

BASIN ELECTRIC POWER COOPERATIVE

**ANTELOPE VALLEY STATION TO NESET
345 kV TRANSMISSION LINE PROJECT**

EMF REPORT



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INTRODUCTION

Basin Electric Power Cooperative (Basin Electric) is proposing to construct a new transmission line in North Dakota, named the Antelope Valley Station to Neset 345 kV Transmission Line Project. The project is needed to deliver electricity to the northwestern part of North Dakota to help meet a rapidly increasing demand for electricity and maintain system reliability.

Enertech Consultants was retained to perform calculations of the power-frequency electric and magnetic fields for the 345 kV transmission project for different load conditions and line configurations. This assessment report includes the electric and magnetic field calculation results.

UNITS OF MEASURE

Magnetic fields are reported using units of gauss (G). However, it is usually more convenient to report magnetic field using milligauss (mG), which is equal to one-thousandth of a gauss (i.e., $1 \text{ mG} = 0.001 \text{ G}$). Some technical reports also use the unit tesla (T) or microtesla (μT ; $1 \mu\text{T} = 0.000001 \text{ T}$) for magnetic field. The conversion between these two units is $1 \text{ mG} = 0.1 \mu\text{T}$ and $1 \mu\text{T} = 10 \text{ mG}$.

Electric fields are reported in volts per meter (V/m) or thousands of volts per meter (kV/m).

DESCRIPTION OF ELECTRIC AND MAGNETIC FIELDS

Electric and magnetic fields (EMF) occur throughout nature and are among the basic forces of nature. An object with an electric charge on it has a voltage (potential) and can create an electric field. The change in voltage over distance is known as the electric field. When electrical charges move together (known as “current”), they can create forces on other nearby electric currents. These forces are represented by magnetic fields. All electric currents create magnetic fields.

Electric Fields

The potential or voltage (electrical pressure) on an object causes an electric field. Any object with an electric charge on it has a voltage (potential) at its surface, caused by the accumulation of more electrons on that surface as compared with another object or surface. The voltage effect is not limited to the surface of the object but exists in the space surrounding the object in diminishing intensity. Electric fields can exert a force on other electric charges at a distance. The change in voltage over distance is known as the electric field. The units describing an electric field are volts per meter (V/m) or kilovolts per meter (kV/m). This unit is a measure of the difference in electrical potential or voltage that exists between two points one meter apart. The electric field becomes stronger near a charged object and decreases with distance away from the object.

Electric fields are a very common phenomenon. Static electric fields can result from friction generated when taking off a sweater, sliding across a car seat, or walking across a carpet. Body voltages have been measured as high as 16,000 volts due to walking on a carpet.⁽¹⁾ The earth

creates a natural static electric field in fair weather that is due to the 300,000 to 400,000 volt potential difference between the ionosphere and the surface of the earth.⁽²⁾ At ground level the average value of the earth's electric field is approximately 120 V/m. This means that a 6-foot tall person would have a static potential of about 220 volts between the top and bottom of their body. The normal fair weather static electric field of the earth varies from month to month, reaching a maximum of about 20 percent above normal in January, when the earth is closest to the sun, and falling to about 20 percent below normal by July, when the earth is farthest from the sun. Much stronger static electric potentials can exist underneath storm clouds, where the electric potential of clouds (with respect to earth) can reach 10 to 100 million volts.⁽²⁾ Natural static electric fields under clouds and in dust storms can reach 3 to 10 kV/m.⁽³⁾

All household appliances and other devices that operate on electricity create electric fields. However, these fields are different from the earth's static or direct current (DC) field and some comparisons between DC and AC fields may not be appropriate. Fields produced by electrical appliances that use alternating current (AC) reverse direction at a frequency of 60 cycles per second (60 Hertz, or Hz) in the United States. In many other countries, this frequency is 50 Hz. The electric field in this case is caused by the changing electric voltage in the appliance. The magnitude of the electric field decreases rapidly with distance from the device. The field caused by point source (compact, small-dimension) household appliances generally attenuates more rapidly with distance than line source fields (such as from power lines).

Magnetic Fields

An electric current flowing in a conductor (electric equipment, household appliance, power circuits, etc.) creates a magnetic field. The most commonly used magnetic field intensity unit of measure is the gauss (G). For most practical applications, the gauss is too large, so a much smaller unit, the milligauss (mG), is used for reporting magnetic field magnitudes. The milligauss is one thousandth of a gauss.

As a general reference, the earth has a natural static or direct current (DC) magnetic field of about 0.590 gauss, or 590 mG, in North Dakota.⁽⁴⁾ As with electric fields, the magnetic fields from electric power facilities and appliances differ from static (or DC) fields because they are caused by the flow of alternating currents.

Since the magnetic field is caused by the flow of an electric current, a device must be operated to create a magnetic field. Magnetic field strengths of a large number of common household appliances have been measured, and typical magnetic field values for some appliances range from about one mG to several gauss.⁽⁵⁾

Transmission Line Electric and Magnetic Fields

Overhead electric transmission lines and distribution lines create 60 Hz electric and magnetic fields. The strength of the electric and magnetic field is primarily a function of line voltage and current respectively, as well as the electrical configuration of the conductors (phasing arrangement and spacing, distance above ground level, etc.) and distance away from the line.

Field strengths from a 3-phase transmission line decrease rapidly with distance away from the line, usually at a rate of approximately one divided by the distance squared ($1/d^2$). In contrast, the field strength from a single conductor typically decreases at a rate of approximately one divided by the distance ($1/d$), while field strengths from appliances usually decreases at a rate of approximately one divided by the distance cubed ($1/d^3$).

Transmission line electric fields can easily be shielded (or weakened) by the presence of conducting objects. For example, a typical house shields about 90 - 95 percent of electric fields from the outside sources.⁽⁶⁾ Other objects, such as trees, shrubs, walls, and fences, will also provide electric field shielding. Unlike electric fields, most ordinary objects cannot easily shield magnetic fields. Many common materials (wood, air, concrete, earth, people, etc.) do not shield magnetic fields. However, ferromagnetic materials (such as iron or steel) and conductive materials (such as copper or aluminum) can shield them.

AVS – NESET 345 kV TRANSMISSION LINE PROJECT DESCRIPTION

Basin Electric is in the process of permitting a 200-mile, high-voltage transmission line from the Antelope Valley Station north of Beulah, ND, to a substation just east of Tioga, ND. Called the Antelope Valley Station (AVS) to Neset 345 kV Transmission Line Project, the line would deliver electricity to the northwestern portion of North Dakota to help meet increasing demand for electricity and to maintain system reliability.

The proposed transmission line would start at Antelope Valley, and proceed west to the Charlie Creek substation (about 18 miles west of Killdeer, ND). From there, the proposed transmission line would travel in a northwesterly direction to Williston, ND, where the proposed line would tie into an existing Western Area Power Administration substation. The proposed transmission line would then travel easterly to where it ends at the Neset substation.

The proposed single circuit 345 kV transmission line would be supported on tubular steel structures and centered within a 115-foot wide right-of-way. A single 1.802-inch diameter conductor would be utilized for each phase conductor. In addition, two single 0.50-inch conductors would be utilized as shield wires. Projected loading was specified as 550 MVA (920.4 amps per phase) for typical loading and 700 MVA (1,171.4 amps per phase) for peak loading conditions. The proposed minimum ground clearance (under maximum sag conditions) for both typical and peak loading conditions will be 30-feet. Horizontal and vertical phase spacing for the proposed line would be dependent upon the transmission line configuration. Figure 1 presents a diagram of the three possible line configurations. The proposed 345 kV line could be configured in one of three different line configurations:

- Delta Configuration
- H-Frame Configuration
- Double Circuit Configuration (345 kV and 115 kV circuits)

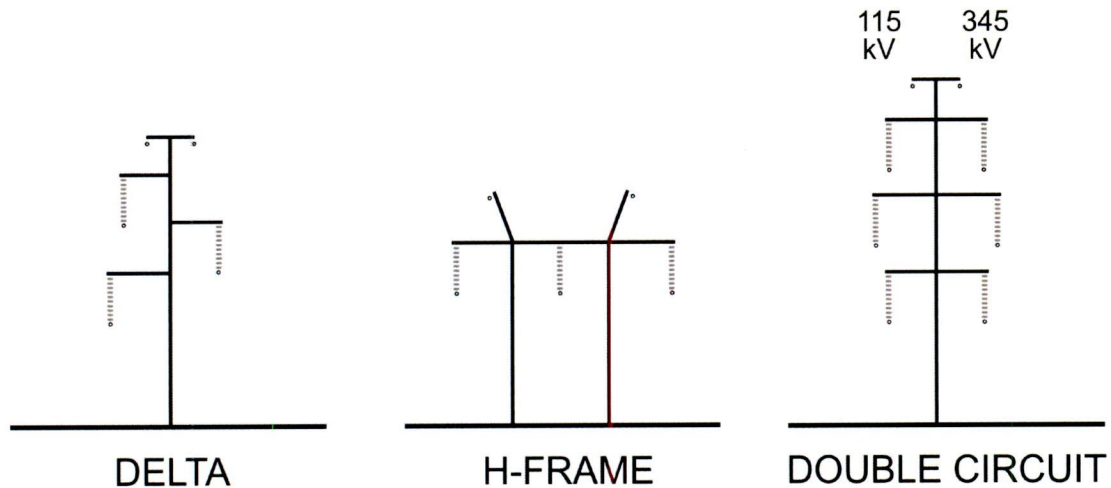


Figure 1. Three Possible Line Configurations for the Proposed 345 kV Transmission Line

DESCRIPTION OF ELECTRIC AND MAGNETIC FIELD CALCULATIONS

Electric and magnetic field calculations were performed for each of the three different line configurations and for both typical and peak loading conditions using the minimum ground clearance. A worst case 5% overvoltage condition was applied for the electric field calculations. The magnetic field was calculated for both typical loading and peak loading.

Electric and magnetic fields were calculated using standard engineering methods. A computer program originally developed by the Bonneville Power Administration was used to perform these calculations.⁽⁷⁾ This popular engineering software uses standard computational algorithms, has been in use for over 30 years, and its accuracy is well documented. This software was used to perform computer modeling of the various transmission line cases and calculate resulting EMF levels.

Electric and magnetic field calculations were performed at 1 meter (3.28-feet) above ground level according to IEEE Standard 644-1994, measurement procedures for power frequency electric and magnetic fields from AC power lines.⁽⁸⁾

SUMMARY OF CALCULATION RESULTS

Electric and magnetic field calculations were performed for the Basin Electric proposed 345 kV transmission line using three different transmission line configurations and for two different loading conditions (typical and peak loading). Table 1 presents a summary of the calculation results.

Table 1
Electric and Magnetic Field Calculation Results

Calculation Parameter	Line Configuration		
	Delta	H-Frame	Double Circuit
Electric Field (kV/m)			
ROW Edge	0.72	1.35	0.15
Max on ROW	4.51	5.08	4.70
ROW Edge	0.88	1.35	0.22
Magnetic Field (mG)			
<i>Typical Loading</i>			
ROW Edge	29.3	51.8	15.9
Max on ROW	140.7	202.6	124.4
ROW Edge	27.6	51.8	34.9
Magnetic Field (mG)			
<i>Peak Loading</i>			
ROW Edge	37.2	66.0	16.9
Max on ROW	179.1	257.8	152.8
ROW Edge	35.1	66.0	38.9

DELTA CONFIGURATION RESULTS

Calculated electric field levels across the right-of-way at midspan range from about 0.72 kV/m to 0.88 kV/m at the right-of-way edges, with a maximum of 4.51 kV/m within the right-of-way.

Under typical loading conditions, calculated magnetic field levels across the right-of-way at midspan range from about 27.6 mG to 29.3 mG at the right-of-way edges, with a maximum of 140.7 mG within the right-of-way. Under peak loading conditions, calculated magnetic field levels across the right-of-way at midspan range from about 35.1 mG to 37.2 mG at the right-of-way edges, with a maximum of 179.1 mG within the right-of-way.

Figure 2 presents the electric and magnetic field calculation results associated with the single circuit delta configuration. A tabular summary of the field calculations is presented in Table 2.

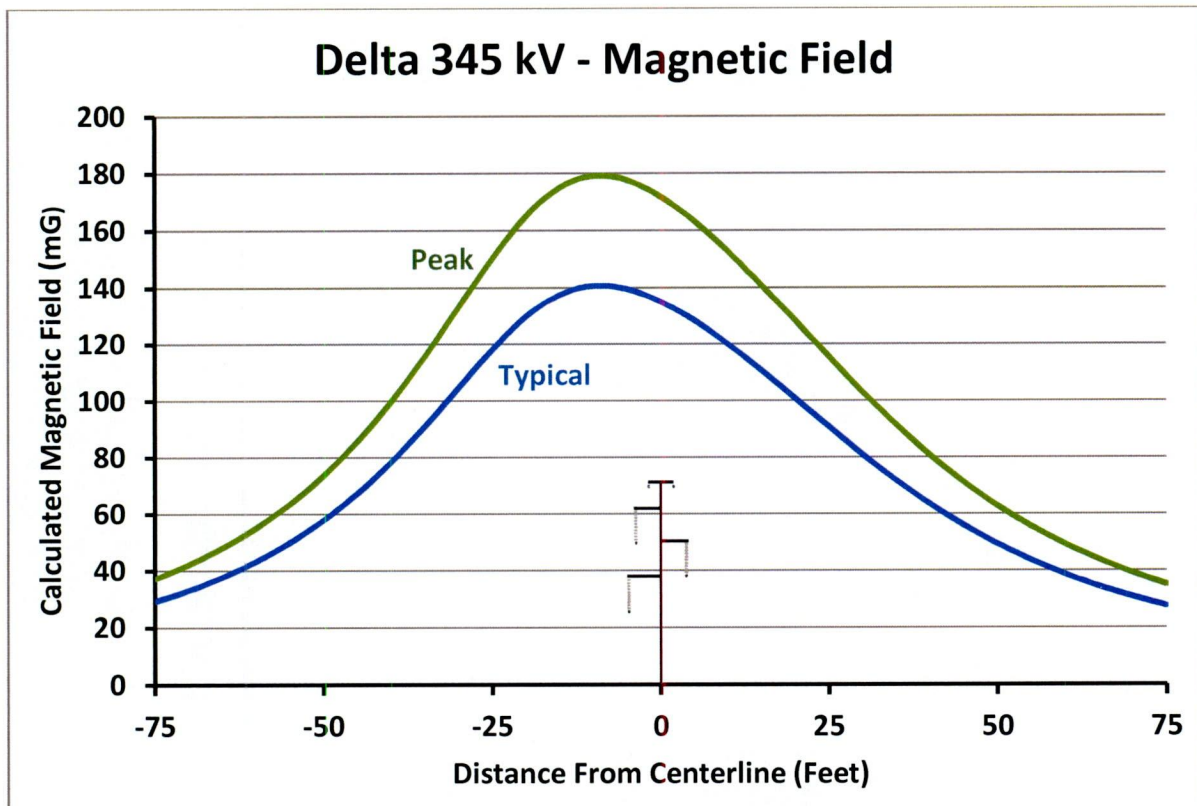
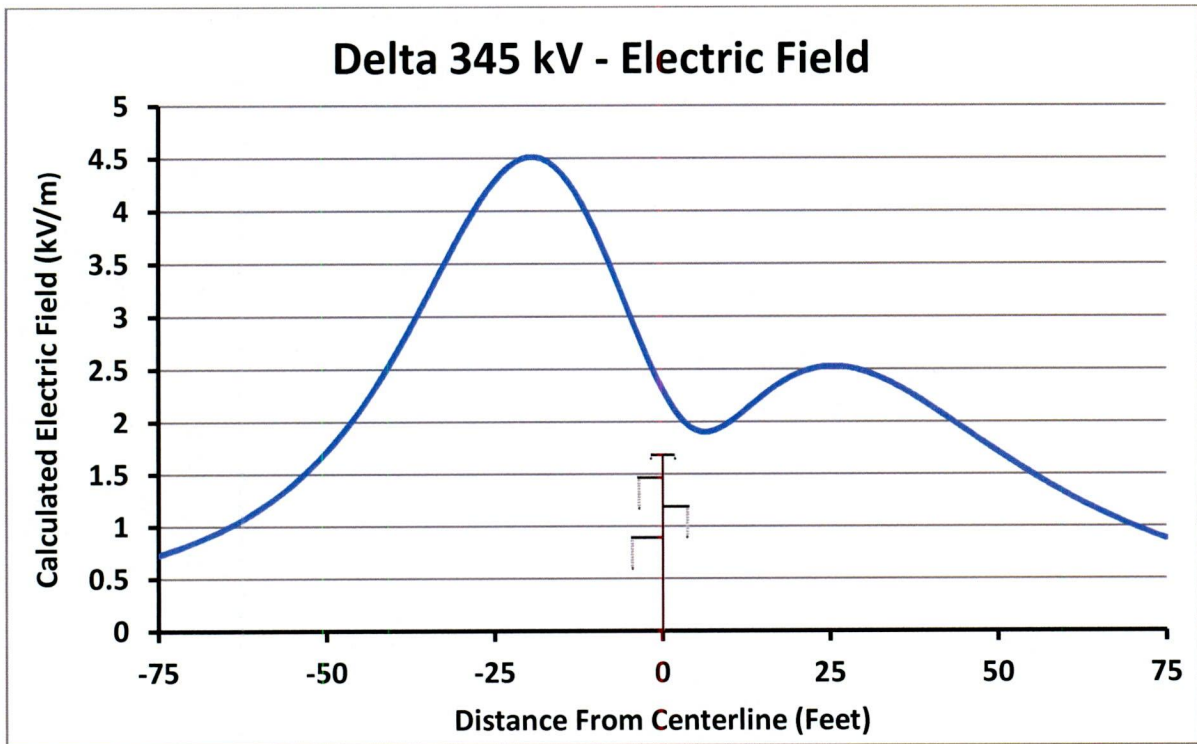


Figure 2. Delta Configuration: Electric and Magnetic Field Calculation Results

Table 2
Single Circuit Delta: Electric and Magnetic Field Calculation Results

Distance from Centerline (Feet)	Electric Field (kV/m)	Magnetic Field (mG)	
		Typical Load	Peak Load
-75	0.72	29.3	37.2
-70	0.84	33.1	42.2
-65	0.98	37.8	48.1
-60	1.16	43.3	55.1
-55	1.40	49.9	63.5
-50	1.71	57.8	73.6
-45	2.11	67.2	85.6
-40	2.61	78.3	99.6
-35	3.19	90.8	115.6
-30	3.79	104.4	132.9
-25	4.28	117.8	150.0
-24	4.35	120.4	153.2
-23	4.41	122.8	156.3
-22	4.46	125.1	159.3
-21	4.49	127.3	162.1
-20	4.51	129.4	164.7
-19	4.51	131.3	167.2
-18	4.50	133.1	169.4
-17	4.47	134.7	171.4
-16	4.42	136.1	173.2
-15	4.35	137.3	174.8
-14	4.27	138.4	176.1
-13	4.18	139.2	177.2
-12	4.07	139.9	178.0
-11	3.95	140.3	178.6
-10	3.82	140.6	179.0
-9	3.67	140.7	179.1
-8	3.52	140.7	179.0
-7	3.37	140.4	178.7
-6	3.21	140.1	178.3
-5	3.05	139.5	177.6
-4	2.89	138.9	176.8
-3	2.74	138.1	175.8
-2	2.59	137.2	174.6
-1	2.45	136.2	173.3
0	2.32	135.1	171.9

Table 2 - Continued
Single Circuit Delta: Electric and Magnetic Field Calculation Results

Distance from Centerline (Feet)	Electric Field (kV/m)	Magnetic Field (mG)	
		Typical Load	Peak Load
0	2.32	135.1	171.9
1	2.20	133.9	170.4
2	2.10	132.6	168.8
3	2.02	131.3	167.1
4	1.96	129.8	165.2
5	1.92	128.3	163.3
6	1.90	126.8	161.4
7	1.90	125.2	159.3
8	1.92	123.5	157.2
9	1.95	121.8	155.0
10	1.99	120.0	152.8
11	2.04	118.2	150.5
12	2.09	116.4	148.2
13	2.14	114.5	145.8
14	2.19	112.6	143.4
15	2.25	110.7	140.9
16	2.29	108.8	138.4
17	2.34	106.8	135.9
18	2.38	104.8	133.4
19	2.42	102.8	130.9
20	2.45	100.8	128.3
21	2.47	98.8	125.8
22	2.50	96.8	123.2
23	2.51	94.8	120.7
24	2.52	92.8	118.1
25	2.53	90.8	115.6
30	2.48	81.0	103.1
35	2.34	71.8	91.4
40	2.15	63.4	80.7
45	1.93	56.0	71.2
50	1.71	49.4	62.8
55	1.51	43.7	55.6
60	1.32	38.7	49.3
65	1.15	34.4	43.8
70	1.01	30.8	39.2
75	0.88	27.6	35.1

H-FRAME CONFIGURATION RESULTS

Calculated electric field levels across the right-of-way at midspan range from about 1.35 kV/m at the right-of-way edges to a maximum of 5.08 kV/m within the right-of-way.

Under typical loading conditions, calculated magnetic field levels across the right-of-way at midspan range from about 51.8 mG at the right-of-way edges to a maximum of 202.6 mG within the right-of-way. Under peak loading conditions, calculated magnetic field levels across the right-of-way at midspan range from about 66.0 mG at the right-of-way edges to a maximum of 257.8 mG within the right-of-way.

Figure 3 presents the electric and magnetic field calculation results associated with the single circuit delta configuration. A tabular summary of the field calculations is presented in Table 3.

DOUBLE CIRCUIT CONFIGURATION RESULTS

For the double circuit configuration, a 115 kV transmission line circuit is located adjacent to the proposed 345 kV transmission line circuit on the same support structure. The phasing arrangement for both circuits was modeled using a reverse (or UNLIKE) phasing arrangement to reduce EMF. The 115 kV circuit was modeled with a minimum ground clearance at midspan of 40-feet, a 25-foot vertical phase spacing, and having a single 1.063-inch diameter conductor per phase. Loading was specified as 55 MVA (276 amps per phase) for typical loading and 120 MVA (602 amps per phase) for peak loading conditions. A 5% overvoltage condition was also applied to the 115 kV circuit for electric field calculations.

Calculated electric field levels across the right-of-way at midspan range from about 0.15 kV/m to 0.22 kV/m at the right-of-way edges, with a maximum of 4.70 kV/m within the right-of-way.

Under typical loading conditions, calculated magnetic field levels across the right-of-way at midspan range from about 15.9 mG to 34.9 mG at the right-of-way edges, with a maximum of 124.4 mG within the right-of-way. Under peak loading conditions, calculated magnetic field levels across the right-of-way at midspan range from about 16.9 mG to 38.9 mG at the right-of-way edges, with a maximum of 152.8 mG within the right-of-way.

Figure 4 presents the electric and magnetic field calculation results associated with the single circuit delta configuration. A tabular summary of the field calculations is presented in Table 4.

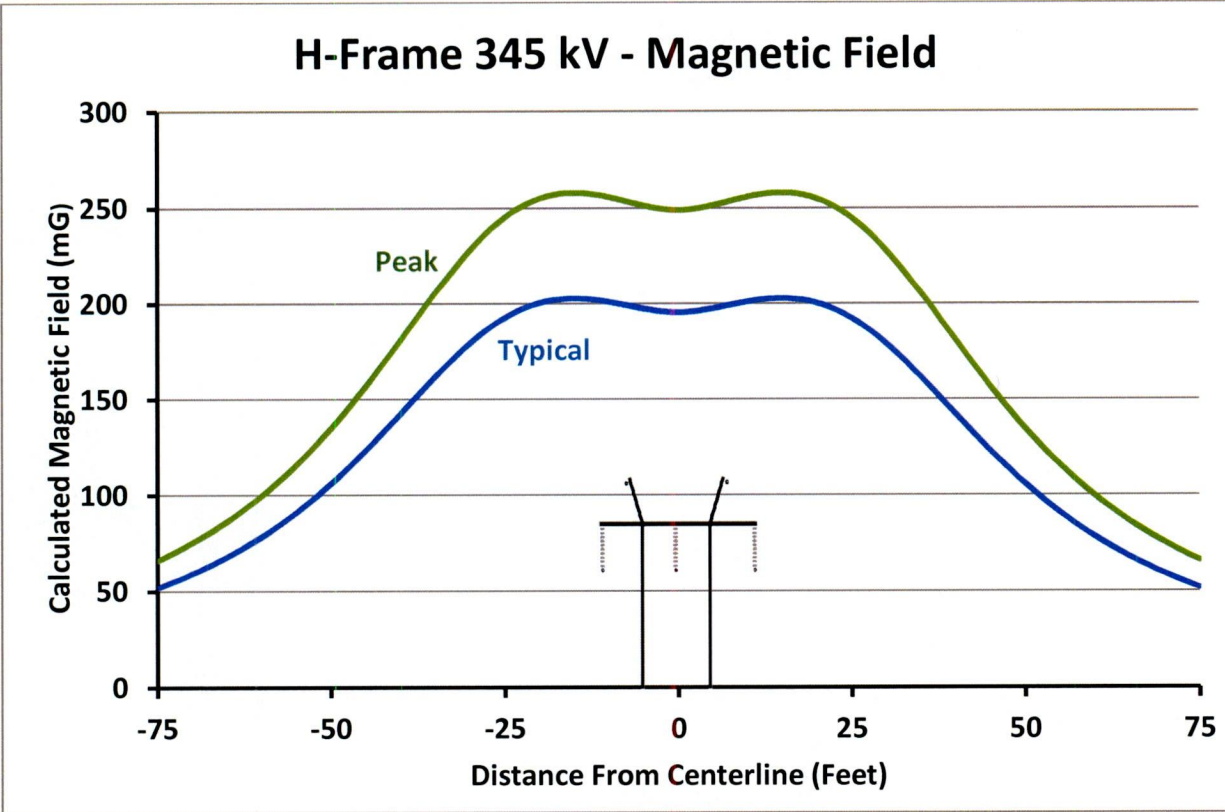
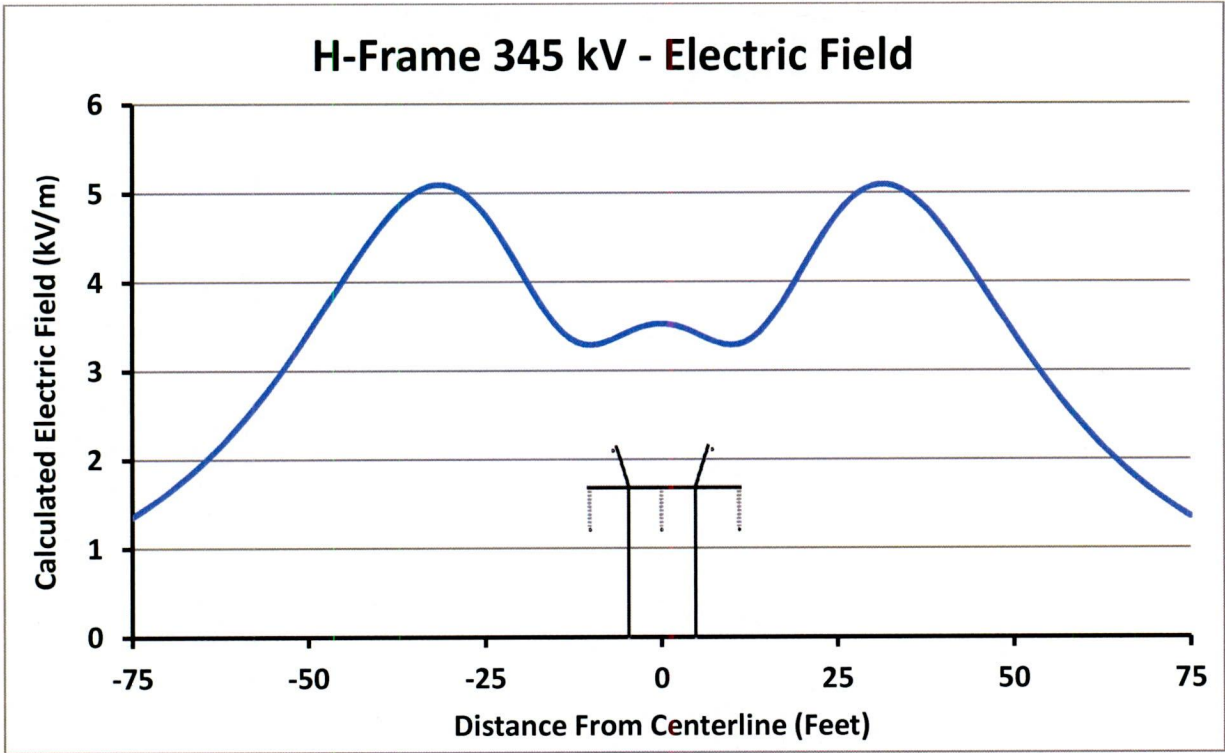


Figure 3. H-Frame Configuration: Electric and Magnetic Field Calculation Results

Table 3
Single Circuit H-Frame: Electric and Magnetic Field Calculation Results

Distance from Centerline (Feet)	Electric Field (kV/m)	Magnetic Field (mG)	
		Typical Load	Peak Load
-75	1.35	51.8	66.0
-70	1.62	59.1	75.2
-65	1.96	67.8	86.3
-60	2.37	78.3	99.7
-55	2.86	90.9	115.7
-50	3.42	105.9	134.7
-45	4.03	123.2	156.8
-40	4.60	142.2	181.0
-35	5.00	161.7	205.8
-30	5.08	179.2	228.1
-25	4.75	192.5	245.0
-24	4.64	194.5	247.5
-23	4.53	196.3	249.8
-22	4.40	197.8	251.8
-21	4.27	199.1	253.4
-20	4.13	200.2	254.8
-19	4.00	201.1	255.9
-18	3.86	201.7	256.8
-17	3.74	202.2	257.4
-16	3.62	202.5	257.7
-15	3.52	202.6	257.8
-14	3.43	202.5	257.7
-13	3.37	202.3	257.4
-12	3.32	201.9	257.0
-11	3.30	201.4	256.4
-10	3.29	200.9	255.6
-9	3.30	200.2	254.8
-8	3.32	199.5	253.9
-7	3.35	198.8	253.0
-6	3.38	198.1	252.1
-5	3.42	197.4	251.2
-4	3.45	196.7	250.4
-3	3.48	196.2	249.7
-2	3.51	195.8	249.2
-1	3.52	195.6	248.9
0	3.52	195.5	248.8

Table 3 - Continued
Single Circuit H-Frame: Electric and Magnetic Field Calculation Results

Distance from Centerline (Feet)	Electric Field (kV/m)	Magnetic Field (mG)	
		Typical Load	Peak Load
0	3.52	195.5	248.8
1	3.52	195.6	248.9
2	3.51	195.8	249.2
3	3.48	196.2	249.7
4	3.45	196.7	250.4
5	3.42	197.4	251.2
6	3.38	198.1	252.1
7	3.35	198.8	253.0
8	3.32	199.5	253.9
9	3.30	200.2	254.8
10	3.29	200.9	255.6
11	3.30	201.4	256.4
12	3.32	201.9	257.0
13	3.37	202.3	257.4
14	3.43	202.5	257.7
15	3.52	202.6	257.8
16	3.62	202.5	257.7
17	3.74	202.2	257.4
18	3.86	201.7	256.8
19	4.00	201.1	255.9
20	4.13	200.2	254.8
21	4.27	199.1	253.4
22	4.40	197.8	251.8
23	4.53	196.3	249.8
24	4.64	194.5	247.5
25	4.75	192.5	245.0
30	5.08	179.2	228.1
35	5.00	161.7	205.8
40	4.60	142.2	181.0
45	4.03	123.2	156.8
50	3.42	105.9	134.7
55	2.86	90.9	115.7
60	2.37	78.3	99.7
65	1.96	67.8	86.3
70	1.62	59.1	75.2
75	1.35	51.8	66.0

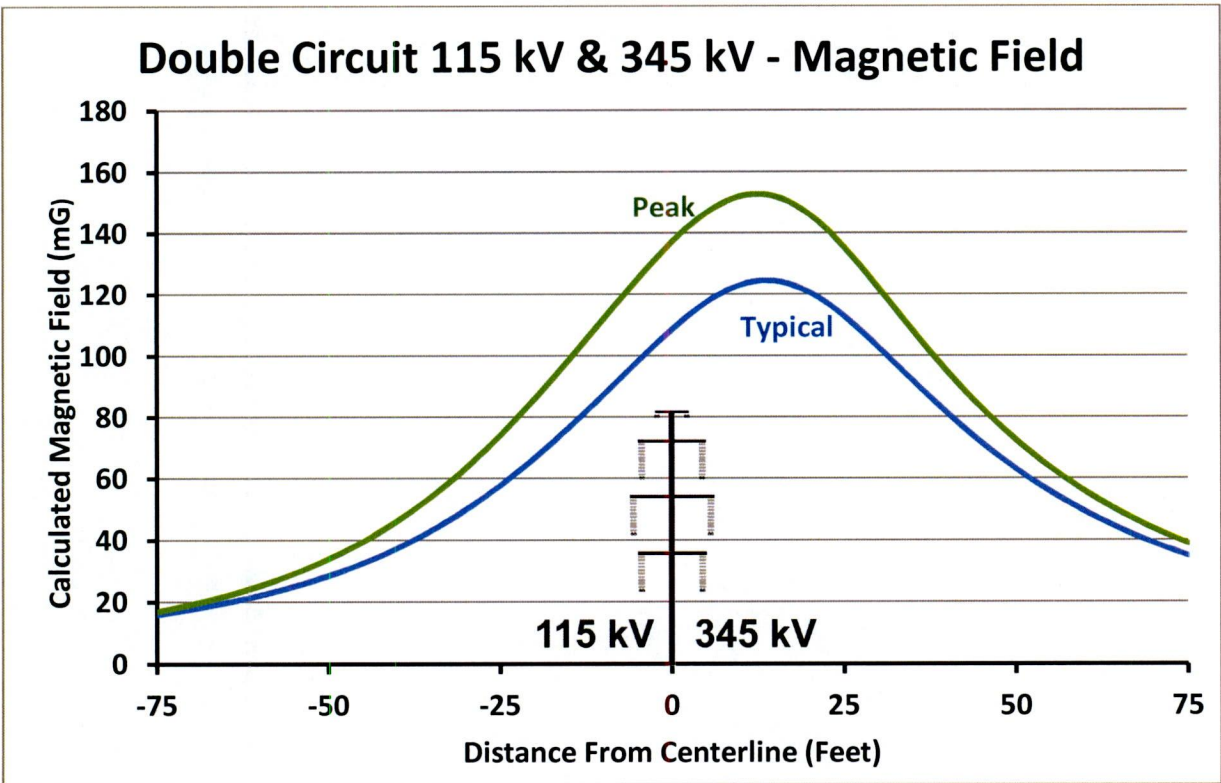
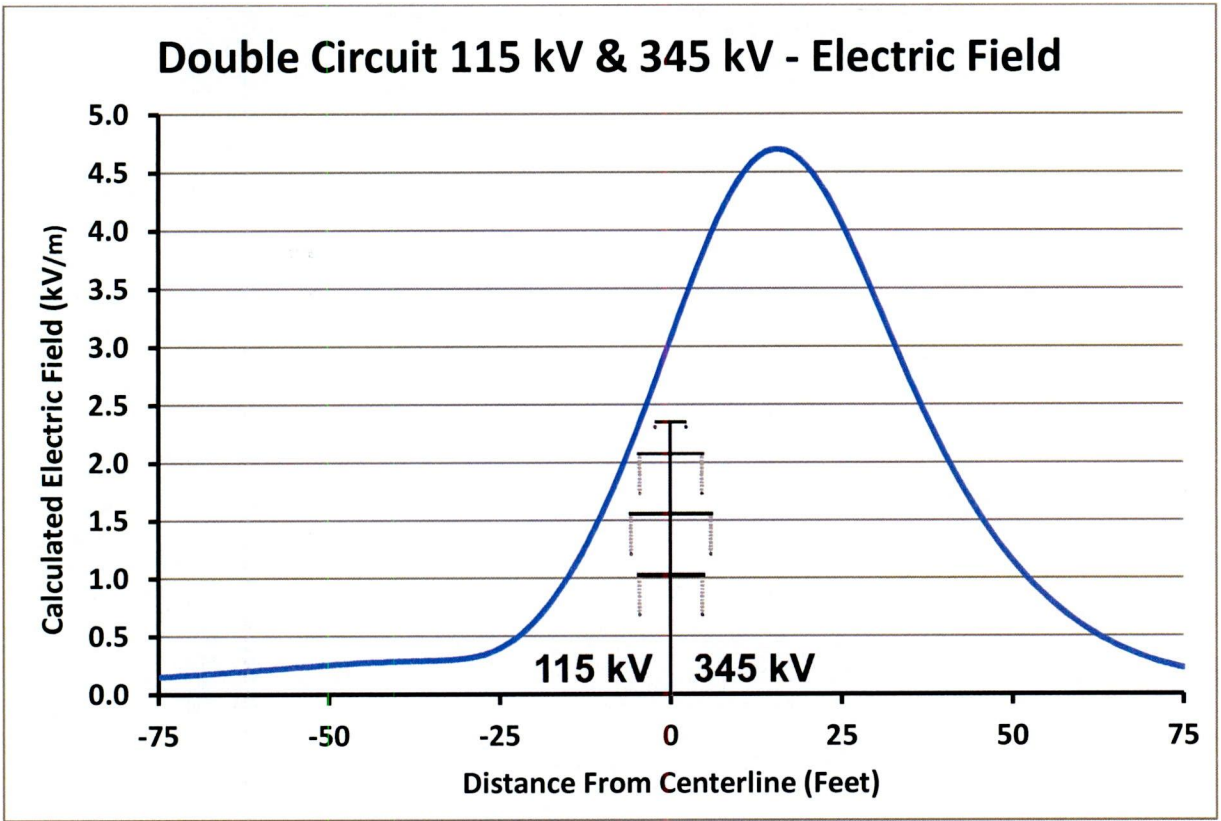


Figure 4. Double Circuit Configuration: Electric and Magnetic Field Calculation Results

Table 4
Double Circuit: Electric and Magnetic Field Calculation Results

Distance from Centerline (Feet)	Electric Field (kV/m)	Magnetic Field (mG)	
		Typical Load	Peak Load
-75	0.15	15.9	16.9
-70	0.17	17.7	19.2
-65	0.19	19.7	21.9
-60	0.21	22.1	25.2
-55	0.23	25.0	29.1
-50	0.25	28.4	33.8
-45	0.27	32.5	39.4
-40	0.28	37.3	46.1
-35	0.29	43.0	54.0
-30	0.31	49.8	63.3
-25	0.39	57.6	73.9
-24	0.42	59.3	76.2
-23	0.46	61.0	78.5
-22	0.51	62.8	80.9
-21	0.56	64.7	83.3
-20	0.62	66.5	85.8
-19	0.68	68.4	88.2
-18	0.75	70.4	90.8
-17	0.83	72.3	93.3
-16	0.91	74.3	95.9
-15	1.00	76.4	98.5
-14	1.10	78.5	101.1
-13	1.21	80.6	103.8
-12	1.32	82.7	106.4
-11	1.43	84.8	109.1
-10	1.56	87.0	111.7
-9	1.69	89.1	114.4
-8	1.82	91.3	117.0
-7	1.96	93.5	119.6
-6	2.11	95.7	122.2
-5	2.26	97.8	124.8
-4	2.41	100.0	127.3
-3	2.57	102.1	129.8
-2	2.73	104.2	132.2
-1	2.89	106.3	134.6
0	3.05	108.3	136.8

Table 4 - Continued
Double Circuit: Electric and Magnetic Field Calculation Results

Distance from Centerline (Feet)	Electric Field (kV/m)	Magnetic Field (mG)	
		Typical Load	Peak Load
0	3.05	108.3	136.8
1	3.21	110.2	139.0
2	3.37	112.1	141.1
3	3.53	113.9	143.0
4	3.68	115.6	144.9
5	3.83	117.2	146.5
6	3.97	118.6	148.0
7	4.10	120.0	149.4
8	4.22	121.1	150.5
9	4.33	122.1	151.4
10	4.43	123.0	152.1
11	4.51	123.6	152.6
12	4.58	124.1	152.8
13	4.63	124.4	152.8
14	4.67	124.4	152.6
15	4.69	124.3	152.1
16	4.70	123.9	151.3
17	4.68	123.4	150.4
18	4.65	122.7	149.2
19	4.61	121.7	147.7
20	4.55	120.6	146.1
21	4.48	119.4	144.3
22	4.39	118.0	142.3
23	4.29	116.4	140.1
24	4.19	114.7	137.8
25	4.07	112.9	135.4
30	3.41	102.8	122.1
35	2.72	91.8	108.1
40	2.09	81.3	94.9
45	1.57	71.6	82.9
50	1.15	63.1	72.5
55	0.84	55.7	63.5
60	0.60	49.3	55.8
65	0.43	43.8	49.3
70	0.30	39.0	43.7
75	0.22	34.9	38.9

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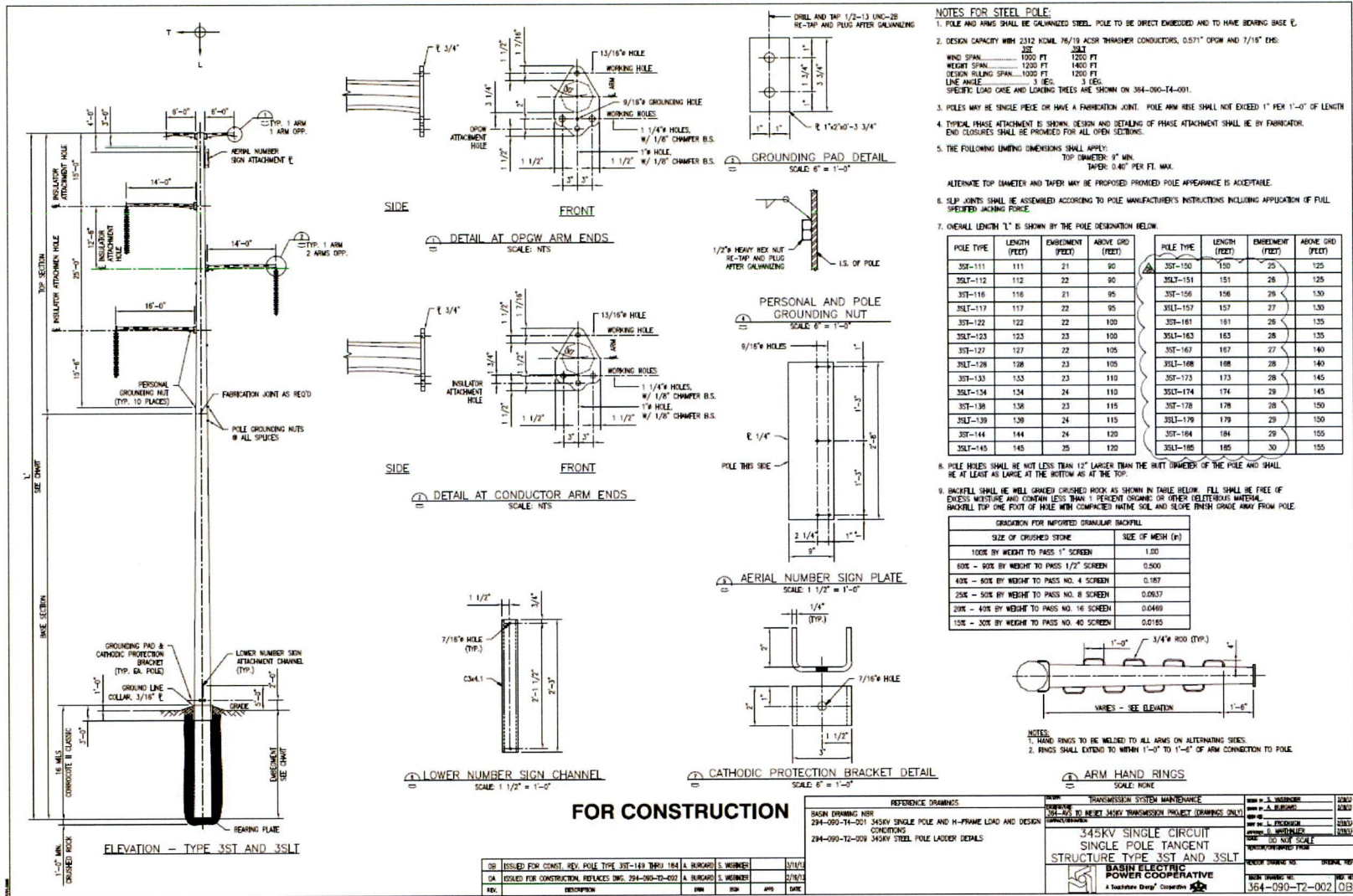
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APPENDIX A

BASIN ELECTRIC

LINE CONFIGURATION DRAWINGS

Figure A-1. Delta Line Configuration Drawing



REFERENCE DRAWINGS		REVISIONS	
BASIN DRAWING NO.	294-090-T4-001 345KV SINGLE POLE AND H-FRAME LOAD AND DESIGN CONDITIONS	NO.	TRANSMISSION SYSTEM MAINTENANCE
294-090-T2-009 345KV STEEL POLE LADDER DETAILS		DATE	304-090-T2-002 (01)
345KV SINGLE CIRCUIT SINGLE POLE TANGENT STRUCTURE TYPE 3ST AND 3SLT		BY	J. WOODRUM
BASIN ELECTRIC POWER COOPERATIVE		CHECKED	J. WOODRUM
A Southern Energy Cooperative		DATE	3/1/11
		SCALE	AS NOTED
		PROJECT	345KV SINGLE CIRCUIT SINGLE POLE TANGENT STRUCTURE TYPE 3ST AND 3SLT

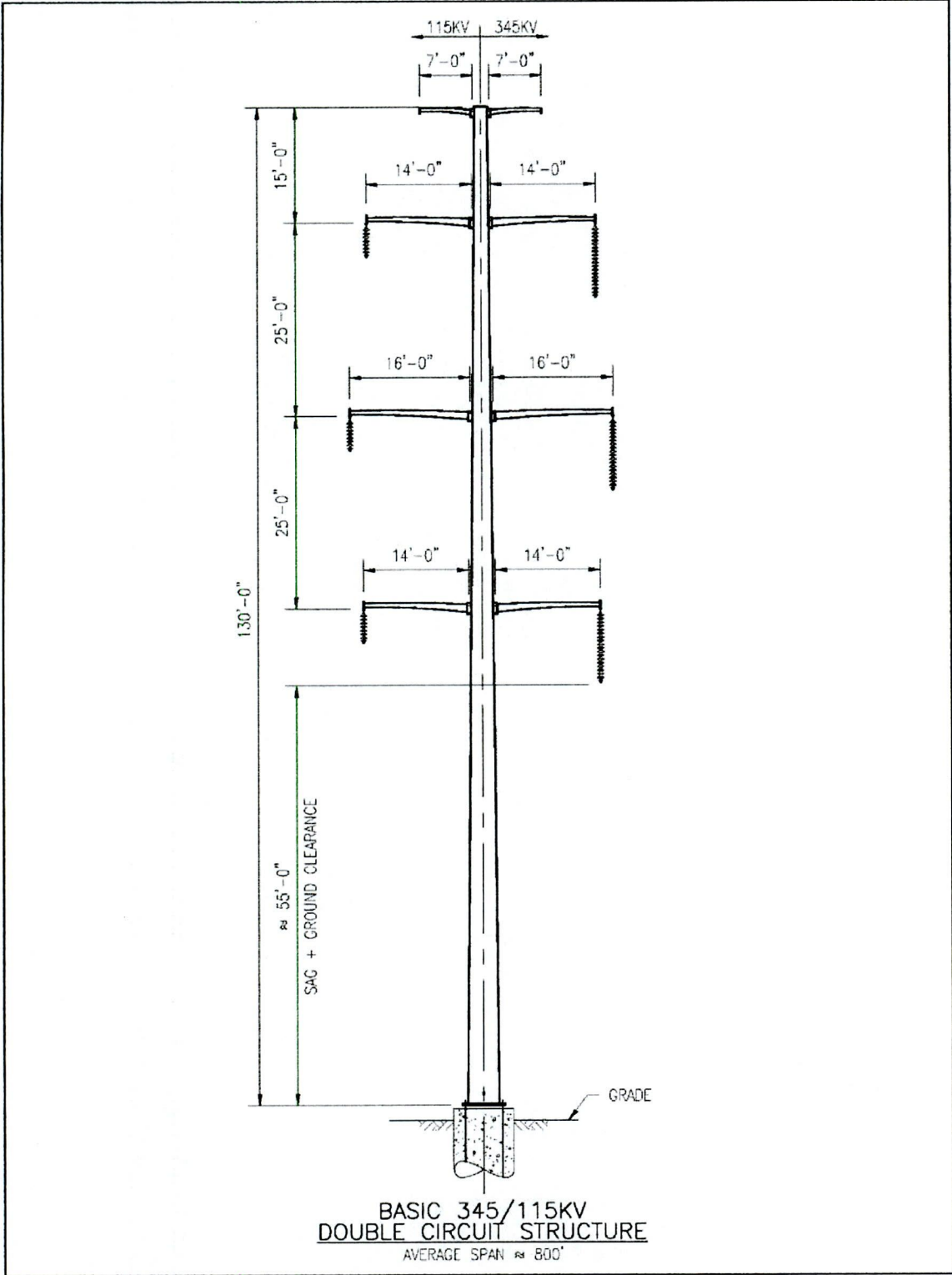


Figure A-3. Double Circuit Line Configuration Drawing