Design of Modular Fixture for Manufacturing Bishoftu Bus Chassis Frame: A Case Study at Bishoftu Automotive and Locomotive Industry Assembly Plant

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Abstract: Ethiopia doesn’t manufacture any vehicle, it imports all the automotive needs from foreign. Recently some Ethiopian companies started to import engines, body structures and spare parts, and assemble locally in collaboration with the exporting foreign industries. Bishoftu Automotive and Locomotive industry (BALI) is one of the industries that imports and assemble the city bus in collaboration with the China’s Huwangai bus company. At this moment even though the industry assemble and distribute the city buses and other vehicles to its customer efficiently, there are some problems seen in the industry, such as:
1. Parts import with partially assembled are distorted during loading and unloading so that maintenance of these parts need extra cost.
2. Since the width of the Chassis is greater than the width of the container during shipping, the end supports of the Chassis are cut off about 8 cm lengths from both sides. Reassembling of these cut parts took almost half of the manufacturing time of the full Chassis.
3. Fear of cost increment by the exporting company.
4. Since the structures import in lot, it has an impact on less quantity orders.
5. To some extent there is limitation in looking forward for modification and improvement.

To solve the above problems this study suggests to design modular fixture to manufacture the bus Chassis Frame locally. Materials for fixture manufacturing are selected through scientific methods considering availability, cost and mechanical properties. Design analysis of the fixture elements are made both geometrically and mathematically in detail.

Keywords: BALI, Chassis, Fixture, Design, Huwangai and Modular.

I. INTRODUCTION

Ethiopia, being one of the developing countries, requires continuous improvement in all sectors, namely agriculture, manufacturing and service sectors. Since Ethiopia doesn’t manufacture vehicles, construction machineries and agricultural equipments locally at present, it imports those from various countries of the world. Some companies only assemble and build bodies of buses, dry and wet cargo on chassis imported with cab. Automobiles importing companies in Ethiopia are importing different types of vehicles to the country’s vehicle market. With the on-going expansion of road construction and consequent increase in access to roads, the demand for vehicles shall also grow significantly. Similarly the possibility of manufacturing related item locally is an important task to build the capacity of local industries and to enhance their role in national economy building.

Currently Bishoftu Automotive and Locomotive industry is working jointly with the China Huwangai bus company in the assembly department. The two companies were agreed to import all the parts of the bus (viz, chassis, body frames sheets for covers, engines and other spare parts) from china and assemble it at Bishoftu Automotive and Locomotive industry assembly plant.

The main objective of this study is to design modular fixture for manufacturing Bishoftu bus chassis frame at Bishoftu Automotive and Locomotive industry assembly plant.
To produce duplicated Chassis frames with better quality and quantity within short time the use of either jig or fixture is significantly important. As Dr EDWARD G.HOFFMAN, states that Jigs and fixtures are production-work holding devices used to manufacture duplicate parts accurately [1]. A jig or fixture is designed and built to hold, support, and locate every part to ensure that each is drilled, machined or welded within the specified limits. Jigs and fixtures are so closely related that the terms are sometimes confused or used interchangeably. The difference is in the way the tool is guided to the workpiece.

Fixtures are normally designed for a definite operation to process a specific workpiece and are designed and manufactured individually. Fixtures were develop for job, batch and mass productions, which are widely used in manufacturing operations locate and hold a part firmly in position so that the required manufacturing process can be carried out according to design specifications.

Fixtures can be generally divided into two categories [1, 2]:

I. Dedicated fixtures
II. Modular fixtures

Fixtures are desired to be reconfigurable, immediate, simple, and cheap (RISC). To date, the most popular RISC fixturing system is the modular fixture [3–7]. Modular fixtures are composed of standard fixture components such as standard locators, clamps, supports and base-plates that can be assembled into a variety of configurations for different workpieces and used in low-volume production applications [8].

In addition to the primary requirements in fixture design, many other demands also found, such as ensuring productivity through easy load and unload of the work piece, utilization of automated or clamping semi automated devices. Special design for reducing formation of weak rigidly parts, simple and safe operation and effective cost reduction.

II. METHODS AND MATERIALS

2.1. Methodology
At the early stages of the thesis work, a basic understanding of the plant and the operations were achieved through first hand observations of on the site. Based on the information assessed from different sources the following methodology is set to carry out the thesis. Information are gathered from both primary and secondary data sources. From the primary data sources interviews and direct observations on the site are the main once, and form secondary data sources books, brochures, drawings came with the product and other relevant sources essential for the thesis are used.

The main data for study obtained from drawings came with sub-assemblies and direct observation of the Chassis frame. Such data's includes dimensions, features, Chassis materials, and assembly methods which are used as a ground for the analysis of the thesis work. The data type used is both quantitative and qualitative data. The qualitative data includes size of the parts, quantity required, No of manufacturers, manufacturing time, etc. and the qualitative data includes tolerances for dimensional accuracy, type of materials used, assembly methods such as welding, riveting and bolt and nut system etc. The data required for the study is identified and collected by communicating different staff members of BALI. Once sufficient information's have been gained, a comprehensive back ground was written.

2.2 Material selection for fixture
The material properties usually are formalized through performance specification and product specifications. Performance specifications delineate the basic functional requirements of the product and set out the basic parameters from which the design can be developed. They are based on the need the product is intended to satisfy and an evaluation of the likely risk and consequence of failure. Product specifications define conditions under which the components of the designs are purchased or
manufactured. The fixture material selection is carried out using digital logic method to achieve the weighting factors and decision matrix strategy as shown in table 2.1. The main requirements during the material selection are: Toughness, thermal expansion, availability, specific heat, yield strength, density and lower cost [9].

2.2.1 The logic approach of rank ordering
- Each design criteria is listed and is compared to every other criteria, two at a time. In making the comparison the property that is considered the more important of the two is given 1 and the less important property is given 0.
- The total number of possible combinations is \( N = n (n-1)/2 \), where \( n \) is the number of criteria’s under consideration.
- Weighting factor for each criteria = total row/15, for example for toughness \( W_T = 3/15 = 0.2 \) and the same procedures for the rest criteria.

### Table 2.1 Determination of weighting factors using digital logic method

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Toughness</th>
<th>Thermal expansion</th>
<th>Availability</th>
<th>Specific heat</th>
<th>Yield strength</th>
<th>Density</th>
<th>Row total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toughness</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>1</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Availability</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Specific heat</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Yield strength</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Density</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

Highest mechanical properties are desirable and highest values in toughness, yield strength, specific heat and availability are given 100 and others rated in proportion. Lower values of thermal expansion and density are desirable. Accordingly lowest values were considered as 100 and other values rated in proportion as indicated in table 2.2 and table 2.3.

The scaled material properties are multiplied by the weighting factors to achieve the scaled performance index as indicated in table 2.4. The performance index shows the technical capability of the material without regard to the cost. Cost can be considered as one of the properties and given appropriate weighting factor. However, if there are a large number of properties to consider, the importance of cost may be emphasized by considering it separately as a modifier to the material performance index as shown in table 2.5.

### Table 2.2 Properties of candidate materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Toughness (Mpa/(\sqrt{m}))</th>
<th>Yield strength (Mpa)</th>
<th>thermal expansion ((10^{6} , ^{0}\text{C}^{-1}))</th>
<th>Specific heat (J/kg-k)</th>
<th>Density (kg/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel alloy 1020</td>
<td>54</td>
<td>210</td>
<td>11.7</td>
<td>486(^a)</td>
<td>7.85</td>
</tr>
<tr>
<td>Steel alloy 1040</td>
<td>54</td>
<td>290</td>
<td>11.3</td>
<td>486(^a)</td>
<td>7.85</td>
</tr>
<tr>
<td>Steel alloy 4140</td>
<td>60</td>
<td>417</td>
<td>12.3</td>
<td>486(^a)</td>
<td>7.85</td>
</tr>
<tr>
<td>Stainless alloy 304</td>
<td>76</td>
<td>515</td>
<td>17.2</td>
<td>500</td>
<td>8.00</td>
</tr>
<tr>
<td>Al alloy 1100</td>
<td>44</td>
<td>34</td>
<td>23.3</td>
<td>904</td>
<td>2.71</td>
</tr>
</tbody>
</table>
Table 2.3 Scaled properties and performance index

<table>
<thead>
<tr>
<th>Material</th>
<th>Scaled properties</th>
<th>Performance index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>toughness</td>
<td>Yield strength</td>
</tr>
<tr>
<td>Steel alloy 1020</td>
<td>71</td>
<td>40.8</td>
</tr>
<tr>
<td>Steel alloy 1040</td>
<td>71</td>
<td>56.3</td>
</tr>
<tr>
<td>Steel alloy 4140</td>
<td>79</td>
<td>81</td>
</tr>
<tr>
<td>Stainless alloy 304</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Al alloy 1100</td>
<td>57.9</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Table 2.4 Scaled properties multiplied by weighting factors and performance index

<table>
<thead>
<tr>
<th>Material</th>
<th>Weighted scaled properties</th>
<th>Performance index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Toughness *0.2</td>
<td>Yield strength *0.27</td>
</tr>
<tr>
<td>Steel alloy 1020</td>
<td>14.2</td>
<td>11.02</td>
</tr>
<tr>
<td>Steel alloy 1040</td>
<td>14.2</td>
<td>15.20</td>
</tr>
<tr>
<td>Steel alloy 4140</td>
<td>15.8</td>
<td>21.87</td>
</tr>
<tr>
<td>Stainless alloy 304</td>
<td>20</td>
<td>27</td>
</tr>
<tr>
<td>Al alloy 1100</td>
<td>11.9</td>
<td>1.78</td>
</tr>
</tbody>
</table>

Table 2.5 Cost, figure of merit and ranking of candidate materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative cost (Birr/kg)</th>
<th>Cost of unit strength*100</th>
<th>Performance index</th>
<th>Figure of merit</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel alloy 1020</td>
<td>20</td>
<td>0.75</td>
<td>83.1</td>
<td>0.53</td>
<td>1</td>
</tr>
<tr>
<td>Steel alloy 1040</td>
<td>23</td>
<td>0.62</td>
<td>86.12</td>
<td>0.48</td>
<td>2</td>
</tr>
<tr>
<td>Steel alloy 4140</td>
<td>40</td>
<td>0.57</td>
<td>97.33</td>
<td>0.31</td>
<td>4</td>
</tr>
<tr>
<td>Stainless alloy 304</td>
<td>50</td>
<td>0.78</td>
<td>121.33</td>
<td>0.30</td>
<td>5</td>
</tr>
<tr>
<td>Al alloy 1100</td>
<td>75</td>
<td>4.78</td>
<td>95.73</td>
<td>0.47</td>
<td>3</td>
</tr>
</tbody>
</table>

Cost of unit strength = c x p/s where, c is cost per unit weight, p is density and s is yield strength. For example, cost of unit strength (steel 1020) = 20 X 7.85/210 = 0.75, and so on for the rest.

Figure of merit, M for the material can be defined as M = y/c x p where, c = cost of the material per unit weight, p = density of the material and y = performance index. For example, for steel 1020, M = 111/ (20 X 7.85) = 0.71 and so on for the rest.

Based on the above analysis steel alloy 1020 is the optimum material to manufacture the fixture. Since more yield strength is required on the support structures, flat irons, steel alloy 1040 is used instead. The rest structural frames are steel alloy 1020.
III. RESULT AND DISCUSSION

In response of the problems stated above, this study suggests to design for modular fixture to manufacture the chassis frame at Bishoftu Automotive and Locomotive industry by local professionals. Due to the nature of flexibility of modular fixtures, the designed fixture enables to produce not only the bus chassis but also other chassis with various sizes and shapes. The design of the fixture incorporates tremendous tasks such as:

- Design of locators, clamps, supports, and drawing the fixture out line
- Restraining degrees of freedoms of Chassis frames
- Design analysis of the fixture elements

3.1 Design considerations

Design of the fixture is required to manufacture a Chassis frame with overall dimensions of 2.4m x 11.72m. The Chassis frame going to be produce is illustrated below in figure 3.1.

![Figure 3.1 3D views a Chassis frame to be manufacture](image)

3.1.1 Analysis of the possible loads on the fixture

The possible loads exist on the fixture are weight of the Chassis and weight of two average men. The Chassis is made of steel 60mm x 180mm x 8mm rectangular hollow section (RHS) with different lengths as indicated in figure 3.2. The weight of Chassis structures such as main frames, cross bars and end supports, are analyzed as follows, all slots and holes on the Chassis frame are neglected.

Chassis weight, \( w_{ch} = w_{mf} + \ w_{cb} + w_{es} \)--------------- (1)

Where, \( w_{mf} \) is weight of main frame, \( w_{cb} \) is weight of cross bars and \( w_{es} \) is weight of end supports.

![Figure 3.2 cross sections of RHS for Chassis frame](image)

Based on this concept, the weight of each Chassis parts are calculated using density of the materials, i.e.

\[ \rho = \frac{m}{v} \]  \------------------------------- (2)
\[ m = \rho v \]  \----------------------------- (3)
\[ w = mg \]  \-------------------- (4)
\[ w = \rho vg \]  \------------------------- (5)

Where, \( \rho \) is density of the material, \( v \) is volume of the material and \( g \) is gravitational force.

Considering the cross section, the weight of each material is calculated as:

\[ W = \rho (bh)Lg \]  \---------------------------- (6)
Where, b is width, h is height and L is length of the materials

*NB. All the RHS cross sections are the same except their length as given below.

Givens:
\( \rho = 7850 \text{ kg/m}^3 \), \( g = 9.8 \text{ m/s}^2 \), \( b = 0.06 \text{ m} \), \( h = 0.18 \text{ m} \), \( t = 0.008 \text{ m} \), \( L_{mf} = L_{\text{me}} = 5.83 \text{ m} \), \( b_{\text{f}} = 0.052 \text{ m} \), \( h_{\text{f}} = 0.172 \text{ m} \), \( L_{\text{cb1}} = L_{\text{cb1}} = L_{\text{es1}} = L_{\text{es1}} = 0.76 \text{ m} \), \( L_{\text{cb2}} = L_{\text{cb2}} = 0.64 \text{ m} \), \( L_{\text{es2}} = L_{\text{es2}} = 0.82 \text{ m} \).

**I. Weight of the main frame**

\[ w_{mf} = \rho g (bhL_{mf} - b_{\text{f}}h_{\text{f}}L_{\text{mf}}) \]
\[ w_{mf} = 7850 \times 9.8 \{(0.06 \times 0.18 \times 5.83) - (0.052 \times 0.172 \times 5.83)\} \]
\[ w_{mf} = 832.42 \text{ N} \]

The total number of main frames is 4, so that the total weight of main frame is 
\[ 4 \times 832.42 \text{ N} = 3329.68 \text{ N} \]

**II. Weight of the crossing bar**

\[ W_{cb} = \rho g (bhL_{cb} - b_{\text{f}}h_{\text{f}}L_{\text{cb}}) \]

\[ W_{cb1} = W_{cb1} + W_{cb2} \]

\[ W_{cb1} = \rho g (bhL_{cb1} - b_{\text{f}}h_{\text{f}}L_{\text{cb1}}) \]
\[ W_{cb1} = 7850 \times 9.8 \{(0.06 \times 0.18 \times 0.76) - (0.052 \times 0.172 \times 0.76)\} \]
\[ W_{cb1} = 108.51 \text{ N} \]

Total \( W_{cb1} = 7 \times 108.51 = 759.57 \text{ N} \)

\[ W_{cb2} = 7850 \times 9.8 \{(0.06 \times 0.18 \times 0.64) - (0.052 \times 0.172 \times 0.64)\} \]
\[ W_{cb2} = 91.38 \text{ N} \]

Total \( W_{cb2} = 6 \times 91.38 \text{ N} = 548.28 \text{ N} \)

Therefore, \( W_{cb} = 759.57 \text{ N} + 548.28 \text{ N} = 1307.85 \text{ N} \)

**III. Weight of end support**

\[ W_{es} = \rho g (bhL_{es} - b_{\text{f}}h_{\text{f}}L_{\text{es}}) \]

\[ W_{es} = W_{es1} + W_{es2} \]

Where \( W_{es1} \) is weight of longer end support and \( W_{es2} \) is weight of shorter end support.

\[ W_{es1} = \rho g (bhL_{es1} - b_{\text{f}}h_{\text{f}}L_{\text{es1}}) \]
\[ W_{es1} = 7850 \times 9.8 \{(0.06 \times 0.18 \times 0.76) - (0.052 \times 0.172 \times 0.76)\} \]
\[ W_{es1} = 108.51 \text{ N} \]

Total \( W_{es1} = 14 \times 108.51 = 1519.14 \text{ N} \)

\[ W_{es2} = \rho g (bhL_{es2} - b_{\text{f}}h_{\text{f}}L_{\text{es2}}) \]
\[ W_{es2} = 7850 \times 9.8 \{(0.06 \times 0.18 \times 0.82) - (0.052 \times 0.172 \times 0.82)\} \]
\[ W_{es2} = 117.08 \text{ N} \]

Total \( W_{es2} = 12 \times 117.08 \text{ N} = 1404.96 \text{ N} \)

Therefore, \( W_{es} = 1519.14 \text{ N} + 1404.96 \text{ N} = 2924.1 \text{ N} \)

The entire weight of the Chassis is \( W_{mf} + W_{cb} + W_{es} \)

\[ W_{ch} = 3329.68 \text{ N} + 1307.85 \text{ N} + 2924.1 \text{ N} = 7561.63 \text{ N} \]

**IV. Weight of a man**

The average mass a welder man is 76 kg, [10] and for two men \( 2 \times 76 \text{ kg} = 152 \text{ kg} \).

\[ \text{In weight } 152 \text{ kg} \times 9.8 \text{ m/s}^2 = 1489.6 \text{ N} \]

Hence, the total load on the fixture neglecting the fixture elements weight is 
\[ 7561.63 \text{ N} + 1489.6 \text{ N} = 9051.23 \text{ N} \]

The basic fixture elements considered are:

1. The fixture table
2. Fasteners (Bolts and nuts)
3. Locators
4. Support structures
5. Clamps

3.1.2 Design of fixture table
The fixture table or the fixture body designed geometrically depending on the existing Chassis size plus some allowances, which is equal to 12m length by 3m width and the comfortable working position of the 5th and 95th percentile female/male from anthropometric data, [11], at 1m height. Figure 3.3 shows the comfortable height for working in standing position.

Figure 3.3 Comfortable working positions on the table in standing situation

All the rest fixture elements will assemble on the table. Rigidity of the fixture table is kept using ten RHS stands welded at 3m apart on table frame made of angle iron and connected each other by 10mm thick flat iron as shown in figure 3.4.

3.1.3 Design of Bolts
Bolts and Nuts are included in the design to avoid doubts around the joints between the load bearer supports and longitudinal table frames, and locators’ s seat and locators as shown in figure 3.5 and 3.6. The bolts and nuts are made of low carbon steel, steel 1020 and the required bolt diameters are two types. In both cases since the bolts are subjected to a single shear the bolts` diameter are calculated using a single shear equation, $\tau = \frac{4P}{\pi D^2}$, [12].
Case 1. Bolts for joining the load bearer support structures and the table frame angle iron:

The maximum load is weight of the chassis divided for sixteen nodes plus weight of a man plus weight of three longitudinal supports divide by seven plus half of weight of transverse supports.

\[ P = \frac{7562}{16} N + \frac{745N}{7} + \frac{3(97N)}{2} N = 1319N \]

From maximum shear theory, the shear strength of a material is generally about half of its yield strength, \[ \sigma_y \approx 120 \text{mpa} \] [9]. The yield strength, \( \sigma_y \) of steel 1020 is 210mpa, [9]. Factor of safety for steel on alternating load is 8, [12]. The maximum shear stress,

\[ \tau_{max} = \frac{\sigma_y}{2} = \frac{210}{2} = 105 \text{mpa} \] (7)

Factor of safety = \( \frac{\tau_{max}}{\tau_{all}} \approx 8 \) (8)

\[ \tau_{all} = \frac{105\text{mpa}}{8} = 13.125\text{mpa} \] (9)

Figure 4.5 A bolt join the load bearer support with table frame

The minimum diameter,

\[ D = \sqrt{\frac{4P}{\pi \tau_{all}}} = \sqrt{\frac{4 \times 1319}{\pi \times 13.125}} = 11.31 \text{mm} \approx 12 \text{mm} \]

Therefore, a minimum diameter of M12x1.75 or above standard bolts can be used.

Case 2. Bolts used to fix locators on RHS support structures:

The maximum possible load is the weight of the Chassis divided by Number of bolts per locator on the main frame from one side of the fixture. Since the Chassis weight pushes the locators to one side, only 4 of 8 locators hold the weight.

Figure 6 Bolts joined locators and locator’s seat

Givens:
Number of bolts per locator, \( n = 2 \)
Maximum load, \( p = \frac{7562}{(2 \times 4)} = 957 \text{ N} \)

The maximum shear stress,
\[
\tau_{\text{max}} = \frac{\sigma}{3} = \frac{210}{2} = 105 \text{ mpa}
\]
Factor of safety = \( \frac{\tau_{\text{max}}}{\tau_{\text{all}}} = 8 \)
\[\tau_{\text{all}} = 105 \text{ mpa}/8 = 13.125 \text{ mpa}.\]
The minimum diameter,
\[D_2 = \sqrt[2]{\frac{4 \times 967}{3.14 \times 13.125}} = 2.64 \text{ mm} \approx 10 \text{ mm}^2\]
For these also M10x1.5 bolts are selected.

### 3.1.4 Design of locating elements and restraining degrees of freedoms

Locating a part is a geometrical concept; the acting forces are not taken into consideration with respect to the magnitude, but only as to their direction, so as to ensure that the part is located in a position of static stability.

Each structure of a chassis frame, when unsupported, has three linear and three rotational degrees of freedom in space. To locate and fix these structures, locators of the fixture are used to prevent any movement of the structures. All the structures, such as main frames, cross bars, and end supports of the chassis are located on their specific position to give the assembled chassis frame profile. Therefore, in this research, L shaped locators were selected to locate and fix the structures in between, as shown in figure 3.7.

![Figure 3.7 Locators fixing the Chassis frame](image)

The L shaped locators were restraining one linear movement along the cross side (i.e., along the y axis) and two rotational movements (i.e., along z and x axes) of the main frames neglecting the bottom supports. Again linear and rotational movements of crossing bars and end supports are also restricted from the cross side linearly (i.e., along the x axis), and along z and y axes (rotationally) by the same type of locators. Therefore, three of the sixth degrees of freedom of each chassis structure are restricted by the locators, as shown in figure 3.8.

![Figure 3.8 position of Chassis structures](image)

The main frames can still move in the vertical axis and longitudinal axis linearly, and can rotate...
about the crosswise axis (i.e. y axis) as shown in figure 3.9. On the other hand end supports and cross bars can also still move linearly along the vertical and longitudinal(y axis) axes, and can rotate about the Crosswise(x axis). The degree of freedoms and restricted directions of the Chassis frames are indicated in figure 3.10.

![Figure 3.9 Linear degrees of freedoms in located structures](image1)

*Figure 3.9 Linear degrees of freedoms in located structures*

The longitudinal linear and the third rotational movements of the main frames are prevented by the middle cross bar at one end and by the spacers at the other end. All cross bars were sandwiched between the main frames to restrain longitudinal movements. The end supports movement also restricted by the main frames from inside and by using spacers from the other side. The spacer is placed between the end supports and table frame made of angle iron, as shown in figure 3.11. The variation in size between the end supports and the crossing bars also identified by using the spacers as a full proofing mechanism, which is used to simply identify unequal sizes of the structures and fit in their proper location.

![Figure 3.10 Rotational degrees of freedoms in located structures](image1)

*Figure 3.10 Rotational degrees of freedoms in located structures*

![Figure 3.11 Spacers used to restrain longitudinal movements of end supports](image1)

*Figure 3.11 Spacers used to restrain longitudinal movements of end supports*
3.1.5 Design of support structures
Supports are parts of fixture used to hold locators and other structures, such as the part to be locate, fasteners and other supports. The designed supports are sufficient in number and strength to absorb all acting loads without causing elastic deformation, as indicated in figure 3.12. On the other hand, they are designed not to interfere with the locating of the part and made being adjustable. In this thesis two types of support structures are used. The first types of supports are those locators are fastened with M 10 x1.5 bolt and nut on it. These supports are made of RHS steel (steel1020) and drilled by 10.5 mm diameter bit sequentially apart 20mm from center to center throughout their length from the top side. On the side surfaces 36mm long slots are provided at a distance of 12mm throughout their length. The second types of supports are made of RHS steel (steel1040) and used to bear all loads of Chassis structures which are clamped firmly on it.

3.1.6 Mathematical analysis of support structures
In one or in other ways, finally all the loads of longitudinal supports are transferred to the transverse supports so that mathematical analysis is made on selective transverse support structures where maximum load is suspected. For mathematical analysis, supports found around the centre of the fixture where the Chassis load concentrated are selected. Load bearer support 1 and 2 are, and locators’ seat 3, 4 and 5 are selected for analysis as shown in figure 3.13.

Procedure of analysis for load bearer supports:
1. Each Chassis structures load are taken as distributed loads over the fixture and these independent distributed loads are analyzed to find the resultant concentrated load at their centroid between two transverse supports, as shown in figure 3.14.
2. The concentrated loads are shared to the longitudinal load bearers as shown in figure 3.15.
3. The loads on each longitudinal load bearers transferred to two transverse load bearers.
4. Each concentrated loads on the longitudinal load bearers also shared to two transverse load bearers, as shown in figure 3.16.
5. The transferred load on transverse support 1 and 2 are collected, as shown in figure 3.17.
6. For support 1 beam load diagram is drawn, as shown in figure 3.18 and.
7. Shear force and moment equations are formulated.
8. Shear force and moment diagrams are drawn for support 1 and 2, as shown in figure 3.19 and 3.20 respectively.

![Shear force and moment diagrams](image)

**Figure 3.13 selected support structures for analysis**

To find the centroid of Chassis structures A & B

\[ X_1 = \frac{A(1.25m) + B(0.236m)}{234N} \]  
\[ X_1 = \frac{117N(1.25m) + 117N(0.236m)}{234N} = 0.763m \]

\[ R_{AB} = R_{0N} = 234N(0.82m) \text{ concentrated at } 0.41m \left( \frac{0.82m}{2} \right) \text{ to the y-axis & 0.763m to the x-axis from left of support 1.} \]

To find the centroid of D & E

\[ X_2 = \frac{D(0.203m) + E(1.078m)}{D+E} \]  
\[ X_2 = \frac{109N(0.203m) + 109N(1.078m)}{218N} = 0.64m \]

\[ R_{D} = R_{E} = 218N(0.76m) \text{ concentrated at } 0.38m \left( \frac{0.76m}{2} \right) \text{ to the y-axis & 0.64m to the x-axis from right of support 2.} \]

To find the centroid of G & H

\[ X_3 = \frac{G(0.314m) + H(2.4m)}{G+H} \]  
\[ X_3 = \frac{91N(0.314m) + 109N(2.4m)}{200N} = 0.557m \]

\[ R_{GR} = 200N(0.7m) \text{ concentrated at } 0.35m \text{ to the y-axis & 0.557m to the x-axis from the right of support 1.} \]

To find the centroid of I & K

\[ X_4 = \frac{I(0.148m) + K(0.931m)}{I+K} \]  
\[ X_4 = \frac{1(0.148m) + K(0.931m)}{1+K} \]  
\[ X_4 = \frac{1(0.148m) + 60N(6m)}{1+60N} \]  
\[ X_4 = 0.026m \text{ to the y-axis & 0.931m to the x-axis from left of support 1.} \]
The reaction forces of $R_a$ to $R_y$ acts against the forces concentrated at the middle of each Chassis part at the contact points with the longitudinal load bearer supports, as shown in figure 3.15.

i. $R_a + R_b = R_g + R_n = 191.9\text{Nm}$
   
   $R_a = R_b = R_g = R_h = 94\text{Nm}$

ii. $R_c + R_d = 58.2\text{Nm}$
    
    $R_c = R_d = 29.1\text{Nm}$

Weight of the main frame,

$W = \rho g(bhl - b'h'l')$ ........................................... (14)

$W = 7850 \times 9.8[(0.06 \times 0.18 \times 2.529) - (0.052 \times 0.172 \times 2.529)] = 361\text{N}$

iii. $R_e + R_f = R_v + R_w = 361\text{N}$

$+ M_{Re} = 0$

$R_f(1.686\text{m}) = 361\text{N}(1.264)$-------(15)

$\begin{align*}
R_f &= \frac{361\text{N}(1.264)}{1.686\text{m}} = 270.75\text{N} \\
R_v &= 270.75\text{N} \\
R_e &= R_w = 90.25\text{N}
\end{align*}$

iv. $R_p + R_o = 96\text{N}$

$R_p = R_o = 48\text{N}$

v. $R_n + R_m = 140\text{N}$

$R_n = R_m = 70\text{N}$

vi. $R_i + R_j = 744.5\text{N}$, i.e. half of the weight of a man.

$R_i = R_j = 372.25\text{N}$

vii. $R_q + R_r = R_s + R_t = R_x + R_y = 165.7\text{Nm}$

$R_q = R_r = R_s = R_t = R_x = R_y = 82.85\text{Nm}$
Figure 4.15 resolved reaction forces

Loads acts on each transverse support structures.

i. \[ R1 + R7 = R2 + R8 = R5 + R11 = R6 + R12 = 94N \]
\[ \theta + M_{R1} = 0 \]
\[ R7 (1.686m) = 94N (0.925m) \]
\[ R7 = \frac{94N (0.925m)}{1.686m} = 51.46N \]
\[ R1 = R2 = R5 = R6 = 94N - 51.46N = 42.54N \]

ii. \[ R3 + R9 = R4 + R10 = 29.1N \]
\[ \theta + M_{R3} = 0 \]
\[ R9 (1.686m) = 29.1Nm (1.1m) \]
\[ R9 = R9 = R10 = 19N \]
\[ R3 = R4 = 10.1N \]

iii. \[ R7 + R13 = R8 + R14 = R11 + R17 = R12 + R18 = 48Nm \]
\[ \theta + M_{R7} = 0 \]
\[ R13 (1.686m) = 48Nm (0.843m) \]
\[ R13 = R13 = R14 = R17 = R18 = 24Nm \]
\[ R7 = R7 = R8 = R11 = R12 = 24Nm \]

iv. \[ R9 + R15 = R10 + R16 = 70Nm \]
\[ \theta + M_{R9} = 0 \]
\[ R15 (1.686m) = 70Nm (0.557m) \]
\[ R15 = R15 = 23.1N \]
\[ R9 = R10 = 23.13Nm \]
\[ R15 = R16 = 23.13Nm \]
\[ R9 = R10 = 70Nm - 23.13Nm = 46.87Nm \]
\[ \theta + M_{R15} = 0 \]
\[ R19 (1.686m) = 82.84Nm (0.64m) \]
\[ R19 = \frac{82.84Nm (0.64m)}{1.686m} = 31.4 \]
\[ R19 = R20 = R23 = R24 = 31.45Nm \]
\[ R14 = R14 = R17 = R18 = 82.84Nm - 31Nm = 51.39Nm \]
vi. \[ R_{15} + R_{21} = R_{16} + R_{22} = 82.84 \text{Nm} \]
\[ M_{R15} = 0 \]
\[ R_{21} (1.686 \text{m}) = 82.84 \text{Nm} (0.539 \text{m}) \]

\[ R_{21} = \frac{82.84 \text{Nm} (0.539 \text{m})}{1.686 \text{m}} = 26.4 \]

\[ R_{21} = R_{22} = 26.48 \text{Nm} \]
\[ R_{15} = R_{16} = 56.36 \text{Nm} \]

Figure 3.16 loads acts on transverse load bearers

collect and add the loads that act at the same point from left and right of support 1.

a. \[ R_{7} = R_{8} = R_{12} = 51.46 \text{Nm} + 24 \text{Nm} = 75.46 \text{N} \]
b. \[ R_{9} = R_{10} = 19 \text{Nm} + 46.87 \text{Nm} = 65.87 \text{Nm} \]
c. \[ R_{11} = 75.46 \text{Nm} + 372.25 \text{Nm} = 447.71 \text{N} \]

collect and add the loads that act at the same point from left and right of support 2.

d. \[ R_{13} = R_{14} = R_{17} = R_{18} = 24 \text{Nm} + 51.39 \text{Nm} = 75.38 \text{Nm} \]
e. \[ R_{15} = R_{16} = 56.36 \text{Nm} + 23.13 \text{Nm} = 79.49 \text{Nm} \]
f. \[ R_{17} = 79.49 \text{Nm} + 372.25 \text{Nm} = 451.74 \text{Nm} \]

Figure 3.17 Collected loads on transverse load bearer 1 and 2

Figure 3.18 load diagram for support 1
From the load Diagram:

\[ \sum F_y = 0 \]
\[ R1 + R9 = 1076.58N \]
\[ R9(2.5m) = 74.46N(0.23m) + 447.71N(0.63m) + 65.87N(1.03m) + 65.87N(1.47m) + 75.46N(1.87m) + 75.46N(2.27m) \]
\[ R9 = \frac{594.64Nm}{25m} = 397.86N \]
\[ R1 = 1076N - 397.86N = 678.72N \]

The Shear force and bending moment at each point on the load diagram analyzed by breaking the load diagram into smaller segments:

Segment 12:

- \( F_{S12} = 678.72N \)
- \( M_{12} = 678.72XN \)

Segment 23:

- \( F_{S23} = 678.72N - 75.46N \)
- \( F_{S23} = 603.26N \)
- \( M_{23} = 678.72N - 75.46N(X-0.23m) \)
- \( M_{23} = 678.72XN - 75.46XN + 17.36Nm \)

Segment 34:

- \( F_{S34} = 678.72N - 75.46N - 447.71N \)
- \( F_{S34} = 155.55N \)
- \( M_{34} = 678.72N - 75.46N (X-0.23m) - 447.71N (X-0.63m) \)
- \( M_{34} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN + 282Nm \)
\[ M_{34} = 155.55XN + 299.36Nm \]

Segment 45:

\[ F_{s45} = 678.72N -75.46N-447.71N-270.75N --- (29) \]
\[ F_{s45} = -115.2N \]
\[ M_{45} = 678.72N -75.46N (X-0.23m) -447.71N (X-0.63m) -270.75N (X-0.796m) ---- (30) \]
\[ M_{45} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN + 282Nm - 270.75XN + 215.5Nm \]
\[ M_{45} = -115.2XN + 514.86Nm \]

Segment 56:

\[ F_{s56} = 678.72N -75.46N-447.71N-270.75N -65.87N ----------------- (31) \]
\[ F_{s56} = -181.07N \]
\[ M_{56} = 678.72N -75.46N (X-0.23m) -447.71N (X-0.63m) -270.75N (X-0.796m) -65.87N (X-1.03m) ----------------- (32) \]
\[ M_{56} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN + 282Nm - 270.75XN + 215.5Nm - 65.87XN + 67.85Nm \]
\[ M_{56} = -181.07XN + 582.71Nm \]

Segment 67:

\[ F_{s67} = 678.72N -75.46N-447.71N-270.75N -65.87N-65.87N ------------------------ (33) \]
\[ F_{s67} = -246.94N \]
\[ M_{67}=678.72N-75.46N(X-0.23m)-447.71N(X-0.63m)-270.75N(X-0.796m)-65.87N(X-1.03m) -65.87N (X-1.47m) ----------- (34) \]
\[ M_{67} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN + 282Nm - 270.75XN + 215.5Nm - 65.87XN + 67.85Nm - 65.87XN + 96.83Nm \]
\[ M_{67} = -246.94XN + 679.54Nm \]

Segment 78:

\[ F_{s78} = 678.72N -75.46N-447.71N-270.75N -65.87N -65.87N -75.46N ----------- (35) \]
\[ F_{s78} = -322.4N \]
\[ M_{78} = 678.72N -75.46N (X-0.23m) -447.71N (X-0.63m) -270.75N (X-0.796m) -65.87N (X-1.03m) -65.87N (X-1.47m) -75.46N (X-1.87m) ----------- (36) \]
\[ M_{78} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN + 282Nm - 270.75XN + 215.5Nm - 65.87XN + 67.85Nm - 65.87XN + 96.83Nm - 75.46XN + 141Nm \]

\[ M_{78} = -322.4XN + 820.54Nm \]

Segment 89:

\[ F_{S89} = 678.72N -75.46N -447.71N -270.75N -65.87N -75.46N -75.46N \]  
\[ F_{S89} = -397.86N \]

\[ M_{89} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN - 270.75XN + 215.5Nm - 65.87XN + 67.85Nm - 65.87XN + 96.83Nm - 75.46XN + 141Nm - 75.46XN + 171.29Nm \]

\[ M_{89} = 678.72XN - 75.46XN + 17.36Nm - 447.71XN + 282Nm - 270.75XN + 215.5Nm - 65.87XN + 67.85Nm - 65.87XN + 96.83Nm - 75.46XN + 141Nm - 75.46XN + 171.29Nm \]

\[ F_{S89} = 678.72N -75.46N -447.71N -270.75N -65.87N -75.46N -75.46N \]  
\[ F_{S89} = -397.86N \]

**Figure 3.19 Shear and moment diagram for support 1**

The maximum bending moment obtained from the bending moment diagram is 423.18Nm. Assuming rectangular hollow section structural steel 1040 with tensile/compressive strength of 520mpa and factor of safety 8 for alternating loads [12].

Allowable bending stress,

\[ \sigma_{all} = \frac{\sigma_s}{8} = \frac{65}{8} = 65 \text{ mpa} = 65N/mm^2 = 6500N/cm^2 \]

\[ \sigma_{all} = \frac{M_{max}}{Z} \]  
\[ Z = \frac{M_{max}}{\sigma_{all}} \]

where \( Z = \frac{1}{C} \) is section (elastic) modulus of the RHS, \( M_{max} \) is maximum bending moment and \( \sigma_{all} \) is allowable stress.

\[ Z = \frac{423.78}{6500} = 6.510\text{cm}^3 \]

Referring to [14], RHS of 60mm x 40mm x 2.3mm has a section modulus of \( Z_{x-x} = 6.88 \text{ cm}^3 \) which is approximately equal to calculated value of 6.510 cm³ and thus gives a suitable solution.

For support 2 the same procedures has been followed for the mathematical analysis, and Shear and
moment diagrams are shown on figure 3.20.

**Figure 3.20 Shear and moment diagram for support 2**

The maximum bending moment obtained from the bending moment diagram is 437.41Nm. Assuming rectangular hollow section structural steel 1040 with tensile/compressive strength of 520mpa and factor of safety 8 for alternating loads [12].

Allowable bending stress,

$$\sigma_{all} = \frac{S_{t}}{S_{c}} = \frac{520}{8} = 65 \text{ mpa} = 65 \text{N/mm}^2 = 6500 \text{N/cm}^2$$

$$\sigma_{all} = \frac{M_{max}}{Z}$$

where $Z = \frac{I}{G}$ is section modulus of the rectangular plate, $M_{max}$ is maximum bending moment and $\sigma_{all}$ is allowable stress.

$$Z = \frac{437413 \text{cm}^3}{6500 \text{N/cm}^2} = 6.729 \text{cm}^3$$

Referring to [14], RHS of 60mm x 40mm x 2.3mm has a section modulus of $Z_{x-x} = 6.88 \text{ cm}^3$ which is approximately equal to calculated value of 6.729 cm$^3$ and thus gives a suitable solution. Therefore, considering the results of support 1 and support 2, for all transverse load bearers 60mm x 40mm x 3mm RHS is selected.

**Procedure of analysis for locator seat supports:**

1. The weight of each locator is taken as a concentrated load at different distances away from the transverse locators’ seat, as shown in figure 3.21.
2. The loads acts on each transverse locator seat are obtained by moment equation.
3. The loads on three transverse locators’ seat are compared and the one which carries maximum load took for further analysis.
4. The load diagram is drawn
5. Shear force and moment equations are formulated.
6. Shear force and moment diagrams are drawn, as shown in figure 3.22.

**Figure 3.21 locators on locators` seat at different distances**
by using moment equation the weight of locators shared on the transverse locators’ seat 3, 4 & 5 are analyzed mathematically and illustrated as shown as figure 3.22.

Figure 3.22 Shear and moment diagram for locators’ seat

The maximum bending moment obtained from the bending moment diagram is 60.060Nm. Assuming RHS structural steel 1020 with tensile/compressive strength of 380mpa and factor of safety 4 for steady loads [12]. Allowable bending stress,

\[ \sigma_{all} = \frac{S}{Z} = \frac{389}{4} = 95 \text{ mpa} = 95 \text{N/mm}^2 = 9300 \text{N/cm}^2 \]

\[ \sigma_{all} = \frac{MC}{I} \]

\[ Z = \frac{M_{max}}{\sigma_{all}}, \text{ where } Z = \frac{I}{C} \text{ is section modulus of the rectangular plate, } M_{max} \text{ is maximum bending moment and } \sigma_{all} \text{ is allowable stress.} \]

\[ Z = \frac{6006N \text{cm}}{9300N/cm^2} = 0.6322 \text{cm}^3 \]

Referring to [14], RHS of 32mm x 16mm x 1.6mm has a section modulus of \( Z_{y-y} = 0.688 \text{ cm}^3 \) which is approximately equal to calculated value of 0.6322 cm³ and thus gives a suitable solution. Locators’ seat must accommodate the locators’ width and also have slots and holes throughout their length as shown in figure 3.25. Considering such things 70mm x 50mm x4mm RHS is selected for all locators’ seat.

3.2 Design of clamping elements

The next step would be to apply real clamping elements such as bolts, cams, straps, C-clamps, etc. A clamp is a force-actuating mechanism of a fixture. The forces exerted by the clamps hold a part securely in the fixture against all other external forces. In addition to locators, clamping device is required to restrain the workpiece completely in the fixture. In this case, standard C-clamp is preferred which purchased from the market. Since the work thickness to be secure is 180mm and the bottom support thickness is 60mm RHS, to clamp 250mm work thickness, the appropriate C size is \( \geq 300 \text{mm} \).

The \( \phi \) of the screw is determined by considering the shear strength of it’s material. Let \( P_t \) is tightening force during clamping, \( T \) is torque which is a product of a force \( F = 130 \text{N} \) of an average man to pull & push a lever [11] and the perpendicular distance \( s = 300 \text{N} \) at the head of the screw as shown in figure 3.26. Therefore, tightening force, \( P_t = T/ \)
0.2d [12]

\[ P_t = \frac{T}{0.2d} \]  

(40)

Where \( T \) is torque and \( d \) is diameter of the screw.

The maximum stress \( \sigma_{\text{max}} \) exerted on the clamp screw is \( P_t/A \) which is \( \leq \) the yield strength of the screw material.

\[ P_t = \sigma_y A = \sigma_y \left( \pi d^2 / 4 \right) \]  

(41)

By substituting equation 88 in to equation 87:

\[ \sigma_y \left( \pi d^2 / 4 \right) = T / 0.2d \]  

(42)

\[ d^3 = 4T / 0.2 \pi \sigma_y \]  

(43)

Where \( \sigma_y \) is yield stress of steel 1040 which is equal to 290 mpa. [9]

\[ d^3 = 4T / 0.2 \pi \tau_y \]  

(44)

The maximum shear stress,

\[ \tau_{\text{max}} = \frac{\sigma_y}{2} = \frac{290}{2} = 145 \text{ mpa} \]

Factor of safety = \( \frac{\tau_{\text{max}}}{\tau_{\text{all}}} = 4 \), factor of safety for steel for steady load is 4, [12].

\[ \tau_{\text{all}} = 145 \text{ mpa}/4 = 36.25 \text{ mpa}. \]

(45)

The minimum diameter,

\[ D = \frac{3 \sqrt{\frac{4T}{0.4 \pi \tau_{\text{all}}}}}{\sqrt[3]{4(380N)(300)}} = 15 \text{ mm}. \]

The diameter might be too small in comparison to the clamp size and may not available in the market with this proportion. Therefore any \( \Phi > 15 \text{ mm} \) available in the market can be used, but for this design 450mm clamp jaw length with M22mm screw size used at BALI is selected.

\[ \text{Figure 3.26 Chassis frame clamped against the load bearer support} \]

The large size C- clamps are selected to hold down each structure of the Chassis frames against the supports to restrain the vertical linear degree of freedom as shown in figure 3.27.
To prevent deformation of the chassis structures due to the clamping pressure, spacers are used between the work and the clamps. The numbers of clamping elements used are not necessarily equal to the number of locators; rather, it could be decided by the chassis manufacturer depending on the occasions. The three dimensional view of the fixture along with the assembled Chassis is shown in figure 3.28. Clamping device should be capable to be unaffected by the vibrations generated during an operation. Things that considered during selection of clamping element are:

- It’s friendly usefulness like easily clamped and released, easy and less time required to use and easy for maintenance.
- Clamping pressure should be directed towards the support surfaces to prevent undesired lifting of the Chassis structures.
- Have tough clamping faces to minimize wearing out

**IV. CONCLUSION**

During fixture design and manufacturing the most important procedures are material selection, fixture design and process planning prior to manufacturing.
Material selection is carried out through scientific methods considering availability, cost and mechanical properties. The selected materials are economical and sufficient in strength to hold all loads available on the fixture.

Design of the fixture is made in two ways. The first is geometrical design of the fixture that considers flexibility, easy to use, durability and accessibility. The second is mathematical design analysis which incorporates analysis of fasteners, support structures and clamps. The size of the bolt is determined by considering its shear stress, and bolts of Ø12mm and Ø10mm are obtained from the analysis. To analyze the support structures two load bearer supports and one locators’ seat that are found around the middle of the fixture, where the load is concentrated, are selected. The section modulus of the load bearer supports are determined by using the maximum bending moment 634.41Nm on support 2 and the allowable bending stress of the material. The result of section modulus helps to refer the appropriate size of the load bearer support from Appendix B. Based on this analysis a rectangular plate of 60mm x 40mm x 3mm is selected for all load bearer supports. The Locators’ seat also determined in the same manner with the load bearer supports by using the maximum bending moment of locators’ seat B. A section modulus of 0.6322 cm³ is obtained by taking the maximum bending moment from the bending moment diagram and its allowable bending stress. Referring to Appendix B 70mm x50mm x 4mm RHS is selected for all locators’ seat. Since the other elements of the fixture have no as such significant loads, the materials are selected in proportion to the above materials.

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