# Ergonomic Design of Passenger Seat Supporting Frame in Urban Bus for Minimum Induced Strain and Fatigue

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**Abstract.** Urban bus act as a major transportation source for human population. Seat supporting frame is one of the important components of the bus which provides support for human weight. Currently, the supporting frame structure causes knee strain to the passenger sitting at the rear side of the seat. The aim of this research work is to improve the ergonomics design of the bus seat support frame in order to reduce bus passenger knee strain. The anthropometry data of passenger relevant to the ergonomic suitability of seat include seat depth, seat height, seat side clearance and support frame dimensions were measured. The passenger anthropometry variable includes buttock-knee length, sitting height,etc. RULA (Rapid Upper Limb Assessment) analysis was carried out for 95th percentile. Based on RULA analysis, alternate concepts are formed based on feasibility. For the selected concept, modelling and finite element analysis was carried out under various loading conditions. Based on the analysis results, optimum design was determined. Accordingly proof of concept prototype will be developed.

**Keywords:** Ergonomics, Knee strain, RULA analysis, Finite element analysis, Prototype.

## 1 Introduction

Seat support frame is one of the important components of the bus. The objective of the research work is to improve the ergonomics design of the bus seat support, so that it will reduce bus passenger knee injuries. The development work will starts from conceptual design, since it is the backbone for ergonomic design and analysis,[1]. The new concept development generally carried out based on the existing product in the market.

Bus is one of the most popular mode of transportation. The urban buses are locally built and used for public transportation. The seat supporting support was designed in such that it supports the seat properly but this informal design of seat support need ergonomic consideration [2].Ergonomics deals with interaction among human and surrounding and the variables that influence that interaction and it can be done in an efficient manner [3]. Excising system can be improved by a) Designing the user-interface to be compatible with activity and user, b) Changing the work environment for safe and appropriate for the task and c) Modification of task for compatible with user characteristics.

The best concept that fulfill the requirements of bus seat support frame are chosen for the final design of the project. Rapid Upper Limb Assessment (RULA) analysis is helpful in determining how a person sits comfortable in an area. Range of motion normally involved in human being are taken into consideration[4]. During long hours of travel, more stress on the

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body parts like neck, lower back and knee in which knee experiences more stress due to frequent contact on the surrounding area [5]. By improving the seat support frame design, the injury or strain caused due to impact on knee against the supporting frame will be minimized.

In general, bus passengers feels more stain and discomfort in an ordinary bus over a long journey. Especially passenger sitting near window seat is directly exposed to knee strain or injury by means of support frame in the seat. In order to enhance strength and load carrying capacity, twisted frame structure is used than a flat frame to support the seat[6].

## 2 Methodology

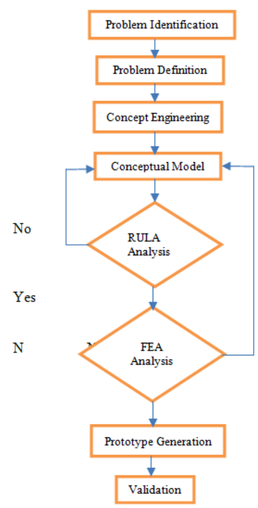



Fig. 1. Methodology for ergonomic design of seat support frame

It is clearly visible that the present design causes knee injury for the passenger. This problem can be solved by redesigning the supporting structure in such a way that it possess the same strength and at the same time it also provide comfort for the bus passengers travelling in urban bus for a long distance. Hence in this work an attempt has been made to perform ergonomic analysis on the proposed model for minimum induced strain.

The proposed methodology for the ergonomic redesign of seat support frame as shown in figure 1. At first market study was carried out on the existing design of seat frame support in the urban bus related patents and journals and industrial trade magazines. The proposed should enable the user to sit in a comfortable position. The optimized conceptual model will be analyzed in CATIA - ergonomics module. Based on the RULA analysis, the decision on acceptance of the proposed model will be carried out. Further FEA analysis on the accepted model will be performed to analyze the effect of the conceptual model under varying loading conditions.

The FEA analysis yields the stress induced in the conceptual frame. The induced stress compared with the stress on the existing frame. It is clear that the new frame must withstand the stress acting on it. If the proposed the concept fails to meet the requirements, the steps need to be repeated again with new modifications in the conceptual design. After successful analysis, appropriate prototype will be created and will be validated in real-time environment.

## 3 Conceptual Design

Various Conceptual design were created in order to understand and interpret the details about the seat support frame. It is clear that the developed concept should have the capability to overcome difficulties with the existing twisted seat support frame. Various concepts were created by replacing the positions of twists in the supporting frame and also ‘I’ section with rips are used in redesign of seat supporting frame.

Fig. 2. Model with twists at both the ends

In the existing conceptual design of seat support frame, twist is presented in the middle. Here the position of twist is placed in both ends and also placed in different orientation as shown in figure 2. Frame is welded to the seat at one end and bolted at the bottom.

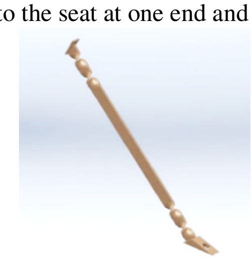


Fig. 3. Model with double twists at the top and bottom

In this concept, double twist are placed at both ends and also placed in different orientation as shown in figure 3. Frame is welded to the seat at one end and bolted at the bottom side.

Fig. 4.Model with one twists at the top and multiple twists at the bottom

In this concept, double twist present at the bottom and one twist at the top as shown in figure 4. Frame is welded to the seat at one end and bolted at the bottom.

Fig. 5.Model with one twists at the top and two twists the bottom

In this concept, multiple twists are present at the bottom and one twist is at the top as shown in figure 5. Frame is welded to the seat at one end and bolted at the bottom.

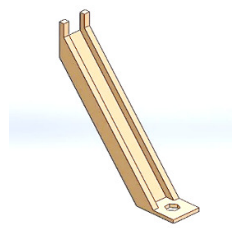


Fig. 6. ‘I’- section model to support the seat

In this concept, ‘I’ section structure is used to support the seat as shown in figure 6. Frame is welded to the seat at one end and bolted at the bottom.

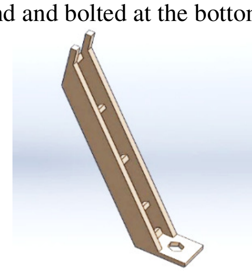


Fig. 7 ‘I’- section model with ribs

In this concept, ‘I’ section structure with ribs as shown in figure 7 is used to support the seat structure. Frame is welded to the seat at one end and bolted at the bottom.

Fig. 8. ‘I’- Section model with cross ribs

In this concept, ‘I’ section structure with cross ribs as shown in figure 8 is used to support the seat structure. Frame is welded to the seat at one end and bolted at the bottom.

## 4 Numerical Analysis

Rapid Upper Limb Assessment (RULA) analysis was carried out in CATIA package and score for the body at different regions include upper arm, lower arm, wrist, neck, trunk, and legs are obtained [7]. The score indicates the risk of Musculoskeletal Disorders (MSD). MSDs are injuries and disorders that affect the human body's movement or musculoskeletal system. The analysis was carried out under various sitting posture conditions.

**Table I RULA Score**

| Score | Level of Risk |
|---|---|
| 1-2 | Negligible risk |
| 3-4 | Low risk |
| 5-6 | Medium risk |
| 6 and above | Very high risk |

Posture which has high level of risk need to evaluated first. Importance should be given for higher level of score.

**A. Rapid Upper Limb Assessment Analysis**

The sitting posture of the bus passenger based on 95th percentile was analyzed [8]. These postures are adopted by the passenger in order to avoid the knee impact against the seat support frame. Passenger will bend and move their knee away from the seat support frame to avoid the impact which results in inconvenient postures which causes pain in neck, shoulder, lower back region, buttock and knee.

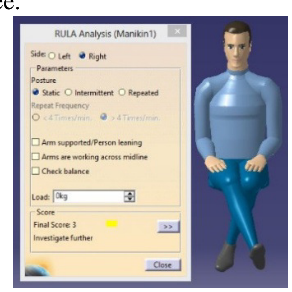


Fig. 9. Posture 1

Passenger sitting with cross legs as shown in figure 9 is to avoid the knee impact against the supporting frame will have score of 3. It shows the posture that should be investigated further.

Fig. 10.Posture 2

Passenger sitting with lifted legs as shown in figure 10 is to avoid the knee impact against the supporting frame will have score of 4. It shows the posture that should be investigated further.

Fig. 11Posture 3

Passenger sitting with straight back and crossed legs as shown in figure 11 is to avoid the knee impact against the supporting frame will have score of 3 which shows the posture needs further investigations.

Fig. 12. Postue 4

Passenger sitting with partially twisted shoulder and crossed legs as shown in figure 12 is to avoid the knee impact against the supporting frame will have score of 5 which shows the posture should be investigated further and should be changed immediately.

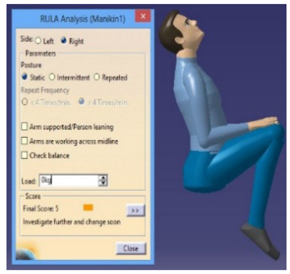



Fig. 13Posture 5

Passenger sitting with lifted legs as shown in figure 13 is to avoid the knee impact against the supporting frame and raising the head up will have score of 5 which shows the posture should be investigated further and should be changed soon.

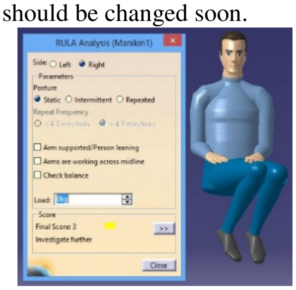



Fig. 14.Posture 6

Passenger sitting with straight back and bended legs as shown in figure 14 is to avoid the knee impact against the supporting frame will have score of 3 which shows the posture should be investigated further.

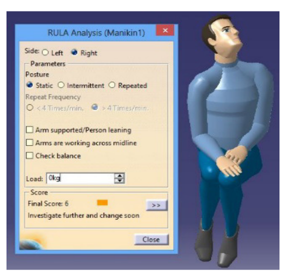



Fig. 15.Posture 7

Passenger sitting with partially twisted shoulder and crossed legs as shown in figure 15 is to avoid the knee impact against the supporting frame and head tilted up will have score of 6 which shows the posture should be investigated further and should be changed soon.


Fig. 16.Posture 8

Passenger sitting with partially twisted shoulder and crossed legs as shown in figure 16 is to avoid the knee impact against the supporting frame will have score of 3 which shows the posture should be investigated further.

**B.Analysis for Existing Flat and Twisted Support Frame**

The boundary conditions applied for the existing flat and twisted frame support and static analysis was carried out for carbon steel and stainless steel material,[9 & 10].

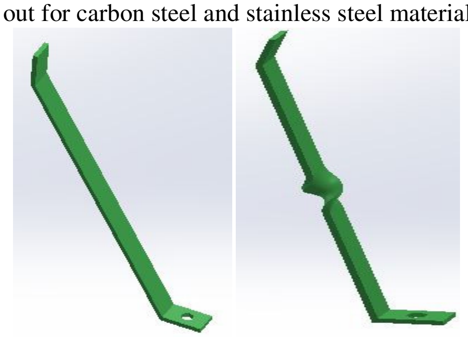


Fig. 17.Cad model of a flat and twisted structure.

- The top portion which support the seat will be welded
- Load of 300 kg is applied on this welded structure

300 kg x 9.81 = 2943 N

Area of seat = 0.001 $m^2$

Pressure = 2943 / 0.001 =2943000 $N/m^2$ is applied

- The bottom portion of the structure bolted

**C.Analysis for Existing Structure**

Static analysis was carried out for low carbon steel with twisted structure

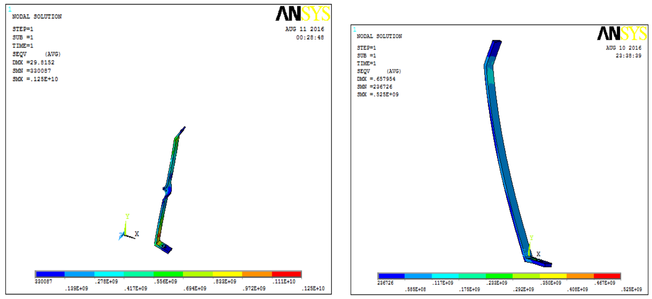
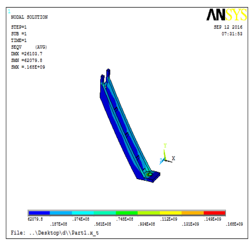
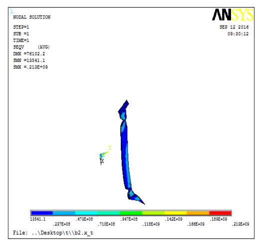


Fig. 18.Low carbon steel twist structure

Maximum deformation and stress were determined for twisted low carbon steel with twisted surface. The values are mentioned in the Table II. Static analysis was carried out for low carbon steel with flat structure.



Maximum stress : 0.21 GPa
Displacement: 7.6 mm
Fig. 21. Concept of Model



Maximum stress :0.09 GPa
Displacement : 3.8 mm
Fig. 22. Concept of I- section

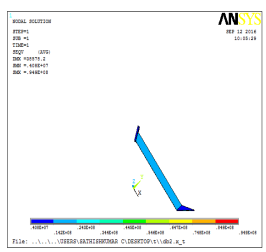


Fig. 19.Low carbon steel flat structure

Maximum deformation and stress were determined for low carbon steel with flat surface. The values are mentioned in the Table II.

Static analysis was carried out for Stainless steel with both twisted and flat structure.

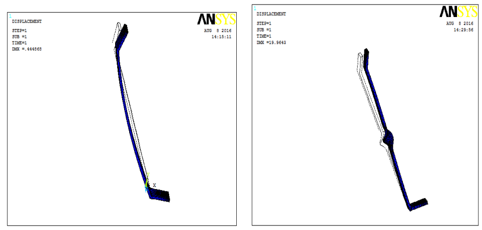
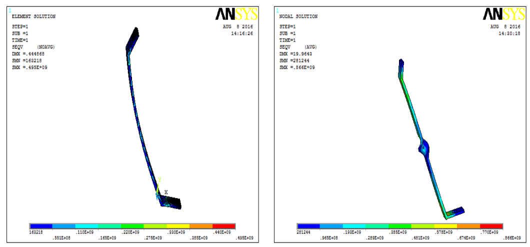


Fig. 23.Concept of I- section
Deformed Model



Maximum stress : 0.168 GPa          Maximum stress :0.172 GPa
Displacement : 3.8 mm          Displacement : 2.1 mm

Fig. 24. Concept of I- section model with ribs model with cross ribs

From the analysis, conceptual design -6 has been chosen as the optimum design among the alternatives.

## 5 Conclusions

In this work, an attempt has been made to perform ergonomic redesign of passenger seat supporting frame. Different concepts were developed by considering various factors. Further RULA analysis was carried out to determine the effects of various postures on human comfort. Selected concept suitability was determined by FEA. It is observed that the I-section concept with rib shown in figure 25 is the optimum one for given functional and comfort requirments.

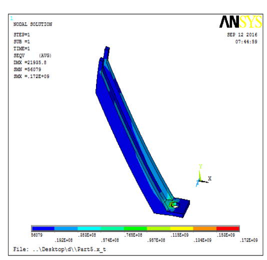


Fig. 20.Low carbon steel twist structure

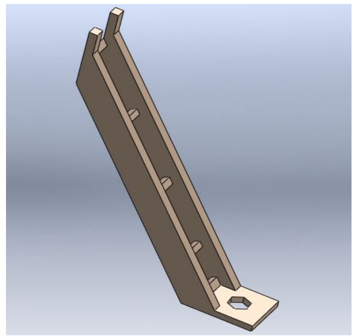


Fig. 25.Selected Final Design after Numerical Analysis

**Table 2 Result for Existing Design**

| No | Product requirement | weight | Concept 1 | | Concept 2 | | Concept 3 | | Concept 4 | | Concept 5 | | Concept 6 | | Concept 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | s | v | s | v | s | V | S | v | s | v | s | v | s | v |
| 1 | Material | 0.15 | 2 | 0.30 | 2 | 0.30 | 2 | 0.30 | 2 | 0.30 | 2 | 0.30 | 2 | 0.30 | 2 | 0.30 |
| 2 | Reliable | 0.25 | 2 | 0.50 | 2 | 0.50 | 2 | 0.50 | 2 | 0.50 | 3 | 0.75 | 4 | 1.00 | 4 | 1.00 |
| 3 | Weight | 0.10 | 4 | 0.40 | 4 | 0.40 | 3 | 0.30 | 2 | 0.20 | 4 | 0.40 | 5 | 0.50 | 2 | 0.20 |
| 4 | Strength | 0.30 | 3 | 0.90 | 3 | 0.90 | 2 | 0.60 | 2 | 0.60 | 5 | 1.50 | 5 | 1.50 | 5 | 1.50 |
| 5 | Design | 0.20 | 3 | 0.60 | 2 | 0.40 | 2 | 0.40 | 2 | 0.40 | 3 | 0.60 | 4 | 0.80 | 5 | 1.00 |
| | Total value | 1.00 | | 2.70 | | 2.50 | | 2.10 | | 2.00 | | 3.55 | | 4.10 | | 4.00 |

**Table 3 Weighted Matrix**

| Properties of Materials | Low Carbon Steel (Flat) | Low Carbon Steel (Twisted) | Stainless Steel (Flat) | Stainless Steel (Twisted) |
|---|---|---|---|---|
| Youngs modulus (E) GPa | 198 | 198 | 198 | 198 |
| Poission ratio | 0.275 | 0.275 | 0.289 | 0.289 |
| Pressure applied (P) $N/m^2$ | 2943000 | 2943000 | 2943000 | 2943000 |
| Max.stressGPa | 0.525 | 1.25 | 0.495 | 0.866 |
| Displacement mm | 6.57954 | 2.98152 | 4.44868 | 1.99643 |

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