DESIGN PROCEDURES FOR WOODEN TRANSMISSION LINE POLES

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SUMMARY

Design procedures for wooden transmission line poles are described in relation to the New Zealand Loadings Code, NZS 4203 [1] and the Timber Structures Code, NZS 3603 [2]. A system of pole classification based on typical design lateral wind loads on tops of poles and a method of production based on that classification are also described. The production method relies on proof testing to the design top load which is demonstrated to be a legitimate procedure under the Timber Structures Code. In view of the number of uncertainties and counteracting effects of the various features of wooden poles, the option of specifying poles that have been proof tested is strongly recommended as a means of optimally satisfying both the designer and the supplier.

1   INTRODUCTION

Wooden poles are widely used for the support of power transmission lines in rural areas in New Zealand. In urban areas new subdivision all have underground power reticulation and existing overhead networks are also gradually being placed underground. The need for poles to support telephone lines has virtually disappeared with the change in technology to microwave transmission and cell phones. For 240V lines, poles of 8 to 10 m length are normally specified while for 11kV lines, poles of 12 to 15 m length are required. For higher voltages steel lattice towers are normally used. There is also a vigorous trade in poles for power reticulation in neighbouring countries, such as Fiji, Hong Kong, the Philippines and New Caledonia.

To meet this market, poles are drawn from selected stands of plantation forest in New Zealand. Corsican pine was the favoured species until recently but is now in short supply so radiata pine is the predominant species. Both of these species are very easy to treat with water-borne preservatives, and for this reason are preferred over other species such as Douglas fir and European larch which also occur to a limited extent in the size and form desired for poles. While distinction between species needs to be made for their treatability, and hence their durability, no such distinction needs to be made in terms of strength because Walford [3] showed that the same density-strength relationship applied to all four species. Hence, in the NZS 3603, softwood poles are classified into two groups; high and normal, on the basis of the density in the outer 20% of their radius. Poles may be designed to the stresses assigned to these two pole categories or

The specifier can simply state the top load capacity required for the poles. In the latter case the producer can follow the proof testing requirements of NZS 3603 to provide adequate poles.

2   PHYSICAL SPECIFICATION OF POLES

The physical features of wooden poles are given in the New Zealand Standard for poles and piles, NZS 3605:1992 [4] and are generally in line with ANSI 05.1:1979 "Specifications and dimensions for wood poles" [5].

The following criteria apply:

Sweep	max 6 mm/m
Short crook	max 25 mm
Checks	max D/4
End splits	none
Knots individual	max C/10
Knot groups	max C/5
Nodal swelling	max 20 mm
Spiral grain	max 1:10

Where C is the circumference and D is the diameter at the defect being considered

3   STRENGTH CLASSIFICTION

The aim of the strength classification system is to simplify the work of the designer. It is intended that the designer specify poles in terms of their length and top load carrying capacity only, while the producer guarantees that they will have the stated load carrying capacity as well as meeting the physical requirements, besides being treated to an H5 hazard classification for durability. Hazard classes refer the exposure to attack by insect or fungi and are defined in MP 3640 [7]. They range from H1 for interior protected situations to immersion in sea water. The strength classes are:

CLASS A	12 kN
CLASS B	9 kN
CLASS C	6 kN
CLASS D	3 kN

Surveys of the design top loads required for poles used in electrical reticulation have shown that the above four top loads classes should satisfy most customers. By contrast the ANSI 05.1 specification cover top load ratings from 370 to 11,400 pounds force, (1.6 to 50.7 kN)

Top load capacity is defined as the ultimate strength design wind load calculated from the dimensions of the pole, the number of conductors, the line span and the wind speed, according the provisions of clause 2.4.3 of NZS 4203. This is different to the top load rating used in ANSI 05.1.

3.1 Wood strength

From a knowledge of the strength of the wood in the pole, its length, its embedment and by making an assumption about the position of the point of load application on the pole, tables of minimum diameters can be constructed.

The expression which relates top load to physical dimensions and wood strength is:

$$P = \frac{f\pi \cdot D^3 x 10^{-6}}{32(L - G - 0.6)} \qquad [1]$$

where;
P is the horizontal top load in kN applied 0.6 m from top of the pole,
f is the design bending stress at the pole groundline in MPa, (or N/mm^2)
D is the groundline diameter in mm,
L is the pole length in m,
G is the butt to groundline distance in m.

The design bending stress, f, is obtained from NZS 3603, where it is related to the density of the outer zone wood in the pole. Two categories are given with the following minimum basic density and characteristic bending strength values for softwood poles:

Outer zone basic density, kg/m^3		Characteristic bending strength
Category	Minimum	f_b, MPa
High	450	52
Normal	350	38

Basic density is defined as the (oven dry weight of the wood)/(volume in the green condition), while the outer zone is defined as the outer 20% of the pole radius.

Design bending stress is calculated from characteristic strength by:

$$f = k\phi f_b \qquad [2]$$

where;
k is the product of relevant modification factors, ($k_{20} = 0.85$ for shaving, $k_{21} = 0.85$ for steaming, and $k_1 = 1.0$ for wind loading), ϕ is the strength reduction factor, ($\phi = 0.8$ for poles).

3.2 Proof testing

Rather than specifying pole diameters from the characteristic stresses given above, the designer may opt to specify top loads only and require the producer to verify the pole strength by proof testing. Section 10 of NZS 3603 gives the requires strength test load (TLB) as:

$$TLB = k_{30} k_{31} \frac{P}{k_1} \qquad\qquad [3]$$

For lateral wind loads on poles, $k_{30} = k_{31} = k_1 = 1.0$. Hence $TLB = P$, the design lateral top wind load on the pole. For lateral loads due to line tension, such as occurs at a change of direction, $k_1 = 0.6$.

The test rigs used in New Zealand normally load the pole in cantilever bending with the force being applied at the groundline position. This force is readily related to the top load by the expression:

$$\text{Groundline load} = \frac{P(L - 0.6)}{G} \text{ kN} \qquad\qquad [4]$$

where L is the overall pole length, G is the butt-groundline distance and it is assumed that the top load is applied at a distance of 0.6 m from the top of the pole.

4   DESIGN PROCEDURE

4.1   The Transmission Pole Design Problem
This procedure is based on the joint Australian/New Zealand Standard "Structural design requirements for utility services poles". This paper is a simplified extract from the above joint Standard and can be used for the straight, level line case.

4.2   Definition of the Problem
It is assumed that the designer has a set of conductors already specified, and wishes to find the size of the timber pole that will be satisfactory in a given situation. Therefore, the geometry of the situation, the topography and placing in New Zealand will be assumed to be known.

Unfortunately the completely general case, where the pole spacing, number of conductors, conductor sags, and alignment of poles are allowed to vary is comparatively complicated. It is usual in the general case to calculate the conductor tensions and resulting pole loads using a special purpose computer programme. However the wind loadings will still have to be found from the loading code, so this procedure is still helpful.

4.3   Assumptions
Structures, such as transmission line poles, are subject to many loads including gravity, wind, earthquake and impact loads. This paper covers only transmission poles and many assumptions have been made, which allow a number of simplifications. While the general design principles are valid for other transmission structures subject to wind, the simplifications may not be suitable. These include the following:

- Impact loads are ignored because it is not intended that poles survive impact.
- Earthquake loads on poles are smaller than wind loads. This follows from the flexible nature of the cables, and the relatively low mass of the structure.
- The conductors are not put up, or taken down in high winds An unbalanced number of conductors, as would occur during construction, puts a high load on a pole. Provided this does not occur during high winds, the loads can be assumed to be due to the smaller gravity loads only. In these circumstances these are smaller than the lateral loads due to wind, and therefore do not require calculation.
- As the conductors get bigger the gravity load increases faster than the wind load. The smaller conductors used with timber poles mean that the wind loads are much higher than the gravity loads.
- The friction wind forces are small compared to the direct pressure forces on the cables. Due to the long thin nature of the structure, the two types of forces do not act simultaneously, therefore wind friction loads can generally be ignored.
- Instability can occur in the cables due to eddy shedding coinciding with resonant frequencies in the cable, and low damping in the structure. Similarly galloping can occur in the conductors, due to the spiral roughness of the conductors or uneven ice coatings on the cables. These effects are more likely to cause problems with the conductors and their mountings, possibly due to fatigue, than to the poles. The forces perpendicular to the wind, caused by eddy shedding almost never exceed 50%

of the direct wind force. Therefore the direct wind force is critical, and for the purposes of designing the pole the other forces may be ignored. These effects can be analysed, and for important structures it is suggested that a comprehensive analysis is undertaken.

- Parabolic equations are adequate to describe the shape of the conductors. The true curve for a conductor is a catenary (or hyperbolic cosine), however the solutions for this are very complicated, and are well approximated by the parabolic equations used here.

Spans either side of the pole
It is common practice to assume an average span in order to simplify calculations. This can be justified partly on the basis that poles are not fixed rigidly in the ground. They will tilt slightly in the soil, which evens up the tension between spans with different tensions. However only the long term (i.e. gravity) loads are balanced out. SHORT TERM LOADINGS DO NOT BALANCE OUT. Since these wind loads are bigger than long term loadings, very large out-of-balance loads can result from relatively small differences in span during high winds. This is discussed further below.

Height differences
A small height difference makes very little difference to the calculations, and can be ignored. The incorporation of the height difference complicates the analysis considerably, and means that it is necessary to use complicated equations.

Pole location
This affects the design wind speed, because some parts of New Zealand have higher winds than others.

Geography
This also affects the design wind speed because hill tops etc. often have higher wind speeds than the surrounding areas.

Conductor diameter
The wind load is proportional to the diameter of the conductor and this is increased if ice accumulation is likely.

Conductor weight
The gravity load on the conductor is proportional to the weight per length of the conductor.

4.4 Design procedure
Loads on poles arise from several causes and a comprehensive design will consider all of them:
- Dead loads due to self weight of the pole, its parts, and all attachments.
- Snow and ice loads.
- Wind loads.
- Earthquake loads although these need be considered only for poles supporting top heavy equipment.
- Live loads and maintenance loads.
- Aerial cable loads

Snow and ice loads.
For transmission lines in areas in New Zealand subject to ice formation, the ice load on the conductors is calculated by assuming a radial accumulation of ice as given in table 1 and a unit weight of 8.6 kN/m^3 for the ice.

Elevation, H, (m)	Radial thickness of ice, (mm)	
	North Island	South Island
H ≤ 600	0	6
600 < H ≤ 900	6	12
900 < H ≤ 1200	12	18

Table 1. Assumed thickness of ice on conductors.

Aerial cable loads

For lines in areas subject to ice formation the additional mass and size of the conductors must be taken into account in calculating gravity loads and wind forces.

Gravity loads

The self weight of the conductor (F_{aG}) is calculated from:

$$F_{aG} = w_g \times 9.8 \times 10^{-3} \times L_{eg} \quad (\text{kN}) \qquad [5]$$

where;

w_g = mass per metre length of conductor, (kg/m)

L_{eg} = the effective span for conductor weight, (m), taken as the sum of the horizontal distances from the centre line of the pole to the lowest point of the catenaries formed on either side of the pole. See figure 1.
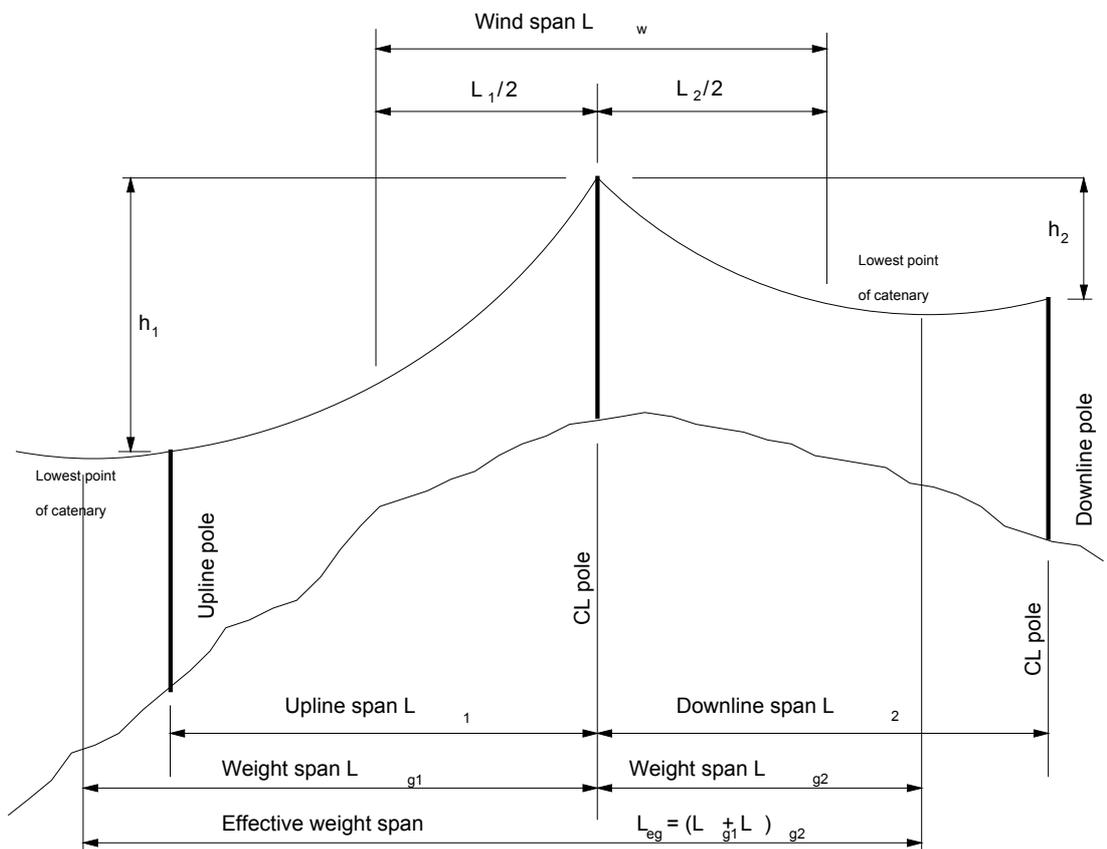
Wind span L_w

$L_1/2$ $L_2/2$

h_1

h_2

Lowest point
of catenary

Lowest point
of catenary

Upline pole

CL pole

Downline pole

CL pole

Upline span L_1 Downline span L_2

Weight span L_{g1} Weight span L_{g2}

Effective weight span $L_{eg} = (L_{g1} + L_{g2})$

Figure 1. Effective spans.

The weight of ice (F_{aS}) is calculated from;

$$F_{aS} = \frac{w_s \pi}{4}\left[d_{cs}^2 - d_c^2\right]L_{eg} \quad \text{(kN)} \qquad\qquad [6]$$

where;
w_s = unit weight of ice (kN/m³),
d_{cs} = nominal overall diameter of the iced conductors, (m).
d_c = nominal external diameter of the conductor, (m)
L_{eg} = the effective span, (m)

Wind loads
The horizontal load on a pole from the supported conductors (F_{aW}), arising from wind at right angles to the span of the cables is calculated from;

$$F_{aW} = np_d d_c k_e L_w C_D \quad \text{(kN)} \qquad\qquad [7]$$

where;
p_d = the design wind pressure, (kPa), determined for the strength limit state.
n = the number of conductors.
d_c = nominal external diameter of the cable, (m), including the increase due to ice accumulation if applicable.
L_w = the wind span, (m)
= $\left(L_1 + L_2\right)/2$. See figure 1.
k_c = a span factor, where:
for $L_w \leq 100$ $k_e = 1.0$
for $100 < L_w < 300$ $k_e = 1-(L_w - 100)/400$
for $L_w \geq 300$ $k_e = 0.5$
C_D = the drag factor

The horizontal design wind pressure (p_d) on poles and conductors is calculated from:

$$p_d = p_b K_z K_T \quad \text{(kPa)} \qquad\qquad [8]$$

where
p_b = the basic regional wind pressure.
K_Z = the terrain category/height factor.
K_T = the topographical factor.

Basic regional wind pressure
The basic regional wind pressure is selected from table 1 for the relevant region. In table 1, the geographic region is determined from Figure 2.
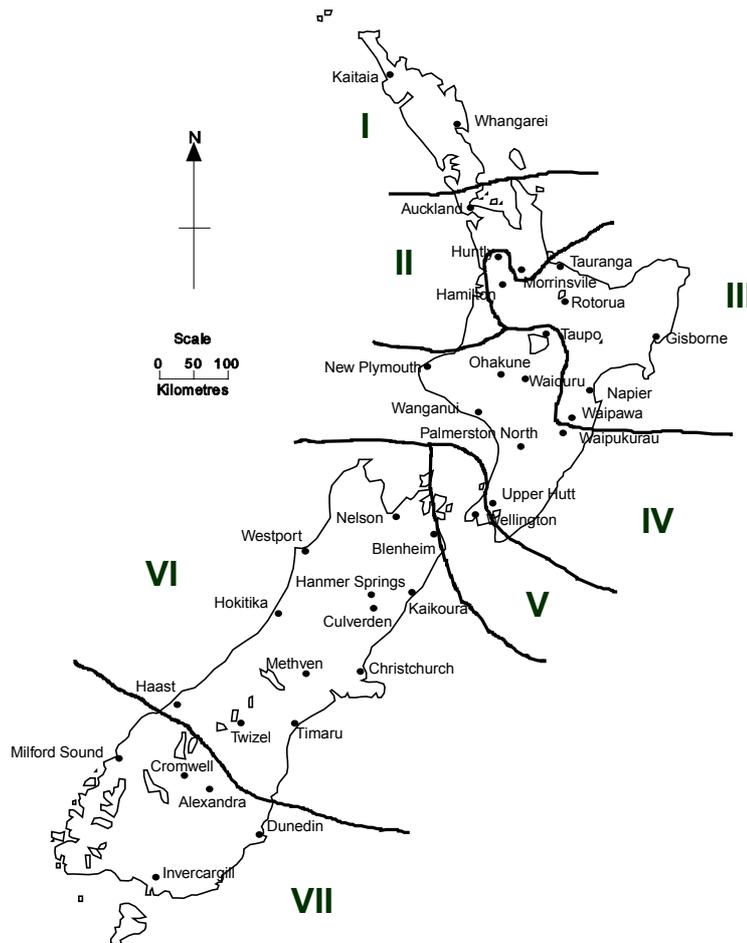
Terrain category/height factor, K_Z

Figure 2. Basic wind pressure regions in New Zealand

Terrain surrounding a pole is classified as category 2 or 3 where:

Terrain category 2 is level or slightly undulating ground with well scattered obstructions less than 5 m high (e.g. open plains, cultivated fields, aerodromes and rural townships).

Terrain category 3 is level, undulating or hilly ground with fairly closely spaced obstructions in the 3 m to 10 m height range (e.g. suburban areas of cities, ground with extensive cover of bush or forest).

The terrain category/height factor is given by table 2. For wind pressure on aerial cables, the height of the cable in a span is taken as the mid-span height of a line joining the points of suspensions of the cable at each end of the span. Intermediate values are obtained by interpolation between the tabulated values.

Geographic region	Basic regional wind pressure, p_b, kPa
II, III, IV, VI	1.2
I, V, VII	1.4

Table 1. Basic regional wind pressures for the strength limit state

Height above ground, m	Factor K_Z	
	Terrain category 2	Terrain category 3
≤ 3	0.72	0.56
5	0.83	0.56
10	1.00	0.69
15	1.10	0.79
20	1.17	0.88
30	1.25	1.00

Table 2. Terrain category/height factors.

Topographical factor, K_T

This factor relates to lines as they cross hills, ridges or escarpments. The factor K_T may be ignored (taken as 1.0) if the height of the feature above the average level of the lowest adjoining terrain is:-
(a)   less than 10 m in terrain category 2; or,
(b)   less than 25 m in terrain category 3; and,
(c)   anywhere outside the topographical zone defined in figure 3.

Maximum gradient[1] (1:x) where x =	Factor K_T			
	Escarpment		Hills or ridges	
	Crest[2]	Slope[2,3]	Crest[2]	Slope[2,3]
2	1.6	1.5	2.0	2.0
3	1.6	1.4	1.9	1.6
4	1.6	1.3	1.8	1.3
5	1.5	1.2	1.6	1.2
7.5	1.3	1.0	1.3	1.0
10	1.0	1.0	1.0	1.0
15	1.0	1.0	1.0	1.0

Table 3. Topographical factor K_T.

Notes to table 3:
1. This is the steepest gradient of either the 'slope' or 'crest' sub zones
2. The relevant factor applies over the whole of each subzone.
3. The slope factor will generally be different on either side of the crest.

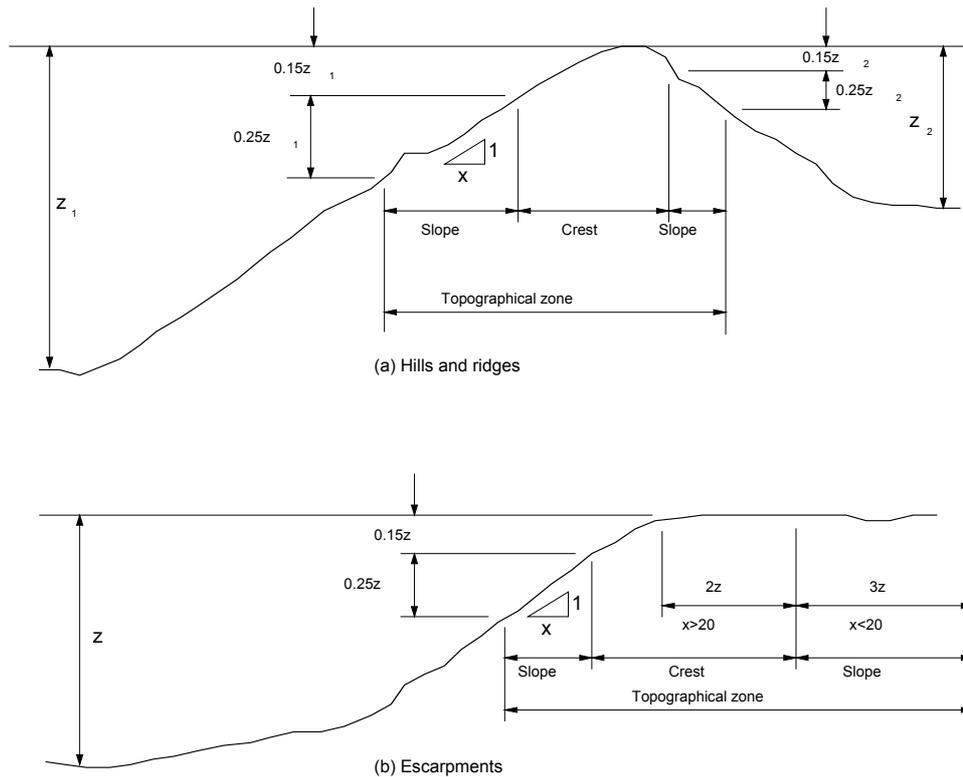For other situations obtain factor K_T from table 3

(a) Hills and ridges

(b) Escarpments

Figure 3. Definition of topographical features and zones.

Drag factor, C_D.
The drag factor, C_D, is equal to 1.2 on the conductors and 0.6 on the pole.

Wind forces on the pole
There is a smaller but still significant force from the wind blowing directly on the pole. In order to relate to the top load capacity, this has to be converted to the equivalent force on the top of the pole. Since the critical point on the pole is usually just above ground level, it is conservative to find the force which would produce the same moment at the ground level as the wind force on the pole. This is equal to the wind force on half the pole. The equivalent horizontal load, (F_{pW}), at the top of the pole due to wind acting on the pole itself is:

$$F_{pW} = \frac{h_p \times p_d \times \left(D_g + D_t\right) \times C_D}{4} \quad \text{(kN)} \qquad [9]$$

where;

h_p	=	the height of the pole above ground level, (m),
p_d	=	the horizontal design wind pressure from equation [8], (kPa)
D_g	=	the pole diameter at groundline, (m)
D_t	=	the pole diameter at the top, (m)
C_d	=	the drag factor from 3.2.2.4

Design loads
For a pole supporting aerial cables, the load combinations for the strength limit state are:
(a) $1.1G + 1.5Q + 1.2S + 1.2F_aT$
(b) $1.1G + k1W_u + S + F_{aT}$
(c) $1.1G + F_{eq}$
(d) $0.9G + k_1Wu$
where:

G = gravity loads	Q = live loads	S = snow loads
F_{aT} = loads due to temperature effects	W_u = wind loads	F_{eq} = earthquake loads
k_1 = the importance factor from table 4		

Importance class	Factor k_I
I	1.00
II	0.85
III	0.75

Table 4. Importance factor (k_I)

Importance Class I includes:
  (a) Transmission line poles providing power to:
    (i)   Essential emergency of life-saving services or;
    (ii)   major industrial plant or;
    (iii)   maximum security places of restraint; and
  (b) Transmission line poles carrying conductors that would cause serious economic or environmental harm if the pole fails.
Importance Class II includes transmission line poles of lesser importance than class I. In general these poles would supply power to residential or light industrial or commercial areas where the loss of service is not considered to be critical, or alternative services can be quickly or easily arranged.
Importance Class III includes all other poles where the consequences of pole failure have less social or economic importance than those for classes I and II.

For this paper, the straight line with equal spans means G and Q balance out to zero. Snow if present will be allowed for by an increase in conductor diameter. Temperature effects balance out and earthquake can be ignored as a design case. Therefore the design horizontal top load, (W_u),on the pole due to wind acting at right angles to the span is:

$$W_u = k_I\left(F_{aW} + F_{pW}\right) \text{ (kN)}$$ [10]

The design top load from equation [10] relates directly to the top load capacity of the four pole classes.

The general case
In the general case, reference should be made to the joint A/NZ Standard "Structural design requirements for utility services poles". Where adjacent spans are different, or change direction, or have unequal sag, or unequal exposure to wind or the poles are at different heights, then surprisingly large loads parallel to the conductor can arise. These are just as serious in their effect on the pole although in this respect wooden poles have an advantage over most other poles which have different strengths along and across the line.

Where wooden poles sustain permanent loads, such as arise at a change in line direction, then the effect of load duration on pole strength must be considered unless the lateral loads are resisted by stays. For permanent loads the load duration factor, (see equation [3]), is equal to 0.6 so for applications where the lateral load on the pole is permanent, the top load capacity of a given class of must be multiplied by 0.6.

5   REFERENCES
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