FAIRFIELD TO NEW HAVEN RAILROAD CORRIDOR TRANSMISSION LINE ASSET CONDITION ASSESSMENT

B&V PROJECT NO. 197505

PREPARED FOR

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I. EXECUTIVE SUMMARY

This report details the comprehensive asset condition assessment performed on the United Illuminating (UI) 115 kV Fairfield to New Haven transmission line corridor. The existing 115 kV transmission line assets are owned by UI and are constructed atop an underlying system of Metro North Railroad (MNR) railroad (RR) catenary structures connected by use of UI owned bonnet structures. In addition to the UI infrastructure, these catenary structures must also support MNR signal and feeder wires, communication lines, trolley wires, etc.

The objective of this asset condition assessment was to analyze the structural integrity of the existing catenary/bonnet structures *(including UI mechanical loading)*; and based on their results determine a preferred solution for supporting UI's 115 kV transmission infrastructure. A comprehensive field inspection and an accompanying structural analysis was performed against multiple boundary scenarios and it was determined that a complete rebuild of the Fairfield to New Haven 115 kV transmission line corridor is required to mitigate an overall failure of these structures.

I.1 FIELD INSPECTION RESULTS

A detailed field inspection was performed along the Fairfield to New Haven 115 kV corridor. Findings included general catenary structure steel corrosion, severe expansive corrosion/section loss, missing catenary arch members, location of wire loads, additional wire loads, etc.

I.2 STRUCTURAL RESULTS

Structural analysis was performed against both As-Designed and Field Condition scenarios. Each of the studied scenarios resulted in numerous member failures *(stress exceedances over design strength)*, and as such, it was concluded that each of the structural models exhibited overall structural failures (i.e. 100% failure rate).

I.3 SOLUTION ALTERNATIVES

Four (4) solution alternatives were evaluated along the Fairfield to New Haven 115 kV corridor (section-by-section basis):

a) Solution Alternatives 1 & 2 considered the addition of monopole structures, double circuit (Alternative 1) and single circuit (Alternative 2) alternatives and;

b) Solution Alternatives 3 & 4 considered a partial catenary upgrade with single circuit monopole additions (Alternative 3) and a complete rebuild of the existing catenary structures (Alternative 4).

I.4 CONCLUSION

Alternative 1 *(double circuit tower monopole)* was chosen as the preferred alternative and was estimated at ***$376,312,416 (+50/-25%)***. Alternative 1 was chosen as the lowest cost alternative among all four that were studied. The expected in-service-date is 2028 and the project is anticipated to have an overall length of 8 years and 5 months years (December 2019 – April 2028). This duration accounts for engineering through construction in consideration of all line segments within the Fairfield – New Haven 115 kV corridor.

1.0 INTRODUCTION

1.1 OBJECTIVE

The United Illuminating Company (UI) owns 115 kV transmission lines, along the New Haven – Fairfield corridor, which are supported by an underlying system of Metro North Railroad (MNR) railroad (RR) catenary structures. In addition to the UI infrastructure, these catenary structures must also support MNR signal and feeder wires, communication lines, trolley wires, etc. The objective of this assessment was to perform a comprehensive field inspection and associated structural evaluation by using elastic analysis on the existing RR catenary support structures and to propose solutions to mitigate those identified asset condition related deficiencies.

a) **Evaluate Asset Condition Deficiencies:** Perform structural analyses of the existing catenary/bonnet structures in conformance with defined loading criteria and evaluate their structural ability to continue supporting the UI 115 kV transmission lines, and

b) **Develop Solutions:** Investigate and propose alternative solutions to support the UI wires based on a comparative cost and schedule analyses between new structure construction and upgrade of existing catenary structures.

The following line segments[1] were evaluated as a part of this assessment:

- **New Haven – Milford**: West River to Milvon Substations (19 circuit miles)
- **Fairfield – Bridgeport**: ES/UI transition Structure B648 in Fairfield, CT to Congress Substation (10.8 circuit miles)

These line segments are located in Connecticut near the towns of Milford, West Haven, New Haven, Fairfield, and Bridgeport. UI is concerned about the structural integrity of the support structures due to the age deterioration of the structures in combination with the present loads imposed on the structures, which in all likelihood have increased over time from the original loads due to the installation of additional utility lines. In addition, recent reliability driven projects, along the 115 kV RR corridor *(i.e. Milvon – Baird)*, have shown to result in significant structural failures when analyzing re-conductoring options on any one side of the catenary structures. Those same studies have previously found significant foundation failures when considering solution options to re-conductor on both sides of the structures. The structural failure on any of the support structures may result in a catastrophic failure of both 115 kV circuits and/or a loss of power to one or more of the Substations along the RR corridor.

[1] 115 kV Infrastructure upgrades between the Congress and Milvon stations were identified in the 2014 SWCT Solutions Assessment and therefore excluded from this assessment.

1.2 BACKGROUND

1.2.1 HISTORY & GEOGRAPHIC LOCATION

The RR catenary structures were originally built in the early 1910's and are located between Fairfield, CT and New Haven, CT. Reference Figures 1.1, 1.2 and 1.3 for plan views of the analyzed line segments.

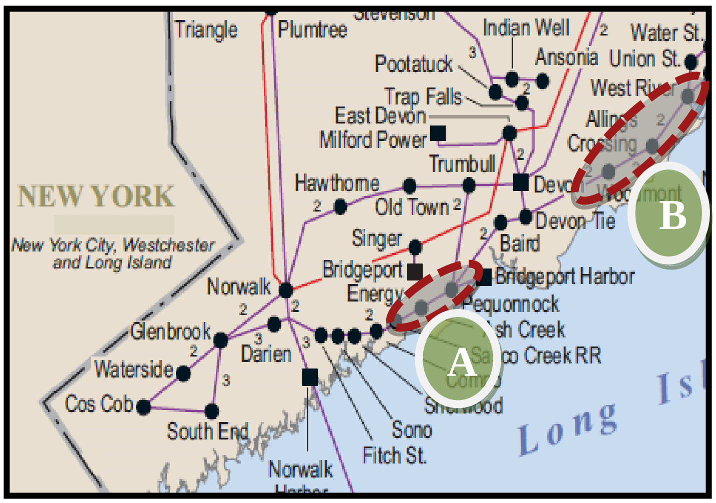


Figure 1.1: Overall Plan View Of Fairfield To Congress And Milvon To West River Transmission Lines

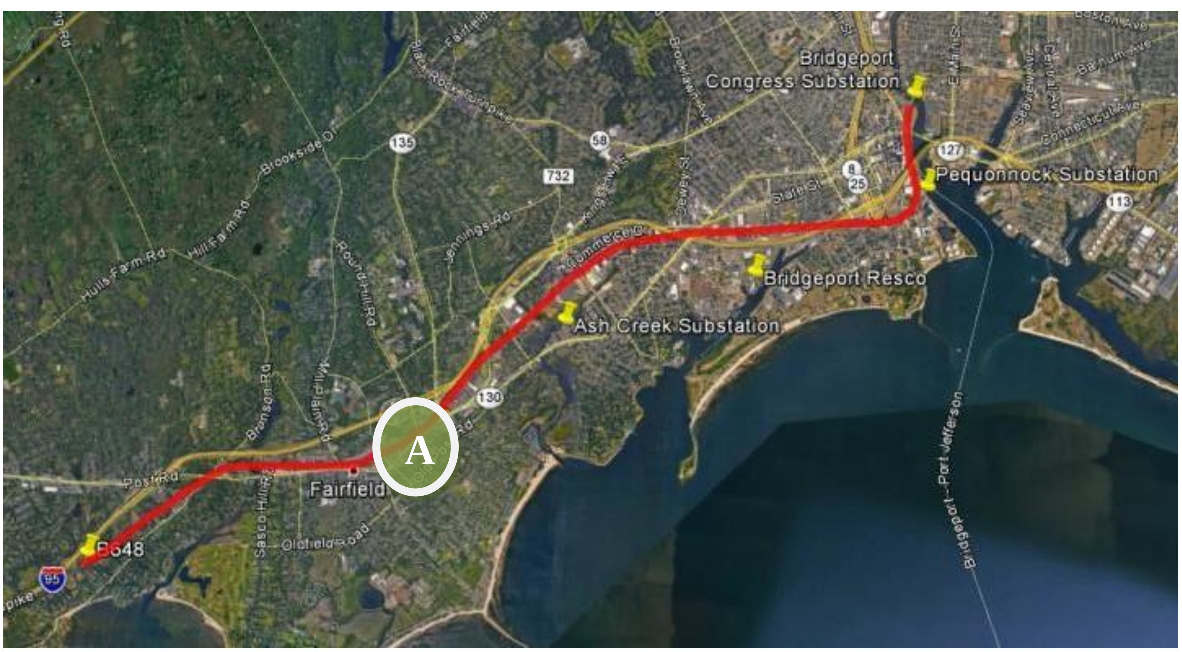


Figure 1.2: Plan View Of Fairfield To Congress Transmission Lines

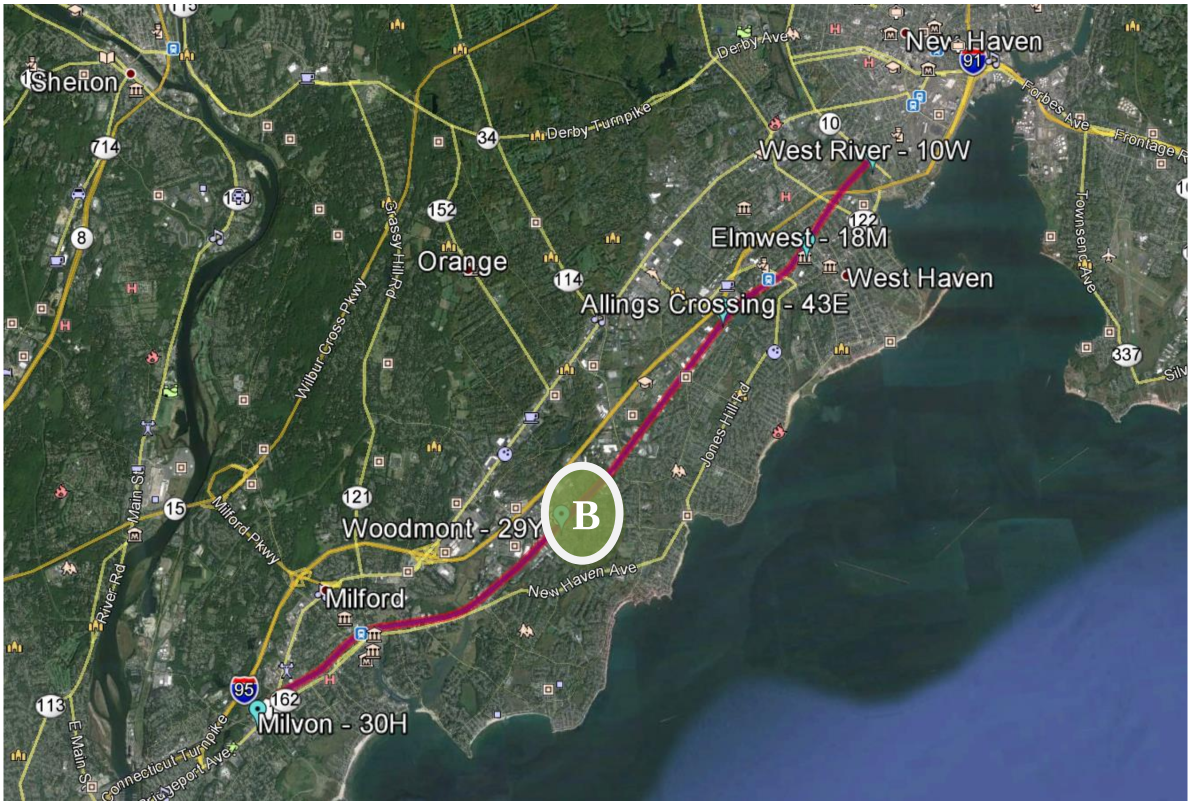


Figure 1.3: Plan View of Milvon To West River Transmission Lines

Map ID	Line Segment	Circuit ID'S	Circuit Mileage
A	Fairfield - Congress	91001, 1430, 1130, 8809A/B	10.8
B	Milvon - West River	88005A/B, 8804A/B, 88003A/B	19

Table 1.1: Total Circuit Mileage Summary

The following summarizes known additional loads and modifications applied to the catenary structures since their initial construction:

Milvon to West River Line Segments *(Structure Types MWR-1&2 – MWR-6)*:

- Catenary structures were originally built in 1912/1914 to support 2/0 and 4/0 copper wires.
- 2- 69kV overhead transmission wires and bonnet/pole extensions were installed in the 1940's.
- In the mid 1960's, the 69kV lines were converted to 115kV. It is understood that only work in the connecting substations were required. The transmission line hardware, insulators and conductors did not need to be replaced.
- In the 1980's, these lines had horizontal vee insulators installed and the conductor size was increased from 795 ACSR 45/7 to 1272 kcmil ACSS.
- In the 2000's, modifications related to the trolley wires support components and wire tensioning were completed per Metro North drawings. (Raytheon Infrastructure Inc.)

Fairfield to Congress Line Segments *(Structure Types FC-1 - FC-8)*:

- Catenary structures were originally built in 1912/1914 to support 2/0 and 4/0 copper wires.
- 1966 – South bonnet/pole extension was added for support of 115kV overhead transmission wires.
- 1991 – North bonnet/pole extension was added to structure "Types" 7 and 8 for support of 115kV overhead transmission wires.
- 2000 – Miscellaneous modifications to catenary support structures related to trolley wires and guy wires was completed per Metro North drawings. (Washington Group International)

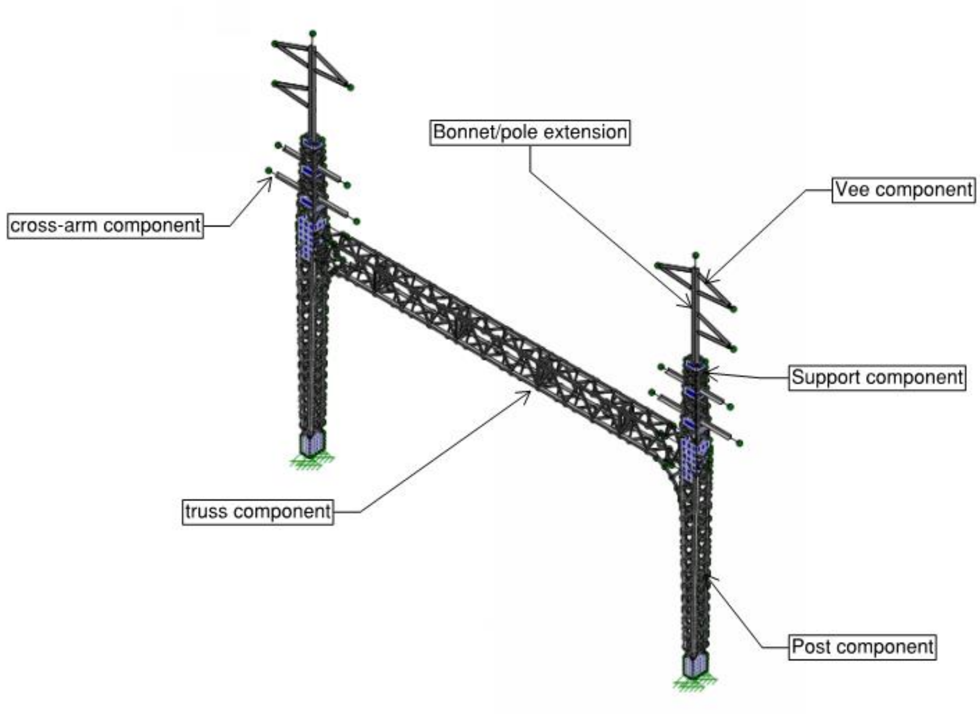
Fairfield to Congress Line Segments *(FC-C Type Structures)*:

- Wide-flange structures were originally built in 1992.
- 2000 – Miscellaneous modifications to catenary support structures related to trolley wires and guy wires was completed per Metro North drawings. (Washington Group International)
- 2013 – Miscellaneous modifications to catenary support structures related to trolley wires and guy wires was completed per Metro North drawings. (URS)

1.2.2 EXISTING TOWER CONSTRUCTION "TYPES"

The catenary support structures are composed of lattice posts with a truss spanning over the railroad. Additional framing and pole extensions are located above one or both of the posts. See Figure 2a for a visual illustration of a typical structure arrangement. The C-Type catenary support structures are composed of wide-flange posts with a wide-flange beam spanning over the railroad. Wide-flange pole extensions are spliced above the posts. Figure 2b shows a typical arrangement for the C-Type structures.

The Railroad (RR) catenary structures, which are owned by CTDOT and operated by MNR, are used to support both UI 115 KV transmission lines as well as MNR signal and feeder wires. While the support components of the structures support the MNR signal and feeder wires, the railroad catenaries, under specific lease agreements, are allowed to support UI owned bonnet/pole extensions along with their conductors, shield wires, insulators and insulator hardware.



General Structure Layout

Figure 2a: General Typical Catenary Support Structure Layout

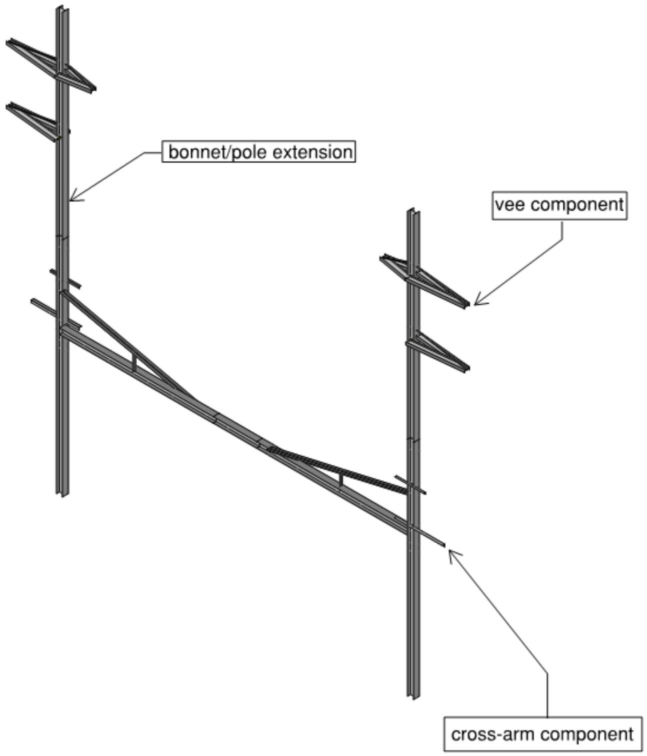


Figure 2b: C-Type Catenary Support Structure Layout

1.2.3 SEGMENT SUMMARY & CATENARY STRUCTURE COUNT

The total length (circuit mileage) of the Fairfield to New Haven 115 kV RR corridor was divided into eight (8) line segments (i.e. Four (4) line segments for Milvon to West River and four (4) line segments for Fairfield to Congress). Detailed structural analysis, focusing on the catenary and bonnet structure components, was performed on these eight (8) line segments.

In total, 237 structures were modeled and included in the detailed structural analysis which represents approximately 79% (237 out of 299) of structures within the Fairfield to New Haven 115 kV RR corridor. Individual structure information for a given line segment is included in Attachments MWR-B, C, D, E and FC-C, D, E, F. For a number of total and analyzed structure counts between line segments, refer to Table 1.2.

Structures Analyzed - Summary									
Analysis	**Milvon to Woodmont (8.2 ckt miles)**	**Woodmont to Allings Crossing (5.8 ckt miles)**	**Allings Crossing to Elmwest (2.6 ckt miles)**	**Elmwest to West River (2.4 ckt miles)**	**B648 to Ash Creek (4 ckt miles)**	**Ash Creek to Bridgeport (2.8 ckt miles)**	**Bridgeport to Pequonnock (2.6 ckt miles)**	**Pequonnock to Congress (1.4 ckt miles)**	**Totals**
Total Analyzed Structures	63	47	15	5	58	24	17	8	**237**
Not Analyzed Structures	6	2	2	14	8	7	4	19	**62**
Total Structures	69	49	17	19	66	31	21	27	**299**
% Analyzed	91.30%	95.92%	88.24%	26.32%	87.88%	77.42%	80.95%	29.63%	**79.26%**

Note: The total circuit mileage of 19.0 miles was considered for Milvon to West River line segments. For Fairfield to Congress line segments 10.8 circuit miles was considered which excludes the portion of the circuit (1130 line from Table 1.1) that is already supported by existing monopoles.

Table 1.2: Structure Counts Between Line Segments

1.2.4 SCOPE BACKGROUND

UI desires to understand the capability of the catenary/bonnet structures to support their existing 115 kV circuits under the NESC 1961 or NESC 1990 load combinations, NESC 2012, UI criteria, and Hurricane Category 3 loads. Please note, that the catenary structure "Types" including bonnets were evaluated against the NESC 1961 criteria since these were adopted by the State of Connecticut and are considered to be the minimum code requirements for all transmission lines, including earlier designed structures. NESC 1990 criteria were considered for the FC-C Type structures only since they were originally designed and constructed around 1992. Future editions of the code follow criteria as given in NESC 2012 Section 1.013.B.3 which allow earlier designed structures to maintain their original design codes for non-structural changes. However, any of the proposed solutions outlined in this report, required structural modifications and therefore, were designed in consideration of the latest NESC codes.

2.0 ANALYSIS DESIGN APPROACH

A detailed asset condition structural analysis was performed on the catenary/bonnet support structures to determine if they could adequately support UI's existing 115 kV transmission equipment. A structural analysis software program, RISA-3D, Version 14, was used to model and analyze these support structures.

The existing catenary structures were grouped into 14 representative models which were then used to perform a comprehensive structural loading assessment. Five (5) representative structural models were developed for the Milvon to West River (M-WR) section and nine (9) representative structural models were developed for the Fairfield to Congress (F-C) section. These 14 available structural models were found to represent a majority of the catenary structures (237 out of 299) based on their structural similarities. This type of modeling approach, along the entire transmission line corridor, provides an accurate representation of the overall structural results *(per structure "type")*. Further details on determination of the representative structure "Types" can be found in Section 2.6: Representative Structure Approach. The representative structures encompass various and unique configurations such as the variance in structural member sizes, truss span, structure framing dimensions, and line angles at the support structures. A representative tributary span was considered for the wires attached to the structure.

For a breakdown of the number of structures analyzed between each line segment of both corridors M-WR and F-C, refer to Table 1.3.

Line Segment Catenary Structure Breakdown					
Milvon to West River					
Catenary Structure Type	Milvon to Woodmont (8.2 ckt miles)	Woodmont to Allings Crossing (5.8 ckt miles)	Allings Crossing to Elmwest (2.6 ckt miles)	Elmwest to West River (2.4 ckt miles)	Totals
MWR - 1&2	29	42	4	4	79
MWR - 3	12	3	2	-	17
MWR - 4	15	-	7	-	22
MWR - 5	7	-	2	-	9
MWR - 6	-	2	-	1	3
Analyzed Structures	**63**	**47**	**15**	**5**	**130**
Fairfield to Congress					
Catenary Structures Type	B648 to Ash Creek (4 ckt miles)	Ash Creek to Bridgeport (2.8 ckt miles)	Bridgeport to Pequonnock (2.6 ckt miles)	Pequonnock to Congress (1.4 ckt miles)	Totals
FC - 1	27	11	-	-	38
FC - 2	6	-	-	-	6
FC - 3	7	2	-	-	9
FC - 4	10	-	1	-	11
FC - 5	4	5	-	-	9
FC - 6	4	-	-	-	4
FC - 7	-	6	12	-	18
FC - 8	-	-	4	-	4
FC - C Type	-	-	-	8	8
Analyzed Structures	**58**	**24**	**17**	**8**	**107**

Note: While several structure "Types" are structurally the same (i.e. MWR-1&2 and FC-1), structures are separated due to variance in analysis including representative loads.

Table 1.3: Line Segment Catenary Structure Breakdown

The following structure "Types" were excluded from the analysis for the *following reasons*:

- **Non-Catenary**: Tap structures located between the railroad and adjacent substations as well as lattice-type structures used for roadway crossings, etc.
- **Non-UI facilities**: Existing catenary structures where UI wires have already been completely removed.
- **New Structures**: New structures where UI wires have been relocated from the existing catenary structures.
- **Catenary Outliers**: Existing catenary structures supporting UI wires that had unique differences in truss and post framing that were inconsistent with other groups of catenary structures.

Structural analysis was performed against two scenarios to determine the extent of asset condition related deficiencies. The following design scenarios were considered *(additional details provided in Section 2.4)*:

- **Scenario A *(As-Designed)***:
  The "As-Designed" scenario was considered to evaluate the structural framing, as defined by the latest available structure drawings and documents, against applicable loading conditions per Section 1.2.4 (NESC 1961 or NESC 1990 for FC-C Type).
- **Scenario B *(Field Condition)***:
  The "Field condition" scenario was considered to evaluate the actual structure conditions as determined by field inspections. The field condition scenario was evaluated against the original load combinations (NESC 1961 or NESC 1990 for FC-C Type per Section 1.2.4) to evaluate the impact of the observed field conditions. The NESC 2012, UI load criteria and Hurricane Loads were also evaluated to illustrate current load combinations which would be applicable for any proposed solutions *(i.e. structural modifications)* as noted in Section 1.2.4.

2.1 DESIGN CODES – STRENGTH CRITERIA

Structural analysis was performed in accordance with all applicable codes and load conditions (NESC 1961 or NESC 1990, NESC 2012, UI load criteria, and Hurricane load). The required strength of the structure is defined as the structure's ability to support these loads without causing permanent deformation (i.e. yield strength exceeded) of its members. With that said a "failure," as referred to in this report, would represent an exceedance in member stresses over code defined stress limits. Refer to Section 4.2 for additional structural qualification criteria.

NESC 1961 or NESC 1990, and NESC 2012 prescribe a projected area method approach with shape factors, to analyze the effects of wind loads on line support structures. The RISA structural analysis software utilizes a more accurate means of analysis by applying the wind load to all members of a structure without the use of shape factors. This procedure was the chosen approach for this structural analysis since it more accurately reflects the wind loading on the structures.

2.2 ANALYSIS MODEL CRITERIA

RISA and PLS-Tower structure analysis software programs were considered for this analysis, and RISA-3D, Version 14 was selected due to PLS-Tower's inability to accurately account for the plate elements (critical catenary structures component). As RISA is utilized for the analysis, the AISC 14th Edition code utilizing Load and Resistance Factored Design (LRFD) was used to evaluate the ultimate strength capacity of the members. The AISC 14th Edition utilizes strength reduction factors of approximately 0.9, and is slightly more conservative than the NESC strength reduction factors of 1.0. The AISC 14th Edition provides the closest criteria to the NESC strength reduction factors since the NESC strength reduction factors cannot be explicitly applied through the RISA program. A 5% increase on the existing structural member capacities was included to more closely approximate the NESC allowable strength. This allowable increase for existing structures is widely accepted within the structural engineering industry and is formally stated within Section 3403.3 of the 2012 International Building Code (IBC).

2.2.1 P-DELTA ANALYSIS CRITERIA

NESC C2-2012, section 26, article 260.A.1, recognizes that deflections of a structure may change the effects of the loads applied; also known as P-Delta effects. NESC 1961 Standard, section 26, article 260 similarly recognizes that deflections of a structure may change the effects of the loads applied.

P-Delta Effects and Analysis Approach[2]:

A model tends to deflect under loaded conditions. Due to this deflection, secondary moments are induced in the members. P-Delta analysis is used to accurately approximate these secondary effects on the model. It is called "P-Delta" analysis since the magnitude of the secondary moments are calculated by the product of the axial force “P” in the member, and the deflection "Delta," which is given by the distance by which one end of the member deflects from the other end.

The analysis calculates secondary shears (as shown in Figure 2c) to accurately model the secondary moments along with the applied member loads.

$P * \Delta = V * L;$ $V = P * \Delta / L$

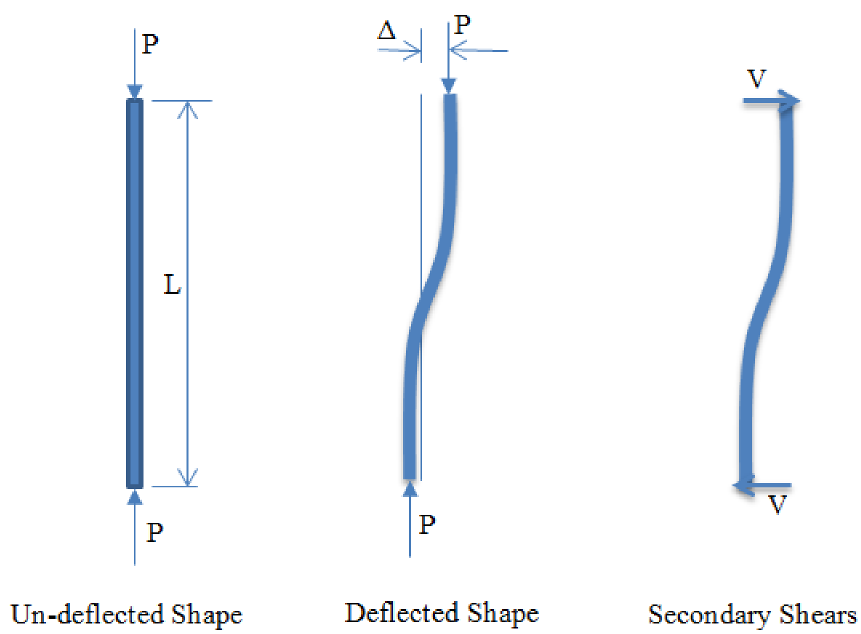


Figure 2c: P-Delta Procedure

[2]RISA-3D, Rapid Interactive Structural Analysis – 3-Dimensional, Version 15-General References, RISA Technologies, Inc., 2017, p. 436

The effects of P-Delta were considered as a part of this analysis. Results are provided with-and-without inclusion of P-Delta effects as noted in Section 4.0 Analysis Results Summary.

2.3 ANALYSIS SCOPE DETAILS

The structural frame components and plates that were analyzed using RISA structural analysis software include the post, truss, bonnet, cross-arm and support components. The vee component members (where applicable) supporting the 115kV wire, the tubular section component members supporting the MNR trolley wire, the connection brackets supporting the guy wire, and trolley tensioning wires were not analyzed since it was determined that these members would not affect the integrity of the catenary support structure. In addition, connections within the structural frame and catenary structure foundations were determined outside the scope of this assessment, and therefore excluded from detailed analysis.

2.4 SCENARIO A (AS-DESIGNED) AND SCENARIO B (FIELD CONDITION) EVALUATION

A detailed modeling assessment was performed against two individual design scenarios to determine their associated results within a defined set of boundary conditions. Scenario A *"As-Designed"* and Scenario B *"Field Condition"* design scenarios were defined as those boundary conditions since it was determined that these two scenarios would adequately capture the most conservative *(Scenario B)* and least conservative *(Scenario A)* modeling assumptions.

The ***"As-Designed"*** condition considered the structural framing and loads as determined from the latest available drawings and documents. The NESC 1961 or NESC 1990 load combinations were considered to evaluate the structure "Types" in accordance with the requirements of NESC 1961 or NESC 1990. The latest known loads on the structures were considered in the analysis since the loads at the time of construction are unknown.

The ***"Field-Condition"*** condition considered the as-built framing, current loads, and structural condition as determined through a comprehensive field assessment, Reference Attachments MWR-G and FC-G. The NESC 2012, UI criteria, and Hurricane Category 3 loads were considered for the "Field-Condition" state. Table 2 compares the various criteria considered and their associated load combinations.

NESC 1961	NESC 1990 (Applicable for FC-C Type Only)	NESC 2012	UI Criteria
Heavy Loading: Combined Ice + Wind 4psf wind, 1/2" ice	**250B:** Combined Ice + Wind (same as NESC 1961 Heavy) 4psf wind, 1/2" ice	**250B:** Combined Ice + Wind (same as NESC 1961 Heavy) 4psf wind, 1/2" ice	UI Standard TST-1.6 Adopts NESC 2012 Code
	250C: Extreme Wind 90 mph basic wind speed 21 psf wind load	**250C:** Extreme Wind 110 mph basic wind speed 31 psf wind load	
		250D: Extreme Ice + Wind 50 mph basic wind speed 6.4 psf wind load, 3/4" ice	
	261A: Extreme Wind Considers no wires attached. Wind direction transverse to 250C. 21psf wind load	**261A:** Extreme Wind Considers no wires attached. Wind direction transverse to 250C. 31 psf wind load	
			Heavy Ice: 1 1/2" ice
			Broken Conductor: 1 Broken Conductor Wire
			Broken Shield Wire: 1 Broken Shield Wire
			Unbalanced: (similar to NESC 1961 Heavy and NESC 1990 & 2012 250B) 4psf wind, 1/2" ice, with no ice on 1 side
			Deflection: Self-weight of structure and attachments only
			Hurricane Category 3: 130 mph basic wind speed 43.3 psf wind load

Table 2: Load Evaluation Criteria Comparison

2.5 LOAD CONSIDERATIONS

The loads included in the analyses were dead load, ice load, wind load, and wire tension load as represented in the applied load combinations for the structure and supported items (i.e. wires). The loads supported by the structure (included in structural analysis) included the 115kV wires, the MNR signal and feeder wires, the trolley wires, guy and pulley system weights for wire tensioning (Milvon to West River structures only[3]), and communication wires. These loads vary between each individual structure, so a typical magnitude and application location was chosen and tested against each of the analyzed structure "Types." A typical wind span was used for each structure type. Refer to Attachments MWR-E.1 and FC-F.1 for maximum and typical design wind and weight spans as well as span outliers.

Information used in the analyses was obtained from existing documents, drawings, photos, and field inspection data. A transmission line analysis software program, PLS-CADD Version 14.20, was

[3] Guy and pulley system weights, used for wire tensioning, were present for a portion of Fairfield to Congress section of structures. However, these elements were excluded from the model since they were not found to be continuously applied throughout the entire section.

also utilized to generate information on the 115kV circuits and Metro North Railroad (MNR) distribution wires. Loading information for the communication wires were obtained from a recent railroad project[4] and the typical wind and weight spans as determined were considered for those loadings. Applicable trolley system wire loads, for each structure type, were determined from the existing Metro North drawings, and the maximum loads and typical arrangements were used. For the communication and trolley wires, a typical number of wires, location, load, and load distribution were determined for each representative structure type.

2.6 REPRESENTATIVE STRUCTURE APPROACH

In order to efficiently and most effectively perform the detailed structural analysis on the Fairfield to New Haven 115 kV RR corridor, it was determined to utilize an approach called representative structural modeling. This approach is commonly utilized when the scope of structural analysis is needed for a large number of similar individual structures. This approach aggregates the various attributes on similar structures and incorporates those attributes into one model. Attributes may include, but are not limited to, dimensions, geometry, member size and length, components, and loads. For this assessment, each structure type was analyzed with a representative model to more efficiently evaluate this long transmission corridor. This approach minimized the number of unique models which would have been required for those minor attribute differences. In addition, it was determined up-front that those minor design differences were negligible, and wouldn't have a measurable effect as compared to the "representative" model results. Therefore, the results from the representative models were considered to appropriately represent the individual structural results.

Some of the structures were found to have deviations from the representative structure model that, if applied to the model, may have a more significant impact on the structural results. However, since these deviations were not commonly found throughout the corridor they were excluded in each of the representative models. These deviations include:

- Taller bonnet member and wire connections,
- Dead end conditions
- Unique frames supported off post or truss
- Balance weight assembly (BWA) or guy wire to adjacent structure (only considered deviation for FC-1 through FC-8 and FC-C Type)
- Smaller post chords and lattice member sizes
- Unique support component and unique vee component configuration
- Bonnet attached to existing support component (only applicable to structures FC-1 through FC-4 – Reference Attachment FC-F.2 FC Bonnet Configuration)
- Larger line angle
- Inset pole and structure component on truss as compared to representative structure type
- Different UI wire connection arrangement
- Additional transformer loads on catenary structure
- Different MNR wire connection arrangement

[4] Network Infrastructure Upgrade for Security New Haven Line Phase 2 (Drawing Reference FC-401)

In summary, the deviations were excluded from the representative structure "Types" as the deviations were determined negligible (categorized as *conservative* or *no impact*) or were determined to produce higher member stresses and likely additional failures in the representative structure (categorized as an *outlier*). A summary of the individual structure deviations are noted in Attachments MWR-E.2 and FC-A.

For the FC-C Type representative structures, the design approach considered the maximum beam span and structure height for the group as the general framing of the FC-C Type structure varied from the other lattice catenary structures within this study. However, the BWA and guy wire loads were treated as outliers similarly to the other FC Structure "Types."

The physical components of the structure models that define the representative structural model are included in Attachments MWR-E.3 and FC-F.3 – Representative Structure Standard Configuration.

2.7 EXISTING CATENARY STRUCTURE ANALYSIS ASSUMPTIONS

The following assumptions were made during the analysis of the catenary structures:

- The steel material for the original catenary structure members was assumed to be ASTM A7 (F_y = 30 ksi) due to the design year on the structure drawings, 1912.
- The steel material for the pole extension members for structure "Types" MWR-1&2 – MWR-6 was assumed to be ASTM A7-39 (F_y = 33 ksi) due to the design year on the structure drawings, 1940.
- The steel material for the south circuit bonnet/pole extension members for structure "Types" FC-1 - FC-8 was assumed to be ASTM A36-62T (F_y = 36 ksi) due to the design year on the structure drawings, 1966.
- The steel material for the FC-C Type structures is listed on the structure drawings as ASTM A36 (F_y = 36 ksi).
- Although NESC 1961 Standard, section 26, article 260 recognizes that deflections of a structure may change the effects of the loads applied, it is highly unlikely the original design of the structure would have considered these effects (known as P-DELTA effects per Section 2.2.1) given the applicable design standards at the time of construction.
    - It was identified up-front that incorporating the effects of P-Delta would likely produce more severe structural results (e.g. non-convergence of the mathematical models). Given P-Delta's greater likelihood of non-convergence, results were represented both with and without P-Delta to understand the magnitude of member failures (with mathematical solutions). Please note that the results shown in Section 4.0 exclude the effects of P-Delta.
- Structural Analysis Procedure directs to use "1961 NESC Code" or "NESC Code when Modified" for the Scenario A "As-Designed" Analysis. As load modifications noted on the Metro North drawings do not define associated structural modifications with provided drawings, the NESC 1961 Code is used as the latest applicable code for analysis of structure "Types" MWR-1&2 – MWR-6 and FC-1 – FC-8 while the NESC 1990 Code is used for analysis of the FC-C Type structures.
- Some of the Metro North drawings have a stamped note stating "This Sheet Not Corrected." As drawings are the latest information provided, they were assumed to reflect actual

conditions and were utilized for determining the design inputs for loadings on the structures including trolley wire, BWA, and guy wire loads, wherever applicable.

- Structure Type MWR-2 is the same structure as Structure Type MWR-1 except for an eye bolt connection mark on the drawings (Drawing 788). Eye bolt connection mark was originally assumed to be a guy connection, however photos do not support a guy connection and a subsequent field inspection confirmed this. Structure Type MWR-1&2 were combined and analyzed as one structure type.
- Structure "Types" MWR-3 – MWR-6 support varied line angles between adjacent structures which affects the load applied to the structures. Line angles varied from tangent to 2° - 15 minutes. For these structure "Types," the max angle (2° - 15 minutes) was utilized as controlling in determining the applied wire loads through the PLS-CADD software.
- Structure "Types" FC-3, FC-4, and FC-6 support varied line angles between adjacent structures which affects the load applied to the structures. Line angles varied from 0˚ to 1˚-6 minutes. For these structures the tangent (0˚) line angle was used in determining the wire loads through the PLS-CADD software due to minor variation in line angle.
- Structure "Types" FC-5, FC-8, and FC-C Type also support varied line angles. For these structures the maximum angle for each type was used in determining the wire loads through the PLS-CADD software. The line angles were 2˚-15 minutes, 3˚-39 minutes, and 4˚ respectively.
- Engineering judgment was used to approximate geometry in models of the catenary support structures when information provided on the drawings was not sufficient. This included the following:
    - Base plate height obtained by scaling
    - Post cross bracing angle of inclination adjusted to fit overall geometry from drawings.
    - Plate/bar connection at bonnet/pole extension connection to the top of the support component framing was approximated in the model.
    - Cross-arm Angles for FC-C Type structures were obtained by scaling. Assumed angle thickness was consistent with other structures.

  (Subsequent field inspection confirmed that the structural models used in the analyses are an acceptable representation of the structure.)
- Minor eccentricities occur at wire connections to vees and cross arm components of the structure due to insulators and connection components. Engineering judgment was used regarding the impact of these eccentricities and it was determined that they are negligible and were not considered during the modeling of these structures.
- For structure "Types" MWR-1&2 – MWR-6, guy wire transverse or longitudinal loads were assumed balanced with a zero net impact on the structure at locations where the guy aligns with an unbalanced load. Only the resulting vertical component of the guy wire loads is considered as applicable. Where the guy wire does not act to balance a load, the longitudinal and vertical component of the guy wire are considered in the analyses. This typically occurs at the base of the structures.
- Communication line loads are approximated by comparison to communication wire load info for an adjacent line segment (Drawing FCI-401).
- Loads shown on the Metro North drawings were assumed to be service loads.

- Loads from applicable trolley and BWA/guy wires as shown on the Metro North drawings are per MNR criteria of 55mph wind, ½" ice on wire, and 0 degree Fahrenheit. All other loadings applicable on the structures are per NESC criteria including loads from MNR signal and feeder wires, UI 115 KV wires, communication wires and other structural attachments. MNR load criteria does not align with NESC wind, ice, and temperature values per each loading combination, but the MNR loads are considered acceptable by engineering judgment to be utilized with the NESC load combinations.

2.8 SOLUTION STRATEGIES

Based on the structural assessment of the catenary structures, any requirement for an upgrade would include: reinforcement of existing members, construction of temporary structural supports, construction access, outage impact on existing transmission line, railroad operations, design efforts for each individual structure, design efforts for catenary structure connections and foundations, and the future cost of maintaining the structures.

With the intent of providing the most cost effective solution for supporting the UI wire loads, alternative options would be investigated along with a comparison study detailing conceptual costs and work schedule estimates.

New pole support structures would also be considered to support the UI transmission lines, including (2) single circuit poles or double circuit poles. New pole structures would consider new structure costs, Right-of-way procurement, construction access, reduction of future maintenance costs, ability to support future increases in transmission wire capacity, reduction of outage impact on existing transmission line and railroad operations, and decreased risk in transmission reliability due to isolation from railroad utilities.

General solution approach considered the following Alternatives:

- **Alternative 1** – Double Circuit Monopoles
- **Alternative 2** – Single Circuit Monopoles
- **Alternative 3** – Single Circuit Monopoles and Catenary Structure Modifications
- **Alternative 4** – Catenary Structure Modifications

The preferred solution alternative would be chosen based on the factors that influence overall cost, schedule, and service reliability for the immediate structural support and future service requirements.

3.0 FIELD INSPECTION OF THE CATENARY STRUCTURES

Detailed field inspections, on the entire 115 kV RR corridor, were performed on a representative sample of the catenary structures. The information gathered from these inspections was critical for the "Scenario B" *(Field Conditions)* analysis since it provided additional modeling data which otherwise wouldn't be available from the "Scenario A" *(As-Designed)* data records (e.g. latest drawings, models).
Attachments MWR-G and FC-G provide a list of inspected structures and a summary of inconsistencies which were observed between the available data records and field inspection findings. Also, Attachments MWR- G and FC-G describe any action that was taken to incorporate these field findings into the "Scenario B" structural models. Only those commonly observed field findings were incorporated into the structural models. In many instances, the field findings were judged to have a negligible effect on the structure's integrity and were not incorporated into the structural models. Furthermore, those, inconsistencies which were found on a limited number of structures were determined to be outliers and were not applied to any of the structural models.

3.1 FIELD CONDITION SUMMARY OF FINDINGS *("Scenario B" Model Inclusions)*:

- General Corrosion: General corrosion was observed on various portions of the original 1912 A7 steel. Expansive corrosion (also known as corrosion pack-out) was typically observed near the base of the catenary structure posts at the interface between the post chord angle and lattice plate. As a result, all field condition analysis models, with the exception of the FC–C Type structures, considered reduced member and plate thicknesses where applicable to account for corrosion loss.

- Severe Expansive Corrosion and Section Loss: Severe expansive corrosion and section loss was observed on the post chord reinforcing plates for structure Type MWR-6 and FC-6. Due to the severe section loss, these reinforcing plates were removed from the field condition analysis model.

- Missing Arch Member: Several structures were noted as missing a portion of the arch members on the south side, north side, or both. When this was observed for a majority of structures within a structure type, the arch or arches were removed from the field condition analysis model.

- Post-Truss Connection: For all non FC-C Type structures (i.e. lattice structures) the cross-bracing at the post-to-truss interface was noted as replaced by a plate. These cross-bracing members were removed from the field condition analysis model and the fixity of the perimeter frame members around the cross-bracing were updated to account for the plate.

- Location of Wire Loads: The majority of structure "Types" FC-1 through FC-6 were found to have the north half of the north cross arms moved to an adjacent monopole. These wire loads were removed from the field condition model (2 locations on each structure). Also, an additional wire was observed on the south support component, below the upper cross arm, and was considered to be the existing 4/0 wire that was moved from the top of the support component to the noted location when the bonnets/pole extensions were added to the structures.

- Additional Wire Loads: The majority of structure "Types," MWR-1 through MWR-6, was found to have additional trolley wire loads applied as compared to available MNR data records. Additional trolley wire loads were applied to account for this condition.

- Plate Connections: The majority of structures, "Types" FC-1 through FC-8, were noted as having plates bolted to the top truss chords. Top truss chord members were modeled as shown on the drawings with a reduction in member thickness to account for corrosion observed during the inspection. No additional considerations for localized corrosion or the plate addition were considered as detailed information was unable to be obtained during the field inspection. The localized condition is not considered to change the overall structure results.

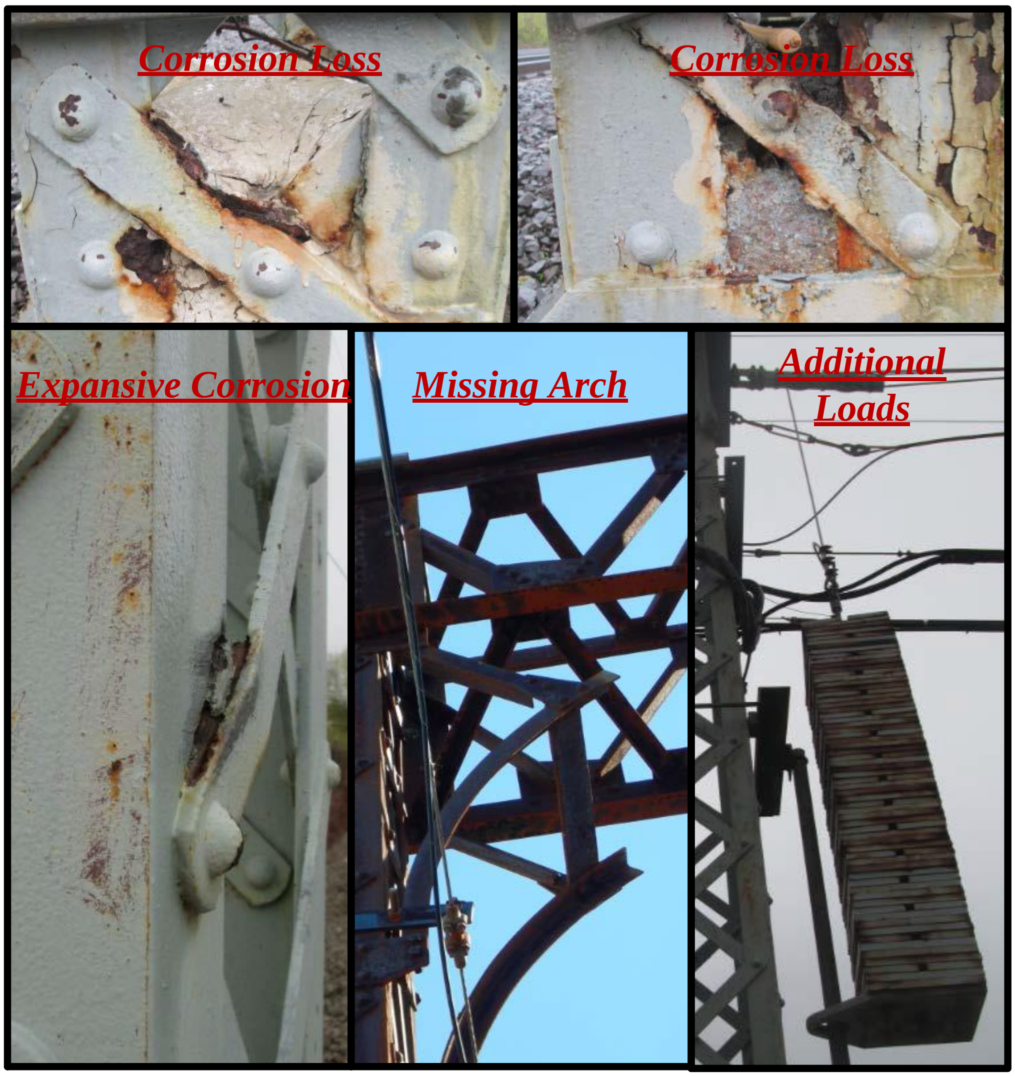


Figure 3.1: Field Condition Visuals

3.2 FIELD CONDITION SUMMARY OF FINDINGS *("Scenario B" Model Exclusions)*:

- Deformed Lattice Members: Various lattice structural cross members were observed to be bent or deformed, and therefore could not be analyzed accurately. All lattice members were modeled as shown on the drawings (i.e. did not include deformation) with a reduction in section thickness, as noted above, due to corrosion observed during the inspection. The deformed state of the lattice members would severely affect their compression capacity and most likely cause additional member failures in the structures if removed from the models.

Field Condition "Deviation" Findings:

- Structures B652, B660, B692, B724, B741, B915, B978, and B992 were found to have a noticeable lean in one of their posts.
- Structures B654, B730, B732, B915, B978, and B1032 were found to have noticeable torsional deformation in one of their cross arms.
- Structures B684 and B701 were found to have a vertical deformation in one of their cross arms.
- Structure B656 was found to have a bent truss chord likely due to impact.
- Structure B657 was found to have a bent post chord and bent lattice members likely due to impact.
- Structures B669, B686, and B693 were found to have a bent arch connection likely due to impact.
- Structure B0965 was observed supporting a ground wire by a "rope".
- Various structures were found to have more than 3 communication lines attached to the structure's post(s), adding additional loads to the structure.
- Various structures were found to have communication lines cantilever supported from the structure's post(s), adding additional loads to the structure.
- One of the top chord horizontal braces was removed from structure B684.
- Several structures were found to have missing lacing sets near the post bases.
- Structure B0940 was found to have significant corrosion of a truss cross brace.
- Various structures have had post lacing sets replaced.
- The south lower cross arm was removed from structure B719.
- Various structures were found to have one or both of their posts encased in concrete.
- The north support component was removed from structures B657, B669, and B670.
- Various structures were found to have the UI 115 kV wires moved off the structure to adjacent monopole support structure(s), reducing the loads on the catenary structure.
- Various structures were found to have one or more missing MNR wires off of the support component members.
- Various structures were found to have less than three communication lines supported off of the structure's post(s), reducing the loads on the catenary structure.

4.0 ANALYSIS RESULTS SUMMARY

The structural analyses and their results were grouped as follows:

- Considering P-Delta Effects
- Neglecting P-Delta Effects[5]

4.1 RESULTS WITH CONSIDERING P-DELTA EFFECTS

The results of P-Delta analysis failed to provide any mathematical solution by considering P-Delta effects. This can be attributed to non-convergence of the mathematical models which is assumed to be the most severe outcome and equivalent to an overall elastic structural failure under the applied loads.

4.2 RESULTS NEGLECTING P-DELTA EFFECTS

The results of the structural analysis yielded numerous member failures (stress exceedances over design strength) across all structure "Types" which were considered. The following summary tables provide a breakdown to the extent and magnitude of member failures for each of the individual structure "Types." As noted in Section 2.0, an "As-Designed" *(Scenario A)* and "Field Condition" *(Scenario B)* evaluation was performed to capture the structural impacts against those defined boundary conditions.

The results associated with analyzed plate elements yielded similar results as compared to the member results and are referenced in Attachments MWR-H through MWR-V and FC-H through FC-AG. Illustrations of structural failures and descriptions of failing members are included under Sections 4.3.2.1 and 4.3.2.2.

4.2.1 MEMBER SUMMARY TABLES

Table 4.1 provides the number of structural members in which their strength capacities, after considering a 5% loading increase, was exceeded relative to AISC code design (LRFD) provisions (see Section 2.2). Results are listed for each of the analyzed structure types and for the two (2) given scenarios (A & B) under the defined loading conditions.

[5] Results without P-Delta were included in order to obtain detailed results from a converged solution.

Member Evaluation Summary - Overstressed Members			
Number of Overstressed Members (Utilization above 105% included - Ref. Section 2.0)			
Structure Type	As-Designed NESC 1961 or NESC 1990 Evaluation	Field Condition NESC 1961 or NESC 1990 Evaluation	Field Condition NESC 2012, UI Criteria, and Hurricane Cat. 3 Evaluation
MWR-1&2	30	122	310
MWR-3	45	62	217
MWR-4	35	15	184
MWR-5	26	2	137
MWR-6	16	98	251
FC-1	32	95	187
FC-2	16	72	222
FC-3	33	33	83
FC-4	33	31	71
FC-5	31	36	112
FC-6	3	2	47
FC-7	12	56	210
FC-8	29	1	16
FC-C Type	8	8	8

Table 4.1: Member Evaluation Summary – Overstressed Members

Table 4.2 provides the maximum utilization percentage by which stresses in the members had exceeded their design based on applicable code provisions (see Section 2.2). Results are listed for each of the analyzed structure types and for the two (2) given scenarios (A & B) under the defined loading conditions

Member Evaluation Summary - Maximum Member Utilization			
	Maximum Member Utilization		
Structure Type	As Designed NESC 1961 or NESC 1990 Evaluation	Field Condition NESC 1961 or NESC 1990 Evaluation	Field Condition NESC 2012, UI Criteria, and Hurricane Cat. 3 Evaluation
MWR-1&2	156%	161%	999%
MWR-3	339%	146%	432%
MWR-4	281%	119%	476%
MWR-5	193%	110%	439%
MWR-6	133%	163%	999%
FC-1	161%	199%	999%
FC-2	380%	169%	999%
FC-3	282%	510%	999%
FC-4	249%	442%	999%
FC-5	235%	437%	999%
FC-6	161%	161%	999%
FC-7	132%	149%	999%
FC-8	218%	121%	999%
FC-C Type	325%	325%	956%

Table 4.2: Member Evaluation Summary – Maximum Member Utilization

4.2.2 STRUCTURE EVALUATION CRITERIA

Results for structural elastic strength "failure" were broken down into two main categories: **(1)** Critical to the underlying structural integrity (i.e. catenary support) or **(2)** Critical for UI equipment support (i.e. bonnet support). In addition, results that failed to converge (i.e. no mathematical solution reached), when considering the effects of P-Delta, were considered the worst case outcome and listed as an overall critical failure. The following criteria were used for each designation of the structure:

Failure Critical to the Underlying Structural Integrity:

- Failure of a main member occurs (main members are considered the post vertical members and truss chord members)
- Significant number of lattice members fail

Failure Critical for UI Equipment Support:

- Failure of bonnet/pole member occurs

Overall Critical Failure:

- P-Delta Failure (non-convergence)

4.2.3 STRUCTURE EVALUATION TABLES

Structure Evaluation Summary As-Designed NESC 1961 or NESC 1990 Evaluation				
Structure Type	P-Delta Failure	Total Number of Structures*	Structural Integrity Failure*	UI Equipment Support Failure*
MWR-1&2	79	79	79	0
MWR-3	17	17	17	17
MWR-4	22	22	0	22
MWR-5	9	9	0	9
MWR-6	3	3	3	3
FC-1	38	38	38	0
FC-2	6	6	6	0
FC-3	9	9	0	0
FC-4	11	11	0	0
FC-5	9	9	0	9
FC-6	4	4	0	0
FC-7	18	18	18	0
FC-8	4	4	0	4
FC-C Type	8	8	8	0**
Total	237	237	169	64
Percentage of Analyzed Structures	100%	-	71.31%	27.00%
* Since the analysis models fail (do not converge on a solution) when P-Delta effects are considered the results in these columns do not include P-Delta effects.				
** Structural Integrity Failure could also be considered a UI Equipment Support Failure for C-Type.				

Table 4.3: Structure Evaluation Summary – As-Designed Nesc 1961 or Nesc 1990 Evaluation

Structure Evaluation Summary For Field Condition NESC 1961 or NESC 1990 Evaluation				
Structure Type	P-Delta Failure	Total Number of Structures*	Structural Integrity Failure*	UI Equipment Support Failure*
MWR-1&2	79	79	79	0
MWR-3	17	17	17	17
MWR-4	22	22	0	22
MWR-5	9	9	0	9
MWR-6	3	3	3	3
FC-1	38	38	38	0
FC-2	6	6	6	0
FC-3	9	9	9	0
FC-4	11	11	0	0
FC-5	9	9	0	9
FC-6	4	4	0	0
FC-7	18	18	18	0
FC-8	4	4	0	4
FC-C Type	8	8	8	0**
Total	237	237	178	64
Percentage of Analyzed Structures	100%	-	75.11%	27.00%
* Since the analysis models fail (do not converge on a solution) when P-Delta effects are considered the results in these columns do not include P-Delta effects.				
** Structural Integrity Failure could also be considered a UI Equipment Support Failure for C-Type.				

Table 4.4: Structure Evaluation Summary – Field Condition Nesc 1961 or Nesc 1990 Evaluation

Structure Evaluation Summary for Field Condition NESC 2012, UI Criteria, and Hurricane Cat. 3				
Structure Type	P-Delta Failure	Total Number of Structures*	Structural Integrity Failure*	UI Equipment Support Failure*
MWR-1&2	79	79	79	79
MWR-3	17	17	17	17
MWR-4	22	22	22	22
MWR-5	9	9	9	9
MWR-6	3	3	3	3
FC-1	38	38	38	38
FC-2	6	6	6	6
FC-3	9	9	9	9
FC-4	11	11	11	11
FC-5	9	9	9	9
FC-6	4	4	4	4
FC-7	18	18	18	18
FC-8	4	4	4	4
FC-C Type	8	8	8	8
Total	237	237	237	237
Percentage of Analyzed Structures	100%	-	100.00%	100.00%
* Since the analysis models fail (do not converge on a solution) when P-Delta effects are considered the results in these columns do not include P-Delta effects.				
** Structural Integrity Failure could also be considered a UI Equipment Support Failure for C-Type.				

Table 4.5: Structure Evaluation Summary - Field Condition Nesc 2012, Ui Criteria, And Hurricane Cat. 3 Evaluation

4.3 STRUCTURE EVALUATION SUMMARY

Please note that any solutions and/or conclusions made as a result of this analysis considered of all relevant NESC criteria (i.e. including P-Delta effects). As discussed in Section 4.1, P-Delta analysis failed to provide a mathematical solution (i.e. non-convergence) in any of its structural simulations. Therefore, in order to provide additional clarity on the magnitude of structural loading results, the following sub-sections were broken out with-and-without consideration of P-Delta.

4.3.1 EVALUATION CONSIDERING P-DELTA EFFECTS

All structural models were found to have exhibited overall critical failures when considering the effects of P-Delta (i.e. 100% failure rate).

4.3.2 EVALUATION NEGLECTING P-DELTA EFFECTS

A structural evaluation against both scenarios *(As-Designed" and "Field Condition")* found critical member failures on all structure "Types."

The “As-designed” and “Field Condition” results for the lattice catenary structures illustrate several failing members for each structure type. The results seem plausible considering that the applied loads are likely greater than the original applied loads on the structure. In addition, since the lattice type structures are typically designed with maximum utilization to save material costs, the results agree with an increase in loads having an adverse impact on the structures. For the “field condition” model, the field conditions including the deterioration of the structure support an increase in magnitude of failures.

For the C-Type “as-designed” models evaluated to NESC 1990, main member failures in the structure are critical and would cause structural collapse. A likely reason for the failures is the full unbraced length of the columns may not have been accounted for when the structures were originally designed which would cause a large part of the over-stress of the column members. Considering that the C-Type columns are approximately 87 feet tall with no means of lateral support, the analysis results are reasonable. The C-Type structure “field condition” model evaluated to NESC 1990 yielded the same results as the “as-designed” model evaluated to NESC 1990 as no field condition modifications were made.

The “field condition” results due to NESC 2012, UI Criteria, and Hurricane Cat. 3 criteria illustrate a complete failure of both the lattice catenary structures and the C-Type structure due to the noted field conditions and more stringent requirements per the later load combinations. A majority of the post members exhibit failure and would lead to a structural collapse. The controlling combinations apply to the broken conductor, broken shield wire, and unbalanced UI load combinations for which the structure was likely not designed.

Also note that per Section 2.0 Analysis Design Approach several “deviation” features were excluded from the analysis. If these features were included in the analysis, it would result in higher member stresses which would adversely affect the integrity of the structures. If detailed modifications were applied to mitigate member failures, analysis on a structure-by-structure basis would be required to account for these “deviation” conditions.

Other considerations for the structural integrity are the connections and foundations. This analysis excluded an evaluation of the connections and foundations. An increase in the loading and base reactions would likely lead to failure of these connections and foundations. The connections were observed during the field inspection and similar to the other structural elements the connections had general corrosion. This corrosion indicates that the connection would likely exhibit some loss in design strength. Connection failures would lead to additional member failures as the imposed loads would redistribute through the structure after members could no longer carry load (due to a failed end connection). Additional analysis would be required to validate the connection and foundation capacities and any required modifications.

4.3.2.1 INDIVIDUAL STUCTURE TYPE ANALYSIS RESULTS FOR MILVON TO WEST RIVER *(STRUCTURE TYPES 1 THROUGH 6)*

See Attachment MWR-G.2.

4.3.2.2 INDIVIDUAL STRUCTURE TYPE ANALYSIS FOR FAIRFIELD TO CONGRESS *(STRUCTURE TYPES 1 THROUGH 8 AND C-TYPE)*

See Attachment FC-G.2.

5.0 SOLUTIONS ALTERNATIVES ANALYSIS

5.1 DESIGN APPROACH FOR SOLUTION ALTERNATIVES

As noted in Section 2.8 "Solution Strategies," four (4) solution alternatives were evaluated along the 115 kV RR corridor (section-by-section basis). The solution alternatives considered the addition of monopole structures, double circuit tower structures, upgrades to the existing catenary structures, and a combination of catenary upgrades/monopoles additions.

- Alternative 1 *(Double-Circuit Monopole)*: New *double-circuit* monopole structures would be constructed to simultaneously support UI's 115 kV north and south circuits (A&B lines).
- Alternative 2 *(Single-Circuit Monopole)*: New *single-circuit* monopole structures would be constructed to independently support UI's 115 kV north and south circuits (A&B lines).
- Alternatives 3 *(Single-Circuit RR Structure Modifications)*: New *single-circuit* monopole structures would be constructed to independently support 1-115 kV circuit and structural modifications to the existing catenary structures would provide support for the remaining circuit.
- Alternative 4 *(Double-Circuit RR Structure Modifications)*: Structural modifications to the existing catenary structures would provide support for the existing UI 115 kV north and south circuits (A&B lines).

Alternative 1 & 2: The existing 115 kV bonnets and UI conductor wires would be removed. The shield wire would be relocated to the top of the remaining catenary structure. New conductors (1590 kcmil ACSS), shield wires (OPGW), insulators, and hardware would be included in the installation.

Alternatives 3& 4: Major structural modifications would be required for these options (e.g. foundation, catenary structure, UI bonnet upgrades, etc.). For option 3, new single circuit monopoles supporting UI 1590 kcmil ACSS conductors and OPGW shield wires would replace existing steel bonnet and UI wires on the Northwest side.

<u>Preliminary analysis found that Alternatives 3 & 4 had significantly higher order of magnitude of costs (+200/-50% estimates, See Appendix E) as compared to Alternative 1 & 2.[6] Therefore, Alternatives 3 & 4 were excluded from further analysis (did not engineer beyond the +200/-50% level). These increased costs were mainly attributed to an increased construction time/schedule length due to work performed immediately next to and above railroad tracks.</u>

5.2 POLE STRUCTURE MODEL CRITERIA

New poles were designed to meet the current UI Standard Loading Criteria and Hurricane Category III Criteria. The "single-circuit" (Alternative 2) monopoles utilized pole structure models from recent RR projects[7]. Where applicable, the "double-circuit" (Alternative1) monopoles utilized the same "single-circuit" pole model and included additional attachment points for the second circuit on a back-to-back configuration. For a portion of the "double-circuit" monopoles, heavier structures were considered, to account for maximum amount of imposed structural loading. Detailed "double-circuit" models will need to be designed by the pole vendor. The new steel structures were analyzed with UI transmission wires ONLY. No under-build or foreign attachments were considered.

5.3 RIGHT OF WAY DESIGN CRITERIA

The addition of pole structures from Alternatives 1 & 2 required the evaluation of available clearance between the railroad tracks and adjacent private and public real estate. A minimum clearance must be maintained between the new poles, railroad tracks, and the existing catenary structures. Right-of-Way (ROW) impacts were determined based on adjacent private and public real estate for the required clearance of the new pole structures. The ROW (acreage) analysis was based on determining the governing offset distance to edge of ROW from the following:

- <u>Blowout ROW Clearance</u>:
    - Conductor blowout @ 6 psf with 7'-0" clearance to edge of ROW; **OR**
    - Conductor blowout @ 25 psf with 1'-0" clearance to edge of ROW; **OR**
    - A minimum of 15'-0" clearance to edge of ROW based on UI standard clearance

[6] Please note that design approaches for developing +200/-50% conceptual cost and schedule estimates as outlined under "Assumptions" per Appendix E, for different alternatives have been refined and updated to develop +50/-25% cost and schedule estimates.
[7] "Baird to Congress" and "Milvon Substation to Devon Tie Switching Station"

Minimum Required Distance to Edge of Right-of-Way
(Conductor at 60°F, No Wind, No Ice)

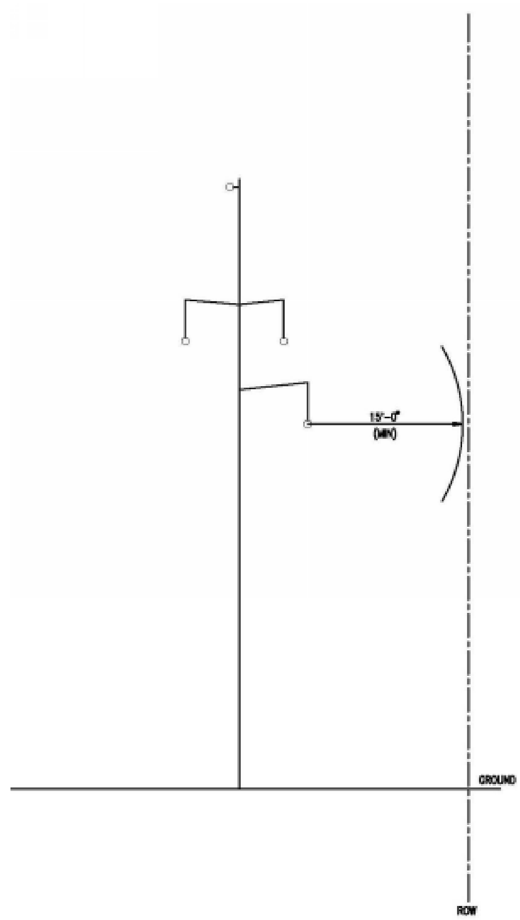


Figure 5a: UI Minimum Edge Of Right Of Way Clearance

- New Monopole Structure Clearance:
  - A relative offset between the existing catenary structures and the new monopoles was applied to meet minimum wire clearance criteria, construction clearance considerations, and existing ROW limits. A typical offset of 25 feet, off of the existing catenary structure post centerlines in the transverse direction, was considered where available. When unavailable, or if a significant ROW easement would be required, a minimum offset of 10-18 feet was utilized to reduce the ROW impact while still meeting the UI clearance criteria. If roadways were directly adjacent the railroad, new monopoles were located across roadway.

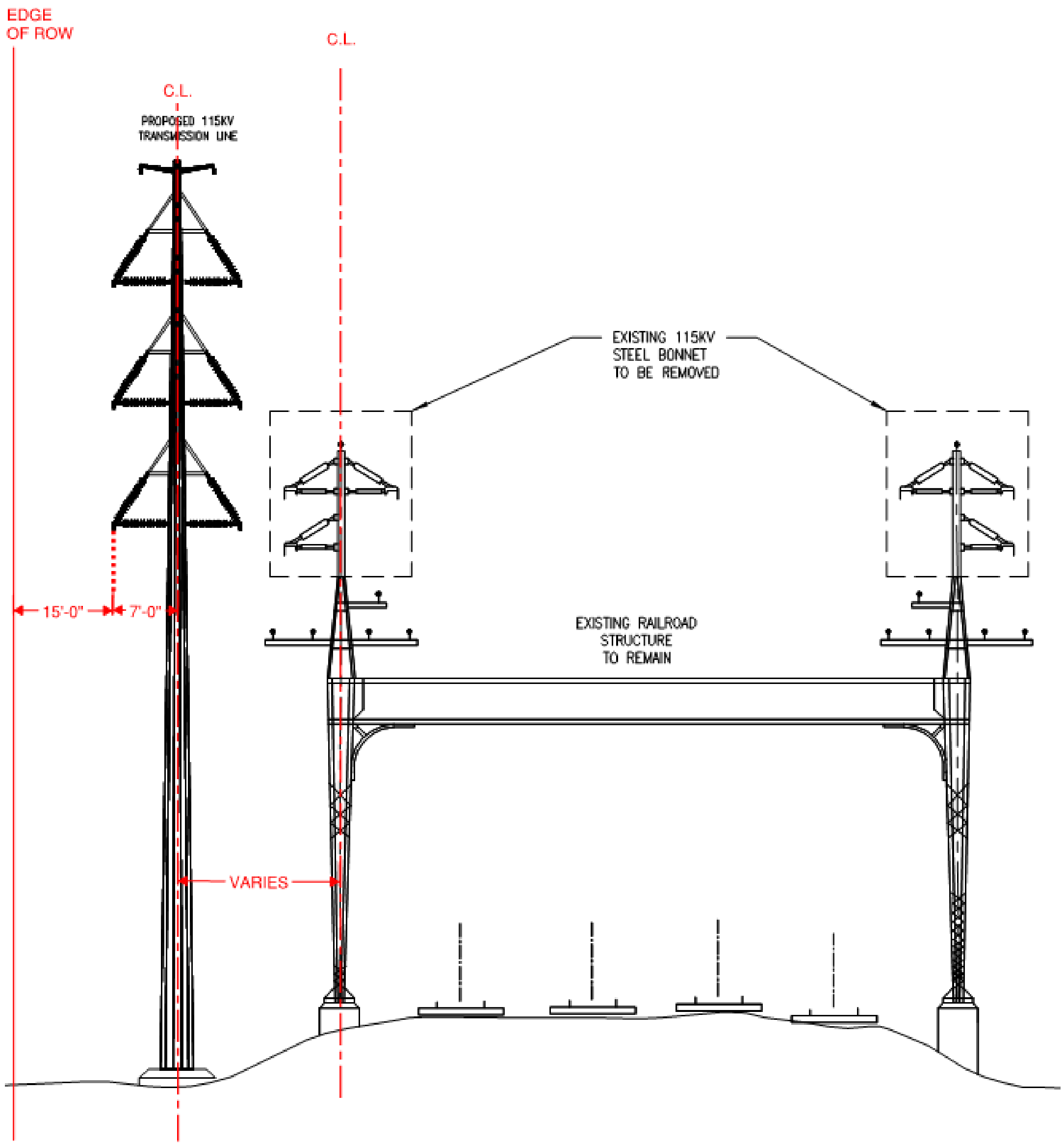


Figure 5b: Elevation of Row Clearance - Alternative 1 Double Circuit Pole

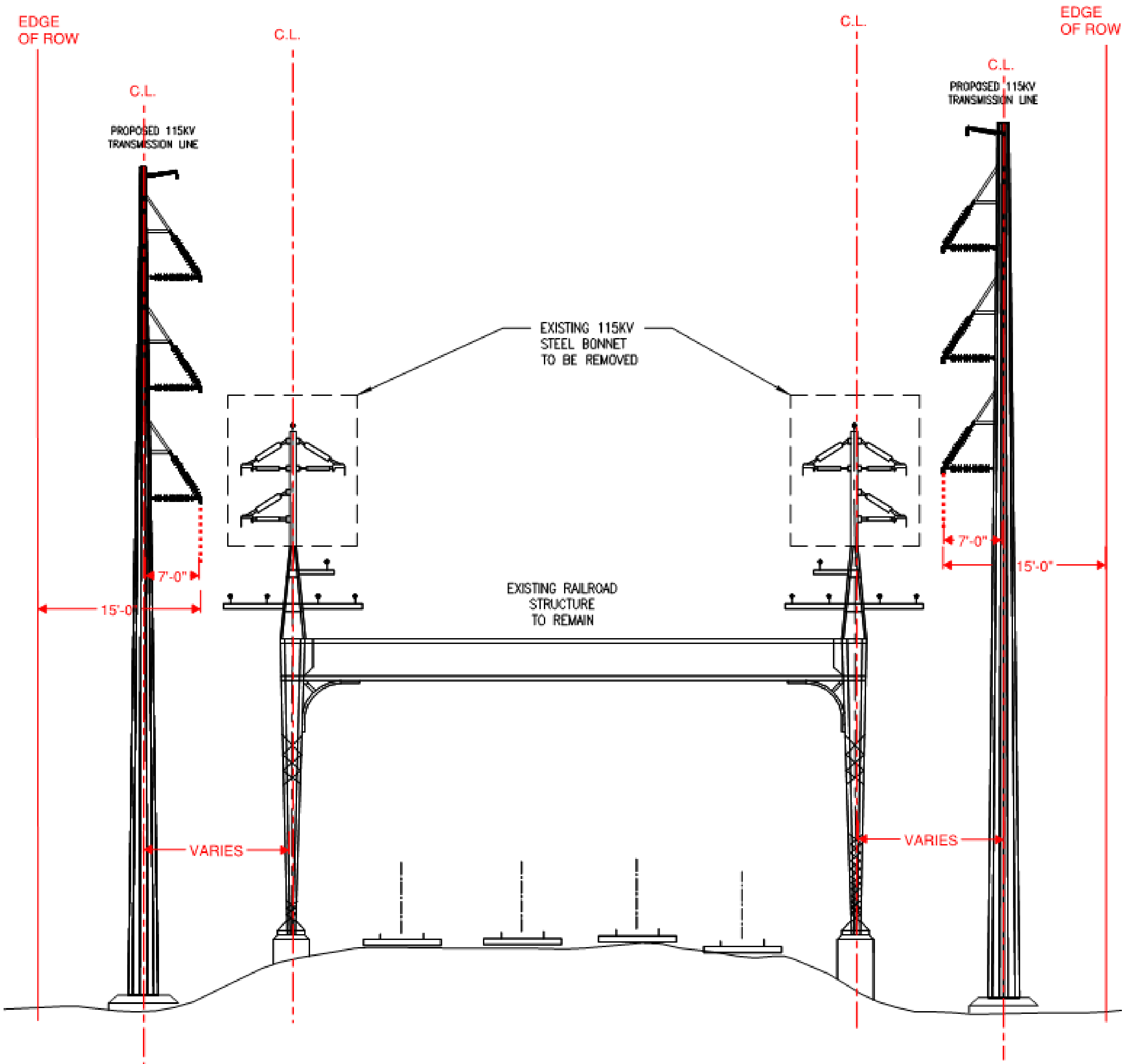


Figure 5c: Elevation of Row Clearance - Alternative 2 Single Circuit Poles

The conductor blowout clearance analysis was evaluated for both 6 psf and 25 psf wind load scenarios. Based on this analysis, it was found, for spans approximately 300 feet in width, the 15 ft. clearance with conductor at 60 degrees, with no wind and no ice condition (see Figure 5a) was most limiting over the additional wind load (6 psf and 25 psf) scenarios, and therefore was used to determine the ROW limit. The 15 foot limit was applied off of the conductor location for the given monopole options as noted in the above Figures 5b and 5c. The ROW easement acreage was determined for Alternatives 1 & 2 and summarized in the following tables, Table 5.1, Table 5.2 and Table 5.3.

ROW Easement Summary - Alternative 1 - Double Circuit Poles (North Side Only for DCT Poles)			
Line Segment	**Acreage Needed for Northwest Circuit (DCT Poles)**	**Acreage Needed for Southeast Circuit (SCT Poles)**	**Total**
Milvon - Woodmont	1.248	0	1.248
Woodmont - Allings Crossing	0.144	0	0.144
Allings Crossing to Elmwest	0.607	0	0.607
Elmwest - West River	0.74	0	0.74
Total Milvon to West River	**2.739**	**0**	**2.739**
Fairfield Eversource UI Transition - Ash Creek	0	2.581	2.581
Ash Creek - Bridgeport Resco	1.416	1.865	3.281
Bridgeport Resco - Pequonnock	2.236	0	2.236
Pequonnock - Congress	1.127	0	1.127
Total Fairfield to Congress	**4.779**	**4.446**	**9.225**
Total	**7.518**	**4.446**	**11.964**

Table 5.1: Alternative 1 – Double Circuit Poles - Row Easement Acreage

ROW Easement Summary - Alternative 1 - Double Circuit Poles (South Side Crossover between Bridgeport-Pequonnock)			
Line Segment	**Acreage Needed for Northwest Circuit**	**Acreage Needed for Southeast Circuit**	**Total**
Milvon - Woodmont	1.248	0	1.248
Woodmont - Allings Crossing	0.144	0	0.144
Allings Crossing to Elmwest	0.607	0	0.607
Elmwest - West River	0.74	0	0.74
Total Milvon to West River	**2.739**	**0**	**2.739**
Fairfield Eversource UI Transition - Ash Creek[A]	0	2.581	2.581
Ash Creek - Bridgeport Resco[A]	1.416	1.865	3.281
Bridgeport Resco - Pequonnock	0.96	1.891	2.851
Pequonnock - Congress	1.127	0	1.127
Total Fairfield to Congress	**3.503**	**6.337**	**9.84**
Total	**6.242**	**6.337**	**12.579**

Notes:
A. New poles on Southeast side for noted line segments are SCT Poles due to existing monopoles on Northeast side.

Table 5.2: Alternative 1 – Double Circuit Poles - Row Easement Acreage – South Crossover

ROW Easement Summary - Alternative 2 - Single Circuit Poles			
Line Segment	**Acreage Needed for Northwest Circuit (SCT Poles)**	**Acreage Needed for Southeast Circuit (SCT Poles)**	**Total**
Milvon - Woodmont	0.177	2.109	2.286
Woodmont - Allings Crossing	0.023	1.538	1.561
Allings Crossing to Elmwest	0	1.23	1.23
Elmwest - West River	0.383	0.988	1.371
Total Milvon to West River	**0.583**	**5.865**	**6.448**
Fairfield Eversource UI Transition - Ash Creek	0	2.581	2.581
Ash Creek - Bridgeport Resco	0.723	2.196	2.919
Bridgeport Resco - Pequonnock	0.89	0.885	1.775
Pequonnock - Congress	1.356	0	1.356
Total Fairfield to Congress	**2.969**	**5.662**	**8.631**
Total	**3.552**	**11.527**	**15.079**

Table 5.3: Alternative 2 – (2) Single Circuit Poles - Row Easement Acreage

5.4 ADDITIONAL HYBRID OPTION FOR FAIRFIELD TO CONGRESS SECTION (COMBINATION OF ALTERNATIVES 1 & 2)

The existing 91001/1130 double-circuit tower (DCT) contingency, between Pequonnock and Resco, was identified as problematic in past Transmission Planning (T-Planning) assessments. During certain system conditions, this one single DCT event can cause overloads on the 115 kV cables out of Pequonnock and this will automatically trigger the runback of the Existing Bridgeport Harbor 3 unit *(or any future generator seeking to interconnect at Pequonnock)*. Based on this concern, T-Planning recommended that an additional "hybrid" alternative be evaluated to mitigate this problematic double-circuit tower (DCT) contingency.

The Hybrid option considers a combination of Alternatives 1 & 2 (i.e. SCT west of Pequonnock, DCT east of Pequonnock) and is laid out in Figure 5d.

This option includes Alternative 2 (single-circuit) monopoles for the first three (3) line segments between Eversource / UI Transition and Pequonnock substations and Alternative 1 (double circuit) monopoles for the last line segment between Pequonnock and Congress substations.

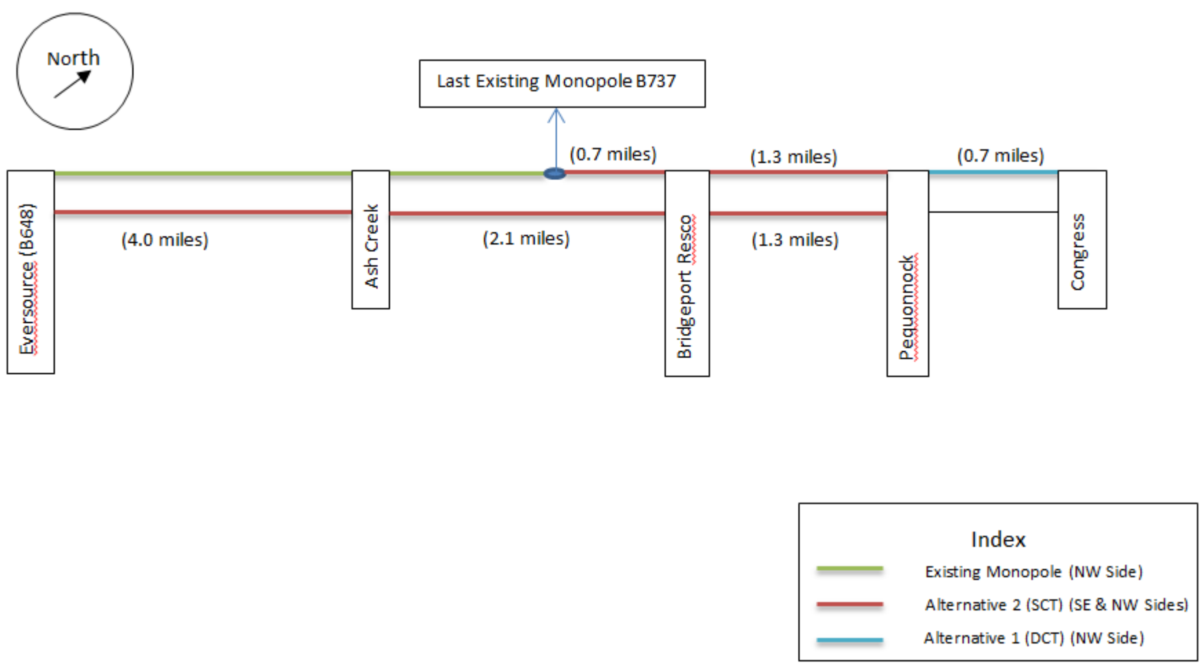


Figure 5d: Hybrid Option (Combination of Alternatives 1 & 2)

For a comparison of total project cost and schedule durations for this option with those of Alternatives 1 & 2, refer to Tables 5.5 and 5.7.

5.5 ASSUMPTIONS

Design Scope Assumptions

1. No work inside the substation yards is included in these cost estimates unless noted otherwise.
2. Project estimates and schedules will not be impacted by CTDOT's other planned projects.
3. Project schedules will not be impacted by a shortage of available flaggers because of other planned MNR projects.
4. Sufficient engineering and PM resources (both external contractors and AVANGRID resources) is assumed available to design all four segments within each line section (Fairfield to Congress and Milvon to West River) in parallel without increasing the duration of engineering activities.
5. Metro-North and CTDOT is assumed to have sufficient engineering resources available to perform timely (90 days for each review) engineering and constructability reviews and walk-downs.
6. MNR can provide sufficient flaggers to cover two survey crews performing survey activities simultaneously in the Fairfield – Congress line section.
7. Each line section (Milvon – West River and Fairfield – Congress) will be a separate project.

Cost Assumptions

8. A markup of 10% is applied to construction costs. Any Substation terminal upgrade costs to meet or exceed the ratings of the overhead lines are not included in the total project cost.
9. A contingency of 25% has been applied to the construction labor, equipment and material costs.
10. 1.75% per year escalation until construction for each line segment has been included in the total project cost. For the two line sections, (a) Fairfield to Congress (F-C) and (b) Milvon to West River (M-WR):
    a. Line segments in F-C section are scheduled in expected construction sequence starting from the smallest line length (Pequonnock to Congress) as the first segment. Detailed Design of the first line segment starts in October 2020 for double circuit monopole option (Alternative 1) as directed by UI. Detailed Design of the first line segment for single circuit monopoles (Alternative 2) will start in June 2021 based on alignment with Milvon to West River Detailed Design;
    b. Line segments in M-WR section are scheduled in expected construction sequence starting from the second smallest line length (Allings Crossing to Elmwest) as the first segment (based on ease of constructability) followed by the smallest line length segment (Elmwest to West River), second longest segment (Woodmont to Allings Crossing) and the longest segment (Milvon to Woodmont). Detailed Design of the first line segment

starts in December 2019 for double circuit monopole option (Alternative 1) as directed by UI. Detailed Design of the first line segment for single circuit monopoles (Alternative 2) is also aligned to start at the same time (December 2019) based on projected completion of survey process for that line segment before 4th quarter of 2019.

11. Sales taxes of 6.35% on applicable materials are included in these cost estimates.
12. Material salvage has not been included in the project costs.
13. Environmental remediation costs for managing regulated material, which includes but is not limited to soil and ground water, have been estimated based on the experience of finding and disposing of these material types on recent MNR projects and are included by UI.
14. No costs impacts have been included for the preservation of historical properties or area with potential for the presence of historical resources due to the fact that the Cultural Resource Review of the project area has not been completed.
15. Police traffic control for construction efforts/access impacting local roadways is included in the cost estimates.
16. Cost for permitting and petition with the Connecticut Siting Counsel (CSC) has been included, along with cost for a full application.
17. The cost for the Allowance for Funds Used during Construction (AFUDC) is not included but will be added once provided by UI.
18. A mileage ratio has been used for the Flagmen, Signalmen/Groundmen, Engineering, and Construction Costs for the line segments based off of the Eversource/UI Transition to Ash Creek section cost for F-C line section and Milvon to Woodmont section cost for M-WR line section. The F-C and M-WR basis line segment costs are based on similar Milvon to Devon Tie project information.
19. An allowance of $10,000 per mile is included for above grade ground survey.
20. An allowance of $6,100 per boring located once every 3 structures and at line angles and $2,800 for subsurface exploration probes at remaining structure locations is included.
21. An allowance of $100,000 for tree restoration on each side of the railroad tracks is considered when applicable.
22. Cost for foundation de-watering has been included by UI.
23. Costs for a lead management plan that is required to meet UI/MNR requirements for any grinding, cutting, or abrasive impact to structures that may contain lead are considered in construction management.
24. Temporary construction easement access cost of $1000 per pole has been considered around each pole for space for cranes and two (2) man lifts.
25. An allowance of $4,000 per cubic yard for rock drilling is included for each foundation.
26. Costs for any lease agreements from private owners for access entrance drives have been included by UI.

27. Right of Way costs are determined by UI on a per parcel basis. Estimated Right of Way easement acreage is included in this report for use in determination of Right of Way costs.

Real Estate Cost Assumptions

28. Real estate estimates are based on preliminary/conceptual pole locations and will need to be refined in detailed engineering based upon final pole locations.
29. A contingency of 15% is included in the estimate.
30. Permanent easement costs are based on the 2016 appraised property values found on the town/city GIS mapping available online. The easement cost is calculated by using per square foot cost of the property (based on the appraised value) and multiplying this by the estimated easement required. Actual per square foot costs of easements can vary greatly and will need to be refined in detailed engineering with the due diligence performed by the real estate group.
31. Temporary easements are estimated at 10% of the permanent easement costs as observed on past railroad projects. This can vary greatly depending upon the access and work pad setup which will be defined in detailed engineering.
32. ROW agent is estimated at $100,000/2.5 miles.
33. Individual property surveys are estimated at $5,000/property.
34. Legal costs for permanent and temporary easements are estimated at $6,000/property.
35. The minimum property per square foot cost used is $4.50.
36. To calculate the total number of temporary easements needed for the DCT alternative, 50% of the total existing catenary locations (with some exceptions for Fairfield to Congress line section) has been used since access locations and pads will not be defined until detailed engineering.
37. Properties which are estimated to have construction extending over the building are estimated at two (2) times the appraised value.
38. Properties which are estimated to have poles installed on the property are estimated at one-and-half (1.5) times the permanent easement value.

Schedule Assumptions

39. It will take 18 months to bid, evaluate, and award the engineering and survey and geotechnical procurement contracts for each line section.
40. Right-of-way surveying and environmental delineation work for each segment must be complete before detailed engineering of that segment can begin.
41. This schedule assumes that the CSC will require a full application and the CSC application can be submitted with 70% designs. The schedule will include 18 months for CSC full application review and permit approval process per client direction.

42. CSC approval is required prior to the start of any real estate activities or award of any material procurement and construction contracts.
43. This schedule assumes that environmental applications can be submitted with 70% designs. Since the environmental permitting is expected to be significant – especially around the Pequonnock Substation for F-C and between Elmwest and West River Substations for M-WR it is assumed that the environmental permitting will take 2 years for approval for each line section. It is assumed that all environmental permit approvals must be received before construction can start.
44. Environmental remediation schedule impacts for managing regulated material, which includes but is not limited to soil and ground water, have not been included.
45. No schedule impacts have been included for the preservation of historical properties or area with potential for the presence of historical resources due to the fact that the Cultural Resource Review of the project area has not been completed.
46. Specific vernal pool issues that might impact the project designs if the environmental delineation work does not take place during the exclusive April/May timeframe, when vernal pools can be identified, have not been included.
47. It is assumed to take twelve months to obtain all final real estate agreements for the first segment of each line section to be constructed. The real estate process (access rights, lease agreements, easement acquisition, etc.) will involve significantly more adjacent properties than on past railroad projects.
    a. In terms of easements for Fairfield to Congress, DCT (Alternative 1) has easements on 127 parcels (north side only), SCT has easements on 179 parcels with each option (DCT & SCT) having exactly the same easements for 76 parcels due to existing monopoles for part of the considered line segments.
    b. In terms of easements for Milvon to West River, DCT (Alternative 1) has easements on 33 parcels (north side only), SCT has easements on 77 parcels.

The real estate processes are expected to take 3 years (assuming full CSC application) for each line section. The real estate process will be performed on a rolling basis, with construction starting as each segment's real estate access rights have been secured.

48. It is assumed to take 12 months to bid, evaluate, and award the material procurement contract for each line section per coordination with the client. The material procurements for each segment within individual line sections (M-WR and F-C) are required by client to be bundled together. Procurement will remain separate between line sections per client to avoid adding time to schedule. The materials RFP can be issued after 70% design. Time for specification and drawings required for procurement are included in Detailed Engineering.
49. This schedule assumes that construction contract procurements for both line sections are not required to be bundled together. Bundling procurement will add time to the schedule.

50. It is assumed that it will take 12 months for the double circuit poles and 24 months for the single circuit poles to manufacture/deliver the steel monopoles and hardware for each line section.
51. It is assumed to take 12 months to bid, evaluate, and award the construction contract for each line section per coordination with UI.
52. The schedule uses a mileage ratio based on previous projects and specific site considerations for construction activities for the individual line segments.
53. Construction activities for individual line segments of a given alternative are aligned in sequence for the Milvon to West River and Fairfield to Congress line sections. Construction of each section is assumed to be able to overlap.
54. The total construction duration for (a) F-C and (b) M-WR:
    a. ranges from approximately 7-20 months for the double circuit monopoles option and 10-20 months for the single circuit monopole option for the varying line segments.
    b. ranges from approximately 8-25 months for the double circuit monopoles option and 11-35 months for the single circuit monopole option for the varying line segments.
55. The schedule includes 6 months for project closeout for each line segment.
56. The schedule does not account for any time of year restrictions pertaining to state or federal listed species (i.e. endangered, threatened, or special concern species).

Design Criteria Assumptions

57. Significant grading including major cuts, benching and imported fill material required to support the build out of access in areas with steep terrain are assumed to be minimal where access entrance drives are utilized.
58. It is assumed that drilling spoils will be assessed in the re-characterization stage of the project and managed according to the CT DEEP Soil Waste Guidelines. UI has provided costs for its removal.
59. Given that no geotechnical information has been provided, it is assumed that 25% of the foundation excavation will contain rock.
60. For the double circuit foundations, 6’ diameter x 22’ deep drilled pier foundations are assumed to be used to support new tangent and dead end steel monopoles. For the single circuit foundations, 6’ diameter x 17’ deep drilled pier foundations are assumed to be used to support the new tangent and dead end steel monopoles. For single circuit foundations in water, 6’ diameter x 40’ deep pier foundations are assumed. For taller monopoles (height ≥ 175 feet), foundations of both dead-end and tangent structures are assumed to be 8’ diameter by 22’ deep drilled piers.

61. Wire heights are applied to meet UI clearance requirements. Wire heights are increased significantly in some areas to clear existing structures.
62. New 1590 ACSS "Lapwing" Conductors and OPGW Shield Wires will be considered off of new monopole structures for construction and estimating material costs. While 1590 ACSS Conductors will be applied, 2156 ACSS Conductors are considered to support future upgrades including all other design requirements of pole heights, clearance limits and associated costs.
63. One spare reel of conductor has been included in the material quantities.
64. New steel poles will be grounded at two locations via 20 foot ground rods with 10 foot leads.
65. Maximum Operating temperature used for ACSS clearance checks is 392°F.
66. The new 1590 kcmil ACSS conductor will be strung at 9,500 lbs at NESC Heavy Initial.
67. The new OPGW shield wire on the circuits will be strung at 5,000 lbs at NESC Heavy Initial to match the conductor sag at 60°F, No Wind.

Layout & Right Of Way Assumptions

68. New monopoles will be installed to the outside of the existing towers in the transverse direction. It is assumed that the majority of new monopoles could be installed directly adjacent to the existing towers or slightly ahead or behind depending on site specific conditions. Offset conditions do exist to accommodate physical placement of pole or typical 300' wire span, but do not greatly affect a 1-for-1 replacement approach.
69. New monopoles are typically assumed to be located 25 feet off of the existing catenary structure post centerlines in the transverse direction where available. When not available or significant right of way easement would be created, a minimum offset of 10-18 feet is utilized to reduce right of way impact while meeting UI clearance criteria. When roadways are directly adjacent the railroad, new monopoles are located across roadway.
70. New monopoles that are placed less than 18 feet from the existing catenary structure centerlines are considered to support MNR wires given UI wire clearance criteria.
71. New double circuit monopoles are assumed to be applied on the Northwest side of the existing railway as the less expensive side when considering right of way, clearing, and access except for a portion between Bridgeport to Pequonnock to avoid residential easements.
72. Where existing street utility poles occupy same area as proposed monopole layouts, relocation of existing utilities onto new pole is assumed.
73. Right of way limits and parcel information of current railroad and adjacent properties are assumed based off of PLS-CADD information provided by UI or town/city GIS information where available.
74. The acreage of right-of-way that is impacted by the new monopole structures is evaluated based off of UI clearance criteria.

75. For Right of way considerations, any evaluation of clearance to adjacent buildings where applicable is approximate per aerial imagery.
76. For location of building within 3-5 feet of new pole location on the south side between Ash Creek and Bridgeport Resco (F-C corridor), use of taller monopoles (height ≥ 175 feet) are assumed with additional cost factor and deeper foundations.

Construction Assumptions

77. Outages on the facilities associated with this work will be required. Generally, it is anticipated that a line outage will be required on each line as it is re-built, while the adjacent line is on "non-reclose".
78. It is assumed that restoration time of the line can take 12 hours or more depending upon the option selected and depending upon where the crews are in the pull.
79. Construction work need not be limited to specific time or months of the year as long as it can be done on one UI circuit at a time.
80. Construction costs and schedule are based on work being performed Monday through Friday, 10 hours per day. Crews will be limited to working short days (10 to 3) and weekends if the work requires track outages.
81. Removal of bonnets and lowering of the shield wire to the top of the MNR distribution conductors will need to be done at night or weekends due to working high adjacent to the tracks with potential to fouling the tracks.
82. Extended outages will have to be taken at times during construction for each circuit; however, the construction sequencing allows that no double circuit outages will be necessary.
83. For areas where access entrance drives to railroad are used, access entrance drives are assumed at every half mile to one mile.
84. For areas where access entrance drives to railroad are used, access drives along railroad are considered for access to structure locations. 16' width of access drives are considered and width of access drives is reduced to 12' for wetland/sensitive areas.
85. For areas where new monopole structures are adjacent to public roadways, use of public roadway, and temporary road closures will be utilized in lieu of access entrance drives.
86. Clearing for proposed monopole structures and access roads considered a 30' width for double circuit monopoles and 15' width for single circuit monopoles. Any clearing for access entrance drives is accounted for in costs as well; however, this is minimal as access paths were chosen to minimize construction effort.

5.6 CONCEPTUAL SCHEDULE SUMMARY

A summary comparison of the Milvon to West River and Fairfield to Congress conceptual schedules were evaluated to determine the relative difference between the two Alternatives. Individual line segment conceptual schedules were included for Alternatives 1 and 2 and can be found in Appendix C.

Milvon to West River Conceptual Schedule Summary Comparison (Years)				
Line Segment No.[A]	Line Segment Description	Line Segment Length (miles)	Alternative 1 - Double Circuit Pole	Alternative 2 - (2) Single Circuit Poles
1	Allings Crossings Substation to Elmwest Substation	1.30	4.17 (January 2024)	5.67 (July 2025)
2	Elmwest Substation to West River Substation	1.20	4.83 (September 2024)	6.58 (June 2026)
3	Woodmont Substation to Allings Crossings Substation	2.90	6.33 (March 2026)	8.5 (May 2028)
4	Milvon Substation to Woodmont Substation	4.10	8.17 (April 2028)	11 (April 2031)
Combined Line Segments[B]			8.50	11.50
Notes: A. Line Segment are listed in order of construction with expected completion date in parenthesis. B. Individual Segment Schedule lengths account for time from Detailed Design through Construction. Combined Line segments account for beginning of Detailed Design of 1st segment to end of construction of last line segment.				

Table 5.4: Milvon to West River Schedule Summary

Level 1 Schedule Summary Comparison (Years)					
Line Segment No.[B]	Line Segment Description	Line Segment Length (miles)	Alternative 1 - Double Circuit Pole	Alternative 2 - (2) Single Circuit Poles	Hybrid Option - (2) SCT + (1) DCT Poles
1	Pequonnock Substation to Congress Substation	0.70	4.25 (December 2024)	5.5 (November 26)	5.5 (July 2026)
2	Bridgeport Resco Substation to Pequonnock Substation	1.30	5.08 (October 2025)	6.58 (December 2027)	6.58 (August 2027)
3	Ash Creek Substation to Structure B737[A]	1.40	5.33[A] (July 2026)	6.75[A] (November 2028)	6.75[A] (July 2028)
	Structure B737 to Bridgeport Resco Substation	0.70			
4	Eversource/UI Transition (B648) to Ash Creek Substation[A]	4.00	7.00[A] (March 2028)	8.42[A] (July 2030)	8.42[A] (March 2030)
Combined Line Segments[C]			7.50	9.17	9.17

Notes:
A. For noted line segment length and Alternative, (1) single circuit pole is utilized due to (1) existing single circuit pole.
B. Line Segment are listed in order of construction with expected completion date in parenthesis.
C. Individual Segment Schedule lengths account for time from Detailed Design through Construction. Combined Line segments account for beginning of Detailed Design of 1st segment to end of construction of last line segment.

Table 5.5: Fairfield to Congress Schedule Summary

5.7 COST ESTIMATE SUMMARY

The cost estimates for Alternative 1 and Alternative 2 were compared on a section-by-section basis along the entire Fairfield to New Haven 115 kV RR corridor *(Milvon to West River and Fairfield to Congress)*. This comparison was based on a +50%/-25% level of accuracy and used to determine the relative cost differences between the two Alternatives. Note that as line segments are assumed to be constructed in sequence, the period of time from the start of the first line segment to the end of the last line segment provided a significant impact on escalation costs as compared to previous projects. Individual line segment conceptual cost estimates are included for Alternatives 1 and 2 in Appendix A. Note that in the tables below, the Engineering/Permitting/Indirect costs include Engineering, Construction Management, Contractor 10% Markup, and UI Costs from the individual line segment summaries. Individual line segment cash flows are also included in Appendix B.

MILVON TO WEST RIVER COST ESTIMATE SUMMARY COMPARISON - TOTAL PROJECT COST		
Cost Category	**Alternative 1 (All line segments)**	**Alternative 2 (All line segments)**
Material	$15,155,571	$22,369,201
Labor	$54,487,484	$71,129,195
Equipment	$0	$0
Engineering/Permitting/ Indirects	$70,907,208	$84,277,663
Escalation	$13,001,186	$23,124,676
AFUDC	$28,877,792	$24,727,599
Contingency (25%)	$14,190,378	$19,932,022
Total Project Cost	**$196,619,618**	**$245,560,355**

Table 5.6: Milvon to West River Cost Summary

FAIRFIELD TO CONGRESS COST ESTIMATE SUMMARY COMPARISON - TOTAL PROJECT COST			
Cost Category	**Alternative 1 (All line segments)**	**Alternative 2 (All line segments)**	**Hybrid Alternative (All line segments)**
Material	$9,528,760	$10,783,316	$10,394,611
Labor	$39,260,674	$44,189,207	$42,789,728
Equipment	$0	$0	$0
Engineering/Permitting/ Indirects	$91,222,359	$96,866,233	$98,841,387
Escalation	$8,445,967	$12,464,310	$12,126,139
AFUDC	$22,204,678	$32,220,238	$31,379,108
Contingency (25%)	$9,030,358	$10,530,507	$10,095,905
Total Project Cost	**$179,692,798**	**$207,053,810**	**$205,626,877**

Table 5.7: Fairfield to Congress Cost Summary

COST ESTIMATE SUMMARY COMPARISON - TOTAL PROJECT COST (ALL LINE SEGMENTS)		
Cost Category	**Alternative 1**	**Alternative 2**
Material	$24,684,331	$33,152,517
Labor	$93,748,158	$115,318,402
Equipment	$0	$0
Engineering/Permitting/ Indirects	$162,129,567	$181,143,896
Escalation	$21,447,153	$35,588,986
AFUDC	$51,082,470	$56,947,837
Contingency (25%)	$23,220,736	$30,462,529
Total Project Cost	**$376,312,416**	**$452,614,167**

Table 5.8: All Line Segments Cost Summary

6.0 CONCLUSION & RECOMMENDATIONS

The Fairfield to New Haven 115 kV RR corridor was evaluated against Alternatives 1 & 2 which took into consideration the overall project cost, schedules and cash flows. As a result, B&V recommends Alternative 1 (Double Circuit Monopoles) as the preferred alternative for the existing double circuit line sections and Alternative 2 (Single Circuit Monopoles) for the existing single circuit line sections (i.e. ES/UI Border and Bridgeport Resco sections only). Please note that the vast majority of exiting line sections are double circuit constructed, and therefore, Alternative 1 acts as the predominant alternative throughout the corridor.

The double circuit monopoles (Alternative 1 portion) will be constructed on the northwest side of the existing line corridor and the single circuit monopoles (Alternative 2 portion) will be constructed on the southeast side of the existing line corridor (i.e. existing 5.4 mile line segment between the ES/UI Border, Ash Creek, and Bridgeport Resco locations). Refer to Figures 6a & 6b below.

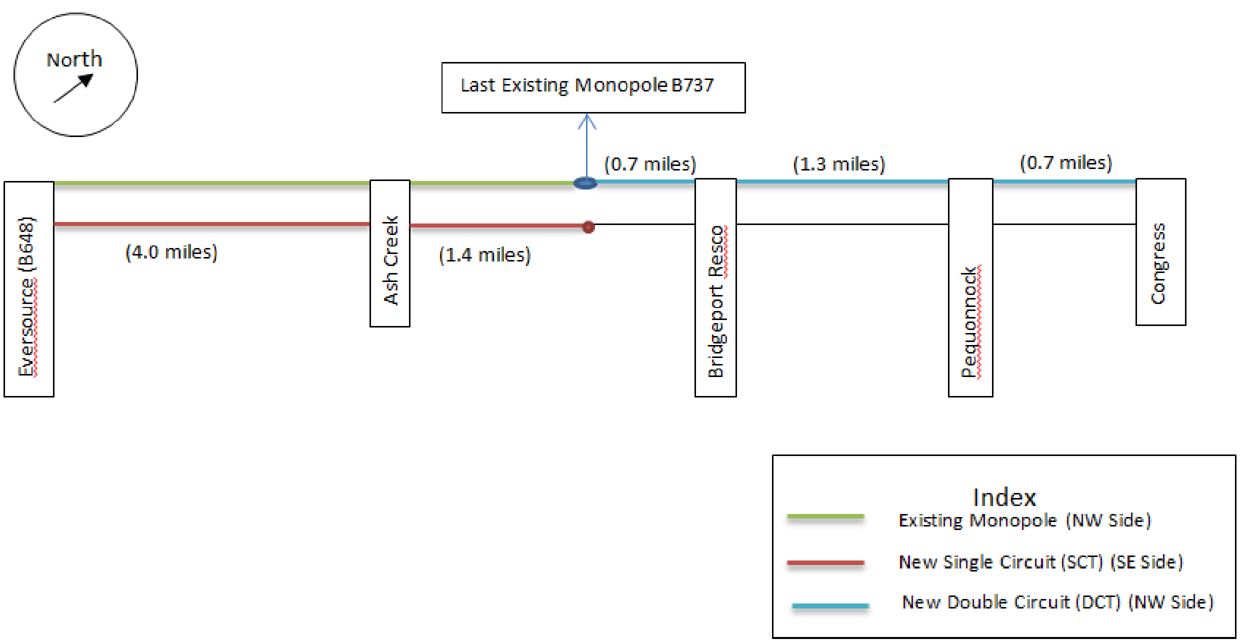


Figure 6a: Alternative 1 (DCT W/SCT's) For Fairfield to Congress

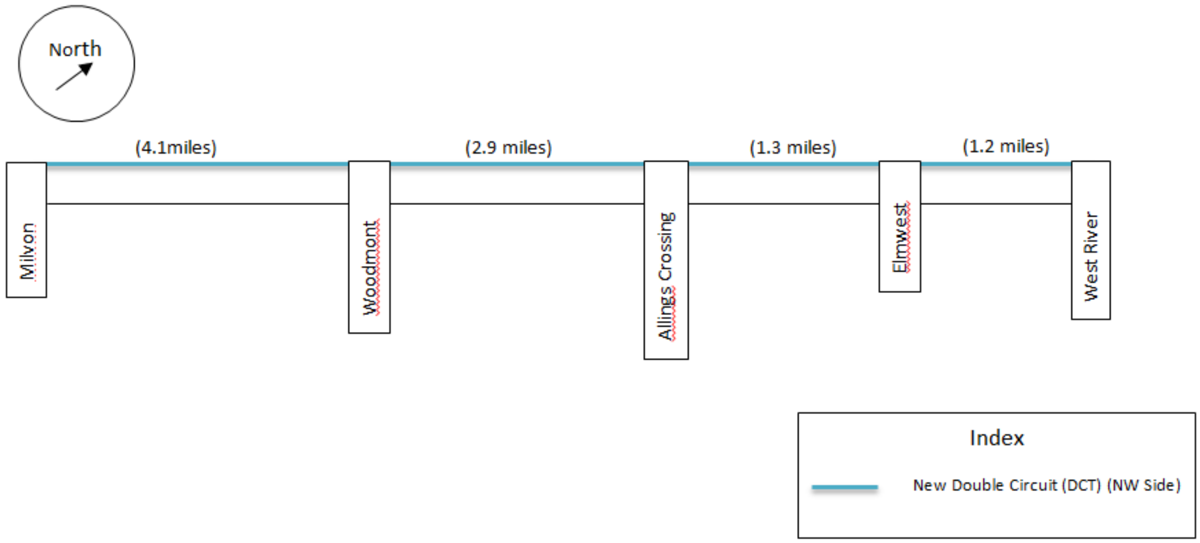


Figure 6b: Alternative 1 (DCT) for Milvon to West River

Milvon to West River: The line sections along the Milvon – West River corridor will implement Alternative 1 and will utilize 1590 kcmil ACSS "Lapwing" Conductor. The following circuits will be relocated from their existing catenary structures and moved to double circuit monopoles: 88005A, 8804A, 88003A, 89005B, 8904B, and 89003B.

Fairfield to Congress: The line sections along the Fairfield – Congress corridor will implement a combination of Alternative 1 and Alternative 2 and will utilize 1590 kcmil ACSS "Lapwing" Conductor. The following circuits will be relocated from their existing catenary structures and moved to double circuit monopoles: 8809A, 8909B, 1130, 91001. The following circuits will be relocated from their existing catenary structures and moved to single circuit monopoles: 91001, 1430.

The bases for this recommendation are as follows:

i) Both conceptual cost estimates and schedule duration are the lowest for Alternative 1
ii) The line segments on the northwest side of the corridor, between Milvon to West River substations and Ash Creek to Congress substations, have better accessibility to Right-of-Way and construction clearances as compared to the Southeast side[8].

[8] At locations where there are existing monopoles supporting UI wires on the Northwest side (i.e. ES/UI Border and Bridgeport Resco), use of Alternative 2 (single circuit monopoles) is recommended on the available Southeast side of these line sections.

iii) There's approximately a 50% reduction in construction materials required for Alternative 1 as compared to Alternative 2 (i.e. number of new monopole structures, their foundations, and other miscellaneous construction materials). Material and labor costs for all installation work in Alternative 1 are less than those in Alternative 2 based on a quantitative comparison of total cost (Refer to Tables 5.6, 5.7 and 5.8 under Section 5.0).

The next step is to obtain subsurface soil and survey information along the ROW. Detailed engineering will follow and then firm pricing from material suppliers and construction subcontractors will be obtained to develop final project costs and schedule.

SECTION 8.0

APPENDICES:

A: Cost Estimates
B: Cash Flows
C: Schedules
D: PLSCADD Drawings
E: +200/-50% Estimates & Assumptions

ATTACHMENT FC

TOTAL 373 PAGES

ATTACHMENT MWR

TOTAL 229 PAGES