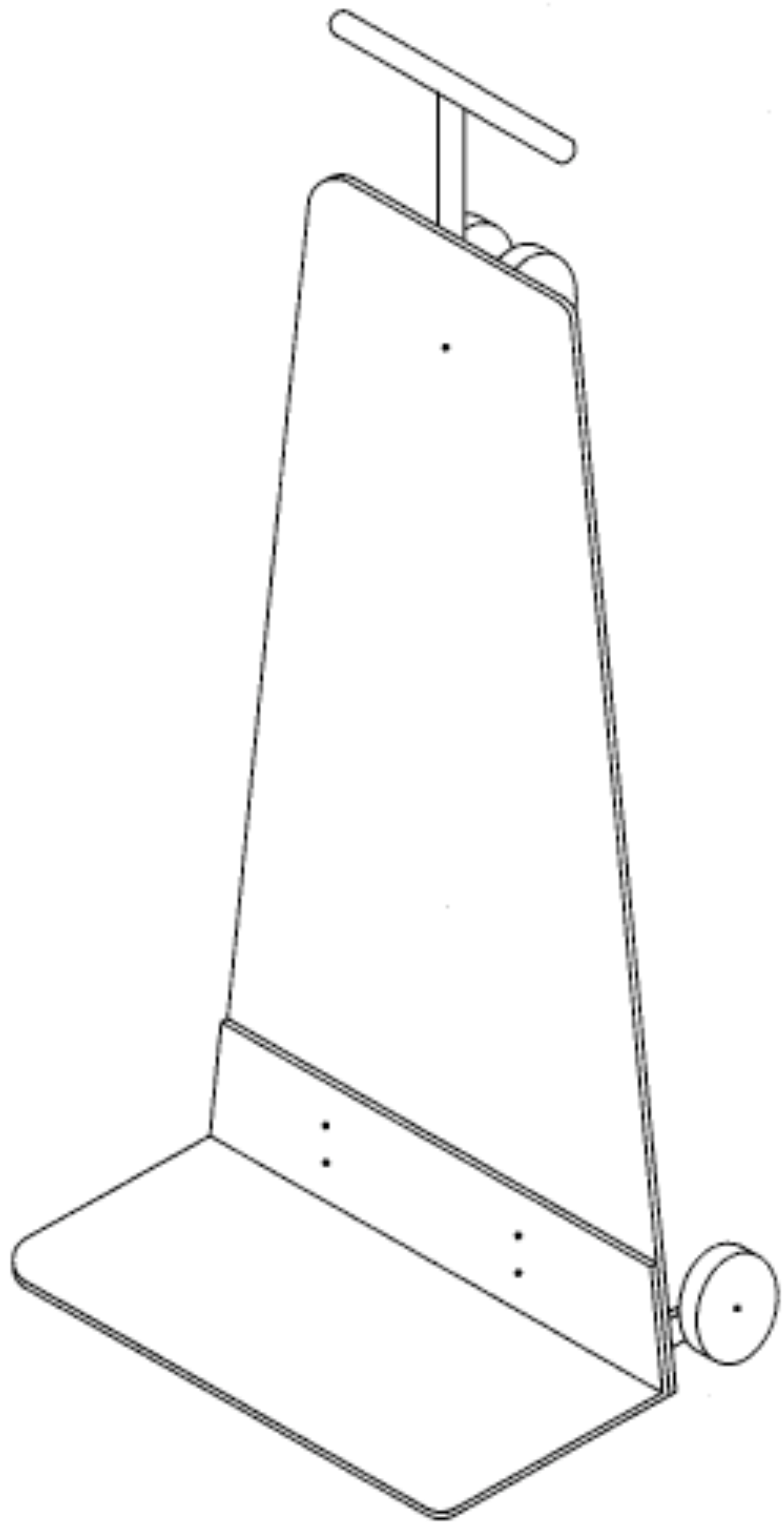
HANDYTRUCKSTER

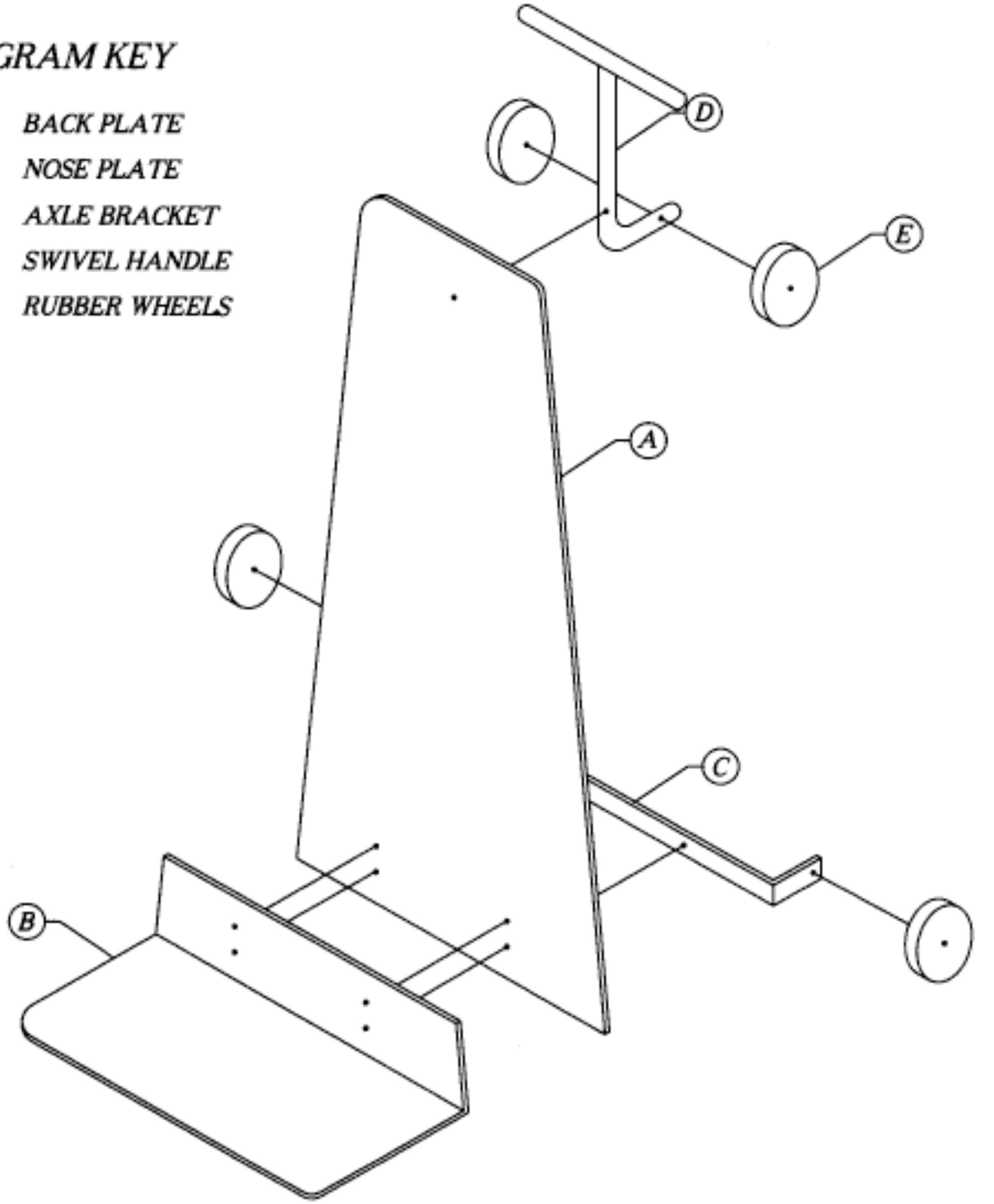


STRENGTH OF MATERIALS
FALL 1997 DESIGN PROJECT

Dennis O'Malley

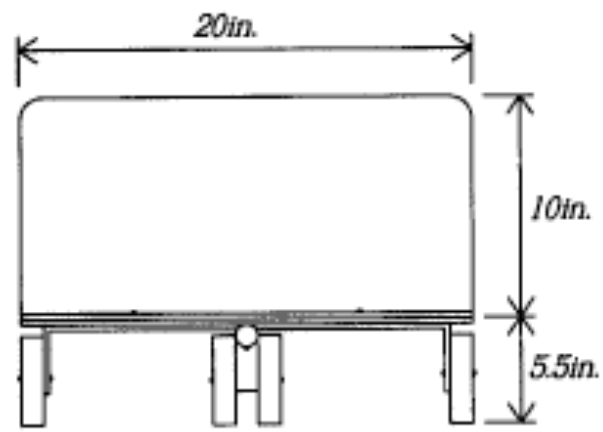
DIAGRAM KEY

- (A) BACK PLATE
- (B) NOSE PLATE
- (C) AXLE BRACKET
- (D) SWIVEL HANDLE
- (E) RUBBER WHEELS

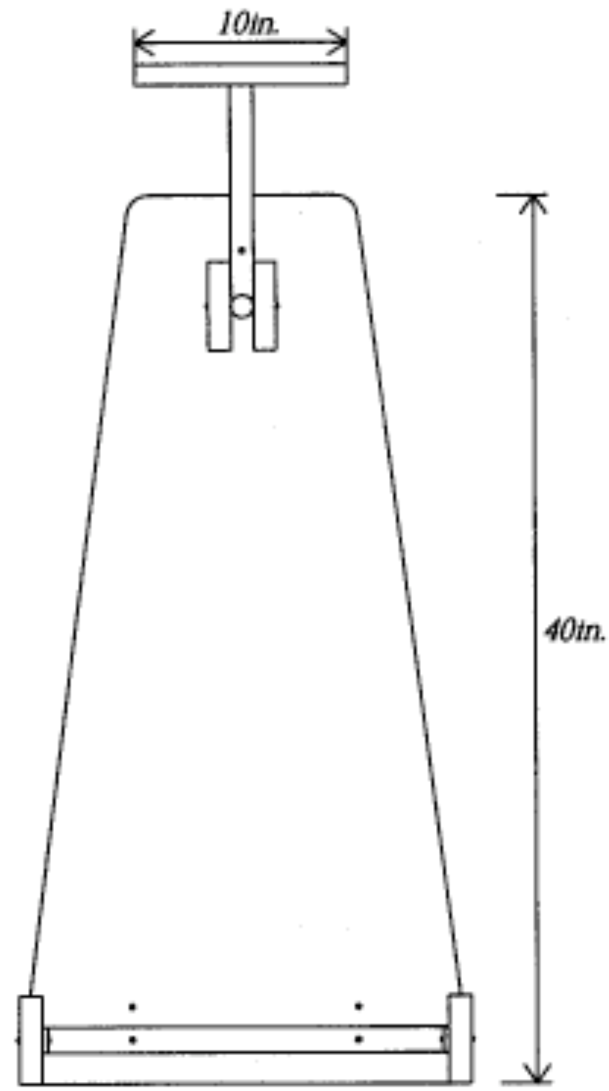


SPECIFICATIONS

WHEELS DIA: 4in. typ.
HANDLE DIA: 1in.
HANDLE EXTENSION: 5in.
SHEET METAL THICKNESS: .16 in. typ.
RIVETS DIA: .25in. typ.
FILLETS: 1in. typ.



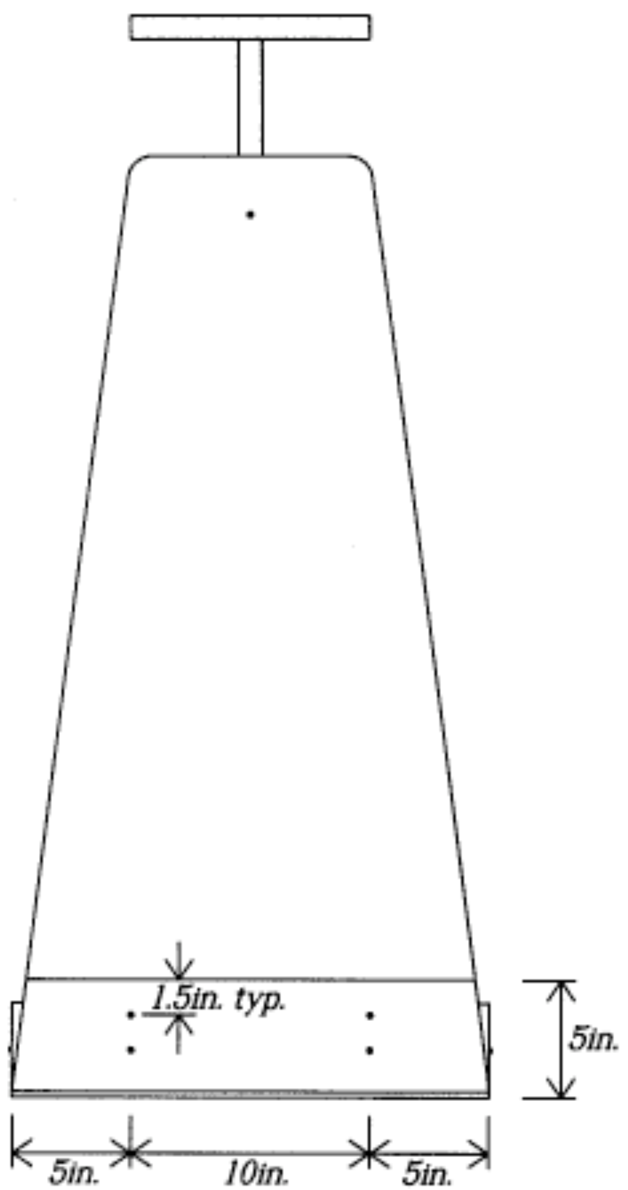
TOP VIEW



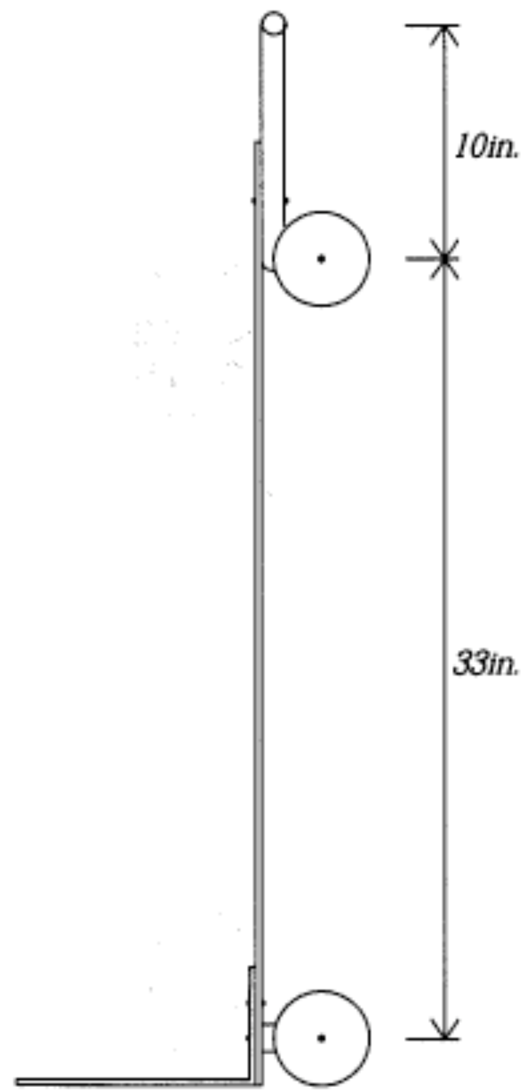
REAR VIEW

SPECIFICATIONS

WHEELS DIA: 4in. typ.
HANDLE DIA: 1in.
HANDLE EXTENSION: 5in.
SHEET METAL THICKNESS: .16 in. typ.
RIVETS DIA: .25in. typ.
FILLETS: 1in. typ.



FRONT VIEW



SIDE VIEW

Bill Of Materials

No.	Parts	Qty	Description	Weight (lb)	Cost
1	Nose and back plates (A & B)	1	20”x50”x0.16” sheet, 2024-T361 Al.	15.7	$41.75
2	Axle Bracket	28 in.	2024-T361 Al. Bar, 1 in. x 0.16 in.	0.7	$3.35
3	Handle (D)	20 in.	2024-T361 Al. Rod, 1 in. dia.	2.4	$7.00
4	Wheels (E)	4	Hard Rubber Tread 4 in. dia.		$38.40
5	Nose-back plate connection	1	Box of bolts ¼ in. dia. x 1”	4.0 (estimate)	$5.00
6	Link	1	Swivel bolt		$2.50
			Total:	22.8	$98.00

Note: Aluminum prices approximated through Ryerson.
Tires and bolts taken from McMaster-Carr Catalogue.

Special Acknowledgement.

This sample is based upon an actual project submitted in Fall 1997 by:

Kevin Choi

Marcel Gordon

Michael Martini

Joseph Sullivan

Note:

This report is flawed by omissions (like quantity and thread size of bolts, size and description of “swivel bolt”) and is more typical of student work rather than professional work. Readers are cautioned to take this into account when reviewing it. And of course feel free to raise and discuss any questionable issues in class.

Methods

To start our design, we selected a list of materials based upon strength and cost and selected aluminum for the structural components because it has a good strength-to-weight ratio compared to steel and it is readily available. Within the aluminum family, we chose a stronger alloy in order to reduce the size of members and exploit strength to weight, hence create an efficient design. We bolted the back plate to the nose plate (instead of welding them together) so that the product could be shipped in a flat box. The handle functions as an extension to the bed in ‘cart mode’ and functions as usual in upright mode. The rubber wheels are gentle on floors and absorb shock. The analysis employed strength of materials, but did not include an advanced theory for the plates. The design was given a distinctive shape to distinguish it from the competition, yet not limit its function.

Assumptions

1. The shear yield stress of ASTM A36 Steel can be approximated by taking 60% of the tensile yield stress based upon comparison of data found for other steels.
2. The shear yield stress of Aluminum 2024-T361 can be approximated by taking 60% of the tensile yield stress based upon comparison of data found for other aluminum alloys.
3. Beam theory applies to the plate structure.

Warnings

1. Wheels themselves were not designed.
2. Weld not analyzed.
3. Swivel attachment of handle not analyzed.

References

"Corrosion Resistance" (Dennis McCrosky), http://www.strongtie.com/Sstcrpg1.htm Simpson Strong-Tie Company, Inc. Viewed (13 Nov. 1997)

"Corrosion Resistance Construction Hardware" (No Author), http://www.hughesmfg.com/Page-45.htm Hughes Manufacturing, Inc. Viewed (17 Nov. 1997)

"Mechanical Properties of Some Materials" http://www-dmso.mit.edu/data/mech/prop-file.html Viewed (24 Nov. 1997)

Hibbler, R.C. (1994) Mechanics of Materials. Engle Wood Cliffs: Prentice Hall.

Ryerson Stock List and Data Book (1987-89) Joseph T. Ryerson & Son Inc., Pittsburgh, PA

Material Properties

Material	σ_{yield} (ksi)	τ_{yield} (ksi)	σ_{allow} (ksi)	τ_{allow} (ksi)	Reference
Al 2024-T361	57	34.2	43.85	26.3	Ryerson (1987-89)
ASTM A36	36	21.6	27.7	16.6	Ryerson (1987-89)

Sample calculations:

$$\sigma_{allow} = \sigma_{yield}/\text{F.S.} = 57/1.3 = 43.85 \text{ ksi}$$
$$\tau_{allow} = \tau_{yield}/\text{F.S.} = 34.2/1.3 = 26.3 \text{ ksi}$$

For both materials, τ_{yield} is approximated as

$$\tau_{yield} = (0.6)\sigma_{yield}$$

Note: Shear yield not available. Taken as 60% based upon data collected for similar materials–see Assumptions, pg. 6.

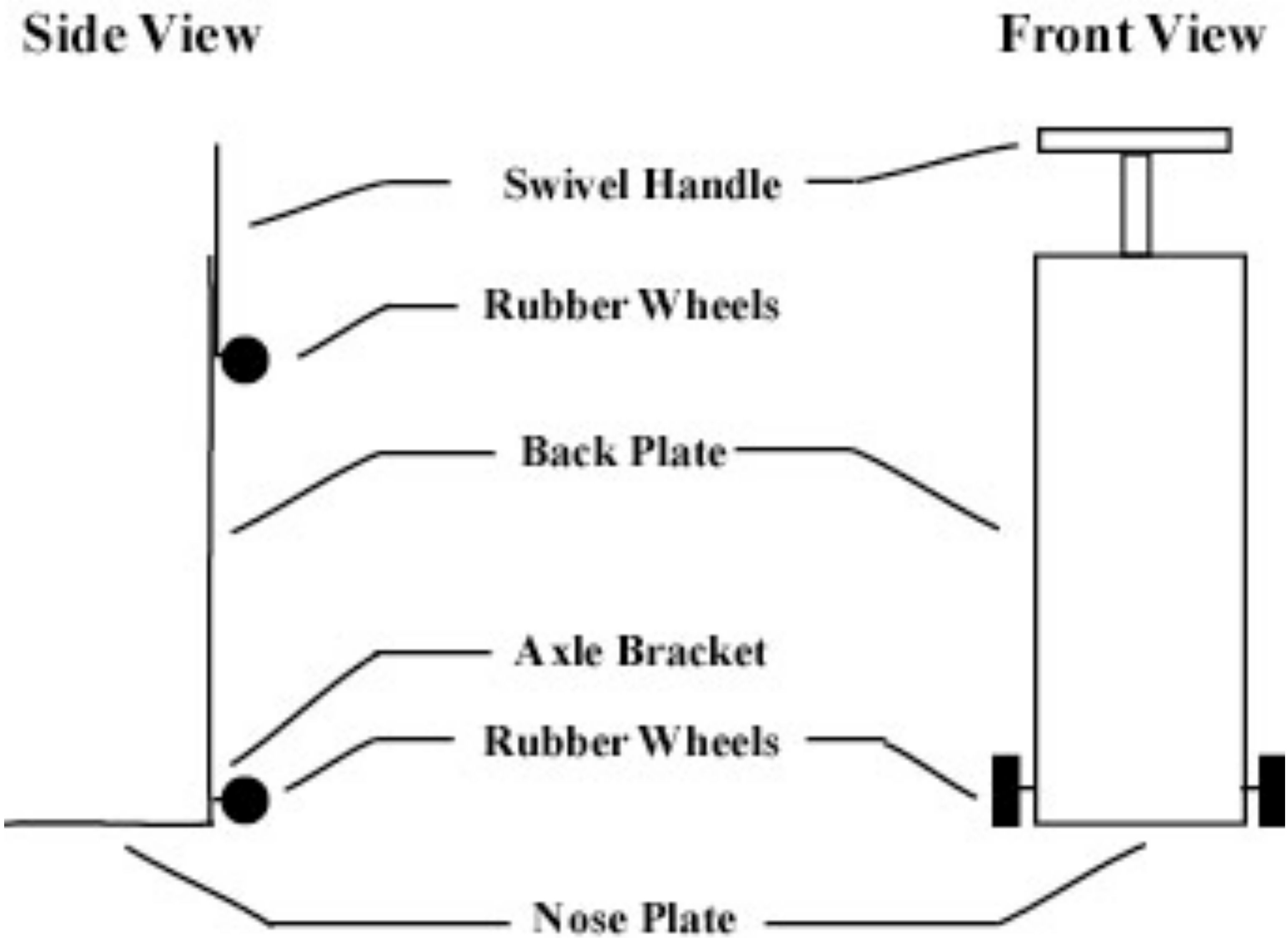
Primary Load Data

Calculation of impact force on nose plate.

Conditions: 1) Specified live load: 300 lb
2) Dropped from a height of 0 feet, equivalent to dropping off a curb.

$$F_{impact} = nF_{dead}$$
$$n = 1 + \sqrt{1 + 2\left(\frac{h}{dst}\right)} \qquad h = 0$$
$$n = 1 + \sqrt{1} = 2$$
$$F_{imp} = 2 * 300lb = 600lb$$

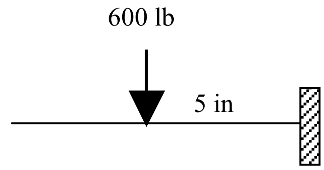
Note: Worst case dictates that this load will be a concentrated point load in the center of the nose plate.


Side View
Front View
Swivel Handle
Rubber Wheels
Back Plate
Axle Bracket
Rubber Wheels
Nose Plate

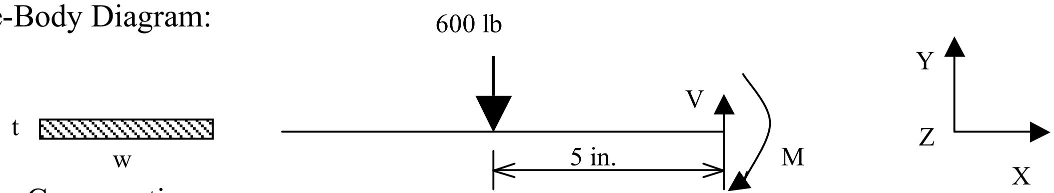
Calculations

Nose Plate

Model: Cantilever beam.



Free-Body Diagram:



Cross section

Calculation for nose plate.

$\sum F_y = 0$ $\quad V = 600lb$ $\quad \sum M_z = 0$ $\quad M = 600lb * 5in = 3000lb ?in$

<u>Bending analysis, determining minimum thickness, t</u>:

$\sigma_{all} = \frac{M ?y}{I_z}$ $\quad I_z = \frac{1}{12}wt^3$ $\quad \sigma_{all} = 43.85ksi$ $\quad y = \frac{t}{2}$

$$t_{\min} = \sqrt{\frac{6M}{\sigma_{all} w}} = \sqrt{\frac{6 * 3000in \cdot lb}{43850\frac{lb}{in^2} * 20in}} \quad w = 20in$$

$$t_{\min} = 0.143in$$

<u>Shear analysis</u>:

$$\tau_{all} = \frac{VQ}{I_x w} = 26300\frac{lb}{in^2} \qquad V = 600lb$$

$$I_x = \frac{1}{12}wt^3 \qquad w = 20in \qquad Q = \frac{t}{4} * \frac{t}{2} * w = \frac{wt^2}{8}$$

$$t_{\min} = \frac{V/8}{\frac{w}{12} * \tau_{all}} = \frac{600lb/8}{(20in/12) * 26300\frac{lb}{in^2}} \qquad t_{\min} = 0.0017in$$

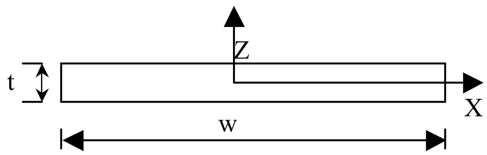
Decision: Round thickness up to 0.16 in which is a nominal value for aluminum sheet.

NOTE TO STUDENTS: What did the team working this example miss? Could there be another loading scenario for shear?

Back Plate.

Model, Free-Body diagram and shear and bending moment diagrams: See pg.16.

Cross-section:



Minimum thickness of Back Plate: V_{max} and M_{max} taken from shear and moment diagrams.

Bending:

$$M_{\max} = 1933.4 lb\ ?in \qquad V_{\max} = 252.3 lb$$

$$\sigma_{all} = \frac{My}{I_x} = 43850 \tfrac{lb}{in^2} \qquad I_x = \frac{1}{12} wt^3 \qquad w \cup 15in \quad atM_{\max} \qquad y = \frac{t}{2}$$

$$t_{\min} = \sqrt{\frac{M/2}{\sigma_{all}\frac{w}{12}}} = \sqrt{\frac{1933.4 lb \cdot in/2}{43850\frac{lb}{in^2} * \frac{15in}{12}}} \qquad t_{\min} = 0.133in$$

Transverse Shear:

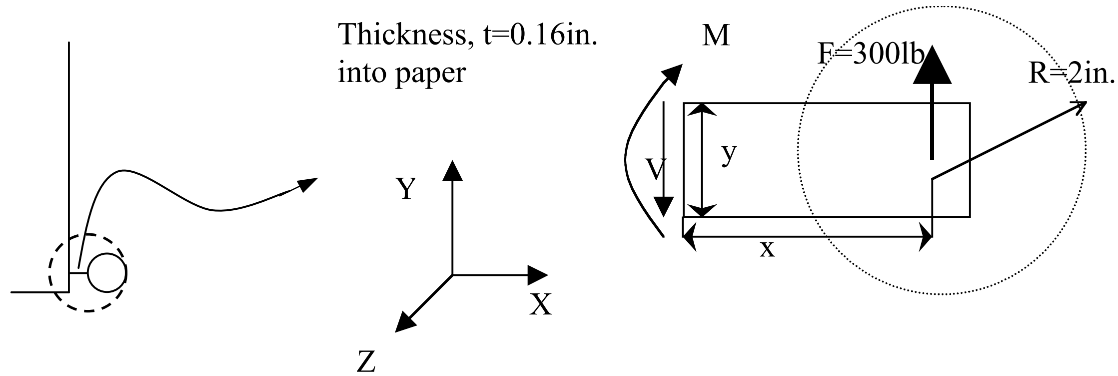
$$\tau_{all} = \frac{V_{\max} Q}{I_x w} = 26300\frac{lb}{in^2} \qquad Q = \frac{t}{2} * w * \frac{t}{4} = \frac{wt^2}{8} \qquad I_x = \frac{1}{12} wt^3 \qquad w \cup 12in @ V_{\max}$$

$$t_{\min} = \frac{V/8}{\tau_{all}\frac{w}{12}} = \frac{252.3 lb/8}{26300\frac{lb}{in^2} \cdot 1in} \qquad t_{\min} = 0.0012in$$

Decision: Thickness of back plate will be 0.16 in. as a nominal value.

<u>Axle Bracket.</u>

Model: Cantilever beam (wall on left).
Free-Body Diagram:



Note: Assume tipping eminent, so that wheel and axle absorb entire load.

For simplification in design, setting x=3.0 in. Determine y dimension:

$$\Sigma F_y = 0; V = 300lb \qquad \Sigma M_z = 0; M = 300lb * 3in = 900in \cdot lb$$

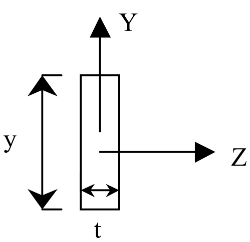
<u>Bending stress analysis, solving for minimum y</u>:

$$\sigma_{all} = \frac{M \cdot (y/2)}{I_z} = 43850 \frac{lb}{in^2} \qquad I_z = \frac{1}{12} t y^3 \qquad y_{\min} = \sqrt{\frac{6M}{\sigma_{all} * t}}$$

$$y_{\min} = \sqrt{\frac{6 * 900 in \cdot lb}{43850 \frac{lb}{in^2} * 0.16in}} \qquad y_{\min} = 0.88in$$

<u>Transverse Shear</u>:

Cross-section:



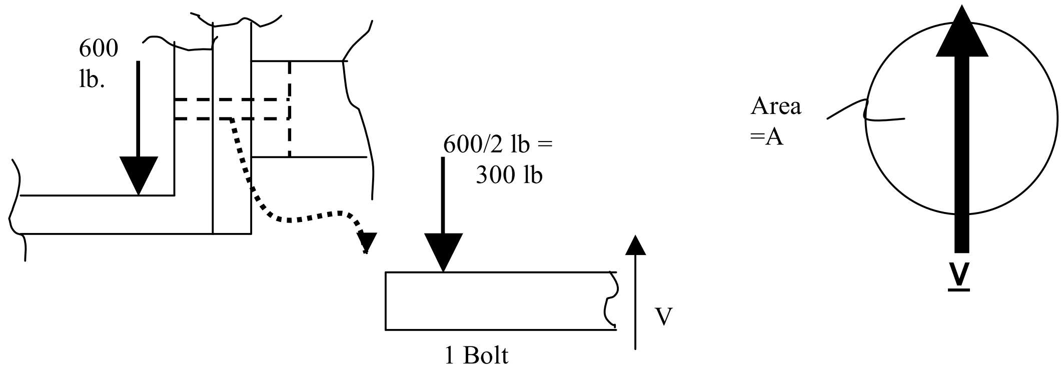
$$\tau_{all} = 26300 \frac{lb}{in^2} \qquad \tau_{all} = \frac{VQ}{I_z t} \qquad I_z = \frac{1}{12} t y^3$$

$$Q = \frac{y}{4} * \frac{y}{2} * t = \frac{t y^2}{8} \qquad y_{\min} = \frac{Vt/8}{\tau_{all} \frac{1}{12} t^2} = \frac{300lb * 0.25in/8}{26300 \frac{lb}{in^2} * 0.16^2 in^2 / 12} = 0.156in$$

Decision: Round y up to 1 in. nominal. Note that y-min is smaller than the chosen diameter for the wheels. Otherwise modifications would be necessary. Also note that x, or thickness, can be solved for instead of y.

Bolts.

Model (load specified near angle), Free-Body Diagram, cross section.



Determining minimum diameter of bolts.
Bolts connect back plate, nose plate, and axle bracket, and are to be made of A-36 Steel.
Four bolts between the nose plate and back plate, two bolts connected to axle bracket.
Therefore, design is for axle bracket connection where two bolts must carry 600 lb load.

Shear calculation:

$$\tau_{all} = \frac{V}{A} = 16600\frac{lb}{in^2} \qquad V = 300lb \qquad A = \pi \cdot r^2$$

$$r_{\min} = \sqrt{\frac{V}{\tau_{all}\pi}} = \sqrt{\frac{300lb}{16600\frac{lb}{in^2} * \pi}} \qquad d_{\min} = 2r_{\min} = 0.1517in$$

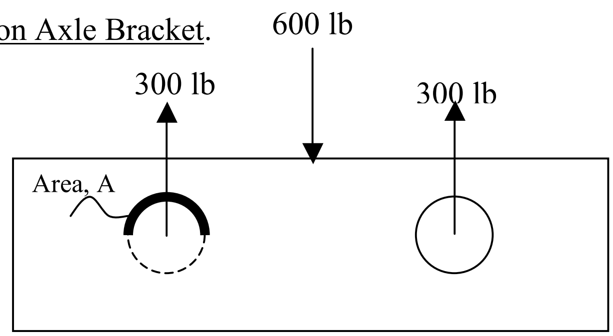
Decision: To allow for added stress from transverse shear, and for simplification, a diameter of 0.25 in will be used.

<u>Axle Bracket (Bearing)</u>

<u>Bearing Stress of Bolts on Axle Bracket</u>.

Free-Body Diagram:

Thickness, t=0.16 in
into paper



Note: Analyzed for axle bracket, which has two bolts to carry the full 600 lbs. Checking if previously calculated diameter (0.25 in) of bolts is acceptable.

<u>Compressive Bearing Stress</u>:

$$\sigma_{all} \le \frac{F/2}{A} \le 43850 \frac{lb}{in^2}$$

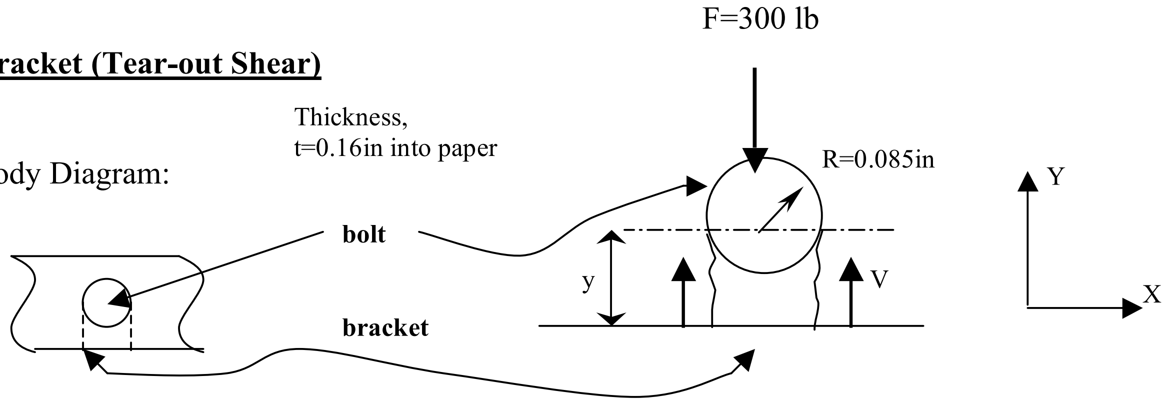
$$A = \pi ?R ?t$$
$$R = 0.125 in$$

$$\sigma = \frac{300 lb}{\pi \cdot 0.125 in \cdot 0.16 in} = 4774.65 \frac{lb}{in^2}$$

Since the compressive stress is much less than the allowable, the bearing stress of the bolts on the axle bracket will be easily handled in the design. Also, this stress can work both ways, meaning that the bearing stress may also be on the bolts in some situations. However, the stress is also significantly smaller than the allowable for the bolts.

Axle Bracket (Tear-out Shear)

Free-Body Diagram:



Tear-Out Shear for plates: axle bracket

Axle bracket has only two bolts carry the 600lb where the nose plate and back plate have four bolts, so the axle bracket calculation will govern design.

$$\sum F_y = 0; V = \frac{F}{2} \qquad F = 300lb : V = 150lb$$

$$\tau_{all} = \frac{V}{A} = 26300\frac{lb}{in^2} \qquad A = y * t$$

$$y_{\min} = \frac{V}{t * \tau_{all}} = \frac{150lb}{0.16in * 26300\frac{lb}{in^2}} = 0.037in$$

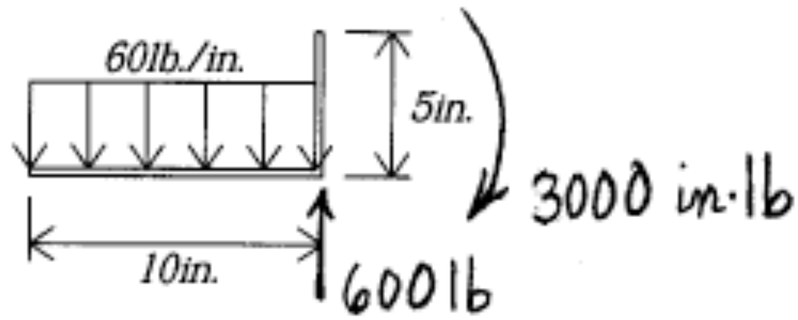
Therefore, the center of the bolts must be at least 0.037 inches from the bottom of the axle bracket or the plates.

Checking with previous calculations:

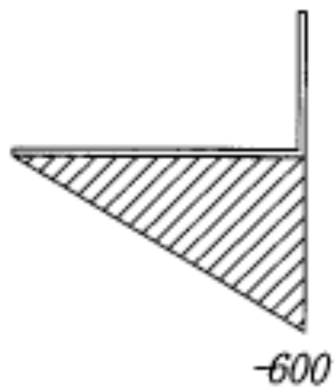
$$y_{bracket} = 1.0in \qquad y_{bracket} - d_{bolt} \ ? \ y_{\min}$$
$$d_{bolts} = 0.25in \qquad 1.0 - 0.25 \ ? \ 0.037$$
$$y_{\min} = 0.037in$$

Decision: Design for axle bracket is suitable, and bolts will be placed in the center of the bracket.

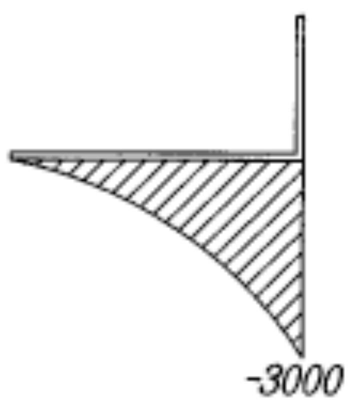
LOADS



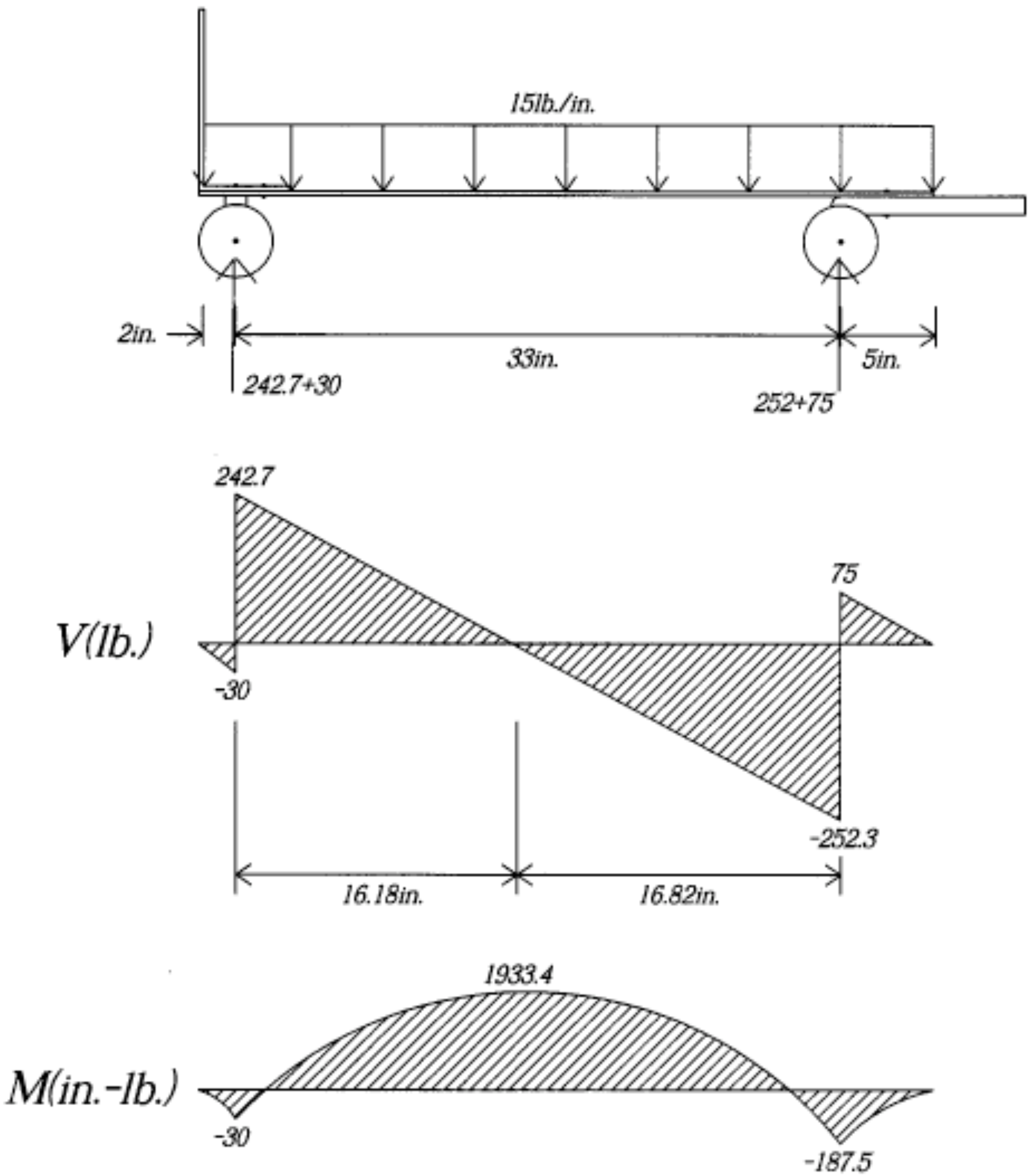
V(lb.)



M(in.-lb.)



NOSE PLATE



15lb./in.
2in.
33in.
5in.
242.7+30
252+75
242.7
75
V(lb.)
-30
-252.3
16.18in.
16.82in.
1933.4
M(in.-lb.)
-30
-187.5

BACK PLATE