Dr. Roberto Grippi
General Manager

From Inspection to Action:
Advanced Strategies in Wind Rotor Blade Maintenance

Seeing Beyond the Surface

2025.10.24

Advanced Strategies in Wind Rotor Blade Maintenance

1) Analysis of the available methods
2) How to analyze the data
3) How to use the data for management decisions
4) YCE competence in inspections and repairs

YCE activities

inspections and structural evaluation

blade maintenance management

blade repairs, reconstructions, retrofits

our numbers

20 repair teams (more being trained)

7 blade inspection teams

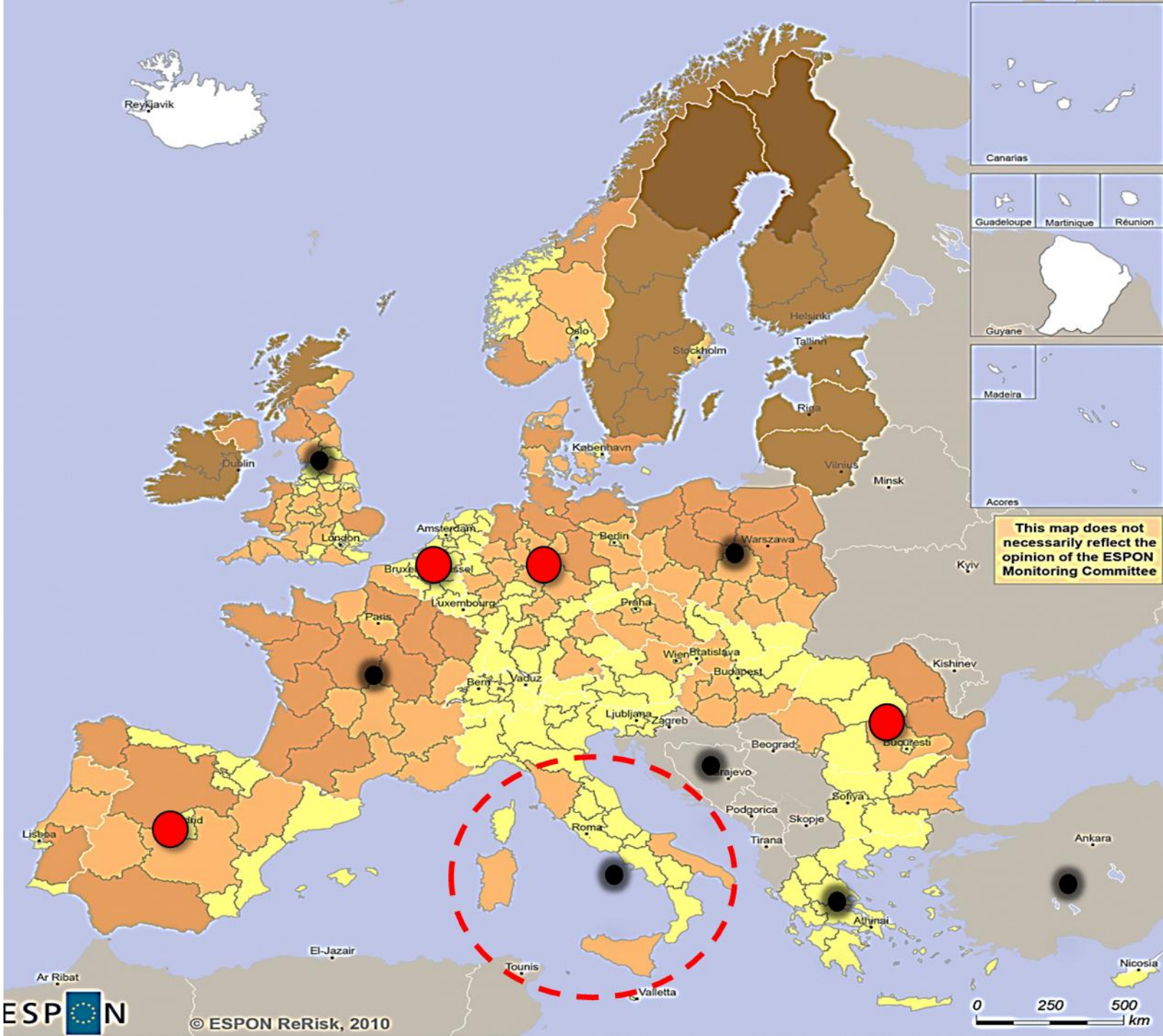
5 structural blade engineers

45 blade technicians

where do we work?

(anywhere our Customers want us to serve their international fleets)

- Existing areas of activity
- J-V development areas



2006-2024:

over 6,500 blades repaired

over 22,000 blades inspected

(update: 12/2024)

3 inspection methods: same structural evaluation quality ?

rope access

drone

ground inspection

Specific advantages and disadvantages of the different technologies

Manual inspections		Remote inspections			
On rope, or with platform		From the ground, with tele-zoom		Drone inspections	
Pros	Cons	Pros	Cons	Pros	Cons
Extreme detail	**expensive (3 technicians, x 6/8 h)**	**Cheap (2 technicians, x ~ 40 min)**	Depending on daylight	**Cheap (2 technicians, x 20/25 min)**	Hardware cost
Phisical inspection possible (tapping test)	**Very long time (4/6 h)**	**Short time (30-45 min)**	**Limited detail, due to the distance from the ground and the inclination**	**Very short time (20-25 min)**	**Flight quality highly dependent on the pilot**
No false positives	**The WTG will not generate energy for the entire time of the activity**		**Very small damages are difficult to interpret**	**Extreme detail, because the drone flies close to the blade**.	AI is a good thing, but inspections must be evaluated by a blade engineer
No need of additional technical evaluation	Restrictive weather limits		Dependent on the location of the WTG (hills, mountains)		
	Dangerous, in absolute terms				

Main disadvantages of the different remote inspection technologies

- **Lack of repeatability:** Missing: the ability to repeat the inspection multiple times while obtaining images that are directly comparable each time.
  This is essential for comparing images from different periodic inspections, to assess both the severity and progression of damage.
- **Image analysis and evaluation:** Around 400-500 images are collected per tower; for a wind farm of 20 generators, this means analyzing no fewer than 8,000–10,000 individual images to detect damages.
- **Dependence on qualified analysts for image assessment:** There are no schools teaching the specific technologies for evaluating and repairing blade damage; therefore, structural engineers are trained internally within the repair companies. Training period: 2 years.

The solution of YCE

Drone inspections

- Equipped with a flight controller that performs the flight fully automatically and therefore repeatable any number of times.
- Combined with artificial intelligence (AI) capable of acquiring a large number of images and processing them to detect anomalies, which will then be verified for certification by a blade engineer.
- and … visual inspection combined with thermographic inspection of blades. Although not necessary most of the times, it gives inside information on the blade.

Step 1
Image detection

The drone inspection is carried out fully automatically from the ground.

The drone captures the necessary images, providing an overall view that ensures precise localisation of any anomalies.

The drone flies ALWAYS the same flight path around the wind blade, unless the operator turn manual on.

Step 2
Image Post-processing

The images are uploaded to the YCE cloud platform.

YCE's AI performs post-processing of the images: Trained using YCE's damage catalogue, it identifies anomalies and selects the relevant images.

It then analyses the severity of each anomaly, providing an assessment based on a severity scale defined by YCE.

Step 3
Report processing

The report produced by the AI is validated by a specialized engineer (the analyst), who reviews the proposed analysis and assumes certifying responsibility.

Finally, the AI automatically generates the final report.

This report together with all images, will be available in the cloud for the customers, who will be able to review and verify the images where needed.

The technical matters

- **All generators require scheduled inspections** in order to perform maintenance; otherwise, they risk being suddenly shut down.
- **YCE holds repair frame contracts for about 50% of the Italian WTGs (Italy = 7,300 WTGs).** Inspections must take place within a three-month period between April and June, in order to plan maintenance during the good-weather season.
- YCE has been carrying out wind-turbine blade inspections for 16 years: today about 1,000 – 1,500 WTGs/year, depending on the inspection frequency set by customers.
  (Not all customers use YCE inspection services, and not all customers inspect every year.)
- Many customers rely on the vigilance of routine maintenance technicians who work daily on-site. Most casual inspections are performed remotely, using photographs taken from the ground.

Our challenge in Italy

- 7,300 installed generators in Italy = **approximately 3.5–4 million images per year** to search for damage. **Even inspecting only 50% of the WTGs means 2 million images**.
- **From the ground, an average of 8 inspections are carried out per day**; 3,750 generators (YCE's market share) correspond to **470 working days** to be completed within 90 days (3 months). Therefore, 7 teams would be required (5 mathematically, but weather is not always perfect, and there are also Sundays...).
- **Each day, one analyst examines an average of 20 generators: 190 man-days**. The image captures must be completed within 3 months, but analysts have only 60 days available. Hence, 4 technicians (engineers specialized in composite materials) are needed to carry out this task.

Automatic drone imaging system specification

- **Flight at approximately 4–6 metres from the blades**, covering each of the 4 sides, for a total of 12 individual flight paths around the 3 blades.
- **Fully automatic flight**, to be completed in 20 minutes (+ 3–5 minutes for setup).
- In 8 hours (+ a 1-hour break at midday), **up to 16 full inspections** could be performed under optimal conditions, **or, more realistically, 10 - 12**.
- The turbine must be locked using only the brake at the start of the inspection; the flight controller will manage the rest, avoiding downtime for additional rotor repositioning. **Our technicians are trained to do it on their own. No need from local operation should be necessary.**
- Insertion of **precise positional metadata is obtained from objective data**.

AI-based analysis system specification

- **Acquisition of positional metadata**, to combine the images so that the location of each damage on the blade and its size are known data.
- **Detection of anomalies using YCE's damage-image database**.
- **Deduction of the root cause** (original cause of the damage), again based on YCE's damage-image database.
- **After confirmation by a human engineer/analyst**, automatic generation of the inspection reports.

Cloud specification (*back-office side and end-customer side)*

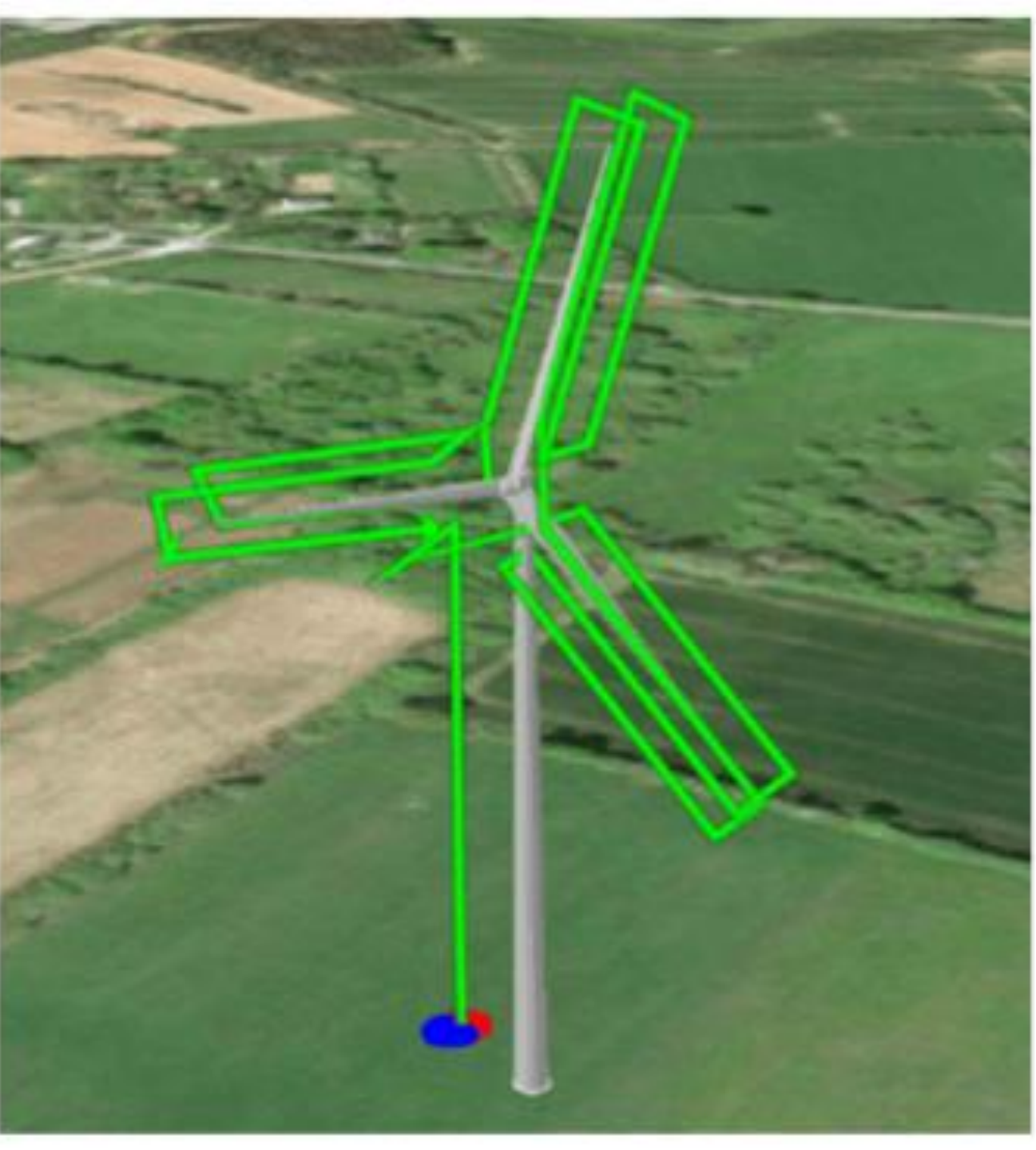
- **Cloud storage of the original images** and the composite images.
- **Interface for the analyst to search for damage in the images**, with functions to enhance or adjust image quality.
- **Interface for the customer to view the overall images** or detailed damage images, with the option to download any individual image.
- **Interface for the customer to analyze complete data** or detailed data per wind-farm, or WTG model, or damage type, or … you name it.
- **Interface for the customer to keep historical data, repair data, his own data**.

YOU

our services, after the inspections

the repair team

… the solution



1) Quick (30 min on average per WTG), you never really stop energy production!

2) 100% repeatability, so you will compare images from the past year with recent images;

3) Automatic flight on all 3 blades in one pass …

4) … and our drone technicians are blade technicians, and interrupt automatic flight to inspect more carefully areas that show high probability of serious damage, adding manual inspection to automatic inspection;

5) … and on request, we fly around the tower and the nacelle, to verify damage/oil spills/rust areas;

6) … and the inspections are assessed by blade engineers; we do not only assess «deviations» from standard, we tell you what it is, what the probable root cause is, how much time is needed to remove the damage, if you can actually continue production, and how long it will take before you need to stop the WTG;

7) … and you get the software tools to check our evaluation, annotate on your own, keep track of repairs: you will have the history of the blades of your windfarm completely under your control.

2006-2024:

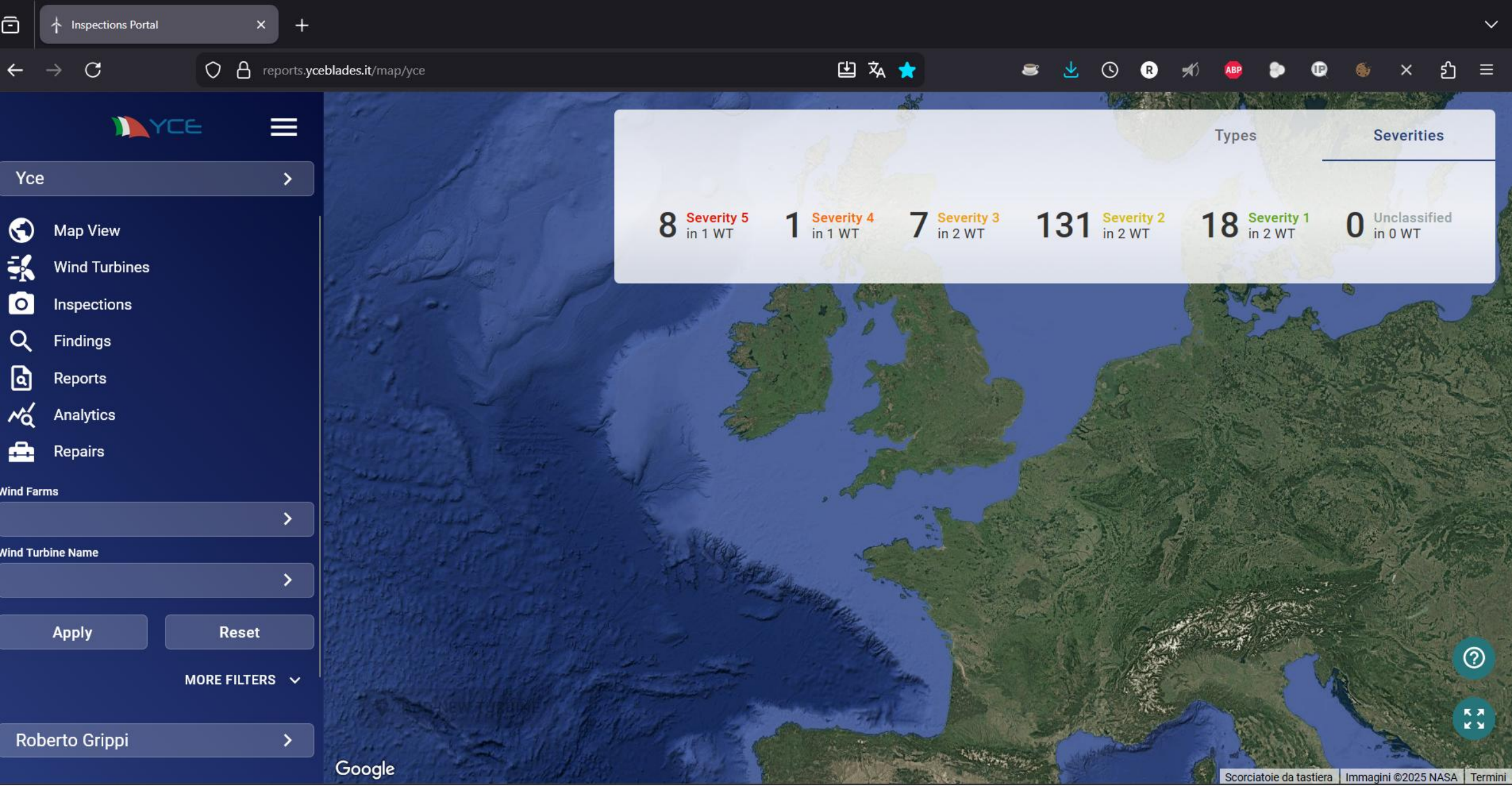
over 6,500 blades repaired

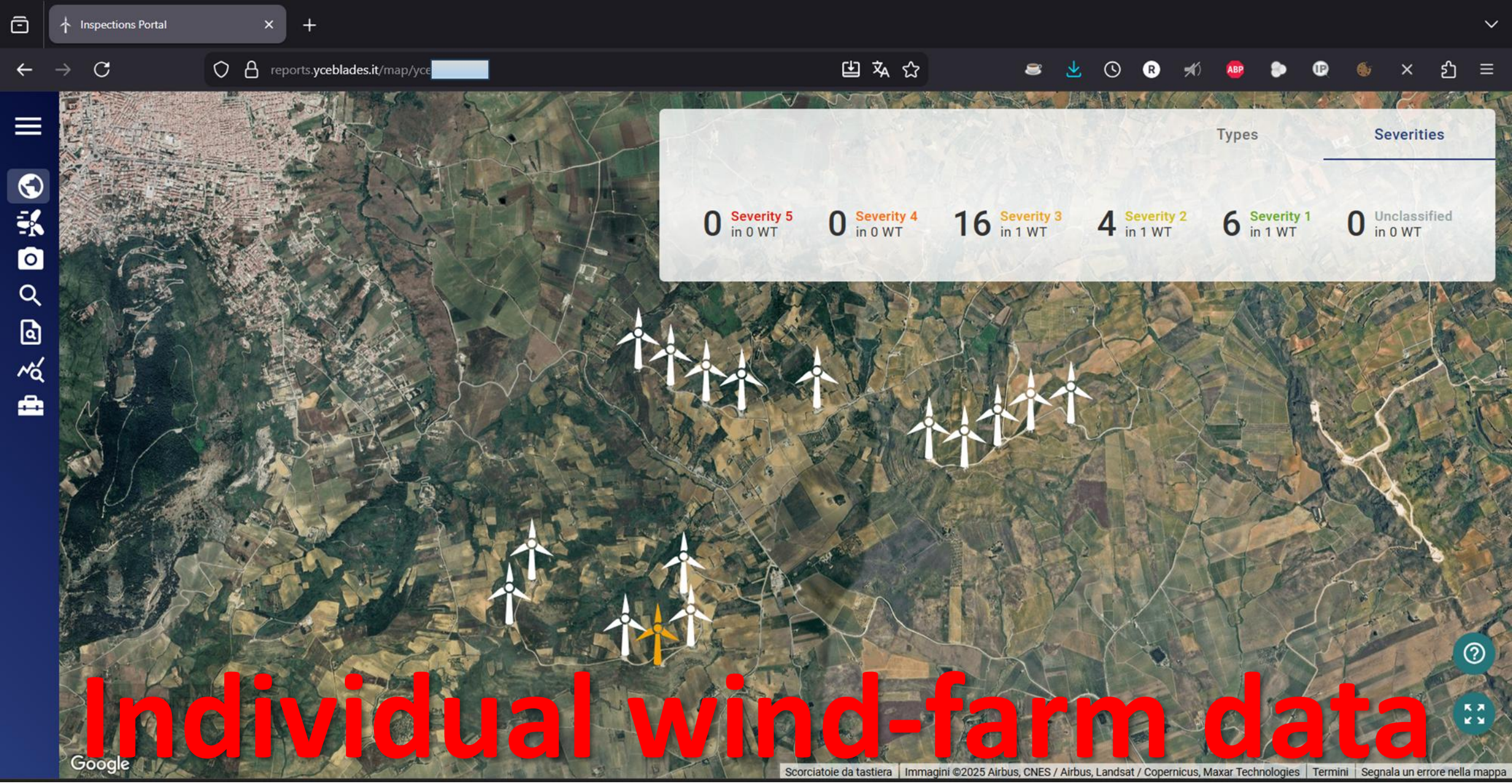
over 22,000 blades inspected

(update: 12/2024)

Your frontend to inspections, with all historical data

(by the way: any inspections, not only ours; also your own, whoever carried them out!)


Inspections Portal
reports.yceblades.it/map/yce
YCE
Yce
Map View
Wind Turbines
Inspections
Findings
Reports
Analytics
Repairs
Wind Farms
Wind Turbine Name
Apply
Reset
MORE FILTERS
Roberto Grippi
Types
Severities
8 Severity 5 in 1 WT
1 Severity 4 in 1 WT
7 Severity 3 in 2 WT
131 Severity 2 in 2 WT
18 Severity 1 in 2 WT
0 Unclassified in 0 WT
Google
Scorciatoie da tastiera
Immagini ©2025 NASA
Termini


Inspections Portal
reports.yceblades.it/map/yce
Types
Severities
0 Severity 5 in 0 WT
0 Severity 4 in 0 WT
16 Severity 3 in 1 WT
4 Severity 2 in 1 WT
6 Severity 1 in 1 WT
0 Unclassified in 0 WT
Individual wind-farm data
Google
Scorciatoie da tastiera
Immagini ©2025 Airbus, CNES / Airbus, Landsat / Copernicus, Maxar Technologies
Termini
Segnala un errore nella mappa

Inspections Portal

reports.yceblades.it/findings/yce

Findings

SHOWING 26 OF 26

Severities

Types

Cost

2000

From 1 selected findings

No Repair Cost

2110

From 1 selected findings

group blade data

All 26 | Selected 1 | Select All (26) | Clear

Edit values | Create report | Create repairs | Delete | EXPORT TABLE

Object type | *Object Side* | *Distance range* | *Assignee* | *Status:*

Short ID	Component	Status	RNR	Cost	No Repair Cost	Side	Severity	Type
413c2b4	T15, bladeB	-	0.40	2,000	806	LE	3	Erosion
4323fe1	T15, bladeB	-	0.42	2,000	844	LE	3	Erosion
48db015	T15, bladeB	-	0.27	2,000	546	LE	3	Erosion

Individual blade data

Inspections Portal

Definitions

> T15

bladeA

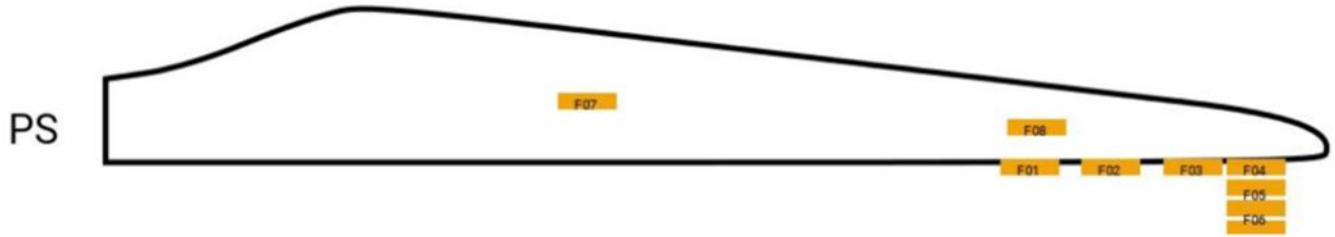
bladeB

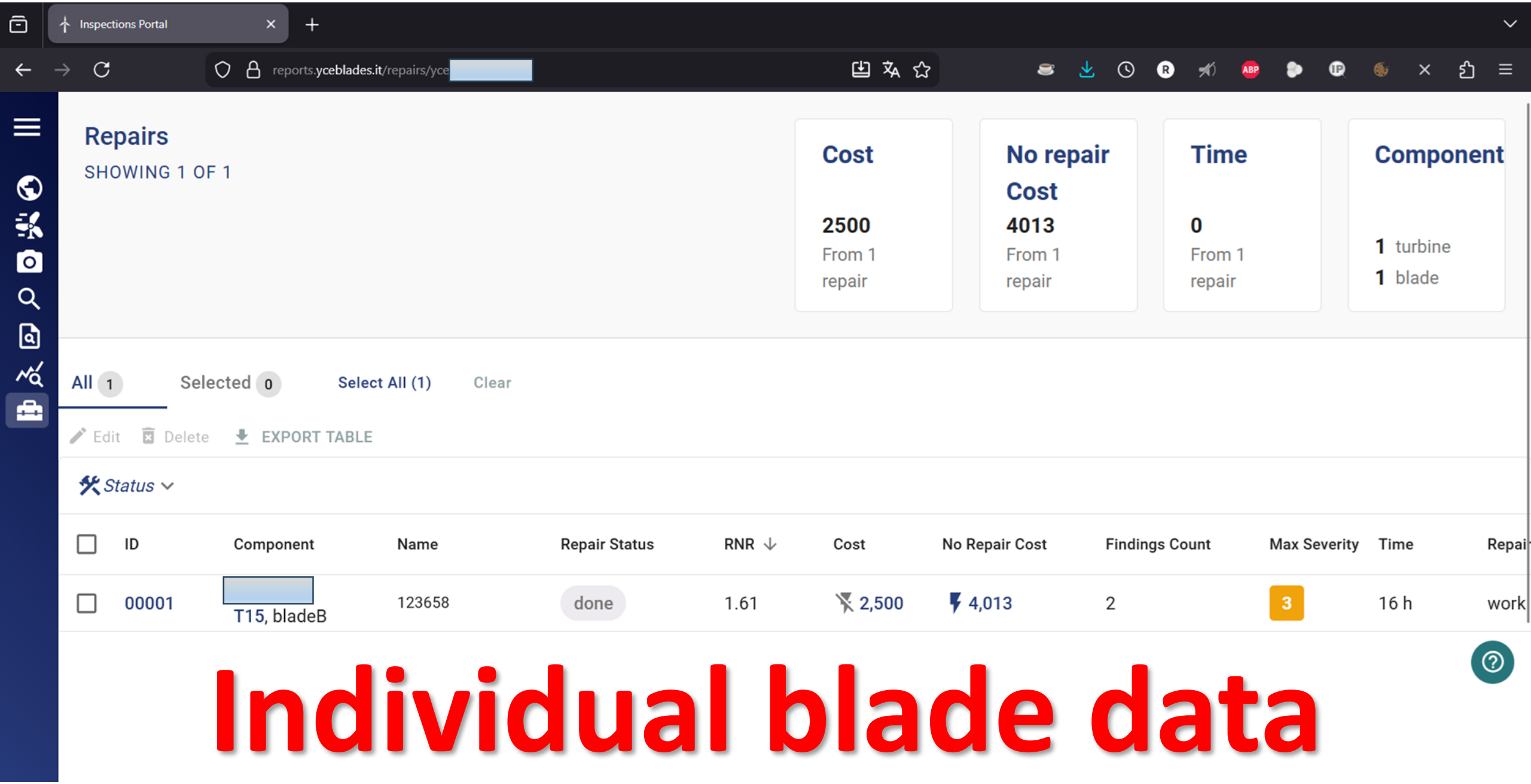
Flight Details

> T15

> bladeA

SID	Type	CAT	Depth	Location	Size (cm)	UID
F01	LE Erosion	3	Top Coat	LE - 34.1 m	64 x 13	bf49ad
F02	LE Erosion	3	Top Coat	LE - 37.0 m	281 x 19	ce75a6
F03	LE Erosion	3	Top Coat	LE - 40.1 m	53 x 14	fe57a5
F04	LE Erosion	3	Top Coat	LE - 42.4 m	5 x 4	0276ca
F05	LE Erosion	3	Top Coat	LE - 43.3 m	5 x 3	045f60
F06	LE Erosion	3	Top Coat	LE - 44.3 m	16 x 9	0059de
F07	Other Cracks on Surface	3	Top Coat	PS - 17.8 m	7 x 5	2b244e
F08	Paint Damages	3	Top Coat	PS - 34.3 m	28 x 8	6ed911
F09	Paint Damages	3	Top Coat	PS - 44.1 m	18 x 13	995736
F10	Paint Damages	3	Top Coat	SS - 44.9 m	5 x 4	f067b9





Individual blade data

Inspections Portal

reports.yceblades.it/windturbine/yce

Findings by severity

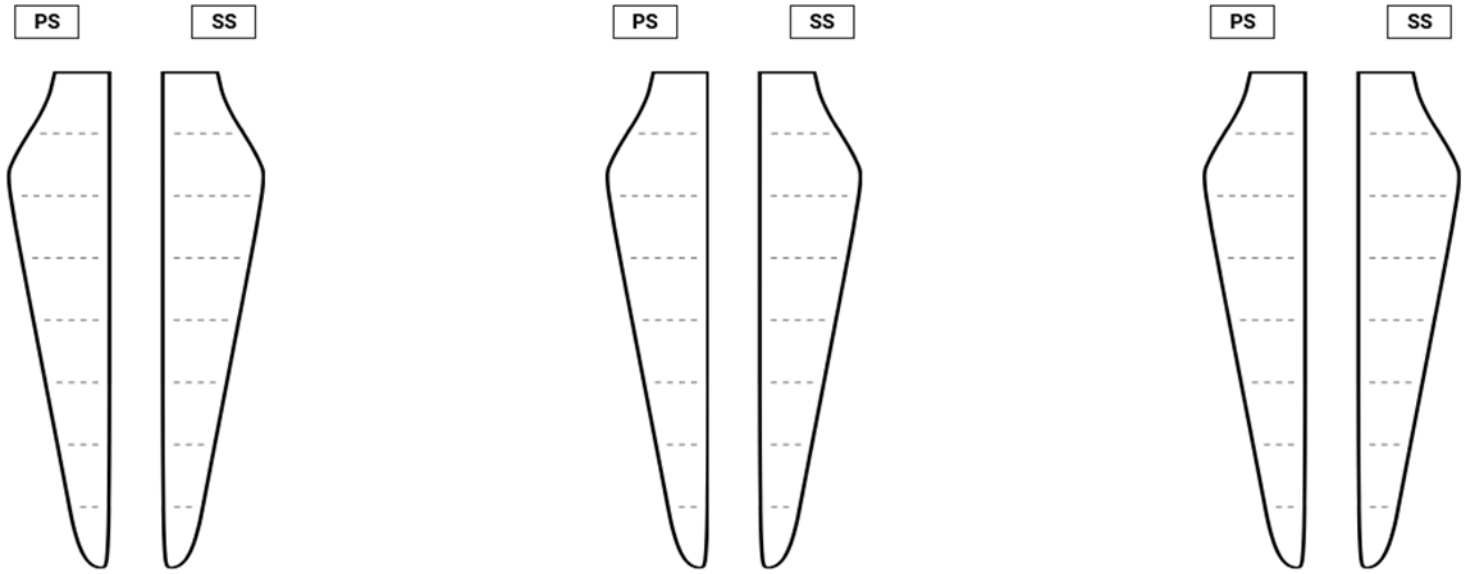
0 Severity 5 in 0 WT | 0 Severity 4 in 0 WT | 0 Severity 3 in 0 WT | 0 Severity 2 in 0 WT | 0 Severity 1 in 0 WT | 0 Unclassified in 0 WT

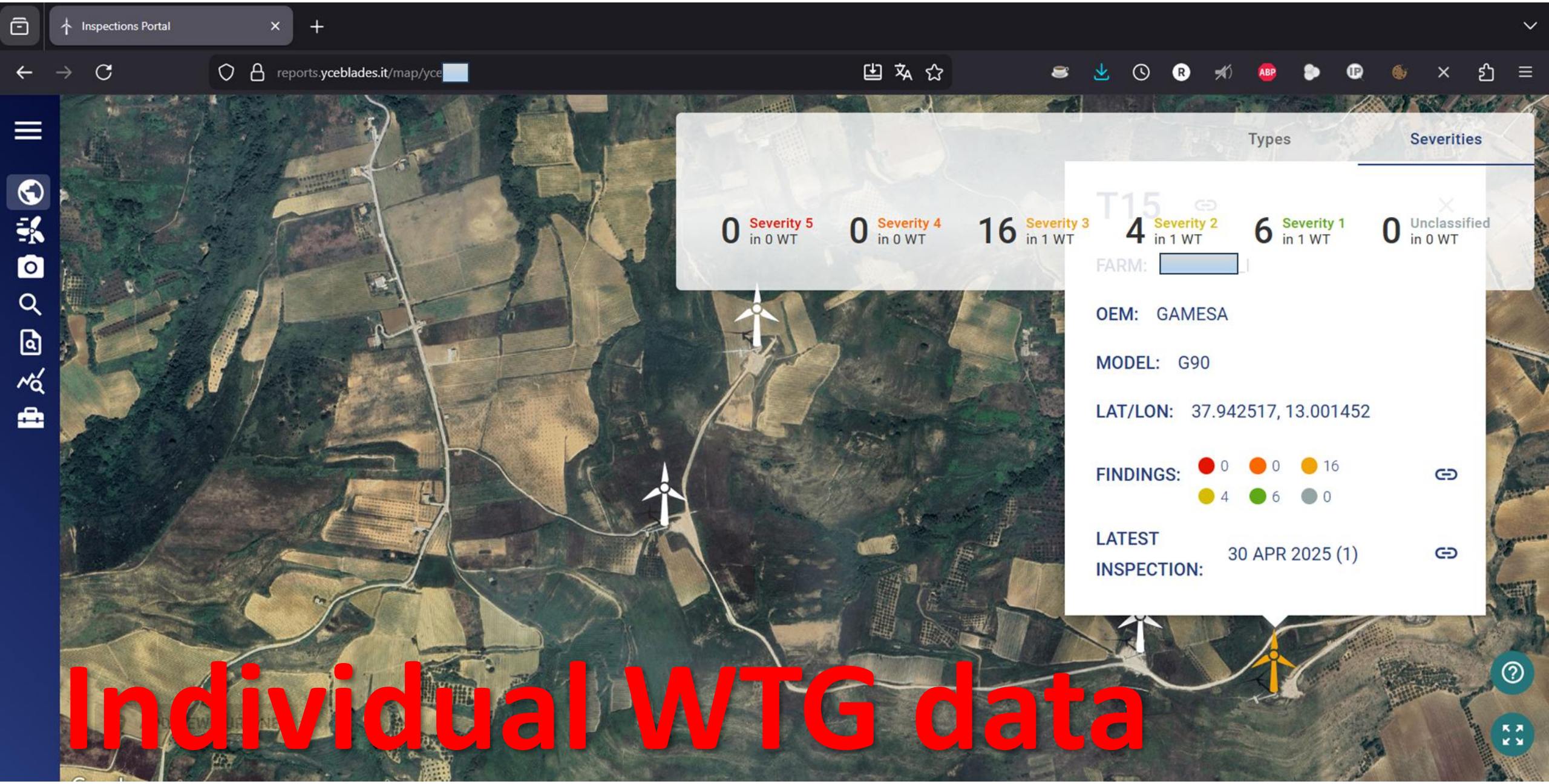
Findings by type

0 Unclassified in 0 WT

Individual WTG data

bladeA | bladeB | bladeC




Inspections Portal
reports.yceblades.it/map/yce
Types
Severities
0 Severity 5 in 0 WT
0 Severity 4 in 0 WT
16 Severity 3 in 1 WT
4 Severity 2 in 1 WT
6 Severity 1 in 1 WT
0 Unclassified in 0 WT
T15
FARM:
OEM: GAMESA
MODEL: G90
LAT/LON: 37.942517, 13.001452
FINDINGS: 0 0 16 4 6 0
LATEST INSPECTION: 30 APR 2025 (1)
Individual WTG data

Inspections Portal

reports.yceblades.it/findings/yce[redacted]WTG03/4c4ec440-4cfe-11f0-8a0d-979c46d8d03a/20

STATUS: #R00002 SEVERITY: 4 TYPE: Lightning damage DEPTH: Inner Laminate ASSIGNEE: Auto

Edit Values Delete

Images 1 Timeline 11

Object Side LE PS TE SS

9 Jun 2025

Individual damage data

The same frontend gives you the data analytics to support your decisions fleet-wide

reports.yceblades.it/analytics/yce

Controls

Farm equals: All

Turbine equals: All

Category equals: All

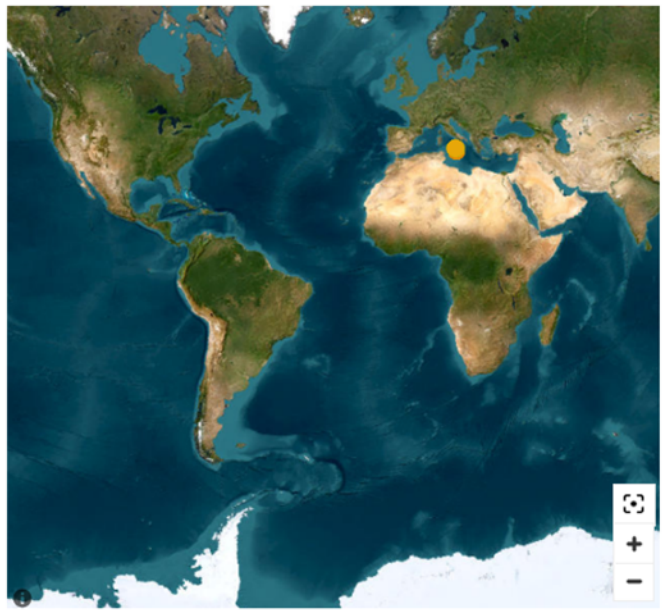
Type equals: All

Date between: 2019/01/01 - 2025/10/22

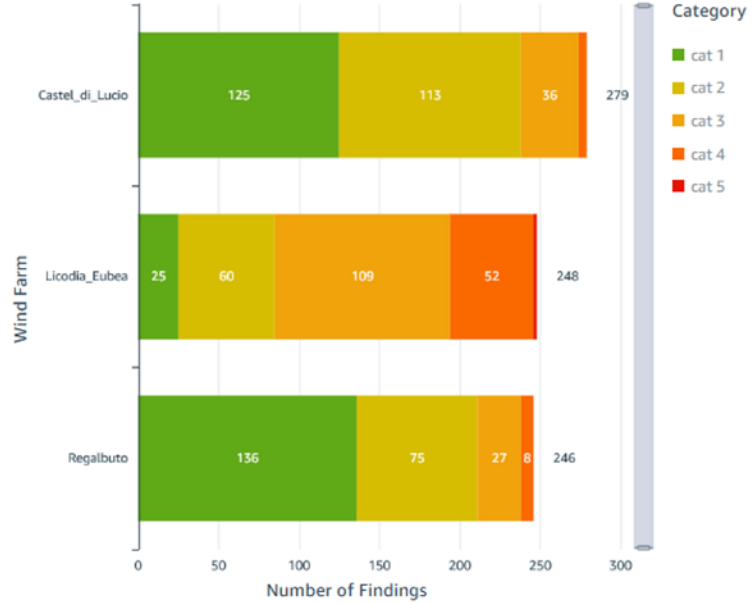
Object Type equals: All

Object Side equals: All

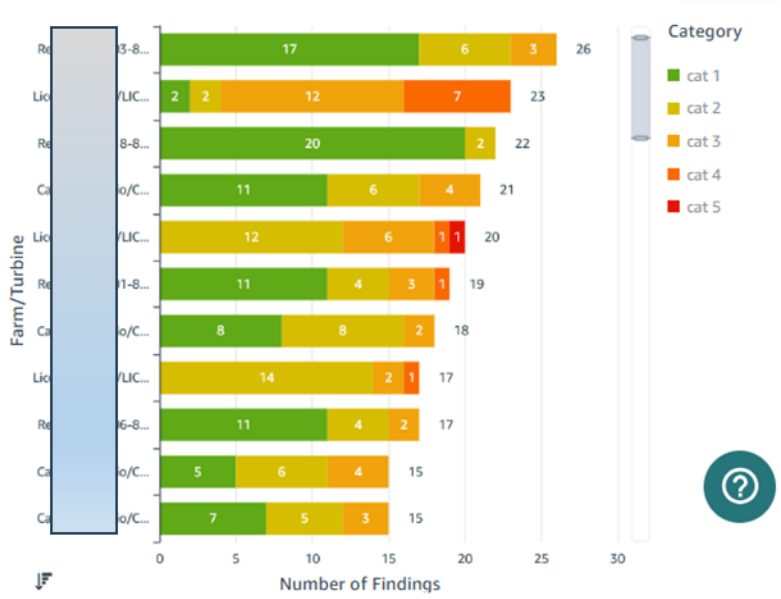
Count of Findings by Turbine and Category



Count of Findings by Category and Wind Farm



Count of Findings by Turbine and Category



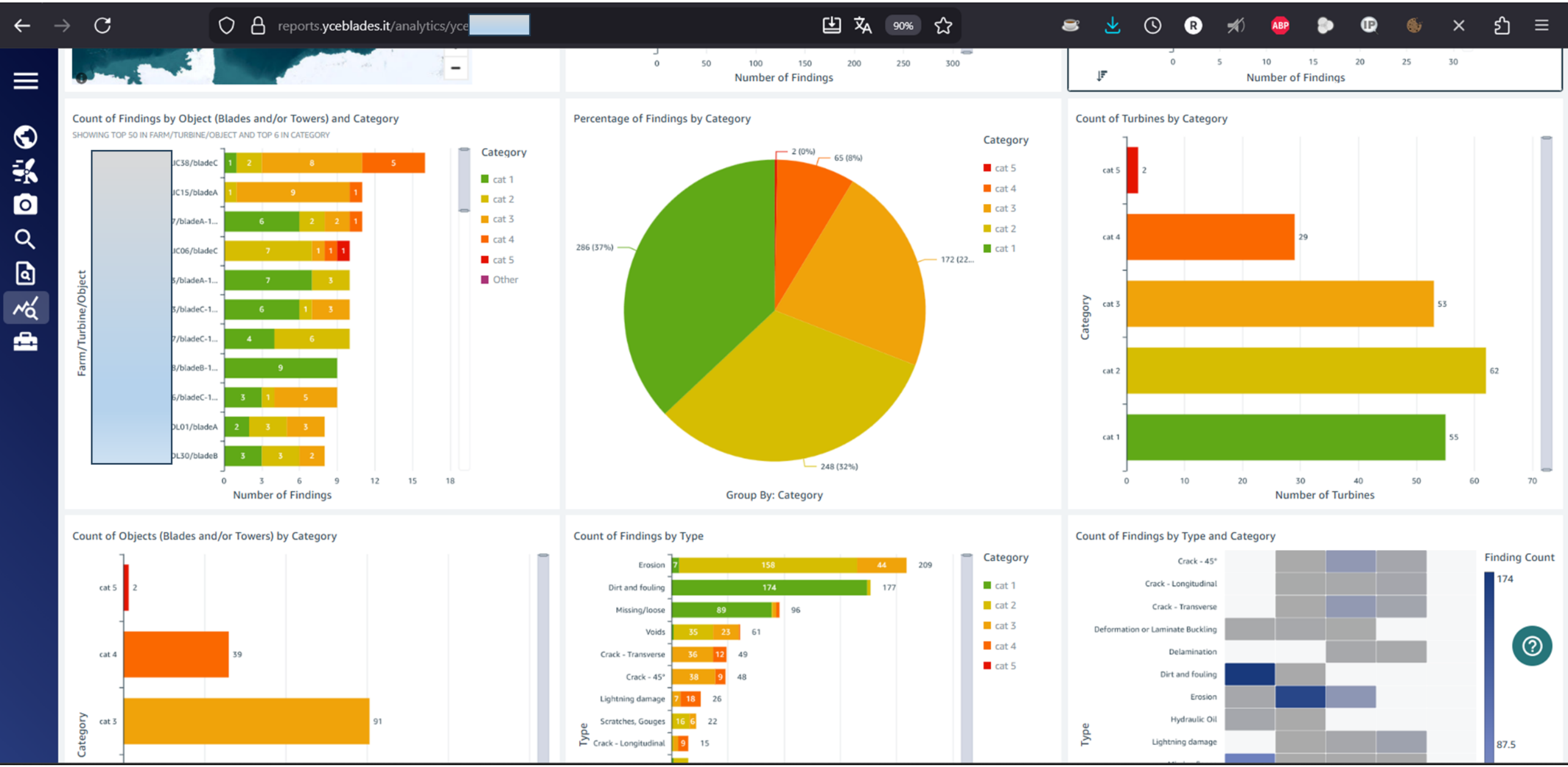
Count of Findings by Object (Blades and/or Towers) and Category

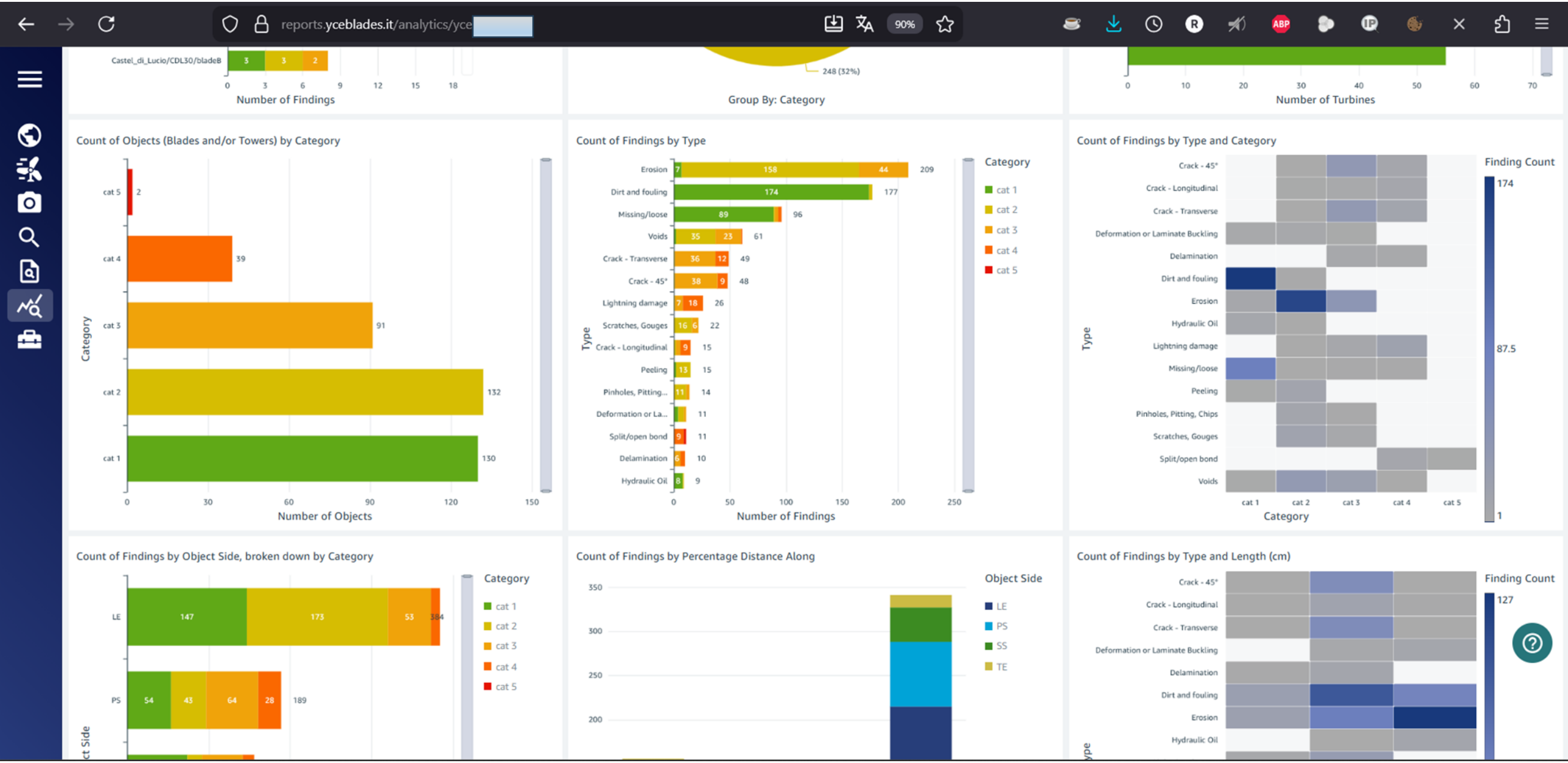
SHOWING TOP 50 IN FARM/TURBINE/OBJECT AND TOP 6 IN CATEGORY

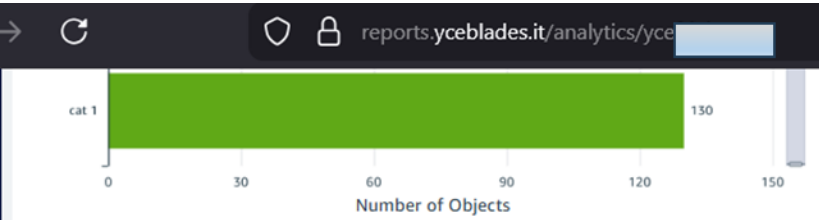
Percentage of Findings by Category

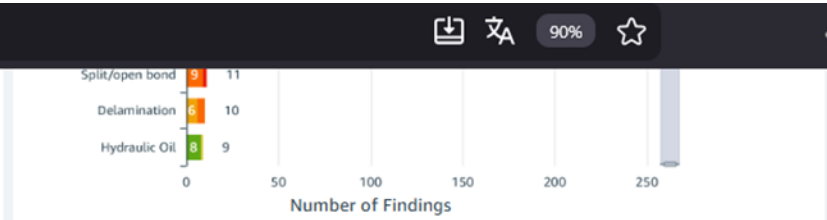
Category

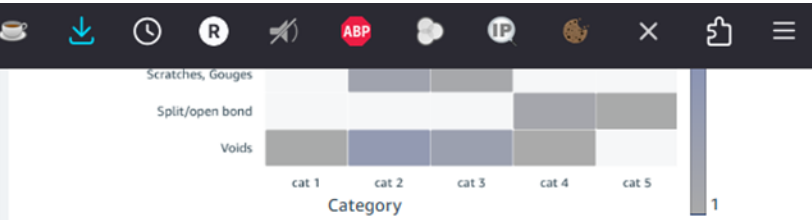
Count of Turbines by Category


reports.yceblades.it/analytics/yce
90%
Number of Findings
Count of Findings by Object (Blades and/or Towers) and Category
SHOWING TOP 50 IN FARM/TURBINE/OBJECT AND TOP 6 IN CATEGORY
Farm/Turbine/Object
Category
cat 1
cat 2
cat 3
cat 4
cat 5
Other
Number of Findings
Percentage of Findings by Category
2 (0%)
65 (8%)
172 (22...
248 (32%)
286 (37%)
Group By: Category
Count of Turbines by Category
cat 5
cat 4
cat 3
cat 2
cat 1
2
29
53
62
55
Number of Turbines
Count of Objects (Blades and/or Towers) by Category
91
Count of Findings by Type
Erosion
Dirt and fouling
Missing/loose
Voids
Crack - Transverse
Crack - 45°
Lightning damage
Scratches, Gouges
Crack - Longitudinal
Type
Count of Findings by Type and Category
Crack - 45°
Crack - Longitudinal
Crack - Transverse
Deformation or Laminate Buckling
Delamination
Dirt and fouling
Erosion
Hydraulic Oil
Lightning damage
Finding Count
174
87.5

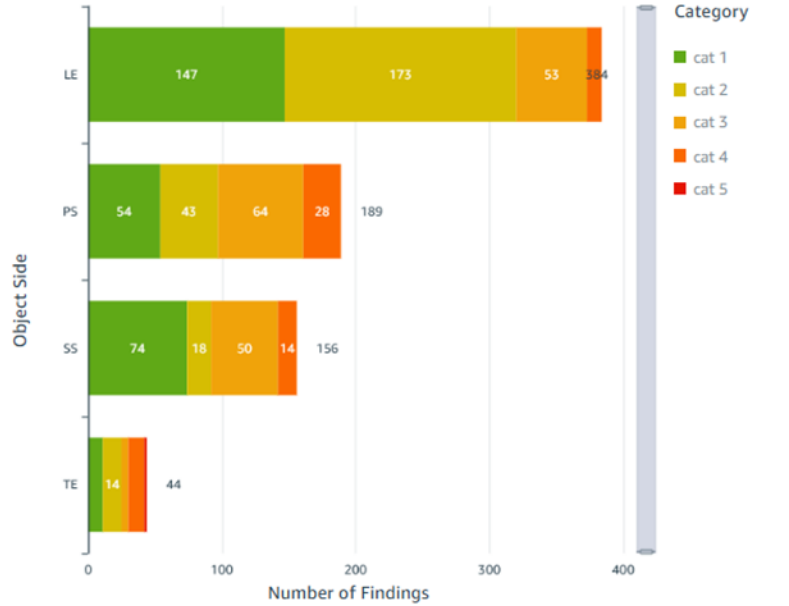

reports.yceblades.it/analytics/yce
90%
Castel_di_Lucio/CDL30/bladeB
3
3
2
0
3
6
9
12
15
18
Number of Findings
248 (32%)
Group By: Category
0
10
20
30
40
50
60
70
Number of Turbines
Count of Objects (Blades and/or Towers) by Category
cat 5
2
cat 4
39
cat 3
91
cat 2
132
cat 1
130
Category
0
30
60
90
120
150
Number of Objects
Count of Findings by Type
Erosion
7
158
44
209
Dirt and fouling
174
177
Missing/loose
89
96
Voids
35
23
61
Crack - Transverse
36
12
49
Crack - 45°
38
9
48
Lightning damage
7
18
26
Scratches, Gouges
16
6
22
Crack - Longitudinal
9
15
Peeling
13
15
Pinholes, Pitting...
11
14
Deformation or La...
11
Split/open bond
9
11
Delamination
6
10
Hydraulic Oil
8
9
Type
0
50
100
150
200
250
Number of Findings
Category
cat 1
cat 2
cat 3
cat 4
cat 5
Count of Findings by Type and Category
Crack - 45°
Crack - Longitudinal
Crack - Transverse
Deformation or Laminate Buckling
Delamination
Dirt and fouling
Erosion
Hydraulic Oil
Lightning damage
Missing/loose
Peeling
Pinholes, Pitting, Chips
Scratches, Gouges
Split/open bond
Voids
Type
cat 1
cat 2
cat 3
cat 4
cat 5
Category
Finding Count
174
87.5
1
Count of Findings by Object Side, broken down by Category
LE
147
173
53
384
PS
54
43
64
28
189
Category
cat 1
cat 2
cat 3
cat 4
cat 5
Count of Findings by Percentage Distance Along
350
300
250
200
Object Side
LE
PS
SS
TE
Count of Findings by Type and Length (cm)
Crack - 45°
Crack - Longitudinal
Crack - Transverse
Deformation or Laminate Buckling
Delamination
Dirt and fouling
Erosion
Hydraulic Oil
Finding Count
127



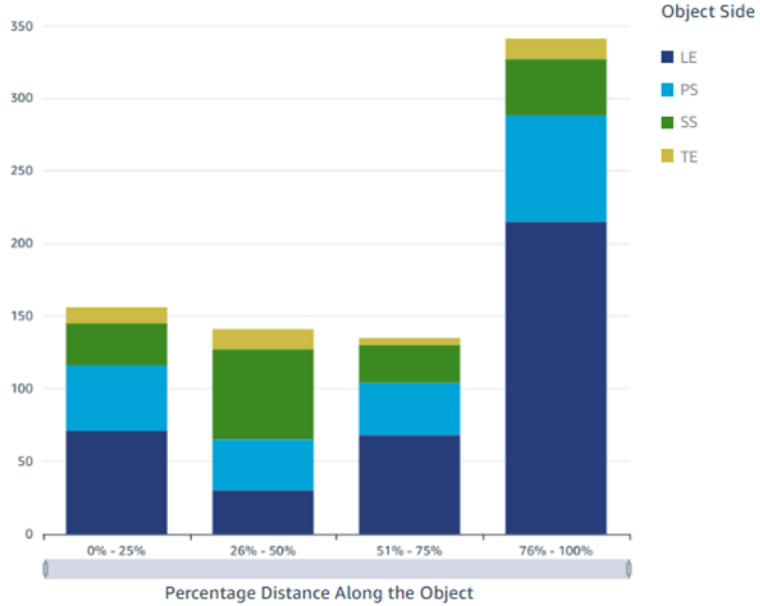




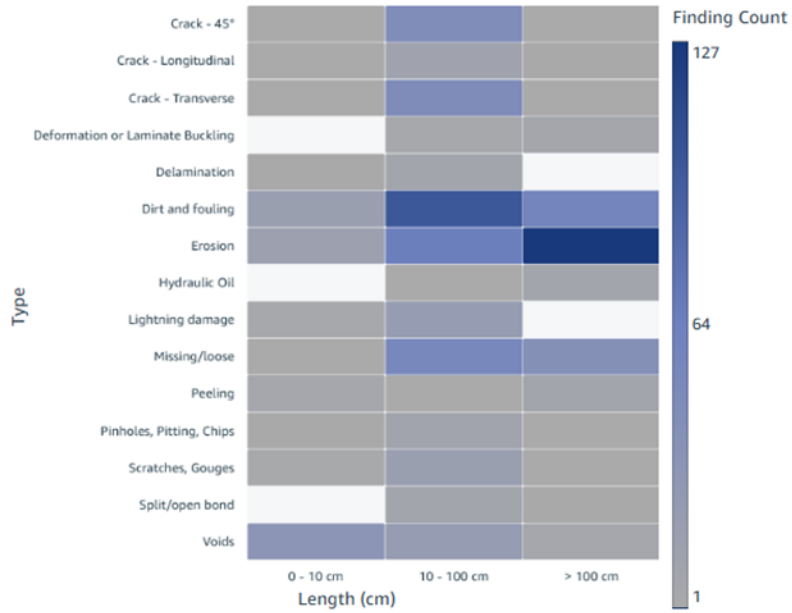
Count of Findings by Object Side, broken down by Category



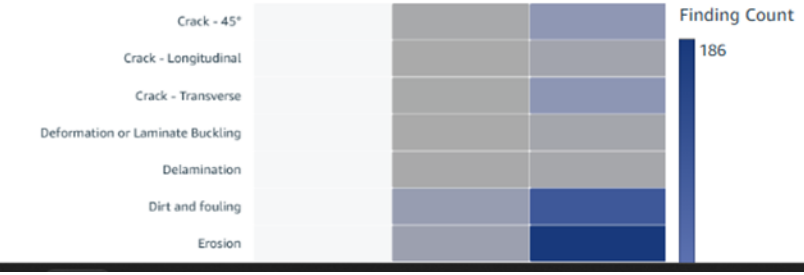
Count of Findings by Percentage Distance Along



Count of Findings by Type and Length (cm)



Count of Findings by Type and Defect Size (cm2)

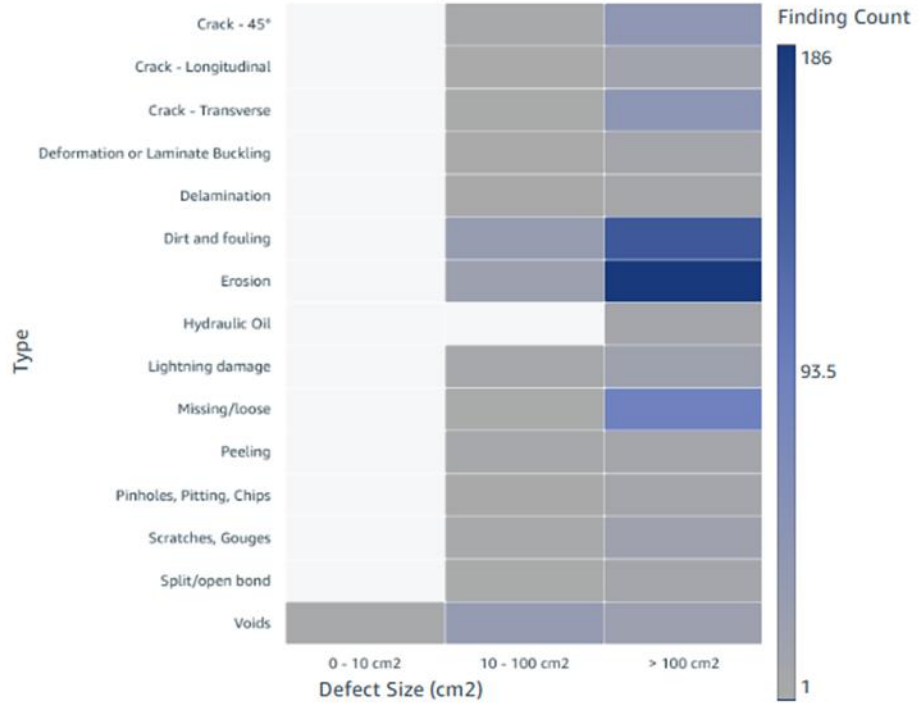


Average Number of Findings per Turbine, by Turbine Model

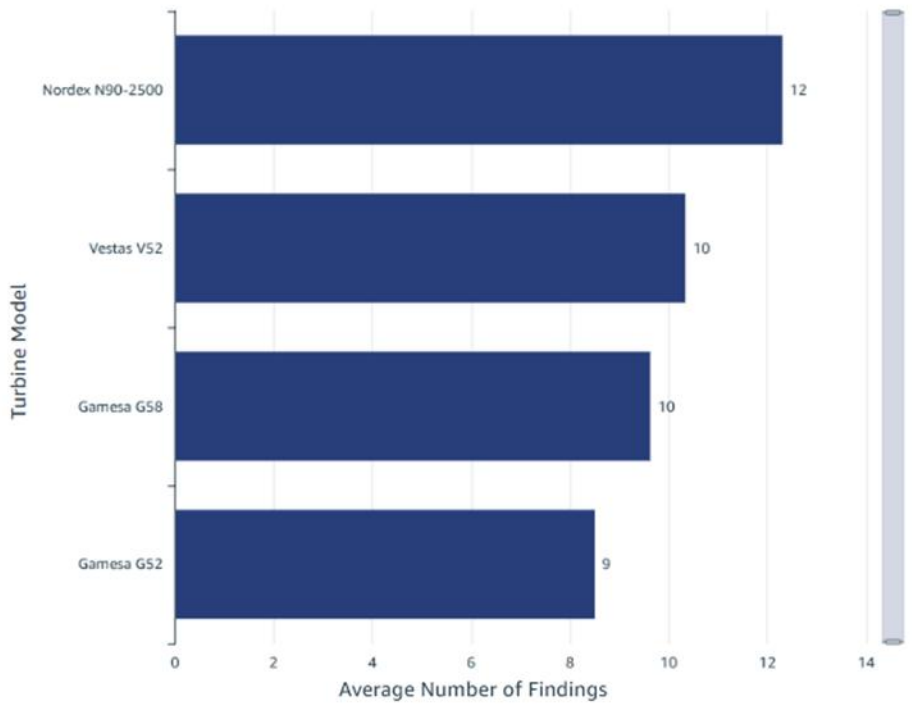
Number of Findings

Percentage Distance Along the Object

Count of Findings by Type and Defect Size (cm2)



Average Number of Findings per Turbine, by Turbine Model



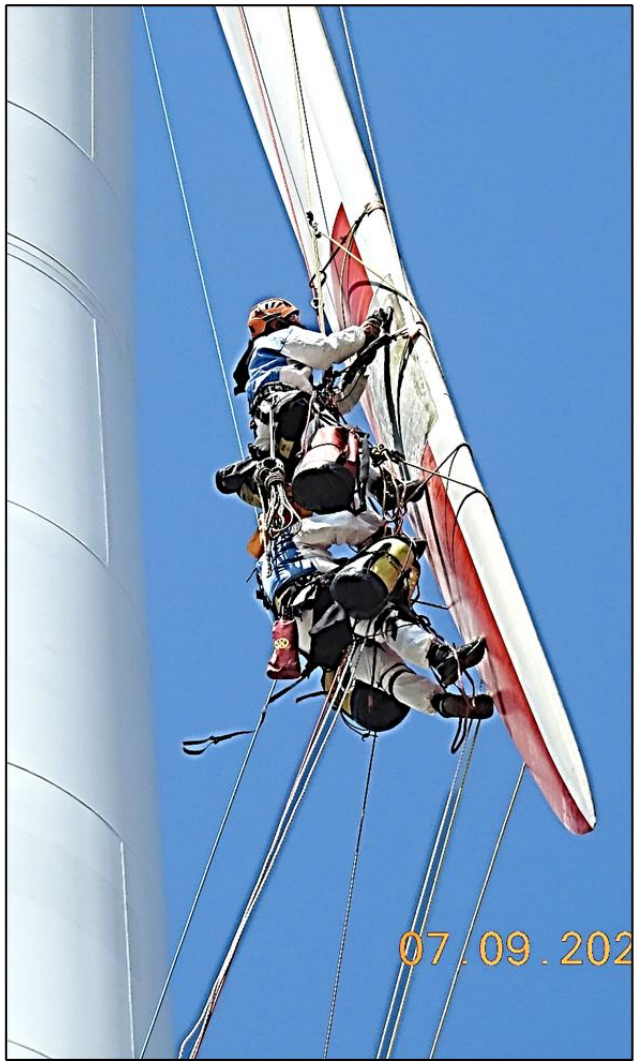
Category, Wind Farm, Turbine, Oem Turbine Model, Type, Object Side, and Finding Url Reference

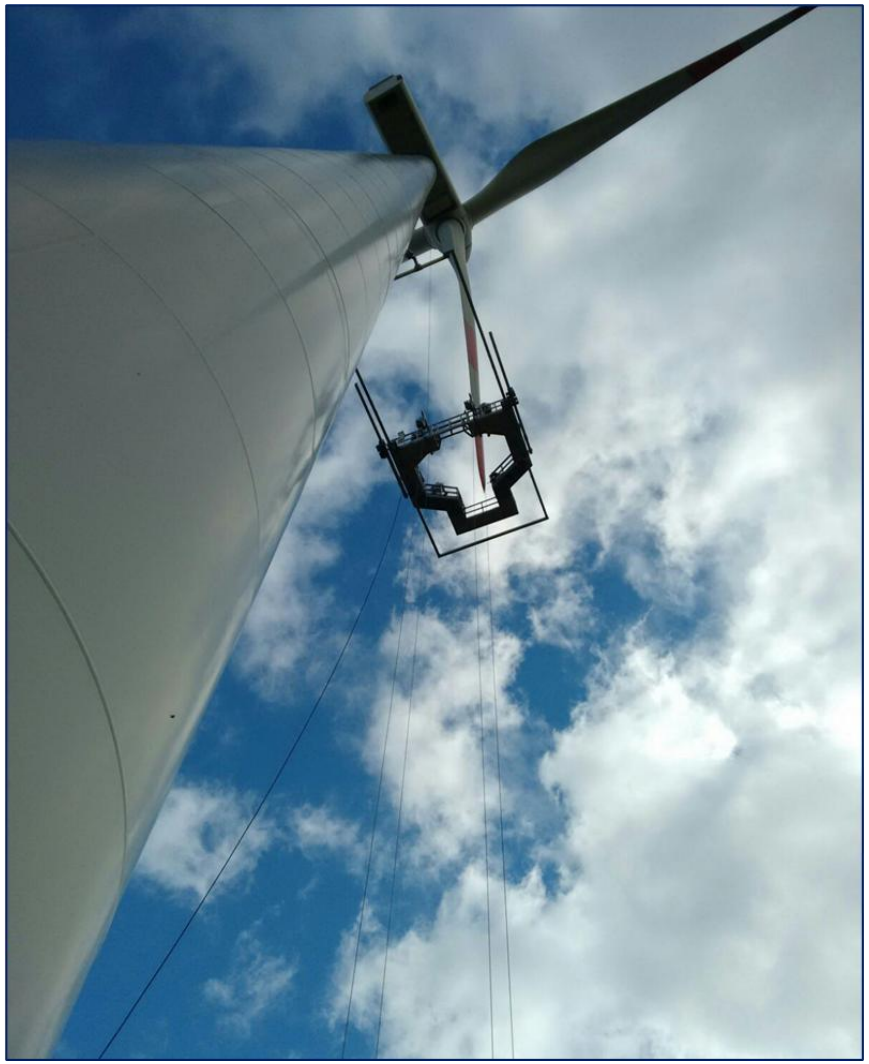
Categ...	Wind Farm	Turbine	OEM Turbine Model	Type	Object Side	Finding URL Reference
cat 5		LIC06	Gamesa G58	Split/open bond	TE	https://reports.yceblades.it/findings Licodia_Eubea/LIC06/18901040-4b65-11f0-9a
cat 5		LIC11	Gamesa G58	Split/open bond	TE	https://reports.yceblades.it/findings Licodia_Eubea/LIC11/89f1f130-4c29-11f0-a9e
cat 4		CDL03	Vestas V52	Missing/loose	PS	https://reports.yceblades.it/findings Castel_di_Lucio/CDL03/a60603f0-37d1-11f0-b
cat 4		CDL03	Vestas V52	Missing/loose	TE	https://reports.yceblades.it/findings Castel_di_Lucio/CDL03/e6019000-37d1-11f0-b
cat 4		CDL19	Vestas V52	Crack - Longitudinal	PS	https://reports.yceblades.it/findings Castel_di_Lucio/CDL19/ab66f150-3d4a-11f0-9
cat 4		CDL27	Vestas V52	Crack - Longitudinal	PS	https://reports.yceblades.it/findings Castel_di_Lucio/CDL27/b0285e20-37b1-11f0-9
cat 4		CDL27	Vestas V52	Split/open bond	TE	https://reports.yceblades.it/findings Castel_di_Lucio/CDL27/ec6e8350-37b1-11f0-9
cat 4		LIC04	Gamesa G58	Lightning damage	SS	https://reports.yceblades.it/findings Licodia_Eubea/LIC04/dfd1c400-4b3d-11f0-81f
cat 4		LIC05	Gamesa G58	Crack - Longitudinal	PS	https://reports.yceblades.it/findings Licodia_Eubea/LIC05/99c4e1e0-4b4c-11f0-842
cat 4		LIC06	Gamesa G58	Crack - Longitudinal	LE	https://reports.yceblades.it/findings Licodia_Eubea/LIC06/685cb630-4b62-11f0-9a
cat 4		LIC07	Gamesa G58	Lightning damage	PS	https://reports.yceblades.it/findings Licodia_Eubea/LIC07/6136c850-4c20-11f0-a9e
cat 4		LIC07	Gamesa G58	Lightning damage	PS	https://reports.yceblades.it/findings Licodia_Eubea/LIC07/6573aeb0-4c20-11f0-a9e
cat 4		LIC09	Gamesa G58	Crack - Transverse	PS	https://reports.yceblades.it/findings Licodia_Eubea/LIC09/08a4c650-4c26-11f0-a9e

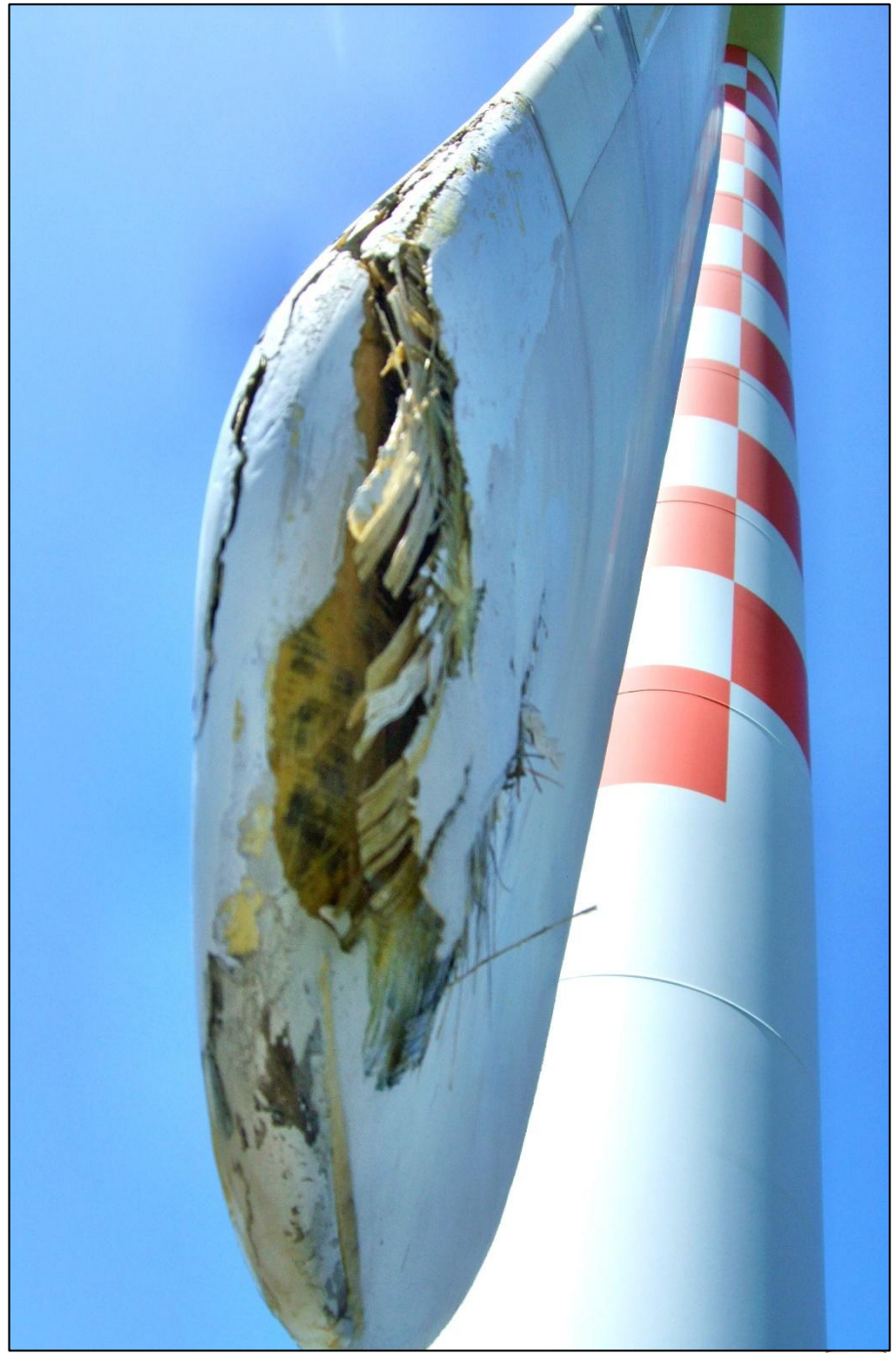
Next step:
how to carry out repairs and maintenance

… from small to big,
from simple to complicated.

Choice of access at height








110
90

SIEMENS SWT 2.3

(one shot blade construction process)

repaired in 2 weeks

GAMESA G90

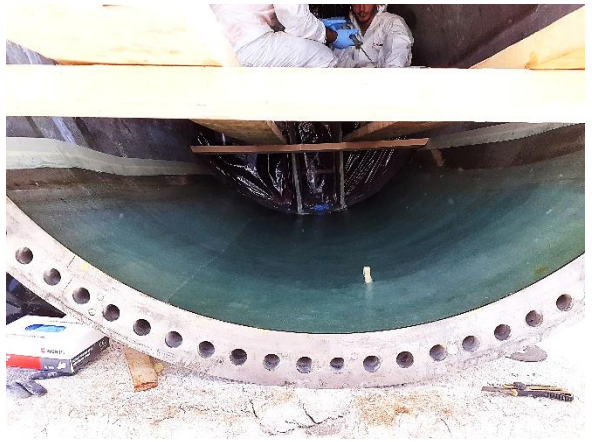
repaired in 1 week

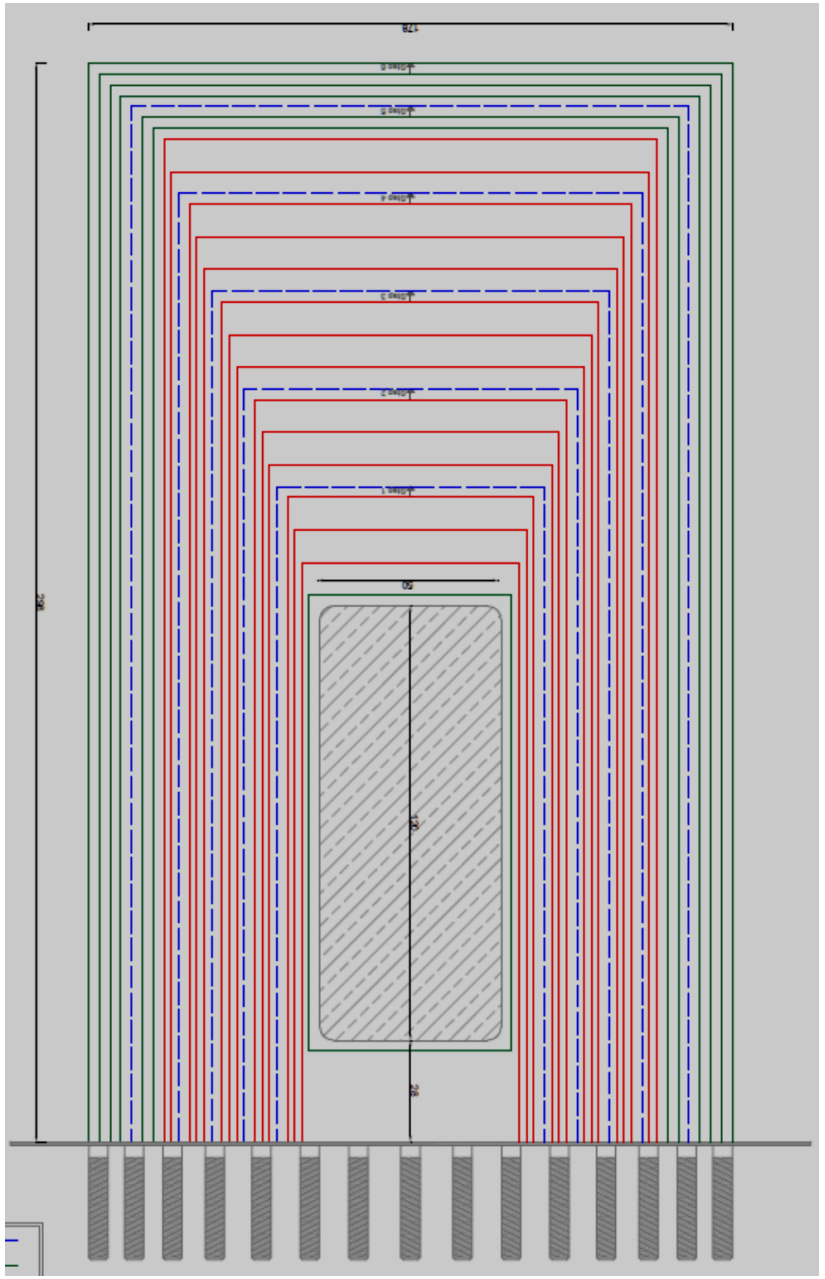
GAMESA G87

repaired in 1,5 weeks

GAMESA G87

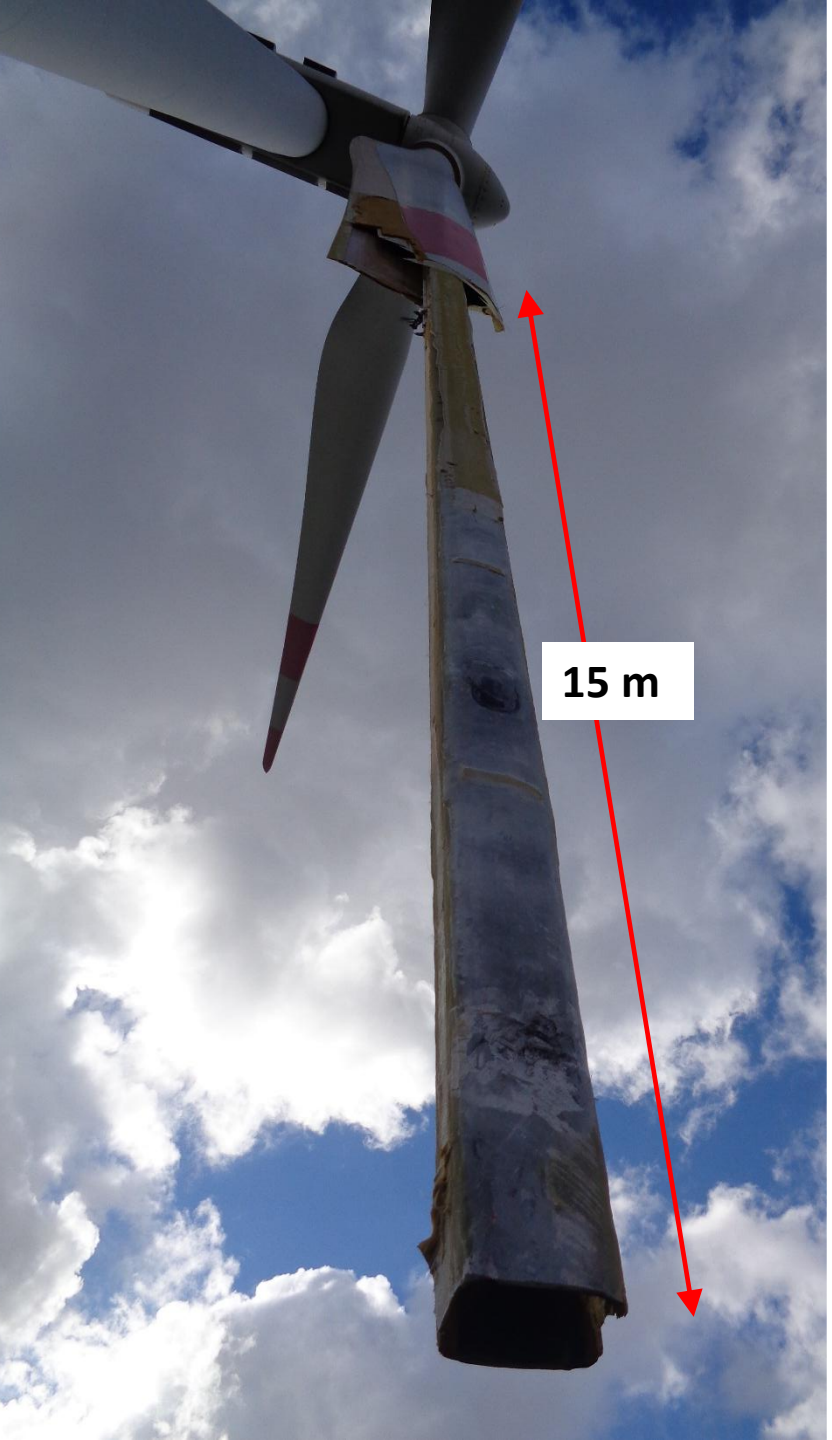
repaired in 2 weeks





2 weeks: final repair area 3 mt x 1,8 mt

25 layers of fiberglass in 6 lamination steps, each cured under vacuum and heating

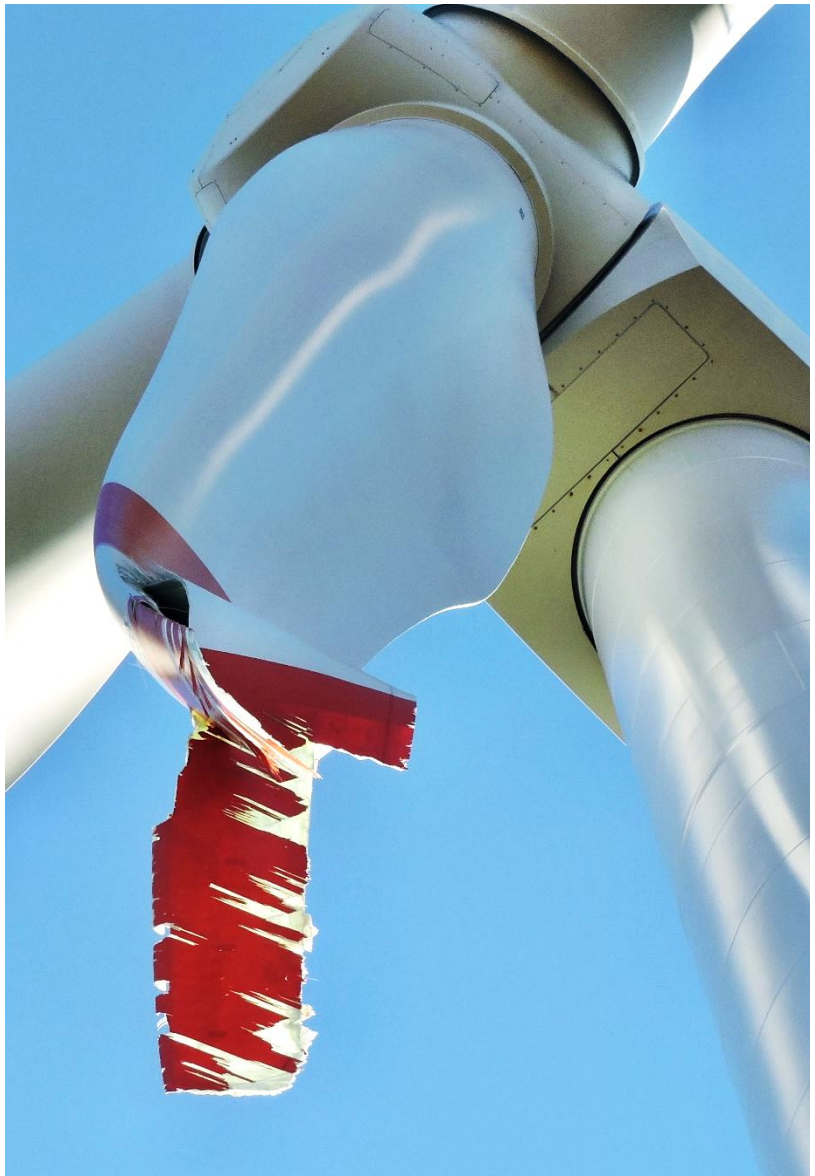


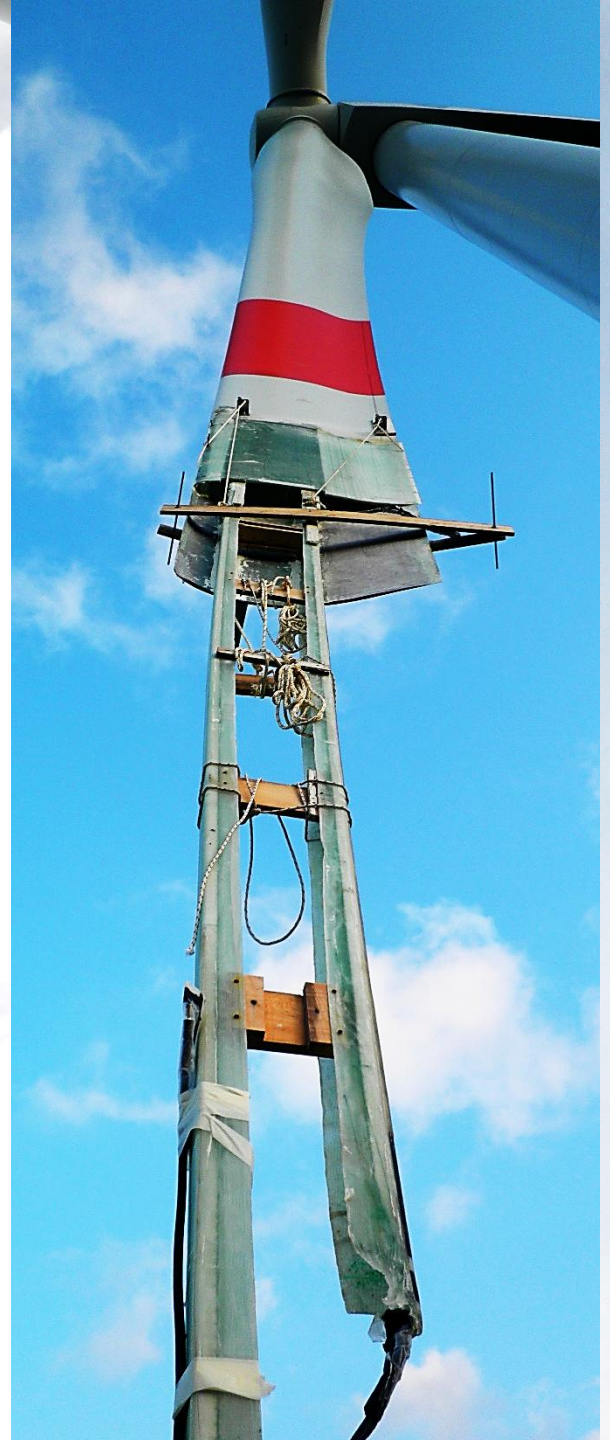
GAMESA G52

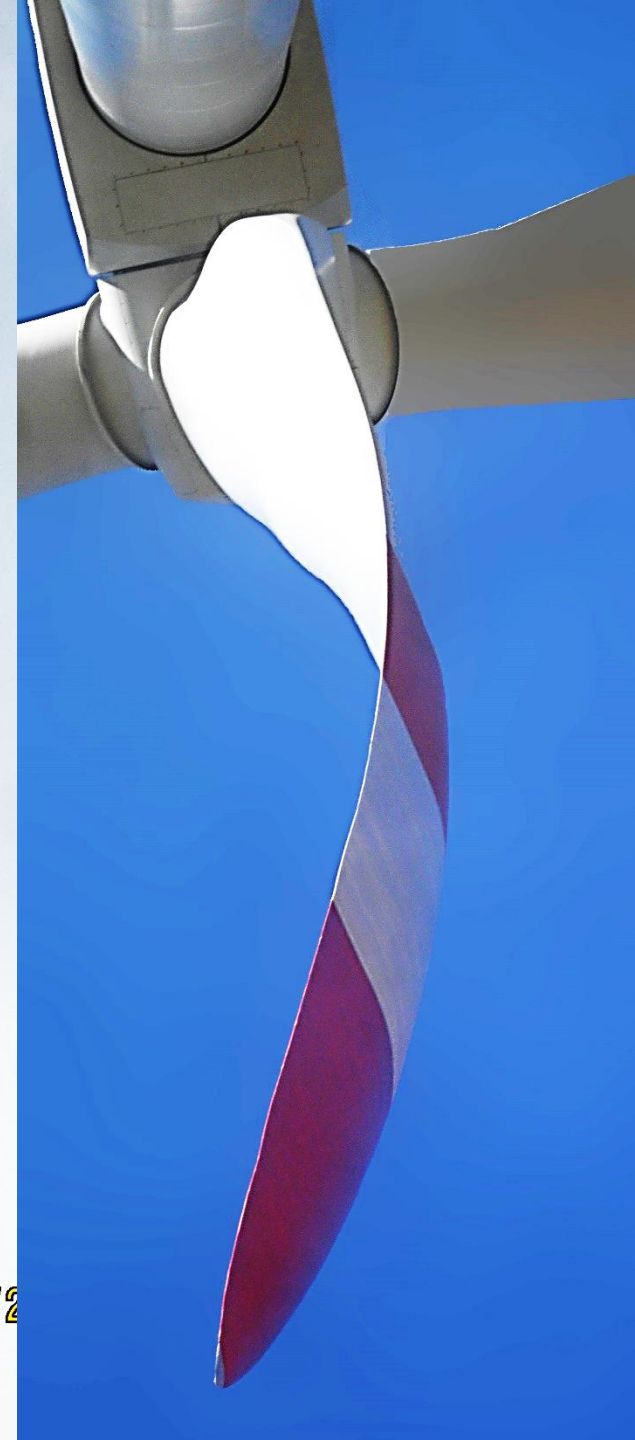
reconstructed in 4 weeks

SENVION 3XM

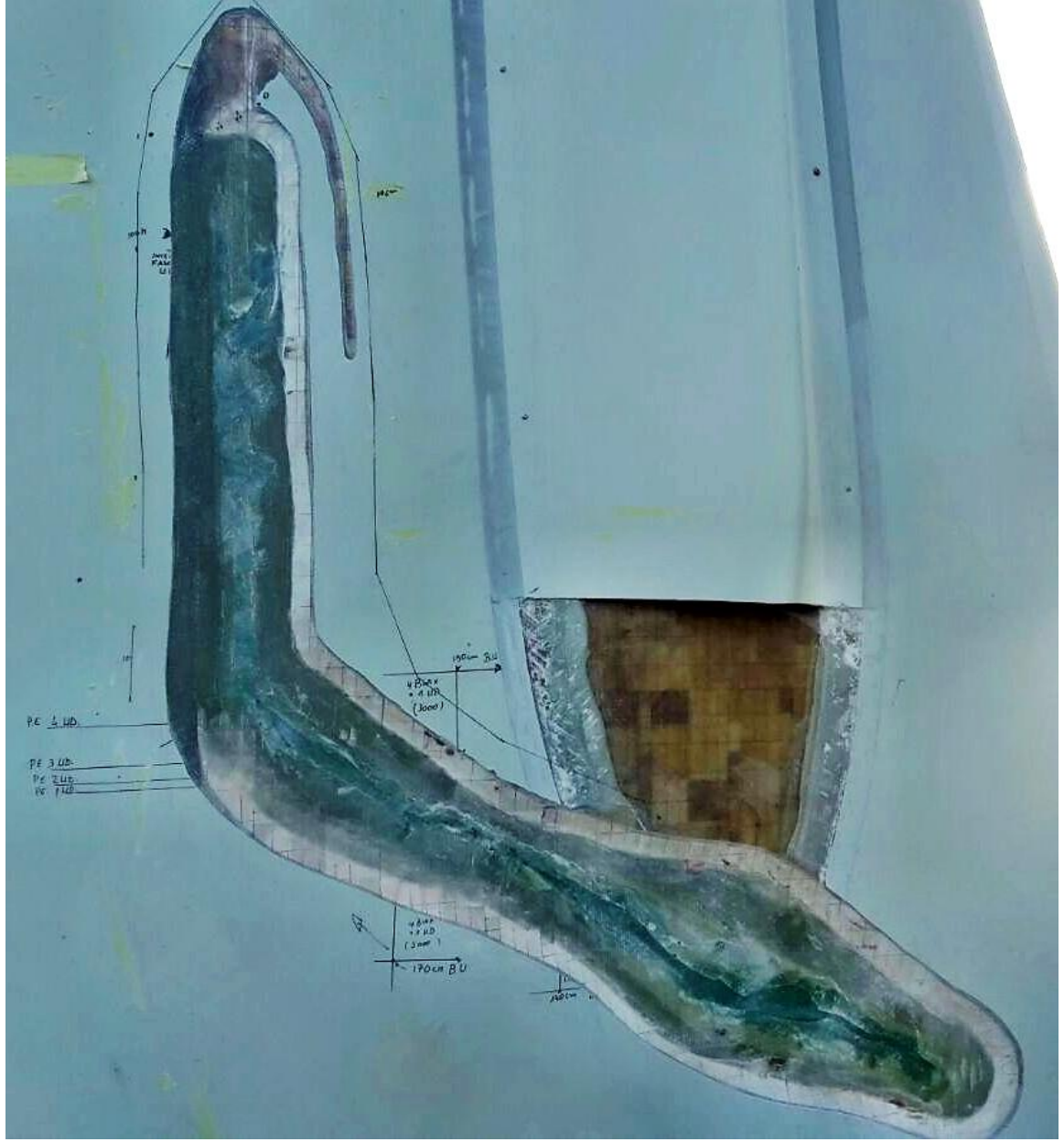
reconstructed in 3 weeks

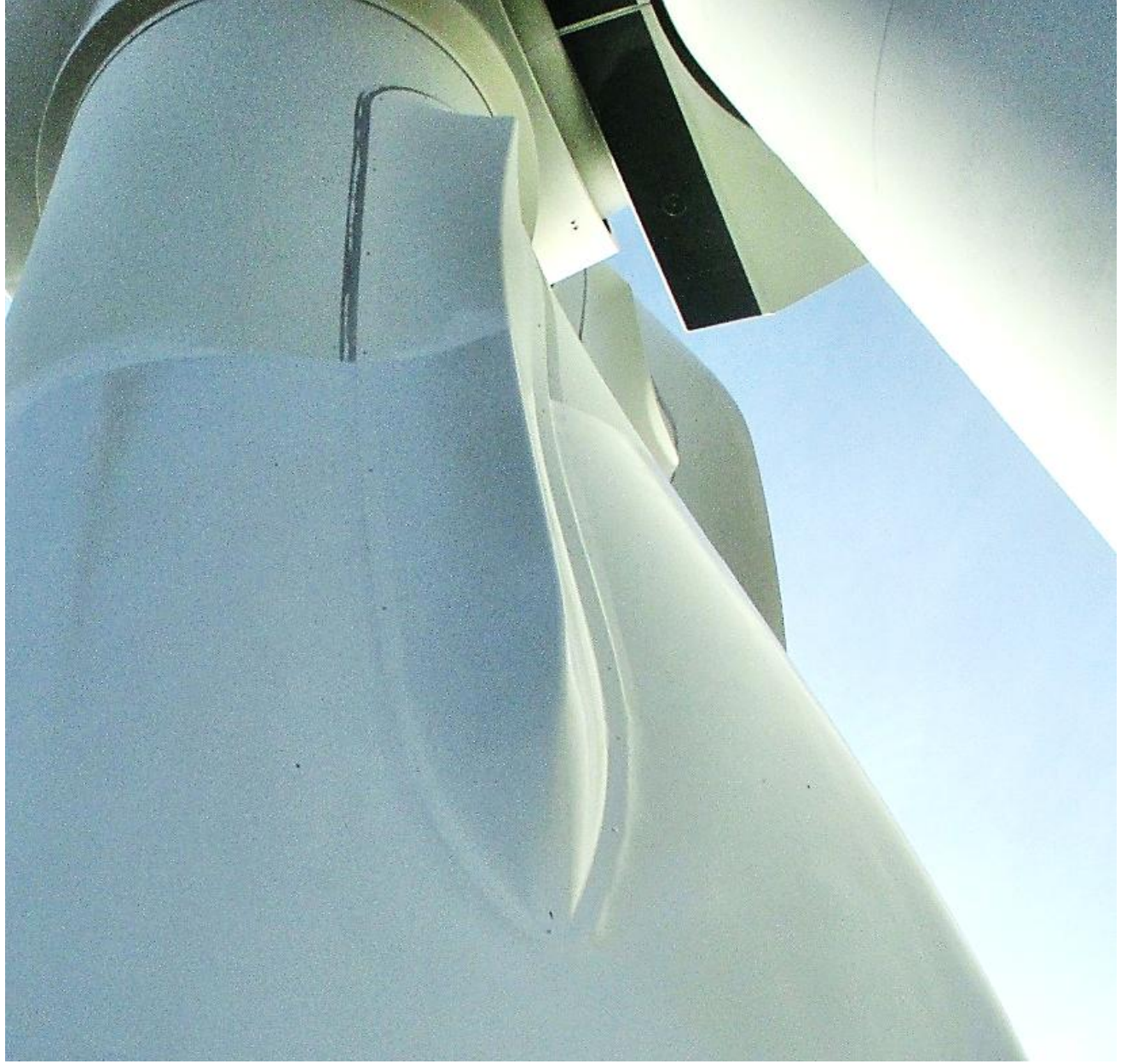






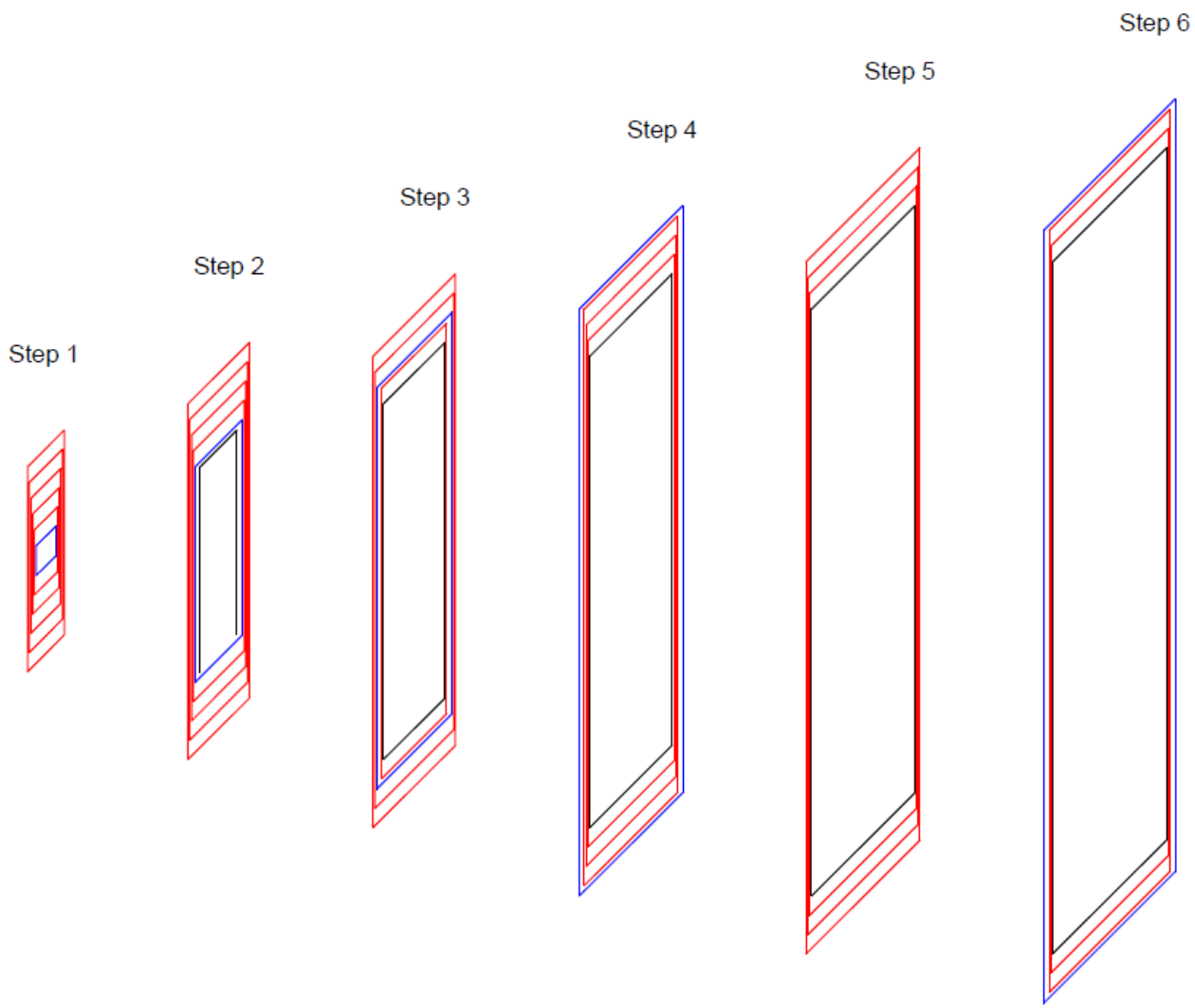
reconstructed in 3 weeks

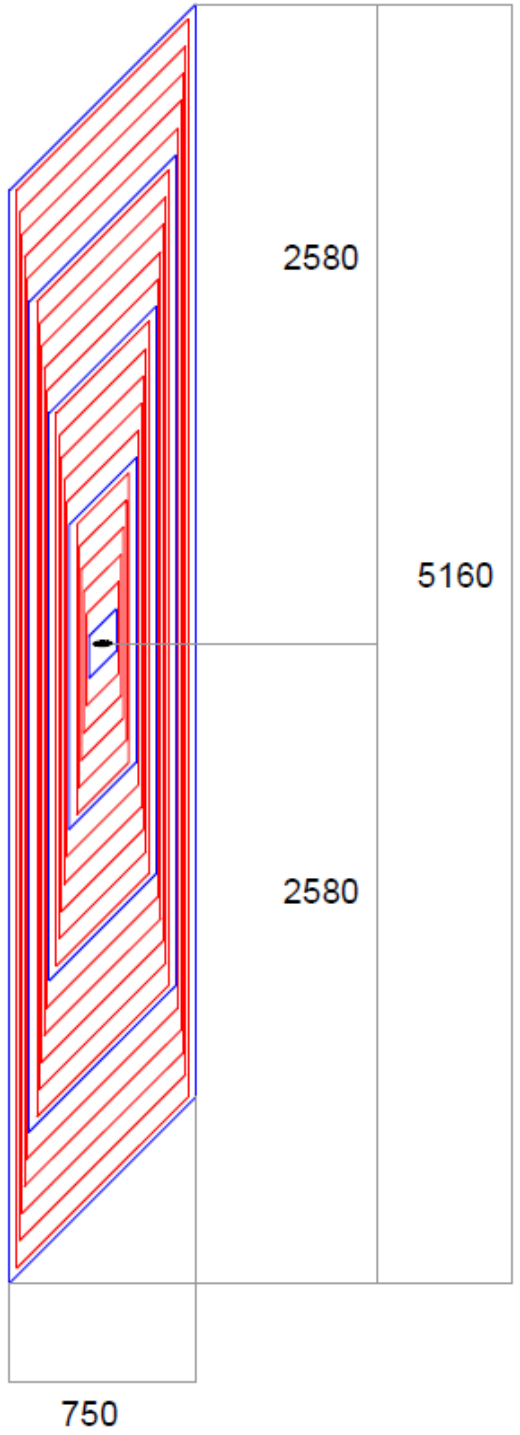




SENVION MM92

repaired in 2 weeks



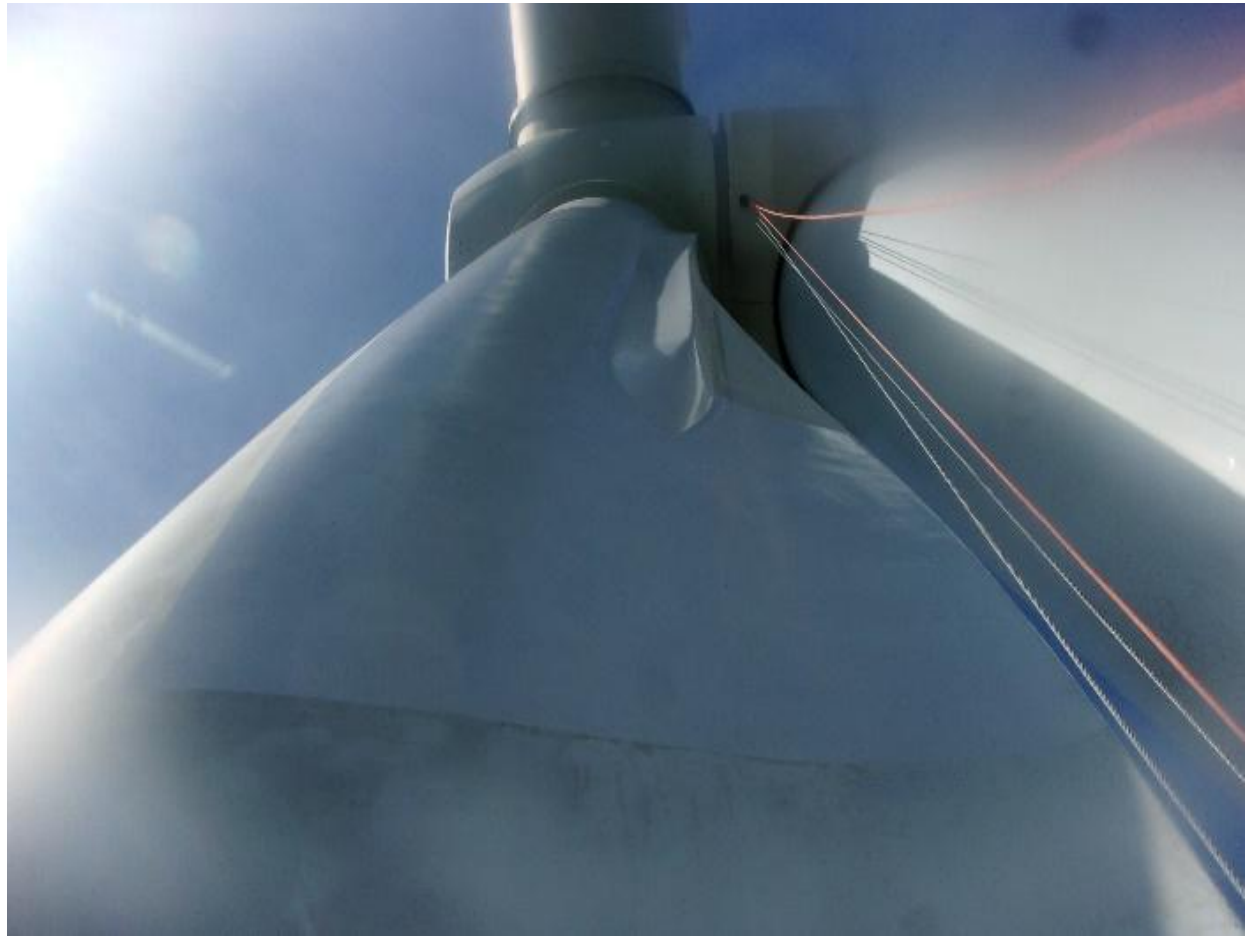


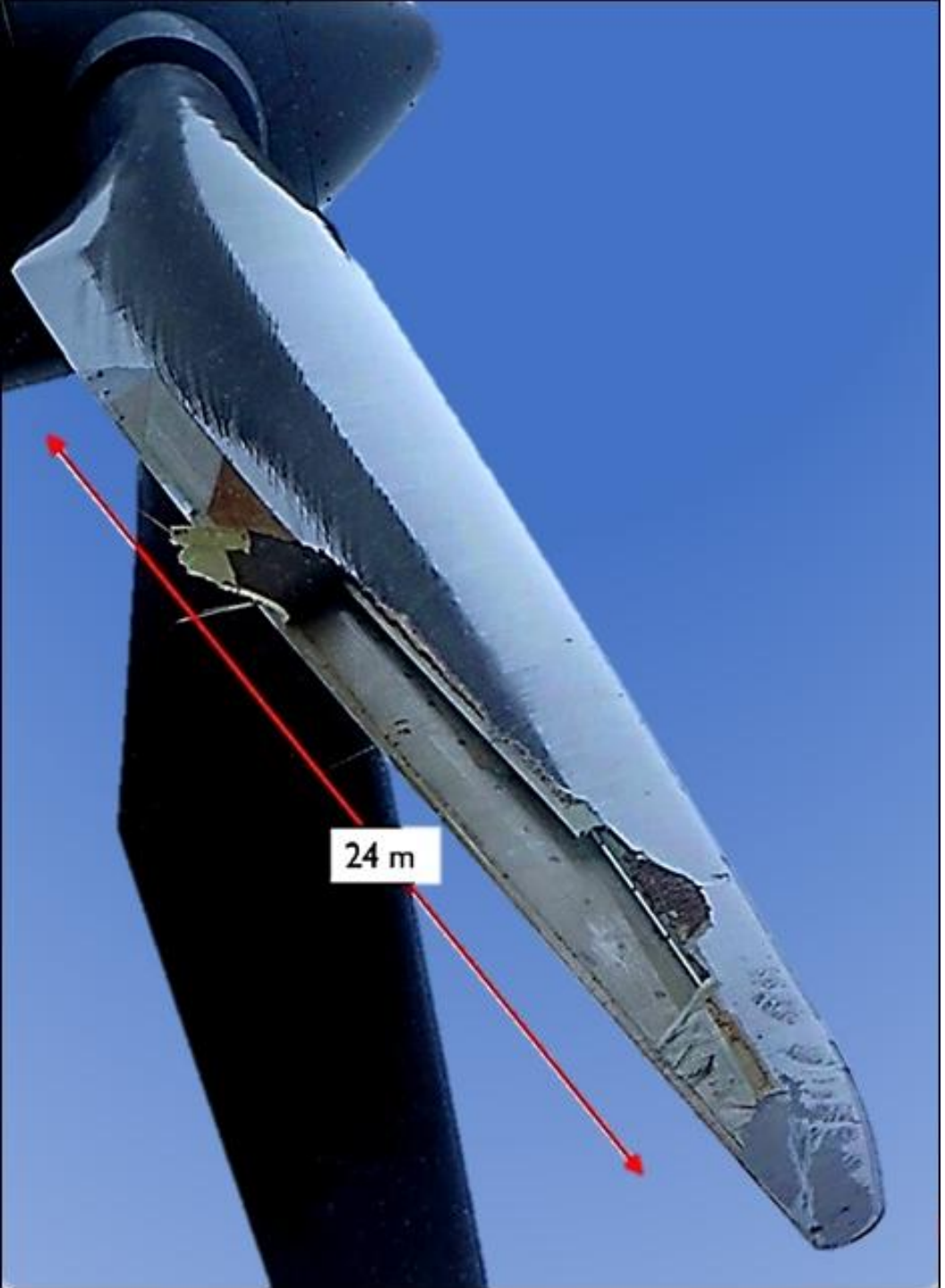
2 weeks: girder (5,2 m x 0,8 m) + transverse crack (~3 m long)

Girder: 30 layers of fiberglass in 6 lamination steps, each cured under vacuum and heating

SENVION MM82

repaired in 3 weeks





VESTAS V66

reconstructed in 4 weeks

(spar broken in 3 parts + missing shell)

Customers evaluate any possible form of price

(price per team or technician, per damage, per damaged area, per damage type, …)

What Customers should look for

Number of available teams

Number of in-house technicians (not externals hired on occasion)?
How/how long are they trained?
Do they work all year long on blades?

Time-to-intervention

Deployment time?
Where are the teams located?
How are they logistically organized?
How long will they stay on site?

Blade engineers

How many?
How are they qualified (university)?
Additional qualification/years of experience?
Really involved in day-by-day business?

Customer – Supplier partnership

Is it perceived really so low? This should be on top,
but it is often considered as the very last advantage!

Qualification of technicians

Where do the technicians come from?
Do they have a career in this business?
Who trains them? And is there a system in place for advanced education and training for technicians?

Continuous education of staff

Quis custodiet ipsos custodes?
Engineers train technicians, who trains the engineers?

experienced, qualified management

What is the core business of the supplier?
Is the supplier really focused on supplying the requested quality level?

GLOCAL

Describing the seamless integration between the local and global;
the comprehensive connectedness produced by travel, business, and communications;
willingness and ability to think globally and act locally.

(2023, www.oxfordreference.com)

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