CONDUCTOR SAFE DESIGN TENSION WITH RESPECT TO AEOLIAN VIBRATIONS

BASED ON CIGRÉ TUTORIAL PRESENTED AT THE INTERNATIONAL COLLOQUIUM ON OVERHEAD TRANSMISSION LINE INNOVATIONS
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Task Force B2.11.04
Convenor: Claude Hardy

Updated for IEEE/TPC Meeting
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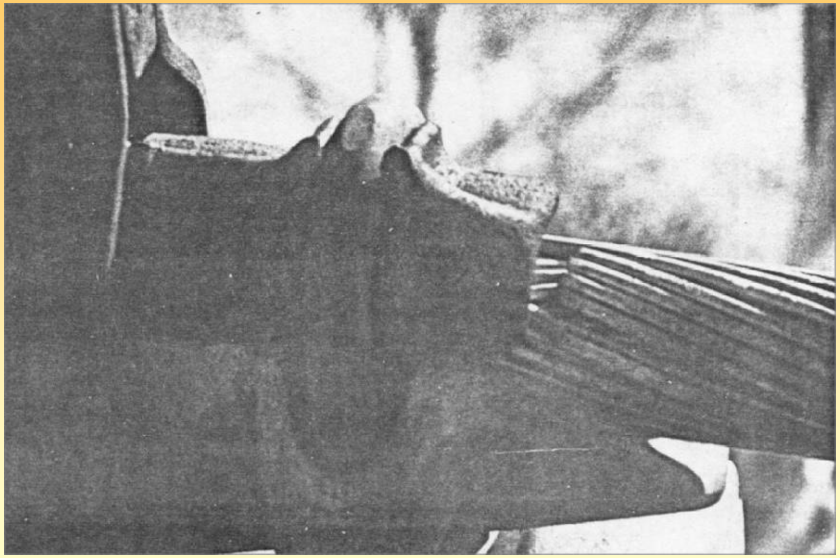
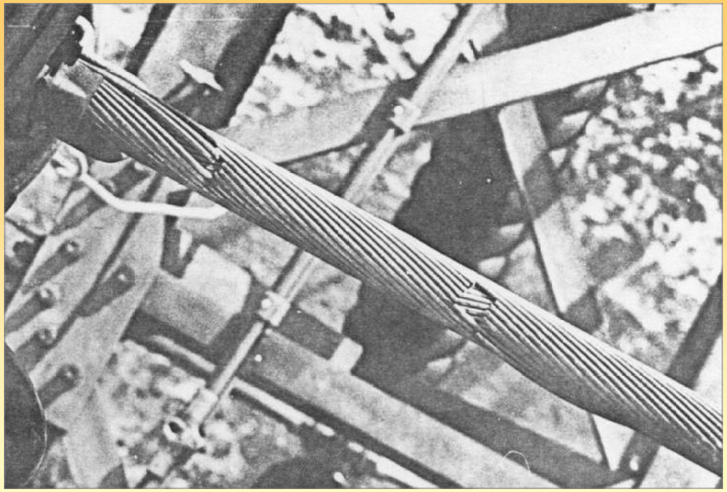
by Dave Havard



Overview - 1

- Reasons for controlling conductor tension
- Review of basics about aeolian vibrations, stranded conductor fatigue and wind turbulence
- Review and analysis of the Every Day Stress (EDS) concept
- Basis for selection of tension parameter, conductor condition, reference temperature and span parameter

Overview - 2



- Strategies for determination of Safe Design Tension for:
  - Single conductors without dampers
  - Single conductors with dampers
  - Bundled conductors
- Predicted Safe Design Tension in each case
- Comparison with field experience in each case
- Recommended Safe Design Tension in each case

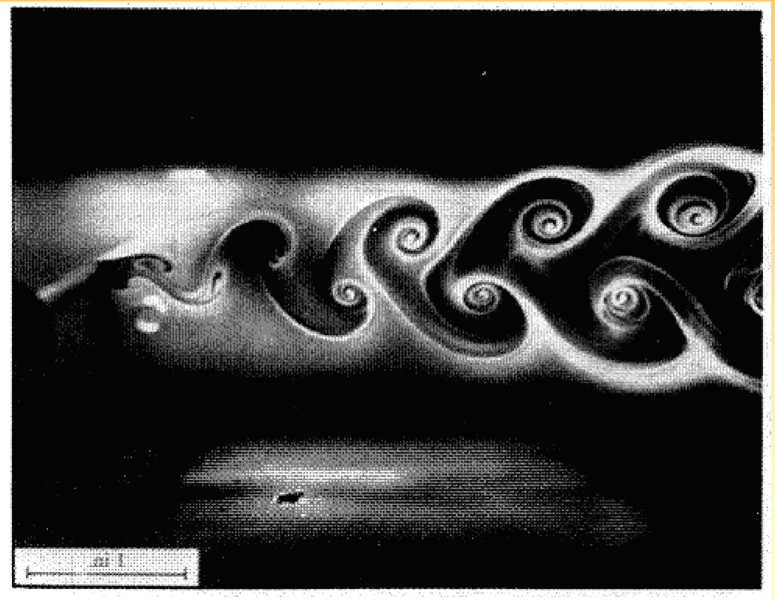
Reasons for Controlling Conductor Tension - 1

- Limit maximum tension resulting from assumed most severe climatic loads (high wind, heavy ice, cold temperature) to avoid tensile failure
- Limit minimum tension while operating at maximum temperature in order not to violate ground clearance
- Control every day tension to limit conductor susceptibility to harmful aeolian vibrations
  - higher tensions reduce conductor self-damping
  - higher tensions result in more severe vibrations
  - higher tensions result in fatigue of strands at clamps

Reasons for Controlling Conductor Tension - 2

- Based on the Every Day Stress (EDS) limits, conductor tensions of up to 35% rated (or ultimate) tensile stress without damping are allowed in the present National Electric Safety Code (NESC)
- Surveys of utilities show many failures at lower conductor tensions without dampers
- NESC does not always assure safe tensions

Aeolian Vibration Mechanism



- Caused by smooth winds with velocity < 6 m/s perpendicular to conductor
- Due to vortex shedding alternately from top and bottom sides of conductor
- Frequency of vortex shedding:
  - Proportional to wind speed
  - Inversely proportional to conductor diameter
- Maximum amplitude of conductor motion is about 1 conductor diameter
- Conductor motion is in the vertical plane
- May induce fatigue at points where conductor is restrained (suspension clamps, spacer clamps, etc.)

Stranded Conductor Fatigue

- A fretting-fatigue phenomenon translating into reduced endurance as compared to plain fatigue
- Fatigue failures occur in the vicinity of clamps at contact points between strands where contact stresses are quite high, in the presence of slipping
- Not always apparent externally; failures often occur in the internal layers first

Review of the Every Day Stress (EDS) Concept

- **Introduced in 1960 by "EDS Panel" within CIGRÉ Study Committee 06 to provide guidance to safe conductor design tension with respect to aeolian vibrations**
- **EDS: conductor tension expressed as % of conductor ultimate or rated tensile strength (UTS or RTS)**
- **EDS defined as "*maximum tensile load to which a conductor may be subjected at the temperature occurring for the longest period without any risk of damage due to aeolian vibrations*"**

“EDS Panel” Conductor Tension Recommendations (% UTS)

Conductor type and condition	Unprotected lines	Lines equipped with		
		Armor rods	Dampers	Armor rods and dampers
Copper conductors	26			
ACSR	18	22	24	24
Aluminium conductors	17			
Aldrey conductors	18		26	
Steel conductors				
1. Rigid clamps	11			
2. Oscillating clamps	13			

Analysis of "EDS Panel" Conductor Tension Recommendations
(ACSR Conductors)

Service life	% of lines damaged	
Years	EDS < 18%	EDS = > 18%
< = 5	5.26	25.00
> 5 < = 10	20.93	35.29
> 10 < = 20	45.00	78.00
> 20	58.93	91.67

Problem: Many conductors failed with tensions below "EDS Panel's" recommended value

CIGRÉ Safe Conductor Tension

Selection of tension parameter

Criterion: looking for the most universal yet relevant tension parameter (H)

- **EDS = H/UTS: not relevant as UTS is not simply related to fatigue failure for different materials**
- **Nominal σ_{al} (stress in the aluminum strands) fairly relevant but hard to measure in laboratory or field measurements**
- **H/w (Tension/mass) the most relevant combined parameter:**
  - **Can be determined from design data**
  - **Fairly well related to self-damping as per proven models**
  - **Proportional to nominal σ_{al} for ACSRs and AACs**
  - **Governs conductor vibration properties (wavelength and speed of propagation)**
  - **Inversely proportional to sag**

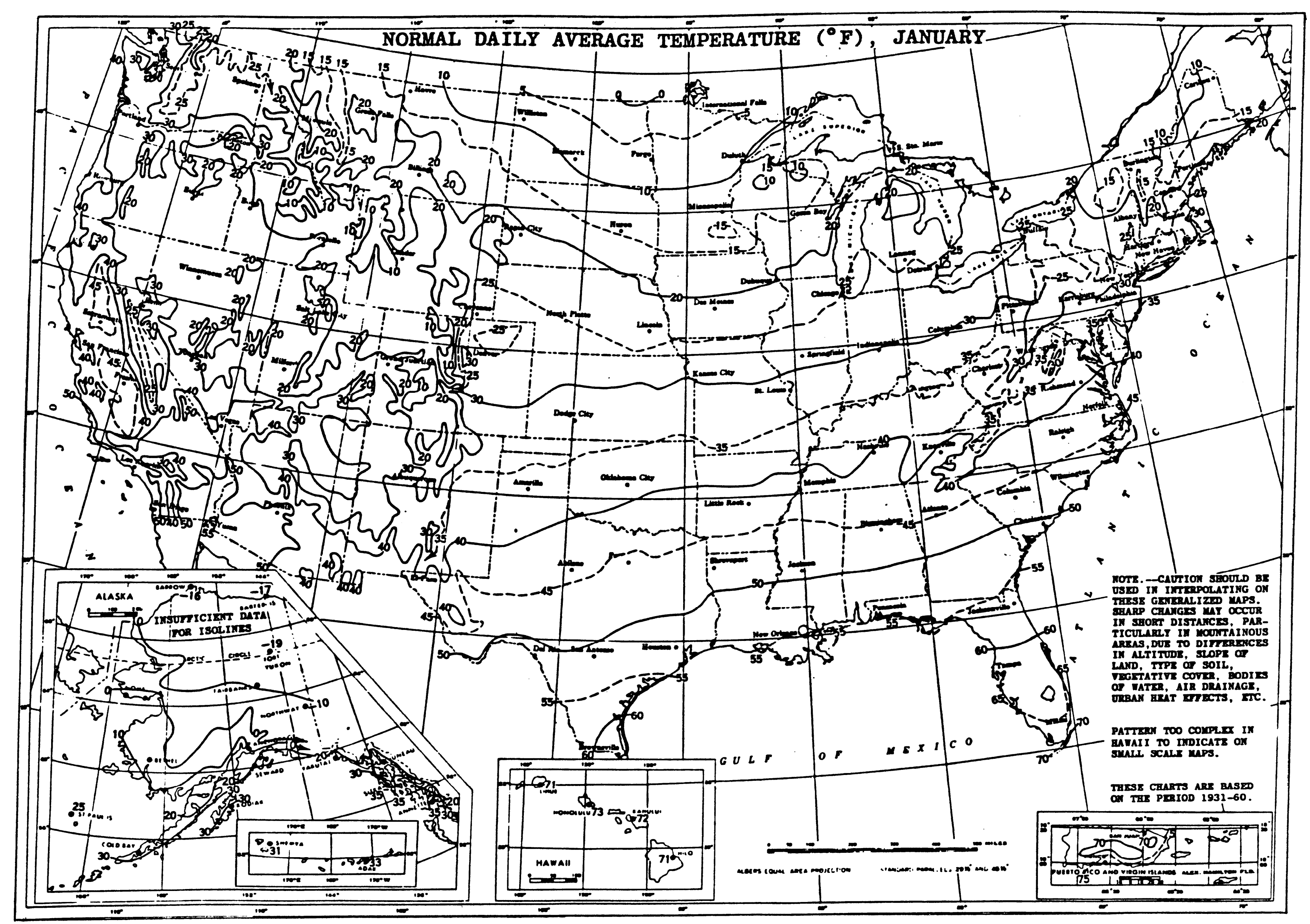
Selection of Conductor Tension Condition

- **Final tension condition**
  - **Not suitable; cannot be known accurately as weather and aging processes can cause creep at different rates**
- **Initial tension chosen**
  - **Stringing condition which can be known more accurately**

Selection of Reference Temperature

- **Average temperature of the coldest month**
  - **Relates closest to worst vibration condition**

AVERAGE JANUARY TEMPERATURES in USA



Courtesy of the U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Service.

Conductor Types to which Recommendations Apply

METAL COMBINATION	COMMON DESIGNATION	IEC DESIGNATION
All 1350-H19	ASC OR AAC	A1
All 6101-T81	AASC OR AAAC	A2
All 6201-T81	AASC OR AAAC	A3
1350-H19 STEEL	ACSR	A1/S1A
1350-H19/6101-T61	ACAR	A1/A2
1350-H19/6201-T81	ACAR	A1/A3

Wind Turbulence as a Function of Terrain

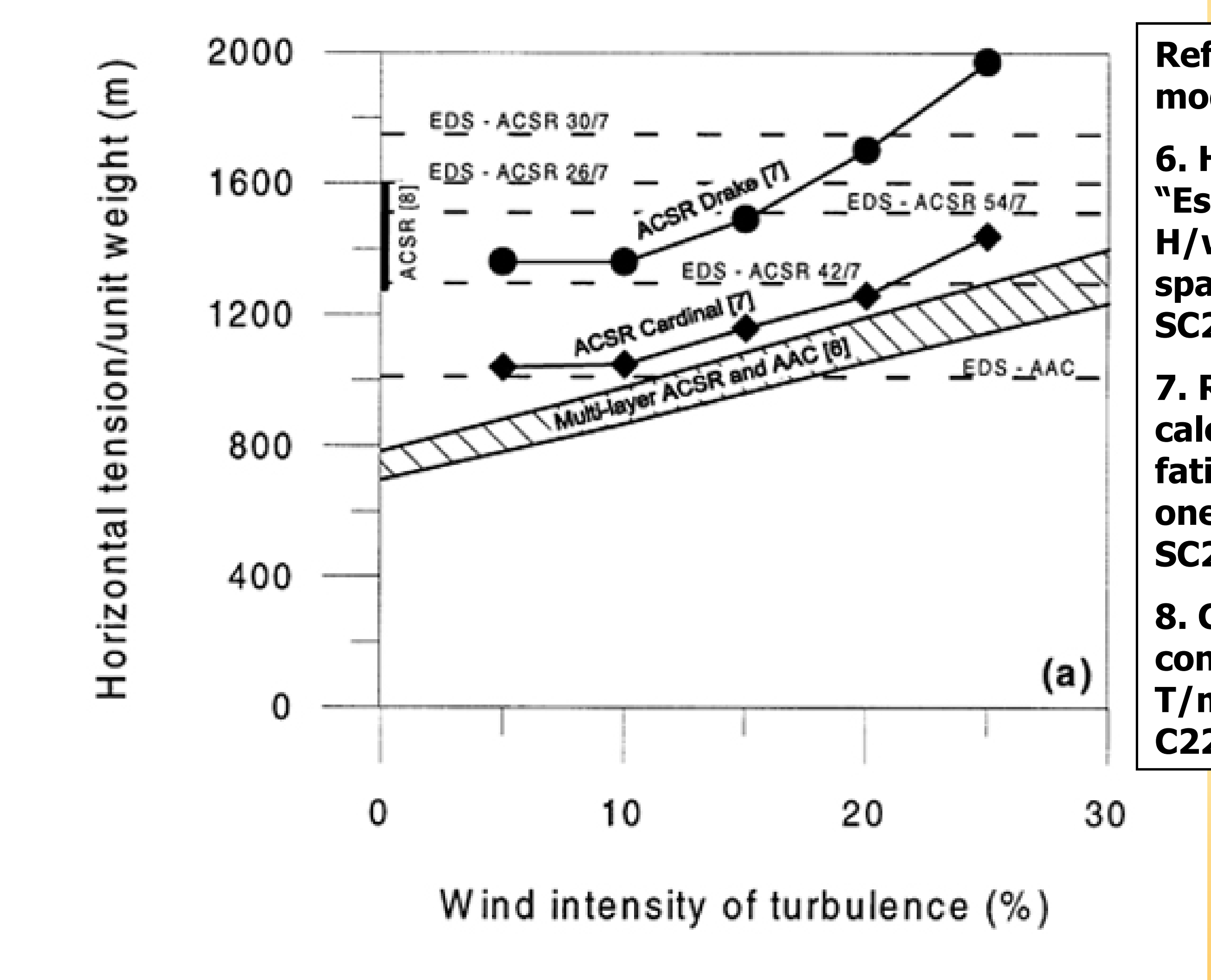
Terrain	Turbulence Intensity
Open sea; large stretches of open water	0.11
Rural areas; open country with few, low, obstacles	0.18
Low-density built-up areas; small town; suburbs; open woodland with small trees	0.25
Town and city centers with high density of buildings; broken country with tall trees	0.35

Higher wind turbulence suppresses coherence of vibration and reduces maximum vibration amplitudes

Determination of Safe Design Tension (SDT): Single Unprotected Conductors (No dampers, no armor rods, with metal clamps)

- **Strategy: recourse to modelling (Energy Balance Principle) to predict safe tension on account of predicted vibration amplitudes and conductor endurance; backed by field experience**
  - ***ENERGY BALANCE PRINCIPLE: under steady winds the conductor vibration amplitude increases until the energy input from the wind is equal to the sum of the energy absorbed by the conductor self damping and the damping of any attached dampers***
- **Four independent investigations: R. Claren, H.J. Krispin, C. Rawlins, and A. Leblond & C. Hardy**
- **Approaches: Fatigue damage defined either by an Endurance Limit and/or by a Cumulative Damage model**
- **Assumptions for conductor self-damping, wind power input, wind recurrence, vibration mode shape & fatigue endurance selected for each investigation**

Predicted Safe H/w versus Wind Turbulence for Unprotected Single ACSR Conductors Comparison of EDS and Analytical Models



References to analytical models:

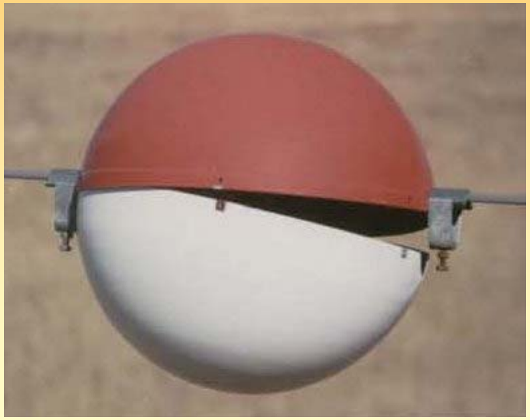
6. Hardy C. and Leblond A., "Estimated maximum safe H/w for undamped conductor spans" CIGRÉ report SC22-WG11-TF4 95-13,1995

7. Rawlins C.B., "Exploratory calculations of the predicted fatigue life of two ACSR and one AAAC" CIGRÉ report SC22-WG11-TF4 96-5, 1996

8. Claren 1994, "A contribution to safe design T/m values", CIGRÉ report C22-WG11-TF4 94-1, 1994

Unprotected Single ACSR Conductors Field Cases H/w < 2000 m

Conductor Diam (mm)	Al / St Strands	Average Span (m)	Tension % UTS	H/w (m)	Fatigue Failure
21.9	36/12	200		707	
21.9	36/12	395		844	
24.2	54/7	137		934	
8.0	6/1	61	10.8	1029	Yes
21.8	26/7	183		1358	
26.6	26/19	362	N.A.	1397	Yes
16.5		310	14.3	1405	Yes
18.8	30/7	396	15.1	1511	Yes
18.8	30/7	350		1554	
10.7	12/7	300	12.9	1607	Yes
21.8	26/7	274		1638	
25.9	30/7	396	14.3	1655	Yes
21.8	26/7	326		1723	
20.5	26/7	300	19.0	1731	Yes
25.4	54/7	346		1735	
19.9	26/7	170		1738	
22.4	30/7	333		1747	
21.0	30/7	390		1761	Yes
12.7	6/1	107		1772	
22.4	30/7	340	19.2	1865	Yes
21.7	48/7	295	22.9	1881	Yes
18.8	30/7	270		1908	
18.8	30/7	360		1959	
11.7	12/7	264	16.0	1996	Yes

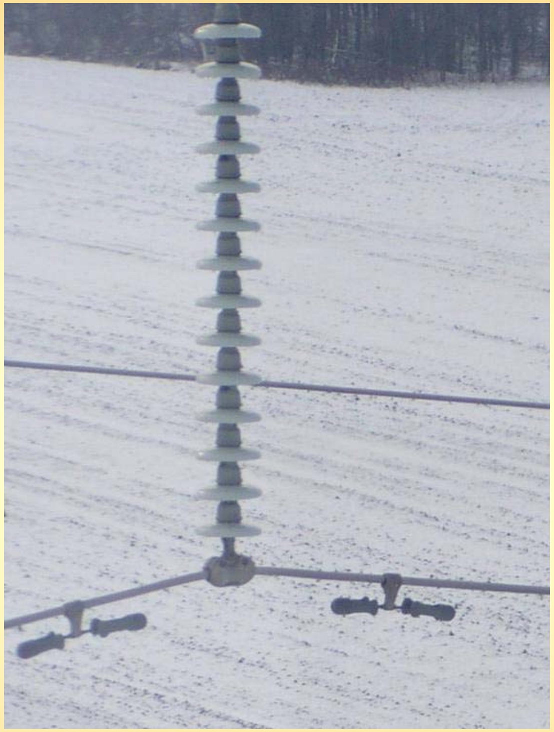


Unprotected Single Conductors Recommended Safe H/w

Terrain category	Terrain characteristics	H/w (m)
1	Open, flat, no trees, no obstruction, with snow cover, or near/across large bodies of water; flat desert.	1000
2	Open, flat, no obstruction, no snow; e.g. farmland without any obstruction, summer time.	1125
3	Open, flat, or undulating with very few obstacles, e.g. open grass or farmland with few trees, hedgerows and other barriers; prairie, tundra.	1225
4	Built-up with some trees and buildings, e.g. residential suburbs; small towns; woodlands and shrubs. Small fields with bushes, trees and hedges.	1425

Single Conductors with Span-End Stockbridge Dampers

Selection of span parameter:

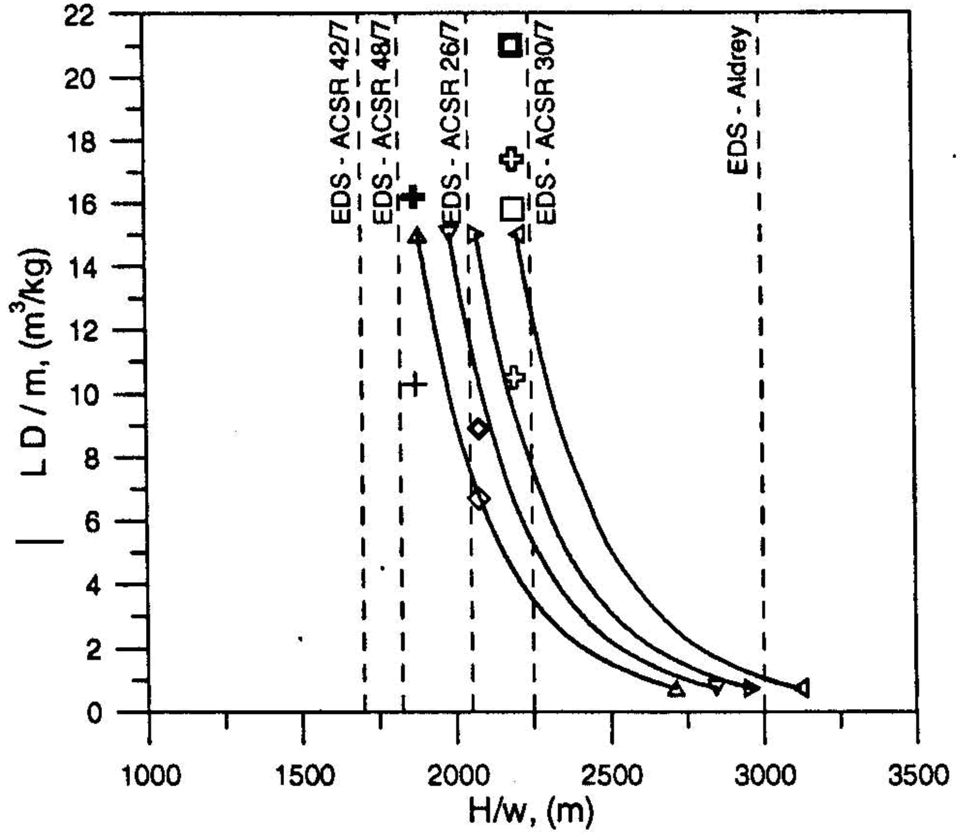


- **Dampers protect a limited length which requires a span parameter to represent span length**
- **Similarity in damping efficiency of dampers from different sources points toward parameter $LD/(Hm)^{1/2}$ for rating their protective capabilities**
- **Combination of $LD/(Hm)^{1/2}$ with tension parameter H/w leads to independent span parameter LD/m**

Determination of Safe Design Tension (SDT): Single Conductors with Dampers

- Strategy: recourse to modelling (Energy Balance Principle) to predict safe tension based on relation between vibration amplitudes and conductor endurance; backed by field experience
- Two independent investigations: C. Rawlins, and A. Leblond & C. Hardy
- Approaches: Endurance limit only
- Assumptions for characterization of conductor-damper interaction selected for each investigation

Predicted Safe H/w for Single Conductors with Dampers for Different Span Lengths and Turbulence Intensity Comparison of EDS and Analytical Predictions



Leblond and Hardy [14] : Bersfort △ 8% turb.; ▽ 15% turb.; ▷ 22% turb.; ◁ 30% turb.
Rawlins [15] : Chukar : + 10% turb.; Condor : ◊ 5% turb.; ◆ 10% turb.
Drake, damper A : □ 5% turb.; ■ 10% turb.; Drake damper B : ✜ 5% turb.; ✚ 10% turb.

Safe conductor tension values for single conductor spans with span-end Stockbridge dampers

References to analytical models:

14. Leblond A. and Hardy C. , "IREQ predicted safe design tension", CIGRÉ report SC22-WG11-TF4 99-6, 1999

15. Rawlins C.B., "Safe tensions with dampers", CIGRÉ report SC22-WG11-TF4 99-5, 1999

Single Conductor Field Damage Cases with Vibration Dampers

Item	Diameter (mm)	Stranding	Span (m)	H/w (m)	LD/m (m^3/kg)	Damper type	Note
1	16.28	26/7	167	1542	4.983	Stockbridge	1
2	31.59	54/7	360	2017	5.755	Torsional	
3	27.00	30/7	290	1851	5.861	Dumbbell	
4	27.00	30/7	305	1851	6.164	Dumbbell	
5	26.60	26/19	380	1994	6.971	Stockbridge	
6	31.77	54/7	320	2031	5.086	Stockbridge	2
7	27.72	54/7	305	1677	5.691	"yes"	3
8	24.20	54/7	268	1406	5.592	"yes"	3
9	26.40	32/19	510	2227	8.496	Bretelles	
10	27.72	54/7	330	1734	6.140	Elgra	

1. Dampers may have been at dead-ends only. H/w based on design tension, actual installed tension was higher.
2. Not all spans were damped. Damage may have been where only armor rods were used.
3. Lines built 1927-1930 before dampers were available. Damage likely before dampers were installed.

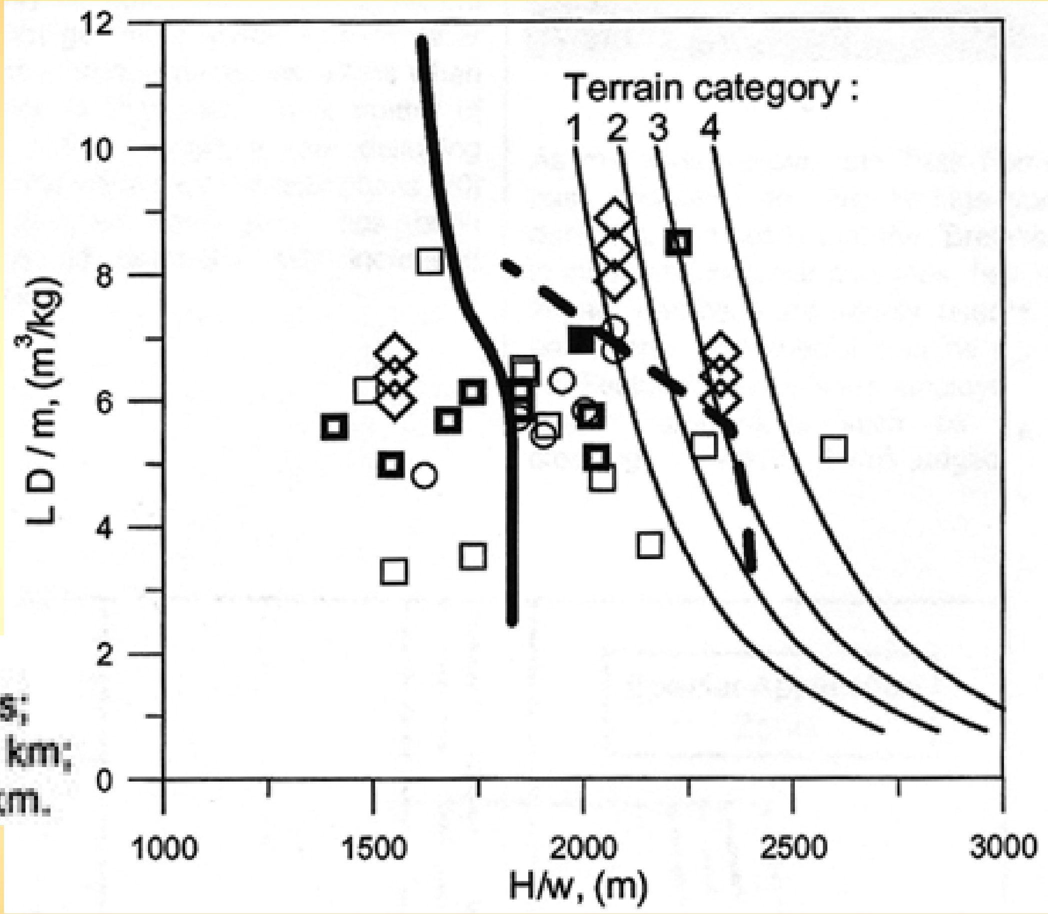
Single Conductor Field Damage Cases with Vibration Dampers vs. Safe Design Tension

Conductor damage reported:

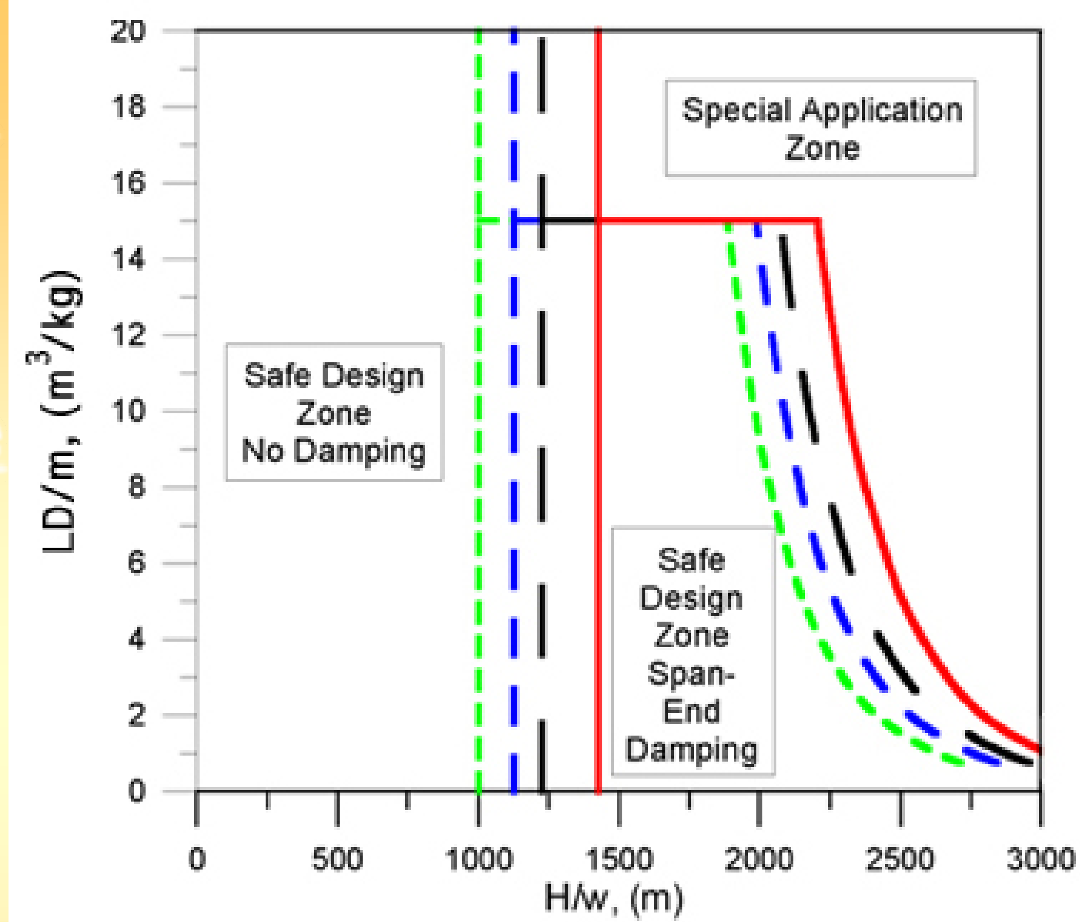
■, valid case;
◘, other cases;
○, other damage reported.

No damage reported:

□, individual spans;
◇, one damper/span test line safe cases;
▬, Zebra conductor over 2800 route km;
▬ ▬, Lynx conductor over 4000 route km.



Recommended Safe Design Tension for Single Conductor Lines with and without Stockbridge Dampers



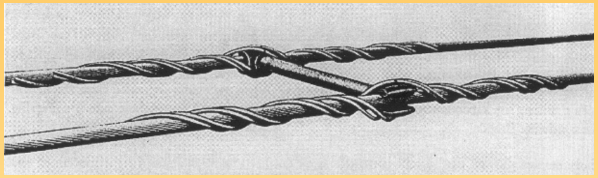
Terrain Category

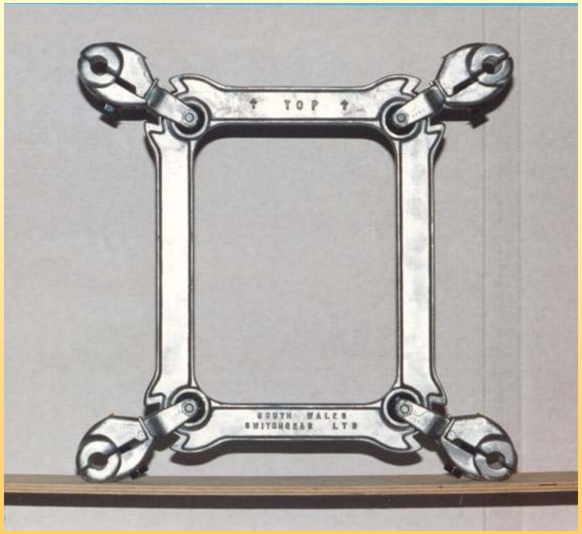
- #1 **Open, flat, no trees, no obstruction, with snow cover, or near/across large bodies of water; flat desert**
- #2 **Open, flat, no obstruction, no snow; e.g. farmland without any obstruction, summer time**
- #3 **Open, flat, or undulating with very few obstacles, e.g. open grass or farmland with few trees, hedgerows and other barriers; prairie, tundra**
- #4 **Built-up with some trees and buildings, e.g. residential suburbs; small towns; woodlands and shrubs. Small fields with bushes, trees and hedges**

Recommended Safe Design Tension for Single Conductor Lines with and without Stockbridge Dampers – Equations of Zone Boundaries

Terrain #	Left-hand boundary (m)	Upper boundary (m^3/kg)	Right-hand boundary (m^3/kg)
1	$H/w = 1000$	$LD/m = 15$	$LD/m = \frac{1.3 \times 10^{28}}{(H/w)^{8.2}}$
2	$H/w = 1125$	$LD/m = 15$	$LD/m = \frac{5.4 \times 10^{28}}{(H/w)^{8.3}}$
3	$H/w = 1225$	$LD/m = 15$	$LD/m = \frac{1.3 \times 10^{29}}{(H/w)^{8.4}}$
4	$H/w = 1425$	$LD/m = 15$	$LD/m = \frac{1.1 \times 10^{30}}{(H/w)^{8.6}}$

Determination of Safe Design Tension – Bundled Conductors





Strategy : due to lack of proven analytical method, rely on field experience and preferably on field test results whenever possible.

- **Bundled systems covered:**
  - **horizontal twin**
  - **triple apex-down**
  - **horizontal quad**

(Protected by non-damping spacers with or without span-end Stockbridge dampers, or by spacer-dampers)

Review of Field Experience

No. of lines	Bundle type	Protection	Range of mean LD/m (m^3/kg)	Range of initial H/w (m)
19	2H	NDS	2.19 - 4.63	802 - 2088
48	2H	NDS+Stk	3.14 - 7.27	910 - 2959
3	2H	DS	5.03 - 6.60	1636 - 1937
1	3AD	NDS	5.62	1627
4	3AD	NDS+Stk	6.20 - 6.93	1166- 2056
9	3AD	DS	3.93 - 7.81	1401 - 2096
3	4H	NDS+Stk	6.63 - 7.89	1452 - 1488
4	4H	DS	7.33 - 8.38	1633 - 1937

2H - Horizontal twin bundles

3AD – Triple bundle apex down

4H – Horizontal quad bundle

NDS – Non damping spacers

Stk – Stockbridge dampers

DS – Spacer dampers

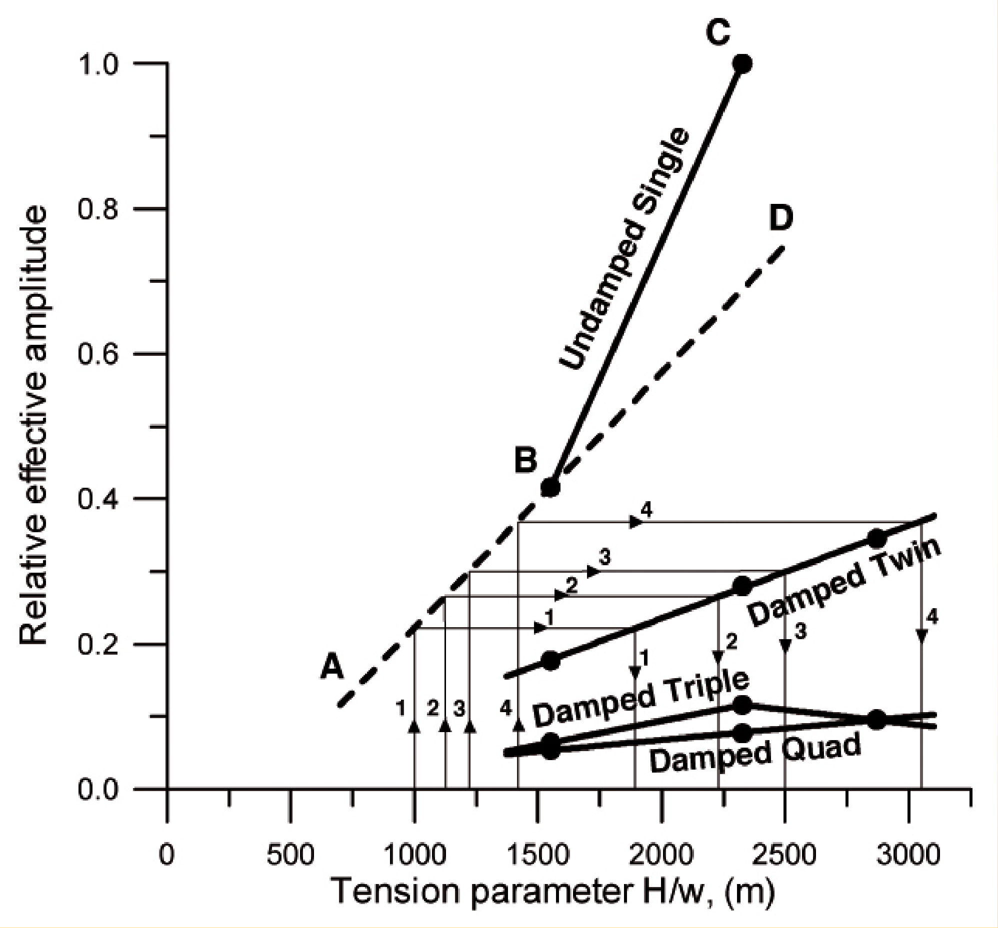
Review of Field Test Experience

Bundle type	Nominal conductor H/w (m)	Test span LD/m (m^3/kg)	Spacer type	End damper	Amplitude ratio single/bundle
Hor. twin	1755	6.3	Articulated	No	>2.1
Hor. twin	1755	6.3	Articulated	Yes	>1.8
Hor. twin	1755	6.3	Ball-&-socket	No	>2.7
Hor. twin	1755	6.3	Ball-&-socket	Yes	>1.9
Hor. twin	1295	6.5	Various	No	~2
Hor. quad	1295	6.5	Various	No	~4
Hor. twin	>1454	6.5	Articulated	No	>1.5
Hor. twin	>1437	7.5	Articulated	No	>1.5
Hor. twin	>1730	6.3	Articulated	No	>1.7
Vert. twin	>1454	6.5	Articulated	No	>1.7
Vert. twin	>1730	6.3	Articulated	No	>5
Triple	>1437	7.5	Grouped twins	No	>5
Hor. quad	>1730	6.3	Grouped twins	No	>5
Hor. twin	1743	7.2	Rigid	No	>1.3
Triple	1743	7.2	Damping spacers	No	>5
Hor. twin	1550	6.8	Damping spacers	No	~2.4
Triple	1550	6.8	Damping spacers	No	~6.5
Hor. quad	1550	6.8	Damping spacers	No	~7.7
Hor. twin	2325	6.8	Damping spacers	No	~3.6
Triple	2325	6.8	Damping spacers	No	~8.6
Hor. quad	2325	6.8	Damping spacers	No	~13.0

Determination of Safe Design Tension – Bundles

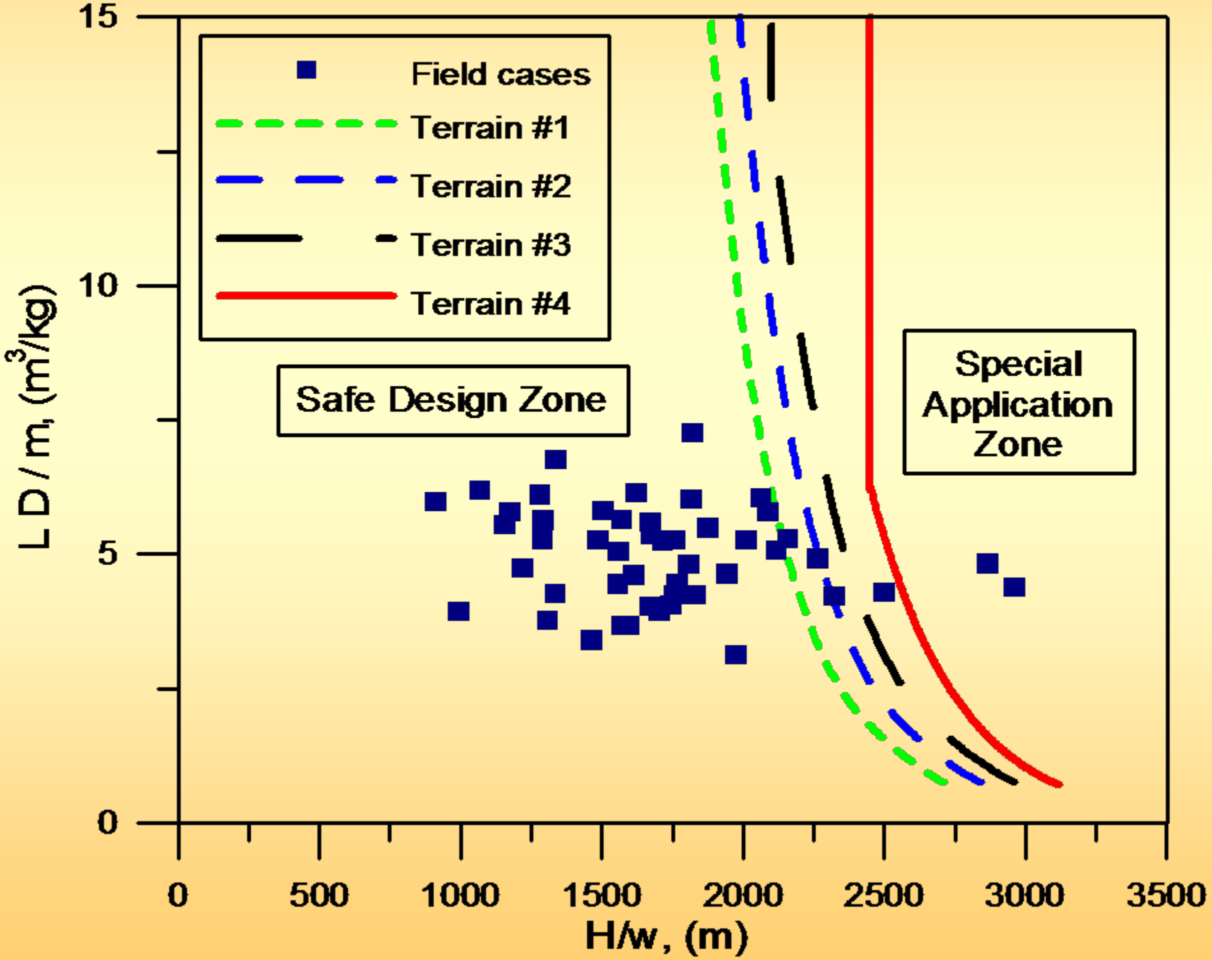
- **Unspaced bundles with or without dampers: same Safe Design Tension as for equivalent single conductors**
- **Bundles with non-damping spacers:**
  - **for twins and quads, Safe Design Tension derived from field experience**
  - **for triples, Safe Design Tension derived from test line results**
- **Bundles with non-damping spacers + dampers:**
  - **the more permissive of the two cases above**
- **In all cases: absolute upper limit H/w ≤ 2500 m**

Determination of Safe Design Tension – Bundles with Spacer-Dampers



Line ABC represents undamped single conductor response. Following line 2, representing terrain category 2 from H/w =1125 m to the same effective amplitude for damped twin bundles gives H/w = 2200 m. For terrain categories 1, 2, 3 and 4 the corresponding values of H/w for damped twin bundles are then 1800 m, 2200 m, 2500 m and 3100 m.

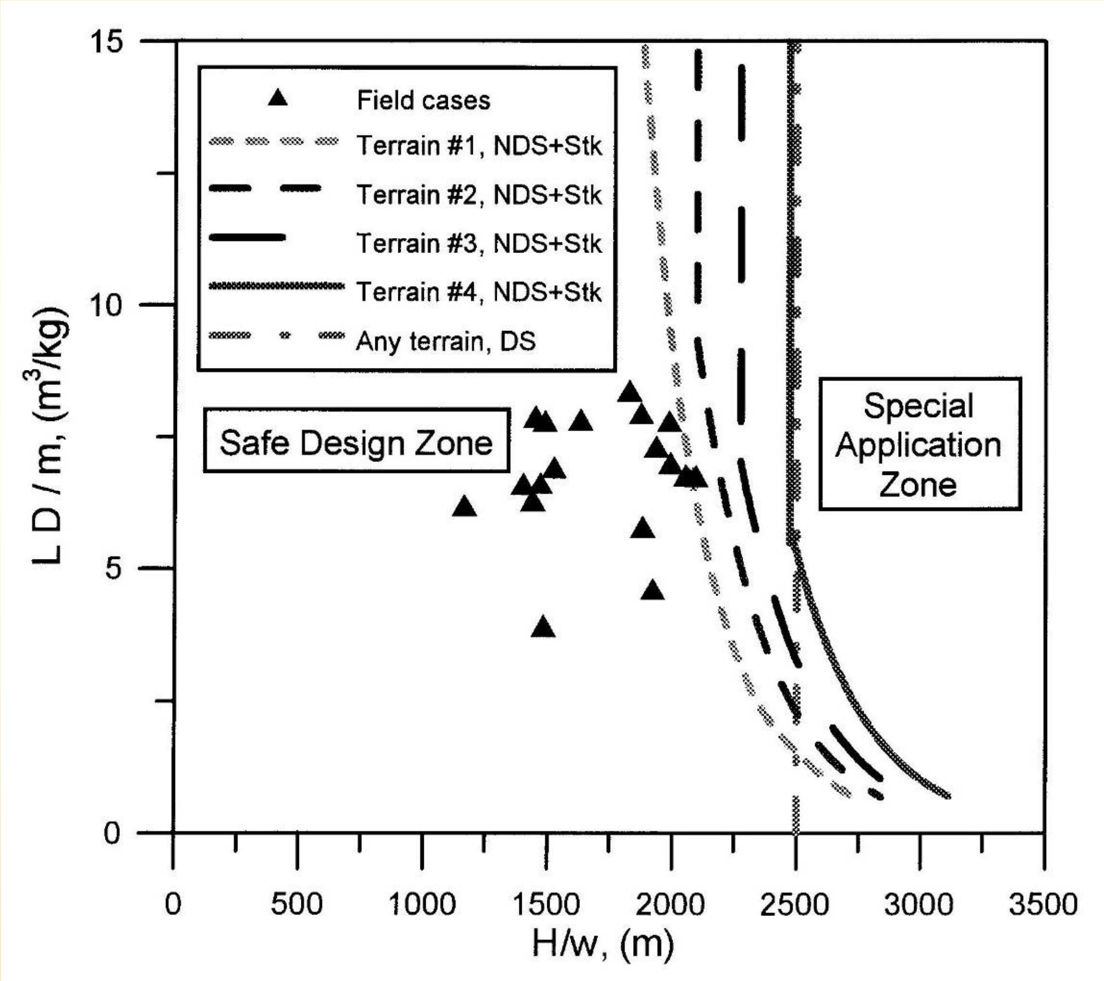
Comparison of Safe Design Tension with Field Experience – Twin Bundles with Non-Damping Spacers and Span-End Dampers



CIGRÉ Safe Design Tension for Horizontal Twin Bundles Values of H/w (m)

Terrain		#1	#2	#3	#4
Undamped, Unspacered Horizontal Twin Bundles	H/w (m)	< 1000 m	< 1125 m	< 1225 m	< 1435 m
Undamped, Unspacered Horizontal Twin Bundles with Span End Stockbridge Dampers	H/w (m)	$< 2615(LD/m)^{0.12}$	$< 2780(LD/m)^{0.12}$	$< 2860(LD/m)^{0.12}$	$< 3030(LD/m)^{0.12}$
	LD/m (m^3/kg)	< 15	< 15	< 15	< 15
Horizontal Twin Bundled Conductors With Non-damping Spacers	H/w (m)	< 1725 m	< 1925 m	< 2100 m	< 2450 m
Horizontal Twin Bundled Conductors with Non-damping Spacers and span end Stockbridge dampers	H/w (m)	$< 2615(LD/m)^{0.12}$	$< 2780(LD/m)^{0.12}$	$< 2860(LD/m)^{0.12}$	$< 3030(LD/m)^{0.12}$
	LD/m (m^3/kg)	< 15	< 15	< 13	< 6
	H/w (m)	-	-	< 2100 m	< 2450 m
	LD/m (m^3/kg)	-	-	> 13, < 15	> 6, < 15
Horizontal Twin Bundled Conductors With Damping Spacers	H/w (m)	< 1900 m	< 2200 m	< 2500 m	< 2500 m

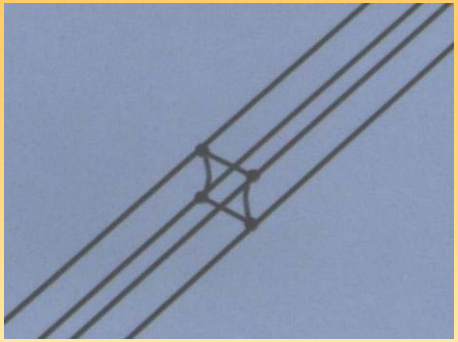
Comparison of Safe Design Tension with Field Experience - Apex-down Triple and Horizontal Quad Bundled Conductors with Non-Damping Spacers and Stockbridge Dampers, or Damping Spacers



CIGRÉ Safe Design Tensions for Apex-Down Triple Bundles Values of H/w (m)

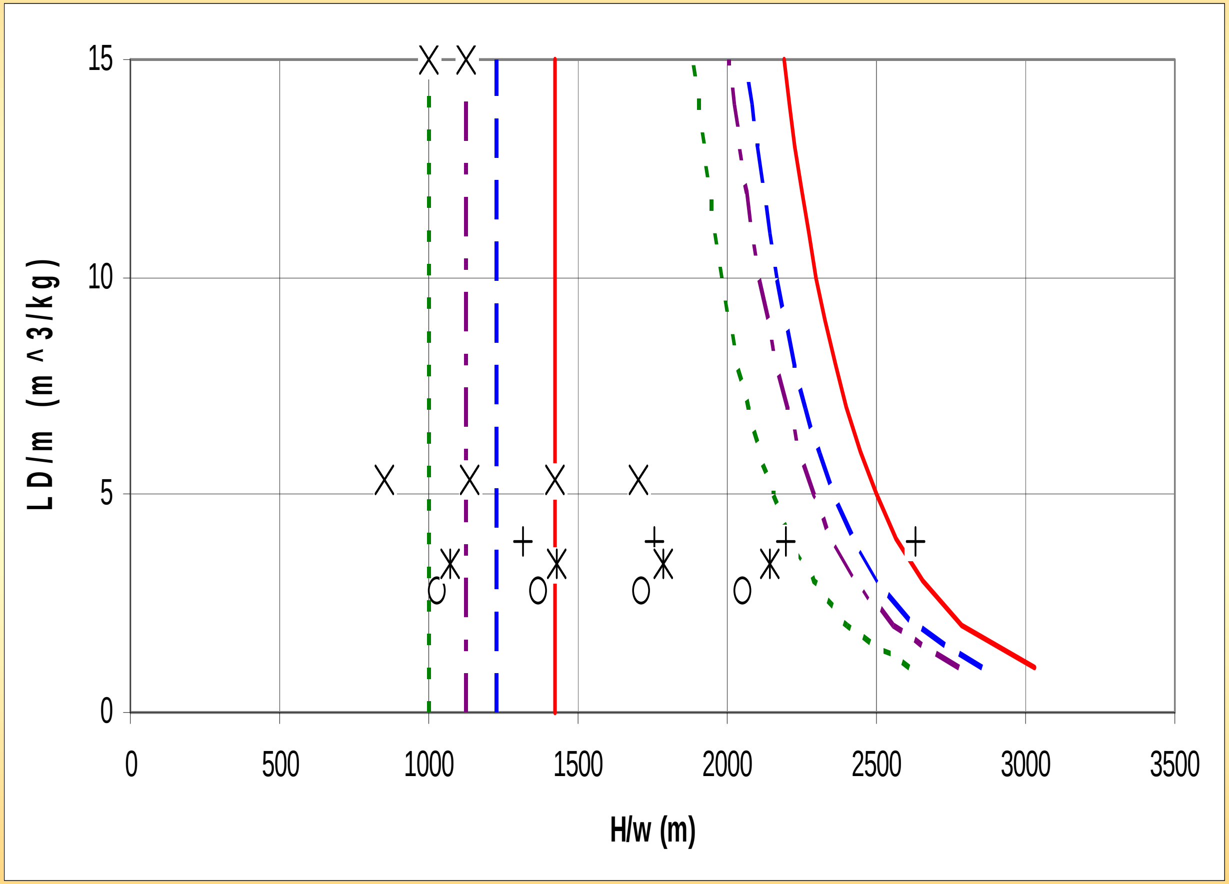
Terrain		#1	#2	#3	#4
Undamped, Unspacered Apex-down Triple Bundles	H/w (m)	< 1000 m	< 1125 m	< 1225 m	< 1435 m
Undamped, Unspacered Apex-down Triple Bundles with Span End Stockbridge Dampers	H/w (m)	$< 2615(LD/m)^{0.12}$	$< 2780(LD/m)^{0.12}$	$< 2860(LD/m)^{0.12}$	$< 3030(LD/m)^{0.12}$
	LD/m (m^3/kg)	< 15	< 15	< 15	< 15
Apex-down Triple Bundled Conductors with Non-damping Spacers	H/w (m)	< 1850 m	< 2100 m	< 2275 m	< 2500 m
Apex-down Triple Bundled Conductors with Non-damping Spacers and span end Stockbridge dampers	H/w (m)	$< 2615(LD/m)^{0.12}$	$< 2780(LD/m)^{0.12}$	$< 2860(LD/m)^{0.12}$	$< 3030(LD/m)^{0.12}$
	LD/m (m^3/kg)	< 15	< 10	< 7	< 5
	H/w (m)	-	< 2100 m	< 2275 m	< 2500 m
	LD/m (m^3/kg)	-	> 10, < 15	> 7, < 15	> 5, < 15
Apex-down Triple Bundled Conductors with Damping Spacers	H/w (m)	< 2500 m	< 2500 m	< 2500 m	< 2500 m

CIGRÉ Safe Design Tensions for Horizontal Quad Bundles Values of H/w (m)



Terrain		#1	#2	#3	#4
Undamped, Unspacered Horizontal Quad Bundles	H/w (m)	< 1000 m	< 1125 m	< 1225 m	< 1435 m
Undamped, Unspacered Horizontal Quad Bundles with Span End Stockbridge Dampers	H/w (m)	< 2615$(LD/m)^{0.12}$	< 2780$(LD/m)^{0.12}$	< 2860$(LD/m)^{0.12}$	< 3030$(LD/m)^{0.12}$
	LD/m (m^3/kg)	< 15	< 15	< 15	< 15
Horizontal Quad Bundled Conductors with Non-damping Spacers	H/w (m)	< 1850 m	< 2100 m	< 2275 m	< 2500 m
Horizontal Quad Bundled Conductors with Non-damping Spacers and span end Stockbridge dampers	H/w (m)	< 2615$(LD/m)^{0.12}$	< 2780$(LD/m)^{0.12}$	< 2860$(LD/m)^{0.12}$	< 3030$(LD/m)^{0.12}$
	LD/m (m^3/kg)	< 15	< 10	< 7	< 5
	H/w (m)	-	< 2100 m	< 2275 m	< 2500 m
	LD/m (m^3/kg)	-	> 10, < 15	> 7, < 15	> 5, < 15
Horizontal Quad Bundled Conductors with Damping Spacers	H/w (m)	< 2500 m	< 2500 m	< 2500 m	< 2500 m

Examples of Application of CIGRÉ Guidelines to Single Conductors



KEY

37 str 795 AAAC kcmil X

Drake 795 kcmil ACSR +

2000 kcmil ACAR *

Thrasher 2312 kcmil ACSR O

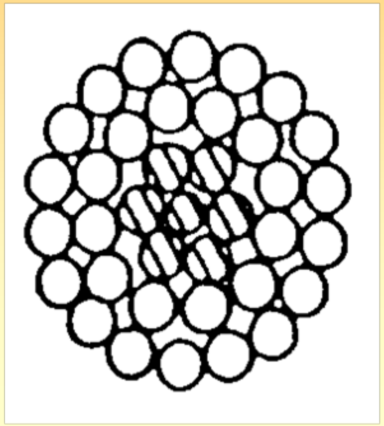
Span lengths:
750 feet

Tensions:
15%, 20%, 25% 30% RTS

Conclusions

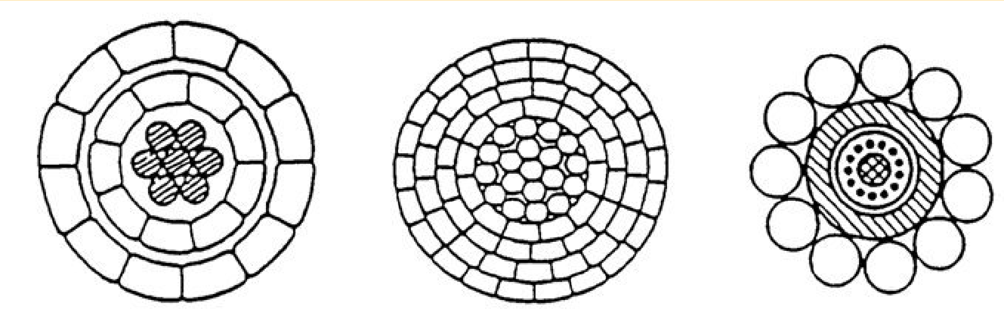
- Conductor tensions need to be controlled to avoid conductor fatigue
- Recent developments lead to a more scientifically based method of selecting conductor tension
- Recommendations apply to most commonly used conductor materials
- Conductor tension is selected based on:
  - Average temperature of the coldest month
  - "Initial" condition of the conductor
  - Conductor weight
  - Span length
  - Terrain condition
- Recommendations are for:
  - Single conductors
  - Horizontal twin bundles
  - Apex down triple bundles
  - Horizontal quad bundles

Conductors and Designs Not Covered



- The recommendations apply to "normal" round strand conductors, and are limited to those composed of the materials listed above.
- There are many types of conductor not specifically covered by these recommendations, due to lack of field experience.
- These include those with different materials, such as copper, galvanized steel, SSAC with annealed aluminum strands, and the various new "high temperature" conductors with special materials replacing the conventional steel core.

Conductors and Designs Not Covered



- Also, conductors with trapezoidal and other shaped strands, conductors containing optical fibers, gap and self-damping conductors, and conductors with non-circular overall cross section, are not covered.
- Further when the recommendation is for some form of protection, there is no guidance regarding the number of dampers or other protection required.
- Bundle designs not covered: Vertical and Oblique Twin, Apex Up Triple, Diamond Quad, Six Conductor Bundles

Publications

- “Report on the Work of the International Study Committee No.6: Bare Conductors and Mechanical Calculation of Overhead Lines”, O.D. Zetterholm, Chairman of the Committee, Report 223, CIGRÉ, Paris, 1960
- “Safe Design Tension with Respect to Aeolian Vibrations – Part 1: Single Unprotected Conductors”, by CIGRÉ Task Force 22.1.04, ELECTRA, No. 186, pp. 53-67, October 1999
- “Safe Design Tension with Respect to Aeolian Vibrations – Part 2: Single Damped Conductors”, by CIGRÉ Task Force 22.1.04, ELECTRA, No. 198, October 2001
- “Overhead Conductor Safe Design Tension with respect to Aeolian Vibrations, Part 3: Bundled Conductor Lines”, by CIGRÉ TF 22.11.04, Electra No. 220, pp.49-59, June 2005
- “Overhead Conductor Safe Design Tension with Respect to Aeolian Vibrations” CIGRÉ Technical Brochure 273, by CIGRÉ Task Force B2.11.04, June 2005

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