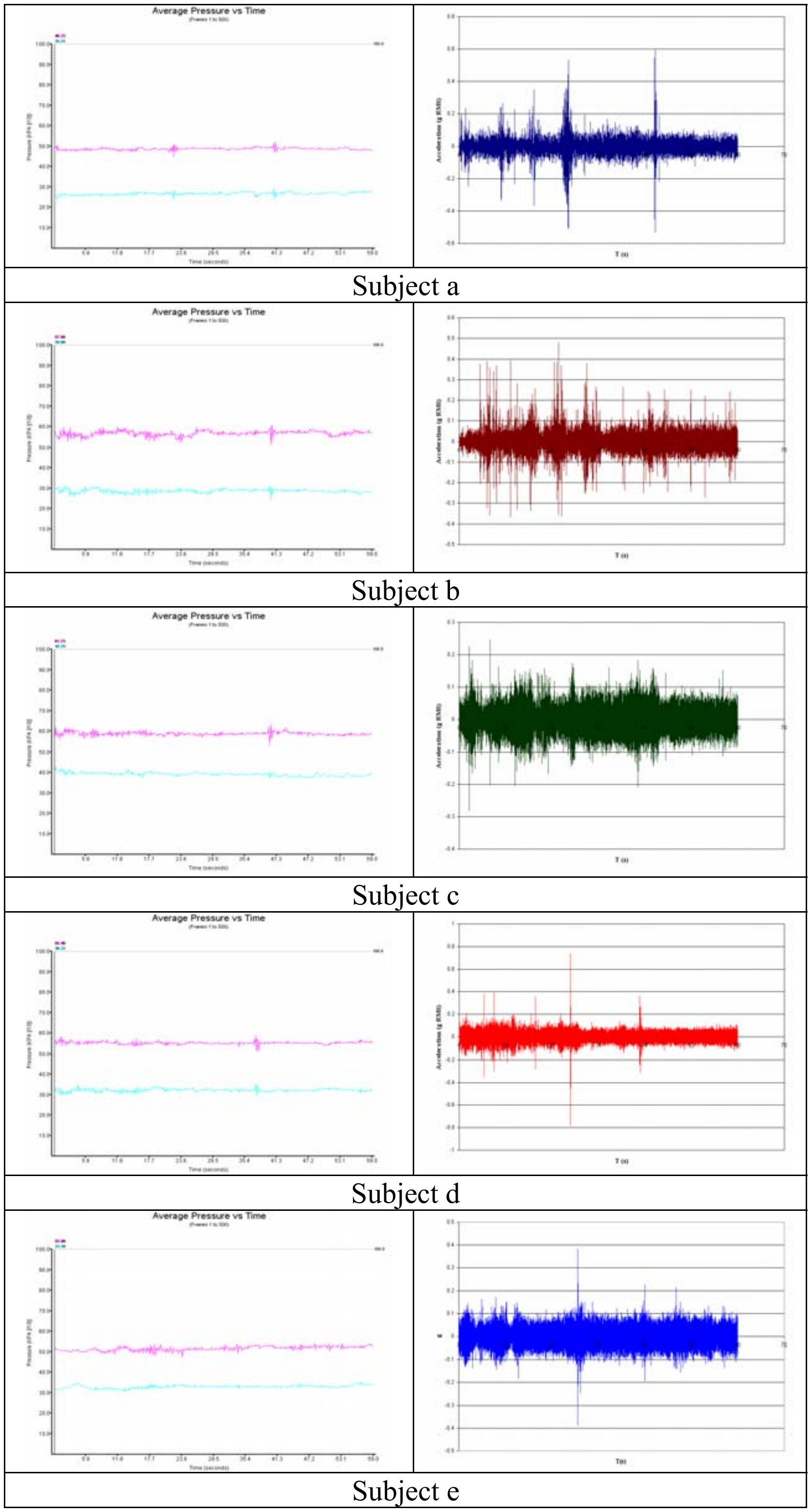
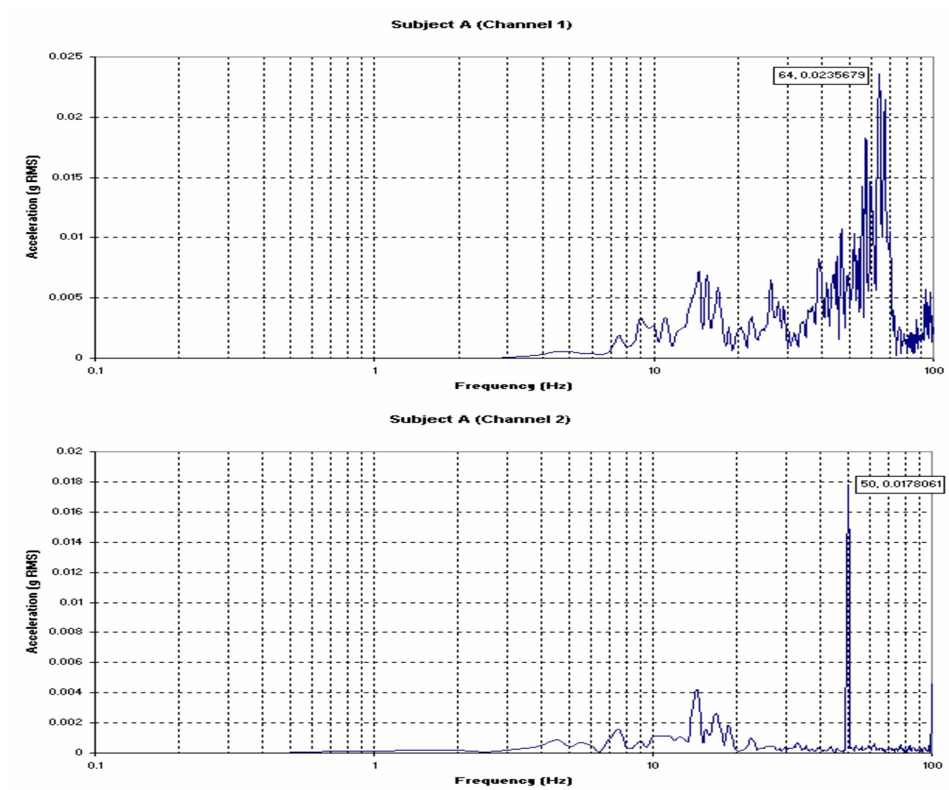
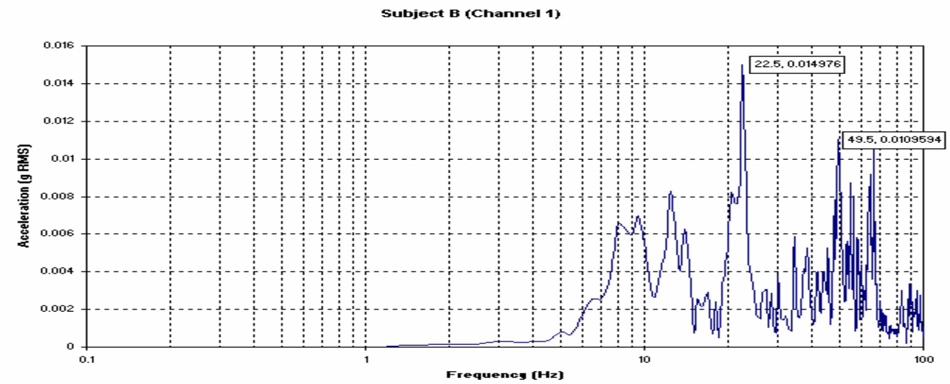


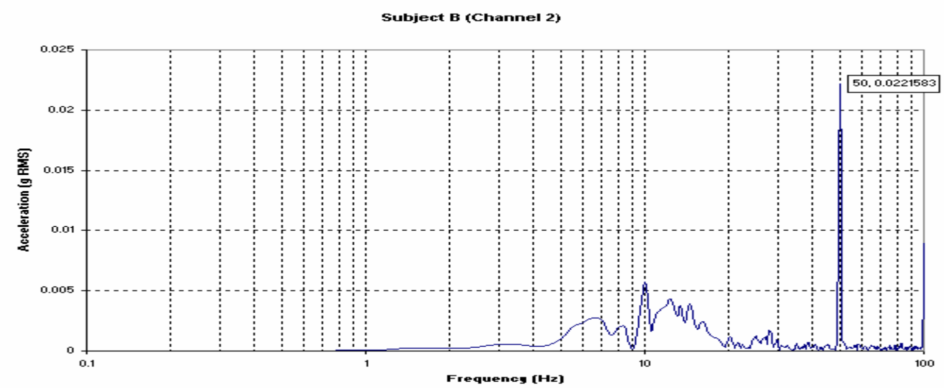
Figure 5.14: Average pressure onto the improved seat with the synchronized vibration for 1 minute each for 5 subjects on straight road

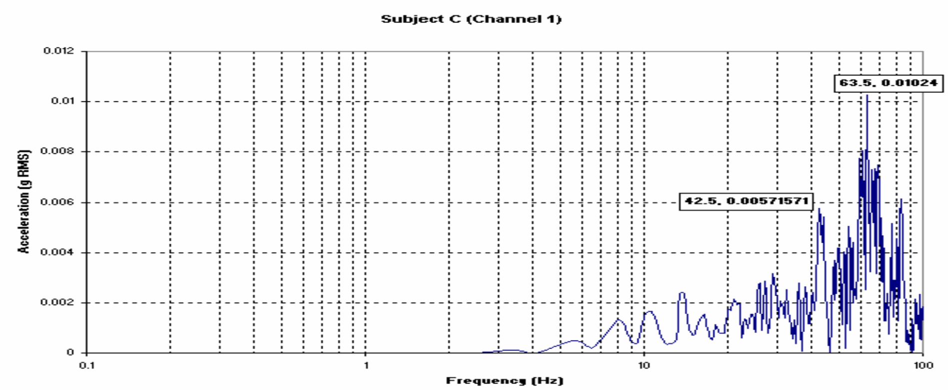
5.3.2 SEAT Test

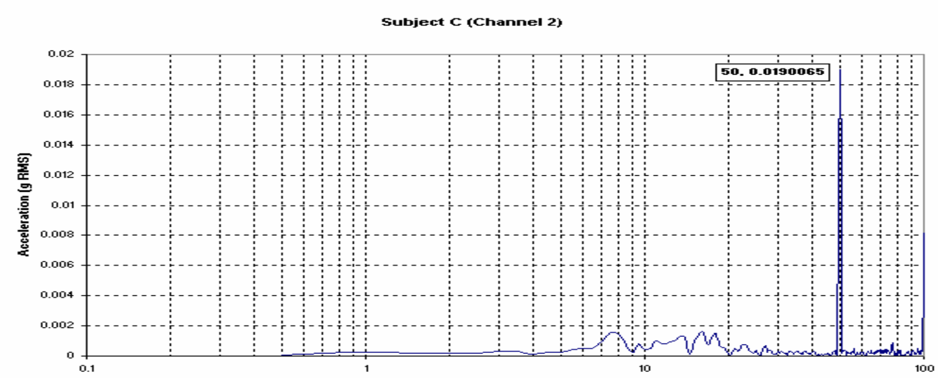
With the same procedures and subjects, SEAT test was conducted onto the improved seat. The results (power spectrum for channel 1 and channel 2) are shown in graphs in Figure 5.15 and Figure 5.16.




Subject B (Channel 1)
Acceleration (g RMS)
Frequency (Hz)
22.5, 0.014976
49.5, 0.0109594


Subject B (Channel 2)
Acceleration (g RMS)
Frequency (Hz)
50, 0.0221583


Subject C (Channel 1)
Acceleration (g RMS)
Frequency (Hz)
63.5, 0.01024
42.5, 0.00571571


Subject C (Channel 2)
Acceleration (g RMS)
Frequency (Hz)
50, 0.0190065

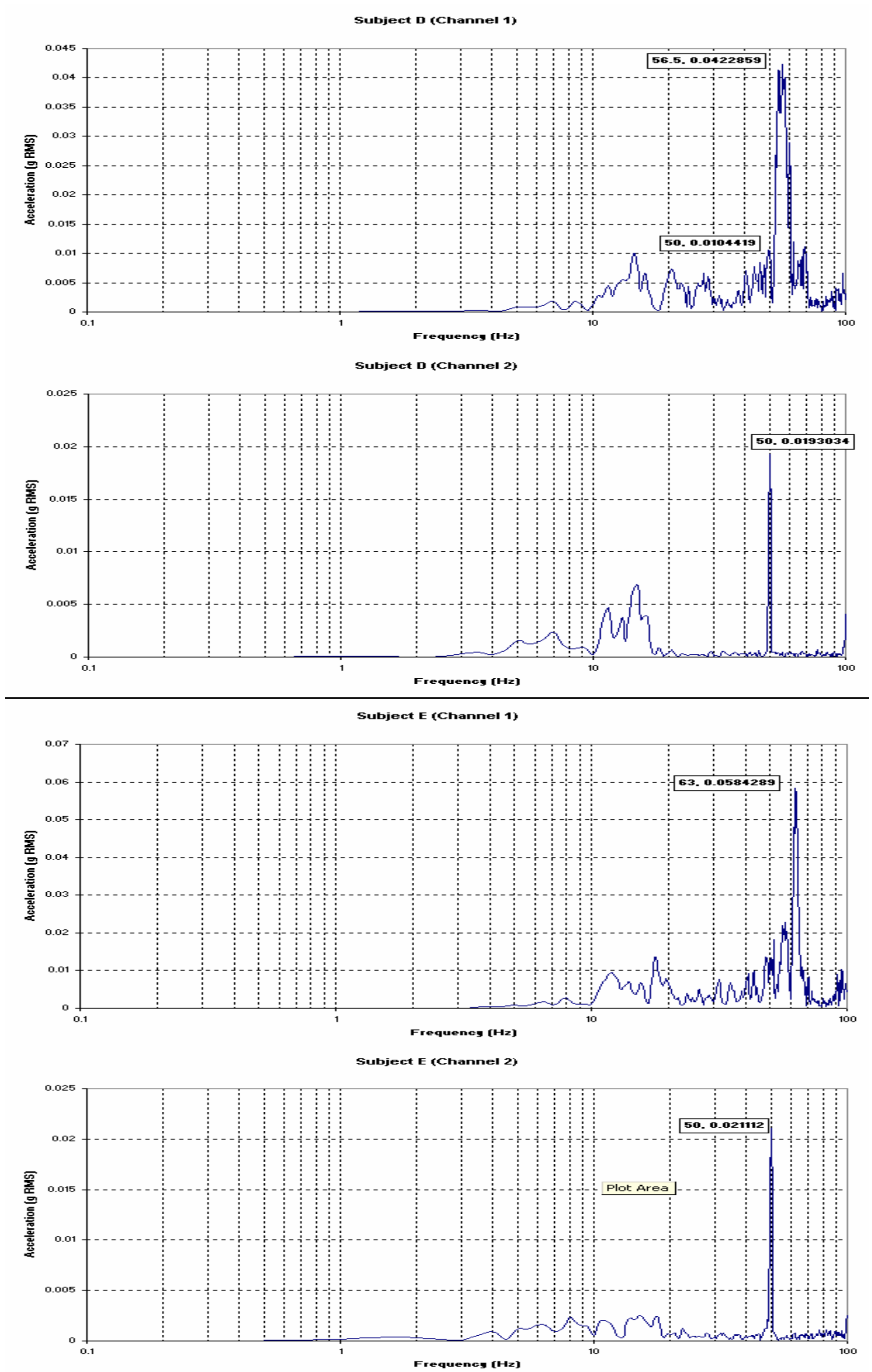
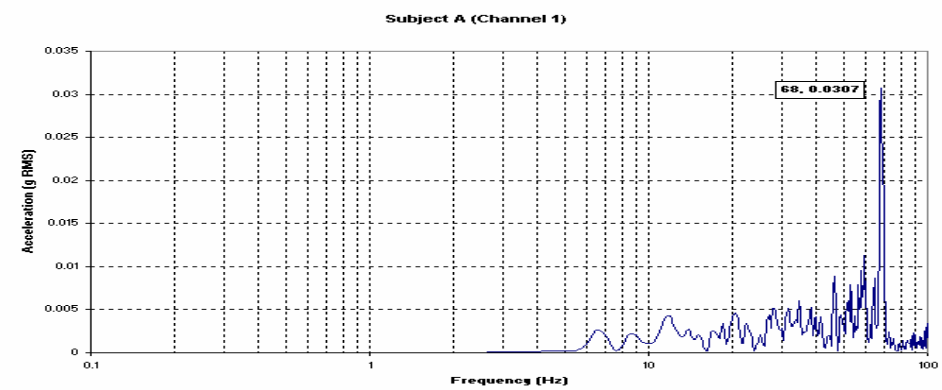
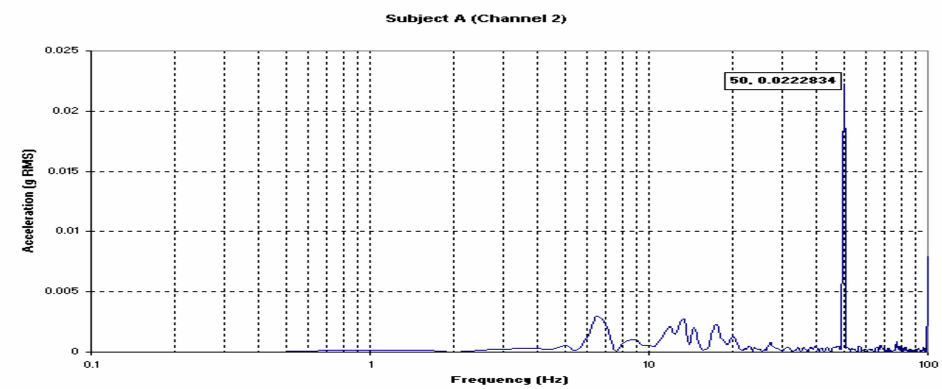
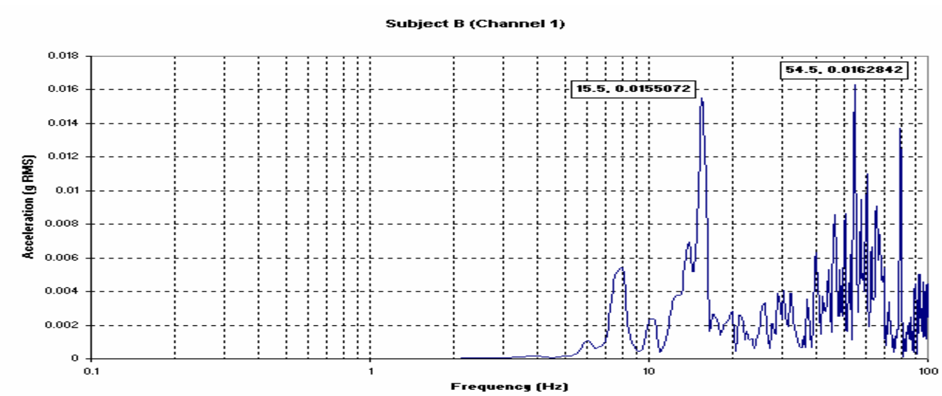
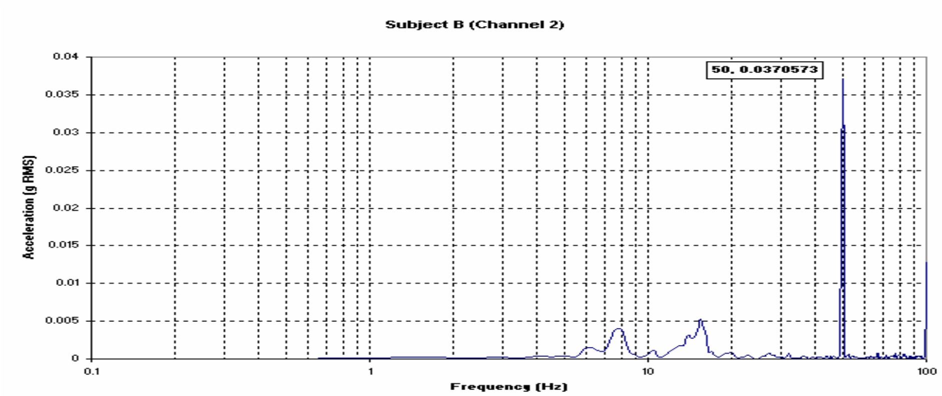


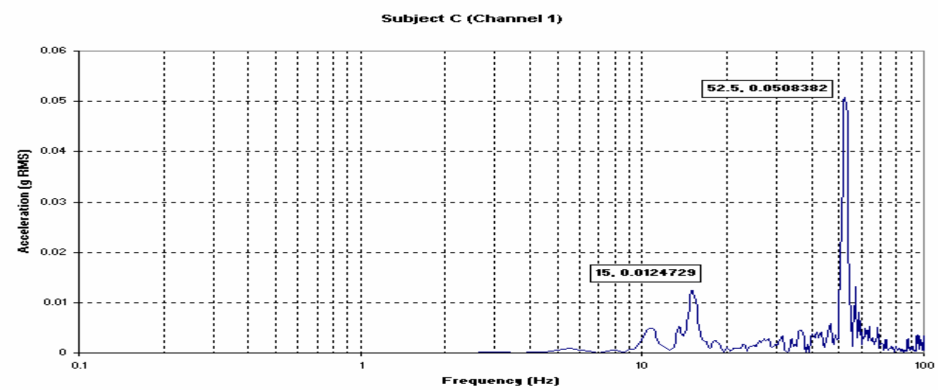
Figure 5.15: Power spectrum of Channel 1 and Channel 2 for the 5 subjects during bumpy road ride

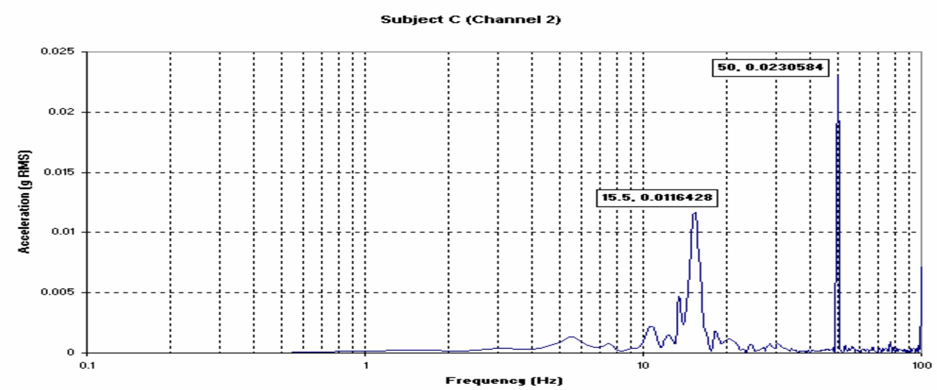

Subject A (Channel 1)
68, 0.0307
Acceleration (g RMS)
Frequency (Hz)

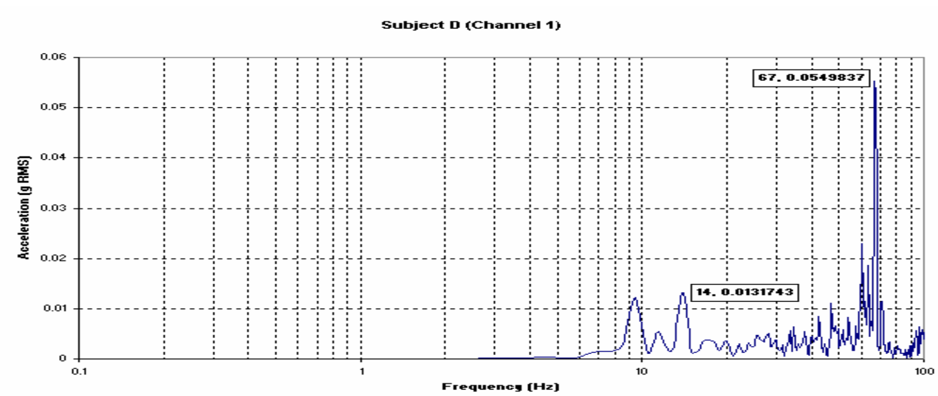

Subject A (Channel 2)
50, 0.0222834
Acceleration (g RMS)
Frequency (Hz)

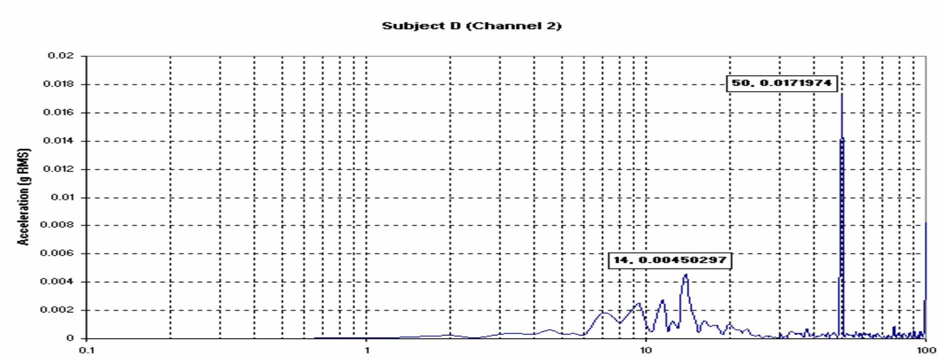

Subject B (Channel 1)
15.5, 0.0155072
54.5, 0.0162842
Acceleration (g RMS)
Frequency (Hz)


Subject B (Channel 2)
50, 0.0370573
Acceleration (g RMS)
Frequency (Hz)


Subject C (Channel 1)
Acceleration (g RMS)
Frequency (Hz)
52.5, 0.0508382
15, 0.0124729


Subject C (Channel 2)
Acceleration (g RMS)
Frequency (Hz)
50, 0.0230584
15.5, 0.0116428


Subject D (Channel 1)
Acceleration (g RMS)
Frequency (Hz)
67, 0.0549837
14, 0.0131743


Subject D (Channel 2)
Acceleration (g RMS)
Frequency (Hz)
50, 0.0171974
14, 0.00450297

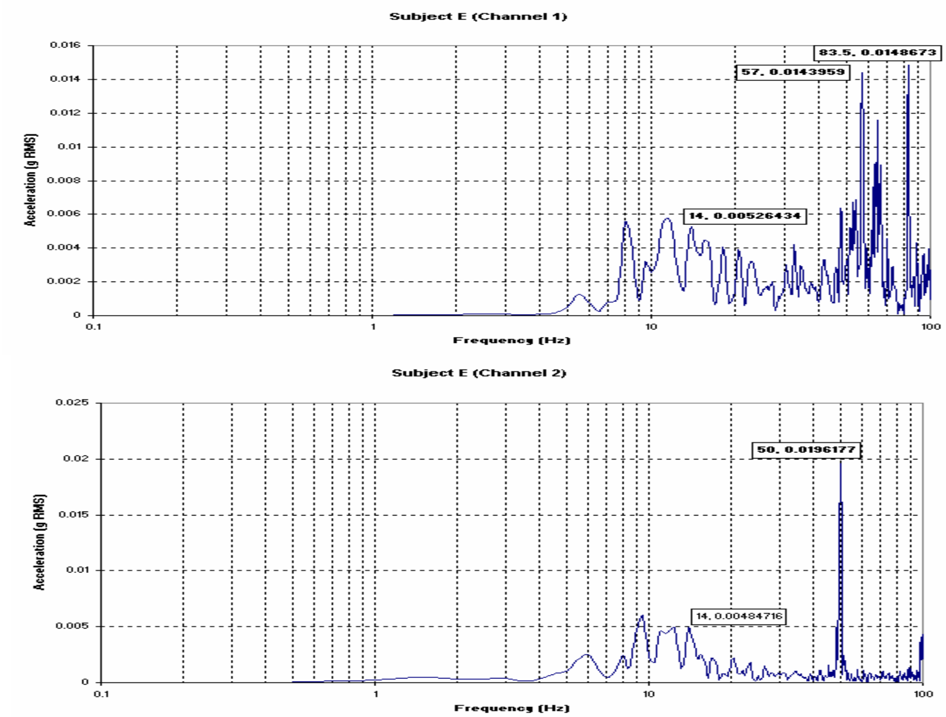


Figure 5.16: Power spectrum of Channel 1 and Channel 2 for the 5 subjects during smooth-surfaced road ride

From all the graphs in Figure 5.15 and Figure 5.16 above, it is shown that for almost all the subjects, first peaks occurred at higher frequencies compared to the data of the previous existing seat, which were in the range of 10-20Hz. First resonance occurred at that range for almost all the subjects. There was second peak after 50 Hz, at higher acceleration. Both situations show that resonance had been delayed from the original frequency of 2-4 Hz and would not likely to occur when the vehicle is moving at low frequency, for example, on a very smooth or flat surface.

From the data, the SEAT values obtained for each subject and for both bumpy and smooth-surfaced roads are as below:

Table 5.3: SEAT values for 5 subjects on the improved seat

Subject / Road	SEAT(%)				
	A	B	C	D	E
Bumpy	50.07	65.97	69.65	60.27	53.26
Smooth-surfaced	83.76	61.34	72.66	51.33	61.04

SEAT values for the 5 subjects are in the range 50-85%. These values which are all less than 100% have shown that vibration had been absorbed and weakened by the improved seat structure. Overall results show that most of the SEAT values are less compared to the SEAT values from the current existing seat. For example, the SEAT value for subject A during bumpy road trial had reduced to at least 40% of the original SEAT value, i.e. from 91.02% to 53.26%. The vibration from the vehicle floor was absorbed and attenuated by the spring and absorber of the new structure. Therefore, the vibration which reached the seat pan would be reduced more compare to the conventional seat. Thus, the vibration transmitted to the passenger's body would be minimized, too. These would reduce the discomfort and result in seating comfort. The reduction in SEAT values between the current existing seat and the improved seat is shown in graphs in Figure 5.17. It is also shown that SEAT value is not affected by both the height and weight of the subjects, whether on bumpy roads or smooth-surfaced roads. Following subchapter shows the repeatability of the random vibration onto the 5 subjects for different channels and road conditions.

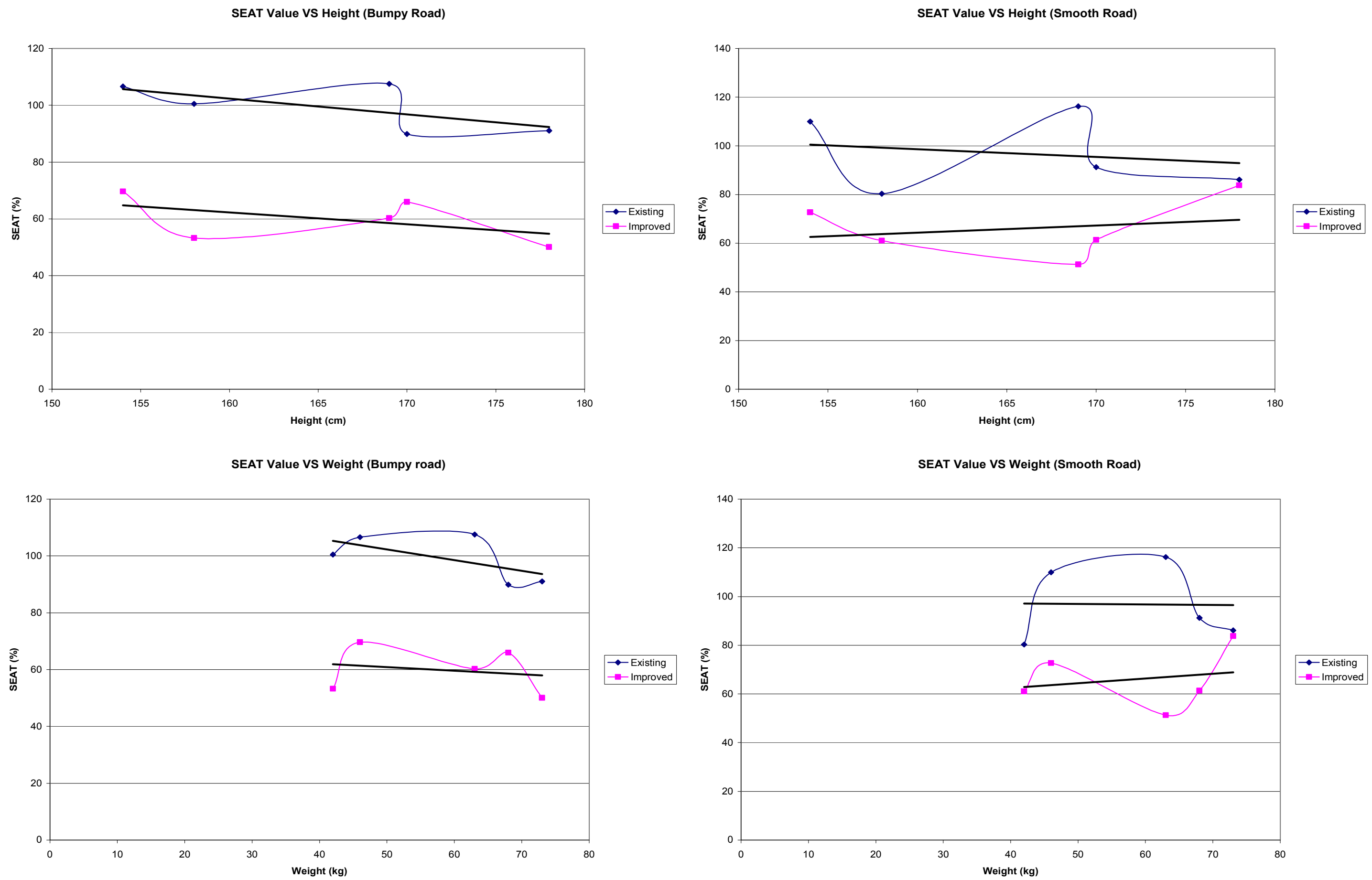


Figure 5.17: Graphs showing SEAT values against subjects' height and weight on both bumpy and smooth-surfaced roads for existing and improved seats

5.3.3 Repeatability

Figures 5.18-5.21 show the peaks at higher frequencies (> 10 Hz) compared to the graphs for the previous testing model (current existing seat). This shows that the resonance of the improved seat most probably occurred at a higher frequency for both seat base and seat pan, unlike the resonance at the range 3-4 Hz for the older seat. For Figure 5.18 and 5.20, the repeatability is lower than the repeatability in Figure 5.19 and 5.21. This shows that the condition on the seat pan is more stable than the seat base which receives the vibration directly from the moving vehicle body. The figures also show that the vibration from the seat base had been absorbed when it reached the seat pan.

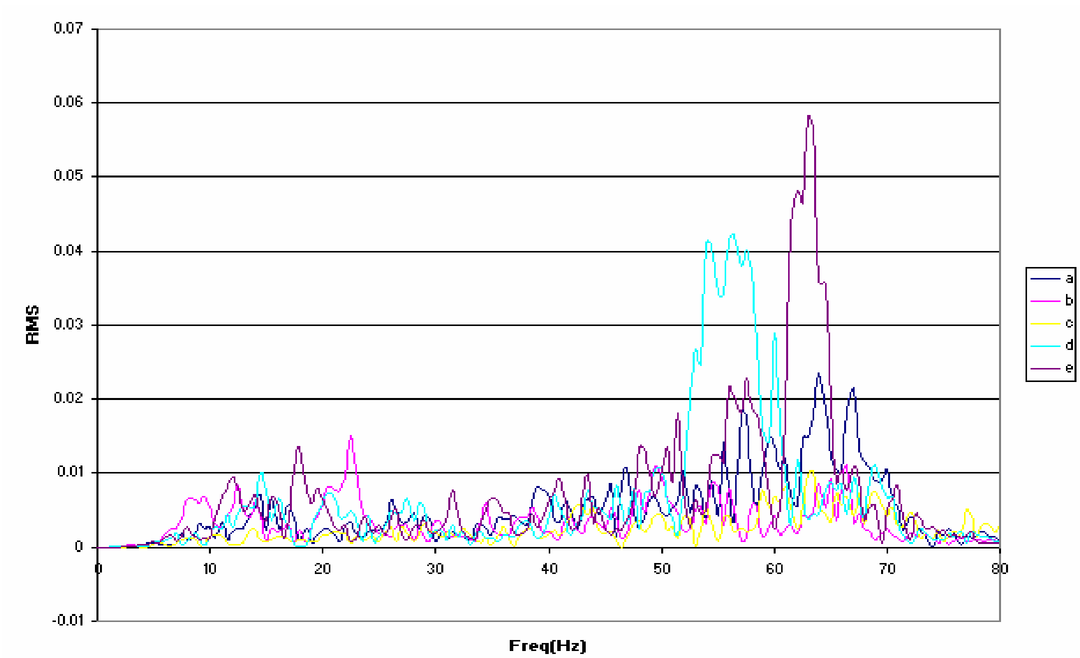


Figure 5.18: Effect of random vibration onto the improved seat base (Channel 1) measured with five subjects a, b, c, d, e through the bumpy roads.

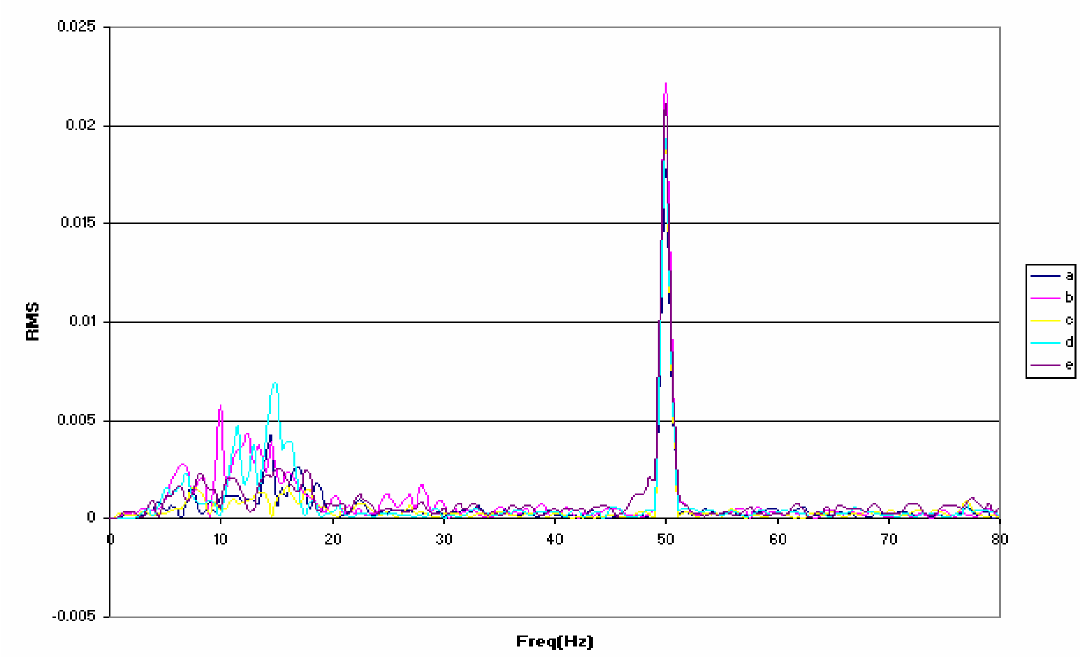


Figure 5.19: Effect of random vibration onto the improved seat pan (Channel 2) measured with five subjects a, b, c, d, e through the bumpy roads.

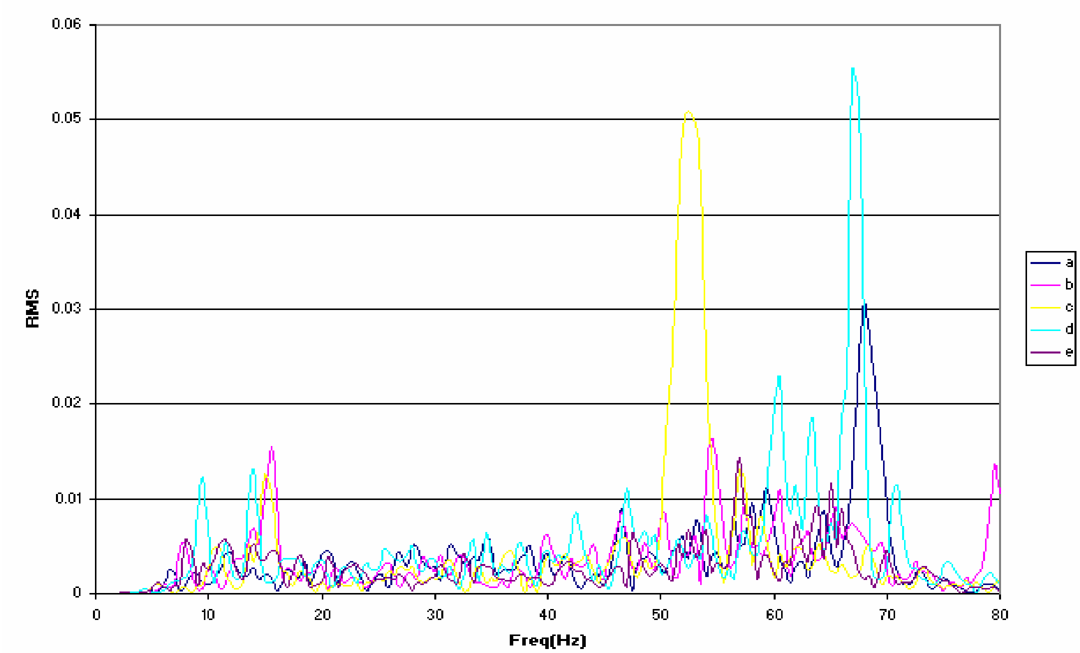


Figure 5.20: Effect of random vibration onto the improved seat base (Channel 1) measured with five subjects a, b, c, d, e through the smooth-surfaced roads.

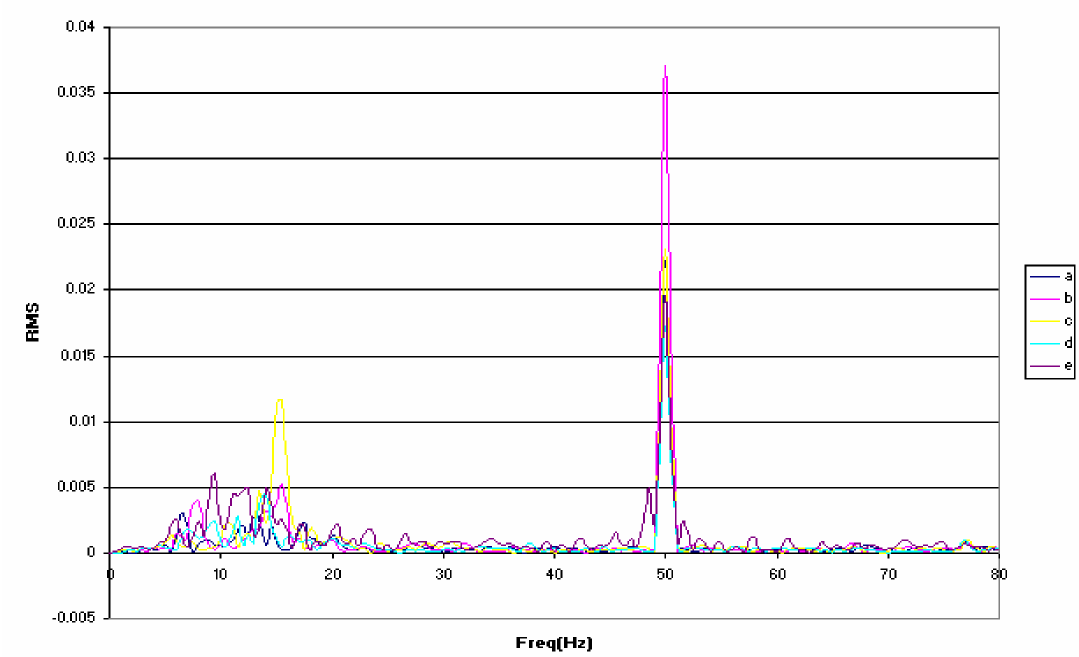


Figure 5.21: Effect of random vibration onto the improved seat pan (Channel 2) measured with five subjects a, b, c, d, e through the smooth-surfaced roads.

CHAPTER 6

OVERALL DISCUSSION

From the survey, it is known that certain seat features were evaluated by respondents as the contributors to ride discomfort during their journey. However, survey statistic had revealed that more than half of the survey respondents (68.8%) were satisfied with the current existing bus passenger seat. This figure shows that the current existing passenger seat has a good level of comfort except for the smaller group who might have experienced discomfort at certain body parts during their long journey, such as shoulder, mid back, thigh and buttock. This comfort level rated by public was later correlated to the objective methods to produce the comfort values for same type of seat through laboratory and field tests.

Seat conditions, such as backrest-seatpan angle and cushion contour (thickness) have effects onto the average pressure, peak pressure and contact area of the human-seat interface. Besides, cushion material also affects seat comfort. The current existing seat cushion which is made of Resilient Polyurethane Foam (PUF) results in lower peak pressure compared to the old seat cushion which is made of pure sponge. Rigid surface is the worst in distributing the human-seat pressure evenly. Erect posture with back supported (EBS) was proven to be better than erect posture with back not supported (ENS) in seat comfort. Although there was not much difference in data reading for the sitting posture with and without cushion added to the backrest, the subjects preferred the sitting with the cushion added as it was more comfortable. It was also discovered in the static pressure distribution test, that time factor also contributes towards the sitting discomfort. Long period of static seating will cause blood pooling and discomfort in the lower extremities, according to H.S. Dhingra et al (200). Blood would accumulate in part of the venous system in the ischial tuberosities, resulting numbness and discomfort.

The dynamic tests in laboratory had shown that although the mass system to simulate human body did not produce the similar pressure contour as the real human body, it showed the human dynamic pressure characteristics, such as average pressure, peak pressure and contact area against frequency, as well as the seat transmissibility, where the resonance produced is similar to the resonance of human-seat.

With correlation with the comfort satisfactory towards the bus passenger seat from the subjective assessment, Seat Effective Amplitude Transmissibility (SEAT) values had been obtained using the same type of seat during road trials. The SEAT values ranged from 80 % to 120 %. Although there was high satisfactory for the passenger seat from the survey respondents, it was found that the comfort level could be further improved by reducing the SEAT values. Lower SEAT values mean a better ride comfort. SEAT values for the seat with new improved structure were found to be lower, which were in the range of 50 % - 85 %, about 2 % - 57 % in reduction from the SEAT values for the current existing seat. Besides, the seat discomfort was also lessened with the frequency delay in resonance, from 2-4 Hz for the current existing seat to about 10 Hz or more for the improved seat. Therefore, there are still rooms to optimize the comfort for current existing passenger seat which is already considered as comfortable in the opinion of most occupants.

CHAPTER 7

GENERAL CONCLUSION

This research consisted of subjective and objective methods. Subjective method had been carried out in the form of interview survey. Static tests and dynamic tests in laboratory and on road are objective methods which require the results (output) in the form of data reading from measuring instruments.

This project is considered a success because all of its objectives had been achieved. The automotive seat on existing vehicle, in this research, which is the long journey bus passenger seat, had been characterized for ride comfort. A new automotive seat structure, foundation and cushion had been developed for better ride comfort. Finally, the project team had succeeded in developing database on vibration and shock to passenger.

Other achievements are:

- Through this research project expertise and skills on evaluation methods and know-how technology of automotive seat for ride comfort has been developed and polished as an aid for further study on this area.
- A design guideline for development of an automotive seat to meet maximum comfort has been presented.
- Based on SEAT values and pressure distribution values gathered from existing bus seats available, a new seat design for maximum ride comfort should be able to give a better value which indicates an improved ride comfort.

This research would definitely assist in the passenger seat design in automotive industry. However, there are still spaces for the development of the automotive seat industry in our country. Seat vibration and pressure distribution are part of the main factors. Cushion properties, such as material, contour, etc, are also items not to be lack in the development of an automotive seat for better ride comfort.

7.1 Recommendations

- There are many factors contributed towards maximum ride comfort, such as seat ergonomic, foot and arm position. Therefore, this research has the potential to be studied in depth.
- Further study on ride comfort required procurement of vibration equipment to conduct tests in a more controlled environment. This project has a very limited budget on procurement of special equipment, thus fully equipped vibration facility for ride comfort tests was unable to be established.
- Cruise control should be used if available. The vehicle should be driven at the same speed for every stretch of routes. If possible, the tests should be carried out on a highway with minimum traffic flow, so that there will be minimum braking and changing in vehicle speed which will indirectly affect the reading from the analyzers.

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APPENDIX A

QUESTIONNAIRES

A1 Sample of Questionnaire for Pilot Test

Sila tanda √ pada kotak yang berkenaan dan isi maklumat yang dikehendaki.

Soalan Demografik

1. Jantina : ☐ Lelaki ☐ Perempuan

2. Umur : _________ tahun

3. Berat : _________ kg   4. Tinggi : __________cm

4. Kaum : Melayu Cina India Lain-lain

5. Sejarah kesihatan:

   Adakah anda pernah menghadapi masalah sakit bahagian belakang:

   ☐ Ya ☐ Tidak

Soalan Am Perjalanan

1. Destinasi perjalanan : Dari : _______________ Ke : _________________

2. Nama Bas : _______________   3. No Pendaftaran : ___________

4. Jenis Tempat duduk

   ☐ Individu ☐ Berkembar

5. Lokasi Tempat Duduk

   ☐ Depan ☐ Tengah ☐ Belakang

6. Tempoh duduk dalam bas sehingga berhenti rehat

   ☐ *1 hingga 2 jam*
   ☐ > 2jam hingga 4 jam
   ☐ Lebih dari 4 jam

6. Berapa kerapkah anda membuat perjalanan jauh dengan menaiki bas

   ☐ Sekali seminggu atau lebih kerap
   ☐ Sebulan sekali
   ☐ Beberapa kali dalam 3 bulan
   ☐ 6 bulan sekali atau jarang

7. Adakah ciri-ciri ini ada pada tempat duduk anda

	Ada	Tiada	Rosak
Penyandar lengan	☐	☐	☐
Penyandar belakang	☐	☐	☐
Penyokong kaki	☐	☐	☐

8. Tempat duduk pilhan anda ialah ☐ Individu ☐ Berkembar ☐ Tidak memilih

9. Lokasi tempat duduk pilihan anda ialah

☐ Depan ☐ Tengah ☐ Belakang ☐ Tidak memilih

Ciri-ciri Tempat Duduk

Sila gunakan skala yang ada (dengan membulatkan nilai terbaik menggambarkan respon anda) untuk menilai ciri-ciri tempat duduk anda seperti yang dinyatakan di bawah : (Tunjukkan gambar tempat duduk untuk membantu dalam soal selidik)

1. Tinggi tempat duduk * Tinggi dari lantai bas ke permukaan atas kusyen tempat duduk.	1 — 2 — 3 — 4 — 5 Terlalu tinggi (1) · Sesuai (3) · Terlalu rendah (5)
2. Lebar tempat duduk * Lebar sisi kanan ke kiri tempat duduk.	1 — 2 — 3 — 4 — 5 Sempit (1) · Betul (3) · Terlalu lebar (5)
3. Kedalaman tempat duduk *Hujung depan tempat duduk hingga ke bahagian penyandar belakang tempat duduk.	1 — 2 — 3 — 4 — 5 Terlalu panjang (1) · Sesuai (3) · Terlalu pendek (5)
4. Kusyen Tempat duduk	1 — 2 — 3 — 4 — 5 Terlalu keras (1) · Sesuai (3) · Terlalu lembut (5)
5. Kestabilan tempat duduk	1 — 2 — 3 — 4 — 5 Kurang stabil (1) · Stabil (3) · Sangat stabil (5)
6. Permukaan tempat duduk	1 — 2 — 3 — 4 — 5 Kurang memuaskan (1) · Memuaskan (3) · Sangat memuaskan (5)

	1	2	3	4	5
7. Ketinggian penyandar lengan	Terlalu tinggi		Sederhana tinggi		Terlalu rendah
8. Kecondongan Penyandar belakang	Terlalui tegak		Sesuai		Terlalu condong
9. Penyokong Belakang (Back Lateral Support)	Terlalu rata	Rata	Sesuai	Melengkung	Terlalu melengkung
10. Penerimaan peribadi terhadap tempat duduk	Sangat tidak suka	Tidak suka	Neutral	Suka	Sangat suka
11. Keselesaan keseluruhan	Tidak selesa	Kurang selesa	Sedikit kurang selesa	Selesa	Sangat selesa

Punca-punca ketidakselesaan

Punca Ketidakselesaan : Sila tandakan punca ketidakselesaan sepanjang perjalanan

Punca	
1. Tempoh perjalanan yang terlalu lama	
2. Keadaan jalan (berbonggol atau berlubang)	
3. Getaran pada tempat duduk atau lantai	
4. Masalah tempat duduk	
• Terlalu kecil atau terlalu besar	
• Ruang untuk kaki terlalu sempit	
• Ketidakselesaan pada bahagian belakang	
• Tempat duduk terlalu keras	
5. Masalah suhu dalam bas (terlalu panas atau sejuk)	
6. Masalah bunyi	

Penilaian umum keselesaan : Sila tanda (√) pada pernyataan yang sesuai.

Saya merasa relaks	______	Saya merasa sangat selesa	______
Saya merasa agak selesa	______	Saya merasa tidak selesa	______
Saya merasa agak sempit	______	Saya merasa kaku	______
Saya merasa kebas	______	Saya merasa sakit	______

Komen lain : (sila kemukakan pendapat anda mengenai tempat duduk)

____

____

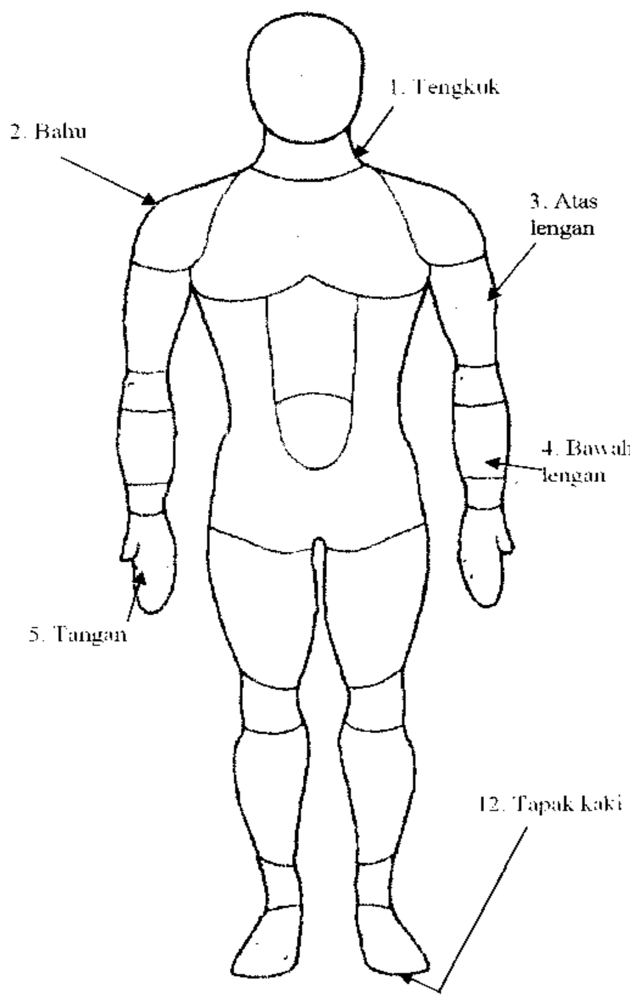
____

____

Skala BPD (Body Part Discomfort) : Nilaikan ketidakselesaan yang mungkin anda hadapi pada bahagian-bahagian tertentu badan anda semasa perjalanan.

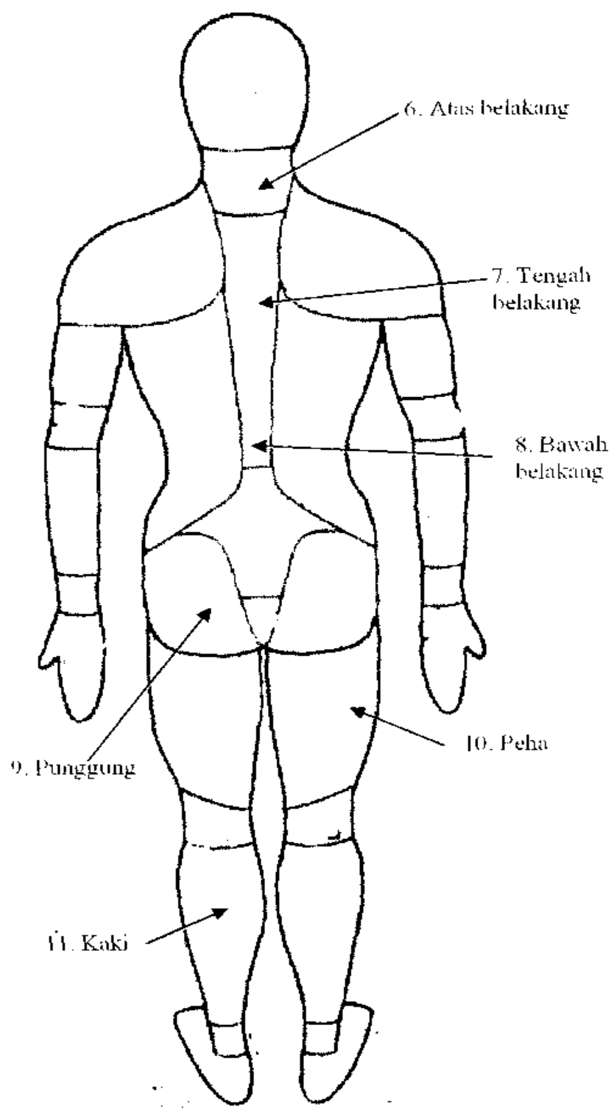
	1	2	3	4	5
1. Tengkuk	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
2. Bahu	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
3. Atas Lengan	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
4. Bawah Lengan	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
5. Tangan	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa

Pandangan Depan



6. Atas Belakang	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
7. Tengah belakang	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
8. Bawah Belakang	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
9. Punggung	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
10. Peha	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
11. Kaki	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
12. Tapak kaki	1	2	3	4	5
	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa

Pandangan Belakang



"Terima Kasih Atas Kerjasama Anda"

A2: Sample of Questionnaire for Actual Test

Soalan Demografik

1. Jantina : Lelaki ☐ Perempuan ☐

2. Umur :

3. Berat : ________kg Tinggi : ___________ cm

4. Pernah mengalami sakit belakang atau leher?

☐ Ya ☐ Tidak

Soalan Am Perjalanan

1. Destinasi Perjalanan : Dari : ______ ke : _________

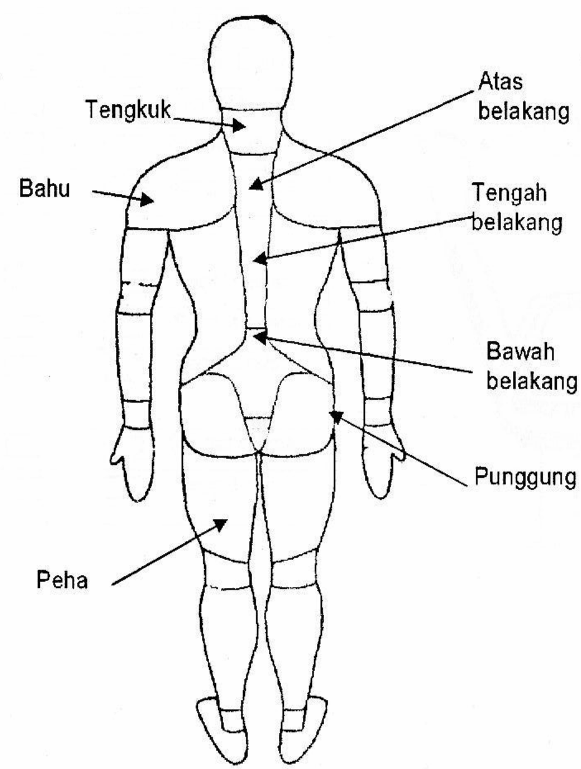
2. Lokasi tempat duduk :

☐ Depan ☐ Tengah ☐ Belakang

"BODY PART DISCOMFORT SCALE (BPD SCALE)"

Sila tandakan **penilaian ketidakselesaan** yang mungkin anda rasakan dengan memilih nombor 1 hingga 5 pada bahagian badan yang disenaraikan di bawah. Sila **baca penunjuk** yang diberikan sebelum memilih.

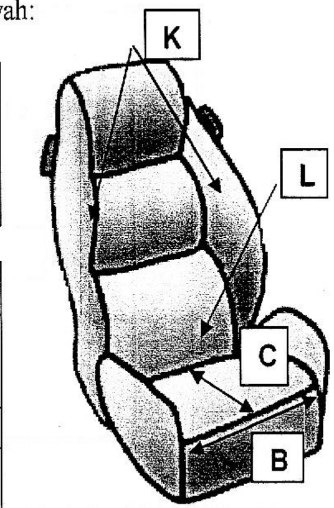
Penilaian	Tiada sakit / selesa		Sederhana sakit / kurang selesa		Sangat sakit / Tidak selesa
1. Tengkuk	1	2	3	4	5
2. Bahu	1	2	3	4	5
3. Atas Lengan	1	2	3	4	5
4. Bawah Lengan	1	2	3	4	5
5. Atas Belakang	1	2	3	4	5
6. Tengah belakang	1	2	3	4	5
7. Bawah Belakang	1	2	3	4	5
8. Punggung	1	2	3	4	5
9. Peha	1	2	3	4	5

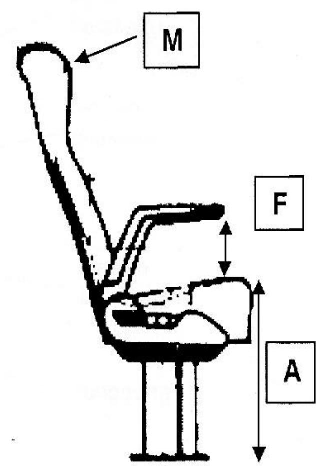


Sila tandakan penilaian yang menepati pendapat anda bagi ciri-ciri tempat duduk yang dinyatakan di bawah:

	Tidak selesa	Kurang selesa	Agak selesa	Selesa	Sangat selesa
Penilaian keseluruhan tentang tempat duduk dalam bas	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

Ciri- Ciri tempat duduk		Sesuai 1	2	3	4	5	
Tempat Duduk:	Penilaian:						
A. Tinggi	Terlalu rendah	☐	☐	☐	☐	☐	Terlalu tinggi
B. Lebar	Terlalu sempit	☐	☐	☐	☐	☐	Terlalu lebar
C. Panjang (hujung depan – penyandar)	Terlalu pendek	☐	☐	☐	☐	☐	Terlalu panjang
D. Kelembutan kusyen	Terlalu lembut	☐	☐	☐	☐	☐	Terlalu keras
E. Kestabilan struktur	Terlalu goyang	☐	☐	☐	☐	☐	Terlalu keras
F. Ketinggian penyandar lengan	Terlalu rendah	☐	☐	☐	☐	☐	Terlalu tinggi
G. keselesaan punggung	Tidak selesa	☐	☐	☐	☐	☐	Sangat selesa
H. Keselesaan peha	Tidak selesa	☐	☐	☐	☐	☐	Sangat selesa
I. Keselesaan penyokong kaki	Tidak selesa	☐	☐	☐	☐	☐	Sangat selesa
Penyandar Belakang:	Penilaian:						
J. Lebar	Terlalu sempit	☐	☐	☐	☐	☐	Terlalu lebar
K. Penyokong sisi (Lateral Support)	Tidak selesa	☐	☐	☐	☐	☐	Sangat selesa
L. Penyokong lumbar (bawah belakang)	Tidak selesa	☐	☐	☐	☐	☐	Sangat selesa
M. Penyokong tengkuk	Tidak selesa	☐	☐	☐	☐	☐	Sangat selesa
Penerimaan peribadi	Tidak suka	☐	☐	☐	☐	☐	Sangat suka





APPENDIX A

SEAT DETAIL

<u>Measurement of Cushion Contour using Coordinate Measuring Machine</u>

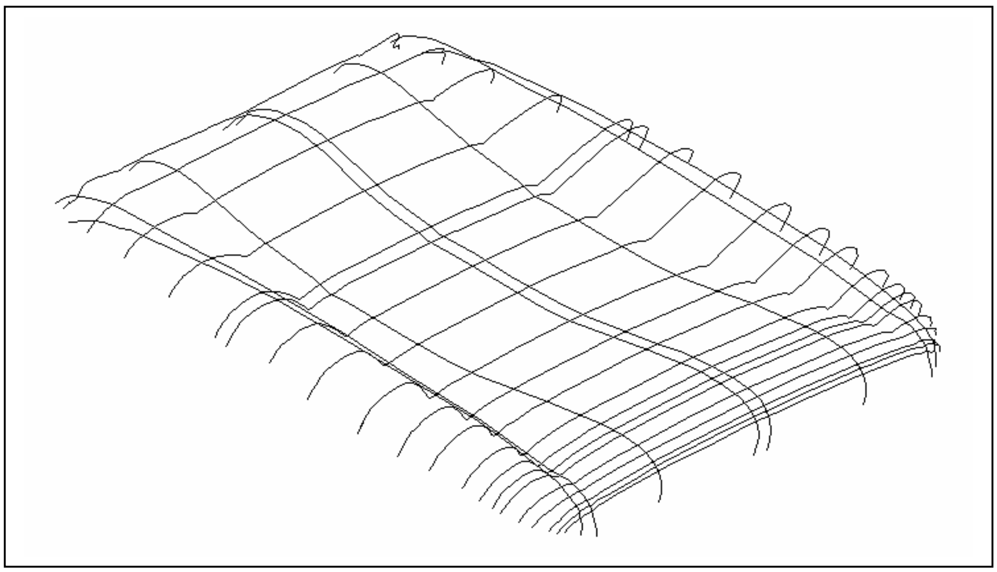


Figure B1: Seat pan (CCM)

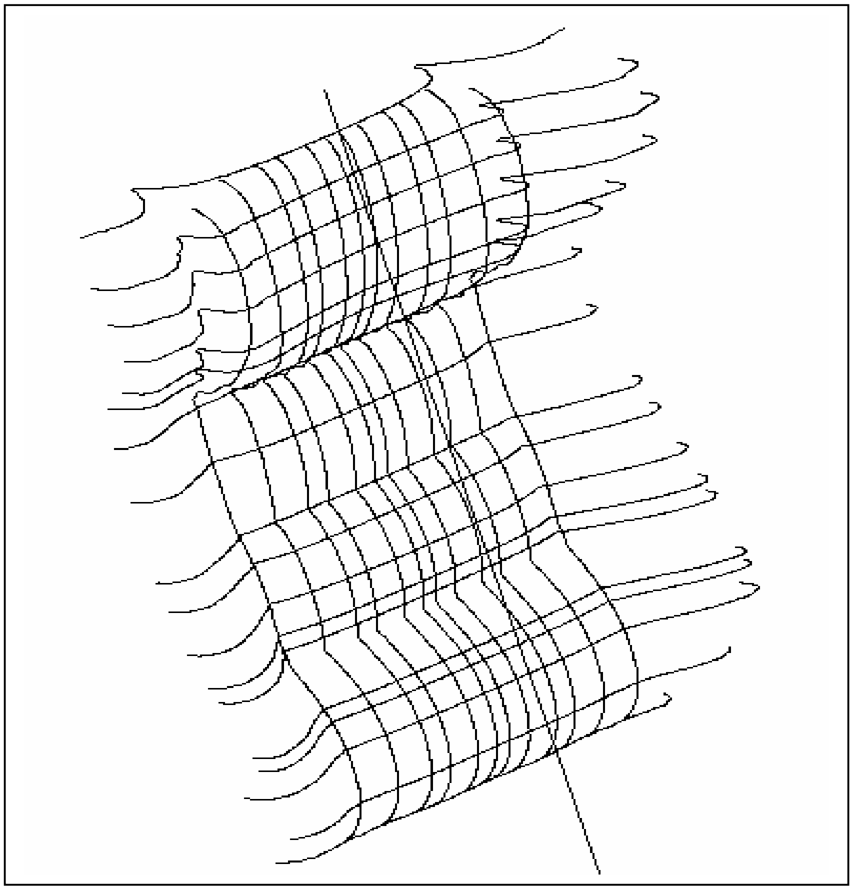


Figure B2: Backrest (CCM)

Measurement Data (CCM)

1. Seat pan data

Contours in Memory (mm)

4494 available points		N		Coord. 3
1 tr1	I	1071	ZX	9.001
2 tr3	I	962	ZX	78.961
3 tr2	I	912	ZX	39.978
4 tr4	I	929	ZX	130.954
5 tr5	I	1007	ZX	184.943
6 tr6	I	1013	ZX	196.990
7 tr7	I	1029	ZX	235.824
8 tr8	I	1020	ZX	277.967
9 tr9	I	1058	ZX	325.969
10 tr10	I	1112	ZX	362.975
11 tr11	I	1041	ZX	390.969
12 tr12	I	1120	ZX	420.970
13 tr13	I	1029	ZX	437.968
14 tr14	I	1024	ZX	448.954
15 tr15	I	987	ZX	456.960
16 tr16	I	991	ZX	471.278
17 tr17	I	887	ZX	480.923
18 tr18	I	916	ZX	489.913
19 tr19	I	895	ZX	495.407
20 tr20	I	900	ZX	497.290
21 wr1	I	937	YZ	26.938
22 wr2	I	962	YZ	38.913
23 wr3	I	924	YZ	120.968
24 wr4	I	1041	YZ	241.944
25 wr5	I	923	YZ	388.938
26 wr6	I	950	YZ	406.673
27 wr7	I	1016	YZ	439.945
28 wr8	I	850	YZ	473.936

2. Backrest data

Contours in Memory (mm)

851 available points		N		Coord 3
1 xb1	I	441	ZX	22.049
2 xb2	I	468	ZX	67.865
3 xb3	I	555	ZX	127.684
4 xb4	I	679	ZX	753.933
5 xb5	I	657	ZX	711.164
6 xb6	I	657	ZX	672.633
7 xb7	I	644	ZX	628.275
8 xb8	I	655	ZX	580.552
9 xb9	I	626	ZX	556.108
10 xb11	I	492	ZX	506.062
11 xb12	I	494	ZX	443.959
12 xb13	I	521	ZX	360.560
13 xb14	I	531	ZX	329.563
14 xb15	I	549	ZX	284.254
15 xb16	I	557	ZX	249.630
16 xb17	I	557	ZX	232.612
17 xb18	I	537	ZX	171.698
18 xb19	I	531	ZX	157.973
19 yb1	I	764	YZ	151.310
20 yb2	I	748	YZ	190.118
21 yb3	I	771	YZ	224.054
22 yb4	I	752	YZ	244.122
23 yb5	I	749	YZ	273.866
24 yb6	I	748	YZ	294.428
25 yb7	I	749	YZ	344.114
26 yb8	I	751	YZ	374.350
27 yb9	I	754	YZ	391.131
28 yb10	I	734	YZ	410.720

Regenerating Cushion Contour using Coordinate Measuring Machine

Seat Pan

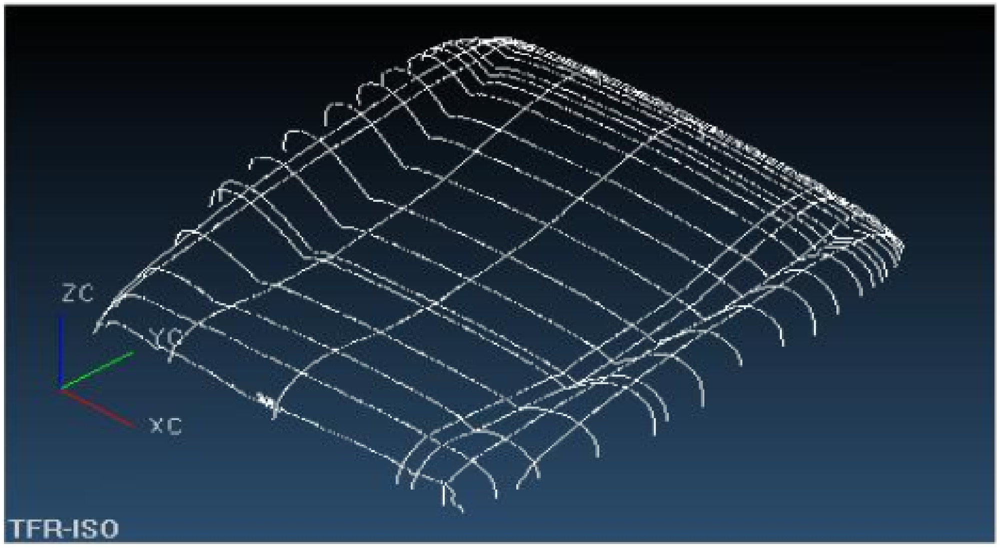


Figure B3: Scanning Cushion Data from CMM

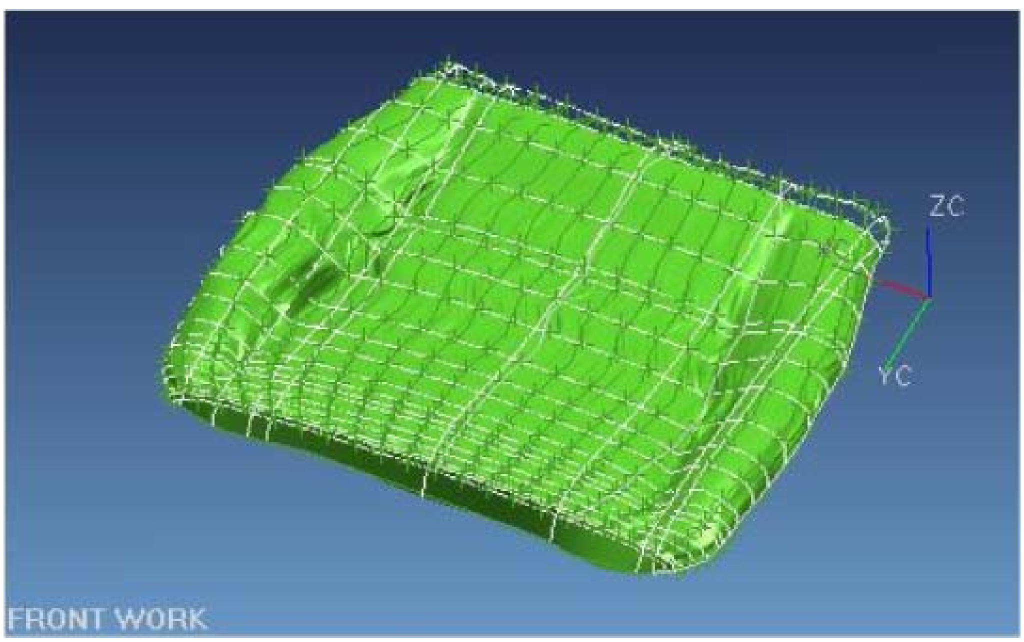


Figure B4: Regenerating surface design process using CAD

Figure B5: VIP passenger seat

Figure B6: Old bus passenger seat

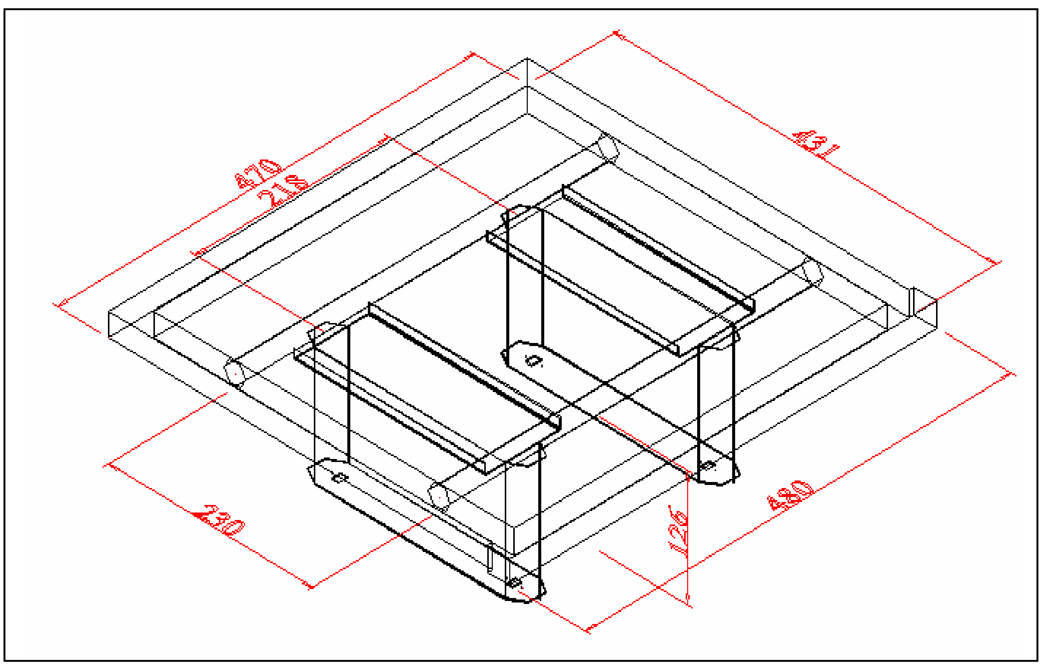


Figure B7: Isometric drawing of current existing seat structure

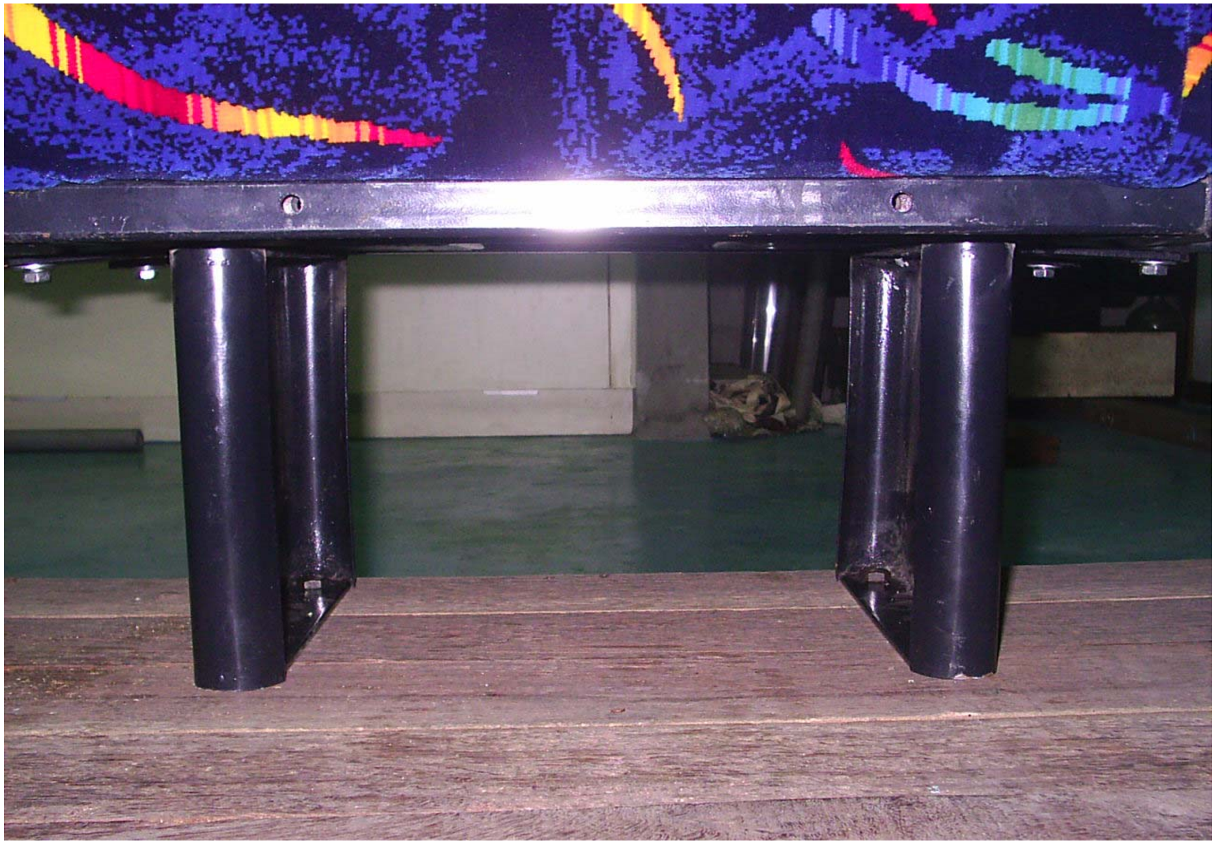


Figure B8: Existing design of Seat Structure

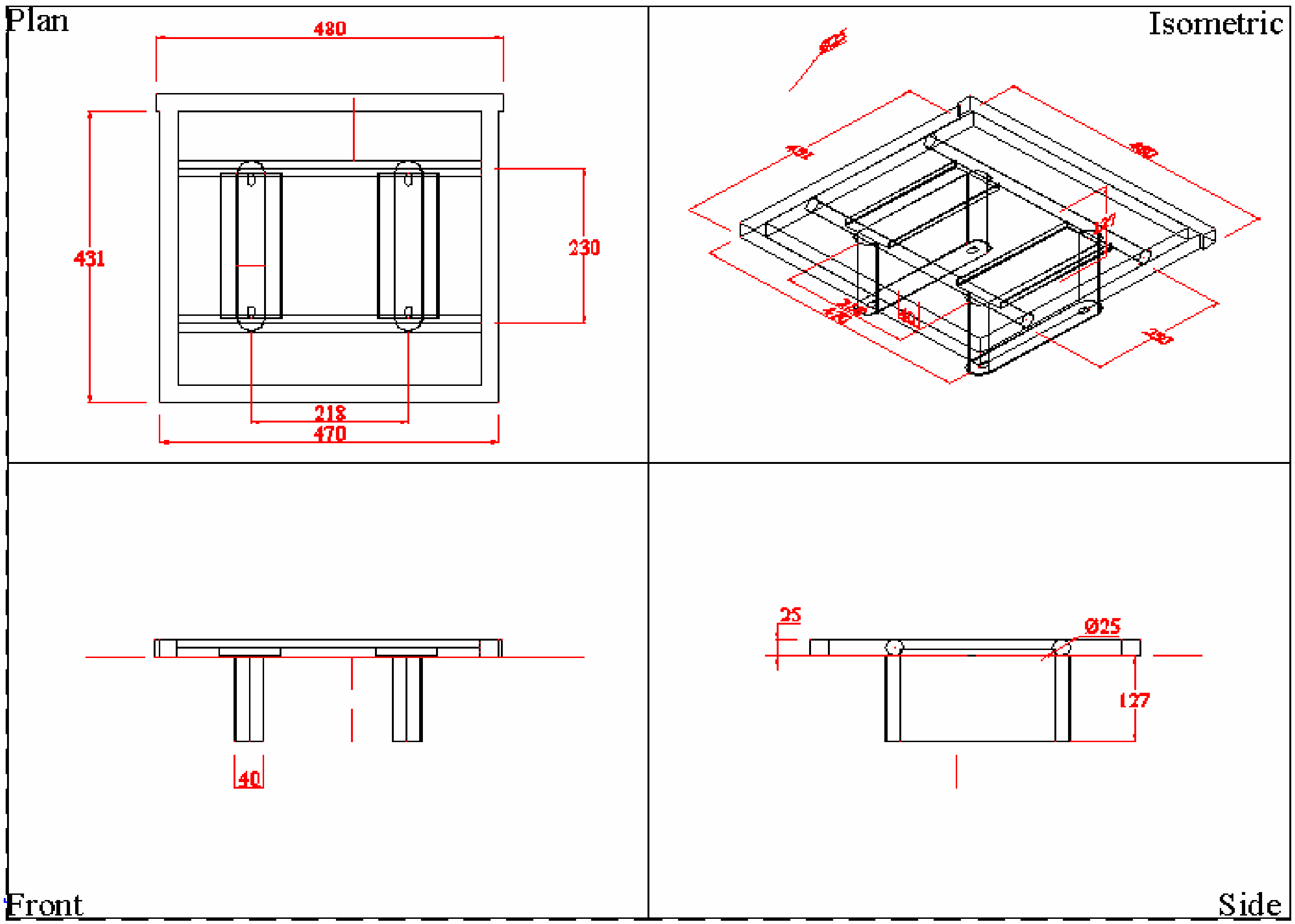


Figure B9: Orthographic drawing of seat structure

Design of Improved Seat Structure

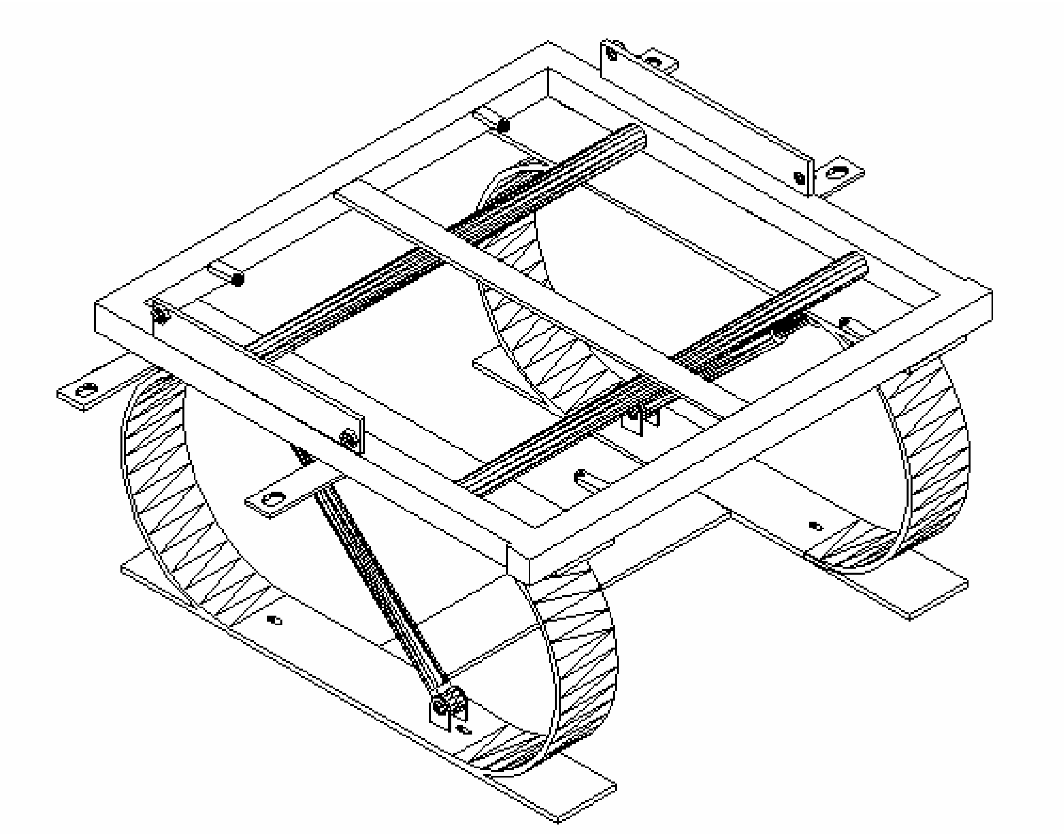


Figure B10: Design of improved seat structure

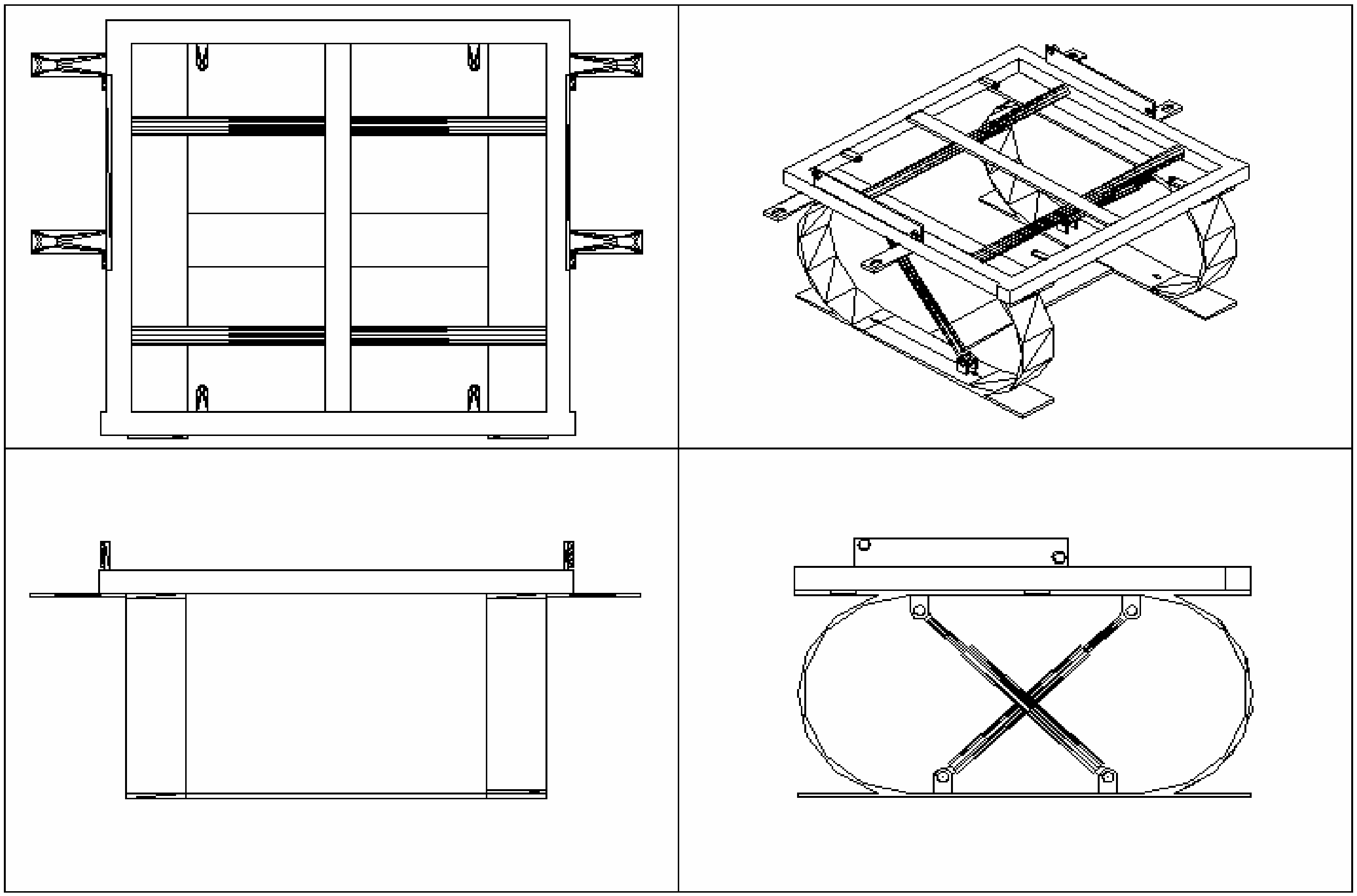


Figure B11: New design of Seat Structure (Orthographic Drawing)

Figure B12: New seat structure (without absorbers)

Figure B13: New seat structure (with absorbers)

Figure B14: New seat structure installed with the existing seat pan, seat back and armrests.

APPENDIX C

OBJECTIVE TEST PROCEDURES

Laboratory Test

1. Pressure Mapping Test

1. Calibrate the transducers: pressure map and accelerometers.
2. Clamp the test rig onto the DARTEC machine, in a horizontal position (angle measured by using inclinometer).
3. Install the bus seat at the end part of the test rig as shown in Figure C2**.**
4. Pressure mapping system is put on the seat cushion and a low frequency accelerometer low frequency is bonded to the test rig below the seat. This is to obtain the pressure value at different frequencies.
5. Setup the analyzer which connects the transducers with the PC.
6. Dummy with dead weight is placed on the seat and is tightened (not too tight) so that the subject will not fall down during high excitation.
7. After the dummy has been adjusted to the wanted posture, operate the DARTEC, from frequency 1Hz, with amplitude of 0.5mm. At the same time, data is recorded in the analyzer.
8. Increase the frequency at an increment of 0.5 Hz, until 4 Hz, and then at increment of 1Hz, until 10 Hz.
9. The DARTEC machine is stopped and the data is saved.

2. Transmissibility Test

1. Calibrate the accelerometers.
2. Continue steps 2-9 in pressure mapping test by replacing the Xsensor pressure map with the seat pad accelerometer. The setup is shown in Figure C3.

3. Road Trial:

1. Calibrate the transducers: pressure map and accelerometers.
2. Seat pad accelerometer is put on the seat and low frequency accelerometer is bonded onto the bus floor below the seat.
3. Setup the analyzer which connects the transducers with the laptop.
4. Subject sits on the seat with the comfortable posture as shown in **Figure C7**.
5. The data is recorded once the vehicle starts moving.
6. The vehicle shall be driven pass some bumpy roads and at least a long smooth surface road for 1 minute each.
7. After passing through these roads for the 1st round, replace the seat pad accelerometer with Xsensor pressure mapping system and then the vehicle is driven back through the original route.
8. Stop the vehicle and the data is saved.
9. The 1st subject gets down and the 2nd subject sits on the seat and steps 4-8 is repeated.

Transducers

Pressure Mapping Test : 1. XSensor Pressure Mapping System
System specification:
As mentioned in Subchapter 3.3
2. Low frequency accelerometer
System specification:
Measuring range - ± 50 g
Sensitivity – 112.1 mV/g
Resonance frequency – 44.0 kHz

Transmissibility Test : 1. Entran Triaxial Sit-Pad Accelerometer
System specification:
As shown in Appendix
2. Low frequency accelerometer
System specification:
Measuring range - ± 50 g
Sensitivity – 112.1 mV/g
Resonance frequency – 44.0 kHz

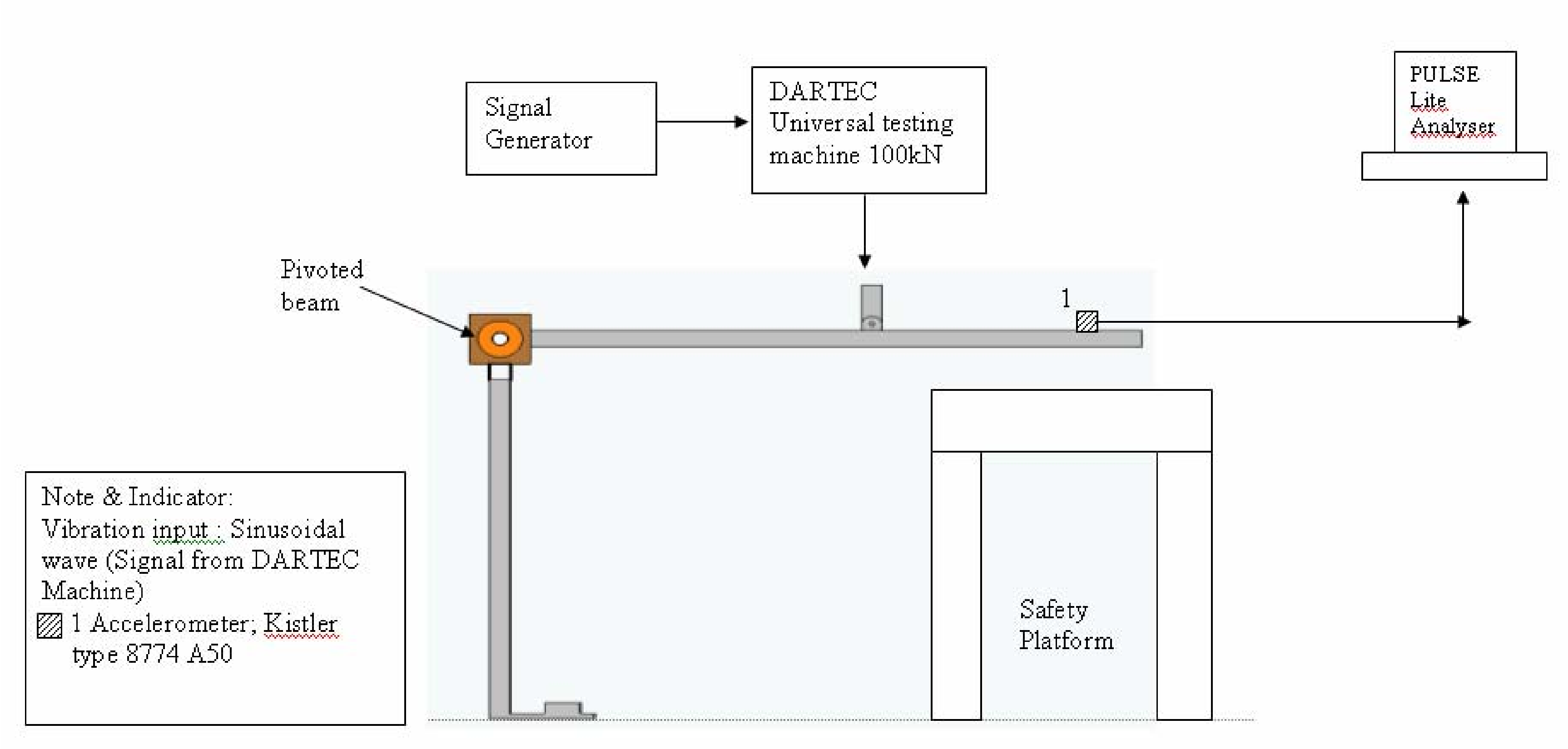


Figure C1: Equipment set up for pretest under vertical vibration

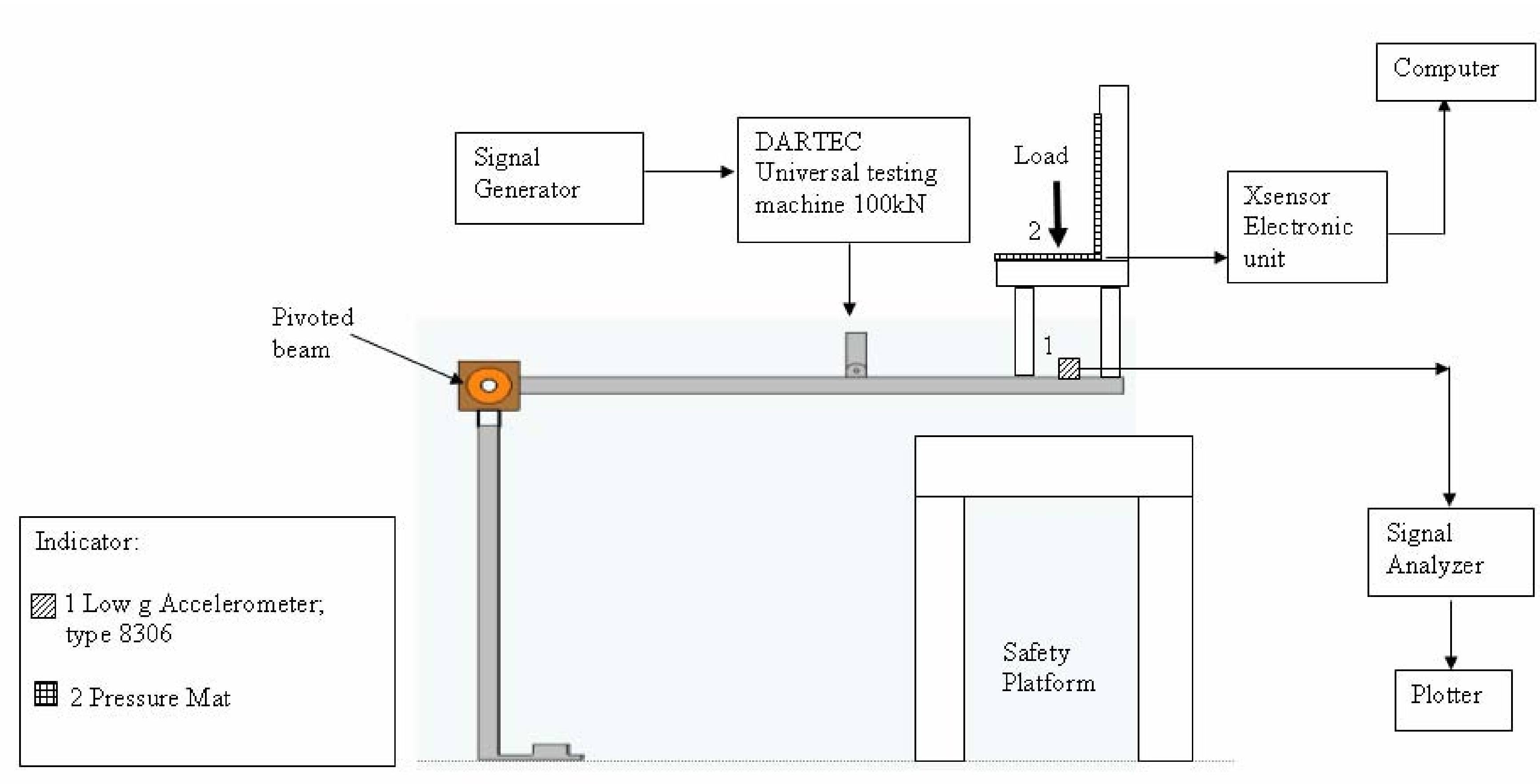


Figure C2: Equipment set up for pressure mapping test under vertical vibration

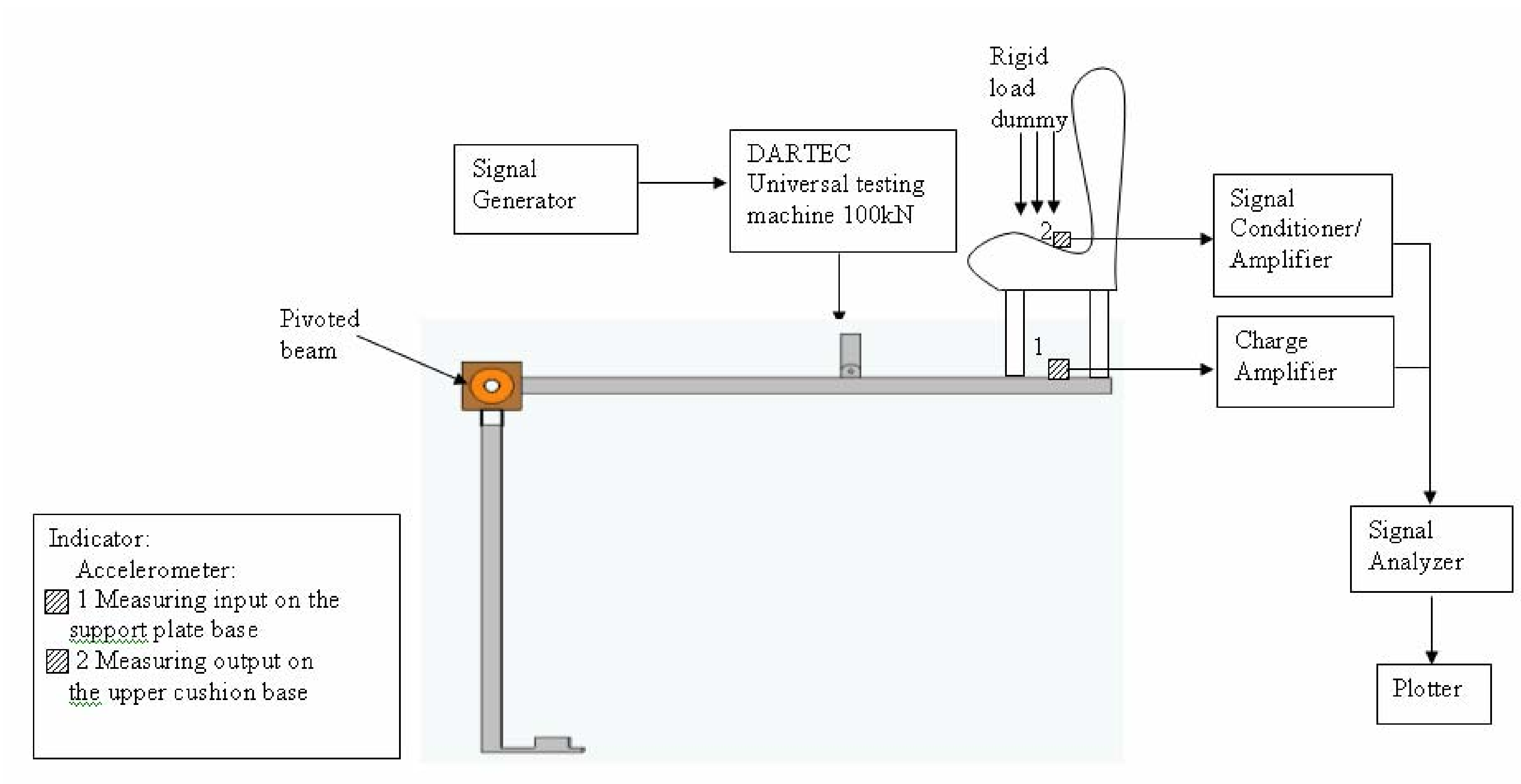


Figure C3: Equipment set up for vibration testing under vertical vibration

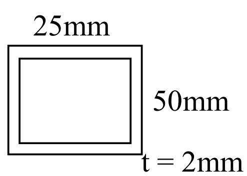
Test Rig Design Analysis

1. **Bending Vibration**

Applied frequency recommended for vibration testing on vehicle seat is within 1-30Hz. The load (vehicle seat) will be applied at one end of beam, which is constrained to move in vertical direction. The natural frequency of the beam must be determined to ensure no resonance frequency occurs within the testing frequency. Thus, the appropriate size of beam; the length of the beam must be determined.

Natural frequency of beam, $W_n = \beta_n\int (EI / ml^4)^{1/2}$

Where
l = length of beam (m)
m = mass per unit length (kg/m)
$\beta_n\int$ = depends on the boundary condition
ρ = density of mild steel
$\rho_{\text{mild steel}} = 7810 kg/m^3$
$\rho = m/V$
$7810 = m/ (A_o – A_i)l$



$A_o = (25 \times 10^{-3})(50 \times 10^{-3})$
$= 1.25 \times 10^{-3} m^2$

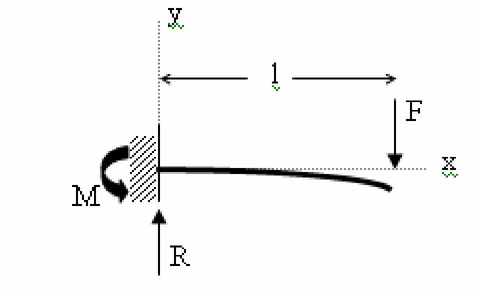
$A_i = (21 \times 10^{-3})(46 \times 10^{-3})$
$= 9.66 \times 10 m^2$

$A_o – A_i = 2.84 \times 10^{-4} m^2$

$m = 7810 (2.84 \times 10^{-4})$
$= 2.218 kg/m$

2. **Deflection and Stiffness Consideration**

The beam for test rig design is considered as a cantilever with one point load applied on the free end of the cantilever.



The relation for curvature of a beam subjected to a bending moment M

$1/þ = M/EI$ where þ = radius of curvature

This equation can also be written as

$$M/EI = d^2y/ dx^2$$

Based on table A-9-1 (Mechanical Engineering Design; Shigley, J.E, 1st Ed.), for cantilever-end load

$R = V = F$ $M = -Fl$

Y $= Fx^2/ 6EI \times (x-3l)$

Y_{max} $= -Fl^3/3EI$

F = {[Seat mass + Rigid mass (average human load as stated in standard)] /2 + beam mass} x g

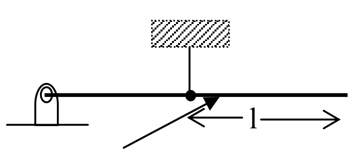
= [(29kg + 75kg)/2 + 2.04kg] x 9.81m/s^2

= 530.138N

V = 530.138N

M = - 530.138N x l

Boundary condition consideration



Considered clamp free

n	$\beta_n∫$
1	1.875
2	4.694
3	7.85
4	10.99
5	14.14

As $n = 1, \beta_n \int = 1.875$

w_n, natural frequency ≥ 50Hz

$2\pi(50) = 1.875 \times (207 \times 10^9 \times I/2.218l^4)^{1/2}$

$2.218l^4 = (207\times10^9 \times 9.01\times10^{-8}) / 167.55^2$

$l^4 = 0.2995\ m^4$

$l = 0.7398\ m$

$l \approx 0.74\ m$

The length of the beam, $l \leq 0.74$ m in order to make sure there will be no resonance exists within the frequency range of 1-50Hz.

$l \leq 0.74$ m

l = l of seat pan + clearance from testing machine

= 0.6375

$M = -\ 530.138N \times 0.6375$

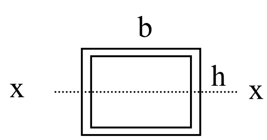
$= -\ 337.96\ Nm$

To calculate maximum deflection of beam when load is applied at the end of the beam,

$Y_{max} = -Fl^3/3EI$

E - Young's modulus of beam for mild steel = 207×10^9

I - the cross-sectional area moment of inertia (m^4)



$I = bh^3/12$

$I_o = 0.025\ (0.05)^3 / 12$

$= 260.417 \times 10^{-9}$

$I_i = 0.021\ (0.0463)^3 / 12$

$= 170.338 \times 10^{-9}$

$I = I_o - I_i$

$= 260.417 \times 10^{-9} - 170.338 \times 10^{-9}$

$= 90.079 \times 10^{-9}$

$y_{max} = -(530.138) \times (0.6375)^3/(3 \times 207 \times 10^9 \times 90.079 \times 10^{-9})$

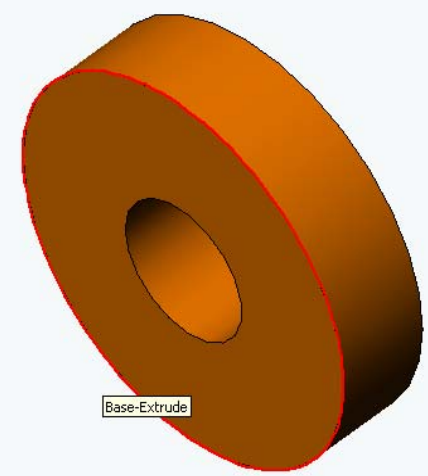
$= -2.46 \times 10^{-3}$ m

$\underline{= -2.46 \text{ mm}}$

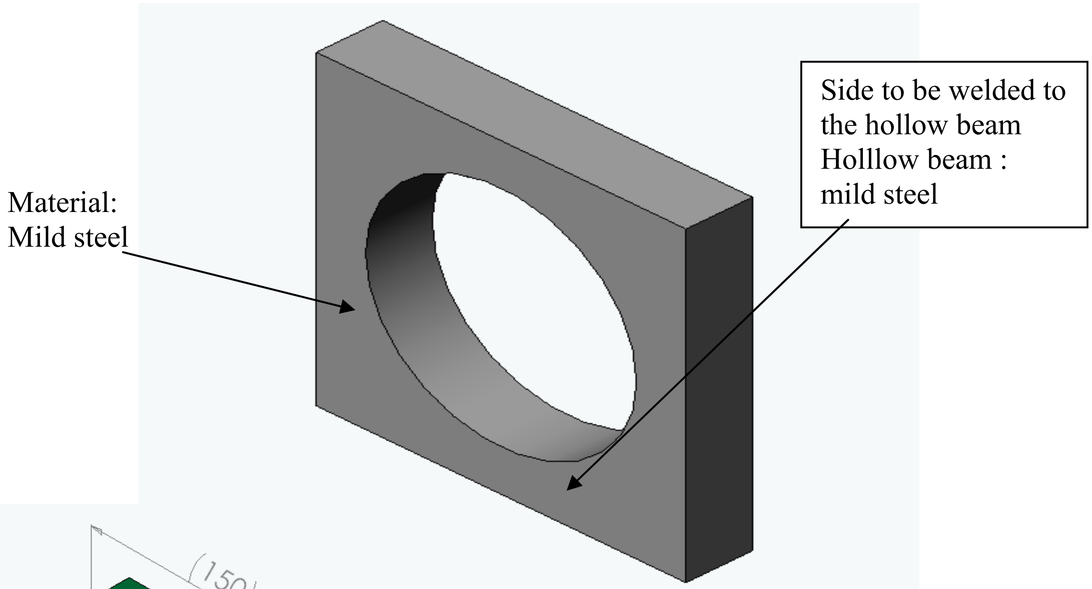
The **maximum deflection** of beam when force applied at the free-end will be **2.46mm** which is considered small compared to the load applied; weight of seat and rigid mass mounted at the end of the beam and its own mass. Thus, the beam is considered rigid when the load is applied.

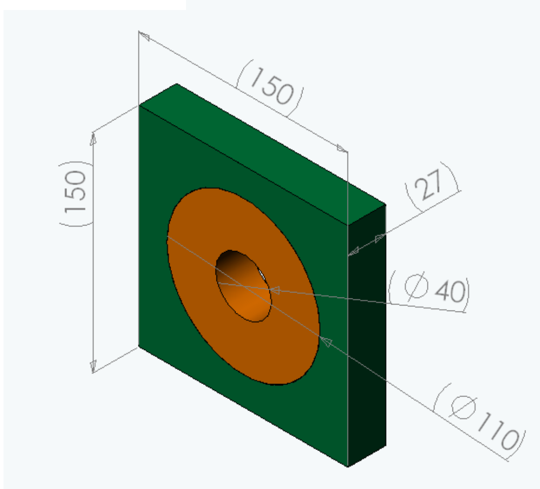
Test Rig Components

<u>Bearing and Housing</u>



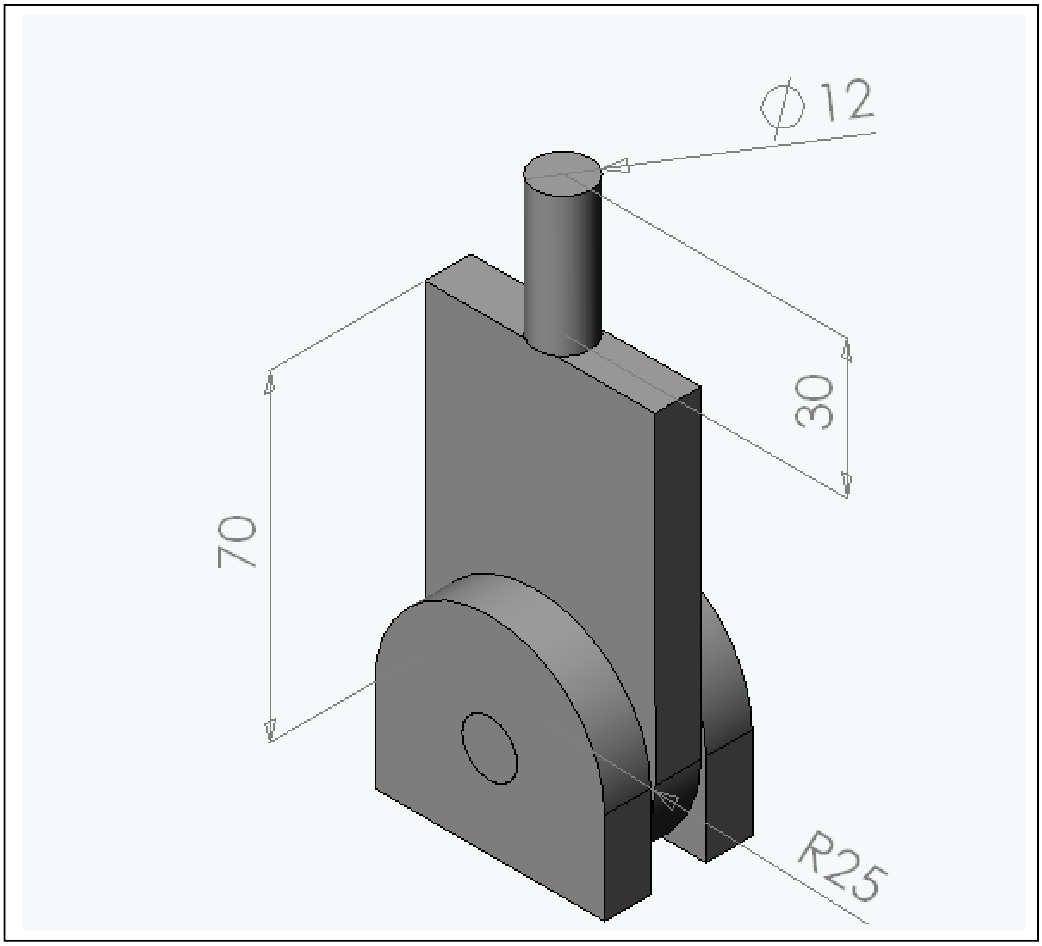
Bearing



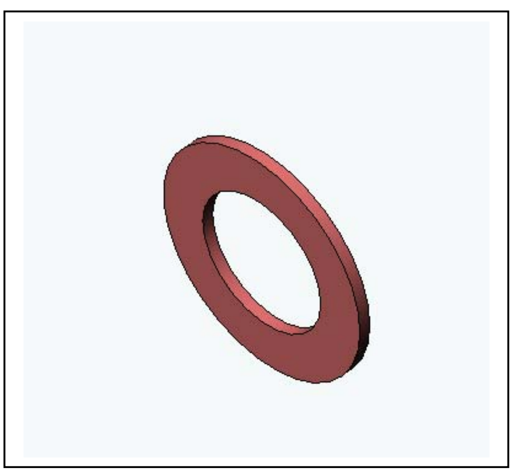


Housing

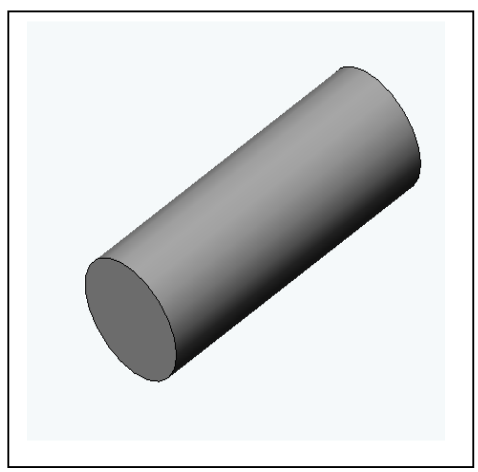
Gripper



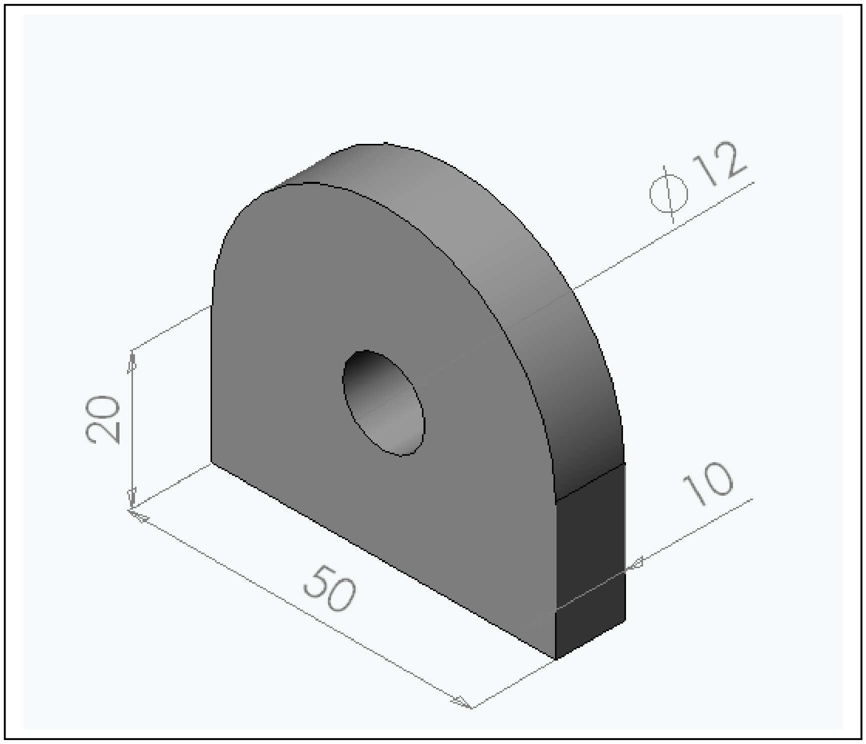
Gripper



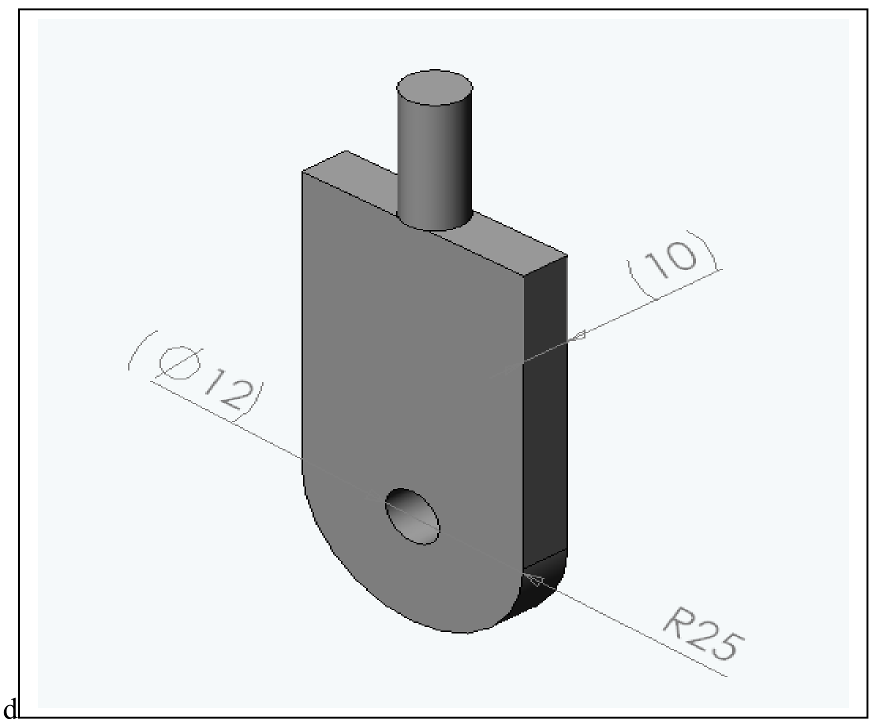
Washer



Pin joint



Support for gripper



d

Main grip

Figure C4: XSensor Pressure Mapping System

Figure C5: Entran Sit Pad Accelerometer

Figure C6: Pressure mapping system on the old seat

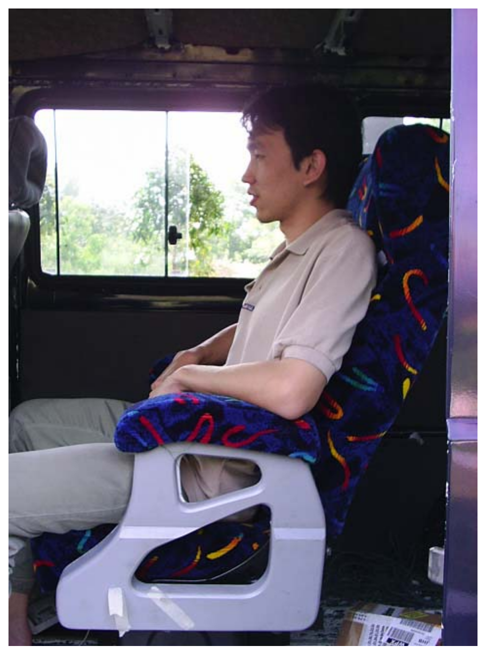


Figure C7: Subject on the seat in vehicle (Field trial)

Figure C8: Thickness added up to the neck

Figure C9: Thickness added at the lumbar support

APPENDIX D

TEST / ANALYSIS DATA

Table D1: Example of time history data during bumpy road ride (pressure distribution test)

T(s)	G(m/s^2)	T(s)	g(m/s^2)	T(s)	g(m/s^2)	T(s)	g(m/s^2)
-1	0	-0.993042	0.0003128	-0.986084	-0.041182	-0.979126	-0.0270997
-0.999878	0	-0.99292	-0.0006548	-0.985962	-0.0413806	-0.979004	-0.0263355
-0.999756	0	-0.992798	-0.0016297	-0.98584	-0.041561	-0.978882	-0.0255692
-0.999634	0	-0.992676	-0.0026073	-0.985718	-0.0417242	-0.97876	-0.0248021
-0.999512	0	-0.992554	-0.0035832	-0.985596	-0.0418713	-0.978638	-0.0240352
-0.99939	0	-0.992432	-0.0045536	-0.985474	-0.0420028	-0.978516	-0.0232684
-0.999268	0	-0.99231	-0.0055147	-0.985352	-0.0421192	-0.978394	-0.0225014
-0.999146	0	-0.992188	-0.0064635	-0.985229	-0.0422204	-0.978271	-0.021733
-0.999023	0	-0.992065	-0.0073973	-0.985107	-0.0423064	-0.978149	-0.0209616
-0.998901	0	-0.991943	-0.0083145	-0.984985	-0.0423771	-0.978027	-0.0201851
-0.998779	0	-0.991821	-0.0092138	-0.984863	-0.0424321	-0.977905	-0.0194011
-0.998657	0	-0.991699	-0.0100949	-0.984741	-0.0424709	-0.977783	-0.018607
-0.998535	0	-0.991577	-0.0109579	-0.984619	-0.0424933	-0.977661	-0.0178
-0.998413	0	-0.991455	-0.0118039	-0.984497	-0.0424988	-0.977539	-0.0169774
-0.998291	0	-0.991333	-0.0126341	-0.984375	-0.0424873	-0.977417	-0.016137
-0.998169	0	-0.991211	-0.0134505	-0.984253	-0.0424586	-0.977295	-0.0152764
-0.998047	0	-0.991089	-0.0142554	-0.984131	-0.0424129	-0.977173	-0.0143942
-0.997925	0	-0.990967	-0.0150514	-0.984009	-0.0423503	-0.977051	-0.0134891
-0.997803	0	-0.990845	-0.015841	-0.983887	-0.0422713	-0.976929	-0.0125608
-0.997681	0	-0.990723	-0.0166268	-0.983765	-0.0421766	-0.976807	-0.0116094
-0.997559	0	-0.990601	-0.0174114	-0.983643	-0.0420669	-0.976685	-0.010636
-0.997437	0	-0.990479	-0.0181971	-0.983521	-0.041943	-0.976563	-0.0096419
-0.997314	0	-0.990356	-0.0189859	-0.983398	-0.0418059	-0.97644	-0.0086294
-0.997192	0	-0.990234	-0.0197796	-0.983276	-0.0416564	-0.976318	-0.0076012
-0.99707	0	-0.990112	-0.0205791	-0.983154	-0.0414956	-0.976196	-0.0065606
-0.996948	0	-0.98999	-0.0213855	-0.983032	-0.0413242	-0.976074	-0.005511
-0.996826	0	-0.989868	-0.022199	-0.98291	-0.0411432	-0.975952	-0.0044562
-0.996704	0	-0.989746	-0.0230195	-0.982788	-0.0409529	-0.97583	-0.0034001
-0.996582	0	-0.989624	-0.0238463	-0.982666	-0.0407537	-0.975708	-0.0023469
-0.99646	0	-0.989502	-0.0246783	-0.982544	-0.0405458	-0.975586	-0.0013004
-0.996338	0	-0.98938	-0.0255141	-0.982422	-0.0403291	-0.975464	-0.0002643
-0.996216	0	-0.989258	-0.0263517	-0.9823	-0.0401032	-0.975342	0.0007582
-0.996094	0	-0.989136	-0.0271891	-0.982178	-0.0398672	-0.97522	0.0017639
-0.995972	0.0165407	-0.989014	-0.0280235	-0.982056	-0.0396202	-0.975098	0.0027502
-0.99585	0.0159991	-0.988892	-0.0288523	-0.981934	-0.0393608	-0.974976	0.0037149
-0.995728	0.0154732	-0.98877	-0.0296726	-0.981812	-0.0390877	-0.974854	0.0046564
-0.995605	0.0149588	-0.988647	-0.0304813	-0.981689	-0.038799	-0.974731	0.0055734
-0.995483	0.0144511	-0.988525	-0.0312754	-0.981567	-0.0384928	-0.974609	0.0064654
-0.995361	0.0139455	-0.988403	-0.0320517	-0.981445	-0.038167	-0.974487	0.0073323
-0.995239	0.0134372	-0.988281	-0.0328072	-0.981323	-0.0378197	-0.974365	0.0081744
-0.995117	0.0129215	-0.988159	-0.033539	-0.981201	-0.0374489	-0.974243	0.0089924
-0.994995	0.0123938	-0.988037	-0.0342445	-0.981079	-0.0370526	-0.974121	0.0097878
-0.994873	0.0118499	-0.987915	-0.0349212	-0.980957	-0.0366293	-0.973999	0.0105623
-0.994751	0.011286	-0.987793	-0.0355672	-0.980835	-0.0361774	-0.973877	0.0113177
-0.994629	0.0106984	-0.987671	-0.0361806	-0.980713	-0.0356959	-0.973755	0.0120565
-0.994507	0.010084	-0.987549	-0.0367602	-0.980591	-0.0351843	-0.973633	0.0127812
-0.994385	0.0094403	-0.987427	-0.0373053	-0.980469	-0.0346424	-0.973511	0.0134945
-0.994263	0.0087652	-0.987305	-0.0378153	-0.980347	-0.0340705	-0.973389	0.0141995
-0.994141	0.0080573	-0.987183	-0.0382904	-0.980225	-0.0334695	-0.973267	0.0148991
-0.994019	0.0073159	-0.987061	-0.038731	-0.980103	-0.0328406	-0.973145	0.0155962
-0.993896	0.0065411	-0.986938	-0.0391382	-0.97998	-0.0321859	-0.973022	0.0162938
-0.993774	0.0057332	-0.986816	-0.0395132	-0.979858	-0.0315075	-0.9729	0.0169946
-0.993652	0.0048937	-0.986694	-0.0398574	-0.979736	-0.0308082	-0.972778	0.0177013
-0.99353	0.0040246	-0.986572	-0.0401726	-0.979614	-0.0300908	-0.972656	0.0184161
-0.993408	0.0031285	-0.98645	-0.0404608	-0.979492	-0.0293582	-0.972534	0.0191409
-0.993286	0.0022087	-0.986328	-0.0407238	-0.97937	-0.0286136	-0.972412	0.0198771

-0.993164	0.0012688	-0.986206	-0.0409636	-0.979248	-0.0278598	-0.97229	0.0206258

Table D2: Example of time history data during bumpy road ride for channel 1 (SEAT test)

T(s)	g(m/s^2)	T(s)	g(m/s^2)	T(s)	g(m/s^2)	T(s)	g(m/s^2)
-1	0	-0.993042	-0.0258142	-0.986084	-0.0492663	-0.979126	-0.056886
-0.999878	0	-0.99292	-0.0265673	-0.985962	-0.0495362	-0.979004	-0.0564384
-0.999756	0	-0.992798	-0.027314	-0.98584	-0.0498297	-0.978882	-0.0559791
-0.999634	0	-0.992676	-0.0280557	-0.985718	-0.0501448	-0.97876	-0.0555132
-0.999512	0	-0.992554	-0.028793	-0.985596	-0.0504789	-0.978638	-0.055046
-0.99939	0	-0.992432	-0.0295264	-0.985474	-0.0508291	-0.978516	-0.0545827
-0.999268	0	-0.99231	-0.0302557	-0.985352	-0.0511922	-0.978394	-0.054128
-0.999146	0	-0.992188	-0.0309806	-0.985229	-0.0515647	-0.978271	-0.0536858
-0.999023	0	-0.992065	-0.0317002	-0.985107	-0.0519433	-0.978149	-0.0532597
-0.998901	0	-0.991943	-0.0324132	-0.984985	-0.0523244	-0.978027	-0.0528525
-0.998779	0	-0.991821	-0.0331184	-0.984863	-0.052705	-0.977905	-0.0524659
-0.998657	0	-0.991699	-0.0338142	-0.984741	-0.053082	-0.977783	-0.0521009
-0.998535	0	-0.991577	-0.0344993	-0.984619	-0.0534528	-0.977661	-0.0517573
-0.998413	0	-0.991455	-0.0351723	-0.984497	-0.0538151	-0.977539	-0.0514341
-0.998291	0	-0.991333	-0.035832	-0.984375	-0.054167	-0.977417	-0.0511295
-0.998169	0	-0.991211	-0.0364774	-0.984253	-0.0545071	-0.977295	-0.0508405
-0.998047	0	-0.991089	-0.0371076	-0.984131	-0.0548345	-0.977173	-0.0505638
-0.997925	0	-0.990967	-0.0377223	-0.984009	-0.0551485	-0.977051	-0.0502949
-0.997803	0	-0.990845	-0.0383214	-0.983887	-0.0554489	-0.976929	-0.0500293
-0.997681	0	-0.990723	-0.0389048	-0.983765	-0.0557359	-0.976807	-0.0497619
-0.997559	0	-0.990601	-0.0394728	-0.983643	-0.0560098	-0.976685	-0.0494876
-0.997437	0	-0.990479	-0.0400257	-0.983521	-0.0562713	-0.976563	-0.0492008
-0.997314	0	-0.990356	-0.0405639	-0.983398	-0.0565212	-0.97644	-0.0488963
-0.997192	0	-0.990234	-0.0410877	-0.983276	-0.0567605	-0.976318	-0.0485692
-0.99707	0	-0.990112	-0.0415974	-0.983154	-0.0569902	-0.976196	-0.0482149
-0.996948	0	-0.98999	-0.042093	-0.983032	-0.0572114	-0.976074	-0.0478294
-0.996826	0	-0.989868	-0.0425741	-0.98291	-0.057425	-0.975952	-0.0474092
-0.996704	0	-0.989746	-0.0430403	-0.982788	-0.057632	-0.97583	-0.0469514
-0.996582	0	-0.989624	-0.0434906	-0.982666	-0.0578331	-0.975708	-0.0464542
-0.99646	0	-0.989502	-0.0439241	-0.982544	-0.058029	-0.975586	-0.0459166
-0.996338	0	-0.98938	-0.0443393	-0.982422	-0.0582202	-0.975464	-0.0453382
-0.996216	0	-0.989258	-0.0447347	-0.9823	-0.0584068	-0.975342	-0.0447199
-0.996094	0	-0.989136	-0.0451085	-0.982178	-0.0585888	-0.97522	-0.044063
-0.995972	-0.0031888	-0.989014	-0.0454592	-0.982056	-0.0587658	-0.975098	-0.0433699
-0.99585	-0.0042135	-0.988892	-0.0457851	-0.981934	-0.0589373	-0.974976	-0.0426435
-0.995728	-0.0052519	-0.98877	-0.046085	-0.981812	-0.0591021	-0.974854	-0.0418876
-0.995605	-0.0063006	-0.988647	-0.0463579	-0.981689	-0.0592589	-0.974731	-0.0411063
-0.995483	-0.0073561	-0.988525	-0.0466032	-0.981567	-0.0594061	-0.974609	-0.0403039
-0.995361	-0.0084148	-0.988403	-0.0468209	-0.981445	-0.0595417	-0.974487	-0.0394851
-0.995239	-0.0094729	-0.988281	-0.0470115	-0.981323	-0.0596634	-0.974365	-0.0386547
-0.995117	-0.0105268	-0.988159	-0.0471763	-0.981201	-0.0597686	-0.974243	-0.0378171
-0.994995	-0.011573	-0.988037	-0.0473172	-0.981079	-0.0598545	-0.974121	-0.0369766
-0.994873	-0.0126079	-0.987915	-0.0474366	-0.980957	-0.0599182	-0.973999	-0.0361368
-0.994751	-0.0136286	-0.987793	-0.0475376	-0.980835	-0.0599566	-0.973877	-0.0353009
-0.994629	-0.0146322	-0.987671	-0.0476238	-0.980713	-0.0599669	-0.973755	-0.0344712
-0.994507	-0.0156166	-0.987549	-0.0476992	-0.980591	-0.0599462	-0.973633	-0.0336493
-0.994385	-0.0165799	-0.987427	-0.0477682	-0.980469	-0.059892	-0.973511	-0.0328361
-0.994263	-0.0175211	-0.987305	-0.0478353	-0.980347	-0.0598021	-0.973389	-0.0320313
-0.994141	-0.0184393	-0.987183	-0.0479052	-0.980225	-0.0596746	-0.973267	-0.0312343
-0.994019	-0.0193346	-0.987061	-0.0479822	-0.980103	-0.0595085	-0.973145	-0.0304434

-0.993896	-0.0202074	-0.986938	-0.0480707	-0.97998	-0.0593033	-0.973022	-0.0296566
-0.993774	-0.0210588	-0.986816	-0.0481746	-0.979858	-0.0590592	-0.9729	-0.0288713
-0.993652	-0.02189	-0.986694	-0.0482972	-0.979736	-0.0587772	-0.972778	-0.0280849
-0.99353	-0.0227031	-0.986572	-0.0484414	-0.979614	-0.058459	-0.972656	-0.0272944
-0.993408	-0.0234998	-0.98645	-0.0486093	-0.979492	-0.0581071	-0.972534	-0.0264973
-0.993286	-0.0242825	-0.986328	-0.0488024	-0.97937	-0.057725	-0.972412	-0.0256913
-0.993164	-0.0250532	-0.986206	-0.0490214	-0.979248	-0.0573165	-0.97229	-0.0248746

Table D3: Example of time history data during bumpy road ride for channel 2 (SEAT test)

T(s)	g(m/s^2)	T(s)	g(m/s^2)	T(s)	g(m/s^2)	T(s)	g(m/s^2)
-1	0	-0.993042	0.0136346	-0.986084	0.0198404	-0.979126	0.060815
-0.999878	0	-0.99292	0.0141259	-0.985962	0.0195815	-0.979004	0.0600367
-0.999756	0	-0.992798	0.0146624	-0.98584	0.0192809	-0.978882	0.0591832
-0.999634	0	-0.992676	0.0152465	-0.985718	0.0189566	-0.97876	0.0582738
-0.999512	0	-0.992554	0.0158807	-0.985596	0.0186304	-0.978638	0.0573273
-0.99939	0	-0.992432	0.0165669	-0.985474	0.0183266	-0.978516	0.0563616
-0.999268	0	-0.99231	0.0173067	-0.985352	0.0180715	-0.978394	0.0553927
-0.999146	0	-0.992188	0.0181006	-0.985229	0.017892	-0.978271	0.0544353
-0.999023	0	-0.992065	0.0189478	-0.985107	0.0178137	-0.978149	0.0535015
-0.998901	0	-0.991943	0.0198461	-0.984985	0.0178599	-0.978027	0.0526013
-0.998779	0	-0.991821	0.0207916	-0.984863	0.0180511	-0.977905	0.0517424
-0.998657	0	-0.991699	0.0217785	-0.984741	0.0184035	-0.977783	0.0509303
-0.998535	0	-0.991577	0.0227986	-0.984619	0.0189278	-0.977661	0.0501686
-0.998413	0	-0.991455	0.0238414	-0.984497	0.0196293	-0.977539	0.0494595
-0.998291	0	-0.991333	0.0248944	-0.984375	0.0205071	-0.977417	0.0488035
-0.998169	0	-0.991211	0.0259424	-0.984253	0.0215542	-0.977295	0.0482003
-0.998047	0	-0.991089	0.0269685	-0.984131	0.0227581	-0.977173	0.0476489
-0.997925	0	-0.990967	0.0279546	-0.984009	0.0241005	-0.977051	0.0471476
-0.997803	0	-0.990845	0.0288815	-0.983887	0.0255588	-0.976929	0.0466944
-0.997681	0	-0.990723	0.0297298	-0.983765	0.0271084	-0.976807	0.0462875
-0.997559	0	-0.990601	0.0304801	-0.983643	0.0287232	-0.976685	0.0459247
-0.997437	0	-0.990479	0.0311141	-0.983521	0.0303754	-0.976563	0.0456038
-0.997314	0	-0.990356	0.0316159	-0.983398	0.032038	-0.97644	0.0453227
-0.997192	0	-0.990234	0.0319717	-0.983276	0.0336865	-0.976318	0.0450796
-0.99707	0	-0.990112	0.032171	-0.983154	0.0352996	-0.976196	0.0448731
-0.996948	0	-0.98999	0.0322074	-0.983032	0.0368601	-0.976074	0.0447019
-0.996826	0	-0.989868	0.0320793	-0.98291	0.0383557	-0.975952	0.0445636
-0.996704	0	-0.989746	0.0317894	-0.982788	0.0397788	-0.97583	0.0444555
-0.996582	0	-0.989624	0.031345	-0.982666	0.0411273	-0.975708	0.0443762
-0.99646	0	-0.989502	0.0307581	-0.982544	0.0424037	-0.975586	0.0443245
-0.996338	0	-0.98938	0.030045	-0.982422	0.0436146	-0.975464	0.0442992
-0.996216	0	-0.989258	0.0292262	-0.9823	0.0447698	-0.975342	0.0442991
-0.996094	0	-0.989136	0.0283251	-0.982178	0.0458816	-0.97522	0.0443232
-0.995972	0.009785	-0.989014	0.0273669	-0.982056	0.0469634	-0.975098	0.0443707
-0.99585	0.0098346	-0.988892	0.0263784	-0.981934	0.0480282	-0.974976	0.0444411
-0.995728	0.0098796	-0.98877	0.0253866	-0.981812	0.049088	-0.974854	0.0445346
-0.995605	0.0099204	-0.988647	0.0244178	-0.981689	0.0501528	-0.974731	0.0446517
-0.995483	0.009958	-0.988525	0.0234973	-0.981567	0.0512296	-0.974609	0.0447932
-0.995361	0.0099943	-0.988403	0.0226477	-0.981445	0.0523211	-0.974487	0.0449601
-0.995239	0.0100317	-0.988281	0.0218861	-0.981323	0.0534261	-0.974365	0.0451537
-0.995117	0.0100726	-0.988159	0.0212263	-0.981201	0.0545391	-0.974243	0.0453754
-0.994995	0.0101195	-0.988037	0.0206782	-0.981079	0.0556503	-0.974121	0.0456266
-0.994873	0.0101752	-0.987915	0.0202463	-0.980957	0.0567466	-0.973999	0.0459087
-0.994751	0.0102425	-0.987793	0.0199302	-0.980835	0.0578113	-0.973877	0.0462224

-0.994629	0.0103244	-0.987671	0.0197242	-0.980713	0.0588253	-0.973755	0.0465688
-0.994507	0.0104234	-0.987549	0.0196183	-0.980591	0.0597681	-0.973633	0.0469498
-0.994385	0.0105418	-0.987427	0.0195986	-0.980469	0.060621	-0.973511	0.0473659
-0.994263	0.0106816	-0.987305	0.019648	-0.980347	0.0613655	-0.973389	0.0478172
-0.994141	0.0108446	-0.987183	0.0197469	-0.980225	0.0619838	-0.973267	0.048304
-0.994019	0.0110325	-0.987061	0.0198745	-0.980103	0.0624617	-0.973145	0.048827
-0.993896	0.0112467	-0.986938	0.0200099	-0.97998	0.0627884	-0.973022	0.0493868
-0.993774	0.011489	-0.986816	0.020133	-0.979858	0.062957	-0.9729	0.0499837
-0.993652	0.0117616	-0.986694	0.0202255	-0.979736	0.0629653	-0.972778	0.0506177
-0.99353	0.0120659	-0.986572	0.0202721	-0.979614	0.0628154	-0.972656	0.0512888
-0.993408	0.0124033	-0.98645	0.0202614	-0.979492	0.0625138	-0.972534	0.0519967
-0.993286	0.0127759	-0.986328	0.0201862	-0.97937	0.0620706	-0.972412	0.0527408
-0.993164	0.0131855	-0.986206	0.0200447	-0.979248	0.0614989	-0.97229	0.0535198

Table D4: Example of SEAT calculation (Road Trial)

	Base	Seat						
Frequency	G_{ss}	G_{ff}	W_b	W_b^2	$G_{ff}W_b^2$	$G_{ff}W_b^2$	$G_{ss}W_b^2$	$G_{ss}W_b^2$
0	4.553E-05	0.0005324	0.4	0.16	7.285E-06	6.623E-05	8.518E-05	0.0001562
0.5	0.0007824	0.0014207	0.4	0.16	0.0001252	0.0001007	0.0002273	0.0003338
1	0.0004765	0.0027513	0.4	0.16	7.624E-05	0.0001484	0.0004402	0.0005331
1.5	0.0013783	0.0039129	0.4	0.16	0.0002205	0.0003212	0.0006261	0.000683
2	0.0026365	0.0046251	0.4	0.16	0.0004218	0.0019418	0.00074	0.0043393
2.5	0.0138473	0.0317544	0.5	0.25	0.0034618	0.0034285	0.0079386	0.0078558
3	0.0094311	0.0215917	0.6	0.36	0.0033952	0.0034054	0.007773	0.0082046
3.5	0.0069707	0.0176247	0.7	0.49	0.0034157	0.0026444	0.0086361	0.0074071
4	0.0029269	0.0096534	0.8	0.64	0.0018732	0.0031843	0.0061782	0.0082445
4.5	0.00555	0.0127295	0.9	0.81	0.0044955	0.0034513	0.0103109	0.0078166
5	0.0024071	0.0053223	1	1	0.0024071	0.0015989	0.0053223	0.0034863
5.5	0.0007906	0.0016504	1	1	0.0007906	0.001912	0.0016504	0.0037825
6	0.0030334	0.0059146	1	1	0.0030334	0.0016915	0.0059146	0.0041145
6.5	0.0003497	0.0023145	1	1	0.0003497	0.0013634	0.0023145	0.0032902
7	0.0023771	0.0042658	1	1	0.0023771	0.0014661	0.0042658	0.0025297
7.5	0.0005551	0.0007936	1	1	0.0005551	0.0008834	0.0007936	0.0017563
8	0.0012117	0.0027191	1	1	0.0012117	0.0008703	0.0027191	0.0023352
8.5	0.0005289	0.0019513	1	1	0.0005289	0.0017974	0.0019513	0.0034198
9	0.0030659	0.0048882	1	1	0.0030659	0.0029625	0.0048882	0.0043076
9.5	0.0028591	0.0037271	1	1	0.0028591	0.0031399	0.0037271	0.0029619
10	0.0034207	0.0021967	1	1	0.0034207	0.0026484	0.0021967	0.0014888
10.5	0.0018762	0.0007808	1	1	0.0018762	0.0023019	0.0007808	0.000656
11	0.0027275	0.0005312	1	1	0.0027275	0.0021471	0.0005312	0.0006822
11.5	0.0015667	0.0008331	1	1	0.0015667	0.0010468	0.0008331	0.0009755
12	0.0005269	0.0011178	1	1	0.0005269	0.0007424	0.0011178	0.0009522
12.5	0.0009579	0.0007867	1	1	0.0009579	0.0016352	0.0007867	0.0009899
13	0.0023124	0.0011931	1	1	0.0023124	0.004277	0.0011931	0.0026341
13.5	0.0062415	0.004075	1	1	0.0062415	0.0059812	0.004075	0.0037789
14	0.0057209	0.0034827	1	1	0.0057209	0.0041073	0.0034827	0.0025084
14.5	0.0024937	0.0015341	1	1	0.0024937	0.0033562	0.0015341	0.0015204
15	0.0042188	0.0015067	1	1	0.0042188	0.0055135	0.0015067	0.0023426
15.5	0.0068083	0.0031786	1	1	0.0068083	0.0057962	0.0031786	0.0027077
16	0.004784	0.0022368	1	1	0.004784	0.0046142	0.0022368	0.0020237

16.5	0.0047237	0.0019242	0.97	0.9409	0.0044445	0.004265	0.0018105	0.0017551
17	0.0046237	0.0019237	0.94	0.8836	0.0040855	0.0036751	0.0016998	0.0014575
17.5	0.0039425	0.0014675	0.91	0.8281	0.0032648	0.0027376	0.0012152	0.0008097
18	0.0027906	0.0005103	0.89	0.7921	0.0022104	0.0017789	0.0004042	0.0002819
18.5	0.0018218	0.0002157	0.86	0.7396	0.0013474	0.001058	0.0001595	0.0002429
19	0.0010893	0.0004623	0.84	0.7056	0.0007686	0.0004354	0.0003262	0.0002134
19.5	0.000152	0.0001495	0.82	0.6724	0.0001022	0.0006747	0.0001005	0.0001325
20	0.0019488	0.0002569	0.8	0.64	0.0012473	0.0015395	0.0001644	0.0003525
20.5	0.0030107	0.0008884	0.78	0.6084	0.0018317	0.0015212	0.0005405	0.0004191
21	0.0020961	0.0005152	0.76	0.5776	0.0012107	0.0023145	0.0002976	0.0008669
21.5	0.0062423	0.0026227	0.74	0.5476	0.0034183	0.0027385	0.0014362	0.0010756
22	0.0038633	0.0013416	0.73	0.5329	0.0020587	0.0021932	0.0007149	0.0007048
22.5	0.0046174	0.001378	0.71	0.5041	0.0023276	0.003051	0.0006946	0.0007579
23	0.0077026	0.0016758	0.7	0.49	0.0037743	0.0041683	0.0008212	0.0013797
23.5	0.0098667	0.0041917	0.68	0.4624	0.0045623	0.0031855	0.0019383	0.0012031
24	0.0040292	0.0010423	0.67	0.4489	0.0018087	0.0017824	0.0004679	0.0003602
24.5	0.0041567	0.0005976	0.65	0.4225	0.0017562	0.0023277	0.0002525	0.0008563
25	0.0070781	0.0035648	0.64	0.4096	0.0028992	0.00304	0.0014601	0.0014825
25.5	0.0080792	0.0038225	0.627451	0.3936947	0.0031807	0.0019748	0.0015049	0.0009919
26	0.0020301	0.0012644	0.6153846	0.3786982	0.0007688	0.0006333	0.0004788	0.0004843
26.5	0.0013657	0.0013433	0.6037736	0.3645425	0.0004979	0.0005131	0.0004897	0.000709
27	0.0015048	0.0026435	0.5925926	0.351166	0.0005284	0.0006776	0.0009283	0.000695
27.5	0.0024425	0.0013641	0.5818182	0.3385124	0.0008268	0.0015029	0.0004618	0.0008687
28	0.0066734	0.0039066	0.5714286	0.3265306	0.0021791	0.0018479	0.0012756	0.0010854
28.5	0.0048125	0.0028403	0.5614035	0.3151739	0.0015168	0.0011784	0.0008952	0.0006645
29	0.0027595	0.0014249	0.5517241	0.3043995	0.00084	0.0009904	0.0004337	0.000779
29.5	0.0038781	0.0038217	0.5423729	0.2941683	0.0011408	0.0008581	0.0011242	0.0009142
30	0.0020228	0.0024757	0.5333333	0.2844444	0.0005754	0.0005196	0.0007042	0.0006331
30.5	0.0016856	0.0020422	0.5245902	0.2751948	0.0004639	0.0010147	0.000562	0.0005204
31	0.0058771	0.0017973	0.516129	0.2663892	0.0015656	0.0016249	0.0004788	0.0005865
31.5	0.0065279	0.0026904	0.5079365	0.2579995	0.0016842	0.0014301	0.0006941	0.0006492
32	0.0047039	0.0024169	0.5	0.25	0.001176	0.0013319	0.0006042	0.0005583
32.5	0.0061391	0.0021137	0.4923077	0.2423669	0.0014879	0.00152	0.0005123	0.0004523
33	0.0066023	0.001669	0.4848485	0.2350781	0.001552	0.0014754	0.0003923	0.000416
33.5	0.0061317	0.0019272	0.4776119	0.2281132	0.0013987	0.0016717	0.0004396	0.0005387
34	0.0087817	0.0028797	0.4705882	0.2214533	0.0019447	0.0013434	0.0006377	0.0004303
34.5	0.0034505	0.0010361	0.4637681	0.2150809	0.0007421	0.0007176	0.0002228	0.0003042
35	0.0033164	0.0018448	0.4571429	0.2089796	0.0006931	0.0019057	0.0003855	0.0007515
35.5	0.0153507	0.0055013	0.4507042	0.2031343	0.0031183	0.0018301	0.0011175	0.0006523
36	0.002744	0.000947	0.4444444	0.1975309	0.000542	0.0005331	0.0001871	0.0001822
36.5	0.0027274	0.0009227	0.4383562	0.1921561	0.0005241	0.000789	0.0001773	0.0002457
37	0.0056359	0.0016799	0.4324324	0.1869978	0.0010539	0.0006654	0.0003141	0.0001847
37.5	0.0015208	0.0003037	0.4266667	0.1820444	0.0002769	0.0003747	5.528E-05	4.477E-05
38	0.0026651	0.0001932	0.4210526	0.1772853	0.0004725	0.0002422	3.426E-05	3.546E-05
38.5	6.878E-05	0.0002122	0.4155844	0.1727104	1.188E-05	0.0002839	3.666E-05	0.0001222
39	0.0033029	0.0012346	0.4102564	0.1683103	0.0005559	0.0003783	0.0002078	0.0001584
39.5	0.0012234	0.0006649	0.4050633	0.1640763	0.0002007	0.0005389	0.0001091	0.0002322
40	0.0054821	0.0022204	0.4	0.16	0.0008771	0.0007313	0.0003553	0.0002635
40.5	0.0037513	0.0011002	0.3950617	0.1560738	0.0005855	0.000441	0.0001717	0.0001294
41	0.0019473	0.0005722	0.3902439	0.1522903	0.0002965	0.0002882	8.714E-05	6.103E-05
41.5	0.0018827	0.000235	0.3855422	0.1486428	0.0002798	0.0004212	3.493E-05	0.0001424
42	0.0038759	0.0017214	0.3809524	0.1451247	0.0005625	0.0003499	0.0002498	0.0001494

42.5	0.0009682	0.0003456	0.3764706	0.1417301	0.0001372	0.0001311	4.898E-05	5.217E-05
43	0.0009025	0.0003999	0.372093	0.1384532	0.000125	0.0001904	5.536E-05	6.589E-05
43.5	0.0018915	0.0005648	0.3678161	0.1352887	0.0002559	0.0003038	7.642E-05	0.0001024
44	0.0026602	0.0009711	0.3636364	0.1322314	0.0003518	0.0003768	0.0001284	0.0001047
44.5	0.0031082	0.0006258	0.3595506	0.1292766	0.0004018	0.0002193	8.09E-05	5.477E-05
45	0.0002913	0.0002265	0.3555556	0.1264198	3.683E-05	7.838E-05	2.864E-05	3.674E-05
45.5	0.0009698	0.0003626	0.3516484	0.1236566	0.0001199	0.0001487	4.484E-05	4.634E-05
46	0.0014663	0.0003954	0.3478261	0.120983	0.0001774	0.0001152	4.783E-05	4.397E-05
46.5	0.0004481	0.0003388	0.344086	0.1183952	5.305E-05	0.0001064	4.011E-05	4.259E-05
47	0.0013789	0.000389	0.3404255	0.1158895	0.0001598	0.0001454	4.508E-05	3.724E-05
47.5	0.001155	0.0002591	0.3368421	0.1134626	0.0001311	0.0001443	2.94E-05	3.69E-05
48	0.0014173	0.0003996	0.3333333	0.1111111	0.0001575	0.000171	4.44E-05	2.788E-05
48.5	0.0016946	0.0001044	0.3298969	0.108832	0.0001844	0.0001917	1.136E-05	2.444E-05
49	0.0018669	0.0003519	0.3265306	0.1066222	0.0001991	0.0002149	3.752E-05	4.565E-05
49.5	0.002208	0.0005148	0.3232323	0.1044791	0.0002307	0.0001782	5.379E-05	0.0002132
50	0.0012279	0.0036382	0.32	0.1024	0.0001257	0.0001028	0.0003725	0.000197
50.5	0.000796	0.0002135	0.3168317	0.1003823	7.99E-05	0.0001083	2.143E-05	2.995E-05
51	0.0013892	0.0003908	0.3137255	0.0984237	0.0001367	8.667E-05	3.847E-05	3.344E-05
51.5	0.0003793	0.0002944	0.3106796	0.0965218	3.661E-05	6.768E-05	2.841E-05	2.539E-05
52	0.001043	0.0002363	0.3076923	0.0946746	9.875E-05	8.773E-05	2.237E-05	2.625E-05
52.5	0.000826	0.0003243	0.3047619	0.0928798	7.672E-05	7.438E-05	3.012E-05	4.359E-05
53	0.0007905	0.0006261	0.3018868	0.0911356	7.205E-05	7.302E-05	5.706E-05	4.292E-05
53.5	0.0008274	0.0003218	0.2990654	0.0894401	7.4E-05	5.837E-05	2.879E-05	3.318E-05
54	0.0004868	0.0004281	0.2962963	0.0877915	4.273E-05	5.543E-05	3.758E-05	4.352E-05
54.5	0.0007904	0.0005739	0.293578	0.086188	6.812E-05	7.288E-05	4.946E-05	4.275E-05
55	0.0009174	0.0004259	0.2909091	0.0846281	7.764E-05	8.721E-05	3.605E-05	3.721E-05
55.5	0.0011645	0.0004617	0.2882883	0.0831101	9.678E-05	8.164E-05	3.837E-05	3.754E-05
56	0.0008146	0.0004496	0.2857143	0.0816327	6.65E-05	6.183E-05	3.67E-05	3.392E-05
56.5	0.0007127	0.0003881	0.2831858	0.0801942	5.716E-05	5.744E-05	3.113E-05	4.087E-05
57	0.0007325	0.0006423	0.2807018	0.0787935	5.771E-05	5.076E-05	5.061E-05	4.1E-05
57.5	0.0005658	0.0004054	0.2782609	0.0774291	4.381E-05	3.074E-05	3.139E-05	2.048E-05
58	0.0002321	0.0001257	0.2758621	0.0760999	1.766E-05	2.108E-05	9.563E-06	2.342E-05
58.5	0.0003274	0.0004984	0.2735043	0.0748046	2.449E-05	5.487E-05	3.728E-05	2.469E-05
59	0.001159	0.0001646	0.2711864	0.0735421	8.524E-05	8.284E-05	1.21E-05	2.221E-05
59.5	0.0011125	0.0004469	0.2689076	0.0723113	8.044E-05	7.773E-05	3.231E-05	1.874E-05
60	0.001055	7.252E-05	0.2666667	0.0711111	7.502E-05	6.504E-05	5.157E-06	1.523E-05
60.5	0.0007871	0.0003619	0.2644628	0.0699406	5.505E-05	6.389E-05	2.531E-05	1.642E-05
61	0.0010572	0.0001094	0.2622951	0.0687987	7.274E-05	5.767E-05	7.527E-06	1.985E-05
61.5	0.0006295	0.0004755	0.2601626	0.0676846	4.261E-05	3.44E-05	3.218E-05	2.445E-05
62	0.0003934	0.0002511	0.2580645	0.0665973	2.62E-05	4.294E-05	1.672E-05	2.827E-05
62.5	0.0009106	0.0006075	0.256	0.065536	5.968E-05	5.517E-05	3.982E-05	2.188E-05
63	0.0007854	6.108E-05	0.2539683	0.0644999	5.066E-05	6.414E-05	3.939E-06	1.097E-05
63.5	0.0012227	0.0002835	0.2519685	0.0634881	7.763E-05	5.785E-05	1.8E-05	1.183E-05
64	0.000609	9.075E-05	0.25	0.0625	3.806E-05	3.505E-05	5.672E-06	3.764E-06
64.5	0.0005204	3.016E-05	0.248062	0.0615348	3.203E-05	2.677E-05	1.856E-06	8.23E-06
65	0.0003551	0.000241	0.2461538	0.0605917	2.152E-05	1.274E-05	1.46E-05	2.066E-05
65.5	6.628E-05	0.0004477	0.2442748	0.0596702	3.955E-06	3.611E-05	2.672E-05	2.859E-05
66	0.0011615	0.0005184	0.2424242	0.0587695	6.826E-05	4.59E-05	3.047E-05	3.038E-05
66.5	0.0004065	0.0005234	0.2406015	0.0578891	2.353E-05	1.821E-05	3.03E-05	2.081E-05
67	0.000226	0.0001987	0.238806	0.0570283	1.289E-05	3.1E-05	1.133E-05	1.931E-05
67.5	0.0008739	0.0004859	0.237037	0.0561866	4.91E-05	3.888E-05	2.73E-05	1.889E-05
68	0.0005177	0.0001894	0.2352941	0.0553633	2.866E-05	2.714E-05	1.049E-05	9.268E-06

68.5	0.0004695	0.0001475	0.2335766	0.054558	2.562E-05	1.849E-05	8.048E-06	1.56E-05
69	0.0002113	0.0004307	0.2318841	0.0537702	1.136E-05	1.512E-05	2.316E-05	1.842E-05
69.5	0.0003564	0.0002583	0.2302158	0.0529993	1.889E-05	2.018E-05	1.369E-05	1.175E-05
70	0.0004111	0.0001876	0.2285714	0.0522449	2.148E-05	2.388E-05	9.804E-06	8.424E-06
70.5	0.0005104	0.0001368	0.2269504	0.0515065	2.629E-05	1.791E-05	7.044E-06	1.451E-05
71	0.0001877	0.0004328	0.2253521	0.0507836	9.532E-06	1.189E-05	2.198E-05	1.539E-05
71.5	0.0002845	0.0001757	0.2237762	0.0500758	1.425E-05	8.931E-06	8.8E-06	1.418E-05
72	7.323E-05	0.000396	0.2222222	0.0493827	3.616E-06	1.287E-05	1.955E-05	1.692E-05
72.5	0.0004543	0.0002934	0.2206897	0.0487039	2.213E-05	2.117E-05	1.429E-05	9.846E-06
73	0.0004209	0.0001124	0.2191781	0.048039	2.022E-05	1.71E-05	5.4E-06	1.145E-05
73.5	0.0002952	0.0003694	0.2176871	0.0473877	1.399E-05	1.7E-05	1.751E-05	2.198E-05
74	0.000428	0.000566	0.2162162	0.0467495	2.001E-05	1.743E-05	2.646E-05	1.89E-05
74.5	0.0003222	0.0002457	0.2147651	0.046124	1.486E-05	2.154E-05	1.133E-05	1.215E-05
75	0.00062	0.0002851	0.2133333	0.0455111	2.822E-05	1.603E-05	1.297E-05	1.636E-05
75.5	8.561E-05	0.0004395	0.2119205	0.0449103	3.845E-06	1.036E-05	1.974E-05	2.091E-05
76	0.000381	0.000498	0.2105263	0.0443213	1.688E-05	2.624E-05	2.207E-05	2.026E-05
76.5	0.0008136	0.0004216	0.2091503	0.0437439	3.559E-05	2.403E-05	1.844E-05	2.028E-05
77	0.0002886	0.000512	0.2077922	0.0431776	1.246E-05	7.966E-06	2.211E-05	2.427E-05
77.5	8.138E-05	0.0006204	0.2064516	0.0426223	3.469E-06	8.369E-06	2.644E-05	1.716E-05
78	0.0003154	0.0001872	0.2051282	0.0420776	1.327E-05	8.654E-06	7.878E-06	9.006E-06
78.5	9.722E-05	0.0002439	0.2038217	0.0415433	4.039E-06	6.809E-06	1.013E-05	1.148E-05
79	0.0002335	0.0003126	0.2025316	0.0410191	9.58E-06	1.116E-05	1.282E-05	1.268E-05
79.5	0.0003144	0.0003096	0.2012579	0.0405047	1.273E-05	2.091E-05	1.254E-05	1.694E-05
80	0.0007274	0.0005334	0.2	0.04	2.91E-05		2.134E-05	
80.5	0.0003603	0.0004459				0.1608164		0.1332261

SEAT = $(0.1332261/0.1608164)^{1/2}$ X 100% = 91.02%

Table D5: Example of SEAT calculation (Laboratory dynamic test)

Frequency	Gf	Gs	Transmissibility	W_b	W_b^2	$G_{ff}W_b^2$	$G_{ff}W_b^2$	$G_{ss}W_b^2$	$G_{ss}W_b^2$
1	4.84	3.6	0.743801653	0.4	0.16	0.7744	0.936	0.576	0.6928
1.5	6.86	5.06	0.737609329	0.4	0.16	1.0976	2.1648	0.8096	1.6208
2	20.2	15.2	0.752475248	0.4	0.16	3.232	5.6285	2.432	4.516
2.5	32.1	26.4	0.822429907	0.5	0.25	8.025	14.3805	6.6	13.092
3	57.6	54.4	0.944444444	0.6	0.36	20.736	29.8945	19.584	30.2985
3.5	79.7	83.7	1.050188206	0.7	0.49	39.053	52.8065	41.013	59.8665
4	104	123	1.182692308	0.8	0.64	66.56	89.78	78.72	98.86
5	113	119	1.053097345	1	1	113	117	119	97.35
6	121	75.7	0.625619835	1	1	121	150.5	75.7	64.9
7	180	54.1	0.300555556	1	1	180	260	54.1	86.05
8	340	118	0.347058824	1	1	340	305.5	118	131.5
9	271	145	0.535055351	1	1	271	259	145	139
10	247	133	0.538461538	1	1	247		133	
							1287.591		727.7466

SEAT = $(727.7466/1287.591)^{1/2}$ X 100% = 75.18%

Table D6: Asymptotic frequency weighting, W(f), used to assess vibration discomfort (f, frequency of vibration, Hz; W(f)=0 where not otherwise defined)

Input	Axis	Frequency weighting	Axis multiplying factor	Weighting, $W(f)$
Seat	x	W_d	1.00	$0.5 < f < 2.0$ $W(f) = 1.00$ $2.0 < f < 80.0$ $W(f) = 2.0/f$
	y	W_d	1.00	$0.5 < f < 2.0$ $W(f) = 1.00$ $2.0 < f < 80.0$ $W(f) = 2.0/f$
	z	W_b	1.00	$0.5 < f < 2.0$ $W(f) = 0.4$ $2.0 < f < 5.0$ $W(f) = f/5.00$ $5.0 < f < 16.0$ $W(f) = 1.00$ $16.0 < f < 80.0$ $W(f) = 16.0/f$
	r_x	W_e	0.63	$0.5 < f < 1.0$ $W(f) = 0.63$ $1.0 < f < 20.0$ $W(f) = 0.63/f$
	r_y	W_e	0.40	$0.5 < f < 1.0$ $W(f) = 0.4$ $1.0 < f < 20.0$ $W(f) = 0.4/f$
	r_z	W_e	0.20	$0.5 < f < 1.0$ $W(f) = 0.2$ $1.0 < f < 20.0$ $W(f) = 0.2/f$
Back	x	W_c	0.80	$0.5 < f < 8.0$ $W(f) = 0.8$ $8.0 < f < 80.0$ $W(f) = 6.4/f$
	y	W_d	0.50	$0.5 < f < 2.0$ $W(f) = 0.5$ $2.0 < f < 80.0$ $W(f) = 1.0/f$
	z	W_d	0.40	$0.5 < f < 2.0$ $W(f) = 0.4$ $2.0 < f < 80.0$ $W(f) = 0.8/f$
Feet	x and y	W_b	0.25	$0.5 < f < 2.0$ $W(f) = 0.1$ $2.0 < f < 5.0$ $W(f) = f/20.0$ $5.0 < f < 16.0$ $W(f) = 0.25$ $16.0 < f < 80.0$ $W(f) = 4.0/f$
	z	W_b	0.40	$0.5 < f < 2.0$ $W(f) = 0.16$ $2.0 < f < 5.0$ $W(f) = f/12.5$ $5.0 < f < 16.0$ $W(f) = 0.4$ $16.0 < f < 80.0$ $W(f) = 6.4/f$

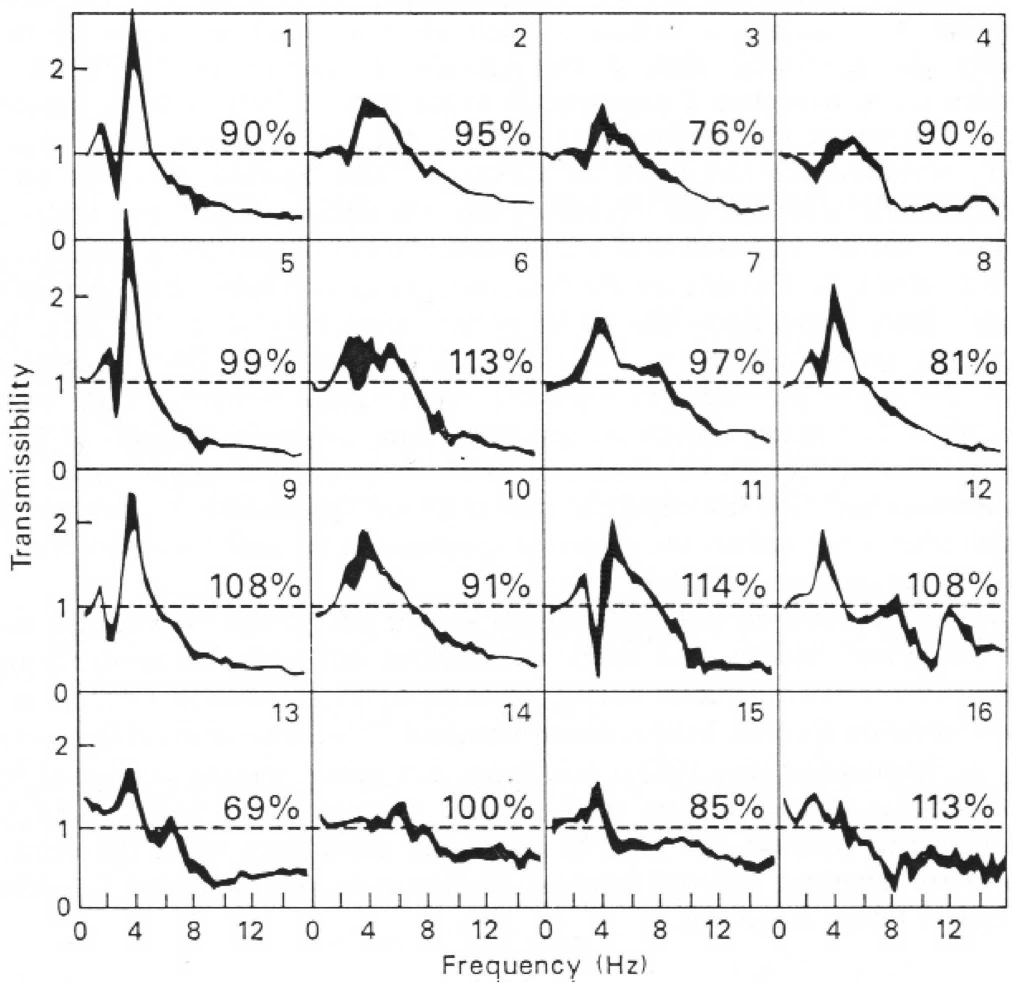


Figure D1: Vertical (z- axis) seat transmissibilities and SEAT values in 16 vehicles (1-11, cars, estates and van; 12, light bus;13, double-deck bus; 14, truck; 15, single-deck bus; 16, train) Black bands indicate 10% to 90% confidence intervals. Data from Griffin (1978)

Table D7: Causes of seating discomfort (Viano and Andrzejak, 1992)

Human experience Mode	Biomechanical		Seat/environment
	Physiology causes	Engineering causes	Source
Pain	Circulation occlusion	Pressure	Cushion stiffness
Pain	Ischemia	Pressure	Cushion stiffness
Pain	Nerve occlusion	Pressure	Seat contour
Discomfort	—	Vibration	Vehicle ride
Perspiration	Heat	Material breathability	Vinyl upholstery
Perception	Visual/auditory tactile	Design/vibration	Vehicle cost

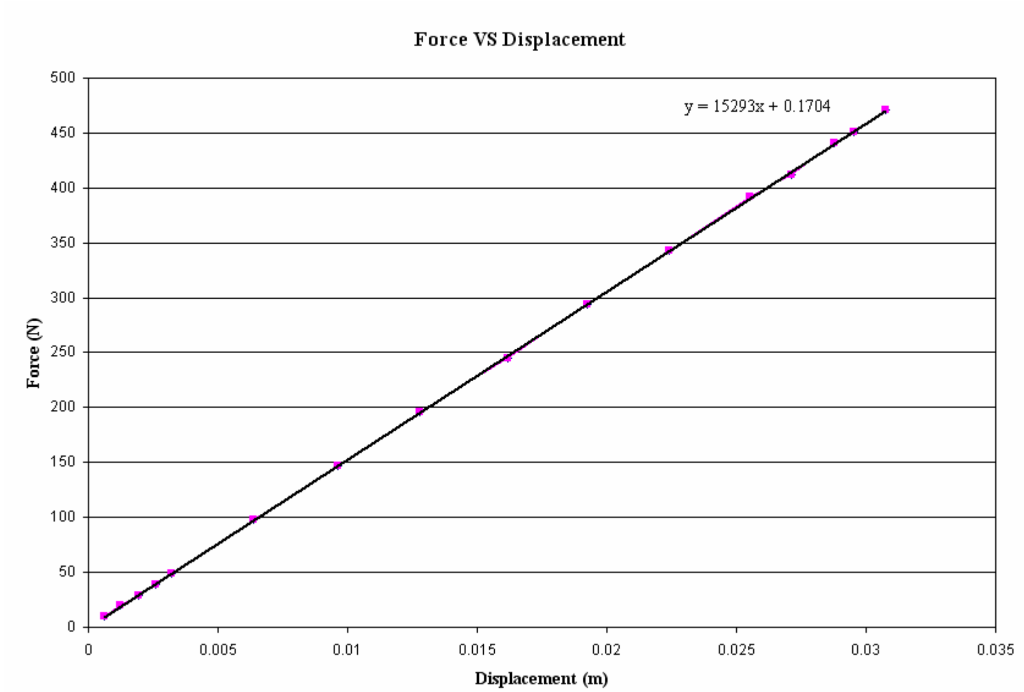


Figure D2: Spring property, k, for improved seat structure without absorbers; k=15293 N/m

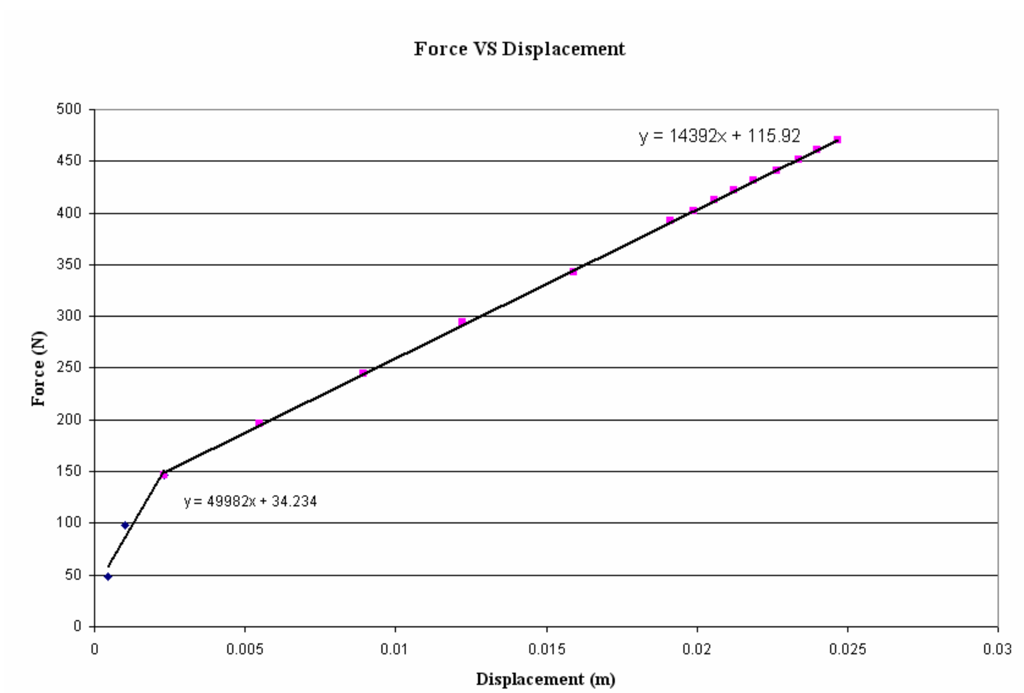


Figure D3: Spring property, k, for improved seat structure with absorbers; k_1 = 49982N/m, k_2 = 14392N/m