STRUCTURAL TESTING OF A GRIDLINK 6.5M WIND TURBINE BLADE

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12/10/2004

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BACKGROUND:

GRIDLINK has been manufacturing wind turbines for some years. To date, no structural testing of the blades has been attempted. The design of the blade, both aerodynamic and structural, has been largely by trial and error. Failures have not been a problem, which suggests that the structural design may be unnecessarily conservative. The tests described below were aimed at demonstrating compliance with IEC 61400-2 and confirming the conservative nature of the structure.

LOADING:

The blade was loaded using a Wiffle tree, applying the load at 4 points: 2·0, 3·0, 4·0 and 6.0 m from the turbine axis.

The actual blade load distribution under both storm (Turbine stopped) and full load conditions is not well known. With this in mind the Wiffle tree was designed to a compromise load distribution having loads representative of the storm conditions near the root and representative of the full load conditions toward the blade tip. This represents the worst case under both loadings.

A design load of 4983 N (508·5 kg force) has been used, leading to a proof load of 5482 N (559 kg) being 10% greater. (The load cell used produced forces in kg.)

The loading points for the first stage of the Wiffle tree were at radii 2·37 m and 5·04 m. the second stage loading point was at a radius of 3·35 m. The resulting loads on the blade, expressed as percentages of the total load applied are shown in the table below:

Radius m	Load %
2	39·9
3	23·4
4	17·6
6	19·1

The resulting shear force and bending moment distributions are shown in *figure 1*:

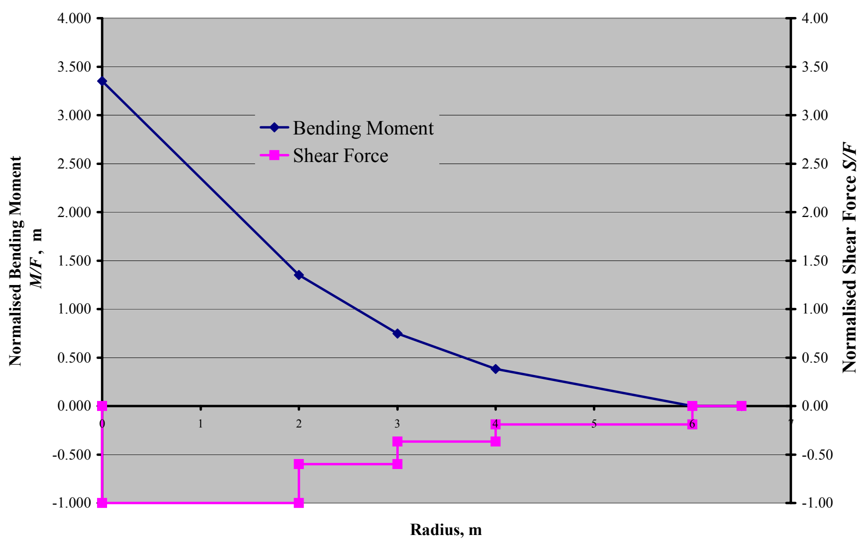

Figure 1. Bending Moment and Shear Force diagrams normalised by dividing by the total load *F*.

The turbine has a diameter of 13 m, giving it a disc area of 132·7 m^2. Each of the three blades has an area of 3·172 m^2, and the overall solidity of the turbine is 7·17 %. An air density of 1·226 kg/m^3 has been used in all the following calculations.

Storm loading:
An extreme gust speed of 38 m/s and the design load corresponds with a force coefficient of 1·77. This is quite conservative; actual force coefficients on the blades would be unlikely to exceed 1·0.

Alternatively, with a force coefficient of 1·0, the design load corresponds to a wind gust speed of 50·6 m/s.

Load at Cut Out:
This turbine is known to deliver 35 kW at wind speeds of 14 m/s. At 14 m/s the design load corresponds to a thrust coefficient of 0·937. This is clearly too high.

An underestimate of the actual thrust coefficient can be obtained from Froude 'actuator disc theory'. To provide 35 kW at 14 m/s the ideal turbine would have a thrust coefficient of 0·164. It seems that the chosen design load is very conservative.

STRAIN GAUGES:

Six strain gauges were attached to the blade, three on the compression surface and three on the tension surface. They were placed as nearly as practicable to the maximum thickness of the aerofoil section, that being the location of the main spar. The main spar has steps in thickness and the gauges were placed to measure longitudinal strain near the step and on the thin section of the spar. The radii from the axis of rotation were 800 mm, 2500 mm and 4500 mm. Strains were measured at 2 second intervals using a Datataker 600 data logger, wired as 6 bridges with a single active gauge. A seventh channel of the data logger was used to record the load applied using a load cell.

Testing:

The load schedule used is shown graphically in *figure 2*.

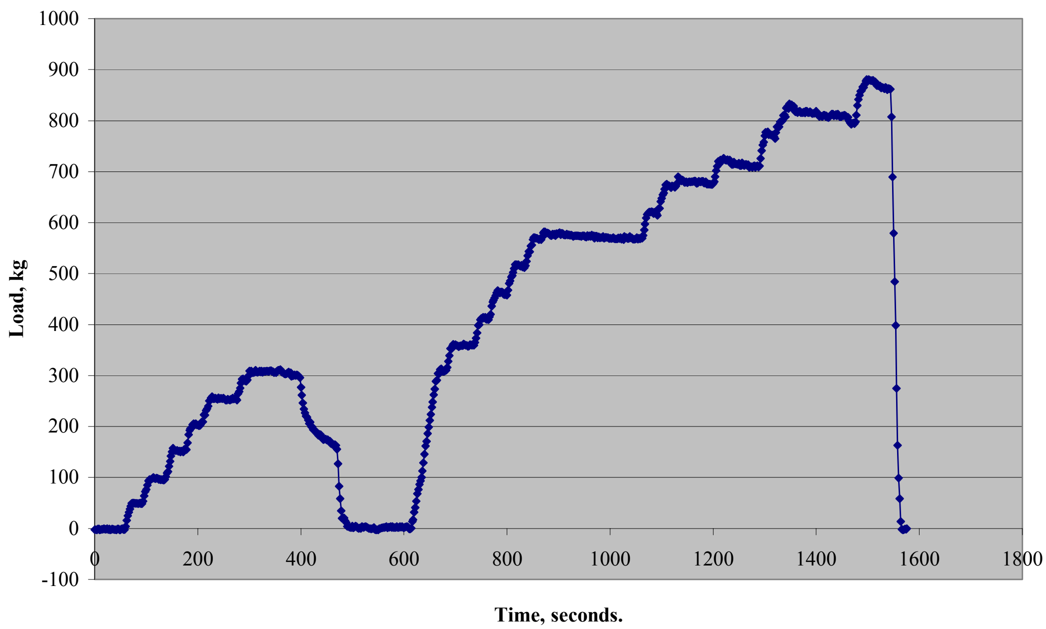

Figure 2. Applied load plotted against time.

The load was applied by a hydraulic ram. It was increased in steps of nominally 50 kg to 300 kg and then released. At each step the tip deflection was measured as the load was held steady.

The load was then released to see whether there was any significant permanent deformation. The load was then increased in steps to the proof load and held for approximately 3 minutes before continuing loading in 100 kg steps to ultimate failure. The observed ultimate failure was not in the blade itself but in the blade root attachment. The bolts attaching the blade root visibly extended and the plate to which the blade was bolted distorted. The measured strains are shown in *figures* 3 to 8.

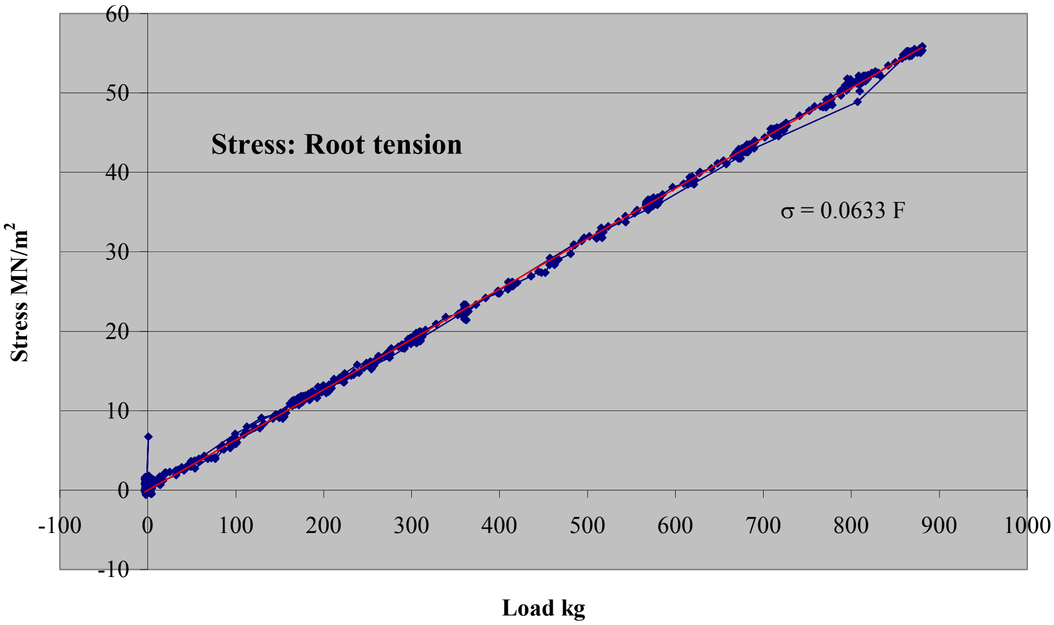

Figure 3. Stress at the root location, tension side.

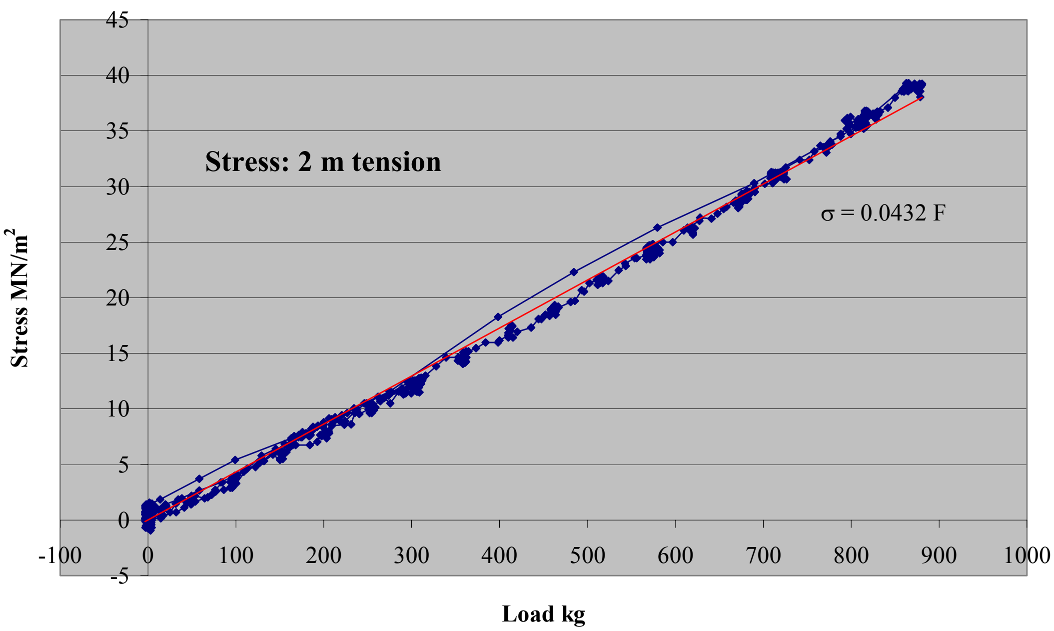

Figure 4. Stress at the 2 m location, tension side.

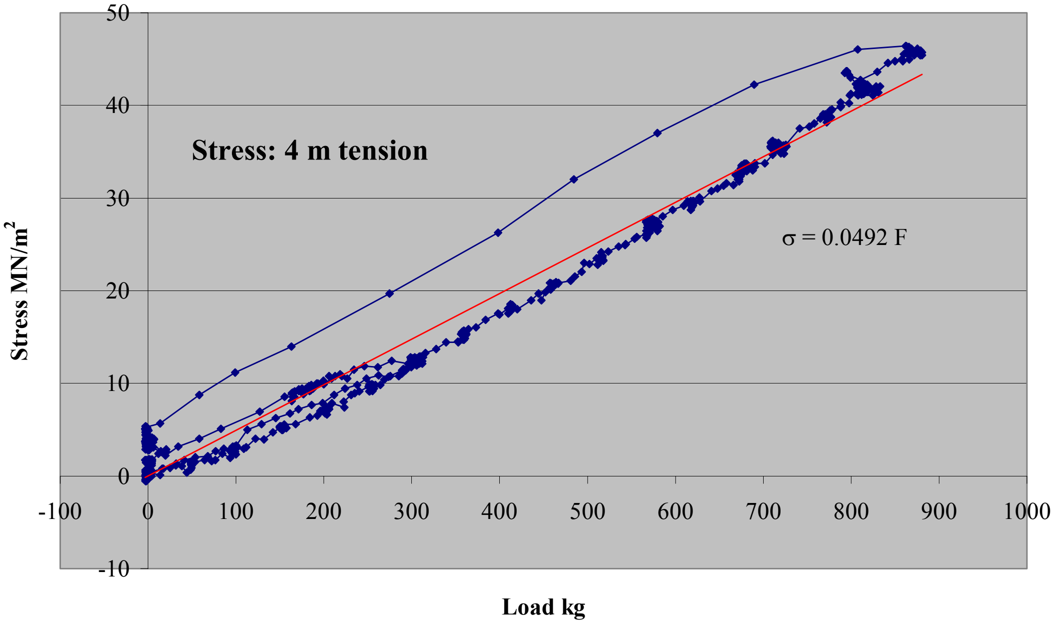

Figure 5. Stress at the 4 m location, tension side.

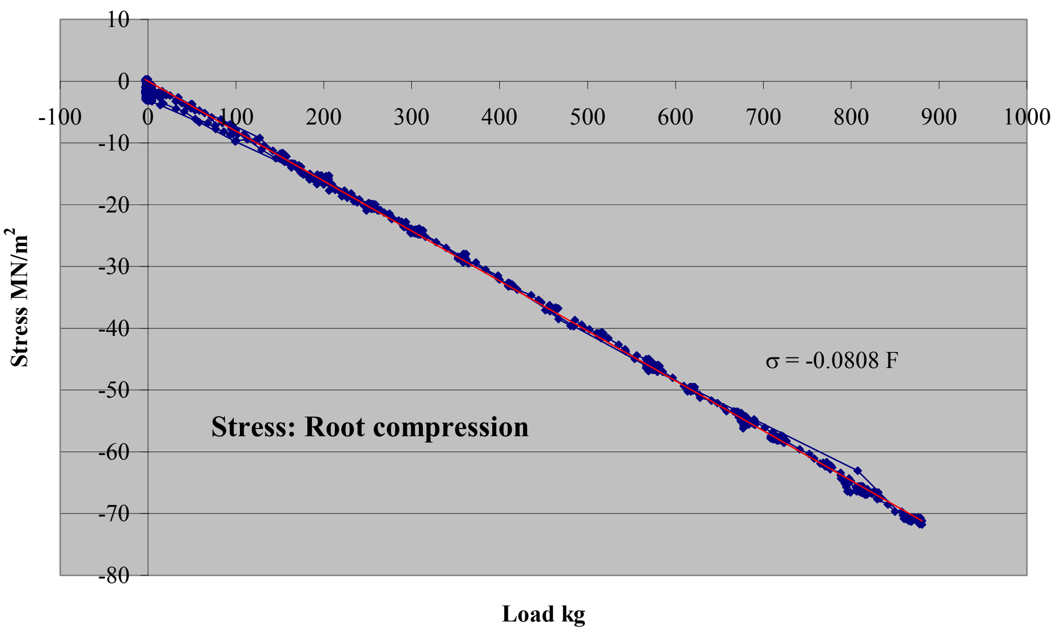

Figure 6. Stress at the root location, compression side.

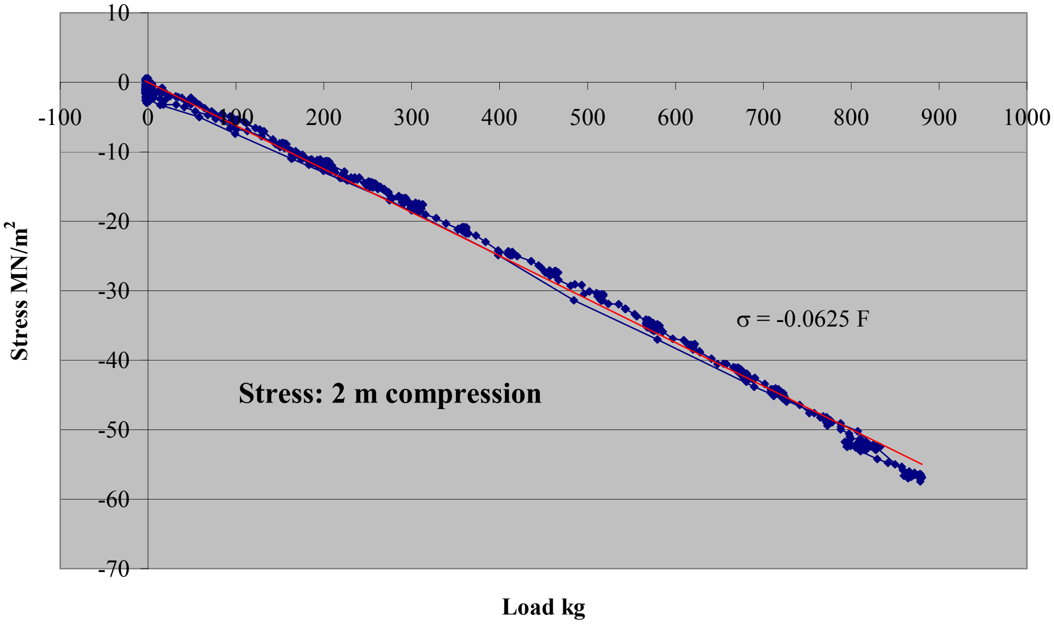

Figure 7. Stress at the 2 m location, compression side.

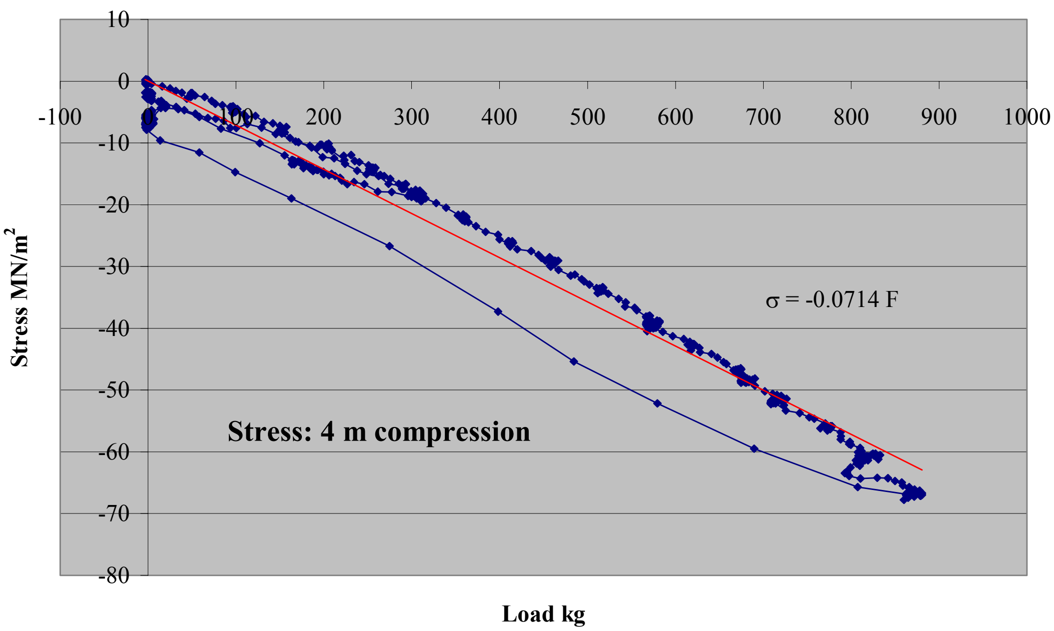

Figure 8. Stress at the 4 m location, compression side.

These graphs of stress against load would be expected to be linear (Hooke's law). In fact they are and a straight line of best fit is shown on each in red, with the formula for the line shown on the graph. The two graphs at the 4 m location display a degree of hysterisis on unloading, which is not unusual in this kind of testing. Most likely it is due to friction in the joints of the Wiffle tree rather than the structure itself. This is supported by the fact that it is most evident at the large radius locations.

The stresses have been calculated using the manufacturer's data for Young's Modulus for the material, 24·4 GN/m^2 and may be compared with the manufacturer's data on tensile strength: 366 MN/m^2. (Arguably one could use the flexural modulus, which is lower and the flexural strength, which is higher, but the conclusions remain the same.) The conclusion reveals that at the proof load of 560 kg the factor of safety on strength is approximately 8.3 and that the highest stress is on the compression side at the root location. This safety factor seems excessive. It would seem that the laminate thickness could be at least halved throughout the structure. Such a recommendation however should be accompanied by caveats that, there may be stress concentrations not revealed by the test, and that thinner laminates may lead to buckling failures. Neither of these seem probable.

BLADE TIP DEFLECTIONS:

Figure 9 shows the tip deflection measured during the test. The departure from linearity is almost certainly due to yielding of the support structure, particularly the bolted joint at the blade root. There was no apparent permanent deformation of the blade.

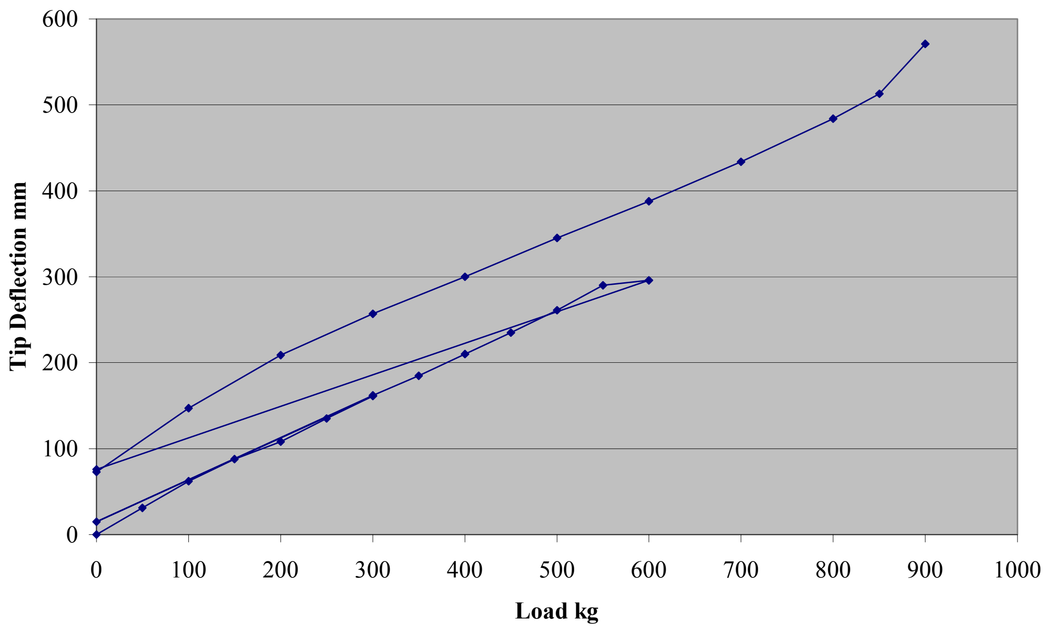

Figure 9, blade tip deflection.

If laminate thickness is reduced in future blades then the tip deflection will increase. The possibility of blades hitting the turbine support tower exists.

CONCLUSIONS:

Despite loading to almost twice the proof load no failure of the blade structure occurred. The failure which did occur was yielding of the bolted joint mounting the blade to the support structure.

The factor of safety on stresses in the blade is over 8, which seems excessive. It may be possible to reduce the laminate thickness to about half that in the blade tested but a blade with the thinner laminate should be tested to check that buckling and stress concentration problems do not arise.

The blade structure conforms to IEC 61400-2 Standard.