

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: NE-EO-2011-00X	Revision Number: 0

CALCULATION COVER SHEET

Supersedes Calculation No.:	Total Number of Attachments:
Analyzed System: E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure	
Purpose of Revision: Initial Issue	
<p>PREPARER</p> <p>P. S. Strons, NE-EO</p> <hr/> <p>Print Name Signature Date</p>	
<p>REVIEWER</p> <hr/> <p>Print Name Signature Date</p>	
<p>VENDOR APPROVER (if vendor-supplied calculation)</p> <p>n.a.</p> <hr/> <p>Print Name Signature Date</p>	
<p>FINAL APPROVER</p> <hr/> <p>Print Name Signature Date</p>	

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: NE-EO-2011-00X	Revision Number: 0

TABLE OF CONTENTS

COVER SHEET..... 1

TABLE OF CONTENTS..... 2

LIST OF EFFECTIVE PAGES 3

1 Objectives 4

2 Limitations 4

3 Acceptance Criteria..... 4

4 Methodology 4

5 Assumptions..... 5

6 Calculation 8

7 Conclusions..... 13

8 References 13

9 Computer Software Specifications 13

APPENDICES

Appendix A-K – Calculation back-up and Commercial reference..... 14

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: NE-EO-2011-00X	Revision Number: 0

LIST OF EFFECTIVE PAGES

Pages	Revision
1 to 23	0

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: NE-EO-2011-00X

Revision Number: 0

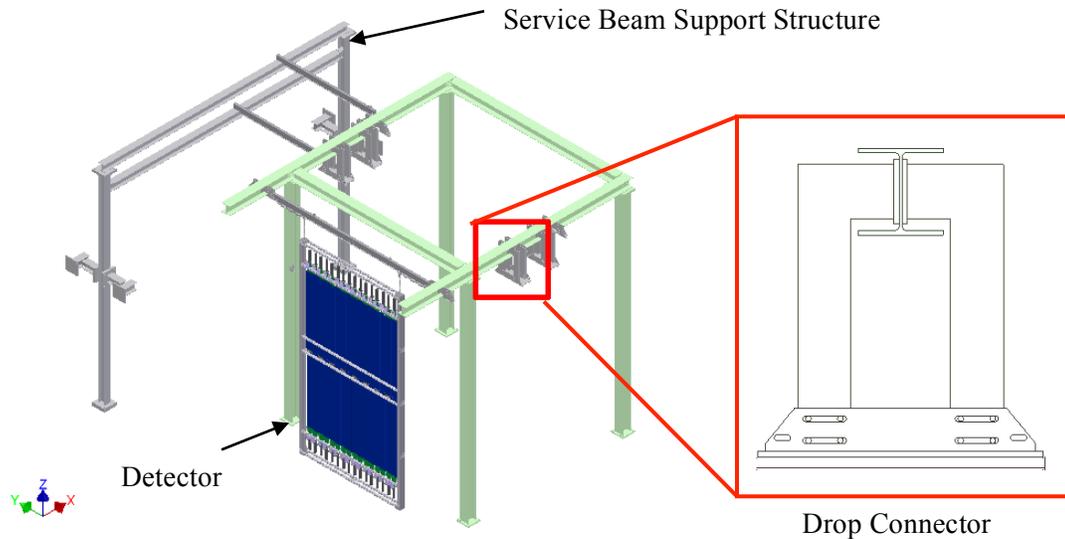


Figure 1 Drop Connectors and Service Beam Support Structure

1 Objectives

The purpose of this note is to document the calculations confirming that the design of E906 Stations 3 & 4 Drop Connectors and the Service Beam Support Structure (see Figure 11) meet requirements of Allowable Strength Design (ASD) as defined by The AISC Steel Construction Manual, 13th Edition.

2 Limitations

This analysis is limited to the Service Beam Support Structure and the Drop Connectors, the components that connect the detectors to the E906 Station 3 & 4 Support Frame. The analysis is contingent upon the use meeting the assumptions specified in section 5.

3 Acceptance Criteria

The acceptance criteria are to meet the requirements of the AISC Steel Construction Manual 13th Edition, using ASD. The requirements are defined in Part 16, Specifications and Codes.

4 Methodology

The methodology of calculation was based on static elastic analysis following the AISC Steel Construction Manual code to determine the allowable loading in the structure.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab
--

Calculation No.: NE-EO-2011-00X
--

Revision Number: 0

5 Assumptions

The following assumptions are made with regard to the construction of the drop connectors and the service beam support structure:

- The material used for construction of the connectors and the service beam structure is A36 steel
- Bolts used in connections are A325 based on bolt head markings in photos
- Filler metal used in welds is type E60XX
- All bolted connections are bearing-type connections only
- The detector support beams rest on the bottom of the Drop Connectors and transmit their load by contact and the bolts that secure it to the connector do not carry any load
- Load data from previous FEA performed on the E906 detector support frame is assumed to be correct
- The beams of the service beam support structure are simply connected to the columns (i.e. no moments are transferred to the columns)
- Only one detector array will be in the service position at a time

5.1 Drop Connector design

The design of the Drop Connector is described by the 3D models h4y_5x2_double_plate_drop.iam and h4y_5x2_plate_drop_bottom.iam.

5.2 Drop Connector applied loads

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: NE-EO-2011-00X

Revision Number: 0

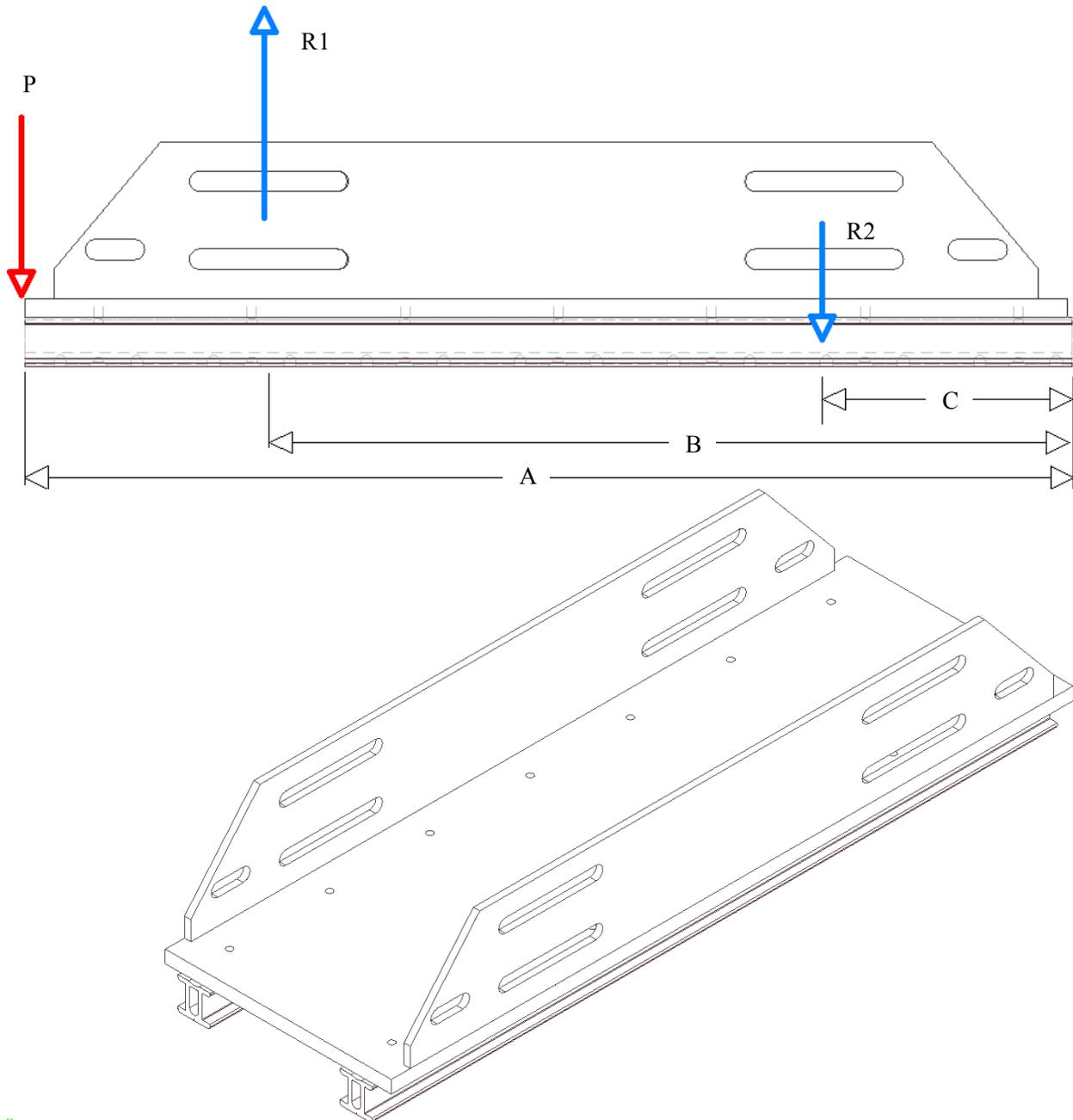


Figure 2 Free body diagram of the bottom portion of the Drop Connector is shown above. The distances A, B, and C are used to sum the moments about a common point. Below is an isometric view of the component.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: NE-EO-2011-00X

Revision Number: 0

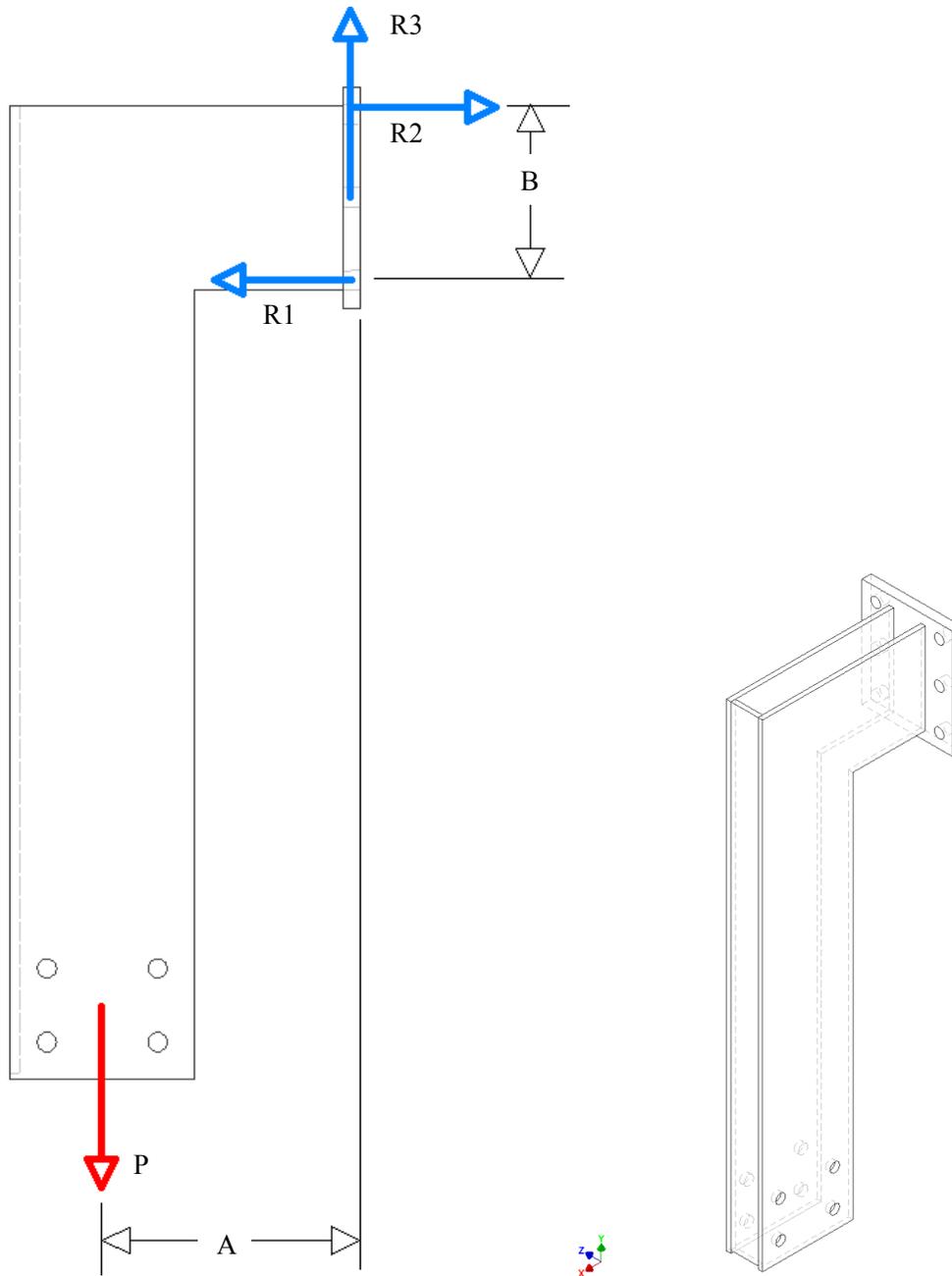


Figure 3 On the left is a free body diagram of the top portion of the Drop Connector. The distances **A** and **B** are used to sum the moments about a common point. An isometric view is shown on the right.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: NE-EO-2011-00X	Revision Number: 0

5.3 Service Beam Support Structure design

The design of the Service Beam Support Structure is described by the 3D model service_beam_frame.iam.

5.4 Service Beam Support Structure applied loads

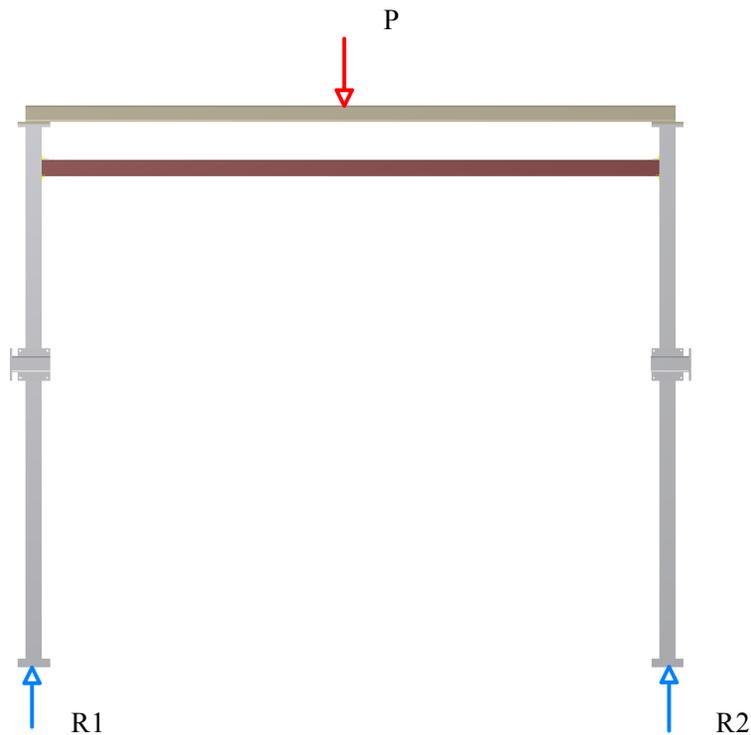


Figure 4 Free body diagram of Service Beam Structure.

6. Calculation

6.1 General description of loads and components analyzed.

Force data for this calculation was taken from the spreadsheet Layout_29_july_2010_plus_modified.xls, which was used by Rick Fischer in his FEA of the detector frame. The free body diagram for the Drop Connector worst loading case is shown in Figure 2 and 3. This connector supports the two Station 4a prop tubes, each applying a load of 870 lbs to the connector. For simplicity, only one side of the connector, both top and bottom portions was analyzed, assuming that each half of the connector carries the load of one detector, which is 870 lbs.

Figure 2 shows that by summing the forces in the vertical direction and summing the moments from those forces yields reaction forces of $R1 = 1253$ lbs and $R2 = 383$ lbs in the directions shown by the blue arrows. See the appendix for the details of the calculation.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: NE-EO-2011-00X	Revision Number: 0

R1 from Figure 2 becomes the applied load P in Figure 3. By examination of the photo below of the as-built geometry of the top portion of the connector, it can be seen that the top and bottom bolt holes are slotted and cannot carry any vertical load. This makes R1 and R2 equal in magnitude, as well as P and R3 being equal in magnitude. Since P is already known, R3 is simply 1253 lbs in the direction shown in Figure 3. By summing moments, we find that R1 and R2 have the value of 1949 lbs. in the directions shown. Details of this calculation are in the appendix.



Figure 5 Photo of the as-built geometry at the top end of the connector.

Figure 4 shows the beams and columns of the Service Beam Support Structure. There are two beams because the various detectors are supported at either height depending on the location of the center height of the individual detector. Only one detector applies a load to only one beam at any time. The worst case load from one detector of 870 lbs is applied as a point load at the center of the beam. Including the weight of the 20 ft beam of 21 lbs/ft gives a worst case moment on the beam of 5400 ft-lbs. For a worst case scenario loading of one of the columns, the total detector load plus half the weight of the beams, a total load of 1290 lbs, is assumed to be supported by one column.

6.2 Bolted connection on bottom portion of Drop Connector

The reaction force R1 shown in Figure 2 is transmitted to the top portion of the connector through four bolts, two in each slot. Section J3.6 gives the allowable shear based on the shear strength for A325 bolts. The ASD safety factor is 2.00. The allowable shear force on the four bolts is 18,850 lbs., but the load is only 1253 lbs. Therefore, the bolts are strong enough for this connection

The bearing strength of the slotted holes for the four bolts is given by Section J3.10. It is based on the minimum tensile strength of the material (58 ksi for A36 steel), the clear distance from the edge of the hole to the edge of the material, and the thickness of the material. The ASD safety factor is 2.00. The allowable force on the slotted holes is 5329 lbs, which is greater than the load of 1253 lbs. So, the slotted holes can handle the applied load.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: NE-EO-2011-00X

Revision Number: 0

6.3 Welded connection between the bottom plate and the vertical plates

There are 5 groove welds, each 2" long, between the bottom plate and the vertical plates of the bottom portion of the Drop Connector, and the welds are on both sides of each of the vertical plates. The throat of the welds is 5/16". See Figure 6 below.

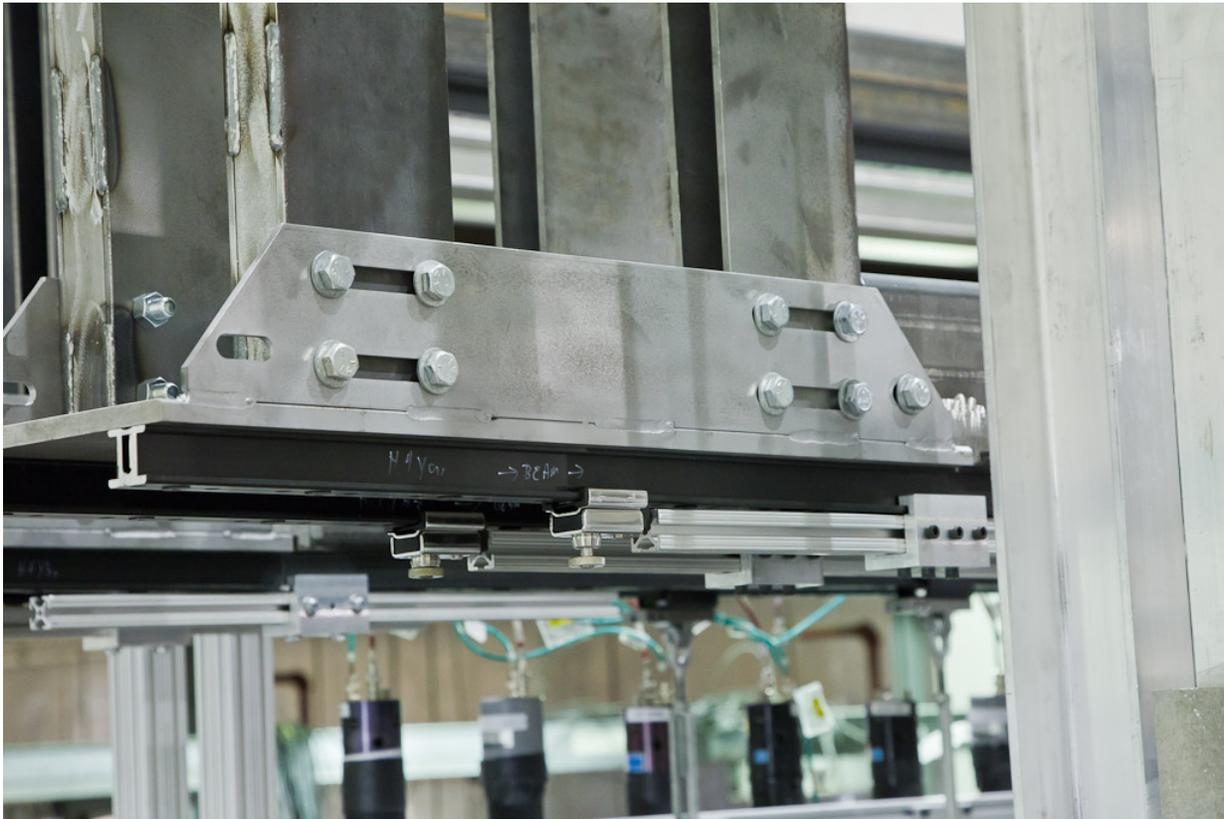


Figure 6 Photo of the groove welds on the bottom portion of the Drop Connector

Assuming only partial joint penetration welds, the strength of the weld joint in this case is found in Section J2.4, Table J2.5. The area of the base metal that is welded is 2.5 in^2 . The strength of the base metal is determined by Section J4.1. In this case, tensile yielding is the limiting factor. The allowable tensile yielding strength is 54,000 lbs. The nominal strength of the filler metal is 36 ksi. The allowable strength of the weld metal is 47,870 lbs. The load of 1253 lbs. is well under these limits.

6.4 Strength of the vertical plate in the bottom portion of the connector

The strength of connecting elements in tension is determined by the lesser of the tensile yielding strength or tensile rupture (Section J4.1). In this case, tensile rupture is the smaller limit with an allowable strength of 84,000 lbs.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: **NE-EO-2011-00X**

Revision Number: 0

6.5 Strength of bolts on the top portion of the Drop Connector

Two bolts carry the vertical or shear load for the top portion of the Drop Connector. Section J3.6 defines the allowable shear on bolts. The bolts have a nominal diameter of $\frac{1}{2}$ " and support a load of 1253 lbs. The allowable shear strength for this case is 9,425 lbs.

The two bolts at the top of the bolt pattern for the top portion of the Drop Connector are in tension with a total load of 1949 lbs. The allowable tensile strength for bolts is also defined by Section J3.6. It is based on the nominal tensile strength of the bolts defined in table J3.2. The allowable tensile load is calculated as 17,670 lbs.

6.6 Shear strength of welds at top portion of Drop Connector

The weld that connects the bolt plate to the rest of the top portion of the Drop Connector is a $\frac{1}{4}$ " fillet weld (0.177" throat) that is 5" in length on each side for a total weld area of 1.768 in². The nominal weld strength for type 60XX filler metal is 36 ksi. The allowable shear strength for this weld is 31,820 lbs.



Figure 7 Photo showing the weld detail at the top of the Drop Connector

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: NE-EO-2011-00X

Revision Number: 0

6.7 Strength of Service Beam Support Structure columns

The columns are W6x15 wide-flange I beams. The height of the column from the base to the tallest connection is 16'-4". The connections with the beams have been redesigned to not transfer any moment to the columns. See Figure 8 below.

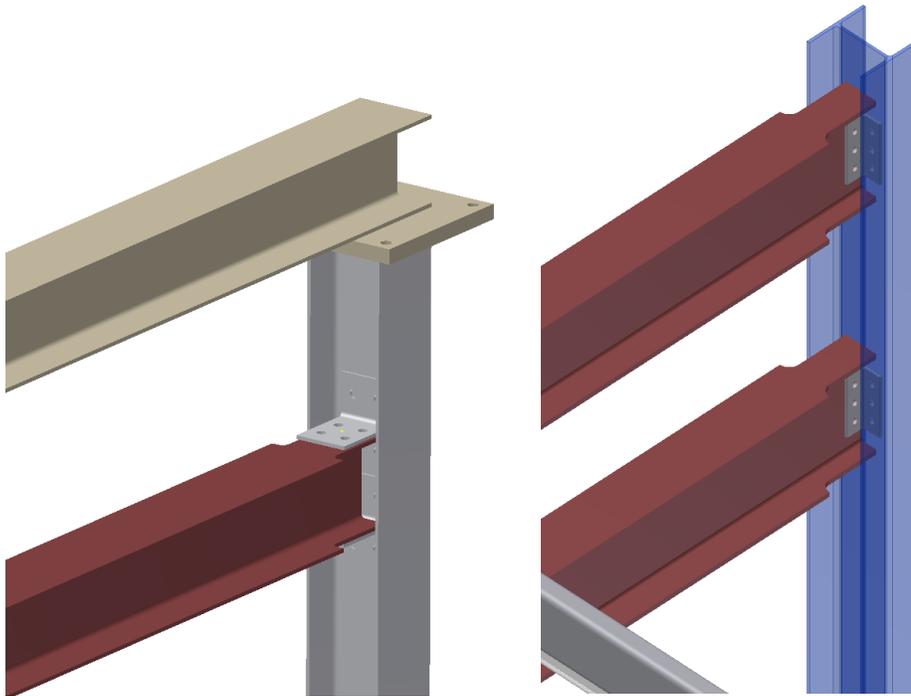


Figure 8 Original design of beam connections is shown on the left. The proposed design, which is on the right, is intended to eliminate the transfer of moments from the beams to the columns.

Section E3 determines nominal compressive strength based on the limit state of flexural buckling. The flexural buckling stress in this case is 13.7 ksi. The cross-sectional area of the W6x15 column is 4.43 in². With the ASD safety factor of 1.67, the allowable strength of the column is 36,440 lbs. The load on the column is only 1290 lbs.

6.8 Strength of Service Beam Support Structure beams

The original beam design called for a W6x15 size section. Using Section F3 of the Steel Construction Manual showed that this was insufficient. Based on the applied load and the resulting moment, a W8x21 beam was selected as a replacement. The W8x21 section has a compact flange and compact web, so the limit states are yielding and lateral-torsional buckling, which falls under Section F2. For yielding, the nominal moment is 61,200 ft-lbs, with the allowable being 36,650 ft-lbs. For lateral-torsional buckling the allowable moment is 23,730 ft-lbs. The applied moment from the 870 lb detector and the weight of the beam is 5400 ft-lbs.

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab
--

Calculation No.: NE-EO-2011-00X
--

Revision Number: 0

7 Conclusions

- 7.1 The drop connector design analyzed within this document under the assumptions presented in section **5** meets the requirements as set out in the acceptance criteria in section **3**.
- 7.2 The service beam support structure design analyzed within this document under the assumptions presented in section **5** meets the requirements as set out in the acceptance criteria in section **3**.
- 7.3 The connections in the service beam support structure are deemed to be adequate by inspection by comparing loading and dimensions to the drop connector.

8 References

1. AISC Steel Construction Manual 13th Edition
2. ASCE 7-05 Minimum Design Loads for Buildings and other Structures

9 Computer Software Specifications

Mathcad 14.0 M020 (14.0.2.5) Parametric Technology Corporation

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab

Calculation No.: **NE-EO-2011-00X**

Revision Number: 0

APPENDIX 1
GENERAL CHECKING CRITERIA SHEET

CALCULATION CHECKLIST	Yes	No	N/A	Comments
1. Are analytical methods appropriate?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
2. Are assumptions appropriate?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
3. Is the calculation complete?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
4. Is the calculation mathematically accurate?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
5. Do calculation parameters comply with design criteria/dimensions?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
6. Were input data appropriate?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
7. Does the calculation reference or list applicable assumptions and major equation sources?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
COMPUTER CODE CHECKLIST	Yes	No	N/A	Comments
1. Was an applicable and valid computer program used?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
2. Are the input assumptions appropriate?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
3. Was the input entered correctly?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
4. Do the input results seem reasonable?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

Title: Engineering Evaluation of E906 Station 3 & 4 Drop Connectors and Service Beam Support Structure at Fermilab	
Calculation No.: NE-EO-2011-00X	Revision Number: 0

APPENDIX 1
GENERAL CHECKING CRITERIA SHEET

ADDITIONAL COMMENTS		
Number	Comment	Resolution
1.		
2.		
3.		
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Appendices A-I

Calculation back-up

See following pages.