MAGLEV INC.

Report

for the Department of Transportation
PENNDOT
Commonwealth of Pennsylvania

PA

Robotic Welding of and I-Beam using a GMAW Gantry System

August 22, 2009

MAGLEV, Inc.
1100 Industry Road, Box 11
McKeesport, Pennsylvania

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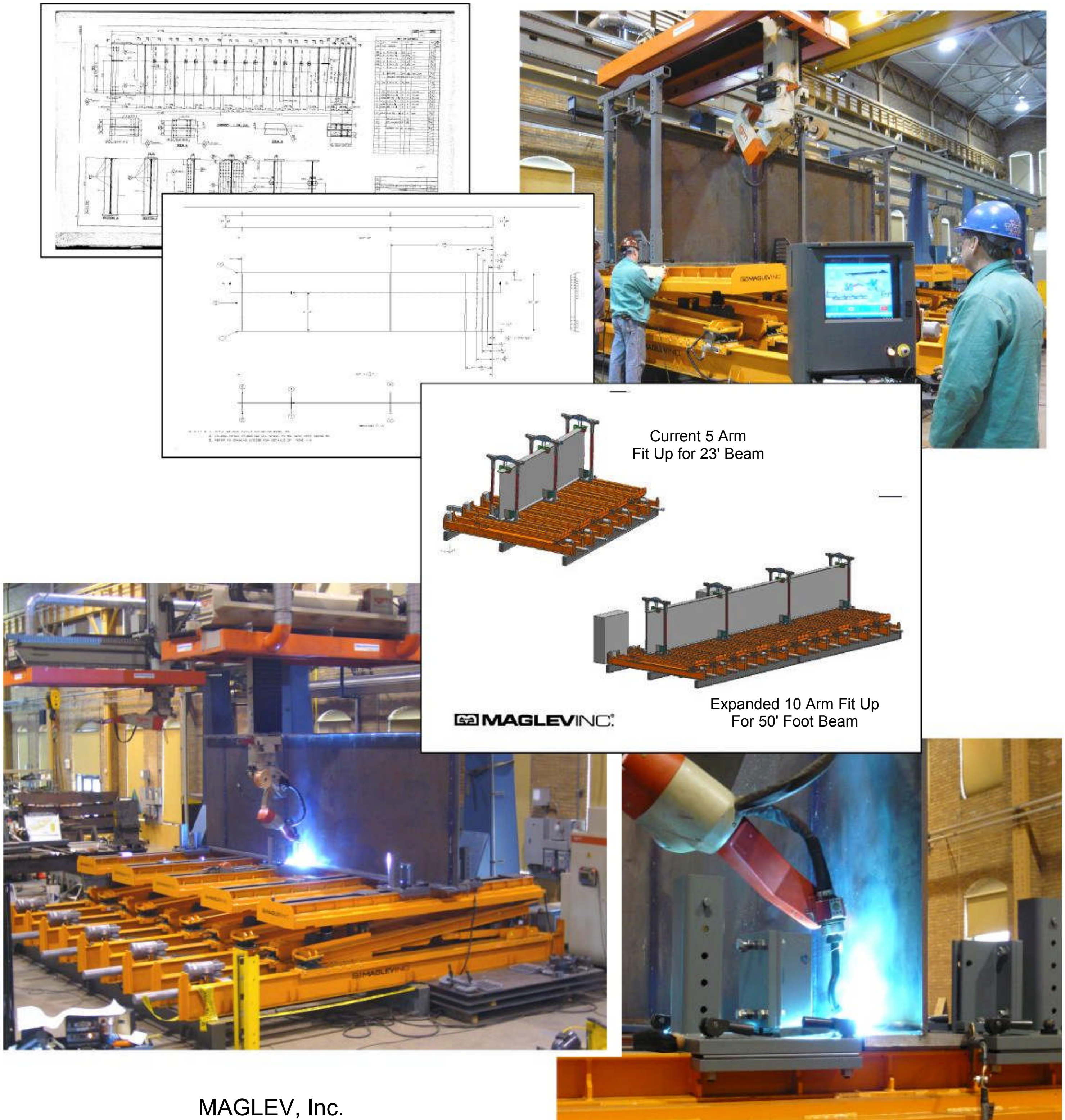

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Table of Contents

List of Figures

1.0 **Background**

During 1999, the Federal Highway Administration and a panel of bridge fabrication technology experts from across the United States conducted a major review of international bridge fabrication technology through visits to leading bridge fabricators in Europe and Asia. The objective of the tour was to develop an overview of the manufacturing techniques that are in use internationally for steel bridge fabrication and erection. The trip included visits to modern steel fabrication facilities in Japan, Italy, Germany, and the United Kingdom.

Upon completion of the tour the reviewers concluded that the Japanese and Europeans were very advanced in the use of computer-aided drawing (CAD) and computer aided manufacturing (CAM). They were also advanced in automated recording of inspection, welding variables, and geometric measurements for quality control and virtual assembly. International steel fabricators were consistent in usage of high-performance steels and coatings, advanced cutting and joining processes including robotics for steel components, members, and structures and advanced design innovation and erection. The tour reviewers concluded that there is a need to modernize structural steel fabrication facilities in the United States if the US fabrication industry were to remain globally competitive.

A report from a symposium held in 2001 to identify the outcomes of the tour provided some additional detail of the findings. One of the issues was that steel bridge components for the US market could be fabricated more efficiently and economically if automation and robots were used. However, the total fabrication-erection process in the US is highly decentralized and no fully integrated design-fabrication-erection process exists. With the large number of steel bridges that are fabricated in the US each year, and with the expanding bridge program, advanced processes including computer integrated manufacturing technology were noted to offer tremendous potential for advancement of the US fabrication industry.

A summary of observations relating to aspects of automation from that tour together with the resulting conclusions and implications for change in US practices were identified as:

- Elimination of submerged-arc welding and its required flux handling systems in favor of automation-friendly GMAW or MIG/MAG welding processes.
- Elimination of radiographic inspection in favor of automation-friendly ultrasonic inspection, which would require new definitions of equipment and operator qualifications and new acceptance specifications based on fitness for purpose rather than the present workmanship requirements.
- Use of a single 3D CAD model as the sole source of information on detailing, shop drawing information, CNC drilling and cutting instruction, automated inspection and virtual assembly for geometry verification.
- Possible contractual ties between fabricator and erector in order to facilitate virtual assembly.

Included as part of the symposium, was a discussion of the technology for fabrication of steel box girders in Japan. The Japanese use of steel box girders is much more prevalent than in the US. The CAD/CAM system utilized in the production of these girders provided a 3D model of fabrication geometry. Another feature of the fabrication plant is extensive use of robotic welding equipment, processes, and attendant automation-friendly detailing.

For the shops visited, the amount of utilization of submerged arc welding (SAW) in proportion to gas metal arc, GMAW, welding varied from country to country. Based on data in the “scanning tour” report, Japan’s usage of GMAW to SAW showed a 90 percent preference for GMAW over SAW. In Italy the ratio was 30 percent for GMAW and 70 percent for SAW. The usage as defied for the countries visited during the “scanning tour” report are summarized in the table below.

	% SAW	**% GMAW**
Japan	10	90
Germany	15	85
UK	50	50
Italy	70	30

As a result of the review, the team also identified six high-priority areas on which the U.S. industry should focus:

- Computer aided drawing and computer aided manufacturing
- Automated recording of inspection, welding variables, and geometric measurements for quality control and virtual assembly; high-performance steels and coatings
- Automated cutting and joining steel components, members, and structures
- Certification and contracting of steel fabrication and erection
- Design innovation.

This survey and its finding are of significant interest to MAGLEV, Inc. in its development of automated technology for fabrication of guiderail beams for high-speed maglev. For high-speed maglev, more than 3000 uniquely dimensioned trapezoidal box beams with compound curves will be required. The close tolerance dimensional requirements for each beam demands that a completely computer integrated system for fabrication be utilized. That system begins with a 3D CAD model and continues with automated cutting, automated fit up table configuration and robotic welding. The welding system offering most promise is GMAW. Interestingly, the needs identified for production of high-speed maglev guiderails parallel those items that are being put into place at the most advanced fabrication shops internationally. Much of this technology is in place at the MAGLEV, Inc. facilities.

MAGLEV, Inc.’s facilities in McKeesport, Pennsylvania have in-place a computer automated fit-up table that is integrated with a side entry dual robot gantry welding system. The gantry welding system extends for 35 meters (115 ft), but the automated fit-up table is currently limited to 6.2 meters (21 ft). The combined system is more advanced than those described in the FHWA “scanning tour” study in its ability to demonstrate the benefits of automated fabrication technology. Additionally, the fabrication capability allows achievement of very high precision dimensional control while producing complex curved box beams. Its capability is directly applicable to production of tub girders and conventional I-beams. The systems at the MAGLEV, Inc. facilities are shown in Figure 1.0.

Figure 1.0 Automated fit-up table and gantry robot weld system at MAGLEV, Inc.

The illustration in Figure 1.0 shows the computer automated fit-up table and dual robot gantry welding system in-place at the MAGLEV, Inc. facilities in McKeesport, Pennsylvania. The illustration shows the dual gantry robots being synchronized for simultaneous welding on opposite sides of a trapezoidal box beam for application to development of high-speed maglev guiderails. Dual robot synchronized welding processes are one mechanism for minimizing distortion from the welding process. Trapezoidal box beams for high-speed maglev are very similar in design and construction to trapezoidal tub girders for highway and bridge applications.

2.0 **Program Objective**

The objective of this program was to fabricate a demonstration section of an I-beam girder for application in a transportation environment. This girder was to be a prototype girder capable of being produced with designed-in curves and be approximately 20-ft in length. The beam selected for this program, however, was a straight section beam of height 6 ft 9 in and length 23 ft.

Satisfaction of this objective was pursued by use of advanced precision fabrication technology employing gantry mounted dual robots and GMAW process to demonstrate the system capability in production of a current design I-beam utilized by PENNDOT. The beam size was to be full cross-section, but of abbreviated length to match to the table capabilities currently in-place. The welding technology to be employed was GMAW with all welds performed utilizing only one initial fit-up. The welds were to be horizontal 2F, vertical 3F and overhead 4F welds. Standard specifications applicable to PENNDOT were to be achieved in the process.

3.0 **Technical Approach**

3.1 CAD Model

The first step in the performance of the overall task was to secure a drawing of a typical I-beam utilized by PENNDOT. The District Bridge Engineer provided that drawing of a common use beam for PENNDOT bridge construction projects. That drawing was converted to a CAD model with drawing and appropriate assessments for a Bill of Material were made. Afterwards, the necessary materials were procured. A copy of the CAD drawing is given in Appendix A. The 3D CAD model of the project beam is shown in Figure 2.0.

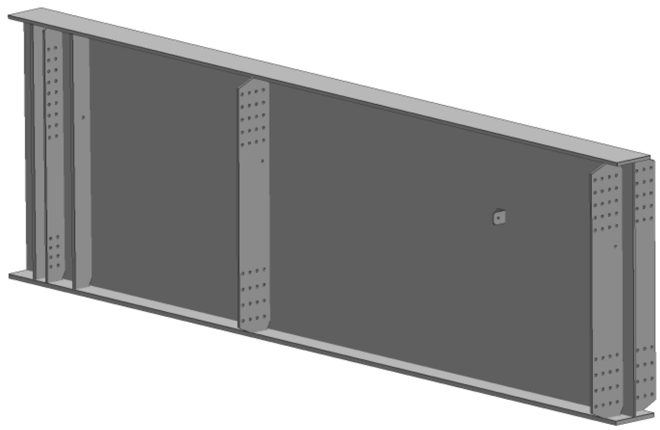


Figure 2.0 3D CAD model of the project beam.

3.2 Material Procurement

Components were arranged by computer lay out from the CAD drawing so that optimum material size procurement and utilization were achieved. After optimization of the CAD component layout, material conforming to the ASTM Specification A572 Grade 50 was procured in sufficient quantities to produce the final product and the prerequisite model beams and developmental tee section coupons.

3.3 Parameter Development with Tee Section Coupons

A series of tee-section coupons of the specified material chemistry and thicknesses were assembled by tack welding. Welding parameters were developed using these tee sections. An isometric schematic of a tee section coupon is shown in Figure 3.0. Weld parameters were also evaluated by use of a three-position test piece shown in Figure 7.0. Welds were made with 5/16 in leg size and with a 3/32 in tack. Weld over tacked section are shown in Figure 4.0.

Sections of the tee that contained the basic weld, basic tack and the weld over tack were cut from the test coupon and etched for further examination of weld soundness. Examination of those etched coupons showed that the final fillet weld completely re-melted the tack weld.

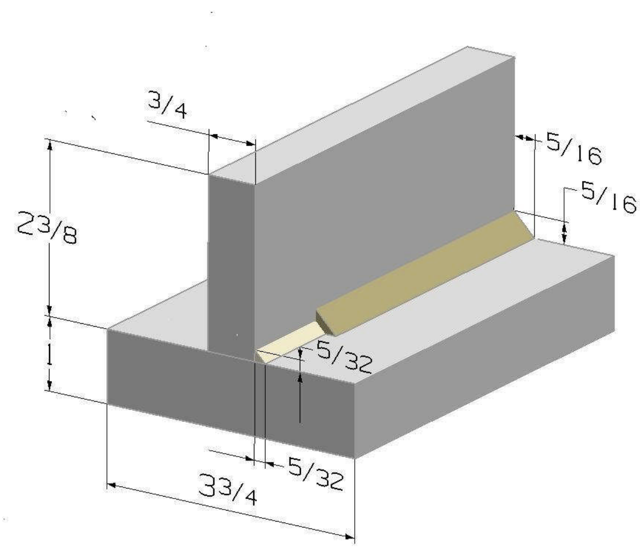


Figure 3.0 Schematic of the tee section coupon utilized for weld evaluation.

The illustration shown in Figure 4.0 shows the different welding situations. The area designated on the section noted by "T" was for the 5/32 in tack weld only. The region noted by "W" was for the 5/16 in weld only and the segment noted by "T + W" was for the segment where the weld was made over the tack. The tack was 5/32 in (4mm) x 3 in long spaced at 21 in on center on the test beam.

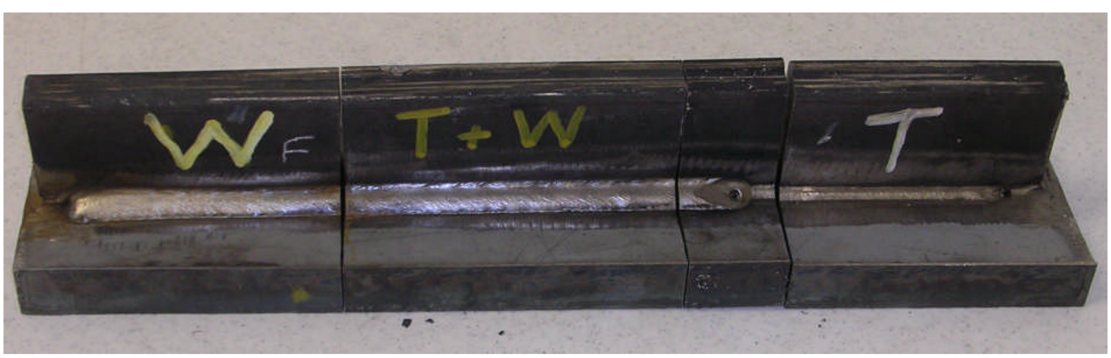


Figure 4.0 Illustration of the tee section coupon showing test welds.

After tacking and welding of the tee-section coupons, segments were sectioned as shown in Figure 4.0 so that each distinct tack, weld or combination could be further examined. Each segment was rough polished, etched and examined visually. The etched segment for the weld and the weld over tack is shown in Figure 5.0.

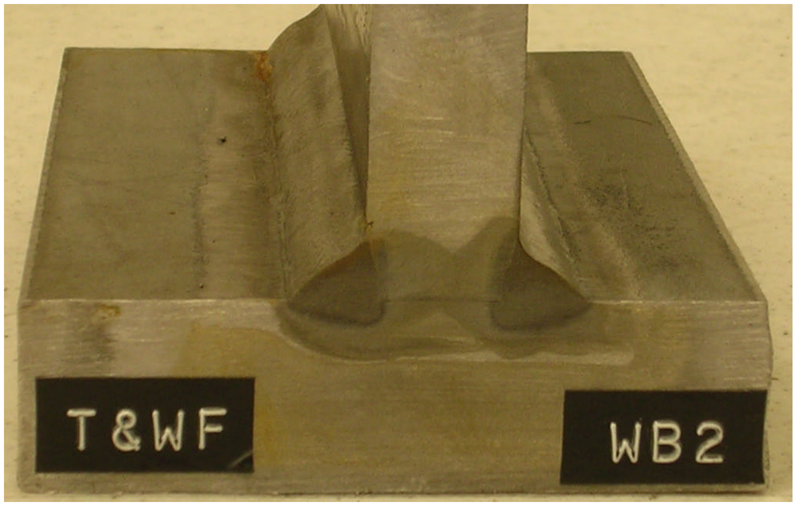


Figure 5.0 Etched cross-section of the GMAW welded tee section.

The illustration of Figure 5.0 shows the etched cross-sections of the GMAW welded tee sections showing the 5/16-inch over the 5/32-inch tack and the 5/16 in weld without tack designated in the illustration as “T&WF”. The weld bead without tack is designated as “WB2”. The tack weld has been completely re-melted.

Fillet welds on the tee-section coupons were produced in the 2F, 3F and 4F positions. The welding parameters were developed from evaluation of these tee-section coupons and those parameters were established as the preliminary WPS. The welding parameters developed from the tee-section coupons for the various position welds are presented in the tables below.

Weld Parameters for Horizontal 2F Welds							
	Speed ipm	Weave Freq in^{-1}	Gas Ar/CO_2	Wire Dia.	Amp	Volt	Wire Feed Speed ipm
5/32 Tack	26	0	85/15	0.052	170	22	170
5/16 Weld	13	125	85/15	0.052	310*	27.5	340
Weld/Tack	13	125	85/15	0.052	310*	27.4	340

* Amperage varied +/- 10 % with weave

Weld Parameters for Vertical 3F Welds							
	Speed ipm	Weave Freq in^{-1}	Gas Ar/CO_2	Wire Dia.	Amp	Volt	Wire Feed Speed ipm
5/32 Tack	21	0	85/15	0.052	127	19	125
5/16 Weld	10	75	85/15	0.052	150*	20	155
Weld/Tack	10	75	85/15	0.052	150*	20	155

* Amperage varied +/- 10 % with weave

Weld Parameters for Overhead 4F Welds							
	Speed ipm	Weave Freq in^{-1}	Gas Ar/CO_2	Wire Dia.	Amp	Volt	Wire Feed Speed ipm
5/32 Tack	30	0	85/15	0.052	130	21	142
5/16 Weld	9.5	90	85/15	0.052	170*	22	205
Weld/Tack	9.5	90	85/15	0.052	170*	22	205

* Amperage varied +/- 10 % with weave

3.4 Submerged Arc Weld Comparison

A limited amount of submerged arc welding was performed for comparison with the GMAW process used for this evaluation. The parameters used for the SAW followed those recommended from Lincoln Electric data.

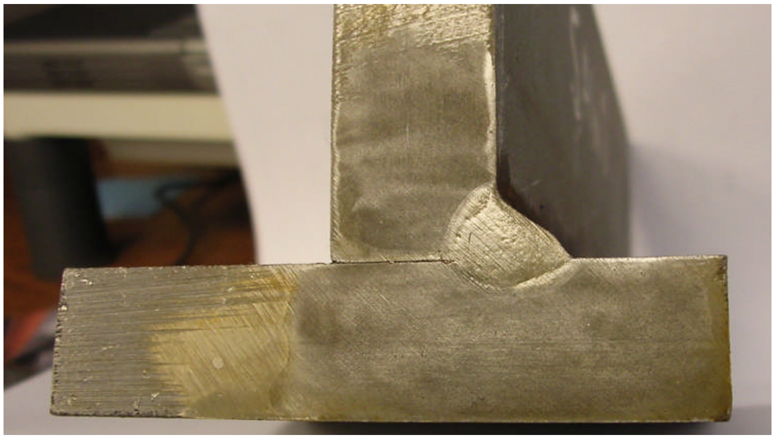


Figure 6.0 Etched cross-sections of SAW used for comparison.

The weld bead penetration and the heat affected zone from the SAW process can be compared to that from the GMAW process by comparison of the sections and etched beads and heat affected zones illustrated in Figure 5.0 and Figure 6.0. The weld penetration and heat-affected zones are similar. Both meet acceptable fillet weld profiles as outlined in AASHTO/AWS D1.5M/D1.5:2002 section 5.19.

3.5 WPS and PQR

A WPS was developed based on the weld parameters developed from the tee section coupons. The WPS was developed in accordance to PENNDOT specification using AASHTO/AWS D1.5M/D1.5:2008. That test coupon for the PQR was performed in the presence of a PENNDOT weld inspection official. Evaluation of the weld was performed by a local approved testing facility. After the desired parameters for welding were selected, a preliminary WPS was developed and arrangements were made for a PENNDOT inspector to review the selected parameters and to be present when the test segments for the PQR evaluation were welded.

PQR test sections were developed for the flat (1G), vertical (3G) and overhead (4G) positions. A three-position welding test section is shown in Figure 7.0. Completed welds are shown in Figures 8.0, for the flat 1G position. A cross-section of the weld for the 1G specimen submitted for PQR evaluation is shown in Figure 9.0.

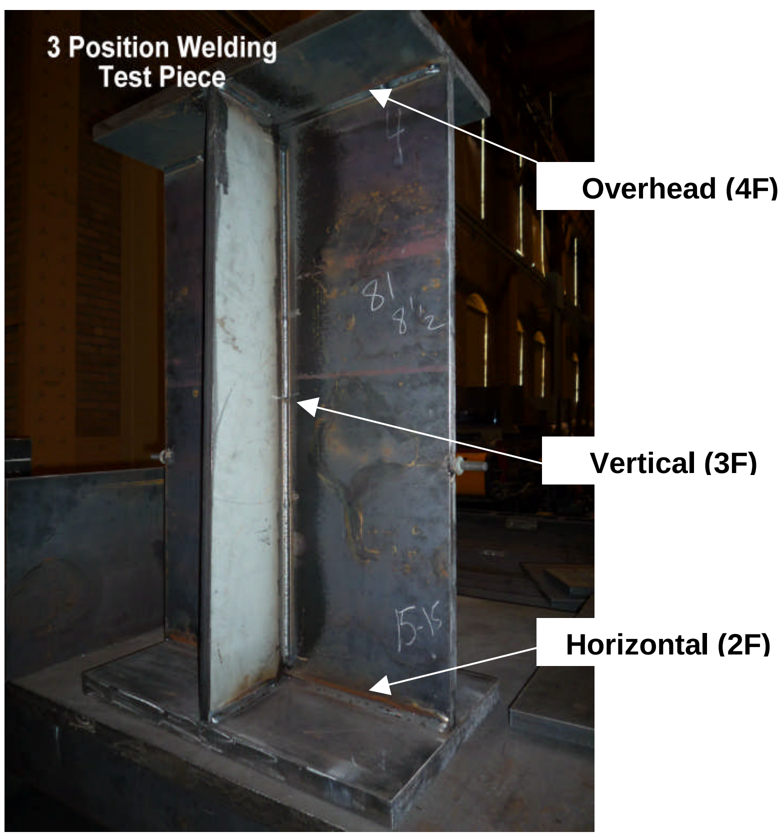


Figure 7.0 Three position test piece for weld parameter development.

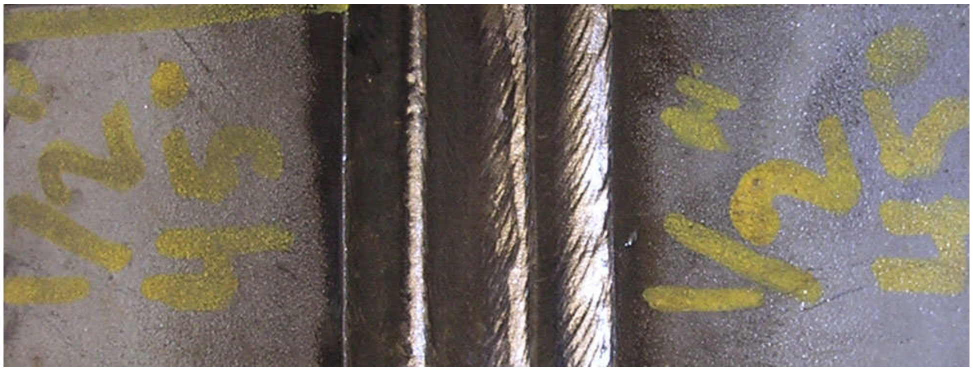


Figure 8.0 Multipass weld in flat 1G position for PQR evaluation.

The etched cross-section of the multipass flat 1G weld is shown in Figure 9.0. This weld was submitted for PQR evaluation.

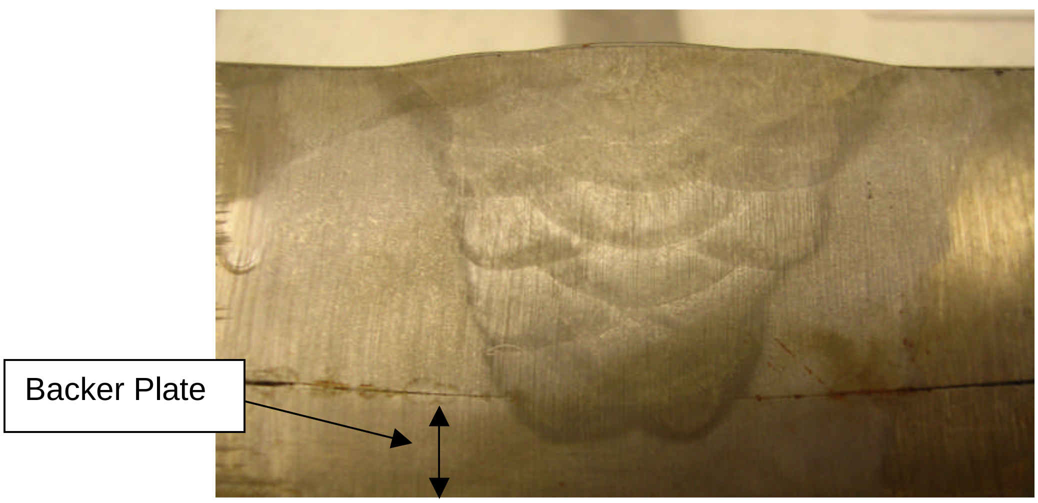


Figure 9.0 Etched cross-section of a multipass weld in flat 1G position.

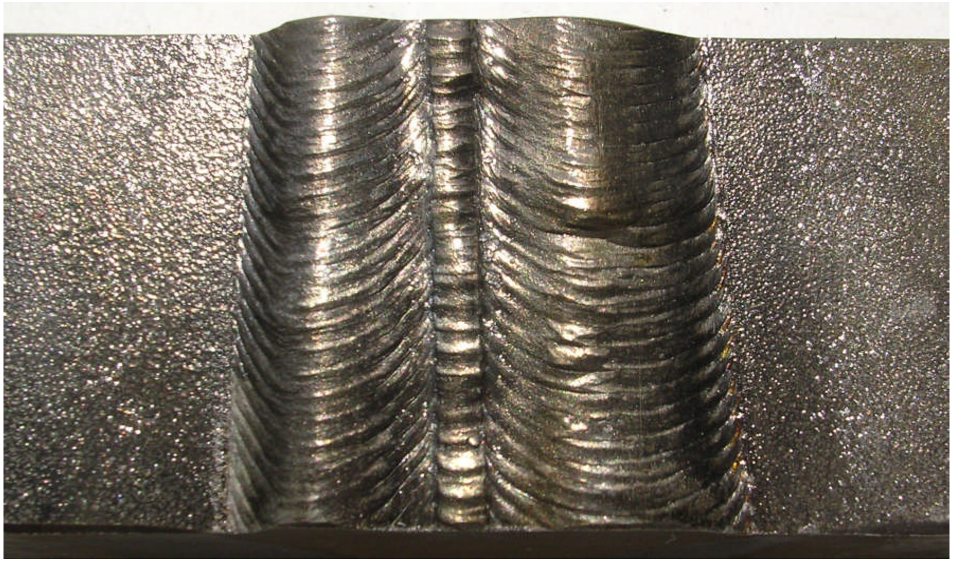


Figure 10.0 Multipass weld in vertical 3G position for PQR evaluation.

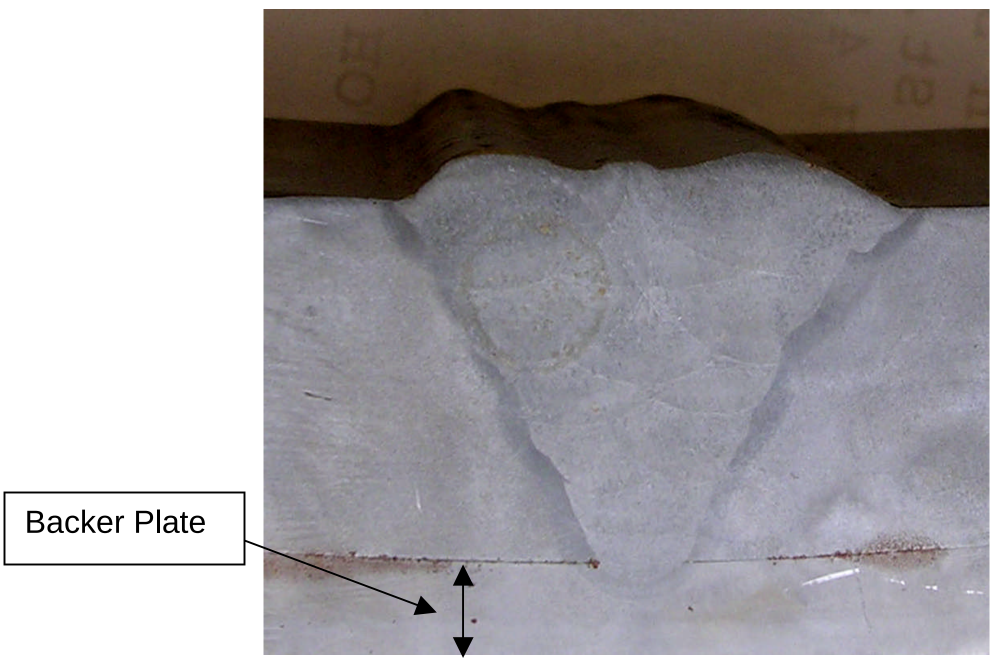


Figure 11.0 Etched cross-section of a multipass weld in vertical 3G position.

The etched cross-section of a multipass weld shown in Figure 11.0 is for a PQR evaluation of the 3G vertical position for PQR evaluation. Fifteen passes can be seen.

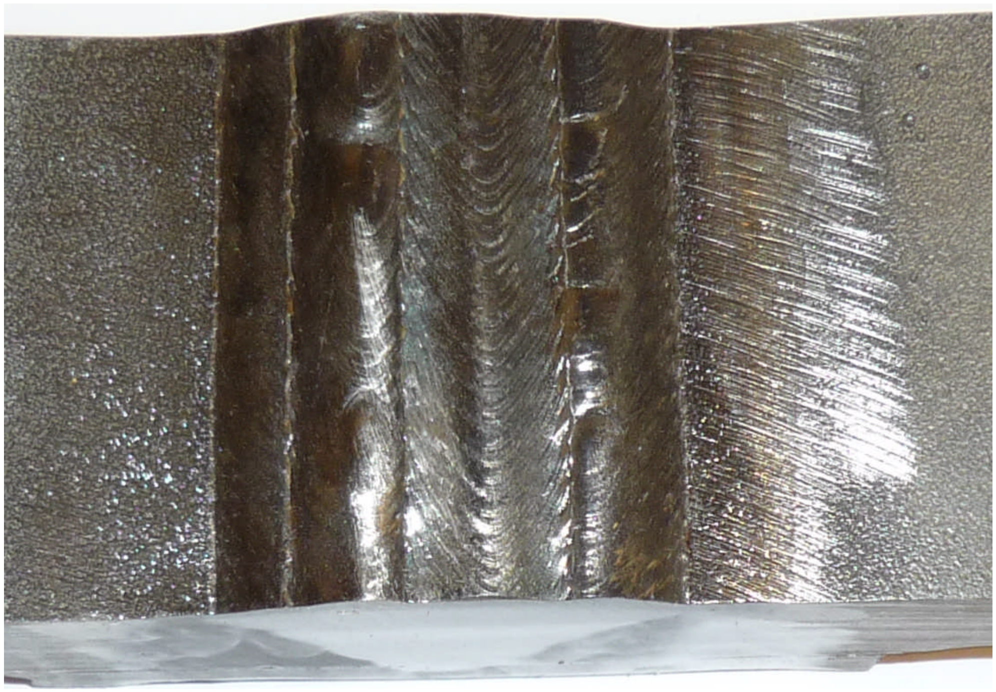


Figure 12.0 Multipass weld in 4G overhead position for PQR evaluation.

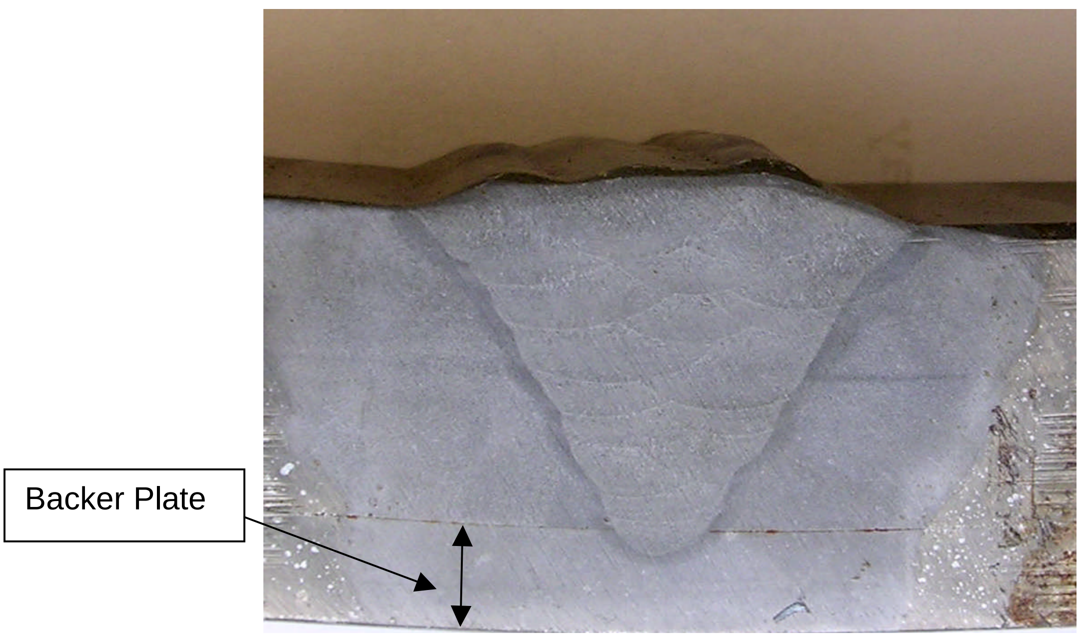
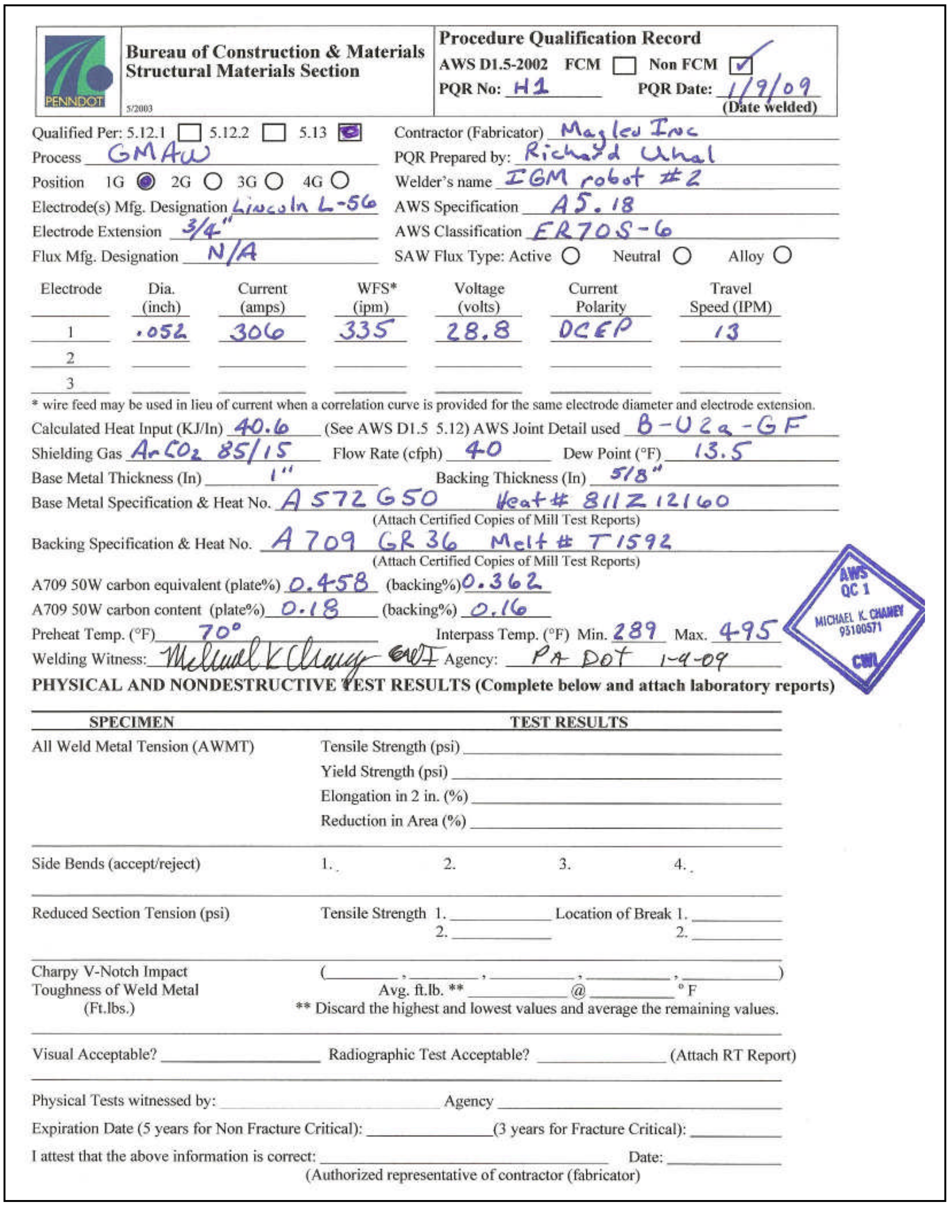


Figure 13.0 Etched cross-section of a multipass weld in overhead 4G position.

The etched cross-section of a multipass weld in the 4G overhead position for PQR evaluation is shown in Figure 13.0. Fifteen passes can be seen.

The PQR weld evaluation process was performed in the presence of the PENNDOT inspector. One page of the PQR documentation is shown in Figure 14.0.



PENNDOT 5/2003

Bureau of Construction & Materials
Structural Materials Section

Procedure Qualification Record
AWS D1.5-2002 FCM ☐ **Non FCM** ☑
PQR No: H1 **PQR Date:** 1/9/09 **(Date welded)**

Qualified Per: 5.12.1 ☐ 5.12.2 ☐ 5.13 ■
Contractor (Fabricator) Magley Inc
Process GMAW
PQR Prepared by: Richard Uhal
Position 1G ● 2G ○ 3G ○ 4G ○
Welder's name IGM robot #2
Electrode(s) Mfg. Designation Lincoln L-56
AWS Specification A5.18
Electrode Extension 3/4"
AWS Classification ER70S-6
Flux Mfg. Designation N/A
SAW Flux Type: Active ○ Neutral ○ Alloy ○

Electrode	Dia. (inch)	Current (amps)	WFS* (ipm)	Voltage (volts)	Current Polarity	Travel Speed (IPM)
1	.052	306	335	28.8	DCEP	13
2						
3						

* wire feed may be used in lieu of current when a correlation curve is provided for the same electrode diameter and electrode extension.

Calculated Heat Input (KJ/In) 40.6 (See AWS D1.5 5.12) AWS Joint Detail used B-U2a-GF
Shielding Gas Ar CO_2 85/15 Flow Rate (cfph) 40 Dew Point (°F) 13.5
Base Metal Thickness (In) 1" Backing Thickness (In) 5/8"
Base Metal Specification & Heat No. A572 G50 Heat # 811Z12160
(Attach Certified Copies of Mill Test Reports)
Backing Specification & Heat No. A709 GR 36 Melt # T1592
(Attach Certified Copies of Mill Test Reports)
A709 50W carbon equivalent (plate%) 0.458 (backing%) 0.362
A709 50W carbon content (plate%) 0.18 (backing%) 0.16
Preheat Temp. (°F) 70° Interpass Temp. (°F) Min. 289 Max. 495
Welding Witness: Michael K Chaney CWI Agency: PA DOT 1-4-09

AWS QC 1 MICHAEL K. CHANEY 93100571 CWI

PHYSICAL AND NONDESTRUCTIVE TEST RESULTS (Complete below and attach laboratory reports)

SPECIMEN	TEST RESULTS
All Weld Metal Tension (AWMT)	Tensile Strength (psi) ____ Yield Strength (psi) ____ Elongation in 2 in. (%) ____ Reduction in Area (%) ____
Side Bends (accept/reject)	1. 2. 3. 4.
Reduced Section Tension (psi)	Tensile Strength 1. ____ 2. ____ Location of Break 1. ____ 2. ____
Charpy V-Notch Impact Toughness of Weld Metal (Ft.lbs.)	(____, ____, ____, ____, ____) Avg. ft.lb. ** ____ @ ____ °F ** Discard the highest and lowest values and average the remaining values.

Visual Acceptable? ____ Radiographic Test Acceptable? ____ (Attach RT Report)

Physical Tests witnessed by: ____ Agency ____

Expiration Date (5 years for Non Fracture Critical): ____ (3 years for Fracture Critical): ____

I attest that the above information is correct: ____ Date: ____
(Authorized representative of contractor (fabricator))

Figure 14.0 One page of the PQR documentation for the task.

4.0 **Hold Down Fixtures**

Hold down fixtures were designed and fabricated for the task. The fixture design included a focus on application flexibility to allow beam fabrication in either vertical or horizontal position. The fixture design also allowed applicability to varying widths and heights of beams. The hold down fixture utilized for this task is shown in Figure 15.0 and Figure 16.0.

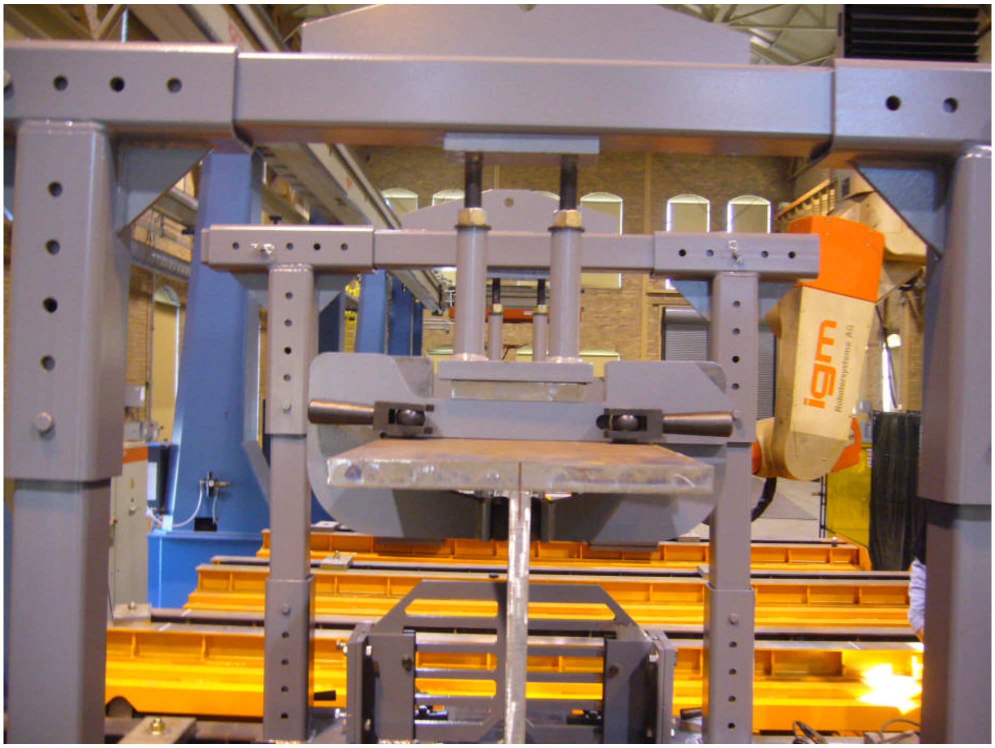


Figure 15.0 Top section of the hold-down fixture with an 8-ft long model beam.

The hold-down fixtures were designed utilizing square tubing and flat plate. The design included features that allowed easy but precise alignment of the web to both the bottom flange and top flange. Movable hydraulic cylinders (not show in any illustrations) were used to force a very tight fit between the web and flanges. Special clamps were used to secure the bottom flange to its exact position on the fit up table. The hold down fixture was designed to allow the removal of the upper portion of the fixture after fit-up and tack welding, without affecting the bottom portion of the fixture. This allowed full access of the robot to the structure for follow-on welding.

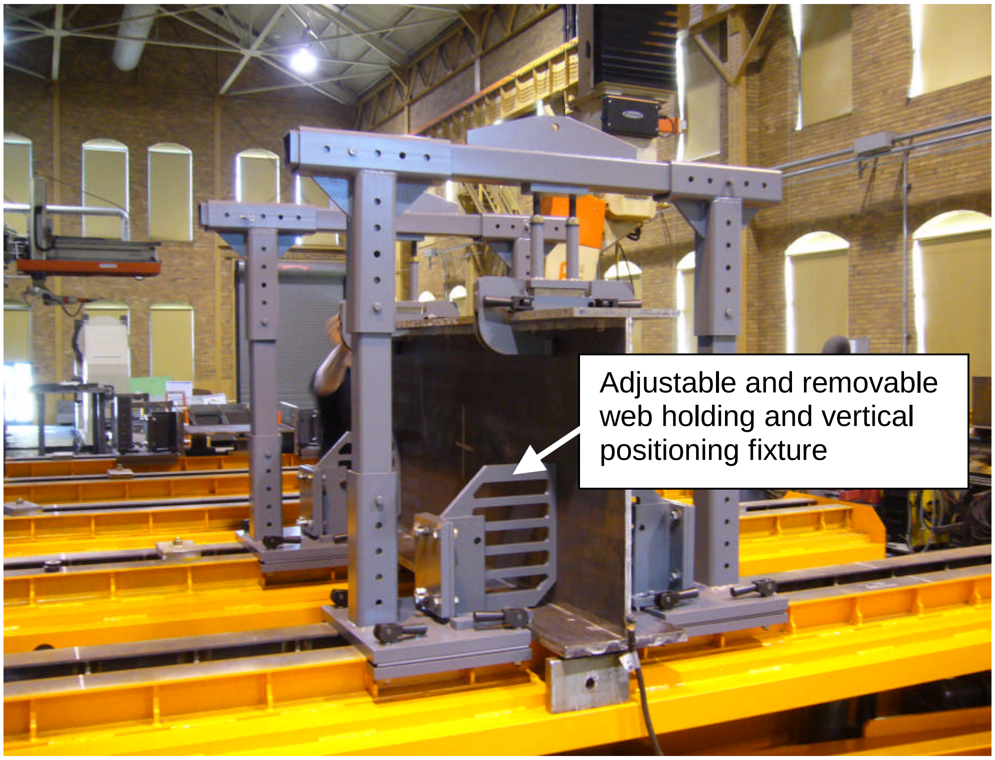


Figure 16.0 Bottom section of the hold-down fixtures with and 8-ft. model beam.

The illustration in Figure 16.0 shows the overall features of the hold-down fixture and emphasizes features of the bottom portion of the fixture with an 8-ft beam. The web positioning fixtures with elongated perforations are both adjustable to yield exact vertical positioning of the web and are also removable after tack welding to allow continuous welding of the fillet between the web and lower flange. The removable portion of the positioning fixture is accomplished without affecting the overall fixturing of the beam. (A work piece grounding lead is attached to the web section of the beam. Special removable clamps were used on the actual beam so welded studs were not required.)

5.0 **Model beam Development**

An interim step in beam fabrication was incorporated in the task. This interim step related to the fabrication of sub-size beams that were utilized to establish welding process steps prior to fabrication of the full cross-section beam. A very small beam approximately two feet long and three feet high was first fabricated using the developed process and this was followed by fabrication of two beams of eight feet in length to model the process. The smaller model is shown in Figure 17.0 with the model beam in the horizontal position and the larger model beam is shown in the vertical position in Figure 18.0.

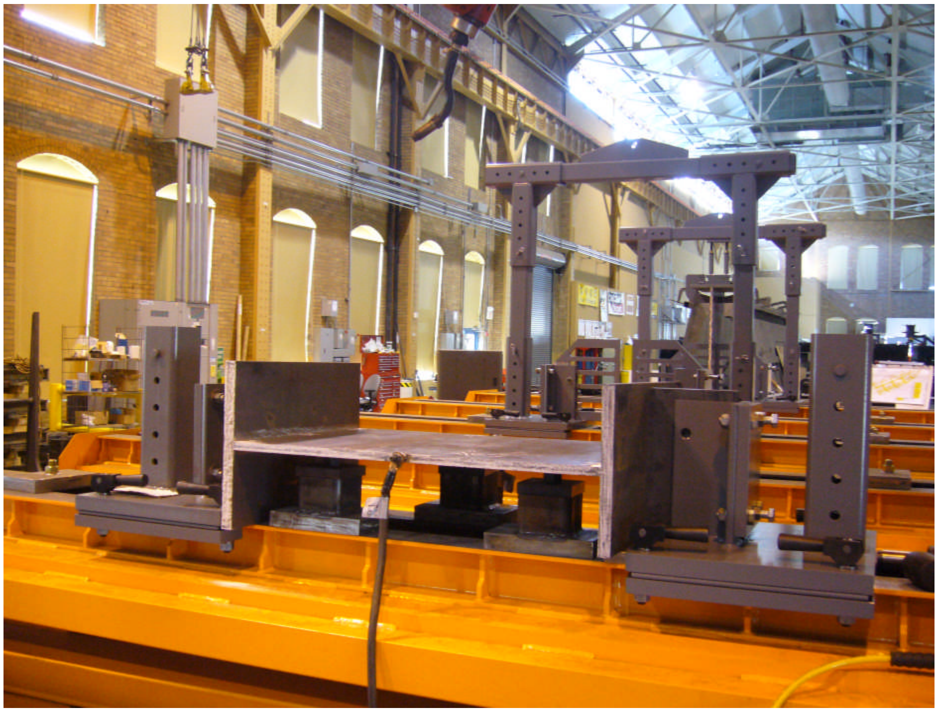


Figure 17.0 Illustration of a 2-ft model beam in the horizontal position.

A 2-ft. long model beam was fabricated in the horizontal position to make a comparison with simpler fixturing that would be associated with the horizontal positioning. This position offered some fixturing advantages but requires additional fixturing and handling process when the beam is flipped to weld the alternate side. Additional handling for flipping and re-fixturing of the beam would be required when submerged arc welding processes were utilized.

Figure 18.0 An 8-ft long model beam being prepared for fabrication in the vertical position.

Fabrication with the beam in the vertical position with modified hold down fixturing can be accomplished with GMSW process where vertical 3F and overhead 4F welding processes are employed. This allows a single fixturing operation to be used for all welds whether in flat or out of-position welds.

6.0 **Full Cross-section Beam**

After satisfactory development of the process through the use of model beams, the full cross-section but abbreviated length I-beam was fit-up and fabricated in the vertical position. The beam measurements are given in Appendix A.

6.1 Beam Fit Up

An illustration of the full cross-section beam is shown mounted on the fit-up table in various steps of welding in Figures 19.0 - 24.0.

Figure 19.0 Full cross-section 23-ft beam in place with hold down fixtures.

The illustration in Figure 19.0 shows the complete hold-down fixture in place for fit up and follow-on tack welding.

6.2 Tack Welding

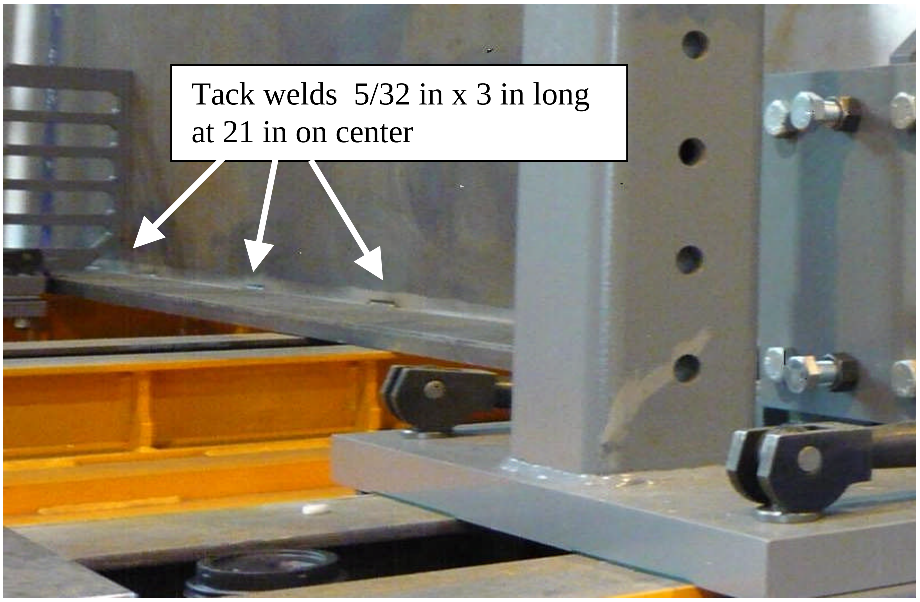


Figure 20.0 Tack welded full cross-sectional beam.

Tack welds utilized for welding of these beams were 5/32 in x 3 in at 21 in on centers. The tack welds were left as welded and not ground down. The regions where the 25 percent additional material in the weld over tack were made were noticeable but not impactive.

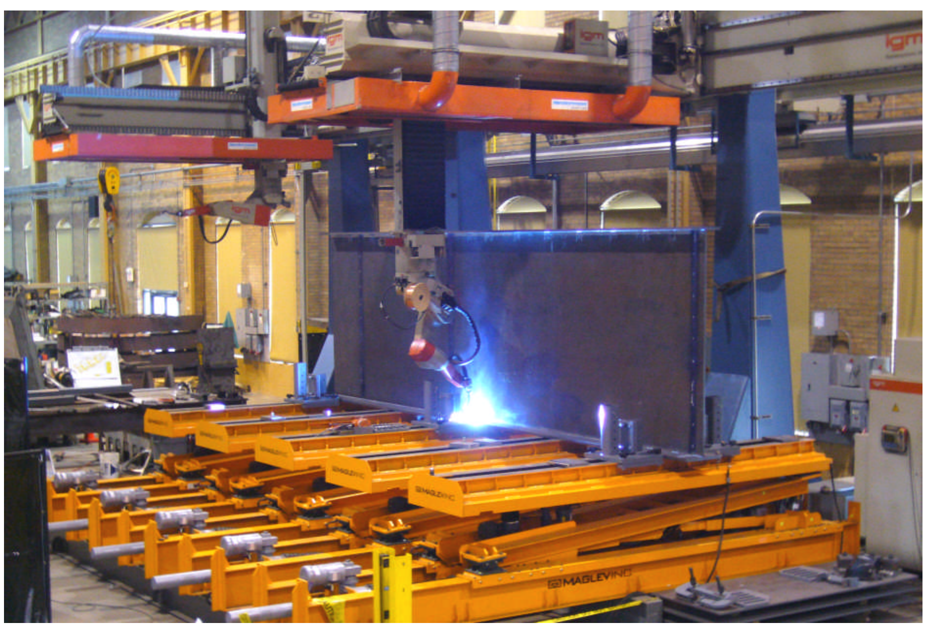


Figure 21.0 Bottom flange of 23-ft beam being welded without upper hold-downs.

6.3 Full Welding

The illustration in Figure 22.0 shows that the upper portion of the hold down fixture has been removed after tack welding to allow easy access to robot movement and allow a continuous GMAW weld to be placed over the full length of the lower flange-web joint.

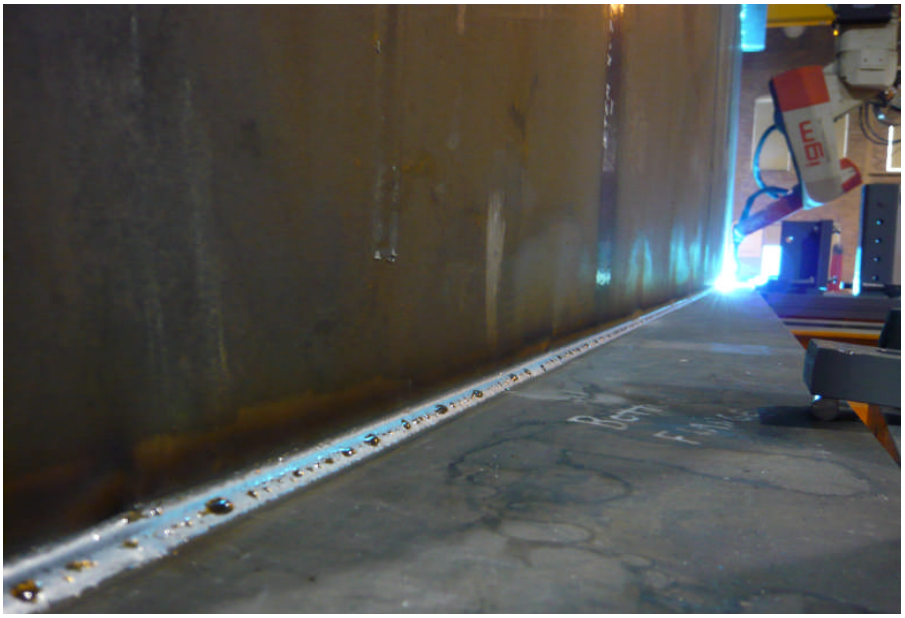


Figure 22.0 GMAW 2F welding of the bottom flange on a 23-ft beam. Some silica bubble beads are present on the weld bead surface.

The illustration in Figure 23.0 shows the upper portion of the hold-down fixture removed after tack welding and before full overhead fillet welding. The lower portion of the hold-down fixture remains in place as established in the original fit-up.

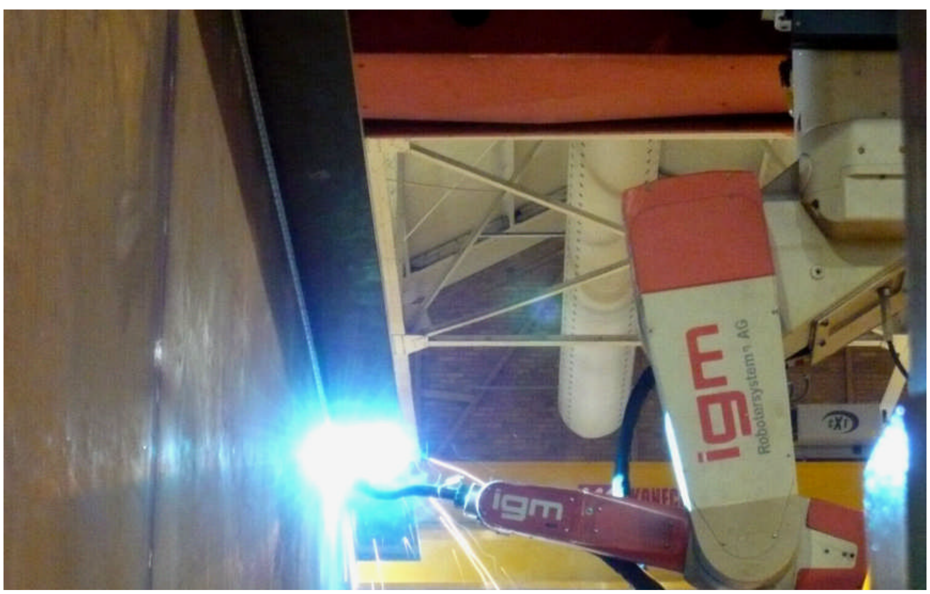


Figure 23.0 GMAW 4F overhead welding of the upper flange on a 23-ft beam.

Figure 24.0 Full cross-section 23-ft beam after welding.

7.0 Capabilities Analysis

Equipment capabilities and fabrication integration currently in place at MAGLEV, Inc.'s McKeesport facilities meet and exceed the needs outlined in the FHWA "scanning tour" report. This includes CAD integrated computer automated fit up table combined with the gantry mounted dual robot GMAW welding. The combined equipment, though currently limited in length capability, will facilitate welding straight or complex curved beams.

The equipment capability has been focused toward the development of guiderails for high-speed maglev that require precise configuration and rapid reconfiguration of the fit up table directly from a digitized computer database that include compound curvatures with cant (twist). The approach at MAGLEV, Inc. is for a totally computerized fabrication process from CAD design configuration to final installation for operational service. While total integration is not yet in place, an objective is to make that total integration system a demonstrated reality with longer length capability table and total system integration.

CAD generated design configurations applied to a 23-ft beam have been developed and fitted to the existing equipment capability. Some examples of the curved beam design fitted onto the existing 23-ft fit up table are shown in Figures 25.0 – 28.0.

Figures 25.0 and 26.0 show a curved beam fitted onto the existing fit-up table in both the vertical and horizontal positions. While these are only shown for a 23-ft long beam, they provide a pictorial view of the curved beam fabrication capability.

The usable table width design capability is currently 15 feet 10 inches, but the individual units of the table are designed to be adjusted in the width position by an additional one meter (3 ft 4 in) of horizontal movement increasing the total horizontal curvature capability of the fit up table system.

Curved beam configuration can be established through location of the hold down mechanism or through the horizontal translation of the individual arms of the table or a combination of both. The illustration in Figure 25.0 shows a flat horizontal curvature of a 23 ft beam using only the hold down fixtures to position and secure the beam.

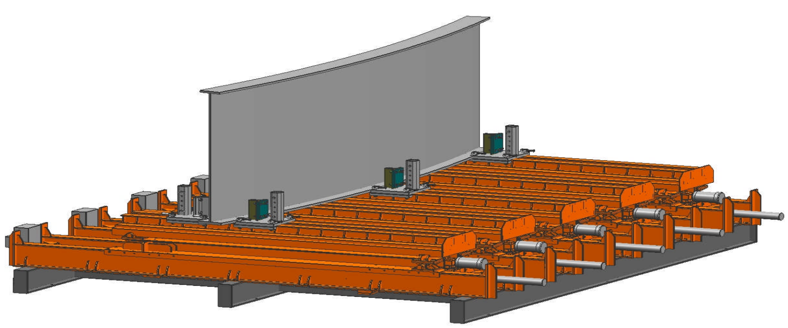


Figure 25.0 Flat horizontal curvature of a 23-ft I beam in the vertical position using only the hold down fixtures to position and secure the beam.

This beam is shown in the vertical position that allows the beam to be totally fit, tacked and welded in the upright position without any flipping of the beam. Straight or curved beams can be fabricated

The illustration in Figure 26.0 shows the same size beam but with the beam in the horizontal position where curvature is secured by the hold down mechanism only.

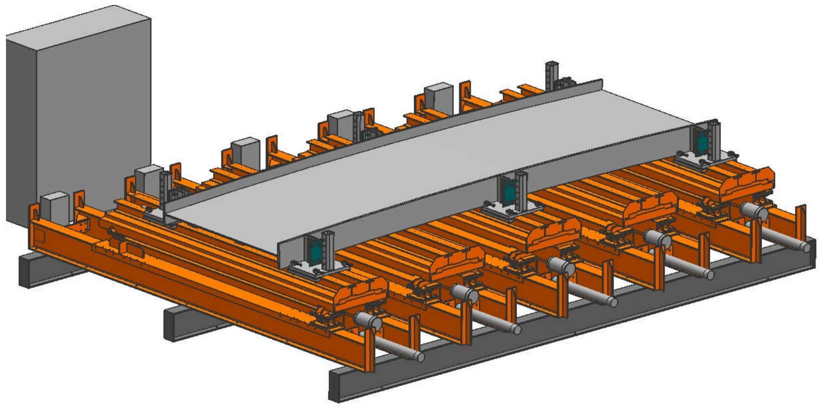


Figure 26.0 Vertical curvature of a 23-ft I beam achieved from horizontal positioning using only the hold down fixtures to position and secure the beam.

The position shown in Figure 26.0 allows the beam to be fit, tacked and welded on one side. The fit-up table is now repositioned into the negative configuration and then the beam is flipped to weld the opposite side.

The illustration in Figure 27.0 shows a vertically positioned beam on the fit-up table with vertical curvature achieved by the vertical lifts from the design characteristic of the fit-up table.

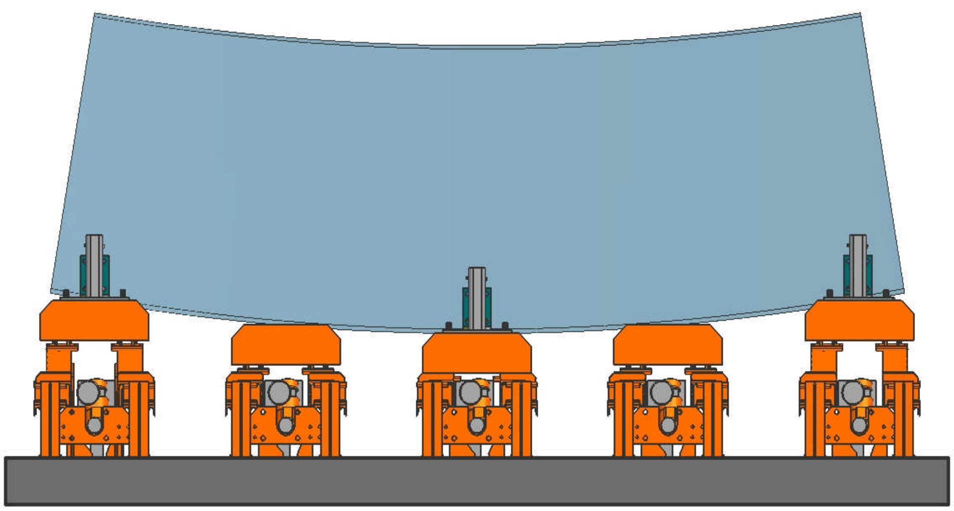


Figure 27.0 Illustration of the vertical lift capability of the MAGLEV, Inc. computer controlled fit up table.

The lift capability of an individual arm is up to one meter (3 ft 4 in). Lifts on the other arms can be configured very precisely by computer controlled automated processes employed on the MAGLEV, Inc. system.

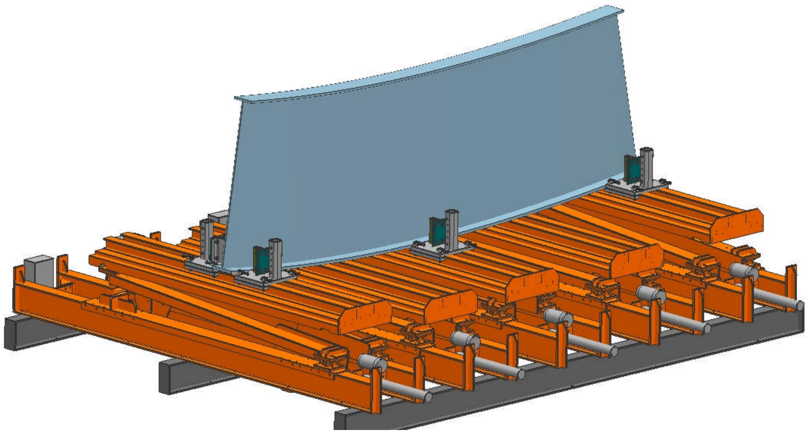


Figure 28.0 A 23-ft I beam illustrated in compound curvature configuration on the MAGLEV, Inc. computer automated fit-up table.

The illustration shown in Figure 28.0 shows the capability of the MAGLEV, Inc. fit up table for fabricating I beams with compound curvatures. The table can also be configured with twist that will allow cants of up to 25 degrees to be incorporated into the beam. Compound curves with cant are developed using a combination of the vertical and horizontal positioning of the top segment of the arms of the fit-up table.

The illustration in Figure 29.0 shows a vertically mounted I beam in a curved configuration with the curve being secured by the hold down fixture mechanisms.

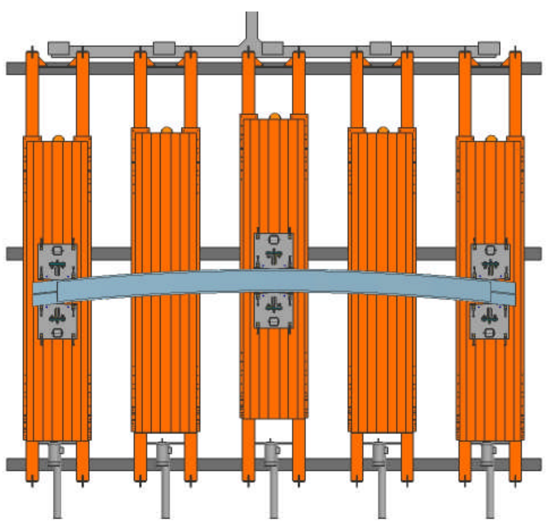


Figure 29.0 Vertical beam curvature achieved by hold down structures and horizontal extensions of the individual arms of the fit-up table.

The illustration in Figure 30.0 shows a 100 ft long I beam of the type used in this GMAW evaluation that has been configured with a 100 ft. horizontal radius. The maximum required chord to arc distance for this configuration is 13 ft 4 ¾ in. The maximum table width capability of the MAGLEV, Inc. table is 15 ft 10 in showing that a 100 ft long beam configured through a 100 ft radius arc can easily fit on the table. Additionally, the same beam can be configured with a compound curvature through a vertical lift of any arm of 26 in and also subjected to a cant (twist) of up to 25 degrees.

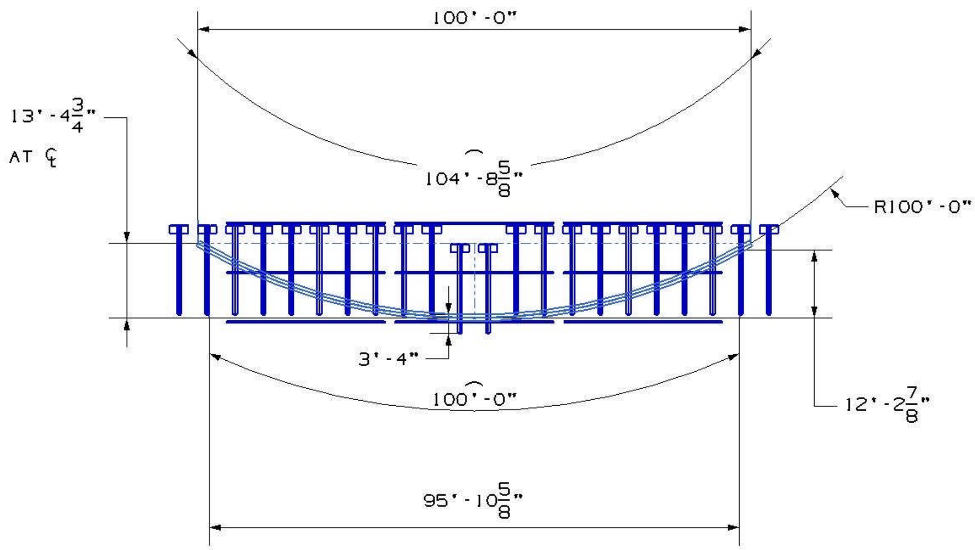


Figure 30.0 Illustration of a 100 ft long beam with a 100 ft horizontal radius.

Also, the illustration in Figure 30.0 shows a 100 ft long beam with a 100 ft horizontal radius fitted onto the current MAGLEV, Inc. fit-up table design that has been expanded to 22 individual arm units. Only the two center sections are shown in the extended horizontal position in the illustration, but all member arms can be moved over a distance of one meter (3 ft 4 in).

8.0 **Conclusions**

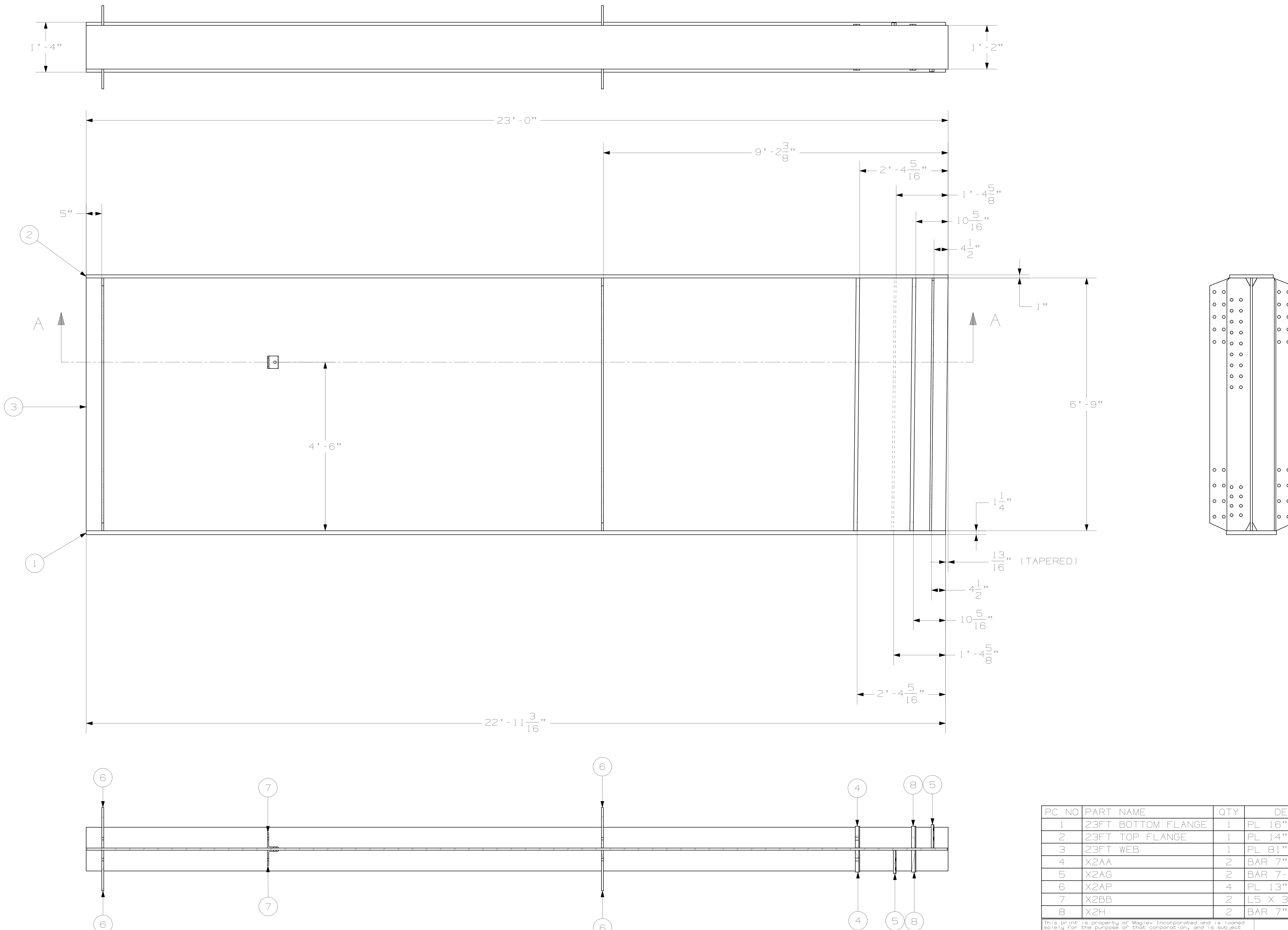
This project has demonstrated the potential improvements in bridge beam fabrication technology recommended in the 2001 DOT Symposium Report. It has demonstrated the capability of using MAGLEV, Inc. guiderail beam equipment for fabricating bridge beams, including CAD driven automated fit up tables and GMAW welding. It has also been demonstrated that the guideway fabrication technology is applicable to highway/bridge beams. The suitability of using the precision processing equipment at the MAGLEV, Inc. facilities to meet the desired criteria for fabrication outlined by the FHWA 2001 Symposium Report is detailed below:

- Fit-Up Table Configuration Driven Directly from CAD Model Digital Data: The specific task covered in this report was for a straight beam-making configuration of the fit-up table easily attained. Establishing fit-up table configuration directly from a CAD model required digital data transfer process and instrumented fit-up table that can respond to the data base information.

- High Dimension Tolerance Control from Computerized Fabrication Systems. The automated fit-up table system in place at the MAGLEV, Inc. facilities has demonstrated capability to achieve very high tolerance fit-up configurations that conform to the requirements for fabrication of high-speed maglev guiderails. The guiderails require precision fabrication employing compound curves that also include super-elevation or twist. Time requirements for fit-up using conventional operations have been shown to be greater than actual welding times. Computer controlled fit-up directly from the CAD model to achieve exact table configurations of complex curved beams has been estimated to result in savings of total fabrication costs of up to 20 percent.

- High Quality GMAW Welding in Flat and Out-of-Position Processes. The GMAW process has been demonstrated to provide high quality welds in flat, vertical and overhead positions. These welds can be achieved with a single set up process that further reduces the total fabrication time and cost.

APPENDIX A



SECTION A-A

NOTES: 1. TOTAL WEIGHT EXCLUDING WELDS 8635 LBS
2. UNLESS NOTED OTHERWISE ALL STEEL TO BE ASTM A572 GRADE 50
3. REFER TO DRAWING 100335 FOR DETAILS OF ITEMS 4-9

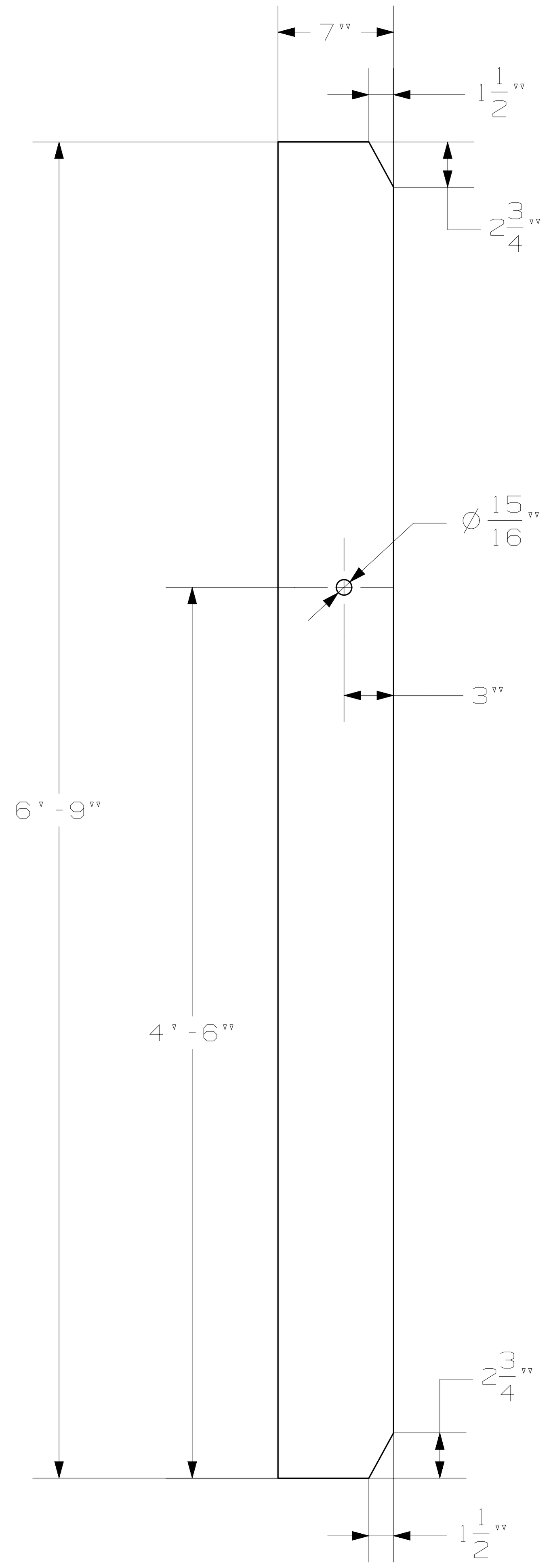
PC NO	PART NAME	QTY	DESCRIPTION	LENGTH	REMARKS
1	23FT BOTTOM FLANGE	1	PL 16" X 1-1/4"	22'-11 3/16"	
2	23FT TOP FLANGE	1	PL 14" X 1"	23'-0"	
3	23FT WEB	1	PL 81" X 3/4"	23'-0" TAPER END	
4	X2AA	2	BAR 7" X 1-1/8"	6'-9"	A36
5	X2AG	2	BAR 7-1/2" X 5/8"	6'-9"	A36
6	X2AP	4	PL 13" X 5/8"	6'-9"	A36
7	X2BB	2	L5 X 3-1/2" X 3/8"	0'-4"	A36
8	X2H	2	BAR 7" X 1-1/8"	6'-9"	A36

MAGLEV INC
MCKEESPORT, PENNSYLVANIA

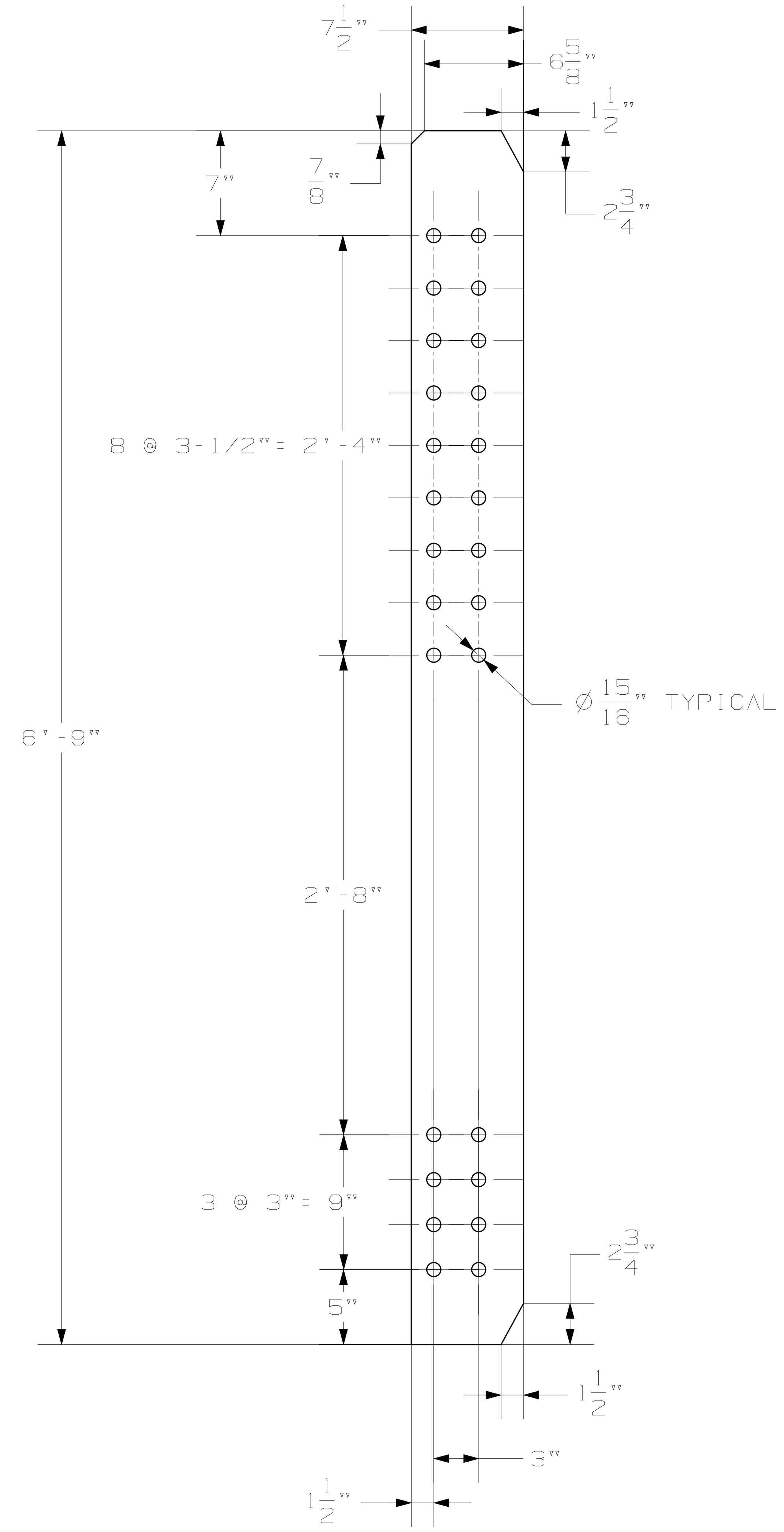
TOLERANCES UNLESS OTHERWISE SPECIFIED

X	±1 MM	X.X	±.04"	X°	±1°
X.X	±0.25 MM	X.XX	±0.01"	X.X°	±0.5°
X.XX	±0.03 MM	X.XXX	±0.001"		

UNITS: IN
SCALE: 1:16
TITLE: 23 FOOT BEAM
CHECKED: X DATE: X
DRAWN: R. UHAL DATE: 14-NOV-2008
FILENAME: J:\Engineering\FAB Group\PENNDOT\NX
DRAWING NO. 100351
SHT 1 OF 1
REV 00



(100333-04)
STIFFENER X2AA
MATERIAL A36 (T)
THICKNESS 1-1/8"
QUANTITY 2



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STIFFENER X2AG
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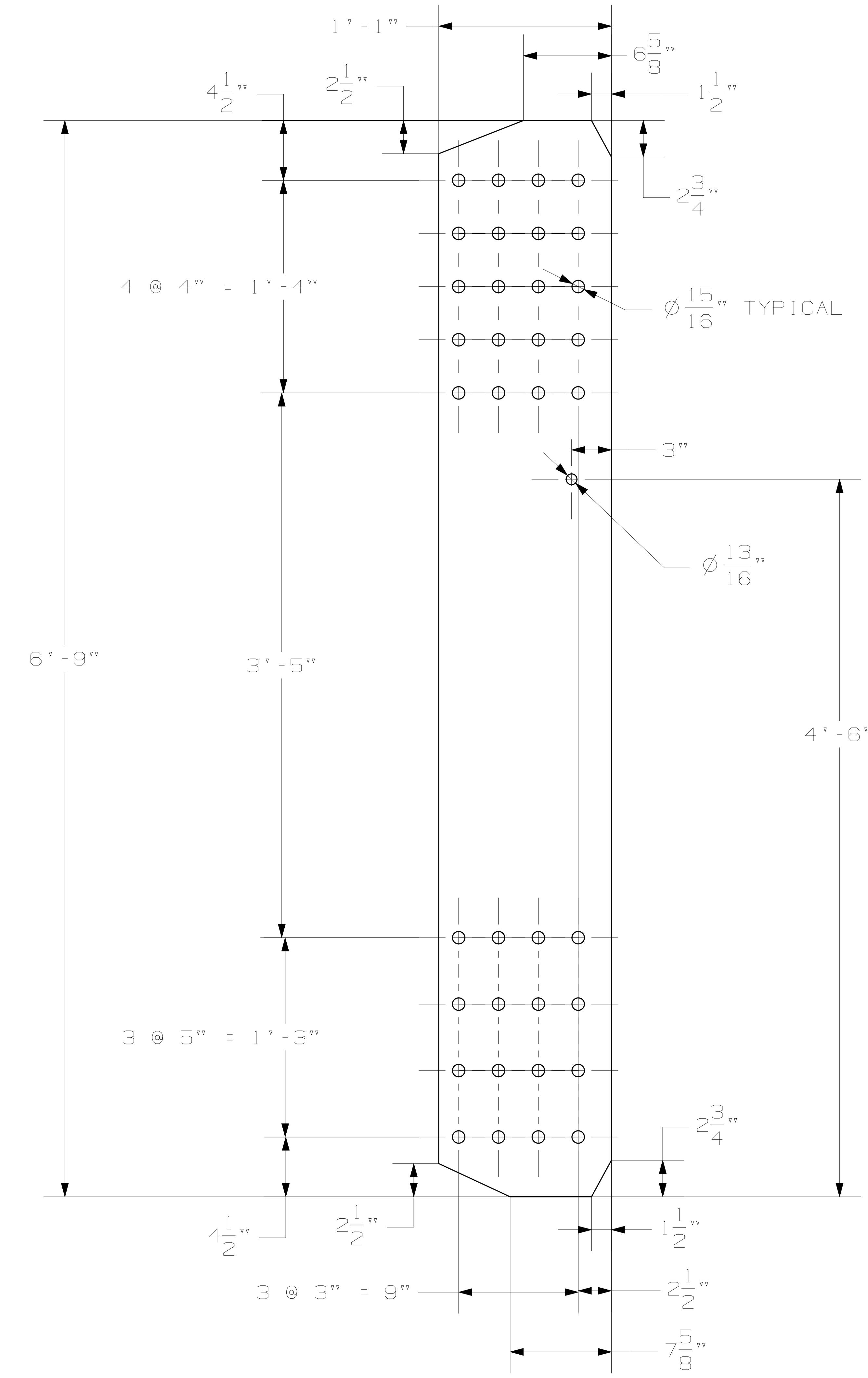
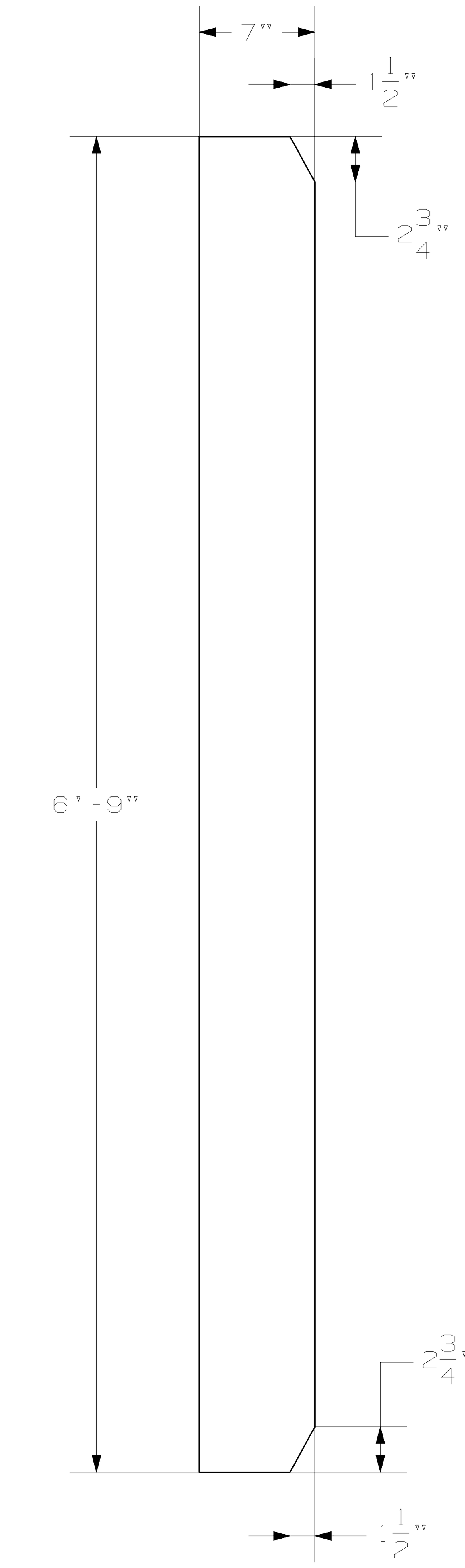
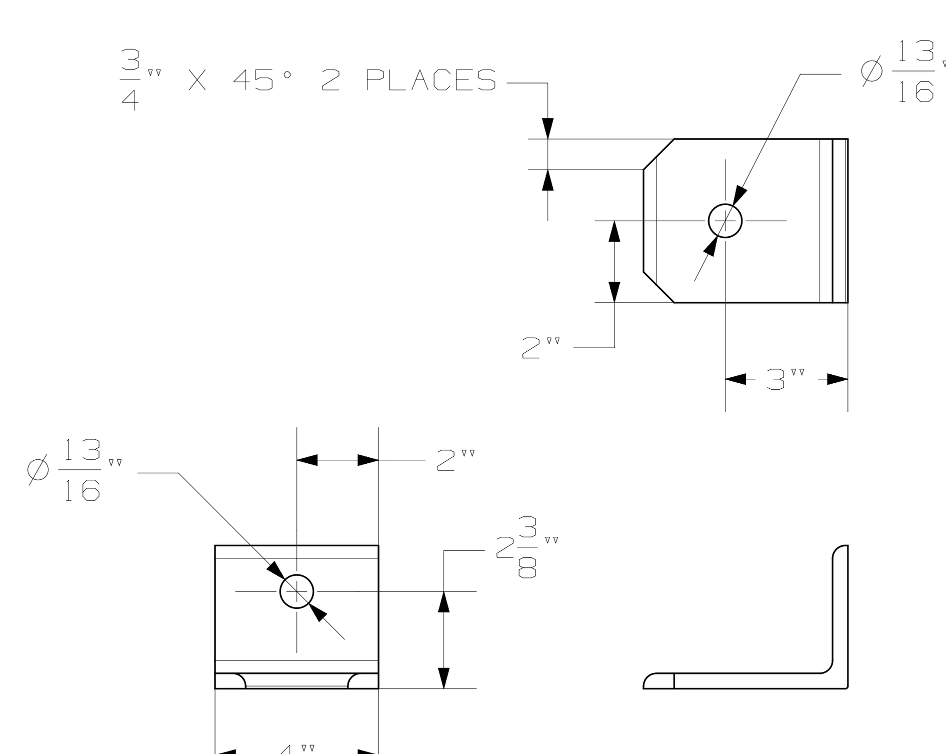
QUANTITY 2



(100333-06)
STIFFENER X2AP
MATERIAL A36 (T)
THICKNESS 5/8"
QUANTITY 4



(100333-08)
STIFFENER X2H
MATERIAL A36 (T)
THICKNESS 1-1/8"
QUANTITY 2



(100333-07)
HANDRAIL ANGLE X2BB
MATERIAL A36
L5 X 3-1/2 X 3/8
QUANTITY 6
SCALE 1/4

NOTE: 1. (T) INDICATES CHARPY V-NOTCH TESTING REQUIRED

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TOLERANCES UNLESS OTHERWISE SPECIFIED			UNITS IN / SCALE 1:8
X ±1 MM	X.X ±.04"	X° ±1°	
X.X ±0.25 MM	X.XX ±0.01"	X.X° ±0.5°	
X.XX ±0.03 MM	X.XXX ±0.001"		

CHECKED	X. XXX	DATE	XX-XXX-2008
DRAWN	R. UHAL	DATE	19-MAY-2008
FILENAME	J:\Engineering\FAB Group\TUB GIRDER\NX		

TITLE
MLI G3C GIRDER SECTION
STIFFENER DETAILS

DRAWING NO.	SHT	REV
100335	1 OF 1	00