Eucalyptus nitens Optimised Engineered Lumber (OEL™) Trial

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EXECUTIVE SUMMARY

The OEL™ (Optimised Engineered Lumber) technology produces structural products with known, uniform and reliable properties. There is financial advantage derived from the fact that all the merchantable OEL™ production output is certified structural grade (no downfall products), this compares with the output from traditional sawmilling where not all production achieves certification as structural grade product.

Wood Engineering Technology Ltd (WET) hold patents of the OEL™ process and are currently in the process of commercialising the OEL™ product. WET was sub-contracted by Scion to undertake this *Eucalyptus nitens* trial for the Special Wood Product Partnership.

The intention of this project was to complete a scoping only study that took *Eucalyptus nitens* material through the OEL™ process followed by an assessment of the mechanical properties with the high level OEL™ economics developed.

Southward Exports supplied 3m^3 of *Eucalyptus nitens* the logs from 19-24 year old trees that had small end diameters under bark ranging from 21.6 – 27.8cm and large end diameters under bark ranging from 25.0 – 34.8cm, with an average Hitman value of 3.8km/sec.

Wood Engineering Technology Ltd (WET) processed these into less than expected 40 pieces of 90x45x2930mm OEL™ due to:

- A significant number of sticks being rejected to dimensional and straightness issues.
- The *Pinus radiata* finger-jointing and lamination process struggled with the high density *Eucalyptus nitens*.

The results of the mechanical testing showed that the *Eucalyptus nitens* OEL™ achieved the strength and stiffness properties of the New Zealand structural grade SG12.

The economic comparisons indicated the superior results of using OEL™ technology in converting 19-24 year old age *Eucalyptus nitens* logs into SG12 structural lumber (glulam), when compared with a saw log from full thirty-year rotation Radiata pine.

INTRODUCTION

Optimised Engineered Lumber (OEL™)

The OEL™ process produces structural products with known, uniform, stable and reliable properties.

Essentially the OEL™ process starts with the production of metre long thin laminates that are of a known stiffness and strength. These laminates are then sorted into stiffness grades with the grade thresholds between the grades being determined from the layup and such that the target final section stiffness is achieved. The graded laminates are then finger-jointed together and then laid up in the predetermined sequence and glued together to form the final finger-jointed, laminated section as shown in Figure 1.

Wood Engineering Technology Ltd (WET) hold patents of the OEL™ process and are currently in the process of commercialising the OEL™ product. WET has been sub-contracted by Scion to undertake this *Eucalyptus nitens* trial for the Special Wood Product Partnership.

Figure 1: *Eucalyptus nitens 90x45 Optimised Engineered Lumber (OEL™)*

STUDY GOAL

The intention of this project was to complete a scoping only study that took *Eucalyptus nitens* material through the OEL™ process followed by an assessment of the mechanical properties. The high level OEL™ economics were also to be developed.

The outcome being to provide (or not) justification for further development, optimisation and potential commercialisation of this opportunity.

This scoping study as with any scoping study has limitations that would need to be further explored prior to commercialisation namely:

- Limited sample size.
- No replication across different forest resources, log types.
- No ability to tailor the processing to the *Eucalyptus nitens*, i.e. The Radiata pine process parameters had to be used.
- Only room for one set of processing variables, i.e. No process optimisation possible.
- Only the major product properties are explored, in this case these were the primary mechanical properties. There are other properties that should be considered to develop this commercial opportunity namely:
    - Laminate bond quality
    - Timber treatment ability, ability to satisfy the H1.2 treatment class
    - Mechanical jointing properties (nail plate, nail, screw & bolt strengths)

LOG PROPERTIES

For this OEL™ trial Southwood Exports were asked to supply:

- 3m^3 of *Eucalyptus nitens* logs, the logs were to be cut to 3.3m long with a tidy square cut ends, the logs also needed to be debarked and cut into two half rounds.
- The logs were to be representative of the forest estate

The half round logs supplied were picked at random from four different Southward forests, three forests planted around 1997 (19 year old trees), one forest planted in 1992 (24 year old trees).

When the logs were received by WET some of the logs showed severe radial splitting and most had at least some radial splitting on the exposed ends, Figure 2. One 1m ½ log fell completely in half, the two 1/4s were put together and cut either side of the split with the centre board being rejected. There were some 7 half logs that had whole boards rejected and one half log which was not broken down. This resulted in the loss of 126 sticks that may have been recovered with freshly harvested logs.

WET measured the half logs for diameter, length and hitman velocity this information is listed Table 1.

WET cut the 3.3m long logs into three 1.05m long logs to fit their process, the logs were supplied cut in half to help with processing in the WET pilot plant, this halving of logs is not a requirement in the final OEL™ commercial operation.

***Figure 2:** Photographs of some of the Eucalyptus nitens logs supplied.*

Table 1: *Eucalyptus nitens half log properties as recorded by WET*

Half Log No:	Under Bark LED (mm)	Under Bark SED (mm)	log length, (m)	Hitman (km/sec)	Taper (mm/m)
1	305	290	3.3	3.71	4.5
2	320	290	3.3	3.90	9.1
3	285	252	3.3	3.85	10.0
4	285	261	3.3	3.76	7.3
5	309	300	3.3	3.76	2.7
6	270	280	3.3	3.68	3.0
7	265	255	3.3	3.84	3.0
8	318	290	3.3	3.88	8.5
9	313	296	3.3	3.70	5.2
10	260	260	3.3	4.49	0.0
11	293	280	3.3	3.85	3.9
12	348	318	3.3	3.59	9.1
13	315	295	3.3	3.87	6.1
14	342	216	3.3	3.59	38.2
15	293	280	3.3	4.07	3.9
16	292	280	3.3	3.65	3.6
17	340	305	3.3	3.42	10.6
18	290	277	3.3	4.21	3.9
19	344	310	3.3	3.43	10.3
20	285	281	3.3	4.02	1.2
21	279	272	3.3	3.65	2.1
22	305	283	3.3	3.74	6.7
23	295	270	3.3	3.73	7.6
24	285	272	3.3	3.62	3.9
25	293	272	3.3	4.01	6.4
26	301	289	3.3	3.88	3.6
27	250	271	3.3	3.57	6.4
28	278	254	3.3	3.74	7.3
29	276	254	3.3	3.50	6.7
30	308	292	3.3	3.90	4.8
31	299	282	3.3	3.96	5.2
32	280	268	3.3	4.04	3.6
Average	298	278		3.80	6.52
Minimum	250	216		3.42	0
Maximum	348	318		4.49	38
Range	98	102		1.07	38
STDev	24	20		0.23	6.37
CoV%	8%	7%		6%	98%
Count	32	32		32	32

In summary the logs supplied had small end diameters under bark ranging from 21.6 – 27.8cm and large end diameters under bark ranging from 25.0 – 34.8cm, with an average Hitman value of 3.8km/sec.

OEL™ PROCESSING

Sawing

The 1.05m long half logs were slabbed off into 50mm slabs (Figure 3) and docked square to a 1m length.

The logs had been halved for quite an extended period which resulted in the halving cut being no longer straight. When the half logs were gang sawed into 1m boards they were held against a fence set up such that the “first” saw blade makes a full cut down the “straight side. If the bowing was any more than the 2.3mm kerf then the first stick was unacceptably tapered and these had to be rejected, 209 sticks due to taper as they came off the gang saw.

Figure 3: *Bowed 50mm cants*

WET expected a 48.5% yield i.e. 3435 sticks and achieved a yield of 3000 approx sticks, a yield of 42%.

Drying

The 3000 sticks were supplied to Scion for drying. WET supplied Scion with its purpose built drying frame which is fabricated in a manner that restrains the sticks from moving whilst drying. The sticks were dried at 45/43°C for around 24 hours (until ~30%MC) then steamed for 2.5 hours to recover collapse, then dried at 70/45°C targeting a final moisture content of 6%. Two sticks per kiln load were oven-dried to determine moisture content, the average moisture content of these sticks was 6.0%.

After drying the sticks were stored for 3 days at 40°C, 26°C wet bulb (EMC = 6%) then were block stacked and sent back to WET. It was observed that the drying quality was surprising good with less than expected checking, collapse or distortion. There is room for optimisation of drying schedule to reduce drying times, and potentially reduce the incidence of collapse or distortion.

Finger- jointing, thicknessing and laminating

WET did not un-pack the dried sticks until they were ready to process them, the dried sticks were kept block stacked in a sealed container in order to keep to the 6% moisture content. As the pilot plant recommissioning took longer than anticipated the sticks were stored 12 weeks which would not happen in a commercial operation.

At the end of this 12 week time period significant numbers of sticks were visually rejecting due to excessive dimensional change and loss of straightness. This high level of dimensional change and loss of straightness was not apparent immediately after drying implying that in a commercial operation the reject rate may be reduced. Some tapered sticks were also found during the thickness processing operation which may have affected the restraint provided to nearby sticks during drying.

The full OEL™ process has a machine process that culls sticks that are too weak or excessively distorted, however this was not available for this trial. It was also found many sticks had developed since drying higher levels of cross-sectional dimension variation and loss of straightness, this resulted in a high numbers of sticks being rejected, Figure 4.
This high reject rate may be less in practice:

- When the sticks are processed immediately after drying
- The drying of thin *Eucalyptus nitens* is better understood and a more optimised drying schedule is developed.
- One 'simple' solution proposed to overcome the change in dimension and collapse would be to over cut by 0.5-1mm and then plane out this thickness variation, this however will have an impact green sawing recovery.

Figure 4: *Collapse and distortion of sticks*

The finger-jointing operation struggled with the high density *Eucalyptus nitens* with difficultly in cutting the finger joints, aligning and pressing the joints, also some of the joints did not have the correct amount of glue applied.

WET believe these issues were a function of the pilot plant and with a better understanding of processing high density Eucalypts these issues could be significantly minimised.

The lamination process was not as successful compared with *Pinus radiata* with some glue application and clamping issues these again are a function of the pilot plant and with a better understanding of processing high density Eucalypts these issues could be significantly minimised.

After curing the OEL™ was plained on four sides to produce the 90x45 samples. Finally WET supplied Scion with 40 pieces of 90x45x2930mm *Eucalyptus nitens* OEL™ this was less than the 70 expected.

TESTING FOR MECHANICAL PROPERTIES

Scion carried out the mechanical tests on the *Eucalyptus nitens* OEL™ 90x45 product supplied by WET.

1. The bending strength and stiffness specimens were tested to destruction in accordance with AS/NZS4063.1:2010. The Scion Grade 1 Baldwin Universal test machine was used for the bending tests.
2. The compression strength specimens were tested to destruction in accordance with AS/NZS4063.1:2010. The Scion Grade 1 Baldwin Universal test machine was used for the compression tests.
3. The shear strength specimens were tested to destruction in accordance with AS/NZS4063.1:2010. The Scion Grade 1 Baldwin Universal test machine was used for the shear tests.
4. The strength and stiffness data was analysed in accordance with AS/NZS4063.2:2010.

Due to the limited number of 90x45 OEL™ samples we were not able to test for tension.

All the testing was completed in the Timber Engineering laboratory of Scion, Rotorua, New Zealand. The testing was carried out over the period 4 July - 11 July 2016.

Mechanical Test Results

The characteristic strength and stiffness properties have been calculated using the calculations and procedures set out in AS/NZS4063.1:2010. The following Table 2 shows the characteristic strength and stiffness values for the *Eucalyptus nitens* OEL™ 90x45 product with Table 3 listing the New Zealand characteristic grade stresses for the SG stress grades.

Table 4 shows a statistical summary of the strength and stiffness data with the Appendix listing the raw test data collected.

***Table 2**: AS/NZS4063.2:2010 Characteristic Strength Properties as Tested*

90x45 ***Eucalyptus nitens*** OEL™	**Bending Stiffness MoE As a Joist GPa**	**Bending Strength MoR As a Joist MPa**	**Tension Parallel Strength MPa**	**Compression Parallel Strength MPa**	**Shear Strength * MPa**
90x45 (Indicated SG grade)	13.71 (SG12)	30.44 (SG12)	Not Tested	51.27 (SG15)	Note 1

Note 1 – Only 4 samples failed in shear all of these either achieved or exceeded the SG8 value of 3.8MPa

***Table 3:** Characteristic stresses for machine graded timber NZS3603 A4*

Moisture Content – Dry (m/c = 16%)						
Species	**Grade**	**Bending Strength MPa**	**Compression Strength MPa**	**Tension Strength MPa**	**Bending Stiffness GPa**	**Lower bound Bending Stiffness GPa**
Radiata Pine	**SG 15**	41.0	35.0	23.0	15.2	11.5
&	**SG 12**	28.0	25.0	14.0	12.0	9.0
Douglas fir	**SG 10**	20.0	20.0	8.0	10.0	7.5
	SG 8	14.0	18.0	6.0	8.0	5.4
	SG 6	10.0	16.0	4.0	6.0	4.0

Note: The shear strength for dry Radiata pine and Douglas fir shall be taken as fs = 3.8 MPa.

Table 4: *Eucalyptus nitens OEL™ 90x45 Strength and Stiffness Statistical Summary as Tested*

90x45 *Eucalyptus nitens* OEL™	**Bending Stiffness MoE As a Joist GPa**	**Bending Strength MoR As a Joist MPa**	**Tension Parallel Strength MPa**	**Compression Parallel Strength MPa**	**Applied Shear Stress * MPa**
Average	13.84	42.94	Not	57.68	-
Minimum	11.61	24.31	Tested	42.35	-
Maximum	15.83	61.62	Due to	69.48	-
Range	4.22	37.31	-lack of	27.13	-
STDev	1.09	7.77	-samples	6.13	-
CoV%	7.89%	18.10%	-	10.63%	-
Count	31	31	-	30	-

***** Note: 23 specimens failed in Shear (7 failed in bending) of the 23 that failed in shear 11 showed signs of poor bond quality.
For the remaining 12 specimens (that failed in shear and with no apparent bond quality issues) all the failure shear stresses exceeded characteristic shear stress of 3.8MPa

The result of the mechanical testing showed that the *Eucalyptus nitens* OEL™ achieved the strength and stiffness properties of the New Zealand structural grade SG12.
Note: SG8 is the common grade used in house framing.

OEL™ ECONOMICS

(Undertaken by Wood Engineering Technology Limited for Scion under its contract with Future Forests Research Limited)

Conclusions regarding relative economics
Economic comparisons indicated the superior results of using OEL™ technology in converting 19 to-24-year-old Eucalyptus (Nitens) pulp logs into SG8 structural lumber (glulam) in fact SG12 a higher value, higher grade superior product was produced, when compared with a saw log from full thirty-year rotation Radiata pine.

The OEL™ technology gives superior financial outcomes to that used of traditional sawmilling as all the merchantable production output is certified structural grade (as evidenced by the Scion test results in this trial) providing a higher total revenue at a similar total cost therefore a much enhanced return on capital employed. Generally, less than half of the output from traditional sawmilling achieves certification as structural grade product.

Trial design
The trial, using Eucalyptus (Nitens) pulp logs with an age range between 19 and 24 years (Trial Logs) with an average SED of 283mm, processed all logs through the Wood Engineering Technology Limited (WET) pilot plant into OEL™ engineered wood products. Scion then measured the resultant OEL™ output at their facility in Rotorua, and confirmed that all of the output exceeded the performance grade required for use as SG8 lumber and achieved a superior grade performance of SG12.

Outcomes and assumptions
The economics were based on applying a pulp grade log input cost of $45/cum. Yields of merchantable lamina sticks was reduced by an estimated amount of 33% compared with Radiata due to the cell collapse during drying that were rejected in process. There was a loss of lamina sticks from split logs estimated at 5%. A lower temperature longer drying regime was utilised.

Financial comparisons
The economics below were derived from the results of one trial only, and more trials will be required to corroborate these calculations. Furthermore, it would be desirable to conduct more trials in order to mitigate the cell collapse that occurs during drying, a known behaviour of Eucalyptus (Nitens) so as to minimise the cost arising and test alternative drying regimes.

Indicative WET Economics processing Euc. nitens using the OEL™ Process (Prepared Sept 2016)			
Key Assumptions:	**Radiata**	**Radiata**	**Euc. nitens**
1 cum log weighs 1 tonne	**Solid Mill**	**OEL™ Process**	**OEL™ Process**
Log Grade	**S30**	**S30**	**Pulp**
SED Average (mm)	300	300	283
Length	4.8m+	4.8m+	4.8m+
Theoretical Yield - Actual Count (90X45)	47.5%	47.5%	44.00%
Additional Euc. nitens Losses - Cell collapse	0.0%	0.0%	33.0%
Additional Euc. nitens Losses - Splitting	0.0%	0.0%	6.5%
Net Theoretical Yield - Actual Count (90X45)	47.5%	47.5%	26.6%
Net Theoretical Yield - Nominal Count (100X50)	**58.6%**	**58.6%**	**32.9%**
Log Price $/cum (Indicative prices May 2016)	104	104	45
Extra handling of small logs in yard	0	0	0
Total Indicative Log Price $/cum	**104**	**104**	**45**
Projected Wood Cost $/cum of Finished Product	**177**	**177**	**137**

CONCLUSION

This scoping study showed:

- That the *Eucalyptus nitens* logs could potentially be converted into OEL™ however several issues where identified;
    - Log splitting and loss of straightness leading to loss of recovery
    - The need to better understand kiln drying thin section *Eucalyptus nitens* and how to minimise the reject rate due to change in dimension/collapse and loss of straightness.
    - The need for a better understanding of finger-jointing and lamination of high density *Eucalyptus nitens,* then developing a customised finger-jointing and lamination process.
- The OEL™ achieved the bending stiffness, and bending, and compression and shear strengths of the common house framing grade of SG12.
- The economic assessment as provided by Wood Engineering Technology Limited showed the projected wood cost per m^3 for the *Eucalyptus nitens* OEL™ being lower than that for Radiata OEL™.
- The OEL™ technology is considered superior to that used in traditional sawmilling because all of the output is converted into first grade structural product.
- There is an opportunity to optimise/tailor the OEL™ process around this *Eucalyptus nitens* material which should lift recoveries, improve the drying, finger-jointing and laminating processes in turn improving the economics.
- As this was just scoping study consideration should be given to
    - Increasing the sample size via replication across different forest resources, log types
    - Timber treatment ability, ability to satisfy the H1.2 treatment class
    - Mechanical jointing properties (nail plate, nail, screw & bolt strengths)

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REFERENCES

1. AS/NZS4063.1:2010, Characterization of structural timber Part 1: Test methods. Standards Australia/Standards New Zealand.

2. AS/NZS4063.2:2010, Characterization of structural timber Part 2: Determination of characteristic values. Standards Australia/Standards New Zealand.

APPENDIX A

***Table A1:** Eucalyptus nitens OEL 90x45 - Bending as a joist Strength and Stiffness*

Lab No	Client No:	Width mm	Depth mm	Slope N/mm	Max Load N	Bending Stiffness MoEj GPa	Bending Strength MoRj MPa
275544	1	45.21	88.04	478.76	9088	14.05	42.01
275545	2	45.04	88.27	528.80	13348	15.46	61.62
275546	3	44.98	88.44	429.45	9768	12.50	44.98
275547	4	45.19	88.07	485.54	9180	14.24	42.43
275548	5	45.10	88.23	433.88	10195	12.68	47.04
275549	6	45.08	88.09	395.11	8616	11.61	39.90
275550	7	45.12	88.06	443.34	10587	13.03	49.02
275551	8	45.18	88.08	462.36	7961	13.56	36.79
275552	9	45.01	87.86	533.84	8277	15.83	38.59
275553	10	45.07	88.17	472.87	12774	13.86	59.06
275554	11	45.08	88.08	523.52	8547	15.39	39.59
275555	12	45.17	88.00	478.92	10212	14.09	47.29
275556	13	45.19	88.03	474.28	12001	13.93	55.52
275557	14	45.17	88.10	469.80	8863	13.77	40.95
275558	15	45.01	87.99	473.58	9316	13.98	43.31
275559	16	45.36	87.96	415.07	9221	12.17	42.56
275560	17	45.05	87.99	425.74	8168	12.56	37.94
275561	18	45.03	88.13	470.77	9861	13.83	45.68
275562	19	45.00	88.04	531.58	7966	15.67	37.00
275563	20	45.05	88.03	460.39	9252	13.56	42.93
275564	21	45.06	88.02	477.68	8429	14.08	39.11
275565	22	45.18	87.93	435.89	8698	12.85	40.34
275566	23	45.11	87.86	477.94	9574	14.14	44.54
275567	24	45.21	88.23	450.74	7439	13.14	34.24
275568	25	45.07	88.18	521.31	9795	15.27	45.28
275569	26	45.01	87.98	463.68	10214	13.70	47.49
275570	27	45.27	87.96	497.38	11521	14.62	53.29
275571	28	45.23	88.03	429.19	6235	12.59	28.82
275572	29	45.20	88.12	508.39	5268	14.88	24.31
275573	30	45.04	87.67	430.75	9164	12.85	42.88
	31	45.14	88.16	519.33	7949	15.20	36.70

Table A2: *Eucalyptus nitens OEL 90x45 Compression Strength*

Lab No	Client No:	Width mm	Depth mm	Max Load N	Compression Strength MPa
275574	1	45.10	88.65	222845	55.74
275575	2	45.39	88.20	250937	62.68
275576	3	44.88	88.34	221643	55.90
275577	4	45.13	88.14	241878	60.81
275578	5	44.84	88.36	256759	64.80
275579	6	45.19	88.06	195756	49.19
275580	7	45.13	88.06	276129	69.48
275581	8	44.80	88.21	240435	60.84
275582	9	44.99	88.09	200480	50.59
275583	10	45.09	88.01	260421	65.62
275584	11	45.06	88.20	218702	55.03
275585	12	44.97	88.06	255743	64.58
275586	13	45.13	88.34	266705	66.90
275587	14	45.34	87.96	225403	56.52
275588	15	45.07	88.11	212857	53.60
275589	16	45.22	88.41	252395	63.13
275590	17	44.94	88.26	188835	47.61
275591	18	45.09	88.08	168197	42.35
275592	19	44.91	87.85	250229	63.42
275593	20	44.97	88.39	224055	56.37
275594	21	45.15	88.24	229654	57.64
275595	22	44.87	87.60	222199	56.53
275596	23	45.05	88.07	208948	52.66
275597	24	45.11	88.07	238244	59.97
275598	25	45.04	88.18	210675	53.05
275599	26	45.12	87.76	230421	58.19
275600	27	45.22	88.39	227763	56.98
275601	28	45.14	87.94	240046	60.47
275602	29	45.15	88.19	203651	51.15
275603	30	45.16	88.10	233590	58.71

Table A3: *Eucalyptus nitens OEL 90x45, Shear as Joist*

Lab No	Client No:	Width mm	Length mm	Max Load N	Applied Shear Stress MPa	Shear / Bending Failure	Potential Bond Quality Issue
275604	1	45.20	88.25	28.32	5.32	Shear	?
275605	2	45.18	88.20	21.89	4.12	Shear	?
275606	3	45.01	87.88	28.64		Bending	?
275607	4	45.25	88.27	23.98		Bending	?
275608	5	44.89	88.03	19.02		Bending	?
275609	6	45.11	87.67	20.71	3.93	Shear	Yes
275610	7	45.37	88.09	34.75	6.52	Shear	No
275611	8	45.01	87.45	34.97	6.66	Shear	No
275612	9	45.02	87.83	19.11	3.63	Shear	?
275613	10	45.12	88.11	34.39	6.49	Shear	No
275614	11	45.19	88.15	31.46	5.92	Shear	No
275615	12	45.07	88.02	30.85	5.83	Shear	No
275616	13	45.04	87.91	37.05	7.02	Shear	No
275617	14	45.12	88.13	23.25	4.38	Shear	No
275618	15	45.16	88.11	30.94	5.83	Shear	No
275619	16	45.16	87.92	20.09	3.80	Shear	Yes
275620	17	45.10	88.08	38.25	7.22	Shear	No
275621	18	45.21	88.09	30.64	5.77	Shear	No
275622	19	44.84	87.83	20.53		Bending	?
275623	20	45.05	87.88	31.54	5.97	Shear	Yes
275624	21	45.17	88.07	33.57	6.33	Shear	Yes
275625	22	44.91	88.36	19.78		Bending	?
275626	23	45.23	87.97	14.56	2.74	Shear	Yes
275627	24	45.30	88.15	31.67	5.95	Shear	Yes
275628	25	45.08	87.97	13.68		Bending	?
275629	26	45.08	88.33	30.38	5.72	Shear	No
275630	27	45.09	88.21	20.14	3.80	Shear	?
275631	28	45.00	88.34	18.30	3.45	Shear	Yes
275632	29	45.26	88.08	16.64		Bending	?
275633	30	45.05	88.1	21.71	4.10	Shear	No