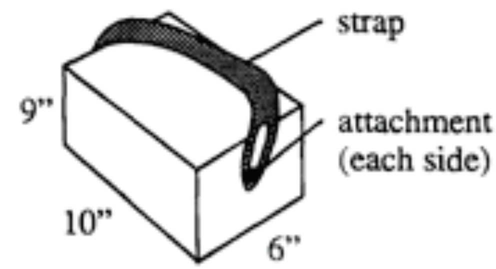
Design Project—An Example

Problem

Design a carrying strap and attachments for a storage battery per the concept drawing shown.

Specifications

- The design includes both the strap and the attachments to fasten the handle to the battery case.
- The strap must safely carry a proof load twice the weight of the battery without signs of yielding.
- The material must be neither a conductor of electricity nor affected by battery acid.
- The strap must optionally fit flush with both the top and 10" sides of the battery when not in use, yet it must extend easily and sufficiently to permit a person's gloved hand to grasp it without a tight fit.



Battery & carrying strap

Weight of battery: 40 lbs

Design objective

The design objectives are minimum cost and material.

Special concerns

Of special concern is sudden failure of the strap or its attachment.

References

Concise Encyclopedia of Polymer Processing and Applications (1992) Pergamon Press, Oxford, p. 60.

CRC Handbook of Materials Science, Vol. III: Nonmetallic... Applications (1975) CRC Press, Cleveland.

CRC Materials Science and Engineering Handbook (1994) ibid.

Encyclopedia of Materials Science and Engineering (1986) Pergamon Press, Oxford.

Hibbeler, R.C. (1994) Mechanics of Materials, Prentice Hall, Englewood Cliffs.

Machinery's Handbook (1974) 19th Edition, Industrial Press, New York, pp. 2246-7, Table 1. American National Standard Weights and Dimensions of Welded and Seamless Wrought Steel Pipe (ANSI B36.10).

Nielsen, Lawrence E. and Robert F. Landel (1994) Mechanical Properties of Polymers and Composites, Marcel Dekker, Inc., New York.

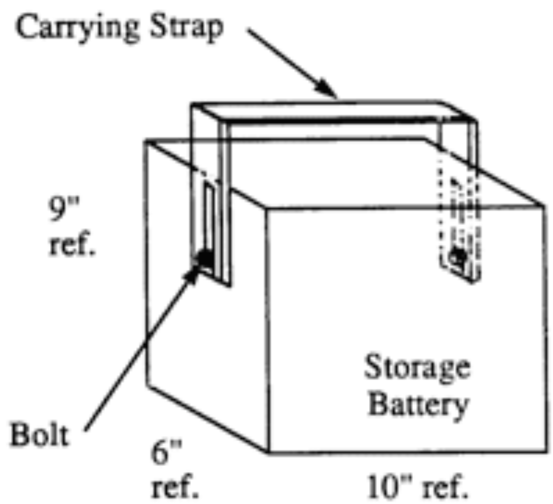
Roark, Raymond J. and W. C. Young (1975) Formulas for Stress and Strain, McGraw-Hill Book Co., New York, Table 37. Formulas of stress concentration for elastic stress.

Internet web site: http://www.voicenet.com/%7Ejmaher/plastics.html

Also, some design and machinery magazines publish handy annual material issues.

Project Drawings and Bill of Materials

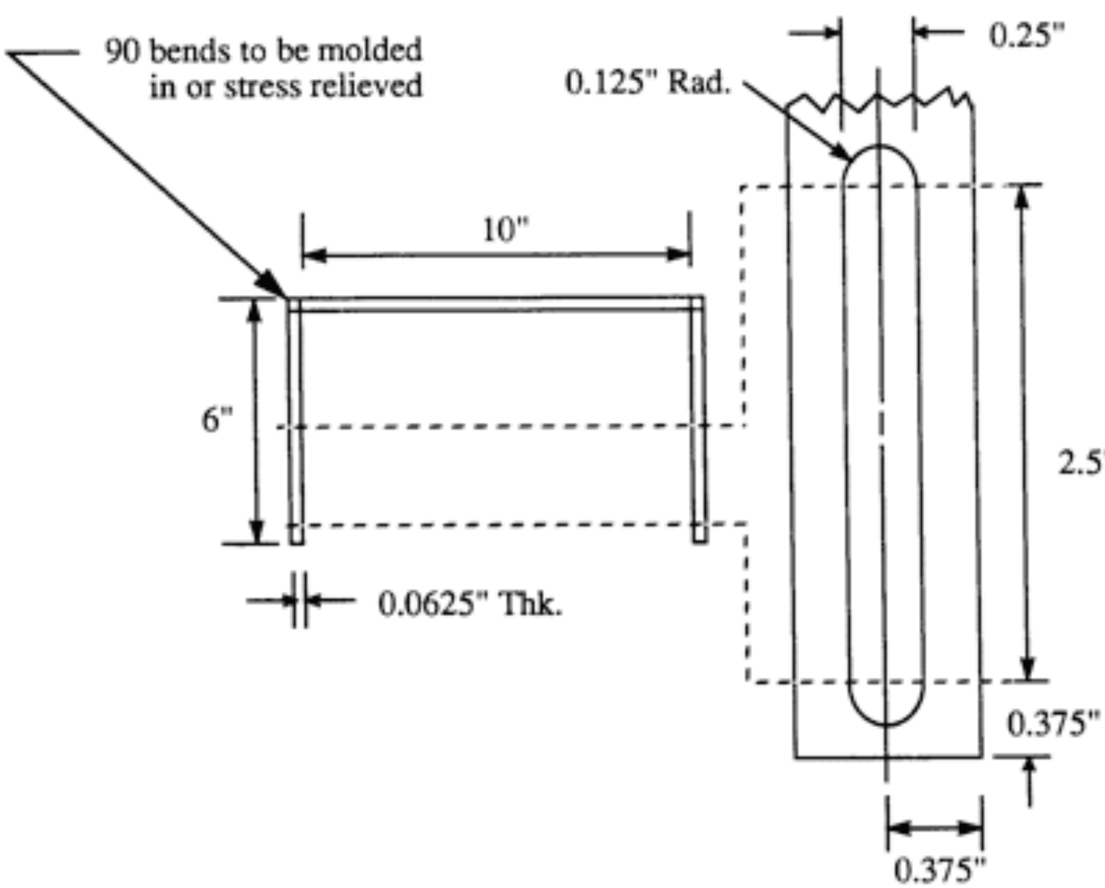
Assembly Drawing and Bill of Materials



Bill of Materials

Item	Material	Specification
1. Strap	Non-filled homopolypropylene	See drawing.
2. Bolt (2 each)	Same as strap	0.25" dia. Thread to fit mfg's specification.

Detailed Drawing of Strap



Example Design Project—Details

Design Procedure

Methods

1. Researched material properties and selected non-filled homopolypropylene for the battery strap -- it is strong, light weight, nonconductive, chemically non-reactive and inexpensive. Note: the same material will be investigated for the attachment.
2. Found the ultimate tensile strength σ_{ult} to be 6000 psi (Rubin, 1994). Since polypropylene is not strictly elastic, established a working normal stress σ_w per Assumption #1, below.
3. Developed a concept design based upon human factors and decided to bolt the strap to the battery casing through slots in the strap as shown in Figure 1.
4. Calculated the minimum bolt diameter to start the design and set the slot width; then the strap thickness and strap length beyond the slot to prevent shear failure. Rounded up to nominal dimensions, e.g., use 1/8-inch for minimum of 0.117". Finally, computed bearing stress and maximum stress to make sure that neither exceeded σ_w for this design (note: bearing stress initially failed this test, so strap thickness had to be increased until sufficient as verified by an additional iteration of the stress calculations).

Assumptions

1. Working normal stress (σ_w) can be approximated using 50% of σ_{ult}.
2. Working shear stress (τ_w) can be approximated using 60% of σ_w. (Based upon comparison of the ratios of ultimate yield strength, tensile to shear, for metals [only available data]).
3. The slot can be treated as a circular hole to calculate maximum stress (σ_{max}).

Warning

- The effects of flexure and right angle bends are <u>not</u> analyzed in this report.

References

Concise Encyclopedia of Polymer Processing and Applications. Oxford: Pergamon Press, 1992. (p. 60)

Hibbeler, R.C. Mechanics of Materials. Englewood Cliffs: Prentice Hall, 1994.

Irvin, Rubin. Handbook of Plastic Materials and Technology. New York: John Wiley & Sons, Inc., 1990. (pp. 446-454)

Modern Plastics Encyclopedia 1996 with Buyer's Guide. New York: McGraw-Hill Book Co., 1995. (p. 193)

Roark, Raymond J. and W. C. Young. Formulas for Stress and Strain. New York: McGraw-Hill Book Co., 1975. (p. 594)

Material Properties

Non-filled polypropylene	$\sigma_{ult} = 6000$ psi (Rubin, 1994)	$\sigma_w = 50\%\ \sigma_{ult} = 3000$ psi	$\tau_w = 60\%\ \sigma_w = 1800$ psi

Concept Sketch

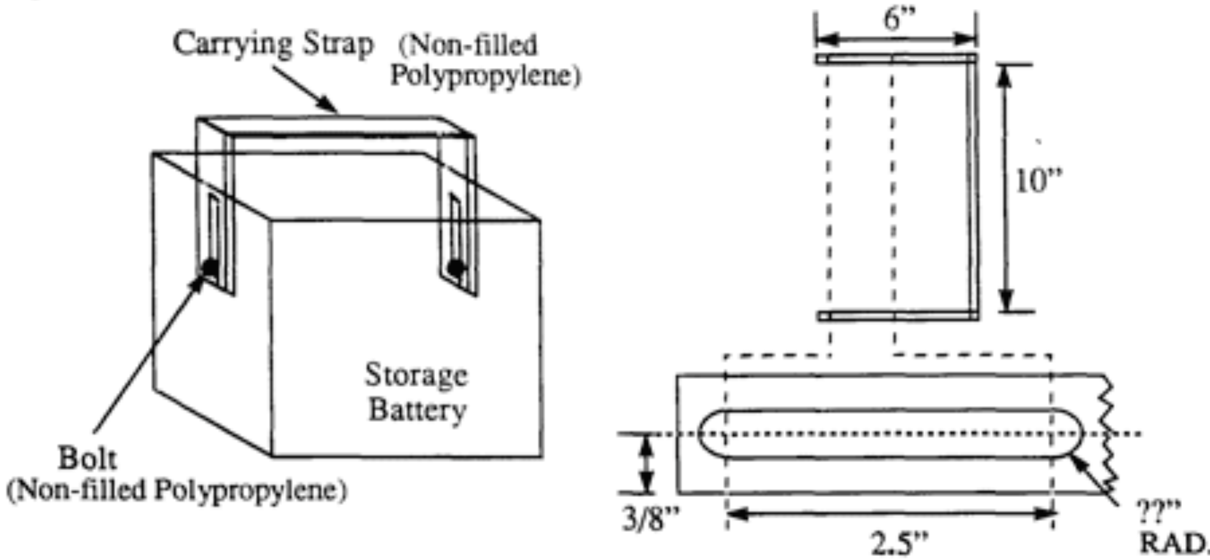
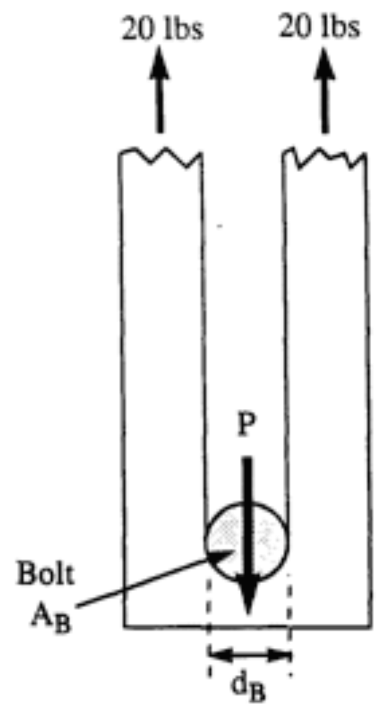


FIGURE 1. Design Concept—Battery Carrying Strap

Calculations—Determining Minimum Dimensions

Bolt Diameter (d_B)



$$\tau_w = \frac{P}{A_B} \rightarrow A_B = \frac{P}{\tau_w}$$

$$\tau_w = (0.6)(\sigma_w) = (0.6)(3000\ \text{psi}) \rightarrow \tau_w = 1800\ \text{psi}$$

$$A_B \geq \frac{40\ \text{lbs}}{1800\ \text{psi}} \rightarrow A_B \geq 0.022\ \text{in}^2$$

$$A_B = \frac{\Pi}{4} \times (d_B)^2 \rightarrow d_B = \sqrt{\frac{4 \times A_B}{\Pi}}$$

$$d_B \geq \sqrt{\frac{4 \times (0.022\ \text{in}^2)}{3.1416}} \Rightarrow d_B \geq 0.168\ \text{in}$$

Decision:

$$\therefore \text{ use } d_B = 0.25\ \text{in}$$

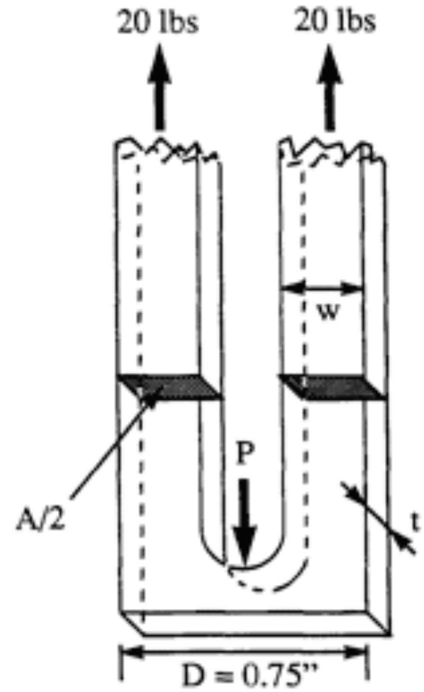
Strap Thickness (t) (Prescribe D = 3/4" for comfort)

Designing for $D = 0.75 \text{ in} \rightarrow w = 0.25 \text{ in}$

$$\sigma_w = \frac{P}{A} \rightarrow A = \frac{P}{\sigma_w}$$

$$A \geq \frac{40 \text{ lbs}}{3000 \text{ psi}} \rightarrow A \geq 0.013 \text{ in}^2$$

(Note that the minimum cross sectional area (**A**) of the strap is found about the slot which divides it into two strands of cross section **A/2**. The minimum thickness required to support the designated load must be determined for these strands.)



$$\frac{A}{2} = (t) \times (w) \rightarrow t = \frac{A}{(2) \times (w)}$$

$$t \geq \frac{0.013 \text{ in}^2}{(2) \times (0.25 \text{ in})} \Rightarrow t \geq 0.027 \text{ in}$$

Decision

$$\therefore \text{ use } t = 0.03125 \text{ in} \approx 1/32 \text{ in}$$

Strap Length Beyond Slot (s)

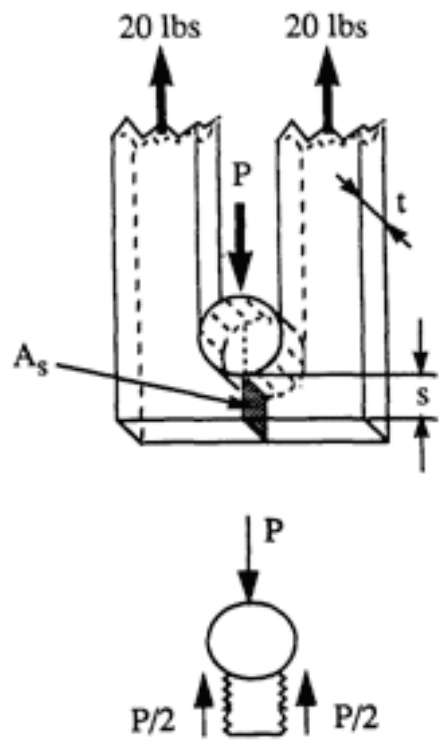
Each strand of the strap around the slot must support the shear of half of the load:

$$\tau_w = \frac{P/2}{A_s} \rightarrow A_s = \frac{P}{(2) \times (\tau_w)}$$

$$A_s \geq \frac{40 \text{ lbs}}{(2) \times (1800 \text{ psi})} \rightarrow A_s = 0.011 \text{ in}^2$$

$$A_s = (s) \times (t) \rightarrow s = \frac{A_s}{t}$$

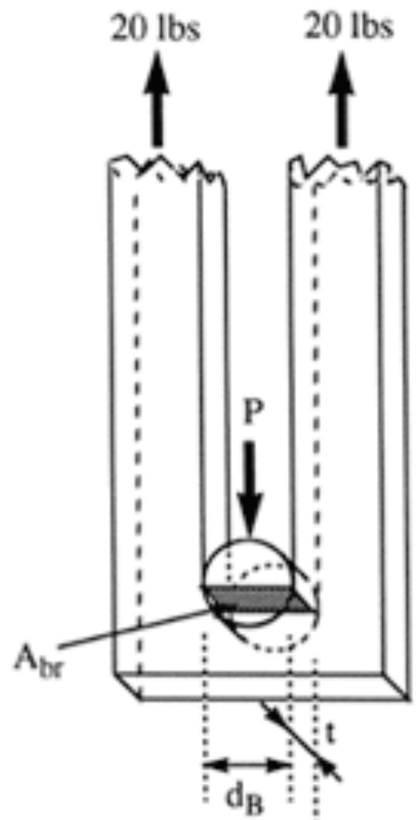
$$s \geq \frac{0.011 \text{ in}^2}{0.03125 \text{ in}} \Rightarrow s \geq 0.356 \text{ in}$$



Decision:

$$\therefore \text{ use } s = 0.375 \text{ in}$$

Check Bearing Stress ($\sigma_{br} \le \sigma_w$?)



$$\sigma_{br} = \frac{P}{A_{br}} = \frac{P}{(t)\times(d_B)}$$

$$\sigma_{br} \ge \frac{40 \text{ lbs}}{(0.03125 \text{ in})\times(0.25 \text{ in})} \Rightarrow \sigma_{br} = 5120 \text{ psi}$$

$5120 > 3000 \rightarrow$ *Bearing Stress could cause failure!*

To reduce σ_{br} to an acceptable value, either t or d_B must be increased. Since it is unlikely that the bolt will fail, t is selected—it is increased by 1/32 inch to 1/16-inch.

Note that **s** must be recalculated since it is based on **t**:

$$s \ge \frac{A_s}{t} \rightarrow s \ge \frac{0.011 \text{ in}^2}{0.0625 \text{ in}} \Rightarrow s \ge 0.178 \text{ in}$$

Decision:

$$\therefore \text{ use } s = 0.25 \text{ in}$$

Then recalculate the bearing stress, using $t = 1/16 \text{ in} \rightarrow 0.0625 \text{ in}$

$$\sigma_{br} \ge \frac{P}{(t)\times(d_B)} \rightarrow \sigma_{br} \ge \frac{40 \text{ lbs}}{(0.0625 \text{ in})\times(0.25 \text{ in})} \Rightarrow \sigma_{br} = 2560 \text{ psi}$$

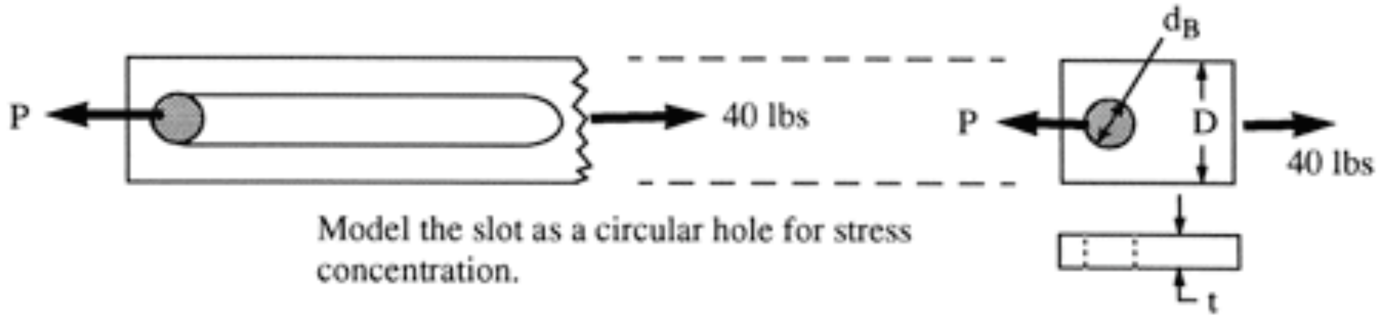
Hence: $2560 < 3000 \rightarrow \sigma_{br} \le \sigma_w$ $\therefore$ The design should now be sufficient.

Notes:

1. In designs where tolerances are “loose”, one may use fractions to the nearest nominal value instead of decimal values. Tolerances may still be given in fractions to insure quality.
2. Since actual designs rarely conform to idealistic shapes presented in texts and for which the theories are derived, engineers must seek accurate approximations (i.e., models) upon which to base their calculations. In this design, we selected a slotted strap which deviates from the idealized uniform cross sections found in the text. This nonuniformity generates axial stresses near the slot which are not constant across a cross section and give rise to what are known as stress concentrations. Before proceeding with this example, we should study stress concentrations under axial loading in the text.

Check Maximum Stress Near Slot ($\sigma_{max} \le \sigma_w$?)

Assumption: The stress concentration generated by the slot can be approximated by that produced by a circular hole.



Model the slot as a circular hole for stress concentration.

Reference: In order to use an equation to find the stress concentration factor (instead of a graph or table), the following employs a formula from Roark and Young (1975).

$\sigma_{max} = (k) \times (\sigma_{nom})$ where k is the stress concentration factor.

$$k = 3 - (3.13)\left(\frac{d_B}{D}\right) + (3.66)\left(\frac{d_B}{D}\right)^2 - (1.53)\left(\frac{d_B}{D}\right)^3 + \ldots$$

We have: $d_B = 0.25$ in, $D = 0.75$ in $\rightarrow \left(\frac{d_B}{D}\right) = 0.333$ so that

$$k = 3 - (3.13)(0.333) + (3.66)(0.333)^2 - (1.53)(0.333)^3 \rightarrow k = 2.307$$

$$\sigma_{nom} = \frac{P}{t(D - d_B)} = \frac{40 \text{ lbs}}{(0.0625)(0.75 - 0.25)} \rightarrow \sigma_{nom} = 1280 \text{ psi}$$

$$\sigma_{max} = (k) \times (\sigma_{nom}) = (2.307) \times (1280 \text{ psi}) \Rightarrow \sigma_{max} = 2950 \text{ psi}$$

Hence: $2950 < 3000 \rightarrow \sigma_{max} \le \sigma_w$ $\therefore$ The design should be sufficient.

Notes to readers:

1. The completed design is presented near the beginning of this report because it serves as the design summary.
2. Because these notes are sometimes mass produced, parts of this example are formatted compactly to conserve paper. Your reports will have limited copies, hence space your work out so as not to compromise clarity.
3. Your reports may vary from this format. Follow class or instructor guidelines.