Fermilab

Particle Physics Division
Mechanical Department Engineering Note

Number: MD-ENG-364 Date: 13 July 2011

Project Internal Reference:

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Title: Structural Analysis of Beams Prior to Coil Short Repair Work

Author(s): Bianca Brandveen

Reviewer(s): 7/13/2011

Key Words: steel, magnet, aluminum, beam, coil pack

Applicable Codes: AISC Steel Construction Manual, 9th ed.
Aluminum Design Manual, 1994.
Specifications for Aluminum Structures, 1986.

Abstract Summary:

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Abstract Summary:

A system comprised of two aluminum beams atop two steel beams will support a 3,500 pound coil pack.

GIVEN:

An aluminum H-beam sits atop of an S-beam made of A36 steel, as shown in Figure 1 below. The aluminum and steel beams are connected with a cable. Together, this system supports a 3,500 pound coil pack. (P = 3500 pounds).

The aluminum beams are concerning because 1) they are not as strong as the steel beams and 2) they are carrying the load of both the coil pack and both steel beams.

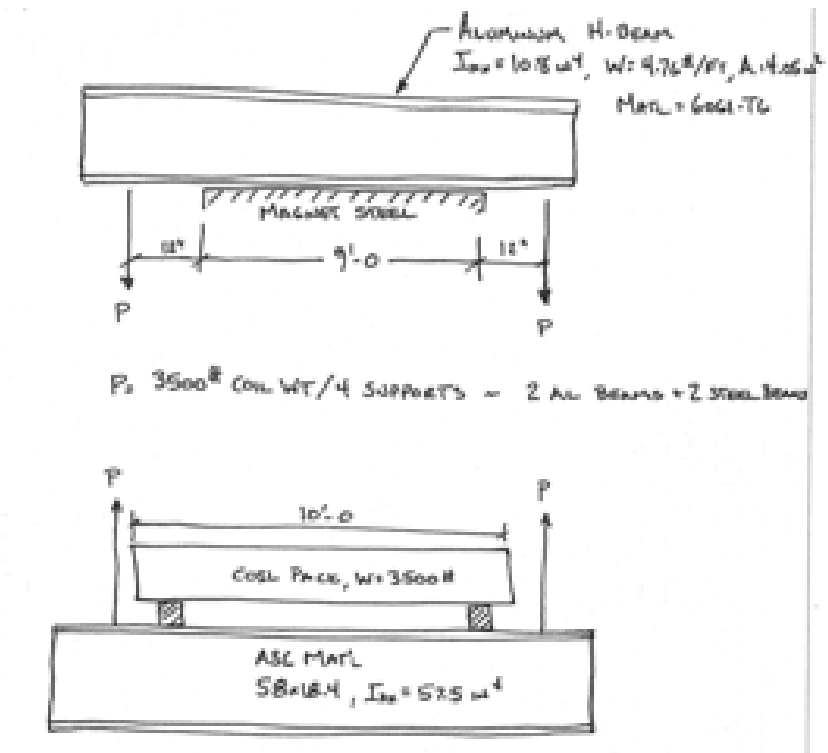

Figure 1: Diagram showing the placement of aluminum and steel beams around the magnet

Figure 2, below, is a side view of the system. The large box on the exterior of the figure represents the steel magnet coil yoke. In this view, you can see that there are four beams: two aluminum beams on the top of the coil and two steel beams below the coil.

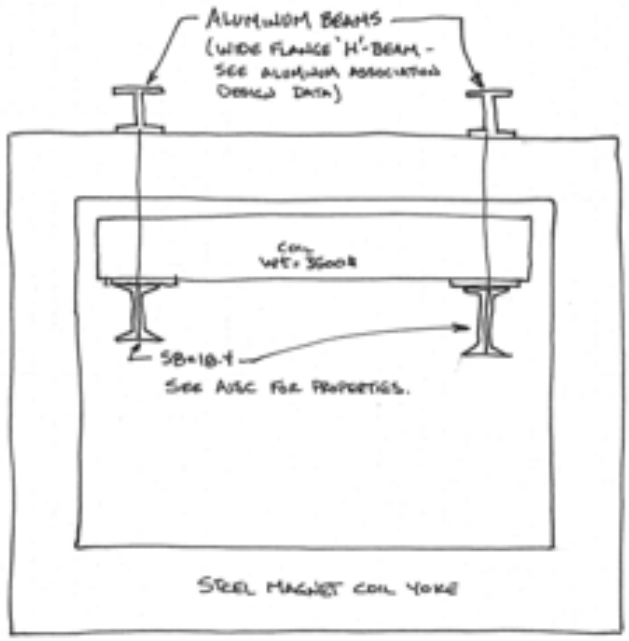

Figure 2: Side view of the system. This view shows that there are four beams in total.

PROPERTIES:

Aluminum Beam	Steel Beam
• I_{xx} = 10.8 in^4 • H-beam (4 x 4) [1] • W= 4.76 lb/ft • A = 4.05 in^2 • 6061 T6 material	• I_{xx} = 57.5 in^4 • S-beam (S 8 x 18.4) • W = 18.4 lb/ft • A = 5.41 in^2 • A36 material
6061 T6 material	A36 material
• F_y = 35 ksi • F_u = 38 ksi [2]	• F_y = 36 ksi • F_u = 58 ksi

[1] Engineering Data for Aluminum Structures. The Aluminum Association, 1986. Page 34.
[2] Aluminum Standards and Data. The Aluminum Association, 1990. Page 184.

CONSTRAINTS:

The allowable bending moment of the steel beam is based on AISC 9th edition, Chapter F1. The allowable strong axis bending stress is (eqn. F1-1):

$$F_b = 0.66\, F_y$$
$$F_b = 0.66\,(36\, ksi) = 23.76\, ksi$$

The allowable stress for the aluminum beams is based on the Specifications for Aluminum Structures book written by the Aluminum Association. The allowable tension in extreme fibers of structural beams bent about the strong axis [(3)] is (Section 3.4.2):

$$F = \frac{F_{ty}}{n_y} \quad OR \quad F = \frac{F_{tu}}{k_t n_u}$$

Solving, this gives:

$$F = \frac{35\, ksi}{1.65} = 21.21\, ksi \quad OR \quad F = \frac{38\, ksi}{(1)(1.95)} = 19.49\, ksi$$

We will use the lower of these two values to establish a "worst-case scenario".

FIND:

- Maximum local bending moment for both beam types

[(3)] The values for k_t, n_y, and n_u are found in Specifications for Aluminum Structures. The Aluminum Association, 1986, page 17-18. In this scenario, it is assumed that the beams are considered the same as "building and similar type structures" and the forces are located more than 1.0 inches away from a weld.

SOLUTION:

This particular loading condition is identical to the loading condition #9 in AISC page 2-298. The maximum moment occurs between the two support loads.

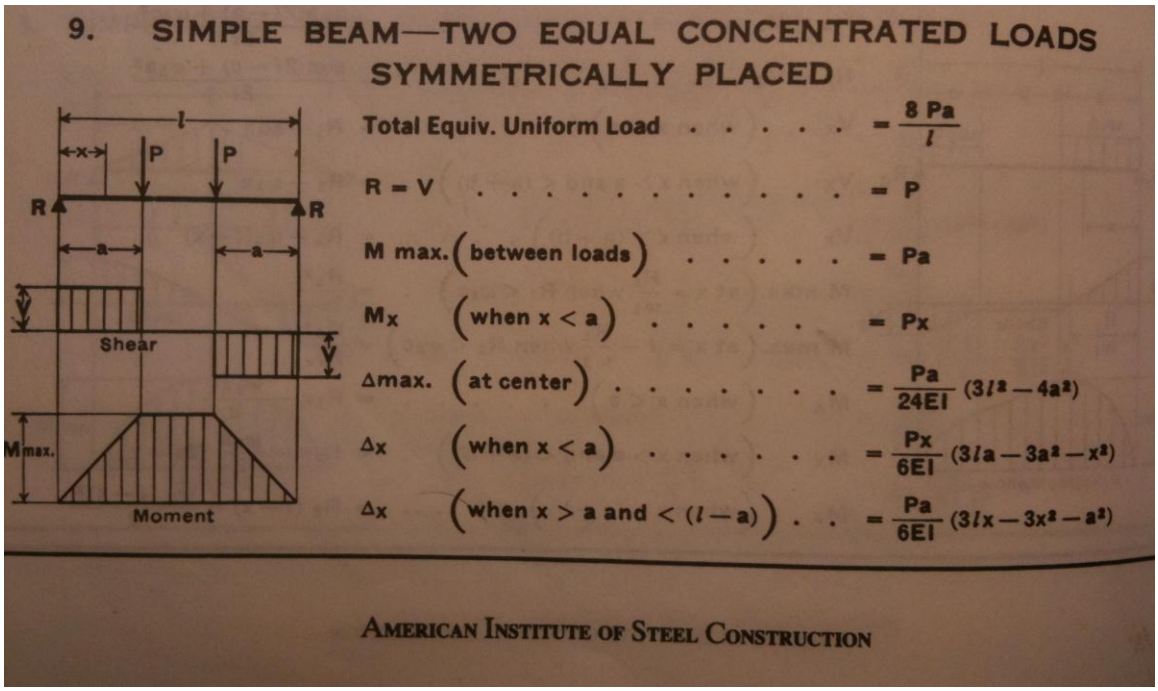

Figure 3: Loading Condition from AISC Manual

The steel beams will experience a positive bending moment because the cables are pulling up on them from both ends (Figure 5). The local bending stress of one steel beam is calculated below.

$$f_{steel} = \frac{M\,y}{I} = \frac{\left(\frac{3.5\ kip}{4} * 12\ in\right) * 4\ in}{57.5\ in^4}$$

$$f_{steel} = 0.73\ ksi$$

The aluminum beams will experience a negative moment since the cables are pulling down on them from both ends (Figure 4). The local bending stress of one aluminum beam is calculated below.

$$f_{Al} = \frac{M\,y}{I} = \frac{\left(\frac{3.5\ kip}{4} * 12\ in\right) * 2\ in}{10.8\ in^4}$$

$$f_{Al} = 1.94\ ksi$$

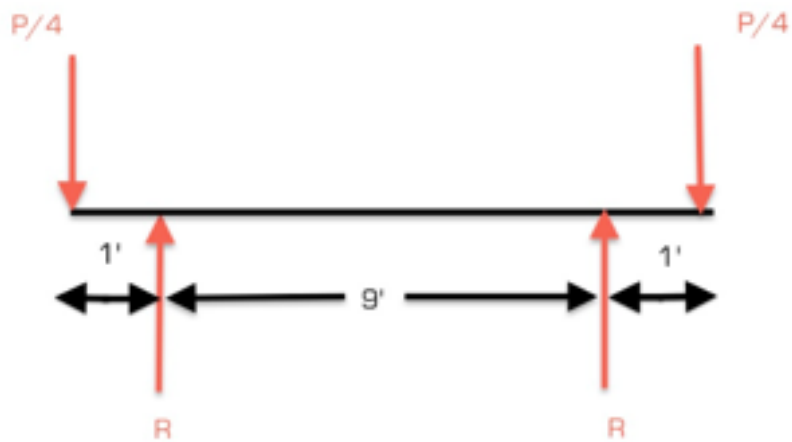

Figure 4: Free body diagram for one of the aluminum beams

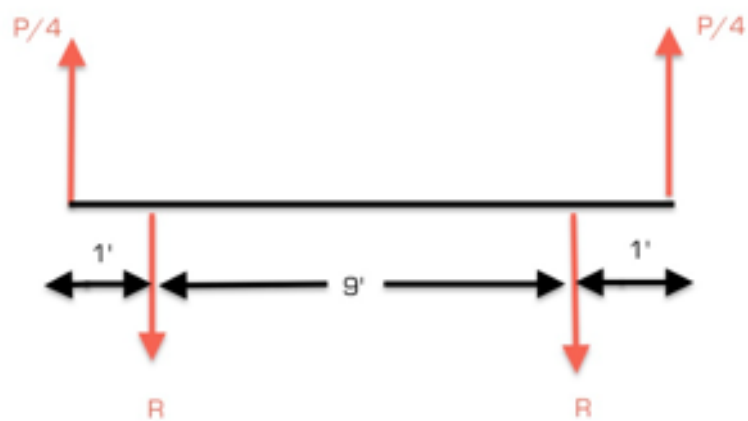

Figure 5: Free body diagram for one of the steel beams

In both of these diagrams, R = P/4 as well.

CONCLUSIONS

Since the calculated stress of the steel beam is well below the allowable stress, both of the steel beams are OK to take this load.

$$f_{steel} \ll F_b$$

Since the calculated stress of the aluminum beam is well below the allowable stress, both of the aluminum beams are OK to take this load.

$$f_{Al} \ll F$$

References

1. AISC Manual of Steel Construction: Allowable Stress Design. 9th edition, 1989.
2. Specifications for Aluminum Structures. The Aluminum Association, 1986.
3. Aluminum Standards and Data. The Aluminum Association, 1990.
4. Engineering Data for Aluminum Structures. The Aluminum Association, 1986.
5. Aluminum Design Manual. The Aluminum Association, 1994.