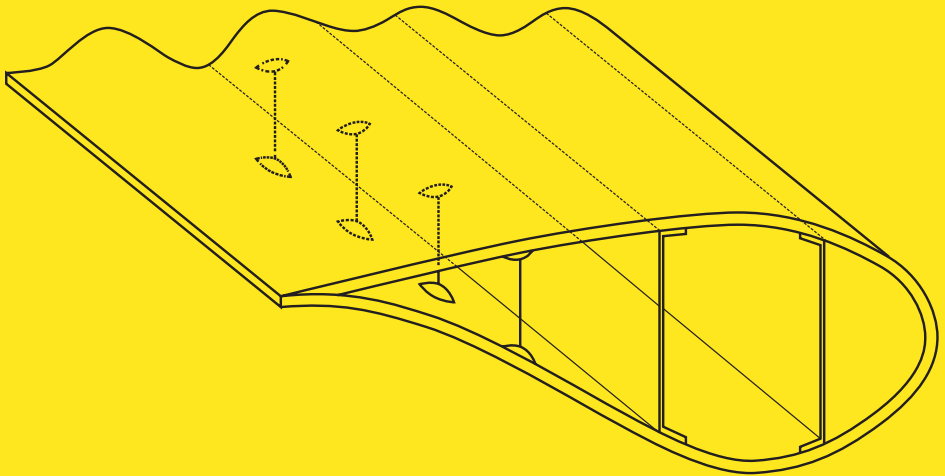


**Bladena**

BLADE ENABLER

# D-String®

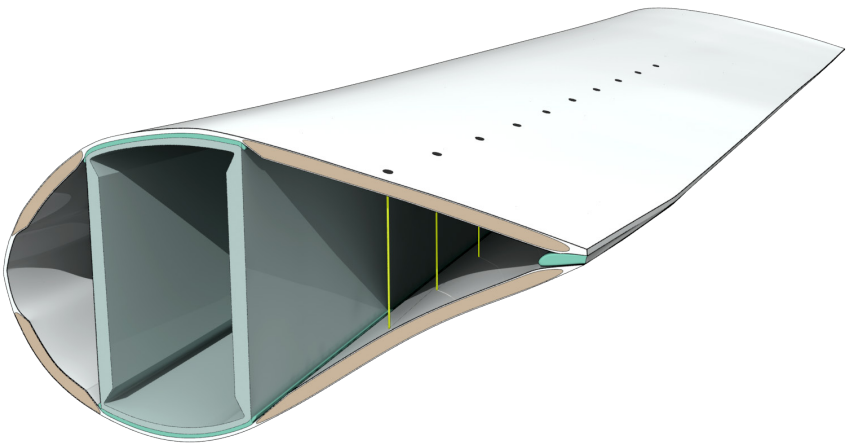
## Technical Documentation



# D-STRING®

## Prevent cracks in the max chord region of the blade

The D-String® is a simple yet effective technology developed to eliminate cracks in the trailing edge max chord area by eliminating breathing as the root cause. The installation of the D-String® positively affect the operation of your wind turbine.



1. Commercially viable solution that eliminates the occurrence of cracks on aging blades.
2. Significantly increase the anticipated life-time of your blades.
3. Secures operation of the blade without added maintenance cost.
4. Decreasing time for maintenance, in turn reduces the LCoE increasing the profit margin.
5. The cost of a single repair equals the cost of a D-String® kit for 3 blades (including installation).

## **Expert opinion by DEWI OCC**

The D-String® documentation has been reviewed by DEWI OCC who found that: the structural properties and integrity of the blades are not negatively affected by the installation of D-Strings®. The D-String® product does not influence the structural safety of the trailing edge panels of a general rotor blade design.

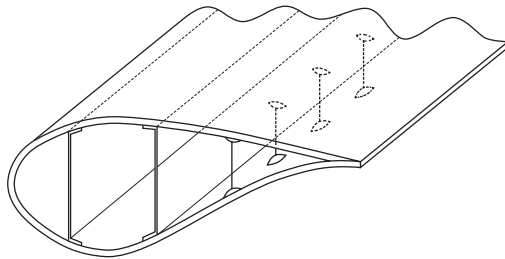


## The D-String® Technical Description

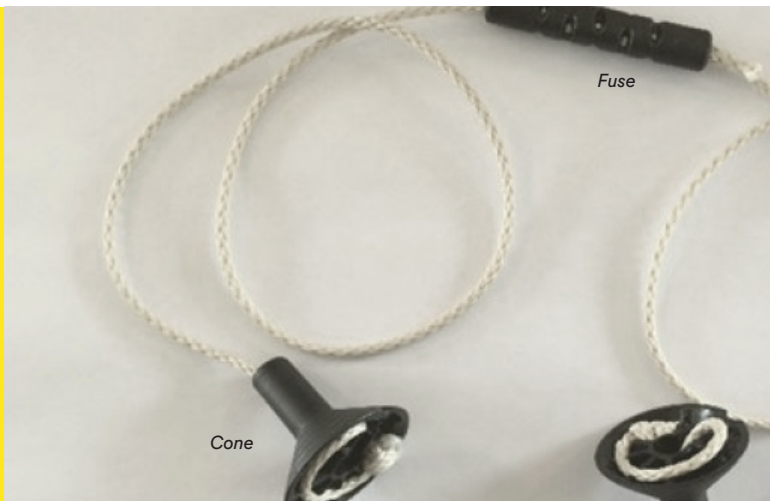
The D-String® product is made out of three components; two cones, a fuse and a Vectran 2,5 mm string.

The D-String® connects the two trailing edge panels, thus reducing the peeling stresses in the blade, thereby eliminating cracks developing in the TE max chord area. The number of D-String® installed are depending on the individual blade types.

The two cones act as anchoring devices in the trailing edge edge panels, while the string transfers the loads between the two cones to the blade panels.



The fuse is placed between the cones as an additional safety to prevent any damages to the panels.



## The D-String® Prevents Breathing

**The D-String® prevents breathing of the trailing edge panels thereby reducing the peeling stresses in the adhesive bondlines.**

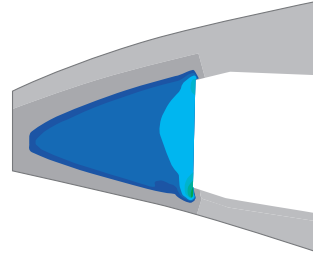
The D-String® directly reduce the deformations of the panels, hence significantly reducing the peeling stresses in the adhesive bondlines.

There is a direct correlation between breathing and the peeling stresses in the adhesive bondlines: the higher the magnitude of the breathing, the higher the peeling stresses.

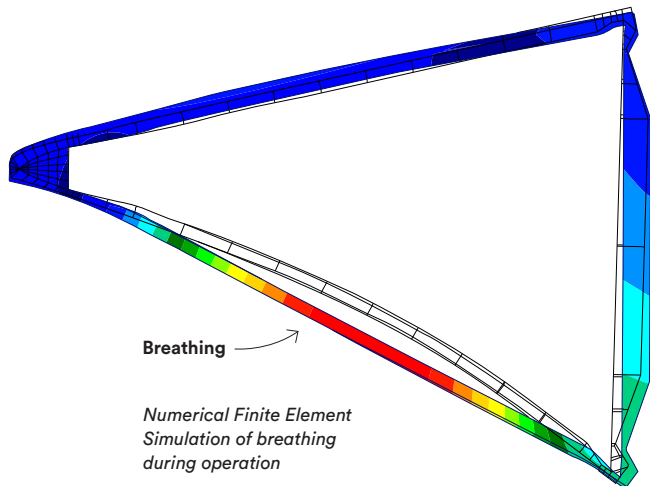
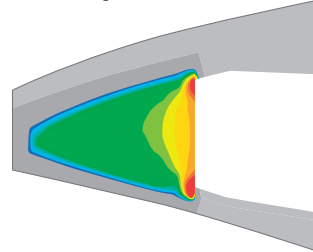
The two figures illustrate a FE simulation of the reduction of the peeling stresses in the trailing edge adhesive bondline, with and without D-Strings® installed.

Field measurements show that the installation of D-String® results in a 95-97% reduction of the breathing.

With D-String®



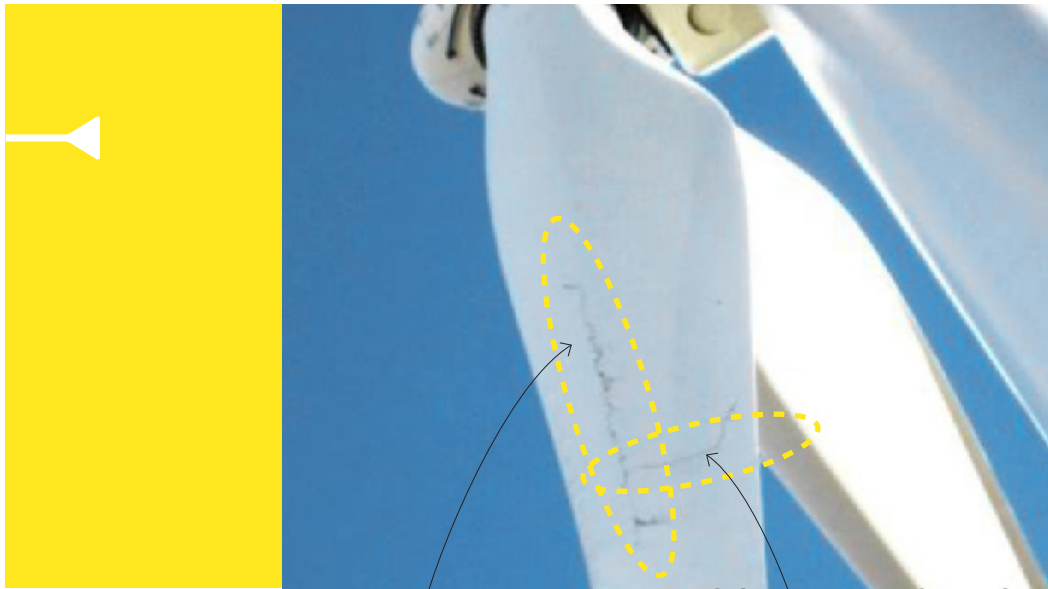
No D-String®





## The D-String® Prevents Debonding

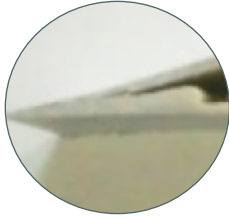
When rotating, the blades are subjected to gravity forces in the edgewise direction regardless of the wind condition. This influence the connection of the outer shell to the aft shear web generating peeling stresses in the connections.



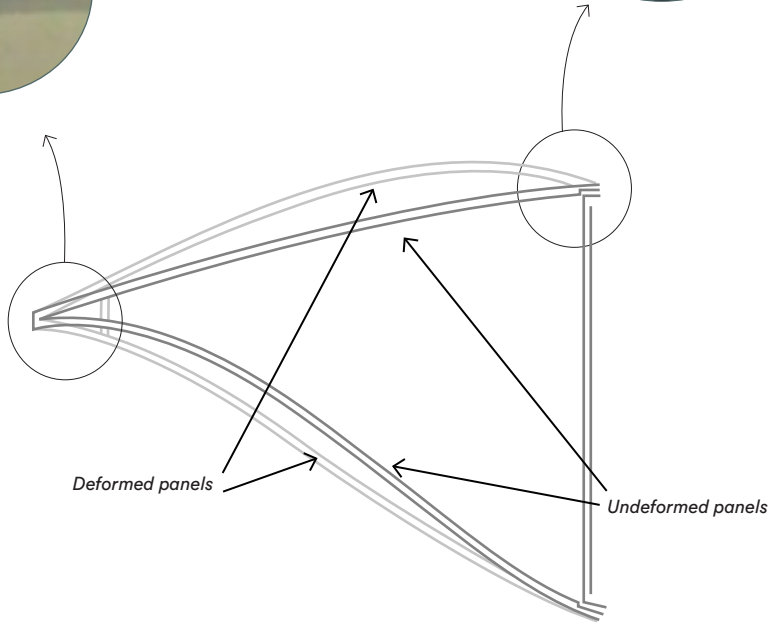
*Longitudinal cracks*

*Transverse cracks*

Peeling in the adhesive bondlines



Debonded shear web



## Peeling and debonding

The installation of D-Strings® reduce peeling stresses significantly in the aft shear web preventing debonding of the skin to the shear web.

Cracks develop due to out-of-plane deformations of the TE panels leading to debonding of the trailing edge bondline and main box.



## Test Program Eliminating Risk

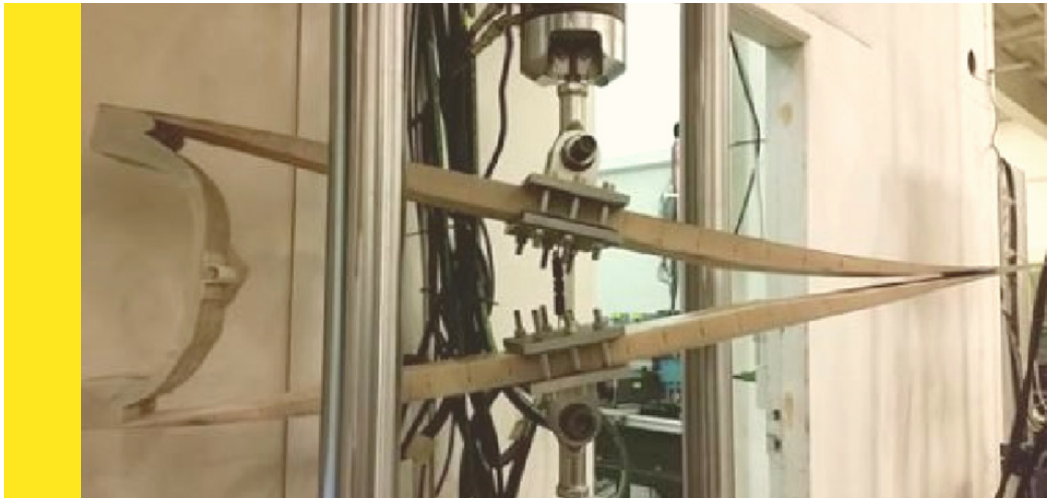
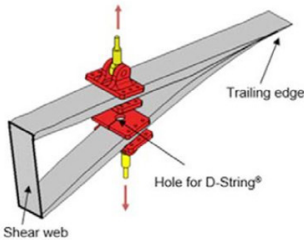
**The D-String® have been thoroughly tested at the Technical University of Denmark to demonstrate the performance under normal and extreme operating conditions.**

### Static- and Dynamic Tests

The D-String® components were tested individually and sub-assembled in different settings.

The full assembled D-String® was tested statically and dynamically in a blade panel using the same D-String® installation technique as for blades in operation.

The test results have verified that the D-String® has the necessary properties in order to remove the breathing, without causing any risk to the blade.



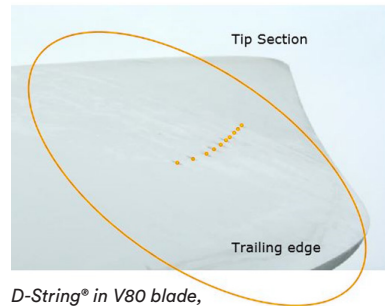


Both Static and dynamic tests of the D-String® have proven that the D-String® can be installed without any concern for harming the blades.

The loads generated by the D-String® are quite small; typically less than 1/10 of what the trailing edge panels of the blades can sustain as depicted in the table below.

### V80 Trial Installation – Years of Operation

- The first operating D-Strings® were installed in a V80 blade in January 2013.
- Recent inspection confirmed that no cracks has formed in the area where the D-strings® are installed.



*D-String® in V80 blade, January 2013*

### D-String® Safety Load Criteria

The applied “safety margin” is the difference between the blade panel breaking load of 300 kg to the normal operational load with the D-String® installed of only 20-30 kg. The fuse will slide at 150 kg thus half the panel breaking load.

Panel Breaking Load, Static Tests	300 kg
Fuse Breaking Load, Static Tests	150 kg
Max Operational Load on the D-String®	80 kg
Normal Operational Load on the D-String®, Field Measurement	20-30 kg

## Easy Installation of D-Strings®

**The D-String® can be installed up-tower using simple tools with either rope access or using a 360 degree platform.**

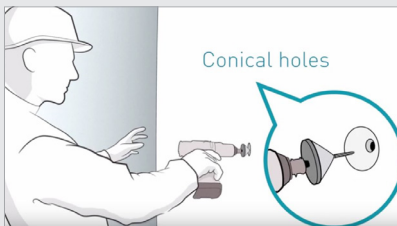
Bladena assists with the installation of the D-Strings® and works with a network of independent service providers who ensures a reliable and cost-effective installation, meeting the highest standards safety and quality.



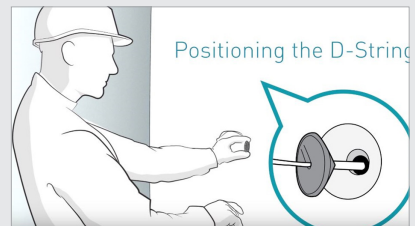
1. Stop the turbine



2. Access the turbine using rope or a basket



3. Drill conical holes



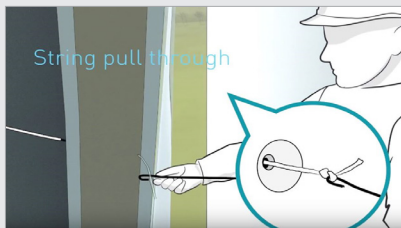
4. Position the D-String®

1. Stop the turbine
2. Access the turbine using rope or a basket
3. Drill conical holes
4. Position the D-String®
5. Pull the string through
6. Position the D-String®
7. Add Pretension
8. Seal the panel

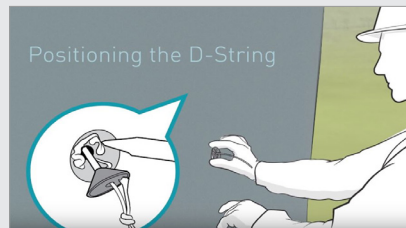
Commercial references for the D-String® is available on different blade types, to mention a few, Vestas, GE and LM portfolio. If you are interested to hear more about your blades in particular, feel free to contact:

Europe: Ryan Lauridsen, no. +45 20 14 59 96

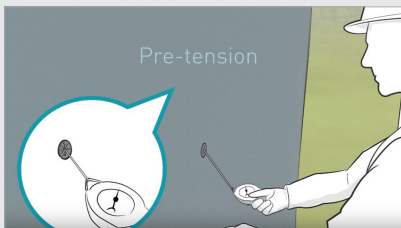
US and Canada: Dave Zanier, no +1 647 339 2924



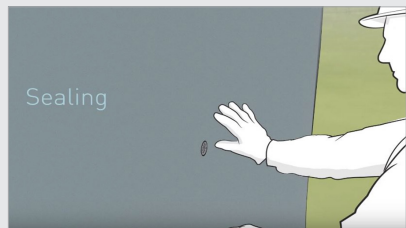
5. Pull the string through



6. Position the D-String®



7. Add Pretension



8. Seal the panel



## Operational and Financial Impact

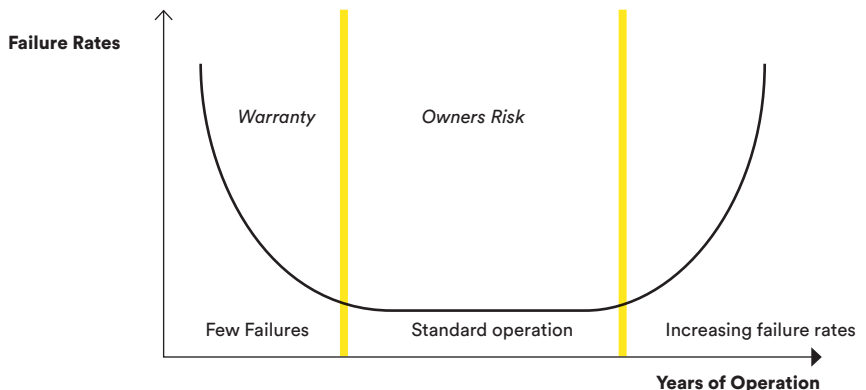
Installation of the D-String® will positively impact the operation of your Wind Turbines by:

1. Decreasing time for maintenance. This in turn reduces the LCoE increasing the profit margin.
2. The cost of a single repair equals the cost of a D-String® kit for 3 blades (including the installation).
3. The D-String® secures operation of the blade in the anticipated lifetime of the turbine without added maintenance cost.



Aging blades have an increasing demand for repairs, due to cracks, this often corresponds to the end of warranty period when the cost of repairs befall the Wind Turbine Owners (see the figure below).

To secure your assets, it is therefore beneficial to install the D-Strings® before the end of warranty to ensure cheap and easy operation going forward.

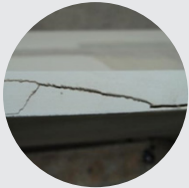


# Examples of Reference Turbines

Installation of the D-String® will positively impact the operation of your wind turbines by reducing cost for O&M, hence lowering the LCoE:



**Turbine** Vestas 80 (Denmark)  
**Year** 2013  
**Failure** Transverse crack in TE panel



**Turbine** 1.5 MW 37c, 34a (US)  
**Year** 2014, 2015, 2016, 2017  
**Failure** Bond line crack, Trailing Edge



**Turbine** Repower MM92 LM 45.3 (US)  
**Year** 2015  
**Failure** Transverse crack in TE panel



**Turbine** Vestas V90 (Canada)  
**Year** 2016, 2017  
**Failure** Longitudinal crack in Trailing Edge



**Turbine** Senvion MM82 LM40  
**Year** 2018  
**Failure** Transverse crack in TE panel

# D-String® Business Case

Based on failure rates in the field the D-String® ROI is 1 year for offshore wind farms with a combined saving in the lifetime of the blade of 13.200.00 Euros.

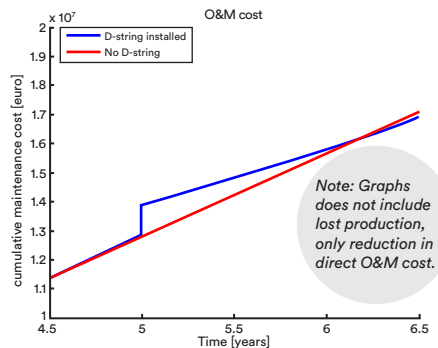
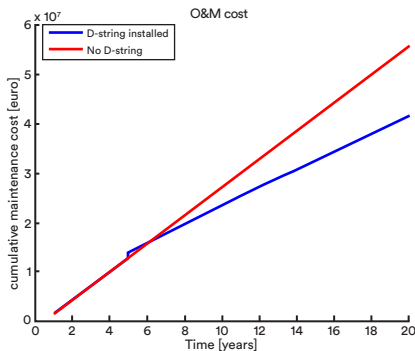
## Off-Shore Wind Farm. 60x 3 MW turbines

Blade O&M Cost without D-String®	2.860.000	Euro/Year
Blade O&M Cost with D-String®	1.980.000	Euro/Year
<b>Savings on O&amp;M Cost due to D-String®</b>	<b>880.000</b>	<b>Euro/Year</b>

Gainned Production due to D-String®		
Turnover pr. Day – without D-String®	2.853	Euro/Day
Turnover pr. Day – with D-String®	2.859	Euro/Day
<b>Gain pr. Year - 60 Turbines</b>	<b>106.592</b>	<b>Euro/Year</b>

<b>Total Gain on O&amp;M and Production</b>	<b>986.592</b>	<b>Euro/Year</b>
<b>Return on Investment</b>	<b>1,0</b>	<b>Years</b>

**Combined saving during lifetime of the blades 13.200.000Euro**



## Investment

D-String® list price per turbine  
 D-String® installation  
 Downtime due to install. 12 hrs.

## Off-Shore

€ 10.000  
 € 5.000  
 € 1.800

## On-Shore

€ 10.000  
 € 3.000  
 € 1.800

**Total Installation Cost**  
**60 Turbine Wind Farm**

€ 16.800  
 € 1.008.000

€ 14.800  
 € 888.000

# On-Shore Wind Farm. 60x 3 MW turbines

Based on failure rates in the field the D-String® ROI is 1,33 years for onshore wind farms with a combined saving in the lifetime of the blades of 7.350.00 Euros.

Blade O&M Cost without D-String®

1.420.000 Euro/Year

Blade O&M Cost with D-String®

930.000 Euro/Year

**Savings on O&M Cost due to D-String®**

**490.000 Euro/Year**

Gained Production due to D-String®

Turnover pr. Day – without D-String®

2.857 Euro/Day

Turnover pr. Day – with D-String®

2.865 Euro/Day

**Gain pr. Year - 60 Turbines**

**176.602 Euro/Year**

**Total Gain on O&M and Production**

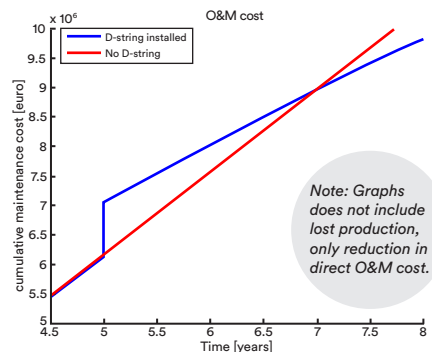
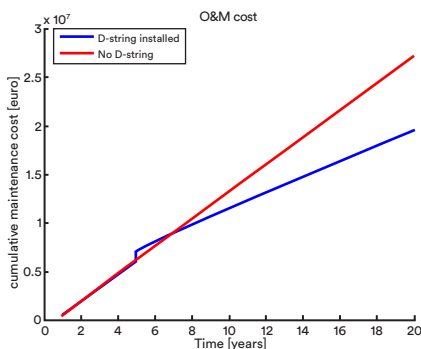
**666.602 Euro/Year**

**Return on Investment**

**1,3 Years**

**Combined saving during lifetime of the blade**

**7.350.000 Euro**



# ”The D-String® does not affect the structural safety of trailing edge panels of a general rotor blade design”

Expert opinion by DEWI OCC

The D-String® has a significant impact on the anticipated lifetime of your blades.

The D-String® decrease the LCoE thus increasing the profit margin.

Return on investment of 1 year for offshore turbines and 1,3 years for onshore turbines!

**Want to hear more about your blades**

Simply contact Bladena