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Field Instrumentation and Analysis of New TBTA Variable Speed Limit Sign Installations of the Throgs Neck Bridge

Ian C. Hodgson

Robert J. Connor

FIELD INSTRUMENTATION AND ANALYSIS OF NEW TBTA VARIABLE SPEED LIMIT SIGN INSTALLATIONS ON THE THROGS NECK BRIDGE

by

Ian C. Hodgson

and

Robert J. Connor

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ATLSS is a National Center for Engineering Research on Advanced Technology for Large Structural Systems

117 ATLSS Drive
Bethlehem, PA 18015-4729

Phone: (610)758-3525
Fax: (610)758-5902

www.atlss.lehigh.edu
Email: inatl@lehigh.edu

1.0 Introduction

This draft report discusses the preliminary results of the VSLS vibration study. The scope of the study has been limited to new VSLS installations on the Throgs Neck Bridge. Limited field instrumentation and dynamic analyses were performed to assess the behavior of three new installations prior to construction. Although only three of the signs were analyzed, it is reasonable to extend these results to other similar installations.

2.0 Background

The Triborough Bridge and Tunnel Authority (TBTA) has instituted a system-wide installation of Variable Speed Limit Signs (VSLS), through project AW-80A – *"INSTALLATION OF VARIABLE SPEED LIMIT SIGNS AT VARIOUS TBTA FACILITIES"*. This project is being led by the firm of DMJM+Harris. The VSLS units consist of a 4 foot wide by 5 foot high sign with an programmable LED display. The focus of this study is VSLS installations on elevated structures. The sign is typically mounted to a new pole which is installed on the bridge. There is concern with installing VSLS on bridges due to the vibration response of the sign due to live load induced vibration of the bridge itself. Researchers at the ATLSS Center of Lehigh University were engaged by DMJM+Harris to perform a vibration study of proposed VSLS installations.

In order to quantify this effect and to make a general assessment of the proposed system, the Throgs Neck Bridge was chosen for analysis. The type of details proposed on this bridge and variety of support conditions are expected to envelope the vibration response of the VSLS in the entire TBTA system.

Three VSLS installations were chosen for analysis. For two of these poles (TN_N5 and TN_S9), dynamic time-history analyses using field-measured acceleration data as input to the model were performed. For the third pole (TN_S10), field measurements were not available. Therefore, modal analyses were performed of both the VSLS (and new supporting framing) and the existing plate girder stringers of the bridge. These analyses provide the natural vibration frequencies of the both the bridge and the VSLS to assess the potential for resonance to occur.

Field measurements were made at the proposed location of VSLS TN_N5 and used in the analyses. This VSLS is located on the Bronx approach of the bridge. For VSLS TN_S9, located on the main suspended span of the bridge, measurements made on the main suspended span of the Bronx-Whitestone bridge for an unrelated light pole study were used as the basis for the dynamic analyses. VSLS TN_S10 is located on the Clearview Expressway approach spans.

3.0 Instrumentation Plan

3.1 VSLS TN_N5

Instrumentation was installed at the proposed location of VSLS TN_N5 on June 19, 2003 by personnel from the TBTA, ATLSS, and DMJM+Harris with assistance from the TBTA maintenance personnel. A triaxial accelerometer was installed at the end of the cantilever floor beam directly beneath the proposed sign pole location using a wrench clamp, as shown in Figure 3.1. A uniaxial accelerometer was installed at the top of the steel barrier plate to measure the out-of-plane vibration of the barrier, however data from this accelerometer were not used in the analysis because the response at this location will be significantly different after the barrier has been stiffened with a steel plate immediately below the new VSLS pole which is to be installed atop the existing barrier.

Data were recorded continuously at a sampling rate of 250 Hz for approximately 40 hours beginning on Thursday June 19 at around noon. The sensors and data acquisition system were removed the following week

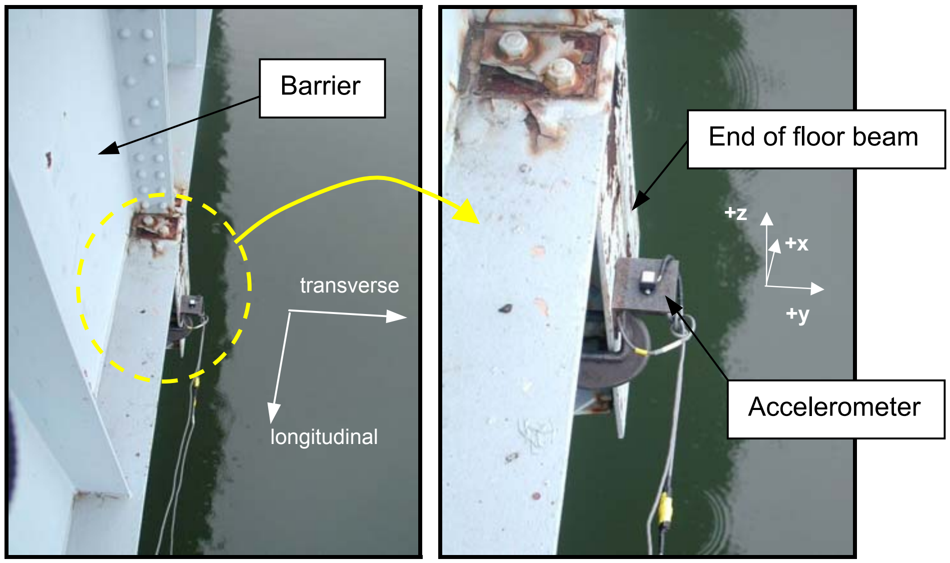


Figure 3.1 – Triaxial accelerometer installed at the end of the floor beam at proposed VSLS TN_N5 (near LP 159)

The data acquisition system consisted of a Campbell Scientific CR9000 Data Logger. This is a high speed, multi-channel, 16-bit digital data acquisition system. The sampling rate was 250Hz during all data collection. In order to ensure a stable, noise-free signal, analog and digital filtering were employed. A high-pass filter with a cutoff frequency of 100 Hz was utilized. Power was provided through nine marine batteries. The entire system was contained in a weather-tight enclosure on the bridge deck behind the temporary barrier along the right northbound lane, as shown in Figure 3.2.

Figure 3.2 – Weather-tight enclosure containing data logger and batteries

3.2 VSLS TN_S9

The analysis of VSLS TN_S9 made use of existing data from the Bronx Whitestone Bridge. These data were obtained as part of a vibration study of new light poles on the suspended portion of the Bronx-Whitestone bridge. A photograph of the light pole is contained in Figure 3.3. A triaxial accelerometer was installed on the orthotropic deck at the connection point to the light pole, as shown in Figure 3.4.

Data were recorded when accelerations at the tip of the light pole cantilever exceeded a predefined threshold value. Data were taken at a sampling rate of 250 Hz for a predefined period of time prior to and following the trigger event. The sensors were installed on March 18, 2003 by ATLSS personnel, and data were recorded between March 18, 2003 and April 25, 2003.

The data acquisition system for this data collection also consisted of a Campbell Scientific CR9000 Data Logger. The system was located in a weather-tight enclosure mounted to the floor beam beneath the bridge. Power was supplied on the bridge. Remote communication from the ATLSS laboratories with the logger for data collection and program modifications was achieved through the use of a Cisco wireless network and high-speed internet connection.

Figure 3.3 – Prototype light pole located on the Bronx-Whitestone Bridge

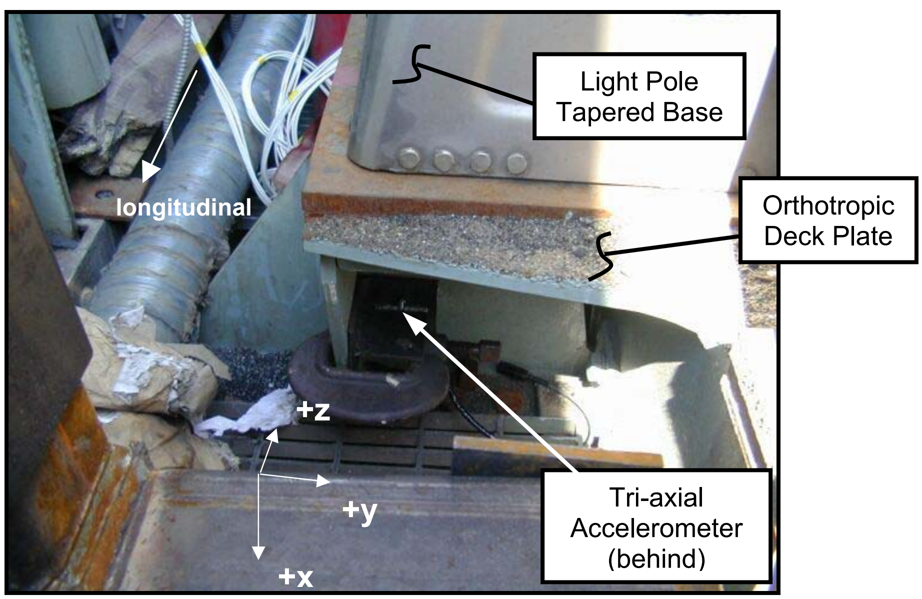


Figure 3.4 - Triaxial accelerometer at the base of the prototype light pole

4.0 Dynamic Analysis

4.1 VSLS TN_N5

A three-dimensional finite element model of the proposed VSLS TN_N5 was created using the preprocessor FEMAP. This program is a graphical user interface which aids in creating the model, and produces the text input file used by the ABAQUS finite element code. Transient modal dynamic analyses of the proposed VSLS were performed. Transient modal dynamic analysis gives the response of the model as a function of time based on a given time-dependent loading, which in this case is the field measured base acceleration excitation. The response of the structure is based on a subset of the eigenmodes (characteristic modes of vibration) of the system. A damping ratio of 1.5% was used for all modes.

The model is composed of beam elements. The pole consists of an eight inch nominal diameter XS schedule 80 pipe. Part of the proposed design for the VSLS includes welding stiffening elements on both sides of the barrier plate. The parapet beneath the VSLS pole was modeled as two different beam elements considering an effective width of the barrier plate. The first represents the built-up barrier below the sidewalk. The second represents the built-up barrier above the sidewalk. Two springs were placed at the connection point to the barrier to represent the flexibility of the pole base plate. The VSLS sign is modeled as a point mass of 64 pounds located at the center of gravity of the VSLS unit. Figure 4.1 contains a plot of the ABAQUS model of VSLS TN_N5. It should be noted that the shape of the sections are shown in the figure for illustration purposes only. For analysis, the elements are one-dimensional beams. A drawing of VSLS TN_N5 is contained in the Appendix.

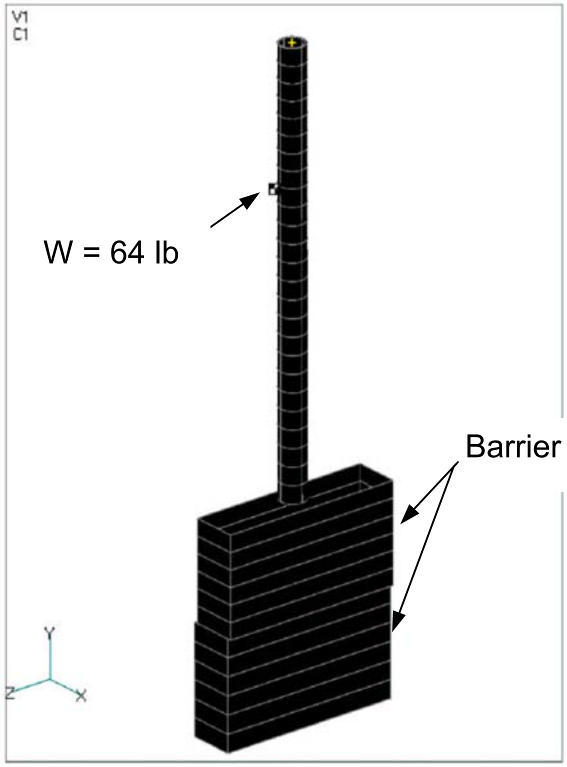
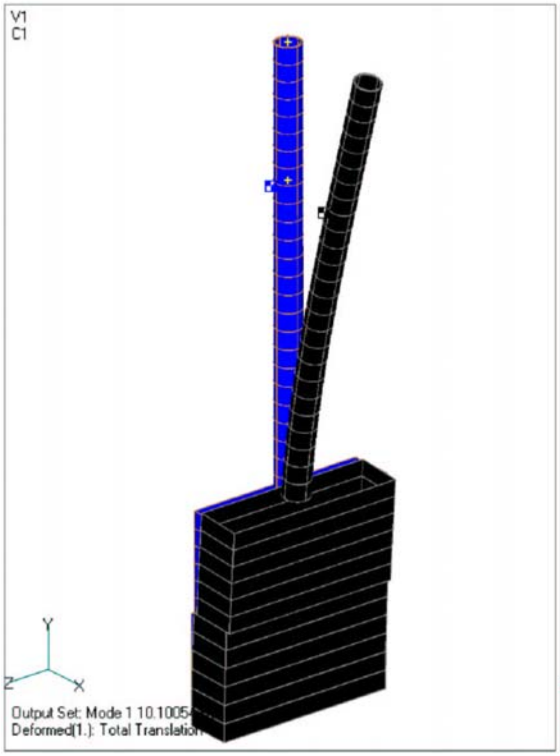
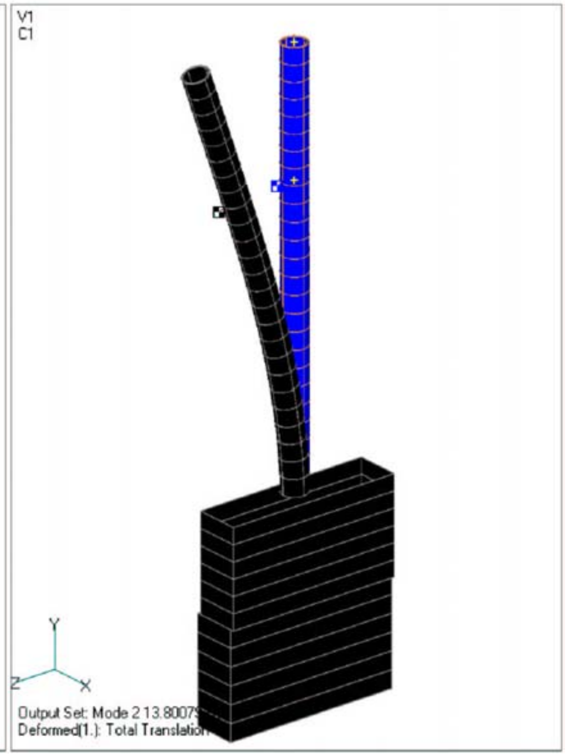


Figure 4.1 – ABAQUS model of VSLS TN_N5. The VSLS unit is modeled as a point mass of 64 lb.

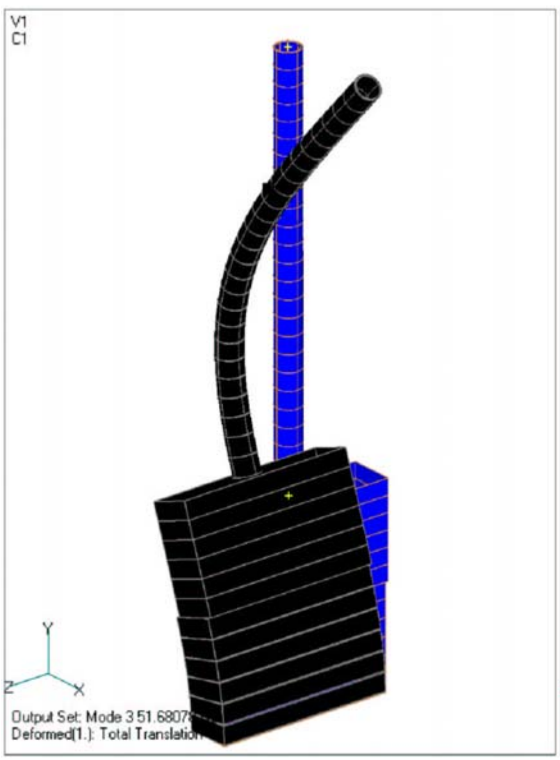
For each analysis, the mode shapes and frequencies are first extracted by ABAQUS. Figures 4.2 (a) through (d) contain the mode shapes and frequencies of the four lowest modes as determined by analysis.



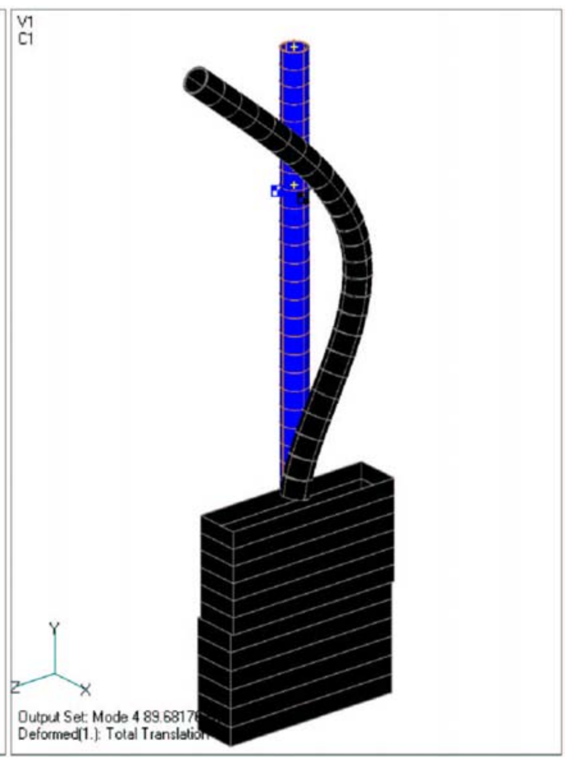
(a) f = 10.10 Hz



(b) f = 13.80 Hz



(c) f = 51.68 Hz



(b) f = 89.68 Hz

Figure 4.2 – Lowest four modes of vibration for VSLS TN_N5

The continuous acceleration data were reviewed. Out of the entire data set, ten acceleration records were selected, each 16.348 seconds long (4096 data points). Each record represents the passage of a heavy vehicle which caused the largest observed accelerations. Each of these ten records was processed by removing low frequency noise (i.e. drift). Then, a modal dynamic analysis was performed with each of the ten acceleration records which are used as base excitation. The displacement and accelerations for the entire time history are determined by ABAQUS. The peak acceleration and displacement at the center of gravity of the VSLS unit was determined for each analysis. These results are summarized in Table 4.1. The table shows that the peak displacement at the VSLS unit is 0.046 inches in the transverse direction and the peak acceleration is 1.1 g in the longitudinal direction. It should be noted however, that only one of the ten records caused peak accelerations at the VSLS center of gravity exceeding 0.5 g.

	Peak Disp. @ C.G. VSLS (in)			Peak Accel. @ C.G. VSLS (g)		
Record No.	**Trans**	**Vert**	**Long**	**Trans**	**Vert**	**Long**
1	0.034	0.002	0.019	0.357	0.172	0.476
2	0.020	0.001	0.011	0.236	0.104	0.300
3	0.025	0.001	0.011	0.288	0.120	0.390
4	0.046	0.001	0.013	0.471	0.201	0.436
5	0.037	0.002	0.016	0.429	0.151	0.429
6	0.027	0.001	0.006	0.303	0.481	1.139
7	0.040	0.001	0.010	0.371	0.198	0.503
8	0.013	0.001	0.008	0.180	0.182	0.464
9	0.025	0.001	0.011	0.289	0.120	0.390
10	0.029	0.001	0.009	0.319	0.175	0.420
Peak =	0.046	0.002	0.019	0.471	0.481	1.139
μ =	0.030	0.001	0.011	0.324	0.190	0.495
σ =	0.010	0.000	0.004	0.087	0.108	0.233
COV =	0.331	0.301	0.333	0.267	0.565	0.472

Table 4.1 – Summary of peak displacements and accelerations predicted by analysis for the ten time-history analyses (VSLS TN_N5)

An FFT was performed on the acceleration response at the center of gravity of the VSLS for each of the ten analyses. The average at each frequency bin was calculated. This is plotted in Figure 4.3. This figure indicates the pole primarily responds at the first two modes, at frequencies of 10.1 and 13.9 Hz.

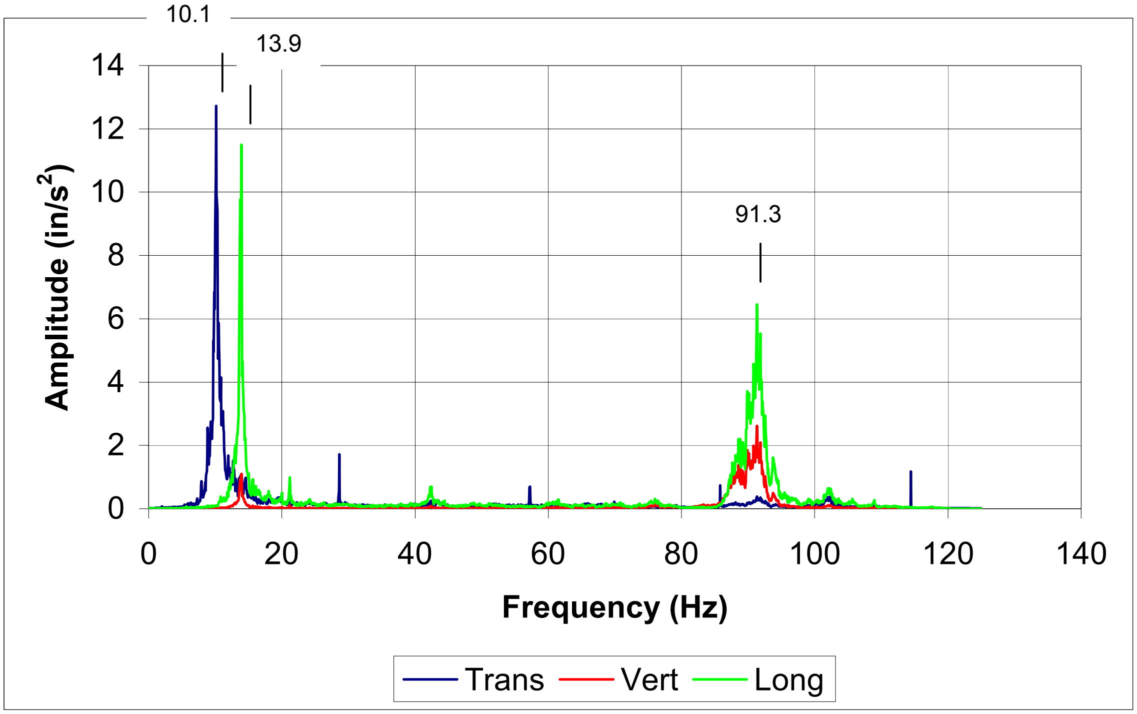


Figure 4.3 – Average FFT of acceleration at the center of gravity of the VSLS unit for all ten time history analyses (VSLS TN_N5)

4.2 VSLS TN_S9

A similar three-dimensional finite element model of the proposed VSLS TN_S9 was created. Transient modal dynamic analyses of the proposed VSLS were also performed. As before, a damping ratio of 1.5% was used for all modes.

This VSLS is located on the main suspended span of the Throgs Neck bridge. The model is composed of beam elements. The pole consists of an eight inch nominal diameter XS schedule 80 pipe, and is mounted directly to the top chord of the floor truss. Two springs were placed at the connection point to the truss to represent the flexibility of the pole base plate. The VSLS sign is modeled as a point mass of 64 pounds located at the center of gravity of the VSLS unit. Figure 4.4 contains a plot of the ABAQUS model of VSLS TN_S9. It should be noted that the shape of the sections are shown in the figure for illustration purposes only. A drawing of VSLS TN_S9 is contained in the Appendix.

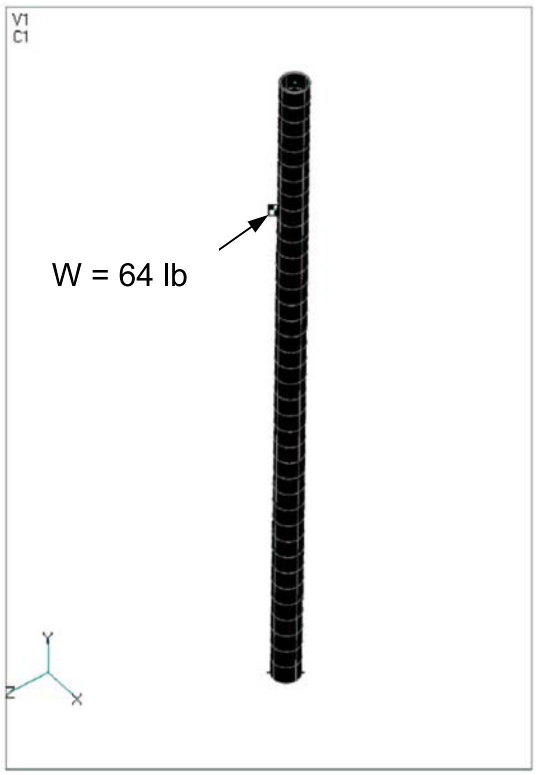
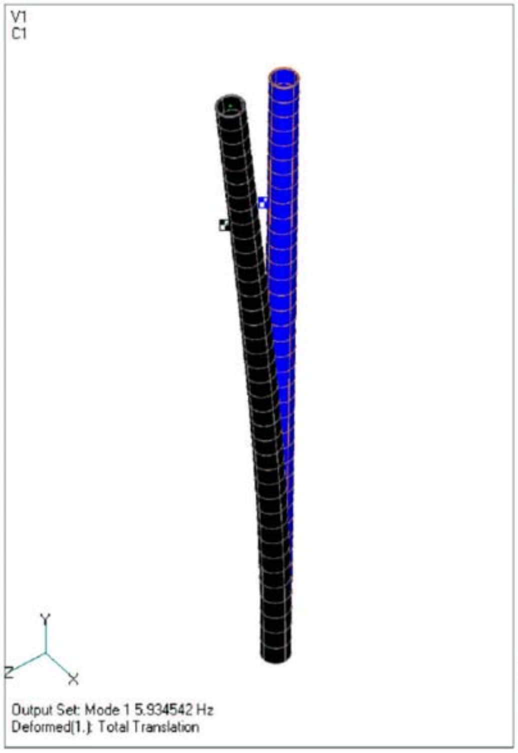
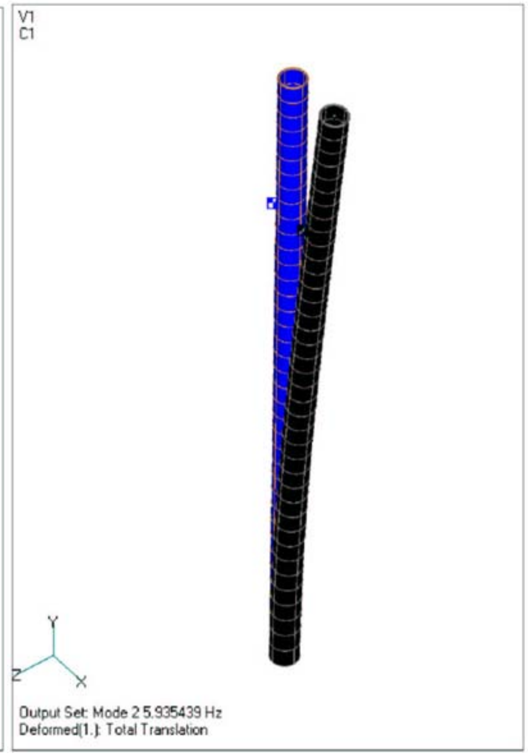


Figure 4.4 – ABAQUS model of VSLS TN_S9. The VSLS unit is modeled as a point mass of 64 lb.

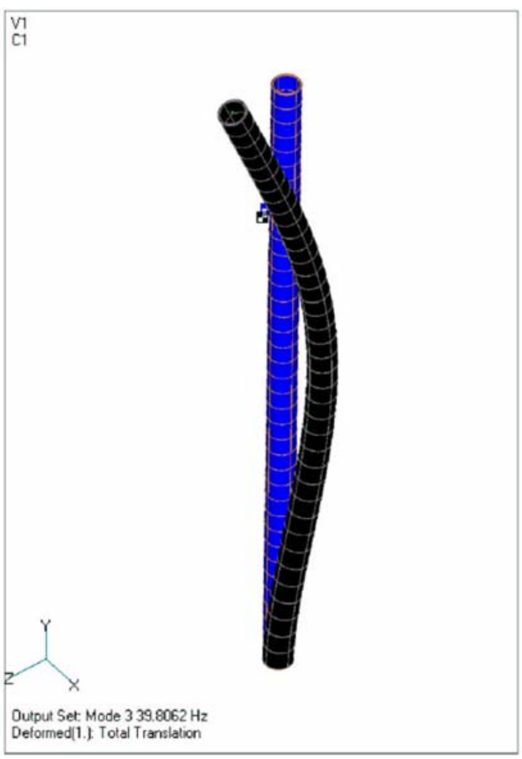
Again, for each analysis, the mode shapes and frequencies are first extracted by ABAQUS. Figures 4.5 (a) through (d) contain the mode shapes and frequencies of the four lowest modes as determined by analysis.



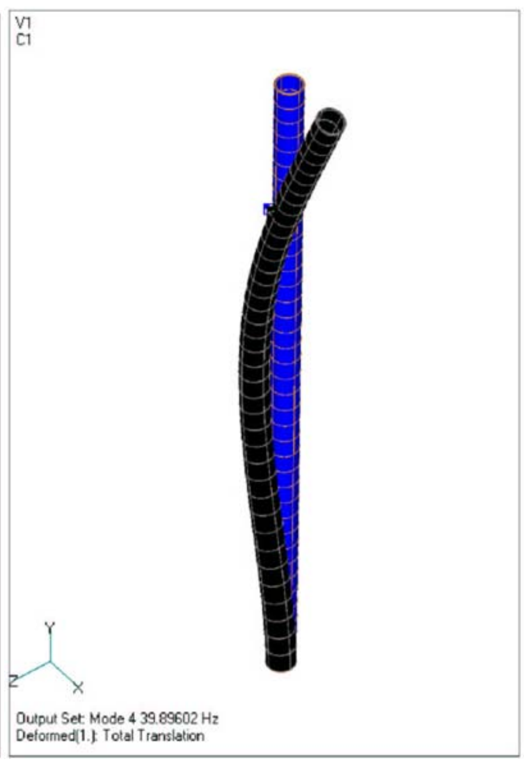
(a) f = 5.93 Hz



(b) f = 5.94 Hz



(c) f = 39.81 Hz



(d) f = 39.90 Hz

Figure 4.5 – Lowest four modes of vibration for VSLS TN_S9

Ten acceleration records were selected from the triggered time history data. Each record is 4.096 seconds long (1024 data points). Each record represents the passage of a heavy vehicle which caused the largest observed accelerations. Each of these ten records was processed by removing low frequency noise (i.e. drift). Then, a modal dynamic analysis was performed with each of the ten acceleration records which are used as base excitation. The displacement and accelerations for the entire time history are determined by ABAQUS using the transient modal analysis procedure. The peak accelerations and displacements at the center of gravity of the VSLS unit were determined for each analysis, and are summarized in Table 4.2. The table shows that the peak displacement at the VSLS unit is 0.019 inches in the longitudinal direction and the peak acceleration is 0.127 g in the longitudinal direction.

	Peak Disp. @ C.G. VSLS (in)			Peak Accel. @ C.G. VSLS (g)		
Record No.	**Trans**	**Vert**	**Long**	**Trans**	**Vert**	**Long**
1	0.010	0.000	0.009	0.065	0.013	0.087
2	0.009	0.001	0.014	0.061	0.013	0.087
3	0.015	0.001	0.015	0.086	0.021	0.116
4	0.012	0.001	0.014	0.073	0.014	0.091
5	0.011	0.001	0.009	0.065	0.018	0.110
6	0.012	0.001	0.013	0.068	0.013	0.099
7	0.010	0.001	0.017	0.062	0.012	0.127
8	0.014	0.000	0.009	0.067	0.013	0.088
9	0.011	0.001	0.019	0.056	0.028	0.091
10	0.014	0.001	0.012	0.064	0.017	0.083
Peak =	0.015	0.001	0.019	0.086	0.028	0.127
μ =	0.012	0.001	0.013	0.067	0.016	0.098
σ =	0.002	0.000	0.004	0.008	0.005	0.015
COV =	0.171	0.263	0.267	0.121	0.306	0.150

Table 4.2 – Summary of peak displacements and accelerations predicted by analysis for the ten time-history analyses (VSLS TN_S9)

An FFT was performed on the acceleration response at the center of gravity of the VSLS for each of the ten analyses. The average at each frequency bin was calculated. This average acceleration FFT is plotted in Figure 4.6. This figure indicates the pole primarily responds at the first modes of vibration, at a frequency of 5.9 Hz.

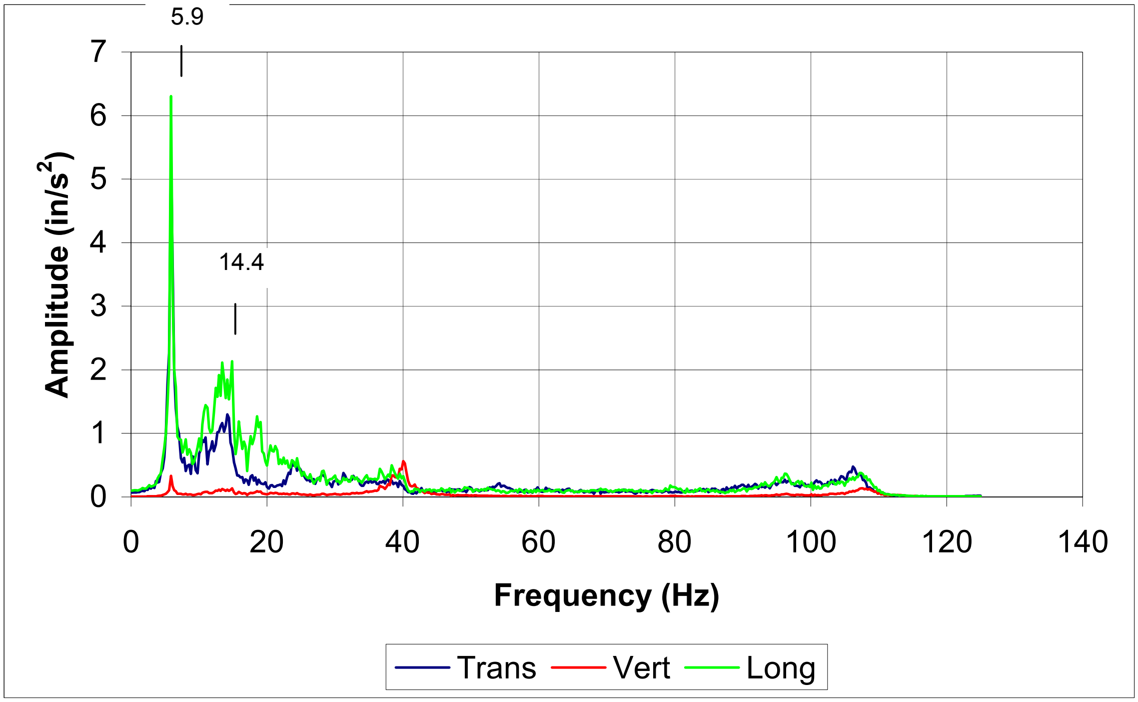


Figure 4.6 – Average FFT of acceleration at the center of gravity of the VSLS unit for all ten time history analyses (VSLS TN_S9)

4.3 VSLS TN_S10

As discussed previously, no data were available at the location of the proposed VSLS TN_S10. This VSLS is located on the Clearview Expressway approach spans between Piers 4 and 5. The structure consists of five built-up plate-girders, approximately 6 feet deep. The girders span approximately 135 feet. A drawing of VSLS TN_S10 is contained in the Appendix.

In the absence of acceleration time-histories, ABAQUS was used to perform modal analyses of both the VSLS assemblage, and two of the main bridge girders. These analyses provide the natural frequencies of vibration of the bridge and VSLS assemblage. Figure 4.7 contains the ABAQUS model of VSLS TN_S10. As depicted in the drawings and model rendering, the VSLS pole is supported by two 5 inch TS beams, which are in turn supported by two W21x62 beams which run into the first interior girder. They are made continuous through the exterior girder using top and bottom clip angles. A spring was used to model the flexibility of the pole base plate.

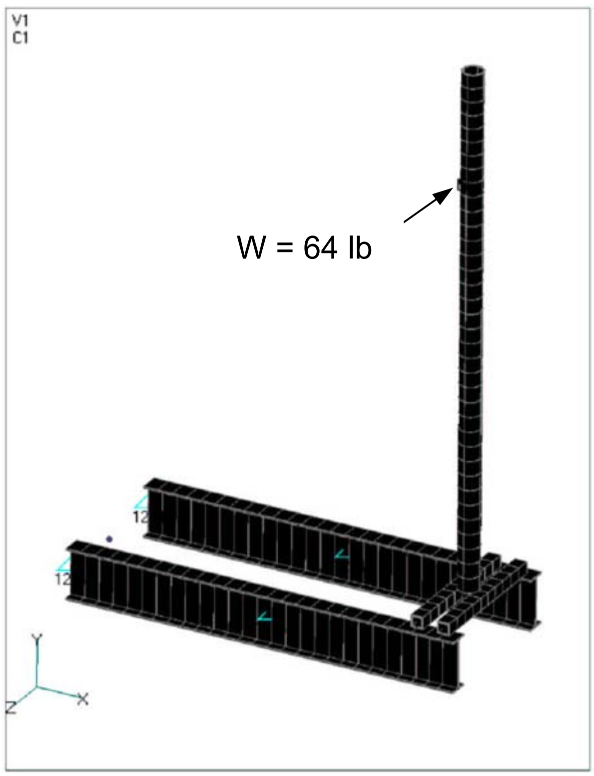
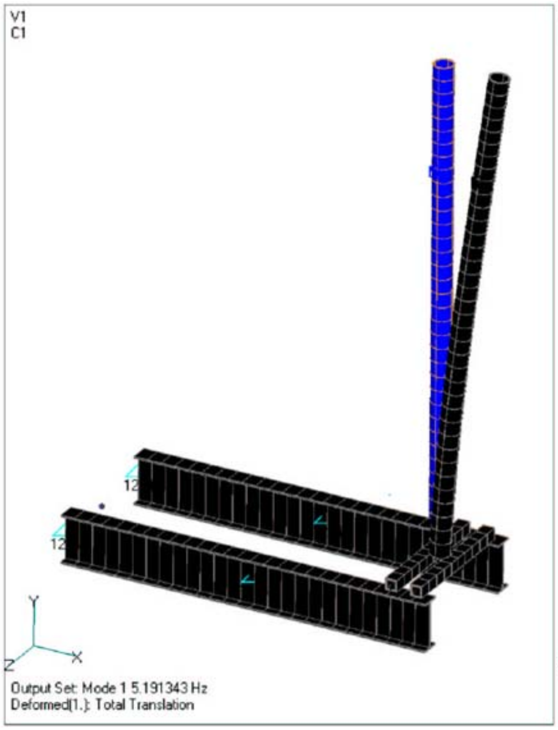
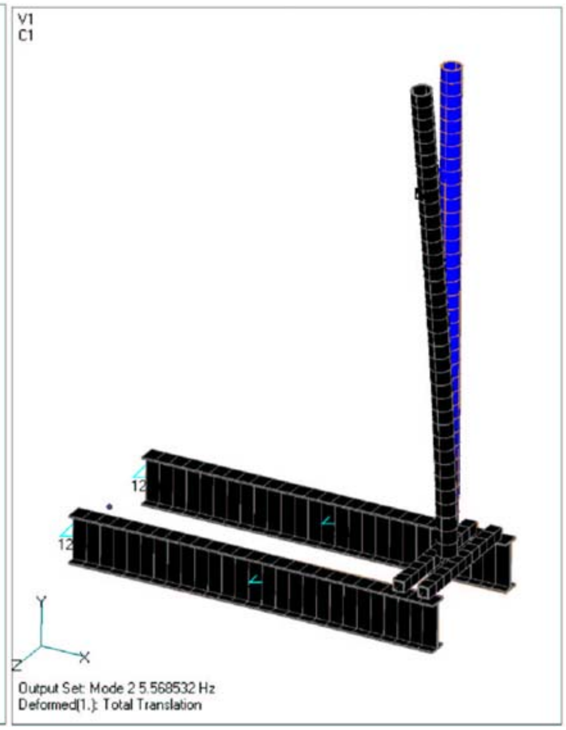


Figure 4.7 – ABAQUS model of VSLS TN_S10. The VSLS unit is modeled as a point mass of 64 lb.

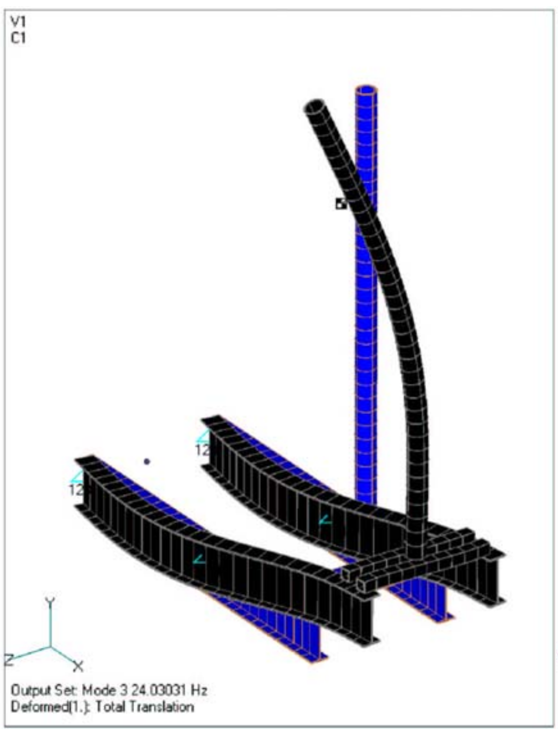
The mode shapes and frequencies of vibration for the four lowest modes are shown in Figures 4.8 (a) through 4.8 (d).



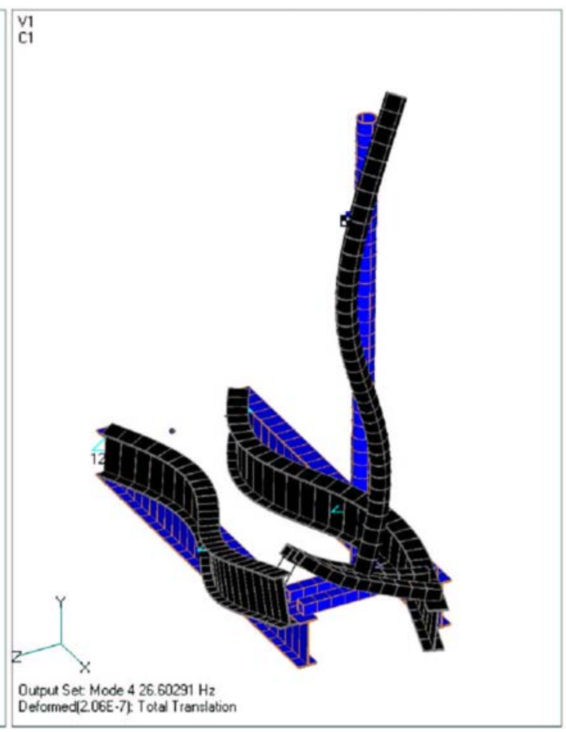
(a) f = 5.19 Hz



(b) f = 5.57 Hz



(c) f = 20.03 Hz



(d) f = 26.60 Hz

Figure 4.8 – Lowest four modes of vibration for VSLS TN_S9

Two girders (P12 and P19) of the approach span support the VSLS were analyzed using ABAQUS. These girders span between pier 4 and 5. They are built-up riveted plate girders. P19 is the exterior girder and P12 is the first interior girder. They were modeled as non-prismatic beams, i.e. the cross-section varied along the length based on the cover plate geometry. The slab was considered as being composite with the steel section. The vertical frequencies of vibration for the two girders are summarized in Table 4.3. As shown in the table, the natural frequencies for the two girders are very similar.

Mode No.	Frequency Girder P12 (Hz)	Frequency Girder P19 (Hz)
1	3.15	3.10
2	11.95	11.80
3	25.82	25.83
4	30.80	30.75
5	44.57	44.89
6	67.47	68.00
7	92.75	92.51
8	93.90	94.75
9	123.45	124.47
10	154.47	154.04

Table 4.3 – Summary of natural frequencies for vertical modes of vibration of the plate girders stringers, P12 (interior) and P19 (exterior)

5.0 Conclusions

The following conclusions can be drawn from the results presented above.

VSLS TN_N5

1. Expected displacements of VSLS TN_N5 are low, on the order of ±0.05 inches maximum. This is well within the manufacturer demonstration test parameters (0.39 inches at 5 Hz).
2. Expected accelerations of VSLS TN_N5 are significant, with a peak value of 1.14 g in the longitudinal direction. This is outside vibration test regime for the manufacturer demonstration test. However, there is significant scatter for the ten analyses. In fact, only one of the ten time-history records caused accelerations exceeding 0.5 g at the VSLS. The average peak longitudinal acceleration is 0.495 g, which is within the demonstration test parameters. Furthermore, the manufacturer demonstration test considers sustained vibration at high accelerations over 24 hours. The peak acceleration noted in the analysis was a single cycle for a very short duration.
3. The response of VSLS TN_N5 is primarily in the two lowest modes (10.1 Hz and 13.9 Hz). There is also significant longitudinal acceleration response at a frequency of approximately 90 Hz.

VSLS TN_S9

4. Expected displacements of VSLS TN_S9 are low, on the order of ±0.02 inches maximum. This is well within the manufacturer demonstration test parameters (0.39 inches at 5 Hz).
5. Expected accelerations of VSLS TN_S9 are low, with a peak value of 0.13 g in the longitudinal direction. This is well within vibration test regime for the manufacturer demonstration test (0.5 g).
6. VSLS TN_S9 responds primarily at the two lowest modes of vibration (transverse and longitudinal), at a frequency of 5.9 Hz.

VSLS TN_S10

7. The lowest transverse and longitudinal modes of vibration of VSLS TN_S10 are 5.19 and 5.57 Hz, respectively.
8. The lowest modes of vertical vibration of the girders P12 and P19 are approximately 3.1 Hz. This is based on finite element analysis, and not on field measured response.
9. It appears that the primary frequency of vibration of VSLS TN_S10 is sufficiently separated from that of the support girders. Therefore, resonance is not expected.
10. Since this installation is located near the pier, the vertical excitation at the base of the pole is expected to be small (compared to a sign located at the midspan of the girder). The magnitude of the longitudinal vibration of the base of the VSLS pole is expected to be larger due to girder end rotation.
11. However without knowing the magnitude of vibration of the bridge that location, it is impossible to predict the amplitude of vibration on the pole.

6.0 Recommendations

In general, the existing details of the proposed VSLS installations on the Throgs Neck bridge appear to be adequate from a vibration standpoint. This is based on the response of the signs predicted through analysis in conjunction with field measurements. Peak accelerations and displacements fall generally within the manufacturer's demonstration test parameters. Assuming the details are similar at other TBTA facilities, favorable performance may be expected elsewhere.

However, it is recommended that all VSLS installations be regularly inspected for local dynamic behavior to confirm these findings. This can be accomplished through the institution of periodic inspections, which can be incorporated into the TBTA maintenance program.

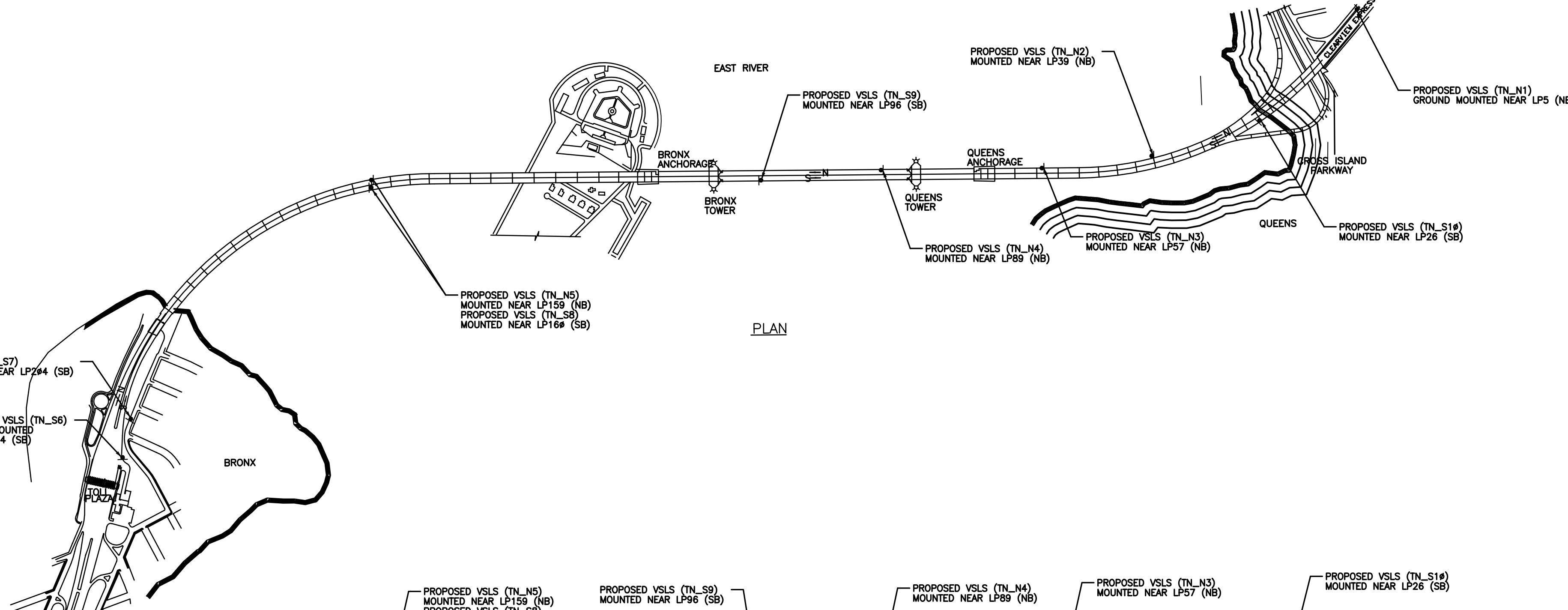
APPENDIX

Design Drawings for:

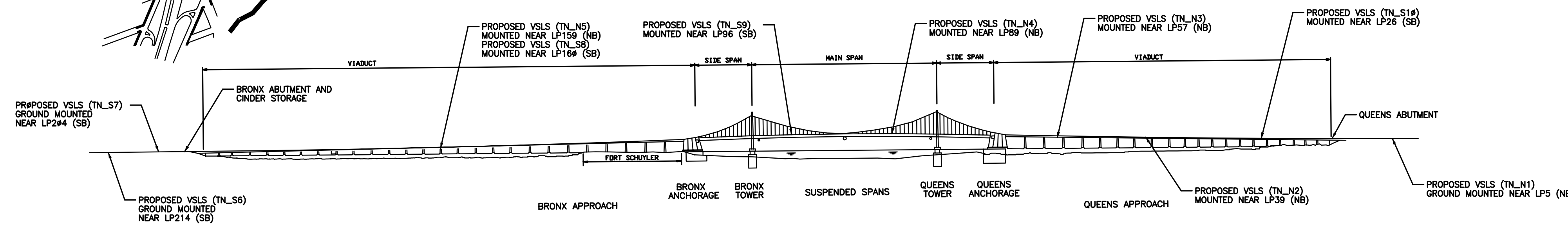
VSLS TN_N5
VSLS TN_S9
VSLS TN_S10

Supporting Plate Girder Stringers P12 & P19 at VSLS TN_S10

***Note:* Drawings are provided for information only. They are not meant for construction.**



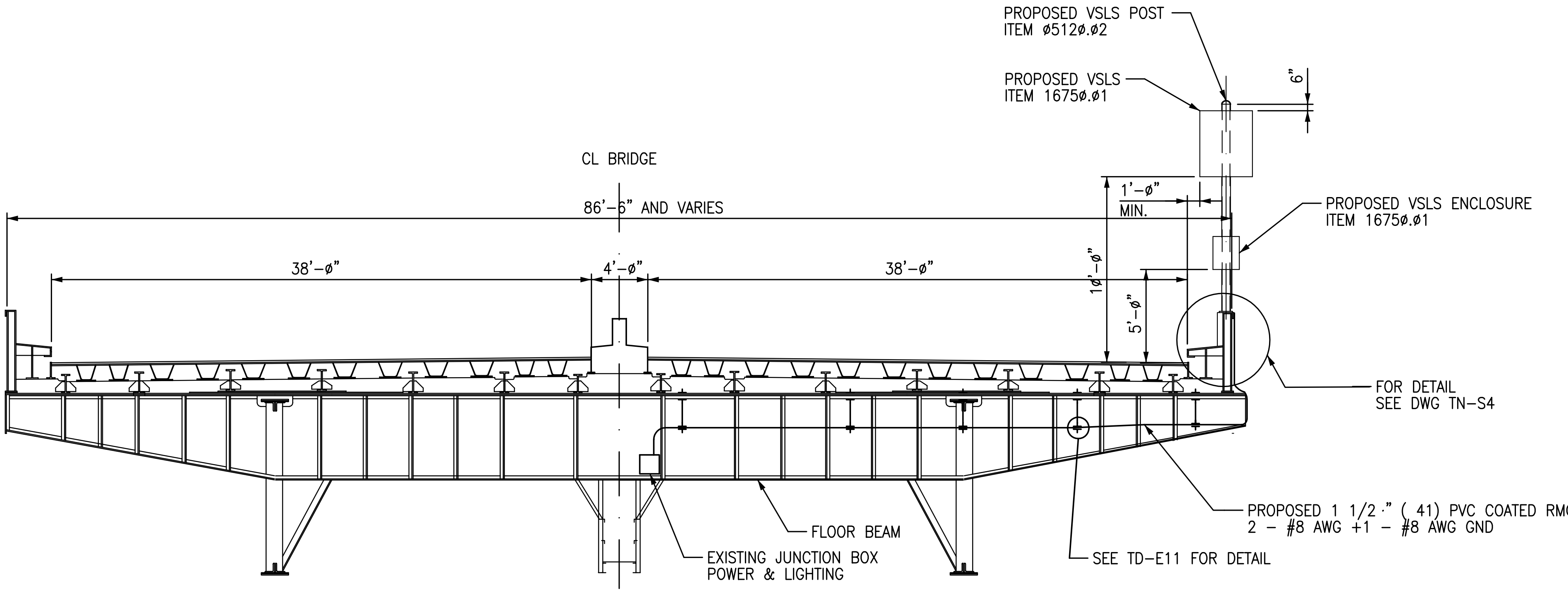
PLAN



ELEVATION

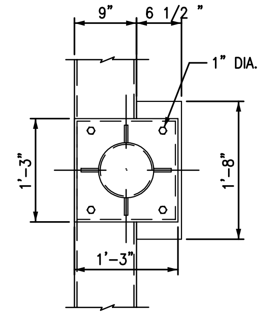
NOTES:

1. GROUND MOUNTED POST DETAILS SEE DWG TD-E5.
2. FOR LOCATIONS OF VSLS SEE ATTACHED ELECTRICAL DWGS FOR THIS BRIDGE.

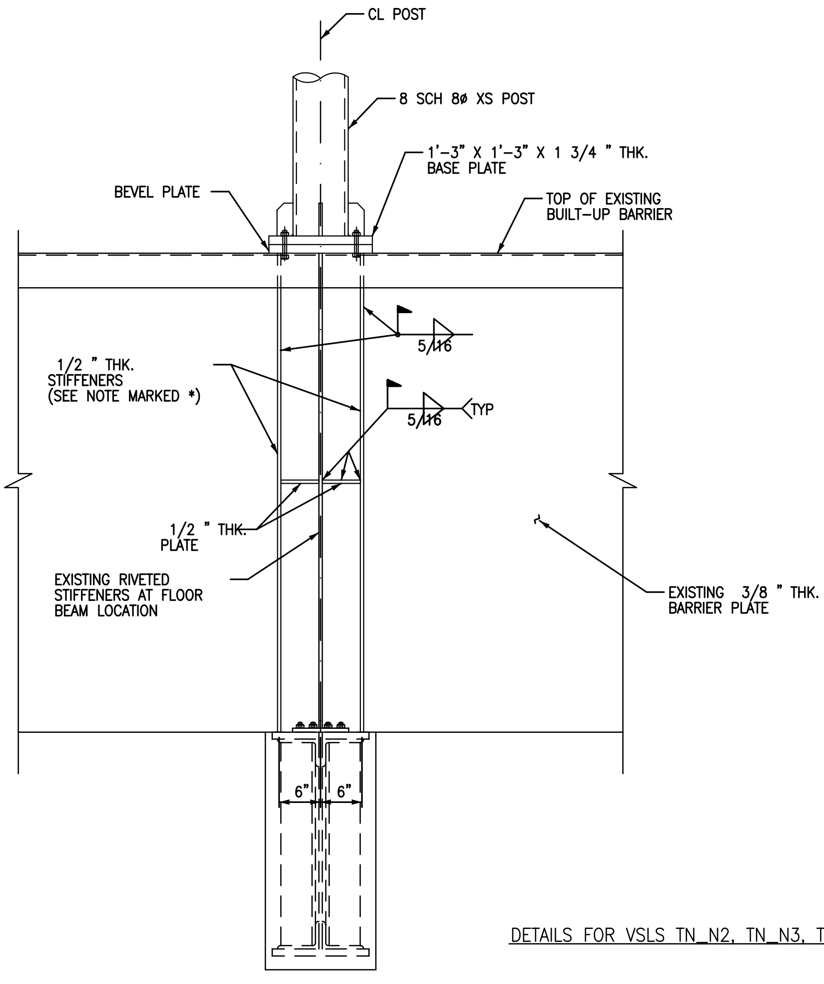


APPROACH SPAN CROSS SECTION

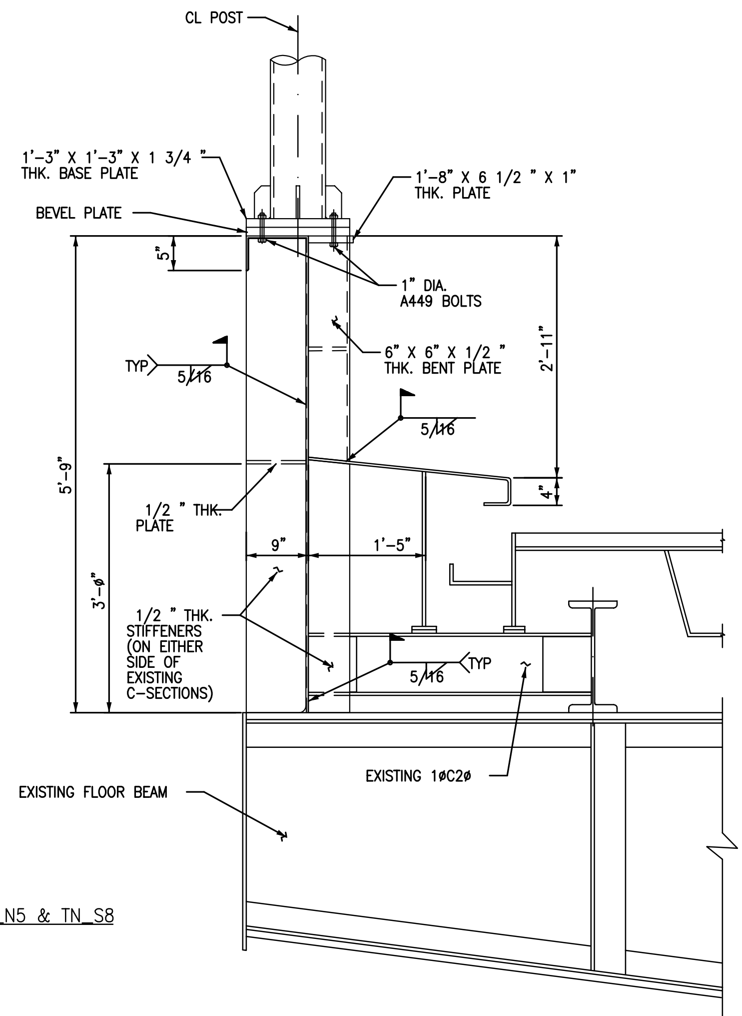
PROPOSED VSLS TN_N2, TN_N3, TN_N5, AND TN_S8



PLAN

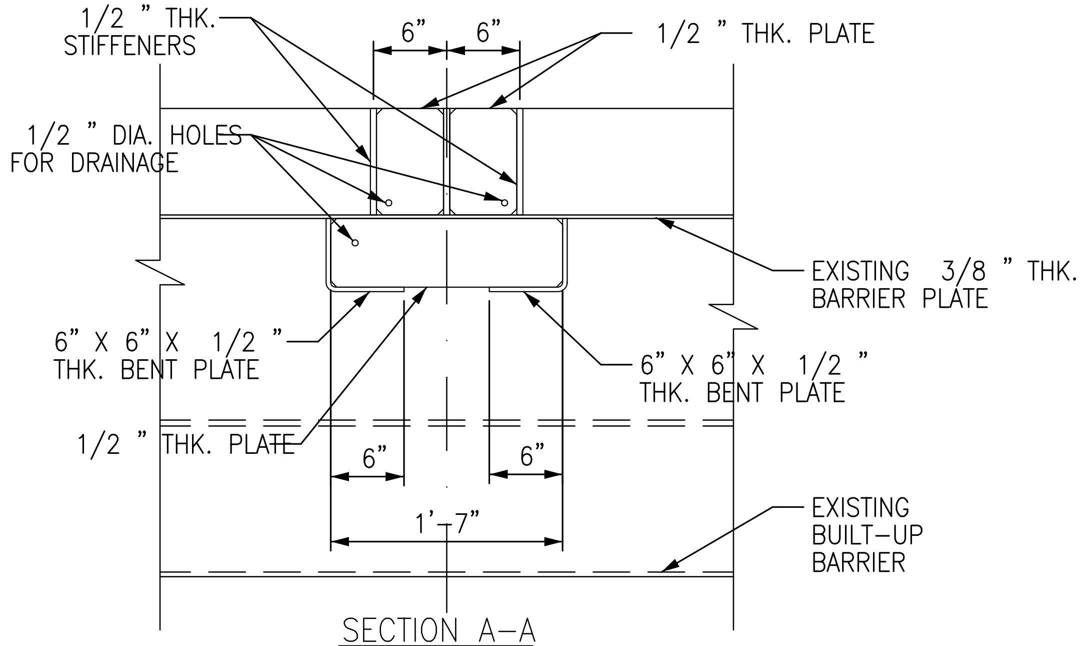


BACK VIEW

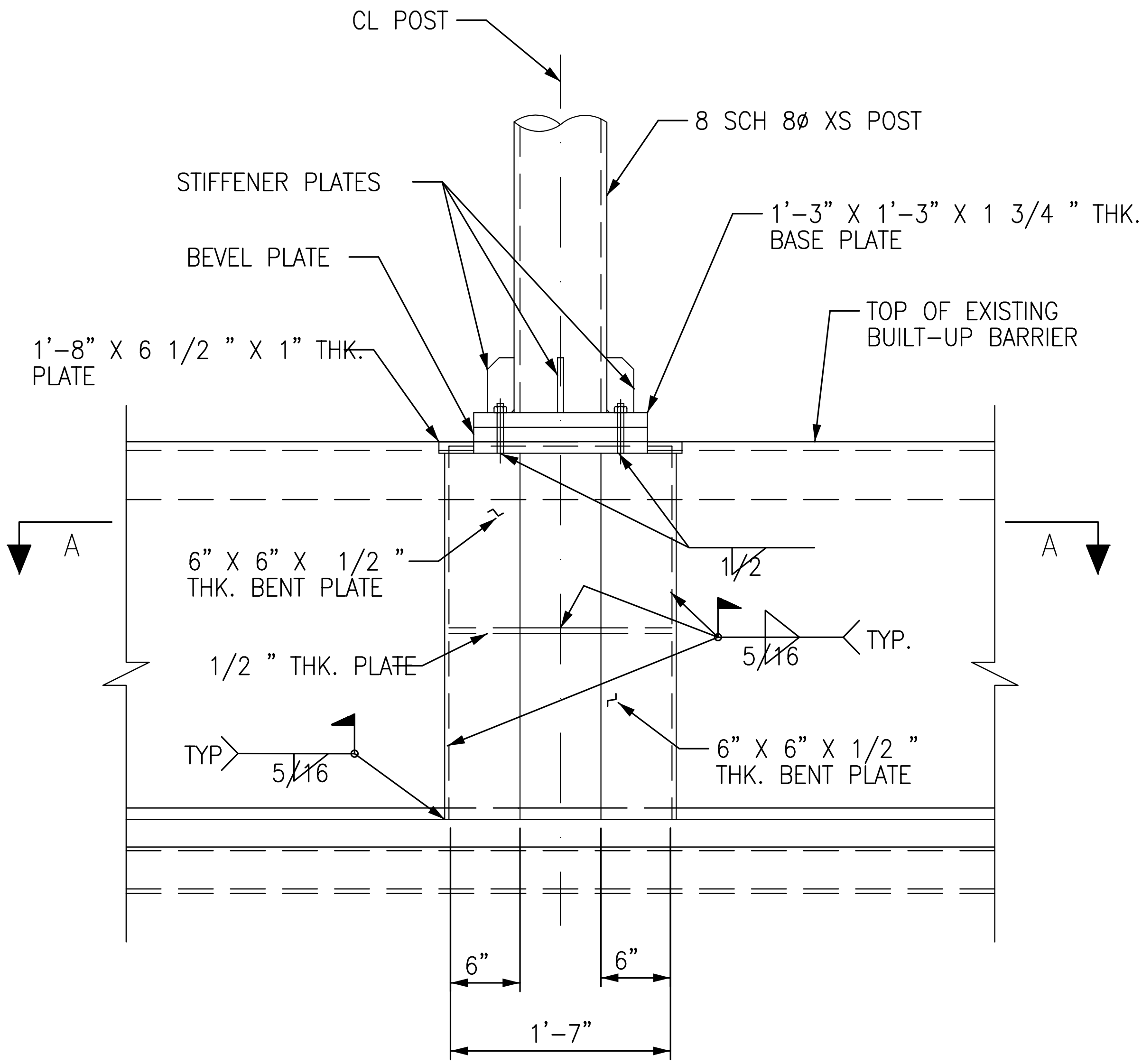


DETAILS FOR VSLS TN_N2, TN_N3, TN_N5 & TN_S8

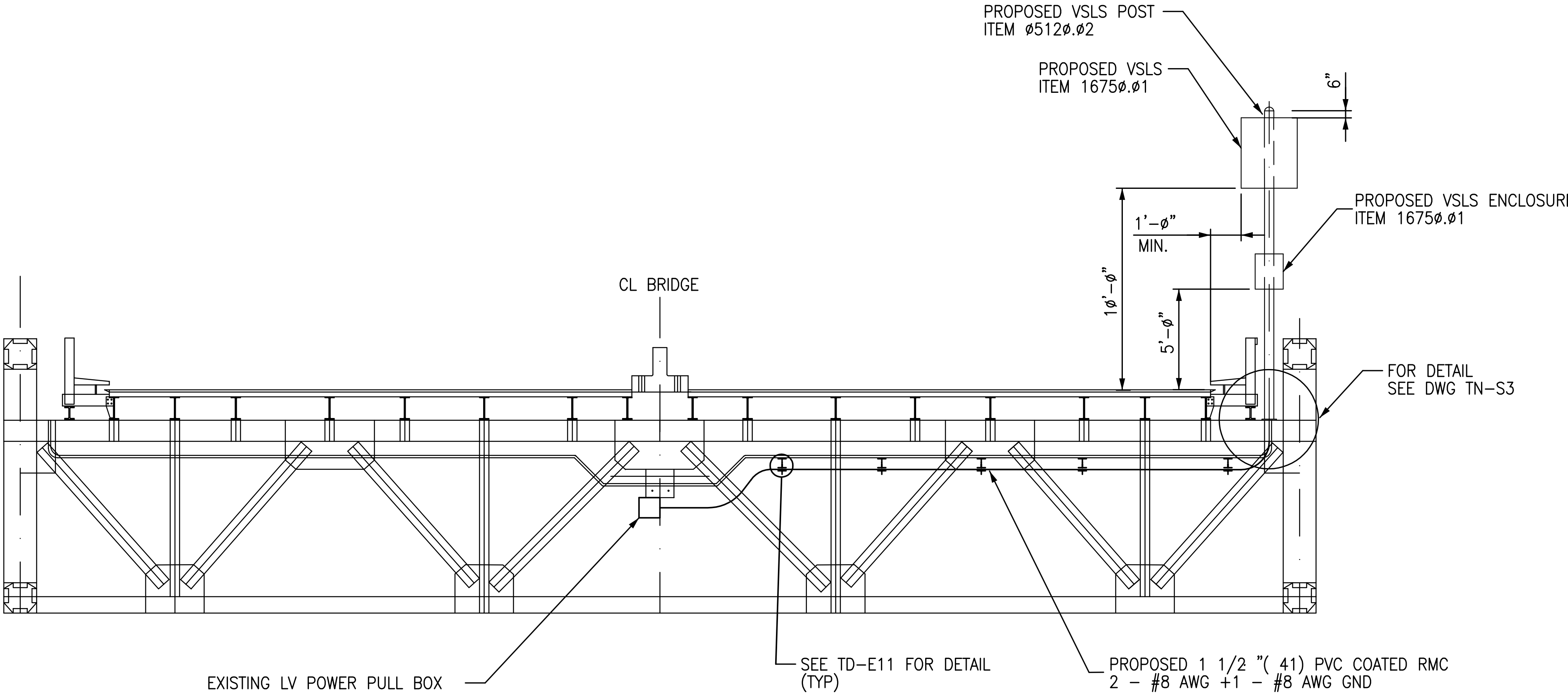
SECTIONAL ELEVATION



SECTION A-A

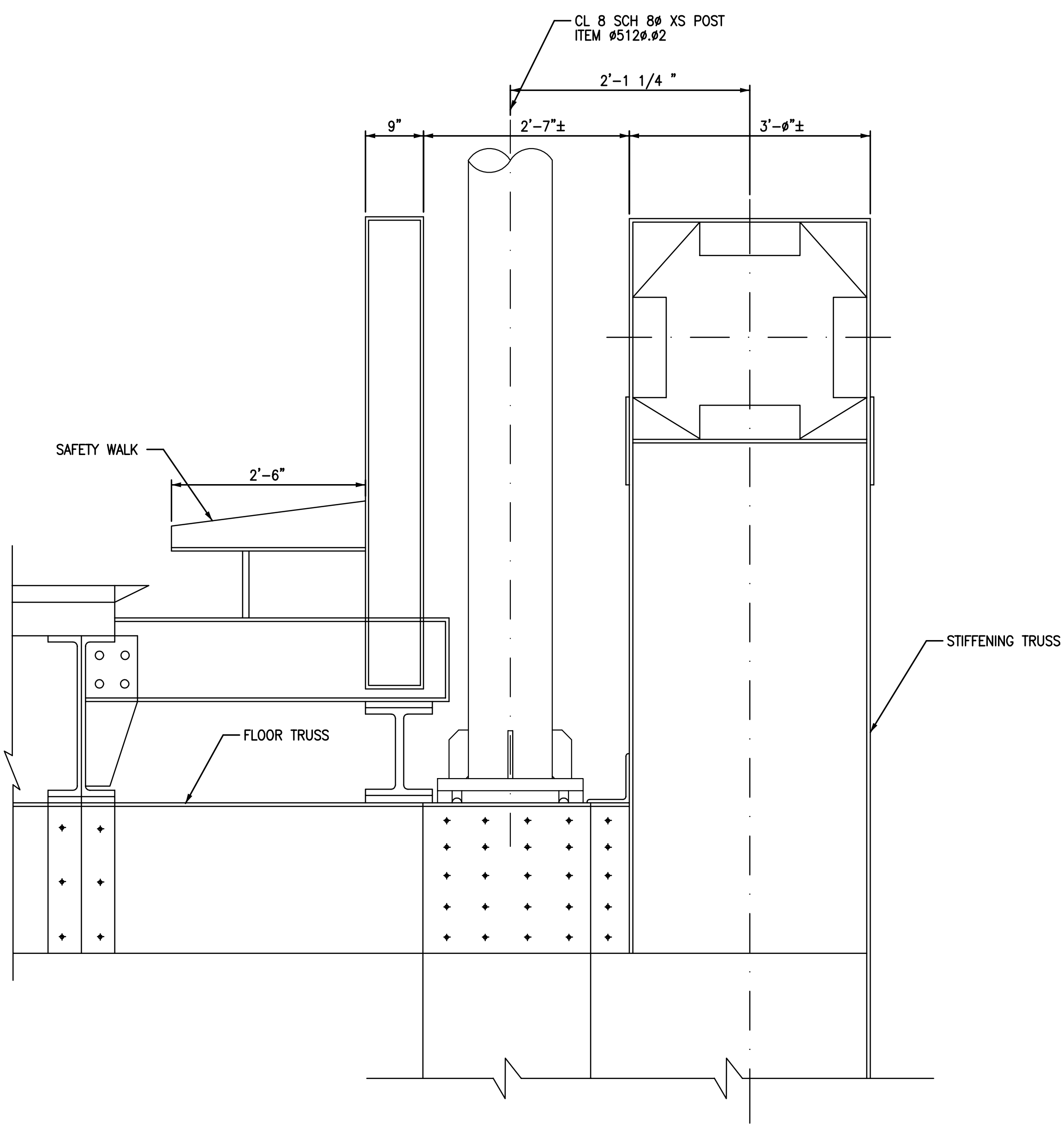


FRONT VIEW



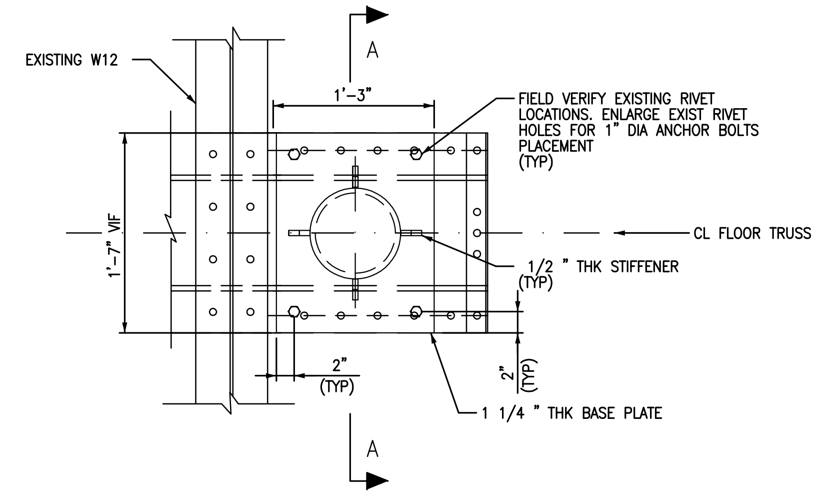
SUSPENDED SPAN CROSS SECTION

PROPOSED VSLS TN_N4 AND TN_S9



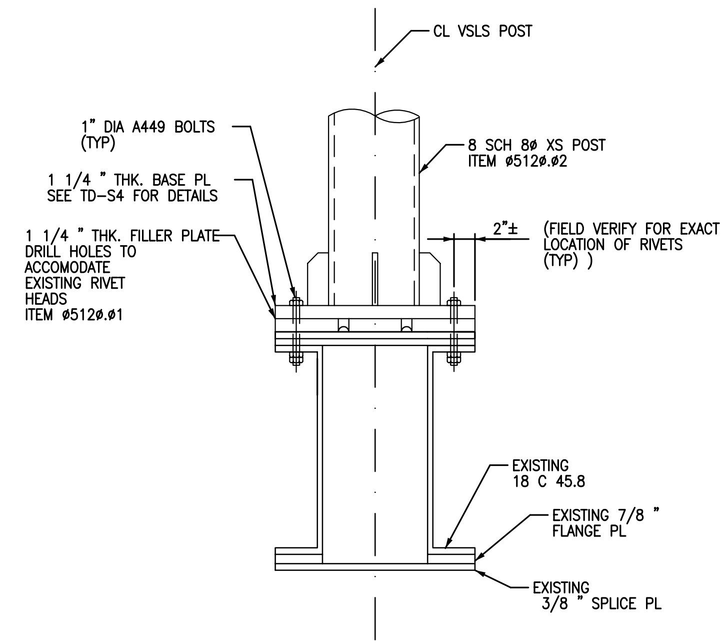
PROPOSED VSLS TN_N4 AND TN_S9

PARTIAL ELEVATION

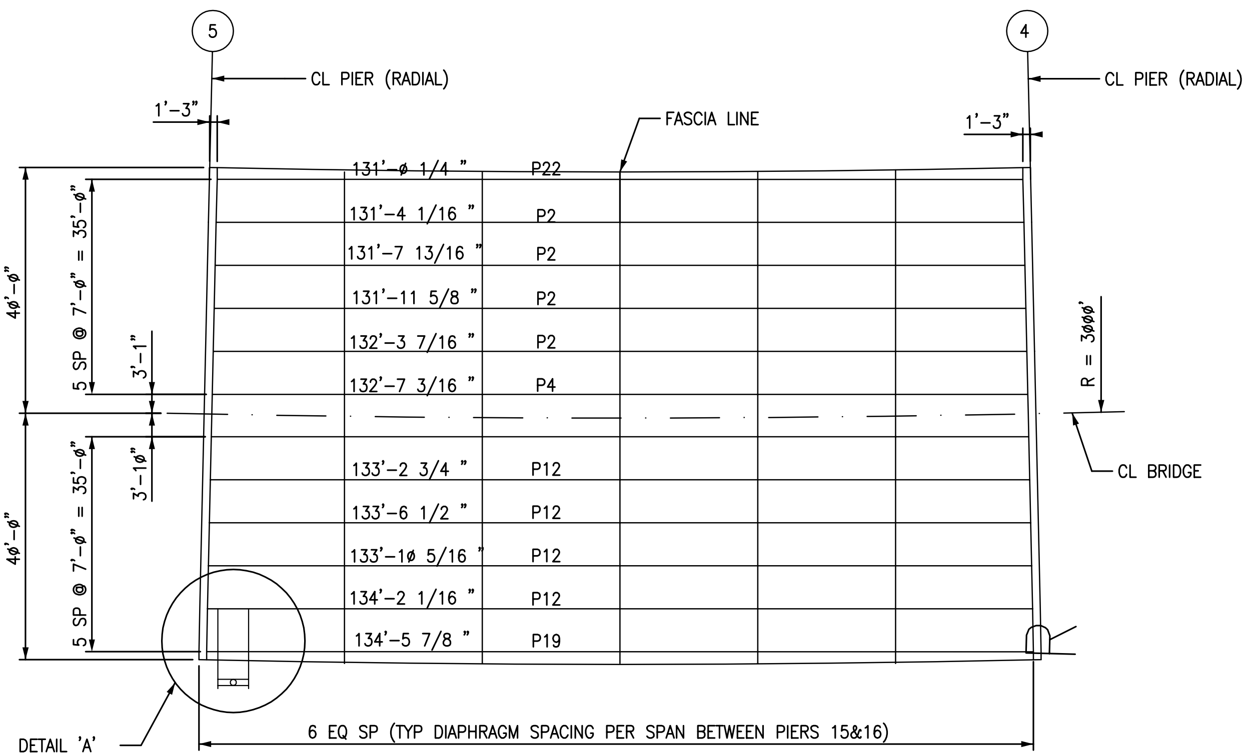


PLAN

POST BASE PLATE

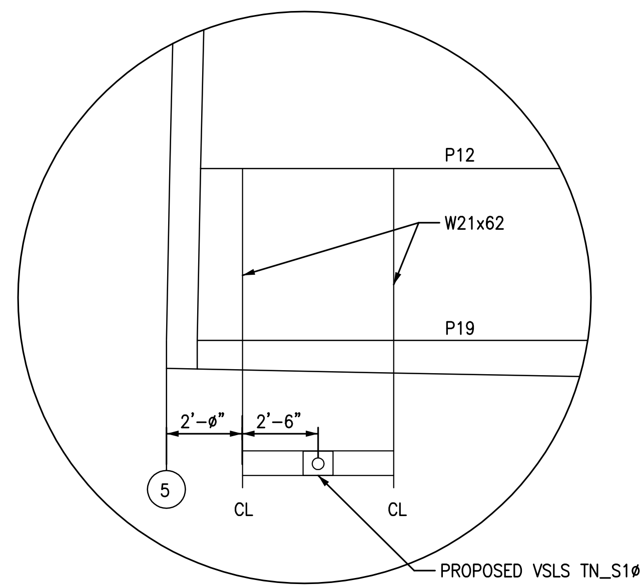


SECTION A-A



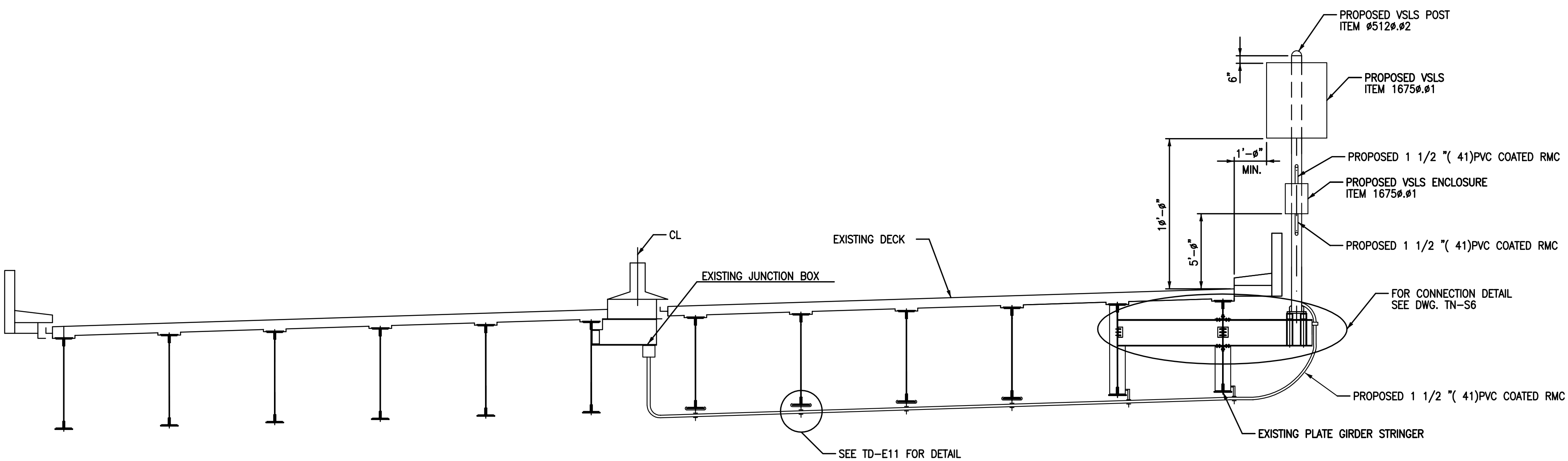
QUEENS APPROACH
FRAMING PLAN – PIER 5 TO 4
PROPOSED VSLS TN_S1ø

SCALE: 1/16 " = 1'-ø"



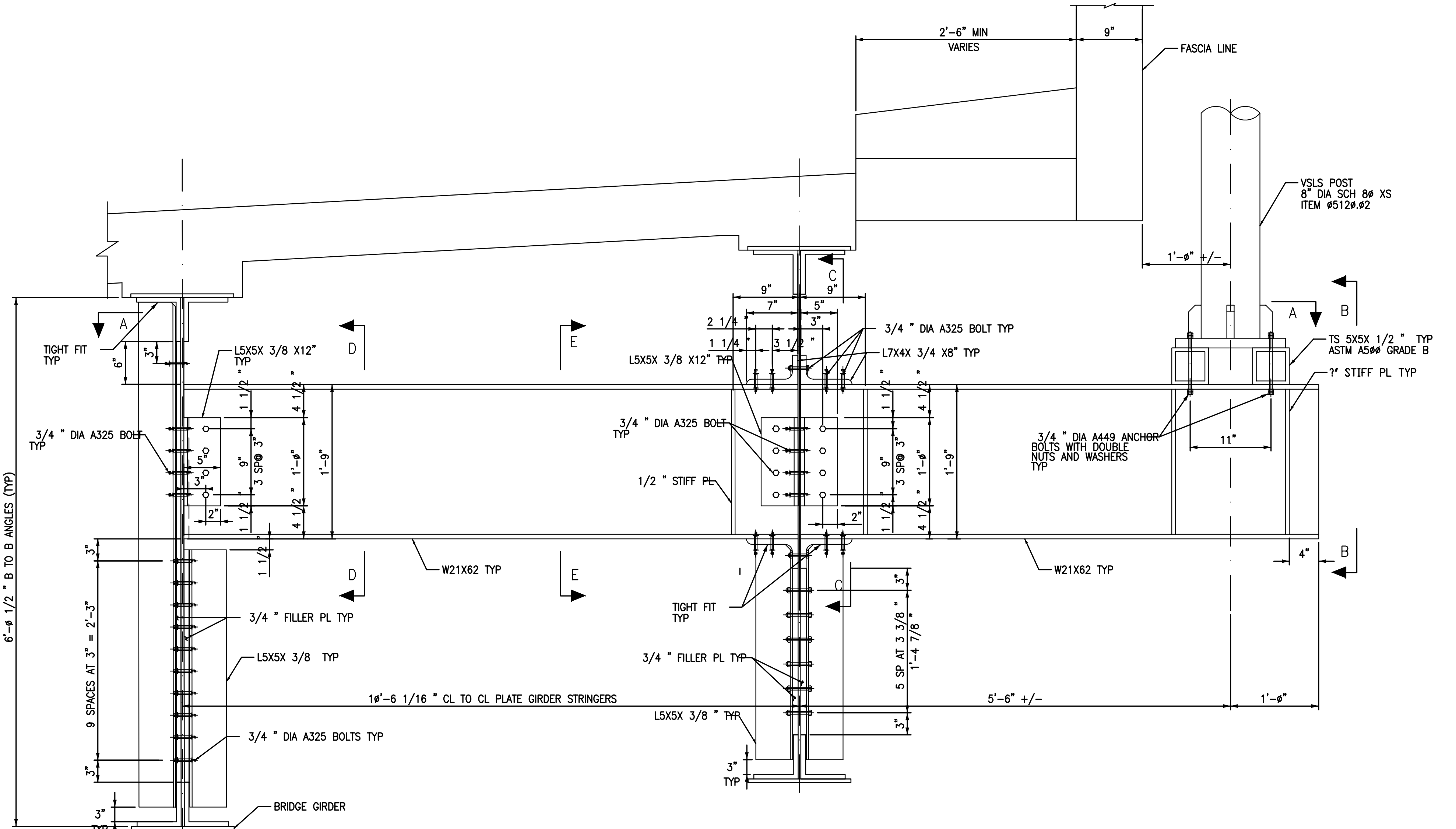
DETAIL 'A'

NTS

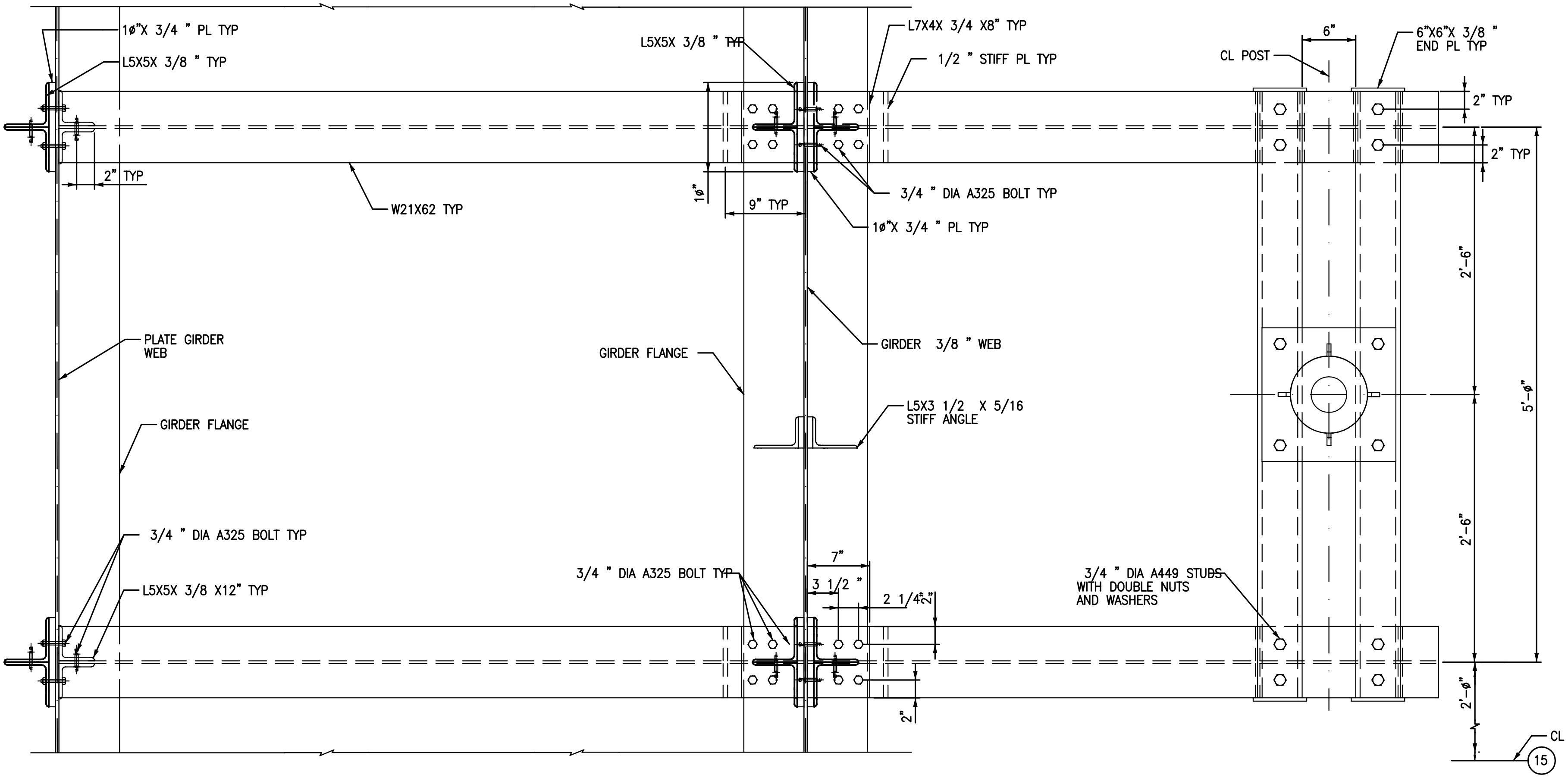


QUEENS APPROACH CROSS SECTION BETWEEN BEARINGS
PLATE GIRDER STRINGER SPAN
PROPOSED VSLS TN_S1Ø

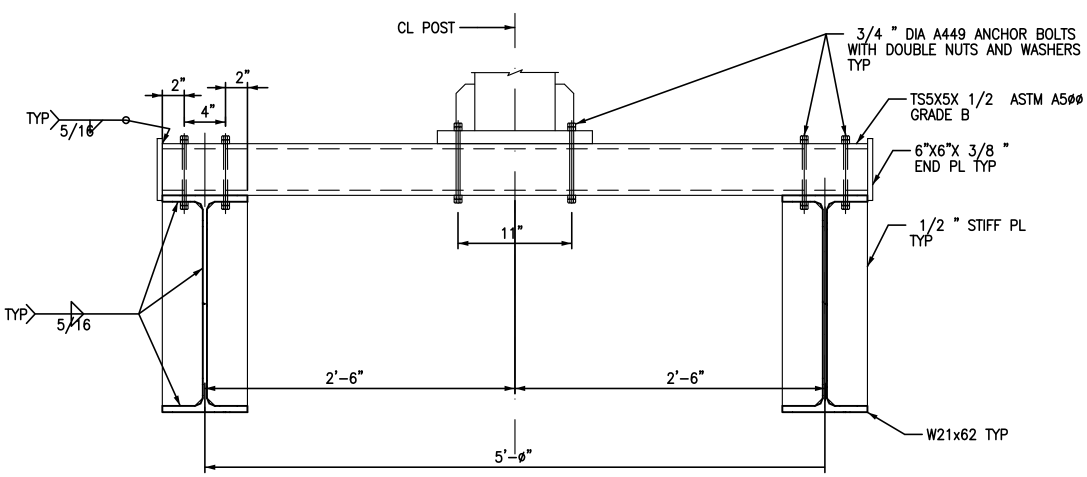
SCALE: 1/4 " = 1'-Ø"



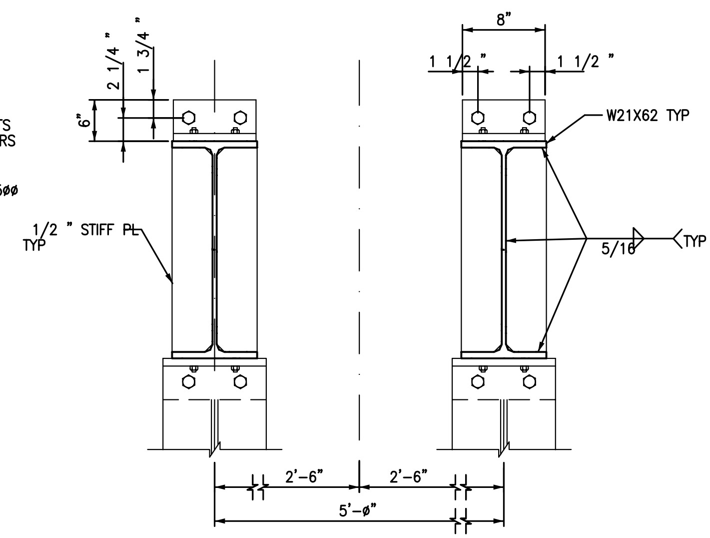
PARTIAL ELEVATION
PROPOSED VSLS TN_S10



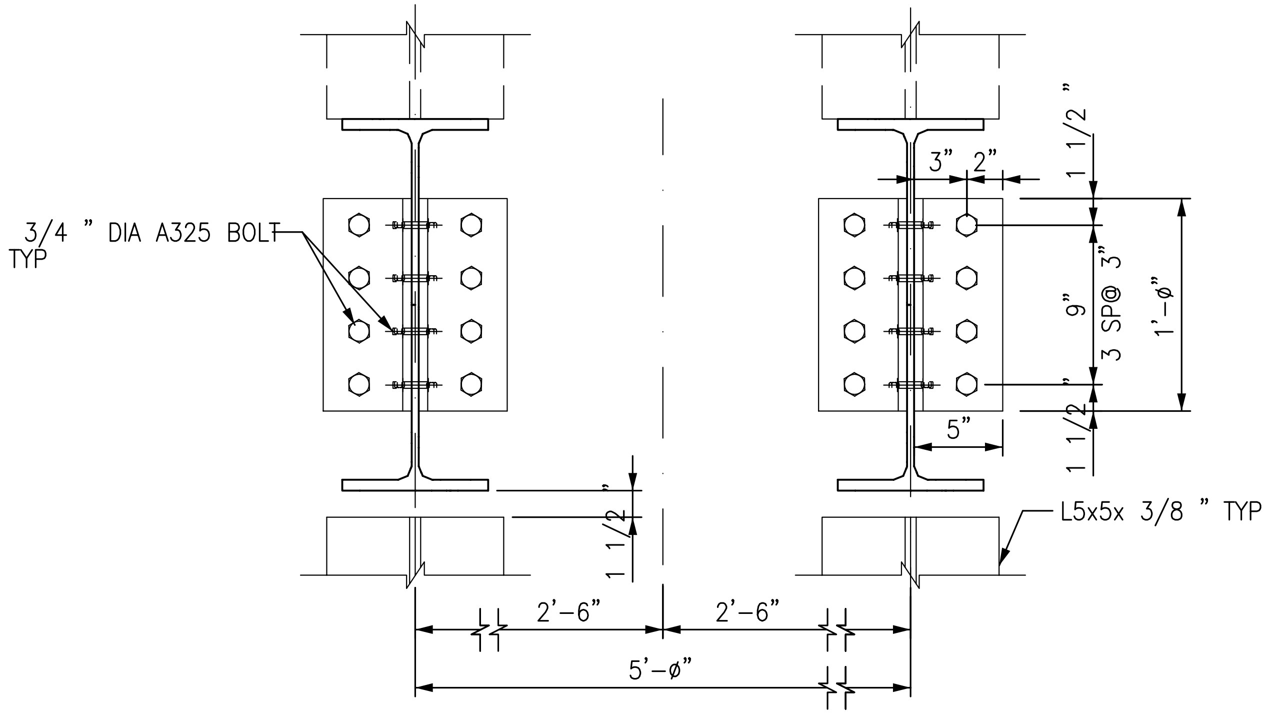
SECTION A-A
PROPOSED VSLS TN_S1Ø



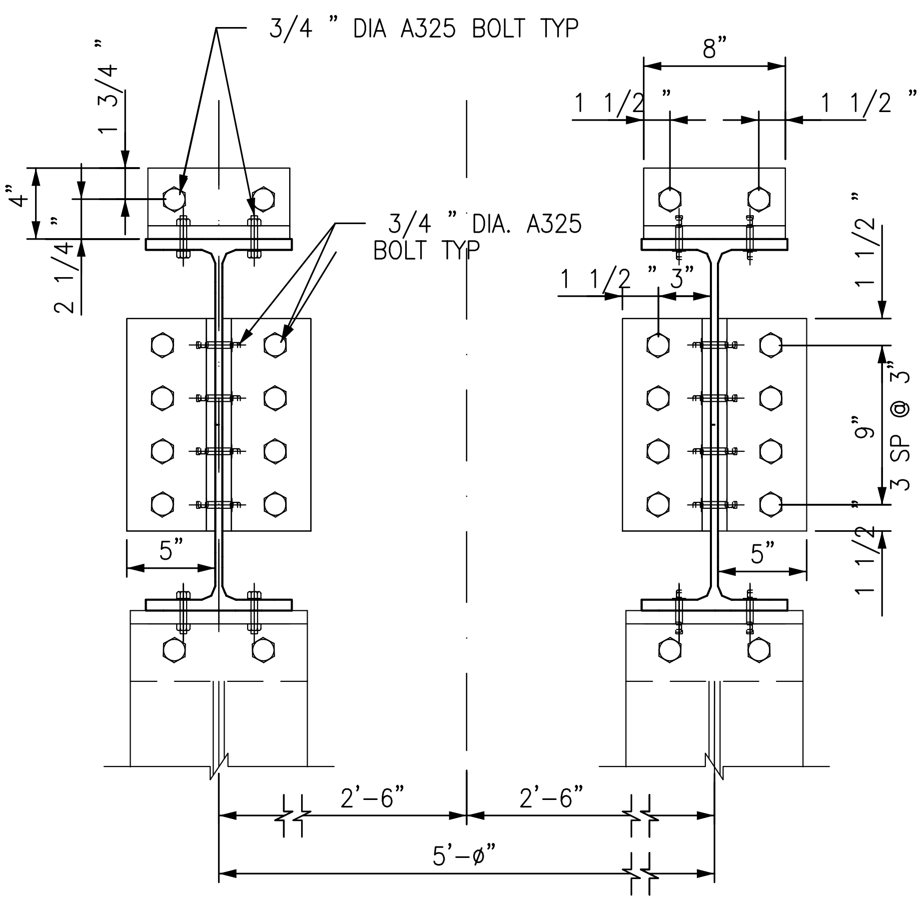
SECTION B-B



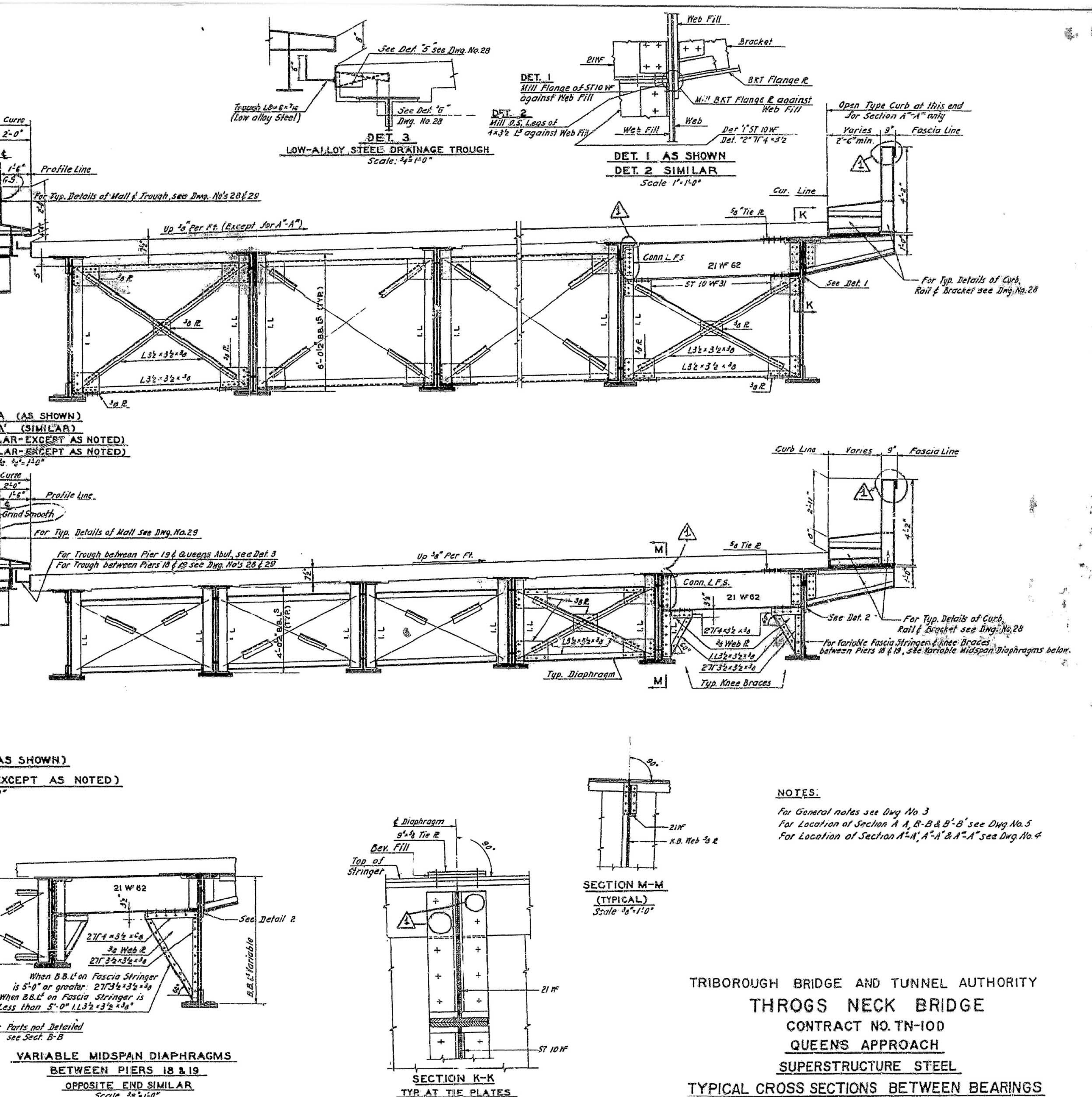
SECTION E-E



SECTION D-D



SECTION C-C



NOTES:

For General notes see Dwg No 3
For Location of Section A-A, B-B & B'-B' see Dwg No.5
For Location of Section A'-A', A"-A" & A'"-A'" see Dwg No.4

As Built	C.H.S.	H.A.B.	3-9-61
1	E.W.	P.H.	3-31-59
Minor Revision	H.A	J.B.	6-18-58
REVISION	BY	CKD	DATE

TRIBOROUGH BRIDGE AND TUNNEL AUTHORITY

THROGS NECK BRIDGE

CONTRACT NO. TN-10D

QUEENS APPROACH

SUPERSTRUCTURE STEEL

TYPICAL CROSS SECTIONS BETWEEN BEARINGS

PLATE GIRDER STRINGER SPANS

SCALE AS NOTED

E.L. PAVLO
CONSULTING ENGINEER

DATE 5-15-58
DRAWING NO.21