Are Radiata Pole Columns a Better Solution for Multistory Timber Buildings?

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Aim of study

To further our understanding in the efficient use of timber as the main structural material in multistory buildings.

Introduction

This article is intended as a preliminary study of the use of radiata poles as the column elements in timber multistory buildings. If radiata poles prove to be practical then a series of allied issues will need to be considered. It is intended that the other structural elements such as beams and floor systems would be timber or timber based.

New Zealand has an increasing number of plantation trees that will need felling over the next 20 years. If timber multistory can be made a viable option, an additional market will become available to the timber industry.

We have specified radiata timber poles as structural elements extensively in NZ -especially over the last 35 years. They are mainly used in house piling, pole platforms, power poles, retaining walls. Many poles of retaining walls exist in a continual state of relatively high bending stress. In these contexts they have gained the reputation of having reliable strength.

To date most of the research into multistory timber buildings has concentrated on gluelam elements and also fixed joints involving gluing. This study will avoid gluelam and onsite gluing of elements, as much as possible and consider methods of mechanical fixing. Fixed joints using gluelam are more expensive than those of steel or reinforced concrete. Glued joints require a high degree of skill and attention to construct and involve more risk than the jointing **of** steel or reinforced concrete.

Another perpetual problem with timber structures are joints involving members with large tension forces. The ends of tension members generally require a large number of bolts and/or nailing which can be awkward and costly. To overcome this issue, it is proposed that the resistance to wind and earthquake forces be provided by steel cross bracing.

A building with timber pole columns presents its own set of design problems. Gluelam elements have the advantage of being virtually completely straight and with defined section dimensions. Poles, while generally straight and regular, all have variations of section and to some extent straightness.
For a building system to be practical the structural elements must be manufactured in a factory with consistent dimensions and be easily erected. Can such a system be achieved when associated with poles that are all slightly irregular?

It is hoped that the final outcome of this study is a building system that is attractive economically, ecologically and will assist the multistory buildings in timber to be a viable if not preferred option when compared to steel or reinforced concrete.

Questions Concerning the Environmental Advantages of using Poles as Columns?

- Timber poles are a renewable resource. Can the same be said for the existing traditional materials used in multistory construction?
- What amount of processing is required for the timber. What is the energy required, waste produced, and heat released to the atmosphere compared to that of steel, concrete or gluelam?
- At present we are using "dry framing" sawn lumber which has not been treated because nothing has been observed attacking dry radiata. Can radiata poles remain treatment free if used in a dry environment?
- Could this type of building be dismantled and erected elsewhere as needs change?

- Is the cost of salvaging a timber building minimal compared to the concrete or steel alternative?

- We know that concrete because of its alkaline nature will be continually breaking down due to the formation of carbonates from carbon dioxide and water absorbed from the air. Does the reliable strength of dry radiata reduce with time?
- Would timber pole columns, like gluelam provide reasonable fire resistance and have a predictable charring rate? For architectural reasons, is it likely the poles would be clad with fire resistant plasterboard which would further help fire resistance?

Questions about the Economic Advantages of using Timber Poles as Columns?

- Is there a considerable cost saving if chemical treatment of the timber with preservatives is not required?
- Can a multistory building, as proposed in this paper, be built more economically than those of steel or reinforced concrete?
- Is this type of building able to be containerized and exported?
- Would New Zealand's carpentry skills adjust to suit the erecting of mechanically fixed multistory timber buildings?
- Can foundation sizes and costs be reduced? The foundation loads should be about 55% of those for steel and reinforced concrete multistory buildings. Would timber buildings due to their lightness be more suited to difficult sites, which are steep or have weak subsoils.

Design Problems Which Would Need to be Resolved

- Do poles have sufficient load carrying capacity to support the design actions in them?
- Can a timber floor system be arranged which
    - can be manufactured with consistent dimensions but absorb pole variations?
    - can easily accommodate services relayed within the floor plane?
    - is quick erecting?
    - is cost effective?
- Can a valid diagonal bracing system be incorporated into a timber pole multistory building? Would diaphragm walls be more suitable than diagonal bracing?
- Can steel braces be detailed so they are ductile? Are parts of the braces able to be sacrificial and thus replaceable if damaged after an earthquake event?
- What is the significance of moisture content and shrinkage changes causing dimensional changes in the timber elements?
- Can this type of building conform to fire standards?
- Can sufficient sound control be established between floors and rented areas?
- What are the architectural implications for this type of building?
- Are there issues of supporting lifts using timber ? e.g. are there significant dimensional changes in the timber columns? Can lift travels to be adjusted to accommodate these?

- Will radial cracking and checking of poles due to drying be significant in terms of reduced pole strength? Can drying be controlled to avoid or reduce cracking? How much is pole strength reduced by radial cracking?

- Are there simple methods for determining pole "straightness" to assist their selection?

- Can poles undergo non-destructive testing to ensure they have reliable strength?

Work has recently been carried out on this subject by various researchers.
Their approaches include,

Machine stress grading by Gaunt, D.J, [1]

Mathematical programming model for choosing timber by Noli, E.; Sicad, B.; Leicester, R.H.; Foliente, G.C., [2]

Mechanical non destructive testing by Partel, P.; Stamato, G.H.; Calil Junior,C., [3]

Prototype Building

A prototype building for studying required pole diameters is illustrated in Figure 2 (Floor Plan) and 3 (Cross section) the following sketches. It is six stories high and is 3 No 7.2m bays wide and 6 No 7.2m bays long. The 7.2m centers between columns are a multiple of 1.2m, standard sheet product width.
The distance between floors is considered at 4m. The floor structure depth is assumed at 1.2m deep. Thus the floor to ceiling height is 2.8m.

Proposed locations of the diagonal bracing are shown on the plan. The section also illustrates the diagonal bracing arrangement. Passive energy dissipaters have been included in the initial building.

The "primary floor beams" and "joists" are cantilevered so that the external walls are 400 beyond the columns. This cantilever is to assist the pole columns remaining dry, to provide a 'sheer' finish to the outside: and for the ease of external cladding.

Figure 1 - *5m to 6m high pole retaining wall which exists in high state of bending stress (surcharge on retained upper level is 70 kPa*

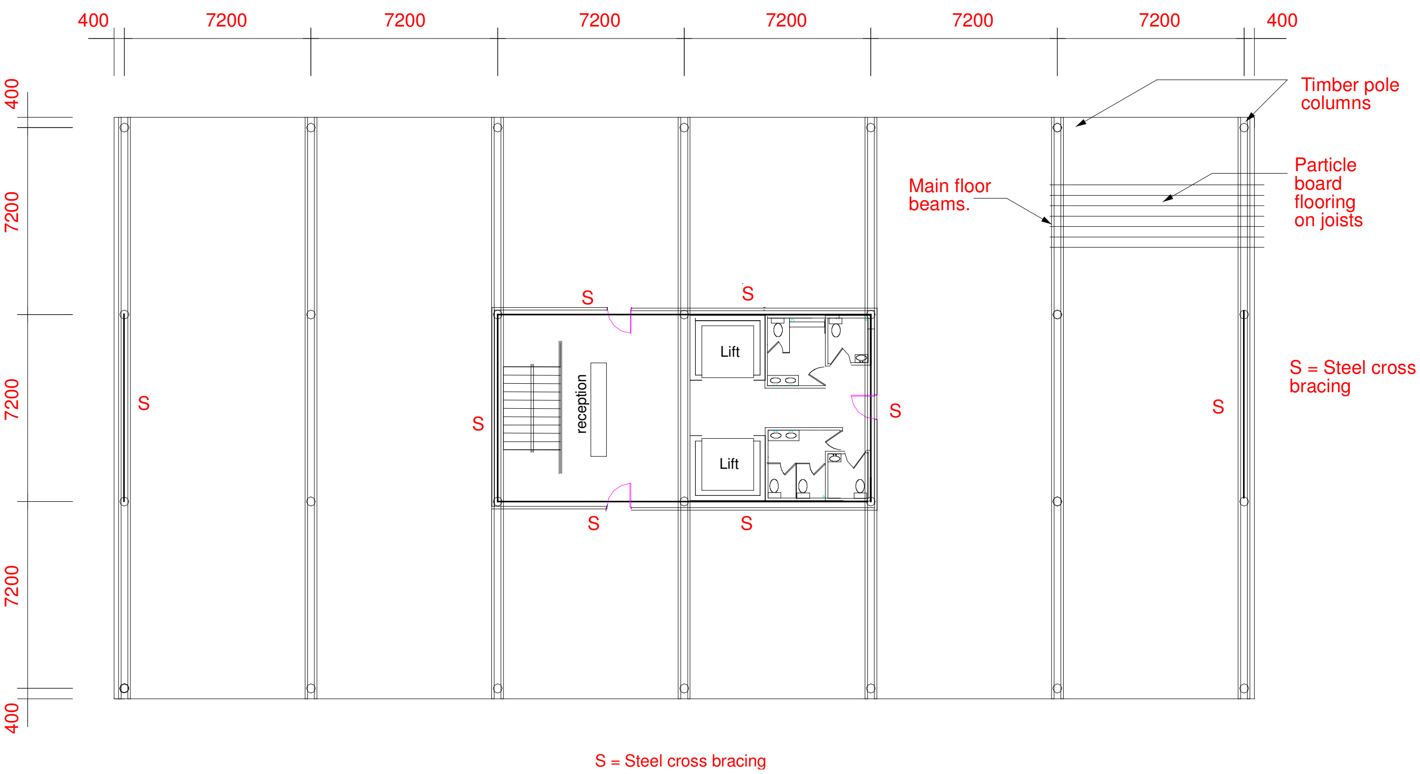

Figure 2*: Timber Pole Multistorey Prototype Building Floor Plan*

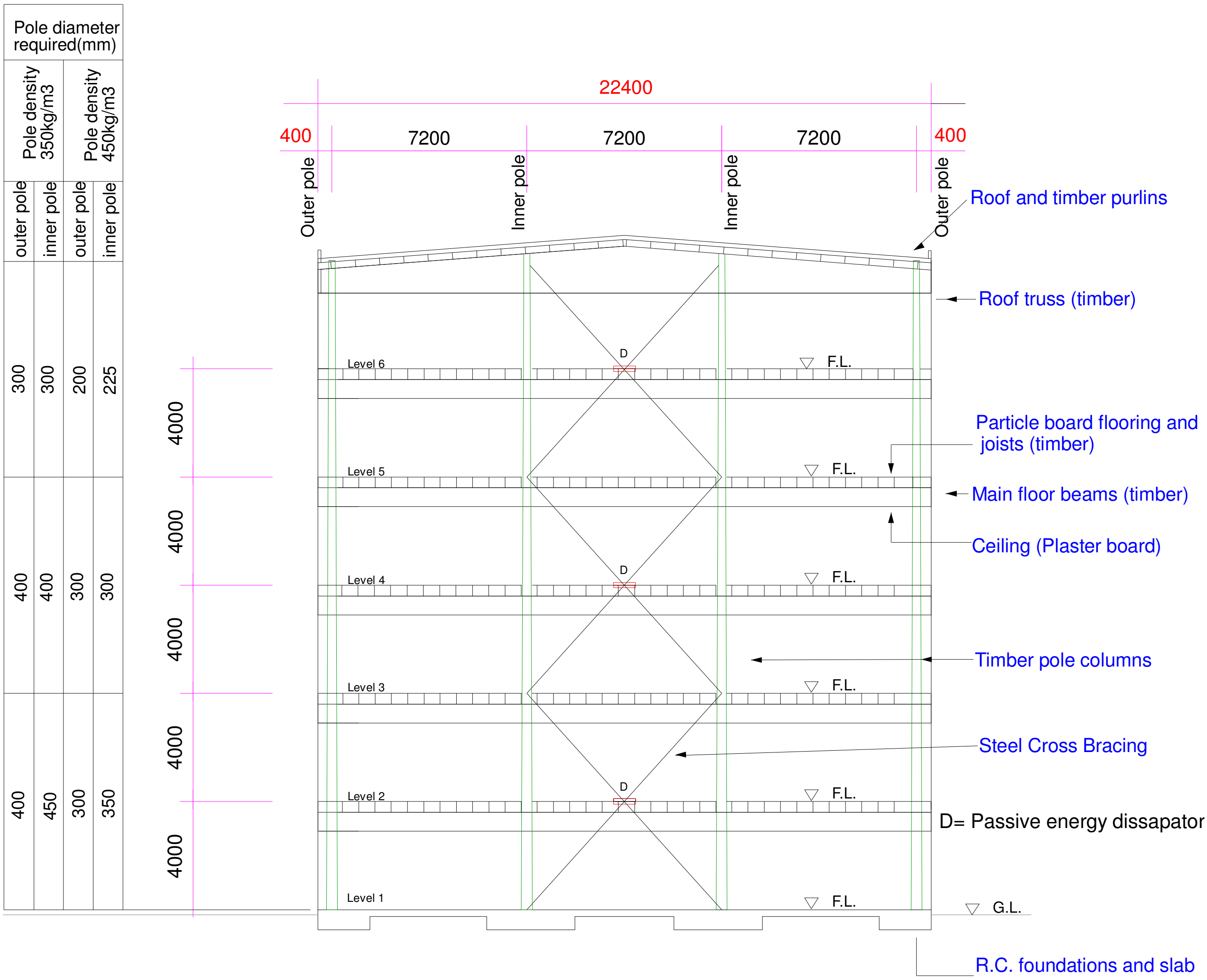

***Figure 3**: Timber Pole Multistorey Prototype Building Cross section*

Preliminary Analysis of Timber Pole Columns.

The following Tables 1 & 2 summarize the calculations for the pole diameters required according to NZS 3603.[4]. Table 1 is for the outer pole density of 350kg/m^3. Table 2 considers the outer pole density to be 450kg/m^3. The calculated pole diameters are also shown on the prototype cross section.

The effective pole length is considered to be 4m. This is conservative because the poles are taken to be 8m long and extend between two floors. Thus an effective length of 71% of the 4m may be more accurate according to NZS3603. [4]

The floor live load is taken as 2.5 pa floor which is, according to NZS 4203, [5] that required by "offices for general use". The floor dead load is estimated as 1.5kPa. The roof dead load is taken as 0.5kPa.

The structure carrying vertical loads is essentially a beam and post arrangement. Pole diameters are selected for this condition.

However, some fixity would occur between the timber columns and "main floor beams".
A further analysis of pole diameters has been carried out assuming full fixity between the poles and primary beams.

The true condition will be somewhere between the above two extremes.

The analysis which assumes full fixity between the columns and the main floor beams was carried out using the "multiframe" structural analysis program. The primary beams spanning between the poles are considered to be two 585mm high by 115mm wide gluelam with 18mm precambers.

Conclusions

This is a preliminary study. The radiata pole diameters required for the 6 storied building with columns spaced at 7.2m centers in both directions vary between 300mm and 450mm for an outer pole density of 350kg/cu.m. For an outer pole density of 450kg/cu.m the required pole diameters are between 200mm and 350mm.

A future study is planned that will consider a diagonal bracing system to resist horizontal, wind and earthquake forces. This analysis may increase the loads in those poles that are associated with the diagonal braces and effect their pole diameter sizings.

Radial cracking may be more severe for poles used under dry internal conditions compared to those in external conditions where there is frequent wetting. NZS 3603 does not mention radial cracking. It may be that it's design parameters were established from testing a group of logs that had a typical range of radial cracking. Perhaps, to overcome this question of how radial cracking affects reliable strength , each dried pole should be compression tested to 2.5 times the expected maximum working load before being used.

To ensure, at the ultimate condition , that the columns are not the first structural element to fail, their required strength may need to be increased - say by around 133%. This will mean that the pole diameters will be larger by 50mm to 75mm compared to those resulting from these preliminary calculations.

Because the required pole sizes established by this initial study are standard and readily available, further study of this type of building is worthwhile.

If we take the maximum pole diameter that is available as 600mm and using poles with an outer density of 450kg/cu.m. for the lower levels, it may be possible to design and construct buildings up to approximately 12 stories high.

References

[1] Gaunt, D.J, 1999: Machine Stress Grading Revisited. Proceedings of the Pacific Timber Conference, Rotorua, N.Z. , Vol 1, pp. 163-170.
[2] Noli, E.; Sicad, B.; Leicester, R.H.; Foliente, G.C.,1999: Logs to Engineered Wood Products: an Enterprise Optimisation Modeling Framework. Proceedings of the Pacific Timber Conference, Rotorua, N.Z. , Vol 1, pp.177-184
[3] Partel, P.; Stamato, G.H.; Calil Junior,C.;1999: A Mechanical Non-Destructive Test for Poles Grading: A Proposal. Proceedings of the Pacific Timber Conference, Rotorua, N.Z. , Vol 1, pp.263-268
[4] Standards New Zealand, 1993; Timber Structures Standard. NZS 3603:1993
[5] Standards New Zealand, 1992; Loadings Standard, Vol 1 Code of practice. NZS 4203:1992

__Table 1 -__ 350kg/m^3 Outer Wood Density Poles

Radiata Pole Diameter Selection							
Outer pole density =		350.00 *kg/m^3*		*(selected dias.hatched)*			
Main Floor Beams simply supported- Live load on all spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	778.00	1555.00	477.00	954.00	176.00	352.00
M*	(kn-m)	0.00	0.00	0.00	0.00	0.00	0.00
Selected pole diameter	(mm)	300.00	400.00	250.00	325.00	200.00	225.00
Effective length/Diameter		13.33	10.00	16.00	12.31	20.00	17.78
K8		0.96	1.00	0.85	0.98	0.67	0.74
phi Nnc	(kn)	868.59	1608.49	534.07	1040.62	269.42	376.61
phi Mn	(kn-m)	65.75	162.36	33.69	85.34	13.60	21.38
(P*/phi Nnc)+(M*/phi Mn)		0.90	0.97	0.89	0.92	0.65	0.93
Main Floor Beams simply supported- Live load on alternate spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	560.00	1026.00	363.00	632.00	166.00	238.00
M*	(kn-m)	0.00	0.00	0.00	0.00	0.00	0.00
Selected pole diameter	(mm)	300.00	400.00	250.00	325.00	200.00	225.00
Effective length/Diameter		13.33	10.00	16.00	12.31	20.00	17.78
K8		0.96	1.00	0.85	0.98	0.67	0.74
phi Nnc	(kn)	868.59	1608.49	534.07	1040.62	269.42	376.61
phi Mn	(kn-m)	65.75	162.36	33.69	85.34	13.60	21.38
(P*/phi Nnc)+(M*/phi Mn)		0.64	0.64	0.68	0.61	0.62	0.63
Main Floor Beams fixed to poles- Live load on all spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	710.00	1623.00	433.00	997.00	154.00	374.00
M*	(kn-m)	36.30	7.10	60.60	3.70	28.00	4.00
Selected pole diameter	(mm)	**400**	**450**	**400**	**400**	**300**	**300**
Effective length/Diameter		9.00	8.00	9.00	9.00	12.00	12.00
K8		1.00	1.00	1.00	1.00	0.98	0.98
phi Nnc	(kn)	1608.49	2035.75	1608.49	1608.49	886.68	886.68
phi Mn	(kn-m)	65.16	92.78	65.16	65.16	26.94	26.94
(P*/phi Nnc)+(M*/phi Mn)		1.00	0.87	1.20	0.68	1.21	0.57
Main Floor Beams fixed to poles- Live load on alternate spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	457.00	1067.00	303.00	661.00	151.00	253.00
M*	(kn-m)	16.90	32.10	9.40	16.80	4.20	4.70
Selected pole diameter	(mm)	400.00	450.00	400.00	400.00	300.00	300.00
Effective length/Diameter		9.00	8.00	9.00	9.00	12.00	12.00
K8		1.00	1.00	1.00	1.00	0.98	0.98
phi Nnc	(kn)	1608.49	2035.75	1608.49	1608.49	886.68	886.68
phi Mn	(kn-m)	162.36	231.17	162.36	162.36	67.12	67.12
(P*/phi Nnc)+(M*/phi Mn)		0.39	0.66	0.25	0.51	0.23	0.36

Table 2 *- 450kg/m^3 Outer Wood Density poles*

Radiata Pole Diameter Selection							
Outer pole density =		450.00 *kg/m^3*			*(selected dias.hatched)*		
Main Floor Beams simply supported- Live load on all spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	778.00	1555.00	477.00	954.00	176.00	352.00
M*	(kn-m)	0.00	0.00	0.00	0.00	0.00	0.00
Selected pole diameter	(mm)	250.00	350.00	225.00	275.00	175.00	200.00
Effective length/Diameter		16.00	11.43	17.78	14.55	22.86	20.00
K8		0.82	0.97	0.74	0.91	0.57	0.66
phi Nnc	(kn)	805.03	1866.50	588.46	1081.00	274.20	414.69
phi Mn	(kn-m)	44.48	144.37	29.26	65.70	10.60	18.33
(P*/phi Nnc)+(M*/phi Mn)		0.97	0.83	0.81	0.88	0.64	0.85
Main Floor Beams simply supported- Live load on alternate spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	560.00	1026.00	363.00	632.00	166.00	238.00
M*	(kn-m)	0.00	0.00	0.00	0.00	0.00	0.00
Selected pole diameter	(mm)	250.00	350.00	225.00	275.00	175.00	200.00
Effective length/Diameter		16.00	11.43	17.78	14.55	22.86	20.00
K8		0.82	0.97	0.74	0.91	0.57	0.66
phi Nnc	(kn)	805.03	1866.50	588.46	1081.00	274.20	414.69
phi Mn	(kn-m)	44.48	144.37	29.26	65.70	10.60	18.33
(P*/phi Nnc)+(M*/phi Mn)		0.70	0.55	0.62	0.58	0.61	0.57
Main Floor Beams fixed to poles- Live load on all spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	679.00	1653.00	416.00	1015.00	149.00	380.00
M*	(kn-m)	23.30	7.50	42.70	5.30	13.80	3.50
Selected pole diameter	(mm)	**300**	**350**	**300**	**300**	**200**	**225**
Effective length/Diameter		12.00	10.29	12.00	12.00	18.00	16.00
K8		0.98	1.00	0.98	0.98	0.75	0.82
phi Nnc	(kn)	1385.44	1924.22	1385.44	1385.44	471.24	652.08
phi Mn	(kn-m)	91.86	148.84	91.86	91.86	20.83	32.42
(P*/phi Nnc)+(M*/phi Mn)		0.74	0.91	0.77	0.79	0.98	0.69
Main Floor Beams fixed to poles- Live load on alternate spans.							
Pole level location		1&2	1&2	3&4	3&4	5&6	5&6
Inner/Outer pole		Outer	Inner	Outer	Inner	Outer	Inner
P*	(kn)	494.00	1091.00	322.00	673.00	147.00	257.00
M*	(kn-m)	29.00	31.10	39.00	15.50	11.70	6.70
Selected pole diameter	(mm)	300.00	350.00	300.00	300.00	200.00	225.00
Effective length/Diameter		12.00	10.29	12.00	12.00	18.00	16.00
K8		0.98	1.00	0.98	0.98	0.75	0.82
phi Nnc	(kn)	1385.44	1924.22	1385.44	1385.44	471.24	652.08
phi Mn	(kn-m)	91.86	148.84	91.86	91.86	20.83	32.42
(P*/phi Nnc)+(M*/phi Mn)		0.67	0.78	0.66	0.65	0.87	0.60