Elevator Rail Bracket Improvement Project

by

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ABSTRACT

New technology was developed by Fujitec America (elevator manufacturer) that allows for the re-location of the traditional machine room (room that houses the traction machine, controller and governor) for an elevator. The new technology moves the machine for lifting the elevator currently in a separate room above the elevator into the elevator shaft. This move has created a problem in the elevator combination rail bracket design. The problem involved the location of the counterweight in relation to the car. The bracket was redesigned utilizing engineering design processes.

The majority of those surveyed stated that lower installation cost and an easy to install bracket were the most important features of the design improvement. The results of the QFD showed the most important feature to be a simple/universal design. This priority was followed closely by cost of manufacturing and installation cost.

Three distinct designs were proposed. The first utilized a plate that extended to the car rail position. This is the design that was incorporated into the first initial Talon’s released for manufacturing. The second design replaced the plate with two angle members and the third used a large section of structural tube in place of the plate. The three separate designs were analyzed utilizing engineering design tools and the bracket with the two angles was selected. This bracket was then analyzed for bending and shear stress to ensure the bracket conformed to ASME A17.1 code for elevators and escalators.

After calculations showed the bracket conformed to all code requirements the current combination bracket and the improved bracket were manufactured to test manufacturing and assembly time. The plate design was run using two different machine operations and the angle design could be run on one machine. Both brackets were then tested for total field installation time. A full scale mock up was built to simulate installing the brackets while in an actual elevator shaft. Both brackets were installed multiple times to determine average installation times.

Testing showed that the improved all angles combination rail bracket saved both time and material cost in manufacturing. The bracket weighed five pounds less than the plate design and took no longer for installation. The welds used on the plate design proved sufficient on the improved design. The total yearly savings utilizing the improved design was determined to be approximately $8,000.00. This figure is based on a five year projected sales goal for the Fujitec Talon MRL product line.

The scheduled completion date for the project was early June 2007. It encompassed three quarters of the school year and was broken into three parts. All scheduled tasks were completed on time. The final budget for this project was $500.00. This was $85.00 over the estimated budget of $415.00 but well within acceptable range for Fujitec management.
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INTRODUCTION

Fujitec America, Inc. manufactures elevators, escalators, moving walkways, elevator controls and other elevator control components. Major components of elevators include the car frame, counterweight, machine and controller. The car frame is the device that carries the cab which transports the people in the building. The counterweight is the counterbalance for the car frame and cab. The machine and controller is the lifting device and control the elevator motion.

The car frame and the counterweight components travel up and down in the elevator shaft. Elevator guide rails (machined steel T-shaped members) are assembled up the hoistway and attached to the building or shaft walls via rail brackets. The car and counterweight ride along these guide rails by roller guide shoes attached to the car frame and counterweight. Rail brackets that support the guide rails are designed for each job to meet the various building conditions and connection types. All the components are governed by ASME A17.1 code or state and local elevator codes. Some examples of items covered by A17.1 are maximum distances between rail brackets and maximum stresses allowed on the brackets. A17.1 also covers seismic code requirements which have stricter requirements on the rail brackets [1].

The focus of this design project was to redesign the rail brackets to meet the demands of Fujitec America’s new “Talon” machine roomless (MRL) product. In traditional elevator systems the car frame and counterweight are lifted by a traction machine via steel cables located above the elevator shaft or “machine room.” The machine-roomless system replaces the traditional traction machine with a small permanent magnet motor machine located inside the elevator shaft over the counterweight. The car and counterweight are still lifted by steel cables, although the traction is provided by a steel reinforced belt. This new design from Fujitec has rendered some of the bracket designs obsolete due to a change in the locations of the guide rails in the elevator shaft (See Figure 1, guide rail locations are clouded).

![Figure 1 Plan Views of Elevator Configurations and Rail Locations](image-url)
BACKGROUND

Three different kinds of elevator bracket systems currently exist. Single car or counterweight, combination (supports more than one rail) and counterweight rail only design (See Appendix A). The single car or counterweight design is typically one of the simpler designs usually consisting of two pieces of steel angle or two angles with a steel plate to act as an extender (See Figure 2). This single rail design works well in traditional elevator systems due to the amount of room granted for the guide rails and their configuration. Once the distance from the back of the guide rail to the building mounting surface is larger than about 5 1/2 "an extender plate is placed between the two angles. This introduces a different material and costs more to manufacture.

[2]

Figure 2 Single Car or Counterweight Rail Brackets
The combination types of brackets are useful when a counterweight is located on the side of the car rather than toward the back (See figure 3 below). Two types of combination brackets exist to deal with the side counterweight locations. One is the “U” style combo bracket which is utilized when the counterweight is located on the side of the car centered on the car rail. This bracket can be difficult to install due to the length and quantity of angles. Although if designed correctly, it can be made with one type of material. The traditional combo bracket is used when the counterweight is on the side of the car but offset from the car rail. This bracket can also pose a problem in installation because the angle supporting the counterweight rail is located under the plate which is difficult to weld. This design also requires multiple material types and is cumbersome to install. Another combination type bracket called the saddle type is utilized when you have multiple cars in an elevator shaft. Divider steel is placed in the elevator shaft to support the car guide rails and a bracket consisting of two angles and a plate is used to support two car rails. This design is simple for the installers as they can weld the plate to the top of the support steel. This design also uses multiple raw material types.

Figure 3 Combination Rail Brackets
Counterweight rail only brackets are relatively simple to install and are typically made of two angles that form a 90 degree angle. Another type of counterweight only design utilizes ½”x 4” steel plate which is bent to form the 90 degree angle (See figure 4). The “Flatbar” design is problematic for field personnel. If the bent steel does not form a true 90 degree angle, shimming is required to square the bracket which increases installation time.

Figure 4 Counterweight Rail Brackets

Some of these current rail bracket designs could prove useful in the new MRL system although currently none of the combination bracket designs will meet the rail configuration. Much of the design effort was placed on the combination rail bracket required to help make the Talon MRL system more efficient to install and manufacture.
FEATURES AND CUSTOMER FEEDBACK

SURVEY

To aid in the design process customer feedback was required. A brief survey was conducted to gather data on important features (See Appendix B). The customers who filled out the survey included installers, mechanics, engineers, designers and sales personnel from Fujitec. Thirty-five surveys were distributed and thirty were returned. The customers were asked to rate the importance of the following features on a 1-5 scale five being most important. The results are in order of importance with averages in parentheses ( ):

1. Installation Costs (4.93)
2. Manufacturing Costs (4.90)
3. Easy to Install (4.77)
4. Same Raw Material throughout Design (4.77)
5. Simple/Universal Design (4.50)
6. Easy to Manufacture (4.47)
7. Uniform Slots (4.43)
8. Lightweight Assembly (4.13)
9. Minimize Number and Size of Welds (4.10)
10. Method of Assembly to Building Support Temporally (3.23)
11. Utilize all slots during Installation (3.13)
12. Bracket Color (.97)

The sorted list above shows that the most important features have to do with installing the brackets. From conversations with various Fujitec construction superintendents the overriding factor to make a bracket successful was its ability to be installed quickly and for the design to be simple. The manufacturing portion was a close second in importance and shop foremen stated that simple is better. If the design can eliminate a part or operation then it is an improvement. Color, welding and supporting the bracket to the building structure prior to welding was the lowest priority in the improved design.

The survey also asked the customers how satisfied they were with the current designs. Once the surveys were tabulated the information was used to help aid in the determination of engineering characteristics for the brackets. The customers were asked to rate how satisfied they were with the following features on a 1-5 scale with five being very satisfied and they are put in order of least to most satisfied with averages in parentheses ( ):

1. Bracket Color (1.50) ¹
2. Simple/Universal Design (2.00)
3. Easy to Install (2.33)
4. Method of Assembly to Building Support Temporally (2.60)
5. Utilize all slots during Installation (2.67)
6. Manufacturing Costs (2.67)
7. Installation Costs (2.83)
8. Lightweight Assembly (3.00)
9. Easy to Manufacture (3.00)

¹ This number is not reflective of the thirty responses due to significant not applicable responses. Installers stated the color did not matter as long as some rust protection was applied.
The survey for satisfaction showed installers are most satisfied with the quantity of welding required for current designs. The weight, ease of manufacturing and the overall weight of the brackets were also in the upper ranges of being satisfied with current design. The value for utilizing the same raw material throughout the design was surprising. Some of the Combo and single car or counterweight brackets with extender plates use more than one type of material. Utilize same raw material throughout was number four on the survey for importance. The features the customer is most unsatisfied with are the lack of a simple/universal design and the ease of installing.

**PRODUCT OBJECTIVES AND PROPOSED FEATURES**

The customer features were cross-referenced with engineering characteristics and rated by the design team if they had strong to weak correlation. The list below contains the features in order of importance and the relative weight out of 100% was placed in parentheses next to it. Below each feature is the engineering characteristic and below the characteristic is the method or objective that was used for the new design to meet the customer needs. This information was derived from the customer survey and a Quality Function Deployment tool to determine the importance of each item (See Appendix C). Based on conversations with field and plant personnel the design was based heavily on reducing installation cost which is why most of the items dealing with installation were given a five in the QFD planned column for the bracket. Cost of the bracket was also given a five and this was based on conversation with plant and field personnel. Fujitec upper management and field sales personnel were contacted to determine which feature improves the ability of our sales team to move the product effectively. These items were given higher scores in the QFD tool to increase the relative weight. The items given the larger scores of 2 in the QFD sales point column involved installation costs and simple designs. These were followed closely by manufacturing cost and manufacturing features. The reasoning behind this was if cost is cut out of producing the product the company can make it more competitive in the market.

1. **Simple/Universal Design (.20)**
   1.1. Common assembly components, same material size
      1.1.1. The prototype was designed so that parts are interchangeable which should reduce inventory stock and engineering time

2. **Easy to Install (.18) and Installation Costs (.15)**
   2.1. Time and materials to install brackets
      2.1.1. The prototype will reduce the amount of time spent installing elevator brackets from the current designs by 25%

3. **Manufacturing Costs (.12) Easy to Manufacture (.08)**
   3.1. Time and materials to manufacture
      3.1.1. The prototype will reduce the amount of time spent manufacturing elevator brackets from current designs

4. **Same Raw Material throughout Design (.08)**
   4.1. Utilize common assembly components and material manufacturability
      4.1.1. The prototype was designed to utilize less material types than the current designs
Based on the findings of the QFD tool the bracket design improvement I concentrated on a simple design that is easy to install. The design concept was kept simple to aid in removing some of the manufacturing cost although installation drove the direction of the design.
DESIGN ALTERNATIVES

DESIGN SELECTION

With the information provided on the customer survey and engineering characteristics brainstorming sessions were conducted. Three different design concepts were chosen for further review. The first utilized a flat plate to extend the car rail bracket (see figure 5). This is the design that was employed on the initial release of the Talon product. This design was employed initially because it closely resembles rail bracket concepts already being utilized. The second was to utilize all the same size raw material (see figure 6). This concept was to minimize the different types of raw material types used and aid in manufacturing.

![Figure 5 Concept #1 Plate Design (used on initial release)](image)

![Figure 6 Concept #2 Extension Angles](image)
The third and final concept was to use a large structural tube cut into a thin section to support the car rail. This concept was chosen because it eliminated two parts for the one tube (see figure 7).

![Figure 7 Concept #3 Extension Tube](image)

The three concepts were evaluated using a weighted decision matrix on a five-point scale, four being excellent and zero being inadequate. The criteria that each concept was evaluated against were the engineering design characteristics from the project objectives. The project objectives had a weight factor calculated based on customer feedback. The score given in each category was multiplied by the weight factor to determine the rating for each concept. The ratings for all design concepts were summed to determine the overall rating for each concept (see Appendix G).

The concept with the highest rating was concept #2 extension angles (see Table 1). This concept then became the focus of this design project and all calculations and testing was conducted to prove the design was feasible (see Figure 8 on following page).

### Weighted Objective Matrix Results

<table>
<thead>
<tr>
<th></th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angles with Plate</td>
<td>1.94</td>
</tr>
<tr>
<td>All Angles</td>
<td>3.31</td>
</tr>
<tr>
<td>Angles with Tube</td>
<td>2.95</td>
</tr>
</tbody>
</table>
LOADING CONDITIONS

Loading conditions on the rail bracket are covered by ASME A17.1 Rule 2403.9 (See Appendix H). The car and counterweight travel up and down the elevator shaft via guide rails. Four roller guide shoes are attached to the car and counterweight at four corners (top and bottom). The overall weight of the car or the counterweight weight is transmitted to the guide rails and then to the brackets through these roller guides. Figure 9 on the following page shows a section of the rail with contact from a set of roller guides.
The car weights used for this design project are for a standard 3500 lb Talon platform with nine foot entrance height. From job to job this car frame weight will remain constant. The factor that has the greatest effect on the weight is the car interior options. These are the aesthetic items the riders would see using the elevator. For this project the interior options were assumed to be the heaviest available to simulate worst case (i.e. stone floors, glass wall panels, drop ceiling, etc.). When the total car weight (car frame and cab w/interiors) was calculated, this weight along with the capacity of car (3,500 lbs) was used to calculate the seismic load. ASME A17.1 calculates seismic load using 100% of the car weight and 40% of the rated capacity for the car and the total weight of the counterweight for loading.

The next step in determining the rail loading was to determine roller guide spacing on car and counterweight in relation to the rail bracket spacing in the building. If the rail bracket spacing is greater than the roller guide spacing on the car and counterweight a more stringent ASME A17.1 formula is utilized. For this project the assumption was made that the roller guide spacing is less than the bracket spacing, this would simulate worst case conditions. In addition, if the elevator is installed in a seismic region more of the calculated load is used in the formulas to find rail forces. For this project all seismic formulas were used to again simulate worst case conditions.
Loads for this project calculated utilizing worst case car and counterweight weights per ASME A17.1 standards can be seen in Figure 10.

Figure 10 Seismic Loading Conditions
DESIGN CALCULATIONS

The rail bracket was analyzed with a distance of 20 inches from mounting surface to the back of the guide rail for the car, and 16 ¾ inches from the mounting surface to the center of the counterweight rail for counterweight. Utilizing these spans the analysis applies for brackets with a shorter span and no further calculations will be required. The design was analyzed for stresses and deflection utilizing MathCAD software (see Appendix I). Using the calculated seismic loads from the last section, the calculations were done in three parts (see Figure 11).

![Figure 11 Sections of Design Analysis](image)

Part one is the analysis of the car side of the bracket. Part one is broken into three sections, two on welding stress and the third on bending stress in the extension angles. The first welded joint closest to the car rail was analyzed for maximum shear stress. This was accomplished using the following equations for primary and secondary shear [3].

### Primary Shear
\[ \tau_{p1} = 2198 \text{ psi} \]

### Secondary Shear
\[ \tau_{s1} = 2481 \text{ psi} \]

The maximum shear was calculated using vector resolution to find shear in ‘x’ and ‘y’ components. These values were then used in the following equation to find maximum shear stress.

### Maximum Shear Stress
\[ \tau = 4644 \text{ psi} \]
This value was used to determine factor of safety based on allowable per AWS D1.1-2004 Table 2.3 [4]. The allowable shear stress per AWS is 40% times the yield strength of the base material or 30% times the tensile strength of filler material. The base material used for this project is A36 steel which \( F_{yB} \) (Yield Strength) = 36,000 psi. The filler material used is an E60 electrode which has a tensile strength of 60,000 psi. Using these values with the maximum shear stress above the factors of safeties were determined.

<table>
<thead>
<tr>
<th>Base Material</th>
<th>Filler Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS = 3.1</td>
<td>FS = 3.9</td>
</tr>
</tbody>
</table>

The second welded area (the one sitting on the shared shelf angle) in part one was analyzed using the same method. The calculated values are as follows.

\[
\tau_{P2} = 1758 \text{ psi} \quad \tau_{S2} = 8577 \text{ psi}
\]

\[
\text{Maximum Shear Stress}
\]

\[
\tau = 10268 \text{ psi}
\]

<table>
<thead>
<tr>
<th>Base Material</th>
<th>Filler Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS = 1.4</td>
<td>FS = 1.8</td>
</tr>
</tbody>
</table>

The final calculation for part one of the car rail was to find the bending stress in the extension angles. This was accomplished by finding bending force due to ‘x’ and ‘y’ forces applied to the rail. The bending moment in the ‘y’ direction was found by the force times the perpendicular distance.

\[
M_{py} = 28148 \text{ in-lbf}
\]

This moment was then used to find bending stress using the moment of inertia of the angles group and the centroid.

\[
\sigma_{py} = 2150 \text{ psi}
\]

Factors of safety for bending in elevator rail brackets are governed by ASME A17.1 1996 Table 2403.7. This table states that the allowable bending stress is 88% times the yield strength of the base material. In this case that is 36,000 psi. The extension angles the factor of safety was calculated.
**Bending Stress Factor of Safety in the “Y” Direction**

\[ F.S. = \frac{0.88 \cdot F_{y}}{\sigma_{P_{y}}} = 14.734 \]

Deflection (\(\Delta\)) of the extension angles in the “Y” direction was calculated. The maximum deflection allowed per ASME A17.1 1996 Table 2403.7 in rail brackets is 0.10 inches.

**Deflection in the “Y” Direction**

\[ \Delta_{\text{max}} = 0.001 \text{ ft \cdot in} \quad \text{<-- Per ASME A17.1-1996 Table 2403.7:} \]

Allowable Deflection = 0.10in

Bending stress and deflection due to forces in the ‘x’ direction were analyzed in a similar manner and the calculated values are as follows.

**Bending Moment created by Force in the "X" Direction**

\[ M_{P_{x}} = 9035 \text{ in \cdot lbf} \]

**Bending Stress in the “X” Direction**

\[ \sigma_{P_{x}} = 9139 \text{ psi} \]

**Bending Stress Factor of Safety in the “X” Direction**

\[ F.S. = \frac{0.88 \cdot F_{y}}{\sigma_{P_{x}}} = 3.5 \]

**Deflection in the “X” Direction**

\[ \Delta_{\text{max}} = 0.000306 \text{ in} \quad \text{<-- Per ASME A17.1-1996 Table 2403.7:} \]

Allowable Deflection = 0.10in
Part two of the calculations involved analysis of the counterweight rail support angle. The methodology to find weld and bending stresses was similar to those used on the car side bracket. Calculated values for weld stress are as follows.

<table>
<thead>
<tr>
<th>Primary Shear</th>
<th>Secondary Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_{P1}$ = 1450 psi</td>
<td>$\tau_{S1}$ = 13703 psi</td>
</tr>
</tbody>
</table>

**Maximum Shear Stress**

\[
\tau = 14846 \text{ psi}
\]

<table>
<thead>
<tr>
<th>Base Material</th>
<th>Filler Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS = 1</td>
<td>FS = 1.2</td>
</tr>
</tbody>
</table>

The calculated values for bending and deflection in the counterweight angle are as follows.

**Bending Moment created by Force in the "Y" Direction**

\[
M_{Py} = 7110 \text{ in-lbf}
\]

**Bending Stress in the “Y” Direction**

\[
\sigma = 3592 \text{ psi}
\]

**Bending Stress Factor of Safety in the “Y” Direction**

\[
F.S. = \frac{0.88 \cdot F_{yp}}{\sigma} = 8.8
\]

**Deflection in the “Y” Direction**

\[
\Delta_{max} = 0.001 \text{ in}
\]

**Bending Moment created by Force in the "X" Direction**

\[
M_{Px} = 47300 \text{ in-lbf}
\]

**Bending Stress in the “X” Direction**

\[
\sigma = 23893 \text{ psi}
\]

**Bending Stress Factor of Safety in the “X” Direction**

\[
F.S. = \frac{0.88 \cdot F_{yp}}{\sigma} = 1.3
\]

**Deflection in the “X” Direction**

\[
\Delta_{max} = 0.057 \text{ in}
\]
The final part of the rail bracket analysis involved finding the stresses in the shared shelf angle. This part was the most difficult due to the combined loading conditions (car and counterweight). The shelf angle is either attached to the building support via welds or bolts into embedded inserts. In the case of welding the shelf angle to the building steel, the basic steps are the same as the other welds except when finding moments in the x and y direction, combined loading is utilized. The moments were summed about the centroid of the weld group. Moment of inertia in the x and y direction was calculated using formulas from the text solutions to design of weldments [5] for this particular weld pattern. These inertias were then used to calculate the maximum stress.

**Maximum Stress (Normal and Shear)**

\[
\tau_{p_x} = 1649 \text{ psi} \quad \tau_{p_y} = 12534 \text{ psi}
\]

\[
\tau = \sqrt{\frac{\tau_{p_x}^2 + \tau_{p_y}^2}{2}} = 12642 \text{ psi}
\]

To determine the factor of safety the same equations were utilized from the previous weld calculations.

**Base Material**

FS = 1.1

**Filler Material**

FS = 1.4

In the second case using two 5/8” bolts to attach the bracket to the support structure was broken into two cases. In the first case the car and counterweight loads assume to act in the same direction (worse case) placing a shear force on the bolts. This shear stress was then calculated.

**For (2) Bolts, Shear Stress**

\[
\tau_b = 10686 \text{ psi}
\]

An AISC guideline for A307, grade 2 bolts is that max shear equates to 40% the ultimate strength of the material. For A307 grade 2 bolts the ultimate strength is 60,000 psi. Factor of safety is then calculated.

**Bolts Shear Stress Factor of Safety**

FS = 2.2

This case will also impose a moment force on the bolts which will cause the bolts to have a tension reaction on them. To find the tensile stress the forces were summed about a point furthest away from the bolts and forces. This equation was then arranged to equal one of the two unknowns (the two bolt locations). Utilizing the lever rule

**Lever Rule**

\[
\frac{Ra_1}{da_1} = \frac{Ra_2}{da_2} \Rightarrow Ra_1 = \frac{Ra_2}{da_2} da_1
\]
The equation derived from summing the moments was plugged into the equation from the lever rule. This enabled one of the unknowns to be solved. This solution was then used to solve for the second unknown. The tension in each of the bolts was calculated.

**Tension in Bolts**

Ra₁ = 962 lbf  
Ra₂ = 4877 lbf

Max tensile strength was then determined with the bolt seeing the greatest load and calculated.

**Maximum Tensile Stress**

\[ \sigma_a = \frac{Ra_2}{A_b} \]
\[ \sigma_a = 21581 \text{ psi} \]

Per AISC for bolts in tension max allowable is 75% ultimate strength of the material [6].

**Bolts Tension Factor of Safety**

\[ x_F = 2 \]

The second and final case for bolts in tension involved only the counterweight force push in towards the mounting surface. Since the load point was offset from the bolts a moment was created imposing tension on the insert bolts. This tensile stress was calculated in a similar manner as the first case. A reaction force at the bolt was calculated summing the moments. This reaction force was then used to find max tensile stress.

**Maximum Tensile Stress**

\[ \sigma_b = \frac{Rb}{A_b} \]
\[ \sigma_b = 12301 \text{ psi} \]

Factor of safety was solved the same as the first case.

**Bolts Tension Factor of Safety**

\[ x_F = 3 \]

All factors of safety calculated for the improved rail bracket design were one or greater meaning they meet all core requirements for design. If a rail bracket is designed with a mounting surface at or less than 20” for car and 16 ¾” for counterweight it will meet all code requirements. If the bracket is designed for greater distances, more analysis will have to be conducted to ensure code compliant.

All raw material used on the improved bracket design is the same type. Approximately six feet of 3”x3”x3/8” angle iron is needed for the bracket used in the calculations. Other than the angle only four rail clips (device used to hold the guide rail to the rail bracket) and some miscellaneous 5/8” nuts and bolts will be used to assemble the angles.
FABRICATION AND ASSEMBLY

Manufacturing detail drawings for both types of combination brackets were generated from 3D Cad files. The drawings for the improved bracket can be seen in Appendix J. The bracket with the plate was fabricated using a plasma torch cutting table (Figure 12) and a beam worker (Figure 13). The improved design required only the beam worker for manufacturing. Both brackets were assembled with 5/8” nuts and bolts and then preceded to testing.

Figure 12 Plasma Torch Cutting Table

Figure 13 Beam Worker
TESTING

MANUFACTURING

Set-up and machine times were documented for each style bracket. Set-up time for both machines was approximately twenty minutes. The biggest difference between the two designs is the improved design is manufactured out of all the same material. The savings between the plasma cutting table and the beam worker resulted in a savings of a minute per bracket. Every elevator manufactured by Fujitec requires rail brackets. This relatively small time savings should reap large savings over time.

The improved design utilized lighter material than the old or current design. This lighter material meant a reduction in the overall bracket weight of five pounds. The cost to purchase the raw material also was reduced by approximately $2.50.

INSTALLATION

Both brackets were tested for installation utilizing a mock-up rig (Figure 14). Each bracket was simulated being installed five times (See Table 2). Times to install each design averaged the same time. The welding lengths and sizes used for each bracket was the same.

<table>
<thead>
<tr>
<th>Run</th>
<th>Old or Current Design (plate) Time (min.)</th>
<th>Improved Design (angles) Run</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>24</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>Average</td>
<td>23.80</td>
<td>Average</td>
<td>23.80</td>
</tr>
</tbody>
</table>

Figure 14 Bracket Mock-Up
CONCLUSION AND RECOMMENDATIONS

The improved bracket design met all requirements for manufacturing. The installation side proved to be no longer than current designs. Manufacturing the improved bracket proved to be the greatest cost savings. The list below summarizes the savings in manufacturing.

- Saved 11% on the overall cost for the raw material
  $2,330.50 / year *

- Reduced manufacturing time by 55 seconds per bracket
  $1,300.00 / year *

- Reduced machine setup time by 50%
  $4,000.00 / year *

- Reduced the overall weight of the bracket by five pounds

* Figures based on installing ten stop Talons (100/year projected sales for the next five years)

All product objectives were exceeded less the overall cost to install. The initial plan was to reduce the install time by 25%. The overall time did not increase so the new bracket design didn’t negatively affect the total cost currently.

Some recommendations would be to assemble a team of elevator installers that can troubleshoot the improved design with the goal of reducing the total installation time. Additional calculations could be completed to reduce the current weld lengths which would reduce installation time. The final recommendation is to present to Fujitec management to utilize the design concepts in the improved design for traditional overhead elevator applications.

SCHEDULE AND BUDGET

A project schedule was created to ensure project completion was accomplished in the allotted time. The schedule is formatted in Gantt style (See Appendix E). The project timeline covers three quarters of the school year and ends 6/9/07. All scheduled dates were met and no changes had to be made to the schedule. Here is a list of some of the keys dates in the project schedule.

- 1/14/07 Proof of design and design agreement with project advisor
- 2/25/07 Design freeze. (end of designing)
- 3/11/07 Design report due
- 3/12/07 Oral presentation of the design
- 5/6/07 Demonstration of the prototype (full size mock-up)
- 5/16/07 Tech Expo
- 5/30/07 Oral presentations
- 6/4/07 Final project report due

A budget was created to ensure overall costs are covered and are in the acceptable range of project scope (See Appendix F). Most of the cost of the project was covered by Fujitec America, Inc. The actual design time needed was split between work and independent locations. The vast majority of the cost was the welding tests of the brackets building the mock-up. The total amount needed for
the project is projected was initially estimated to be $415.00. The actual cost of the entire project was $500.00. This overage was within 25% of the estimated budget and within an acceptable range for Fujitec management.
REFERENCES


**APPENDIX A CURRENT RAIL BRACKET DESIGNS**

**9/27/06 Traditional Combo Rail Bracket, Fujitec America Inc.**

- Good application for traditional applications.
- Different material types and sizes used.
- Extensive welding required.

Used on traditional elevator configuration with counter located on side of car. Counterweight is offset the car guide rail.
• Applied to traditional elevator configuration when counterweight is centered on the car rail.
• Installation can be time consuming
• Can utilize the same material type.

Used on traditional elevator configuration with counter located on side of car. Counterweight is centered on the car guide rail.
• Applied to traditional elevator configuration when cars are grouped.
• Installation is simple.

Used on elevator configuration with cars side by side sharing hoist ways
Only non-seismic regions.
Simple design.
Material is same type.

Heavy duty guide rail brackets are designed to securely attach car and counterweight rails to the building structure. H-W supplies rail brackets with all necessary mounting hardware. Our engineers will provide you with custom designs to accommodate all bracket conditions except seismic zone 3 or greater or cornerpost car brackets.
Applied to elevator car rail.
Applies to only one rail.
Different material type.
Can be used on counterweight rail in some instances.

Used on elevator car rails with counterweight located towards the rear of the car.
- Applied to elevator car or counterweight rail.
- Can utilize the same material type.
- Only applies to one rail

Used on elevator car or counterweight guide rail.
• Applied to elevator counterweight rail.
• Can utilize the same material type.
• Only applies to one rail.
• Simple.

Used on elevator counterweight guide rail when not grouped with car rail
9/27/06 Flat bar Counterweight Rail Bracket, Fujitec America Inc.

- Applied to elevator counterweight rail.
- Only one material type.
- Only applies to one rail.
- Simple.
- Little to no adjustment

Used on elevator counterweight guide rail when not grouped with car rail.
## Fujitec Talon MRL Product Rail Bracket Design Survey

The development of a new MRL rail bracket design to reduce overall cost of installation is being considered. Please take a few minutes to complete this survey so that your needs are addressed in the development of the product. (Total Responses – 30)

Rate the following product features according to their importance to you:
(1 = Not important to 5 = Very Important) (Frequency’s next to rate value)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Not Important</th>
<th>Very Important</th>
<th>Not Applicable</th>
<th>Averages</th>
</tr>
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<tbody>
<tr>
<td>Minimize Welding Required</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(9)</td>
<td>4(9)</td>
</tr>
<tr>
<td>Simple/Universal Design</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(5)</td>
<td>4(5)</td>
</tr>
<tr>
<td>Lightweight Assembly</td>
<td>1(0)</td>
<td>2(2)</td>
<td>3(4)</td>
<td>4(12)</td>
</tr>
<tr>
<td>Method of Assembly to Building Support Temporarily (Supported prior to welding)</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(15)</td>
<td>4(13)</td>
</tr>
<tr>
<td>Easy to Install</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(2)</td>
<td>4(3)</td>
</tr>
<tr>
<td>Utilize Same Raw Material Throughout Uniform Slots (Size, orientation)</td>
<td>1(0)</td>
<td>2(1)</td>
<td>3(0)</td>
<td>4(4)</td>
</tr>
<tr>
<td>Easy to Manufacture</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(2)</td>
<td>4(13)</td>
</tr>
<tr>
<td>Color of Bracket</td>
<td>1(27)</td>
<td>2(1)</td>
<td>3(0)</td>
<td>4(0)</td>
</tr>
<tr>
<td>Utilize all slots during Installation (Brackets with universal slots)</td>
<td>1(0)</td>
<td>2(4)</td>
<td>3(22)</td>
<td>4(0)</td>
</tr>
<tr>
<td>Low Installation Cost</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(1)</td>
<td>4(0)</td>
</tr>
<tr>
<td>Low Manufacturing Cost</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(0)</td>
<td>4(3)</td>
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</table>

Rate the following product features according to their how satisfied you are with current designs:
(1 = Very Unsatisfied to 5 = Very Satisfied)

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<th>Very Satisfied</th>
<th>Not Applicable</th>
<th>Averages</th>
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<td>2(2)</td>
<td>3(15)</td>
<td>4(10)</td>
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<td>Simple/Universal Design</td>
<td>1(5)</td>
<td>2(20)</td>
<td>3(5)</td>
<td>4(0)</td>
</tr>
<tr>
<td>Lightweight Assembly</td>
<td>1(0)</td>
<td>2(5)</td>
<td>3(20)</td>
<td>4(5)</td>
</tr>
<tr>
<td>Method of Assembly to Building Support Temporarily (Supported prior to welding)</td>
<td>1(0)</td>
<td>2(4)</td>
<td>3(15)</td>
<td>4(4)</td>
</tr>
<tr>
<td>Easy to Install</td>
<td>1(0)</td>
<td>2(10)</td>
<td>3(10)</td>
<td>4(3)</td>
</tr>
<tr>
<td>Utilize Same Raw Material Throughout Uniform Slots (Size, orientation)</td>
<td>1(0)</td>
<td>2(10)</td>
<td>3(10)</td>
<td>4(10)</td>
</tr>
<tr>
<td>Easy to Manufacture</td>
<td>1(0)</td>
<td>2(0)</td>
<td>3(0)</td>
<td>4(0)</td>
</tr>
<tr>
<td>Color of Bracket</td>
<td>1(0)</td>
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<td>3(5)</td>
<td>4(5)</td>
</tr>
<tr>
<td>Utilize all slots during Installation (Brackets with universal slots)</td>
<td>1(0)</td>
<td>2(5)</td>
<td>3(10)</td>
<td>4(10)</td>
</tr>
<tr>
<td>Low Installation Cost</td>
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<td>3(25)</td>
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<tr>
<td>Low Manufacturing Cost</td>
<td>1(0)</td>
<td>2(10)</td>
<td>3(20)</td>
<td>4(0)</td>
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### APPENDIX C QUALITY FUNCTION DEPLOYMENT

9 = Strong  
3 = Moderate  
1 = Weak  
no relation = blank

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Cost</th>
<th>Common Assembly Components</th>
<th>Component Weight</th>
<th>Material Manufacturability</th>
<th>Layout Geometry</th>
<th>Component Ease to Install</th>
<th>Component Ease to Manufacture</th>
<th>Customer Importance</th>
<th>Satisfaction</th>
<th>Planned Bracket Design</th>
<th>Improvement Ratio</th>
<th>Sales Points</th>
<th>Improvement (Absolute Weight) Ratio</th>
<th>Relative Weight</th>
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<tr>
<td>Installation</td>
<td>1. Minimize welding</td>
<td>1</td>
<td>1</td>
<td>9</td>
<td>4.1</td>
<td>3.27</td>
<td>4</td>
<td>1.2</td>
<td>1.0</td>
<td>5.0</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Simple/ Universal Design</td>
<td>3</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td>4.5</td>
<td>2</td>
<td>5</td>
<td>2.5</td>
<td>2.0</td>
<td>22.5</td>
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<tr>
<td>3. Light assembly</td>
<td>3</td>
<td>9</td>
<td>3</td>
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<td>1.0</td>
<td>1.0</td>
<td>4.1</td>
<td>0.04</td>
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<td></td>
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<tr>
<td>4. Temporary attachment</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>3.2</td>
<td>2.6</td>
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<td>0.8</td>
<td>1.0</td>
<td>2.5</td>
<td>0.02</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5. Easy to install</td>
<td>9</td>
<td>9</td>
<td>4.8</td>
<td>2.33</td>
<td>5</td>
<td>2.1</td>
<td>2.0</td>
<td>20.47</td>
<td>0.18</td>
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<td></td>
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</tr>
<tr>
<td>Manufacturing</td>
<td>6. Same raw material size</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4.8</td>
<td>3.17</td>
<td>4</td>
<td>1.3</td>
<td>1.5</td>
<td>9.1</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Uniform slots</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td>4.4</td>
<td>3</td>
<td>4</td>
<td>1.3</td>
<td>1.5</td>
<td>8.9</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Easy to manufacture</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>9</td>
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<td>1.3</td>
<td>1.5</td>
<td>8.9</td>
<td>0.08</td>
<td></td>
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<td></td>
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<tr>
<td>Aesthetics</td>
<td>9. Bracket Color</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
<td>1.5</td>
<td>1</td>
<td>0.7</td>
<td>1.0</td>
<td>0.6</td>
<td>0.01</td>
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<tr>
<td>10. No visible unused slots</td>
<td>1</td>
<td>1</td>
<td>3.1</td>
<td>2.67</td>
<td>1</td>
<td>0.4</td>
<td>1.0</td>
<td>1.2</td>
<td>0.01</td>
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<tr>
<td>Cost</td>
<td>11. Installation cost</td>
<td>3</td>
<td>9</td>
<td>4.9</td>
<td>2.83</td>
<td>5</td>
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</tr>
<tr>
<td>12. Manufacturing cost</td>
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<td>3</td>
<td>9</td>
<td>4.9</td>
<td>2.67</td>
<td>5</td>
<td>1.9</td>
<td>1.5</td>
<td>13.76</td>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
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</table>

| Absolute Importance | 17.01 |
| Relative Importance | 114.5 | 1.00 |
| Direction of movement | Down 0.10 | Up 0.12 | 2.01 | X 0.08 | 1.37 | X 0.05 | 0.79 | X 0.00 | 0.05 | Down 0.31 | 5.28 |
| Units | s | lbs. | sec | Down 0.19 | 3.31 |

Appendix C1
## APPENDIX D PRODUCT OBJECTIVES

<table>
<thead>
<tr>
<th>Objective</th>
<th>Desired Characteristics</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Reduce the amount of Welding</td>
<td>Just enough to meet ASME A17.1</td>
<td>The prototype was designed with enough welds to meet code requirements but no more than required.</td>
</tr>
<tr>
<td>Simple/Universal Design</td>
<td>Common assembly components</td>
<td>The prototype was designed so that some parts are interchangeable which should reduce inventory stock and engineering time.</td>
</tr>
<tr>
<td>Lightweight Assembly</td>
<td>Weight</td>
<td>The prototype will weight not more than current designs</td>
</tr>
<tr>
<td>Temporary Attachment</td>
<td>Layout Geometry</td>
<td>The prototype will have capability of being temporarily attached to building steel prior to welding to aid in adjustment phase.</td>
</tr>
<tr>
<td>Easy to Install</td>
<td>Time Taken to Install</td>
<td>The prototype will reduce the amount of time spent installing elevator brackets from the current designs.</td>
</tr>
<tr>
<td>Same Raw Material Size</td>
<td>Common assembly components and material manufacturability</td>
<td>The prototype was designed to utilize less material types than current designs.</td>
</tr>
<tr>
<td>Uniform Slots</td>
<td>Standard Tooling on same datum.</td>
<td>The prototype will use standard tooling dies and have fewer variations of slots than current designs.</td>
</tr>
<tr>
<td>Easy to Manufacture</td>
<td>Time to Manufacture</td>
<td>The prototype will reduce the amount of time spent manufacturing elevator brackets from current designs.</td>
</tr>
<tr>
<td>Bracket Color</td>
<td>Finish by code</td>
<td>The prototype will have the minimum finish required to meet code or specifications.</td>
</tr>
<tr>
<td>No Visible Unused Slots</td>
<td>Layout of slots</td>
<td>The prototype will have the minimum slots required to achieve objective.</td>
</tr>
<tr>
<td>Installation Costs</td>
<td>Time and Material to Install</td>
<td>The prototype will reduce the amount of time spent installing elevator brackets from current designs.</td>
</tr>
<tr>
<td>Manufacturing Costs</td>
<td>Time and Material to Manufacture</td>
<td>The prototype will reduce the amount of time spent manufacturing elevator brackets from current designs.</td>
</tr>
</tbody>
</table>
APPENDIX E SCHEDULE

Hummeldorf, Paul Elevator Rail Bracket Improvement

Dates
Winter Quarter
Surpass
Spring Quarter

Tasks (Deadlines)

<table>
<thead>
<tr>
<th>Dates</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1-1/7</td>
<td>Proof of design/Agreement (1/14/07)</td>
</tr>
<tr>
<td>1/8-1/14</td>
<td>Weighted Objective Method</td>
</tr>
<tr>
<td>1/15-1/21</td>
<td>Design of Bracket</td>
</tr>
<tr>
<td>1/22-1/28</td>
<td>FEA analysis</td>
</tr>
<tr>
<td>1/29-2/4</td>
<td>Excel Sheet for sizing Bracket</td>
</tr>
<tr>
<td>2/5-2/11</td>
<td>ASME A.17 Code Check</td>
</tr>
<tr>
<td>2/12-2/18</td>
<td>Design of Manufacturing</td>
</tr>
<tr>
<td>2/19-2/25</td>
<td>Design Freeze (2/25/07)</td>
</tr>
<tr>
<td>2/26-3/4</td>
<td>Order Parts</td>
</tr>
<tr>
<td>3/5-3/11</td>
<td>Oral Design Presentation (3/12/07)</td>
</tr>
<tr>
<td>3/12-3/18</td>
<td>Touch up design</td>
</tr>
<tr>
<td>3/26-4/1</td>
<td>Spring Break</td>
</tr>
<tr>
<td>4/2-4/8</td>
<td>Build Bracket</td>
</tr>
<tr>
<td>4/9-4/15</td>
<td>Build mock-up building support</td>
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<tr>
<td>4/16-4/22</td>
<td>Install Bracket on Mock-up or Test Tower</td>
</tr>
<tr>
<td>4/30-5/6</td>
<td>Demonstration (5/6/07)</td>
</tr>
<tr>
<td>5/7-5/13</td>
<td>Correct problems</td>
</tr>
<tr>
<td>5/14-5/20</td>
<td>Tech EXPO (5/16/07)</td>
</tr>
<tr>
<td>5/21-5/27</td>
<td>Start Oral Presentation (5/30/07)</td>
</tr>
<tr>
<td>6/7-6/13</td>
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Appendix E1
APPENDIX F BUDGET

Hummeldorf, Paul

Elevator Rail Bracket Project

<table>
<thead>
<tr>
<th>Materials, Components or Labor</th>
<th>Forecasted Amount</th>
<th>Actual Amount</th>
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<tbody>
<tr>
<td>Bracket</td>
<td>$75.00</td>
<td>$85.00</td>
</tr>
<tr>
<td>Hardware and clips</td>
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<td>$20.00</td>
</tr>
<tr>
<td>Machine time (two hours)</td>
<td>$160.00</td>
<td>$195.00</td>
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<tr>
<td>Welding booth (two hours)</td>
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<td>$200.00</td>
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<td>Total</td>
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<td>$500.00</td>
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# APPENDIX G WEIGHTED DECISION MATRIX

## Weighted Decision Matrix for Elevator Rail Bracket Improvement

<table>
<thead>
<tr>
<th>Design Criterion</th>
<th>Weight Factor</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
<th>Magnitude</th>
<th>Score</th>
<th>Rating</th>
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</thead>
<tbody>
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<td>Component Cost</td>
<td>0.10</td>
<td>Satisfactory</td>
<td>2</td>
<td>0.20</td>
<td>Good</td>
<td>3</td>
<td>0.30</td>
<td>Weak</td>
<td>1</td>
<td>0.10</td>
</tr>
<tr>
<td>Common assembly Components</td>
<td>0.12</td>
<td>Weak</td>
<td>1</td>
<td>0.12</td>
<td>Excellent</td>
<td>4</td>
<td>0.48</td>
<td>Good</td>
<td>3</td>
<td>0.36</td>
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<td>Component Weight</td>
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<td>0.28</td>
<td>Good</td>
<td>3</td>
<td>0.42</td>
<td>Excellent</td>
<td>4</td>
<td>0.56</td>
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<td>0.24</td>
<td>Excellent</td>
<td>4</td>
<td>0.32</td>
<td>Satisfactory</td>
<td>2</td>
<td>0.16</td>
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<td>Layout Geometry</td>
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<td>2</td>
<td>0.10</td>
<td>Satisfactory</td>
<td>2</td>
<td>0.10</td>
<td>Good</td>
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<td>2</td>
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<td>2</td>
<td>0.00</td>
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<td>2</td>
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<tr>
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<td>Satisfactory</td>
<td>2</td>
<td>0.62</td>
<td>Good</td>
<td>3</td>
<td>0.93</td>
<td>Excellent</td>
<td>4</td>
<td>1.24</td>
</tr>
<tr>
<td>Component Easy to Manufacture</td>
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<td>Satisfactory</td>
<td>2</td>
<td>0.38</td>
<td>Excellent</td>
<td>4</td>
<td>0.76</td>
<td>Satisfactory</td>
<td>2</td>
<td>0.38</td>
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<table>
<thead>
<tr>
<th></th>
<th>Angles with Extension Plate</th>
<th>All Angles</th>
<th>Angles with Large Tube</th>
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<tbody>
<tr>
<td></td>
<td>Magnitude</td>
<td>Score</td>
<td>Rating</td>
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<tr>
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<td>Inadequate</td>
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## TABLE 2403.7

<table>
<thead>
<tr>
<th>Guide Rail Bracket</th>
<th>Bracket Type</th>
<th>Vertical Location</th>
<th>Typical Figure</th>
<th>Moment of Inertia, in.²</th>
<th>Bracket Design Load P, lb</th>
<th>Band Stress, psi</th>
<th>Deflection, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main (Car and counterweight)</td>
<td>Any Building supports</td>
<td>...</td>
<td>W/3</td>
<td>...</td>
<td>0.10</td>
<td></td>
<td></td>
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<tr>
<td>Intermediate tie (Counterweight)</td>
<td>Double U bracket</td>
<td>Mid-span 1/3 span</td>
<td>W/6</td>
<td></td>
<td>0.89/Fyp</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Single U bracket</td>
<td>Mid-span 1/3 span</td>
<td>W/6</td>
<td></td>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where
- \( F_p \) = minimum yield stress of material, psi
- \( I_d \) = moment of inertia of single "U" intermediate, tie bracket, in.², in a double "U" bracket arrangement
- \( L \) = vertical distance between the upper and lower position restraints required by Rules 2404.2 and 2406.1, in.
- \( e \) = distance (rail span) between adjacent main guide rail brackets, in.
- \( W \) = maximum weight of car with 40% rated capacity or counterweight, lb
- \( P \) = horizontal seismic load, lb

*For hydraulic elevator main bracket design load (car) add 1/4 the weight of the plunger (zone 3 or greater).*

1 For Zone 2, multiply design load \( P \) by 0.5

### General Note:

1 in. = 25.4 mm
1 lb = 0.454 kg

### Rule 2403.9 Information on Elevator Layouts

The following information is required on elevator layout drawings:

1. The horizontal seismic forces imposed on the guide rail faces by the lower position restraints of the car or counterweight. The forces are to be determined as follows (see Fig. 2403.9):
   - (1) Where \( L \geq e \) (see Table 2403.7):
     - (a) Force normal to the (x-x) axis of the guide rail:
       - (SI Units) \( F_{ex} = 9.807 \left( \frac{W}{3} \right) \) (Zone 2)
       - (Customary Units) \( F_{ex} = \frac{W}{3} \) (Zone 2)
   - (2) Where \( L < e \) (see Table 2403.7):
     - (SI Units) \( F_{ex} = 9.807 \left( \frac{W}{6} \right) \) (Zone 2)
     - (Customary Units) \( F_{ex} = \frac{W}{6} \) (Zone 2)
   
2. Where \( L < e \) (see Table 2403.7):
Appendix H3

ASME A17.1-1996

Rule 2403.3—Rule 2404.2

(Fig. 2403.9 Guide Rail Axes)

guide rail force at the lower position restraint to not
more than 1/4 of the total seismic force due to the
weight of the counterweight assembly when it is
subjected to a horizontal seismic force of not less
than that required to produce an acceleration of:
(a) 1/4 gravity (zone 3 or greater)
(b) 1/4 gravity (zone 2)
The clearance between the counterweight frame
and the face of the counterweight guide rail measured
at a point 1/4 the vertical distance between the
upper and lower guiding members shall not exceed 1/4
in. (13 mm).

Rule 2404.2 Guiding Members and Position
Restrains

(a) Upper and lower position restraints attached
to the counterweight frame shall be provided. The
distance between the upper and lower position re-
straints shall be not less than the height of the
counterweight frame. Separate position restraints are
not required where such restraints are an integral
part of guiding member.
(b) Position restraints and their attachments to
counterweight frames shall be designed to withstand
a seismic force acting horizontally upon the counter-
weight assembly of not less than that required to
produce an acceleration of:
(i) 1/4 gravity (zone 3 or greater)
(ii) 1/4 gravity (zone 2)
(c) When the counterweight is centrally located
between its guide rails, the clearance between each
running face of the guide rail and the position re-
straint shall not exceed 1/4 in. (4.8 mm) and the

SECTION 2404 COUNTERWEIGHTS

Rule 2404.1 Design

The counterweight frame and its weight sections
shall be so designed and arranged as to limit the

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where

F = seismic force, lb (N)
W = total weight of car plus 40% of its rated load,
or the total weight of the counterweight, lb
(kg)
APPENDIX I RAIL BRACKET CALCULATIONS

Part 1a: Analysis of Car Rail Bracket Support

Combination rail brackets will be of an "Angle-Angles-Angle" type design. By analysis of the stresses and deflection of the rail brackets, this will determine if the design is sufficient for the rail forces induced.

\[
\begin{align*}
\text{Car}P_x & = 2780 \text{ lb} \\
\text{Cwt}P_x & = 3440 \text{ lb} \\
\text{Car}P_y & = 1390 \text{ lb} \\
\text{Cwt}P_y & = 1720 \text{ lb}
\end{align*}
\]

<Fujitec Talon calculated rail loads for seismic zone 3 or 4>
Weld 1  Assume the weld in question is in shear only, no bending.

\[ \begin{align*}
L_1 & = 2\text{ in} \quad \text{(Length of weld)} \\
h & = .25\text{ in} \quad \text{(Size of weld)} \\
c & = 8.0\text{ in} \quad \text{(Spacing between welds)} \\
x_1 & = 5.0\text{ in} \quad \text{(Dist. from load to centroid of weld group)} \\
M_{Py} & = \text{CarPy}(r_1) \\
A_{Weld} & = \sqrt{2 \cdot h \cdot L_1} \\
J_u & = \frac{L_1 \left(3 \cdot c^2 + L_1^2\right)}{6} \\
A_{Weld} & = 0.707 \text{ in}^2 \\
\end{align*} \]

Primary Shear

\[ \tau_{P1} = \frac{V}{A_{Weld}} \]

\[ \tau_{P1} = 21.98 \text{ psi} \]

Secondary Shear

\[ \tau_{S1} = \frac{M_{Py}r_1}{J} \]

\[ \tau_{S1} = 2481 \text{ psi} \]

Determine Maximum Shear

\[ \tau_x = \frac{\tau_{S1} \cdot r_1}{2} + \tau_{P1} \]

\[ \tau_y = \frac{\tau_{S1} \cdot r_1}{2} \]

\[ \tau = \sqrt{\tau_x^2 + \tau_y^2} \]

\[ \tau = 4644 \text{ psi} \]

Allowable Stress = 0.40 \( F_{yp} \) or = 0.30* tensile strength of weld filler metal

(per AWS D1.1-2004, Table 2.3, Allowable Stresses on Fillet Welds loaded in shear)

\[ F_{yp} = 36000 \text{ psi} \]

\[ S_{LE60} = 60000 \text{ psi} \quad \text{(for E60 electrode)} \]

Base material

\[ \frac{0.40 \cdot F_{yp}}{\tau} \quad \text{FS} = 3.1 \]

Filler material

\[ \frac{0.30 \cdot S_{LE60}}{\tau} \quad \text{FS} = 3.9 \]
Talon Elevator Bracket Design

Seismic Zone 3 & 4 Rail Brackets

\[ \tau_{\text{max}} \]

\[ L/2 \]

\[ c/2 \]

\[ 90^\circ \]

\[ r_1 \]

\[ \frac{c}{2} = 0.97 \] (Cosine, X)

\[ \frac{L_1}{r_1} = 0.243 \] (Sine, Y)

\[ f := \text{atan} \left( \frac{L_1}{\frac{c}{2}} \right) \]

\[ f = 14.036 \text{ deg} \]

Talon Combo Rail Bracket Seismic Analysis
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Talon Elevator Bracket Design
Seismic Zone 3 & 4 Rail Brackets

Weld 2 (Similar analysis as 1)

\[ L_2 = 2.5 \text{in} \text{ (Length of weld)} \]
\[ h = .25 \text{in} \text{ (Size of weld)} \]
\[ e = 8 \text{in} \text{ (Spacing between welds)} \]
\[ x_2 = 21.5 \text{in} \text{ (Dist. from load to centroid of weld group)} \]
\[ M_2 = \text{CarP}_y(x_2) \]
\[ A_{Weld} = \sqrt{2} \times h \times L_2 \]
\[ A_{Weld} = 0.884 \text{in}^2 \]
\[ J_2 = \frac{L_2}{6} \left( 3 \times e^2 + L_2 \right) \]

**Primary Shear**

\[ \tau_{p2} = \frac{V}{A_{Weld}} \]
\[ \tau_{p2} = 1758 \text{psi} \]

**Secondary Shear**

\[ \tau_{s2} = \frac{M_2 r_2}{J} \]
\[ \tau_{s2} = 8577 \text{psi} \]

**Determine Maximum Shear**

\[ \tau_x = \tau_{s2} + \tau_{p2} \]
\[ \tau_y = \tau_{s2} + \tau_{p2} \]
\[ \tau = \sqrt{\tau_x^2 + \tau_y^2} \]
\[ \tau = 10268 \text{psi} \]

Allowable Stress = 0.40 F_y, or = 0.30* tensile strength of weld filler metal
(per AWS D1.1-2004, Table 2.3, Allowable Stresses on Fillet Welds loaded in shear)

\[ F_y = 36000 \text{psi} \]
\[ S_{E60} = 66000 \text{psi} \text{ (for E60 electrode)} \]

Base material
\[ \text{FS} = \frac{0.40 \times F_y}{\tau} \]
\[ \text{FS} = 1.4 \]

Filter material
\[ \text{FS} = \frac{0.30 \times S_{E60}}{\tau} \]
\[ \text{FS} = 1.8 \]

Talon Combo Rail Bracket Seismic Analysis
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Part 1b: Analysis of Car Rail Bracket Extension Angles

Calculate the Maximum Bending Stress in Angles from Py:

\[ x_4 = 20.25\text{in} \]

\[ M_{Py} = CarPy\left(x_4\right) \quad \text{Bending Moment created by Rail Force} \]

\[ M_{Py} = 28148 \text{ in-lbf} \]

\[ \sigma_{Py} = \frac{M_{Py}c}{I} \quad \text{Where} \quad I = 11.49\text{in}^4 \quad c = 0.877\text{in} \]

\[ \sigma_{Py} = \frac{2150}{14.734} = 2150 \text{psi} \quad \text{F.S.} = \frac{0.88\cdot \sigma_{fl}}{\sigma_{Py}} = 14.734 \quad \text{(Per ASME A17.1-1996 Table 2403.7)} \]
Calculate the deflection in Angles from $P_Y$:

\[ \Delta_{\text{max}} = -\frac{P \cdot L^3}{3 \cdot E \cdot I} \]

Where: $E = 300,000,000$ psi (for steel)

\[ \Delta_{\text{max}} = \frac{C \cdot P_Y \cdot (z_1)^3}{3 \cdot E \cdot I} \]

\[ \Delta_{\text{max}} = 0.011 \text{ in} \quad \text{-- Per ASME A17.1-1996 Table 2403.7:} \]

Allowable Deflection = 0.10 in

Calculate the Maximum Bending Stress in Angles from $P_X$:

\[ z_1 = 3.25 \text{ in} \]

\[ M_{P_X} = C \cdot P_X \cdot (z_1) \quad \text{Bending Moment created by Rail Force} \]

\[ M_{P_X} = 9035 \text{ in-lbf} \]

\[ \sigma_{P_X} = \frac{M_{P_X} \cdot c}{I} \quad \text{Where} \quad I = 3.46 \text{ in}^4 \quad \text{and} \quad c = 3.50 \text{ in} \]

\[ P_{P_X} = 9199 \text{ psi} \quad \text{F.S.} = \frac{0.88 \cdot F_Y}{\sigma_{P_X}} = 3.5 \quad \text{(Per ASME A17.1-1996 Table 2403.7)} \]

Calculate the deflection in Angles from $P_X$:

\[ \Delta_{\text{max}} = \frac{C \cdot P_X \cdot (z_1)^3}{3 \cdot E \cdot I} \]

\[ \Delta_{\text{max}} = 0.000306 \text{ in} \quad \text{-- Per ASME A17.1-1996 Table 2403.7:} \]

Allowable Deflection = 0.10 in
Part 2a: Analysis of Cwt Rail Angle

Fujitec Talon counterweight bracket is an Angle type design. By analysis of the stresses induced in the counterweight rail bracket, this will determine if the design is sufficient for the rail forces induced.

[Diagram of Talon Elevator Bracket Design]

Talon Elevator Bracket Design
Seismic Zone 3 & 4 Rail Brackets
Weld 3  Assume the weld in question is in shear only, no bending.

\[ L_1 = 2.5 \text{in (Length of weld)} \quad h = .375 \text{in (Size of weld)} \quad c = 3 \text{in} \]

\[ y_1 = 15 \text{in} \quad M_{px} = \text{Cwt}_{p_x}(y_1) \]

\[ A_{\text{Weld}} = \sqrt{2 \cdot b \cdot L_1} \quad A_{\text{Weld}} = 1.326 \text{in}^2 \]

\[ J_u = \left(\frac{c + L_1}{6}\right)^3 \]

Primary Shear

\[ \tau_{p1} = \frac{V}{A_{\text{Weld}}} \]

\[ \tau_{p1} = 1450 \text{psi} \]

Secondary Shear

\[ \tau_{s1} = \frac{M_{px} \cdot T_1}{J} \]

\[ \tau_{s1} = 1370 \text{psi} \]

Determine Maximum Shear

\[ \tau_x = \tau_{s1} \cdot \frac{c}{T_1} + \tau_{p1} \]

\[ \tau_y = \tau_{s1} \cdot \frac{L_1}{T_1} \]

\[ \tau = \sqrt{\tau_x^2 + \tau_y^2} \quad \tau = 1484 \text{ psi} \]

Allowable Stress = 0.40 \( F_{yp} \) or = 0.30* tensile strength of weld filler metal

(Per AWS D1.1-2004, Table 2.3, Allowable Stresses on Fillet Welds loaded in shear)

\[ F_{yp} = 36000 \text{psi} \quad S_{E60} = 60000 \text{psi} \text{ (for E60 electrode)} \]

Base material  Filler material

\[ FS = \frac{0.40 \cdot F_{yp}}{\tau} \quad FS = 1 \]

\[ FS = \frac{0.30 \cdot S_{E60}}{\tau} \quad FS = 1.2 \]
\[ \frac{c}{r_1} = 0.768 \quad \frac{L_1}{r_1} = 0.64 \]

(Cosine, X) \quad (Sine, Y)

\[ f = \text{atan} \left( \frac{L_1}{\frac{c}{2}} \right) \]

\[ f = 39.806 \text{ deg} \]
Part 2b: Analysis of Stresses and Deflection in Cwt Rail Bracket Angle

\[ y_2 = 13 \frac{3}{4}'' \]

\[ \text{L3' x 3' x 3/8''} \]

\[ c = \text{NEUTRAL AXIS} \]
Calculate the Maximum Bending Stress in rail angle member from Py:

\[ c = 0.884\text{in} \]
\[ s_1 = c + 3.25\text{in} \]

\[ M_{Py} = C_{w}tP_y(s_1) \quad \text{Bending Moment created by Rail Force} \]

\[ M_{Py} = 7110\text{ in-lbf} \]

\[ \sigma = \frac{M_{Py}c}{I} \]
\[ \text{Where} \quad I = 1.75\text{in}^4 \quad \text{(Per AISC for [L3" x 3" x 3/8"] angles)} \]

\[ \sigma = 3592\text{ psi} \quad \text{F.S.} = \frac{0.88-F_{y}}{\sigma} = 8.8 \quad \text{(Per ASME A17.1-1996 Table 2403.7)} \]

Calculate the deflection in angle member from Py:

\[ \lambda_{max} = \frac{P L^3}{3 E I} \]

\[ \text{Where;} \quad E = 30000000\text{ psi} \quad \text{(for steel)} \]

\[ \lambda_{max} = \frac{C_{w}tP_y(s_1)}{3 E I} \]

\[ \lambda_{max} = 0.001\text{in} \quad \text{-- Per ASME A17.1-1996 Table 2403.7: Allowable Deflection = 0.10in} \]
**Calculate the Maximum Bending Stress in rail angle member from Px:**

\[
c = 0.884\text{in} \quad \gamma = 13.75\text{in}
\]

\[
M_{Px} = CwP_x (\gamma)
\]

Bending Moment created by Rail Force

\[
M_{Px} = 47300\text{ in-lbf}
\]

\[
\sigma = \frac{M_{Px} \cdot c}{I}
\]

Where \( I = 1.75\text{in}^4 \) (Per AISC for [L3" x 3" x 3/8"] angles)

\[
\sigma = \frac{M_{Px} \cdot c}{I}
\]

\[
\sigma = 23893\text{ psi} \quad \text{F.S.} = \frac{0.88 \cdot F_{yP}}{\sigma} = 1.3
\]

(Per ASME A17.1-1996 Table 2403.7)

**Calculate the deflection in angle member from Px:**

\[
\Delta_{max} = \frac{P \cdot L^3}{3 \cdot E \cdot I}
\]

Where; \( E = 30000000 \text{psi} \) (for steel)

\[
\Delta_{max} = \frac{CwP_x (\gamma)^3}{3 \cdot E \cdot I}
\]

\[
\Delta_{max} = 0.057\text{in}
\]

← Per ASME A17.1-1996 Table 2403.7:

Allowable Deflection = 0.10in
Part 3: Analysis of Stresses in Shared Shelf Angle

For Bolted Connection

Talon Combo Rail Bracket Seismic Analysis
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Case 1 (only):  Welded Building Connection:

Weld 4  
Assume the weld in question is subject to bending stress and shear stress.

\[ L_3 = 3\text{ in} \quad (\text{Length of weld}) \quad h = .25\text{in} \quad (\text{Size of weld}) \quad d = 21.25\text{in} \quad (\text{Spacing between welds}) \]

\[ x_3 = 23.25\text{in} \quad (\text{Dist. from Car load to centroid of weld group - shear}) \]
\[ x_4 = 16.75\text{in} \quad (\text{Dist. from Cwt load to centroid of weld group - shear}) \]
\[ z_1 = 3\text{in} \quad (\text{Dist. from Cwt load to centroid of weld group - bending}) \]

\[ M_{3x} = CwtP_y \left( x_4 \right) \quad M_{3y} = \left[ CwtP_y \left( x_3 \right) \right] + \left[ CwtP_x \left( x_4 \right) \right] \]

\[ A_{Weld} = \sqrt{2} \cdot h \cdot L_3 \quad A_{Weld} = 1.061\text{in}^2 \]

\[ I_{xu} = \frac{d^3}{6} \]
\[ I_{yu} = \frac{L_3 \cdot d^2}{2} \]

**Determine Maximum Stress (Normal & Shear)**

\[ \tau_{px} = \frac{CwtP_y}{A_{Weld}} \cdot \frac{M_{3x}}{L_3} \]
\[ \tau_{py} = \frac{CwtP_y + CwtP_x}{A_{Weld}} \cdot \frac{M_{3y}}{L_3} \]

\[ \tau_{px} = 1649\text{psi} \quad \tau_{py} = 12534\text{psi} \]

\[ \tau = \sqrt{\tau_{px}^2 + \tau_{py}^2} \quad \tau = 12642\text{psi} \]

Allowable Stress = 0.40 F_y, or = 0.30* tensile strength of weld filler metal

(per AWS D1.1-2004, Table 2.3, Allowable Stresses on Fillet Welds loaded in shear)

\[ F_y = 36000\text{psi} \quad S_t\ E_{60} = 60000\text{psi} \quad (\text{for E60 electrode}) \]

**Base material**

\[ FS = \frac{0.40 \cdot F_y}{\tau} \quad FS = 1.3 \]

**Filler material**

\[ FS = \frac{0.30 \cdot S_t\ E_{60}}{\tau} \quad FS = 1.4 \]
Case 2 only (Insert Building Connection w/ (2) 5/8" UNC bolts):

Case "a" (shear):
ΣFy = 0
Ra3 = CarPy + CwtP3

For 5/8" UNC bolt the tensile stress area is:
A_b = .226 in²

For (2) bolts, the shear stress is:
τ_b = \frac{Ra3}{2 \cdot A_b}
τ_b = 10886 psi

Per AISC, for bolts in shear:
For A307, Grade 2 bolts:
S_{ut} = 60000 psi
τ_{max} = .40 S_{ut}
FS = \frac{τ_{max}}{τ_b} = 2.2

Talon Elevator Bracket Design
Seismic Zone 3 & 4 Rail Brackets

Talon Combo Rail Bracket Seismic Analysis
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Case "a" (tension):

Given:
- CarP_y = 1390 lbf
- da_1 := 3.50 in
- da_2 := 17.75 in
- CwtP_x = 3446 lbf
- x_3 = 23.25 in
- x_4 = 16.75 in

Unknown:
- Ra_1=?
- Ra_2=?

Eq. 1: \[ \Sigma M_o=0 \quad 0 = (CarP_y \cdot x_3) + (CwtP_x \cdot x_4) - (da_1 \cdot Ra_1) - (da_2 \cdot Ra_2) \]

\[ Ra_2 = \frac{-(CarP_y \cdot x_3 + da_1 \cdot Ra_1 - CwtP_x \cdot x_4)}{da_2} \]  
(Lever Rule)

Eq. 2: \[ \frac{Ra_1}{da_1} = \frac{Ra_2}{da_2} \Rightarrow \frac{Ra_1}{da_2} = \frac{Ra_2}{da_1} \]

\[ Ra_1 = \frac{da_2}{da_1} \cdot Ra_2 \]

\[ Ra_1 = \left( CarP_y \cdot x_3 + CwtP_x \cdot x_4 \right) \cdot \frac{da_2}{da_1^2 + da_1^2} \]

\[ Ra_1 = 962 \text{ lbf} \]

\[ Ra_2 = \frac{-(CarP_y \cdot x_3 + da_1 \cdot Ra_1 - CwtP_x \cdot x_4)}{da_2} \]

\[ Ra_2 = 4877 \text{ lbf} \]

Max load per bolt = Ra2

Tensile stress: \[ \sigma_a = \frac{Ra_2}{A_b} \quad \sigma_a = 2158 \text{ psi} \]

Per AISC, for bolts in tension: For A307, Grade 2 bolts:

\[ S_{ut} := 60000 \text{ psi} \]
\[ S_{max} := 0.75 \cdot S_{ut} \]

\[ FS := \frac{\sigma_{max}}{\sigma_a} \]

FS = 2.09
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Talon Elevator Bracket Design

Seismic Zone 3 & 4 Rail Brackets

Case "b" (tension):

Given:
Cwt Py = 1720 lbf  db1 := 1.5in  db2 := 1.5in

Unknown:
Rb=?

Eq. 1:  \( \Sigma M = 0 \)  0 = (P1 db1) - (db2 Rb)
Rb := CarP_x/db2  Rb = 2780 lbf

Tensile stress:
\( \sigma_b = \frac{Rb}{A_b} \)  \( \sigma_b = 12361 \) psi

Per AISC, for bolts in tension:
For A307, Grade 2 bolts:
\( S_{ut} = 60000 \) psi  \( \sigma_{max} = .75 S_{ut} \)  FS := \( \frac{\sigma_{max}}{\sigma_b} \)  FS = 3.66