



Electric and Magnetic Field Effect Estimates

Center to Grand Forks Transmission Project

Minnkota Power Cooperative, Inc.
Grand Forks, ND

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Minnkota Power Cooperative, Inc.

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Section 1

Introduction

General

Minnkota Power Cooperative, Inc. (MPC) has proposed the construction of a new 345 kV single circuit transmission line from the Center Substation near Center, North Dakota, to the Prairie Substation near Grand Forks, North Dakota. The power output of the Milton R. Young 2 Plant will be transferred from the Center, North Dakota, to Duluth, MN, DC tie line to the Center to Grand Forks (CGF) Transmission Line.

This report provides estimates of the electric and magnetic fields associated with the operation of the CGF transmission line.

Report Organization

This report is organized in sections which describe the estimated electric and magnetic field effects within the transmission right-of-way resulting from the construction and operation of the CGF transmission line. Each section builds on discussion from previous sections. The report describes the various aspects of the analyses performed; the line construction, the unperturbed electric field estimates, the magnetic field estimates, and a summary of recommendations.

References

This report refers to other studies and reports. References are listed in Appendix A. Superscripts reference the numbers listed in Appendix A.

Electric Field Estimates

The unperturbed electric field calculations are performed using transmission line modeling software¹. The audible noise calculations were made with the same software. The Electromagnetic Field (EMF) effect calculations by this software are based on the EPRI methodology².

Magnetic Field Estimates

Estimates of the magnetic fields are calculated for two loading conditions: the maximum cruise loading of 404 MVA⁴ and the maximum emergency line rating (thermal limit) of 1,686 MVA³. The calculations were performed using software¹ based on the EPRI methodology².

345 kV Transmission Line Description

Line Route and Right-of-Way

The CGF transmission line will be approximately 260 miles in length. The right-of-way (ROW) is 150 feet wide for most of the route. Small portions of the route may require a wider ROW to facilitate construction. The area within the transmission line ROW is primarily agricultural use. Elevation varies from 2,200 feet in the western portion of the line to 800 feet at the eastern end of the line (see Figure 2-1). ROW cross sections are assumed to have level terrain for analysis purposes.

Conductors

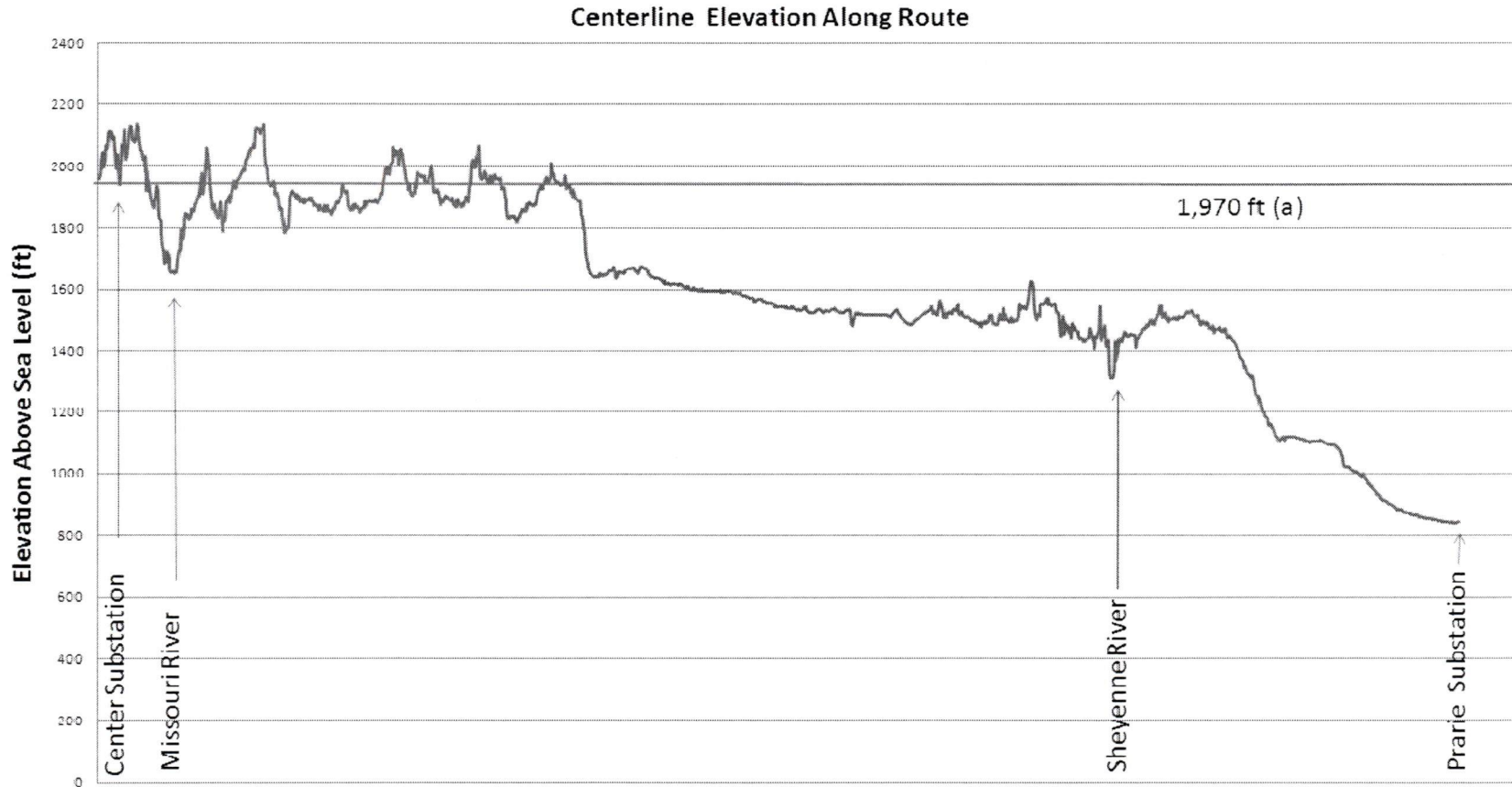
The CGF Transmission Line is comprised of single circuit transmission structures with conductor sizes of 959.6 kcmil ACSR/TW, Suwannee/TW phase conductors, 1/2" EHS Steel shield wire, and 0.561 inch O.D. optical ground wire (OPGW). Each phase consists of a two-conductor vertical bundle with 18-inch bundle spacing. The OPGW described above serves as one of the two shield conductors.

Configuration

Configuration for the CGF transmission line tangent structures is shown in Figure 2-2. Structure height shown is typical for the design ruling span of 1,000 feet. Calculations of the field effect estimates are based on the structure geometry shown in Figure 2-2. Orientation of the structure in Figure 2-2 is looking east as viewed along the route.

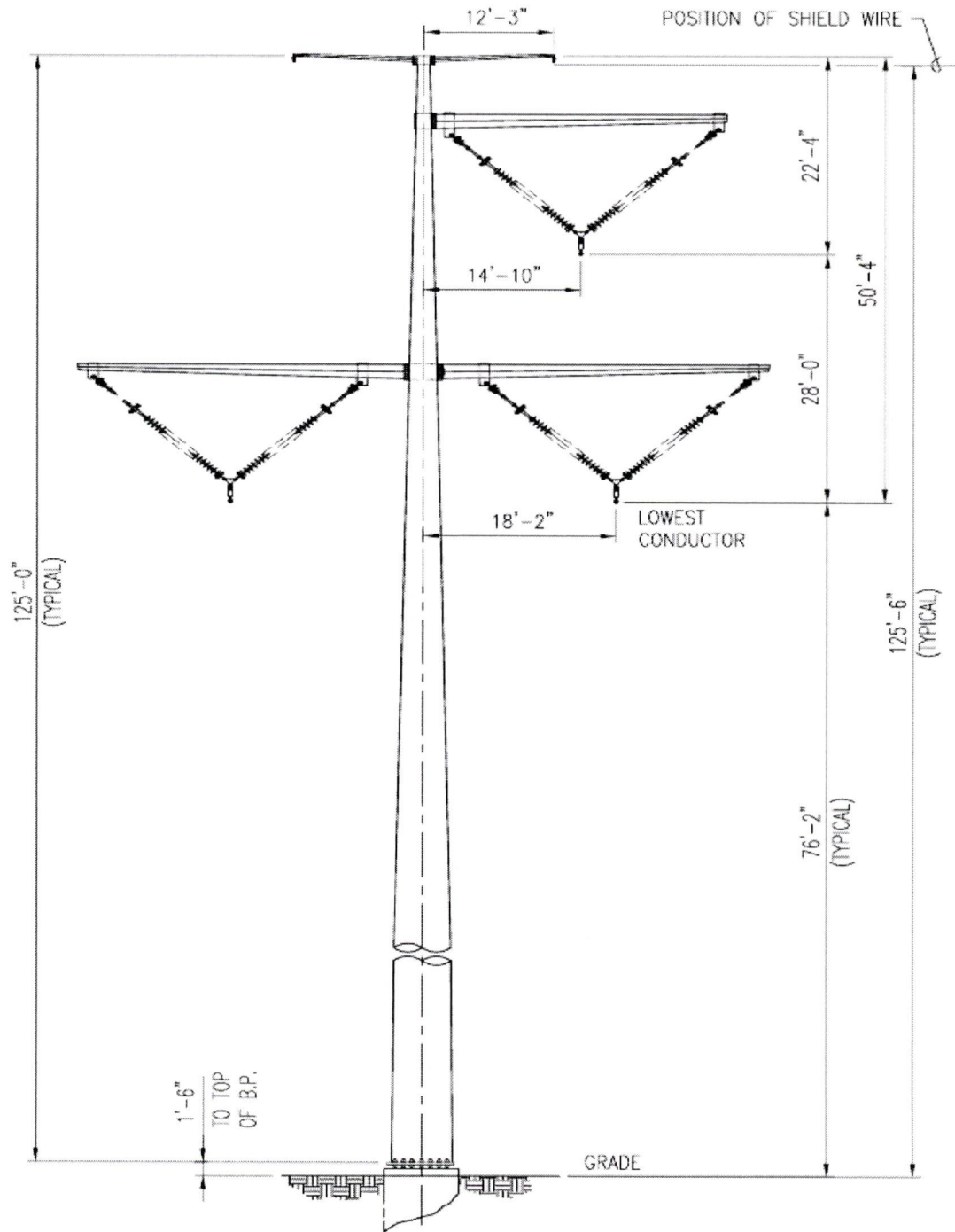
Operating Voltage

The circuit's nominal line voltage is 345 kV. Maximum insulation design operating voltage is 1.10 p.u. (380 kV)³. Maximum sustained operating voltage is 1.05 p.u. (362 kV) based on system operating parameters. The field effect estimates are performed at an operating voltage of 1.05 p.u.



(a) Audible Noise Evaluation level is estimated based on 10 percent of structures located at higher elevations and 90 percent of structures located at lower elevations

Centerline Elevations Along Route
Figure 2-1



Typical Tangent Structure
Figure 2-2

Unperturbed Electric Field Effects

Introduction

Electric fields from transmission lines are functions of the voltage of the conductors and the line geometry. The line geometry parameters include conductor size, bundle arrangement and spacing, phase spacing, and elevation above a ground plane (Earth). The geometry of the circuit combines the electric fields from the phase locations in such a way as to increase the fields in some areas and cancel or reduce the fields in other places. This magnification and cancellation is a vector super-positioning of the fields. For the CGF transmission line, there is an increase slightly “off center” of the structure centerline on the side supporting the two phases. The electric field is described in terms of kilovolts per meter (kV/m).

When calculating electric fields due to a long cylinder (cable) of charges, the electric field is evaluated along a lateral axis perpendicular to the line. The typical method of displaying electric field data is on a two dimensional graph with the horizontal axis being a unit of distance along the axis perpendicular to a transmission line and the vertical axis showing the electric field magnitude. The elevation above the ground-line of the electric field evaluation must be identified for the graph to be valid. This type of graph is used throughout this report. Where specific points of interest are identified, a table has been incorporated to summarize key graph data.

The evaluations are performed without the presence of buildings, any other structures or equipment along the ROW to determine the “unperturbed” or non-influenced electric field. The electric field may be affected by the presence of grounded objects (such as static wires, other overhead utility lines, buildings, or other objects) nearby.

Electric Field Analysis

In the analysis, the conductors were modeled at three elevations above the ground line. These elevations were based on various weather and conductor physical/electrical loading conditions leading to varying conductor sag values. The calculations were performed at the mid span (least

ground clearance) at the phase conductor and shield wire maximum design sag condition (32°F, 1.5" radial ice). The electric field scan perpendicular to the centerline was calculated at a height of 1.0 meter above ground per industry standard.⁵ The results are presented in Appendix B. This graphical information is summarized in Table 3-1. All scans are lateral (perpendicular) to the ROW. The ROW is 150 feet wide and the centerline of the structures is located in the center of the ROW. The graph has a vertical gridline at +75 and -75 feet representing the edges of the ROW. The figures display a total of 100 feet each side of the structure centerline. The electric field data calculated at the edges of the ROW is presented in Table 3-1.

Table 3-1 Estimated Unperturbed Electric Fields in ROW^{(a)(b)}

Condition	Maximum In ROW (kV/m)	Left Edge ROW^(c) (kV/m)	Right Edge ROW^(c) (kV/m)
Maximum Sag Condition at Midspan	4.5	1.2	1.0

- a) No buildings or other obstructions with flat ROW
- b) All values computed at 1.0 meter above ground-line (standard measurement height per IEEE)⁵
- c) As viewed looking east along route

Source: Stanley Consultants

Audible Noise Analysis

One of the field effects of high voltage transmission line operation is that of elevated conductor surface gradients (kV/cm) leading to audible noise phenomenon during foul weather conditions. In the analysis, the data represents values estimated for a wet conductor (L50 Rain). The audible noise levels are described in units of dBA (decibels A weighted). The structures were modeled at an elevation exceeding ninety percent of the CGF line structure elevations above sea level. The conductors were modeled at a 60°F ambient temperature weather condition. The corresponding conductor operating temperature at the 292 MVA summer design load level⁴ is 93°F. The calculations were performed at the average conductor height during the 60°F ambient (93°F conductor operating temperature) sag condition. The perpendicular scan was calculated at a height of 2.0 meters above ground to approximate the height of an adult's ear. The results are presented in Appendix C. The graphical data is summarized in Table 3-2. All scans are lateral (perpendicular) to the ROW. The ROW is 150 feet wide and the centerline of the structures is in the center of the ROW. The graph has a vertical gridline at +75 and -75 feet representing the edges of the ROW. The maximum audible noise level calculated at the edge of the ROW is 45.1 dBA as shown in Table 3-2. The calculated noise level is within the 45.3 dBA design limit established for the CGF Transmission Line Project³.

Table 3-2 Estimated Audible Noise Levels in ROW^{(a)(b)(c)(d)}

Condition	Maximum In ROW (dBA)	Left Edge ROW^(e) (dBA)	Right Edge ROW^(e) (dBA)
Average Conductor Height, 60°F ambient	47.2	44.6	45.1

- a) No buildings or other obstructions with flat ROW
- b) 2.0 meters above ground
- c) L50 Rain
- d) 1,970 feet elevation above sea level
- e) As viewed looking east along route

Source: Stanley Consultants

Magnetic Fields

Introduction

While transmission line electric fields are a function of voltage, magnetic fields are a function of the electric current flowing in the line. Line geometry and line current play the largest roles in determining magnetic field levels at any point in nearby space. The line geometry parameters are the same as the electric fields. The magnetic field intensity (H) is described in units of Ampere/meter (A/m). The common unit used to discuss magnetic fields in terms of induction is the magnetic flux density (B) described in units of Tesla (T). The magnetic flux density is equal to the magnetic field intensity times the magnetic permeability of free space ($\mu = 4\pi \times 10^{-7} \text{ N/A}^2$). One Gauss is equal to 10^{-4} Tesla which is the fundamental unit of measurement of magnetic flux density. The unit of milliGauss (mG) is more convenient to discuss transmission line magnetic field values and will be the unit of display in this report.

When calculating magnetic fields due to a long cylinder (cable) of line current, the field is evaluated along a lateral axis perpendicular to the line. The display is similar to electric fields with the horizontal axis being a unit of distance along the axis perpendicular to a transmission line and the vertical axis being the magnetic field (mG) magnitude. The elevation of the magnetic field evaluation locations must be identified for the graph to be valid.

The geometry of the circuit combines the magnetic fields from the phase locations in such a way as to increase the fields in some areas and cancel or reduce the fields in other places. This magnification and cancellation is a vector super-positioning of the fields. The increase is slightly off center on the side carrying the single phase.

Unlike electric fields, transmission line magnetic fields are not perturbed by buildings or non-magnetic objects nearby. When there is zero current in these objects, the magnetic field directly outside the buildings may be the same as directly inside. This greatly simplifies the evaluation and presentation of data.

Magnetic Field Analysis

The structure geometry is the same as assumed for the electric field effects and is shown in Figure 2-2. The lateral scan is taken at midspan.

The calculations are based on the assumption of a flat earth plane beneath the transmission line. The magnetic field values for two levels of current were evaluated. The effect from increased current is twofold: 1) stronger field; 2) greater sag which also increases the field. The first load case is for the thermal limit emergency line rating of 1,686 MVA associated with a 212°F conductor temperature (1,411 amperes per sub-conductor). The second load case is for the maximum expected loading of 338 amperes per sub-conductor corresponding to 404 MVA winter design load⁴.

These currents generally may not be sustained throughout the day but will vary depending on the actual line current flow and power transfer. Therefore, the magnetic fields will also vary proportional to the current in the line.

Scans of the magnetic field at the locations described above are presented in Appendix D. They are calculated at a height of 1.0 meter above the ground. The maximum magnetic field in the ROW is near the center of the ROW.

A summary of key values can be seen in Table 4-1.

Table 4-1 Estimated Magnetic Fields^{(a)(b)}

Condition	Maximum In ROW (mG)	Left Edge ROW^(c) (mG)	Right Edge ROW^(c) (mG)
Thermal Limit Emergency Rating (1,686 MVA)	341.3	99.6	85.3
Maximum Expected Load (404 MVA)	74.9	23.2	19.9

- a) No buildings or other obstructions with flat ROW
- b) 1.0 meter above ground (standard measurement height per IEEE) ⁵
- c) As viewed looking east along route

Source: Stanley Consultants

Summary

Introduction

This report presents estimates of the Electric Field, Audible Noise, and Magnetic Field levels which can be expected within the right-of-way of the proposed Center to Grand Forks 345 kV Transmission Line. The common themes in the analysis of both electric and magnetic fields are the line geometry, operating voltage, line current, and distance from the circuits. The maximum values for the field levels within and at the edge of the right-of-way are summarized in Table 5-1.

Table 5-1 Summary of Maximum Calculated levels in ROW

Condition	Maximum Values	
	Within ROW	Edge of ROW
Electric Field	4.5 kV/m	1.2 kV/m
Magnetic Field	341.3 mG	99.6 mG
Audible Noise (L50 Rain)	47.2 dB(A)	45.1 dB(A)

Source: Stanley Consultants

Appendix A

References

Documents utilized as the basis of this report are listed in this Appendix:

1. EMF Tools; Software developed at the Bonneville Power Administration (BPA), based on the methodology in Reference 2.
2. *Transmission Line Reference Book – 345kV and Above*; Second Edition, 1982, Electric Power Research Institute, Inc., Palo Alto, CA, USA.
3. *CGF Transmission Design Outline*, Stanley Consultants, Inc.
4. Gunderson, Grant. “*CGF 345 kV Line Requirements (Thermal Analysis Only)*,” 28 July 2009.
5. *ANSI/IEEE Std 644-1987*. IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines; June 19, 1986.

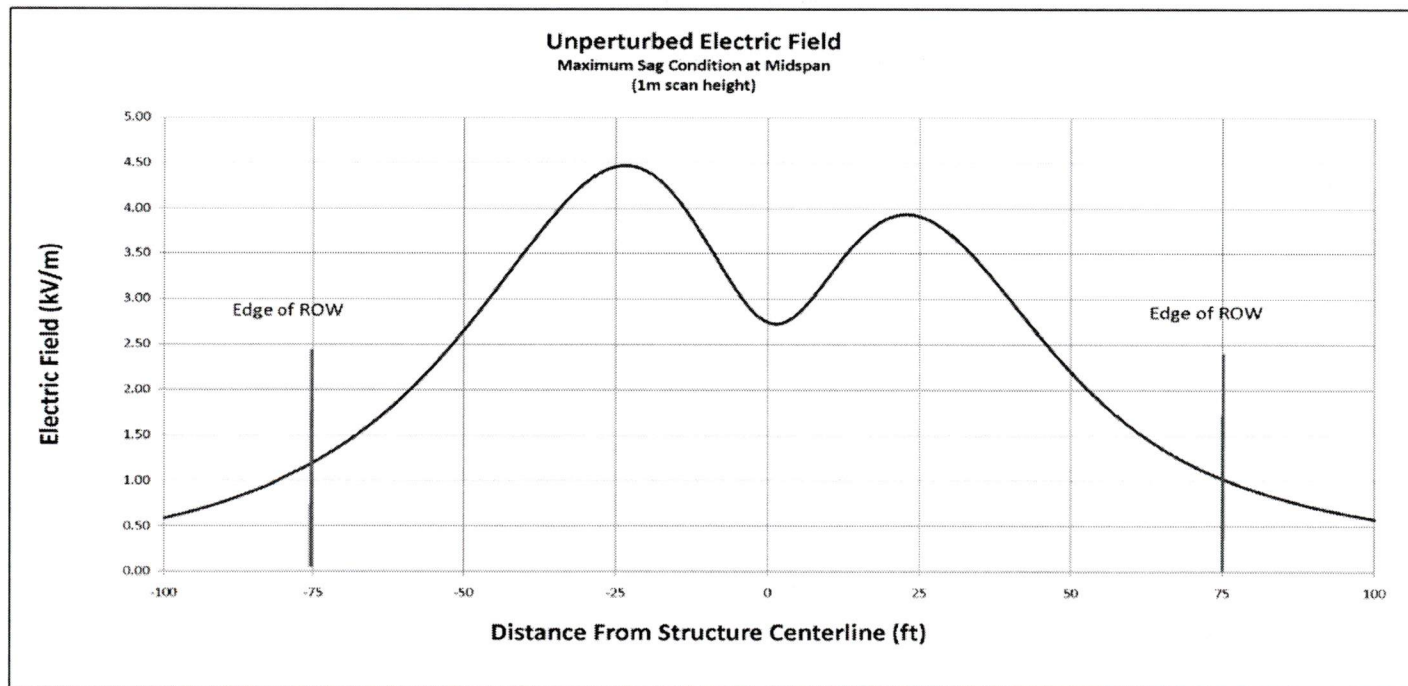
Appendix B

Electric Field Estimates

Appendix B includes the following figures containing the electric field estimates for the locations described below.

Figure List

B-1: Unperturbed Electric Field



As viewed looking east along route

Unperturbed Electric Field
Figure B-1

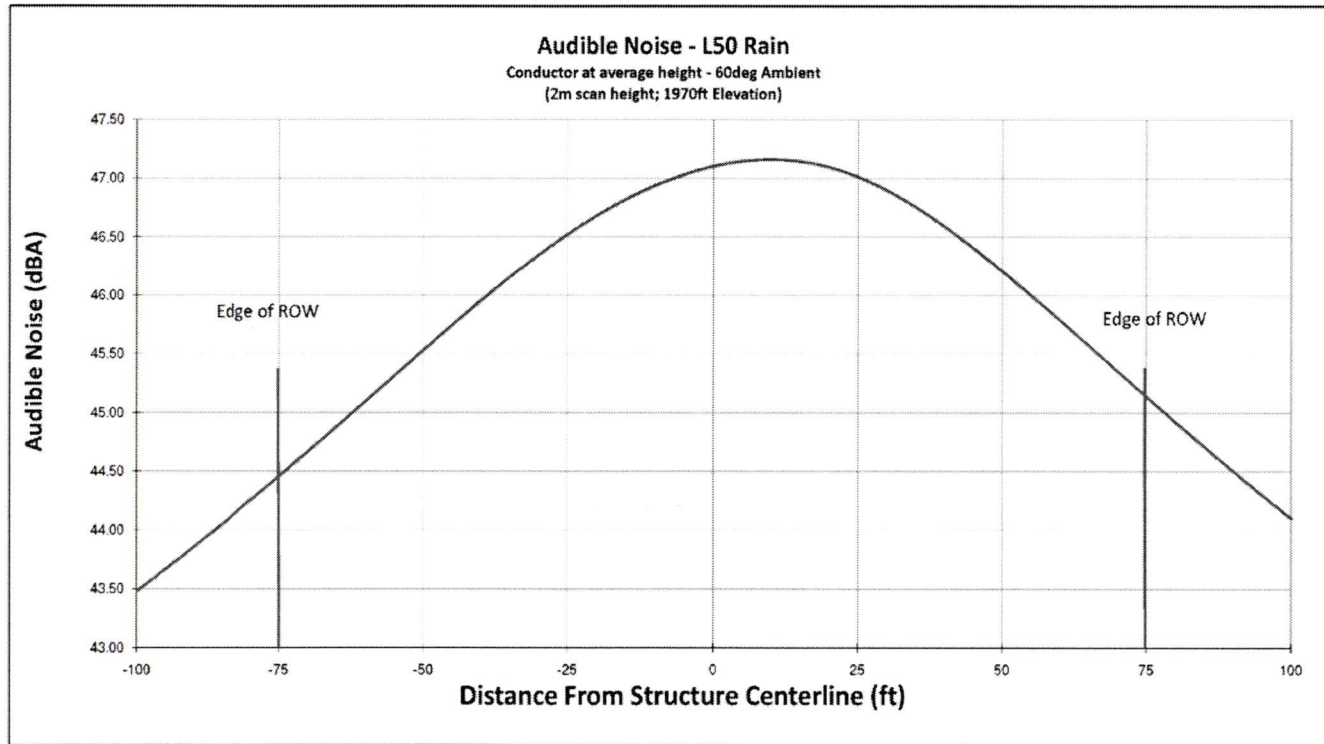
Appendix C

Audible Noise Estimates

Appendix C contains the following estimates of the Audible Noise levels for an L50 rain at 1970 feet elevation.

Figure List

C-1: Audible Noise – L50 Rain



As viewed looking east along route

Audible Noise - L50 Rain
Figure C-1

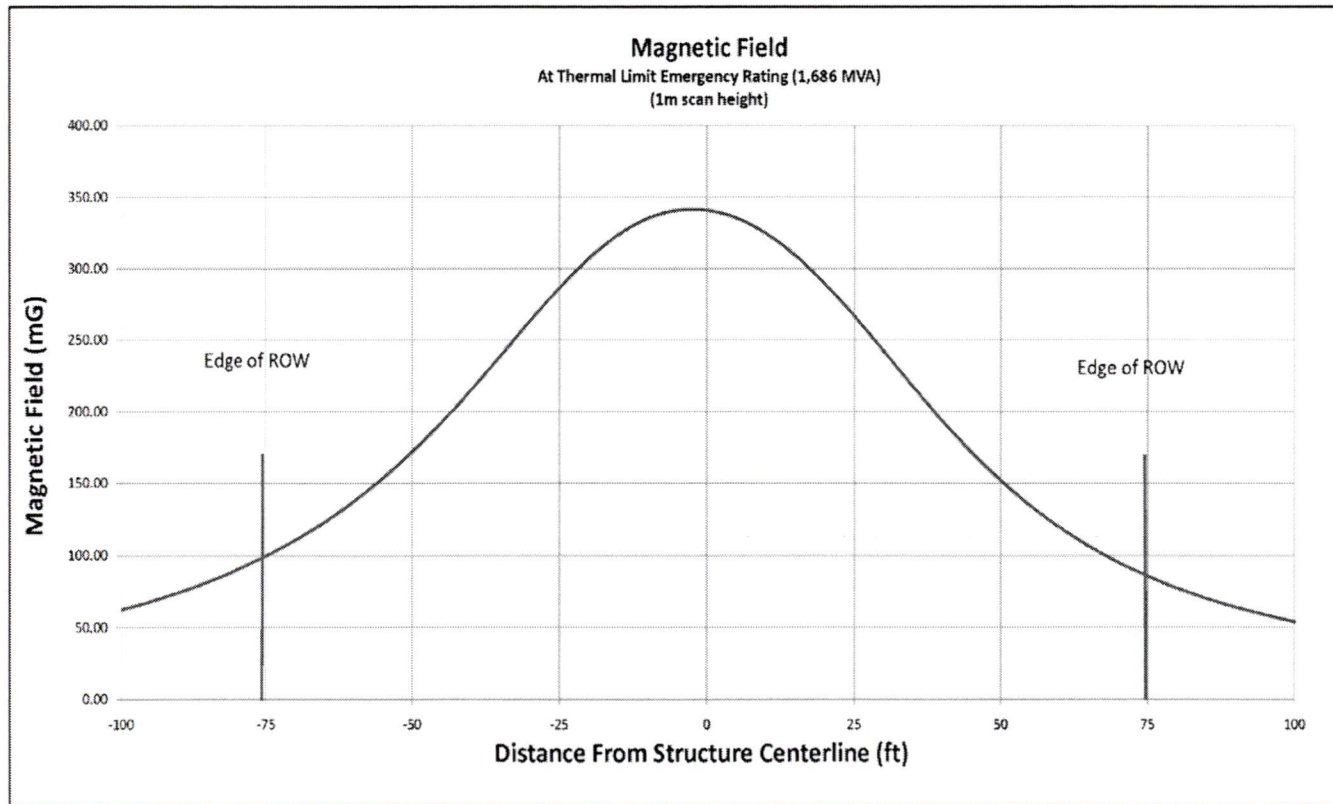
Magnetic Field Estimates

Appendix D contains magnetic field profile estimates with conductor at rest.

Figure List

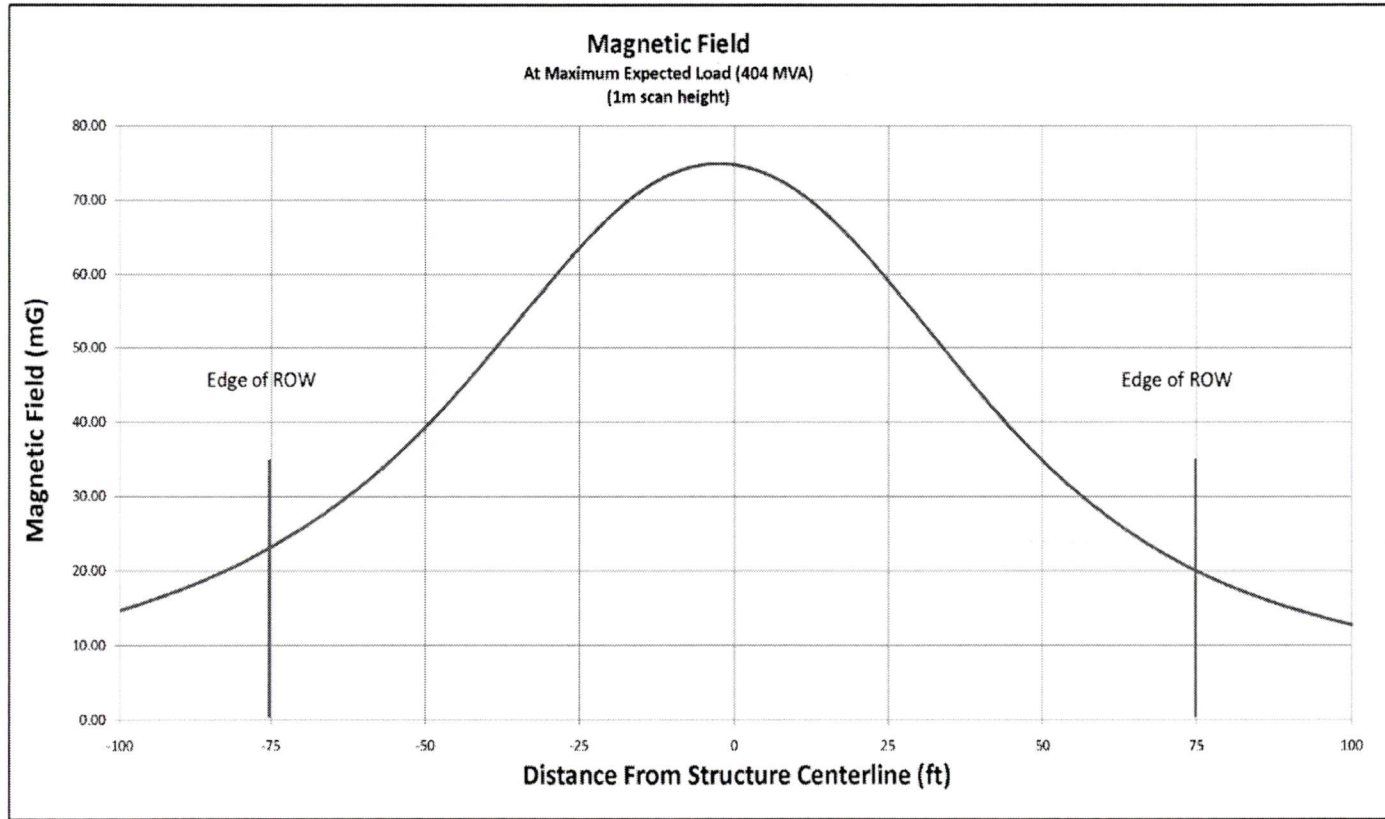
D-1: Magnetic Field at Thermal Limit Emergency Rating

D-2: Magnetic Field at Maximum Expected Load



As viewed looking east along route

Magnetic Field at Thermal Limit Emergency Rating
Figure D-1



As viewed looking east along route

Magnetic Field at Maximum Expected Load
Figure D-2