HUGHES BROTHERS, INC.
SEWARD, NE

TRANSMISSION DESIGN

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Since the early 1920’s, the Hughes Brothers’ engineering staff has assisted in the construction of more than a hundred thousand circuit miles of overhead construction.

Our engineering staff is prepared to offer their assistance by providing:

- Structural analysis of tower configurations
- Full scale testing
- Design & computer aided drafting
- Cost analysis and competitive bid analysis
- Project administration i.e., order processing, expediting, delivery coordination for the materials we supply.
- Field inspection and customer service

Transmission engineers are fully aware that the mere assembly of poles, arms, braces, insulators, conductors, guys and hardware is not transmission construction. Properly designed transmission structures result from a complete study of all the conditions affecting the project.

This catalog section gives full consideration to the following important design criteria:

1) The most economically designed tangent structure, which considers only a maximum span, does not usually or necessarily result in the most economical transmission line.

2) Properly designed, efficient transmission structures result from a complete study of the route of the line, including profile, soil types, number and magnitude of angles, and the unusual and local conditions which are a part of any line.

3) Braced H-Frame lines have been built at a savings over unbraced H-Frame lines, resulting in greater strength and lower maintenance.

4) H-Frame lines can and have been built at a savings in cost over single pole lines.

5) Full size tests should be made on new developments before they are used in actual construction.

6) Successful transmission line construction is not based on the length of time in service, but whether it has been subjected to the load for which it was designed.

In the presentation of this manual, we have tried to indicate to designers, operators and builders of overhead construction that our staff of engineers and our testing laboratory are available to the utility industry.
The selection of the design of the tangent structure should be made with reference to the overall cost of the line which will include an analysis of the profile, conductor, right of way and local conditions affecting span lengths.

In general, Type C construction shown below, will rarely produce the most economical line. The span length will be limited, requiring more structures and associated parts; the deflection and earth pressure will be excessive.

The simple installation of the X-brace, as in Type B will eliminate deflection, reduce earth pressure, permit the use of smaller poles and result in longer spans and greater safety factors.

The Type A design will usually result in the safest, strongest and most economical long span, high voltage structure. The knee or vee braces permit the pole tops to act as guided cantilevers by introducing a point of inflection between the cross arm and top of the X-braces. Without these braces, the poles above the X-Braces act as simple cantilevers.

Taken from Hughes Brothers 1937 catalog.
Full Scale Structure Tests - A Continuing Process

1935

1955

1986
Principles that were used 50 years ago are still applicable today

The figure shows the principal forces acting on a pole set in compressible soil and subjected to a horizontal load at a certain distance above the ground line. The pressures developed are considered as the ordinates to a parabola located such that the pressure area on one side of the pole bears the same relation to that on the other side as $R$ does to $P$, these being the butt reactions. By the principle of Moments,

$$P = \frac{W}{x} \text{ and } R = P + W.$$  

Maximum unit pressures developed are calculated by the formula

$$p = \frac{0.003 \, R}{d \times \bar{D}}$$

where

- $d =$ setting depth in feet
- $D =$ butt diameter in feet.

Since the effective point of load application of a braced structure is lowered to about 2/5 that of an unbraced fixture (Examples at bottom of page), the corresponding earth pressures are greatly reduced. Hence, a properly braced structure will stay in alignment under severe loading conditions whereas an unbraced structure will not. Maintenance costs of a braced line are thereby sharply reduced.
X-BRACED H FRAMES

Structural Analysis

Reprinted by request from Hughes Brothers Catalog No. 11, circa late 1940's
Theoretical Maximum Transverse Span Analysis of Hughes Brothers H-Frame Structures

Initial Conditions:
1. Bending stress of pole = 8,000 psi
2. Y = 6'-6"
3. Crossarm height = 8'-9"
4. Z = Pole spacing minus 1 ft
5. 70', class 2 Douglas-fir poles
6. Set depth = 9'-0"
7. Pole spacing = 15'-6"

Find ultimate pole moments at locations a, b, c, d:

\[ M = s f = \frac{\pi d^3}{(12)32} (f) = \frac{\pi c^3}{32r^3} (f) \] therefore:

\[ M = 0.000264fc^3 \text{ (ft - lbs.)} \]

\[ f = \text{Bending stress of pole} \]
\[ c = \text{Circumference(inches) at each location} \]
\[ s = \text{Section modulus at each location(in}^3) \]
\[ M = \text{Moment (ft - lbs.)} \]

<table>
<thead>
<tr>
<th>Location</th>
<th>Circumference in Inches</th>
<th>Ultimate Pole Moment (ft-lbs.)</th>
</tr>
</thead>
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<tr>
<td>a</td>
<td>46.92</td>
<td>218,183</td>
</tr>
<tr>
<td>b</td>
<td>35.69</td>
<td>96,025</td>
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<tr>
<td>c</td>
<td>30.48</td>
<td>59,808</td>
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<tr>
<td>d</td>
<td>28.14</td>
<td>46,804</td>
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NOTE: Circumferences are based on ANSI minimum dimensions.

Find location of planes of contraflexure:

\[ X_0 = \frac{X Ma}{Ma + Mb} = \frac{31.25 \text{ ft.} \times 218,183 \text{ ft - lbs.}}{218,183 \text{ ft - lbs.} + 96,025 \text{ ft - lbs.}} = 21.70 \text{ ft.} \]

\[ X_1 = X - X_0 = 31.25 \text{ ft.} - 21.70 \text{ ft.} = 9.55 \text{ ft.} \]

\[ Y_0 = \frac{YMc}{Mc + Md} = \frac{6.5 \text{ ft.} \times 59,808 \text{ ft - lbs.}}{59,808 \text{ ft - lbs.} + 47,084 \text{ ft - lbs.}} = 3.64 \text{ ft.} \]

\[ X_0 = Y - Y_0 = 6.5 \text{ ft.} - 3.64 \text{ ft.} = 2.86 \]

List of Assumptions

1. Plane surfaces will remain plane and bracing will create a plane of contraflexure (point of zero moment).
2. Horizontal load is equally distributed between the poles.
3. Pole taper is to be uniform for the entire length of pole.
4. Foundations are rigid and fixed.
### Structural Analysis

**H-Frame Structure Strength Analysis (cont'd)**

*List of Assumptions*

1. Plane surfaces will remain plane and bracing will create a plane of contraflexure (point of zero moment).
2. Horizontal load is equally distributed between the poles.
3. Pole taper is uniform for the entire length of pole.
4. Foundations are rigid and fixed.

---

**Find maximum load (P) to fail poles at each location:**

\[ P_a = \frac{2Ma}{X_0} = \frac{2 \times 218,183 \text{ ft-lbs.}}{21.70 \text{ ft.}} = 20,109 \text{ lbs.} \]

\[ P_b = \frac{2Mb}{X_1} = \frac{2 \times 96,025 \text{ ft-lbs.}}{9.55 \text{ ft.}} = 20,109 \text{ lbs.} \]

\[ P_c = \frac{2Mc}{Y_0} = \frac{2 \times 59,808 \text{ ft-lbs.}}{3.64 \text{ ft.}} = 32,890 \text{ lbs.} \]

\[ P_d = \frac{2Md}{Y_1} = \frac{2 \times 47,084 \text{ ft-lbs.}}{2.86 \text{ ft.}} = 32,890 \text{ lbs.} \]

**Maximum P allowed:**

Assume 15% strength reduction due to bolt holes etc.

\[ 20,109 \text{ lbs.} - (0.85) = 17,093 \text{ lbs.} \]

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**II. Check Strength of 1042 style X - Brace**

**A. Compression**

Theoretical X - Brace Strength \([P_x]\) from Euler's Formula

\[ P_x = \frac{\pi^2 El}{L^2} \]

where:

- \(L\) = Unbraced length in inches, assumed to be 1/2 of the brace length
- \(I\) = Moment of inertia
- \(E\) = Modulus of Elasticity

\[ P_x = \frac{\pi^2 x 1.6 \times 10^6 \text{ psi} x 17.22 \text{ in.}^4}{(14.5 \cos 45 \text{ (0.5)ft. x 12 in./ft.})^2} = 17,963 \text{ lbs.} \]

**B. Tension**

The Hughes Brothers 1042X - Brace is limited to 20,000 pounds which is determined empirically.
H-Frame Structure
Strength Analysis (cont'd)

List of Assumptions

1. Plane surfaces will remain plane and bracing will create a plane of contraflexure (point of zero moment).
2. Horizontal load is equally distributed between the poles.
3. Pole taper is uniform for the entire length of pole.
4. Foundations are rigid and fixed.

C. Load to Fail the X-Brace

Note: Starting from the top of the structure and moving down

1. \( \sum F_v = 0, \quad V_1 = V_1 \)

Assume: The transverse load is equally divided between the poles.

\[ \sum ME = 0: \quad [P \times L] = [V_1 \times b] \]

\[ V_1 = \frac{P \times L}{b} \]

2. \( \sum MF = 0: \)

\[ 2\left[\frac{P}{2}(Y_0 + Z + X_1)\right] + [V_1 \times b] - [V_2 \times b] = 0 \]

\[ V_2 = \frac{P(Y_0 + Z + X_1) + V_1}{b} \]

\( \phi = 45^\circ \)

\[ \sum MG = 0: \]

\[ [XBr_2 \times Z \cos \phi] - [[P / 2 \times Y_0] + [P / 2 \times (Z + X_1)]] = 0 \]

\[ XBr_2 = \frac{P / 2(Y_0 + Z + X_1)}{Z \cos \phi} \]

\[ \sum MH = 0: \]

\[ [XBr_1 \times Z \sin \phi] - [[P / 2 \times Y_1] + [P / 2 \times (Z + Y_0)]] = 0 \]

\[ XBr_1 = \frac{P / 2(Y_0 + Z + X_1)}{Z \sin \phi} \]

Since \( \phi = 45^\circ \)

\[ XBr_2 = XBr_1 \]

Note: Replace XBr, with Px (Theoretical X-Brace Strength) and solve for P (Load to Fail X-Brace).

\[ P = \frac{2 \times \text{Px} \times Z \sin \phi}{X_1 + Z + Y_0} = \frac{2 \times 17,963 \text{ lbs.} \times 14.5 \text{ ft.} \times \sin 45^\circ}{(9.55 \text{ ft.} + 14.5 \text{ ft.} + 3.64 \text{ ft.})} = 13,303 \text{ lbs.} \]
III. Wind Loading

Assume: 3/8" Shield, 795 ACSR 26/7
NESC "Light" Loading - 9 lb Wind on Bare Conductor
Overload Factor = 4.0

A. Wind on Pole (w)

\[ w = \text{Wind Load on One Pole Applied at the Crossarm Position} \]
\[ = 9 \text{ lbs./ft}^2 \times \frac{(25 \text{ in.} + 46.9 \text{ in.})}{2 \pi \times 12 \text{ in./ft.}} \times 61 \text{ ft.} \times 4.0 = 2,094 \text{ lbs.} \]

B. Wire Loads - (per ft.)

Conductor Loads (3) = \[ 9 \text{ lbs./ft}^2 \times \frac{1.108 \text{ in.}}{12 \text{ in./ft.}} \times 4.0 \times 3 = 9.972 \text{ lbs./ft.} \]

Shield Wire (2) = \[ 9 \text{ lbs./ft}^2 \times \frac{0.375 \text{ in.}}{12 \text{ in./ft.}} \times 4.0 \times 2 = 2.160 \text{ lbs./ft.} \]

Total wire load = 12.132 lb./ft.

IV. Maximum Span

Maximum Span = \[ \frac{13,303 \text{ lbs.} - 2,094 \text{ lbs.}}{12.132 \text{ lbs./ft.}} = 924 \text{ ft.*} \]

* X - Brace Strength Controls

See Hughes Brothers computer span analysis on next page
**Maximum Theoretical Transverse Spans**

X-Brace = 1042
Fiber Stress = 8000 psi
Crossarm Height = 8.75 ft
  Y = 6.5 ft
Pole Spacing = 15.5 ft
Conductor - 795 ACSR, 26/7 "Drake"
Shield Wire - 3/8" EHS
X-Brace Height = 3.375 in
X-Brace Width = 5.375 in
X-Brace Strength = 20,000 lbs

Wind Load = 9 lbs
Radial Ice = 0 in
Safety Factor = 4
# of Conductors = 3
# of Shield Wires = 2
Conductor Diameter = 1.108 in
Shield Wire Diameter = 0.36 in
Transverse Wire Tension = 0 lbs

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<th>POLE HEIGHT</th>
<th>POLE CLASS</th>
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<td>H2</td>
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<td>555*</td>
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<tr>
<td>115</td>
<td>521*</td>
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<tr>
<td>120</td>
<td>491*</td>
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</tbody>
</table>

*Denotes X-brace controlling.
Determining Pole Diameters

To determine the diameter of a pole at any given distance from the top:
1. Find the butt circumference by selecting the pole class in row  1
2. Move down the column to the desired pole length
3. Select the pole top circumference from row  2
4. Perform the following calculation:

\[
\text{Circumference at any point} = \frac{\text{Circumference at } 6 \text{ ft. from Butt} - \text{Top Circumference}}{\text{(Pole Length} - 6)} \times \text{Distrance from Top} + \text{Top Circumference}
\]

\[
\text{Diameter at any point} = \frac{\text{Circumference}}{\pi} \quad \pi = 3.14
\]

Special Note: The diameter found is a minimum pole dimension, based on ANSI 05.1. Most poles will run larger than this dimension.
### Pole Dimensions

**Dimensions of Douglas-fir (both types) and Southern Pine Poles from ANSI 05.1-1992**

<table>
<thead>
<tr>
<th>Class</th>
<th>H-6</th>
<th>H-5</th>
<th>H-4</th>
<th>H-3</th>
<th>H-2</th>
<th>H-1</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<th>6</th>
<th>7</th>
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<tr>
<td>Minimum circumference at top (in.)</td>
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<td>31.0</td>
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<td>Minimum circumference at 6 ft from butt (in.)</td>
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**NOTE:** Classes and lengths for which circumferences at 6 feet from the butt are listed in boldface type are the preferred standard sizes. Those shown in light type are included for engineering purposes only.

**The figures in this column are intended for use only when a definition of groundline is necessary in order to apply requirements relating to scars, straightness, etc.**
### Dimensions of Western Red Cedar* and Ponderosa Pine Poles from ANSI 05.1-1992

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**NOTE:** Classes and lengths for which circumferences at 6 feet from the butt are listed in boldface type are the preferred standard sizes. Those shown in light type are included for engineering purposes only.

* Dimensions of H classes are applicable for western red cedar only.

** The figures in this column are intended for use only when a definition of groundline is necessary in order to apply requirements relating to scars, straightness, etc.
Determining Stresses in Down Guys

Trigonometric Diagram

NOTE: To find the angle a guy wire makes with the ground line, divide Height “H” by the lead. The result will be the Tangent of the Angle.

Find the Secant of this Angle from the table of Natural Trigonometric Functions and Multiply by Pull “s”, the result of which will be the stress in the Guy Wire.

Note: Reprinted by request from Hughes Brothers Catalog - circa 1940
Double Arm Assemblies

Eliminate Eccentric Loading with Hughes Brothers Double Arm Assemblies and Adjustable Spacer Fittings

Single Arm

Twisting action due to eccentric loading

Double Arm

Hughes Adjustable Spacer Fittings

Hughes Adjustable Spacer Fittings with double arm assemblies eliminate eccentric loading and distribute shear forces on mounting hardware. The adjustable spacer fitting allows for variations in pole diameter. It also helps ease installation of the pre-assembled crossarms by enabling crews to widen the arm assemblies, slide them over the top of the poles, and tighten the arm assembly.

See Pole Line Hardware section for Adjustable Spacer Fitting information.
Post Insulators vs Davit Arm Construction

Hughes Brothers Davit Arm vs Post Insulator

Post Insulator Construction

Case 1  
NESC "Heavy"  
230 kv line  
Conductor: 795 26/7 ACSR (Drake) bundled  
Vert. load = 2.0942 lbs./ft x 2 x 1.5 OCF = 6.2826 lb./ft.  
Post Insulator  
L = 73.75 in.  
Max. vert. = 2800 lbs.  
Max. span = 445 ft.  11.86 structures/mile

Case 2  
NESC "Heavy"  
230 kv line  
Conductor: 795 54/7 ACSR (Condor) bundled  
Vert load = 2.4421 lb/ft x 2 x 1.5 OCF = 7.3263 lb/ft  
Post Insulator  
L = 73.75 in.  
Max. vert. = 2800 lbs  
Max. span = 382 ft.  13.82 structures/mile
### Davit Arm Construction

**Case 1**  
NESC "Heavy"  
230 kv line  
Conductor: 795 26/7 ACSR (Drake) bundled  
Vert. load = 2.0942 lbs./ft x 2 x 1.5 OCF = 6.2826 lbs./ft.  
**Davit Arm** 6'-6" arm - Hughes No. 4020A6.5C50G  
Max. vert. = 3630 lbs.  
Max. span = 577 ft.  9.15 structures/mile

**Case 2**  
NESC "Heavy"  
230kv line  
Conductor: 795 54/7 ACSR (Condor) bundled  
Vert load = 2.4421 lbs./ft x 2 x 1.5 OCF = 7.3263 lbs./ft.  
**Davit Arm** 6'-6" arm - Hughes No. 4020A6.5C50G  
Max. vert. = 3630 lbs.  
Max. span = 495 ft.  10.66 structures/mile

### Conclusion

Hughes Brothers Davit Arms can provide a more economical means of supporting conductors than post insulators. The longer spans that are obtained with davit arm construction translate into total project cost savings. Fewer poles, insulators, and less labor lower the construction cost. In the long run, less equipment in the fields means lower maintenance costs.

Please contact Hughes Brothers for cost comparisons of single pole post-insulator construction versus H-frame construction.
Full scale testing is used by Hughes Brothers, Inc. to confirm design calculations. Hughes’ design methods have been proven by dozens of full scale structure tests.

Dairyland Power Cooperative
Type C2214-AR1 Reframed 161 kV
Construction Tangent Structure
November 10, 1988

Test Purpose: The purpose of this test was to verify the structural integrity of a 38 yr. old, reframed wood H-frame structure.

Test No. 1

**Vertical Loads** - Conductor (each) 4,000 lbs.
Shield Wire (each) 2,500 lbs.

### Transverse Loads

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<tr>
<td>12</td>
<td>1650</td>
<td>2167</td>
<td>9800</td>
<td>21-5/8</td>
<td>21-1/2</td>
<td>16-1/4</td>
</tr>
<tr>
<td>13</td>
<td>1800</td>
<td>2367</td>
<td>10700</td>
<td>20-7/8</td>
<td>21</td>
<td>16-1/8</td>
</tr>
</tbody>
</table>

**Test Procedure**

Vertical loads are applied by suspending pre-weighed concrete and steel weights at each phase and shield wire position. The weights are raised by remotely operated hydraulic cylinders. Transverse loads are applied by means of power operated winches. The loads are monitored by certified dynamometers. Deflections are measured at selected points on the structure by reading calibrated rulers with a transit. All data is recorded at the time it is generated.
Full Scale Testing

Load 3
1,800 lbs.

Load 7
5,300 lbs.

Load 8
6,200 lbs.

Load 9
7,100 lbs.

Load 12
9,800 lbs.

Load 13
Failure
The above figures indicate the bending strengths of the poles predicted through nondestructive evaluation as well as the actual stresses at failure determined through structural analysis. While strength predictions will not always be this accurate (strength prediction was within 1% of stress failure), the test results illustrate the value of assessing the reliability of existing structures and making improved upgrading and reframing decisions.
Transmission Design Configurations

Since 1921, Hughes Brothers has been developing a diverse selection of framing designs for wood, concrete and steel construction. Each structure is designed to meet the specific loading, geographical, right of way and construction preferences of the project at hand.

Our library of structure designs is without equal in the industry. Before embarking on a new transmission structure design, we hope that you will contact Hughes Brothers engineering staff. Our tower design expertise is offered without obligation.

<table>
<thead>
<tr>
<th>69 kV - 161 kV</th>
<th>69 kV - 230 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wood tension braces</strong> provide maximum conductor clearance. Compression braces (braces attached below the crossarms) are also available.</td>
<td>&quot;Wishbone&quot; framing with single or double arm assemblies is a very cost effective type of framing for single pole construction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>69 kV - 161 kV</th>
<th>69 kV - 230 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fiberglass</strong> is an attractive option for both single and double circuit construction with either wood, concrete or steel poles.</td>
<td></td>
</tr>
</tbody>
</table>
**69 kV - 230 kV**

Fiberglass framing in conjunction with wood X-Bracing is an effective option for maintenance or upgrading existing structures.

**69 kV - 161 kV**

Double or single (laminated or solid sawn) arms are available for the standard H-Frame with or without knee or vee braces.

**69 kV - 161 kV**

The framing for a typical H-Frame in this voltage range may be sized for either a single or bundled conductor.

**230 kV**

The framing for this typical H-Frame is sized to provide electrical clearances required for lines of this voltage and may be sized for either a single or bundled conductor. Typically pole spacings are greater than for 69 - 161 kV construction.

**230 kV**

The framing for this K-Frame structure uses relatively short crossarm timbers which are more readily available from solid sawn lumber. The timbers may be sized for either a single or bundled conductor.

**345 kV**

This wide based H-Frame with the center phase supported by a vee string, reduces the length and cost of framing members and also reduces potential uplift and thrust problems.

**345 kV**

This narrow pole spacing H-Frame uses a vee string for support of the center phase and is especially suited for narrow right-of-way applications.

**345 kV**

This is a typical H-Frame for EHV. The framing members are custom designed for specified wire sizes and span lengths.
### 345 kV

This H-Frame is constructed with extended double center crossarm braces to support the shield wires and is often used when the shield wires are insulated or if the structure is designed for large transverse loads.

### 69 kV - 230 kV

Wood double circuit tangent structures have proven to be reliable and very economical for most voltage ranges.

### 345 kV / 230 kV

Wood double circuit tangent structures with different voltages are effective and economical for voltages through 345 kV / 230 kV.

### 345 kV

The 345 kV K-Frame structure utilizes shorter, more readily available timbers. The shorter members are also easier to transport in rough terrain.
Angled Structures for Single Conductor Lines

- Small Angle
- Medium Angle
- Large Angle & Dead End
- Tangent Dead End
- Transposition
- Long Span
Angle Structures for Bundled Conductor Lines

- Small Angle
- Medium Angle
- Large Angle
- Large Dead End Angle
- Transposition