S/D = 1.3? 2?

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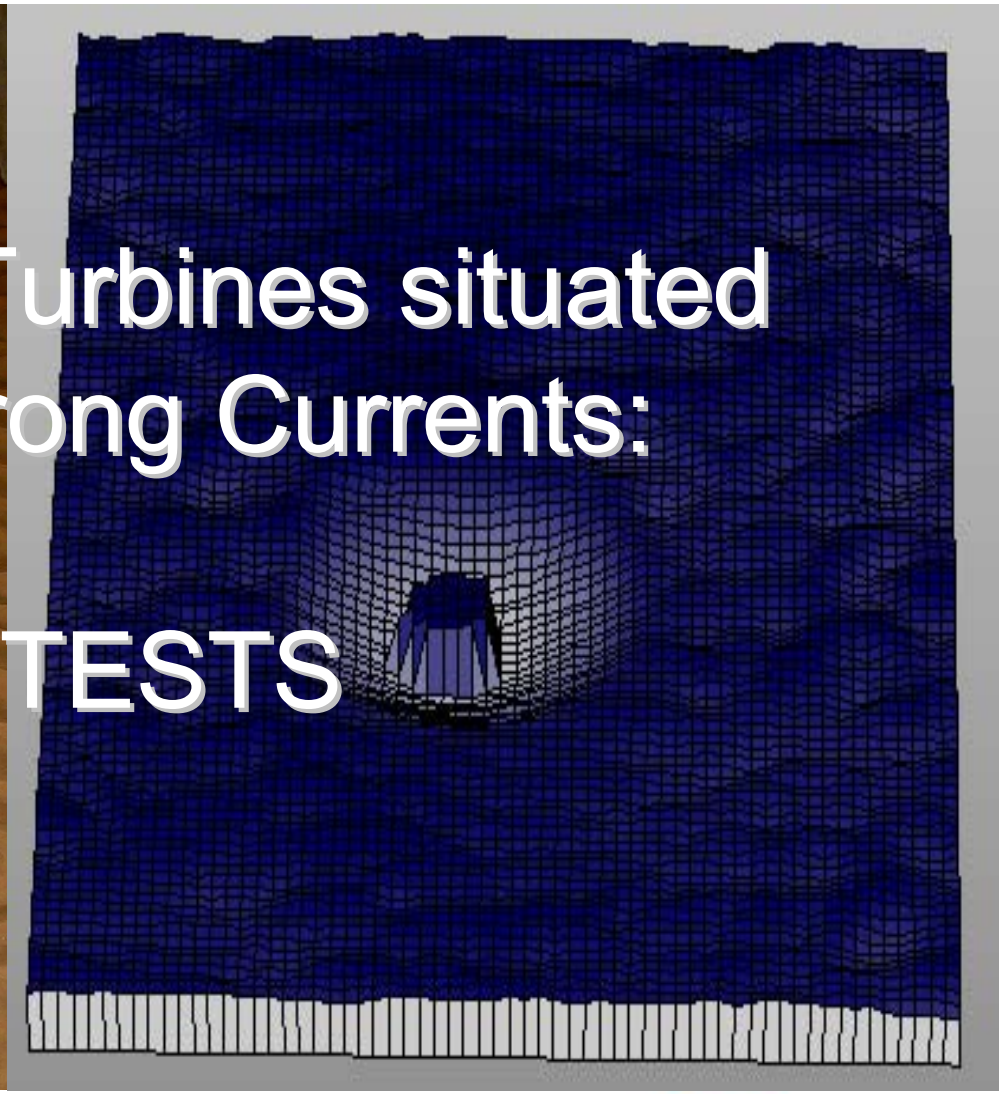
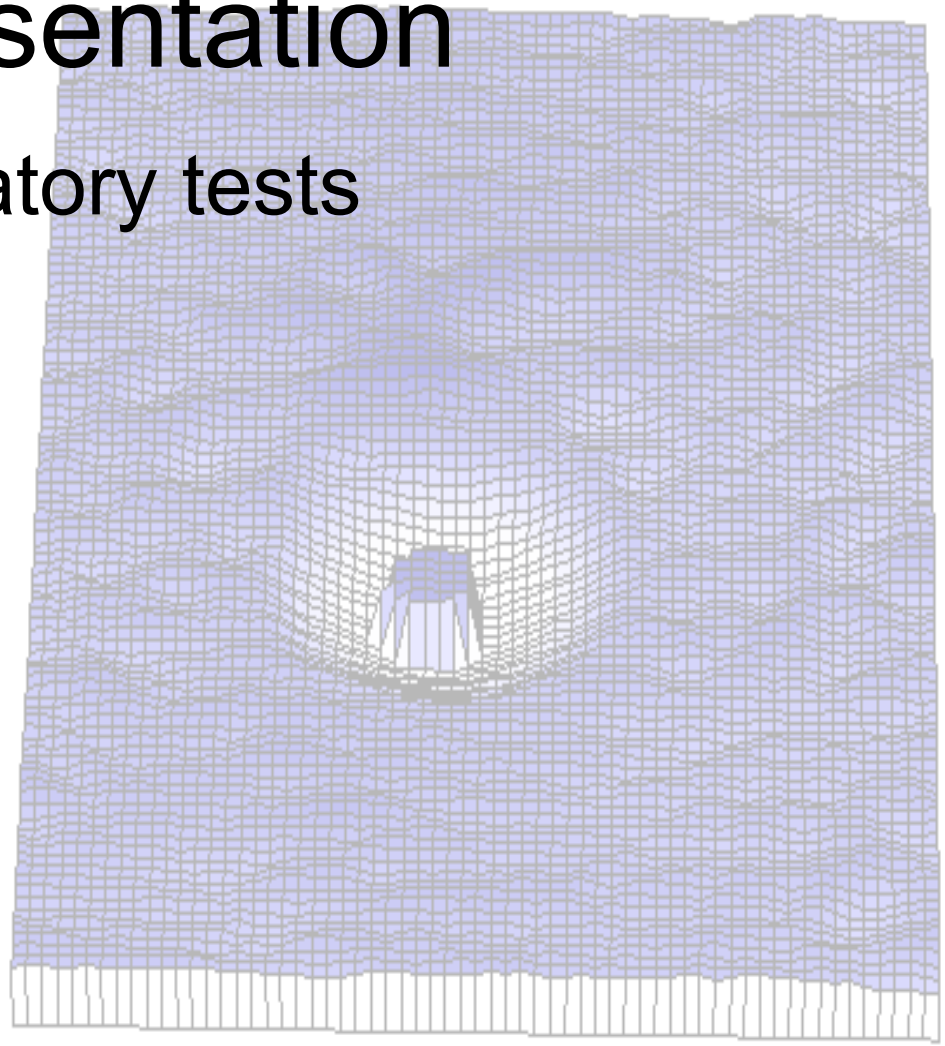
LABORATORY TESTS



Peter Frigaard Aalborg University
Leen De Vos Ghent University

Contents of presentation

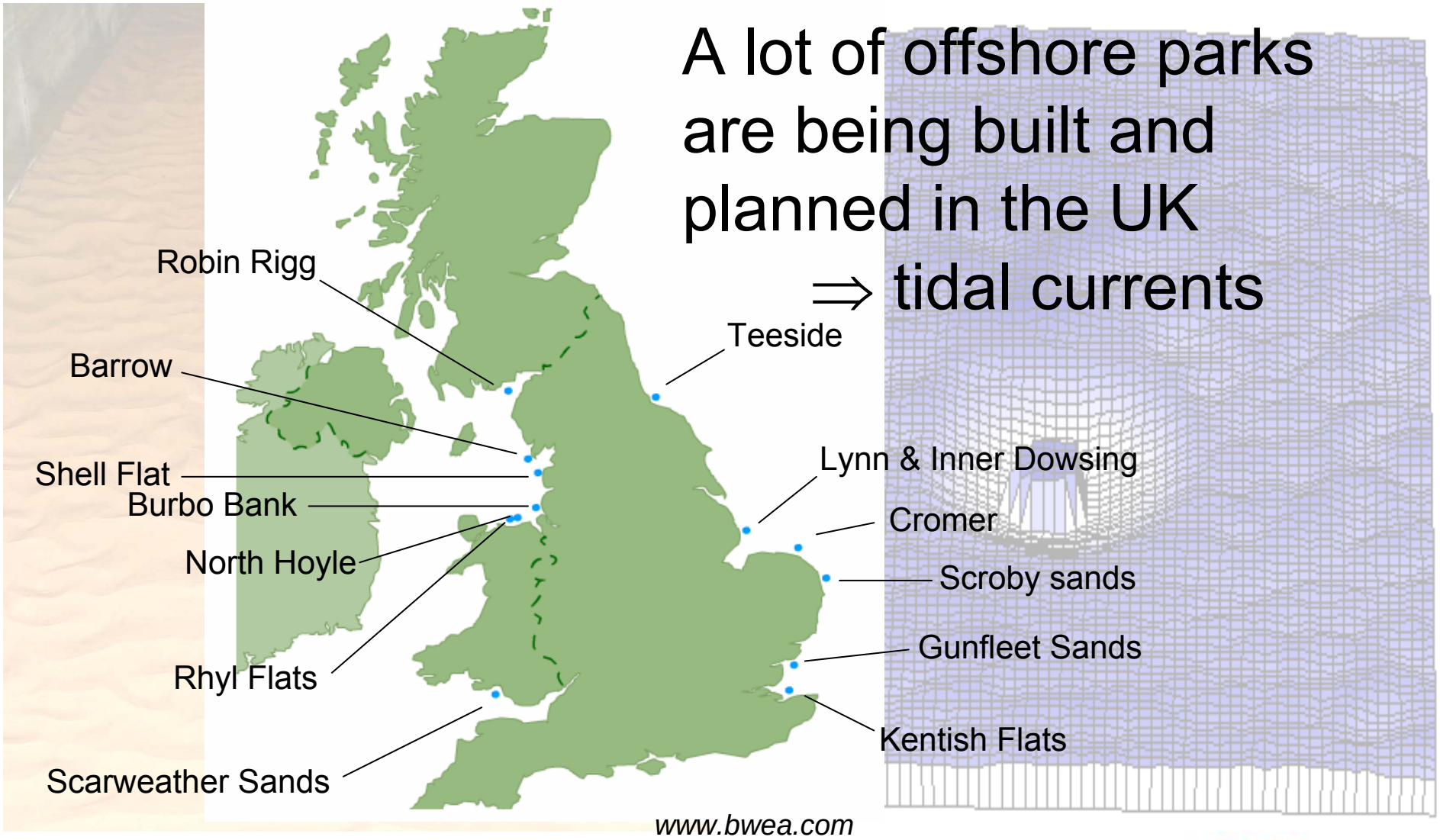
- Background for laboratory tests
- Experimental set-up
  - Model and Set-up
  - Test program
  - Main results
- Tidal currents
- Breaking waves
  - Scour tests
  - PIV measurements



	Equilibrium state		Development in time	
	Scour hole	**Scour protection**	**Scour hole**	**Scour protection**
Unidirectional current	Sumer, Whitehouse + others	Optipile + others	Sumer, Whitehouse + others	
Non-breaking waves	Sumer + others	Fredsoe + others		
Tidal current "very long waves"	This project			
Breaking waves	This project			

A lot of offshore parks are being built and planned in the UK

⇒ tidal currents



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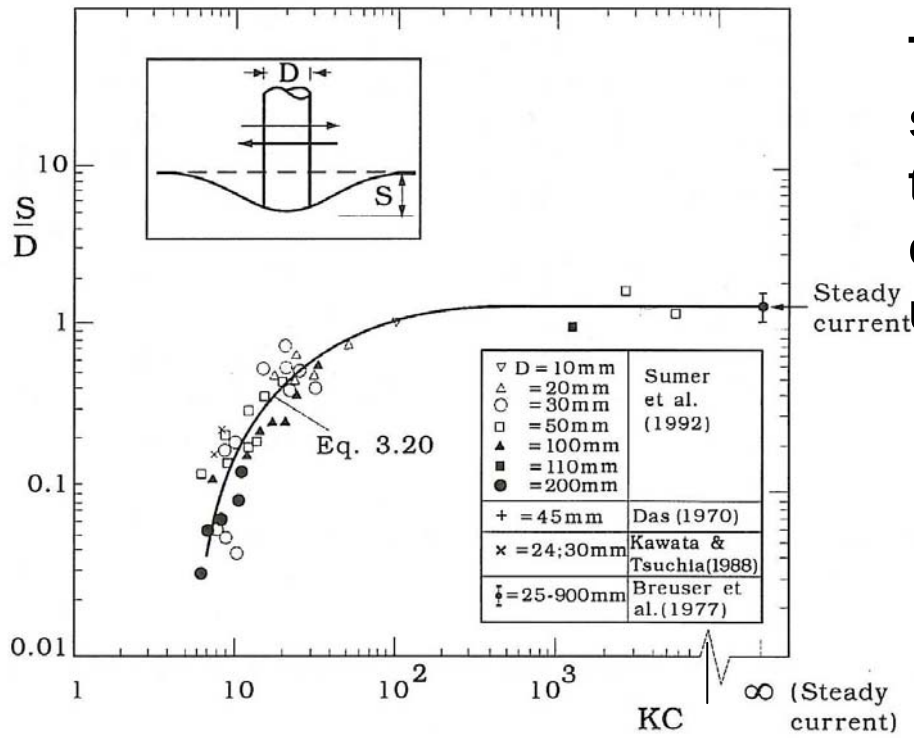
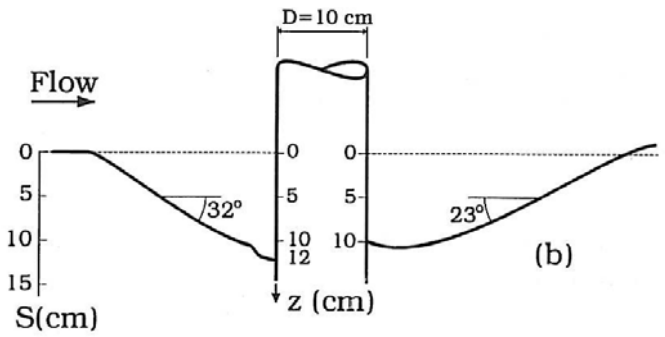
Offshore Center Danmark

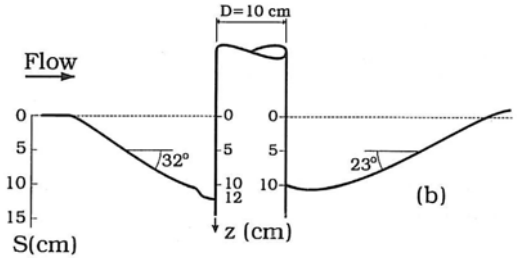


The Sumer & Fredsoe curve suggests that scour depths from tidal currents (KC ≈ 8.000) are equal to scour depths from unidirectional currents



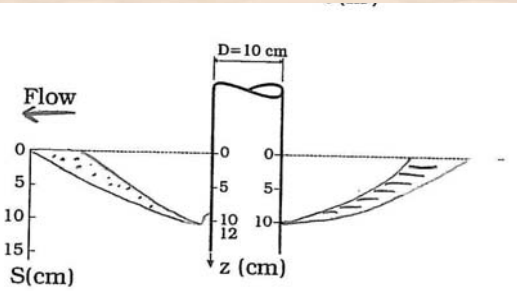
The asymmetric scour hole could however suggest deeper scour holes

1



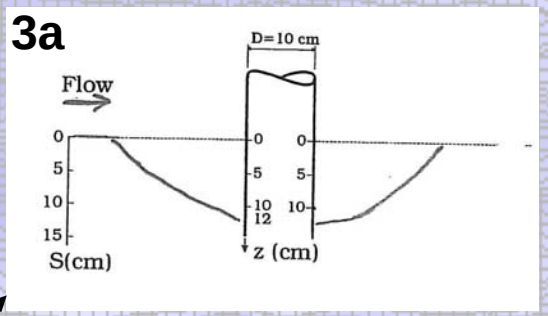
1 Equilibrium scour hole due to unidirectional current - scour depth after first half of tidal period: steep slope on the front, flat slope at the backside of the pile

2

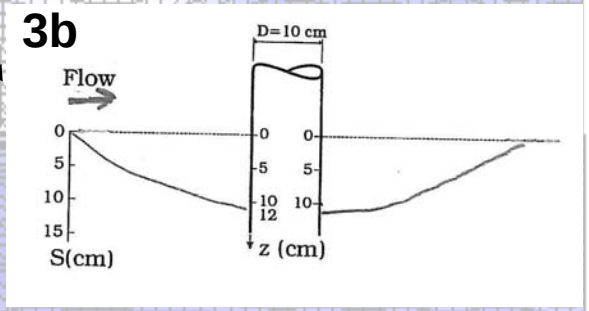


2 Reversing of the flow: deposition on the flat slope - erosion of the steep slope. What is the time scale for each?

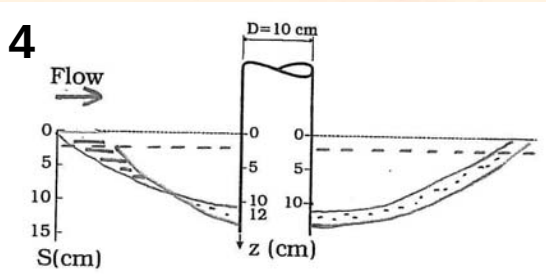
3a



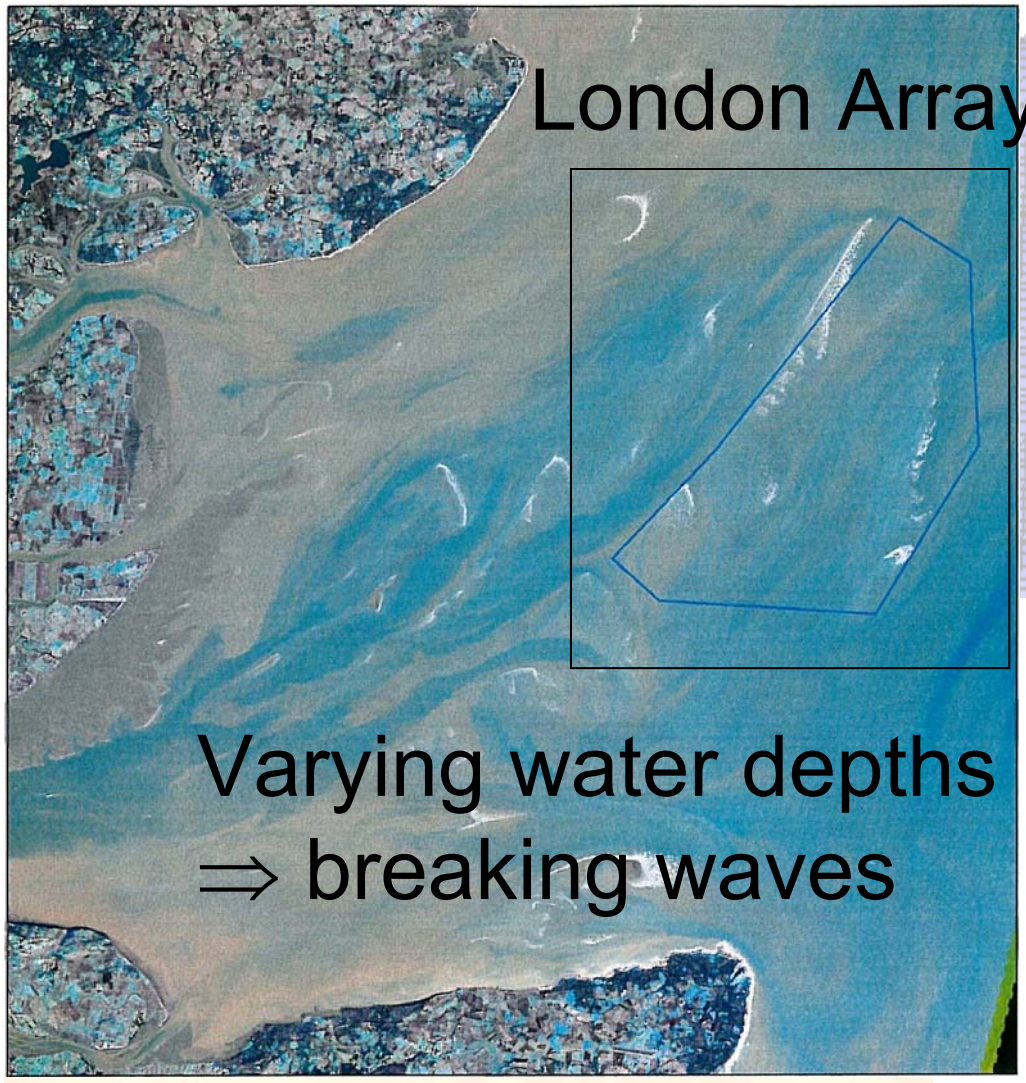
3b

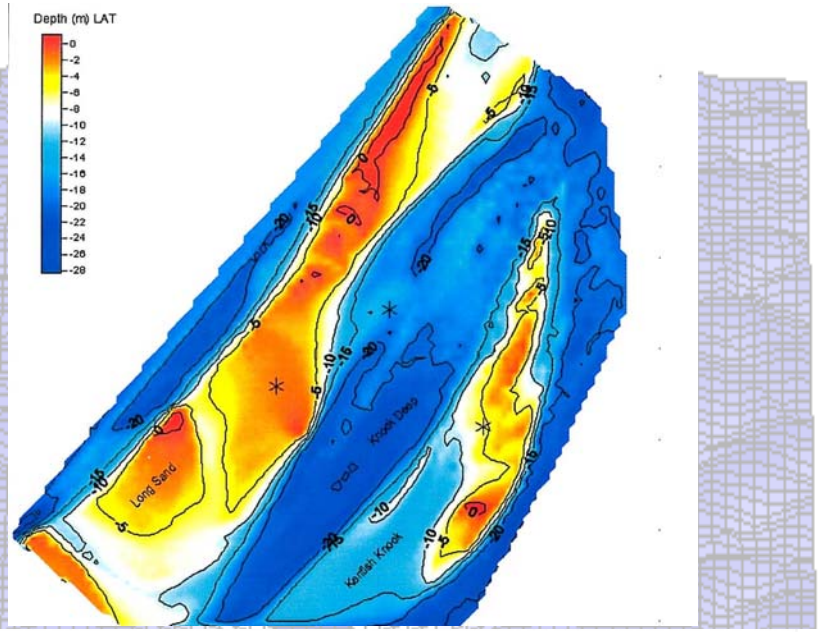


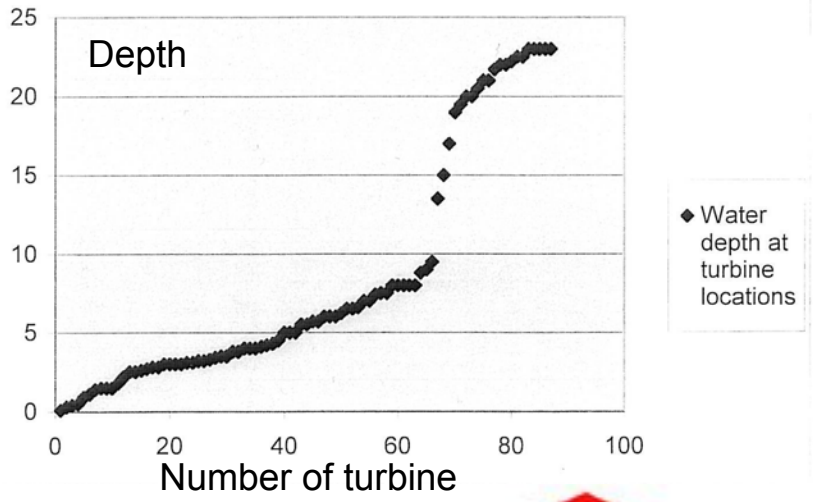
4



4 If situation 3b occurs, we might expect this to be considered as a global lowering of the bed and scour depth will be increased?







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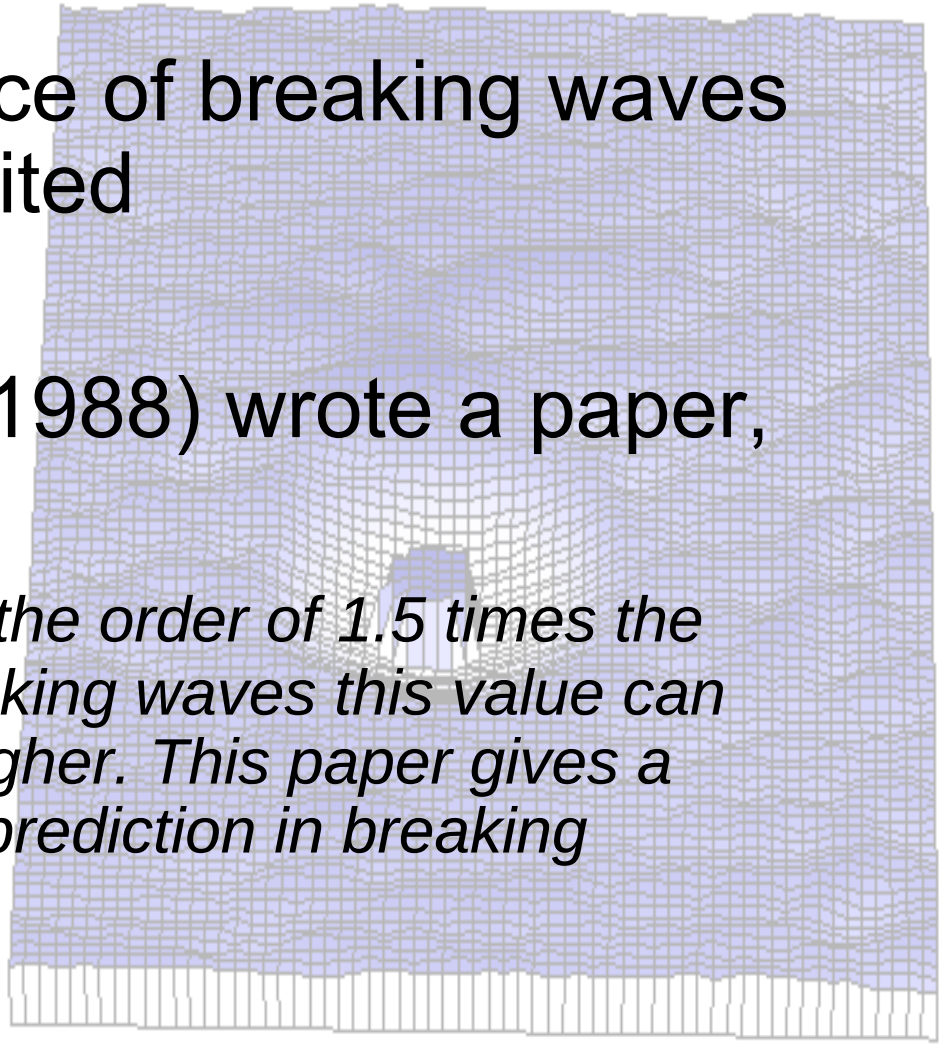
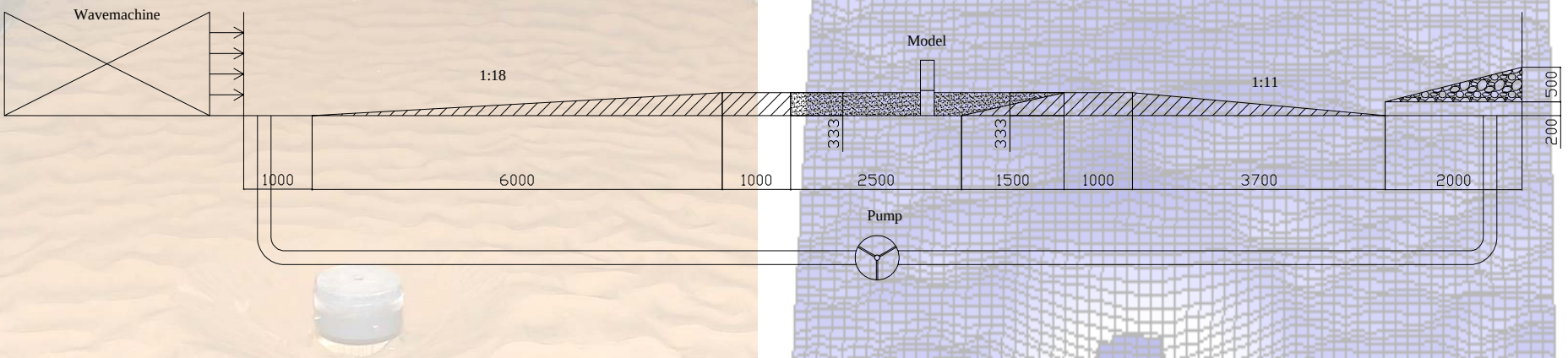
Knowledge on influence of breaking waves on scour depths is limited

Bijker and De Bruyn (1988) wrote a paper, saying:

"The depth of the scour is in the order of 1.5 times the pile diameter. In case of breaking waves this value can be, however, considerably higher. This paper gives a large influence on the scour prediction in breaking waves"

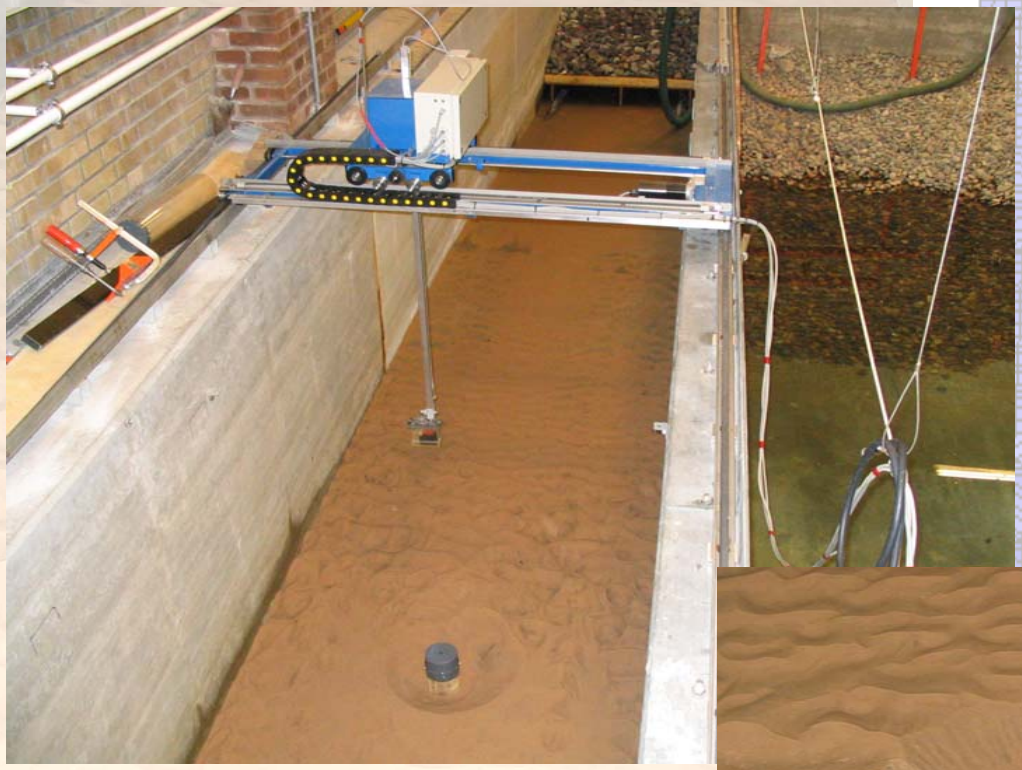


Model and Set-up

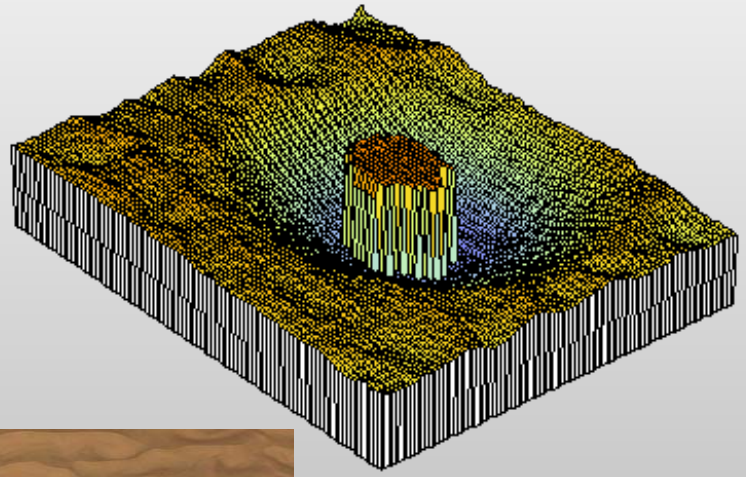


- Flume: L x W x H = 25m x 1.2m x 1.5m
- Sand box: 4m length, sand d_{50}: 0.17 mm
- Possible to make strong tidal currents (Q_{max} = 650 l/s)
- Slope 1:18 ⇒ breaking waves
- Scale of tests: 1:30 (length scale)

Model and Set-up



Measurements are done with non-contact profiling system



Top part of pile is removed for measurements

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Test program

Test series	Comments	Diameter of monopile D [m]	Sign. Wave height H_s [m]	Spectral peak period T_p [s]	Water depth at pile h_t [m]	Current induced velocity U_c[m/s]
1	Breaking waves	0.10	0.07 – 0.12	1.28 – 1.97	0.17 – 0.29	0.00 – 0.30
2	Tidal current	0.10 – 0.20	-	-	0.10 – 0.29	0.30 – 0.50
3	Unidirect. current	0.10 – 0.20	-	-	0.10 – 0.29	0.30 – 0.50
4	Regular waves	0.20	0.09 – 0.11	1.28 – 2.50	0.17	0.00

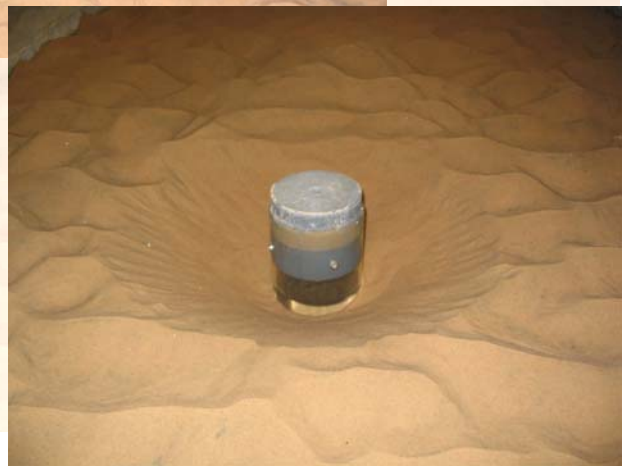
Examples of scour holes

Waves only

Waves and current

Examples of scour holes

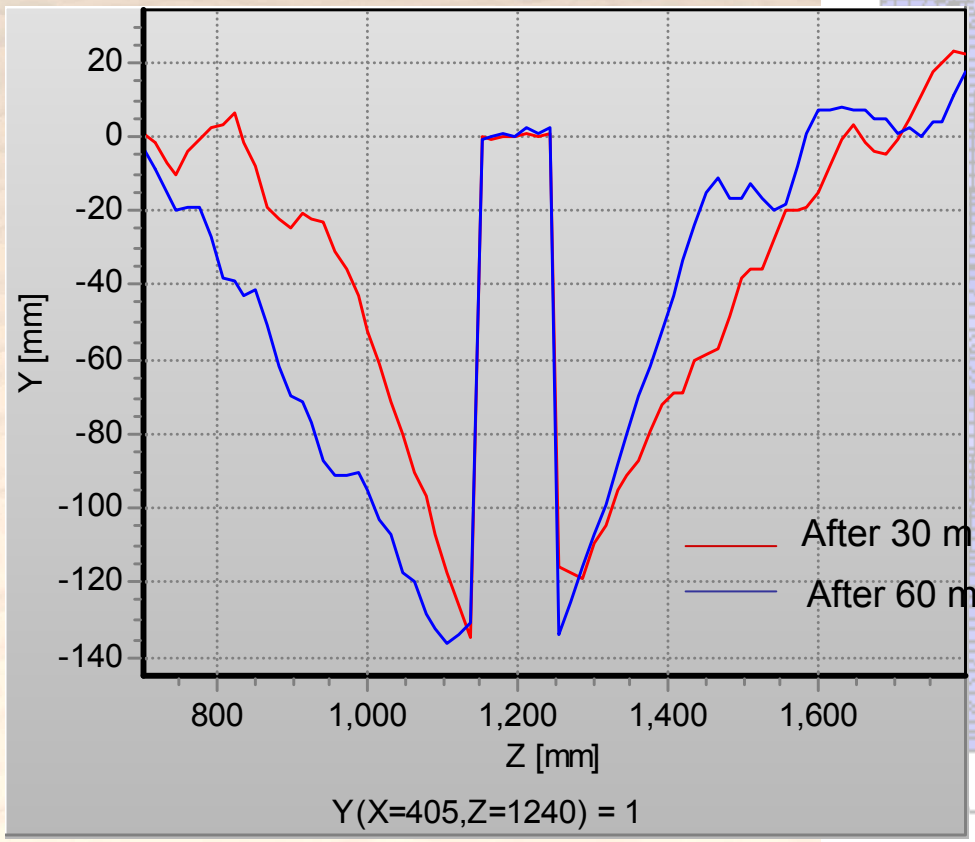
Unidirectional current



Tidal current

Tidal current: measured effect of tidal current

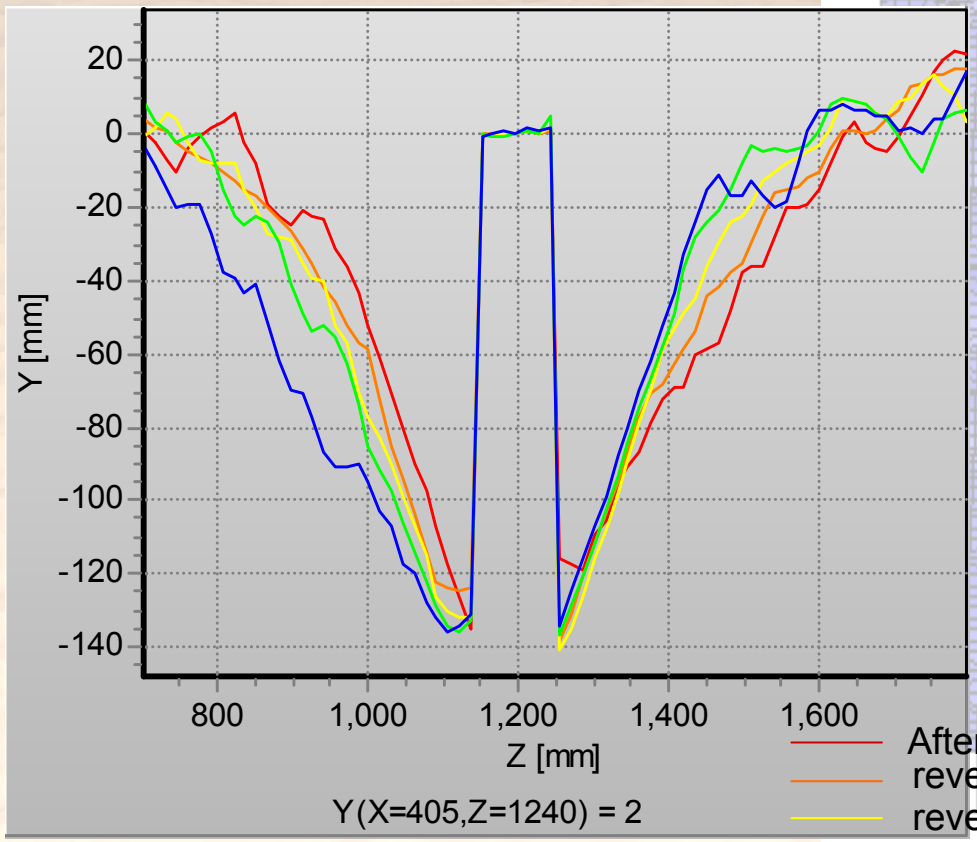
STRONG TIDAL CURRENT: U = 0.5 m/s



Large current velocity: equilibrium is almost reached after the first tidal cycle. We indeed see both the deposition on the flat side and the erosion of the steep side

Tidal current: measured effect of tidal current

STRONG TIDAL CURRENT: U = 0.5 m/s

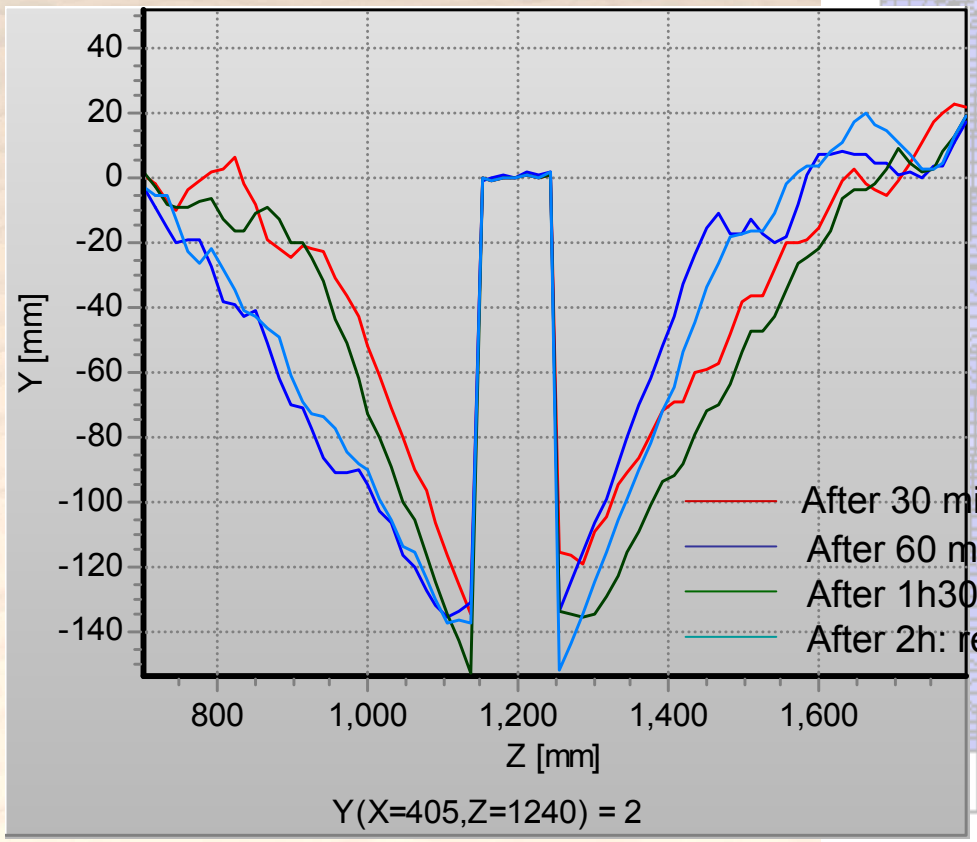


What goes the fastest? Deposition on the flat side or erosion of the steep side?

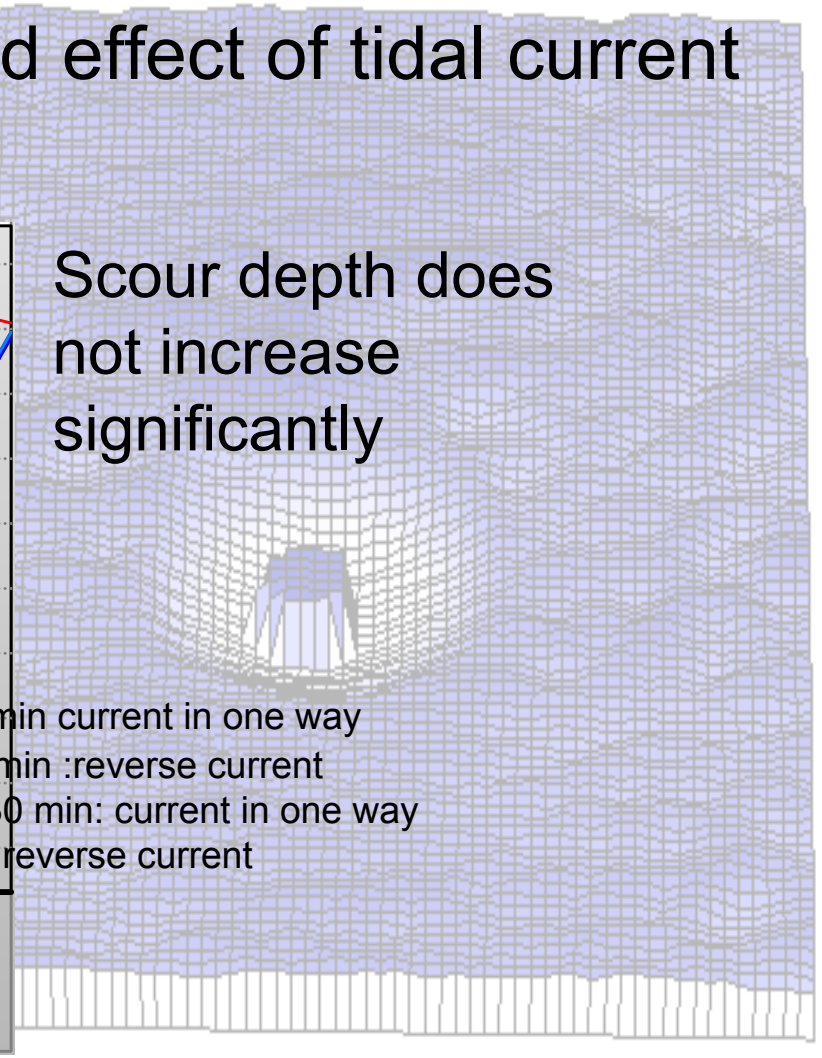
$\Rightarrow$ in case of a strong current (U = 0.5 m/s in the model), the backfilling goes faster. But both erosion and deposition are finished after 30 min of current velocity (= half of the tidal cycle)

Tidal current: measured effect of tidal current

STRONG TIDAL CURRENT: U = 0.5 m/s



Scour depth does not increase significantly



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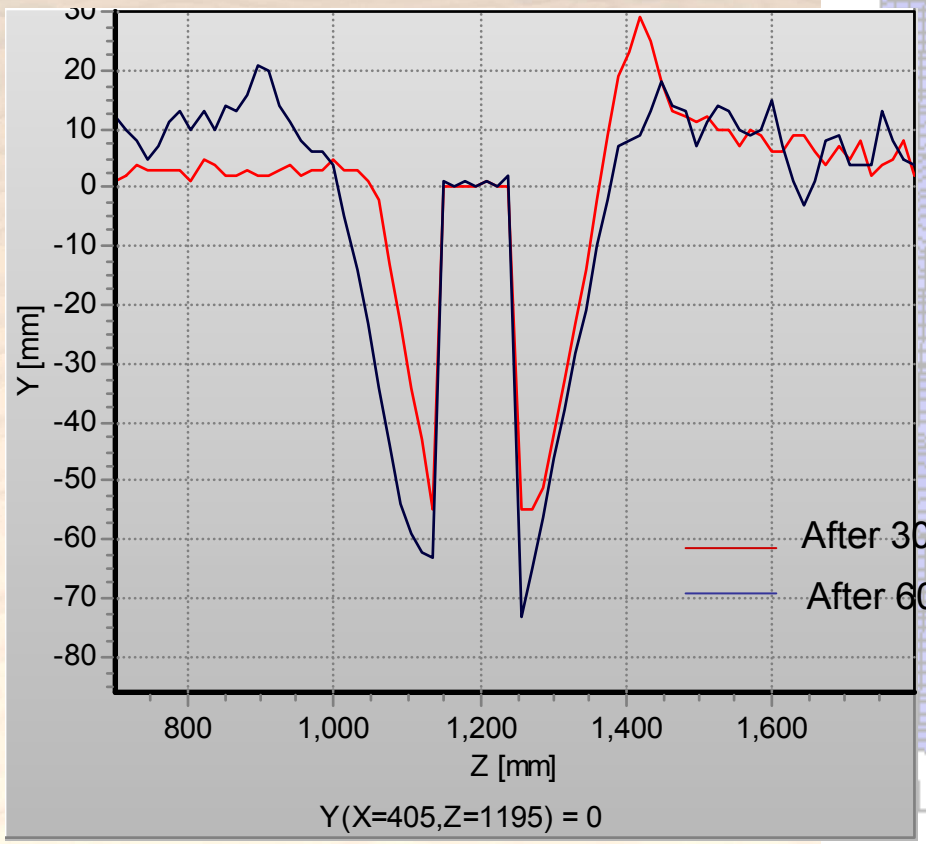
Tidal current: measured effect of tidal current

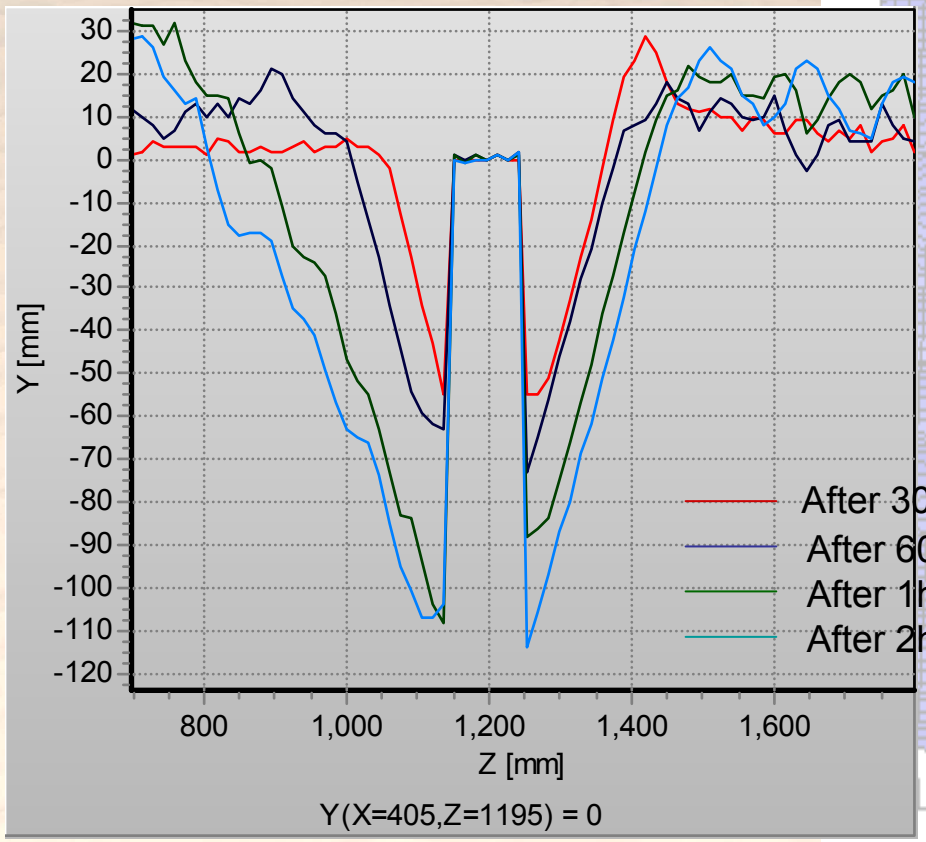
SMALLER TIDAL CURRENT: U = 0.3 m/s



For a smaller current velocity, equilibrium is not reached after 30 min. We see no deposition on the flat slope, but only an increase in the scour depth. The steep slope however is eroded when reversing the current

Tidal current: measured effect of tidal current

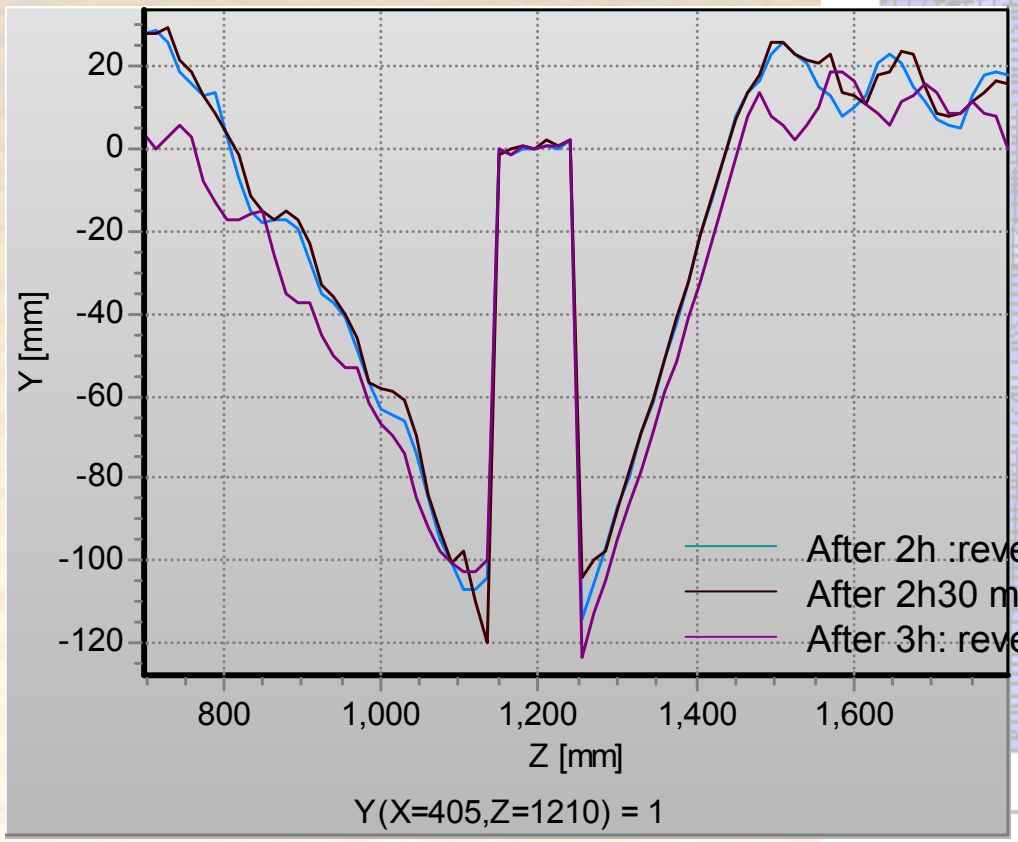
SMALLER TIDAL CURRENT: U = 0.3 m/s



For a smaller current velocity, the scour hole continues to grow, every time the current is reversed, until the equilibrium scour depth is reached.

Tidal current: measured effect of tidal current

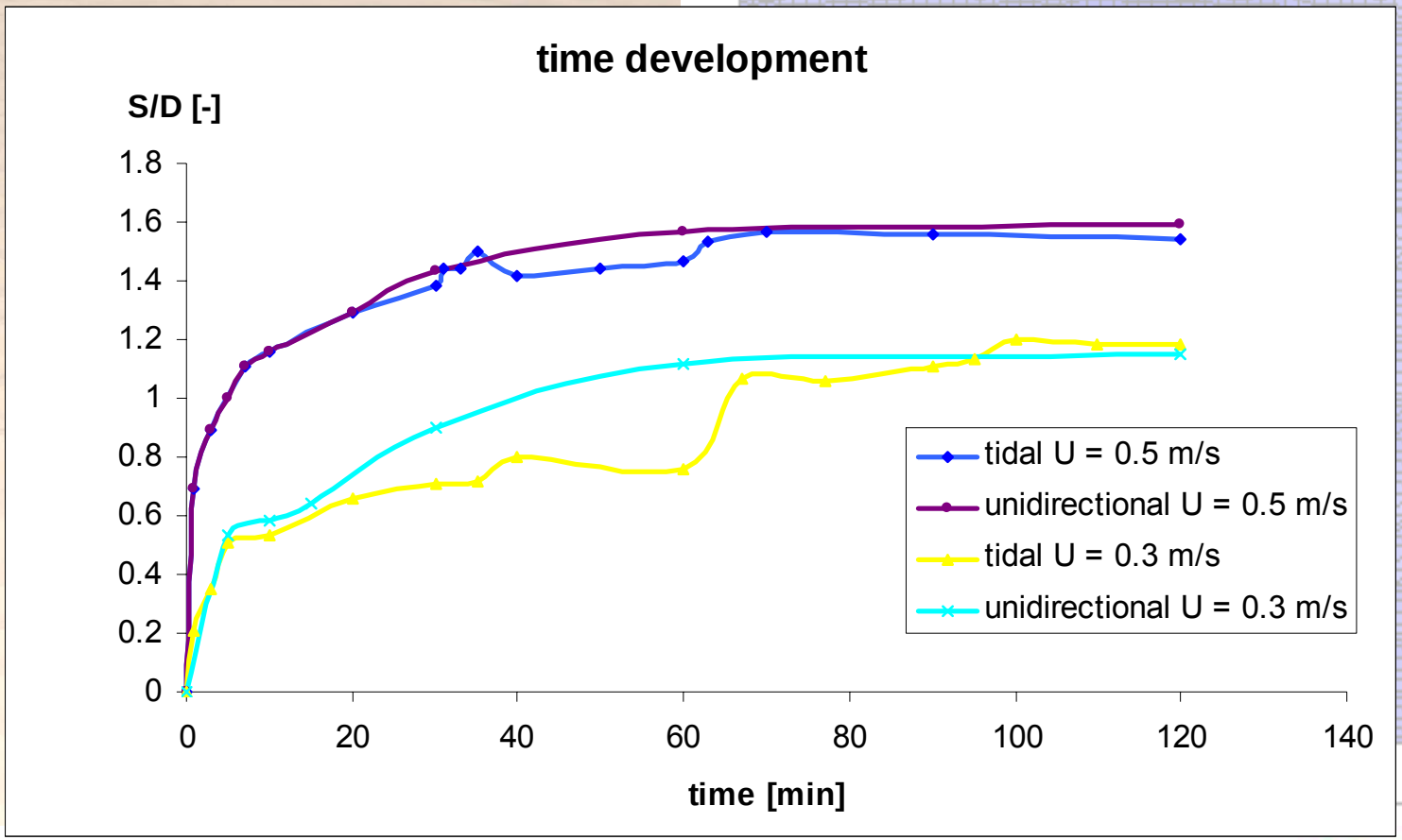
SMALLER TIDAL CURRENT: U = 0.3 m/s



Once equilibrium is reached, scour depth does not increase significantly

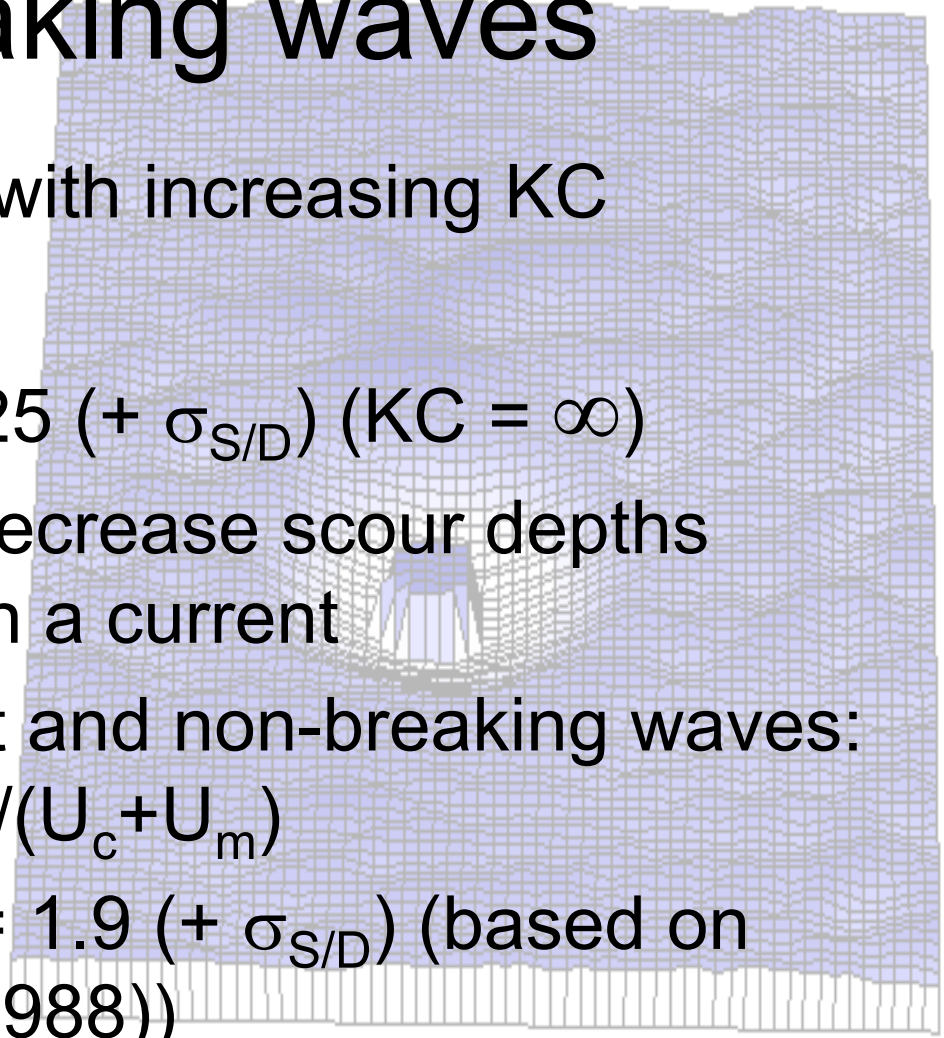
Evolution of scour hole in time:

tidal current versus unidirectional current: U = 0.5 m/s

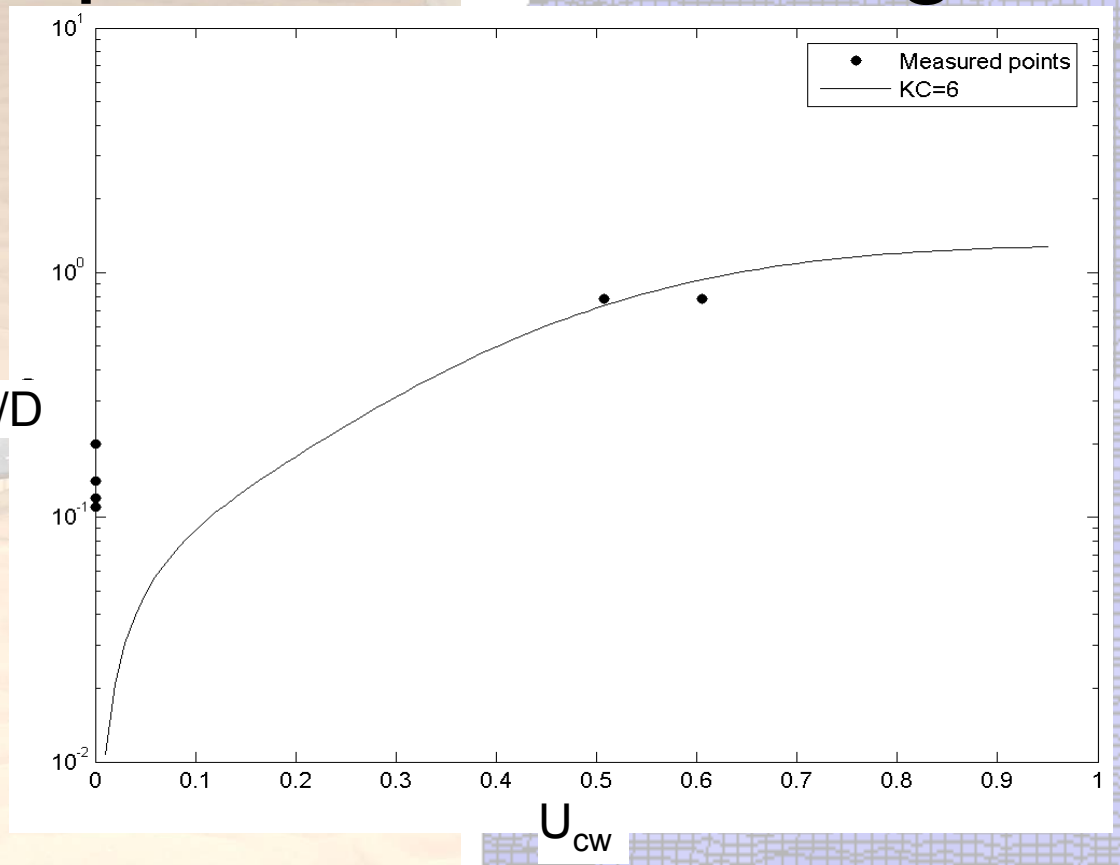


Scour from breaking waves

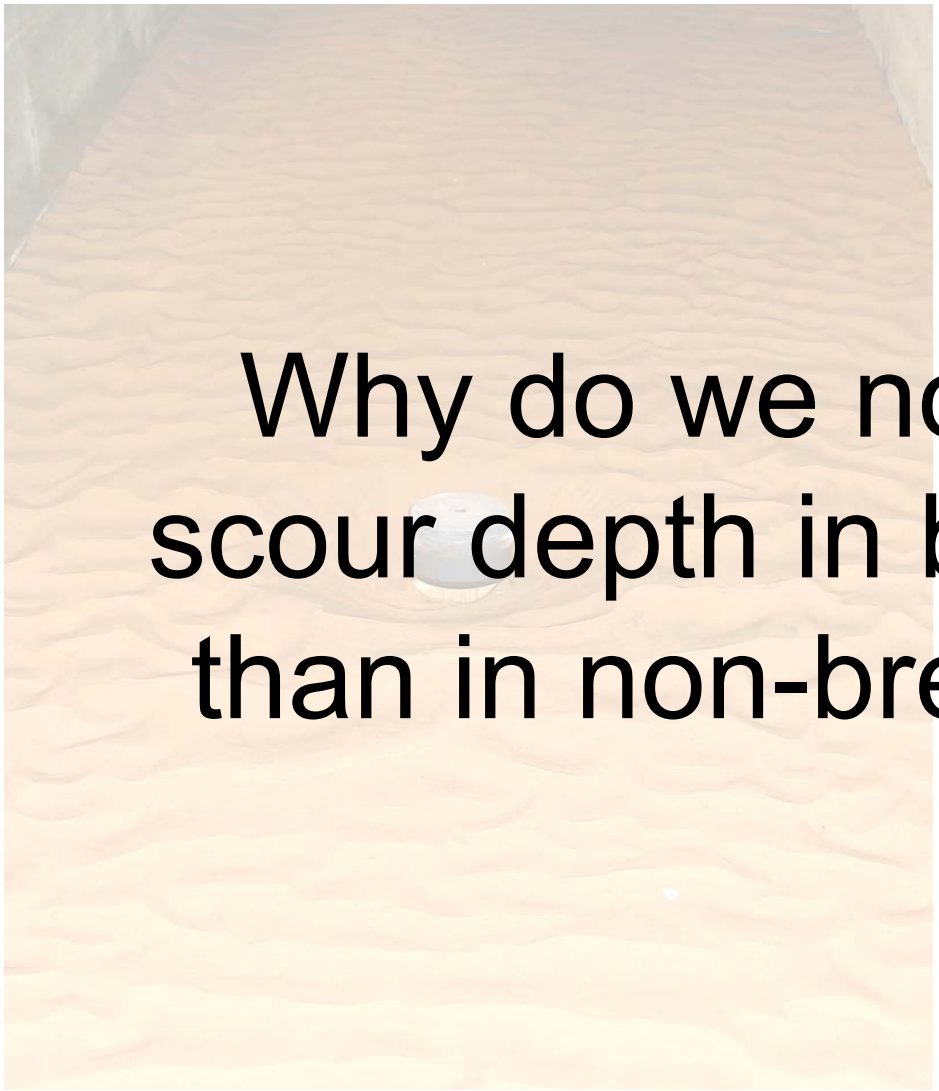
- wave scour increases with increasing KC number
- Current only: S/D = 1.25 (+ $\sigma_{S/D}$) (KC = ∞)
- Non-breaking waves decrease scour depths when superimposed on a current
- Combination of current and non-breaking waves: S/D = F(U_{cw}); $U_{cw} = U_c/(U_c+U_m)$
- Breaking waves: S/D = 1.9 (+ $\sigma_{S/D}$) (based on Bijker and De Bruyn (1988))



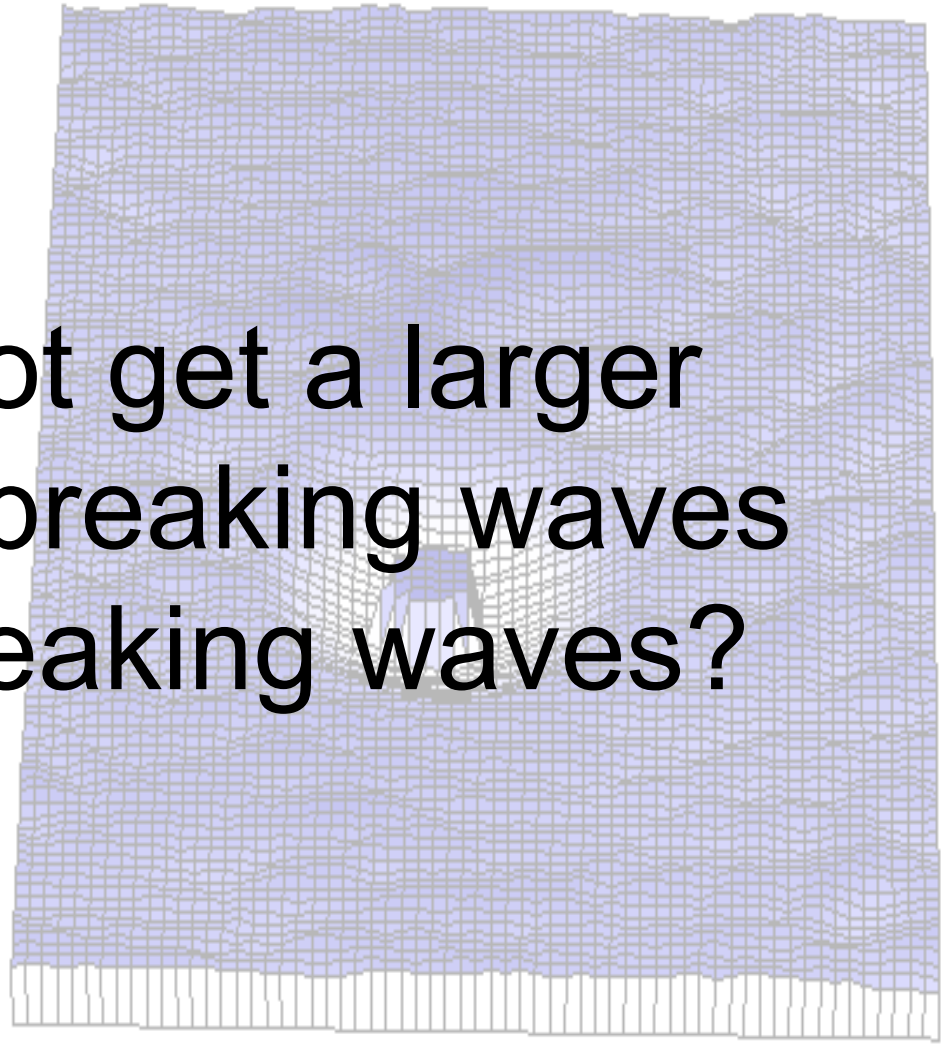
Scour depths from breaking waves



Measured scour from breaking waves compared to scour prediction according to Sumer and Fredsøe (non-breaking waves, KC=6)



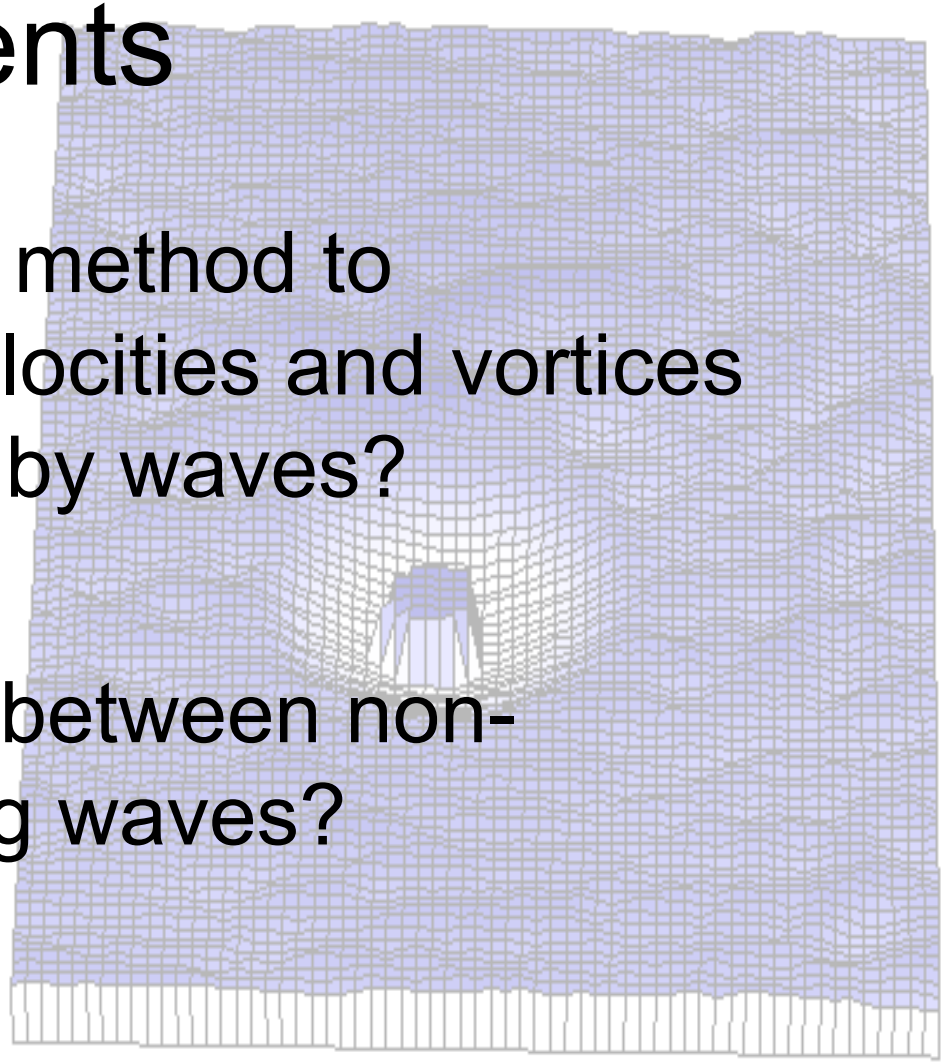
Why do we not get a larger scour depth in breaking waves than in non-breaking waves?



PIV measurements

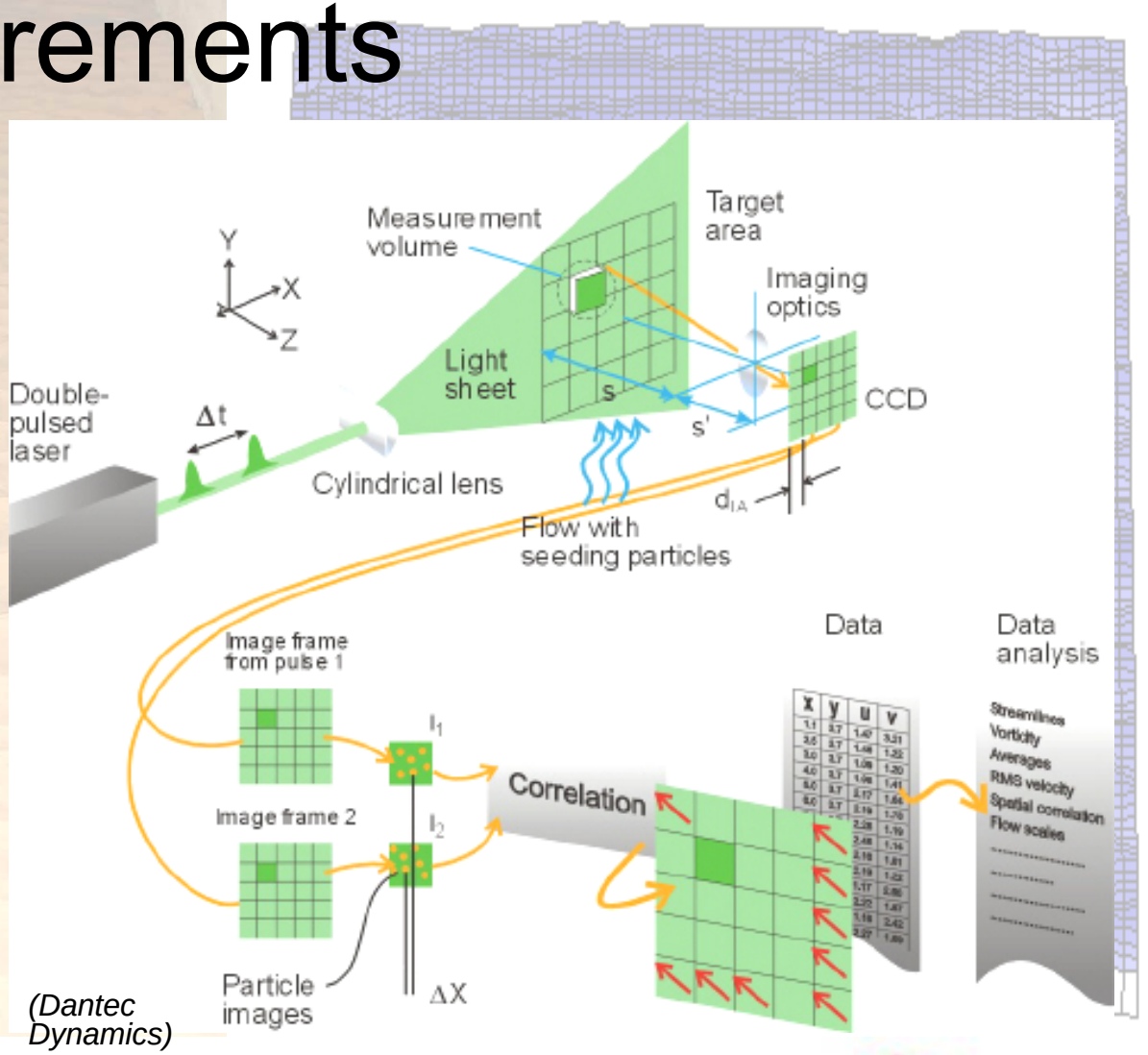
Is PIV an appropriate method to investigate bottom-velocities and vortices around a pile caused by waves?

What are differences between non-breaking and breaking waves?



PIV measurements

2D Particle Image Velocimetry (PIV) is a whole-flow-field technique providing instantaneous velocity vector measurements in a cross-section of a flow



(Dantec Dynamics)

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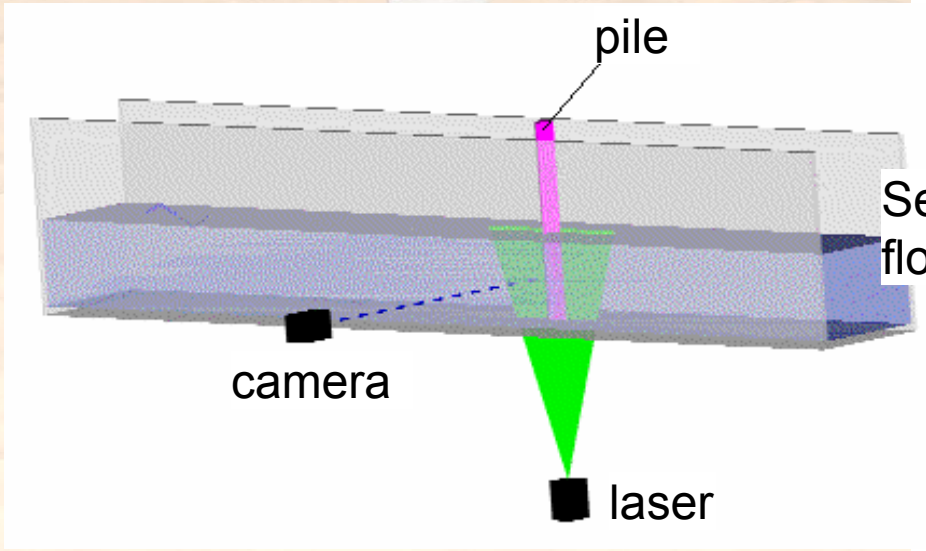
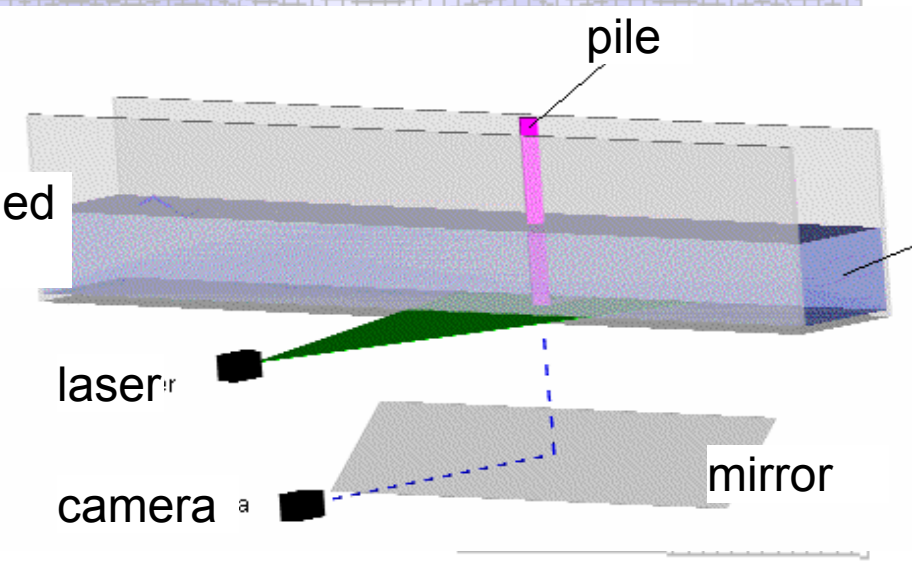
PIV measurements

Two set-ups:

- Vertical image through centre of pile
- Horizontal image near bottom



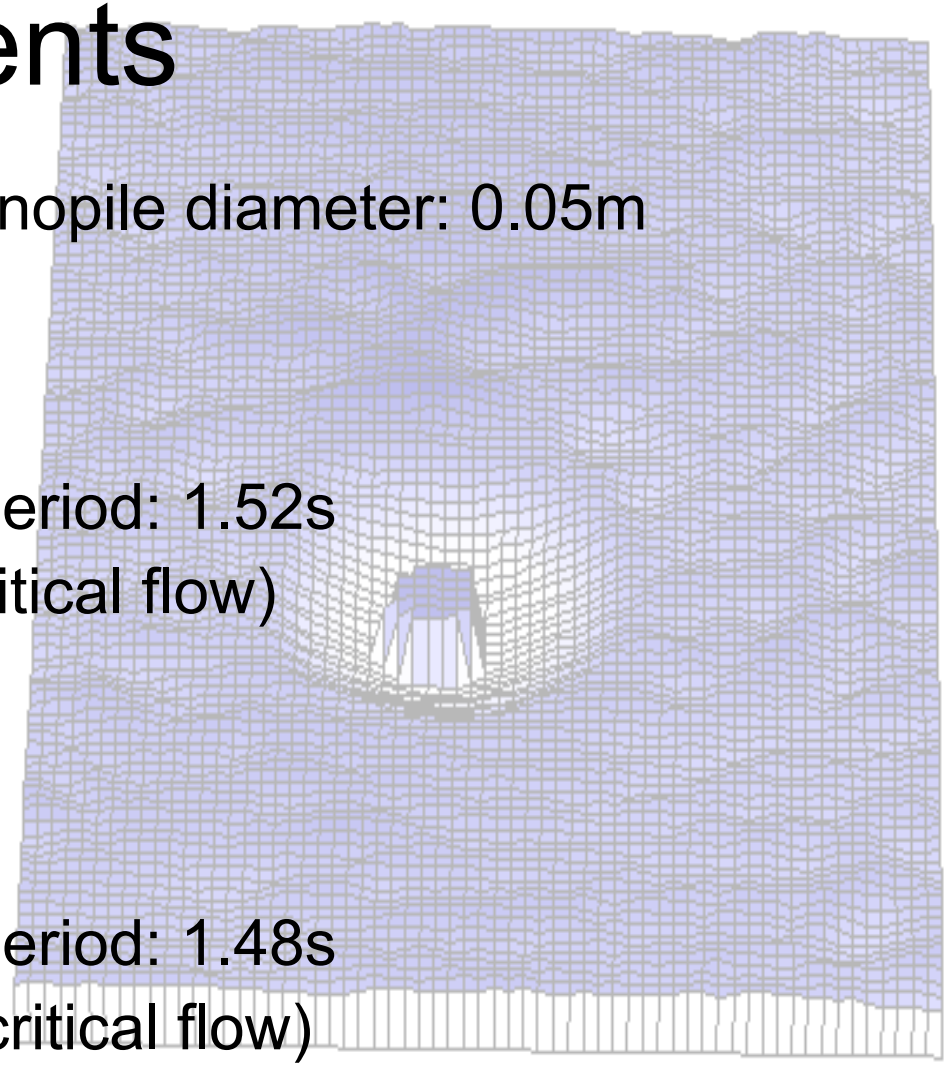
Seeded flow



PIV measurements

Horizontal set-up

PIV measurements



2 tests: regular waves, monopile diameter: 0.05m

Non-breaking wave

Water depth at pile: 0.22m

Wave height: 0.10m, Wave period: 1.52s

KC: 8.8, Re = 1.5×10^4 (subcritical flow)

Breaking wave

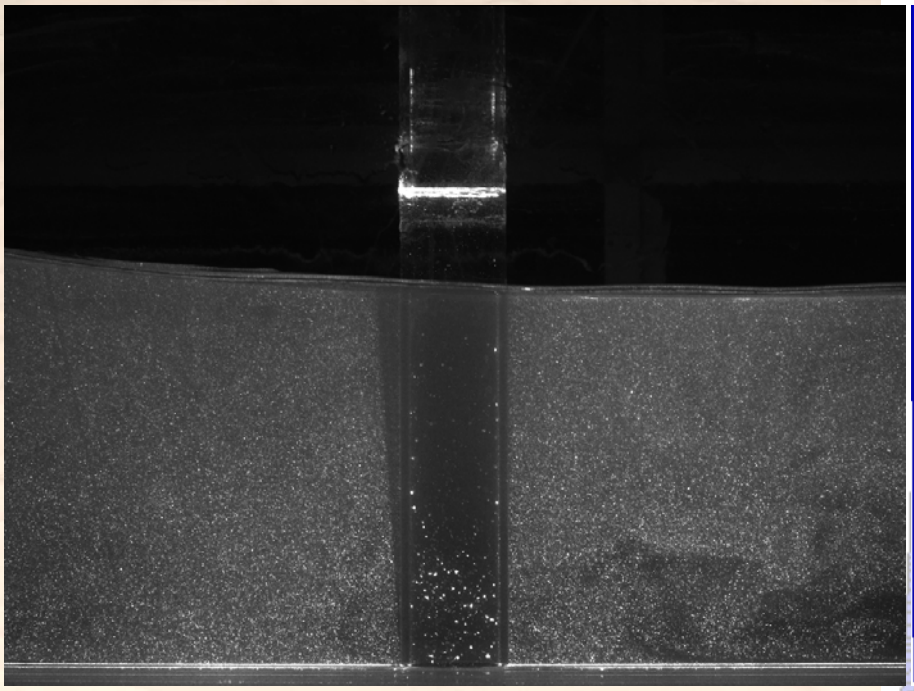
Water depth at pile: 0.12m

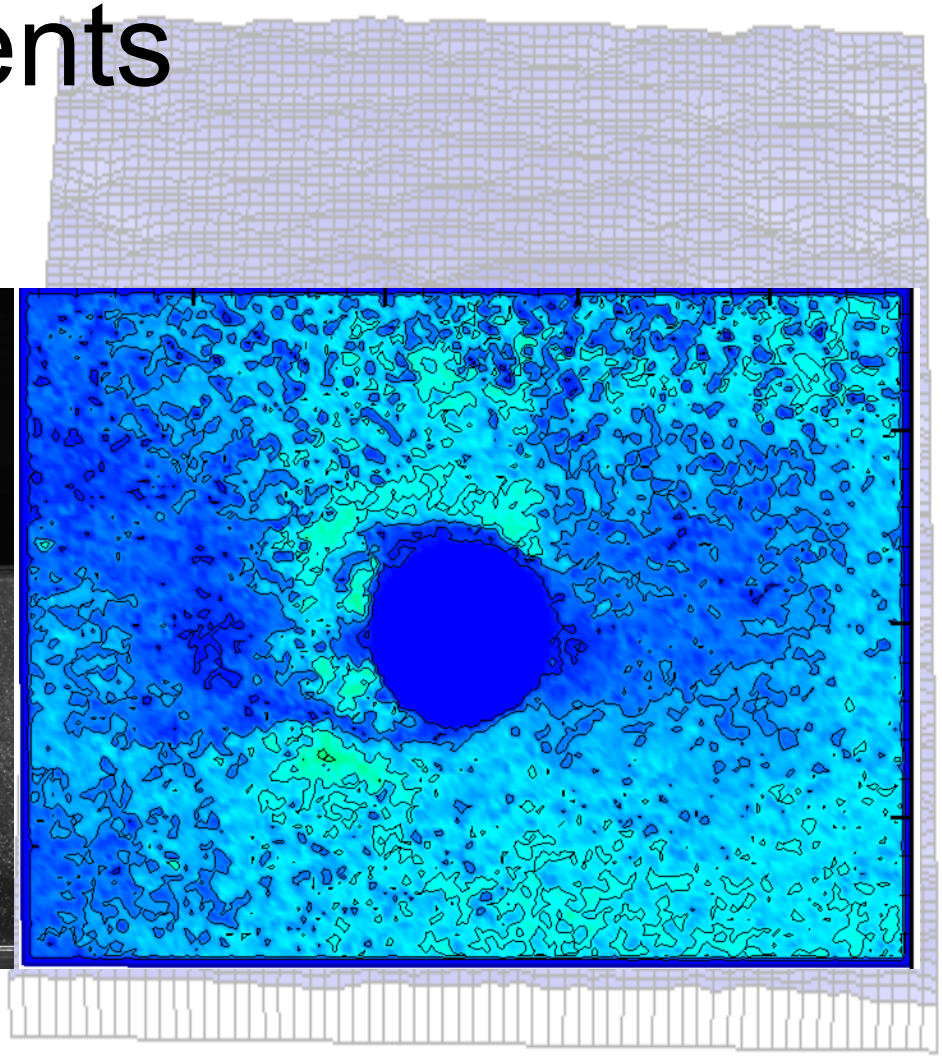
Wave height: 0.10m, Wave period: 1.48s

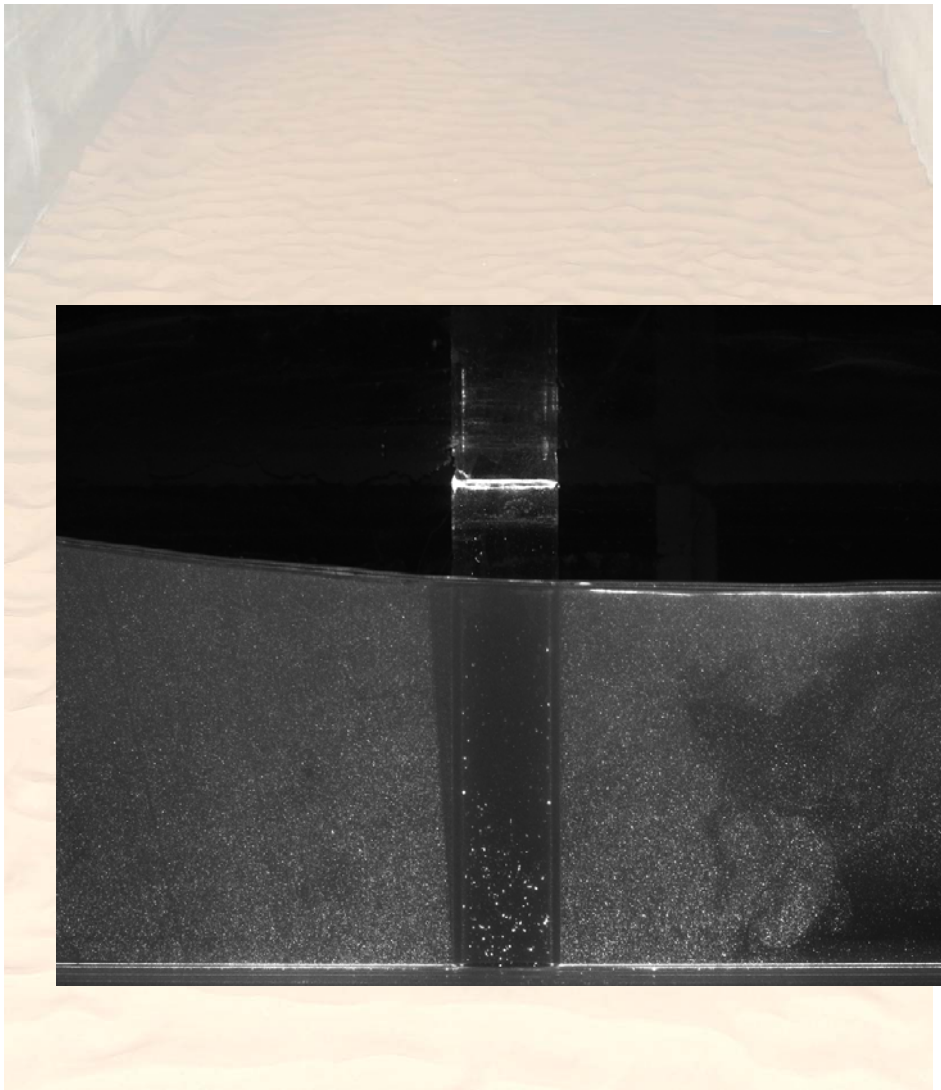
KC: 12.4, Re = 2.1×10^4 (subcritical flow)

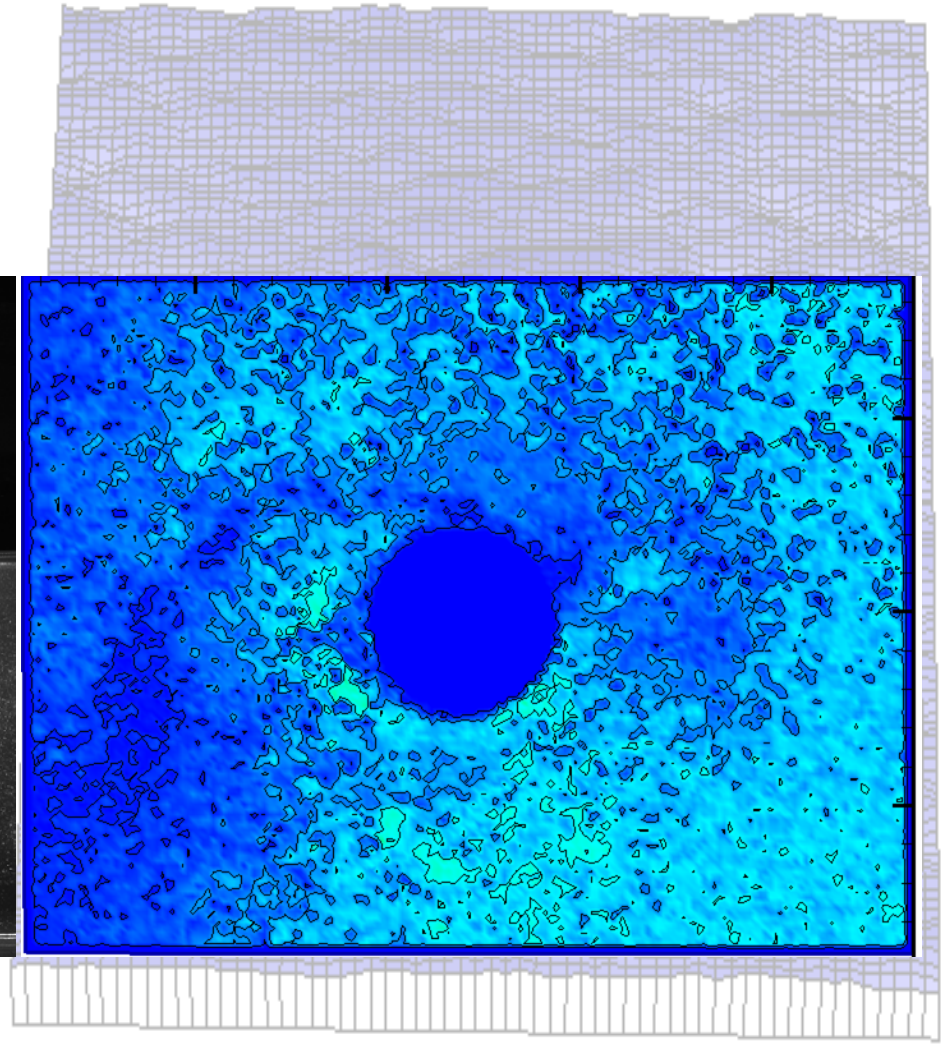
PIV measurements

non-breaking wave









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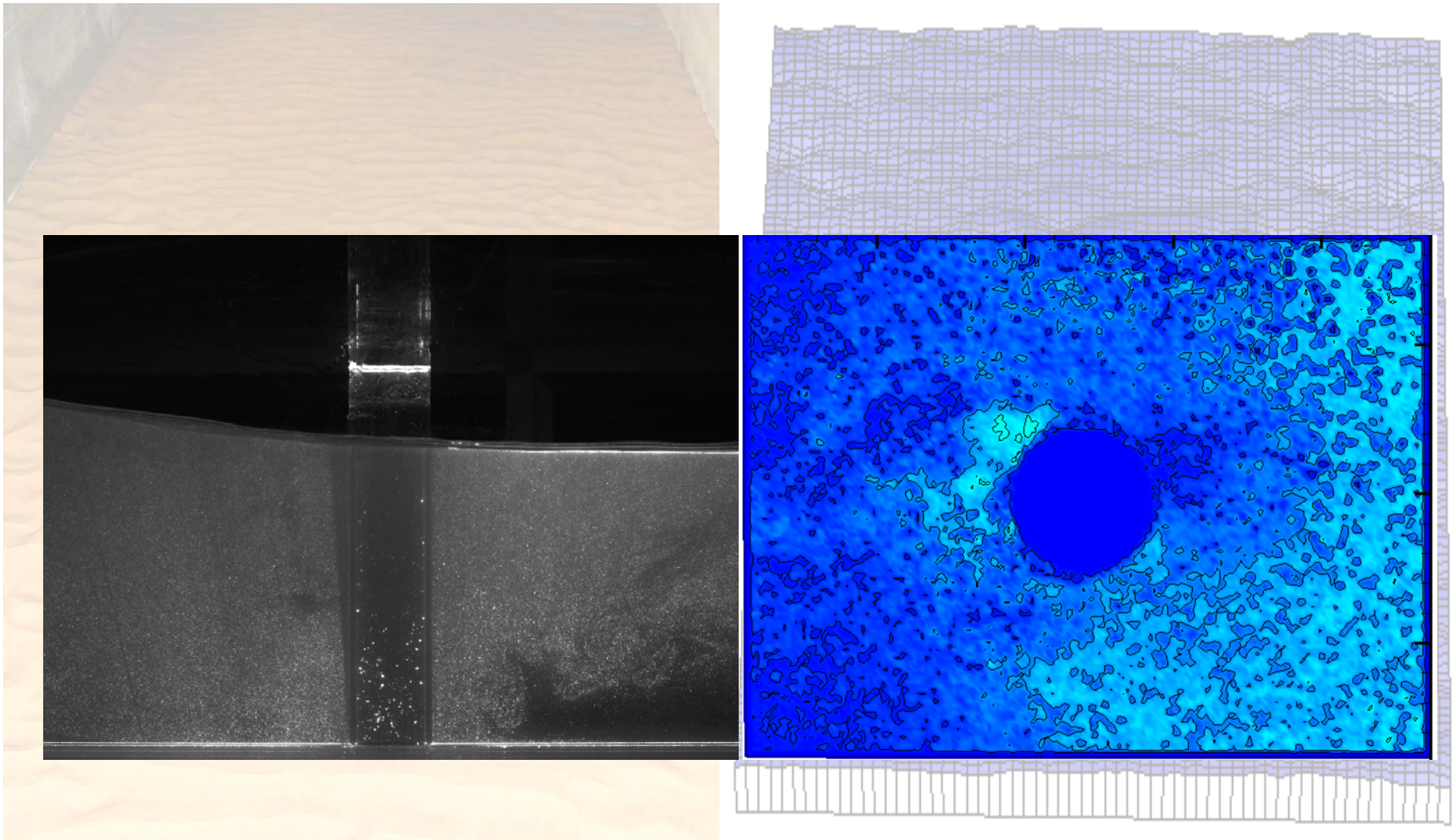

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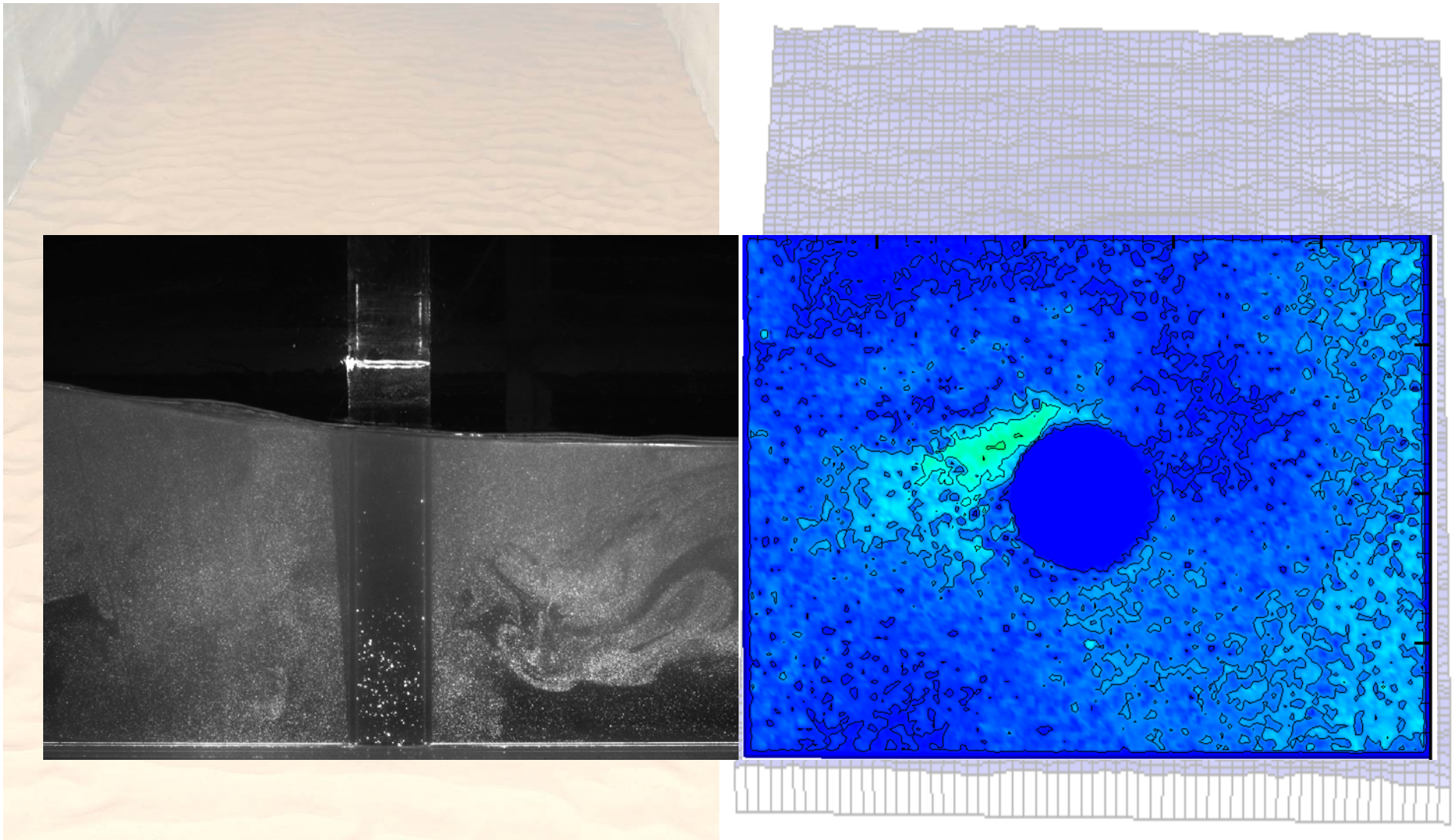

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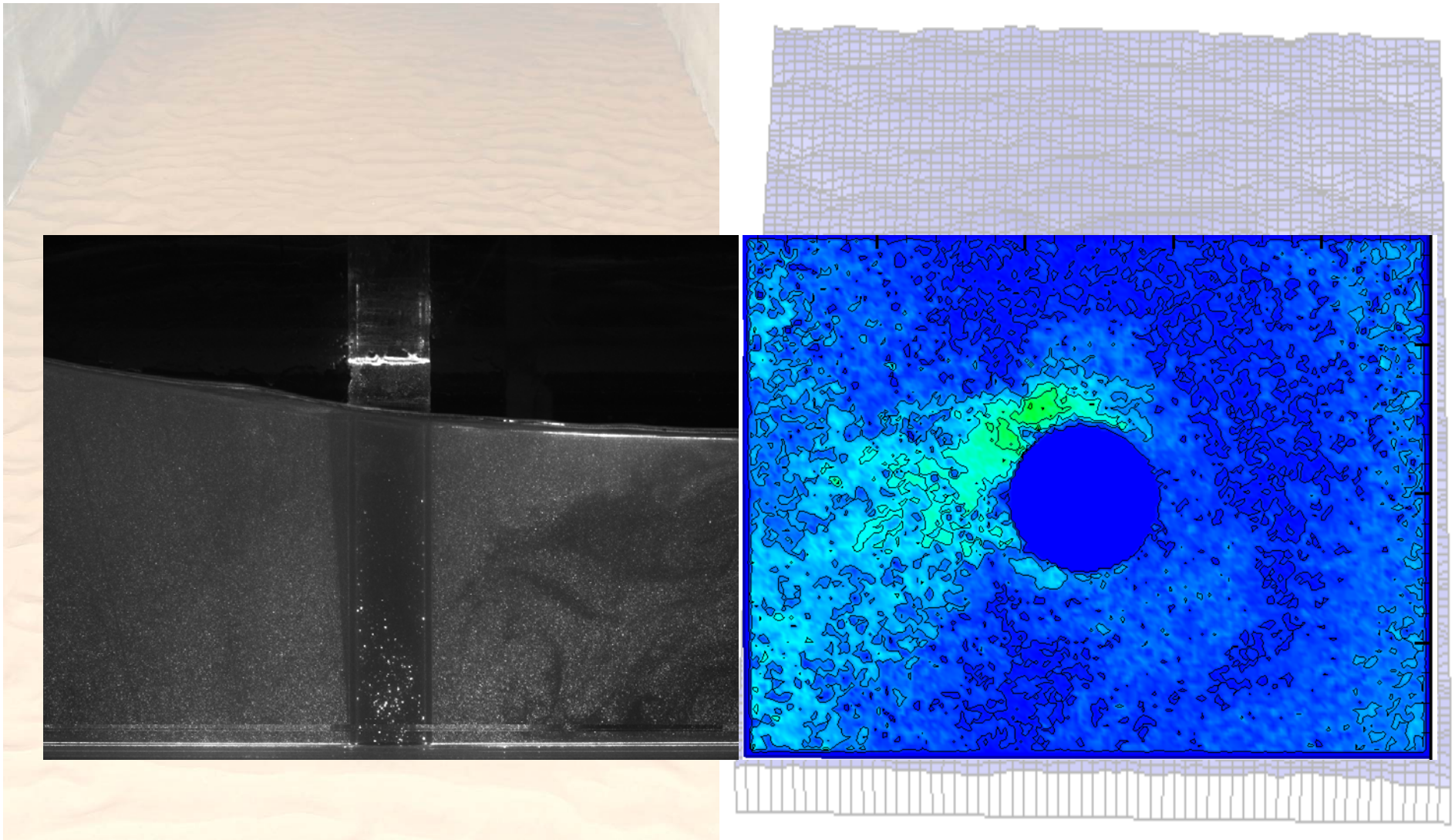

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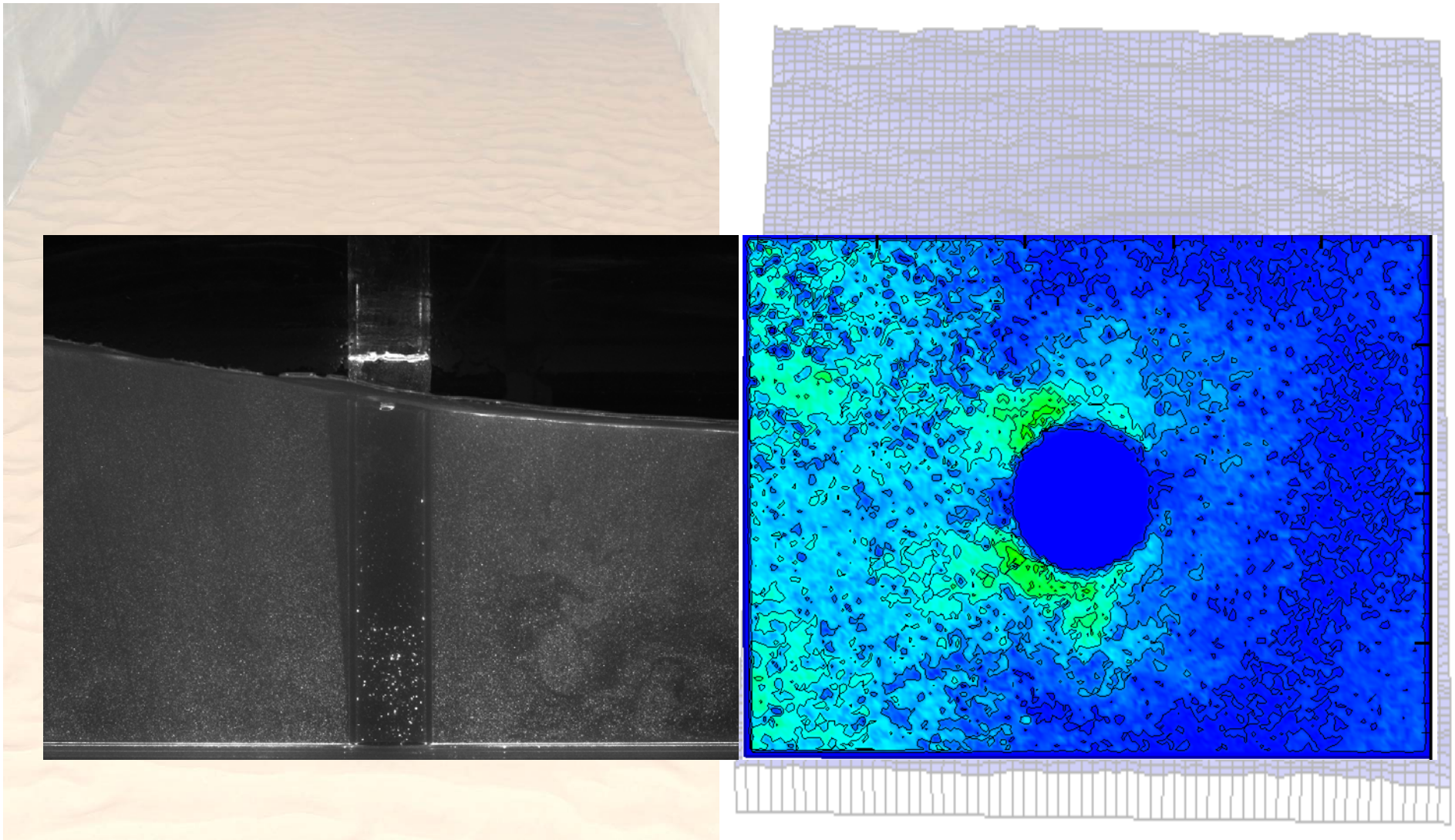

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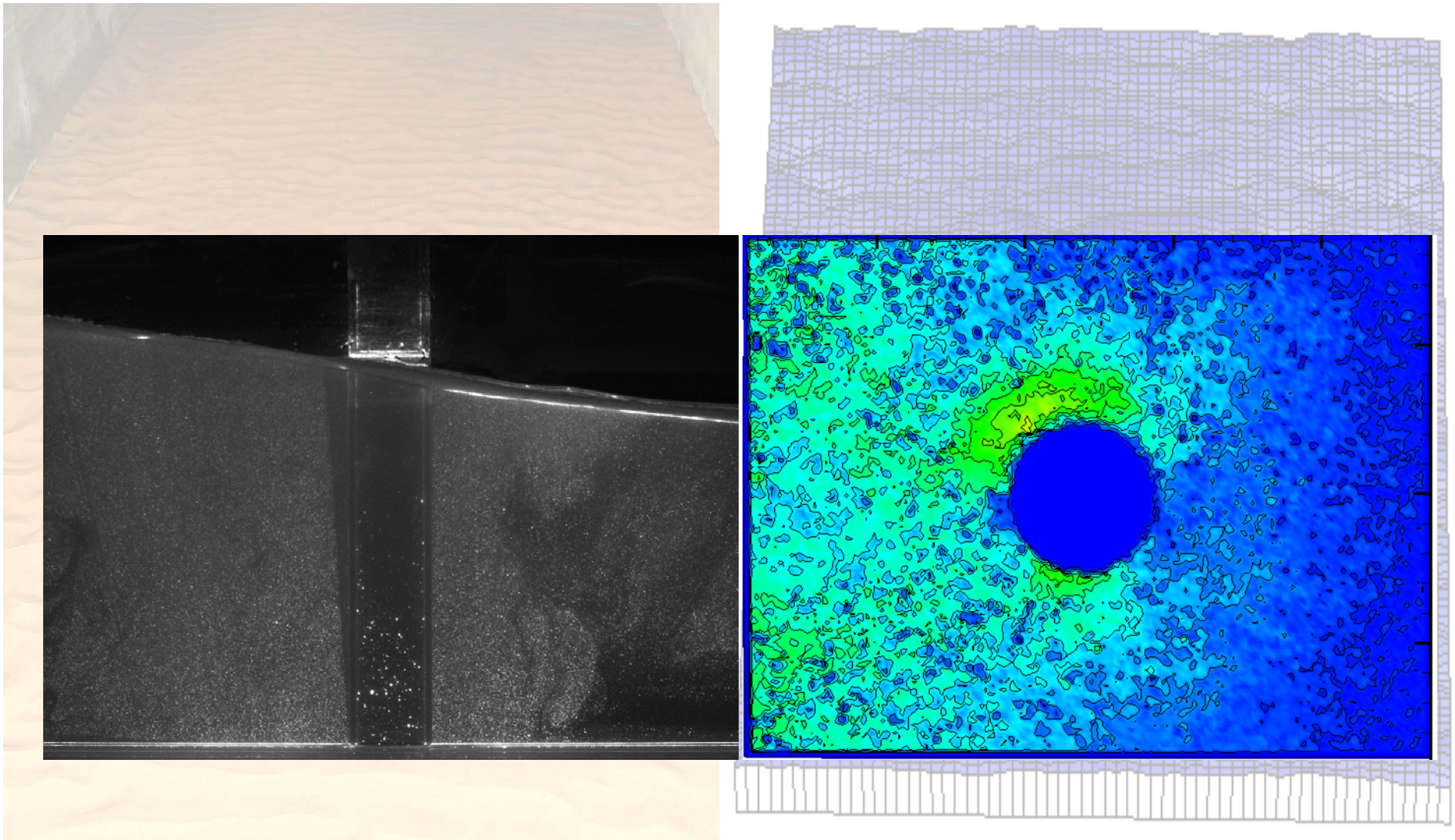

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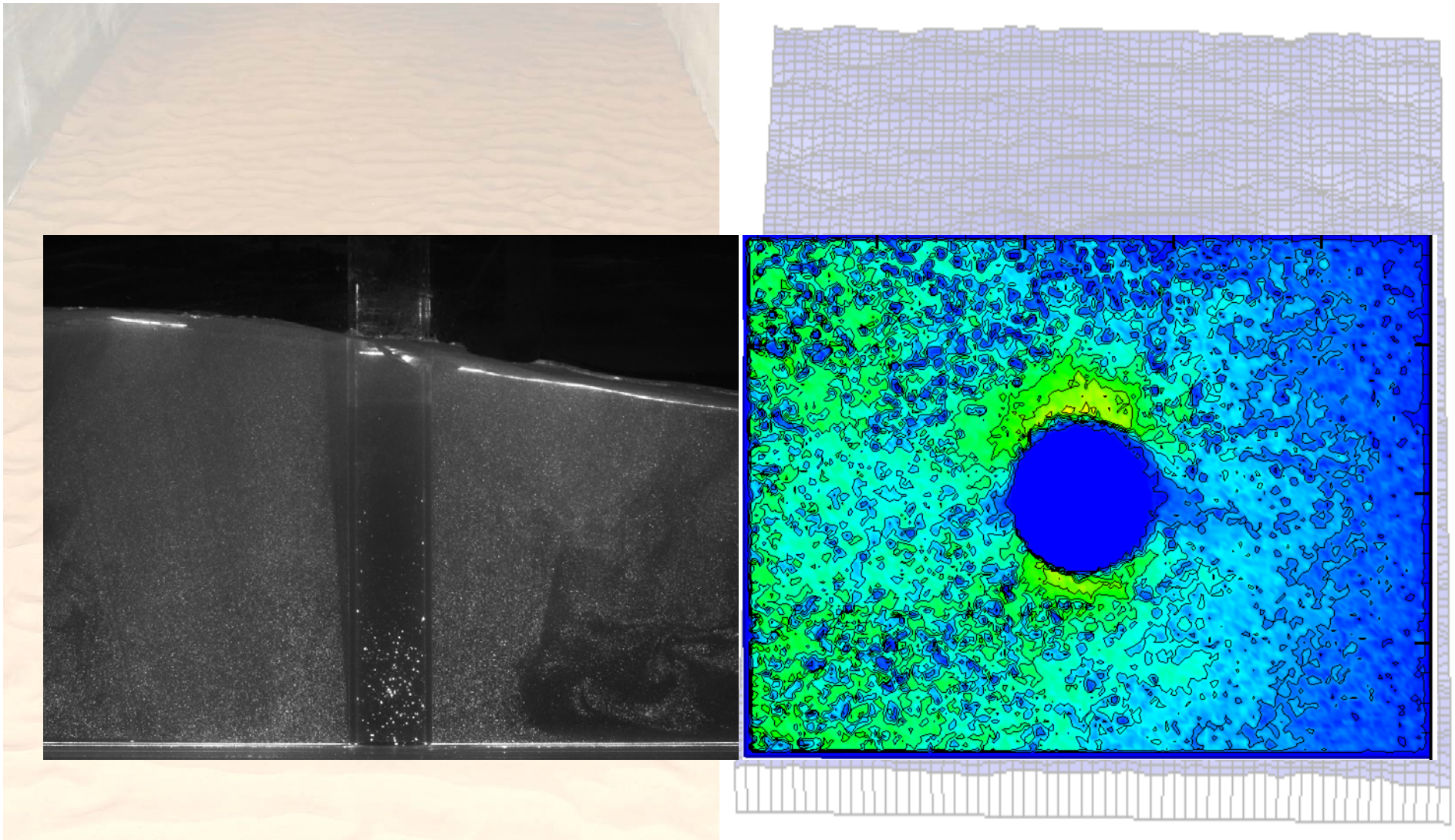

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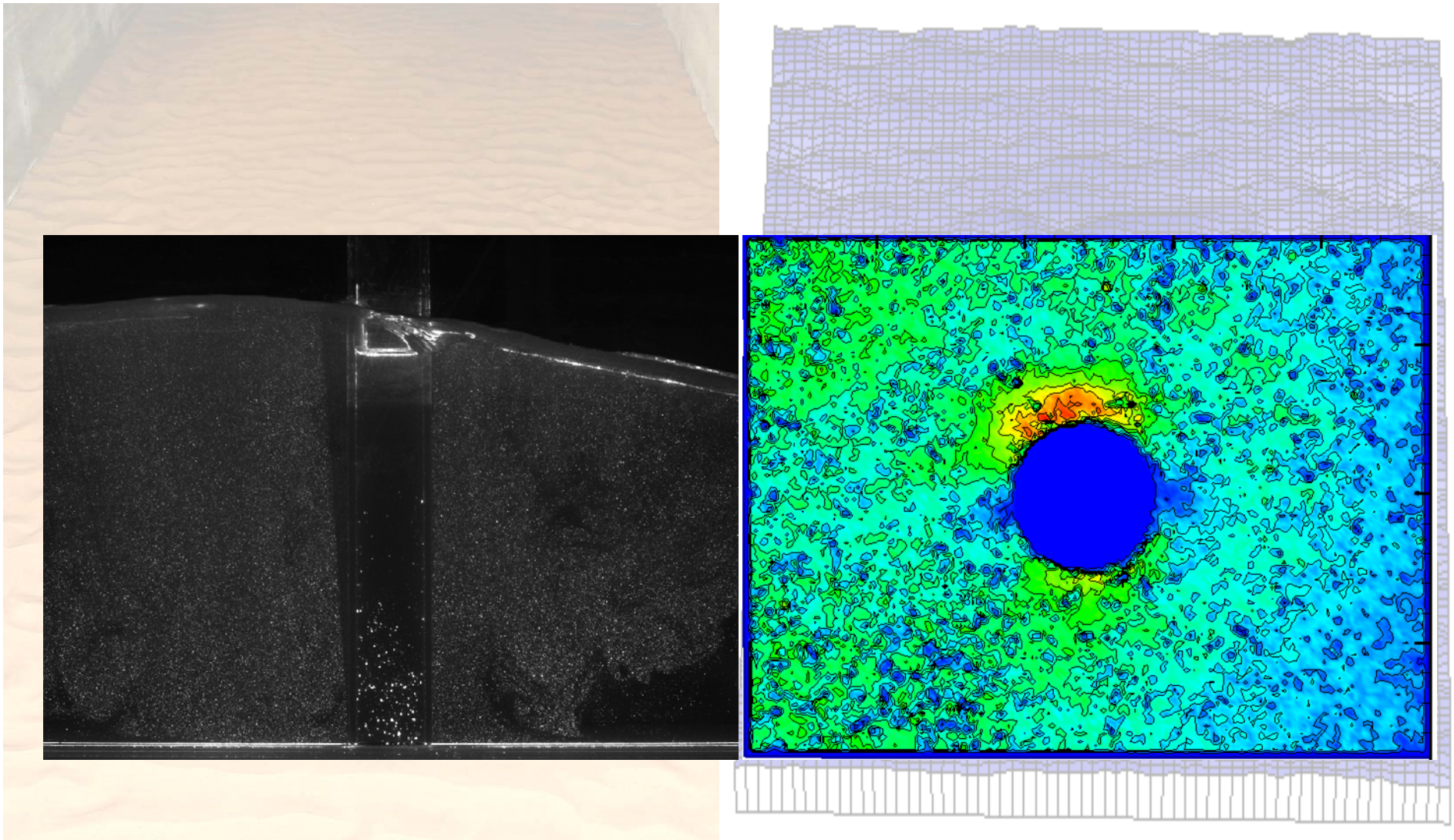

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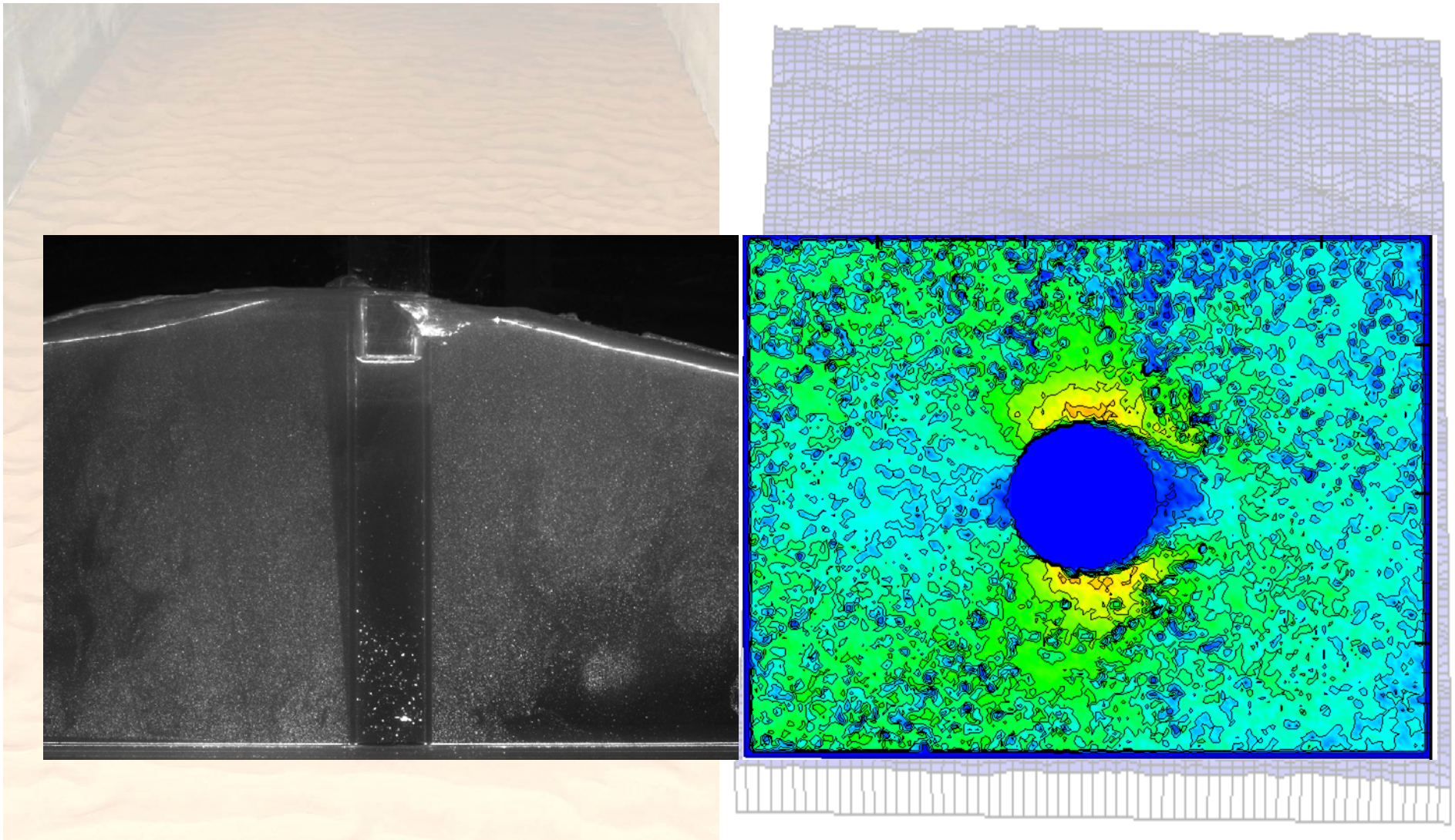

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Offshore Wind Turbines situated
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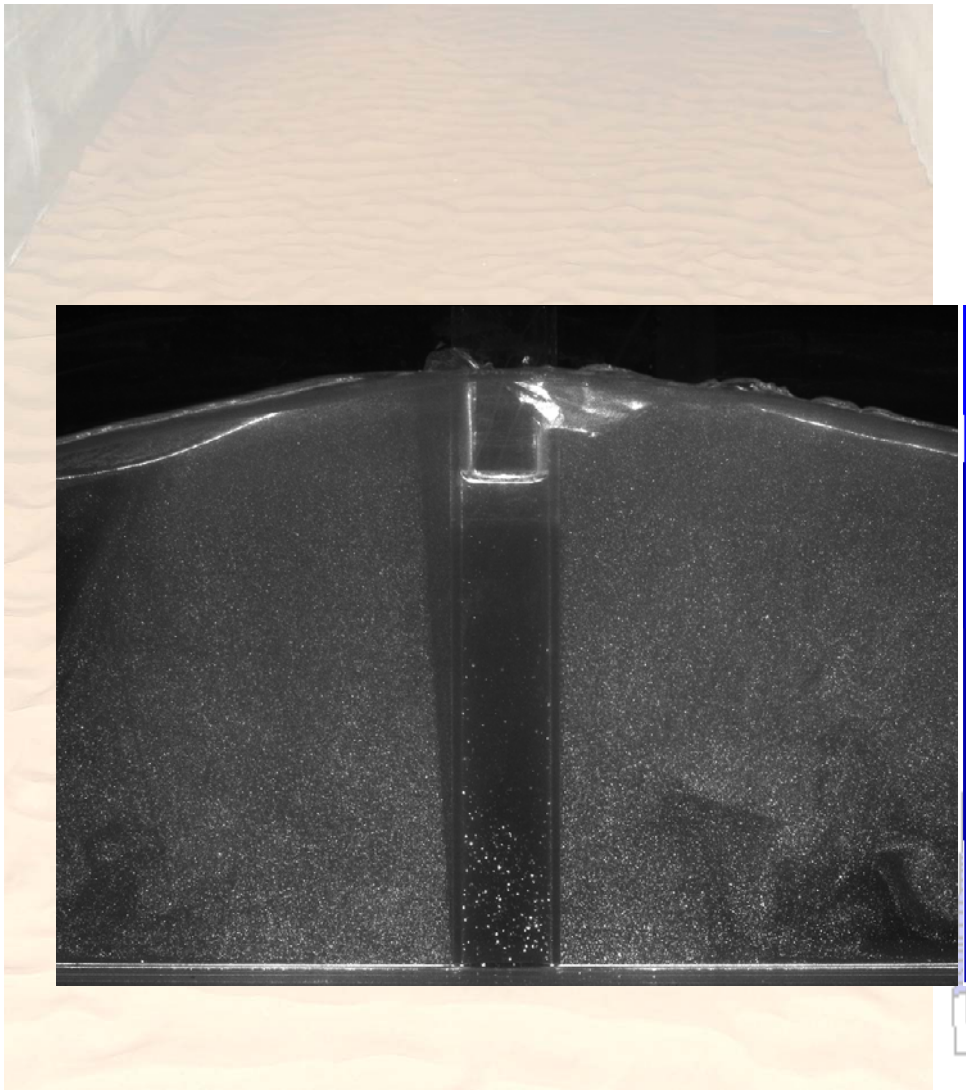

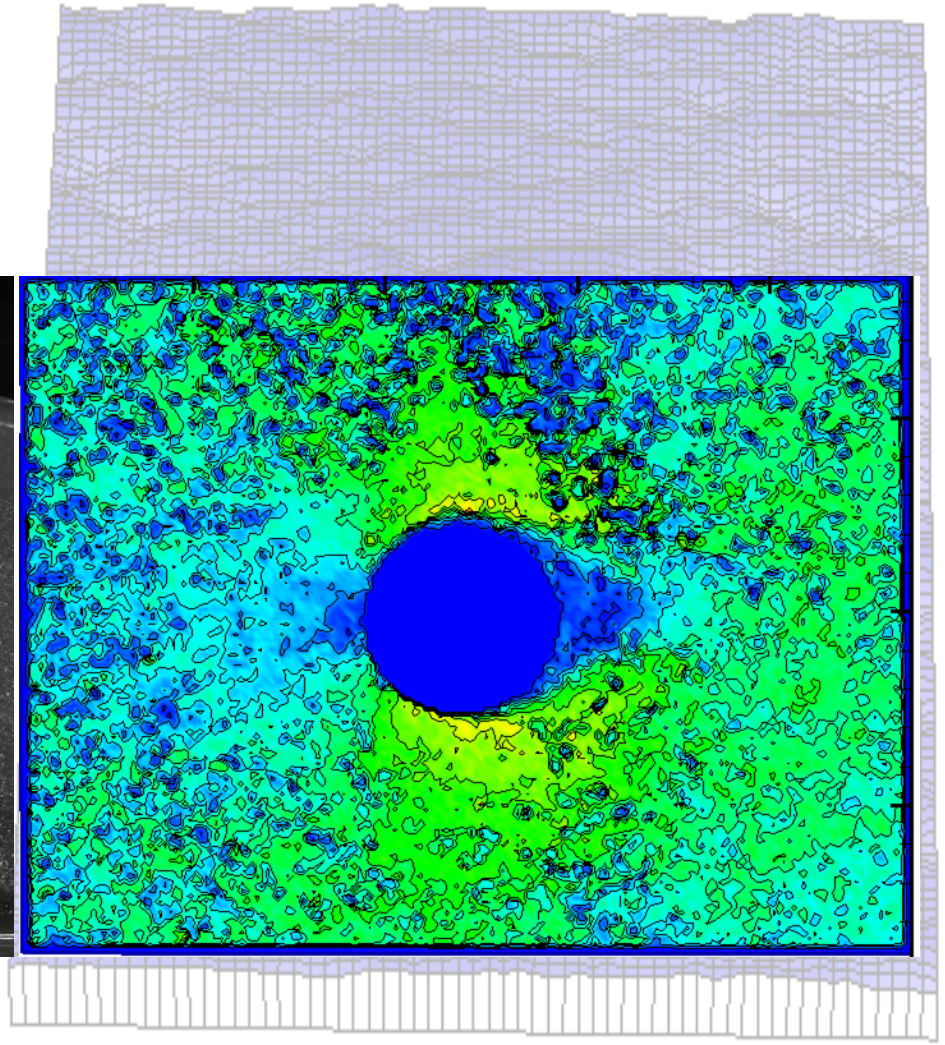

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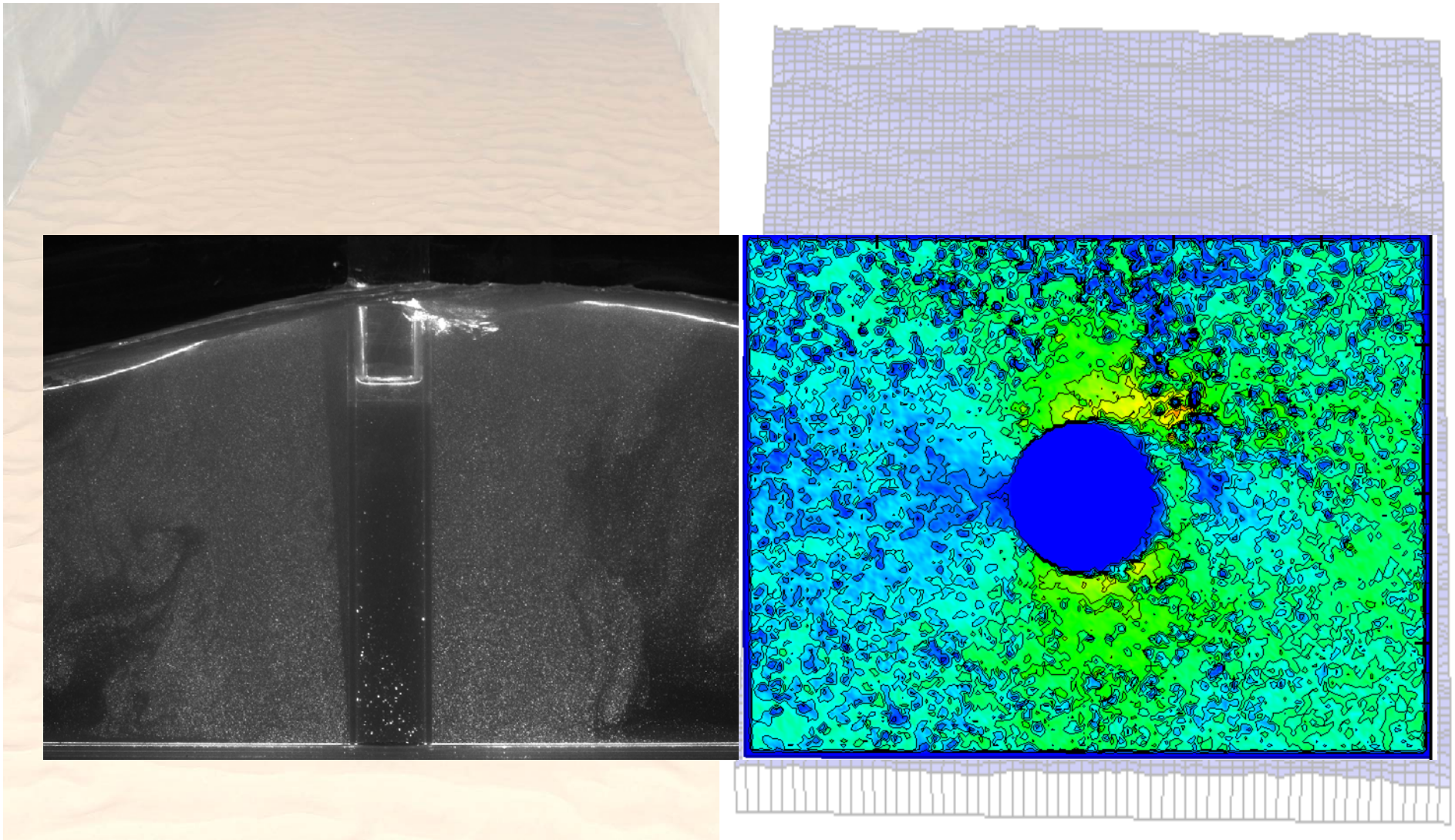

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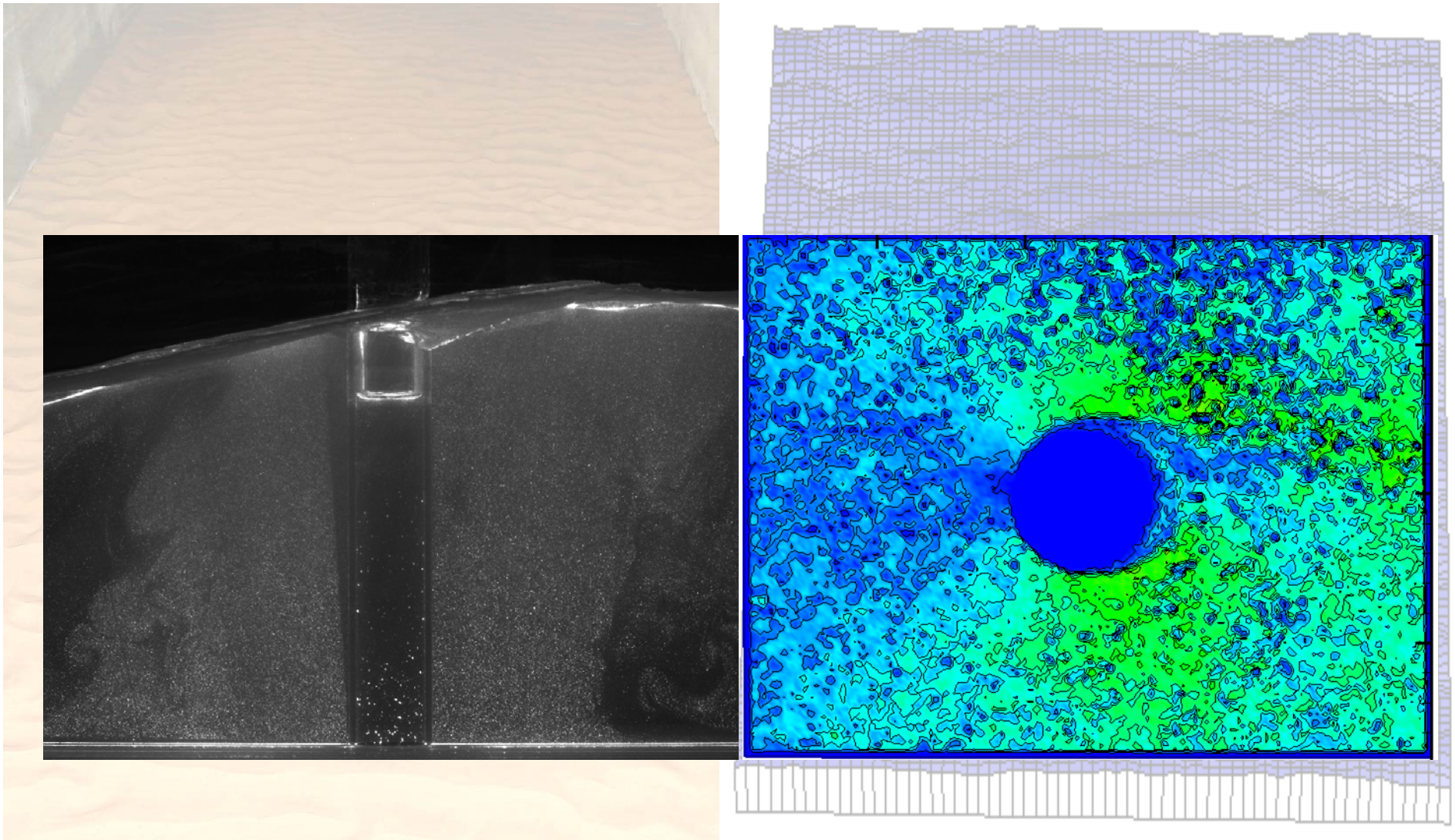

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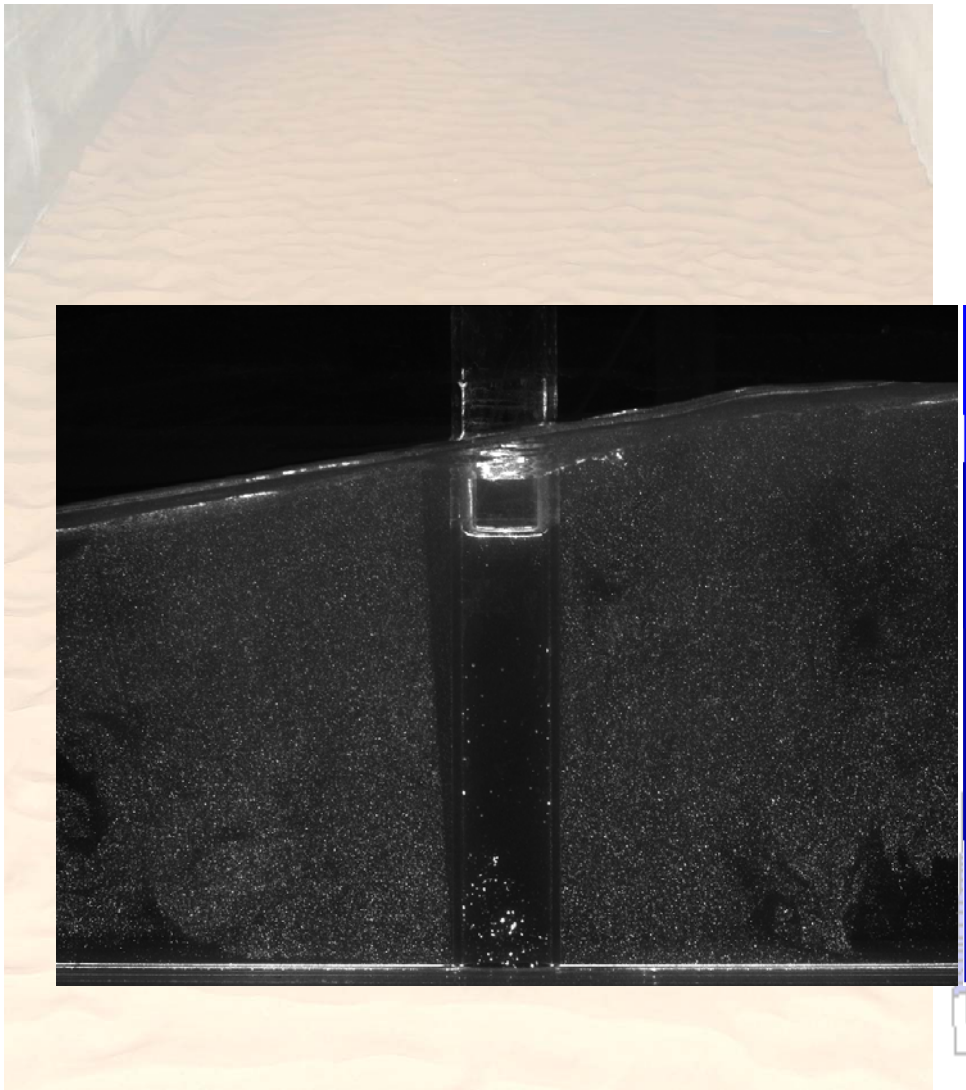

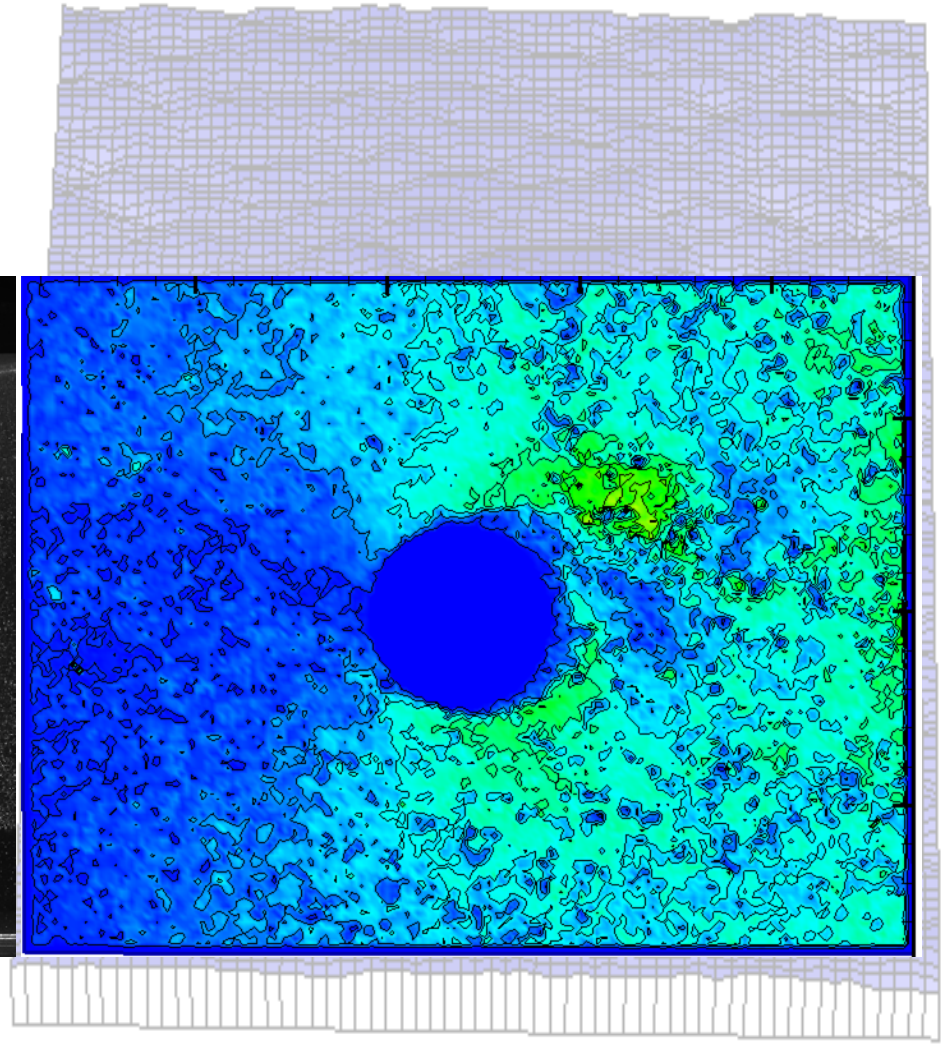

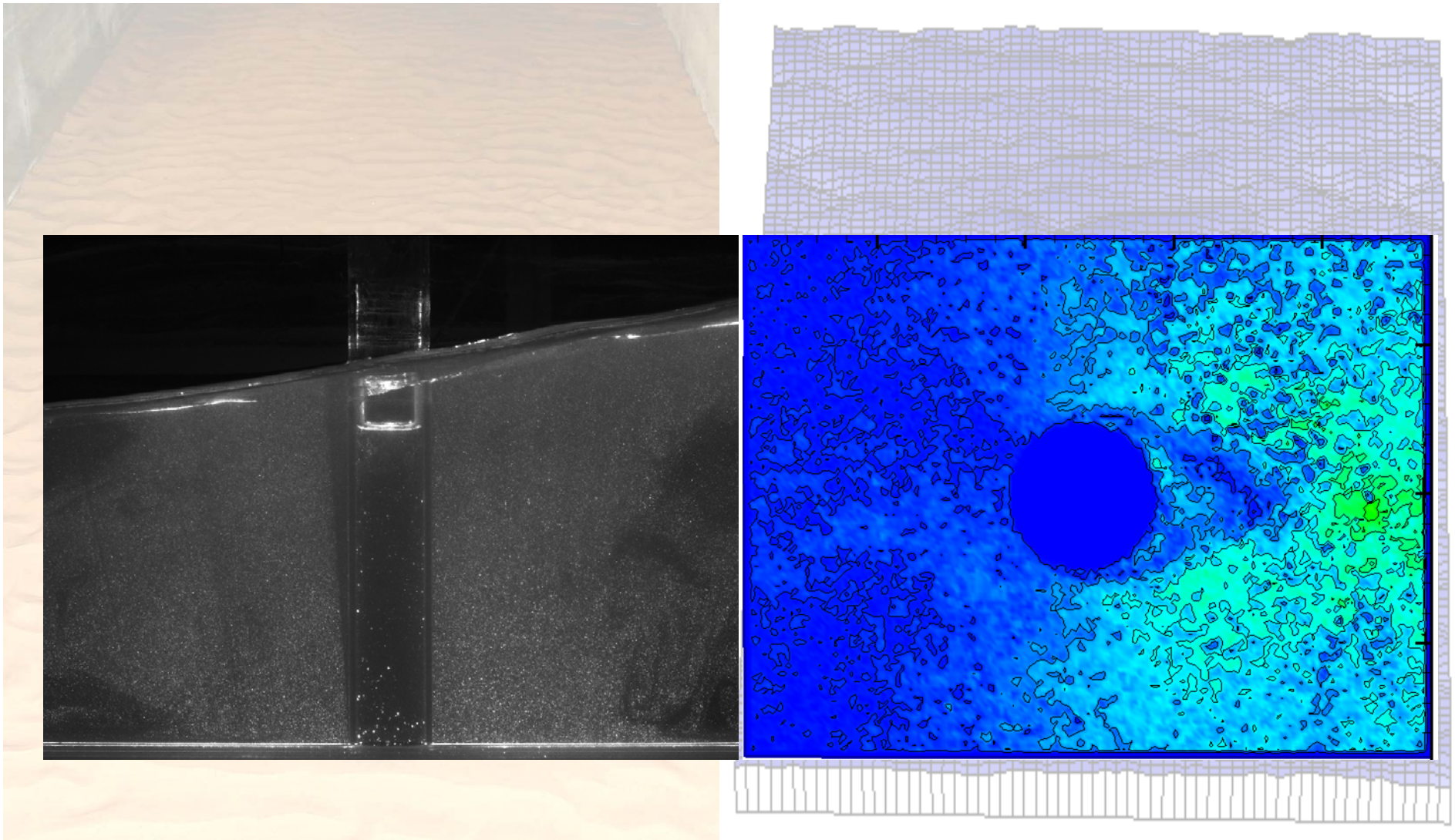

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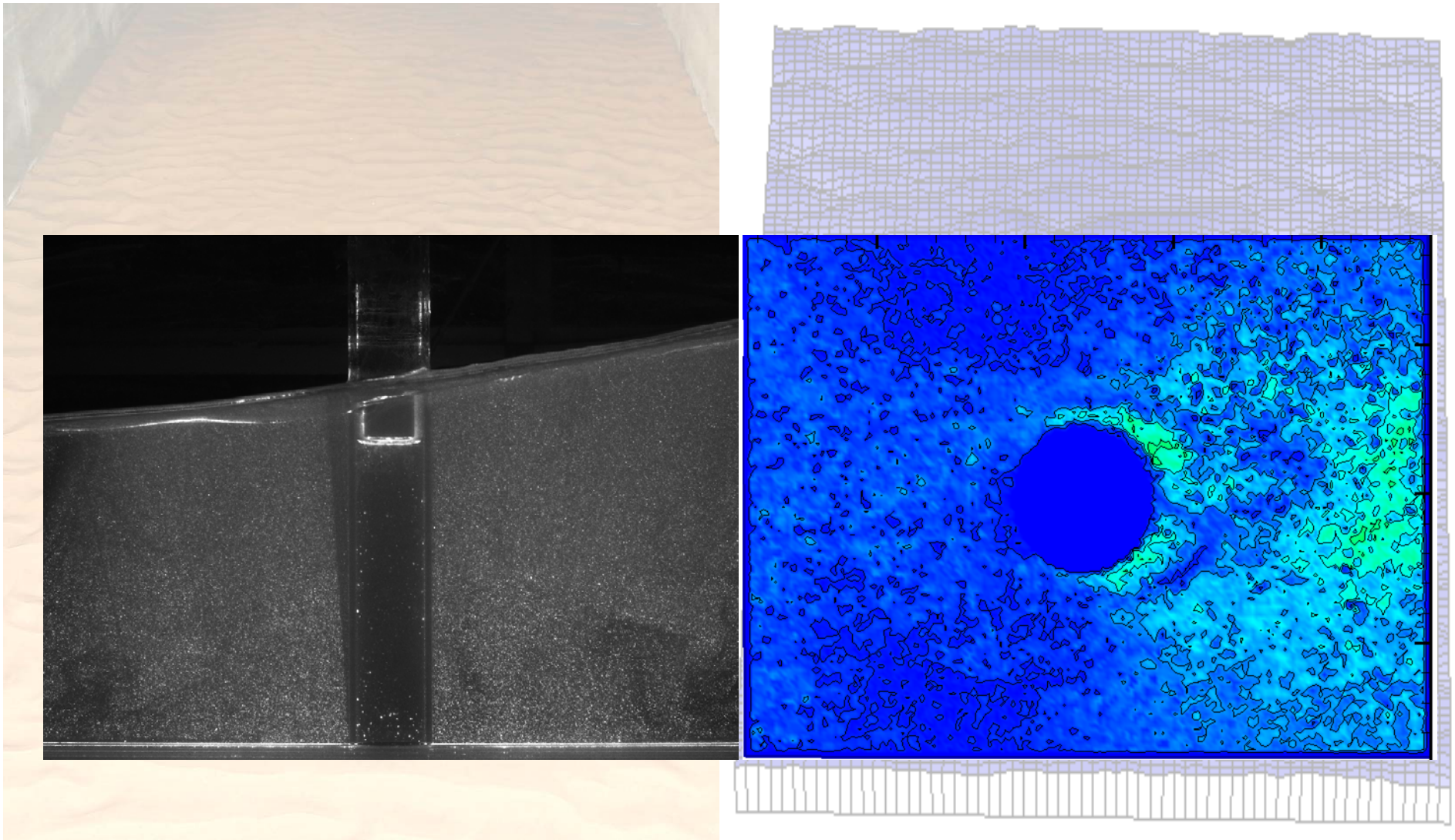

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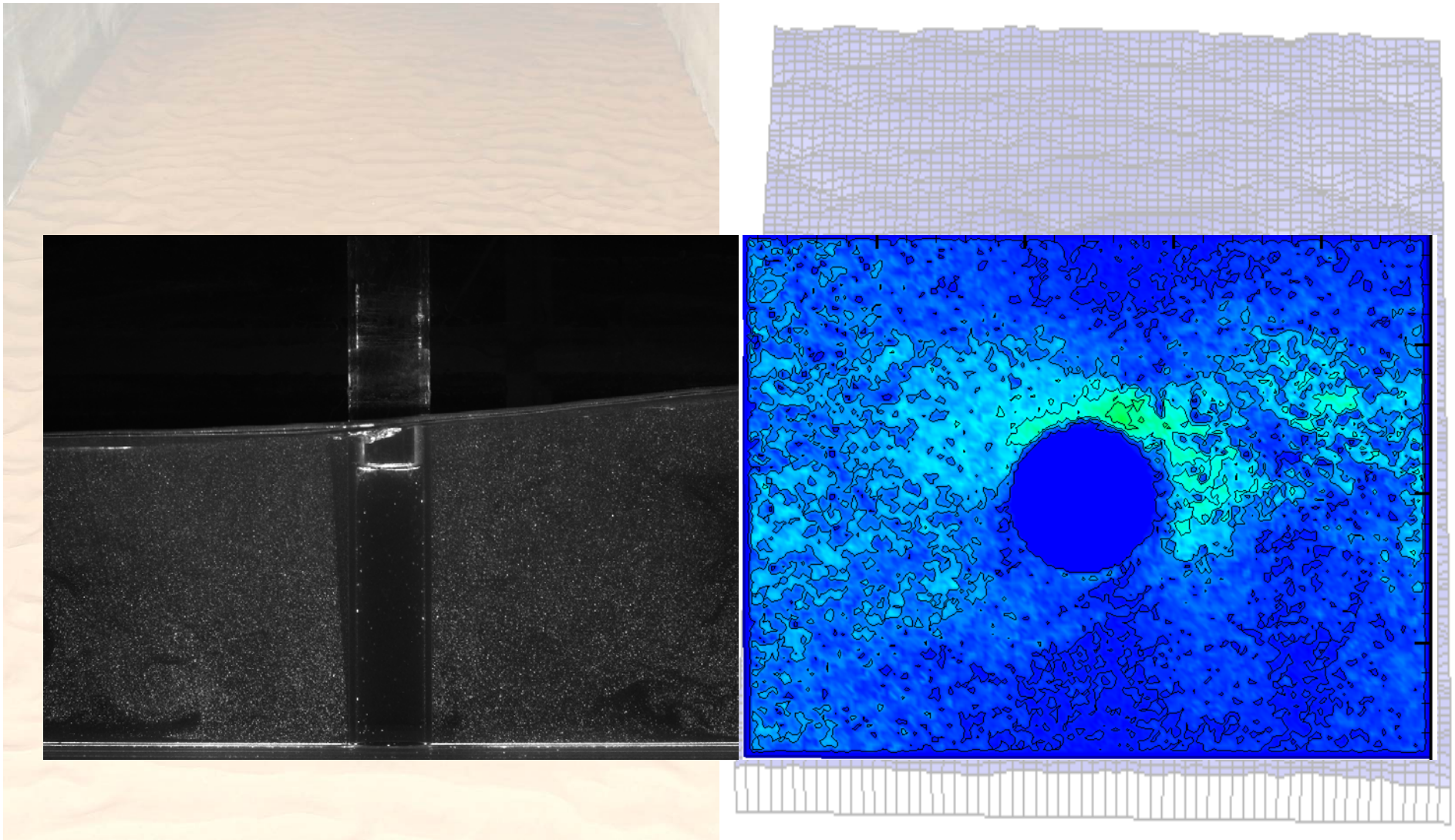

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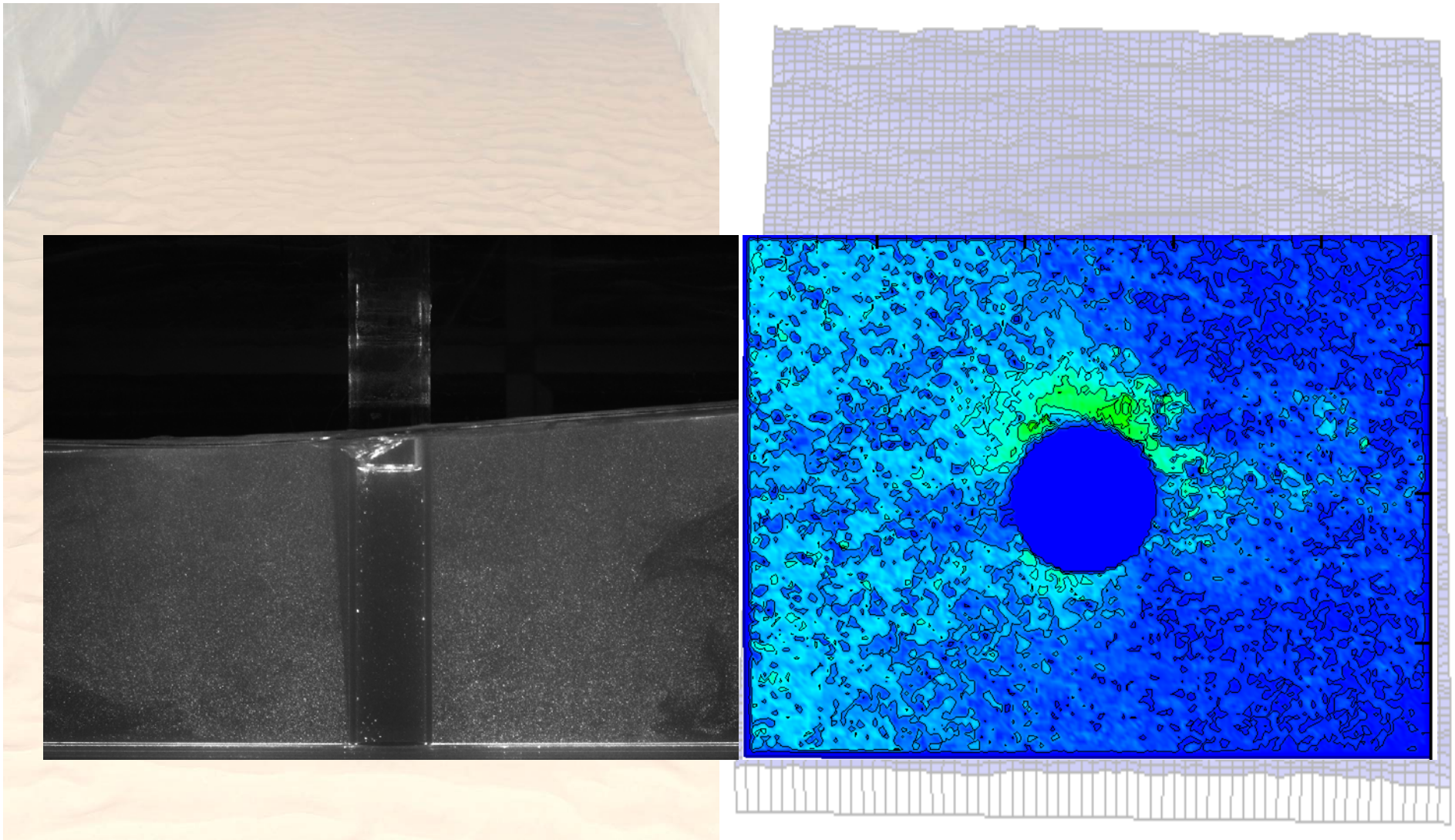

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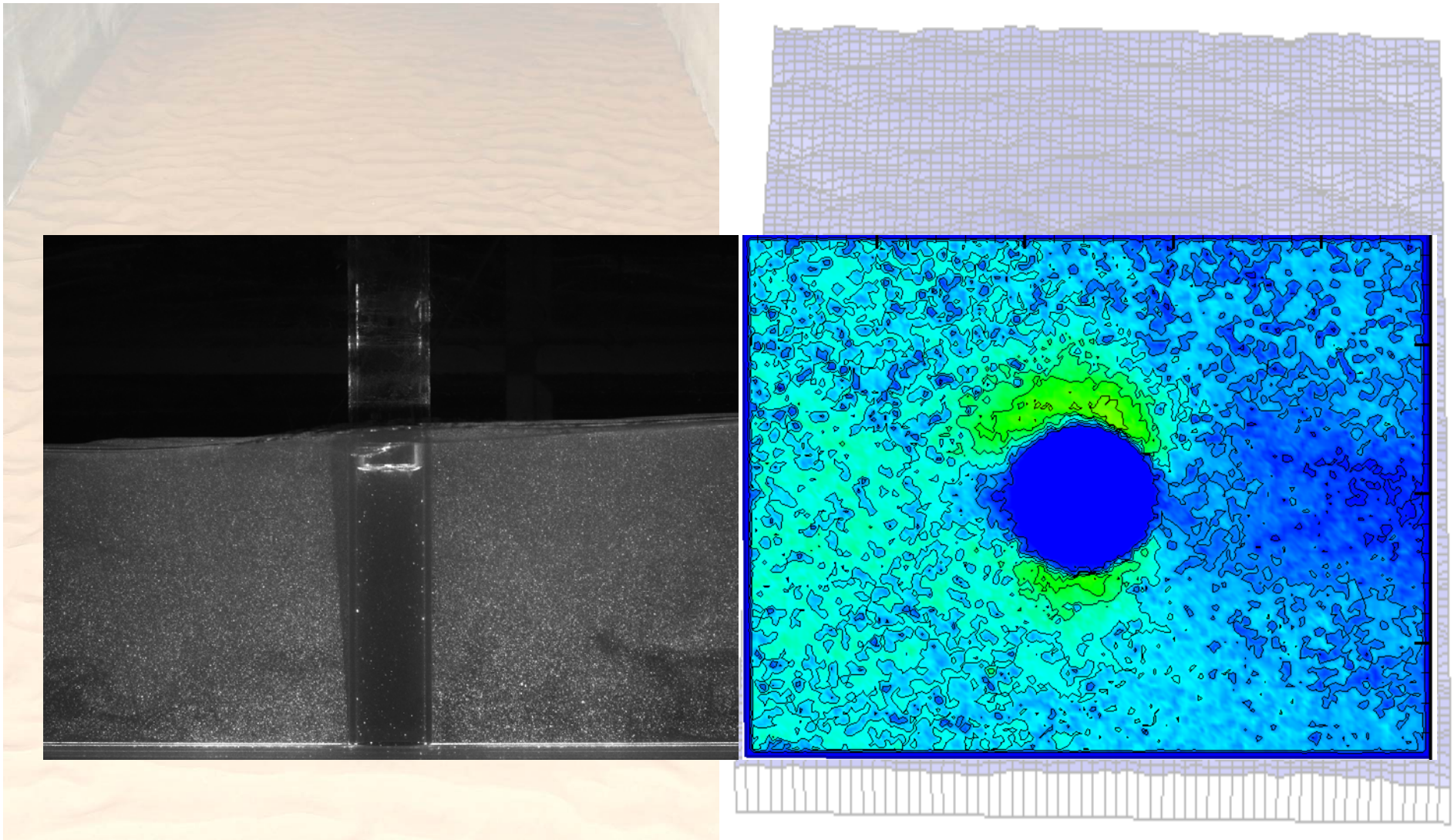

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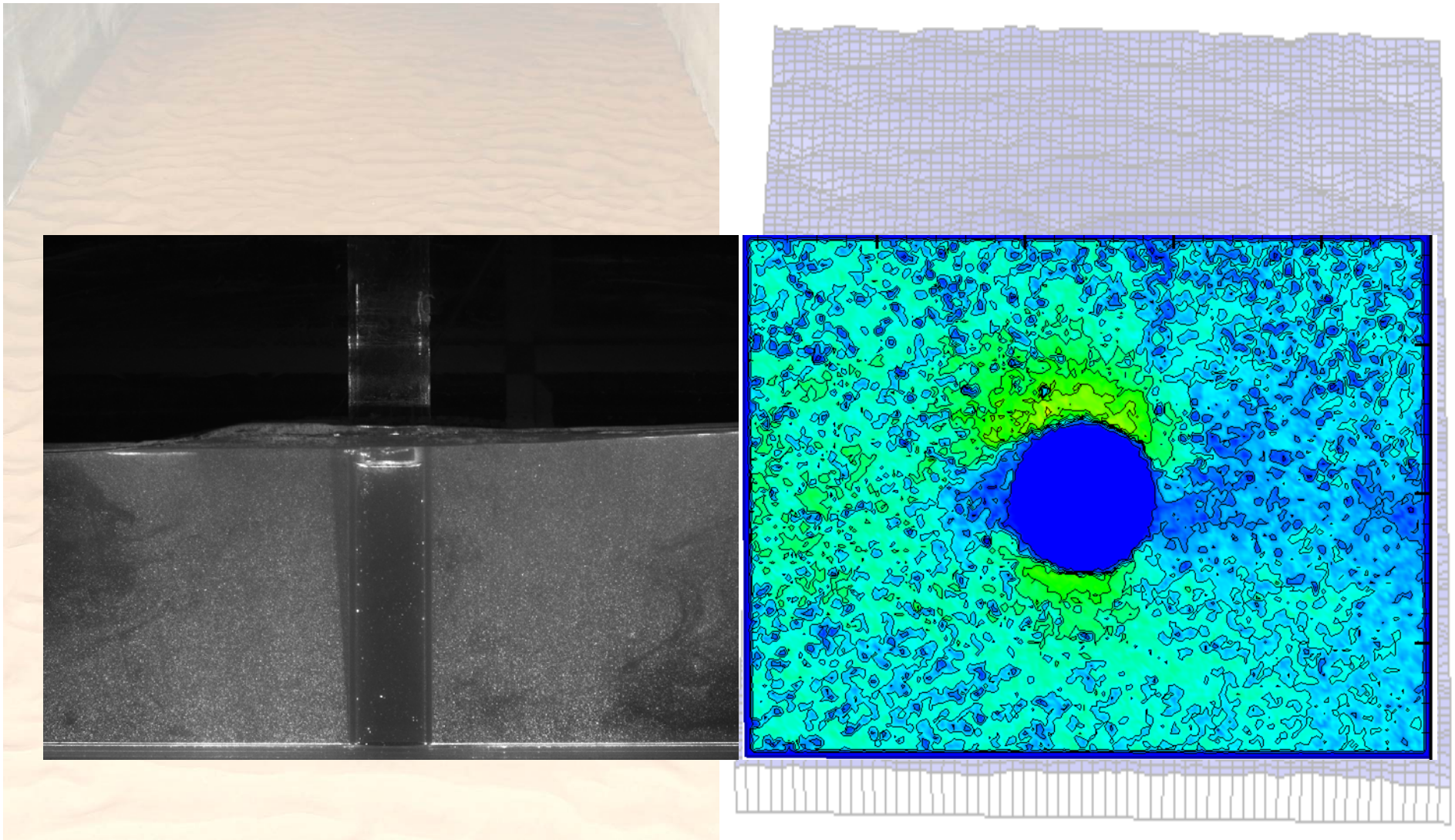

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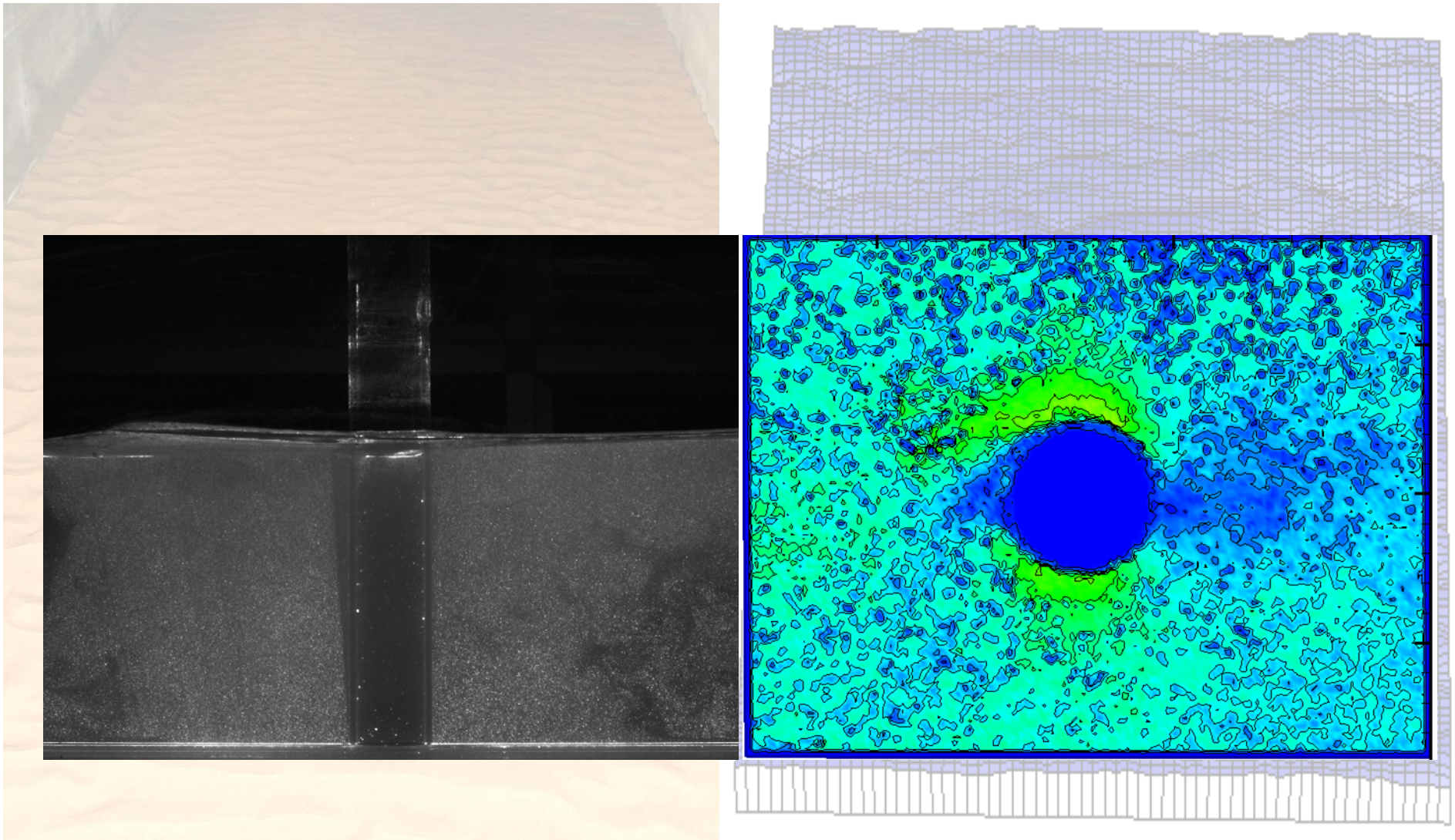

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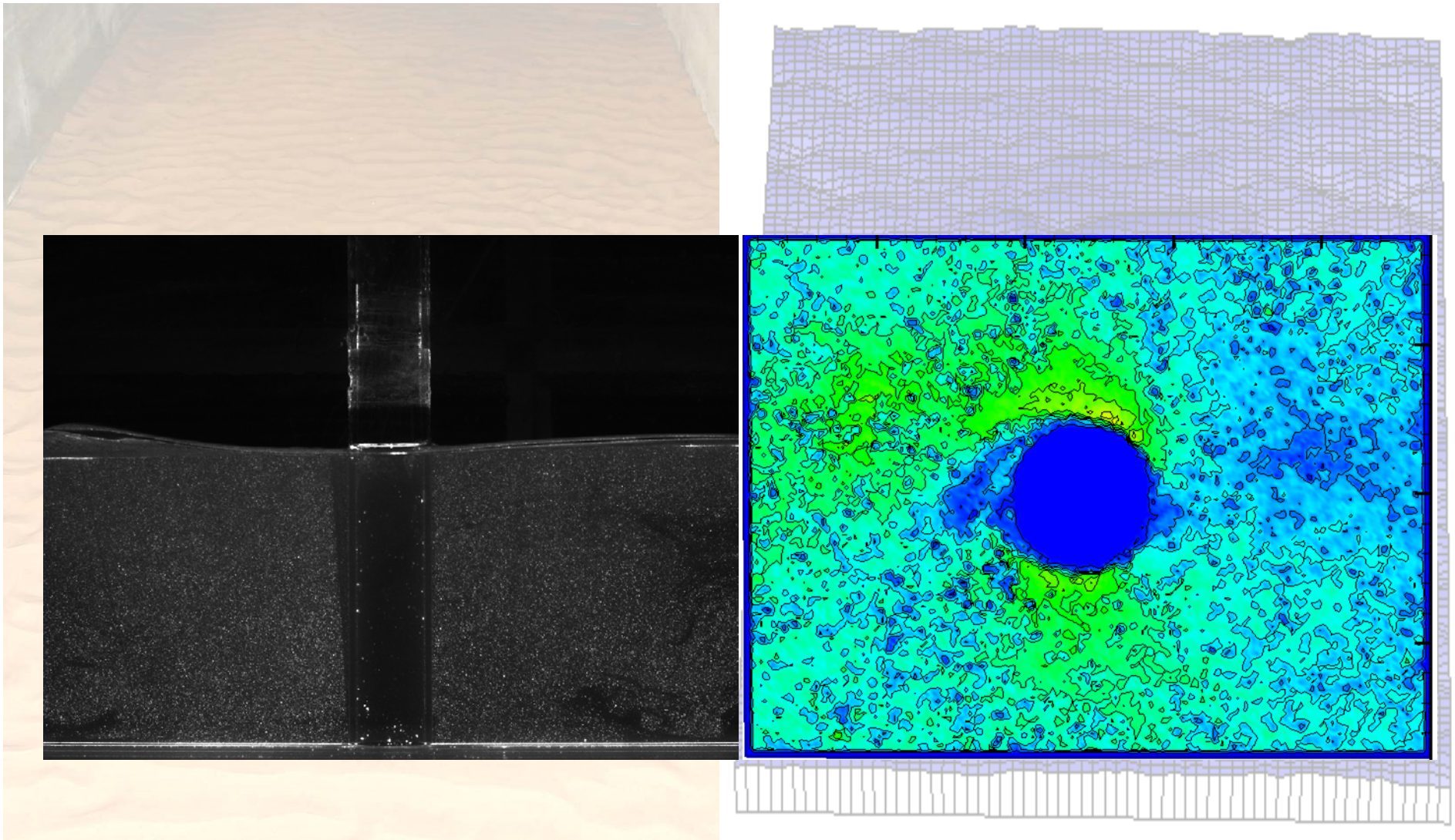

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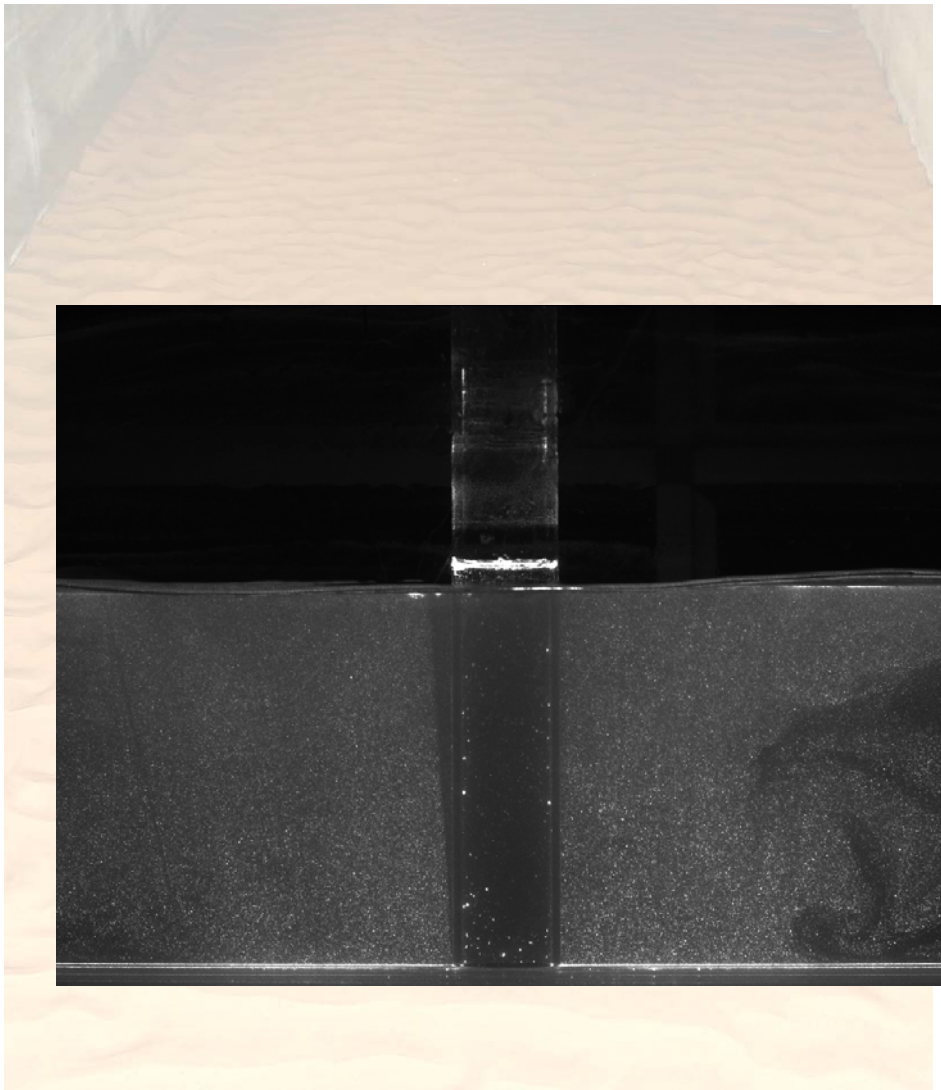

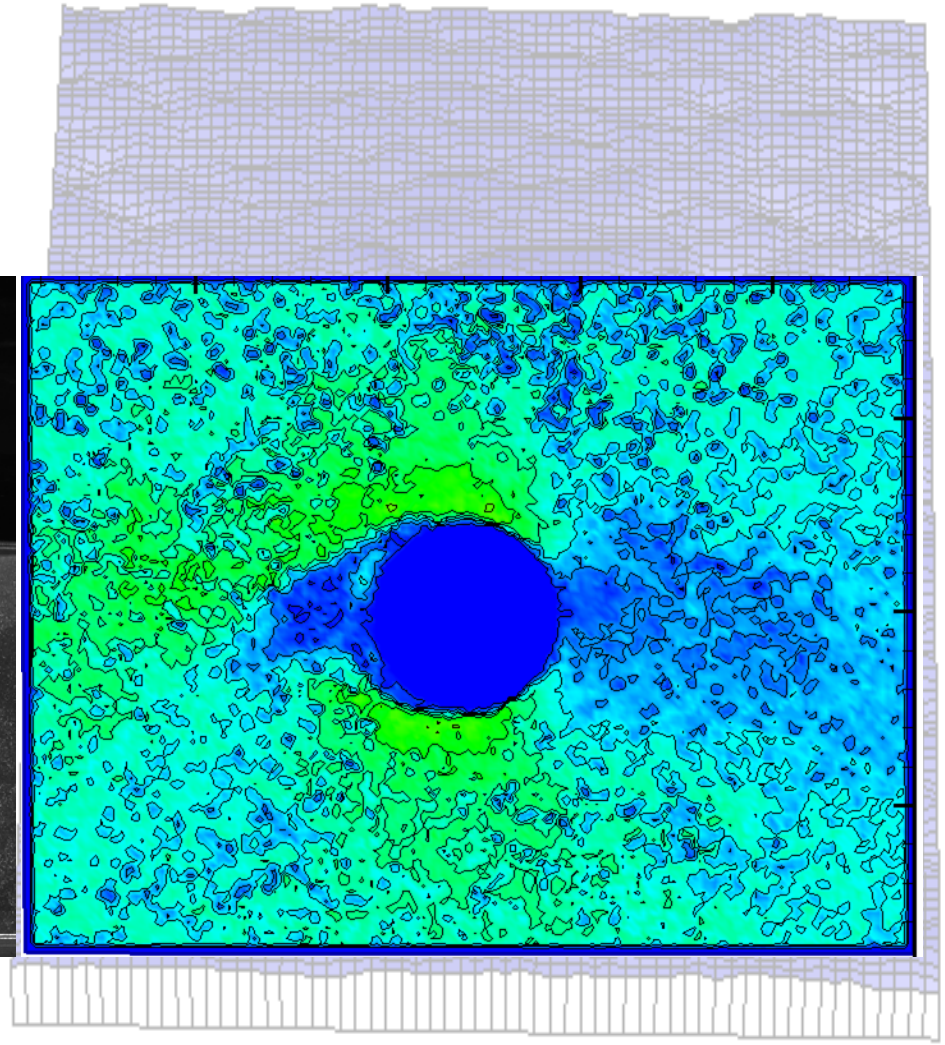

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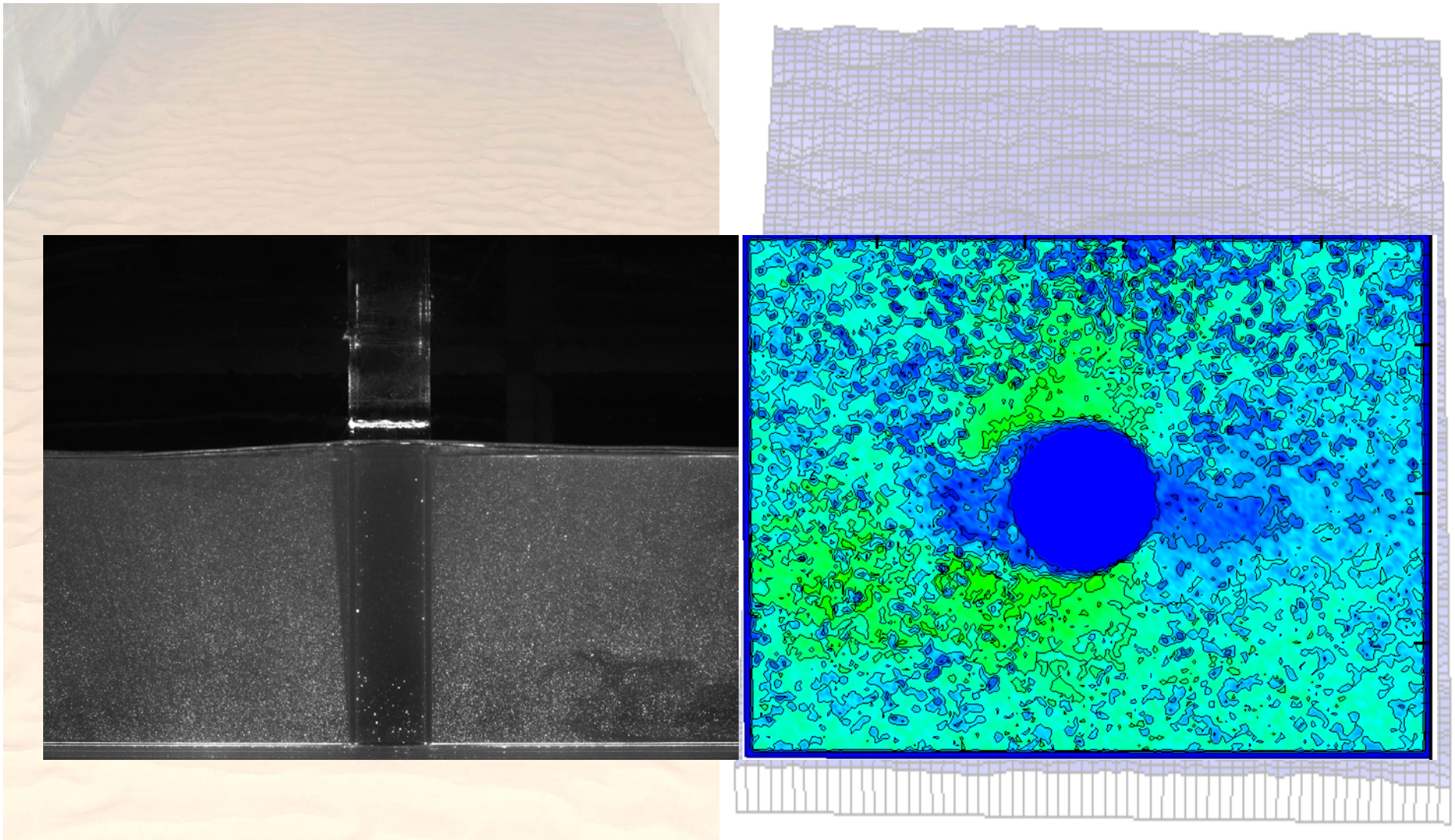

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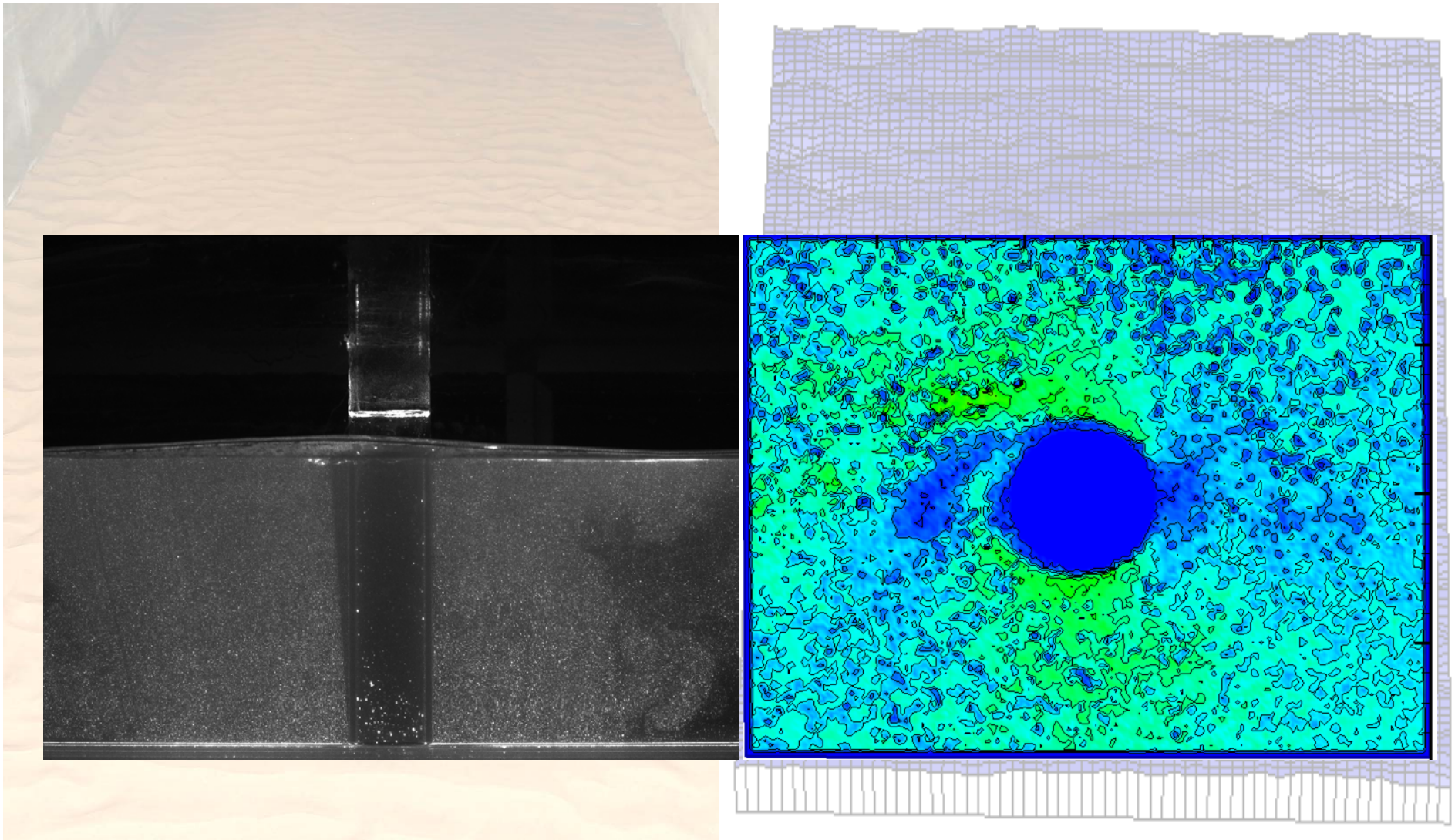

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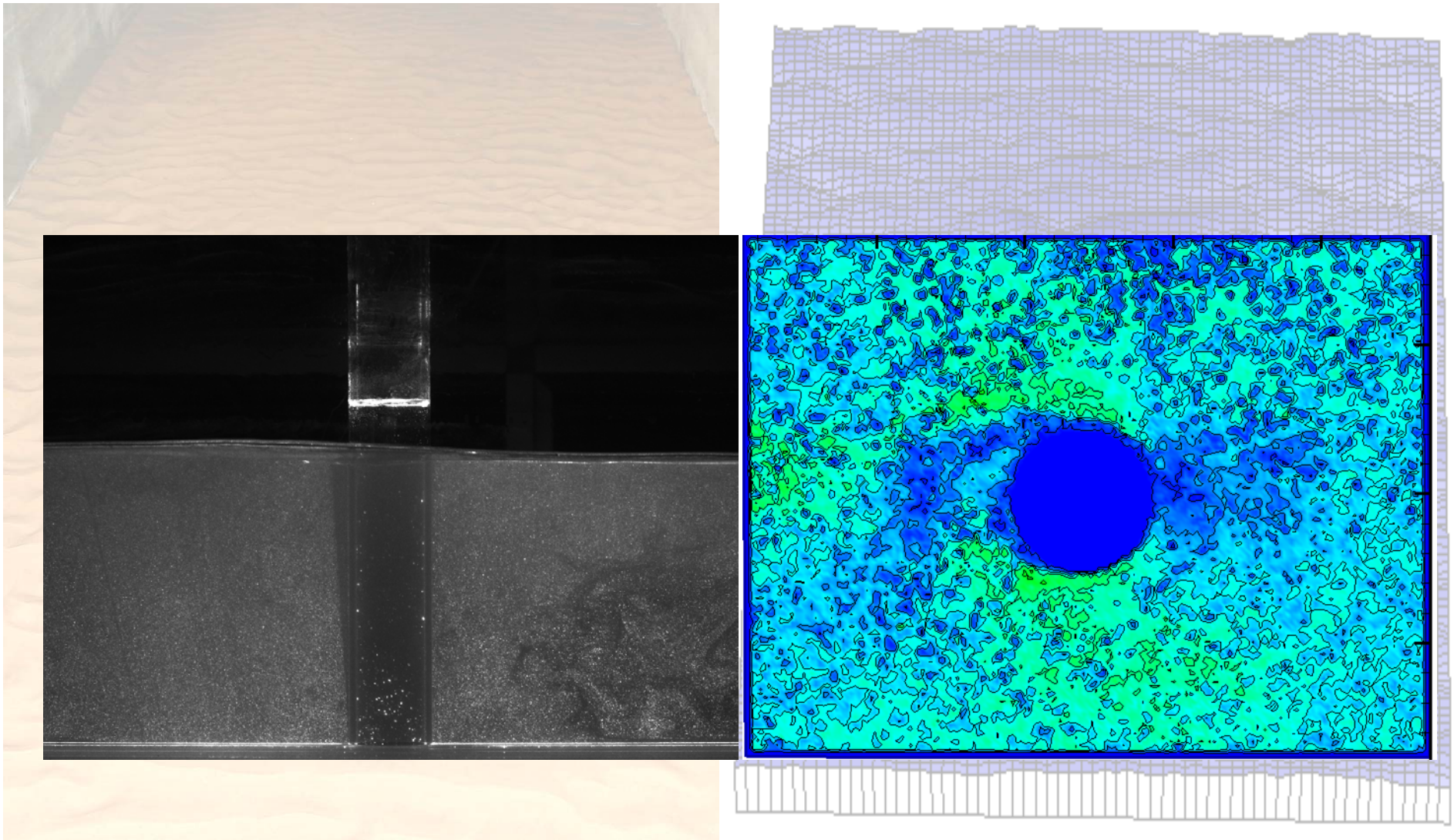

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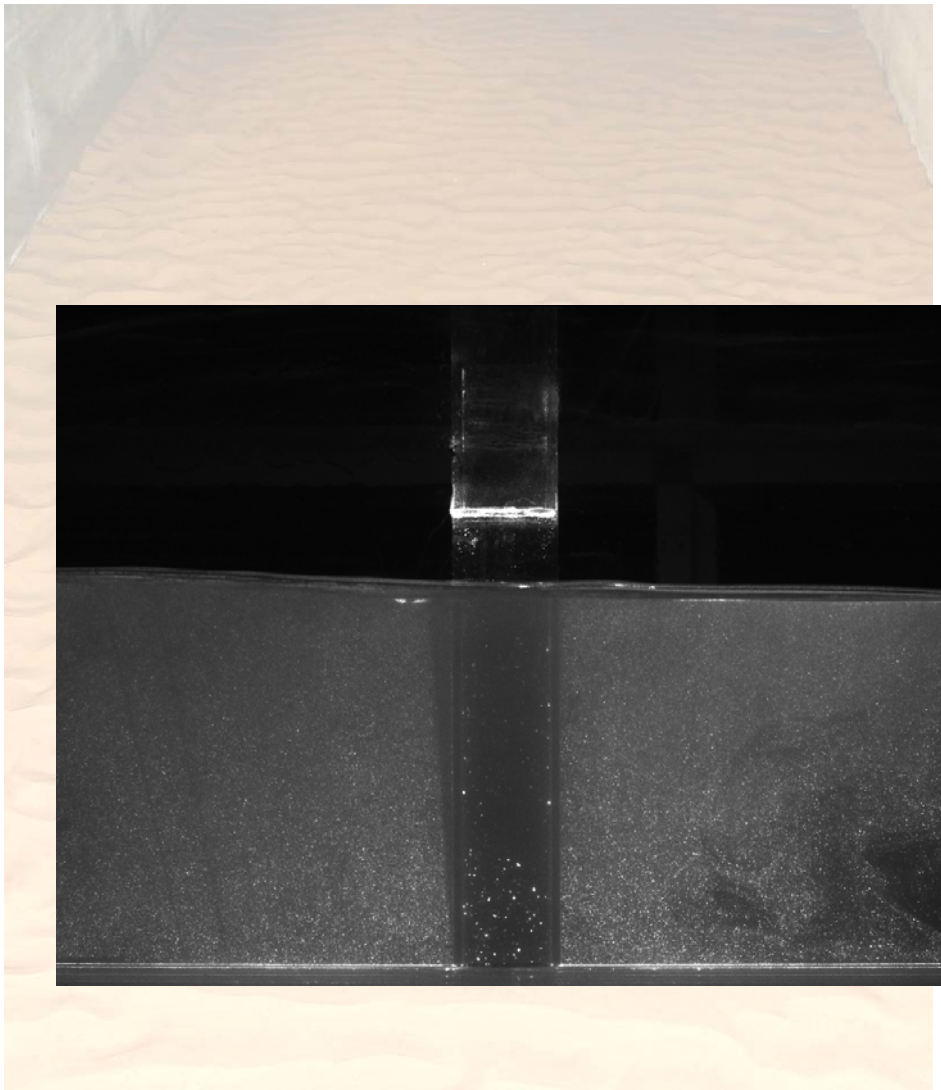

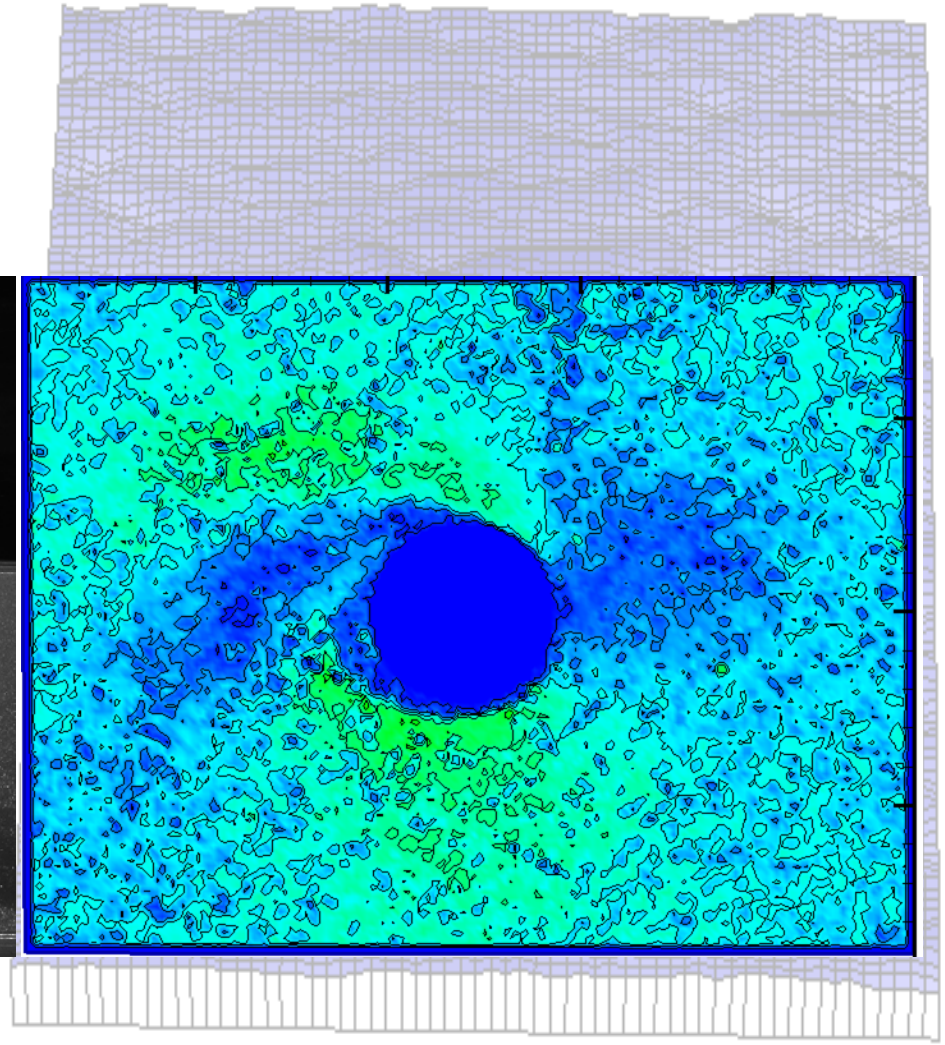

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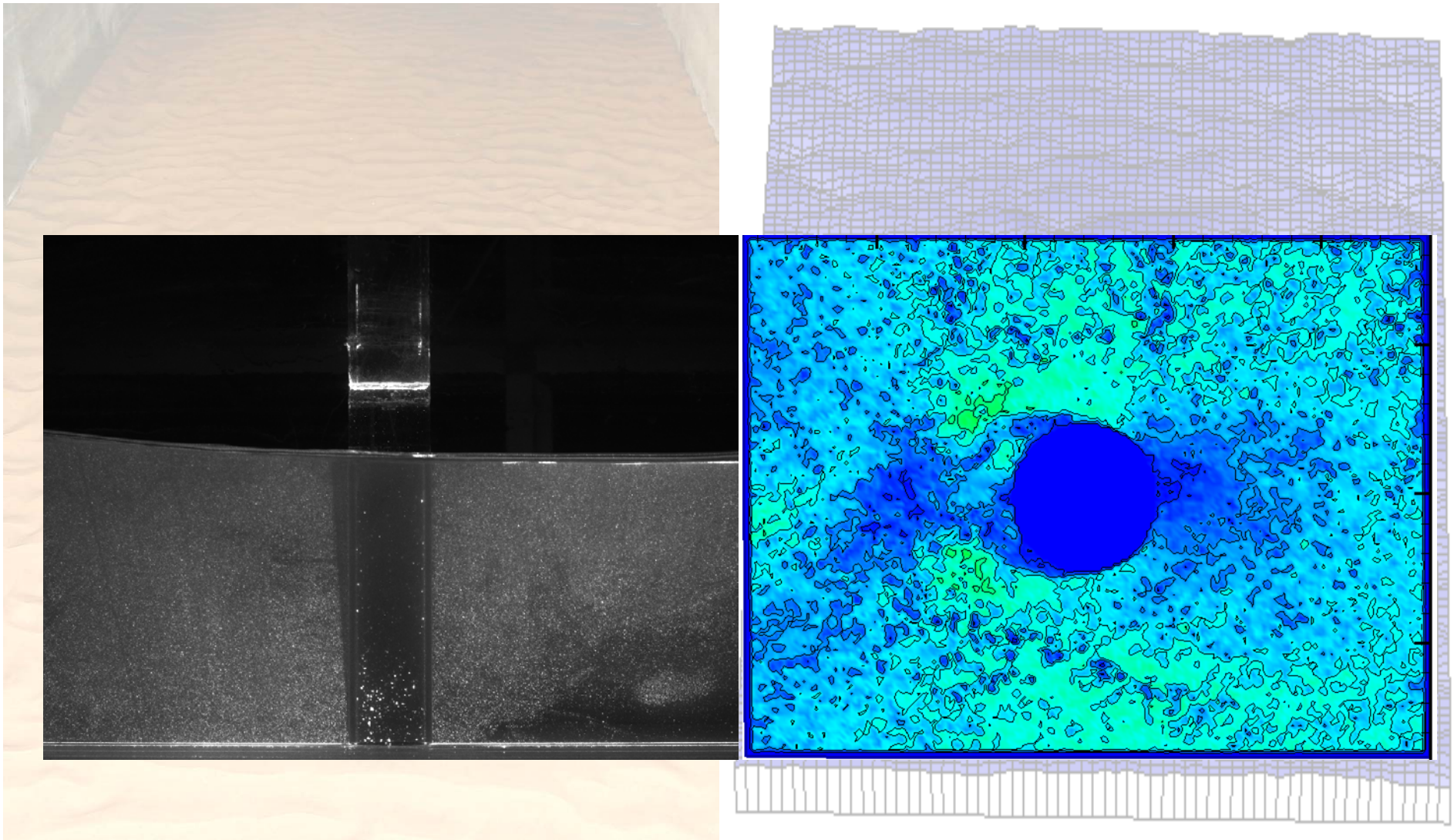

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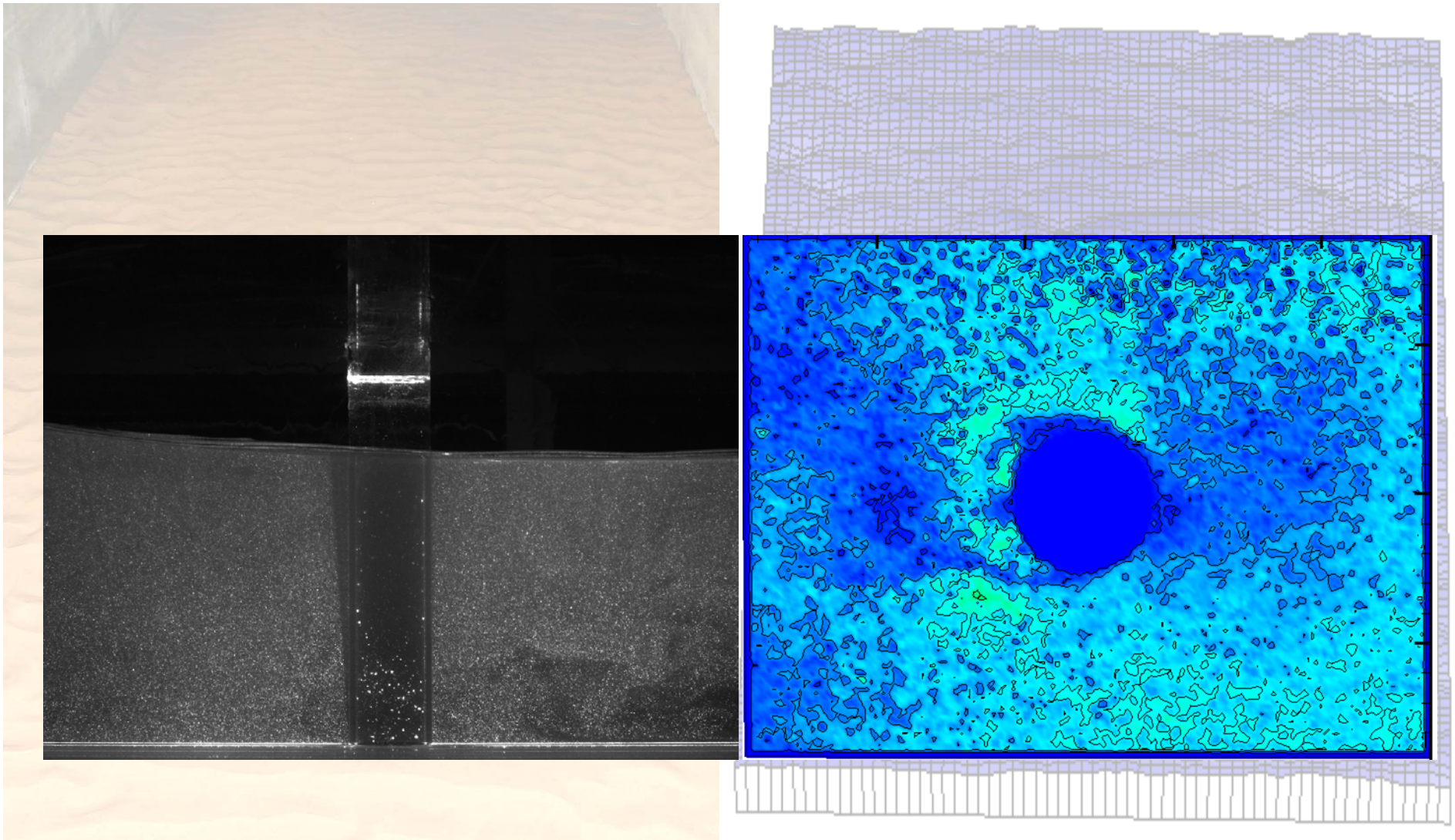

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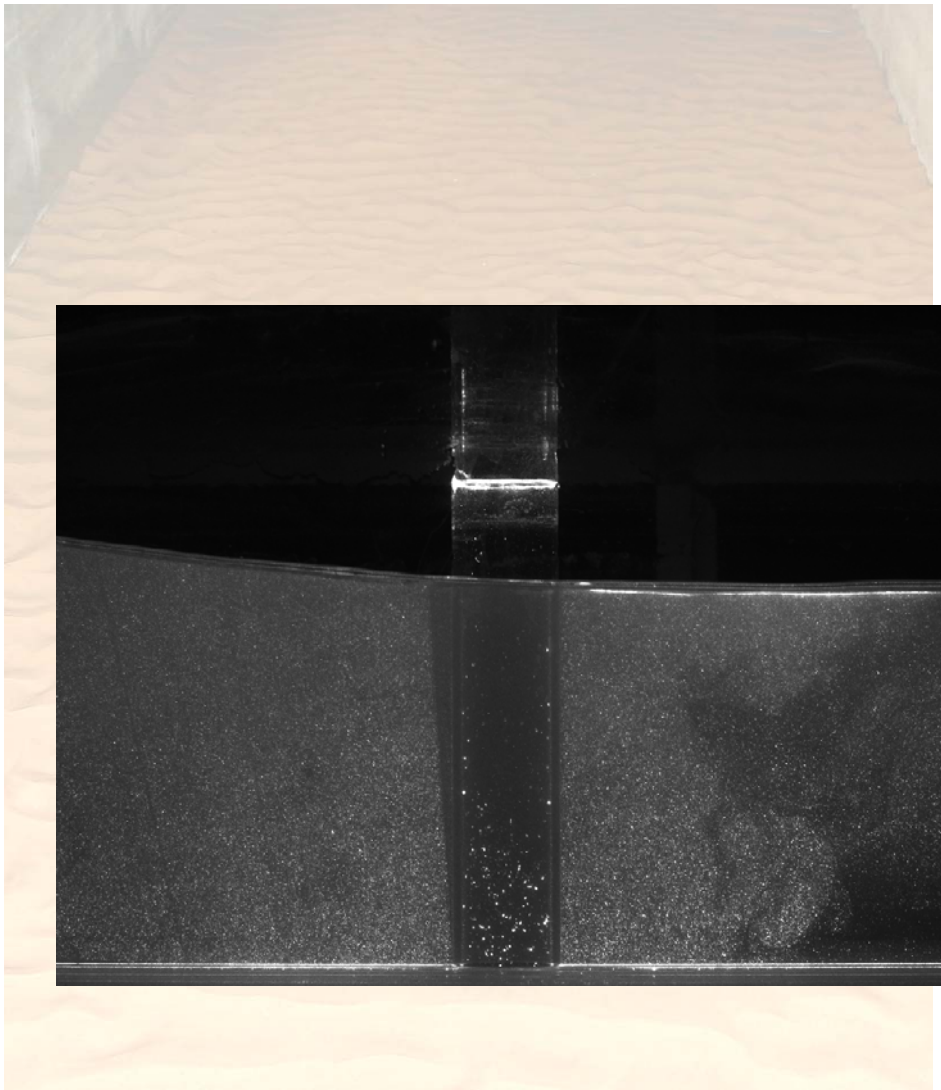

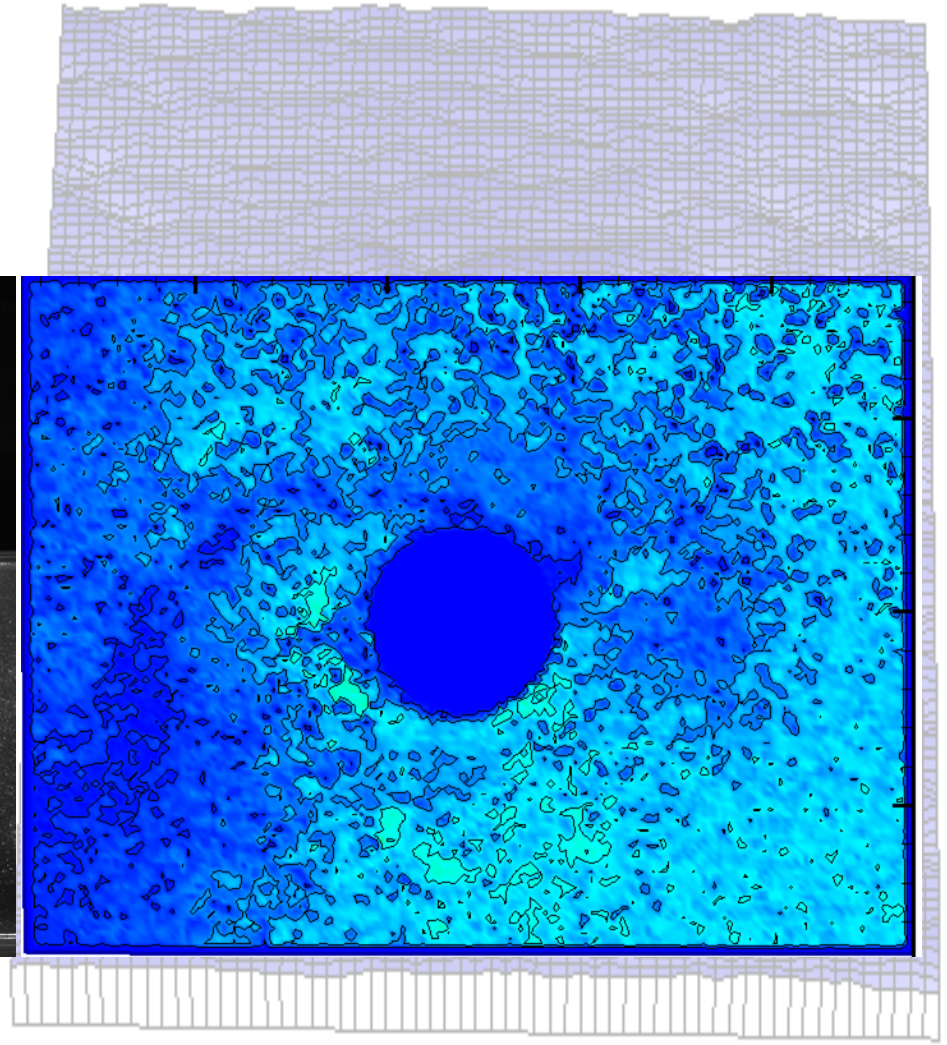

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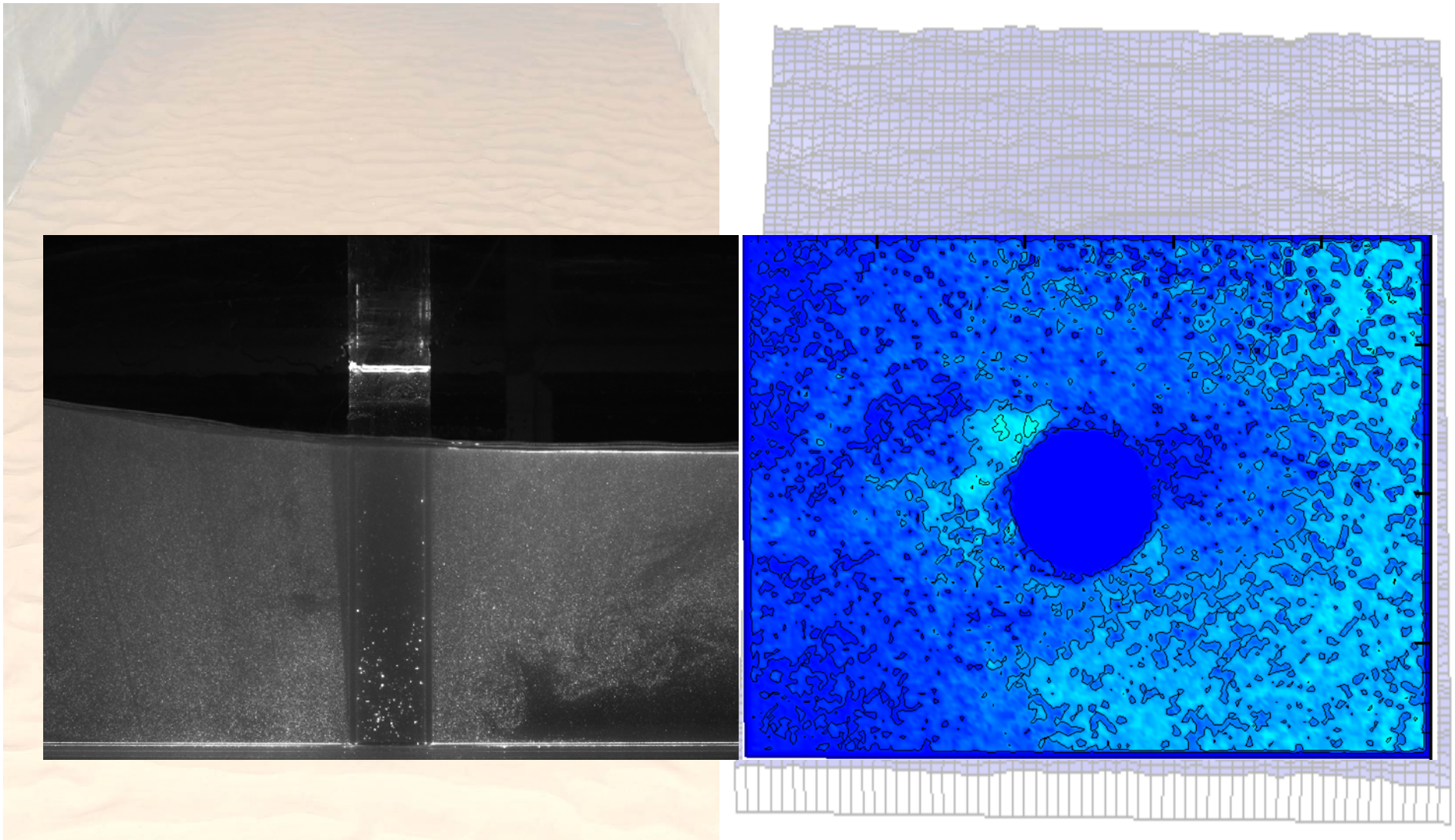

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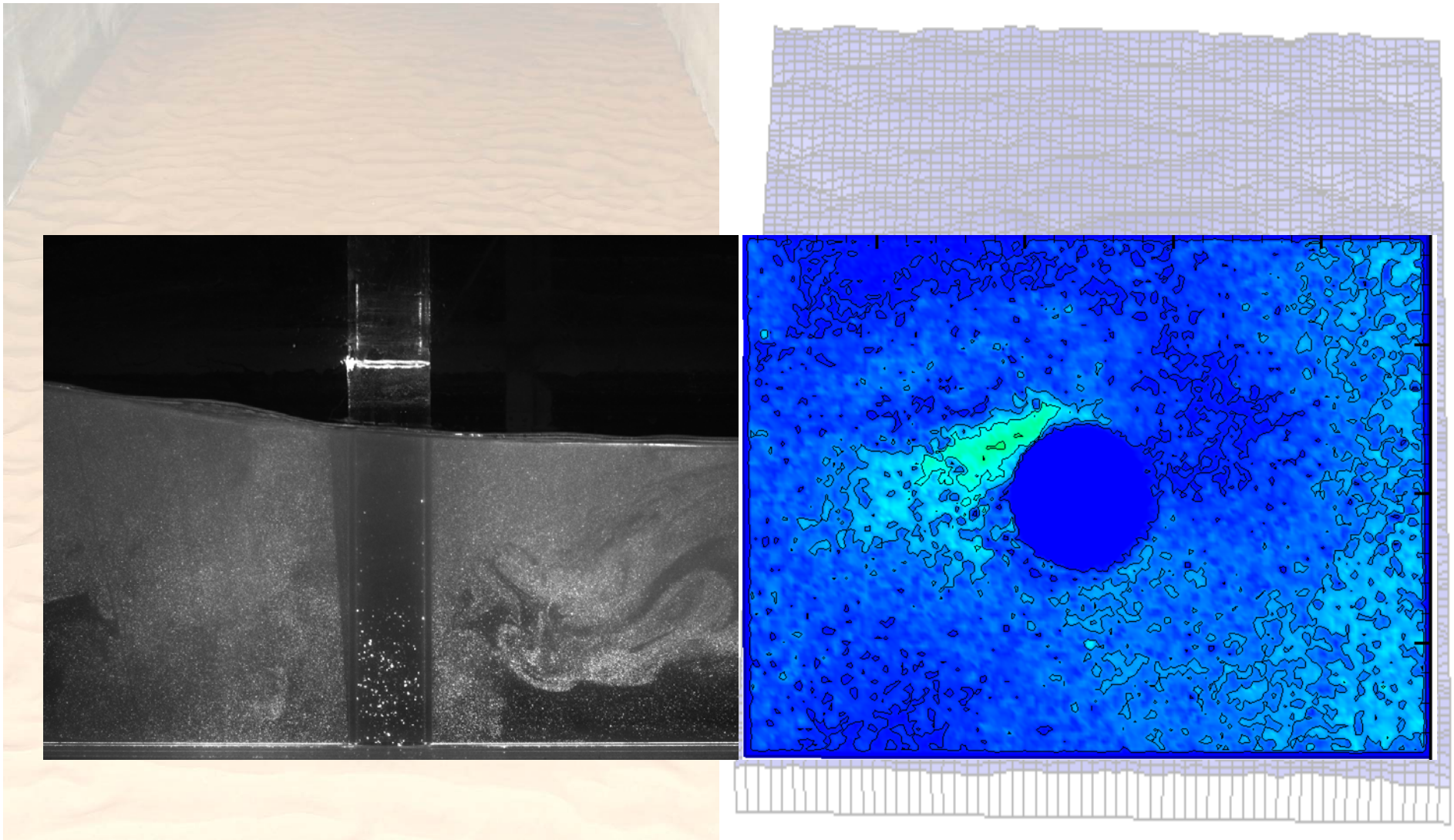

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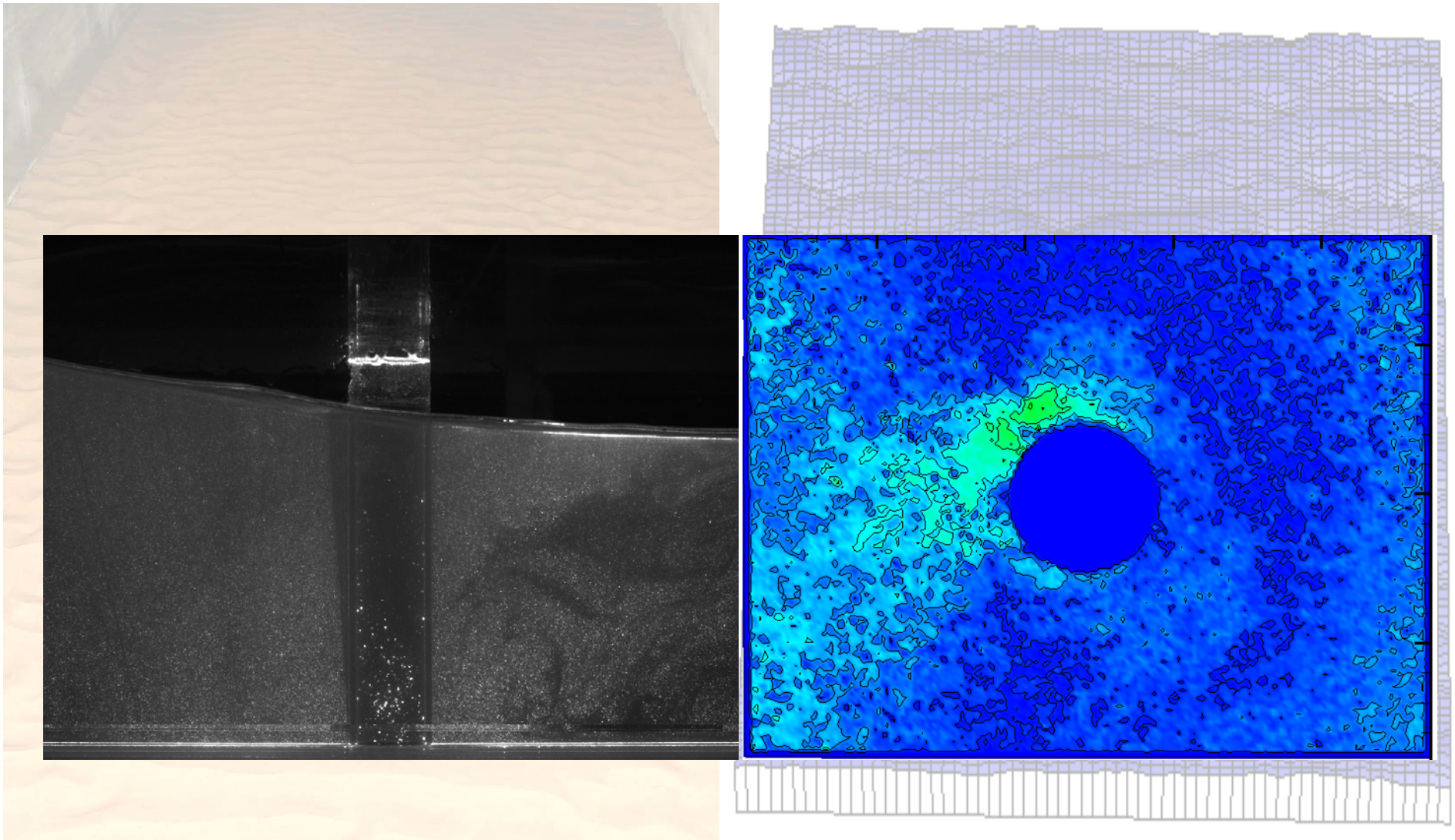

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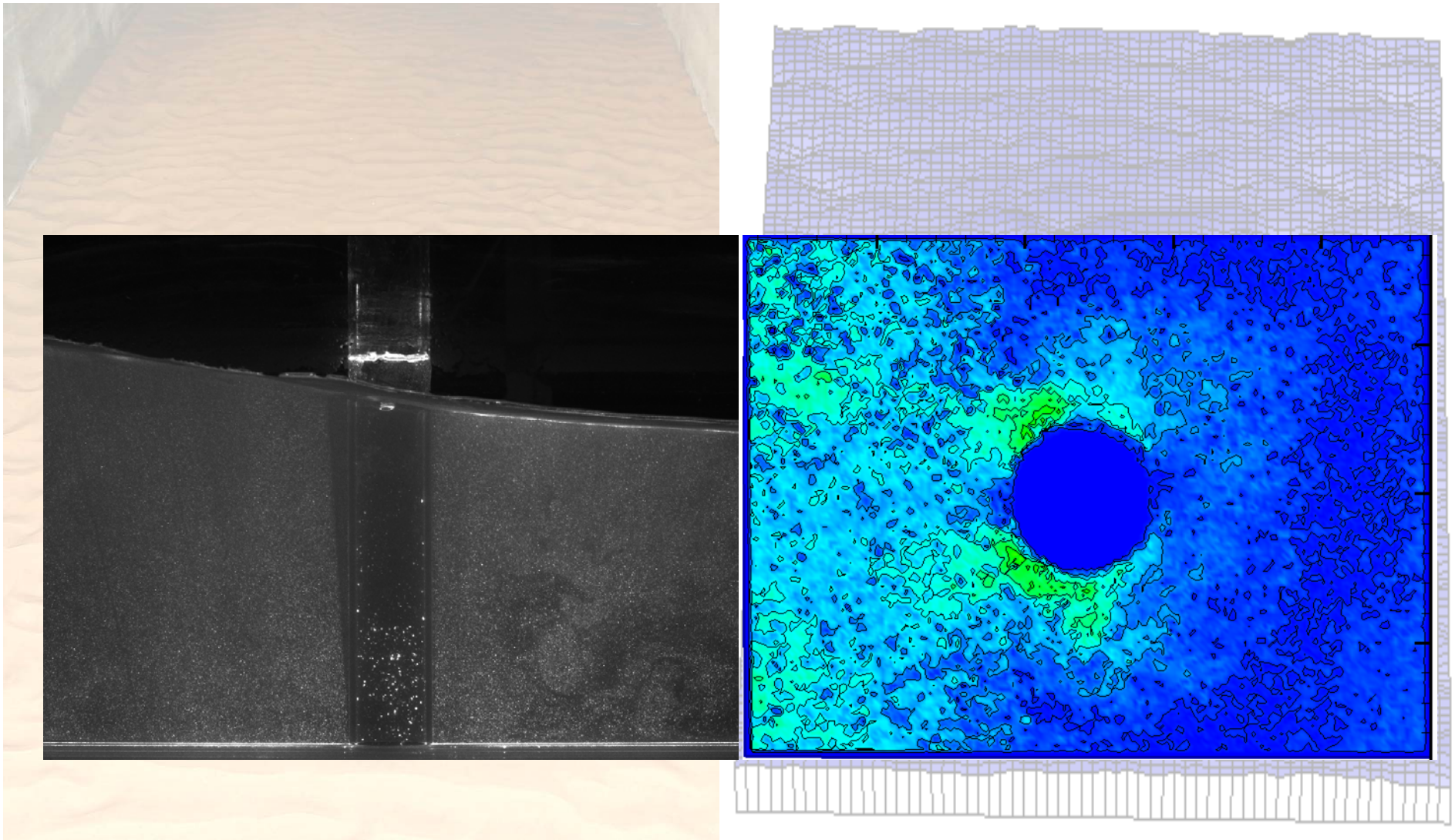

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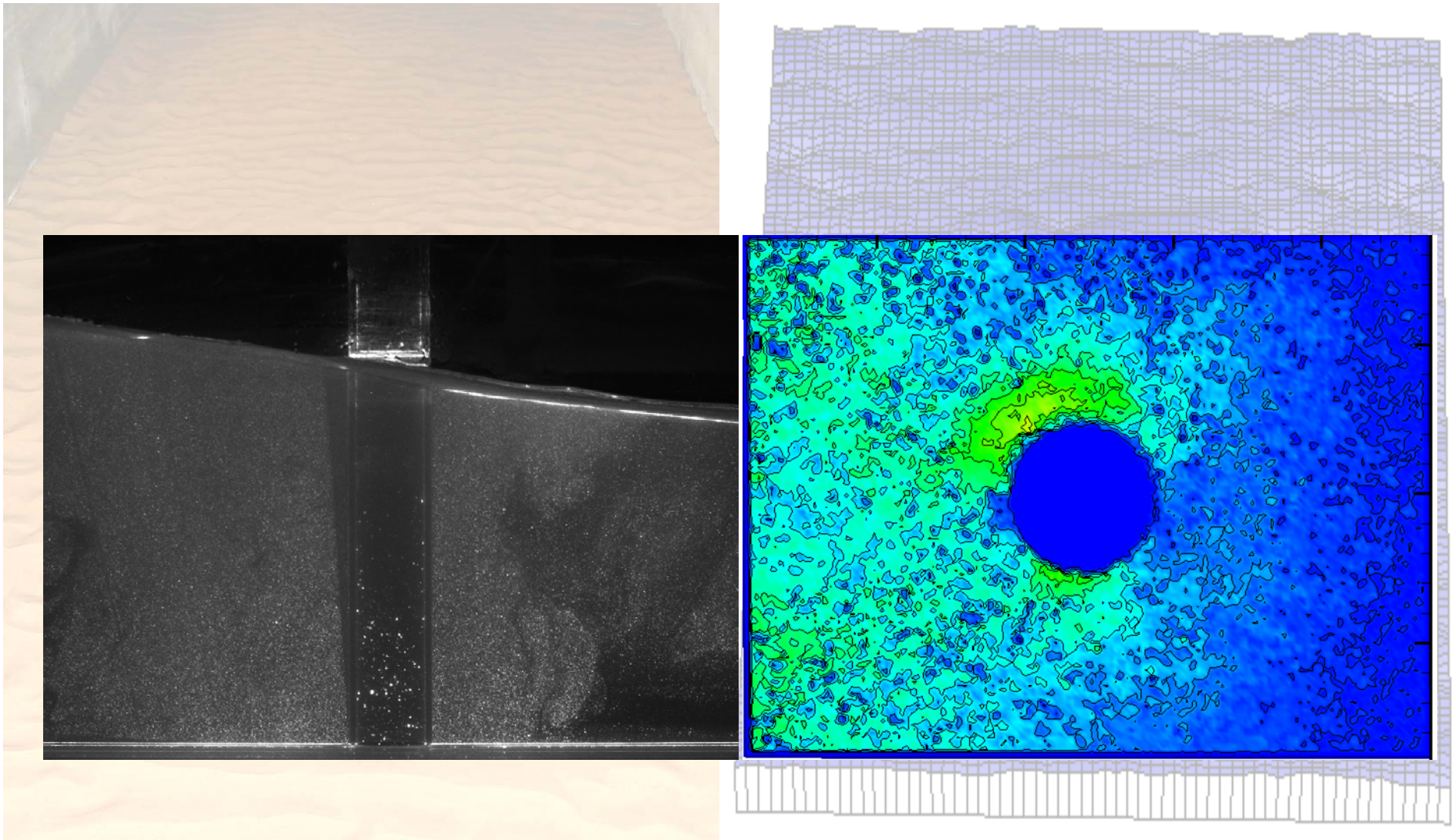

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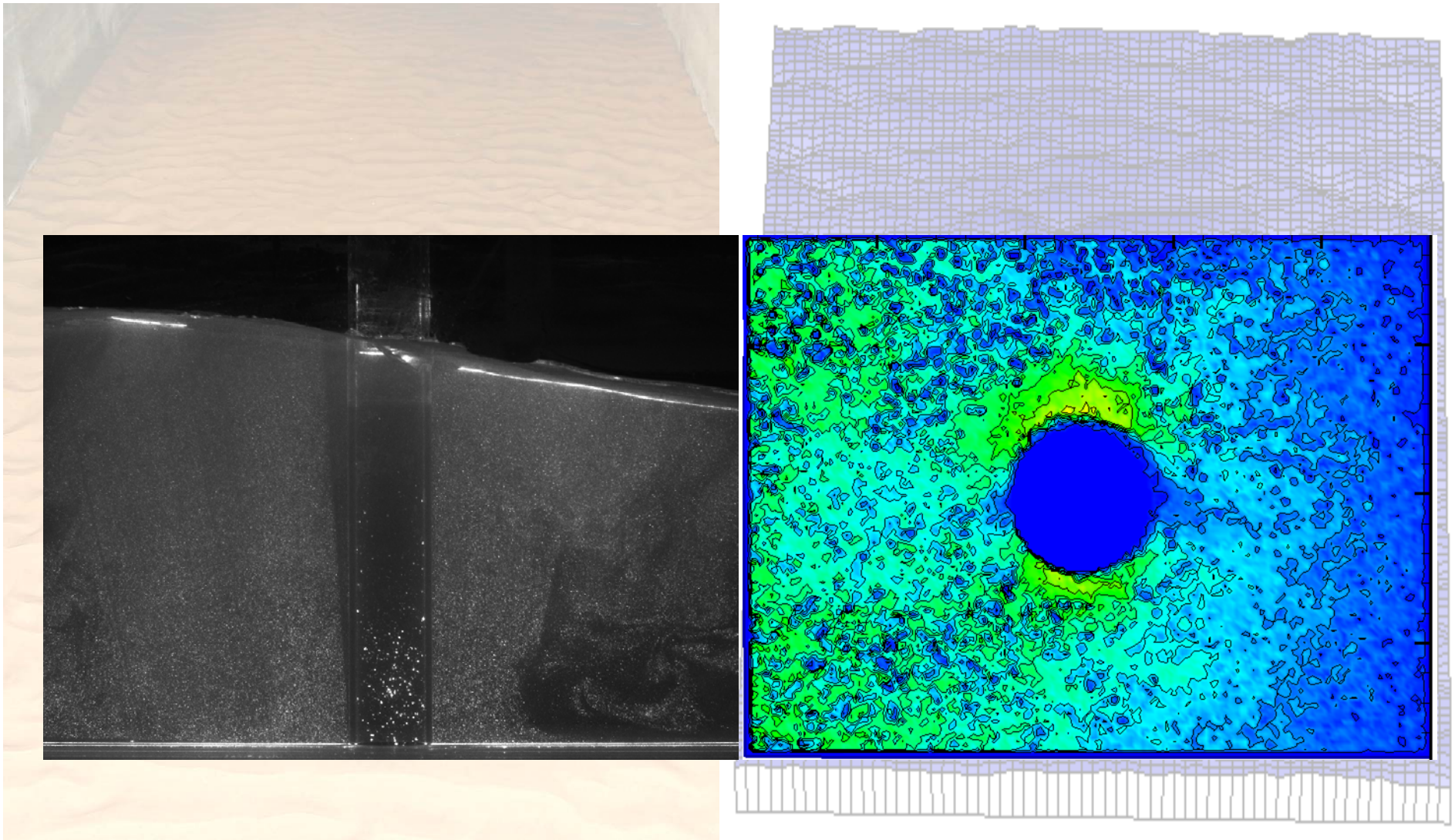

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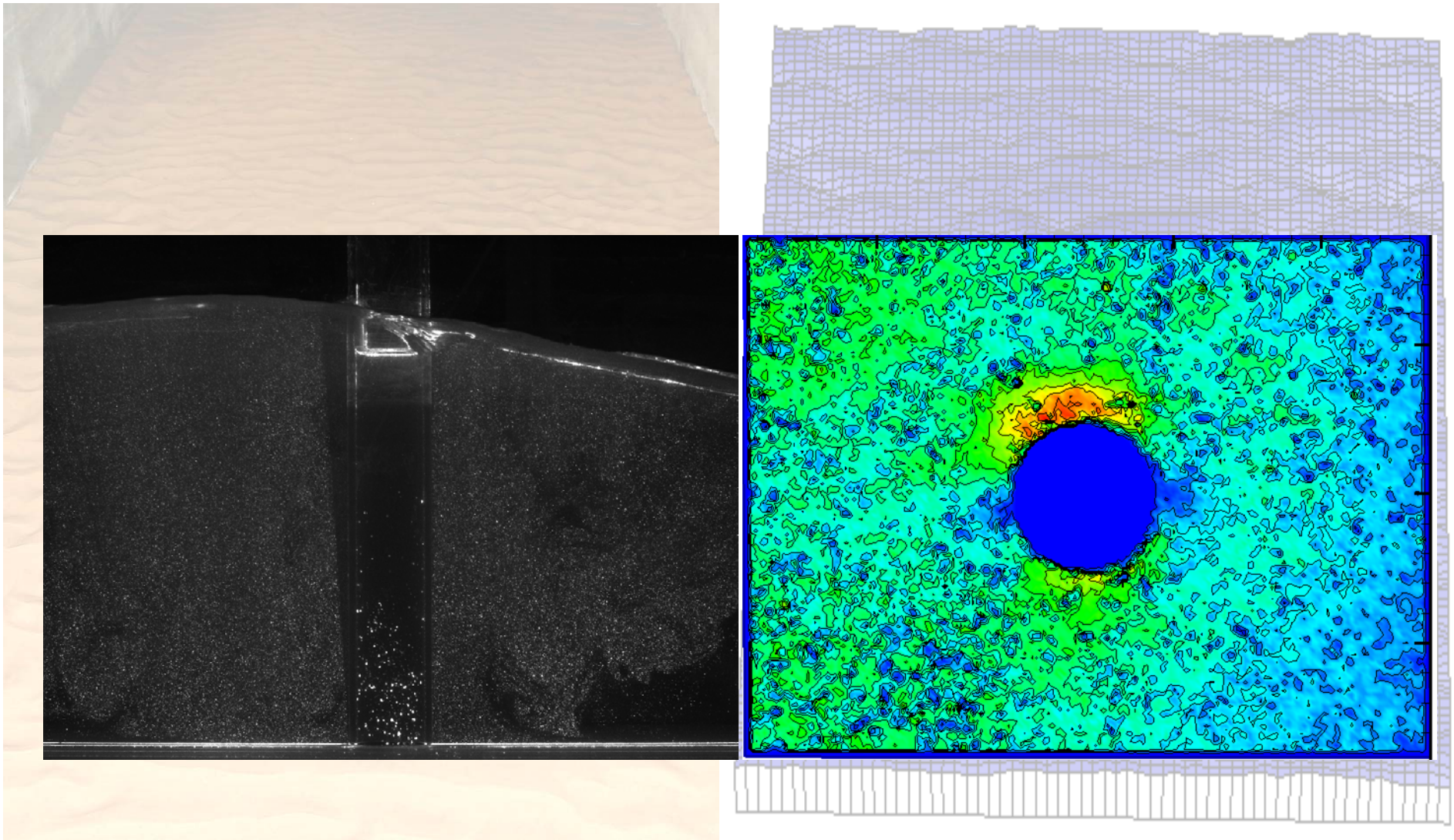

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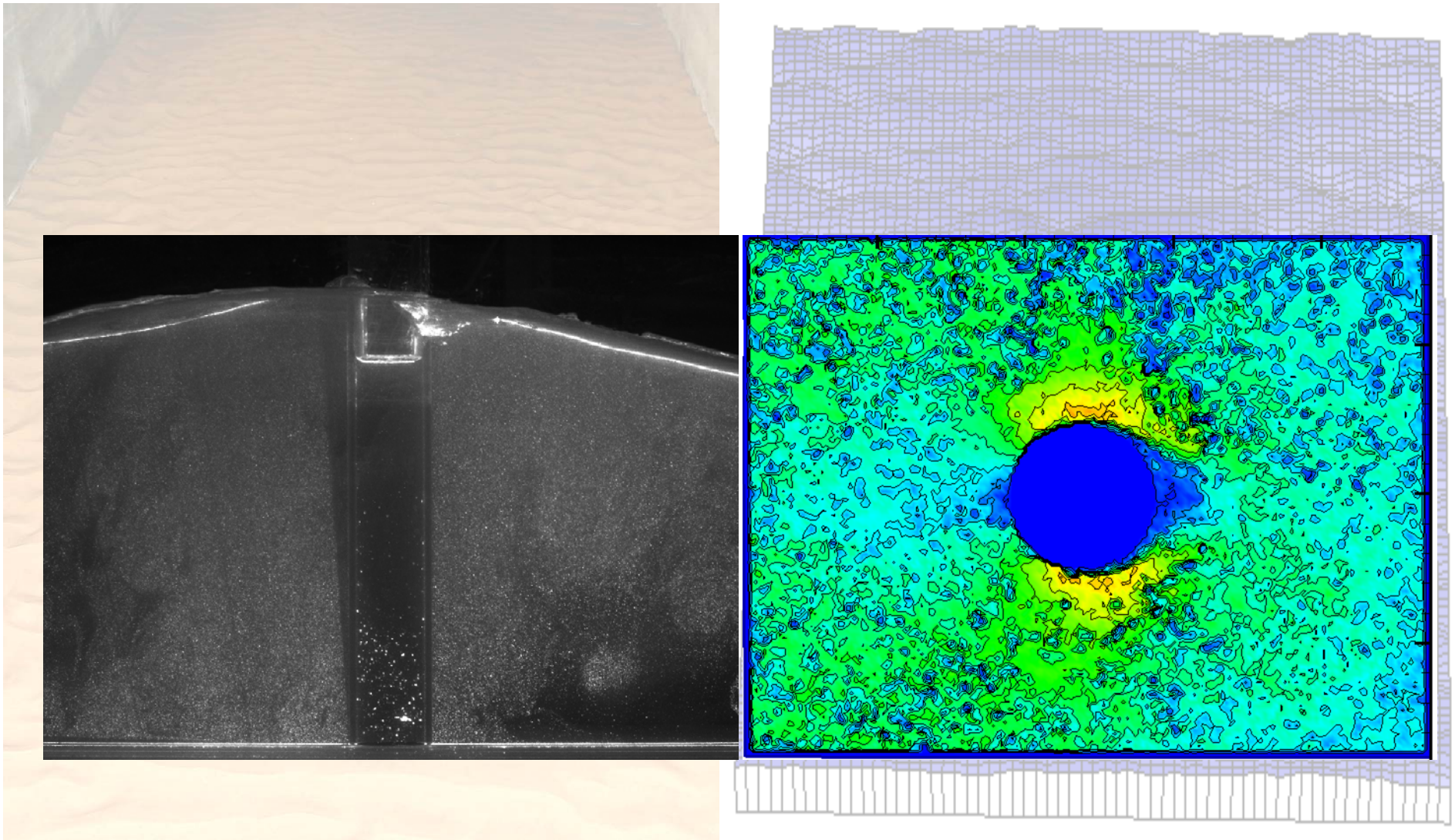

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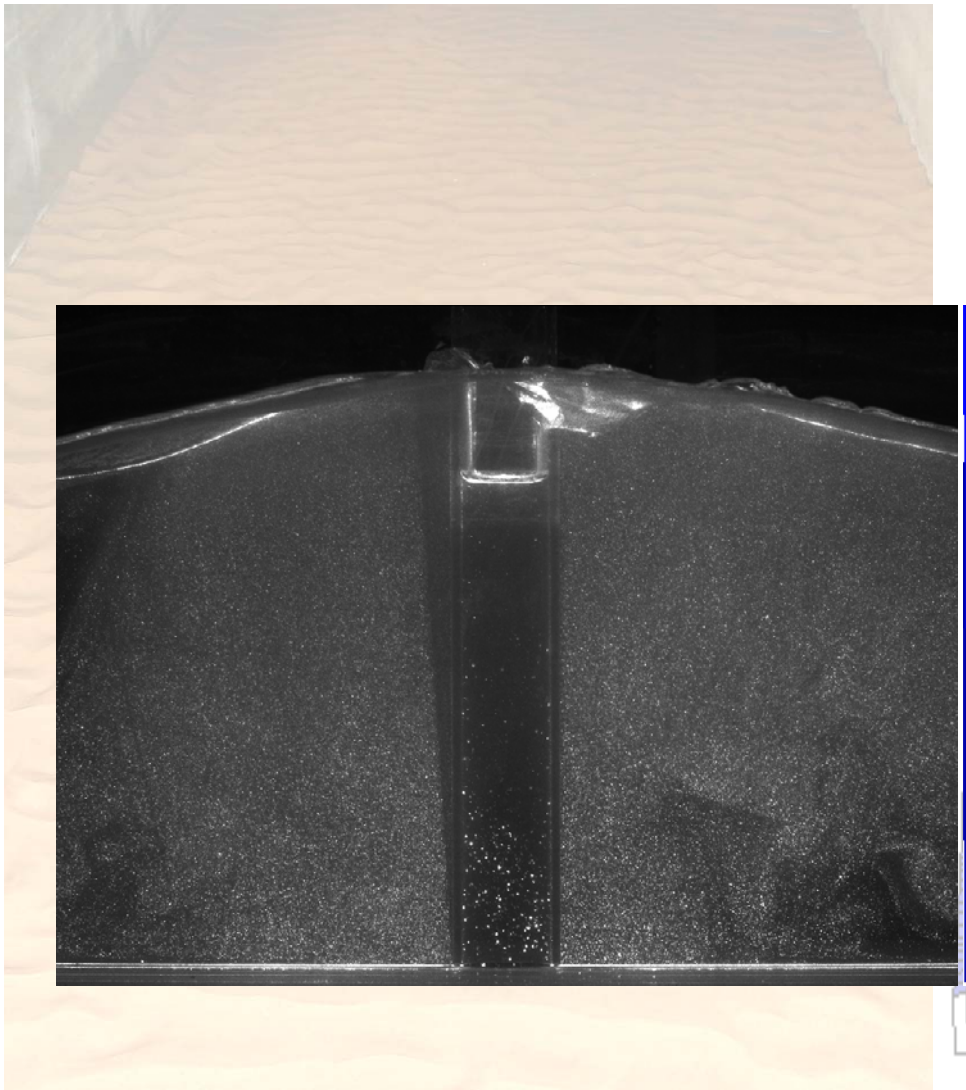

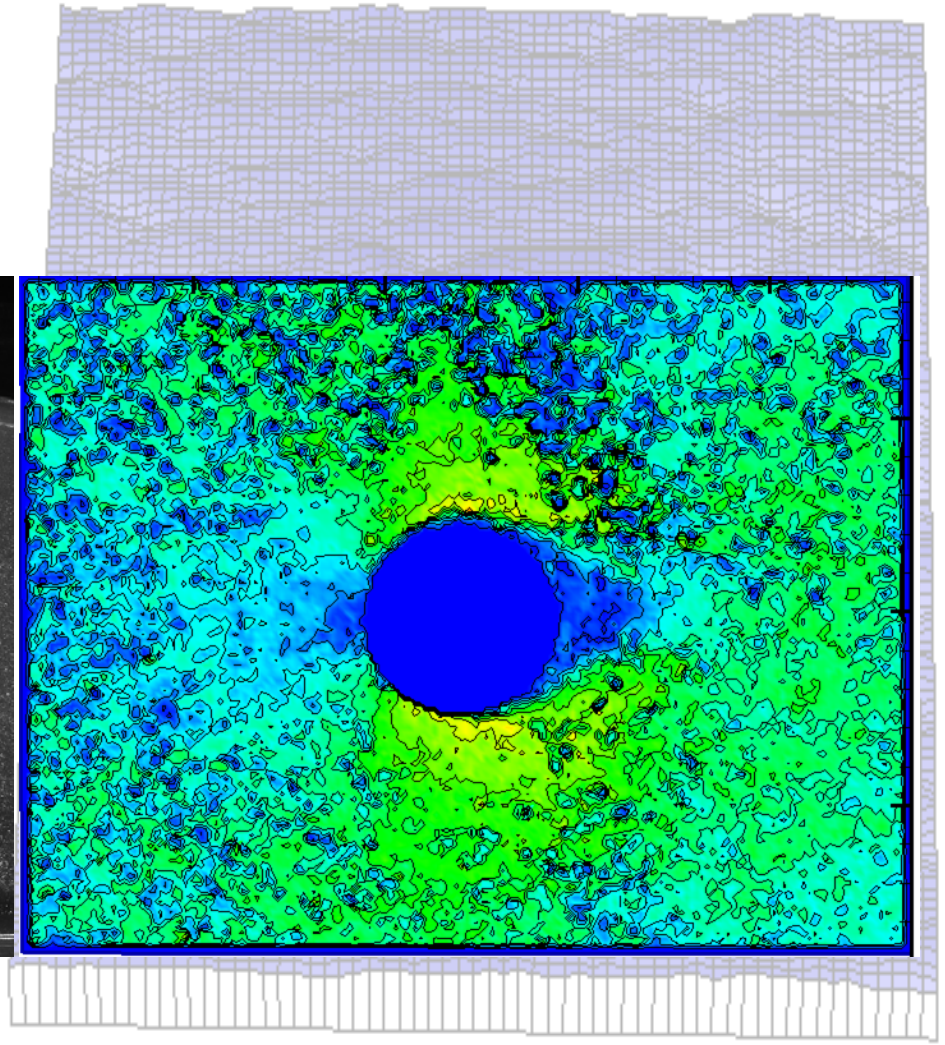

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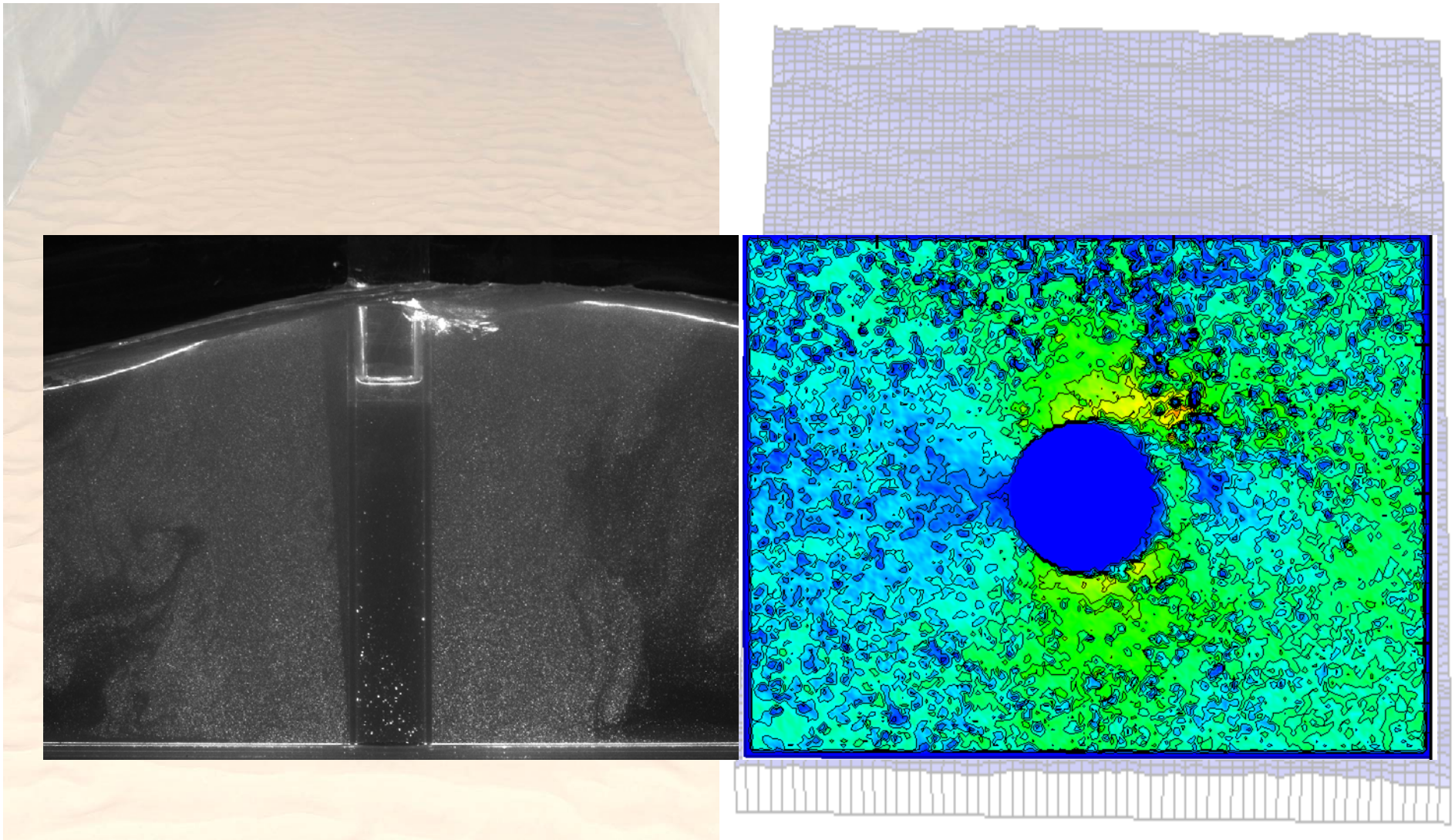

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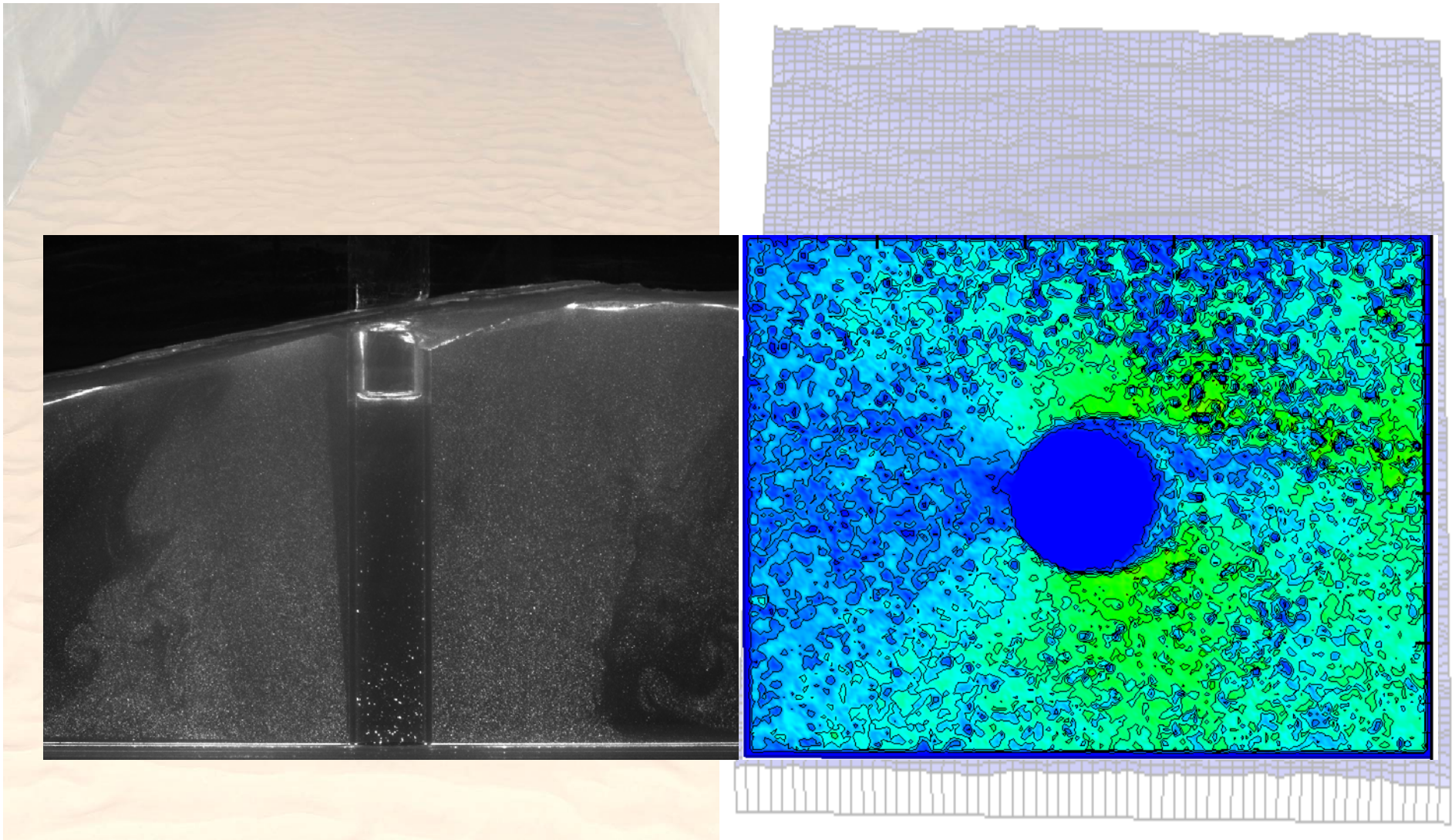

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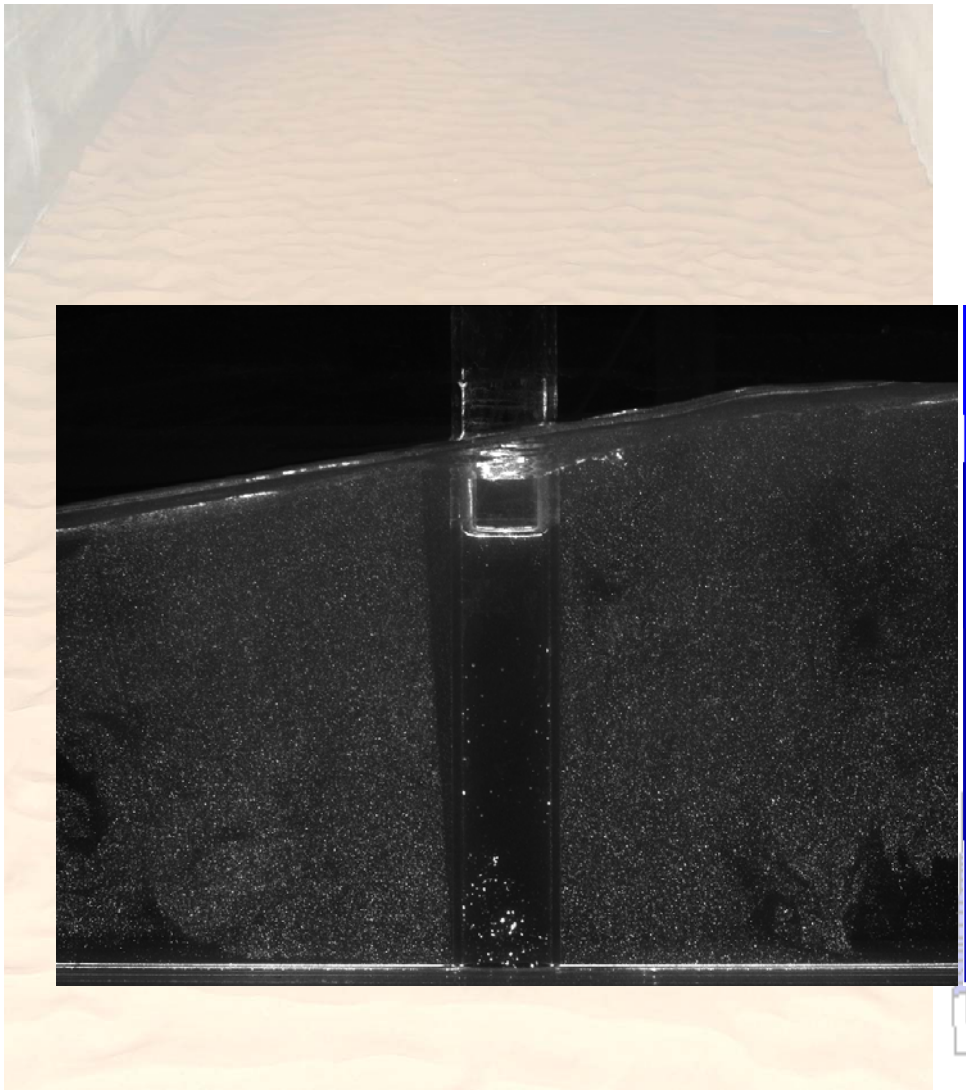

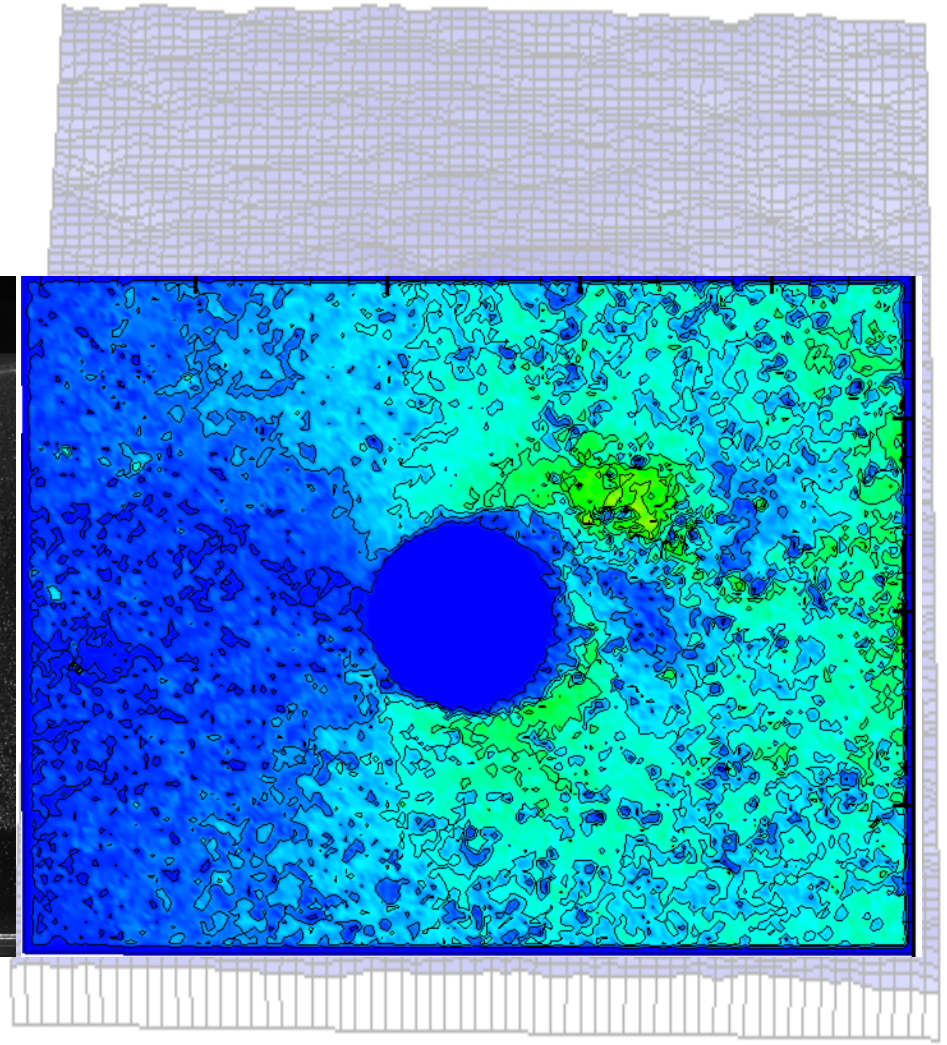

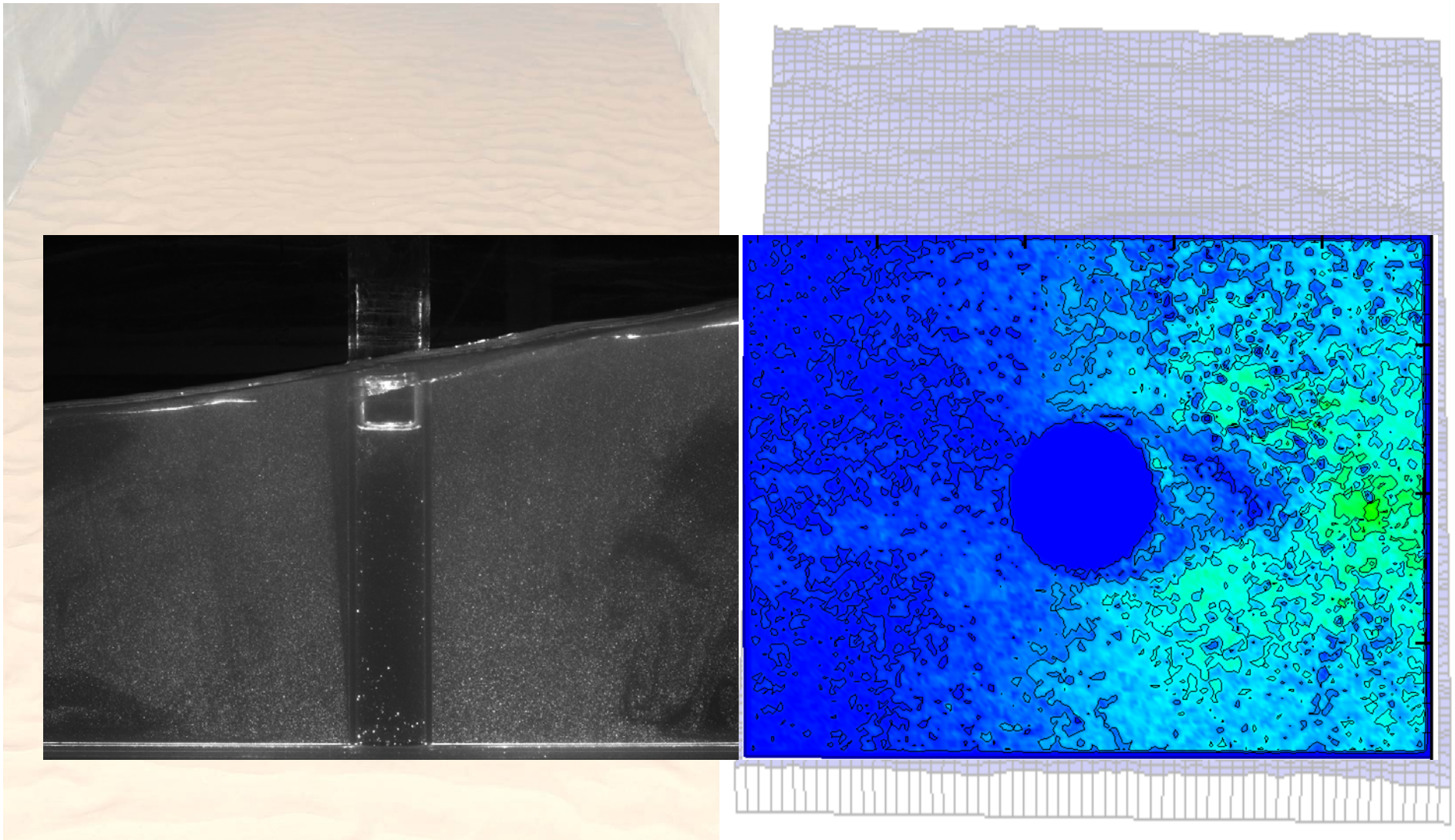

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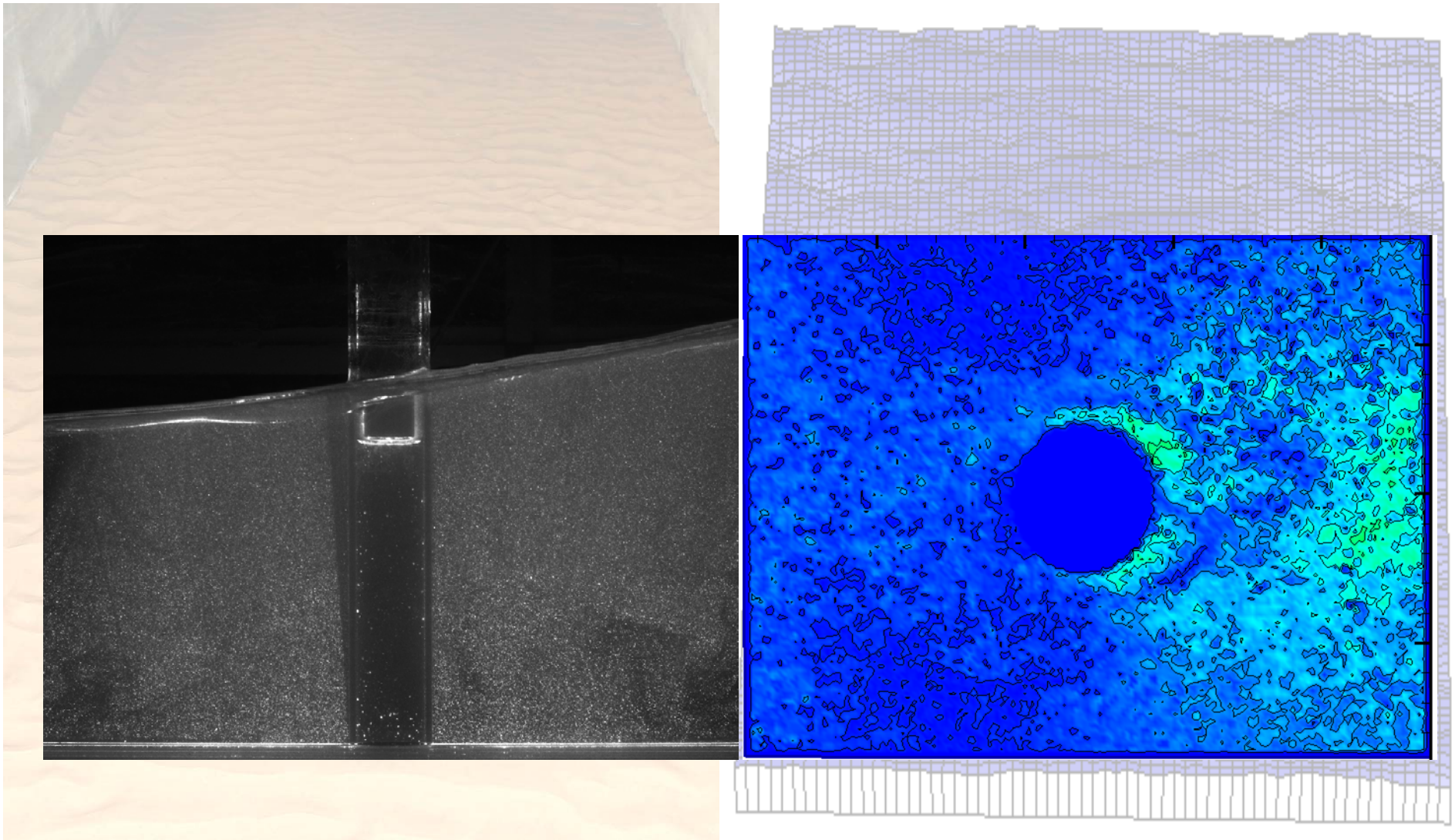

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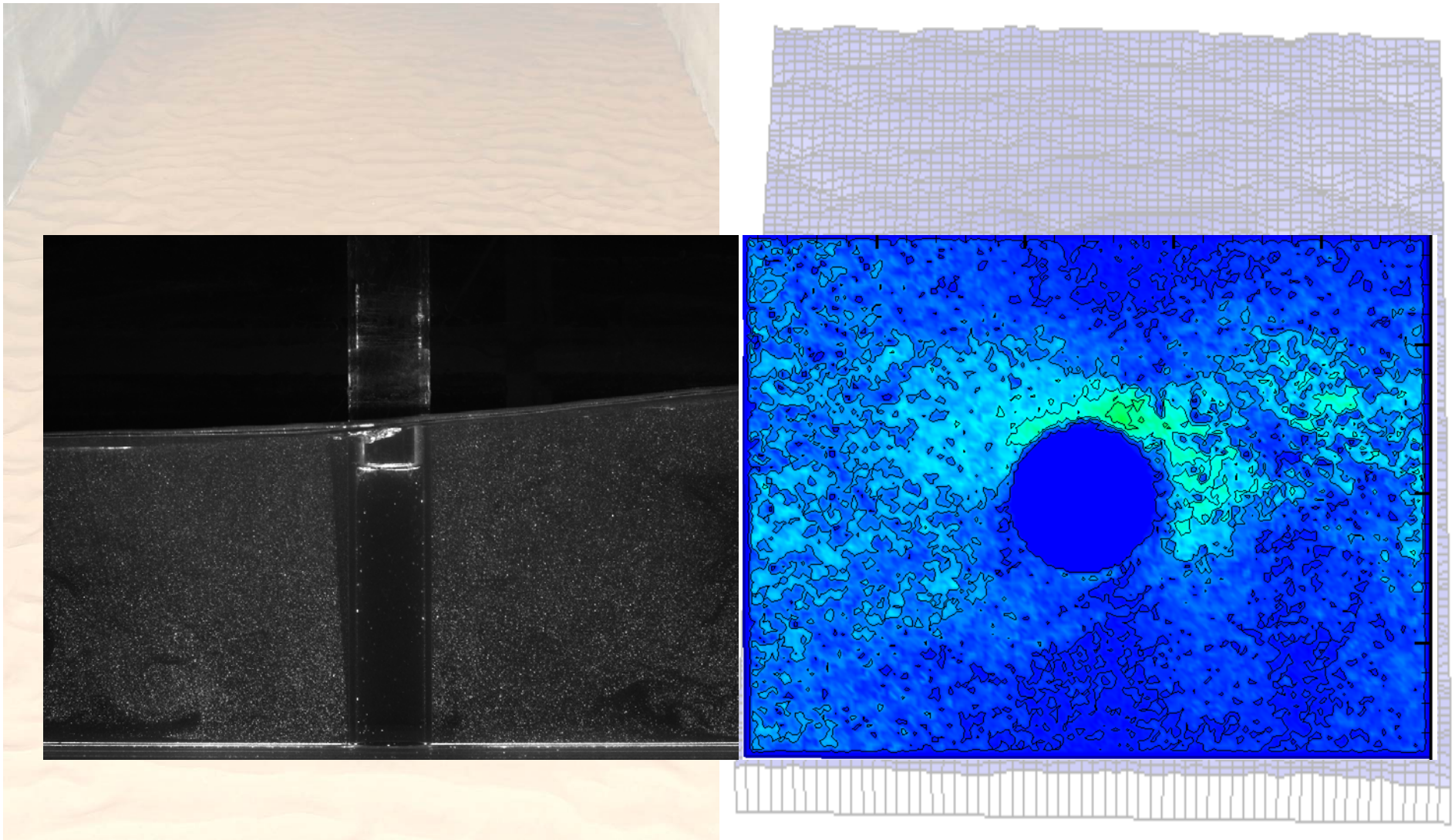

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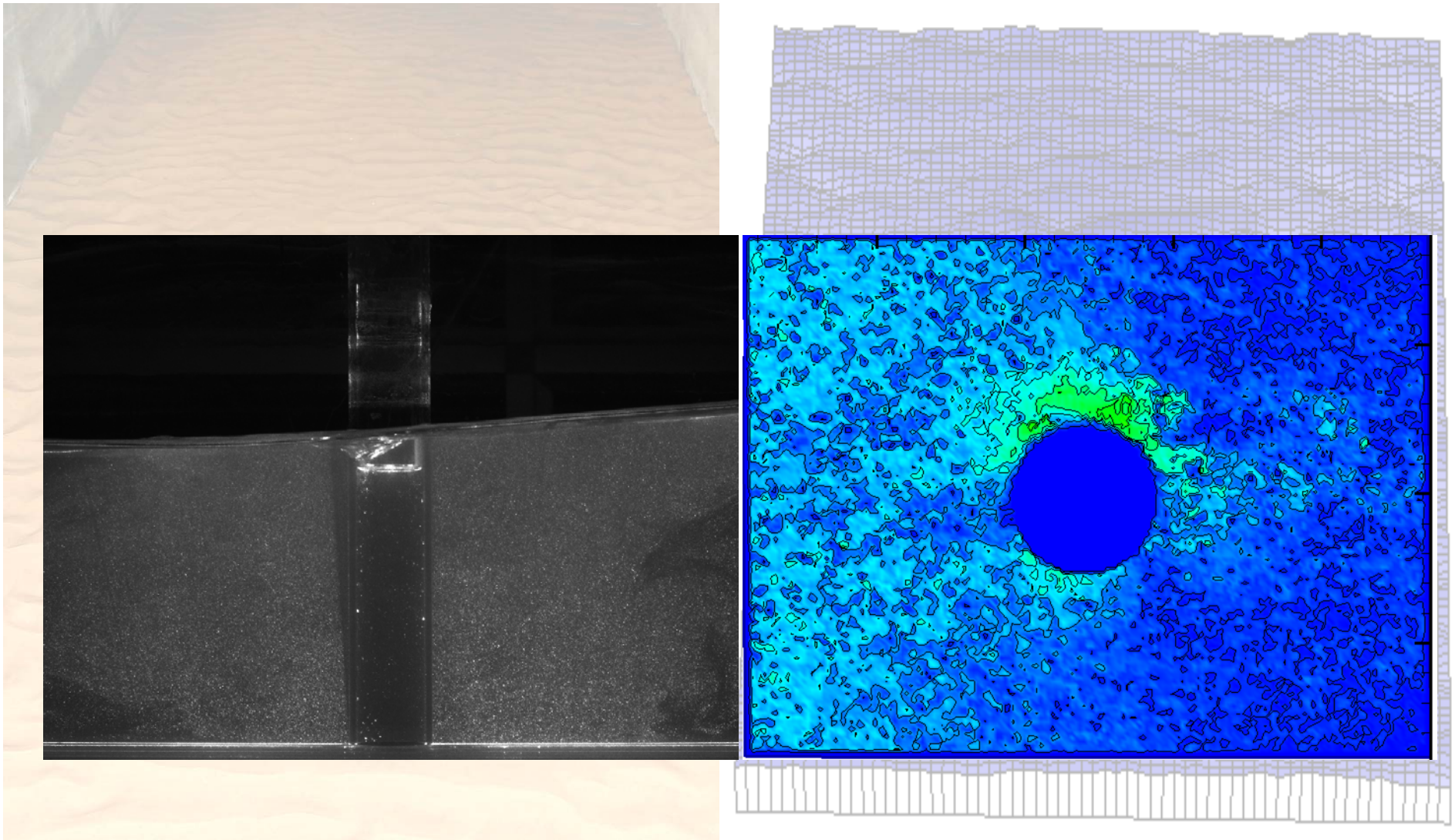

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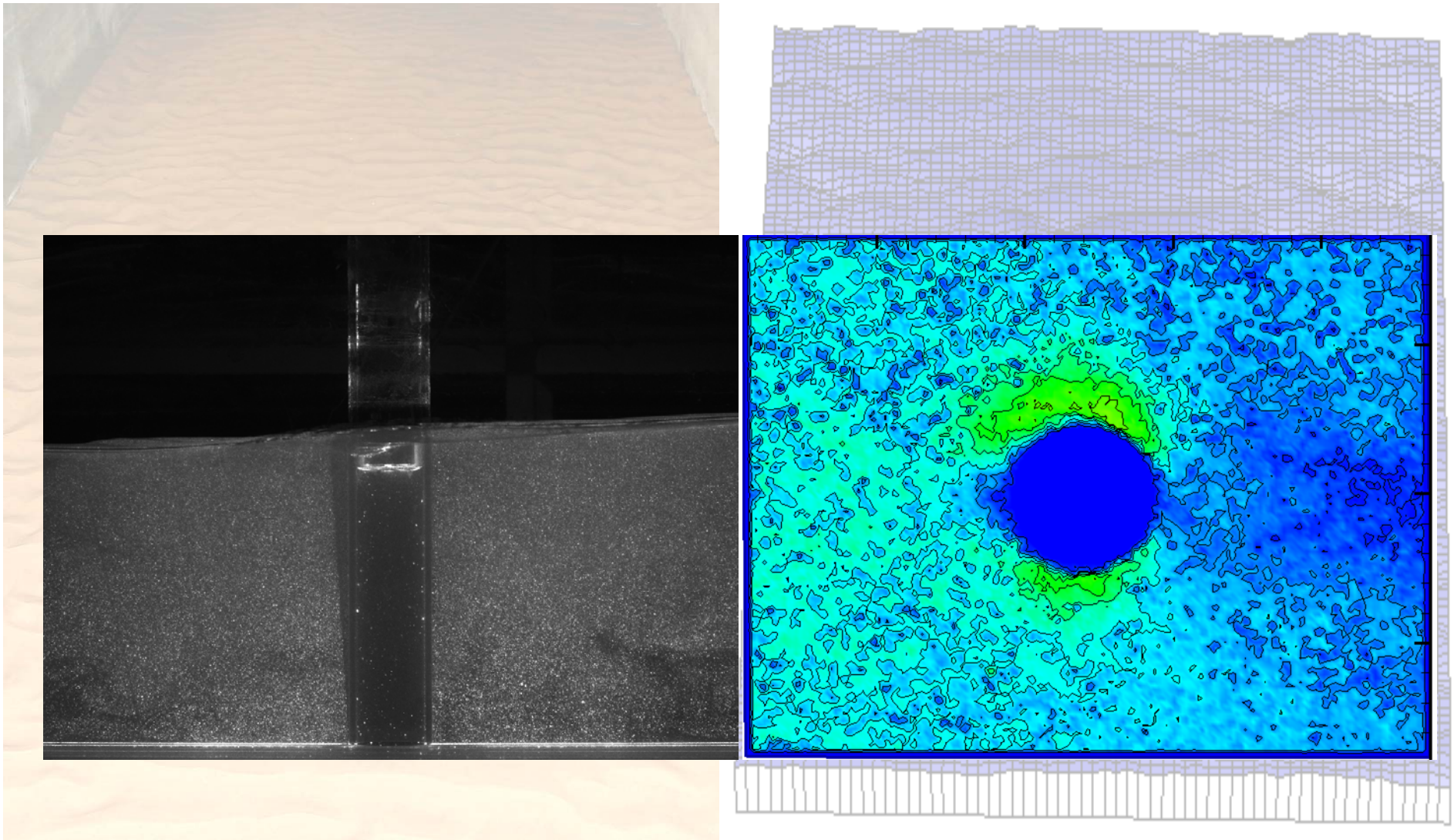

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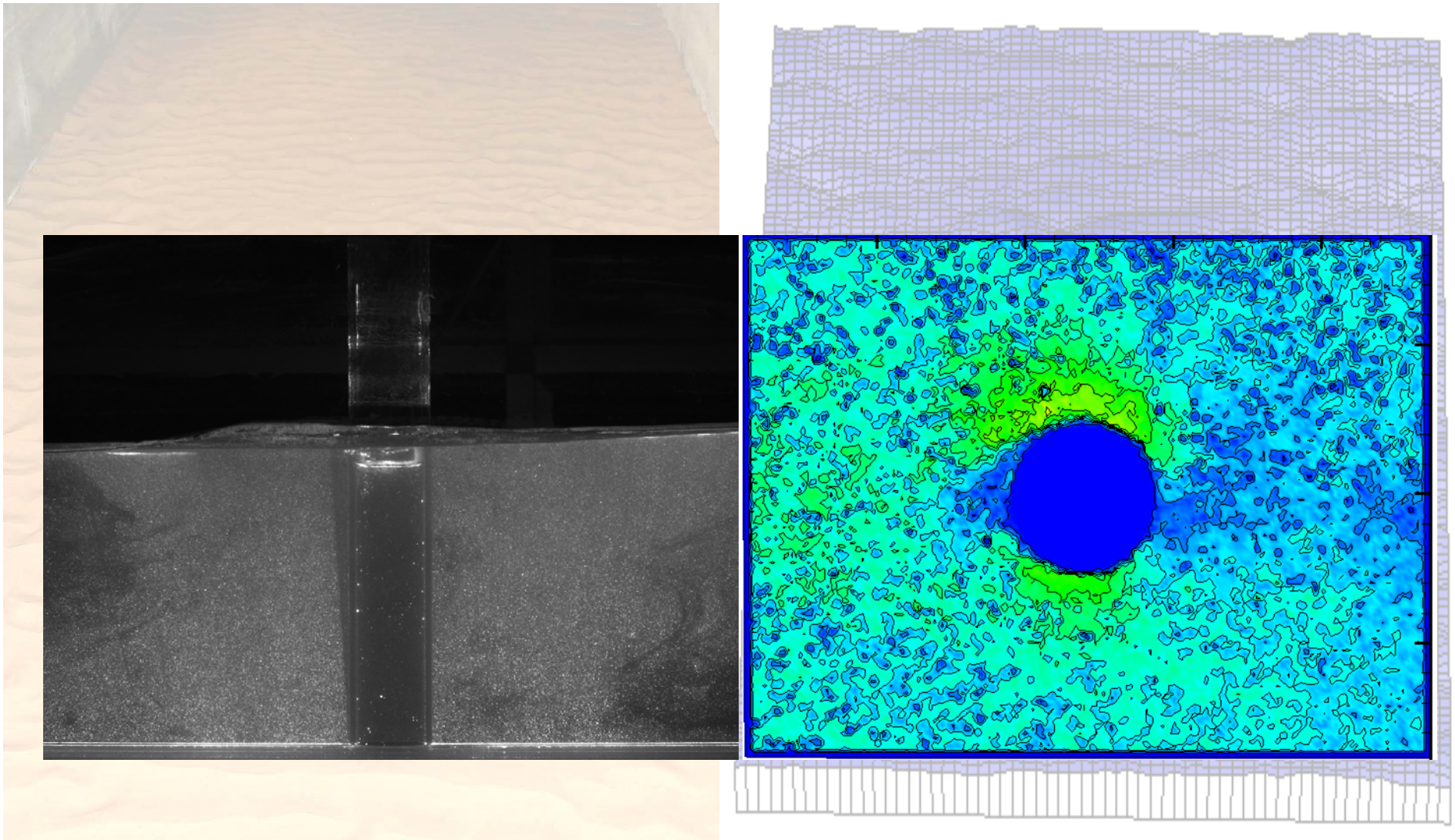

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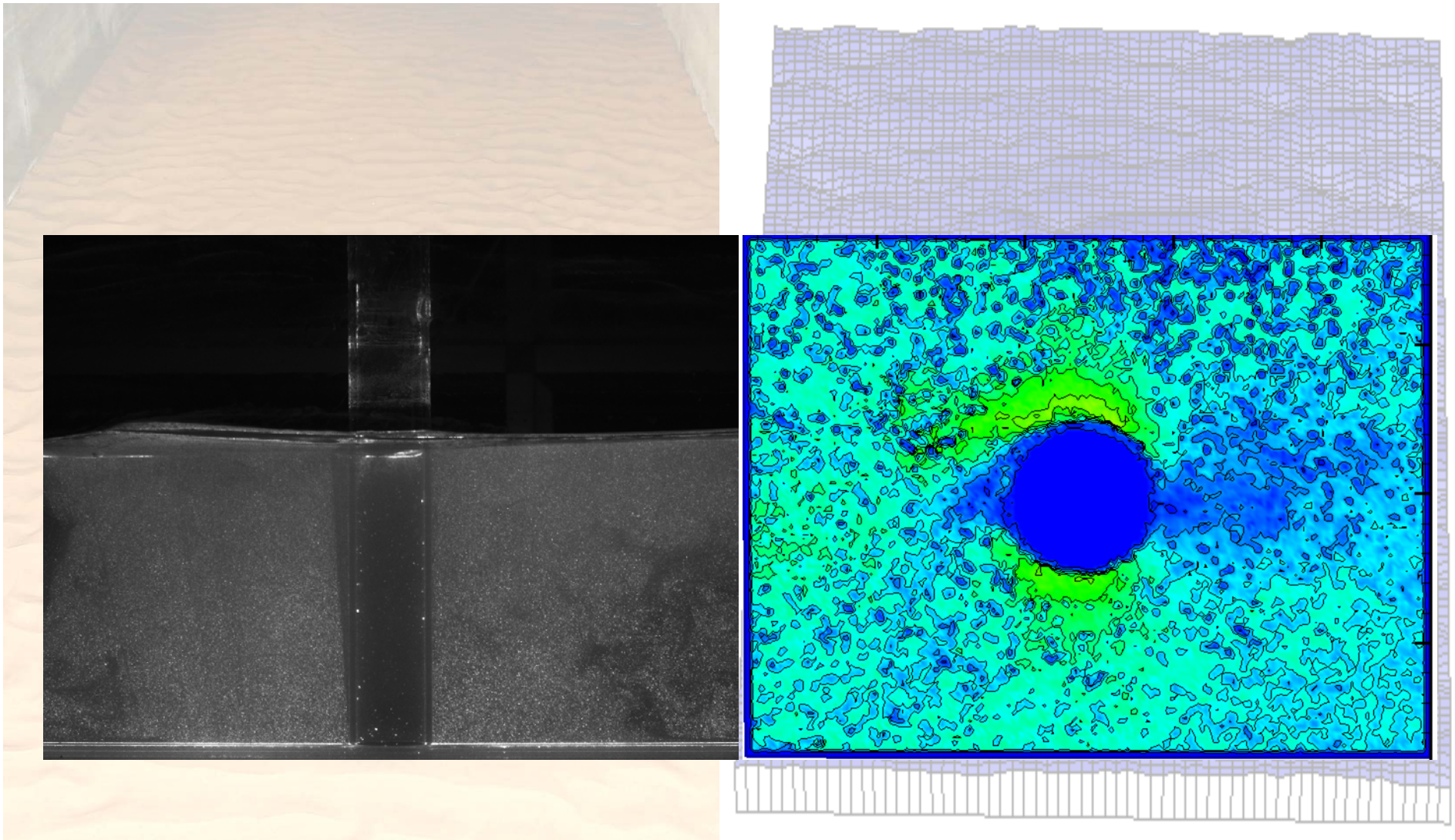

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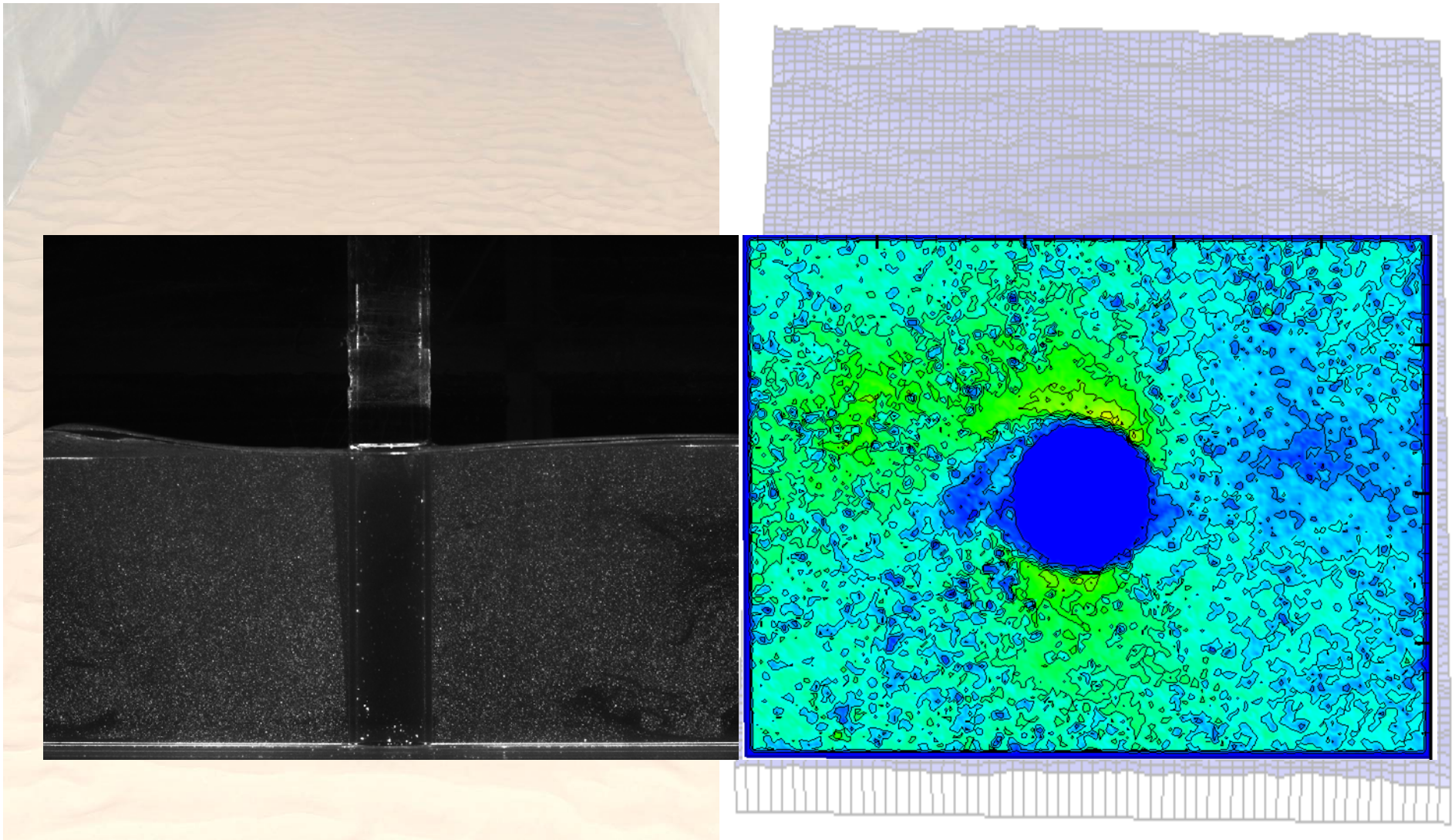

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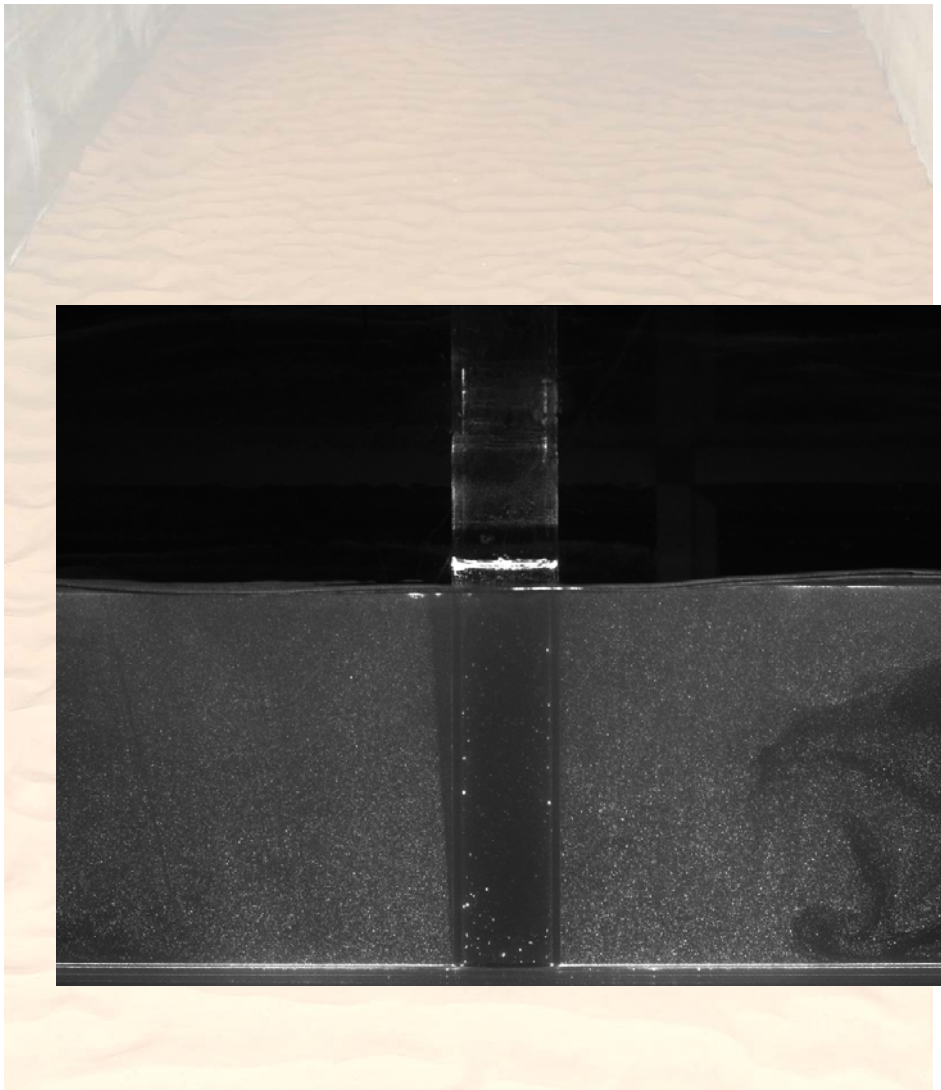

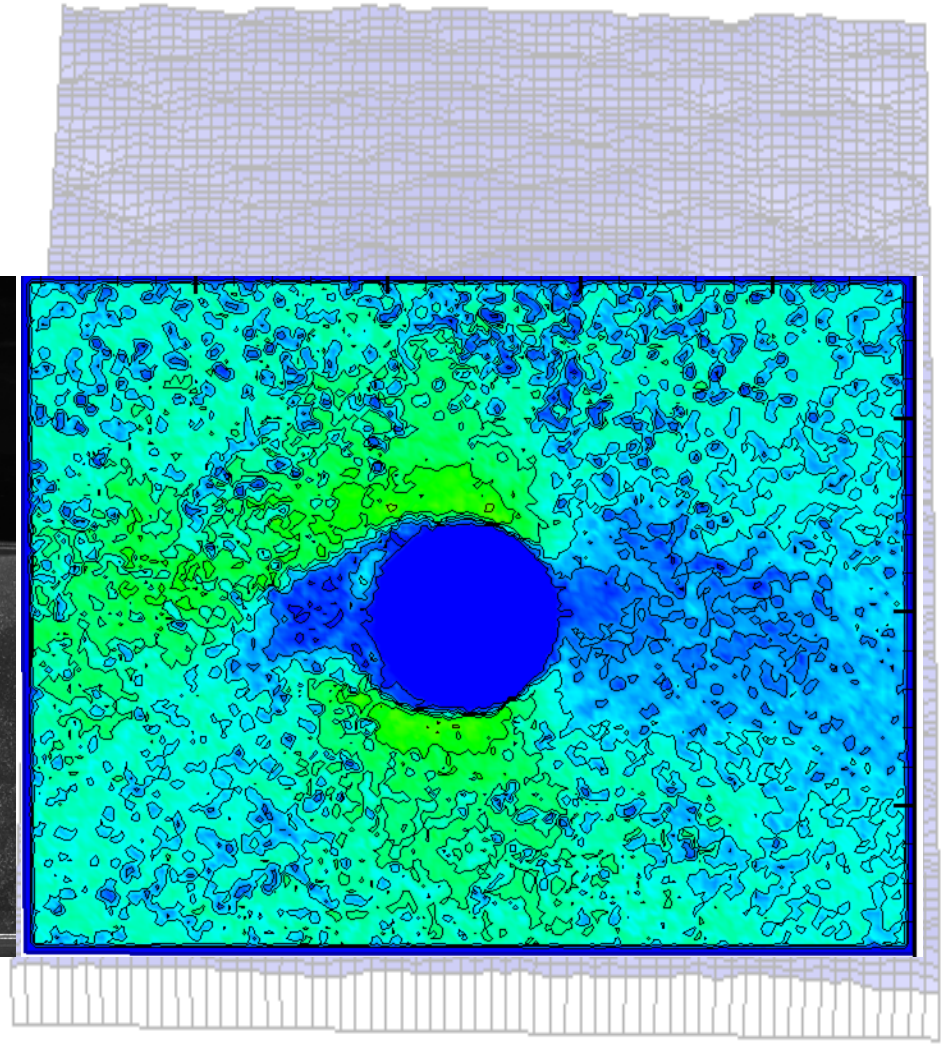

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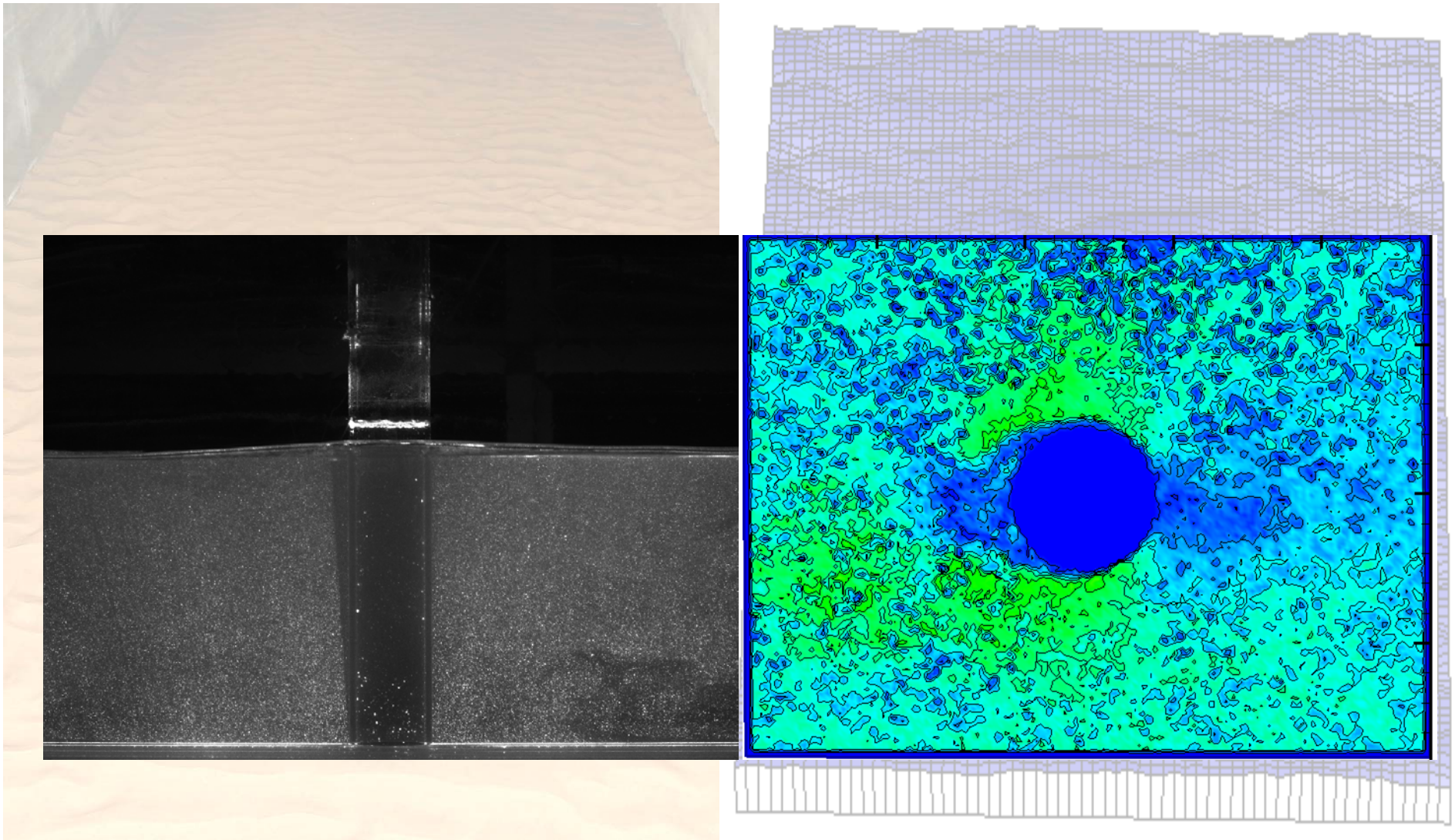

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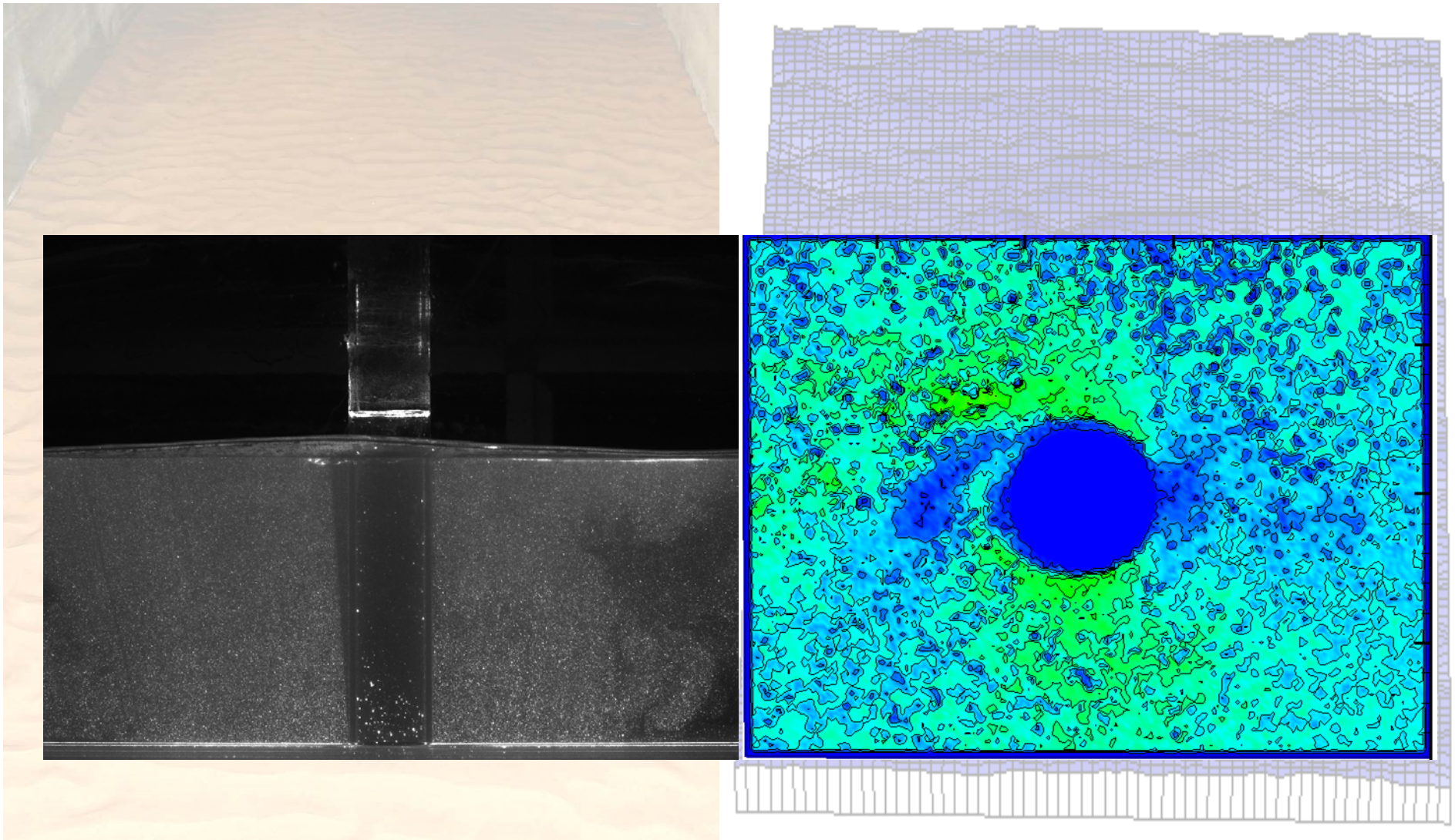

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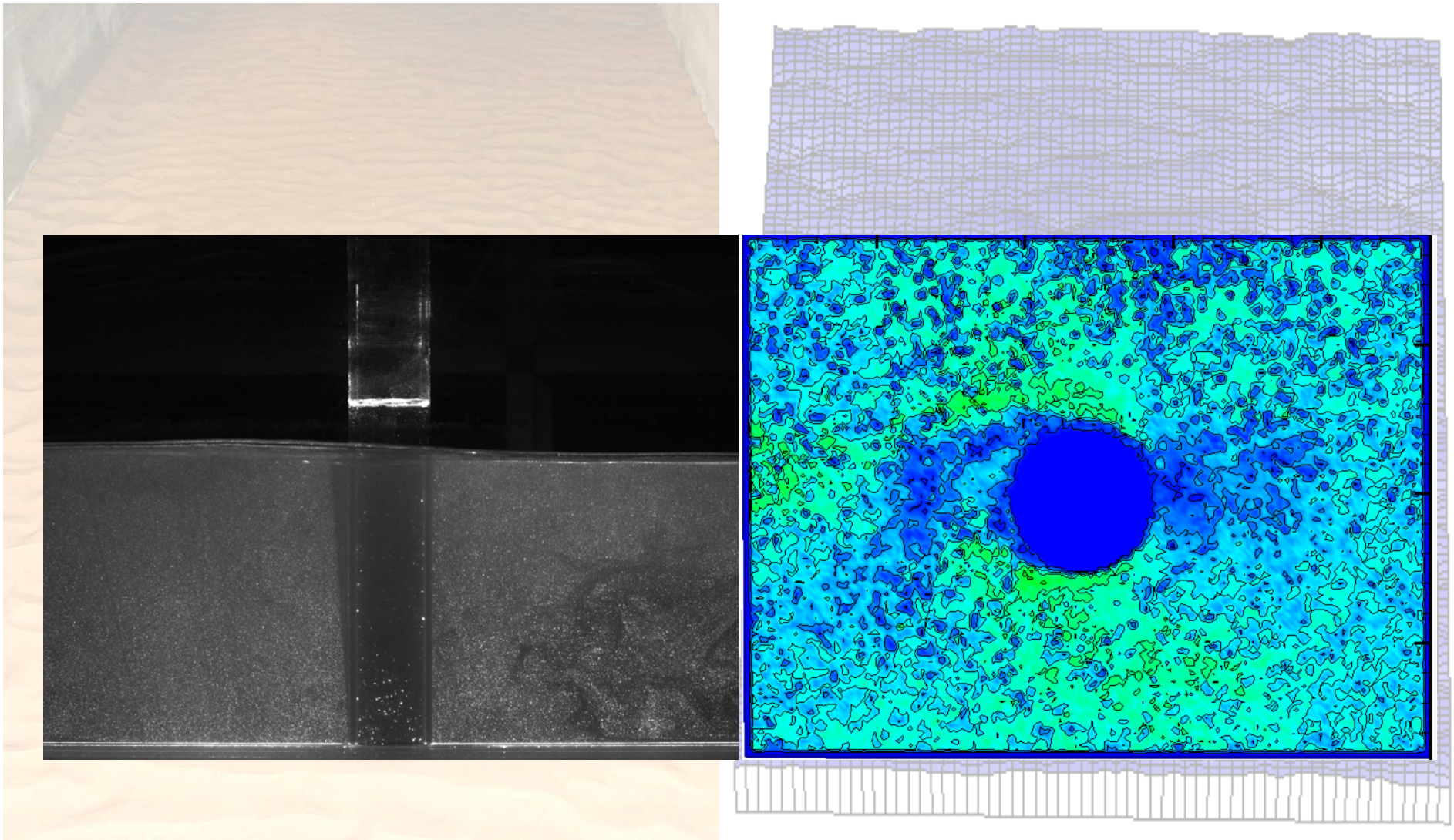
Offshore Wind Turbines situated
in areas with Strong Currents

Offshore Center Danmark



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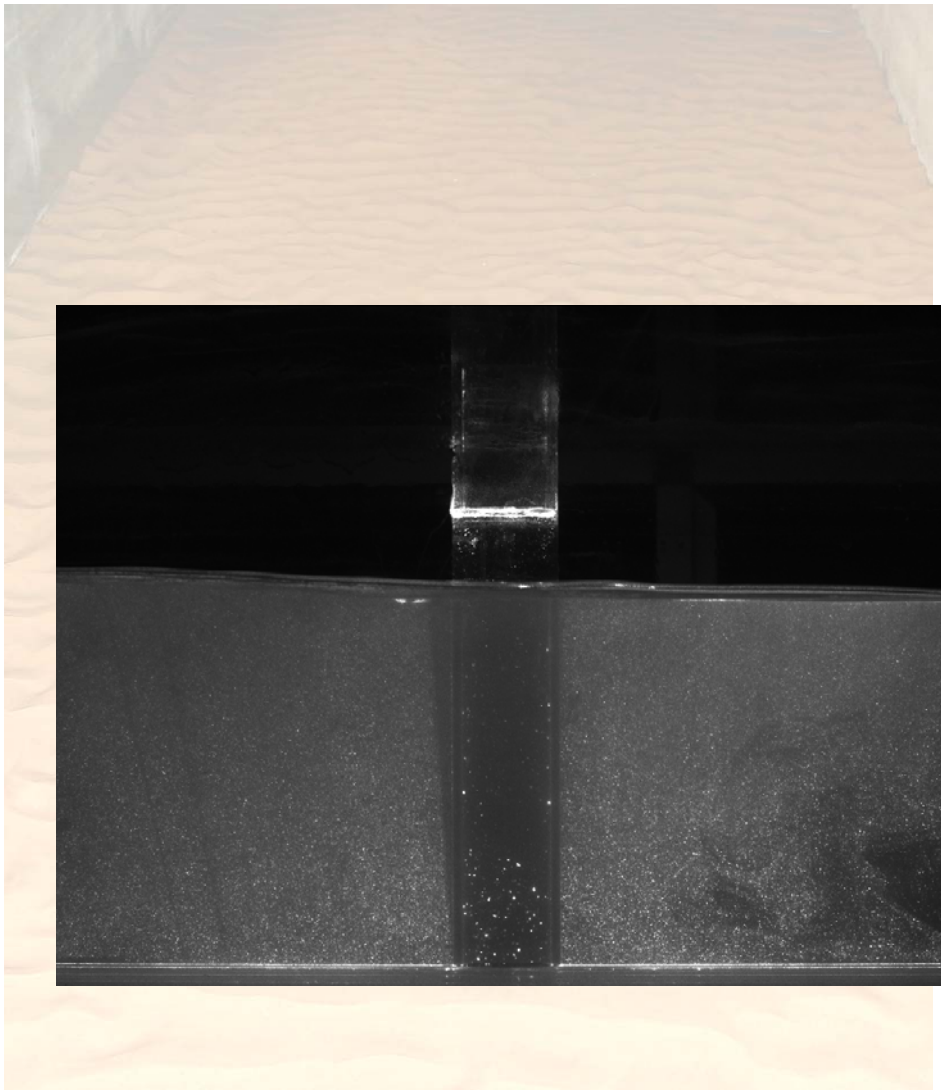

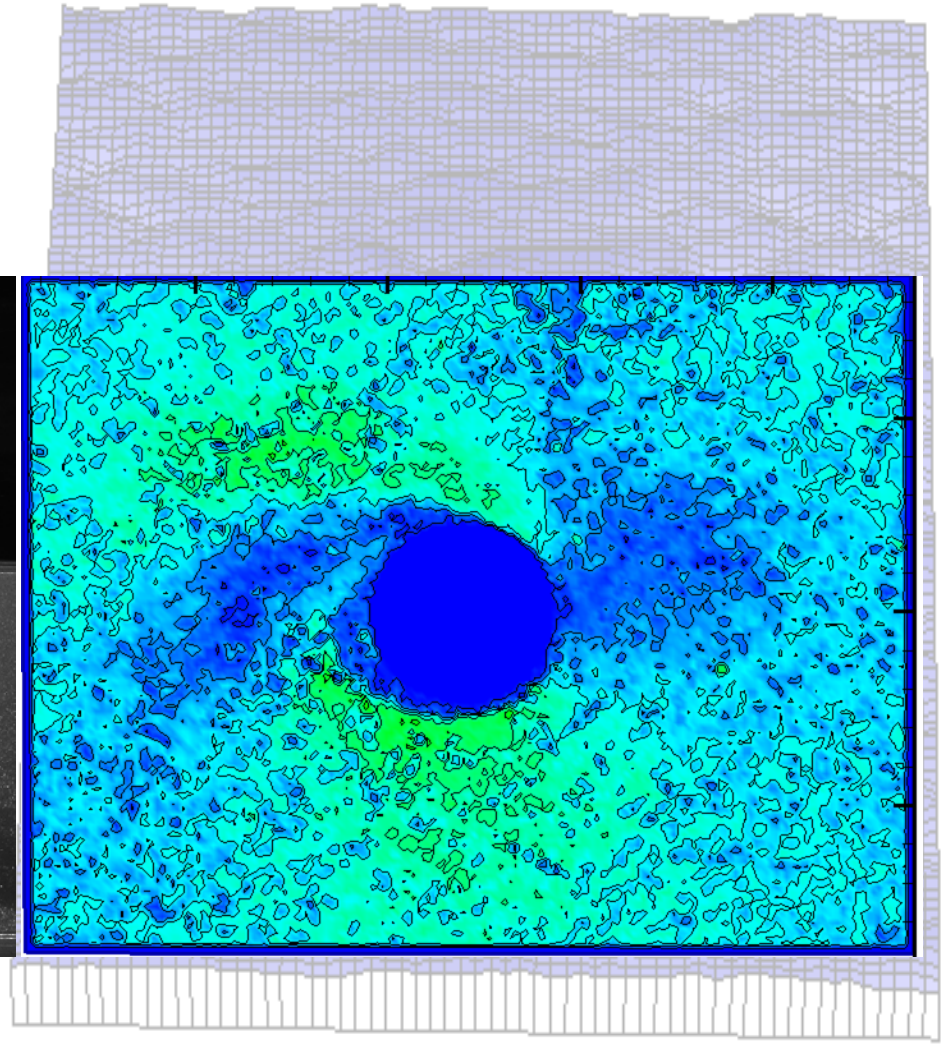

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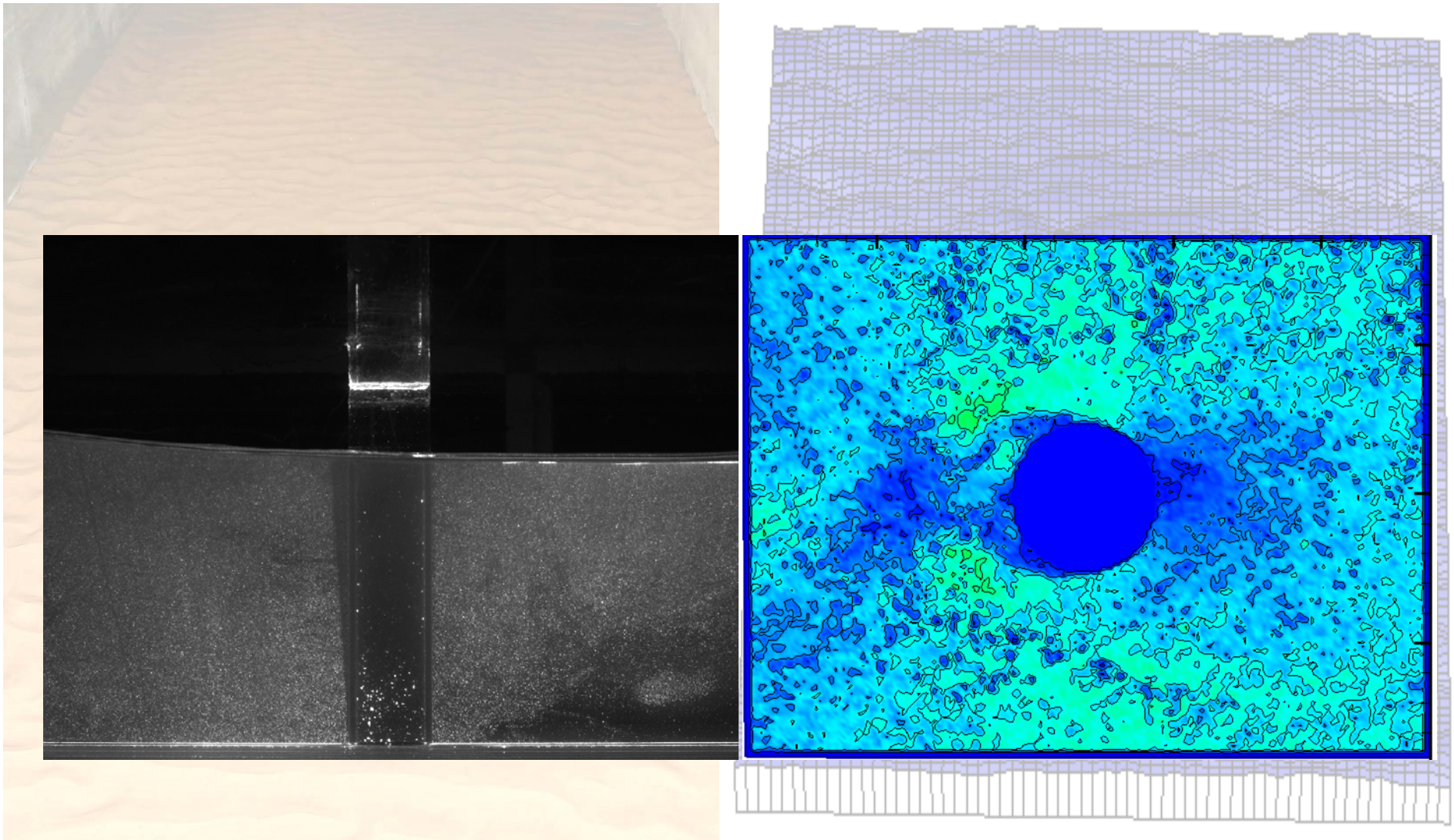

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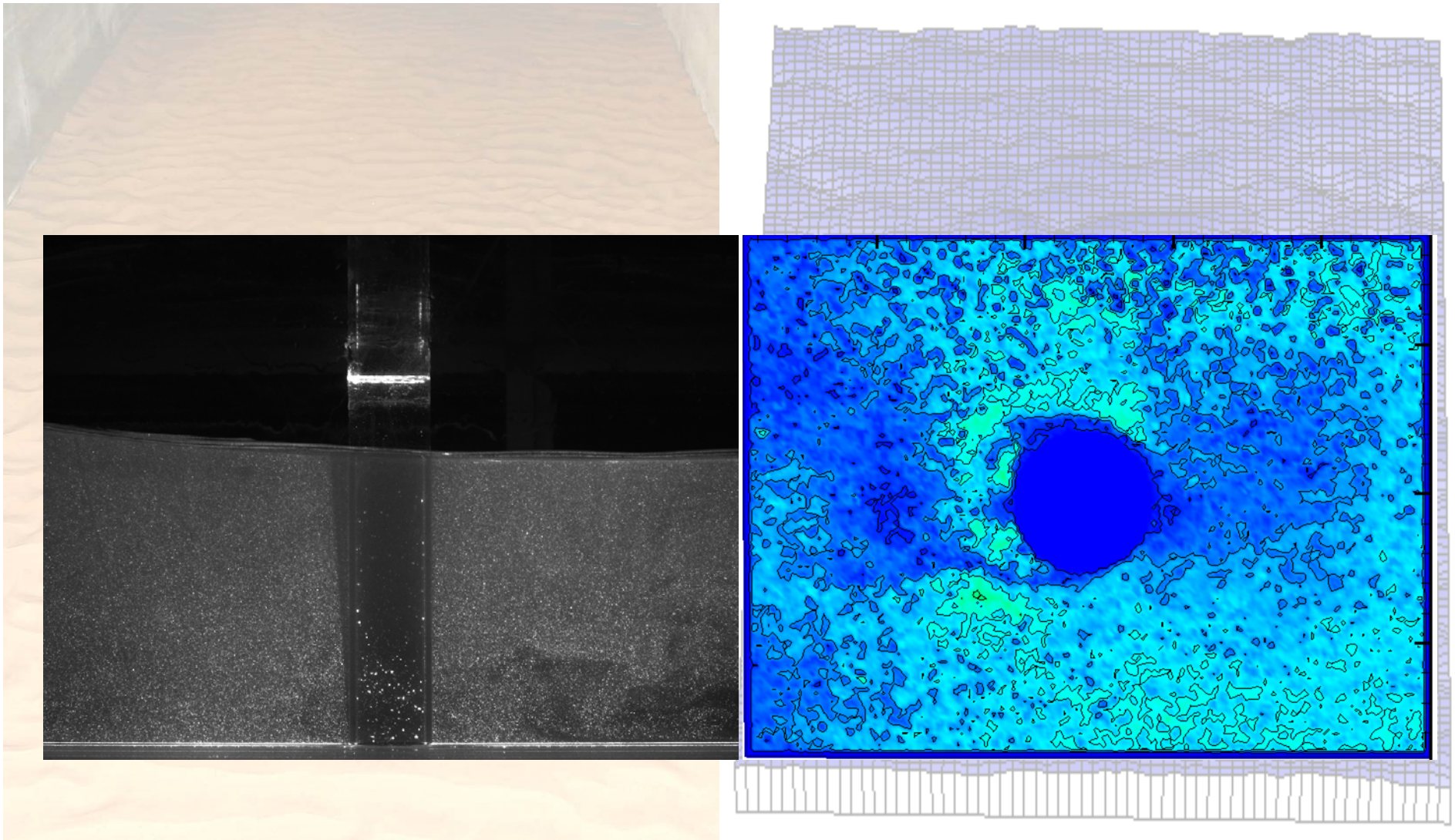

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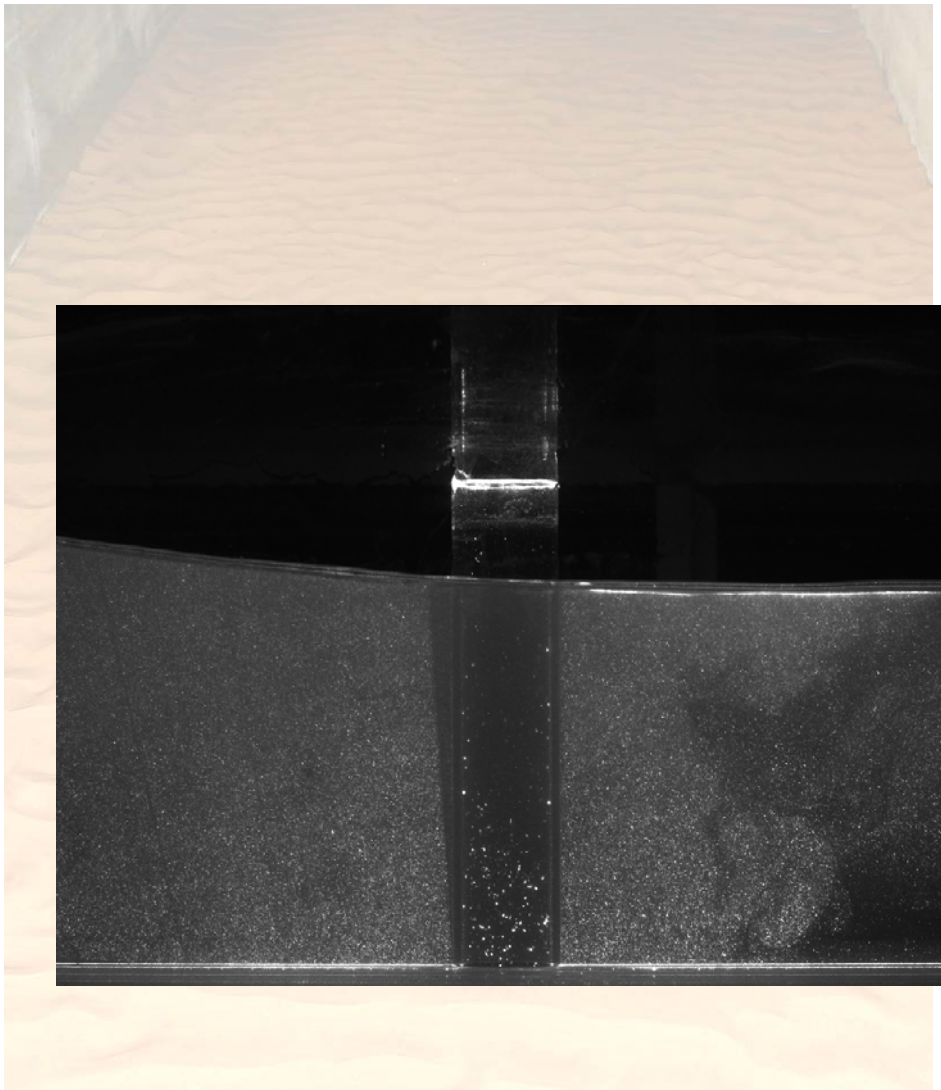

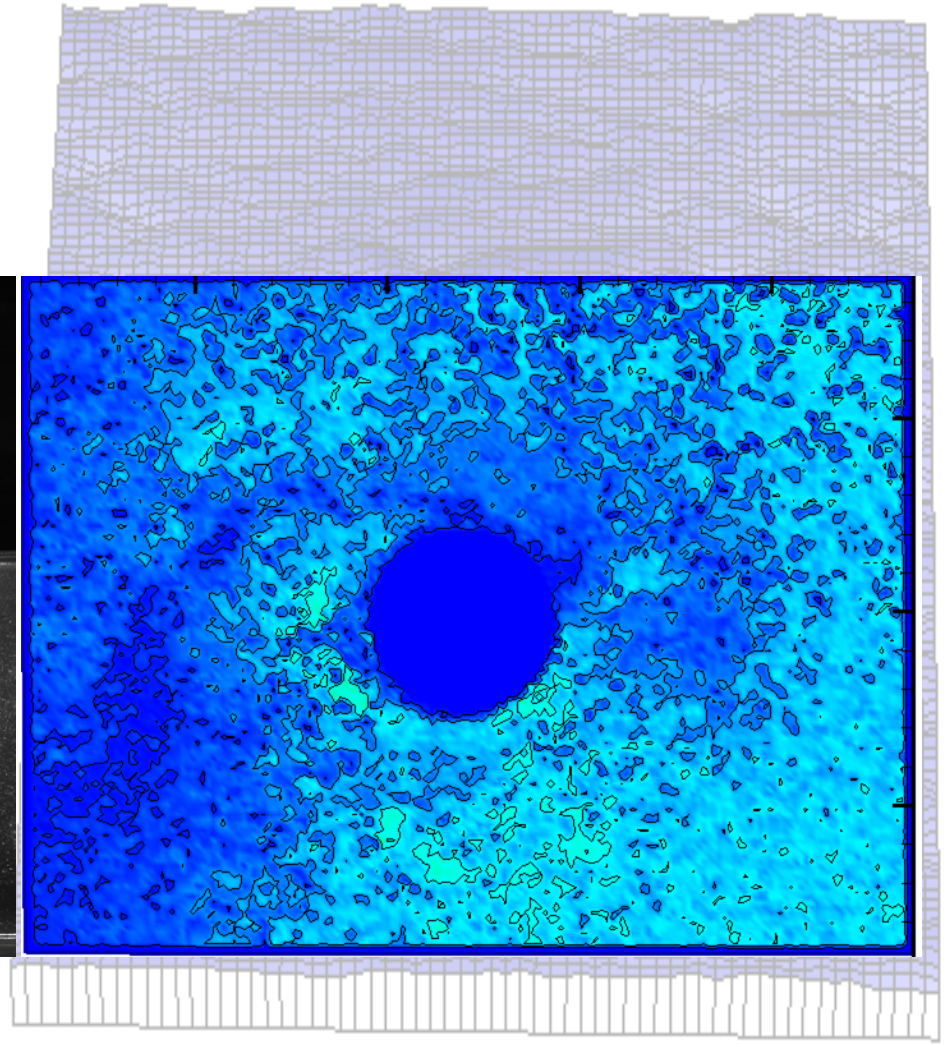

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Offshore Wind Turbines situated
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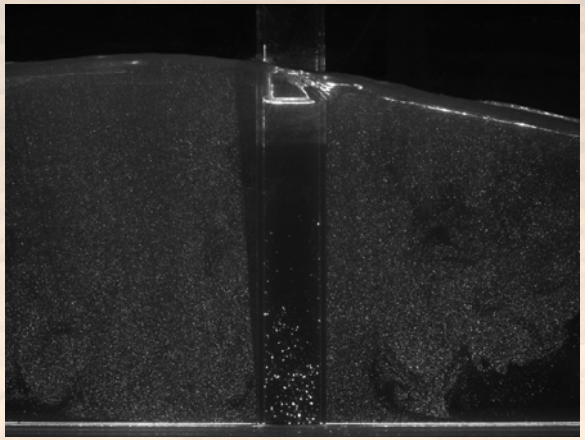
Offshore Center Danmark

PIV measurements

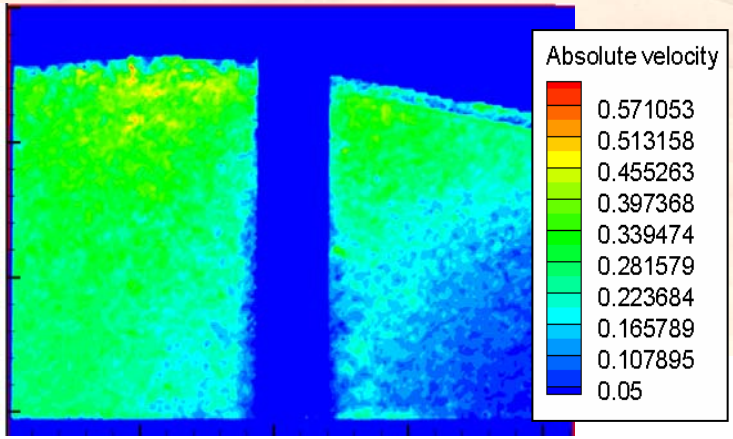
non-breaking wave

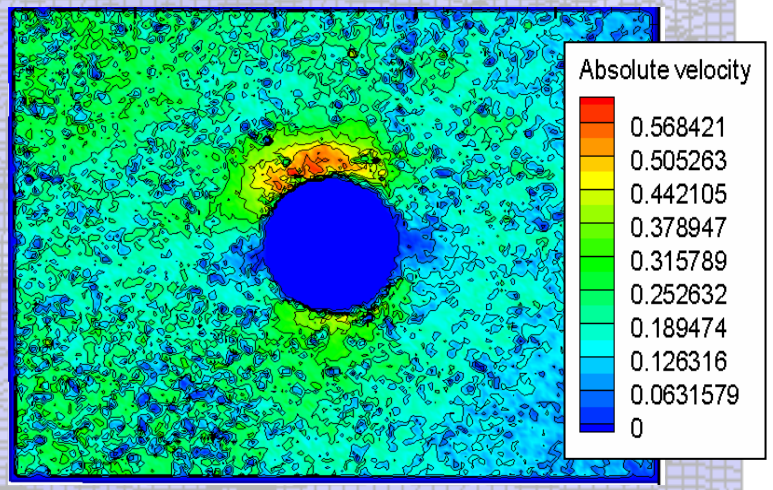


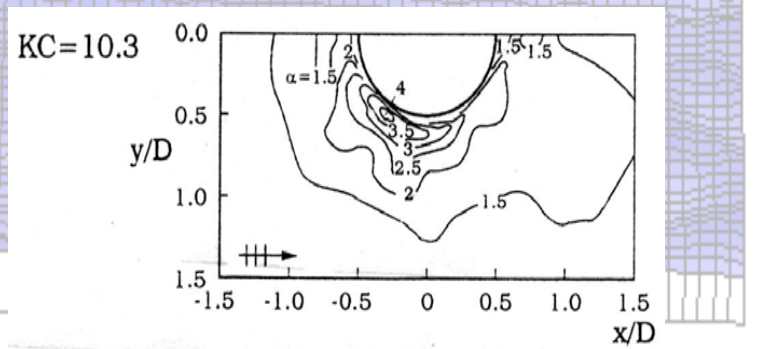
Maximum velocity: U_m = 0.29 m/s

Maximum velocity near pile: U = 0.60 m/s

Amplification of shear stress = τ/τ_∞ : 4.3 ($\tau \sim U^2$)







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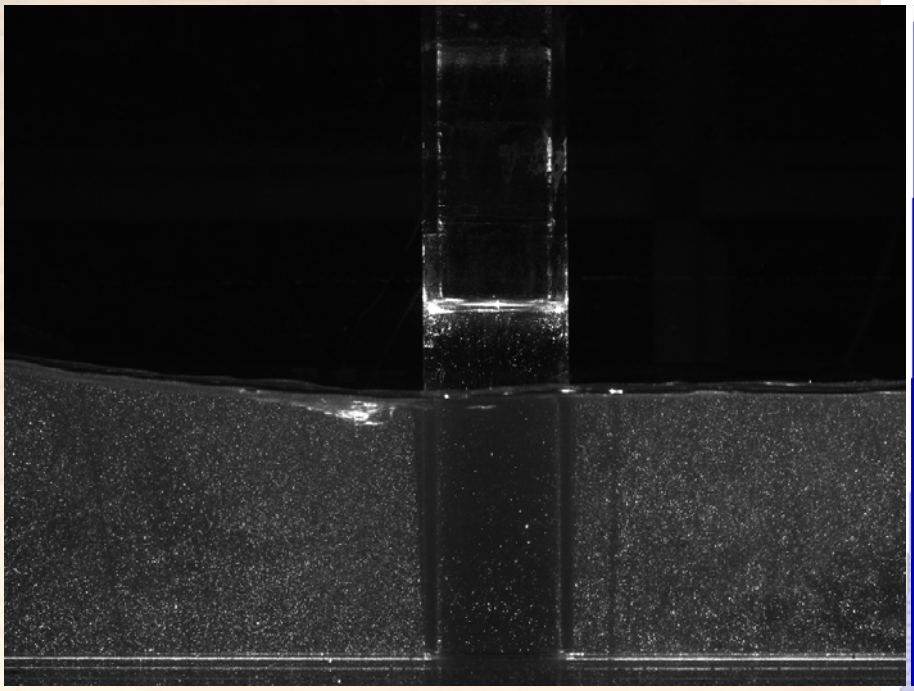
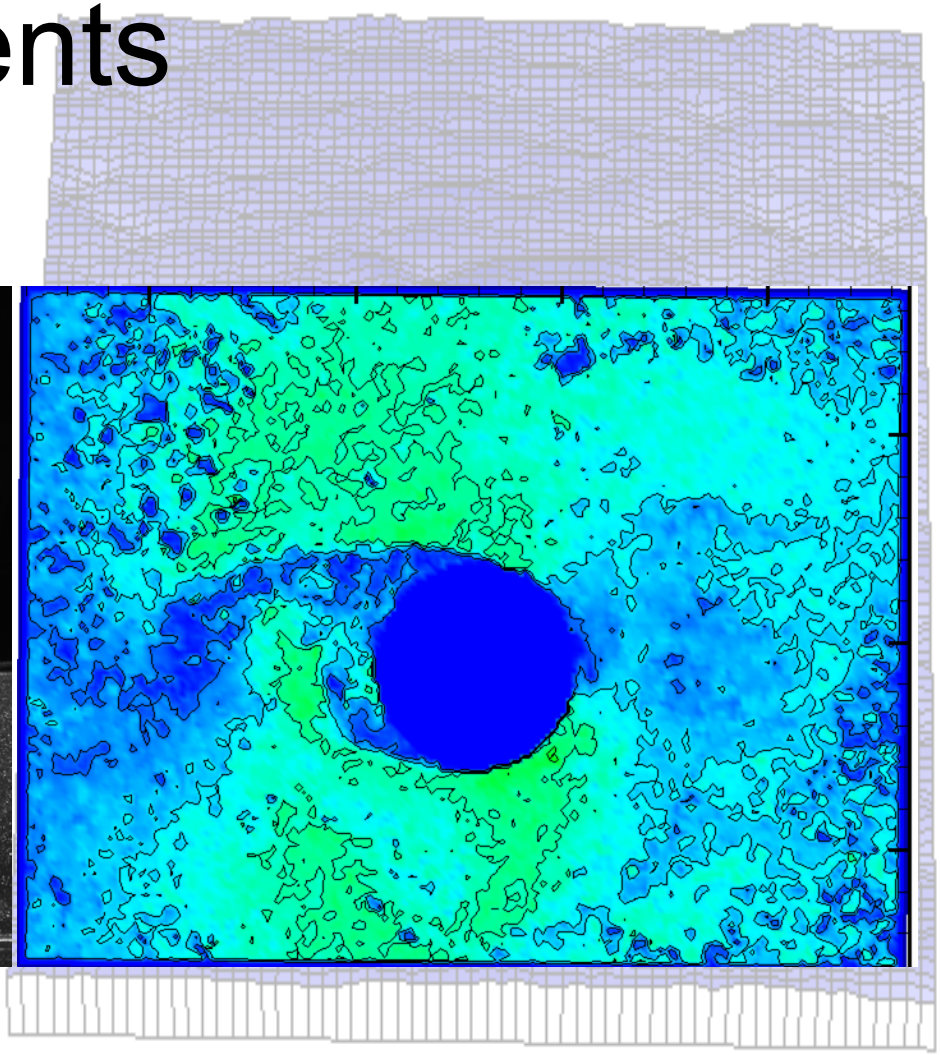
Offshore Wind Turbines situated in areas with Strong Currents

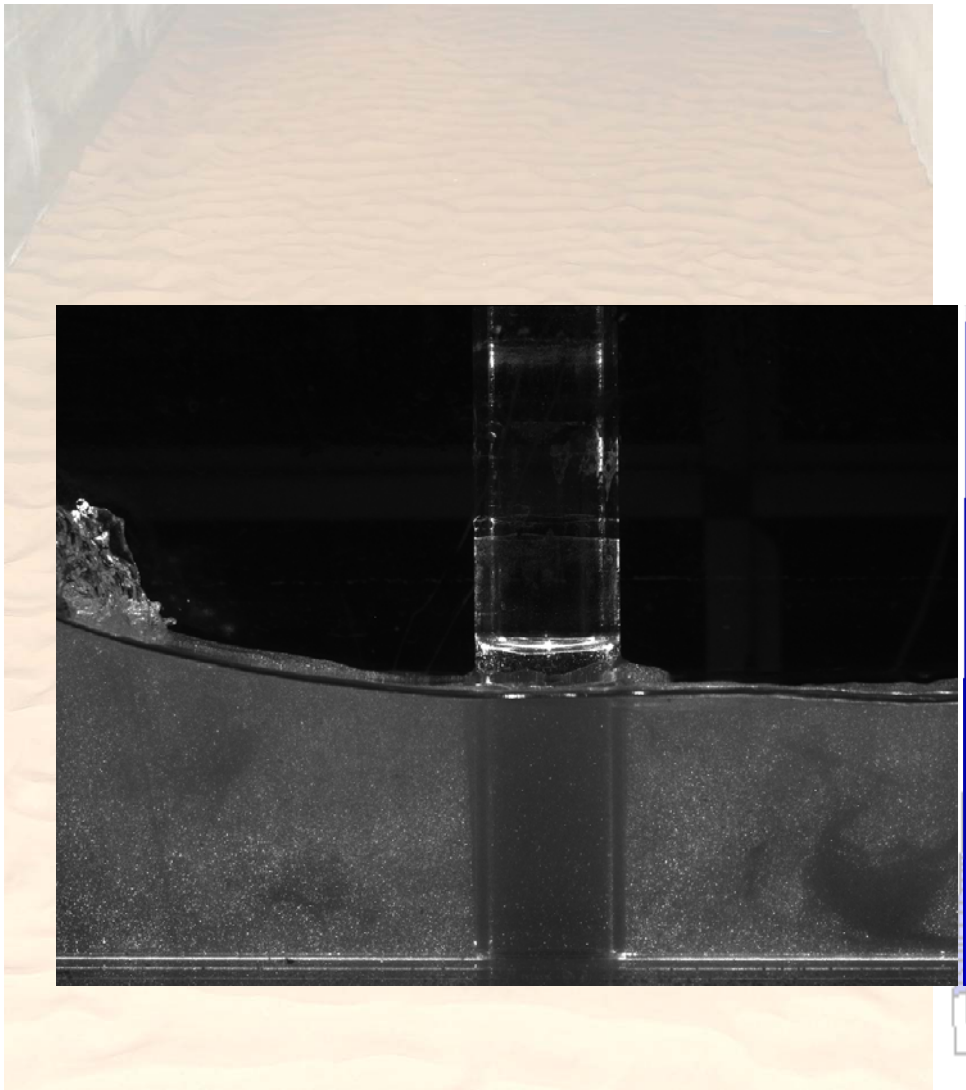
Offshore Center Danmark

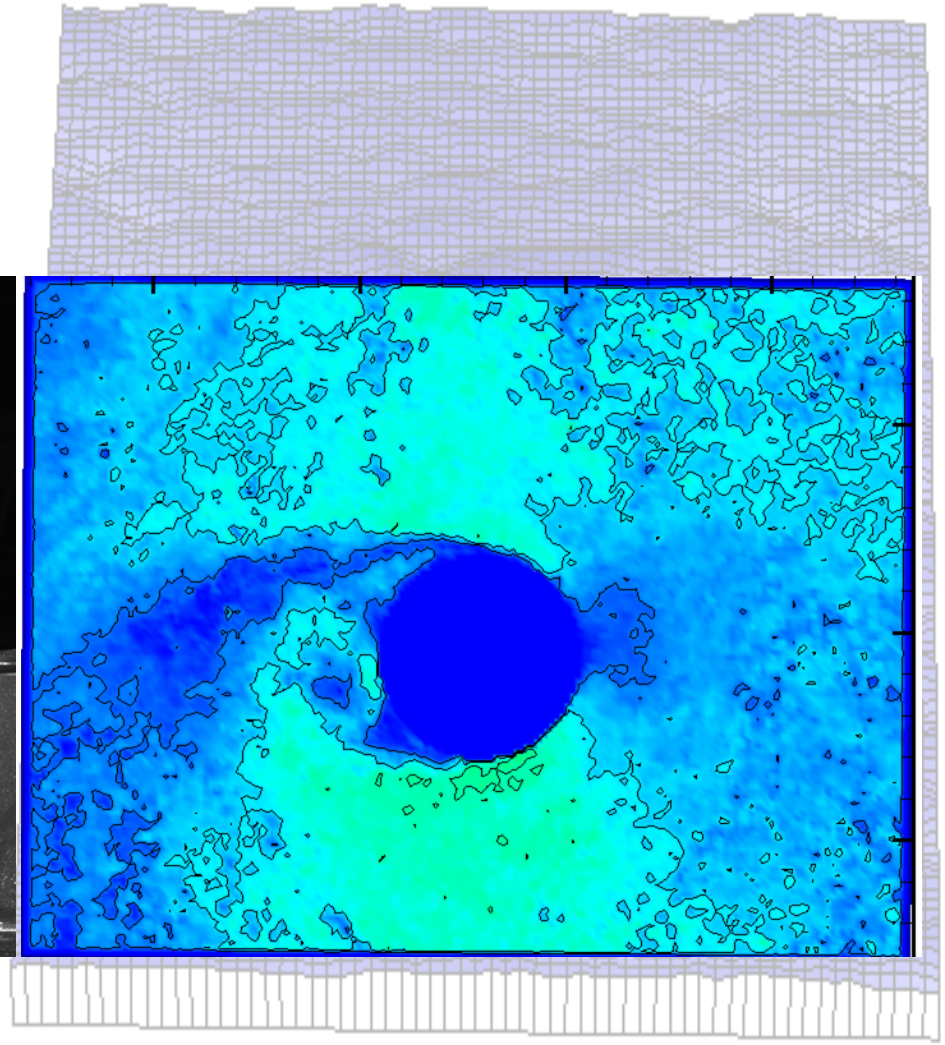
PIV measurements

breaking wave









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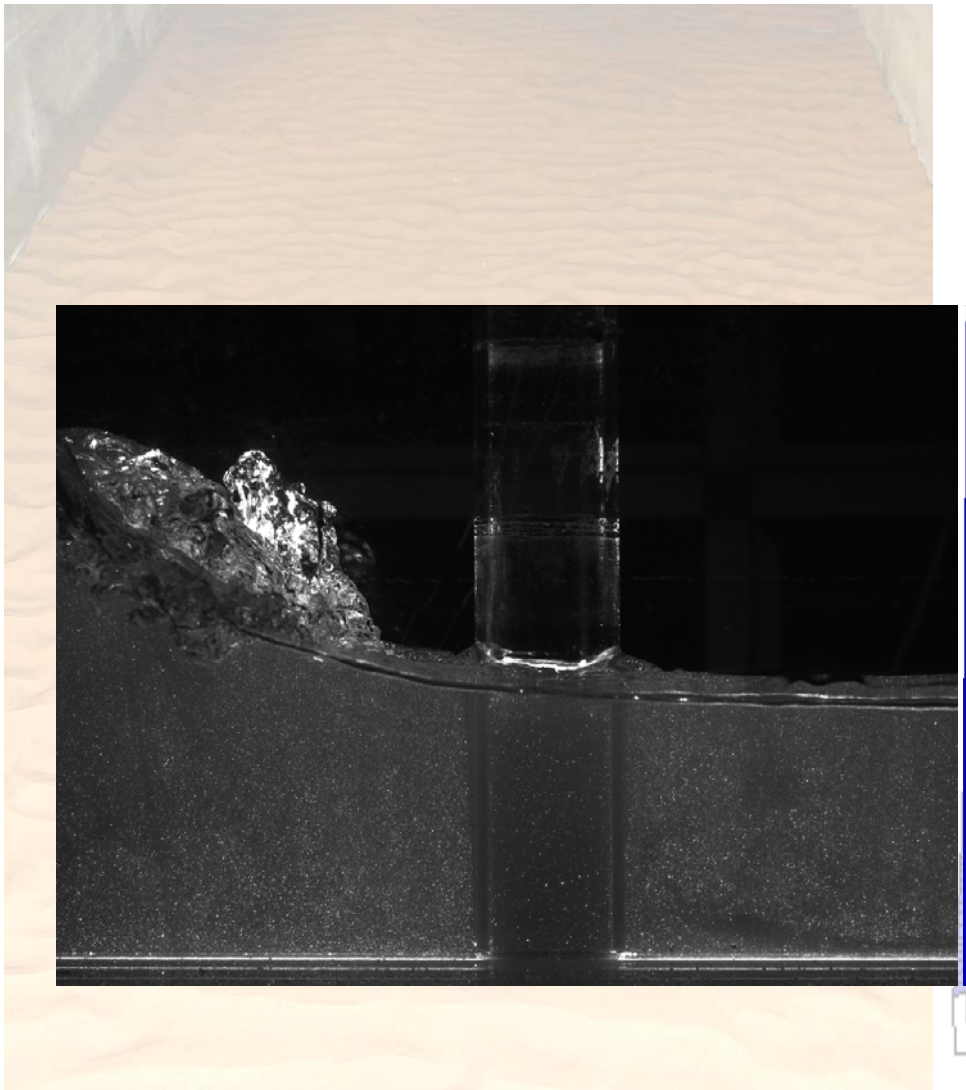

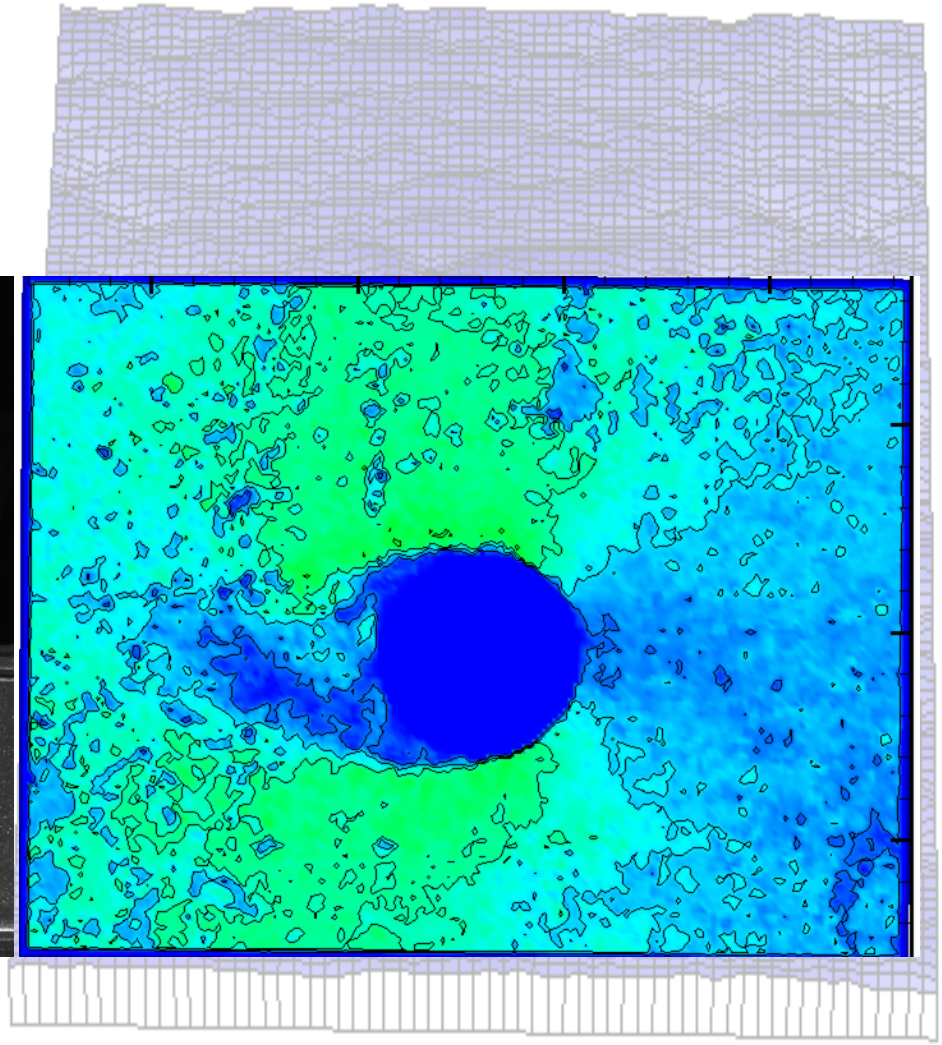

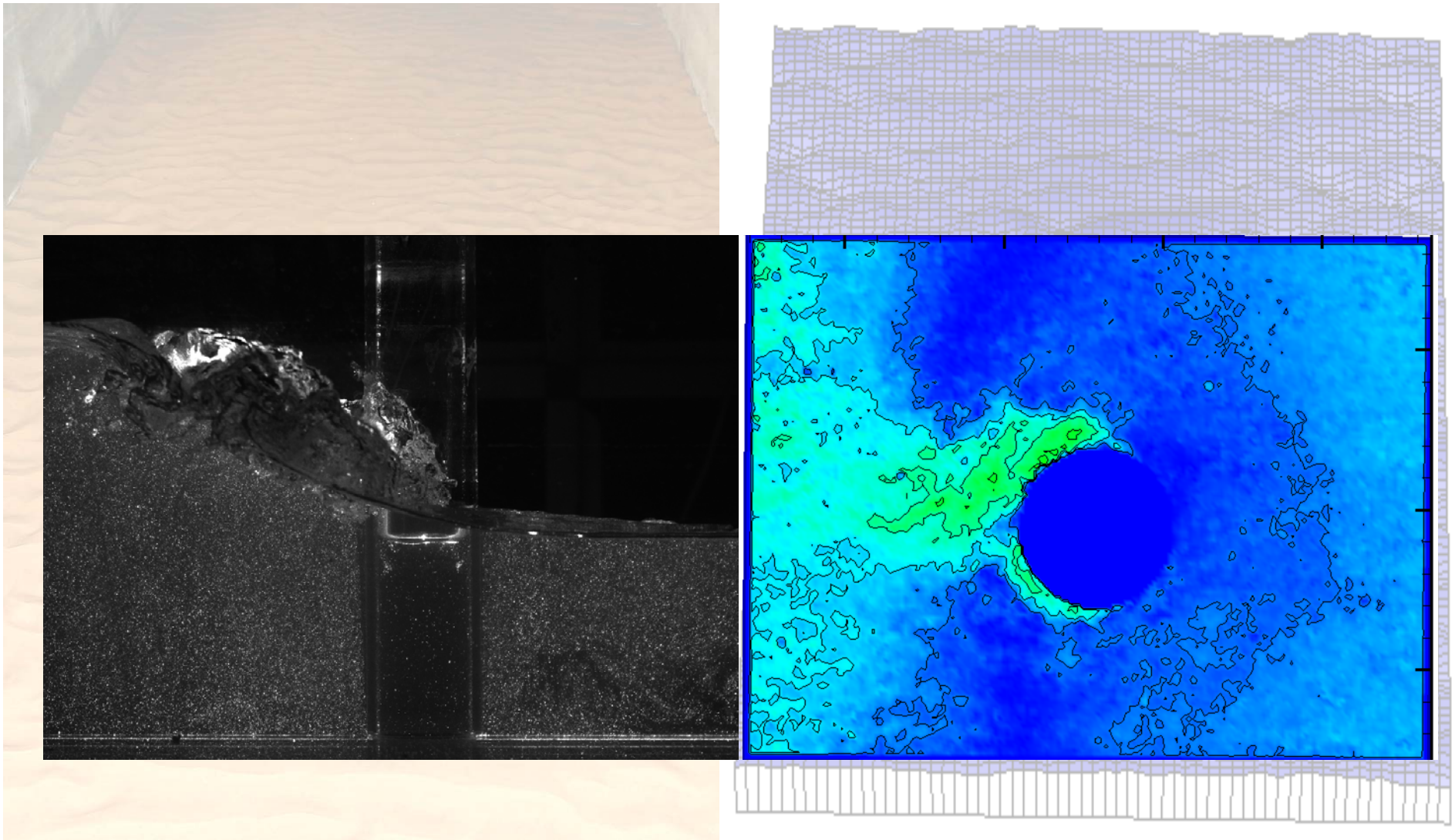

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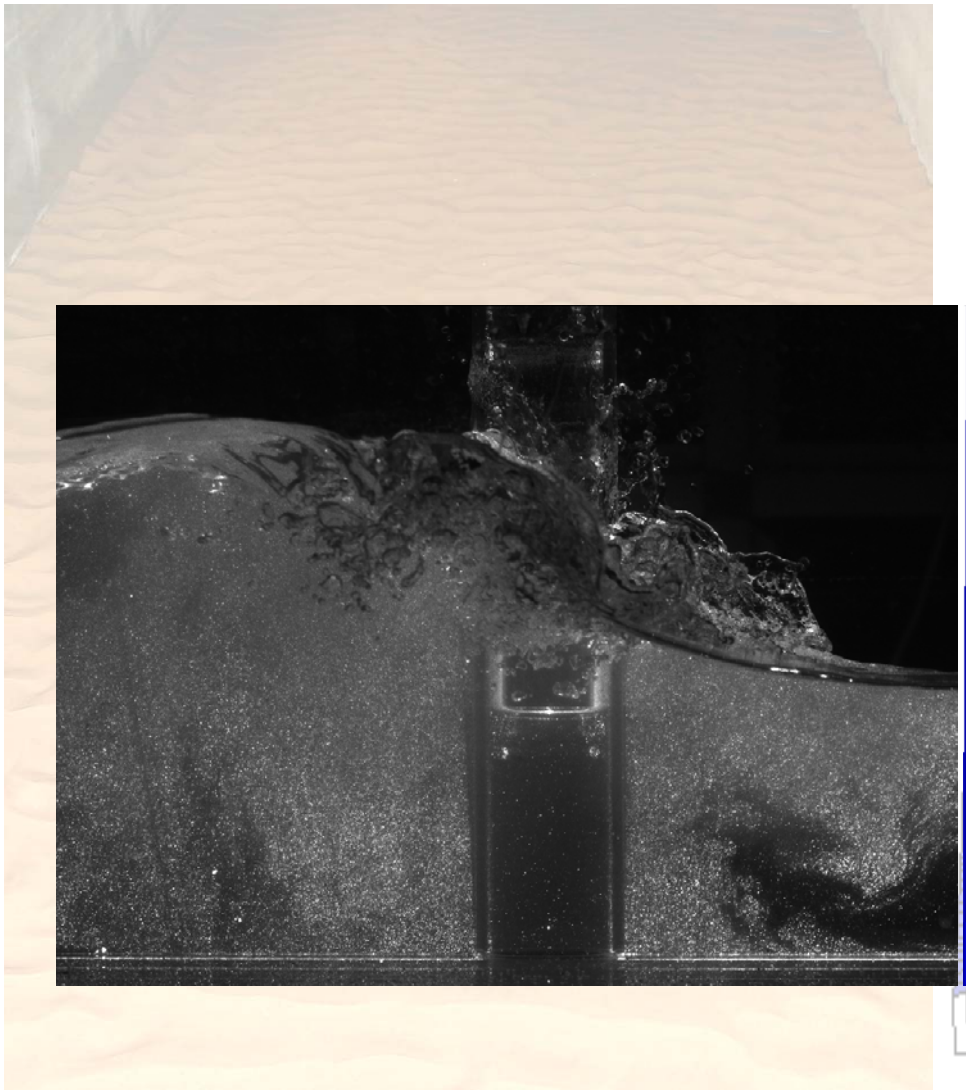

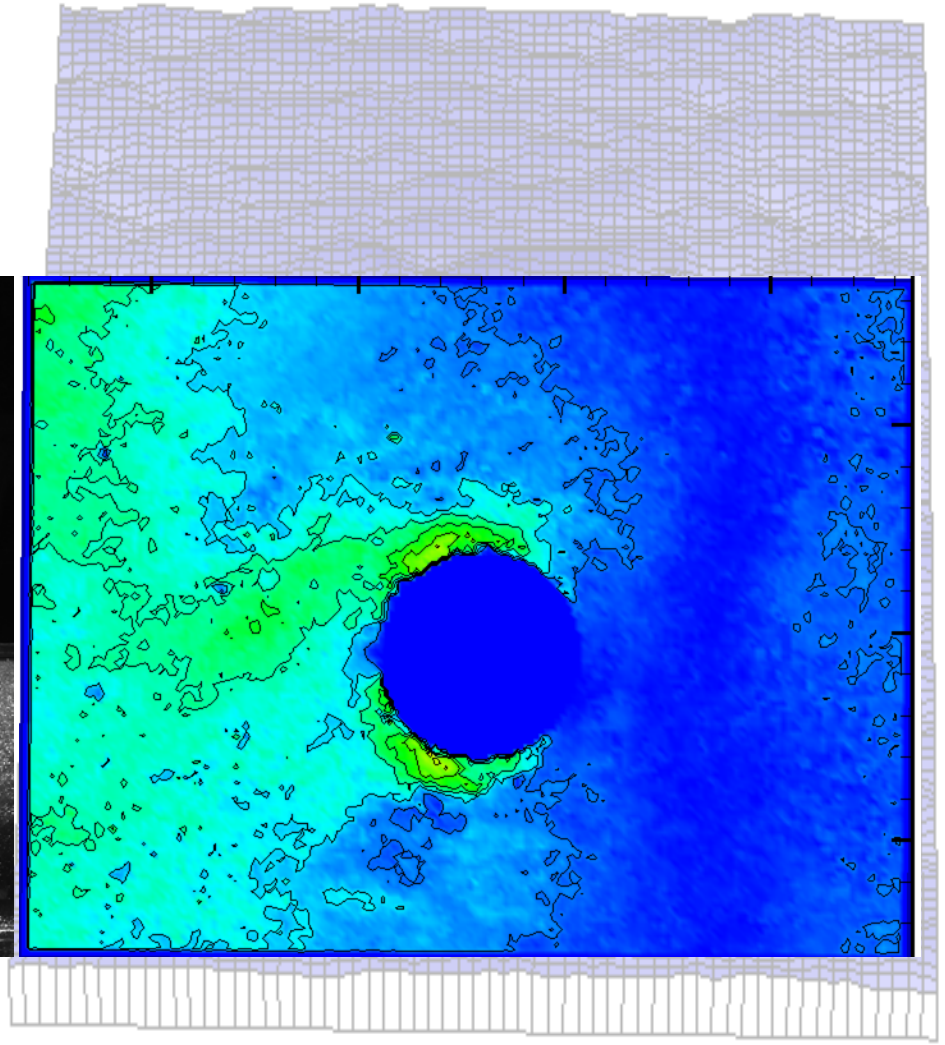

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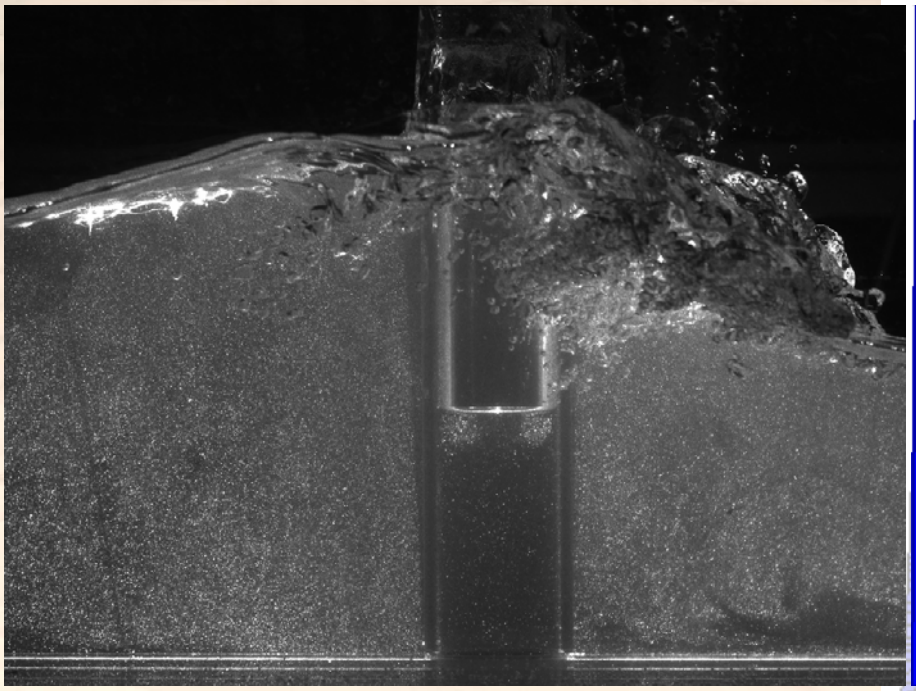

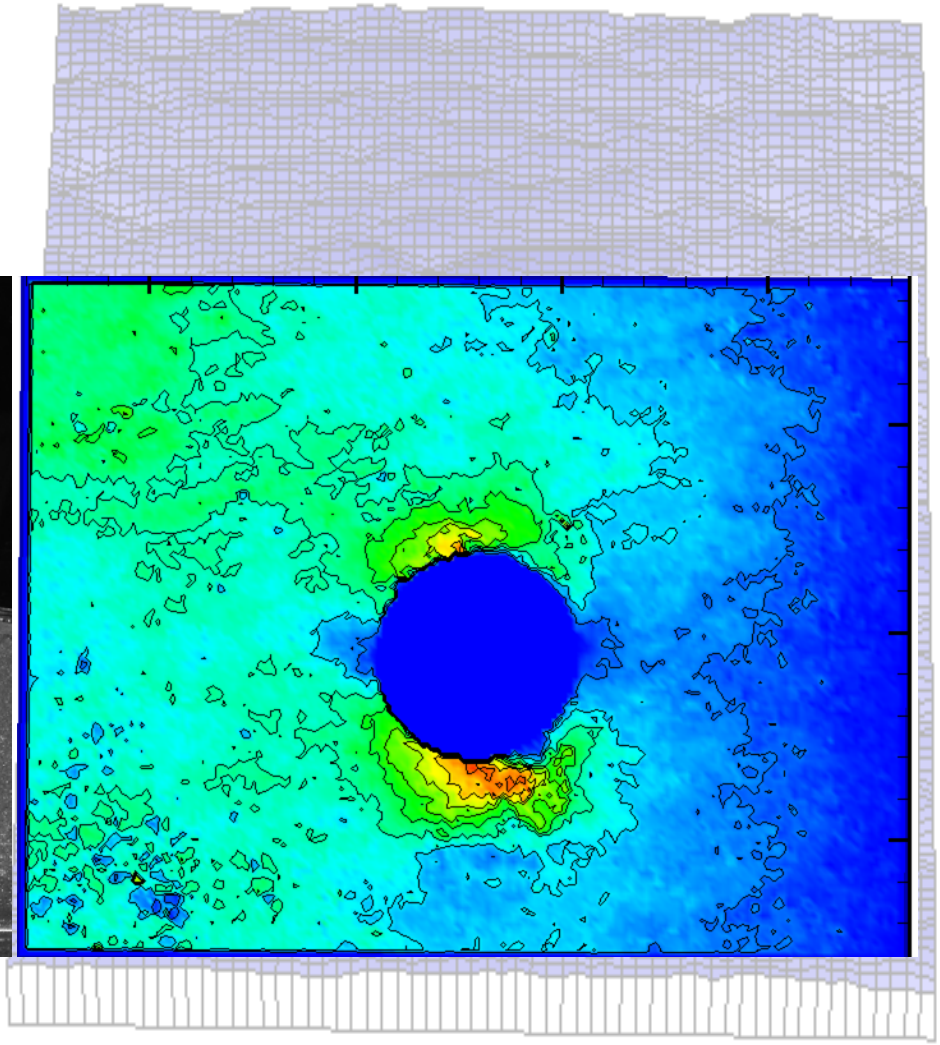

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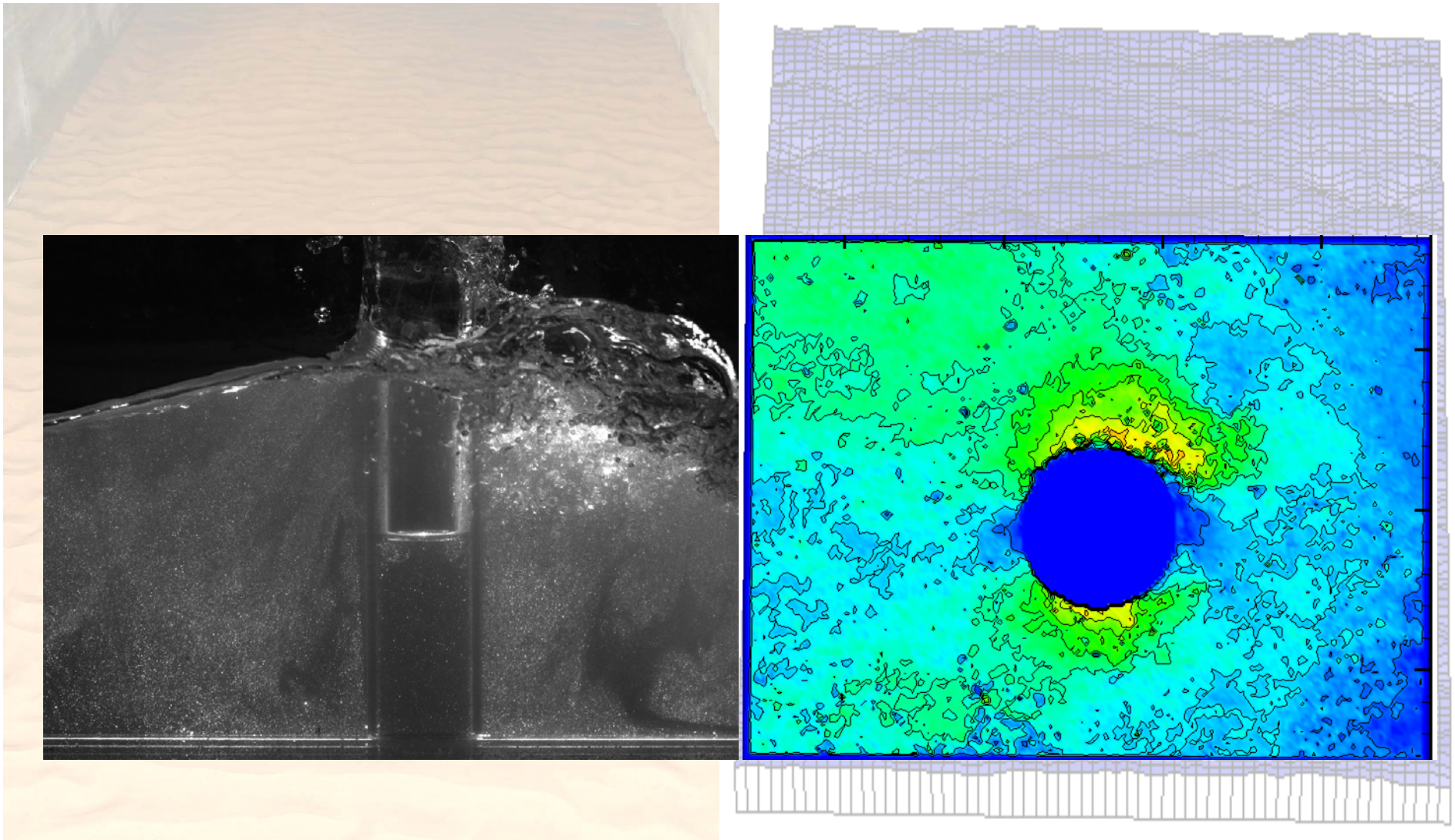

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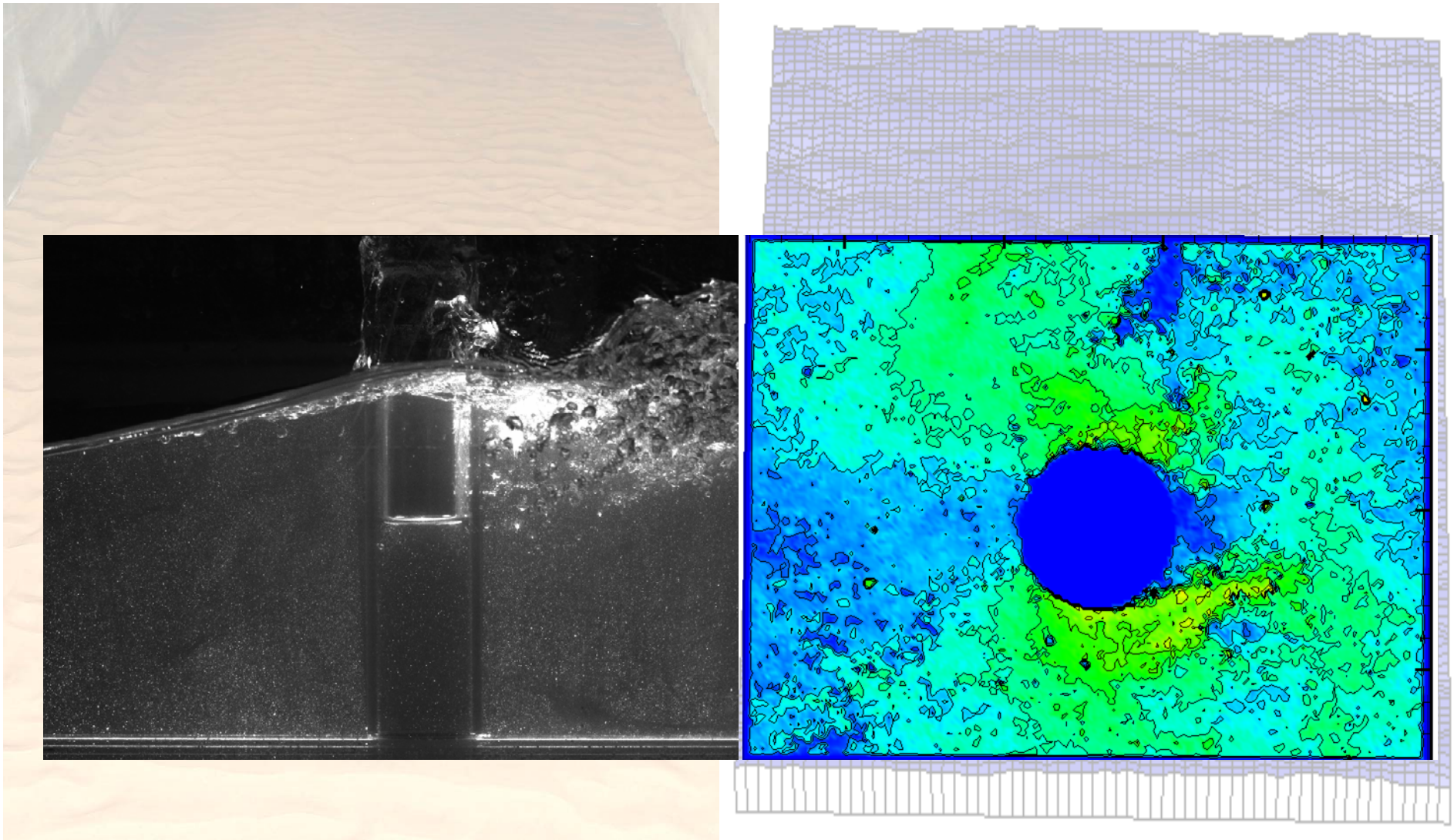

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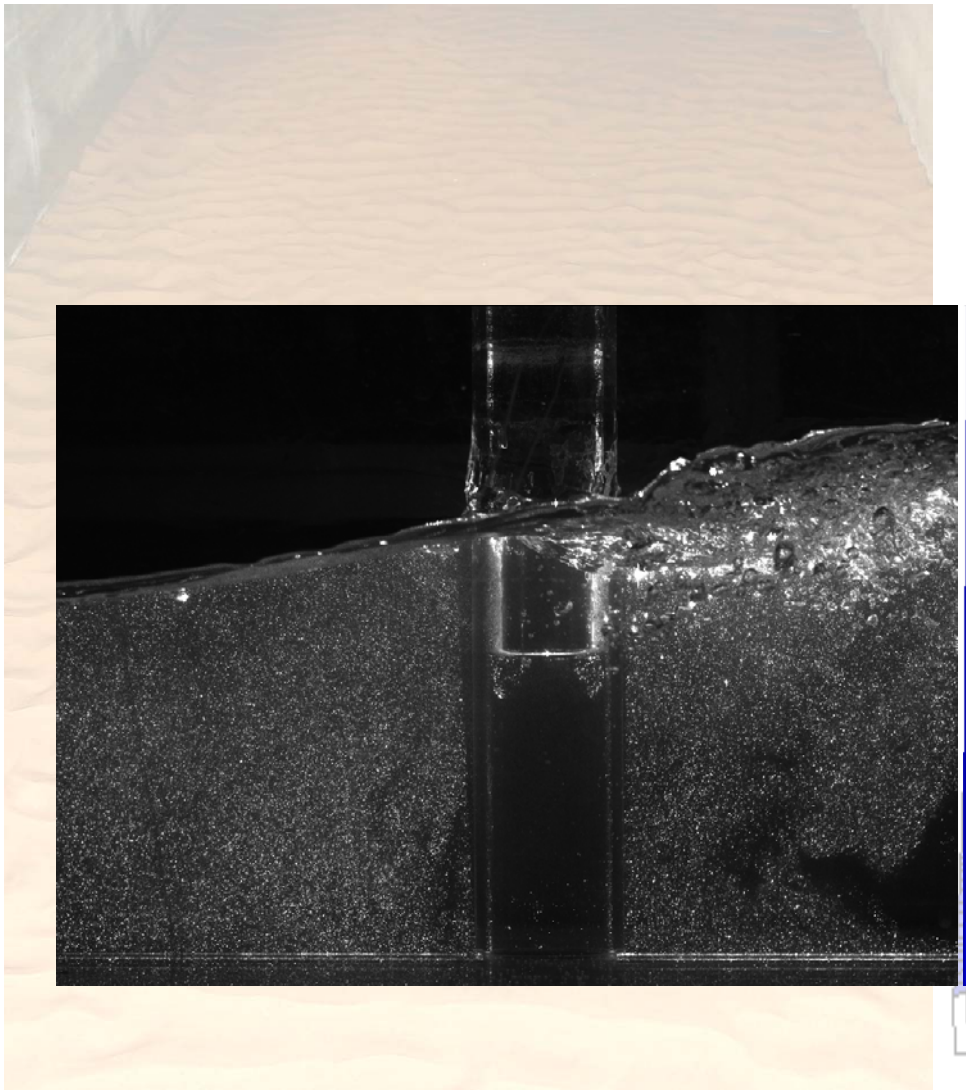

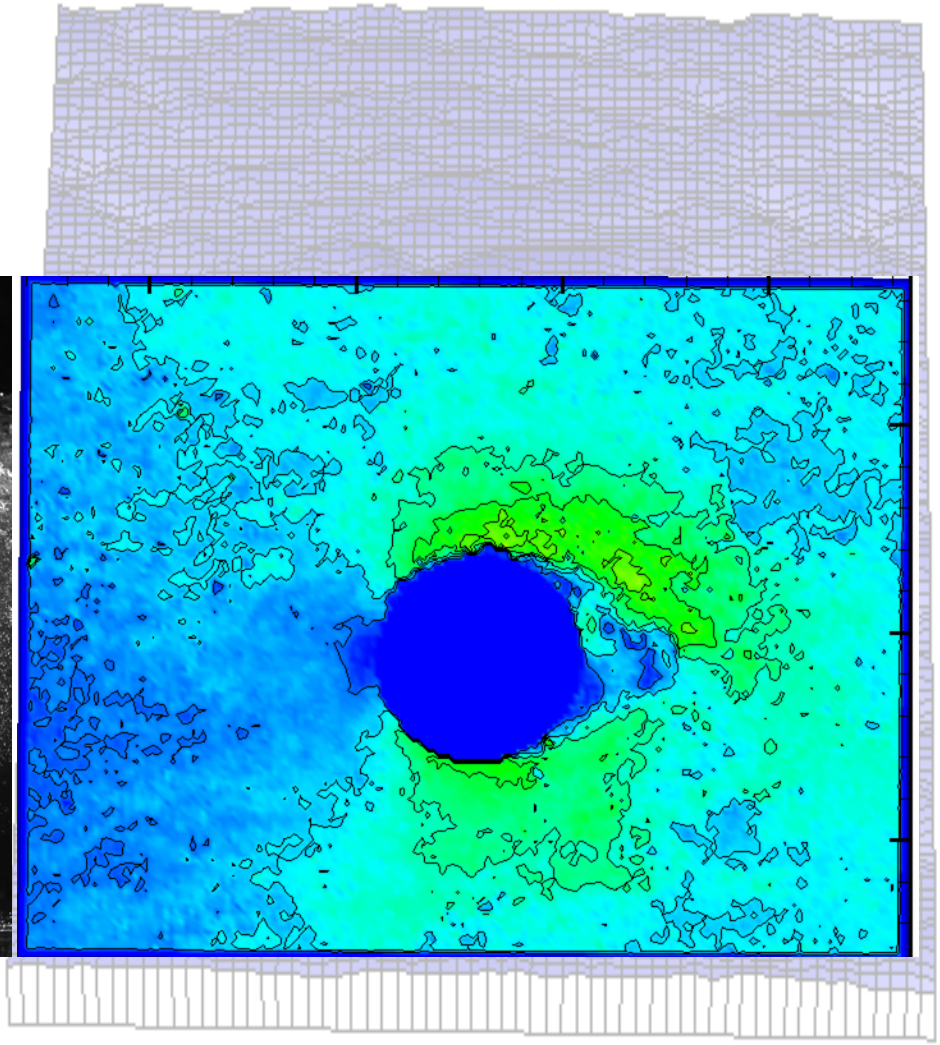

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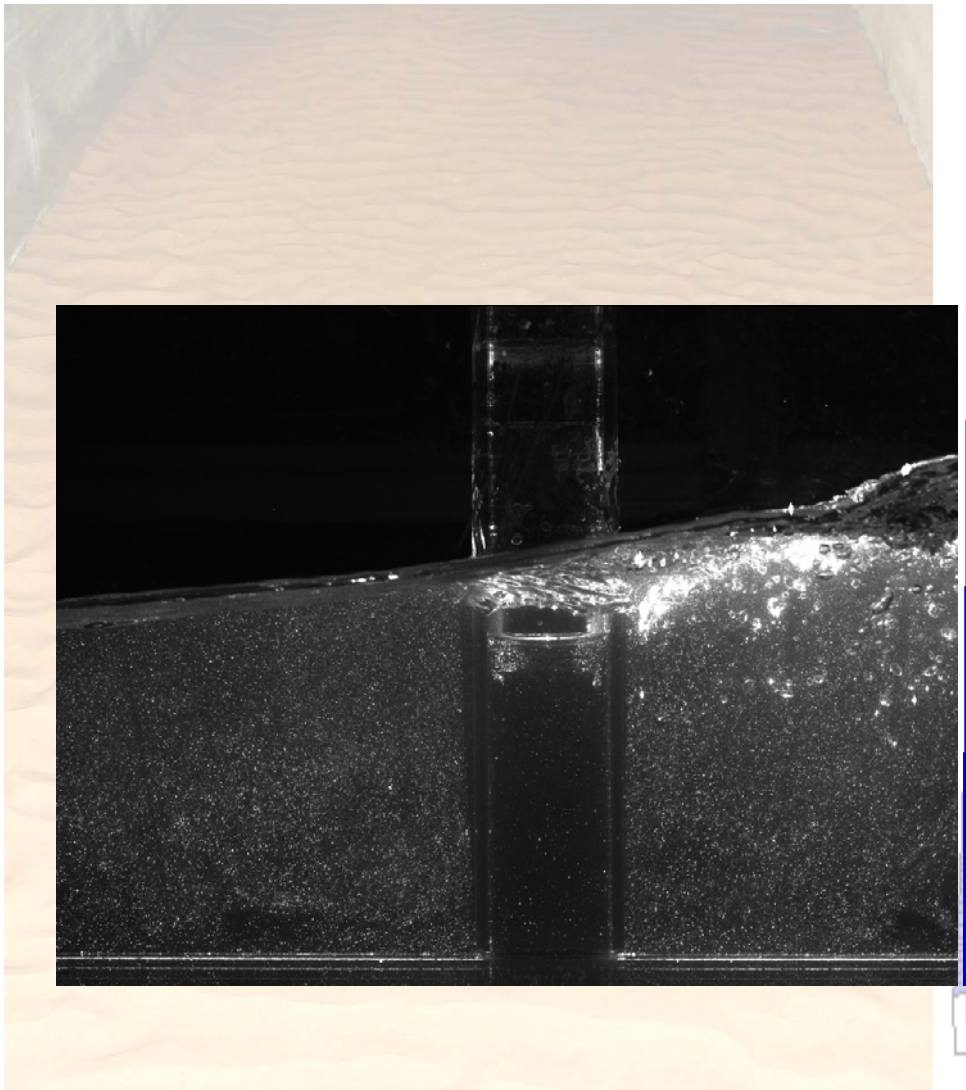

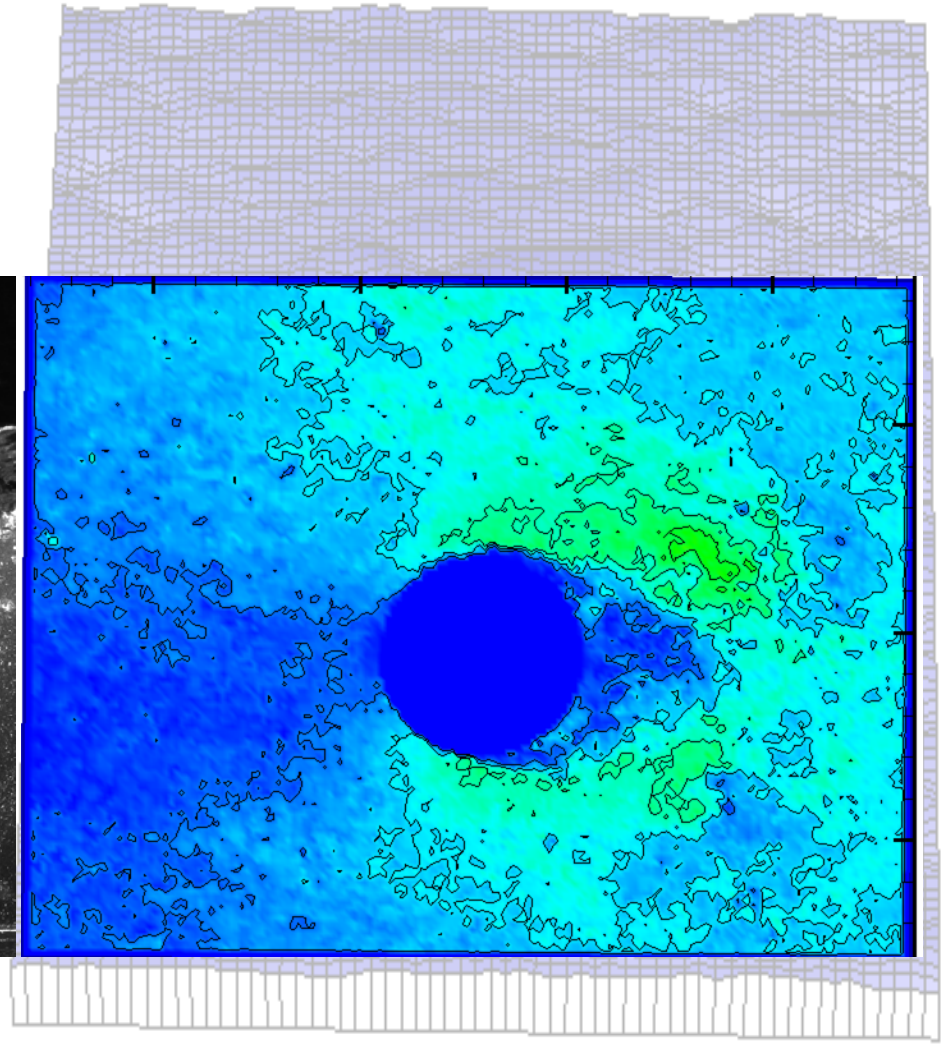

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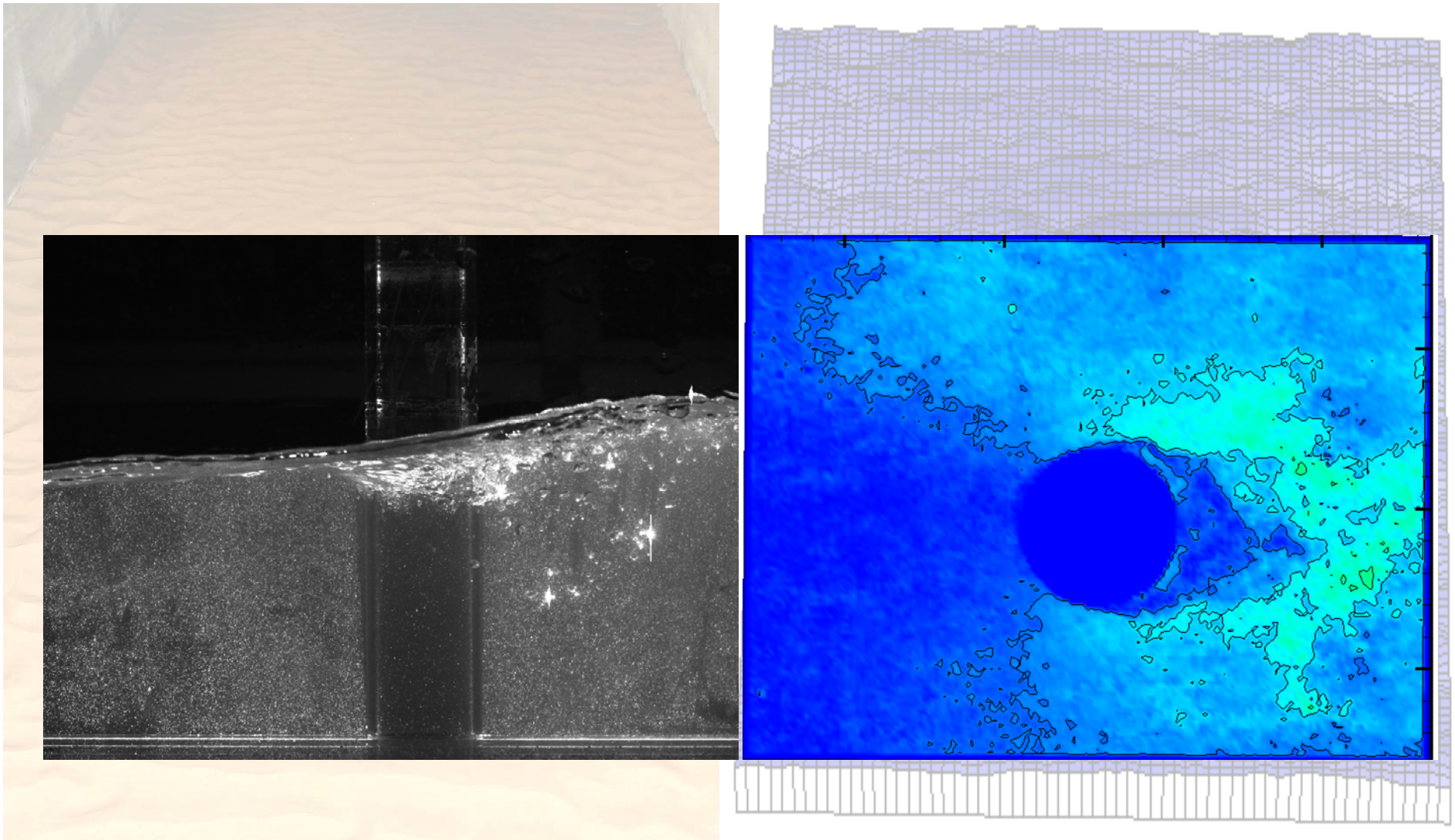

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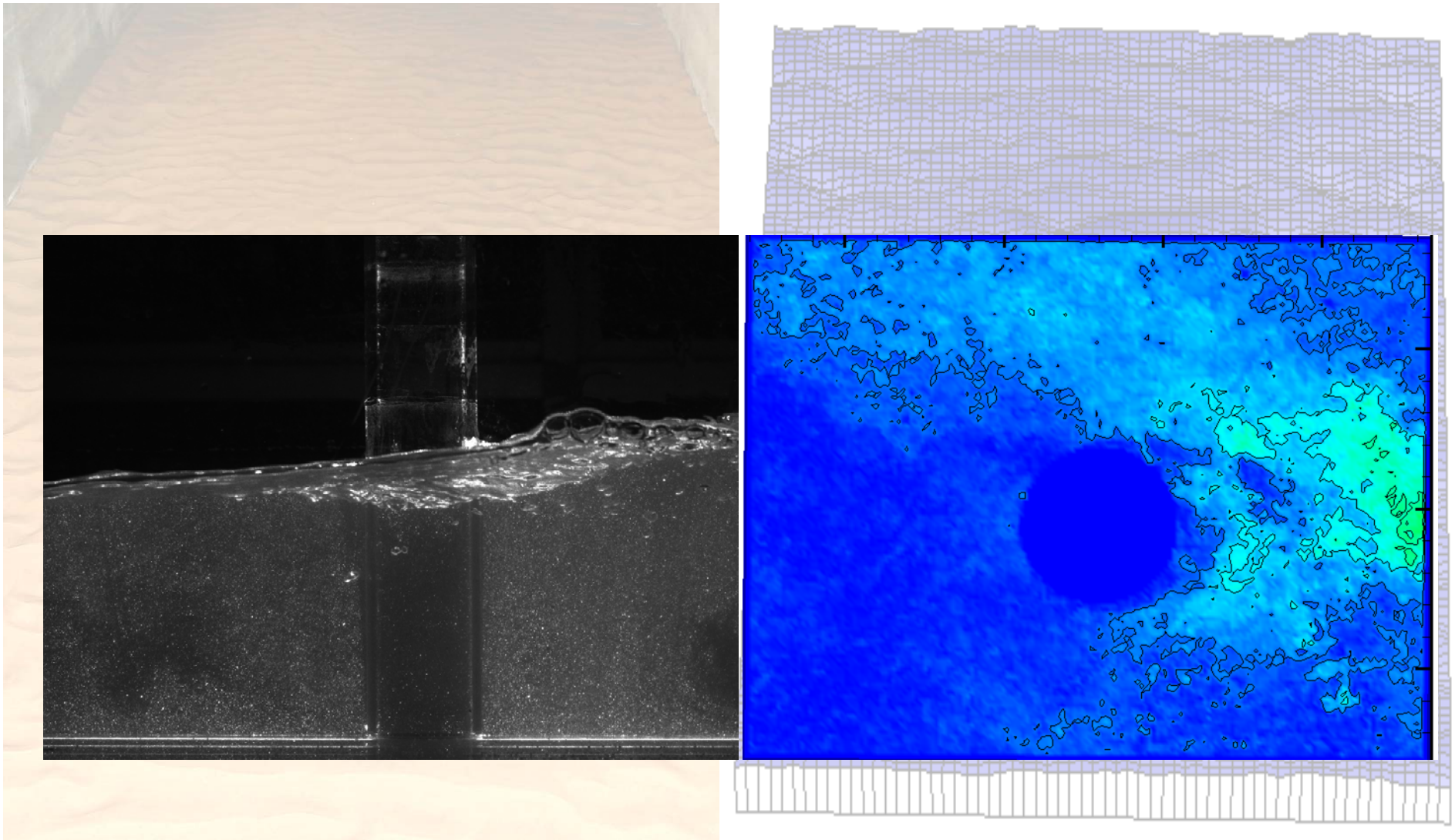

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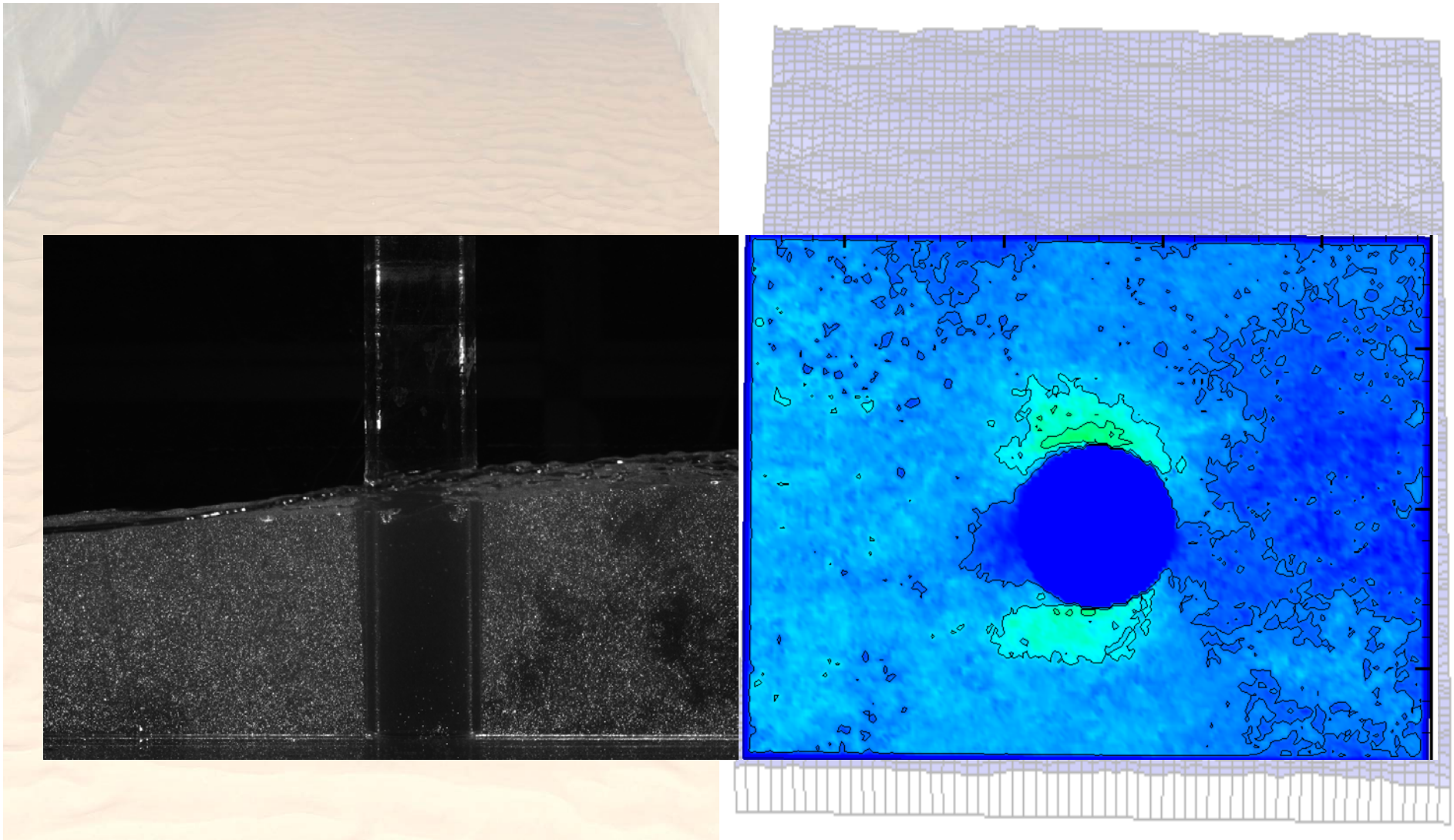

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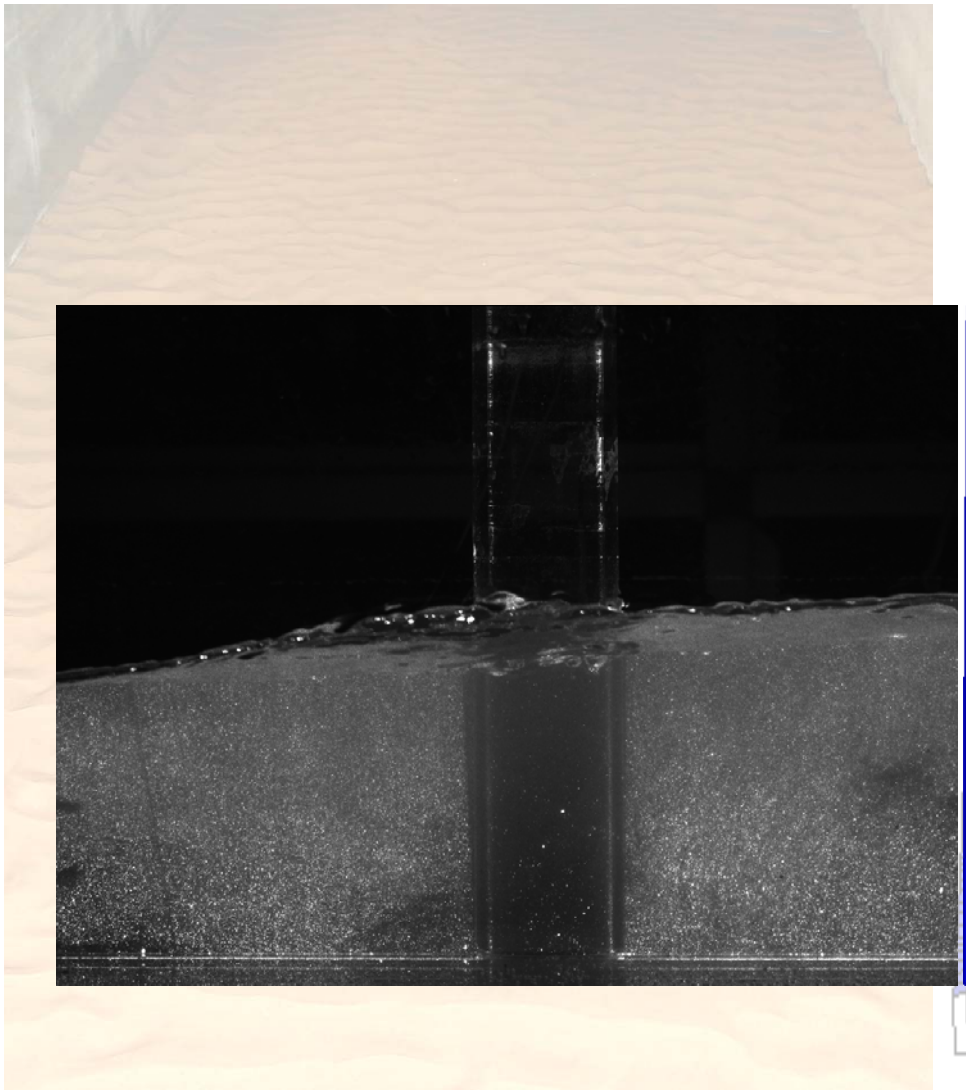

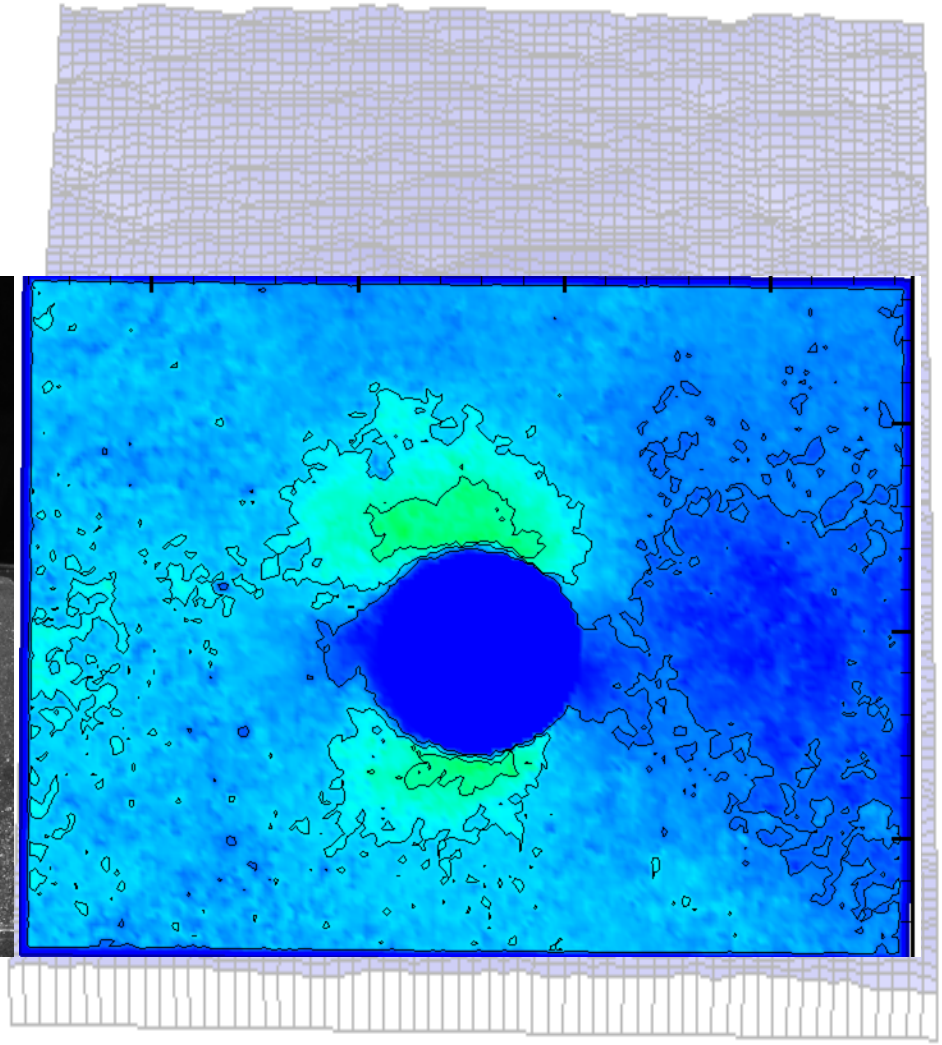

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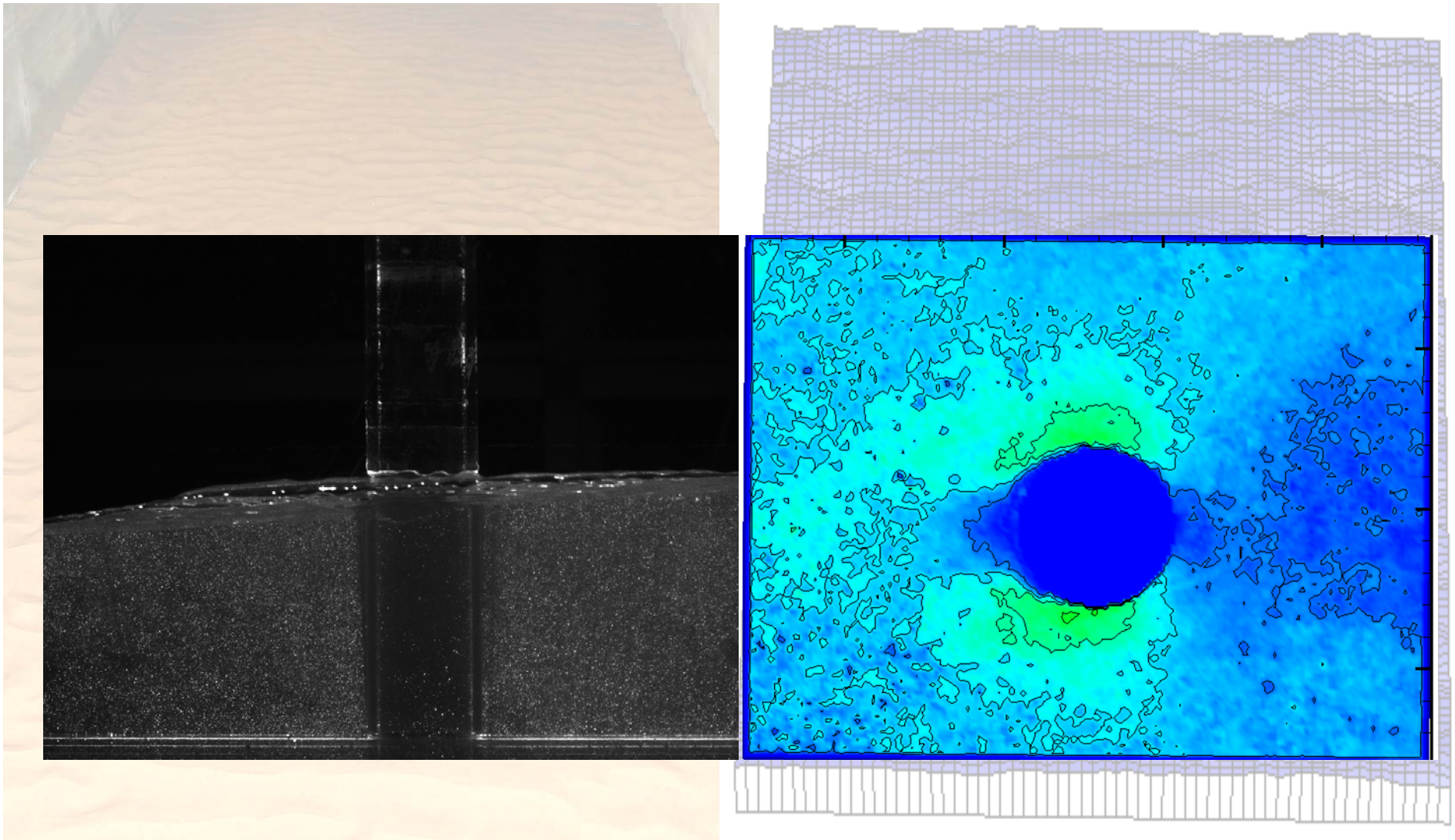

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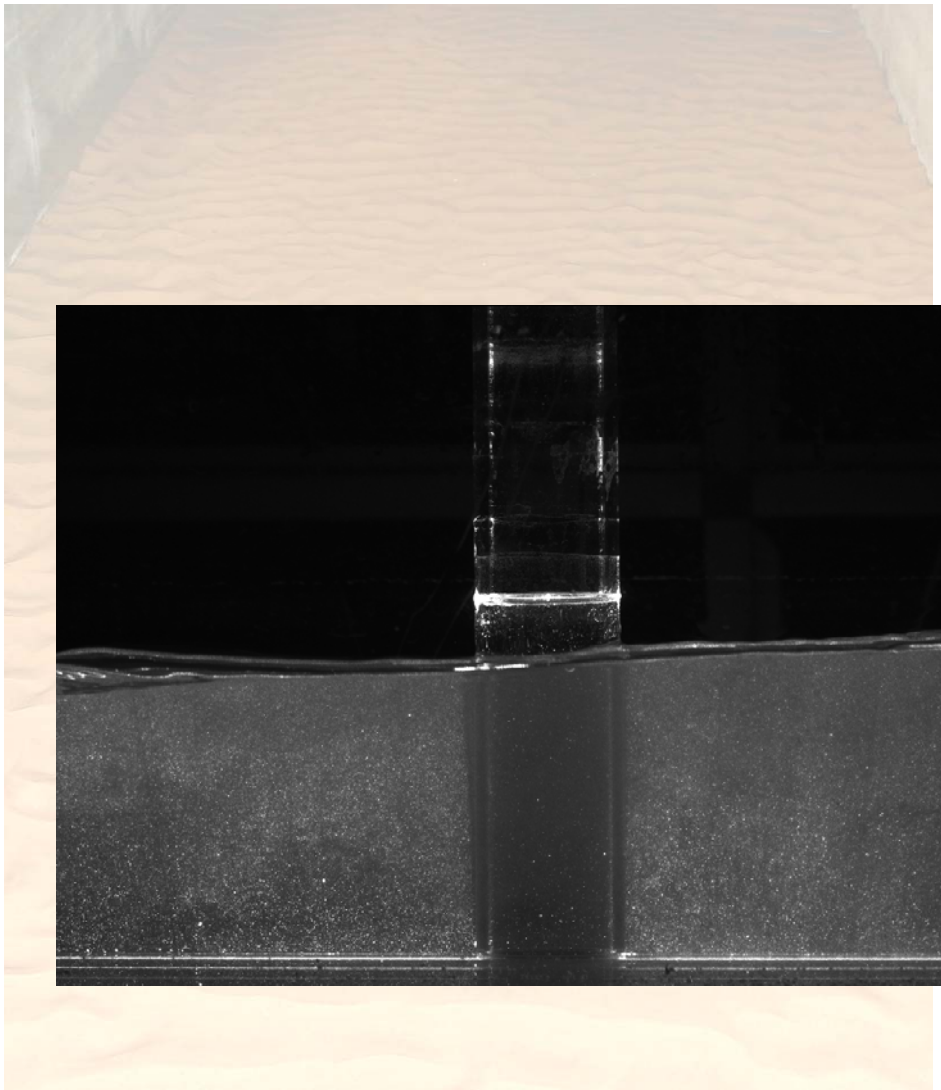

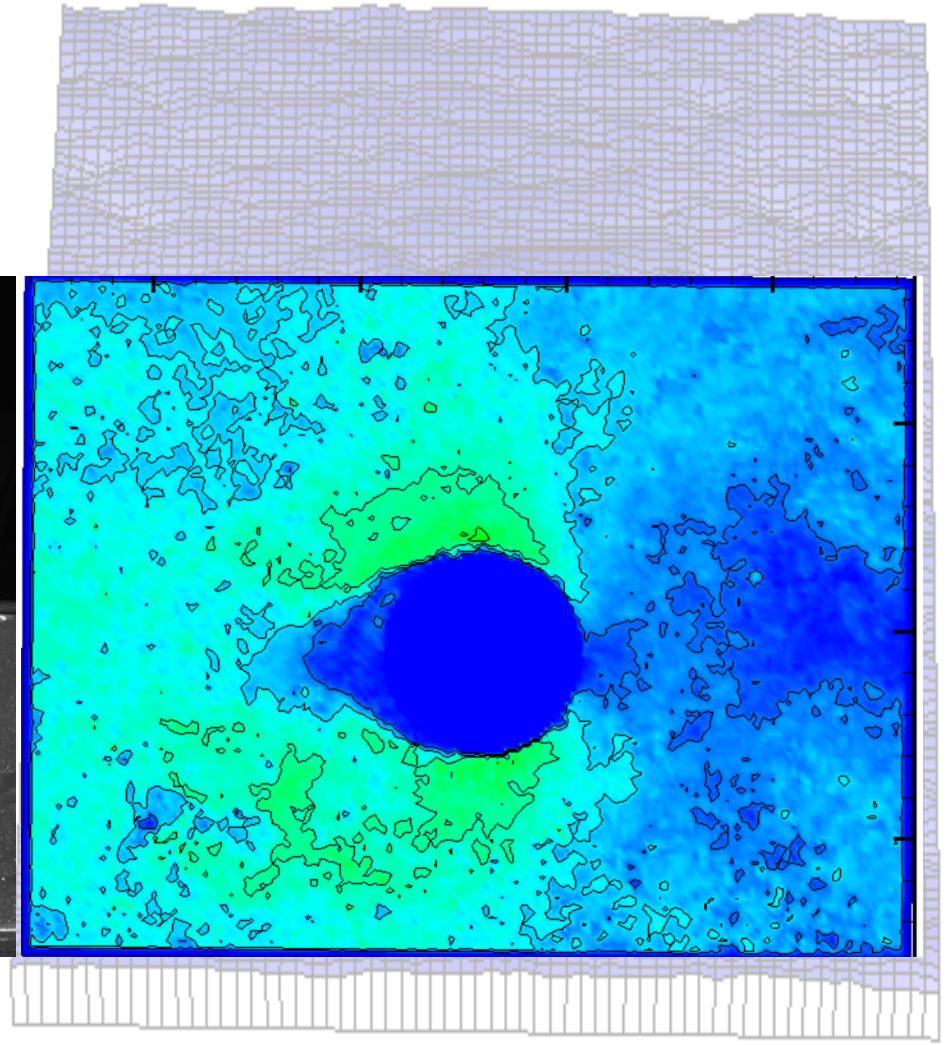

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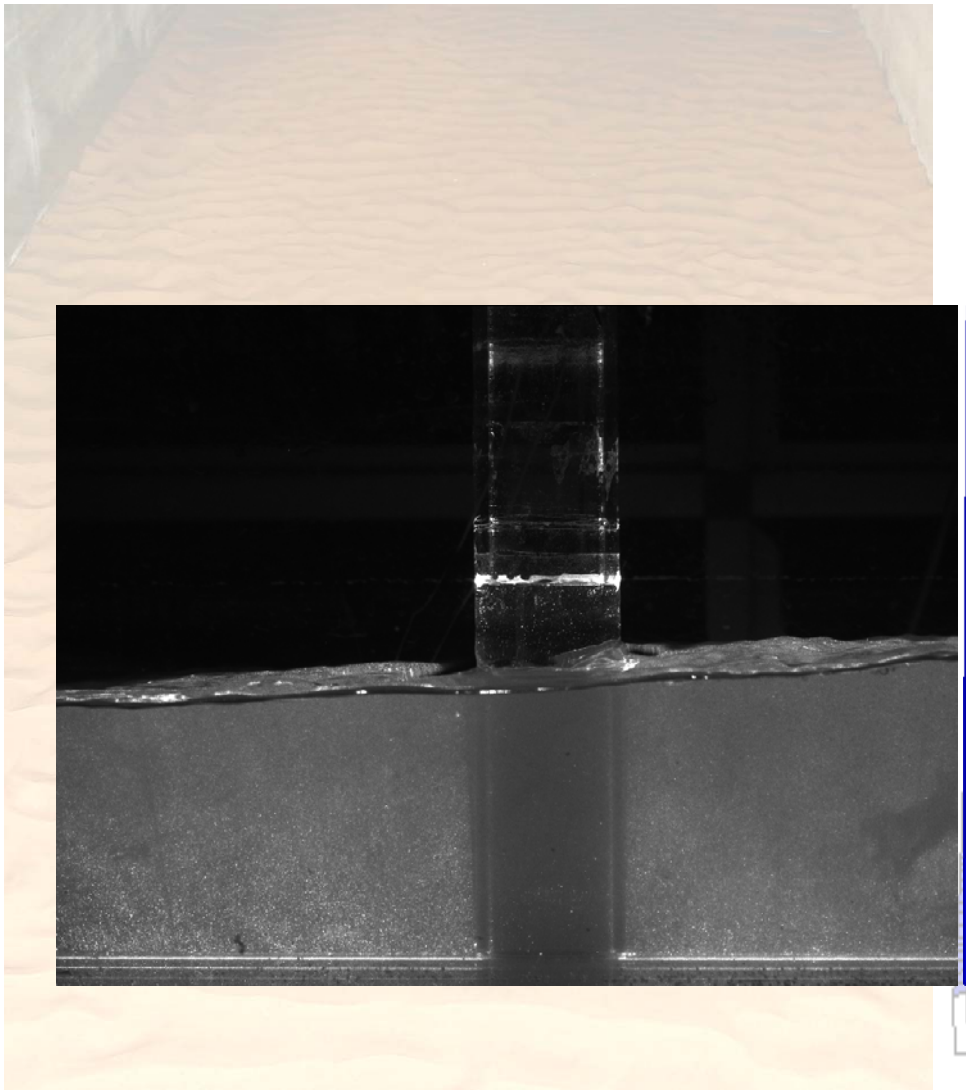

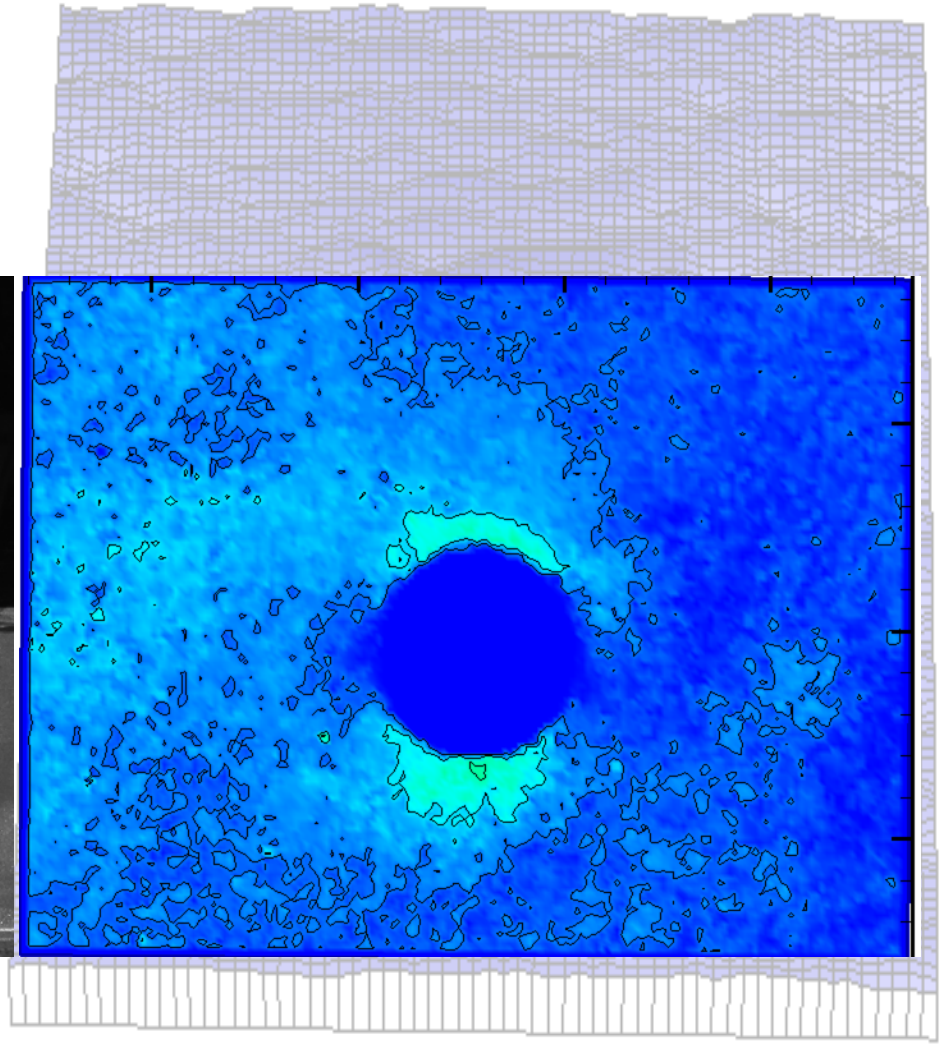

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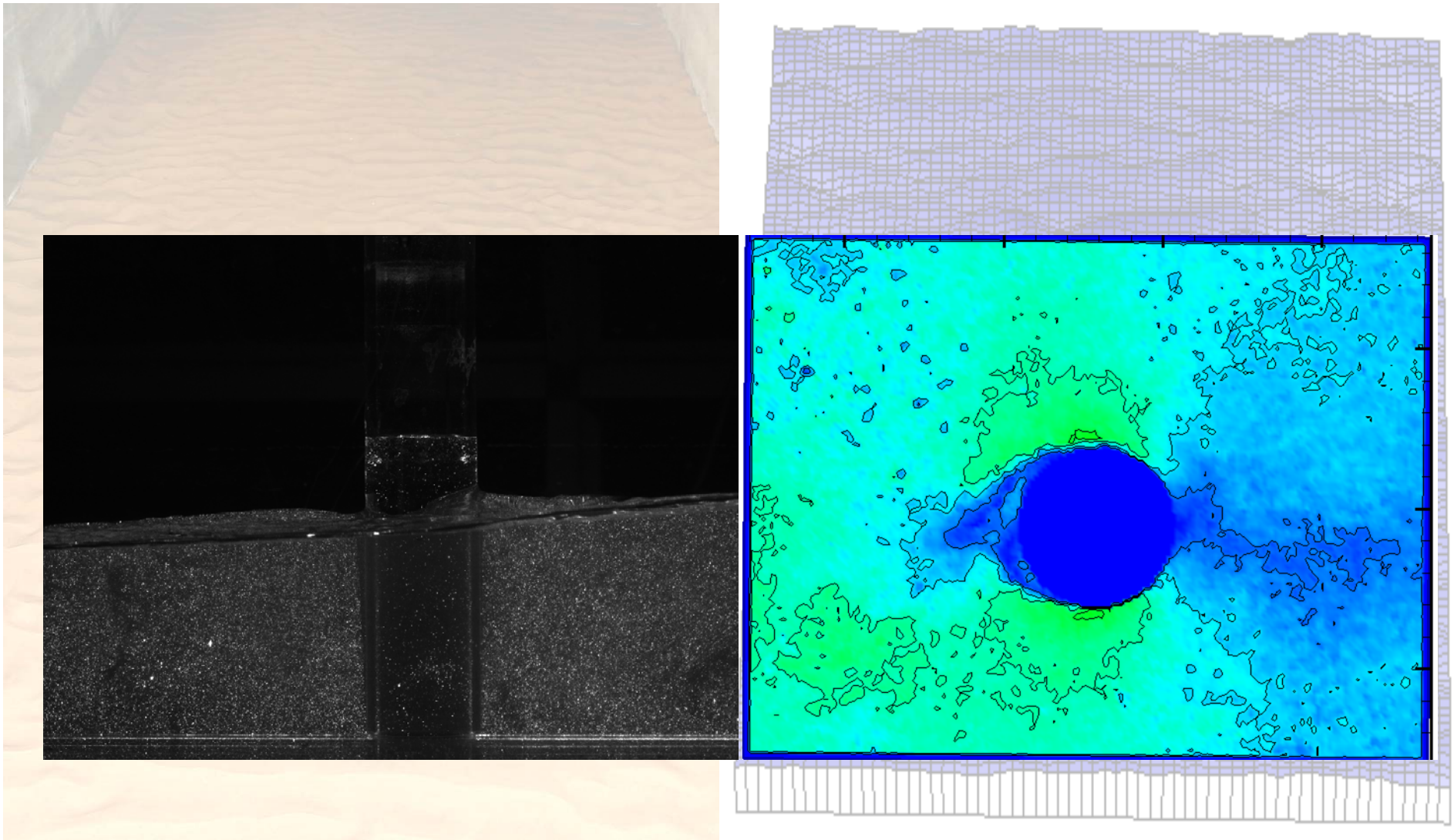

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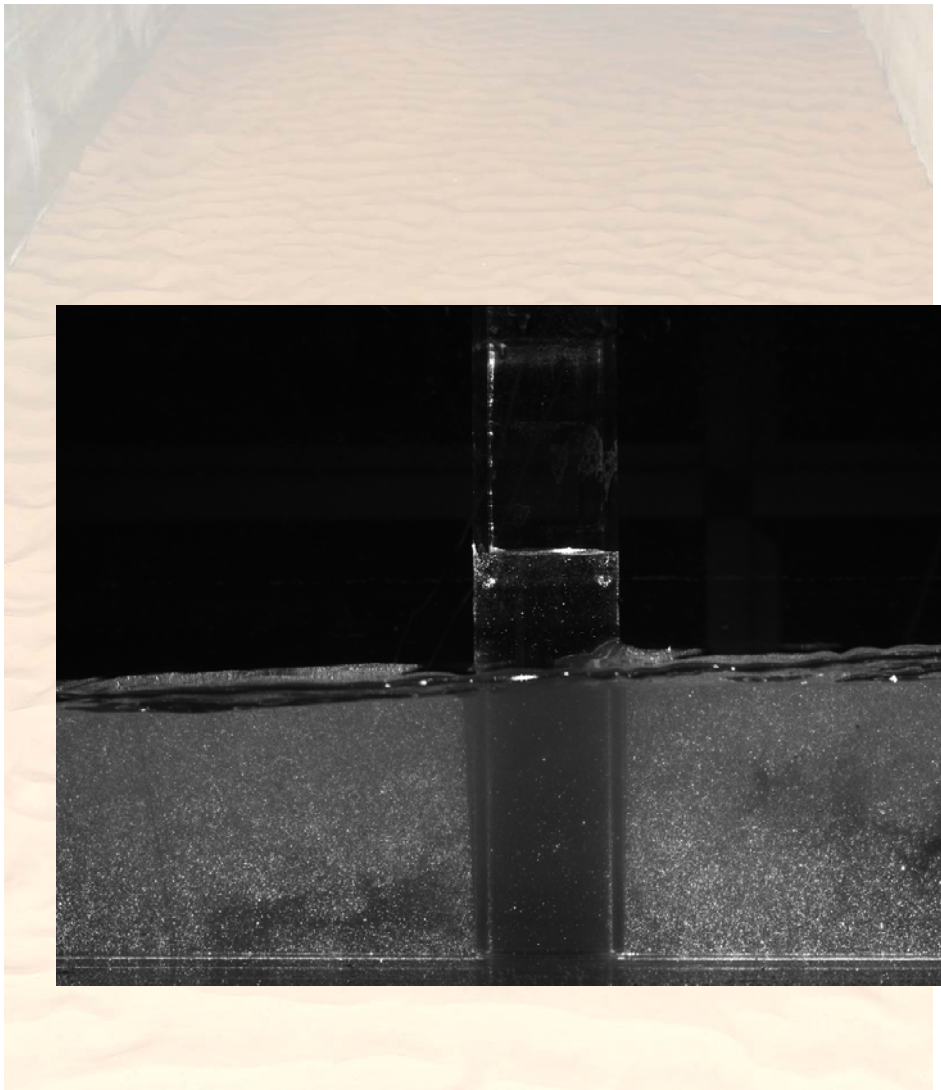

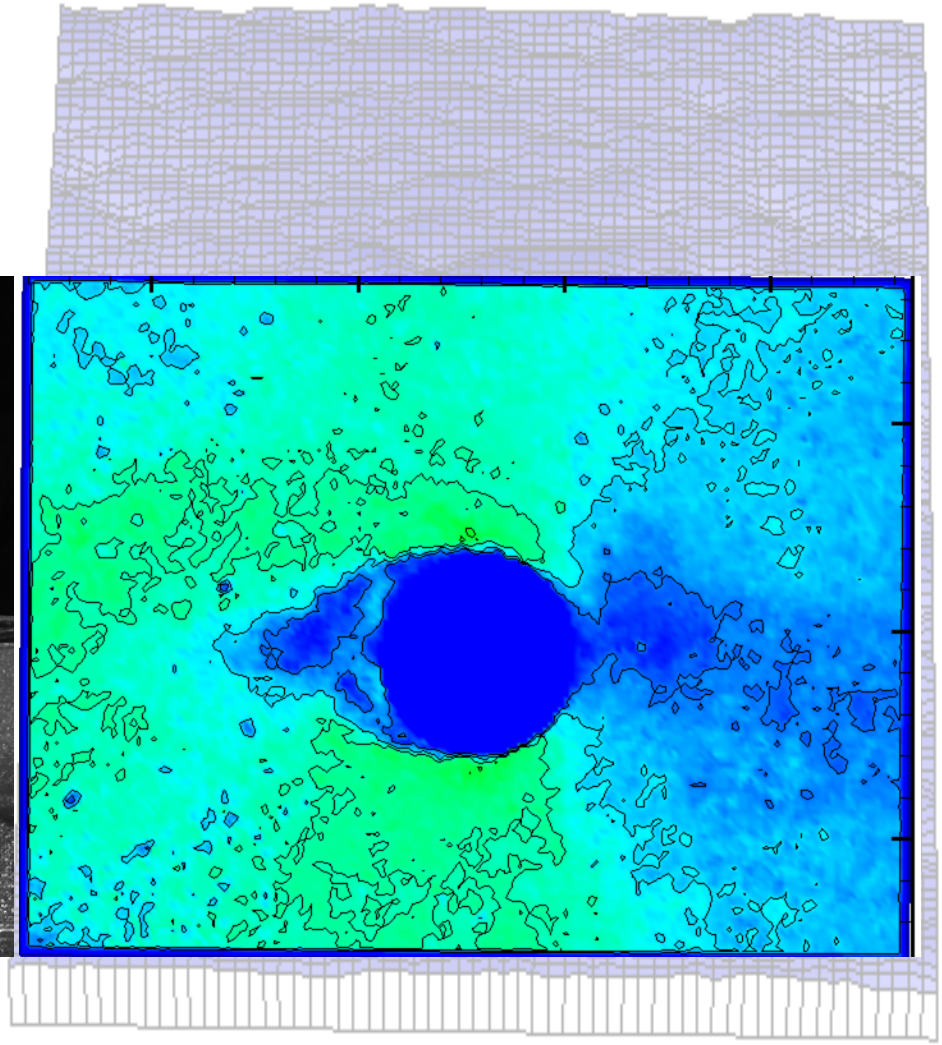

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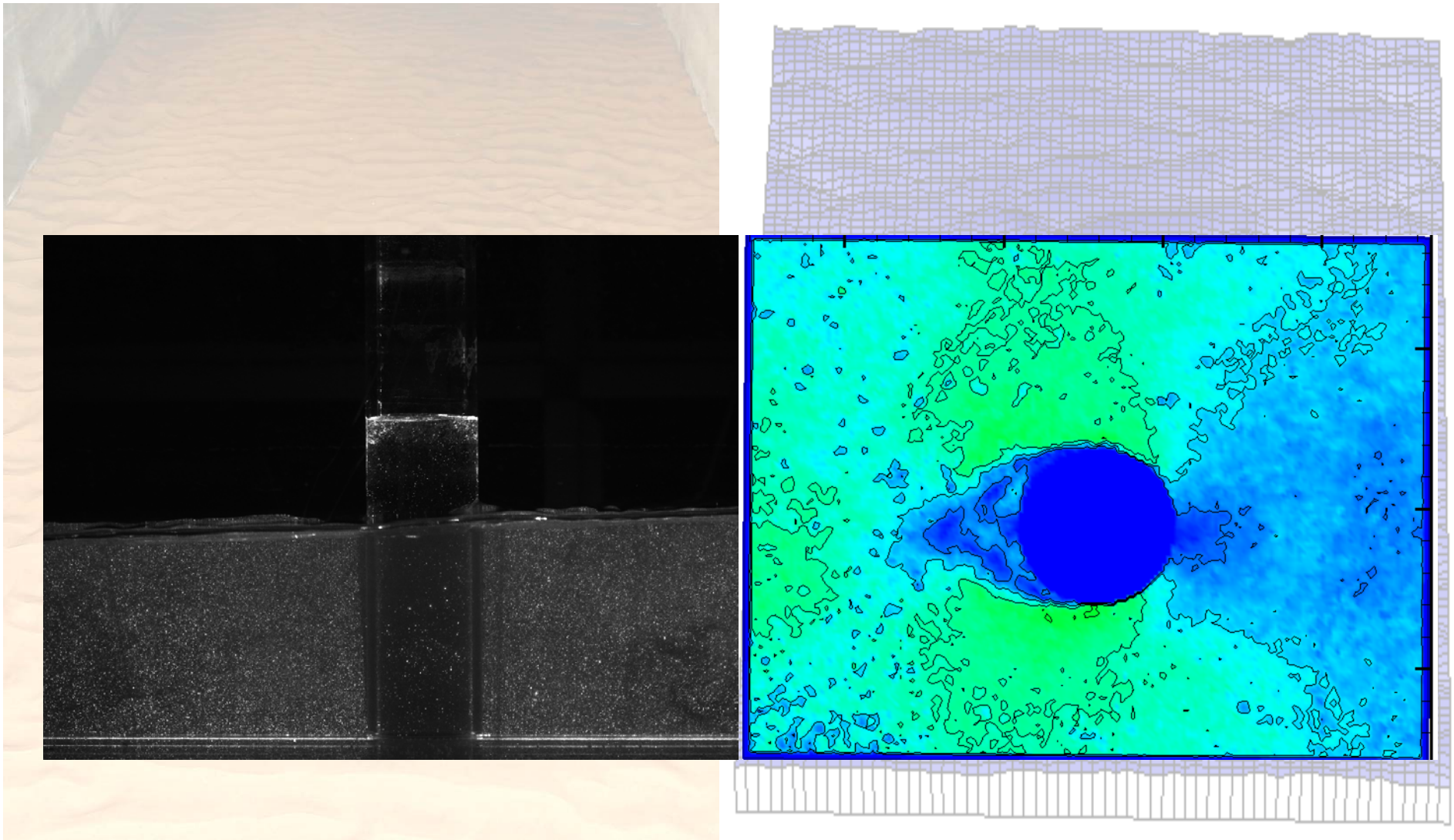

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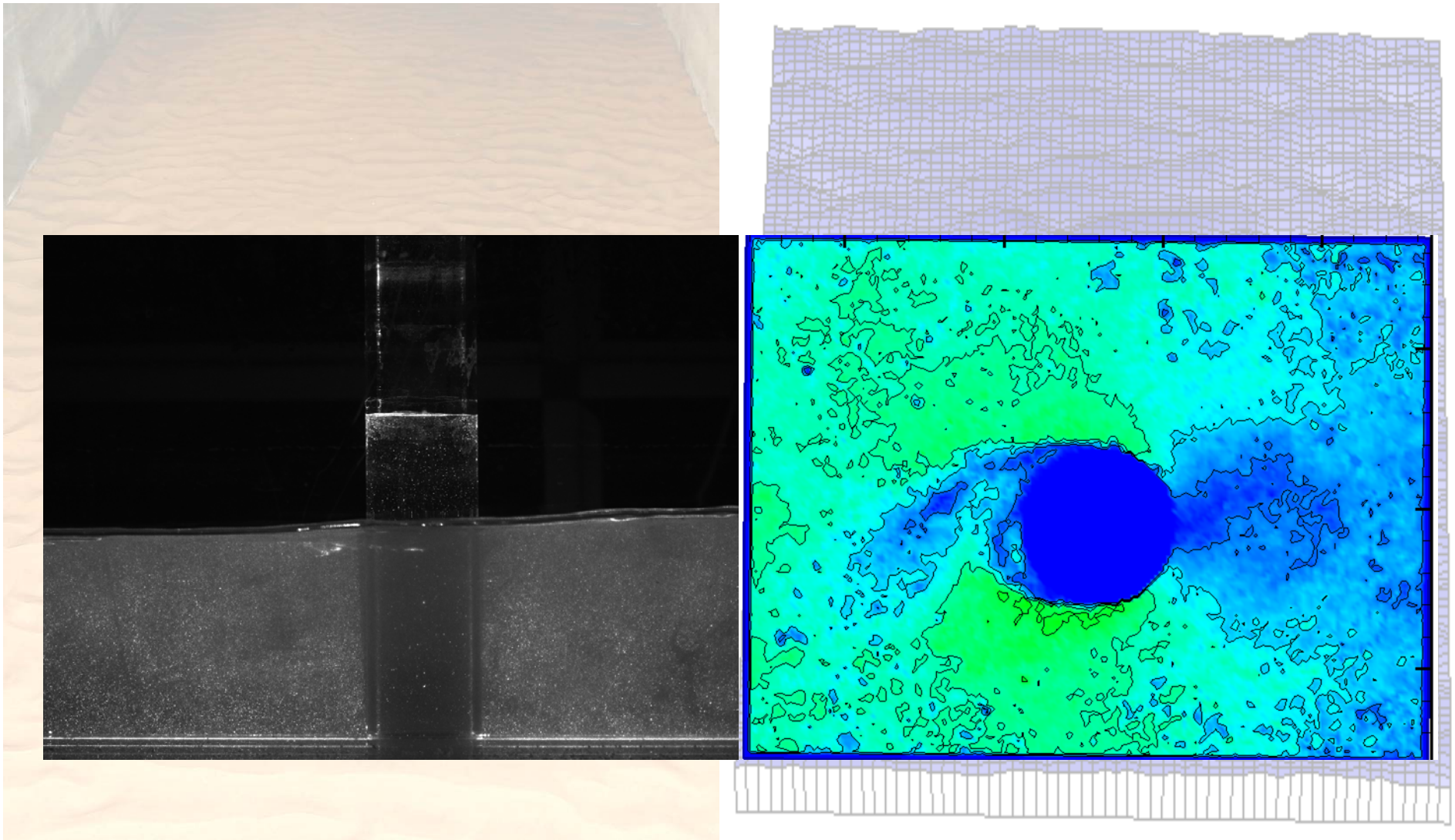

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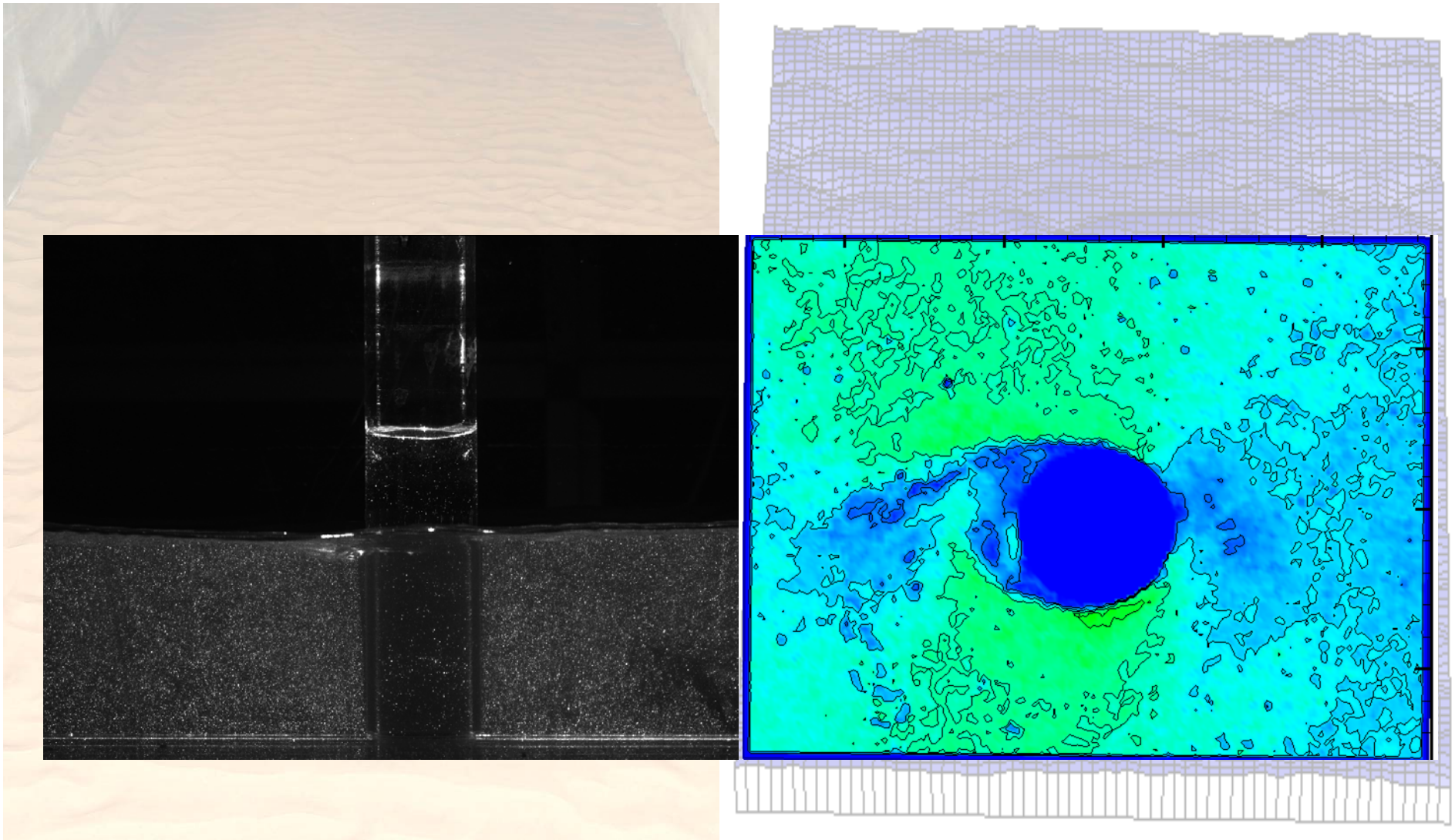

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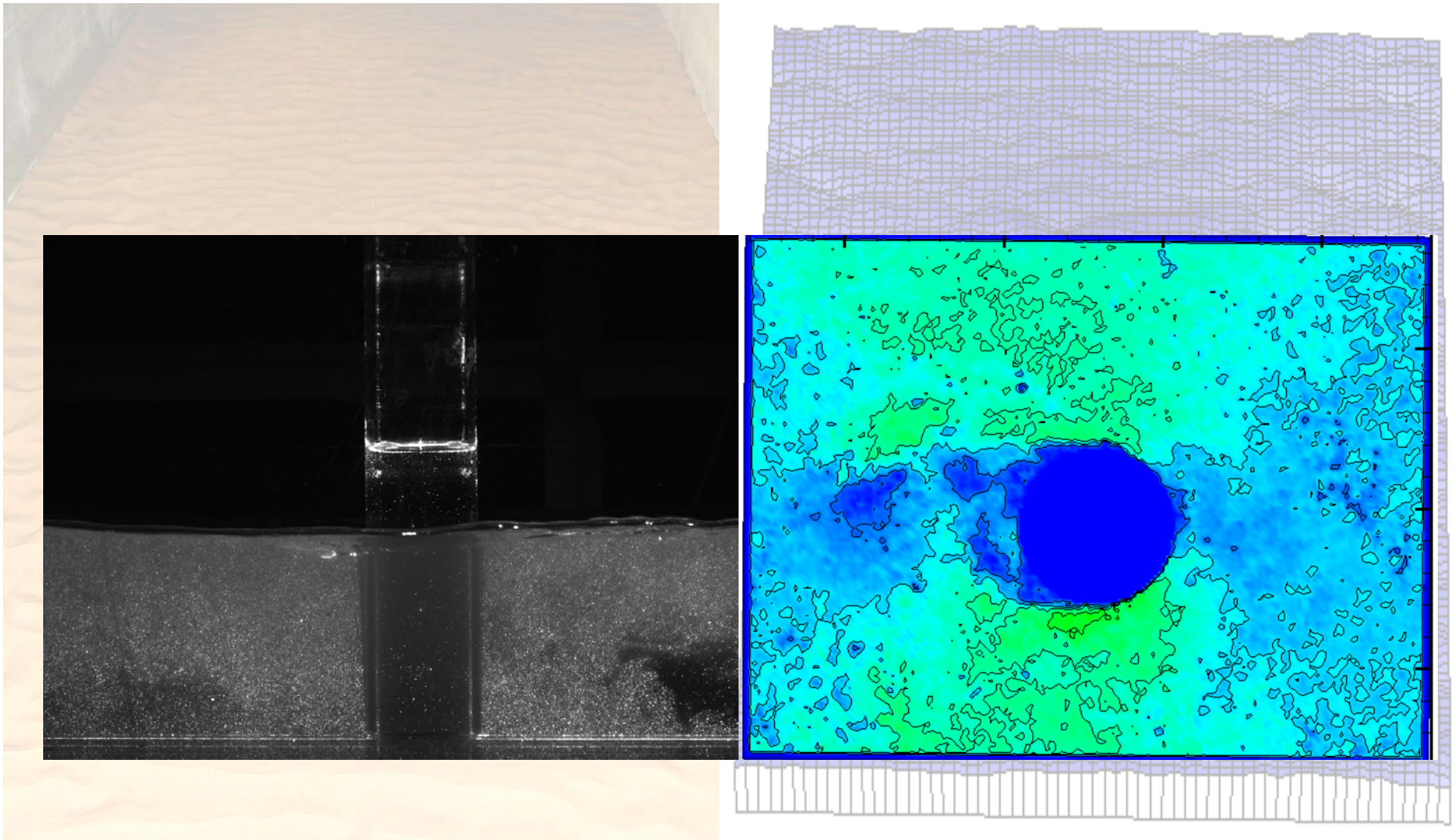

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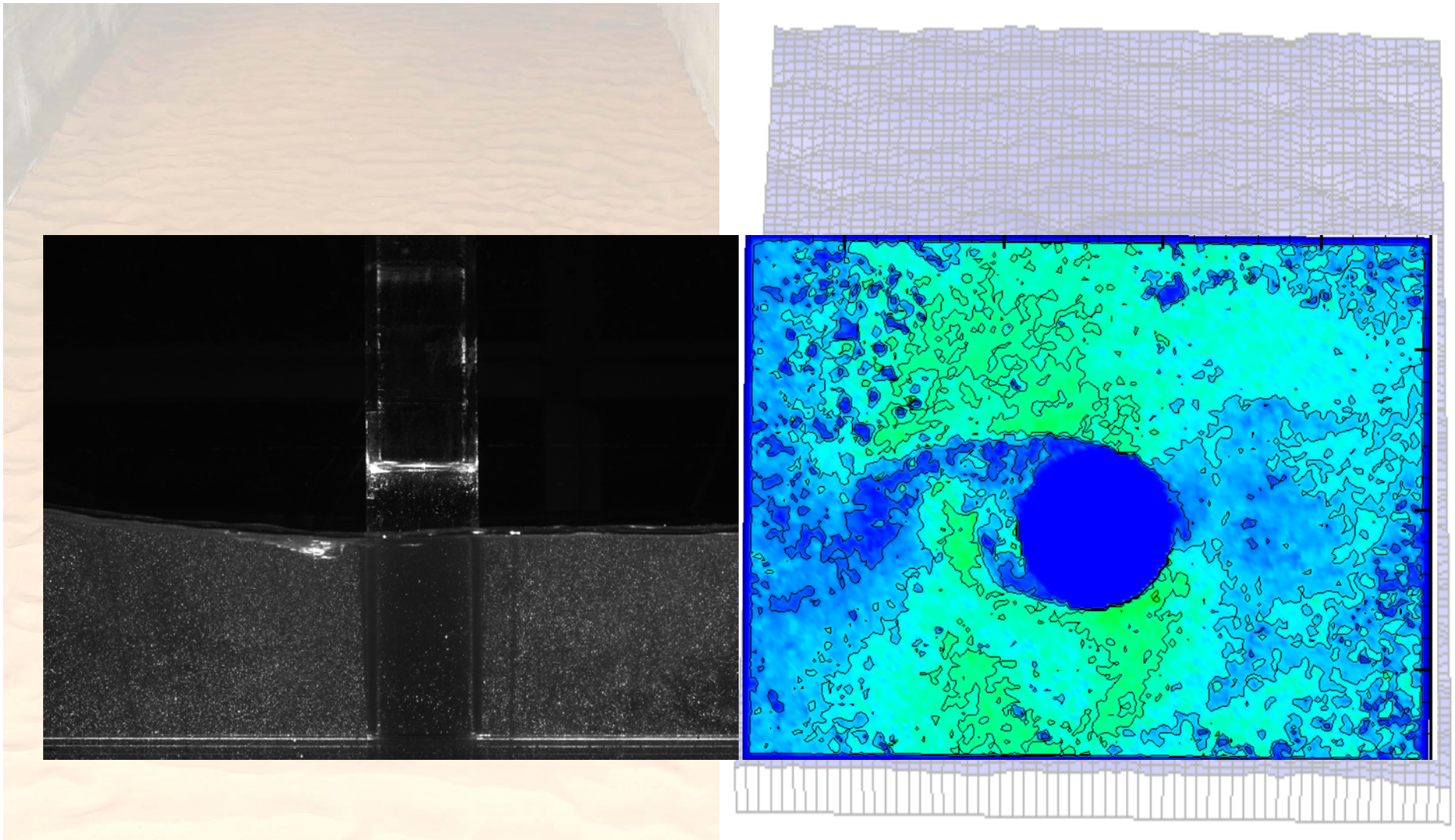

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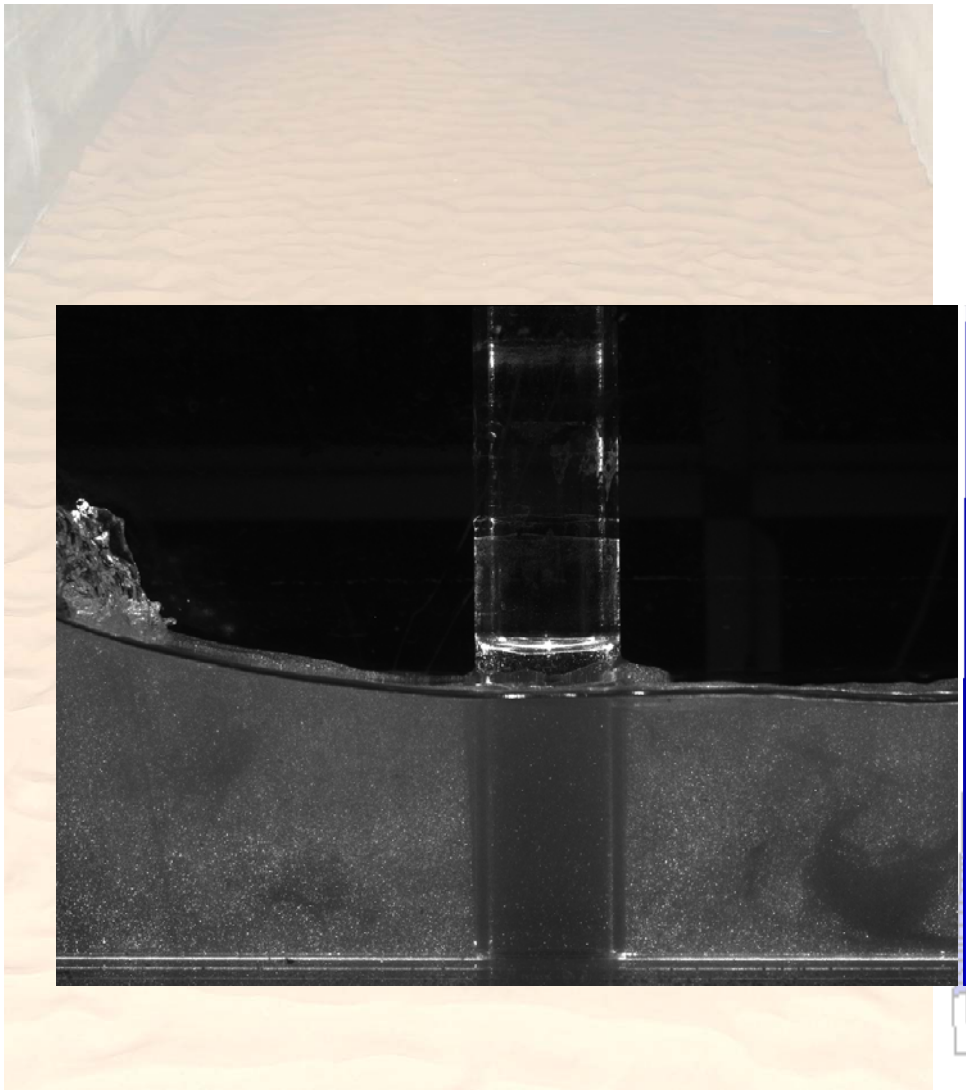

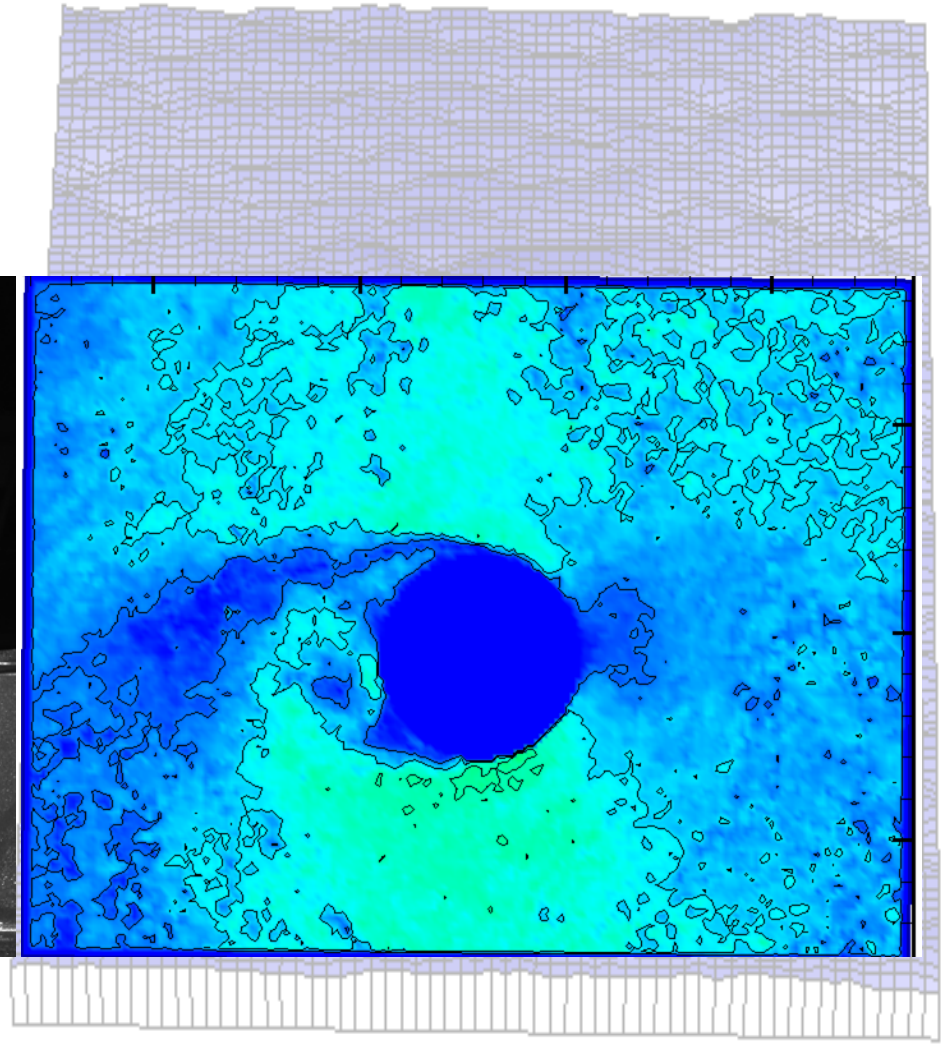

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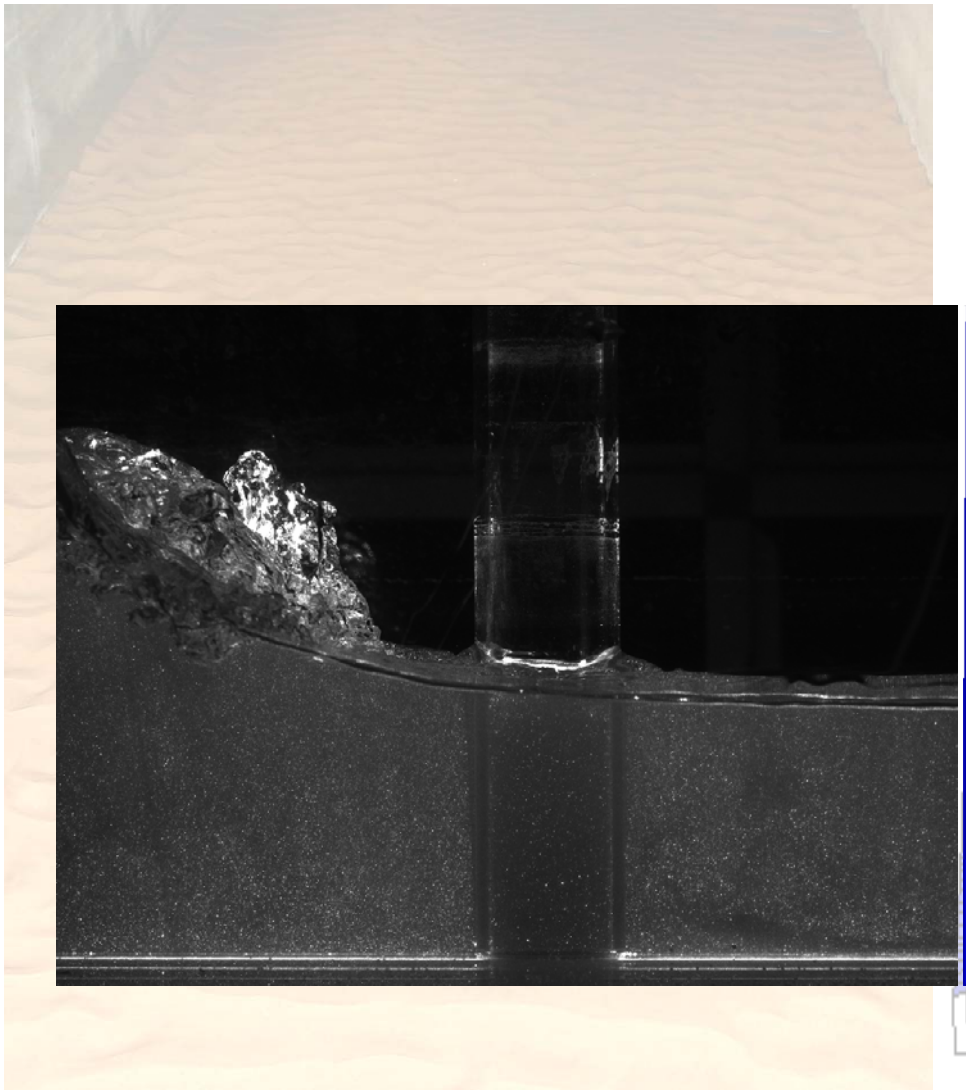

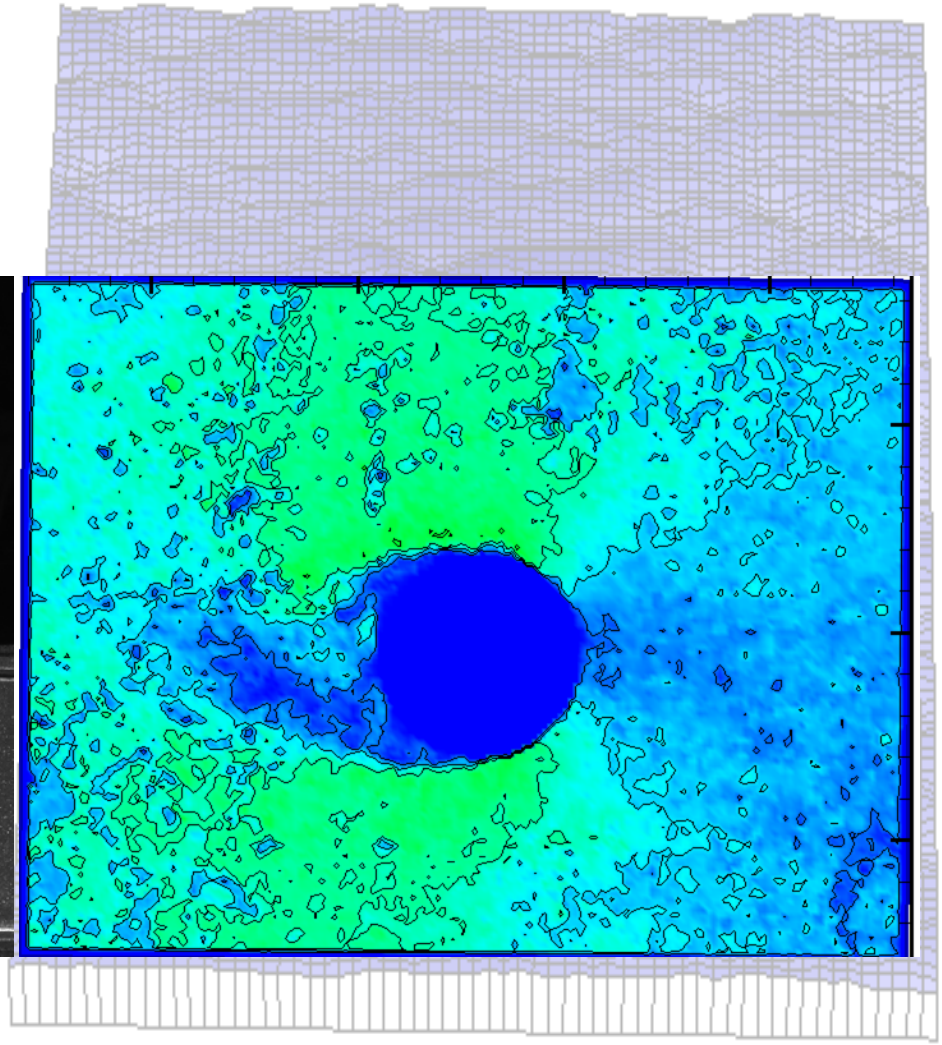

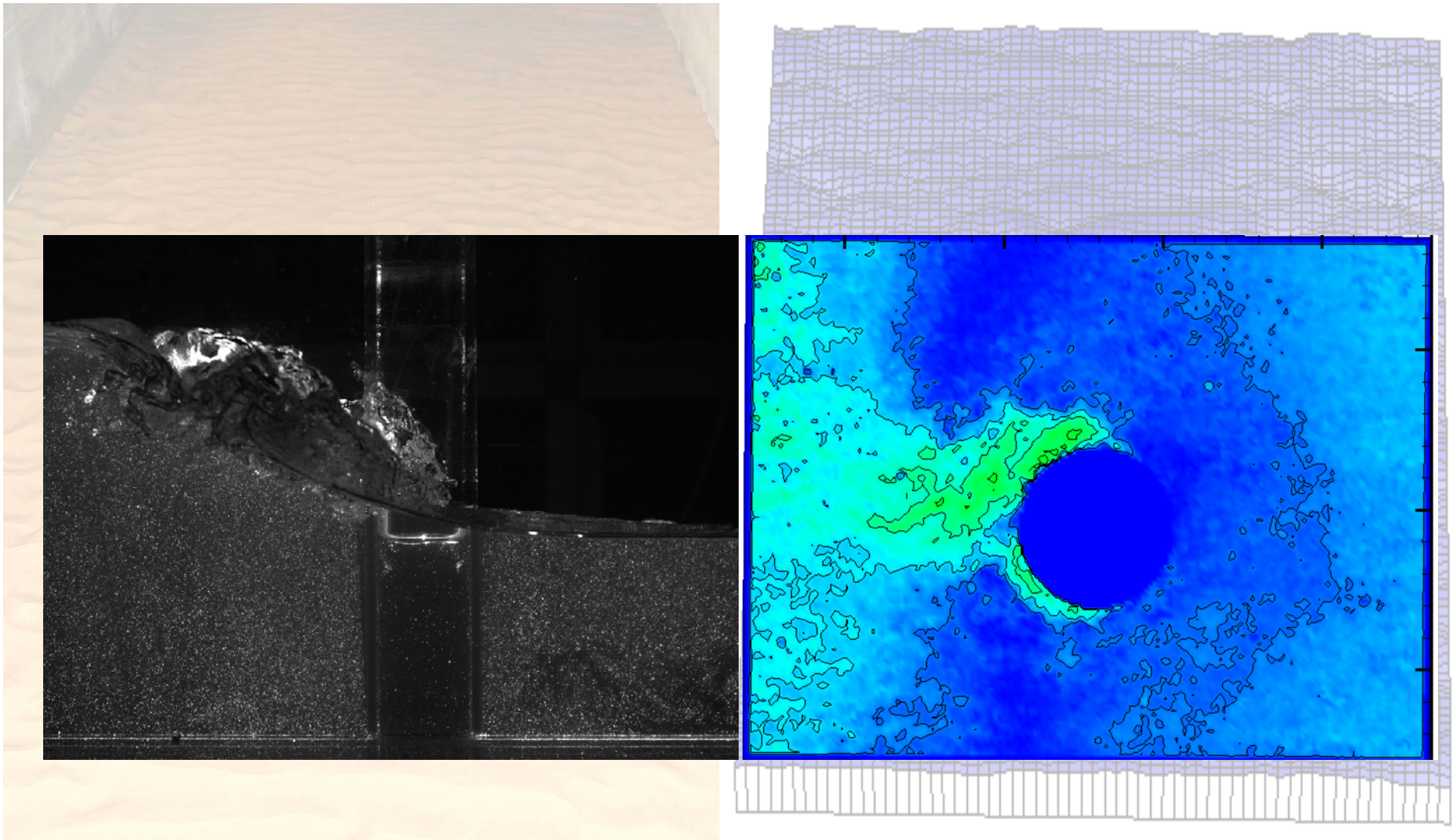

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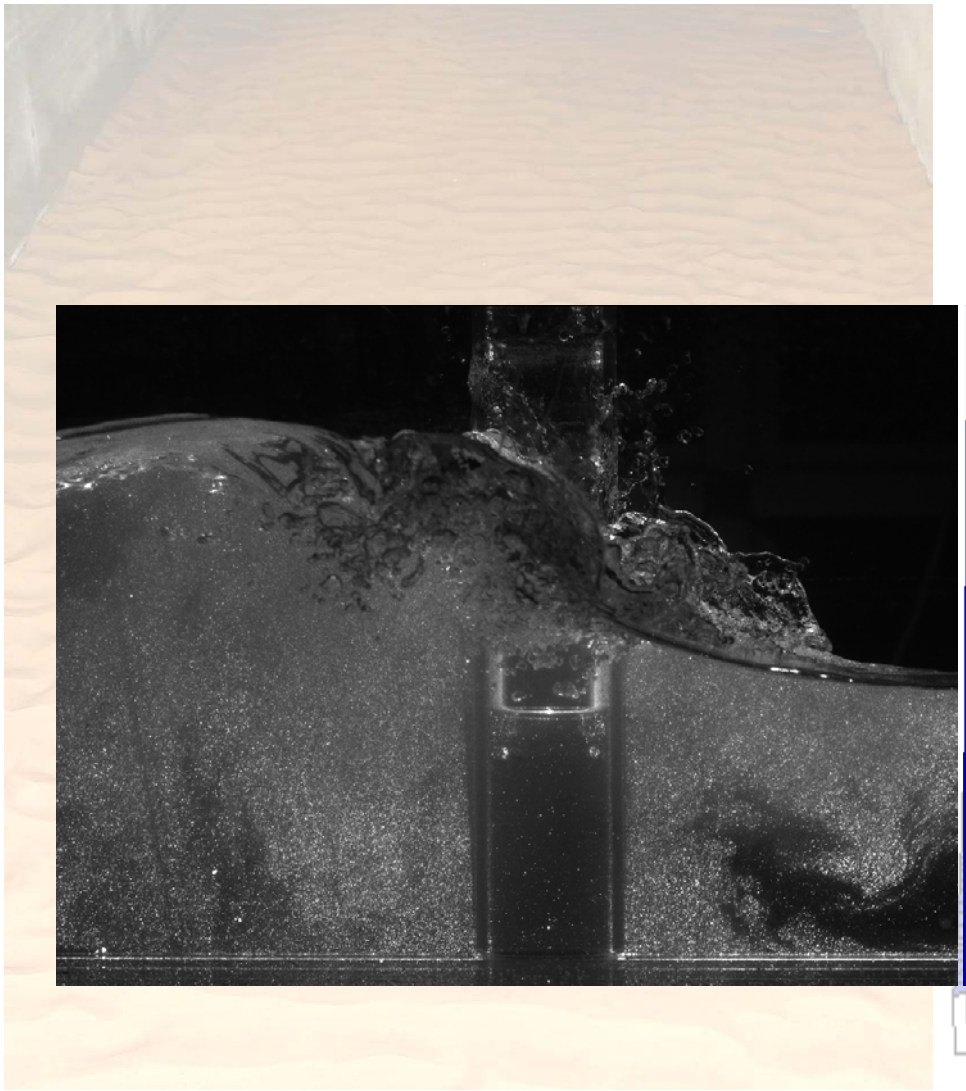

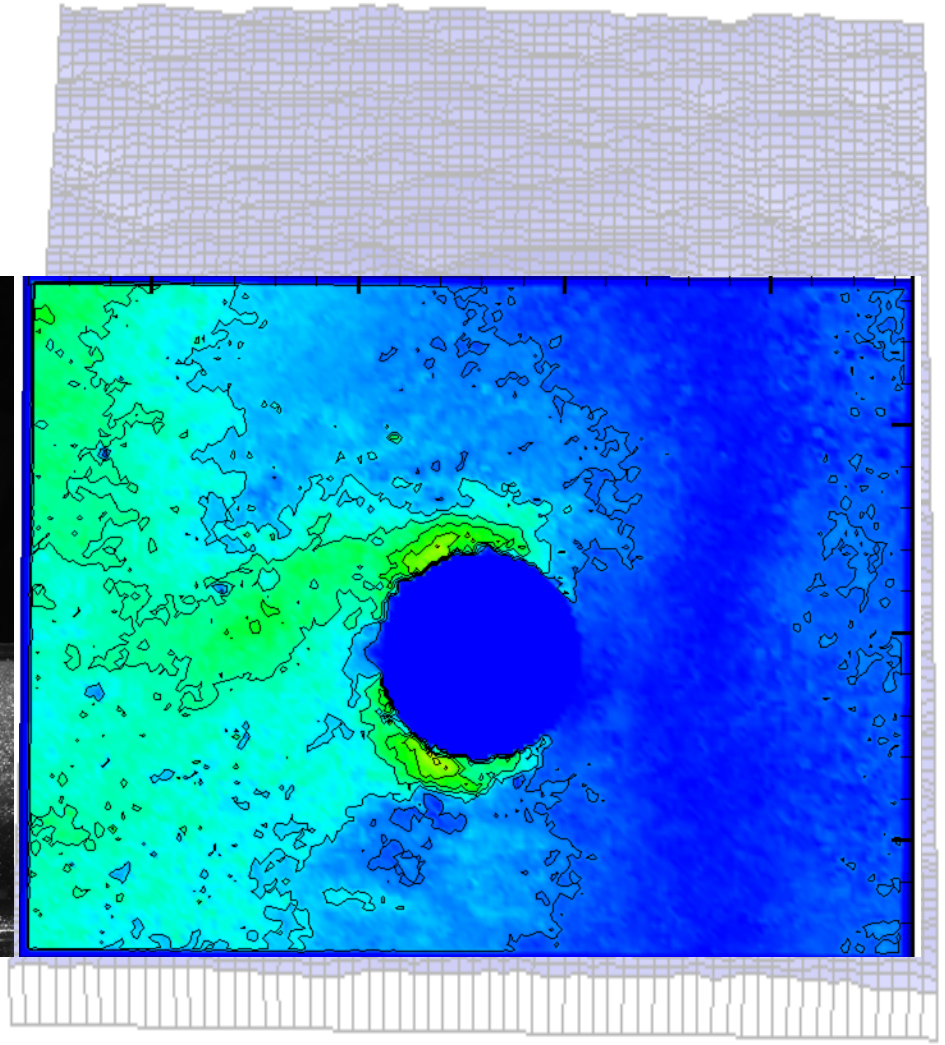

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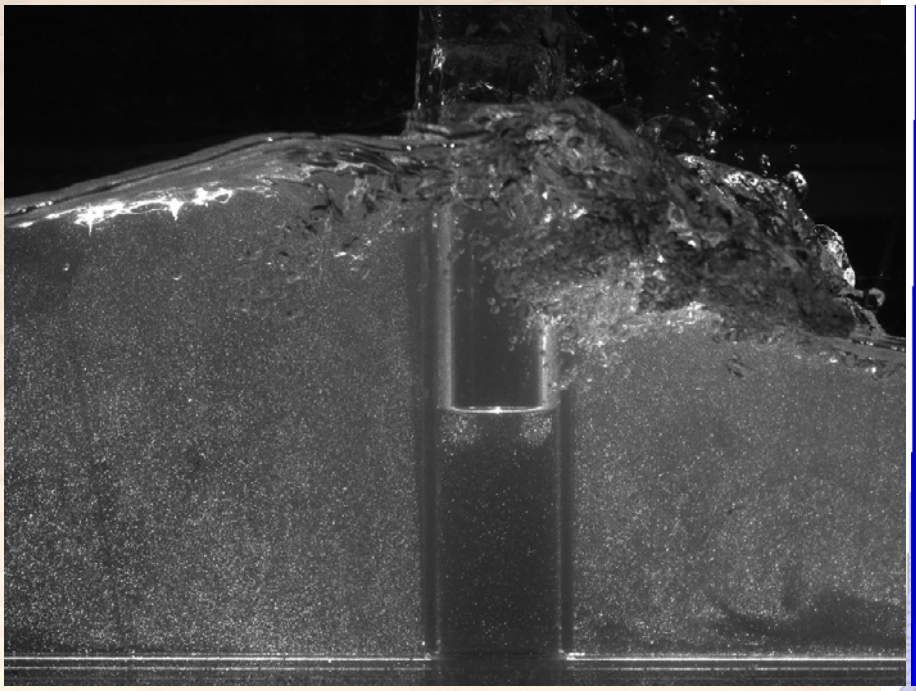
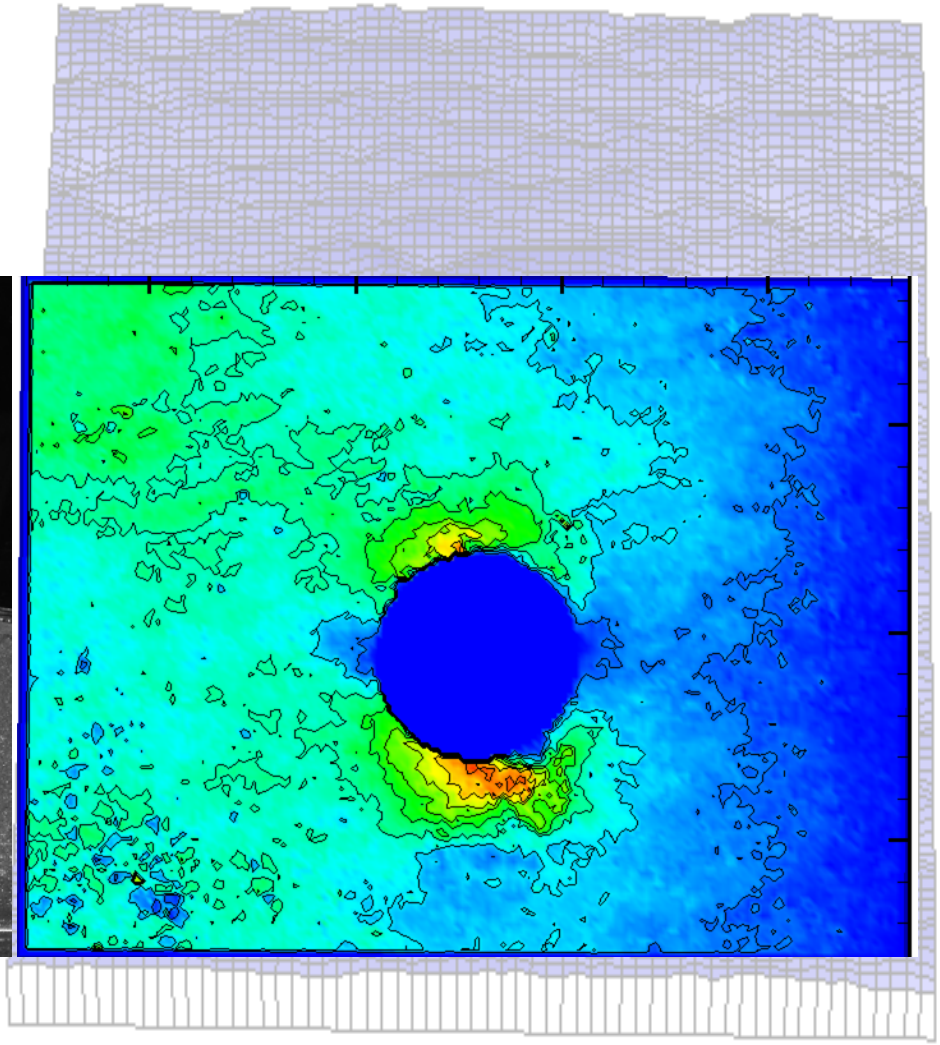
Offshore Center Danmark





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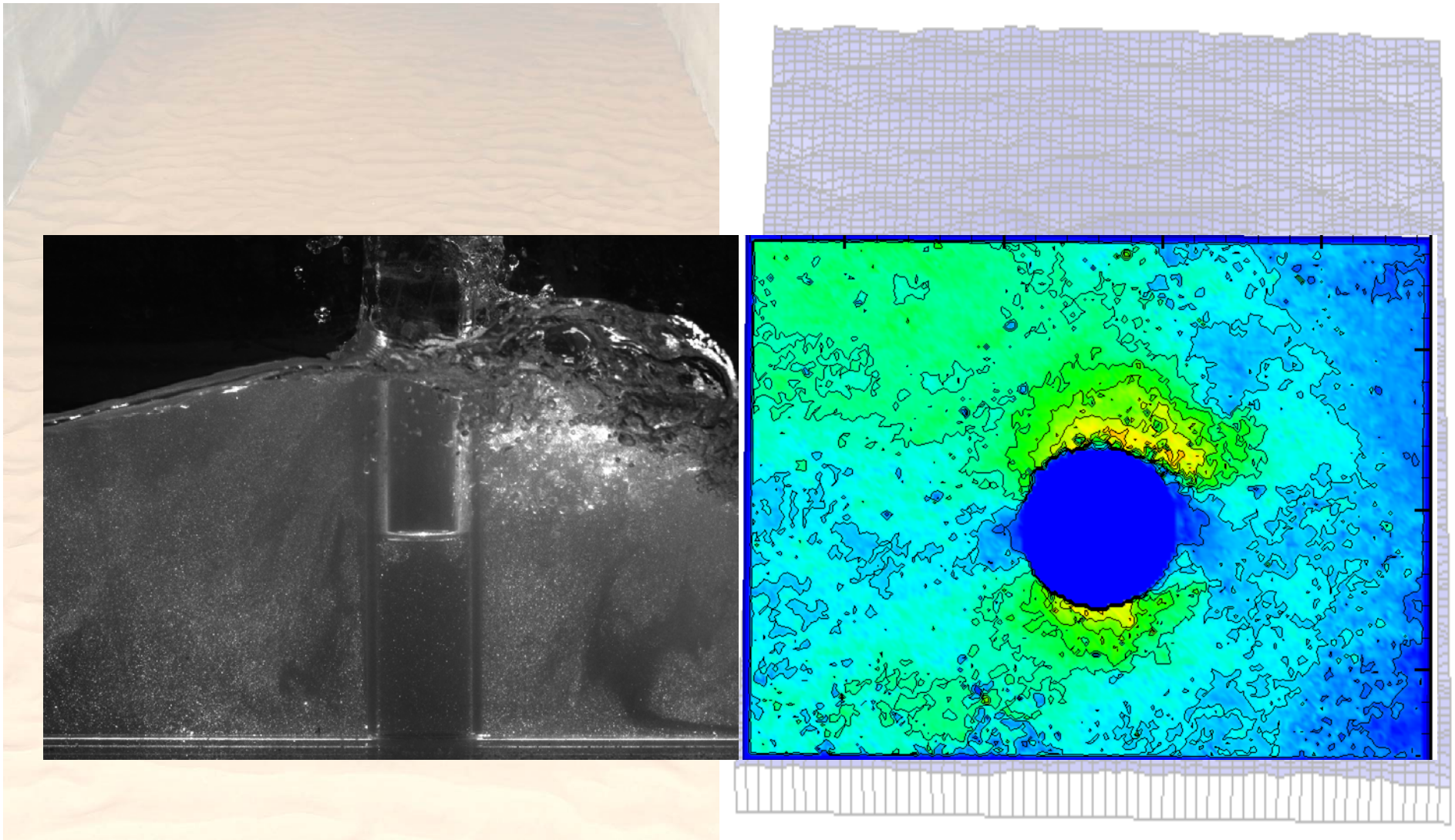

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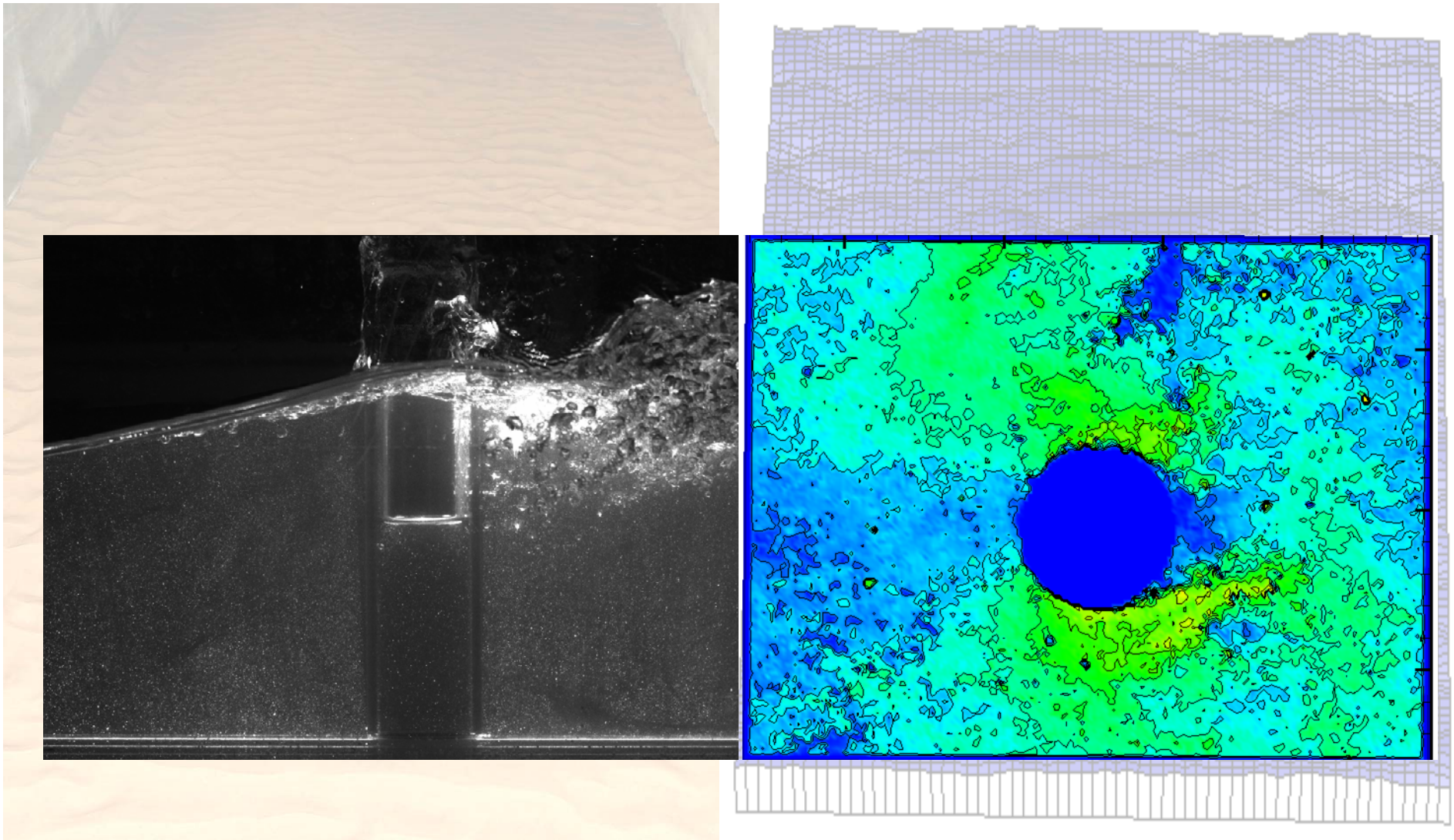

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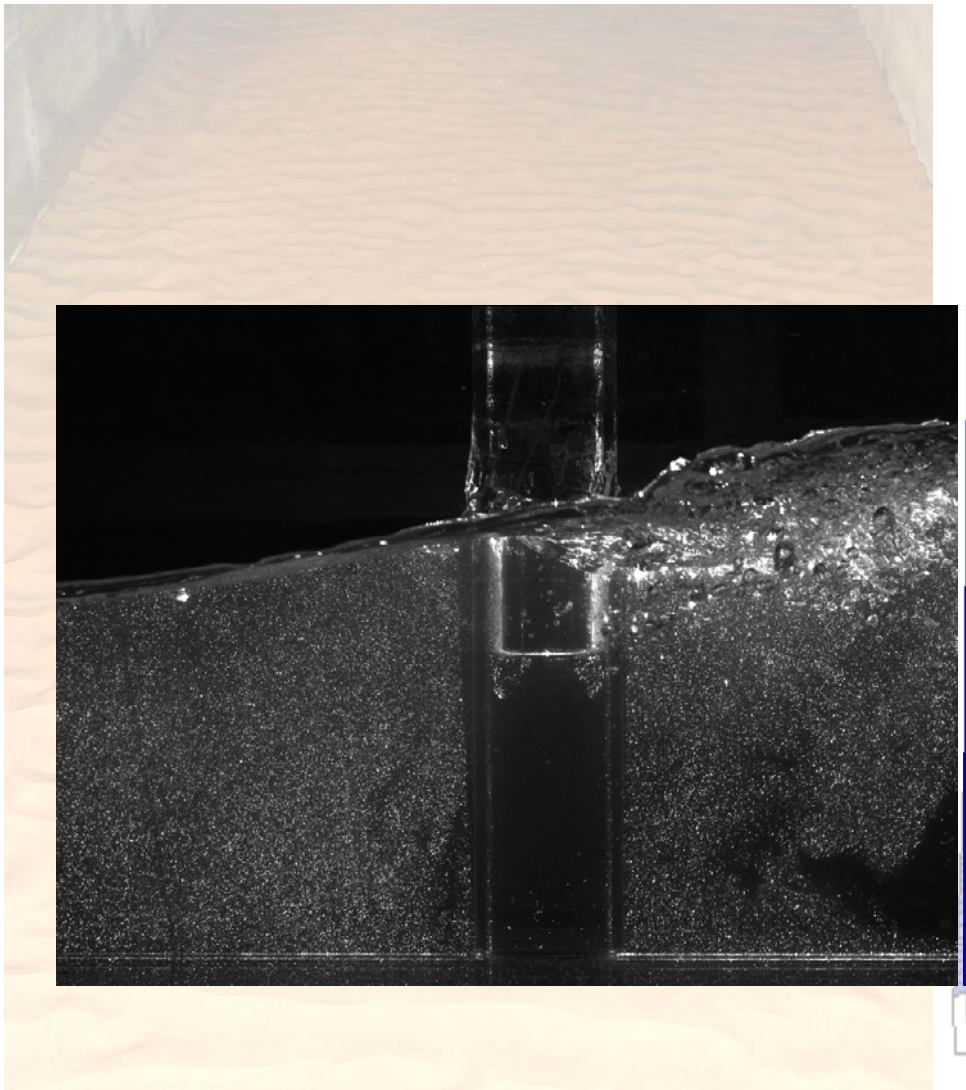

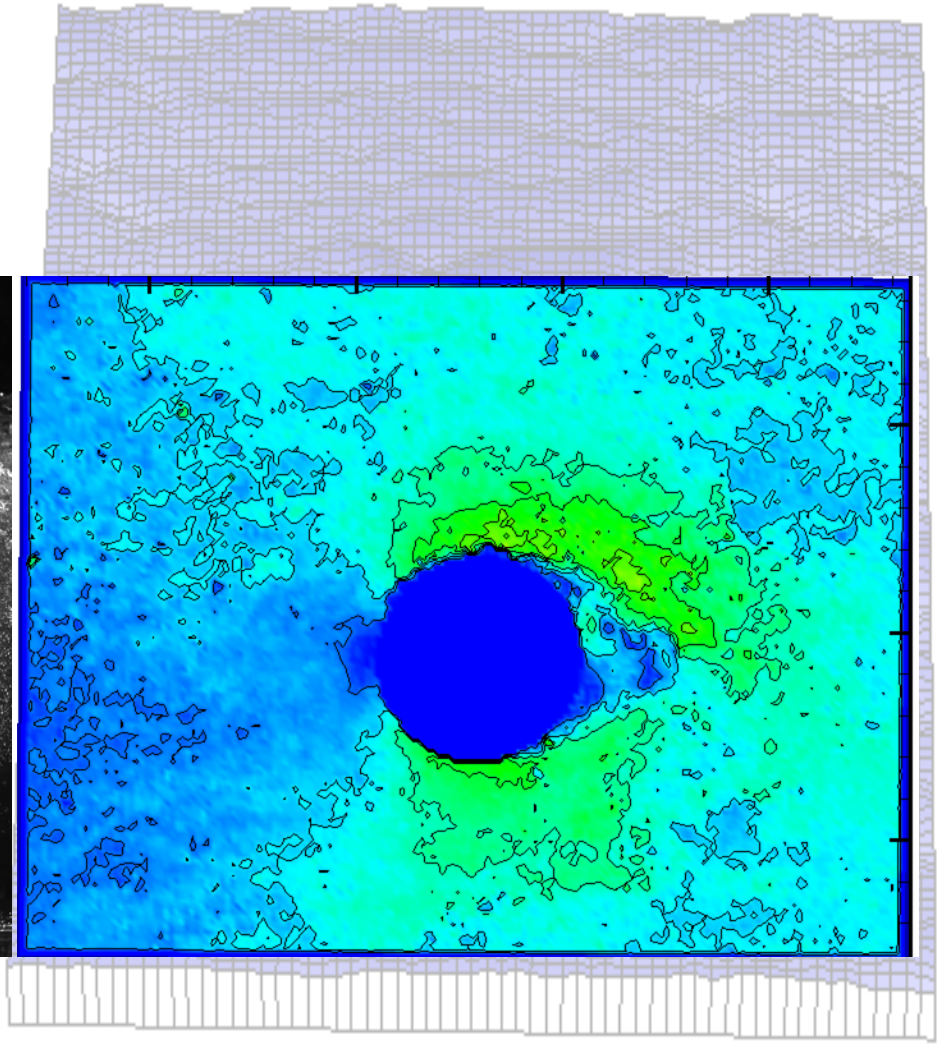

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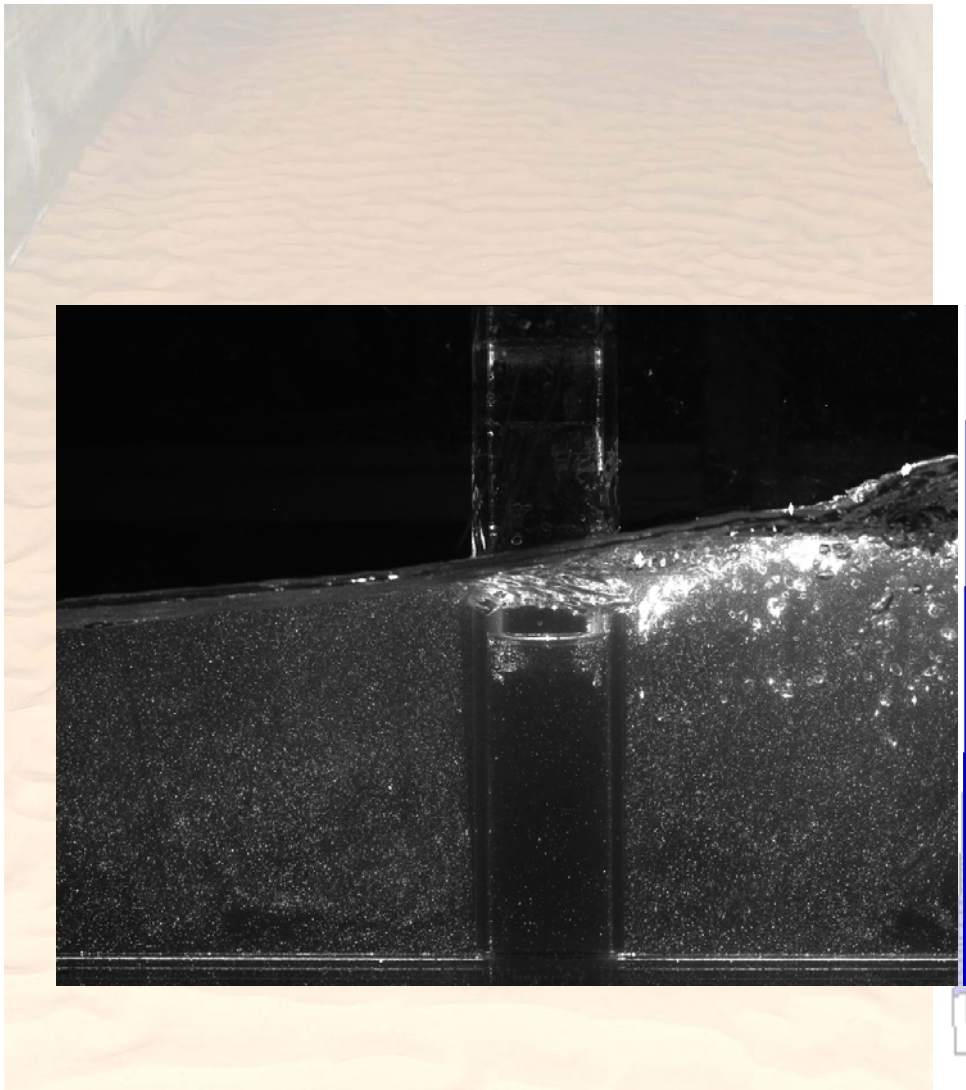

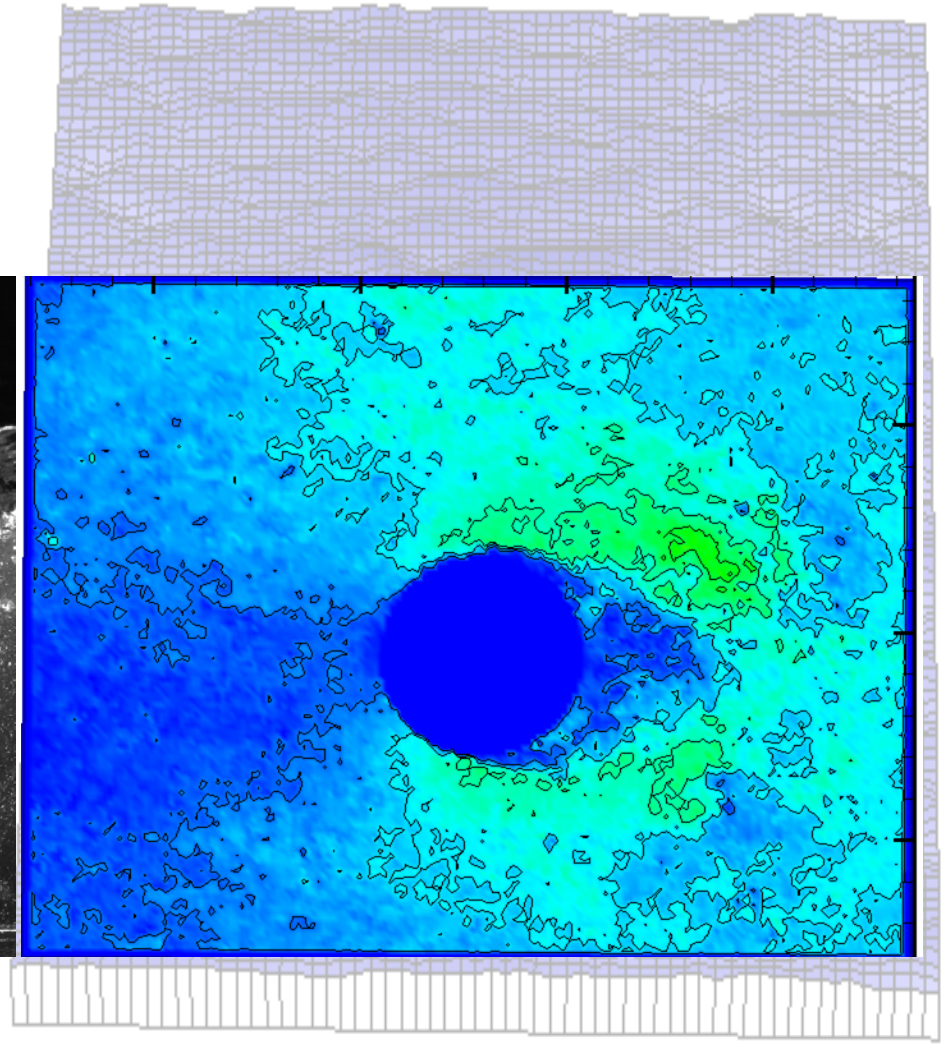

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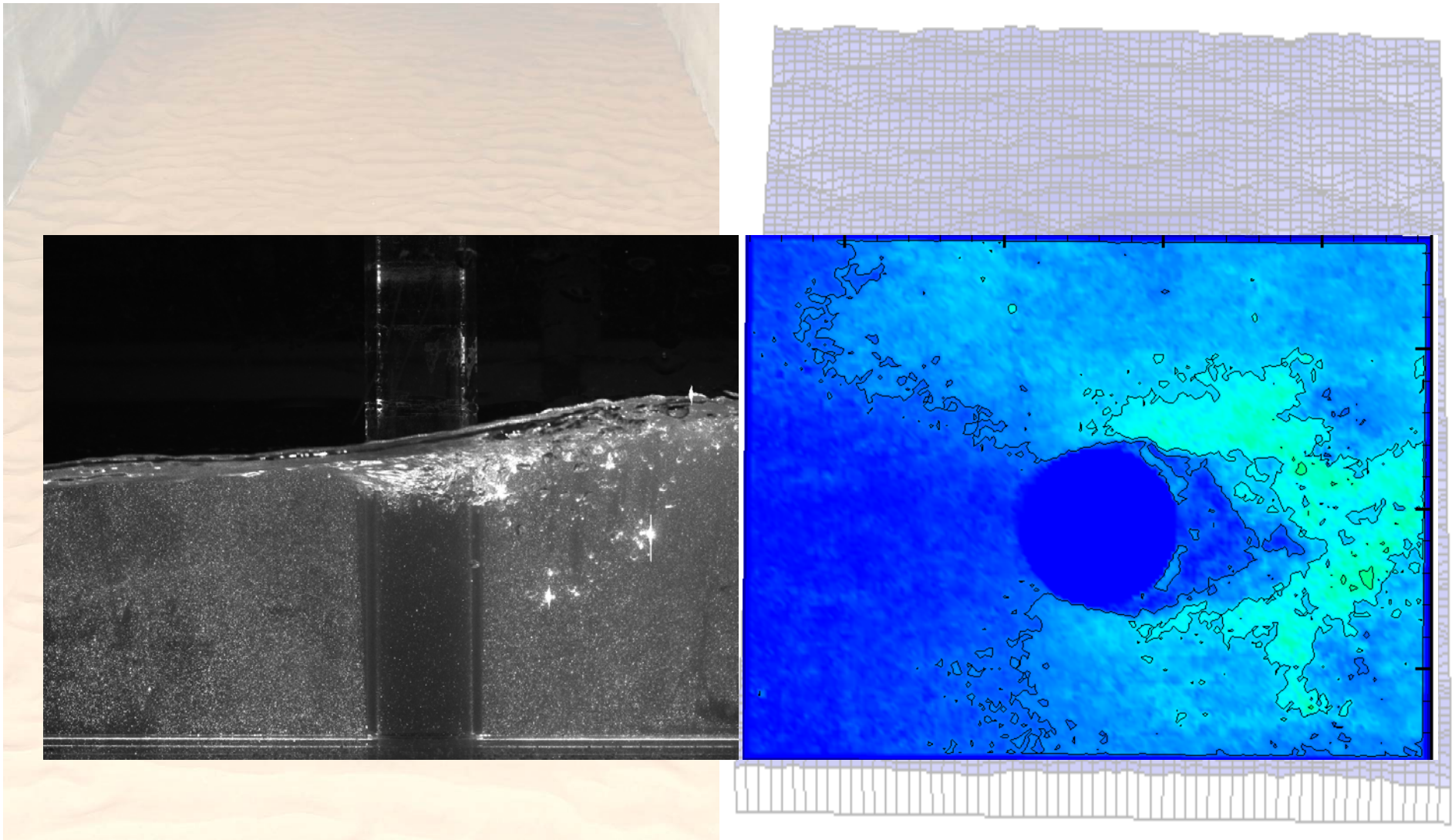

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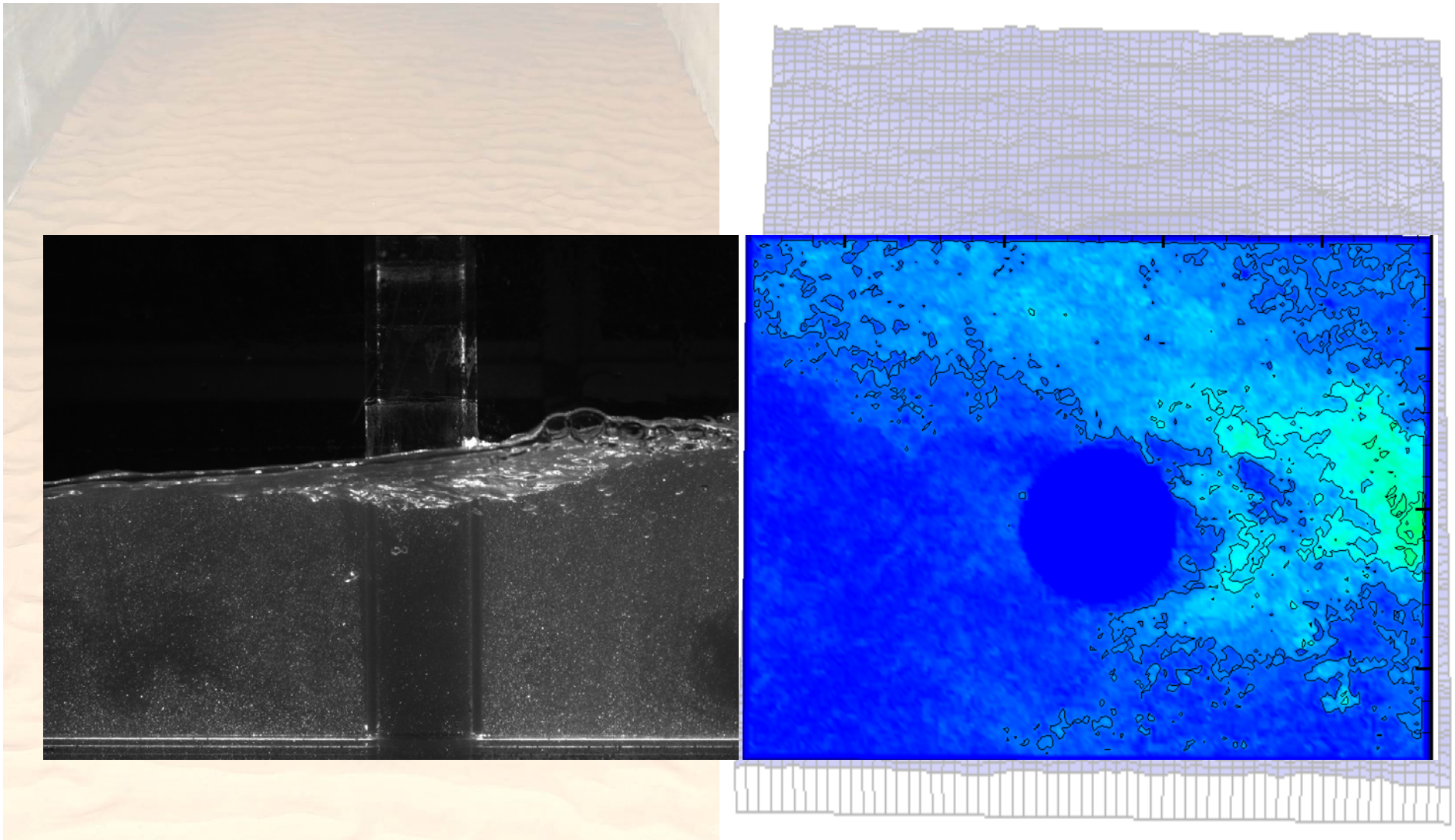

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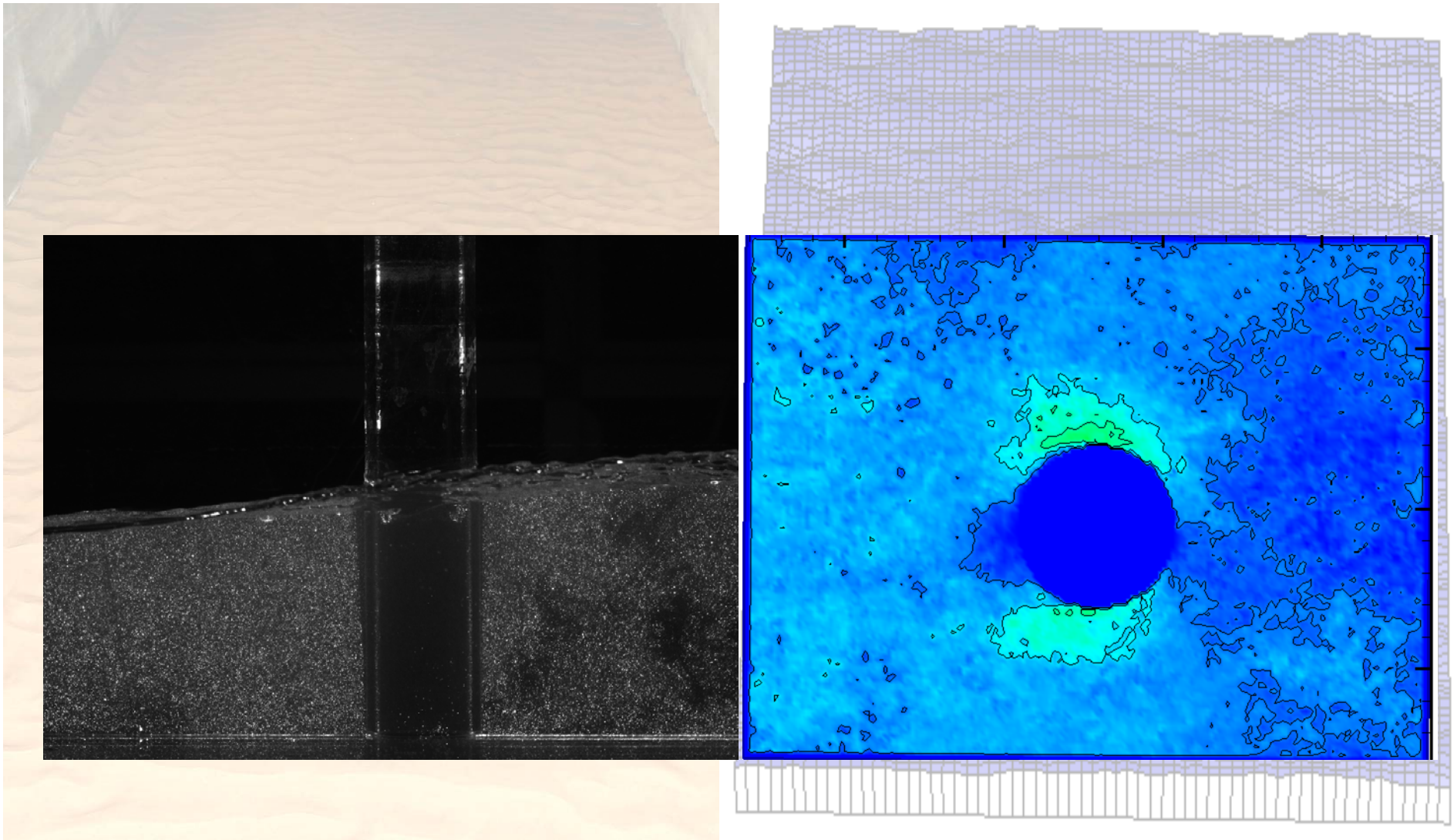

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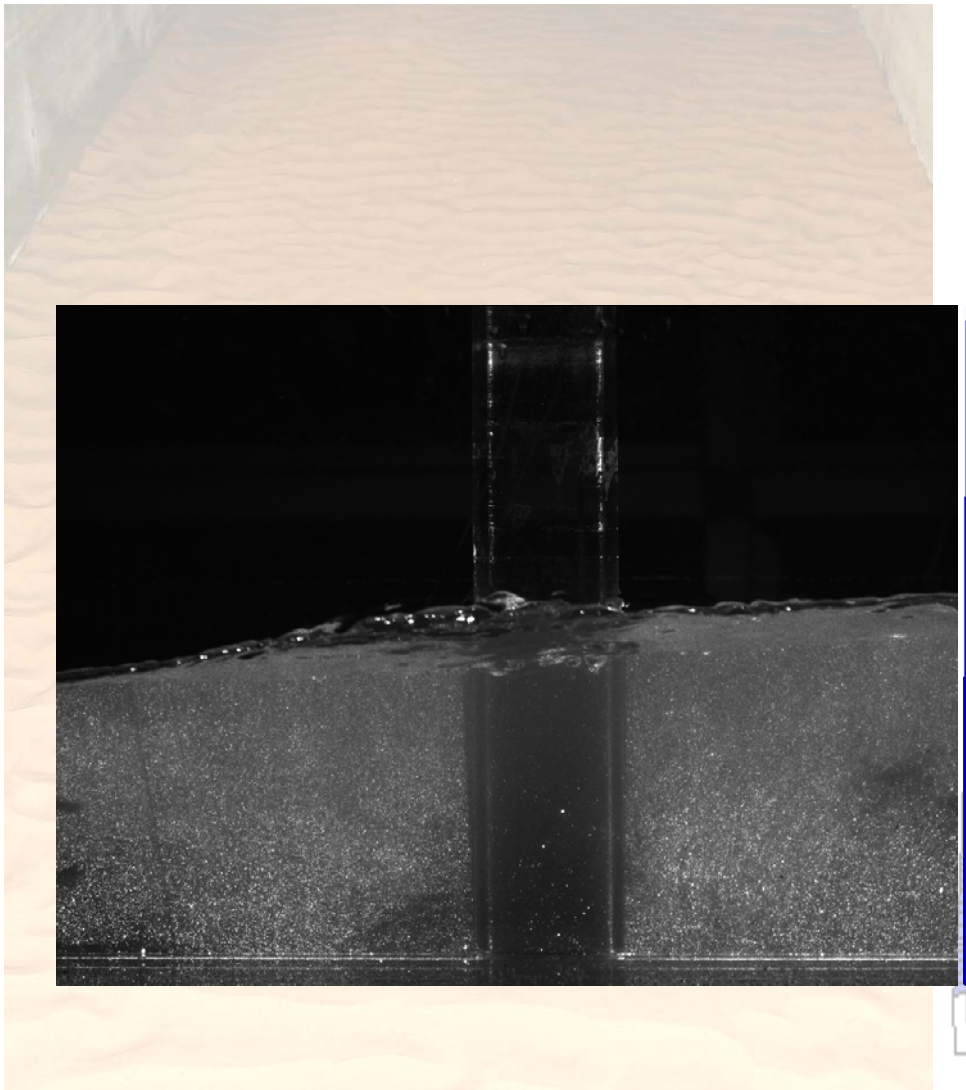

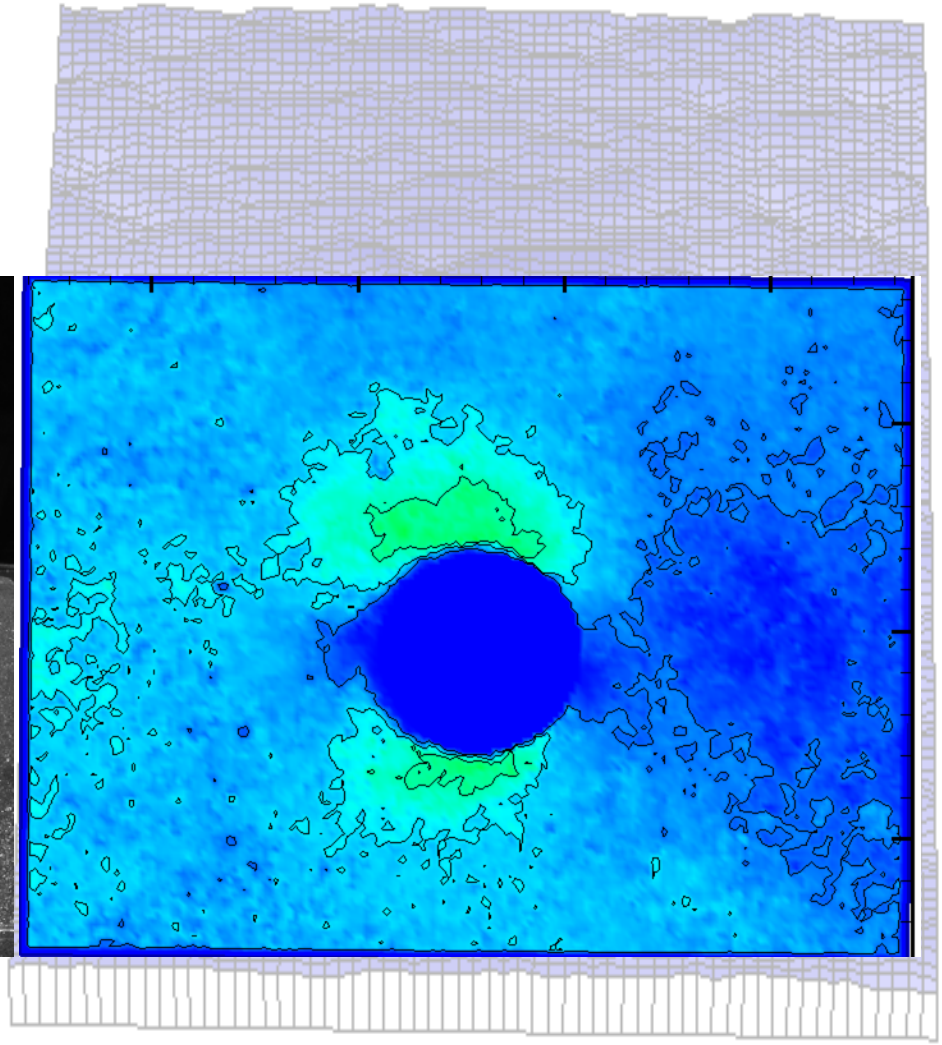

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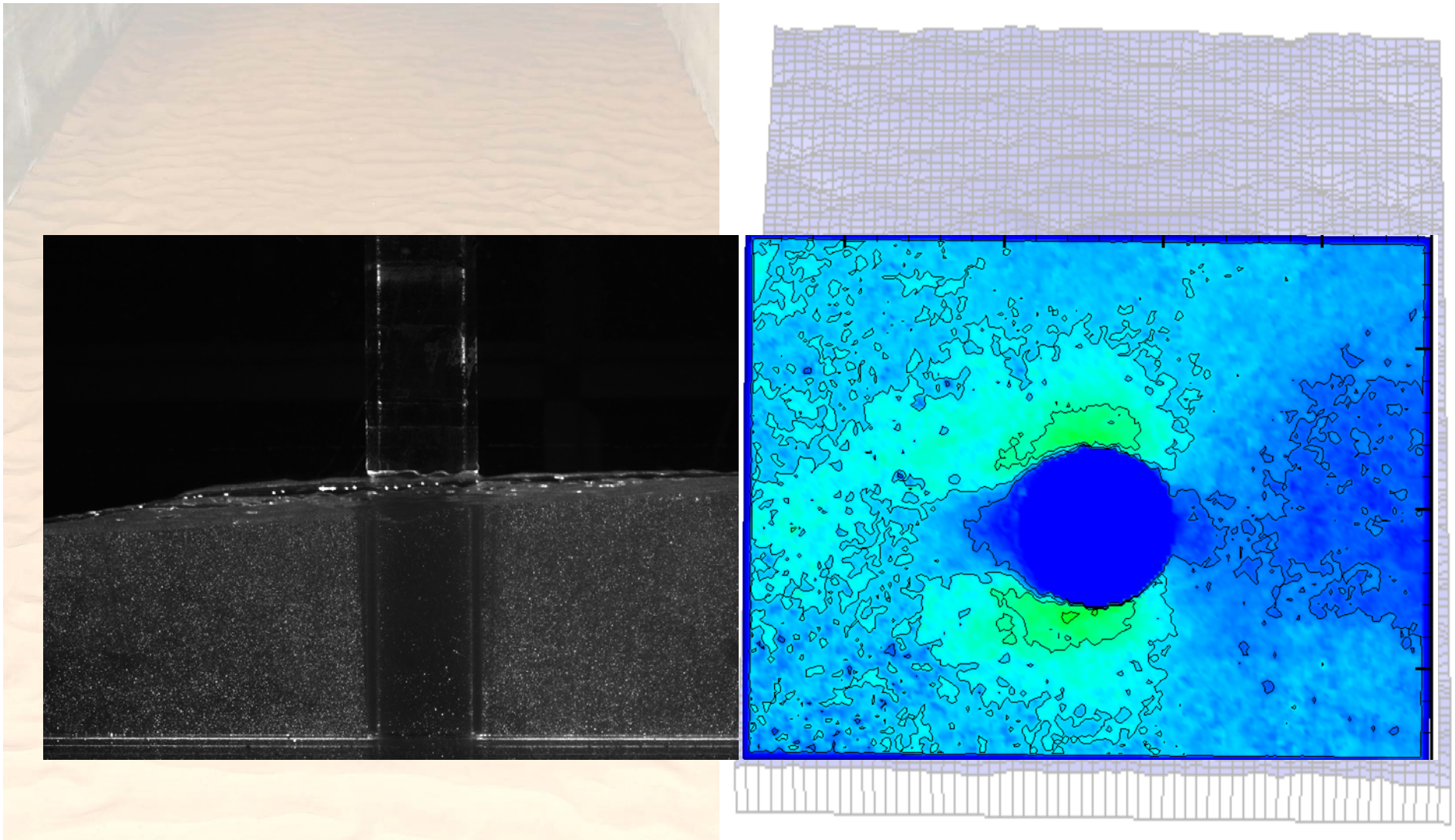

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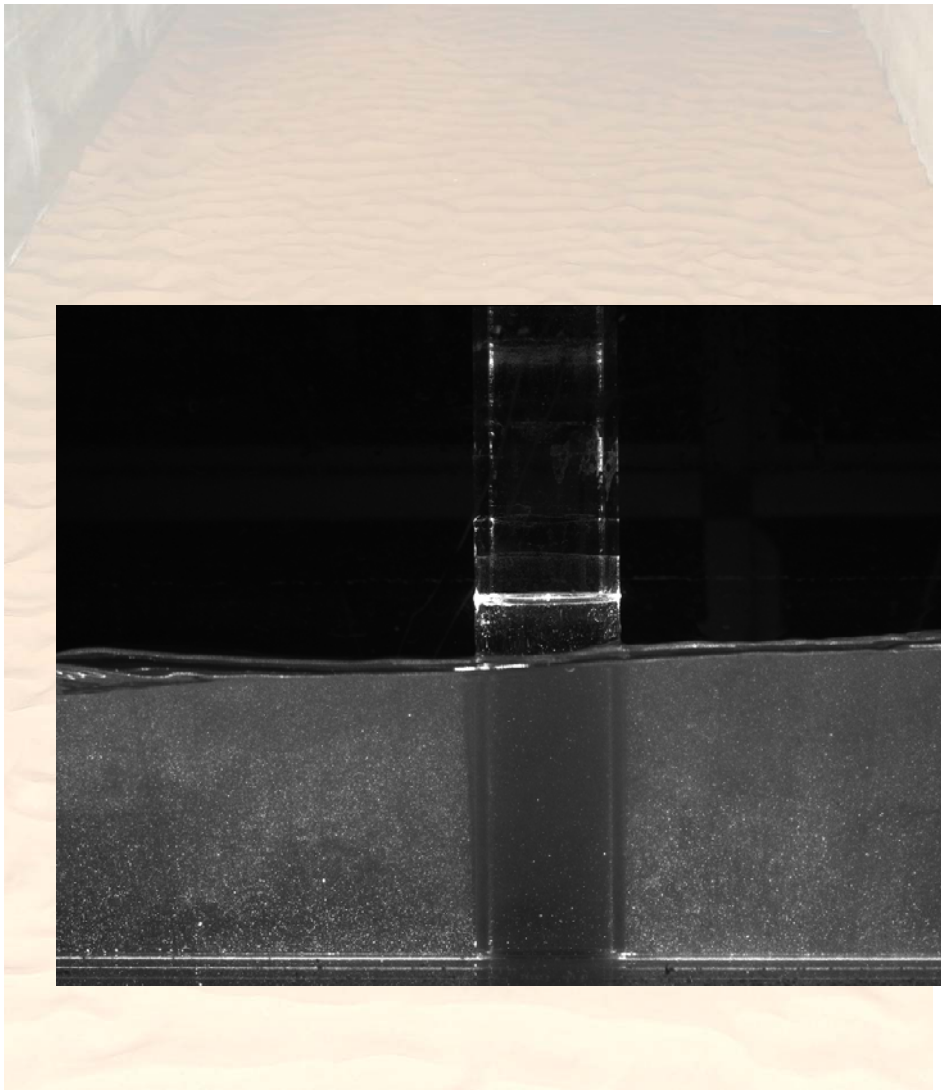

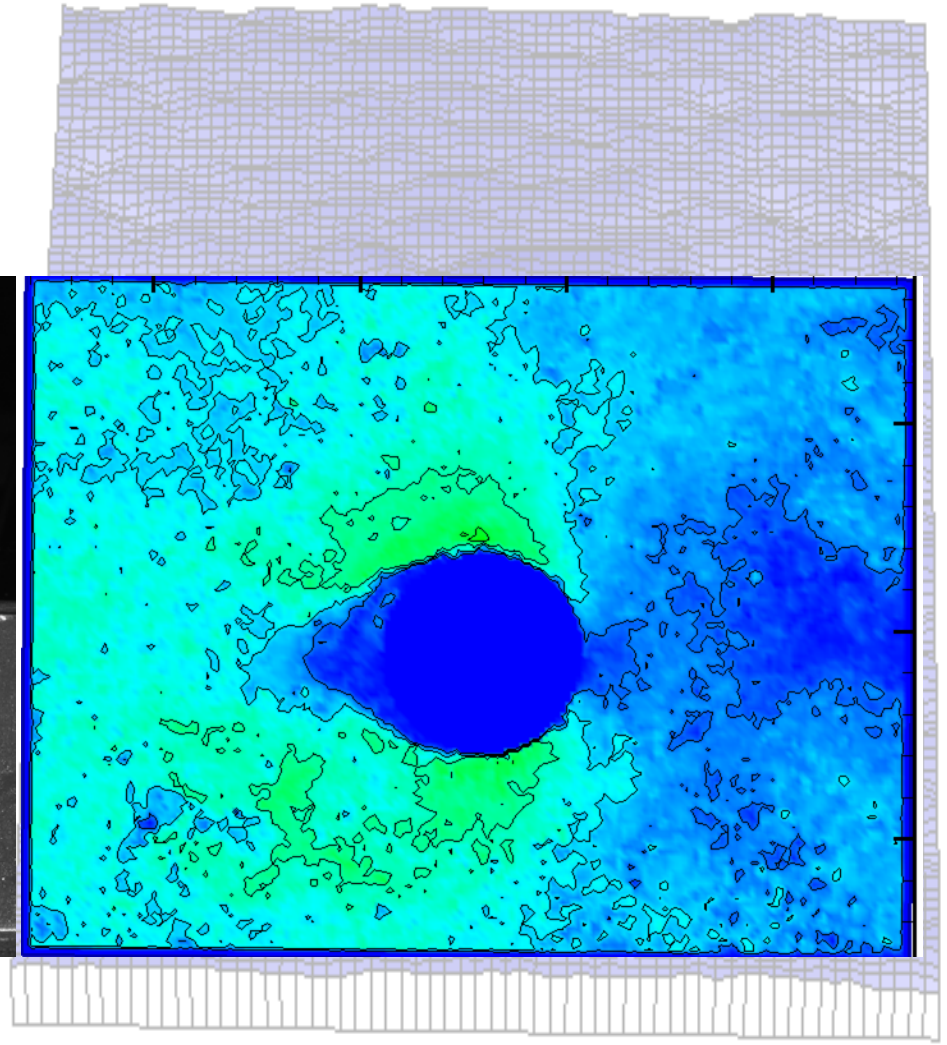

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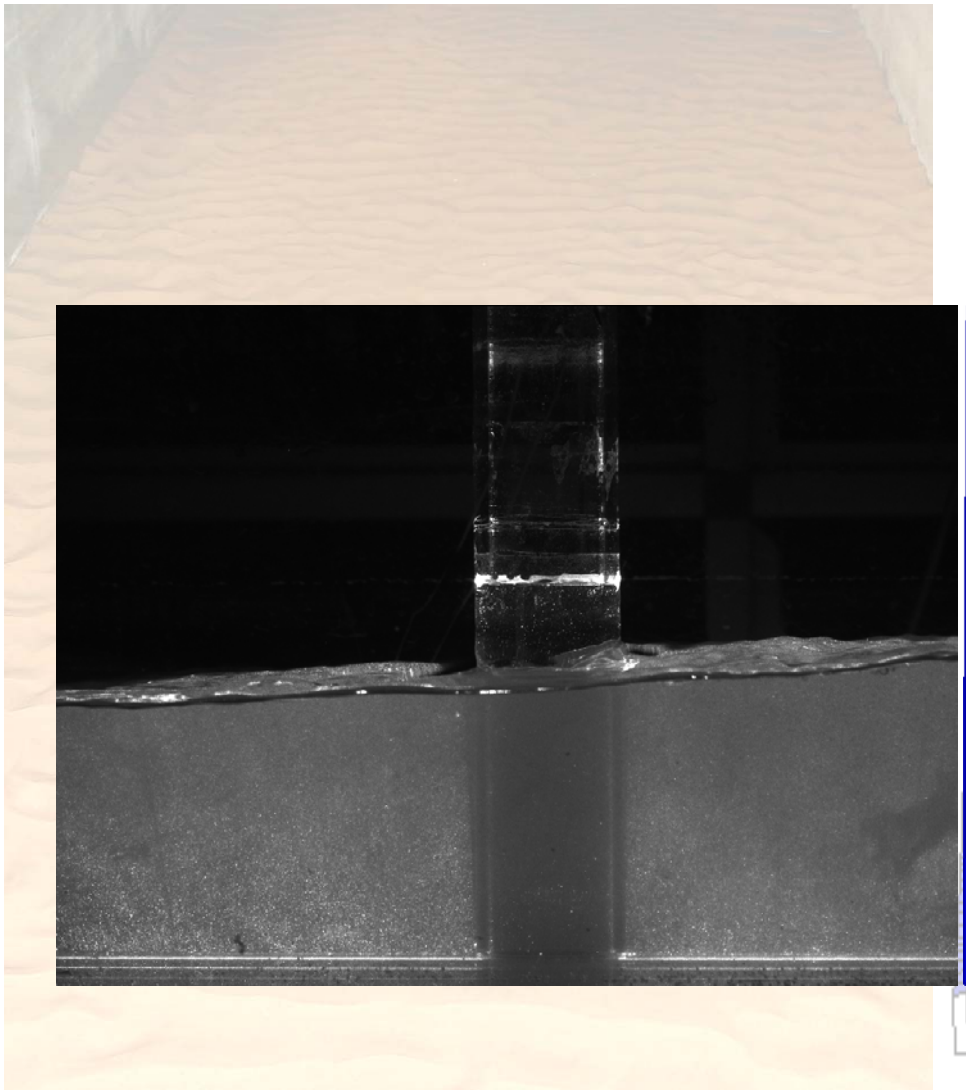

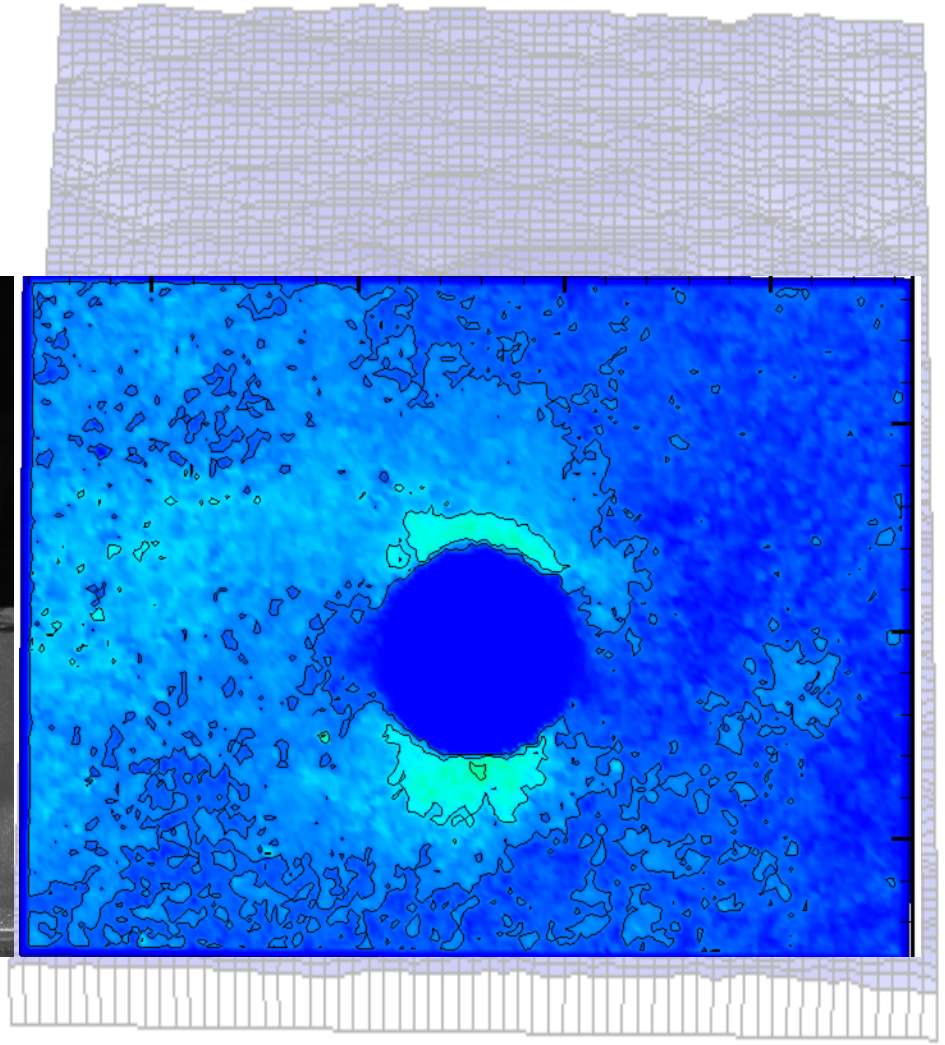

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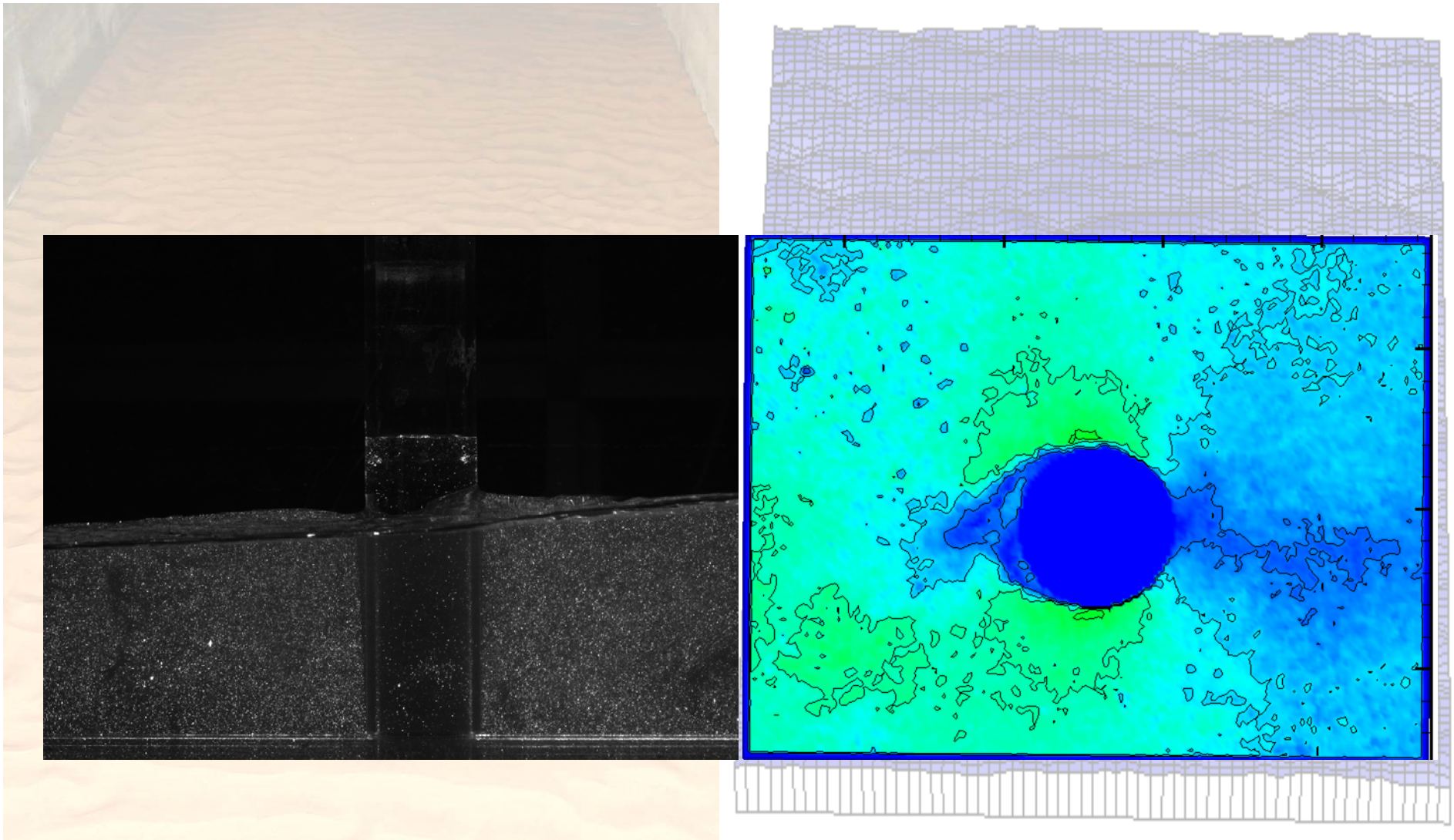

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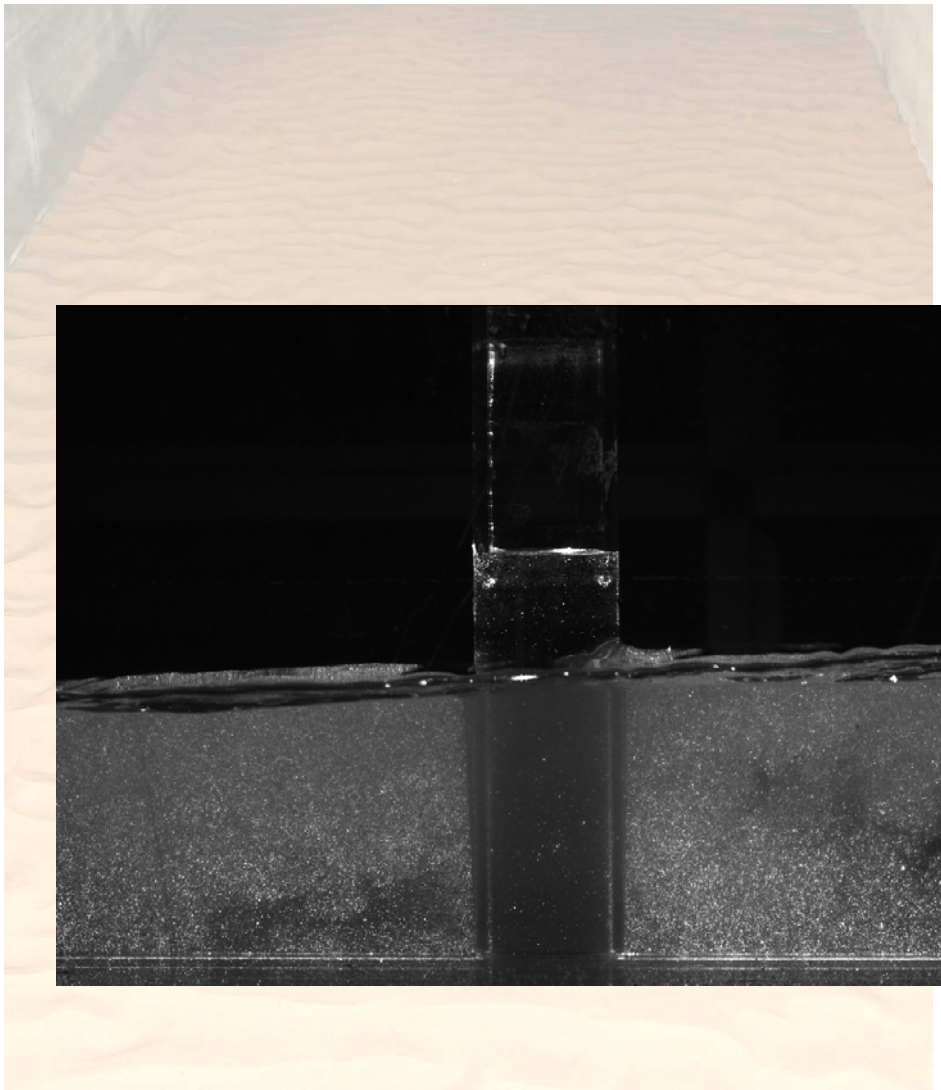

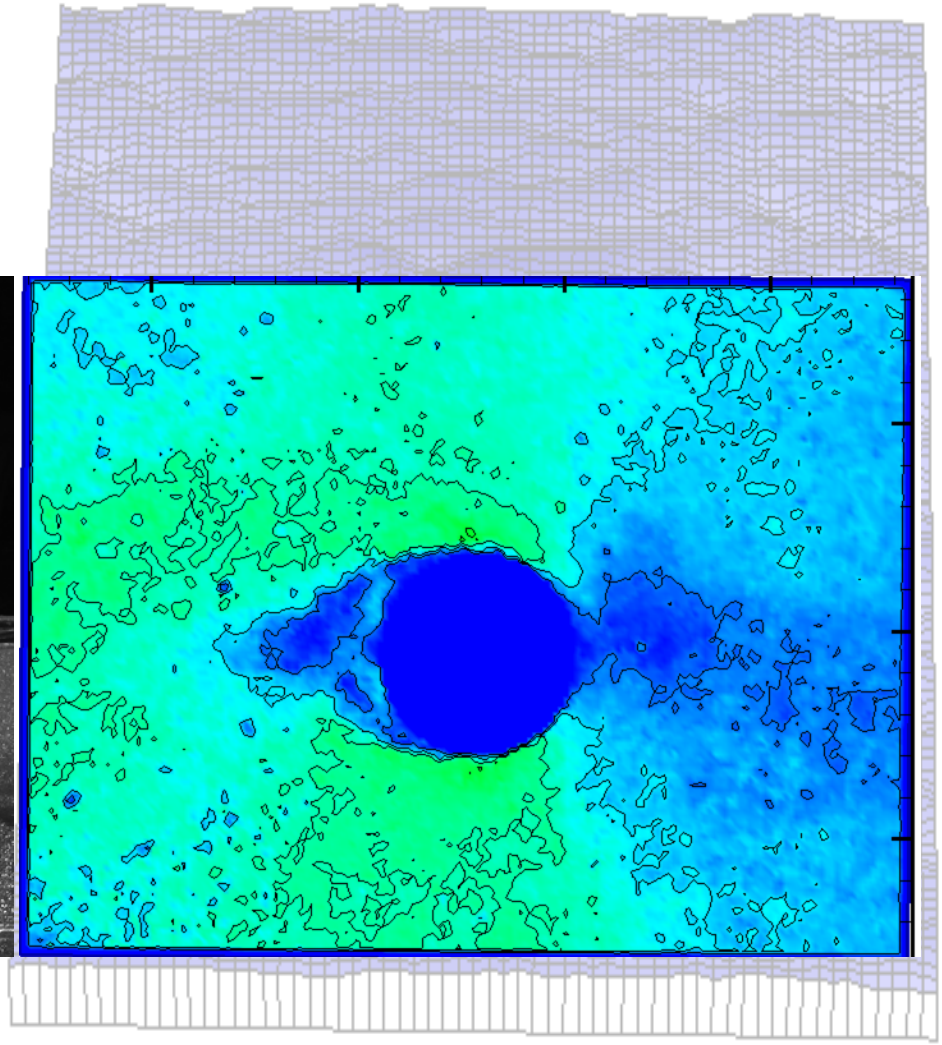

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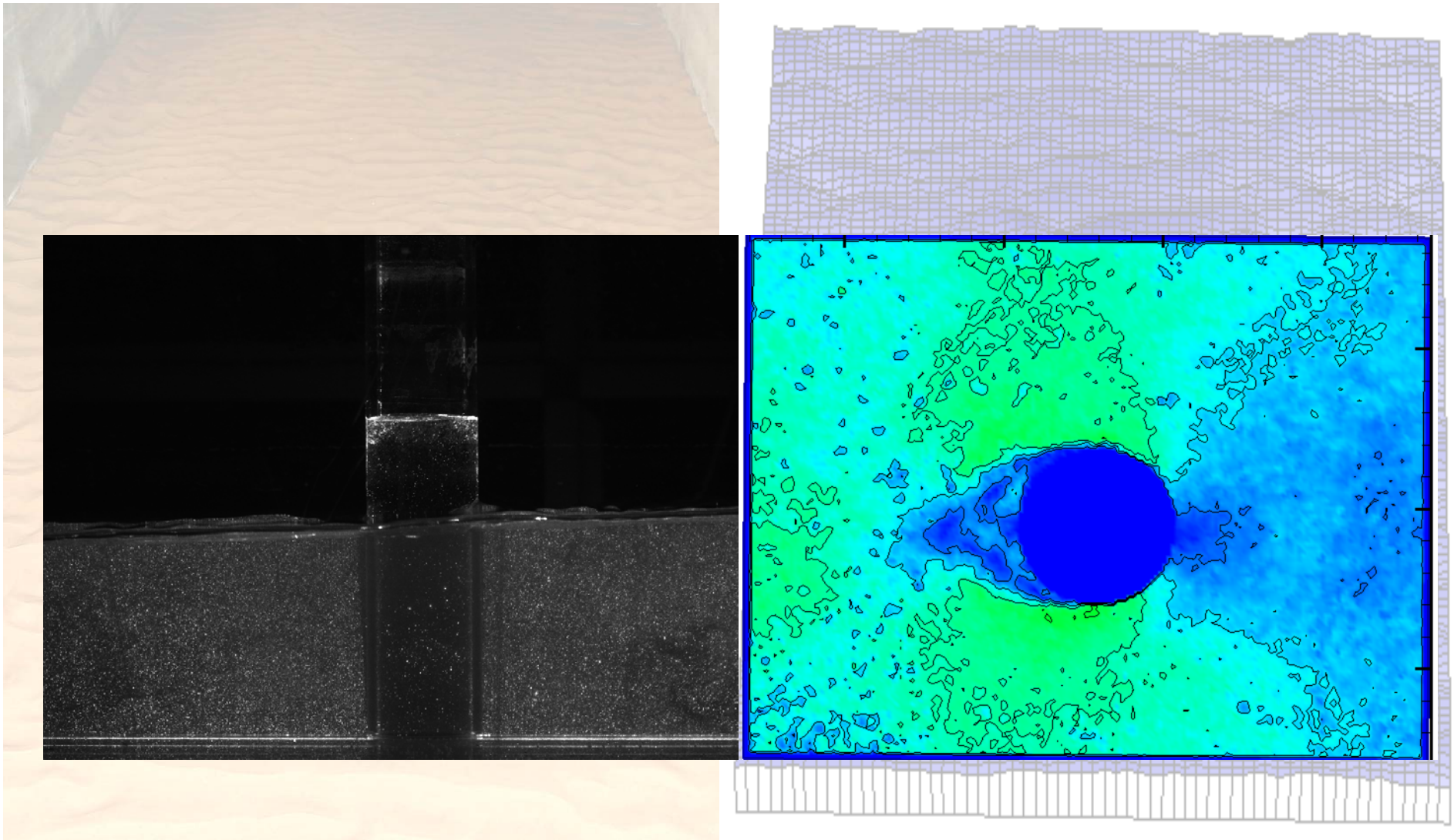

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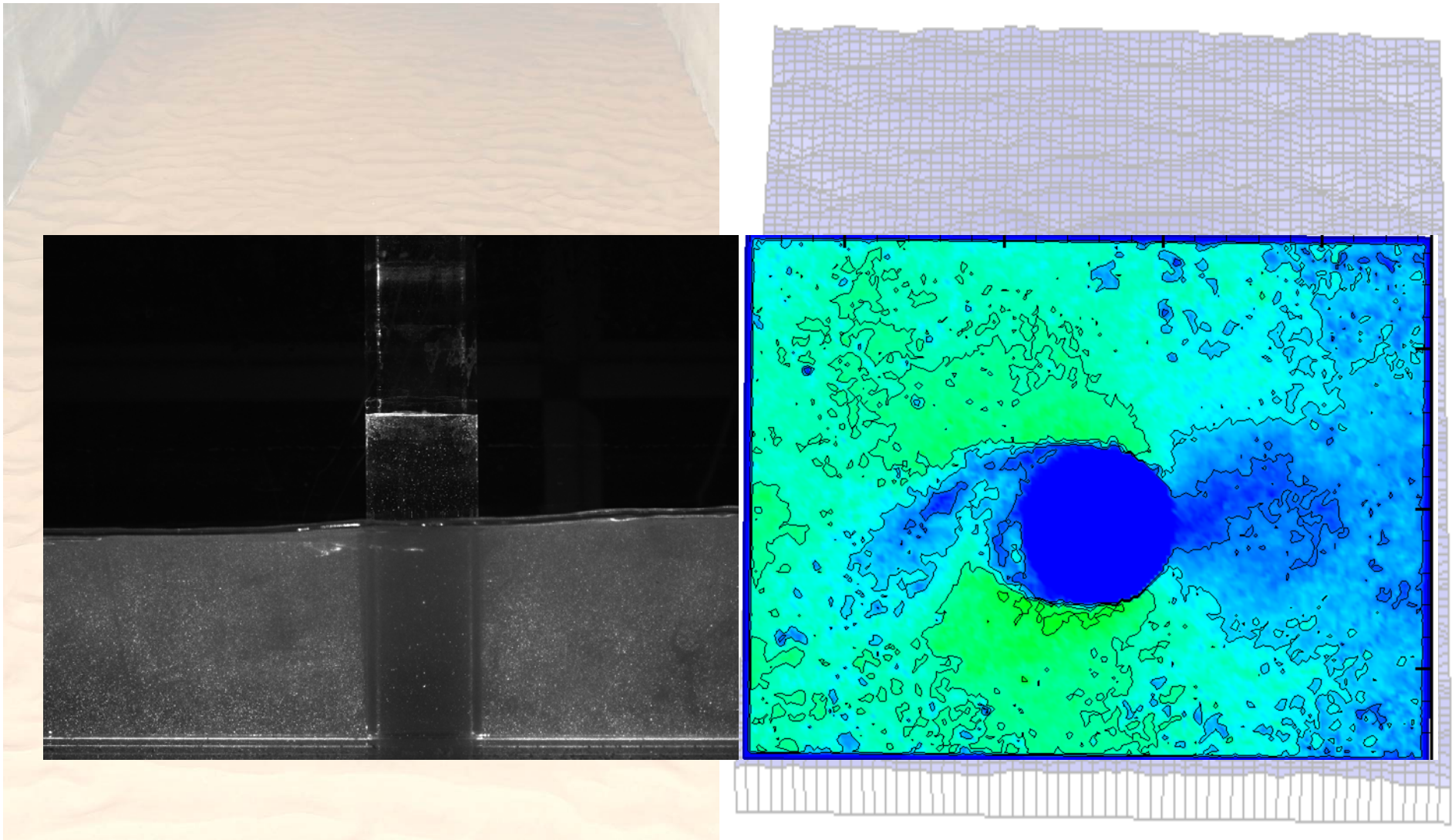

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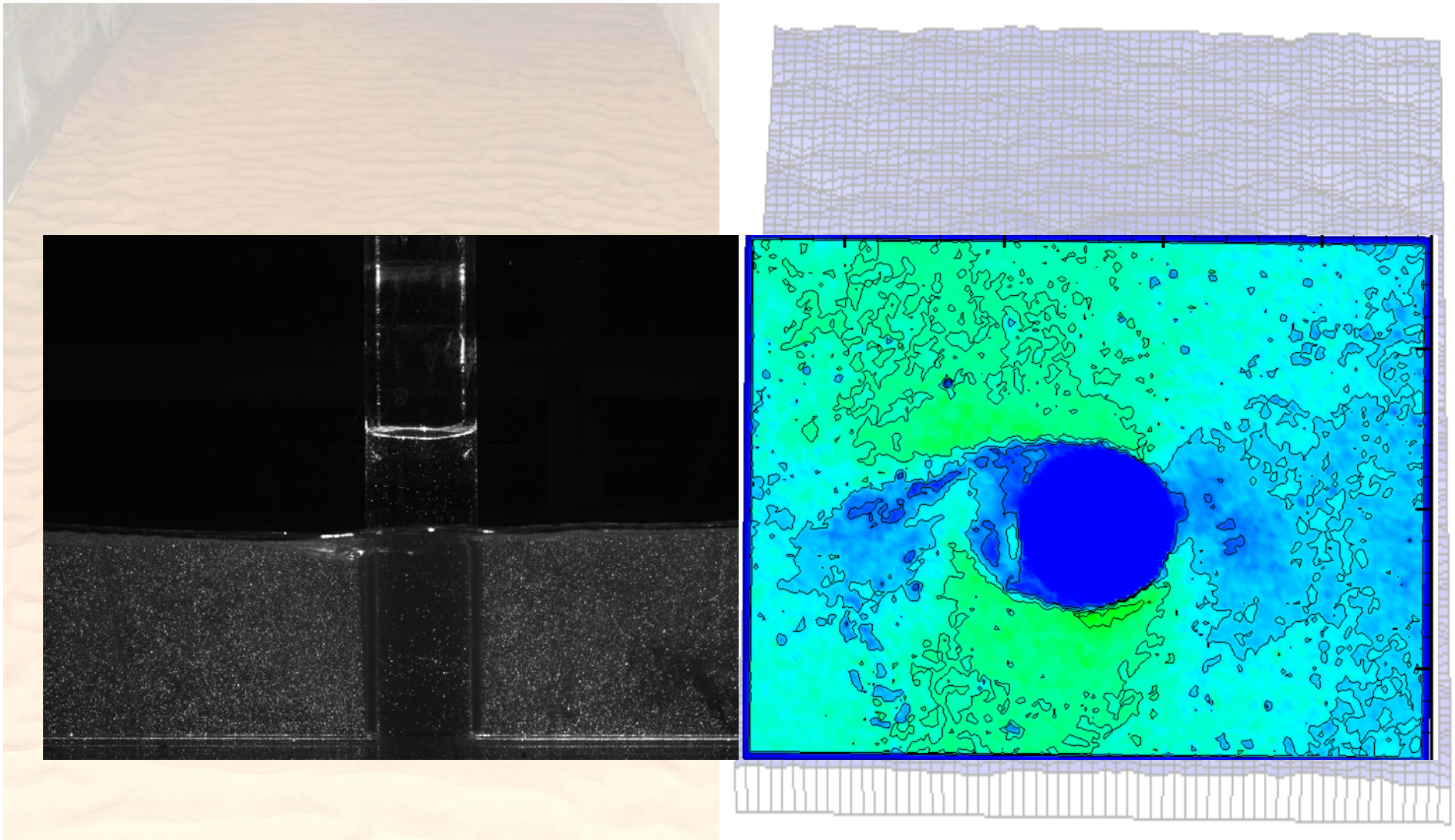

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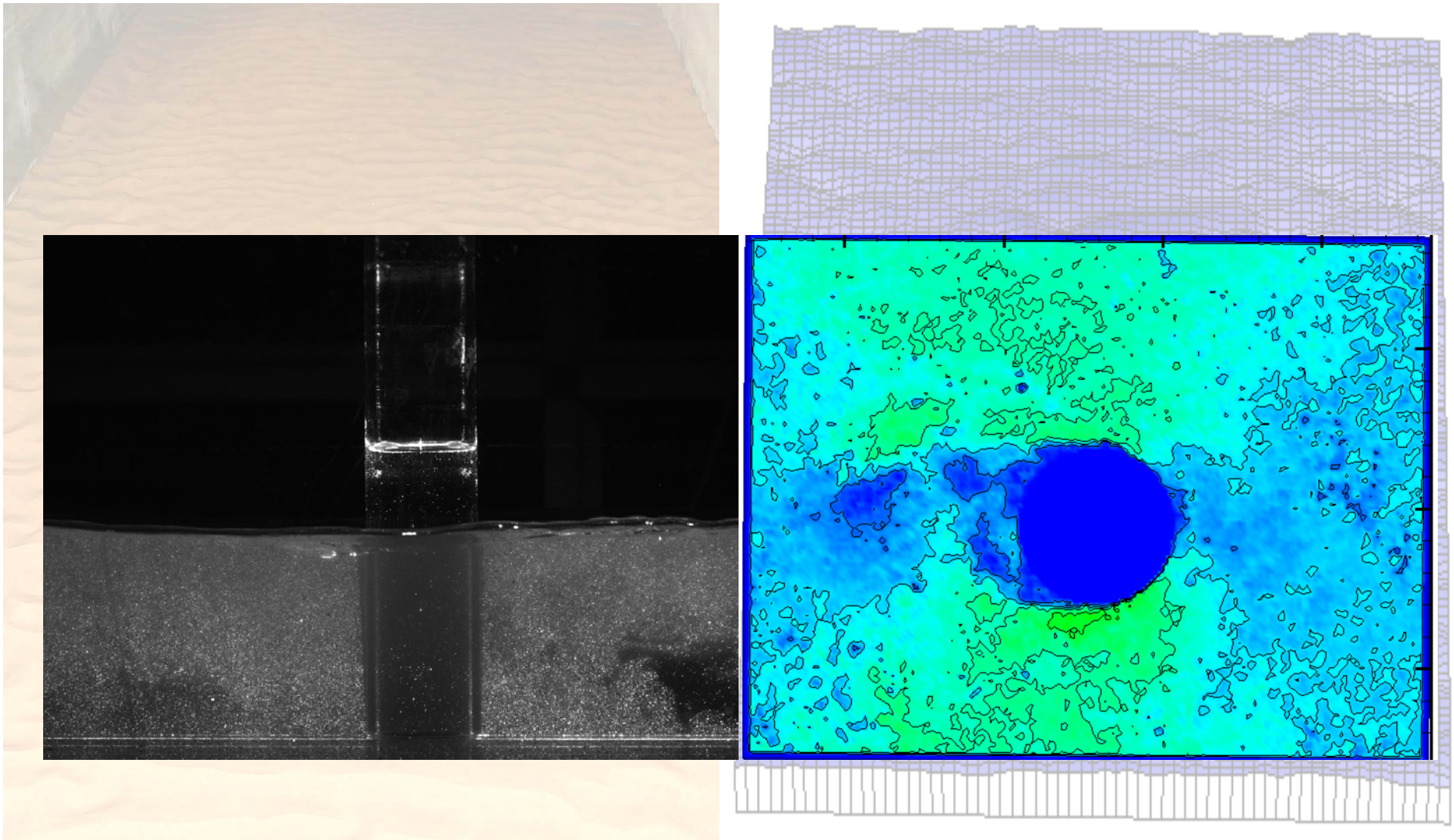

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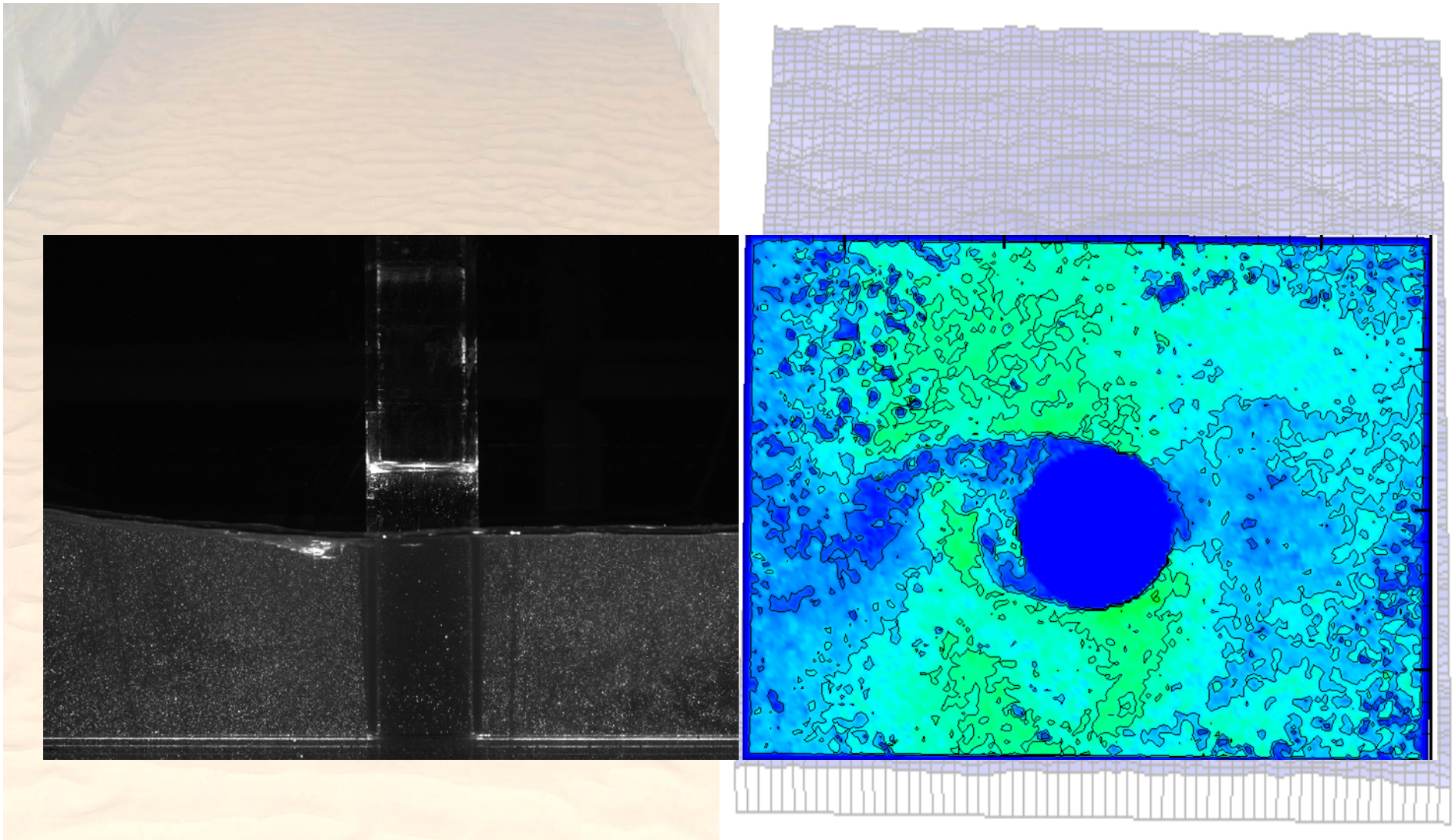

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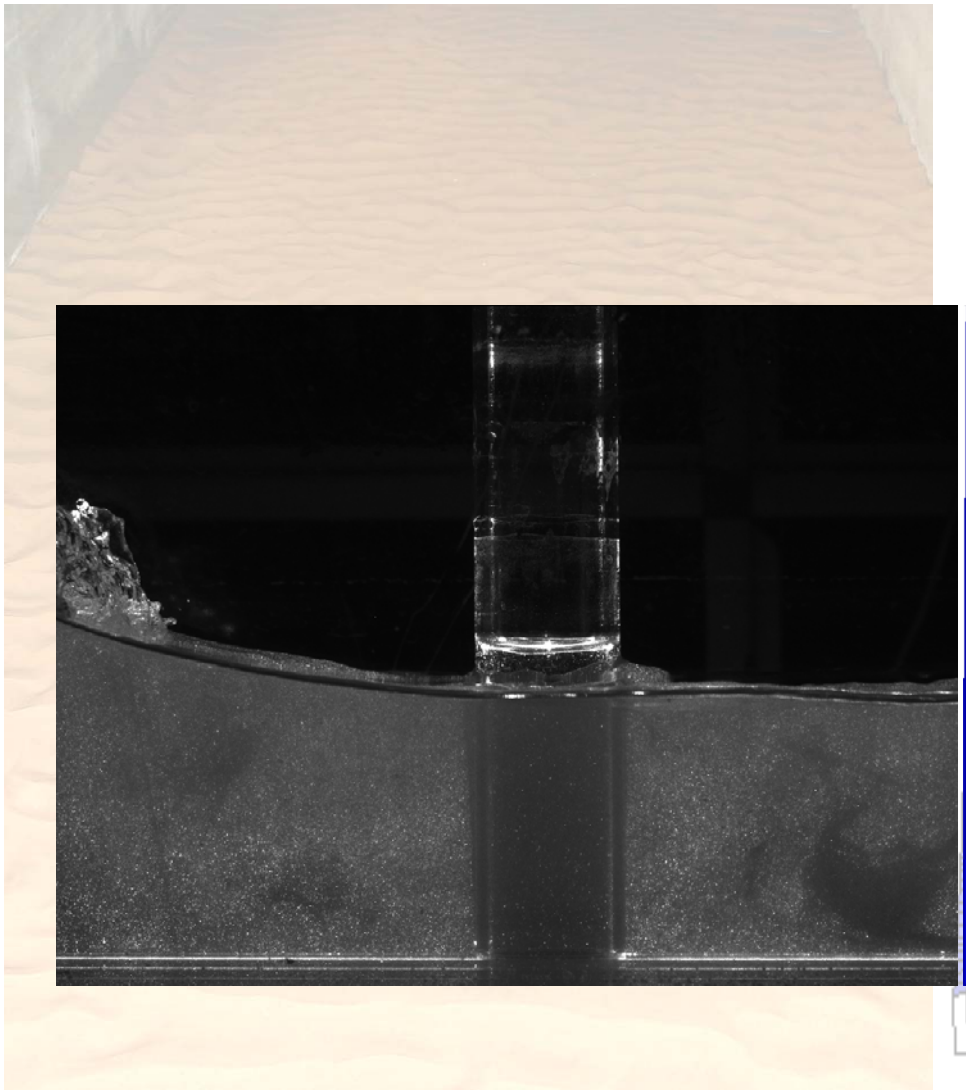

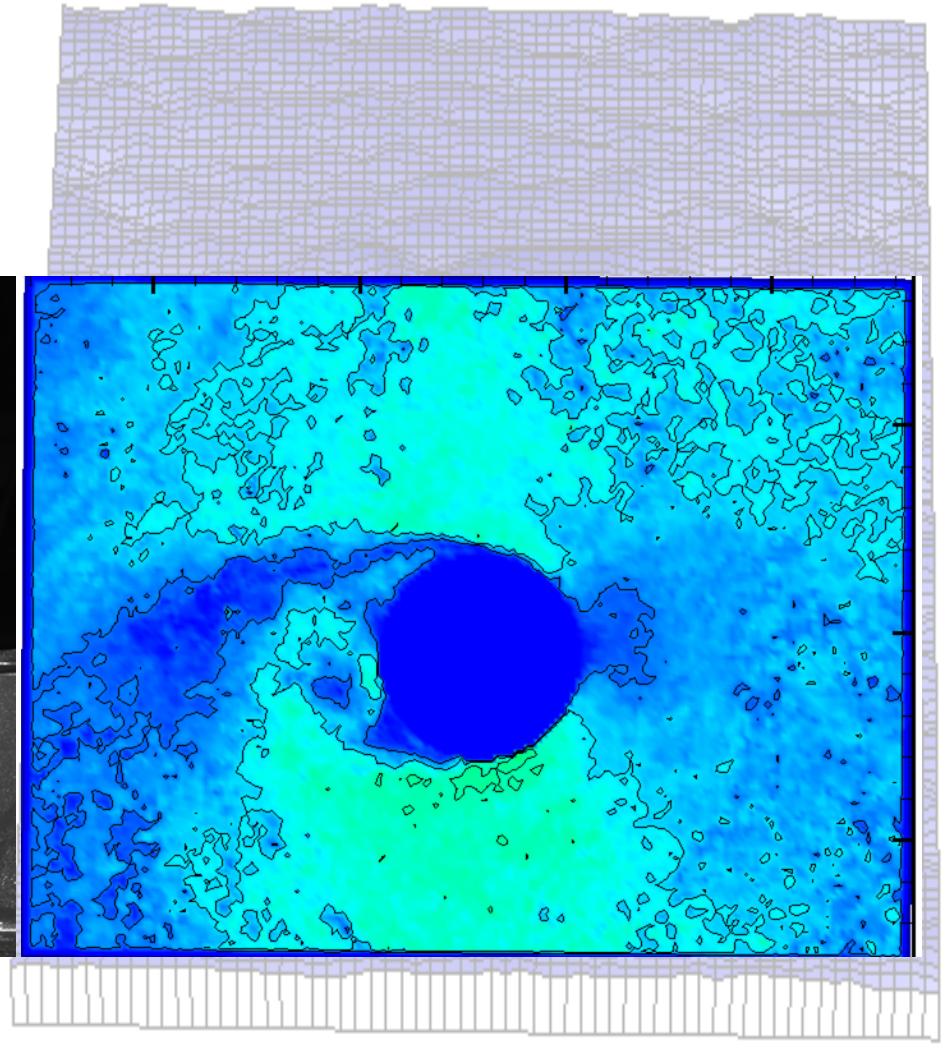

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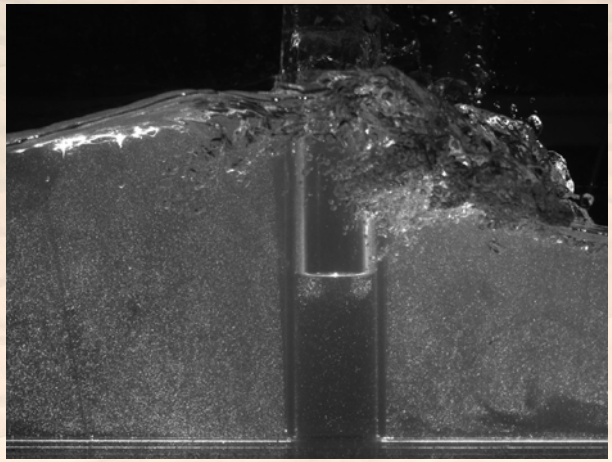
PIV measurements

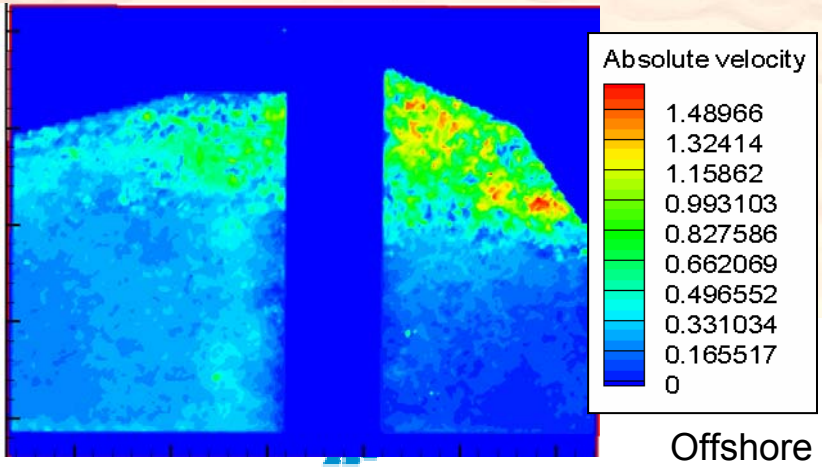
breaking wave

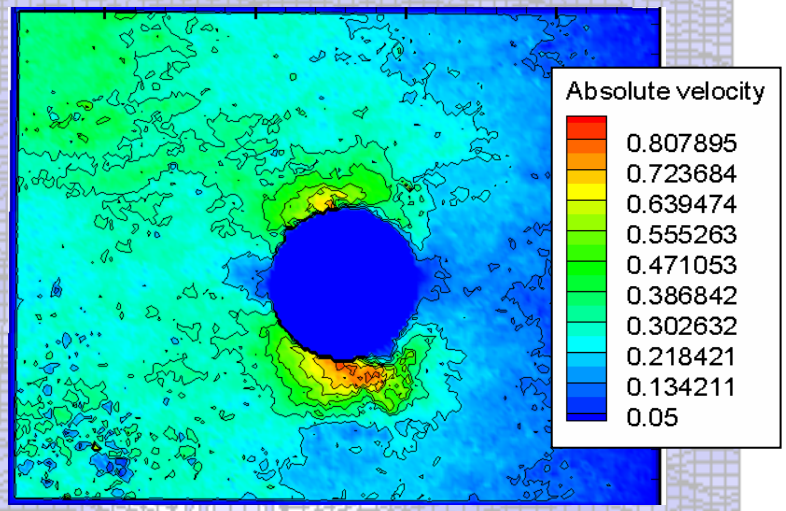


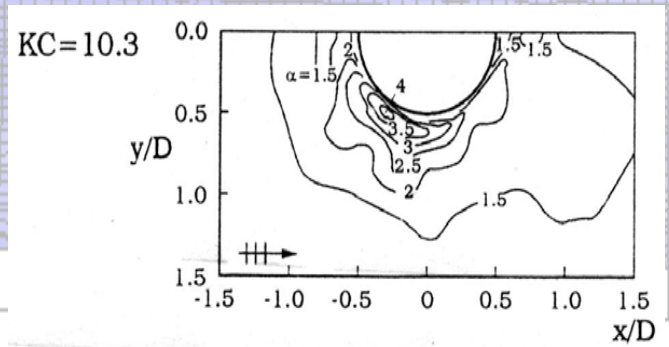
Maximum velocity: U_m = 0.42 m/s

Maximum velocity near pile: U = 0.85 m/s

Amplification of shear stress: 4.1







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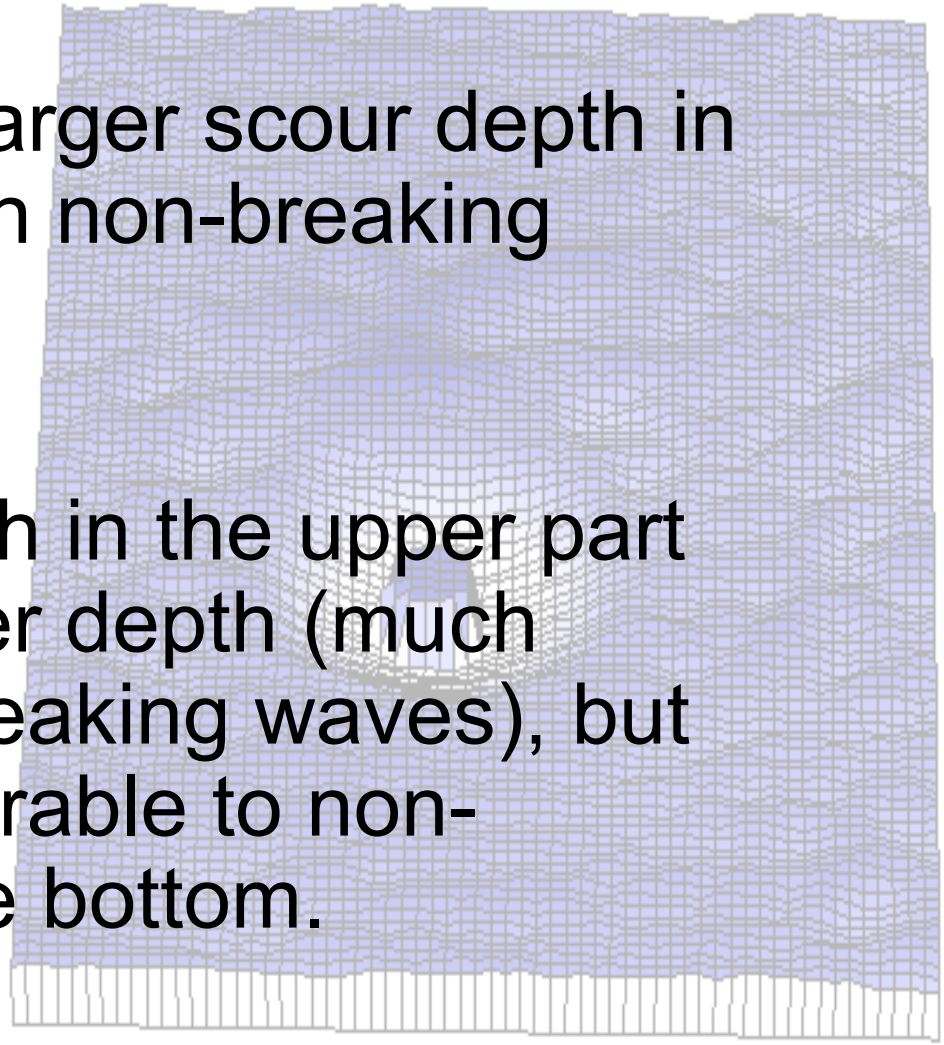
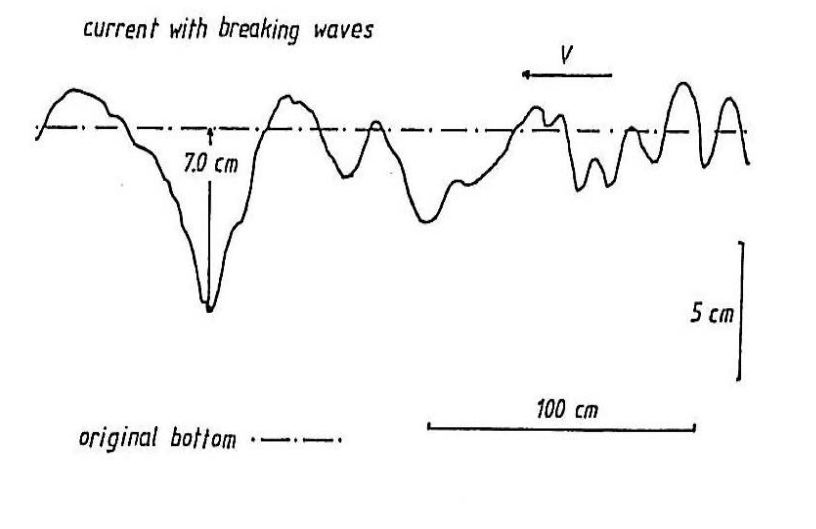
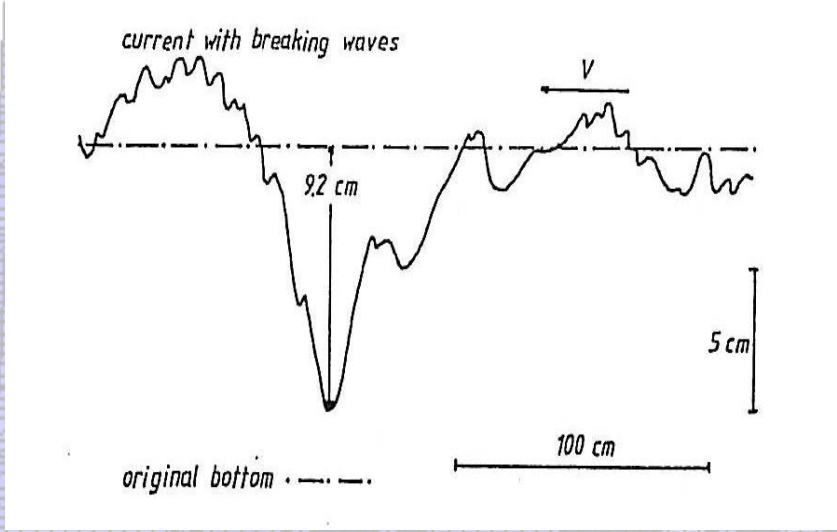
Why do we not get a larger scour depth in breaking waves than in non-breaking waves?

Velocities are very high in the upper part (1/2 to 2/3) of the water depth (much higher than for non-breaking waves), but remain limited (comparable to non-breaking waves) at the bottom.



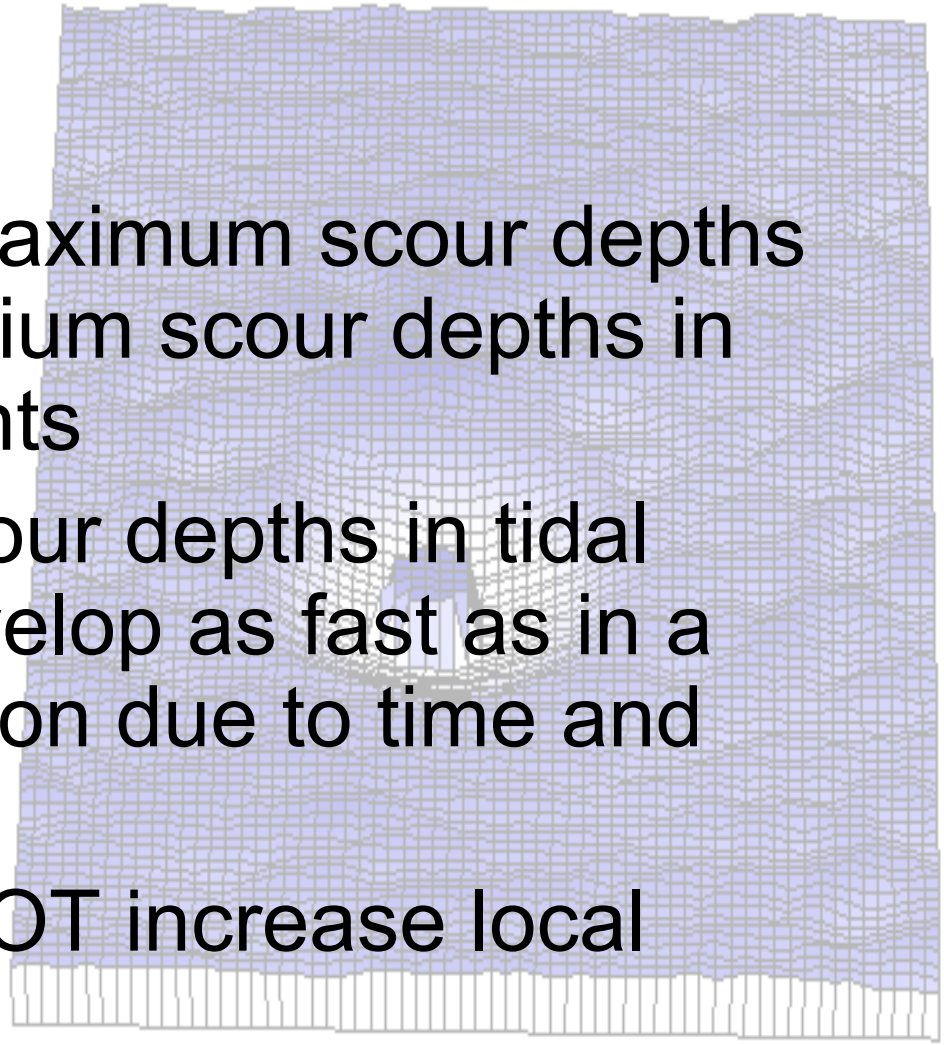
Why did Bijker and De Bruyn measure larger scour depths?





It is not the presence of the pile that causes the large scour depths, but it is the bed itself which is subjected to large changes due to ripple formation and dynamics

Conclusions



- In tidal currents the maximum scour depths are equal to equilibrium scour depths in unidirectional currents
- In many cases the scour depths in tidal currents will not develop as fast as in a unidirectional situation due to time and velocity constraints
- Breaking waves do NOT increase local scour depths