FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT OF CIVIL ENGINEERING
MARITIME TECHNOLOGY DIVISION

DRAG CHARACTERISTICS OF NEWLY APPLIED MARINE COATINGS AND POTENTIAL APPLICATIONS IN COMBINATION WITH ULTRASONIC DEVICES

Maxim Candries

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OUTLINE

1. Background and objectives
2. Tested coatings
3. Experimental set-up
4. Results
5. In-situ evaluation of the coatings in combination with an Ultrasonic device
6. Conclusions

1. BACKGROUND AND OBJECTIVES

- Photographic records taken in drydock have shown that dredging vessels of DEME can be covered with heavy calcareous fouling over a large extent of the wetted surface area.
- DEME is considering to apply alternatives in replacement of the copper-containing antifoulings that they normally use..
- One coating that was proposed, is a novel hard nanostructured coating that claims 6% drag reduction
- Investigate the roughness and boundary layer characteristics of three commercial coatings
- Roughness and boundary layer characteristics of coatings are compared
- Perform an in-situ evaluation in combination with an ultrasonic device

2. TESTED COATINGS

- Commissioned by Dredging International (DEME)
- These vessels are a lot of the time operational at low speeds (dredging mode), often in tropical waters
- After drydock observations, alternatives, preferrably without biocides, are sought to replace standard tin-free SPC (=**Coat-1**)
- Two candidates, new on the market, which both claim significant drag benefits:
- **Coat-2**: A new generation Foul Release system with added biocides for extra fouling defence, suitable for suitable for vessels with long idle periods, which in this case are better called “very active” periods
- **Coat-3**: A novel biocide-free “nanostructured” coating that would be combined with an active ultrasonic antifouling device

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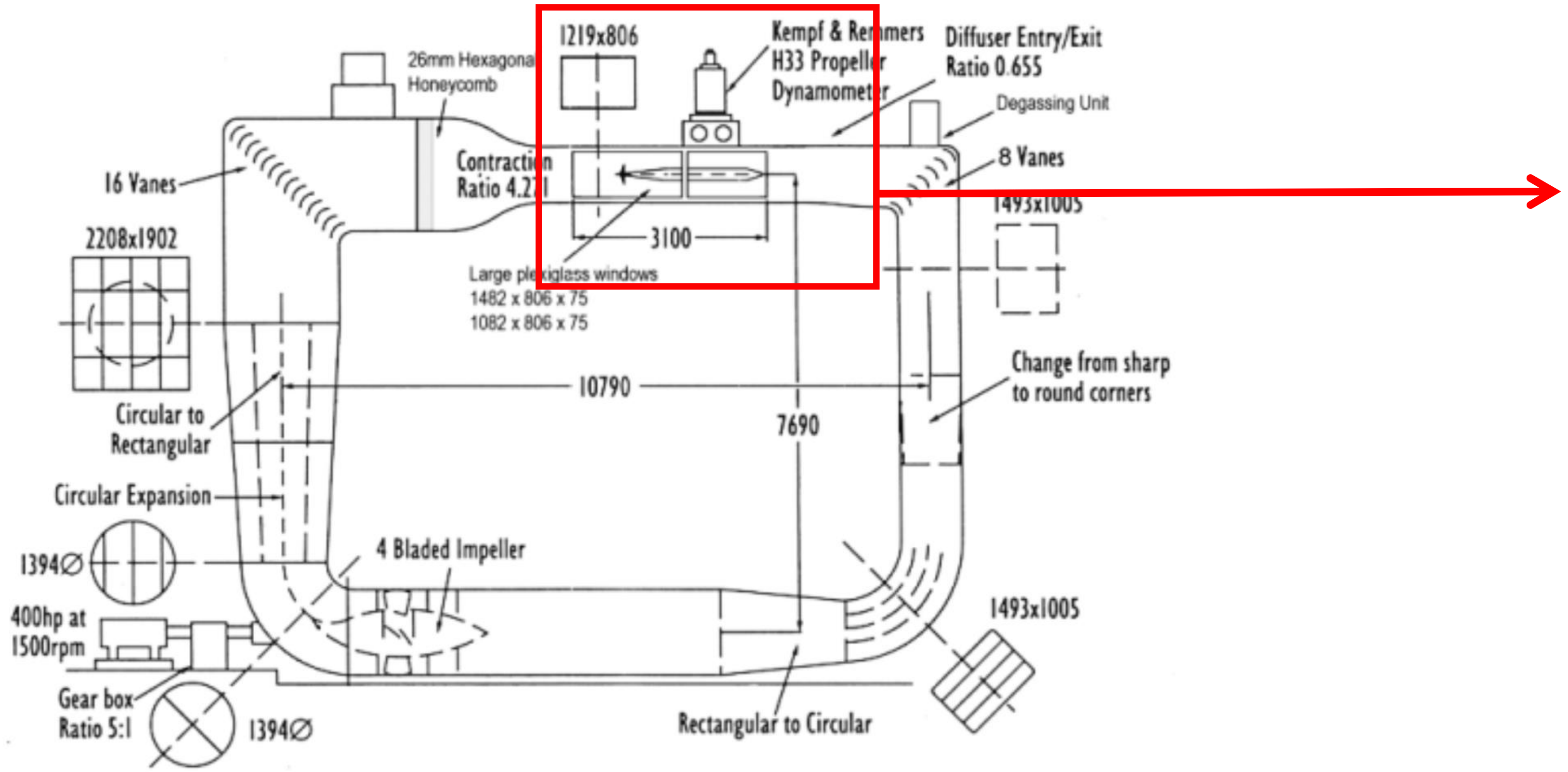
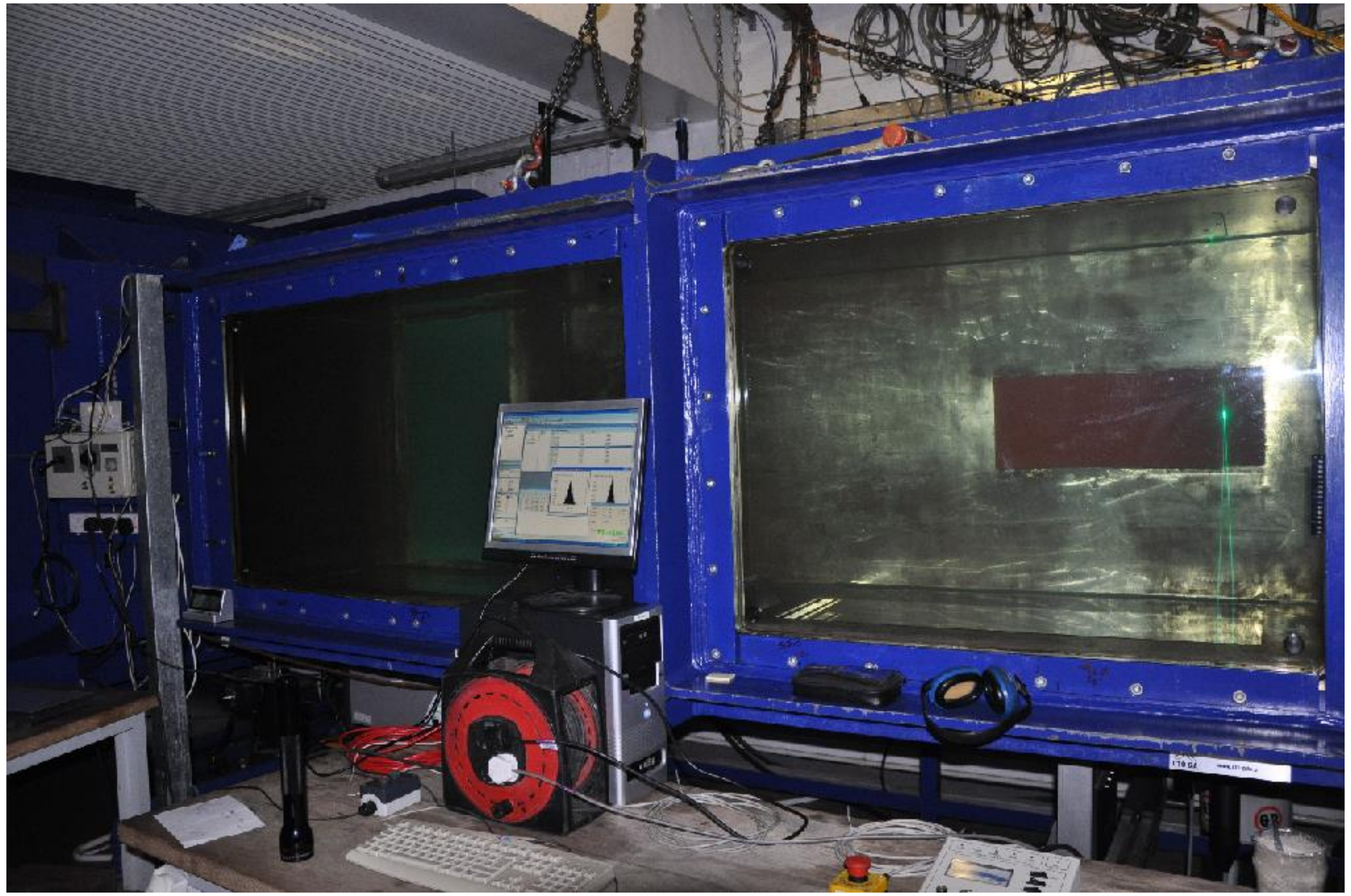
3. EXPERIMENTAL SET-UP

LDV Boundary layer experiments

- Boundary layer characteristics are measured with LDV system in the Emerson Cavitation Tunnel
- Maximum speed in the measuring section is 8 m/s.
- Large observation windows on the side walls and floor





Measuring section of Emerson cavitation tunnel

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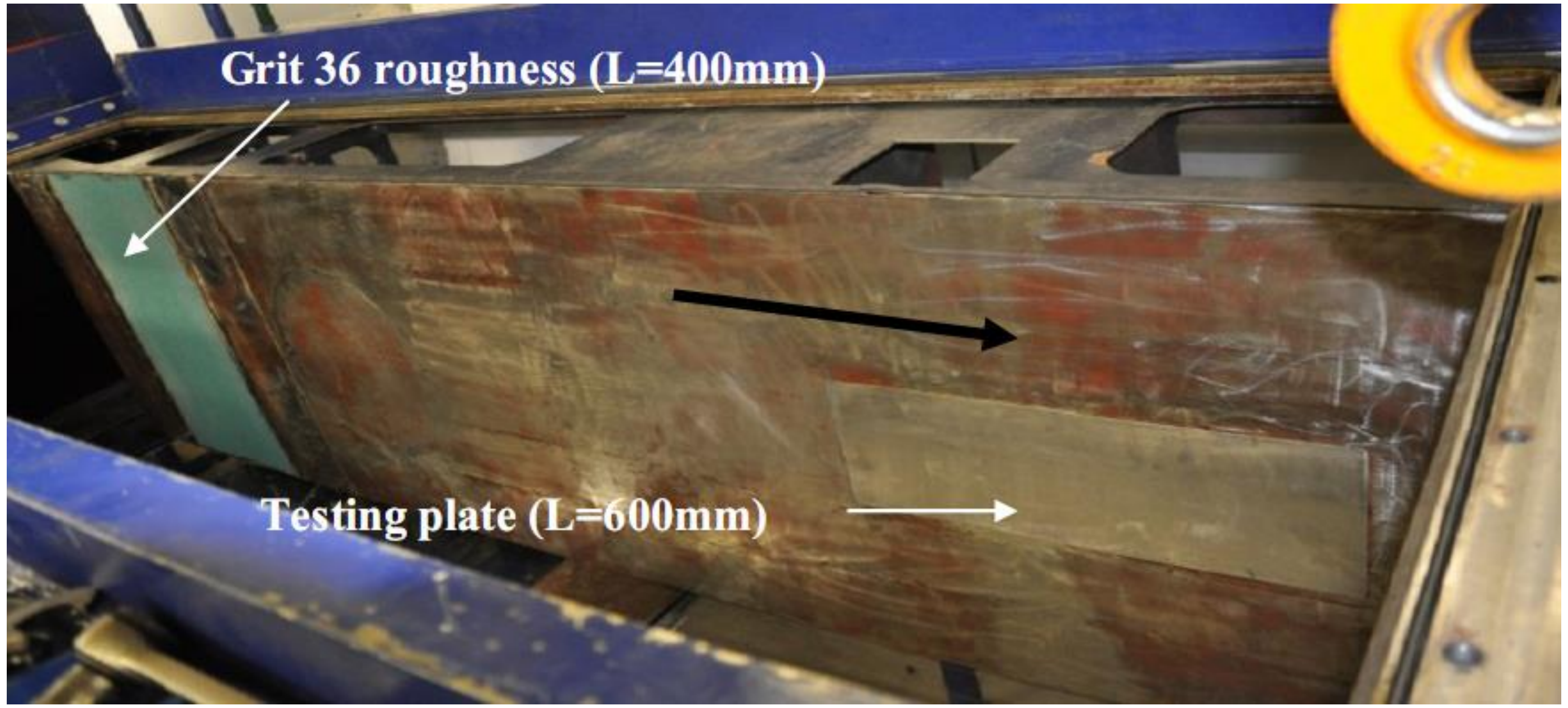
3. EXPERIMENTAL SET-UP

LDV Boundary layer experiments

- "high speed insert"
- Test specimens have a 218 by 598 mm² coated area
- Preferably on acrylic substrate



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3. EXPERIMENTAL SET-UP

LDV Boundary layer experiments

- Test speciments can be replaced rapidly (in 1-2 hours);
- 5- 6 boundary layer profiles → 1 coated surface can be tested per day;

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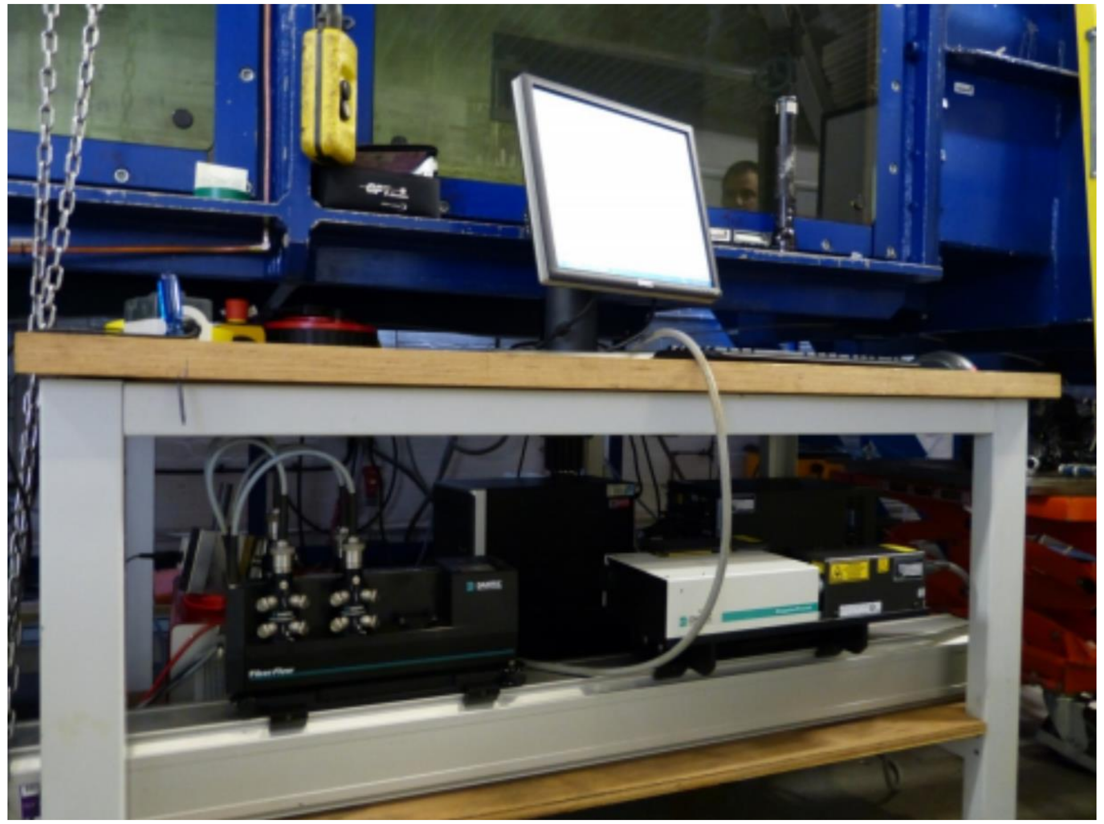
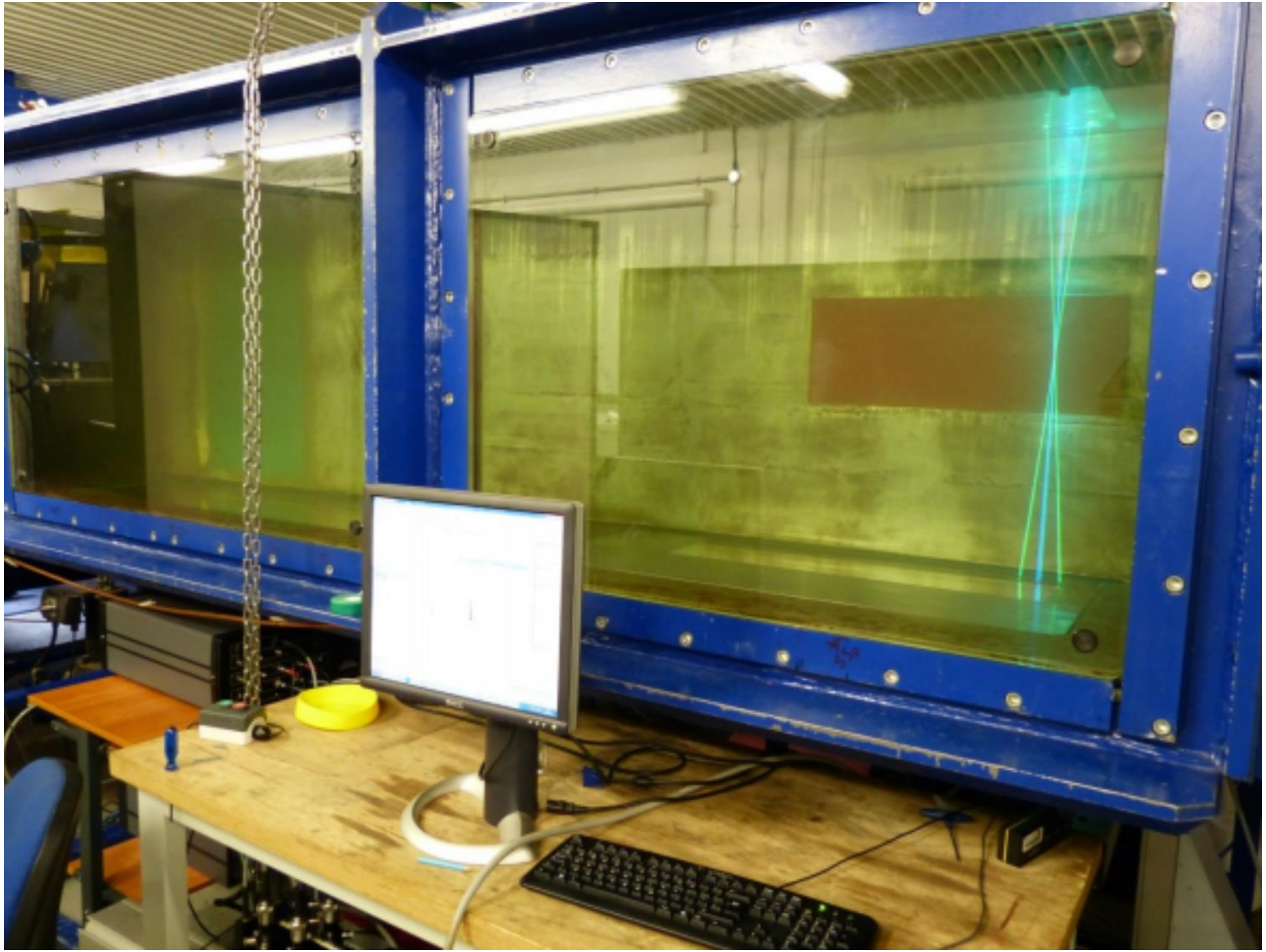
3. EXPERIMENTAL SET-UP

LDV Boundary layer experiments

- Laser Doppler Velocimetry





Measuring section of Emerson cavitation tunnel

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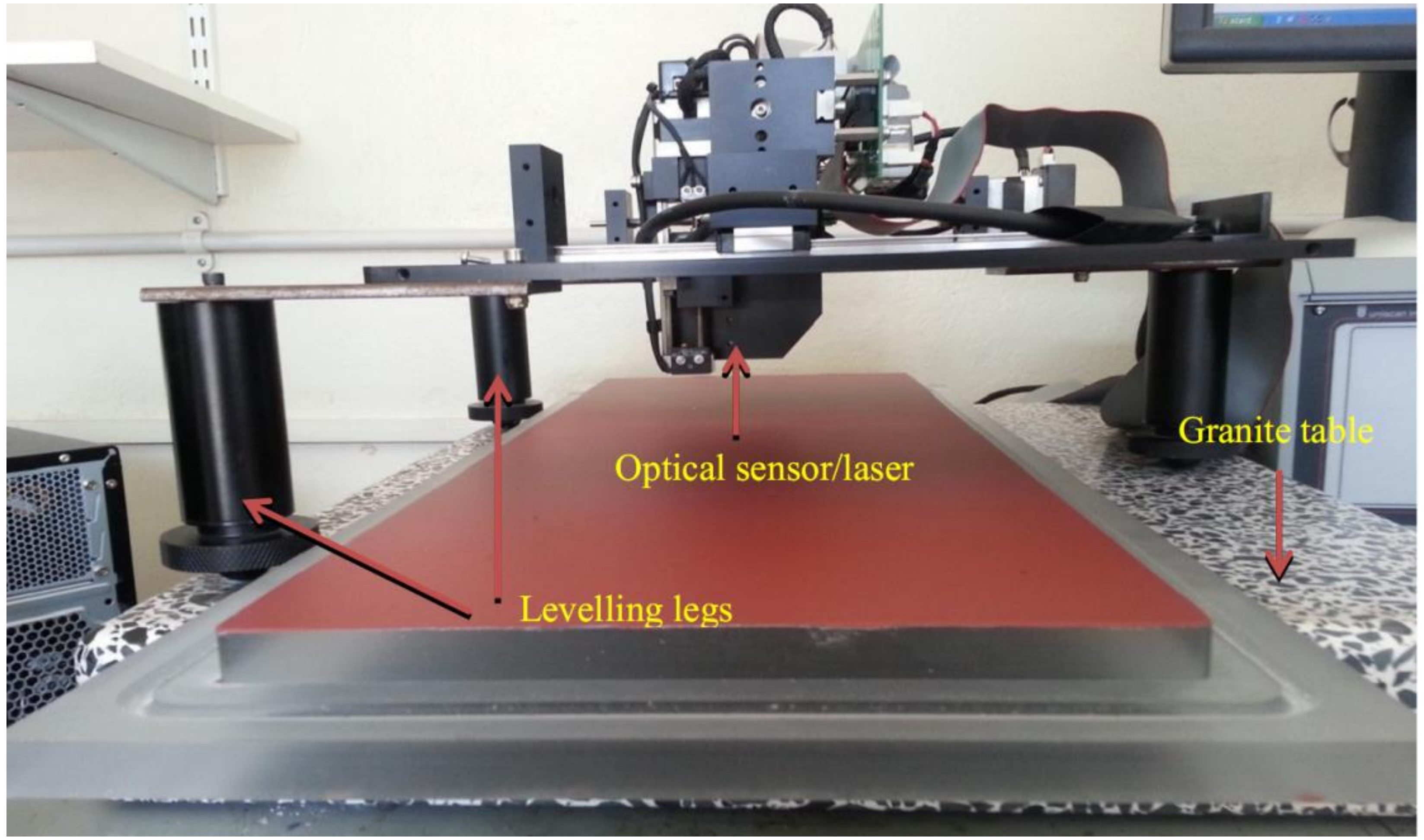
3. EXPERIMENTAL SET-UP

Roughness measurements

- Roughness characteristics of same test specimens are measured with optical laser profilometer (Uniscan OSP100) and stylus instrument (Surtronic 25)



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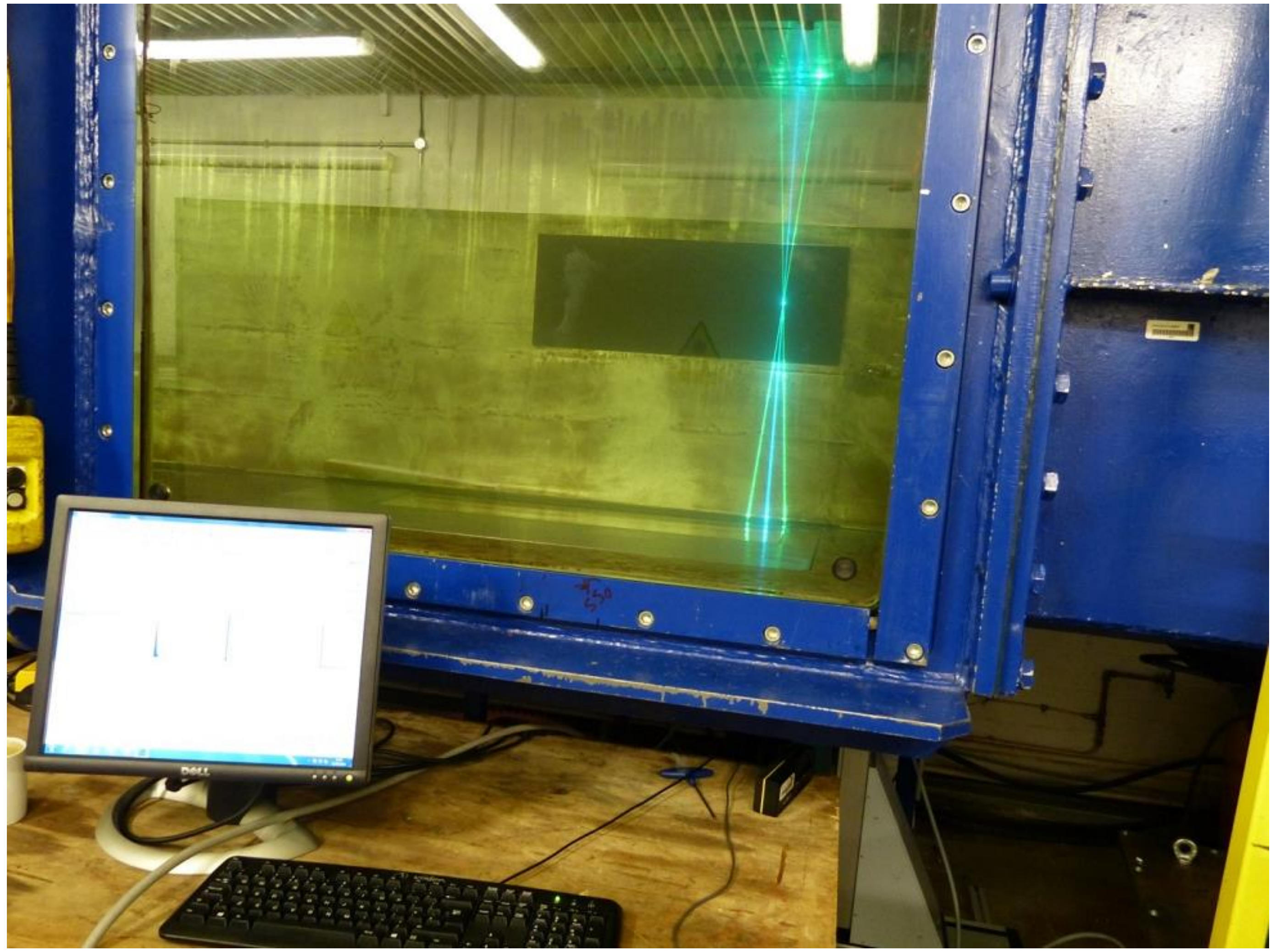
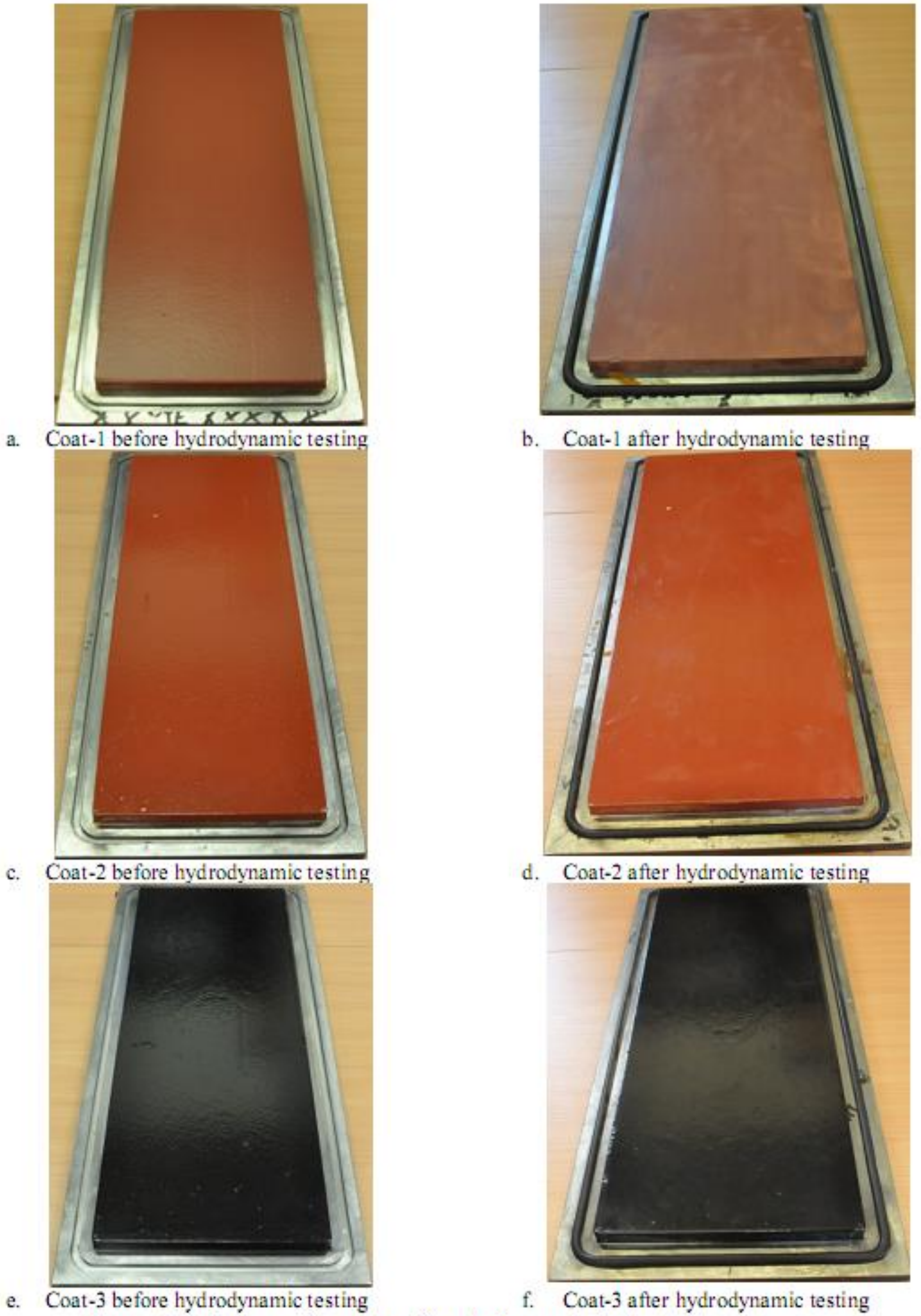
3. EXPERIMENTAL SET-UP

- Full coating schemes applied on steel test specimens at shipyard, then transported to Newcastle





a. Coat-1 before hydrodynamic testing
b. Coat-1 after hydrodynamic testing
c. Coat-2 before hydrodynamic testing
d. Coat-2 after hydrodynamic testing
e. Coat-3 before hydrodynamic testing
f. Coat-3 after hydrodynamic testing

Figure 1.1 Pictures of coated surfaces before and after hydrodynamic testing

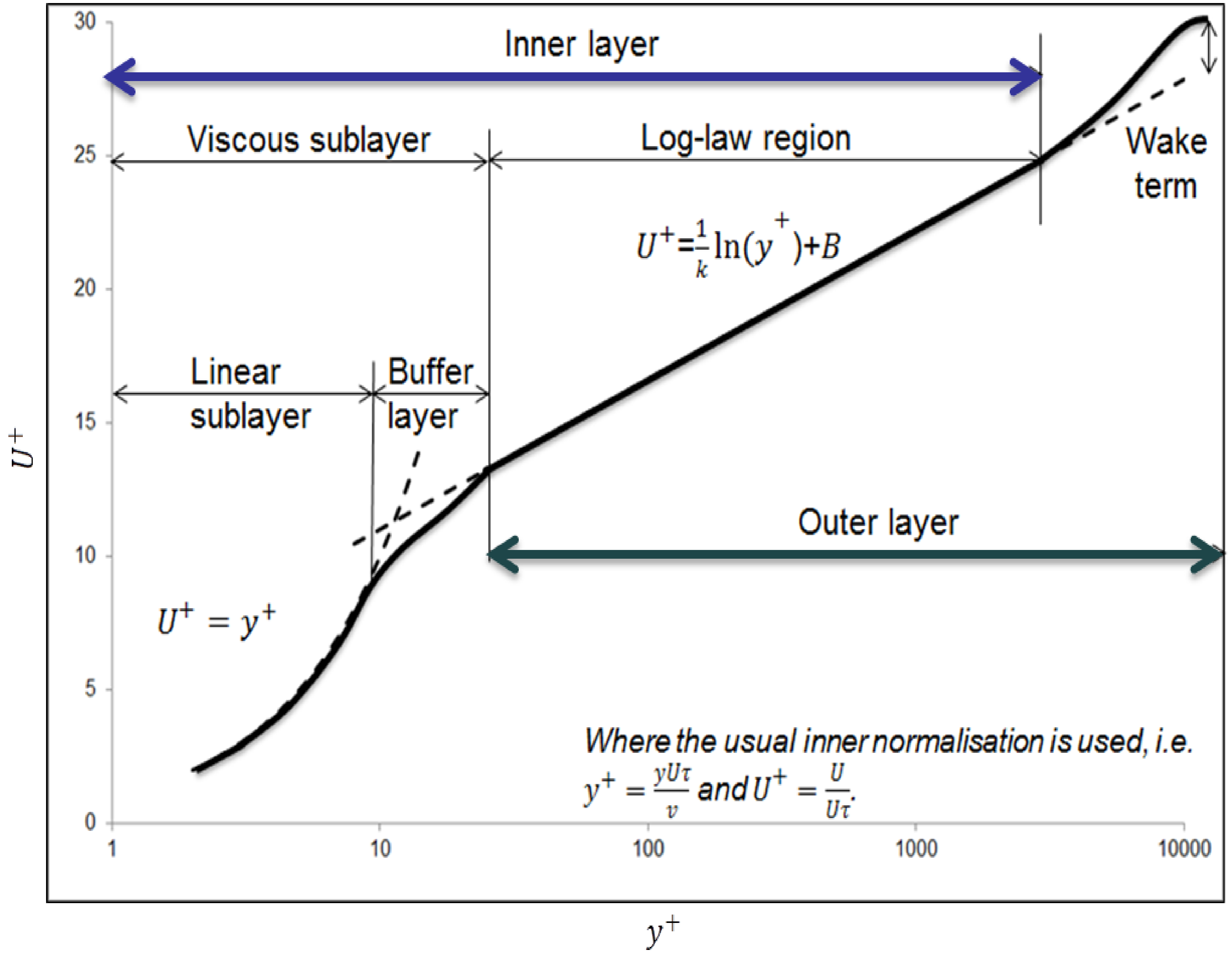
4. RESULTS

Boundary layer characteristics

- A thin layer that is developed as the fluid flows over the surface where the effects of viscosity are significant;
- The velocity varies from zero at the wall to the free-stream velocity
- Surface roughness affects the boundary layer near the wall by creating higher wall shear stress (and hence drag).

$$c_f = \frac{\tau_w}{\frac{1}{2}\rho U_e^2}$$

$$U_\tau = \sqrt{\frac{\tau_w}{\rho}} = \sqrt{\frac{c_f}{2}}U_e$$



Yeginbayeva et al. (2014)

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4. RESULTS

Boundary layer characteristics

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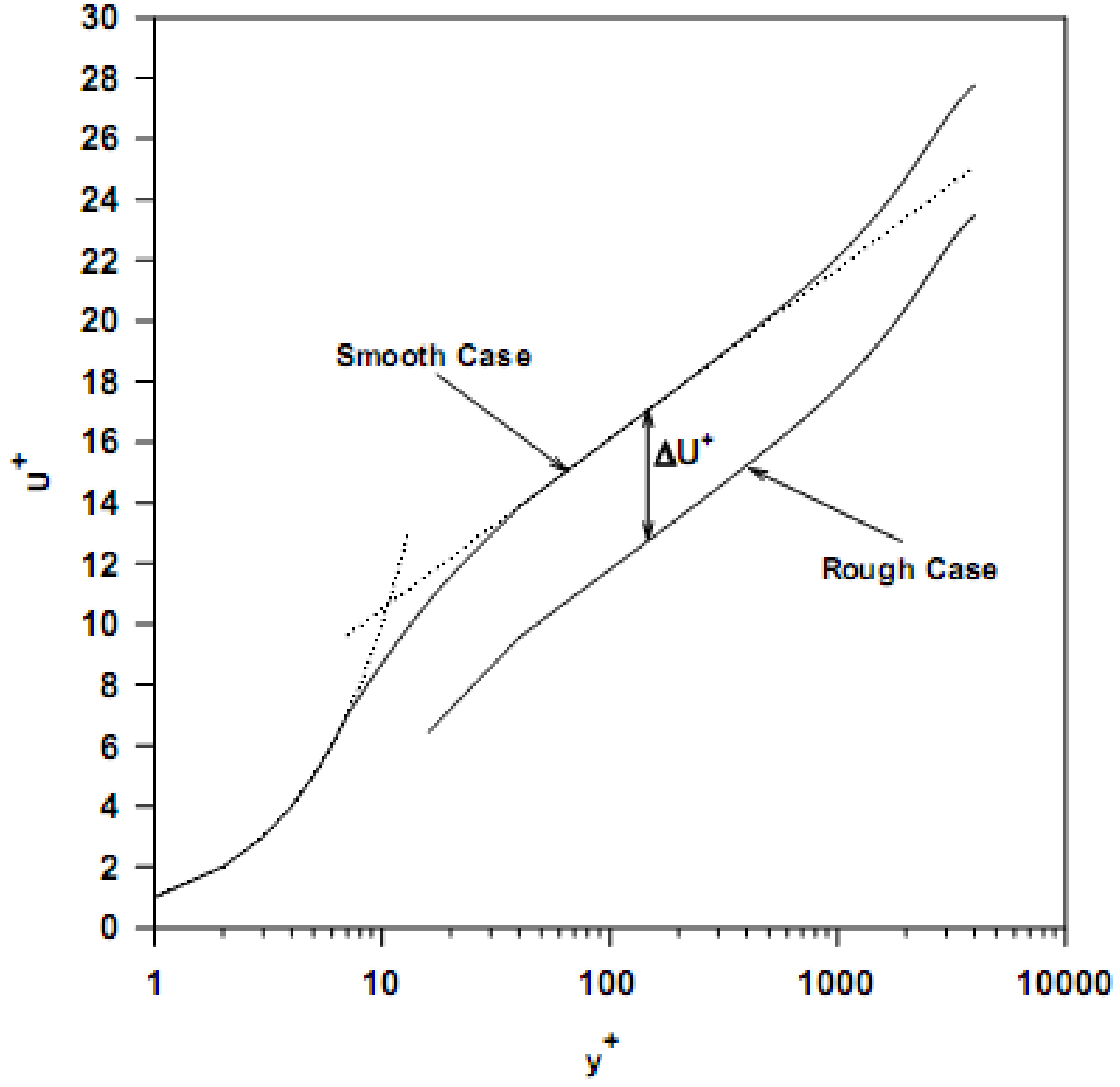
$$U^+ = \frac{1}{\kappa}\ln(y^+) + B - \Delta U^+.$$

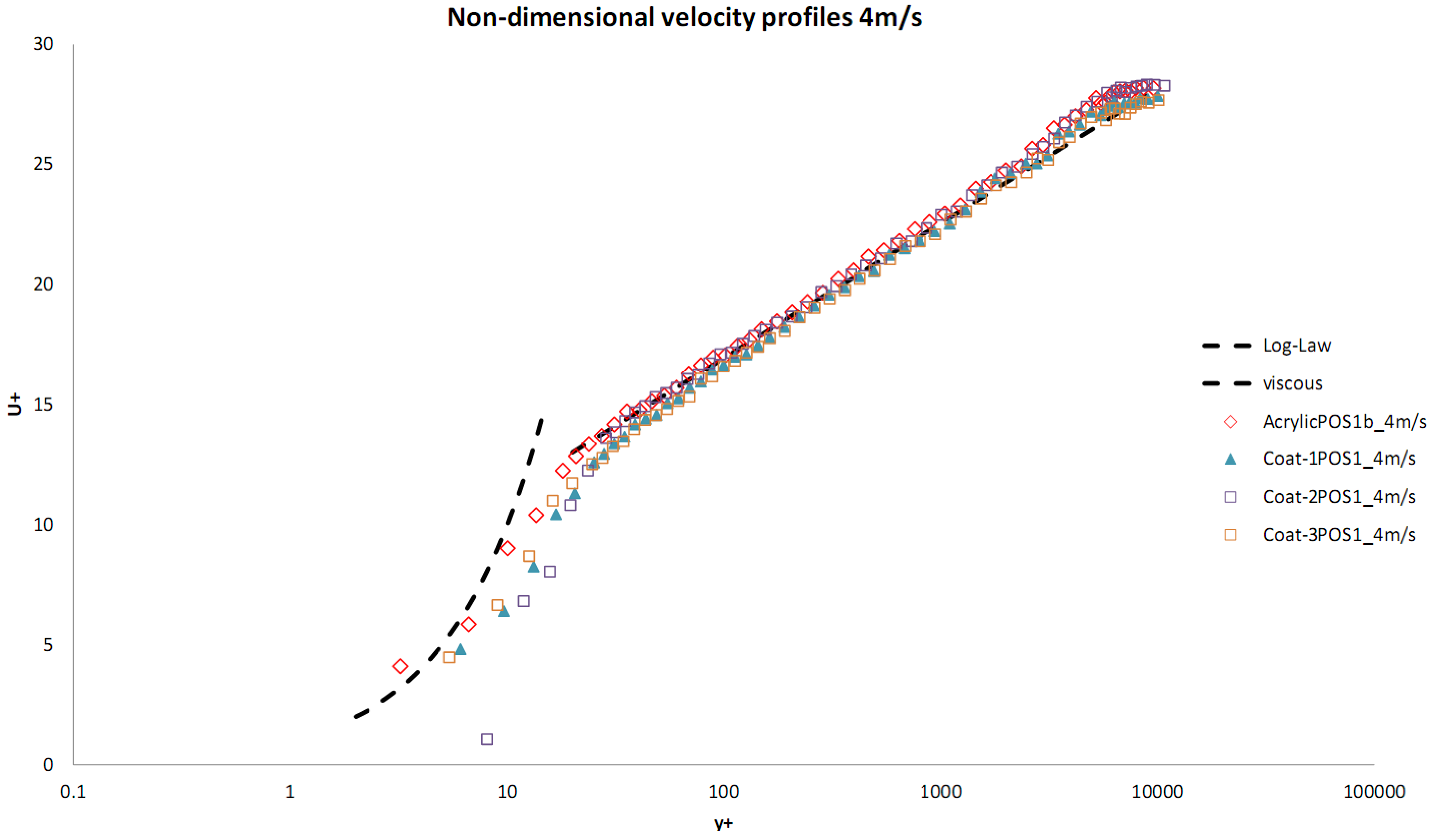
$$\Delta U^+ = \left(\sqrt{\frac{2}{c_f}}\right)_S - \left(\sqrt{\frac{2}{c_f}}\right)_R.$$



4. RESULTS

Boundary layer characteristics

- at least three boundary layer profiles of each surface
- Different methods were used to determine the wall shear stress velocity,and the error in origin
- Coat-2 is hydraulically smooth (i.e. ΔU+ = 0 over the tested range of viscous lengths)
- Followed by Coat-1 and Coat-3 (both still have low ΔU+)



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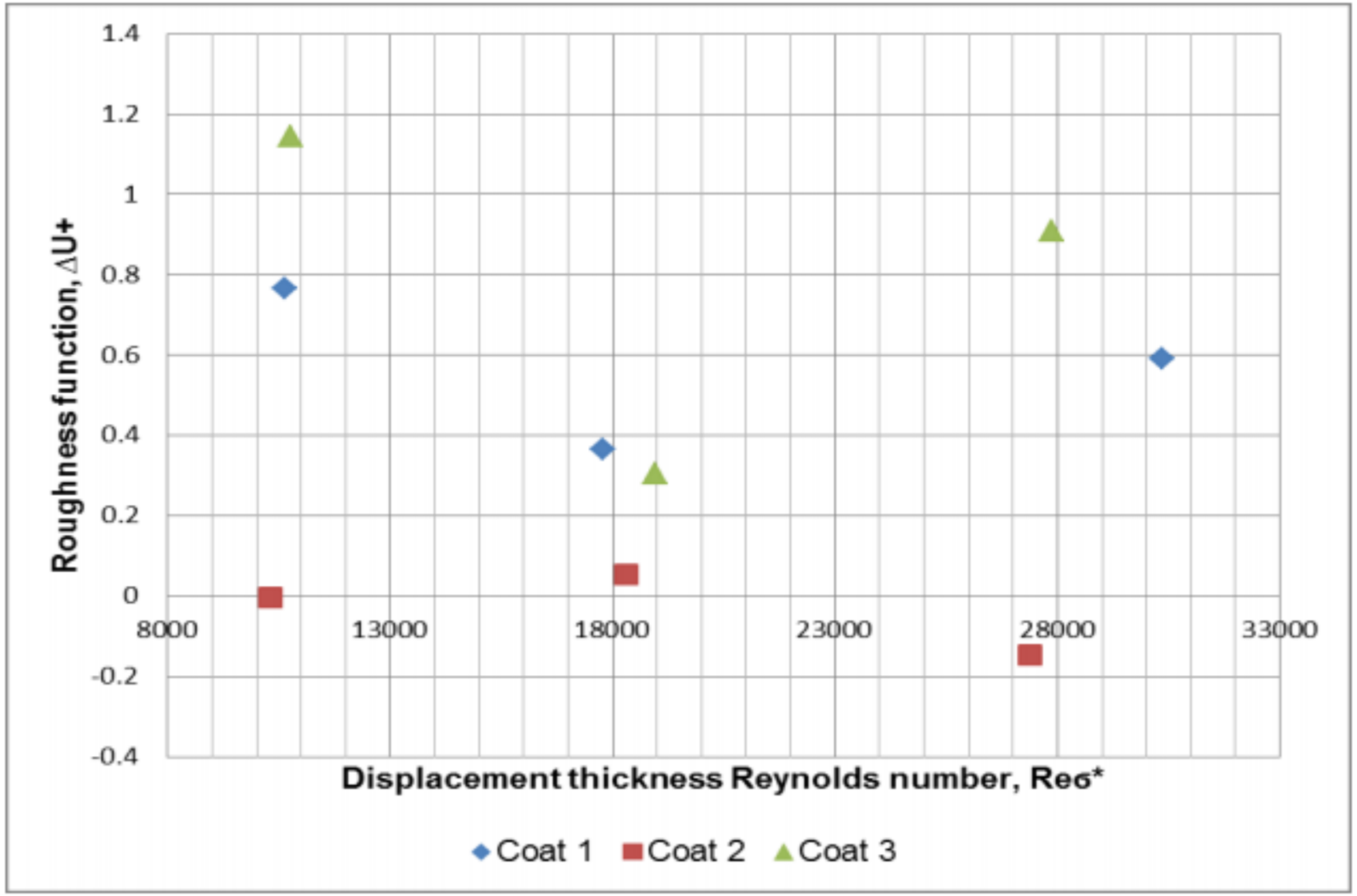

Figure 13. Local skin friction coefficients and roughness functions for surfaces (HAMA)

4. RESULTS

Boundary layer characteristics

- The roughness functions are (much) smaller than 15 years ago

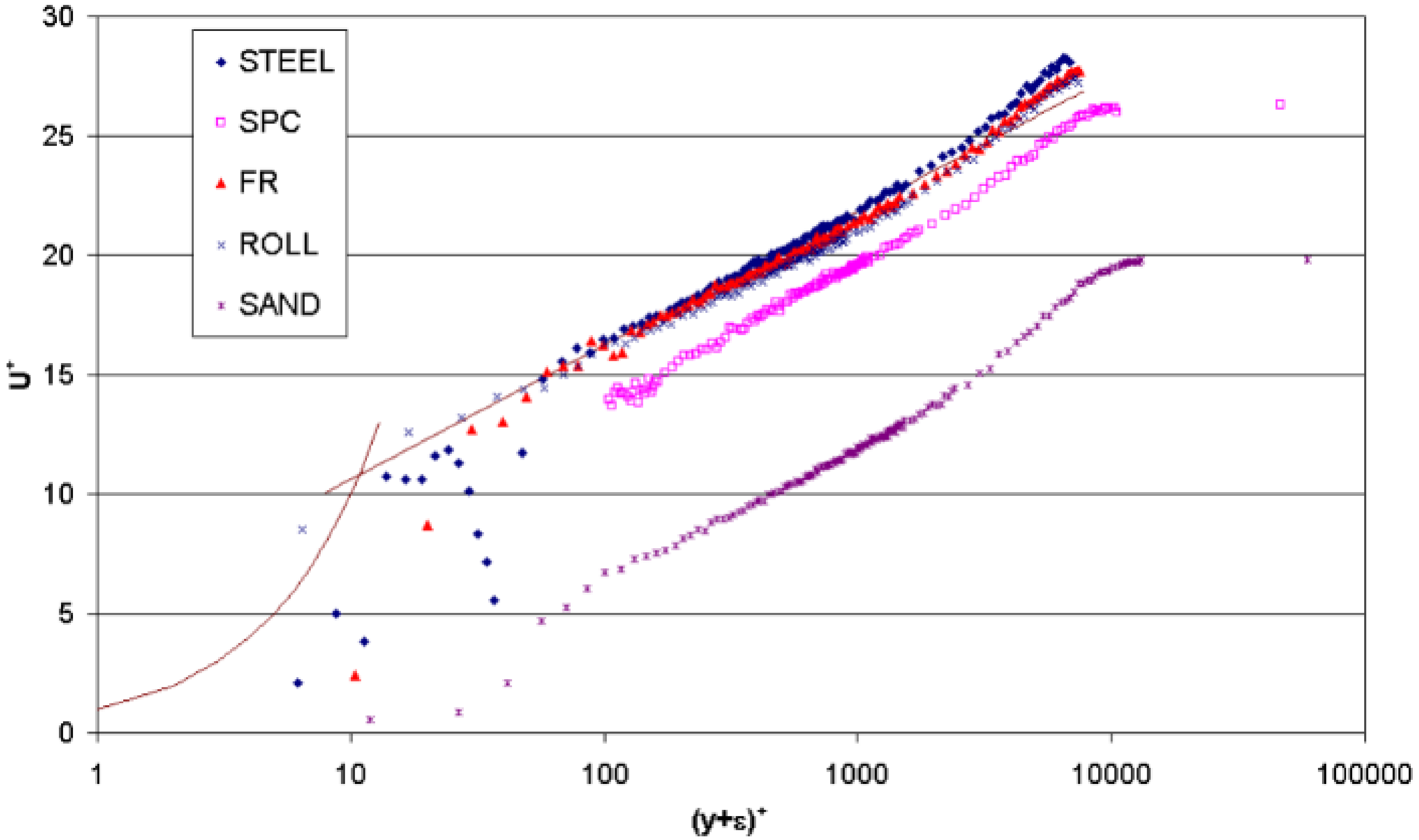

Fig. 5 Comparative velocity profiles at 5 m/s and 1.607 m from the leading edge [uncertainty in U^+ for $50<(y+\epsilon)^+<0.8\delta^+$: ±1.72% for the STEEL surface, ±1.94% for the rough surfaces]

From: Candries and Atlar (2005) Journal of Fluids Engineering

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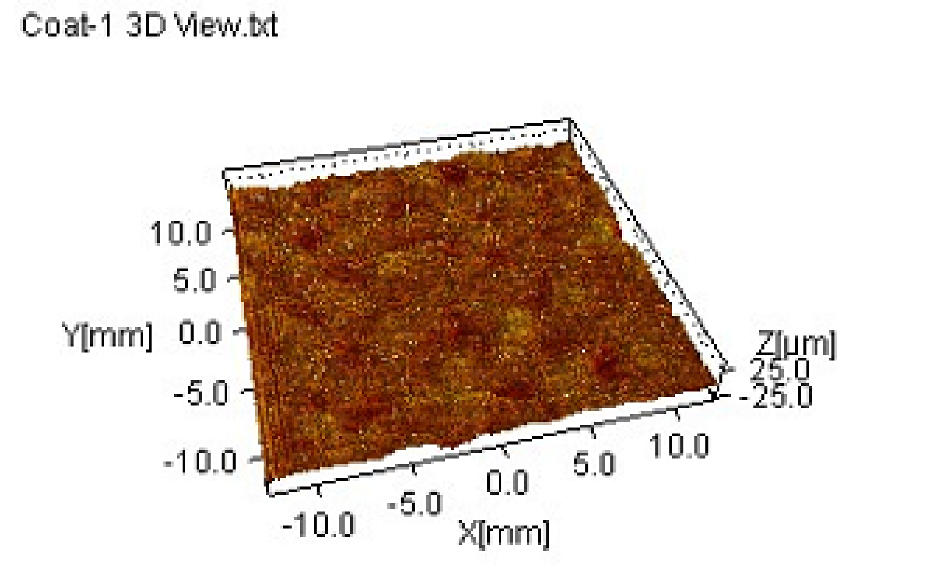
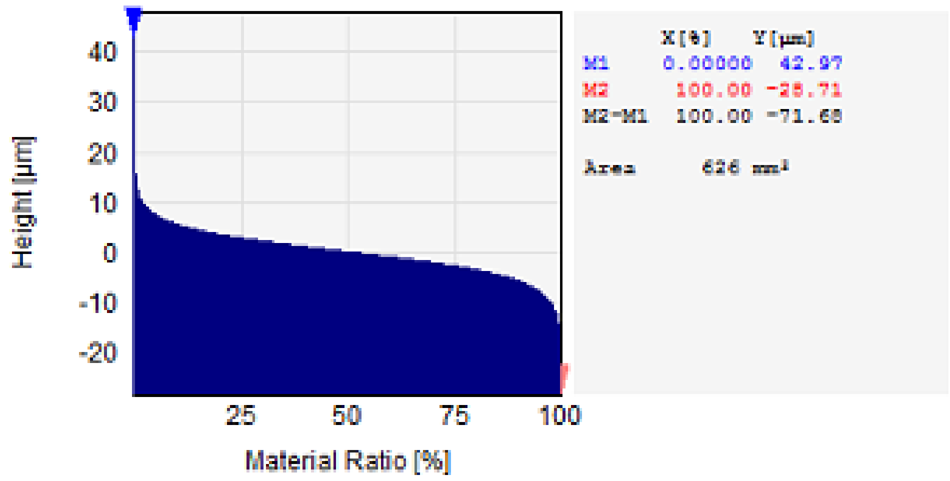
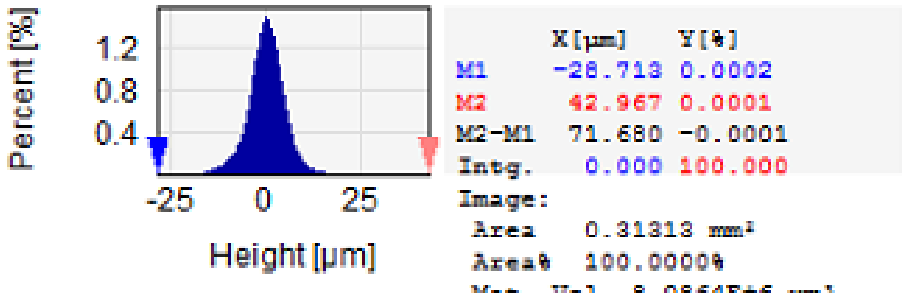
4. RESULTS

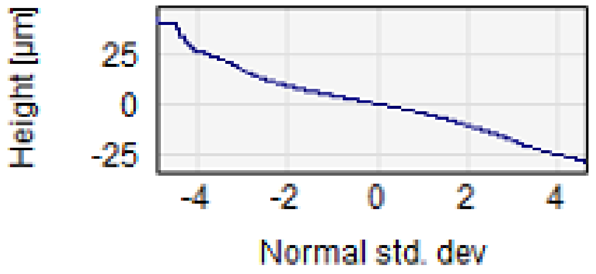
Roughness measurements

Sa [µm]	3.5579
Sq [µm]	4.7009
Ssk	-0.17587
Sku	4.39
Sy [µm]	71.68
St [µm]	71.68
Sz [µm]	71.68
S10z [µm]	65.927
Sz_tph [µm]	65.927
Sds [1/µm²]	0.00015934
Ssc [1/µm]	0.009105
Sv [µm]	28.713
Sp [µm]	42.967
Smean [µm]	-5.01E-10
Sdq	0.13248
Sdq6	0.10241
Sdr [%]	0.87205
S2A [µm²]	6.25E+08
S3A [µm²]	6.30E+08
Sbi	0.13038
Sci	1.482
Svi	0.13821
Spk [µm]	6.7958
Sk [µm]	10.376
Svk [µm]	6.1561
Smr1 [%]	11.262
Smr2 [%]	88.061
Std [°]	0
Stdi	0.41021
Srw [µm]	2226.4
Srwi	0.050251
Shw [µm]	2272.7
Sfd	2.4572
Scl20 [µm]	900.9
Str20	0.67925
Scl37 [µm]	600.6
Str37	0.64865
Sdc0_5 [µm]	35.624
Sdc5_10 [µm]	1.8674
Sdc10_50 [µm]	5.4586
Sdc50_95 [µm]	8.0442
Sch [°]	69.106









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4. RESULTS

Roughness measurements

- All three coatings are very smooth but Coat-3 exhibits higher Rt
- Coat-1 and Coat-2 not significantly different for amplitudes but Coat-2 has a more open texture.

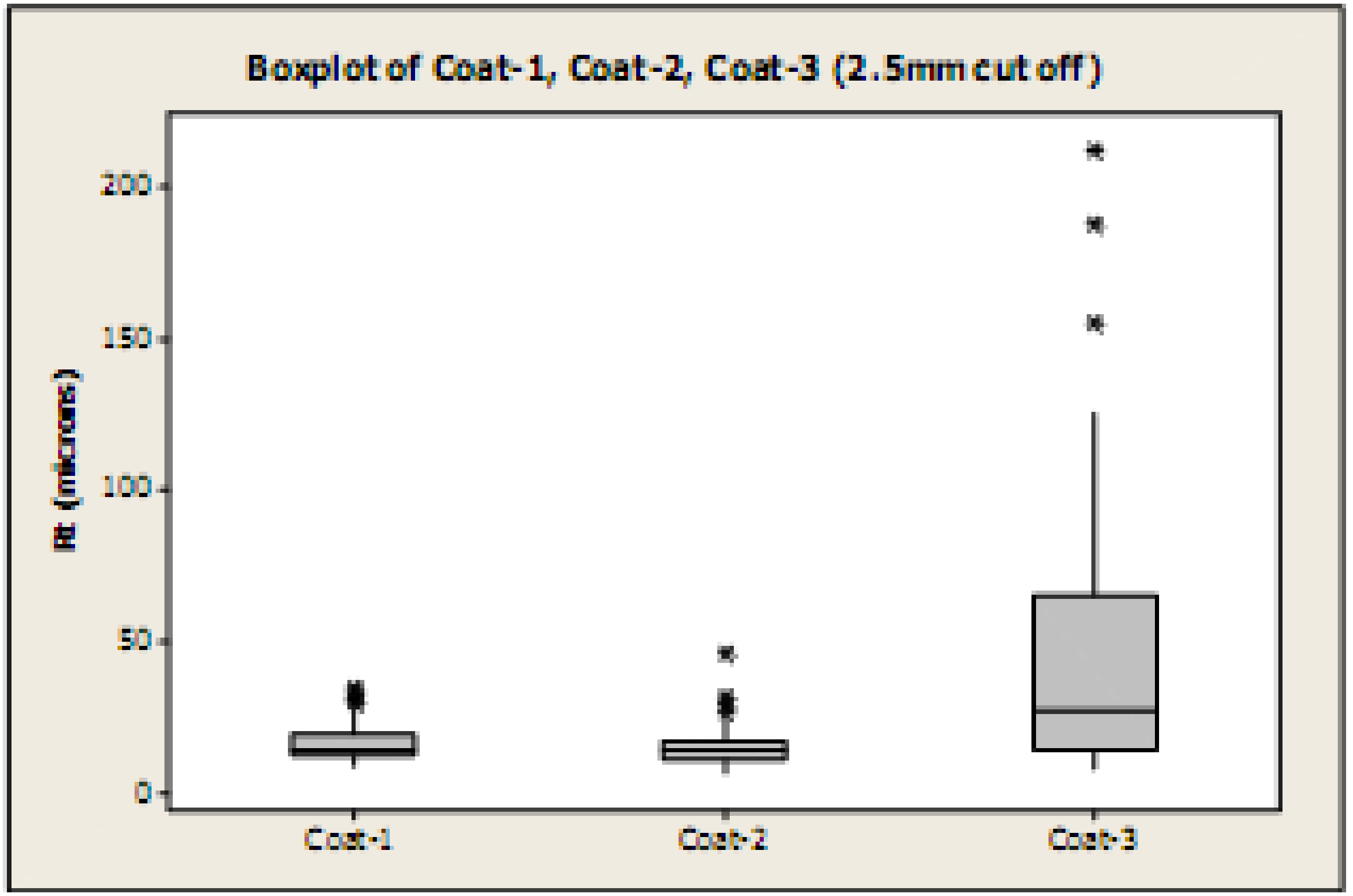

Figure 3.2 Maximum peak to valley heights for the three coatings

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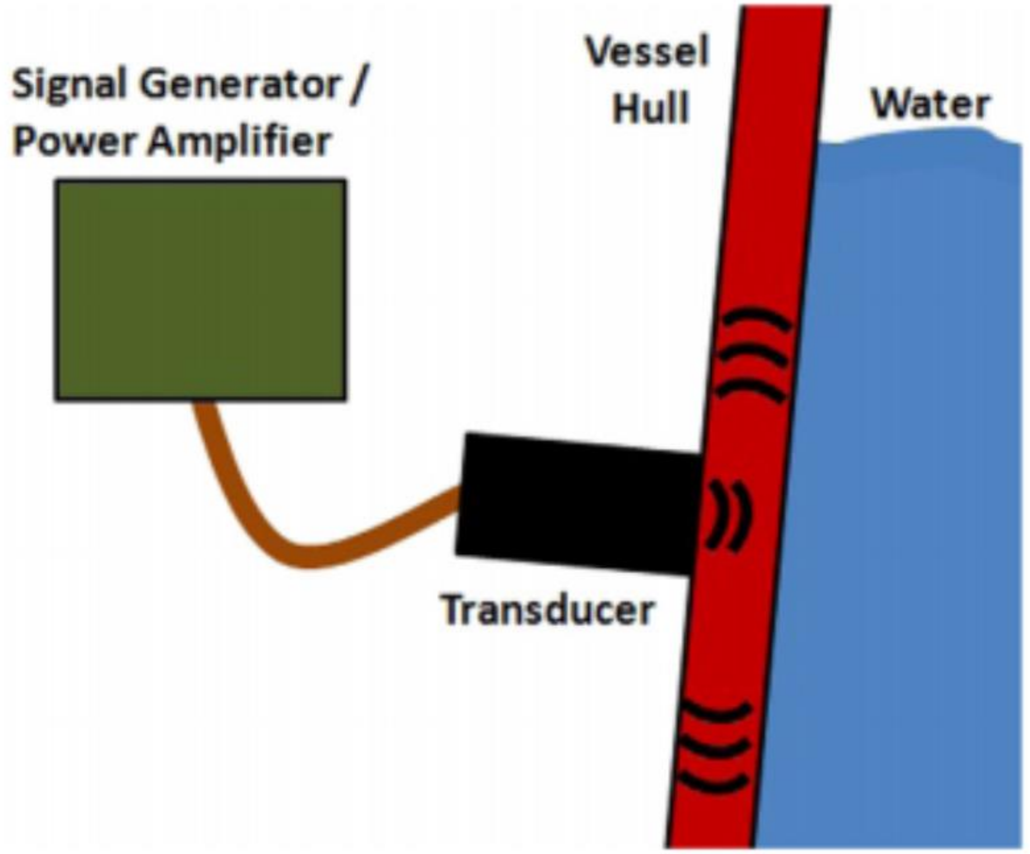
5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

Ultrasonic devices to control fouling

- Biofilm control and removal can be achieved by the application of ultrasound, and an optimum condition can be reached by the consideration of frequency and amplitude
- By operating ultrasound at 40 kHz for 10 s, biofilm could be removed from food processing equipment (Oulahal-Lagsir et al. 2000). 87.5% of biofilms formed on water filled glass tubes could be removed using 20 kHz ultrasound treatment with pulsed operations (Mott et al. 1998)
- Also effective against bacteria (e.g. Monsen et al. 2009)
- And algae . Ultrasound cavitation plays a significant role on algae removal (Ma et al, 2005). Except ultrasonic cavitation, ultrasound induced resonant vibration was found to damage algae cells more easily when the applied ultrasonic frequency was close to the natural frequency of algae cell (Hao et al, 2004)

- The effect of ultrasound on barnacle induced marine fouling control has also been extensively studied. For example, in a field test, ultrasound frequency range between 20 to 100 kHz was effective in keeping an area free of fouling marine organisms (Fischer et al. 1984).
- Guo et al. (2011): effect on barnacle larvae inhibition



From: Legg et al (2015), Ocean Engineering

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5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

Ultrasonic devices to control fouling

- Several companies have commercialized products using ultrasound, which are mainly marketed for marine fouling prevention on berthed pleasure crafts.
- Sometimes the power levels are high enough to cause cavitation
- Different combinations of duration and frequencies, placement of the probes/transducers

Table 1
Example information from the literature on ultrasonic frequency range acoustic treatment of biofouling. In this table, the citations have been sorted by transmission frequency. Where more than one frequency was used, reported optimal frequency has been used for sorting.

Treatment types	Frequency	Organism type	Power	Treatment duration	Application	Comments
Magnetostrictive transducer	17–30 kHz	Biofouling	200 W	–	Ship (fixed to inner hull)	Prevention achieved. Settlement inhibition only (Sheherbakov et al., 1974)
Transducer	20 kHz	Biofouling	1000 W	–	Boat	Biofoulers and other foulers removed. Cleaning rate 4–6 cm/s (Mazue et al., 2011)
PZT transducer	23, 63, 102 kHz	Barnacle	9, 12, 22 kPa pressure	30–300 s	Laboratory	23 kHz optimal frequency at 22 kPa for 30 s. Settlement inhibition. Mortality observed only in long duration. Cavitation (Guo et al., 2011a,b)
Transducer	20–25, 63 and 102 kHz	Barnacle	10.5 nm substratum vibration and 5 kPa pressure.	Continuous and "5 min on 20 min off" treatment.	Laboratory	23 kHz optimal frequency. Settlement inhibition. Intermittent signal achieved same efficacy with continuous signal treatment. Not cavitation (Guo et al., 2012)
PVF_2 piezo-film strips	24 kHz	Barnacles worms, mussels	2 A–12 V. Acceleration 0.004–1g	6–7 months	Fiberglass yacht hull. No antifouling on 3 m^2 section.	No fouling observed (Latour and Murphy, 1981)

From: Legg et al (2015), Ocean Engineering

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5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

In-situ evaluation

- Three tested coatings + anticorrosive primer were applied on four pontoons (5 m long, 2.2. m wide)

- Exposed over 6 month period (May – December) in Persian Gulf

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5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

In-situ evaluation

- The pontoons were located at the starboard side of the 65 m long cutter suction dredger "Kallo"
- The probe of the ultrasonic antifouling device was attached to pontoon DI-06, located at the aft stern, and was connected to the power supply of the "Kallo".
- Pontoons DI-04 and DI-09 were positioned at a distance of approximately 20 resp. 40 m towards the bow. Pontoon DI-08 was put at a distance of 150 m from the other pontoons.
- This set-up would allow to evaluate the effectiveness of the USAF device with increasing distance from the sound-emitting probe.
- Intermediate underwater surveys were carried out in June and in August.

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5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

In-situ evaluation

- Power cut occurred during the testing period
- Tin-free SPC and Foul Eelease perform well
- Evident fouling on nanstructured and anticorrosive

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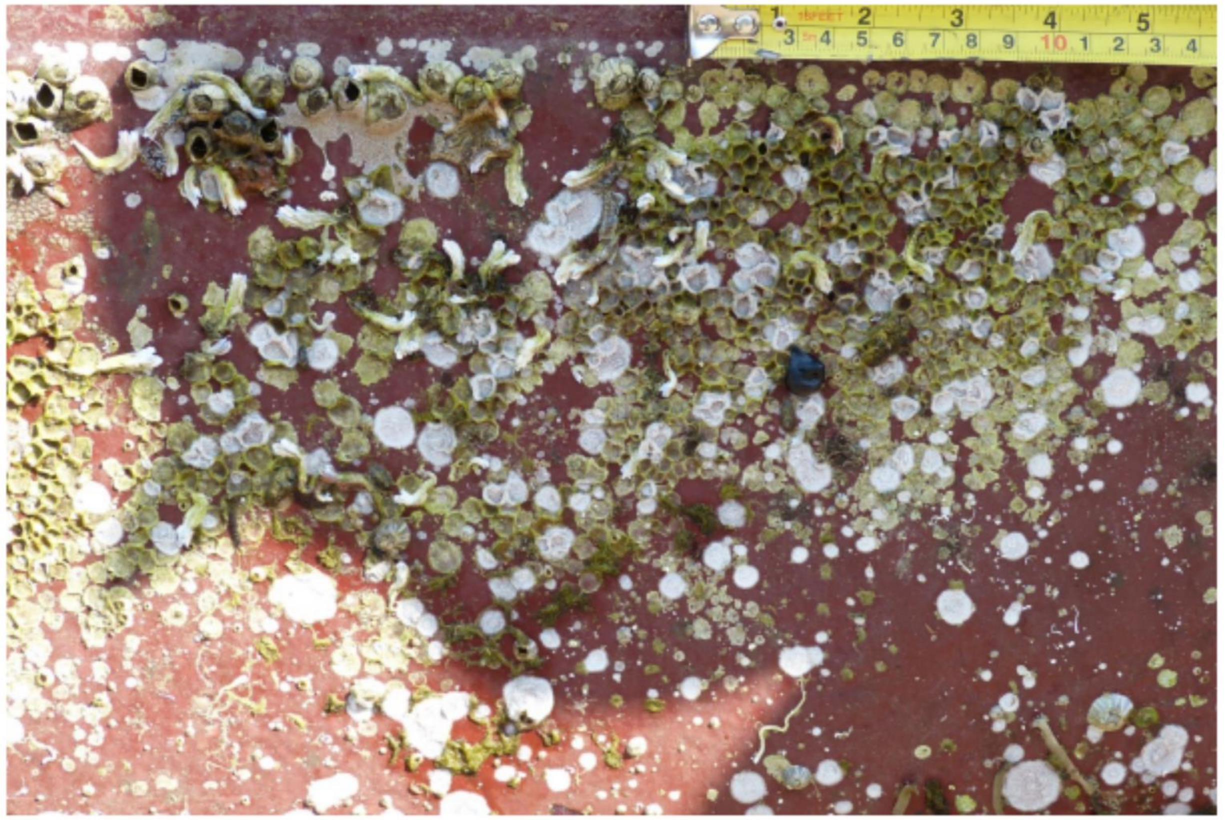
5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

In-situ evaluation

- NSTM ratings: A clean surface (FR0) will first be fouled by a slime layer (FR 10 to FR20), followed by weeds (FR30). This is followed by hard fouling from early to mature stages (FR40 to FR90)



Nanostructured: FR70-50%, FR20-50%

Tin-free SPC: FR10-80%, FR20-20%

Foul Release: FR10-60%, FR-20%, FR0- 20%

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5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

In-situ evaluation

- Pontoon 8

Anticorrosive: FR90-100%

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5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

In-situ evaluation

- Overall average score

		Nanostructured	Anticorrosive	Tin-free SPC	Foul Release
	Overall FR	**56**	**68**	**11**	**7**
Pontoon DI-06	port	45	52	10	10
	starboard	49	55	10	9
Pontoon DI-04	port	60	64	6	2
	starboard	61	66	10	4
Pontoon DI-09	port	50	69	12	2
	starboard	55	61	15	9
Pontoon DI-08	port	38	86	9	7
	starboard	90	90	12	11

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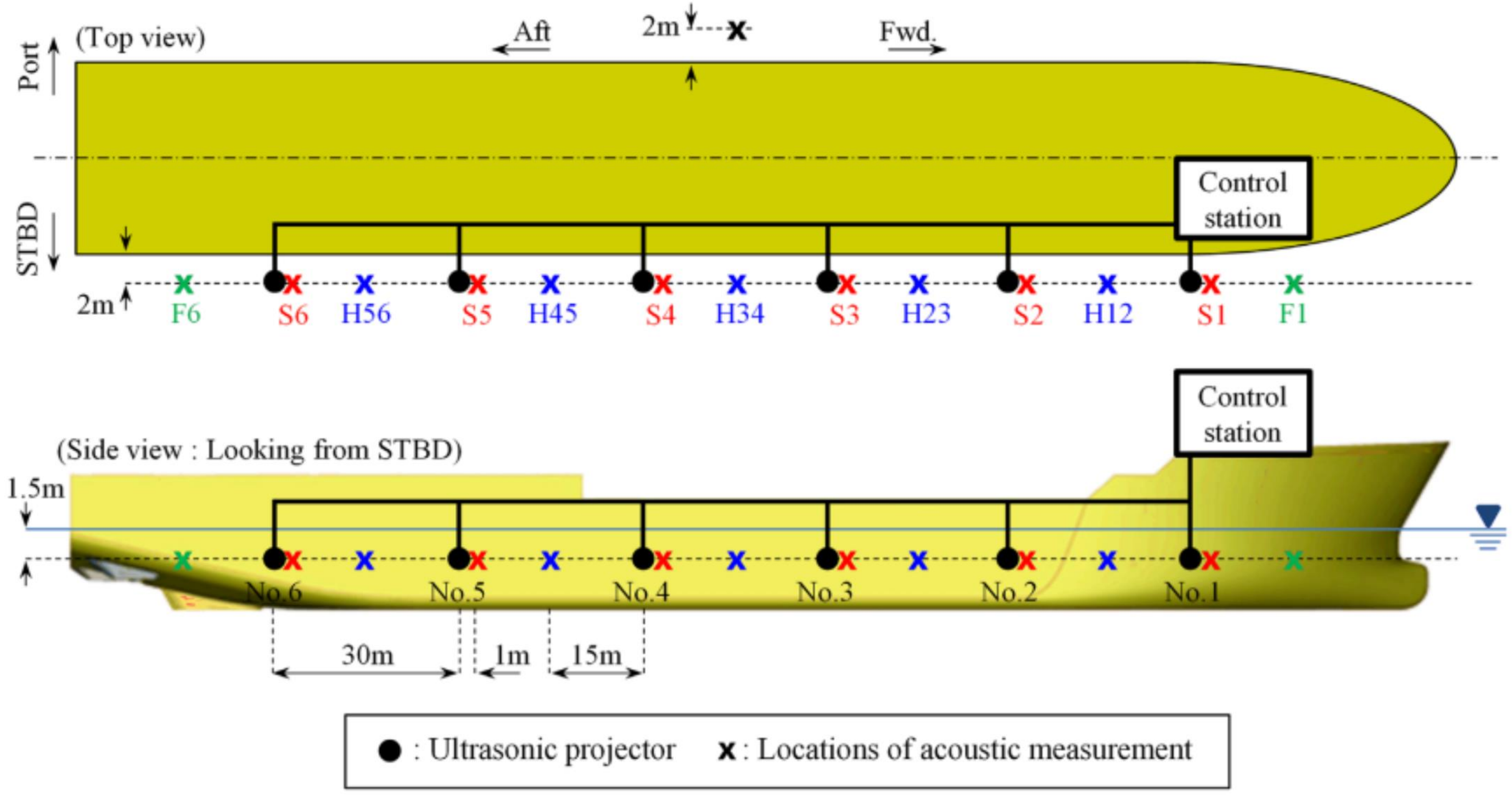
5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

Ultrasonic devices to control fouling: Park and Lee (2018)

- Park and Lee (2018) performed a field test on a 96000m³ 230m long drill ship
- six ultrasonic projectors were evenly deployed around the starboard shell plate.

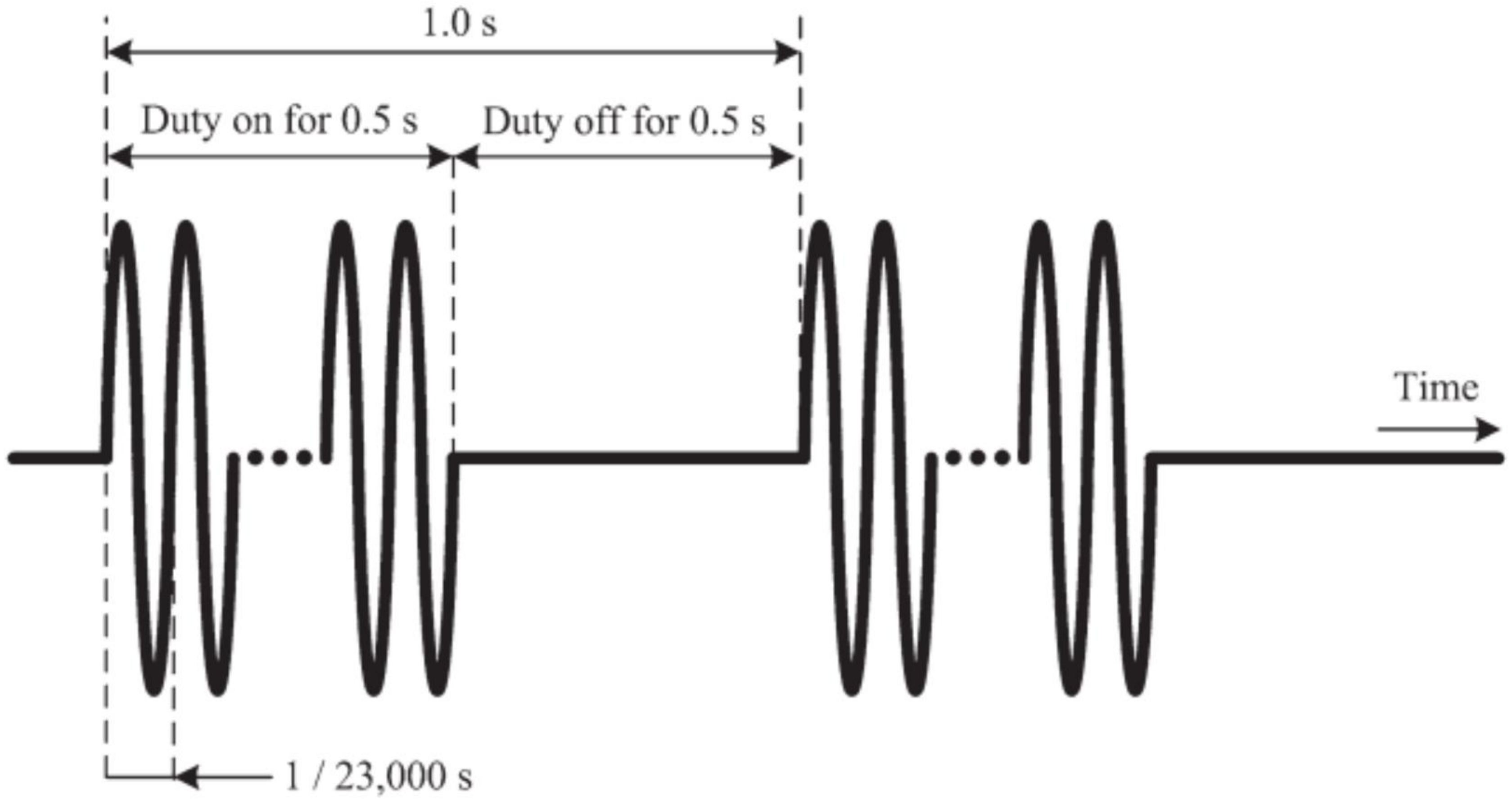


From: Park and Lee (2018), Biofouling

5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

Ultrasonic devices to control fouling: Park and Lee (2018)

- Driven by 23 kHz sinusoidal intermittent ultrasound in an intermittent manner, the projectors emitted a high-intensity sound reaching 214 dB at the source level causing cavitation around the adjacent water and eventually deterring the settlement of marine fouling organisms.



From: Park and Lee (2018), Biofouling

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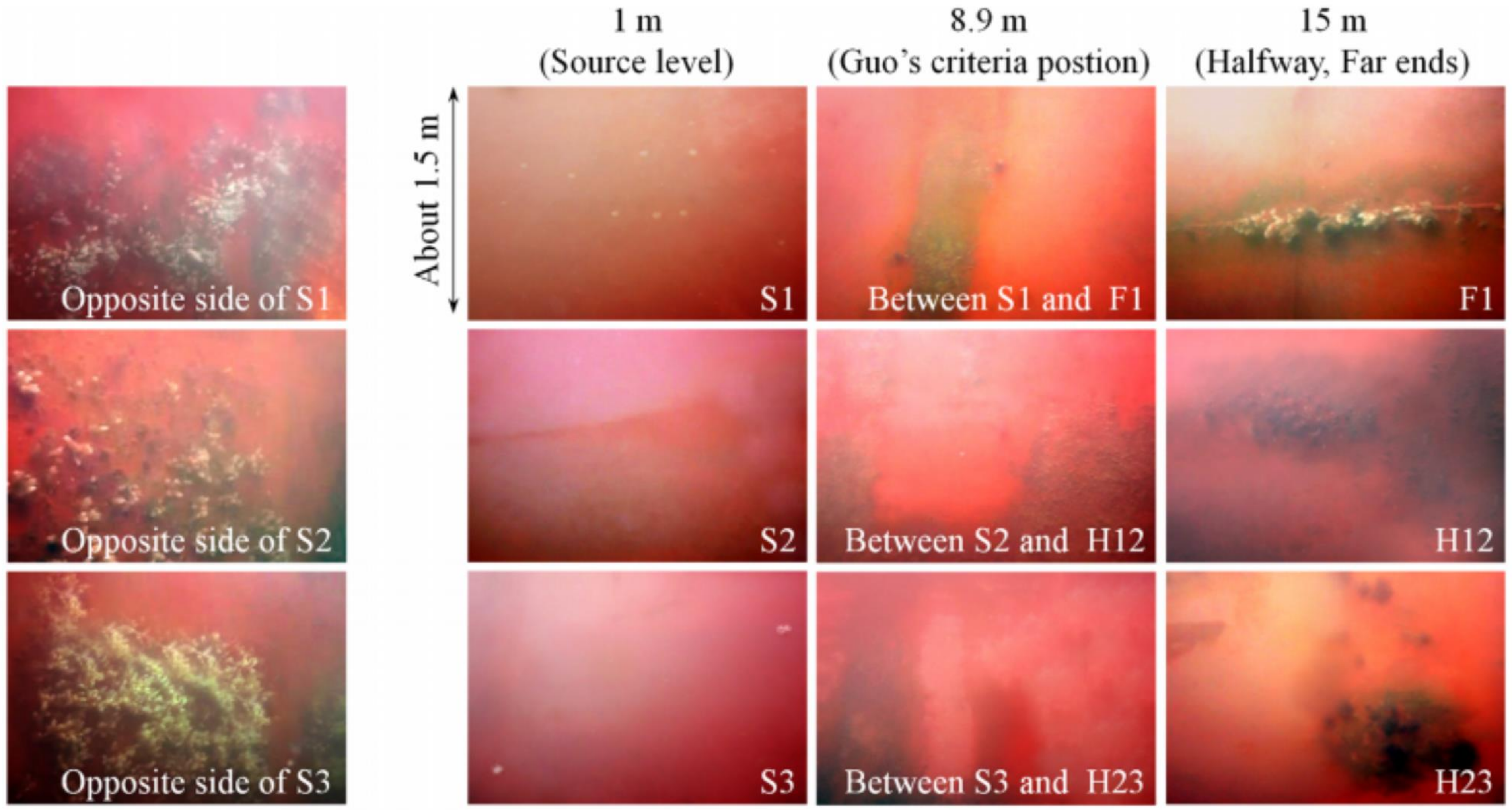
5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

Ultrasonic devices to control fouling

- Underwater photographs acquired after four months showed fairly clean slabs on the starboard side, but heavy fouling on the port side



From: Park and Lee (2018), Biofouling

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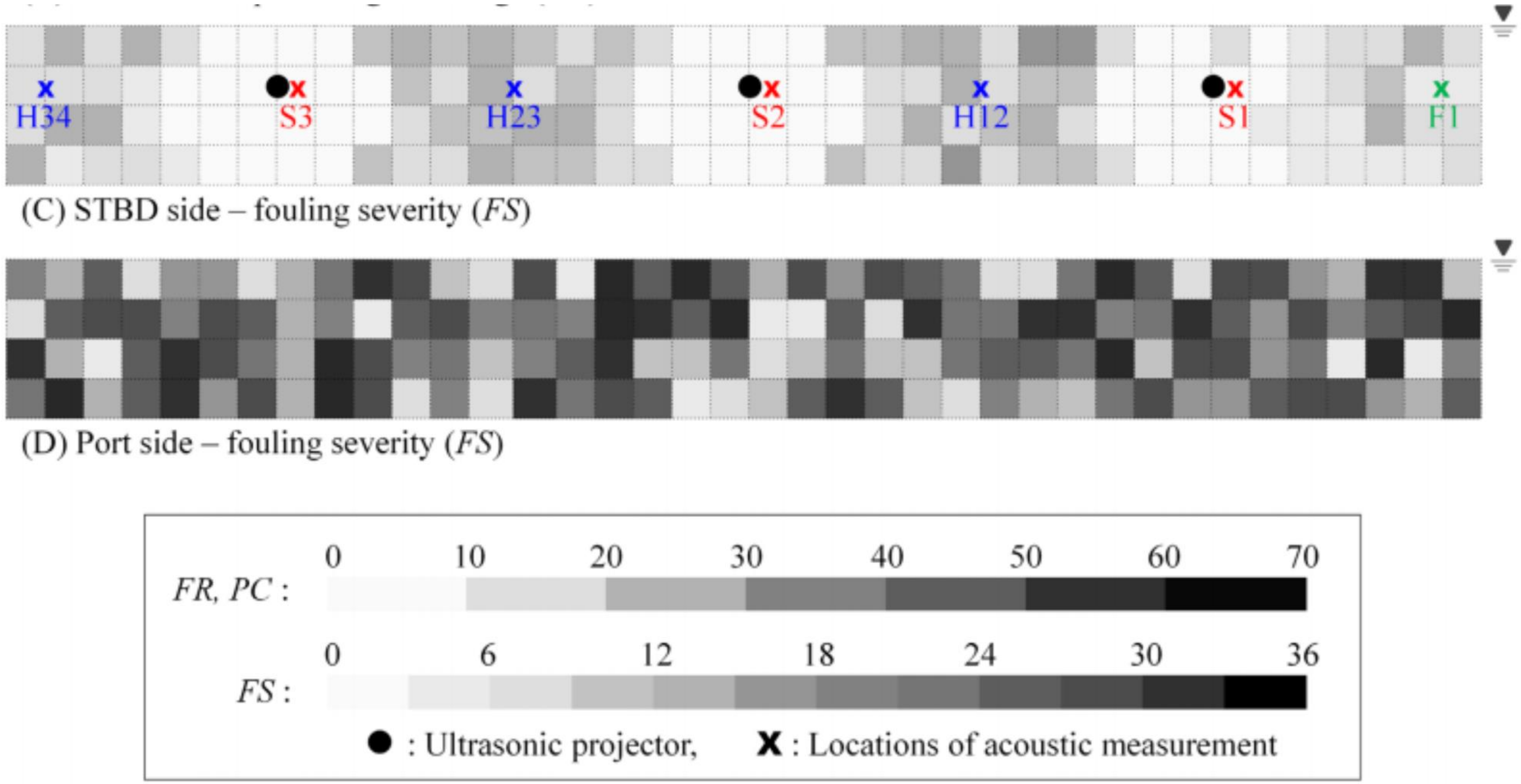
5. IN-SITU EVALUATION OF THE COATINGS IN COMBINATION WITH AN ULTRASONIC DEVICE

Ultrasonic devices to control fouling

- 4 month test period



From: Park and Lee (2018), Biofouling

6. CONCLUSIONS

- Overall, new coatings exhibit lower drag than 15 years ago
- An in-situ test was carried out to evaluate the performance of coatings in combination with an ultrasonic device
- Ultrasonic antifouling devices have shown promise in literature, but
    - 1. they need to perform at all times (active devices)
    - 2. noise: environmental concerns (behavorial disorder in marine mammals)

7. POWERING PERFORMANCE OF SISTER VESSELS

- Powering performance of 122m long sister vessels (trailing suction hopper dredgers)
- Data for bare hull towing tank data available: frictional resistance 42% at service speed of 13 knots
- Effect of the three coatings is less than 1.5% added effective power in new condition (0.9, 0.0 and 1.5% respectively)
- 2001: Foul Release 2.5%, Tin-free SPC : 4.2%
- Deteriorated coating: 7.6%, heavy slime: 13.5%, algae: 25.8% (based on roughness functions equal to 3, 5 and 8 resp. cf. Schultz, 2007)
- In terms of speed losses: about 35% of added power
- Percentages are higher at lower speeds

Length overall submerged	L	122.20	m
Breadth on waterline	B	28.00	m
Draught	T	9.05	m
Displacement volume	∇	24697.3	m^3
Displacement mass (seawater)	Δ	25314.7	tons
Wetted surface area (incl. appendages)	S	5215.8	m^2
Block coefficient	C_B	0.875	-

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FACULTY OF ENGINEERING
AND ARCHITECTURE

Maxim Candries

Researcher

MARITIME TECHNOLOGY DIVISION

E maxim.candries@ugent.be

T +32 9 264 55 58

www.ugent.be

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