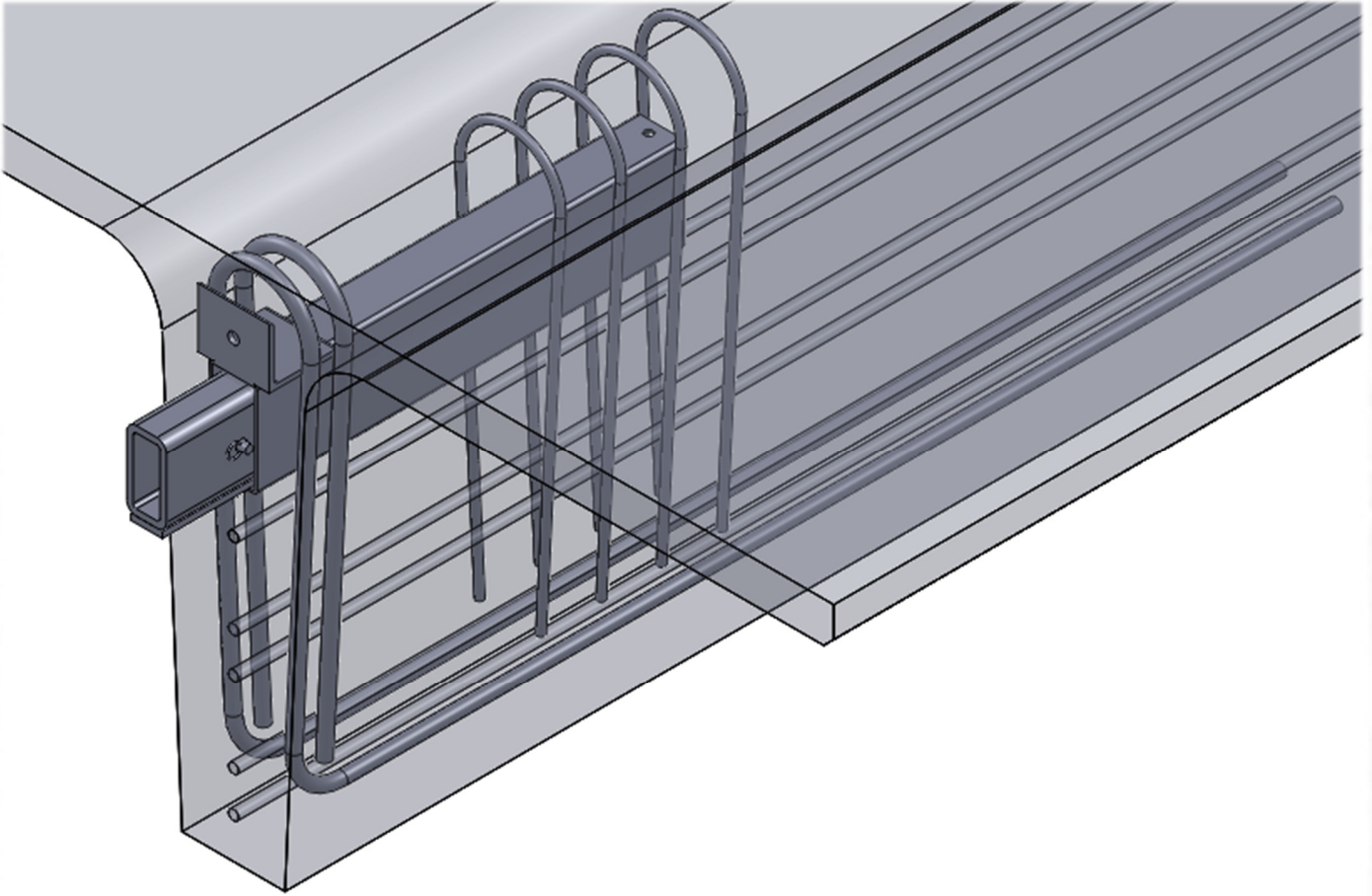


# The **SHOOTER**

## Technical Data



REVISED 12.5.2016

Second Edition – 03.29.2016



**YOUR CONNECTION CONNECTION**

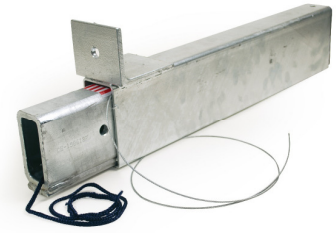
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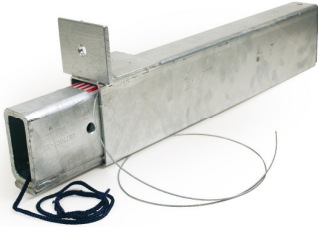
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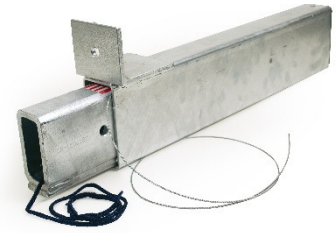
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# The **SHOOTER**

## Part 1 - Executive Summary



### Keywords

Invisible Connection, Gravity Support, Embedded Steel Section, Double Tee, Strut-And-Tie Model, Corbel, Haunch, Dap, Precast, Prestressed, Concrete

### Introduction

The Shooter is an invisible, gravity connection designed to eliminate the need for aesthetically undesirable corbels, haunches, or daps when building a precast/prestressed concrete structure incorporating double tees.

More specifically, it is a tube within a tube which is cast into the ends of the double tee stems at their widest point. The inner tube is recessed during casting and extended at erection into a receiving pocket in a spandrel, wall, or beam. To prevent the inner tube from recessing back into the double tee, a pin is installed through the projected inner tube after the double tee is set in its final position.

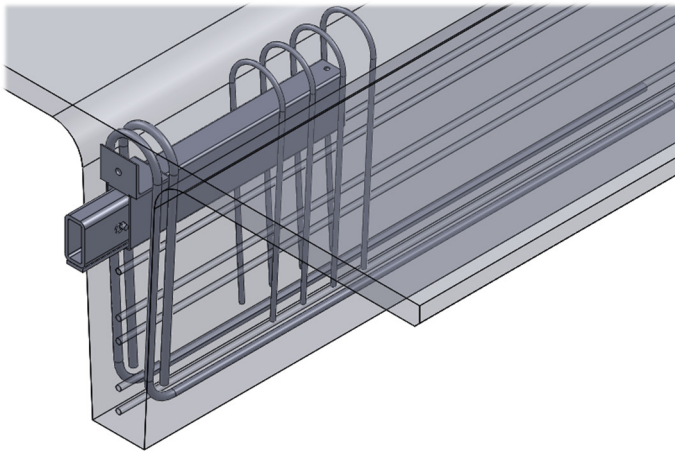


Figure 1.1 Shooter at end of Double tee leg

### Practical Advantages

The Shooter connection system is a simple, efficient connection that creates clean, elegant lines. Beyond aesthetics, some benefits are:

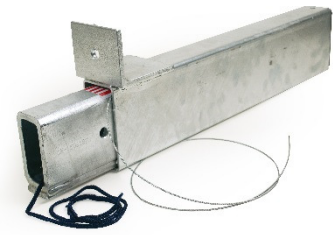
- Eliminates weld on corbels and ledges
- Reduces torsion on supporting members
- Reduces the size of the pocket in the spandrel
- Eliminates dap forming, bearing plate, and reinforcing
- Simplified erection does not require “diving” of double tees into pockets
- Allows for axial volume movements due to creep, shrinkage and temperature change
- Can increase ceiling height or reduce overall height of the structure
- Full-scale tested solution to verify design methodology





# The SHOOTER

## Part 1 - Executive Summary



### Product Dimensions

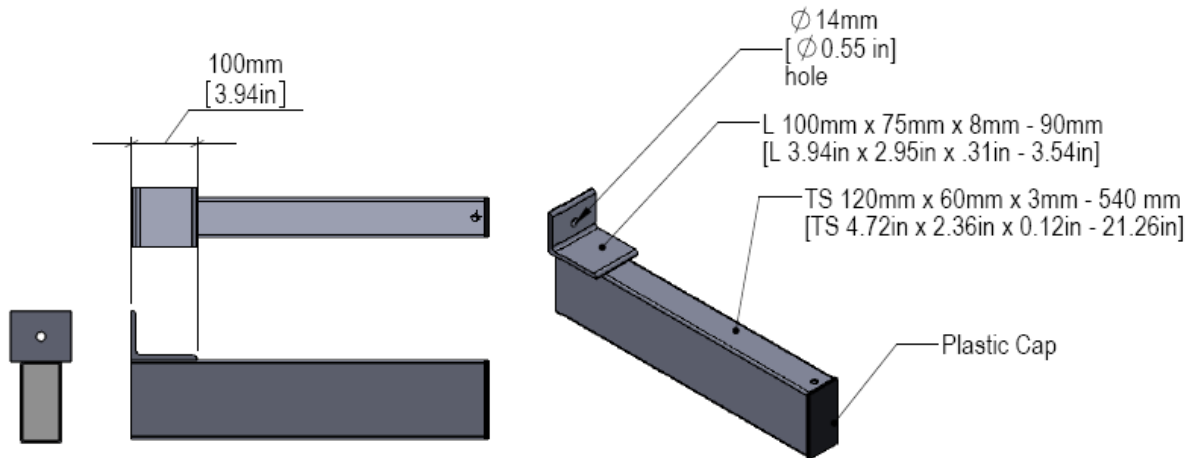


Figure 1.2 Outer Tube Dimension

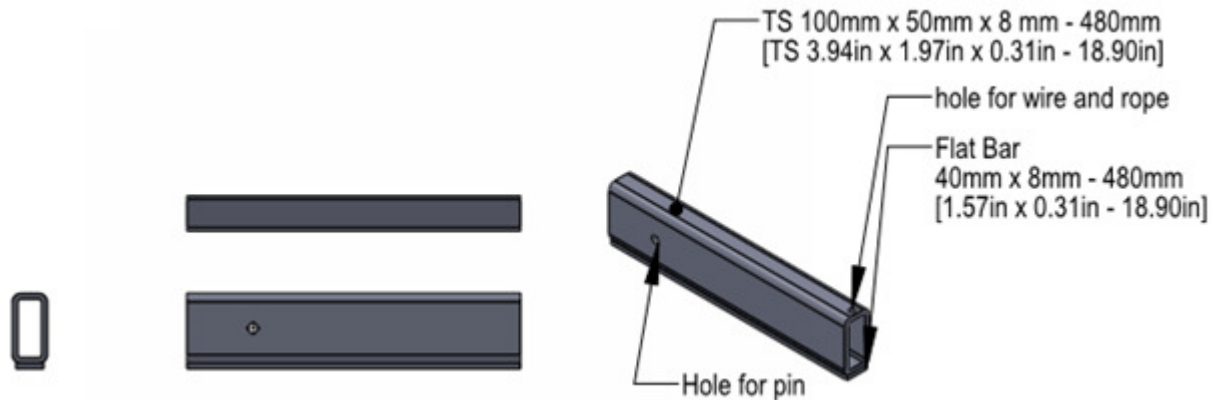


Figure 1.3 Inner Tube Dimensions

### Material

The Shooter is composed of steel meeting the requirements of the European Standard EN 10025. The European grade of material provided is S355, where the S denotes the fact that it is structural steel and the 355 is related to the minimum yield strength of the steel in MPa. The US equivalent grade of S355 is A572, Gr50<sup>1</sup> for flat bar and ASTM A500 Gr C for rectangular HSS. The material properties for both S355, A572 and A500 are shown in table 1.1.

Material Property	ASTM A572, GR. 50/A500 GR. C	S355
F <sub>y</sub> Minimum Yield Stress, ksi	50/50	50
F <sub>u</sub> Tensile Strength, ksi	65/62	68-91
Modulus of Elasticity, ksi	29,000	29,000

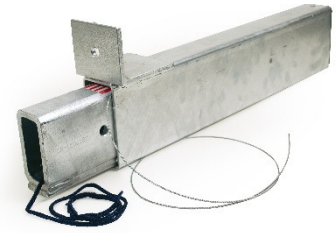
Table 1.1 Equivalent Material Properties





# The SHOOTER

## Part 1 - Executive Summary

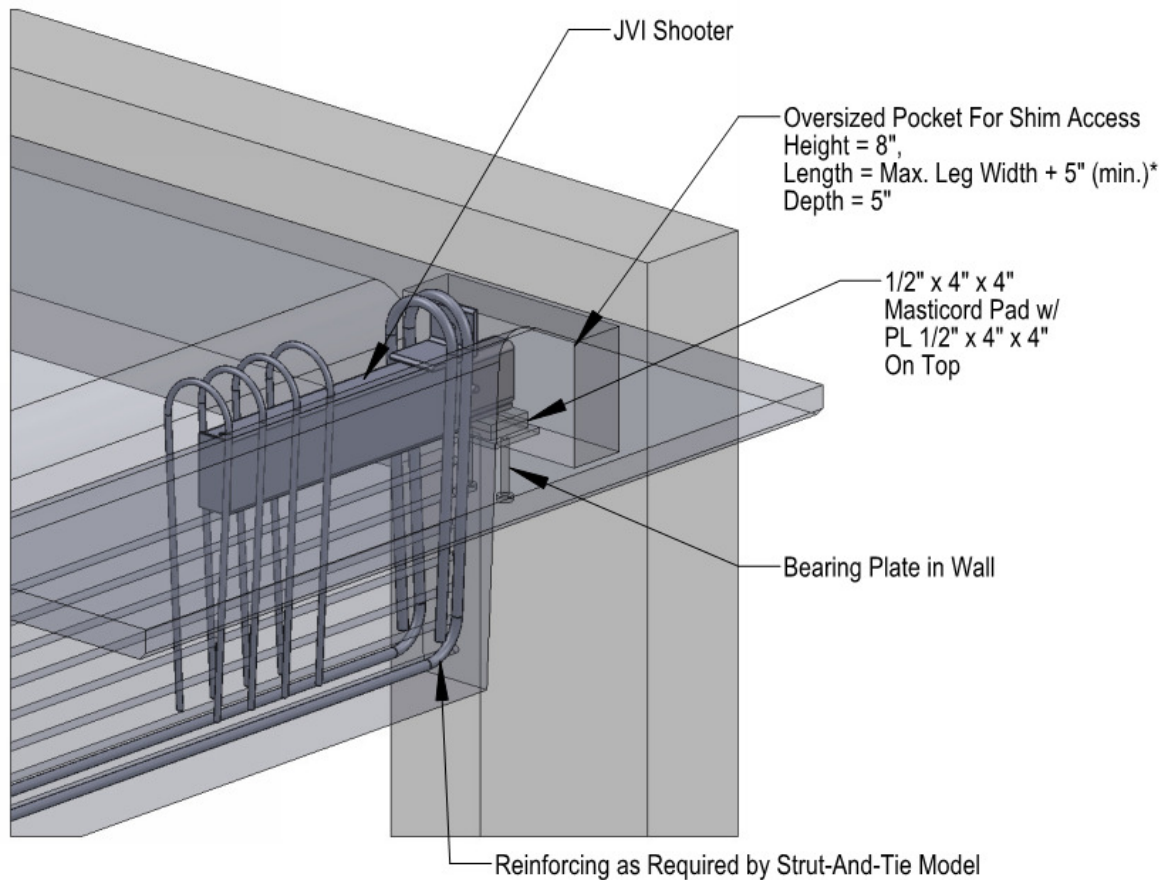


The Shooter is provided with a hot dipped galvanized finish according to the European specification NS-EN ISO 1461. ISO 1461 is essentially equivalent to ASTM A123<sup>2</sup>.

### Mechanical Design Strength

Full scale test results<sup>3</sup> have indicated that the Shooter has a mechanical design Strength in excess of 40,000 lbs. The testing also indicated that a strut-and-tie model can be used to design any member using the shooter as a connection. To achieve the mechanical design capacity of the Shooter sufficient concrete must surround the shooter to develop the required compression strut capacity and reinforcing must be supplied to develop the required tension strut capacity.

### Example Detailing



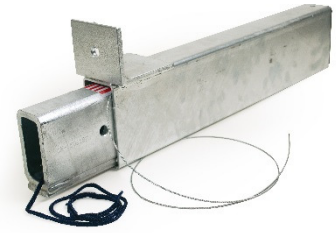
\* For a pocket with pin access on both sides of the DT leg, the pocket width should increase to Max. Leg Width + 10" min.

Figure 1.4 Example Detailing

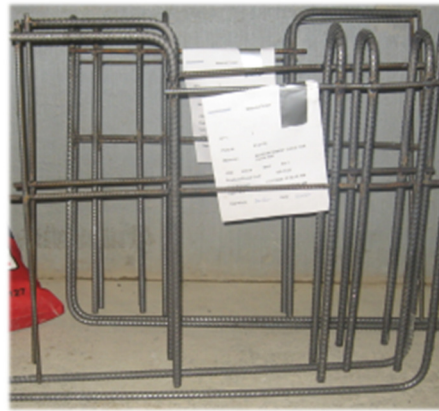
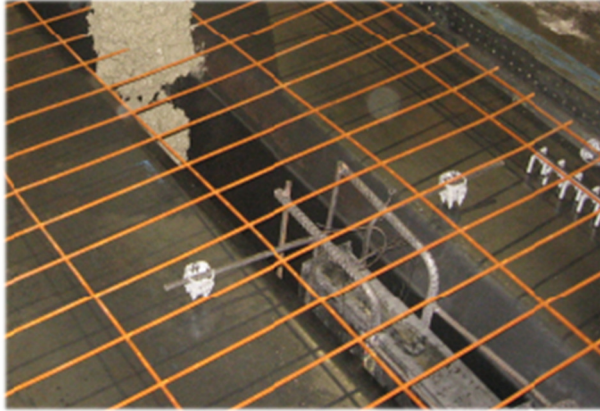


# The **SHOOTER**

## Part 1 - Executive Summary



### In Production



### In the Field

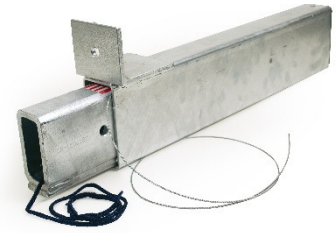






# The **SHOOTER**

## Part 1 - Executive Summary



### References

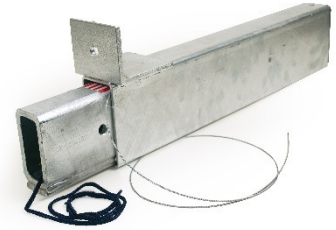
- [1] Gilbert, Nick (2012). Structural Steel - S235, S275, S355 Chemical Composition, Mechanical Properties and Common Applications. <http://www.azom.com/article.aspx?ArticleID=6022>
- [2] Langill, Tom, (2002). ISO 1461 and ASTM A123. <http://www.galvanizeit.org/education-and-resources/resources/technical-faq-dr-galv/iso-1461-and-astm-a-123>
- [3] Poore, Lois E (2009). The Development of a Steel Embedded Connection for Double-Tee Beams. Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.





# The SHOOTER

## Part 2 – Design and Detail



### Introduction

The design and detailing of the Shooter will be presented in 7 sections as noted below.

1. Mechanical Design Strength of the Shooter
2. Concrete Design Strength Using a Strut-And-Tie Model
3. Estimated Design Strengths based on Strut-And-Tie Model
4. Design and Detailing of the bearing pocket
5. Detailing Considerations
6. Summary of full scale test results
7. Further Research

Where applicable, design equations will be referenced directly to the appropriate design guide.

### Disclaimer

The information provided in this reference for the use of the Shooter connection system is not intended to replace the Engineer's judgment and skill in creating a building with appropriate structural integrity and permanent connections required to withstand code prescribed gravity, lateral and torsional forces. The examples presented are concepts intended as guide for the Engineer of Record's consideration and are not to be considered "for construction" documents. Neither JVI nor any of its consultants or suppliers have any Engineer of Record responsibility, or responsibility for contractor use or application of the Shooter connection system.

### Mechanical Design Strength of the Shooter

The Shooter outer tube will be assumed to act as a shim, transferring forces from the inner tube to the concrete. Compression blocks will be assumed starting at the face of concrete and centered on the back of the inner tube as detailed in figure 2.1. The compression block width at the front of the tube will be assumed equal to the width of the angle welded to the outer tube, provided the front compression block length is no longer than the angle leg length. The compression block at the back of the inner tube will be assumed equal to the width of the outer tube.

Force equilibrium can be represented by equations 2.1 and 2.2 and Figure 2.1.

$$\text{Sum of Forces:} \quad V_u + a_2 f_{bu\_back} b_{back} - a_1 f_{bu\_front} b_{front} = 0 \quad \text{Eq. 2.1}$$

$$\text{Sum of Moments:} \quad V_u \left( ecc + \frac{a_1}{2} \right) - a_2 f_{bu\_back} b_{back} \left( L_{inner} - Tube_{ext} - \frac{a_1}{2} \right) = 0 \quad \text{Eq. 2.2}$$

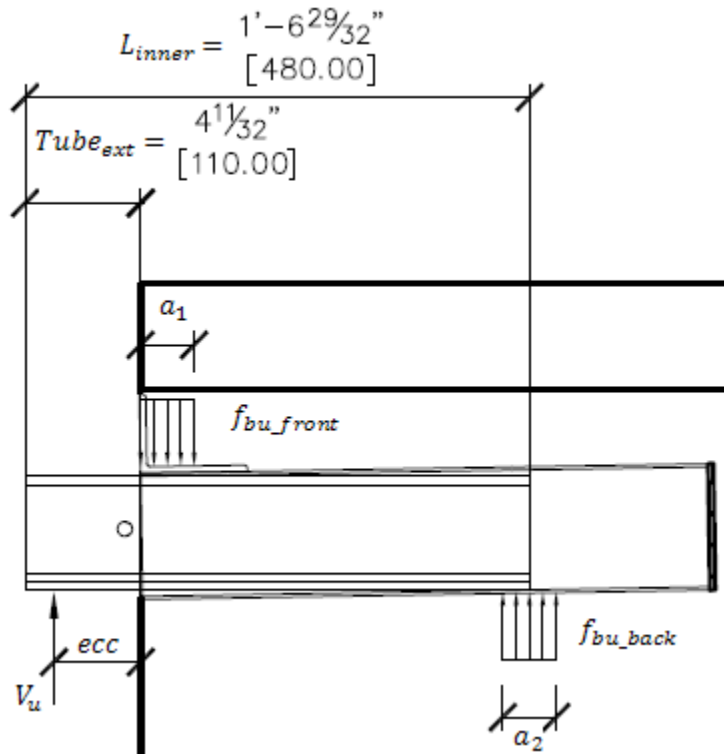
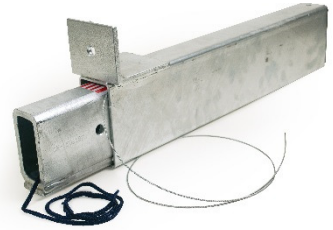
$$\text{Where:} \quad f_{bu} = 0.85 \phi f'_c \sqrt{\frac{b_w}{b}} \leq 1.1 f'_c \quad \text{Eq. 2.3} \\ \text{PCI 7}^{\text{th}} \text{ Ed. (6-83)}$$

$b_w$  = width of the component in which the shooter is cast  
 $b = b_{front}; b_{back}$  based on location of compression block



# The SHOOTER

## Part 2 – Design and Detail



**Figure 2.1 Shooter Equilibrium**

Note: The stress distributions assumed at the face of the concrete and the back of the inner tube are based on PCI 7<sup>th</sup> Edition Handbook , Eq. 6-83<sup>1</sup>. Other stress distributions<sup>2</sup> and simplifying assumptions<sup>3</sup> have been applied to embedded steel sections and may be substituted in lieu of the model presented at the discretion of the engineer.

### Assuming:

$$\begin{aligned} V_u &= 40 \text{ kip} \\ ecc &= 82.55 \text{ mm} = 3.25 \text{ in} \\ f'_c &= 5000 \text{ psi} \\ b_{front} &= 90 \text{ mm} = 3.543 \text{ in} \\ b_{back} &= 60 \text{ mm} = 2.364 \text{ in} \\ b_w &= 190.5 \text{ mm} = 7.5 \text{ in} \end{aligned}$$

### Solving equations 2.1 and 2.2:

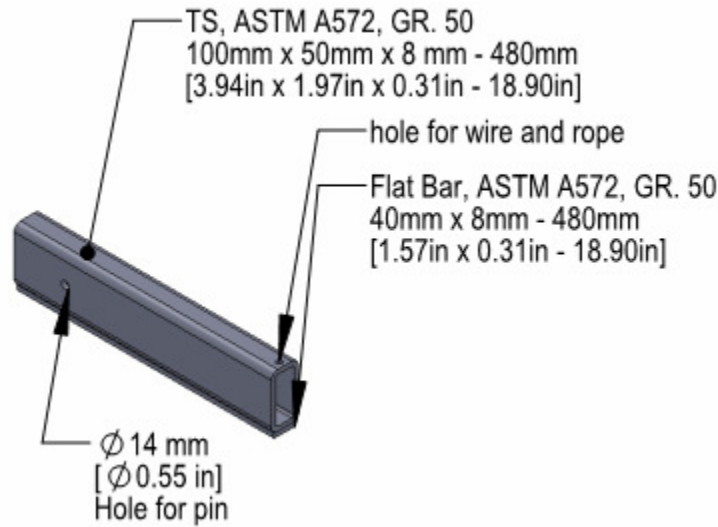
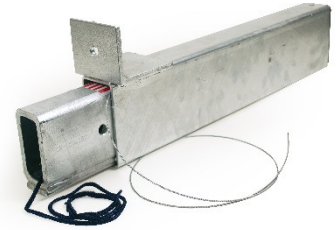
$$\begin{aligned} a_1 &= 3.979 \text{ in} \\ a_2 &= 1.433 \text{ in} \end{aligned}$$

Apply the results of equilibrium to evaluate the inner tube for shear and moment capacity.



# The SHOOTER

## Part 2 – Design and Detail



**Figure 2.2 Shooter Inner Tube Geometry and Material Properties**

Shear capacity of the inner tube, neglecting the flat bar welded to the bottom of the tube can be represented by equation 2.4.

$$V_n = (0.6F_y)A_wC_v \quad \text{Eq. 2.4}$$

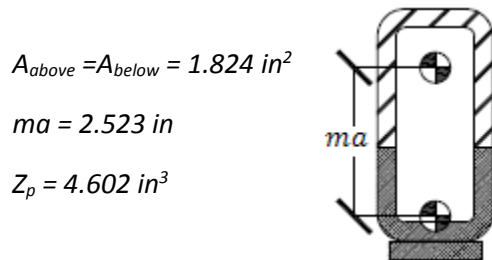
$$A_w = 2(h - 3t - \text{hole})t \quad \text{Eq. 2.5}$$

### **Mechanical Design Strength Based on Steel Shear**

$$\phi V_n = 0.9(0.6 \cdot 50\text{ksi})2(3.94\text{in} - 3 \cdot .315\text{in} - .55\text{in}) \cdot .315\text{in} = 41.5 \text{ kip}$$

Evaluation of equation 2.4 verifies that the mechanical design strength of the shooter exceeds 40 kips when considering a steel shear failure.

Moment capacity of the inner tube can be represented by equation 2.6.

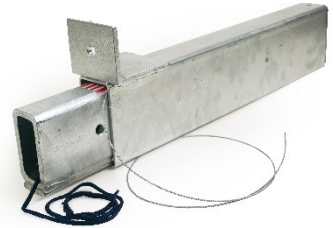


$$\phi M_n = \phi F_y Z_p \quad \text{Eq. 2.6}$$

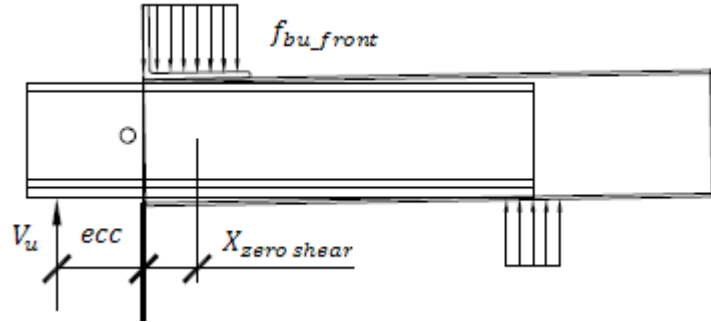
$$\phi M_n = 0.9 \cdot 50\text{ksi} \cdot 4.602\text{in}^3 = 207.1 \text{ in} \cdot \text{kip}$$

**Figure 2.3 Plastic Section Modulus**





The maximum moment is located a zero shear. The location of zero shear measured from the face of concrete, see figure 2.4, can be given by equation 2.7.



**Figure 2.4 Free Body Diagram**

$$X_{zero\ shear} = \frac{V_u}{f_{bu\_front} b_{front}} = \frac{V_u}{0.85 \phi f'_c \sqrt{\frac{b_w}{b_{front}}} \cdot b_{front}} \quad \text{Eq. 2.7}$$

$$X_{zero\ shear} = \frac{40,000\ lbs}{0.85 \cdot 0.65 \cdot 5000\ psi \sqrt{\frac{7.5in}{3.543in}} \cdot 3.543in} = 2.809\ in$$

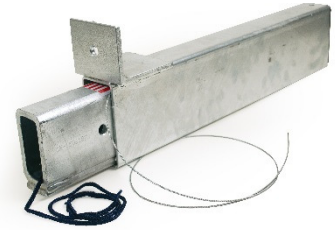
The maximum moment under an ultimate load of 40 kips can then be given by equation 2.8

$$M_u = V_u(ecc + X_{zero\ shear}) - f_{bu\_front} b_{front} \frac{X_{zero\ shear}^2}{2} \quad \text{Eq. 2.8}$$

$$M_u = 40\ kip(3.25in + 2.809in) - 0.85 \cdot 0.65 \cdot 5\ ksi \sqrt{\frac{7.5in}{3.543in}} \cdot 3.543in \frac{2.809in^2}{2}$$

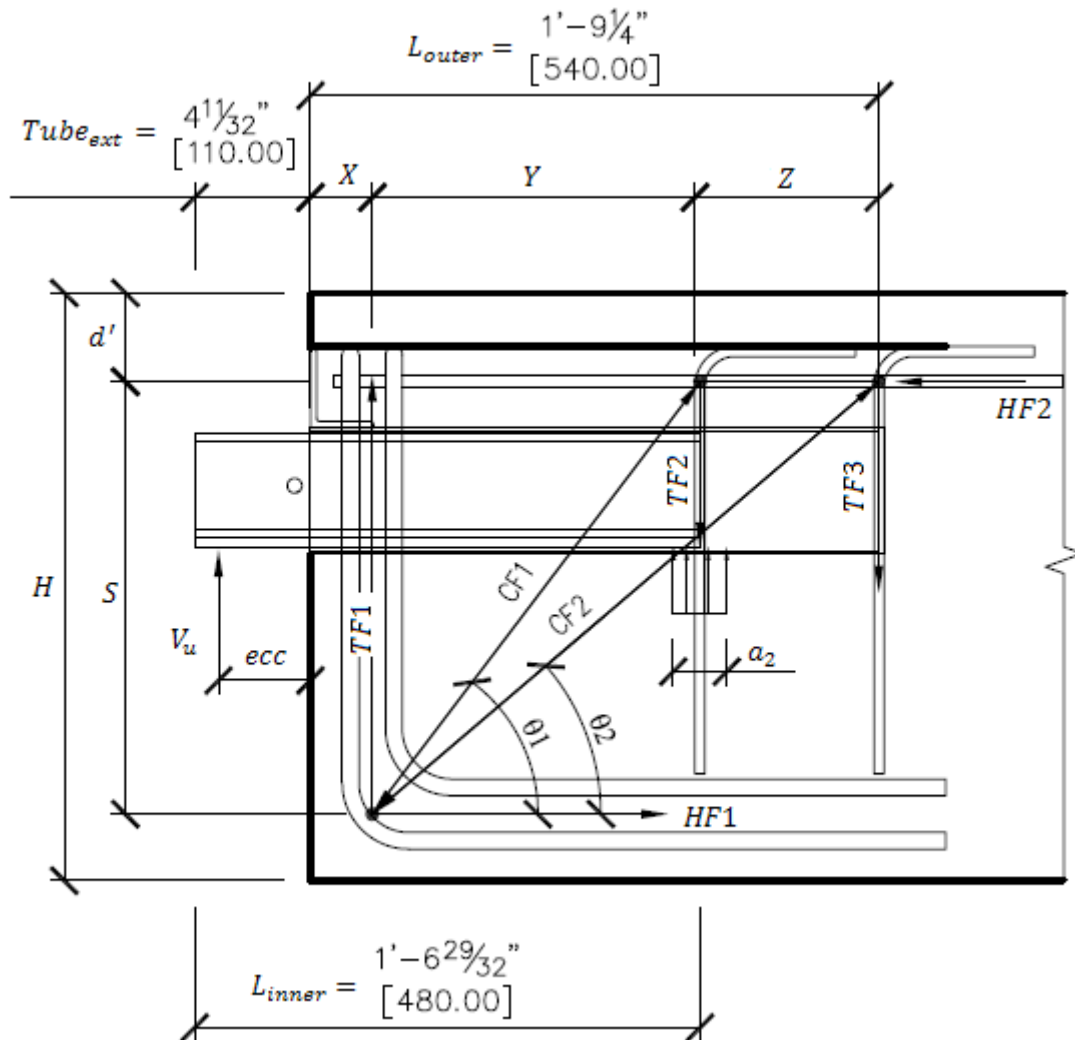
$$= 186.18\ in - kips < \phi M_n = 207.09\ in \cdot kip$$

Evaluation of equation 2.8 verifies that the mechanical design strength of the shooter exceeds 40 kips when considering a steel plastic moment failure.



### Concrete Design Strength Using a Strut-And-Tie Model

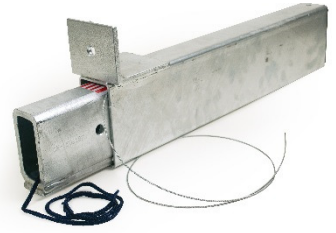
Full scale tests have shown that a strut-and-tie model may be used to design any member using the Shooter as a connection<sup>3</sup>. The model will be developed assuming struts at the location of the reactions of the inner tube (see figure 2.1) as well as the location of supplied reinforcing. Strut locations must also be within the ACI 318-11 limits defined by A2.5. Figure 2.5 represents the assumed model.



**Figure 2.5 Strut-And-Tie Model**

It should be noted that the “X” dimension in Figure 2.5 is located at the centroid of the reinforcing supplied for TF1. Since this reinforcing is not mechanically attached to the Shooter and the force must be transferred to the reinforcing steel through an assumed front compression block in the concrete, it is suggested that the reinforcing steel be distributed evenly over the length of the compression block with the centroid ideally located at the center of the front compression block.

Using the geometry represented in Figure 2.5 the forces in the struts can be give by equations 2.9-2.17.



$$TF1 = V_u \cdot \left( \frac{ecc + X + Y}{Y} \right) \quad \text{Eq. 2.9}$$

$$TF2 = TF1 - V_u \quad \text{Eq. 2.10}$$

$$TF3 = TF1 - TF2 \quad \text{Eq. 2.11}$$

$$\theta_1 = \text{atan} \left( \frac{S}{Y} \right) \quad \text{Eq. 2.12}$$

$$\theta_2 = \text{atan} \left( \frac{S}{Y + Z} \right) \quad \text{Eq. 2.13}$$

$$CF1 = TF2 \cdot \frac{\sqrt{Y^2 + S^2}}{S} \quad \text{Eq. 2.14}$$

$$CF2 = TF3 \cdot \frac{\sqrt{(Y + Z)^2 + S^2}}{S} \quad \text{Eq. 2.15}$$

$$HF1 = TF2 \cdot \left( \frac{Y}{S} \right) + TF3 \cdot \left( \frac{Y + Z}{S} \right) \quad \text{Eq. 2.16}$$

$$HF2 = HF1 \quad \text{Eq. 2.17}$$

Equations 2.14 and 2.15 can be combined so as to consider a resultant concrete strut.

$$CFR = CF1 + CF2 \quad \text{Eq. 2.18}$$

The applied vertical shear stress along the resultant concrete strut must be less than the allowable shear stress for the design to be satisfactory. The allowable shear stress is given by equations 2.19-2.21.

$$v_c = 2\sqrt{f'_c} \lambda \quad \text{Eq. 2.19}$$

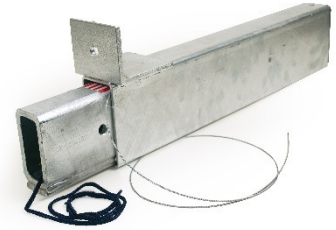
ACI 318-11 [11.2.1.1]

$$v_s = 8\sqrt{f'_c} \quad \text{Eq. 2.20}$$

ACI 318-11 [11.4.7.9]

$$\phi v_{allowable} = \phi(v_c + v_s) \quad \text{Eq. 2.21}$$



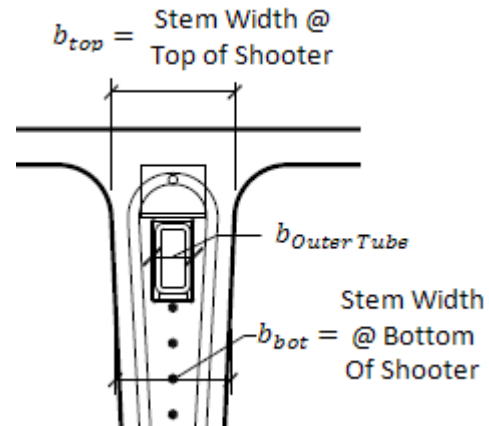


The applied vertical shear stress can be represented by equations 2.22-2.24.

$$b = \frac{b_{top} + b_{bot}}{2} \quad \text{Eq. 2.22}$$

$$A_v = (b - b_{Outer Tube})(H - d') \quad \text{Eq. 2.23}$$

$$v_u = \frac{TF1}{A_v} \quad \text{Eq. 2.24}$$



**Figure 2.6 Stem Dimensions**

The effective strength of nodal zones is governed by ACI 318-11 A.5 and can be given by equation 2.25. The effective strength of the nodal zone must be greater than the applied stress at the node due to the resultant compression strut for the design to be satisfactory.

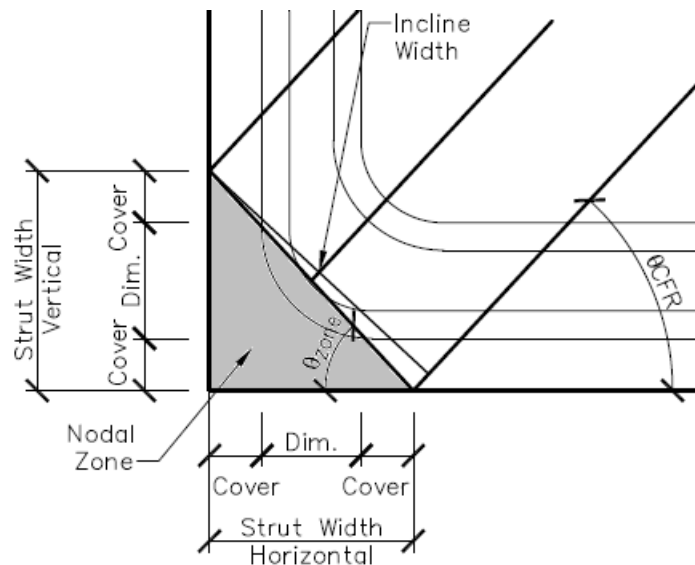
$$\phi f_{ce} = \phi 0.85 \cdot \beta_n f'_c \quad \text{Eq. 2.25}$$

$$\beta_n = 0.6\lambda \quad \text{ACI 318-11 [A5.2]}$$

$$\quad \text{Eq. 2.26}$$

$$\quad \text{ACI 318-11 [A5.2.3]}$$

Node geometry is dependent on reinforcing geometry. The width of the nodal zone can be determined assuming a distance between reinforcing bars plus 2 times the cover (see figure 2.7).

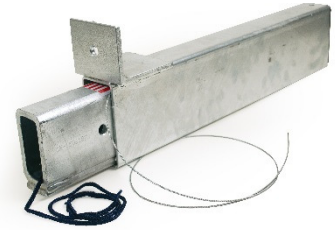


**Figure 2.7 Example Nodal Zone**



# The SHOOTER

## Part 2 – Design and Detail



Prestressing strand can be considered with regard to nodal zone reinforcing and overall strut geometry at the discretion of the engineer.

Assuming the geometry given by figure 2.7, the applied stress at the nodal zone can be given by equations 2.27-2.28.

$$A_{nz} = \sqrt{\text{Strut Width Vertical}^2 + \text{Strut Width Horizontal}^2} \cdot t_{node} \quad \text{Eq. 2.27}$$

$$f_u = \frac{CFR}{A_{nz}} \quad \text{Eq. 2.28}$$

The effective strength of compression struts is governed by ACI 318-11 A.3 and can be given by equations 2.29-2.30. The effective strength of the compression strut must be greater than the applied stress at the node due to the resultant compression strut for the design to be satisfactory.

$$\phi f_{ce} = \phi 0.85 \cdot \beta_s f'_c \quad \text{Eq. 2.29}$$

$$\beta_s = 0.6\lambda \quad \text{ACI 318-11 [A3.2]}$$

$$\quad \text{Eq. 2.30}$$

$$\quad \text{ACI 318-11 [A3.2.2]}$$

The strut will be critical at the location of the shooter, where the strut width should be reduced by the width of the outer tube. Still applying the geometry from figures 2.6 and 2.7, the stress in the strut can be given by equations 2.31-2.32.

$$A_{cs} = \sqrt{\text{Strut Width Vertical}^2 + \text{Strut Width Horizontal}^2} \cdot (b - b_{out}) \quad \text{Eq. 2.31}$$

$$f_u = \frac{CFR}{A_{cs}} \quad \text{Eq. 2.32}$$

It should be noted that assuming an inclined width, see figure 2.7, of the compression strut would result in a strut width less than the nodal width. This reduces the capacity of the compression strut by less than 4% and has been neglected.

The reported value of  $\beta_s$  in equation 2.30 can be increased based on supplied reinforcement as defined by ACI 318-11 A3.2.2(a).

The required reinforcement for strut forces TF1, TF2, TF3 and HF1 should be supplied based on equation 2.33 and ACI 318-11 A.4.

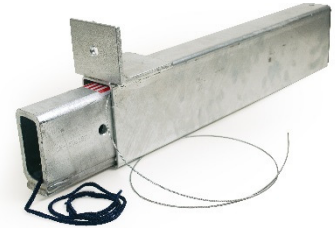
$$A_{ts} = \frac{\text{Strut Force}}{\phi f_y} \quad \text{Eq. 2.33}$$

Where  $f_y$  is the yield strength of the supplied reinforcing.



# The SHOOTER

## Part 2 – Design and Detail



The HF1 reinforcing requirement can consider contributions due to prestressing strand through the use of an extended nodal zone per ACI 318-11 RA.4.3. Due to the variance in supplied prestressing strand geometry, the prestressing strand contribution has not been covered. A detailed example of how to apply the extended nodal zone can be found in reference 3.

The compression strut resulting from HF2 can be resolved by using the effective compression strut strength represented by equation 2.29. The stress in the compression strut can be given by Eq. 2.34 and 2.35.

$$A_{cs} = 2 \cdot d' \cdot b \quad \text{Eq. 2.34}$$

$$f_{cu} = \frac{HF2}{A_{cs}} \quad \text{Eq. 2.35}$$

If effective strength of the compression strut is greater than the applied stress, the strut is satisfactory.

The strut reinforcing should be located so as to maintain the initial geometry of the assumed strut-and-tie model.

The contribution of a normal force has been neglected due to the inherent ability of the Shooter to allow for axial volume movements.

### Recommended Design Strengths based on Strut-An-Tie Model

Using the strut-and-tie model described above, assuming the simplified double tee geometry shown in figure 2.8, and assigning  $d' = 4in$ ,  $S = H - d' - 2.5in$ , and  $Strut\ Width\ Vertical = Strut\ Width\ Horizontal = 5.5in$  the following recommendations for design strength are presented.

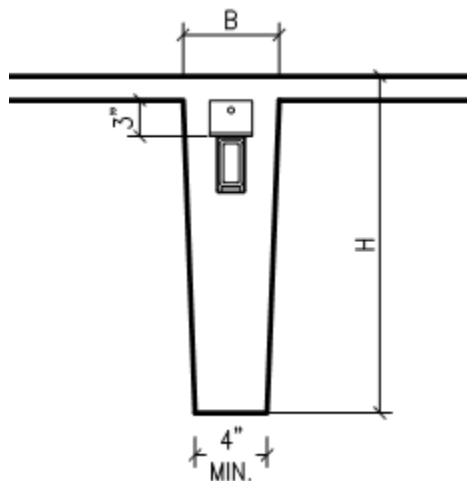


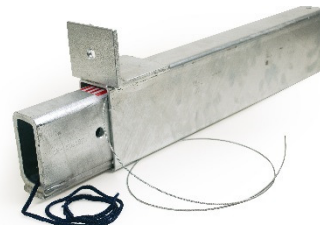
Figure 2.8 Simplified Double Tee Geometry





# The **SHOOTER**

## Part 2 – Design and Detail



Recommended Design Strength Based on $f'_c = 5000$ psi			
H (in)	B (in)	$\phi V_n$ (kip)	Controlling Factor
24	6	24.25	Compression Stress at Resultant Concrete Strut @ Shooter (CFR) Eq. 2-29
	8	30.25	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29*
	10	30.5	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29
28	6	27.0	Compression Stress at Resultant Concrete Strut @ Shooter (CFR) Eq. 2-29
	8	33.0	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29 *
	10	33.25	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29*
32	6	29.0	Compression Stress at Resultant Concrete Strut @ Shooter (CFR) Eq. 2-29
	8	35.0	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29*
	10	35.5	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29*
Recommended Design Strength Based on $f'_c = 6000$ psi			
24	6	27.5	Vertical Shear Along Resultant Concrete Strut @ Shooter (CFR) Eq. 2.21
	8	36.25	Vertical Shear Along Resultant Concrete Strut @ Node (CFR) Eq. 2.21*
	10	40.0	Mechanical Design Strength of the Shooter
28	6	32.5	Compression Stress at Resultant Concrete Strut @ Shooter (CFR) Eq. 2-29
	8	39.75	Compression Stress at Resultant Concrete Strut @ Node (CFR) Eq. 2-29 *
	10	40.0	Mechanical Design Strength of the Shooter
32	6	35.0	Compression Stress at Resultant Concrete Strut @ Shooter (CFR) Eq. 2-29
	8	40.0	Mechanical Design Strength of the Shooter
	10	40.0	Mechanical Design Strength of the Shooter

\* Failure modes “@ Node” are governed by 4” minimum bottom of leg dimension. If the bottom of the leg is wider than the 4” additional capacity is available beyond that reported.

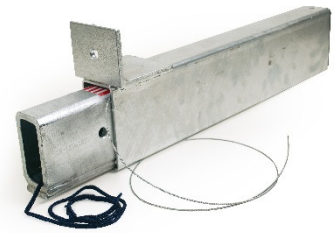
**Table 2.1 Recommended Design Strength**

Values in table 2.1 should be considered estimates and not for construction values. For actual design strength of member, the correct geometry and concrete strengths should be applied by a qualified engineer. The table does not take into consideration of the required reinforcing at the tension struts and whether or not adequate room would be available within the concrete section.



# The SHOOTER

## Part 2 – Design and Detail



### Design and Detailing of the bearing pocket

The bearing width of the Shooter inner tube is minimal (figure 2.9). In general the bearing width will need to be increased to allow for the design of the concrete bearing surface.

If steel shims are used a bearing plate should be embedded in the receiving pocket with adequate thickness to distribute the load from the inner tube to a sufficient concrete area that satisfies plain concrete bearing.

Additionally, the use of a bearing pad may be desired to account for non-uniform bearing due to double tee rotation and inner tube rotation inside the outer tube (Figure 2.10). A sufficient area of bearing pad needs to be engaged to allow the bearing pad to design as well as satisfy plain concrete bearing of the receiving pocket. This can be accomplished by installing a plate with sufficient thickness to engage the required area of bearing pad. The bearing pad can be designed assuming the engaged area and utilizing the equations in Masticord Design Guide Third Edition<sup>6</sup>. The use of an embedded bearing plate in the receiving pocket in addition to the bearing pad may be detailed to provide redundancy in the design at the discretion of the engineer.

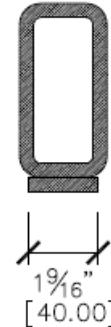


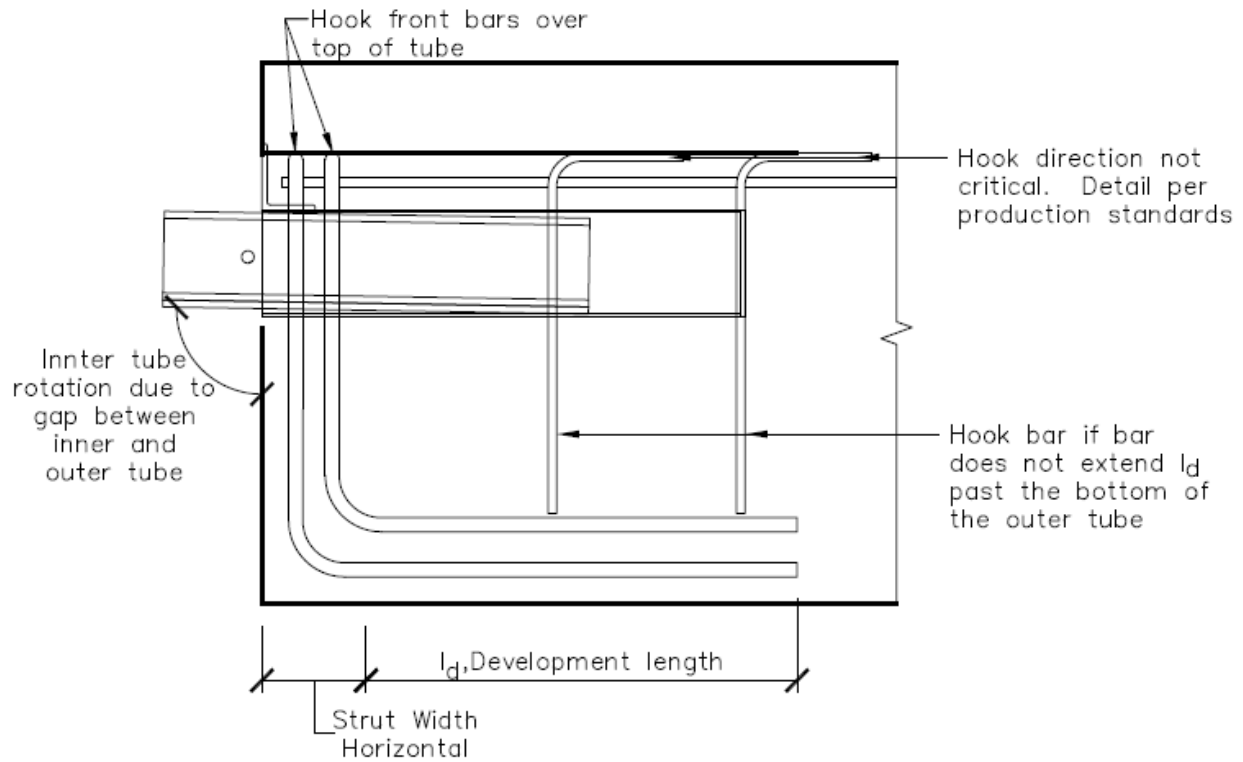
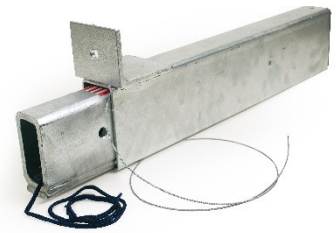
Figure 2.9 Bearing Width

The bearing shim or pad should be located so as to consider spall concerns of the receiving pocket and to minimize eccentricity on the Shooter. Actual eccentricity based on joint geometry and bearing shim or pad location should be considered in the final design of the Shooter.

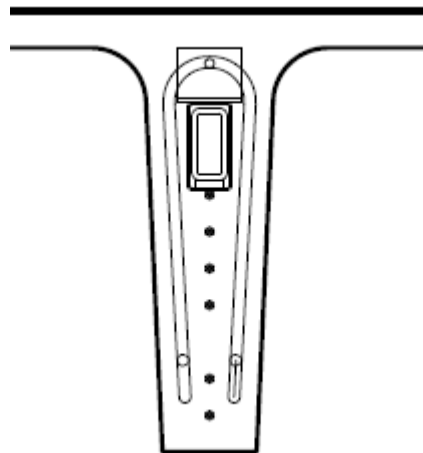
### Detailing Considerations

Figure 2.10 illustrates detailing concerns for the Shooter.

1. The front bars should hook over the top of the shooter (figure 2.11) and be developed past the bottom of the outer tube. If they do not extend the development length past the bottom of the outer tube, they should be hooked or otherwise mechanically anchored.
2. The front bar(s) should also be hooked to develop the horizontal tension strut, HF1 (figure 2.5). They should extend the development length past the horizontal strut width at the nodal zone.
3. Vertical strut reinforcing not at the front of the shooter should extend the development length past the bottom of the tube. The bottom of the tube is assumed to provide developed reinforcing crossing a potential crack plane at the interface between the tube and the concrete. If sufficient depth is not available to develop the bars, the bars should be hooked or otherwise mechanically anchored to develop the bar. The bars also need to be developed above the top of the outer tube. This can be achieved by hooking the bars or otherwise mechanically anchoring the bars. Unlike the front bars, the direction of the hook is not critical and can be detailed per preferred production standards.
4. Shooter reinforcing is considered in addition to shear and flexural reinforcing.
5. Additional longitudinal reinforcing (not shown) can be provided as crack control, normal force reinforcement and to assist in cage assembly above and below the tube.



**Figure 2.10 Detailing Considerations**



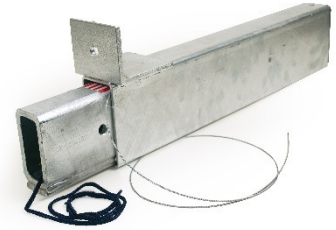
**Figure 2.11 Front Bar Hook Requirement**





# The SHOOTER

## Part 2 – Design and Detail



### Summary of full scale test results

Full scale tests were performed at Virginia Polytechnic Institute and State University in 2009. The full report can be found in reference 2. Please consult the reference for complete details.

A total of (4) tests were conducted. In each test, the Shooter mechanical capacity was not in question.

Strain gauges applied to the reinforcing bars for each test indicate that the reinforcing closest to the end of the double tee experienced larger strains than bars located farther from the end of the double tee. The strain in the bars closest to the end of the double tee increased linearly as the load was increased. The strut-and-tie model was superimposed on the results of the test strains. The results indicated that the strut-and-tie model was conservative.

### Further Research

The shooter was initially tested assuming flat bearing conditions. Slopes due to traditional drainage and camber are considered to be addressed by the initial testing. Additional testing was completed to validate the shooter on a parking ramp as illustrated in figure 2.12. The slope was limited to 6.67%, the maximum parking slope allowed by the International Building code. The maximum end reaction obtained during tested was 30.8 kips. The test was stopped as the double tee was not to be tested to failure. The results indicate that the inclusion of a ramp does not lead to any additional cracking of the concrete nor impact on steel performance.

Additional testing should be complete to failure to assess a final design strength of the shooter on a ramped double tee.

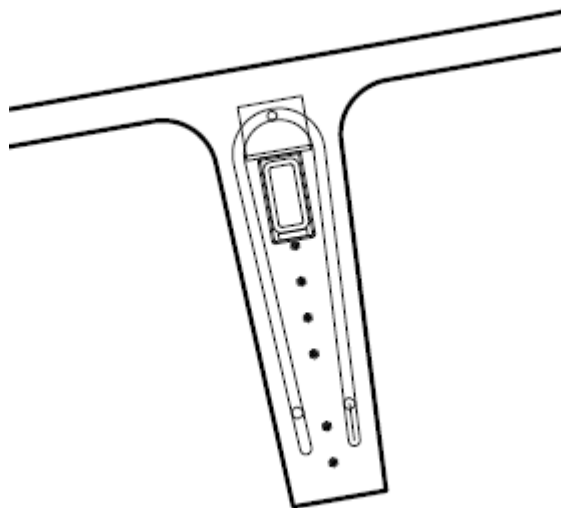
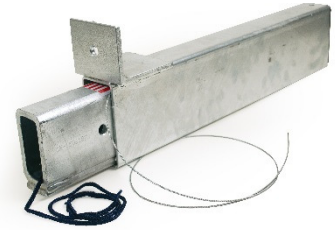


Figure 2.12 Parking Ramp Slope



# The **SHOOTER**

## Part 2 – Design and Detail



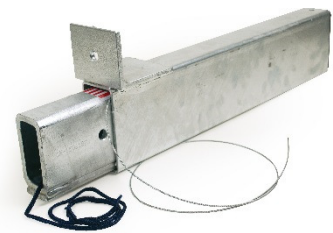
### References

- [1] Precast Concrete Handbook Committee (2010). PCI Design Handbook 7<sup>th</sup> Edition, Precast Concrete institute, Chicago, IL
- [2] Marcakis, K., and D. Mitchell (1980). Precast Concrete Connections with Embedded Steel Members. PCI Journal, V. 25, No. 4 (July-August).
- [3] Poore, Lois E (2009). The Development of a Steel Embedded Connection for Double-Tee Beams. Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA.
- [4] American Institute of Steel Construction (2005). Manual of Steel Construction, 13<sup>th</sup> edition, AISC, Chicago, IL
- [5] ACI Committee 318-11 (2011). Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary (318R-11), American Concrete Institute, Chicago, IL.
- [6] Masticord Design Guided Third Edition (1996). JVI, Inc, Lincolnwood, IL.



# The SHOOTER

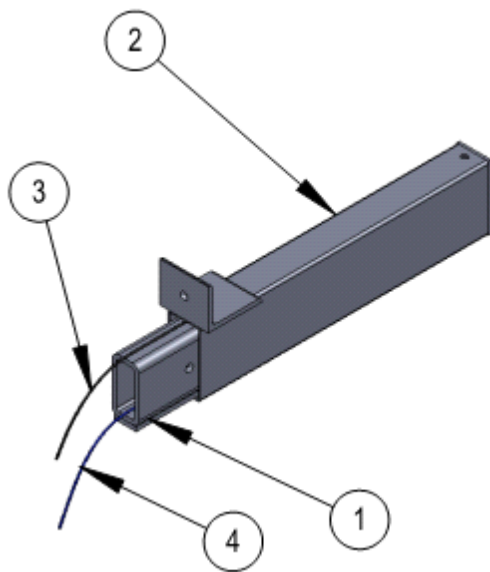
## Part 3 – Production



The following discussion contains recommendations for production procedures to facilitate the installation of the Shooter. Plant practices, processes and facilities may dictate alternate procedures. A production plan specific to each facility, with consideration of the following recommendations, should be evaluated prior to incorporating the Shooter into production.

### Installation

The Shooter assembly, see figure 3.1, is installed as a single component. The nylon string and steel wire should be inserted into the inner tube and secured in place during casting. To ensure that concrete does not get inside the inner tube, the end of the Shooter at the bulkhead should be taped or otherwise sealed.



Item No.	Description
1	Inner Tube
2	Outer Tube
3	Pull Out Steel Wire
4	Pull In Nylon Wire

**Figure 3.1 Shooter Assembly**

It is recommended that the Shooter reinforcing cage be assembled and considered as a single element for installation in lieu of individually detailing and installing the rebar at the bed to facilitate accurate installation locations. See Figure 3.2.

The Shooter must be adequately anchored to the bulkhead to ensure the assembly does not rotate during casting. A rubber mandrel that is fitted to the outer tube and bolted to the bulk head, along with the back end tied to a “U” shaped rebar has been employed to secure the Shooter with success.



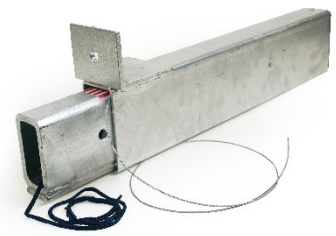
**Figure 3.2 Assembled Rebar Cage**





# The **SHOOTER**

## Part 3 – Production



### Casting

Due to congestion at the Shooter reinforcing, consolidation of concrete should be observed. The same process used to ensure consolidation at dapped end reinforcing should be employed at the Shooter.

### Storage

No special storage needs are required beyond the taping of the exposed end of the shooter. This prevents water from getting into the tube and assists in securing the inner tube in place during transportation and prior to erection. See Figures 3.3.

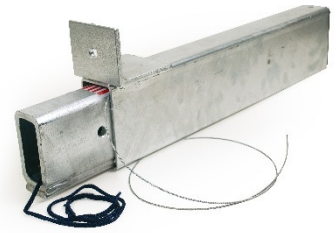


**Figure 3.3 Taped End of the Shooter**



## The **SHOOTER**

### Part 4 – Erection



The following discussion contains recommendations for erection procedures to facilitate erection of a precast double tee using the Shooter as a gravity support. Erector or project specific requirements may dictate alternate procedures. An erection plan specific to each erector and project, with consideration of the following recommendations, should be evaluated prior to incorporating the Shooter.

### Preparation

The exposed ends of the Shooter should arrive sealed with tape or a similar tool. The sealant should be removed and the push and pull strings placed on the top surface of the double tee. See figure 4.1.



**Figure 4.1 the Shooter Push/Pull Strings Removed.**

Bearing pads and associated shims should be put in place in the receiving pocket.

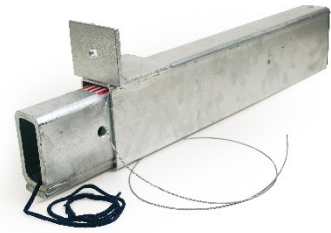
### Installation

During placement of the double tee, the inner tube of the shooter is flush with the end of the double tee. This allows the double tee to be moved into position without requiring an elevation change between ends of the double tee, sometimes referred to as diving of the double tee. See figure 4.2.



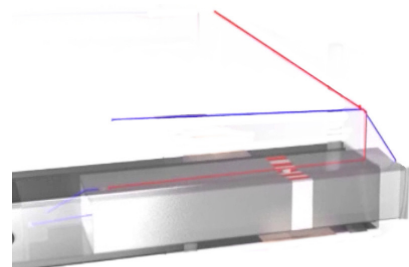
# The **SHOOTER**

## Part 4 – Erection



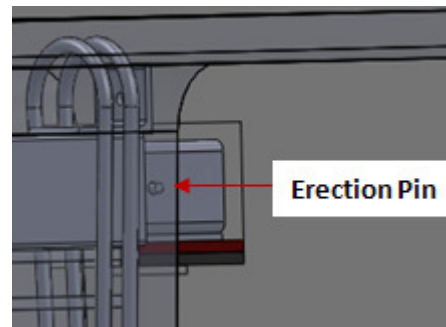
**Figure 4.2 Erection Orientation of Double Tee with the Shooter Bearing in Pocket**

Once the double tee is lowered to the correct elevation, a steel wire is used to pull out the inner tube. The top of the inner tube is marked to indicate when the tube has been sufficiently removed. A nylon string is available to pull the inner tube back into the outer tube if the initial projection is excessive. See Figure 4.3.



**Figure 4.3 Inner Tube Extraction**

Once the tubes have been extracted the erection pin should be installed. This pin prevents the inner tube from retracting back into the outer tube (Figure 4.4). The receiving pocket is intentionally oversized in the horizontal direction to allow the installation of the pin. See Figure 4.5. Additionally, the receiving pocket is oversized in the vertical direction to allow for any elevation adjustments to be made with the inner tube remaining projected.



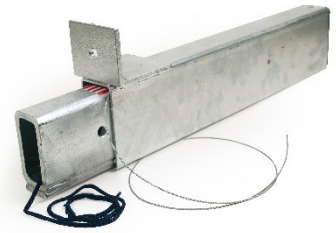
**Figure 4.4 Erection Pin**





## The **SHOOTER**

### Part 4 – Erection



**Figure 4.5 Installation of Erection Pin**

### **Fireproofing**

The bearing pocket should not be grouted to obtain a required fire rating. Instead an appropriate flexible spray or fire proofing material should be utilized.

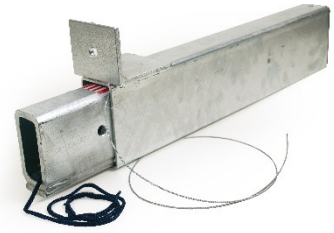
### **Maintenance**

Standard inspection processes for precast structures should be applied to the Shooter connection.



# The **SHOOTER**

## Appendix

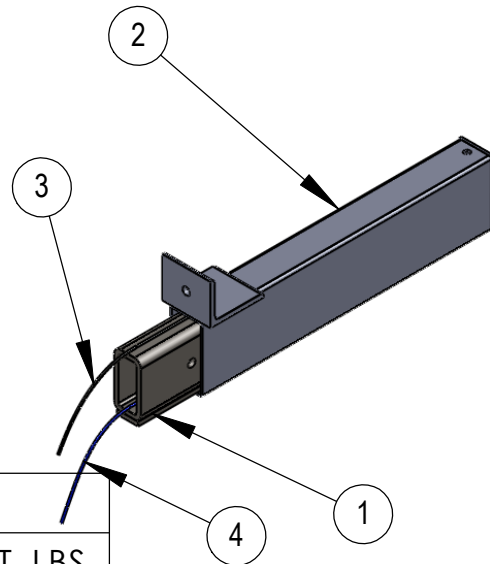
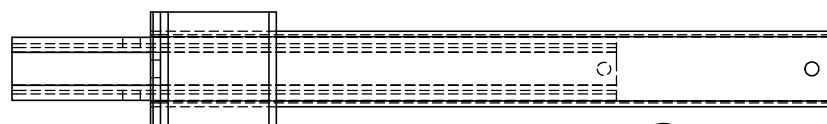
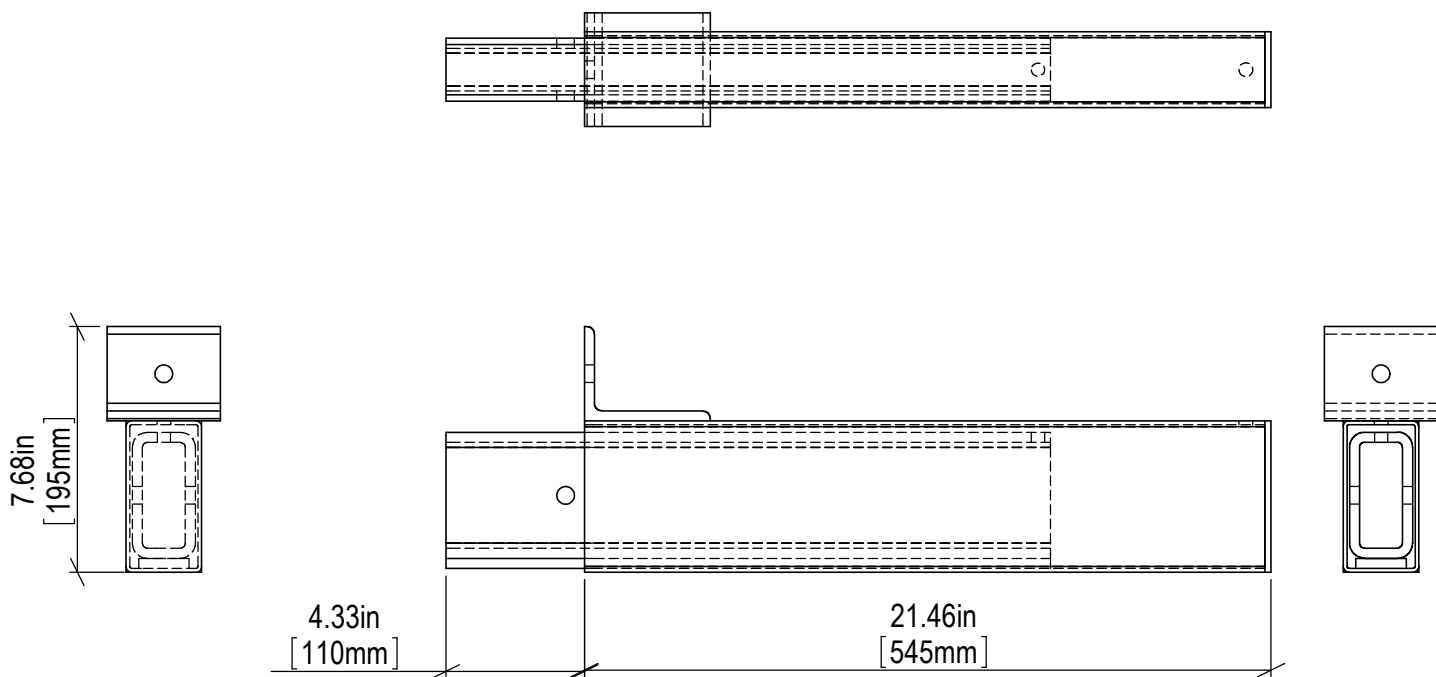


### Appendix

The appendix consists of:

1. Plate Drawings
2. Example Detailing
3. Example Reinforcing
4. Example Calculations for the Strut-and-Tie Method
5. Example Calculations for bearing pad design

All are provided for concept only and should not be used for construction use.



ALL STEEL IS GALVANIZED ACCORDING TO NS-EN ISO 1461

#### PART LIST

ITEM	DESCRIPTION	MATERIAL	CUTTING L	QTY	wT. LBS
1	INNER TUBE			1	19.6
2	OUTER TUBE			1	11.7
3	WHITE ROPE	NYLON	1500	1	
4	BLUE ROPE	NYLON	1500	1	

TOTAL WEIGHT : 31.3 LBS



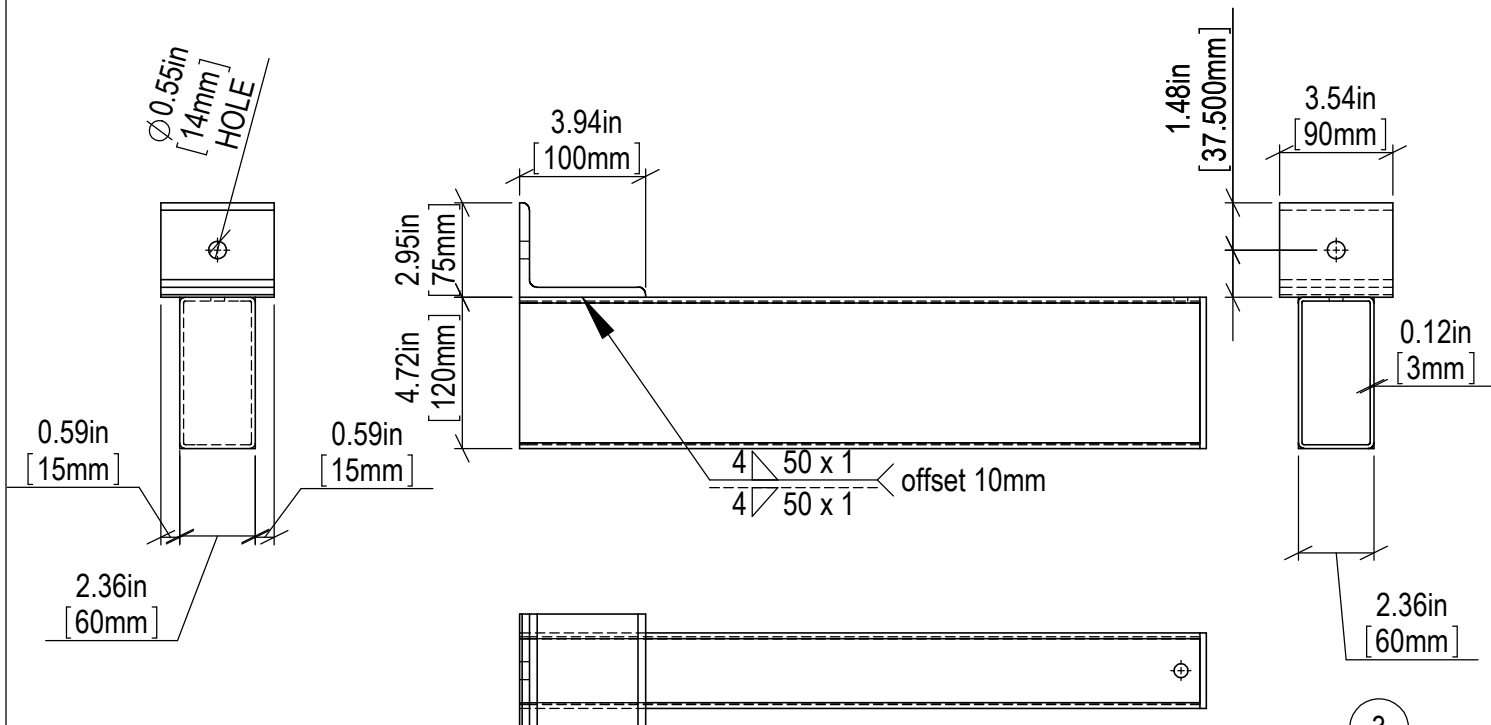
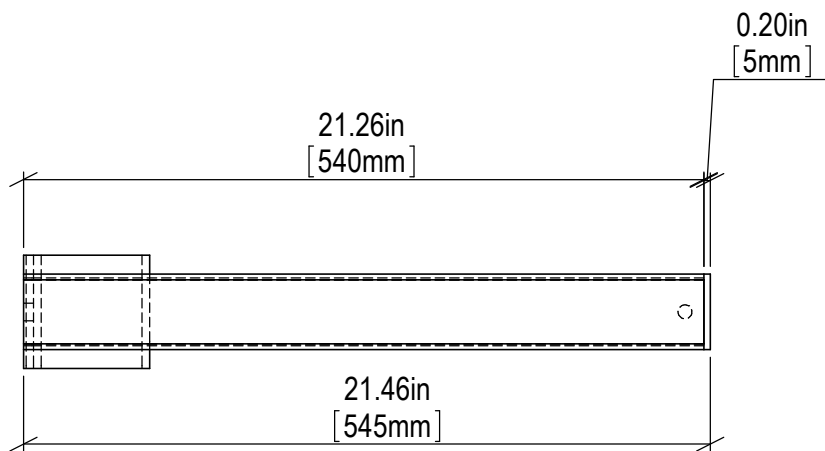
7131 North Ridgeway Avenue  
Lincolnwood, Illinois 60712 USA  
Tel. 847/675-1560 - Fax 847/675-0083

JVI DT SHOOTER

INNER AND OUTER TUBE ASSEMBLED  
WITH WIRE AND ROPE

DATE	DRAWN	CHECKED	SCALE
02.15.2016	JVI	---	---

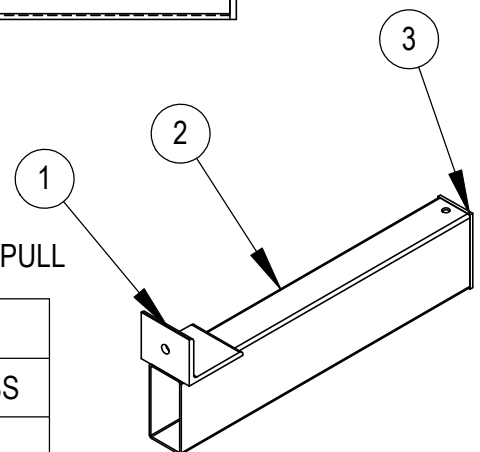




# NOTES:

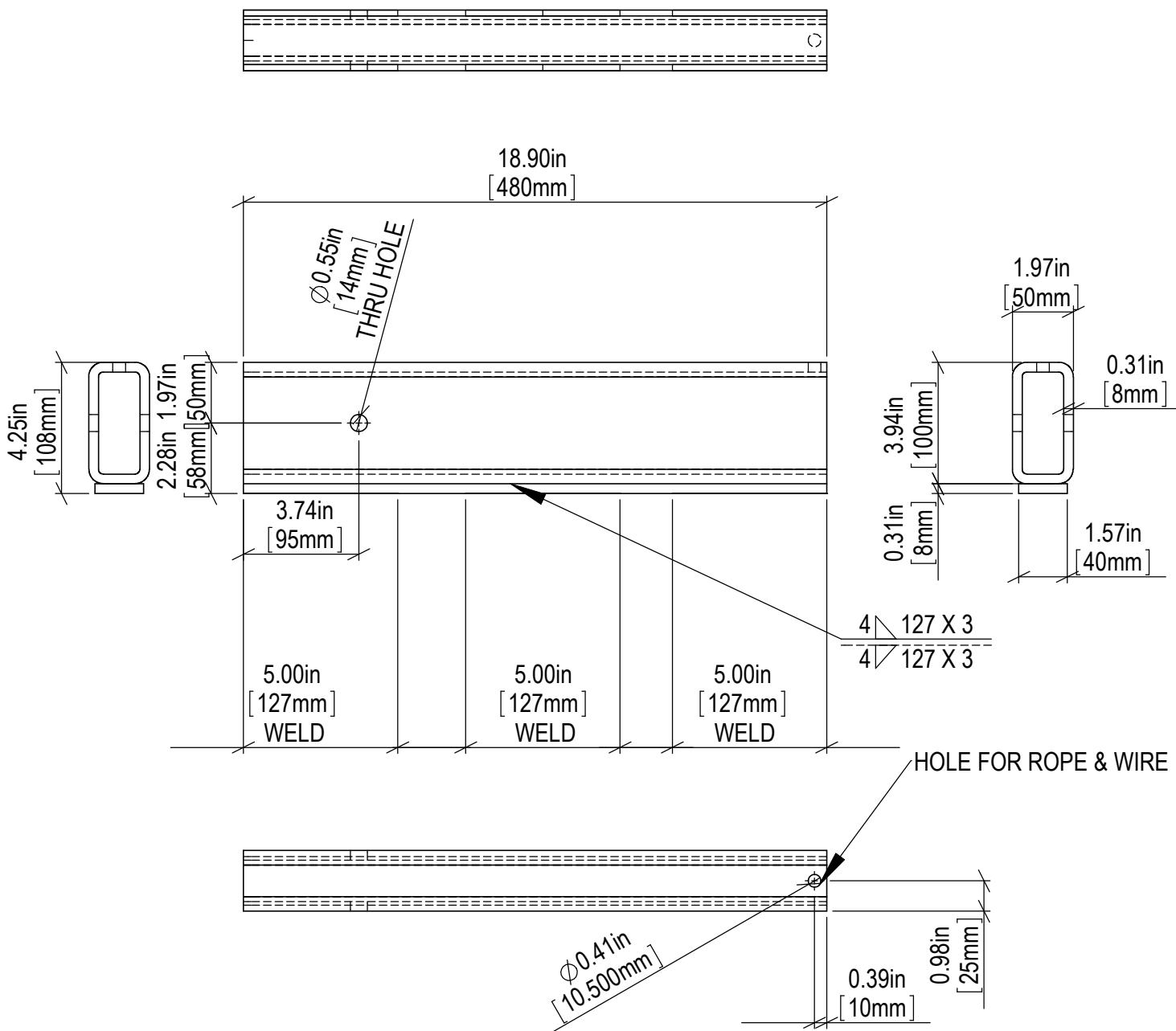
1. PLASTIC TOP SHOULD BE REINFORCED TO PREVENT FAILURE DURING PULL

PART LIST					
ITEM	DESCRIPTION	MATERIAL	CUTTING L	QTY	WT. LBS
1	L 100X75X8 L=90	S355	90	1	2.1
2	TS 120X60X3 L=540	S355	540	1	9.6
3	PLASTIC TOP (SEE NOTE 1)			1	



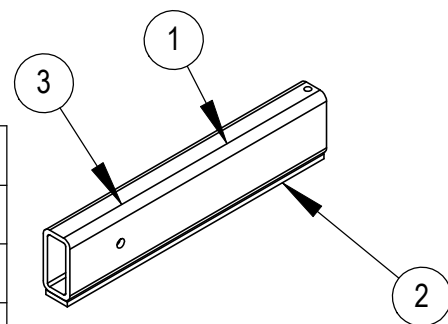
TOTAL WEIGHT : 11.7 LBS

 <p>7131 North Ridgeway Avenue Lincolnwood, Illinois 60712 USA Tel. 847/675-1560 - Fax 847/675-0083</p>				JVI DT SHOOTER	
				OUTER TUBE	
DATE 02.15.2016	DRAWN JVI	CHECKED _____	SCALE _____		



#### PART LIST

ITEM	DESCRIPTION	MATERIAL	CUTTING L	QTY	WT. LBS
1	TS 100X50X8 L=480	S355	480	1	16.9
2	FLAT BAR 40X8 L=480	S355	480	1	2.7
3	STOP LABEL			1	



TOTAL WEIGHT : 19.6 LBS

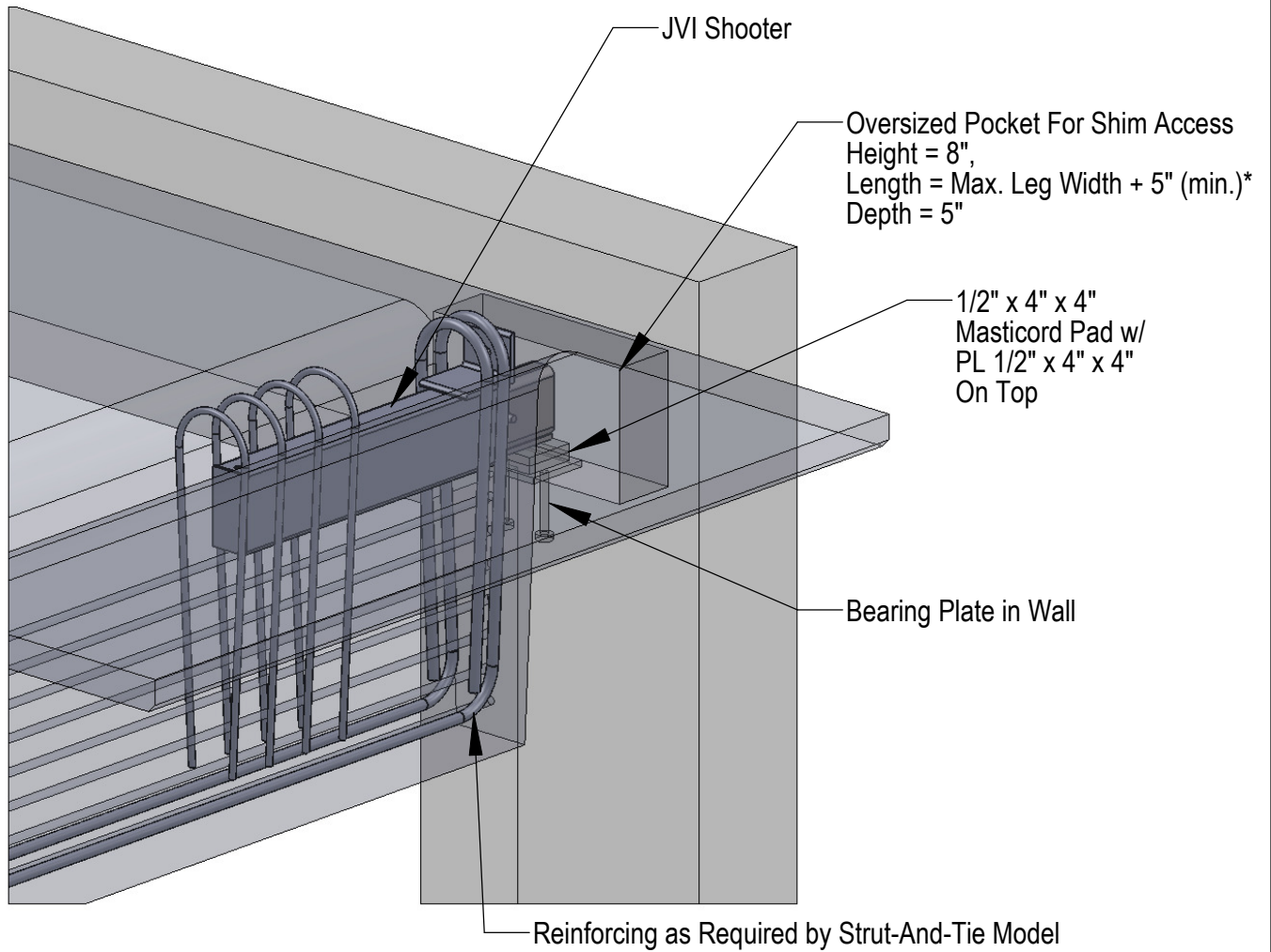


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Lincolnwood, Illinois 60712 USA  
Tel. 847/675-1560 - Fax 847/675-0083

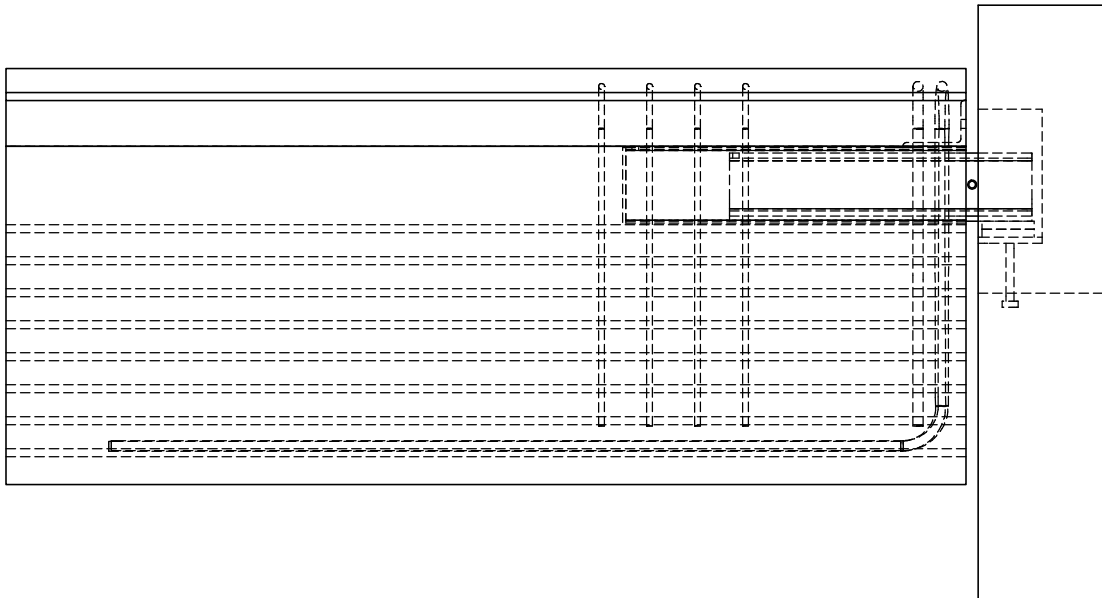
JVI DT SHOOTER

INNER TUBE

DATE	DRAWN	CHECKED	SCALE
06.23.2014	JVI	---	---



\* For a pocket with pin access on both sides of the DT leg, the pocket width should increase to Max. Leg Width + 10" min.



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JVI SHOOTER

DOUBLE TEE BEARING ON WALL

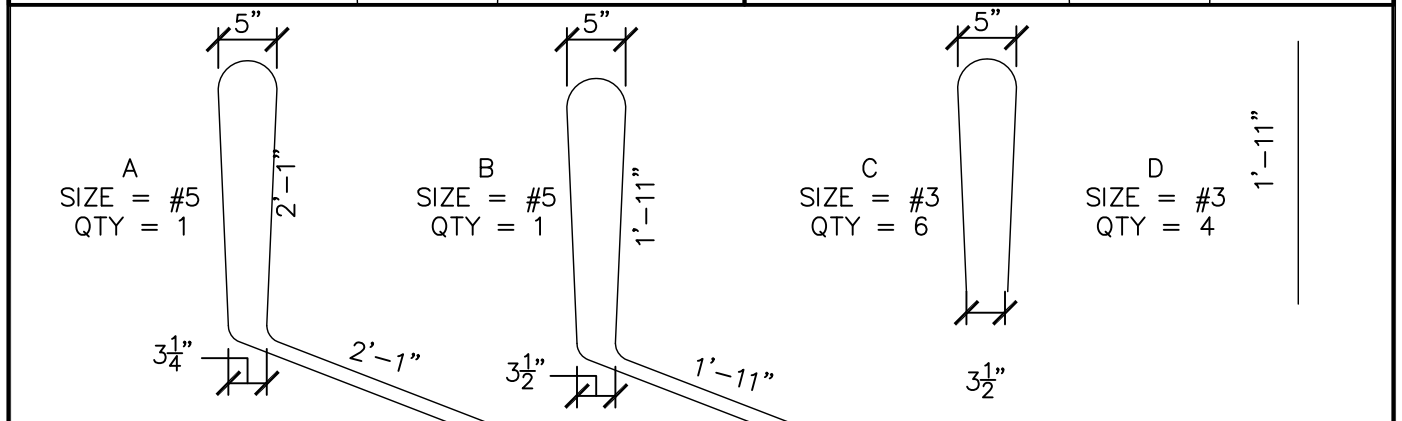
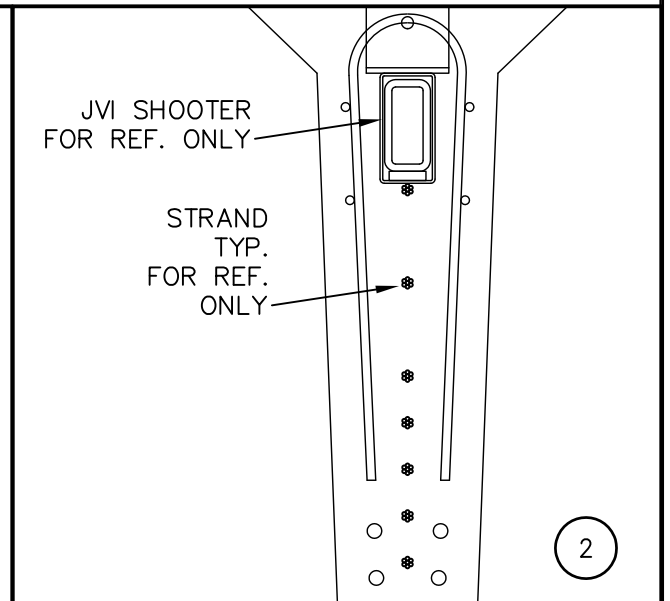
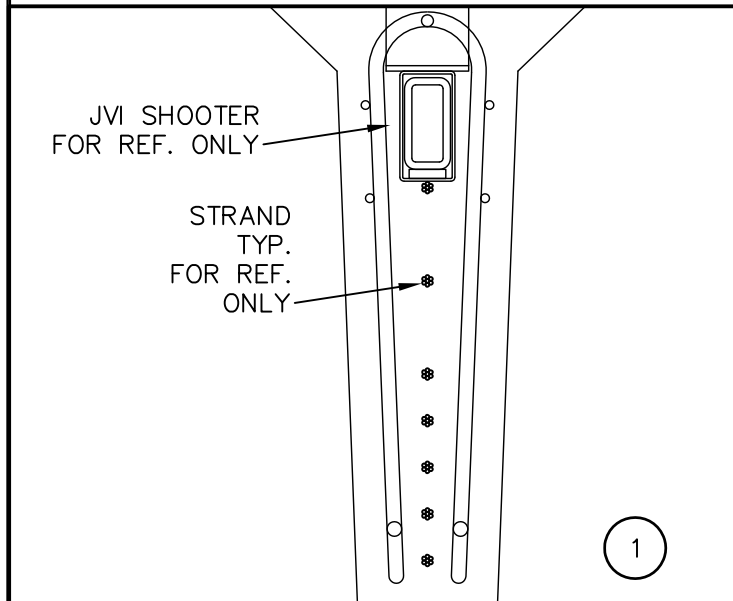
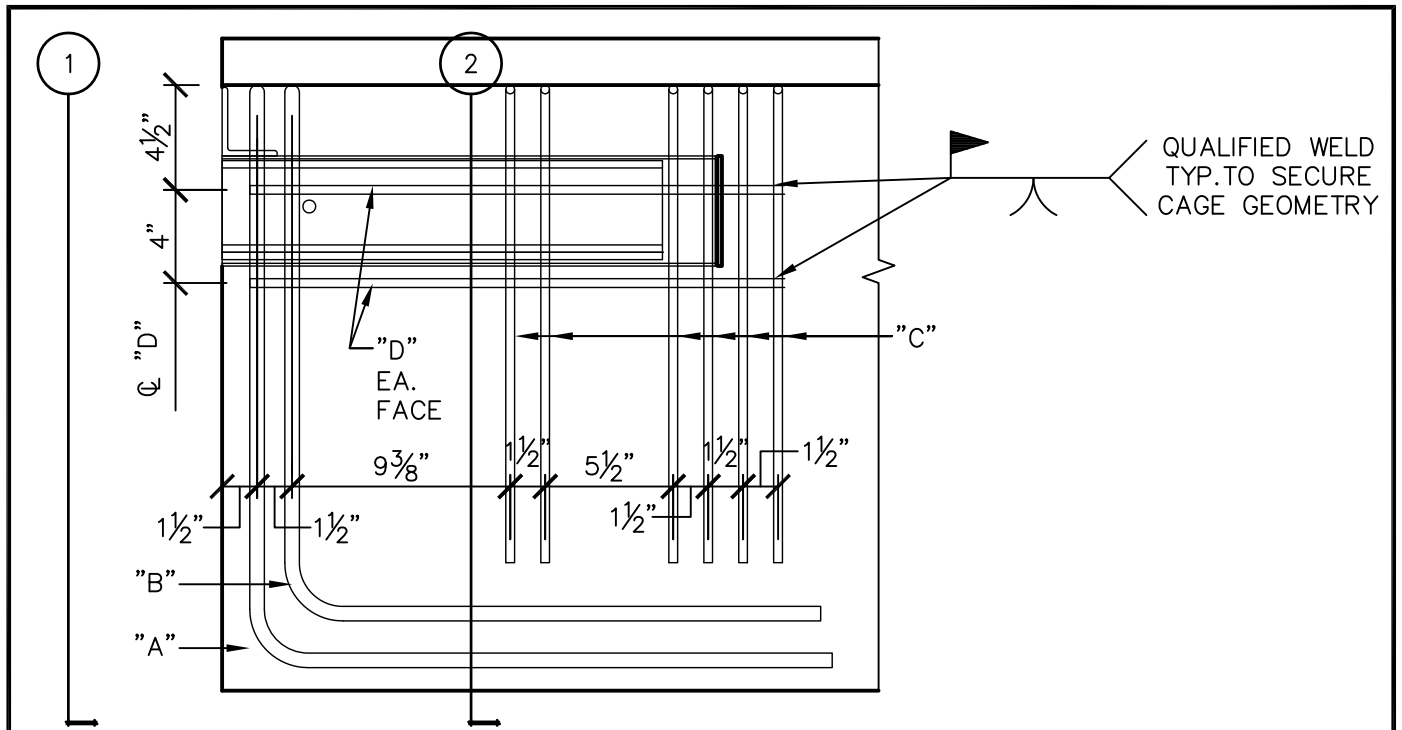
DATE  
07.24.2014

DRAWN  
JVI

CHECKED  
---

SCALE  
N/A





7131 North Ridgeway Avenue  
Lincolnwood, Illinois 60712 USA  
Tel. 847/675-1560 - Fax 847/675-0083

JVI SHOOTER REINFORCING

DT28 EXAMPLE  
SHOOTER REINFORCING

DATE  
07.24.2014

DRAWN  
JVI

CHECKED

SCALE  
1 1/2" = 1'

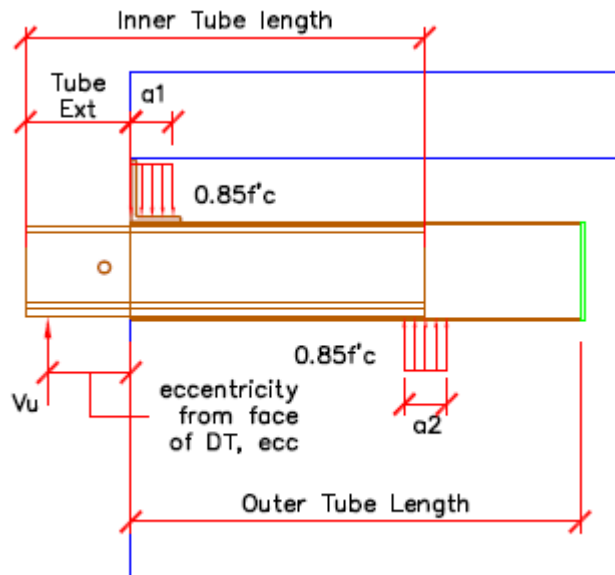


Title: \_\_\_\_\_ Job No.: \_\_\_\_\_ Date: 3.28.16  
 Subject: JVI 40 Kip Shooter Analysis

7131 North Ridgeway Ave.  
 Lincolnwood, Illinois 60712  
 1-800-742-8127  
 www.jvi-inc.com

## Strut-Tie Model

Determine the forces at the front and the back of the inner tube using basic statics



Vertical Load	$V_u := 40\text{-kip}$
Normal Load	$N_u := 20\% \cdot V_u$
Inner Tube Length	$L_{inner} := 480\text{mm}$
Outer Tube Length	$L_{outer} := 540\text{mm}$
Eccentricity	$ecc := 3.25\text{-in}$
Tube Extension	$Tube_{ext} := 110\text{mm}$
Concrete 28-day Strength	$f_c := 5000\text{-psi}$
Concrete Bearing Width Front	$b_{front} := 90\text{mm} \cdot \sqrt{\frac{8\text{-in}}{90\text{-mm}}}$
Back	$b_{back} := 60\text{-mm} \cdot \sqrt{\frac{7.5\text{-in}}{60\text{-mm}}}$
Strength Reduction Factor	$\phi := .65$

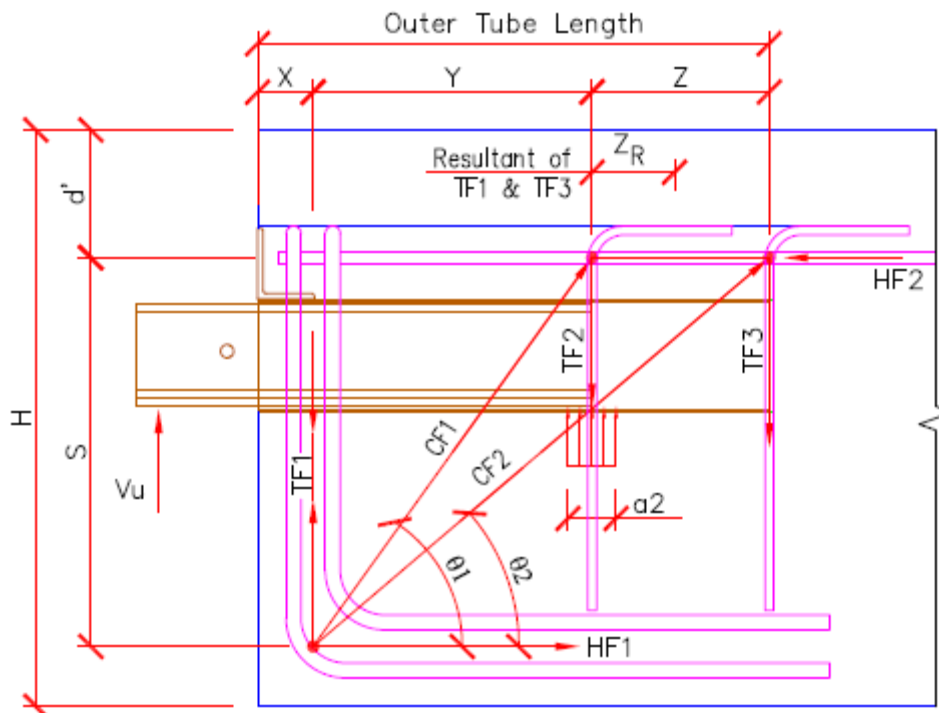
Equations of Equilibrium

Sum of Forces  $V_u + a_2 \cdot .85 \cdot \phi \cdot f_c \cdot b_{back} - a_1 \cdot .85 \cdot \phi \cdot f_c \cdot b_{front} = 0$

Sum of Moments  $V_u \cdot \left( ecc + \frac{a_1}{2} \right) - a_2 \cdot .85 \cdot \phi \cdot f_c \cdot b_{back} \cdot \left( L_{inner} - Tube_{ext} - \frac{a_1}{2} \right) = 0$

Solve Block Solution  $CompressionBlocks := Find(a_1, a_2)$   $a_1 := CompressionBlocks_1$   $a_1 = 3.83\text{-in}$   $a_2 := CompressionBlocks_2$   $a_2 = 1.404\text{-in}$

The front compression block will transfer the force in the concrete to tension bars located near the face of the double tee. The centroid of the tension bars, X, will be used in the strut-tie model to determine the node location for the strut-tie model. The centroid of the back compression block will be used to locate the node for the CF1 Strut. The elevation of the node will be determined based on the centroid of strut reinforcement. CF2 will be located within ACI 318-11 A2.5 provisions and centered on the provided reinforcing.



$$X := \frac{a_1}{2} \quad X = 1.915\text{-in}$$

$$Y := L_{inner} - Tube_{ext} - X$$

$$Y = 12.652\text{-in}$$

$$d' := 2.25\text{-in}$$

$$H := 28\text{-in}$$

$$S := H - d' - 2.5\text{-in}$$

$$S = 23.25\text{-in}$$

$$a_2 = 1.404\text{-in}$$

$$Z := L_{outer} - X - Y$$

$$Z = 6.693\text{-in}$$



Title: \_\_\_\_\_ Job No. \_\_\_\_\_ Date: 3.28.16  
 Subject: \_\_\_\_\_ JVI 40 Kip Shooter Analysis

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 www.jvi-inc.com

### Calculate Forces in Strut-Tie Model

TF1	$TF1 := V_u \cdot \left( \frac{ecc + X + Y}{Y} \right)$	TF1 = 56.329-kip
TF2	$TF2 := TF1 - V_u$	TF2 = 16.329-kip
TF3	$TF3 := TF1 - TF2$	TF3 = 40-kip
CF1 Angle	$\theta_1 := \text{atan}\left(\frac{S}{Y}\right)$	$\theta_1 = 61.446\text{-deg}$
CF2 Angle	$\theta_1 := \text{atan}\left(\frac{S}{Y + Z}\right)$	$\theta_1 = 50.238\text{-deg}$
min angle = 25 deg ACI 318-11 A2.5		
CF1	$CF1 := TF2 \cdot \frac{\sqrt{Y^2 + S^2}}{S}$	CF1 = 18.59-kip
CF2	$CF2 := \frac{TF3 \cdot \sqrt{(Y + Z)^2 + S^2}}{S}$	CF2 = 52.035-kip
CF1 + CF2	$CF1 + CF2 := CF1 + CF2$	CF1+CF2 = 70.626-kip
Location of TF2 and TF3 Resultant Force	$Z_r := \frac{TF2 \cdot 0\text{-in} + TF3 \cdot Z}{TF2 + TF3}$	$Z_r = 4.753\text{-in}$
HF1	$HF1 := TF2 \cdot \left( \frac{Y}{S} \right) + TF3 \cdot \left( \frac{Y + Z}{S} \right)$	HF1 = 42.167-kip
HF2	$HF2 := HF1$	HF2 = 42.167-kip

### Beam Reinforcement as Required by forces in Strut-Tie Model

<b>Material Properties</b>	<b>Concrete</b>	$f_c = 5000\text{-psi}$	$\lambda := 1.0$	<b>Rebar</b>	$f_y = 60\text{-ksi}$	
<b>Strength Reduction Factors</b>	<b>Flexure</b>	$\phi_f := 0.9$	<b>Shear</b>	$\phi_v := 0.75$	<b>Strut-Tie Models</b>	$\phi_{st} := 0.75$

#### Vertical Shear Along Diagonal Strut

##### Allowable Shear Stress

Shear Capacity of Concrete  $V_c := 2 \cdot \sqrt{f_c} \cdot \sqrt{\text{psi}} \cdot \lambda$   $V_c = 141.421\text{-psi}$   
 [ACI 318-02 11.2.1.1]

Steel Shear Strength Limit  $V_s := 8 \cdot \sqrt{f_c} \cdot \sqrt{\text{psi}}$   $V_s = 565.685\text{-psi}$   
 [ACI 318-11 11.4.7.9]

Shear capacity of Concrete and Steel  $\phi V_{total} := \phi_v \cdot (V_c + V_s)$   $\phi V_{total} = 530.33\text{-psi}$

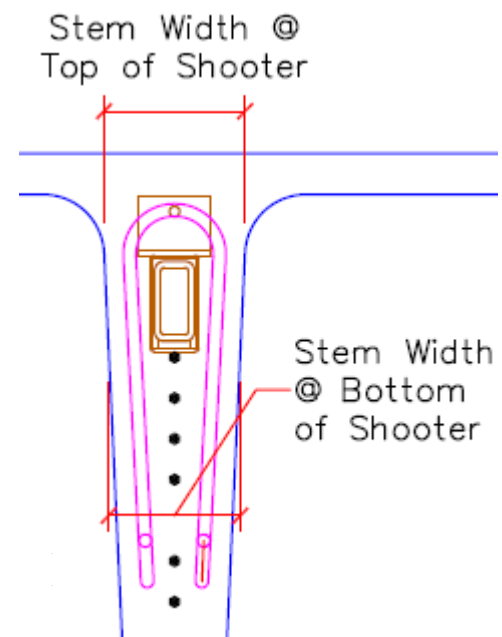
#### Vertical Shear at Resultant Concrete Strut, CFR

Stem Width @ Top of Shooter	$b_{top} := (8)\text{-in}$
Stem Width @ Bottom of Shooter	$b_{bot} := 7.5\text{-in}$
Average Stem Width	$b := \frac{b_{top} + b_{bot}}{2}$ $b = 7.75\text{-in}$
Width of Outer Tube	$b_{out} := 60\text{-mm}$ $b_{out} = 60\text{-mm}$

Shear Area  $A_v := (b - b_{out}) \cdot (H - d')$

Shear Stress  $v_u := \frac{TF1}{A_v}$   $v_u = 406.018\text{-psi}$

**Shear Capacity as Defined by ACI 318-11 is Adequate**







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## Diagonal Compression Strut

### Allowable Compression Strut Stress @ Node Zone ACI 318-11 A.5

Factor to account for the effect of cracking and reinforcement  
 [ACI 318-11 A 5.2.3]

$$\beta_s := 0.6 \cdot \lambda$$

Effective Compressive Strength of Concrete Strut  
 [ACI 318-11 A 5.2.]

$$\phi f_{ce} := \phi_{st} \cdot 0.85 \cdot \beta_s \cdot f_c \quad \phi f_{ce} = 1912.5 \text{ psi}$$

### Compression Stress at Resultant Concrete Strut CFR @ Node

Strut geometry is dependent on reinfocing. The distance between reinforcing bars + 2 (cover) should be used to determine the width of the strut.

Strut Width Vertical

[ACI 318-11 RA 4.2]

$$SW_{\text{vertical}} := 1.5 \cdot \text{in} \cdot 2 + 2.5 \cdot \text{in}$$

$$SW_{\text{vertical}} = 5.5 \cdot \text{in}$$

Strut Width Horizontal

[ACI 318-11 RA 4.2]

$$SW_{\text{horizontal}} := 1.5 \cdot \text{in} \cdot 2 + 2.5 \cdot \text{in}$$

$$SW_{\text{horizontal}} = 5.5 \cdot \text{in}$$

Zone Thickness

$$t := 6 \cdot \text{in}$$

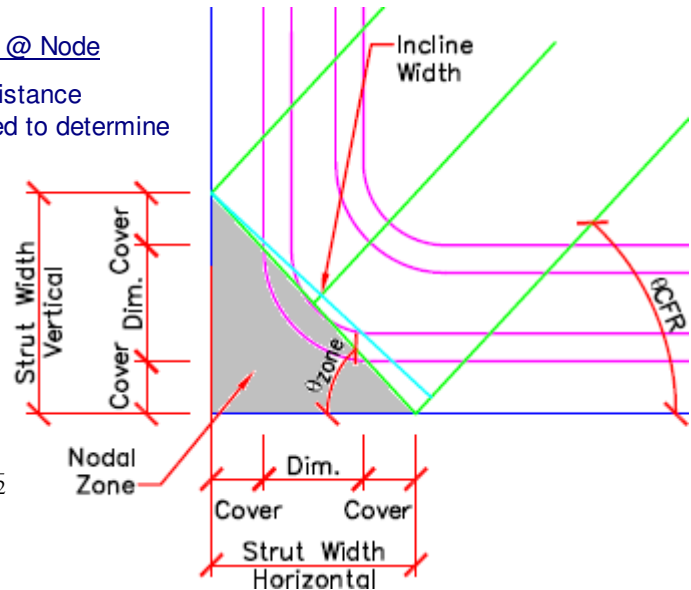
Zone Width

$$w := \sqrt{SW_{\text{vertical}}^2 + SW_{\text{horizontal}}^2}$$

$$w = 7.778 \cdot \text{in}$$

Area of Nodal Zone

$$A_{nz} := w \cdot t \quad A_{nz} = 46.669 \cdot \text{in}^2$$



Stress in Compression Strut

$$f_u := \frac{CF1 + CF2}{A_{nz}} \quad f_u = 1513.328 \text{ psi}$$

**Compressive Strut Limit as Defined by ACI 318-11 is Adequate**

### Allowable Compression Strut Stress @ Strut ACI 318-11 A.3

Factor to account for the effect of cracking and reinforcement  
 [ACI 318-11 A 3.2.2 (b)]

$$\beta_s := 0.75 \cdot \lambda$$

Effective Compressive Strength of Concrete Strut  
 [ACI 318-11 A 3.]

$$\phi f_{ce} := \phi_{st} \cdot 0.85 \cdot \beta_s \cdot f_c \quad \phi f_{ce} = 2390.625 \text{ psi}$$

### Compression Stress at Resultant Concrete Strut CFR @ Shooter Elevation ACI 318-11 A.3

Strut Thickness

$$t := b - b_{out} \quad t = 5.388 \cdot \text{in}$$

Strut Thickness reduced by outer tube thickness

Resultant Compression Strut Angle

$$\theta_{CFR} := \text{atan}\left(\frac{S}{Y + Z_r}\right) \quad \theta_{CFR} = 53.182 \cdot \text{deg}$$

Nodal Zone Angle

$$\theta_{zone} := \text{atan}\left(\left(\frac{SW_{\text{vertical}}}{SW_{\text{horizontal}}}\right)\right) \quad \theta_{zone} = 45 \cdot \text{deg}$$

Inclined Width

$$w := \sqrt{SW_{\text{vertical}}^2 + SW_{\text{horizontal}}^2} \cdot \cos(90 - \theta_{CFR} - \theta_{zone}) \quad w = 7.379 \cdot \text{in}$$

Area of Strut

$$A_{cs} := w \cdot t \quad A_{cs} = 39.756 \cdot \text{in}^2$$

Stress in Compression Strut

$$f_u := \frac{CF1 + CF2}{w \cdot t} \quad f_u = 1776.481 \text{ psi}$$

**Compressive Strut Limit as Defined by ACI 318-11 is Adequate**



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### Required Reinforcement for TF1(Hanger Reinforcement)

TF1 = 56.329·kip

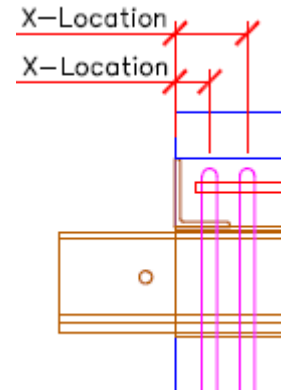
#### Required Steel

$$As_1 := \frac{TF1}{\phi_f \cdot f_y}$$

$$As_1 = 1.043 \cdot \text{in}^2$$

#### Supplied Steel

"Quantity"	"Bar Size"	"X-Location"
2	5	1
2	5	2.25



#### Steel Supplied

$$\text{Supplied } As_1 = 1.24 \cdot \text{in}^2$$

#### Supplied As1 Steel is Adequate

Input CG for Hanger Reinforcement was 1.91 Actual CG is 1.63

### Required Reinforcement for TF2

TF2 = 16.329·kip

Assumes Stirrup Geometry when considering quantity

#### Required Steel

$$As_{2\_1} := \frac{TF2}{\phi_f \cdot f_y}$$

$$As_{2\_1} = 0.302 \cdot \text{in}^2$$

#### Supplied Steel

"Quantity"	"Stirrup Size"
2	3

#### Stirrup Quantity Calculator

Preferred Stirrup Size Stirrup := 5

$$\text{Quantity Required } QTY := \text{ceil} \left( \frac{As_{2\_1}}{A_{rb\text{Stirrup}} \cdot 2} \right)$$

$$QTY = 1$$

#### Steel Supplied

$$\text{Supplied } As_{2\_1} = 0.44 \cdot \text{in}^2$$

#### Supplied As2\_1 Steel is Adequate

### Required Reinforcement for TF3

TF3 = 40·kip

Assumes Stirrup Geometry when considering quantity

#### Required Steel

$$As_{2\_2} := \frac{TF3}{\phi_f \cdot f_y}$$

$$As_{2\_2} = 0.741 \cdot \text{in}^2$$

#### Supplied Steel

"Quantity"	"Stirrup Size"
4	3

#### Stirrup Quantity Calculator

Preferred Stirrup Size Stirrup := 4

$$\text{Quantity Required } QTY := \text{ceil} \left( \frac{As_{2\_2}}{A_{rb\text{Stirrup}} \cdot 2} \right)$$

$$QTY = 2$$

#### Steel Supplied

$$\text{Supplied } As_{2\_2} = 0.88 \cdot \text{in}^2$$

#### Supplied As2\_2 Steel is Adequate



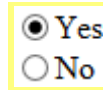
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## Required Reinforcement for HF1

HF1 = 42.167·kip

Hook  $A_{s1}$  Reinforcement  
 to Satisfy  $A_{s5}$



**Input Not Required Supplied Steel  
 Based on As1**

Required Steel  $A_{s5} := \frac{HF1}{\phi_f \cdot f_y}$

$$A_{s5} = 0.781 \cdot \text{in}^2$$

Supplied Steel

$A_{s\text{Steel}} :=$	
"Quantity"	"Bar Size"
2	5

Steel Supplied

$$\text{Supplied } A_{s5} = 1.24 \cdot \text{in}^2$$

**Supplied As5 Steel is Adequate**

Steel Quantities and Bar Size information Based on As1 Input

## Required Reinforcement for HF2

HF2 = 42.167·kip

Concrete Compression Strut Capacity

Factor to account for the effect of cracking and reinforcement  $\beta_s := 0.75 \cdot \lambda$   
 [ACI 318-02 A 3.2.2 (b)]

Effective Compressive Strength of Concrete Strut  
 [ACI 318-02 A 3.2]

$$\phi f_{cu} := \phi_v \cdot 0.85 \cdot \beta_s \cdot f_c \quad \phi f_{cu} = 2390.625 \text{ psi}$$

Compressive Stress Area

$$A_c := d' \cdot 2 \cdot b \quad A_c = 34.875 \cdot \text{in}^2$$

Estimated Required Steel

$$A_{s3} := \frac{HF2 - A_c \cdot \phi f_{cu}}{\phi_f \cdot f_y}$$

$$A_{s3} = -0.763 \cdot \text{in}^2$$

Supplied Steel

"Quantity"	"BarSize"
1·10-8	4

Supplied Steel Capacity is Reduced based on supplied development length as Compression development length, where the assumed supplied development length is equal to the zone width. Concrete Compressive stress area is reduced by the area of compression steel supplied.

Supplied Compression Capacity

$$\text{CompressionCapacity} = 83.373 \cdot \text{kip}$$

**Supplied Compression Capacity is Adequate**

## Required Reinforcement for $F_{nu}$

Required Steel

$$A_{s4} := \frac{N_u}{\phi_f \cdot f_y}$$

$$A_{s4} = 0.148 \cdot \text{in}^2$$

Supplied Steel

"Quantity"	"BarSize"
2	3

Steel Supplied

$$\text{Supplied } A_{s4} = 0.22 \cdot \text{in}^2$$

**Supplied As4 Steel is Adequate**





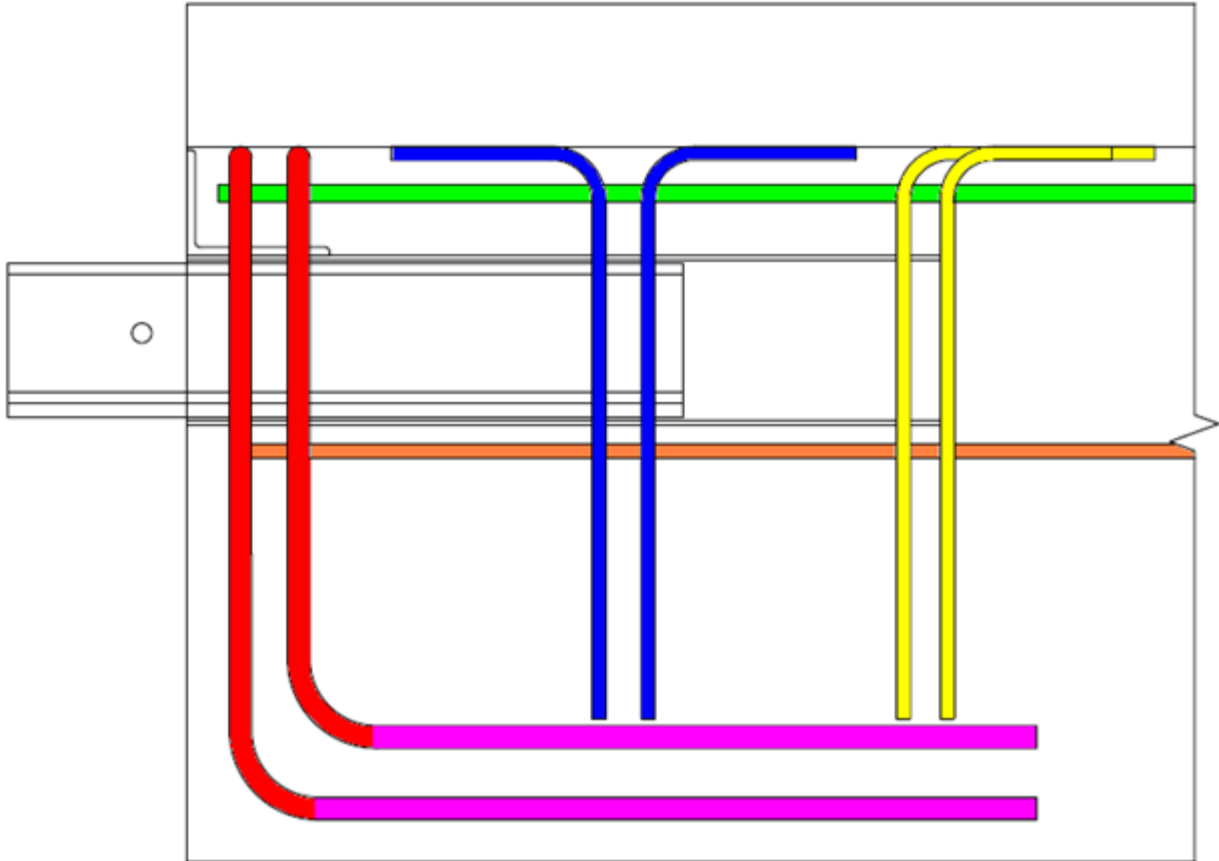
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**Design is Sufficient for:**

$V_u = 40$  kips

$N_u = 8$  kips



*Image may not reflect bar quantities required in table below. Supply steel per table and not per image.*

As <sub>1</sub> Steel			As <sub>2,1</sub> Steel			As <sub>2,2</sub> Steel		
Quantity	Bar Size	X-Location	Quantity	Stirrup Size		Quantity	Stirrup Size	
2	5	1	2	3		4	3	
2	5	2.25						
As <sub>3</sub> Steel			As <sub>4</sub> Steel			As <sub>5</sub> Steel		
Quantity	Bar Size		Quantity	Bar Size		Quantity	Bar Size	
0.00	4		2	3		2	5	
						2	5	



Title: \_\_\_\_\_ Job No.: \_\_\_\_\_ Date: 7.25.14  
 Subject: Example Bearing Pad Design for Shooter Bearing

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## Pad Geometry

Pad Width  $b_1 := 4\text{-in}$

Pad Length  $w_1 := 4\text{-in}$

Thickness  $t := .5\text{-in}$

## Loading

Service Level Reaction  $V_{\text{service}} := 29.845\text{-kip}$

## Calculations

### Shape Factor

$$SF := \frac{b_1 \cdot w_1}{2 \cdot (b_1 + w_1) \cdot t} \quad SF = 2$$

### Maximum Allowable Compressive Load

$e_{\text{max}} := 40$  Recommended Design Value

$$V_{\text{nr}} := (0.6 \cdot SF + 2) \cdot e_{\text{max}}^{1.8} \cdot b_1 \cdot w_1 \cdot \text{psi} \quad V_{\text{nr}} = 39.172\text{-kip}$$

### Angle of Rotation

$$A := 0.025\text{-rad}$$

*Rotation of Shooter in outer tube counter acts DT Camber. Shooter rotation is 0.017 rad. Assume a total rotation under a deflected DT of .025 rad.*

### Bearing Length w/ Rotation

$$w_2 := \min\left(w_1, \frac{40 \cdot t}{100 \cdot \tan(A)}\right) \quad w_2 = 4\text{-in}$$

### Maximum Compressive Stress

$$S_{\text{nr}} := \frac{V_{\text{nr}}}{b_1 \cdot w_2} \quad S_{\text{nr}} = 2448.262\text{-psi} \quad \text{Must be less than 2500 psi}$$

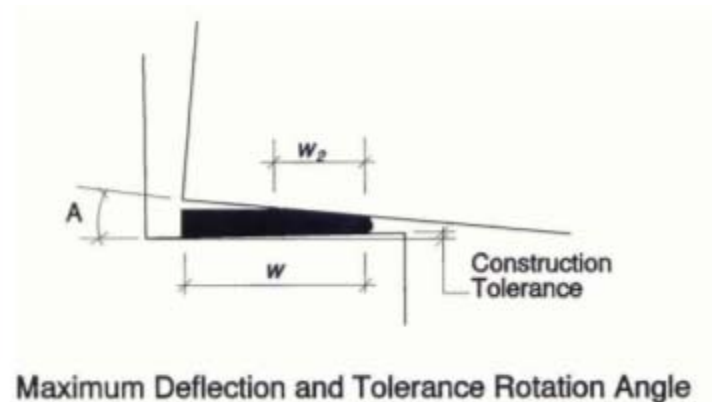
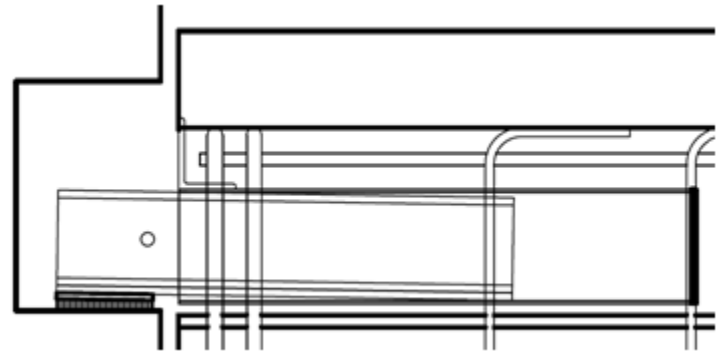
### Reduction Factor

$$k_t = 500$$

$$R := \frac{1}{k_t \cdot \left(\frac{A}{\text{rad}}\right)^2 + 1} \quad R = 0.762$$

### Allowable Compressive Load w/ Rotation

$$V_{\text{ar}} := R \cdot V_{\text{nr}} \quad V_{\text{ar}} = 29.845\text{-kip}$$



$t$	1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	1"
$k_t$	4000	2500	1500	500	400	325	275



Shooter Inner Tube is not wide enough to engage entire bearing area of pad. Install Pad with a plate on top to distribute load to the entire pad. Determine Plate Thickness by modeling the plate using 2-D shell elements with the bearing pad modeled assuming linear compression springs.

Determine spring constant assuming a shape factor for the entire pad geometry and applying the stress to an area equal to the element area.

Shape Factor for 4 x 4 pad  $SF = 2$

Stress equation for  $SF = 2$   $\sigma(e) := (0.6 \cdot SF + 2) \cdot e^{1.8} \cdot \text{psi}$

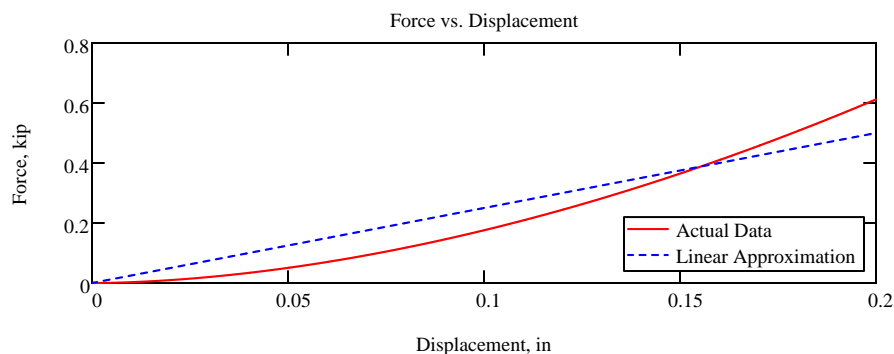
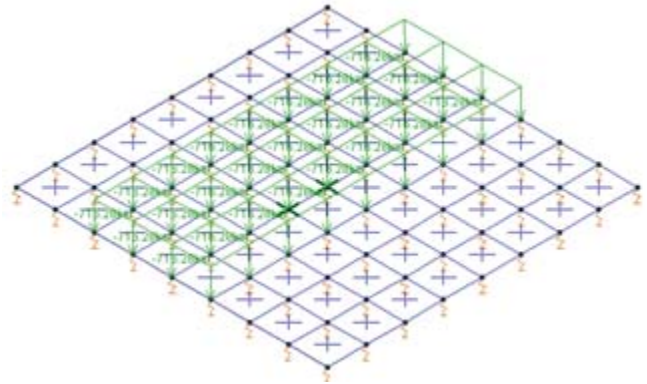
Strain Distribution

$$e := 0, .01 \dots e_{\max}$$

Element Area

$$\text{Area}_{\text{element}} := .5 \cdot .5 \cdot \text{in}^2$$

$$\text{Area}_{\text{element}} = 0.25 \cdot \text{in}^2$$



The slope of the linear fit, assuming a y intercept of zero will be used as a spring constant

$$k := \text{Slope} \cdot \frac{\text{kip}}{\text{in}} \quad k = 2.5 \cdot \frac{\text{kip}}{\text{in}}$$

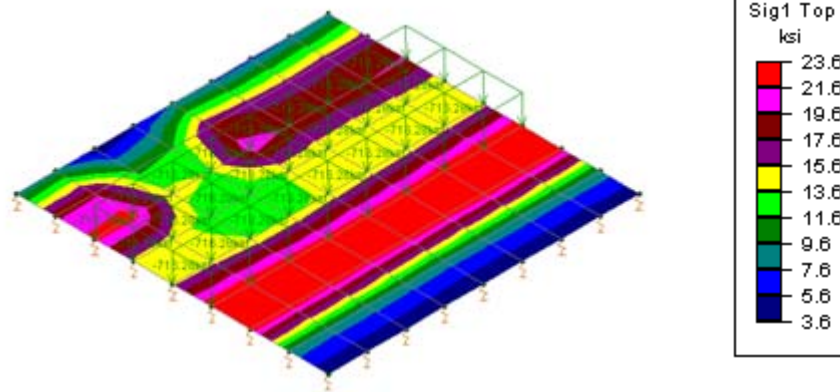
Apply a surface load to shell elements at the location of the inner tube only.

Distributed Load Applied over 1.5" x 4" of Tube Bearing Area  $\omega := \frac{V_{\text{service}}}{1.5 \text{ in} \cdot 4 \text{ in}} \quad \omega = 716.28 \cdot \frac{\text{kip}}{\text{ft}^2}$

Check FEA output to ensure that

- Maximum displacement is not greater than  $\frac{e_{\max}}{100} \cdot t = 0.2 \cdot \text{in}$
- Maximum Reaction at any Compression Spring is less than the maximum compressive stress without rotation x element area  $\text{Reaction}_{\max} := (\text{Area}_{\text{element}} \cdot S_{\text{nr}}) \quad \text{Reaction}_{\max} = 0.612 \cdot \text{kip}$
- Stresses in plate, not within the inner tube bearing area, are less than yield  
 (increase element thickness at inner tube bearing area to simulate additional stiffness due to tube bearing.)





LC	Joint Label	X [k]	Y [k]	Z [k]	MX [k-ft]	MY [k-ft]	MZ [k-ft]
1	N28	0	0	.474	0	0	0
1	N27	0	0	.473	0	0	0
1	N29	0	0	.473	0	0	0
1	N26	0	0	.473	0	0	0

LC	Joint Label	X [in]	Y [in]	Z [in]	X Rotation [rad]	Y Rotat...
1	N28	0	0	-.189	-5.602e-7	-1.885e-2
1	N27	0	0	-.189	1.562e-4	-1.884e-2
1	N29	0	0	-.189	-1.261e-4	-1.868e-2
1	N26	0	0	-.189	2.502e-4	-1.867e-2

Analysis run with a plate thickness of 1/2" and A36 Steel at areas without inner tube bearing and 1" thick and A36 steel at areas with direct inner tube bearing. Tube was assumed to be offset 1/2" from the center of the plate to create a worst case condition.

