Current- and Wave-Induced Loads on Objects on the Seafloor

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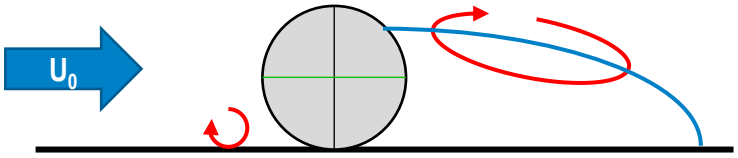
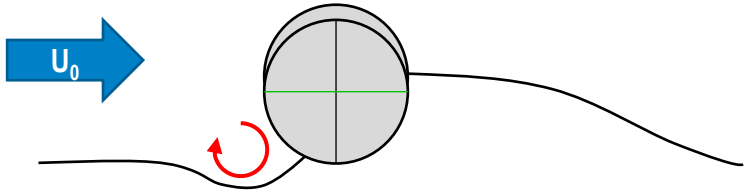
Current-Induced Self-Burial

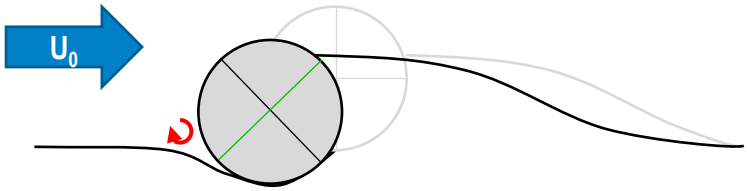
1. developing of the Horseshoe vortex



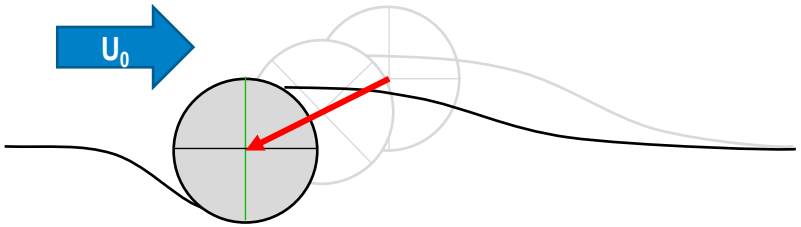
2. Scour and tilting



3. rolling/sliping into the scour hole



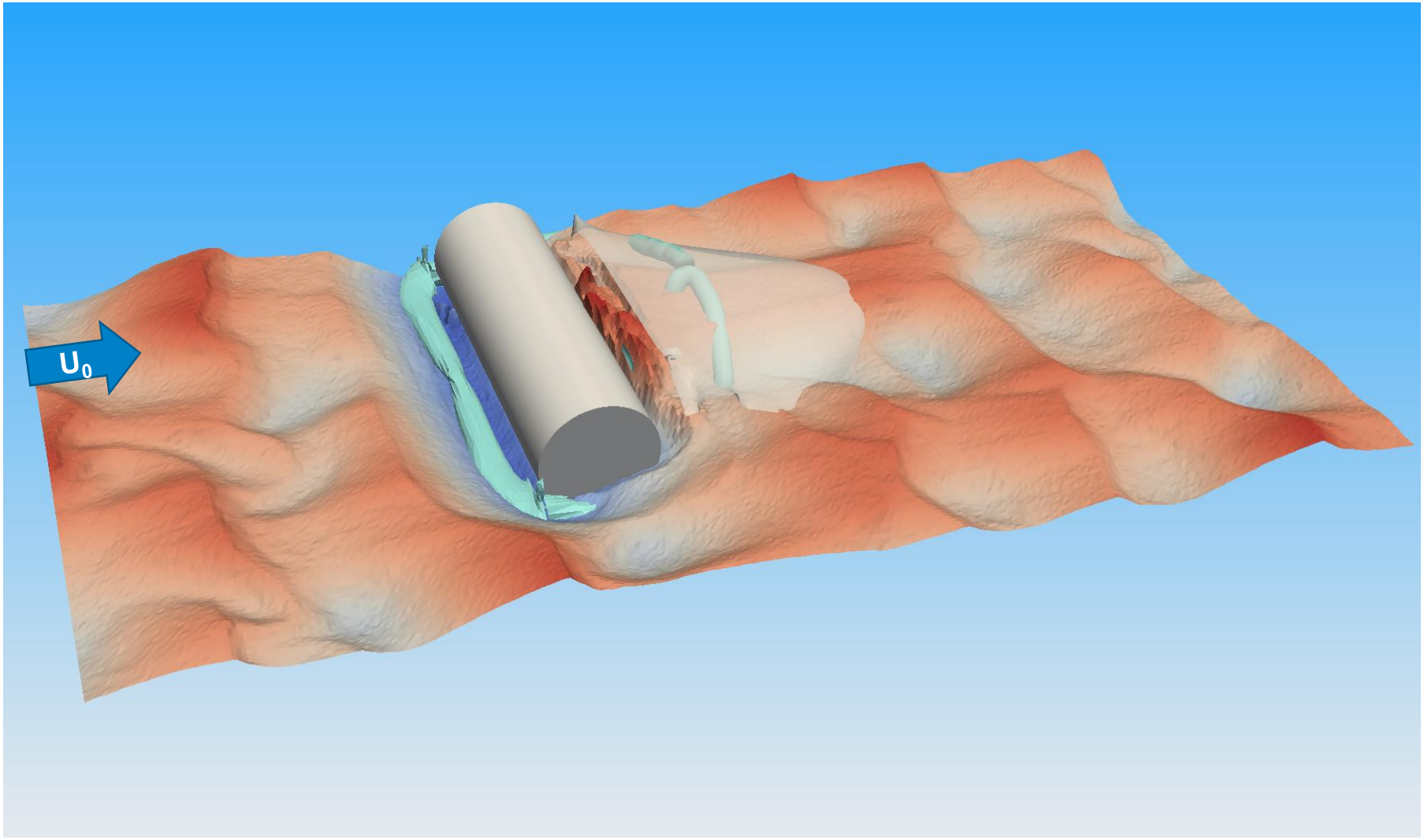
4. Again developing of a scour hole and rolling/sliping into the scour hole



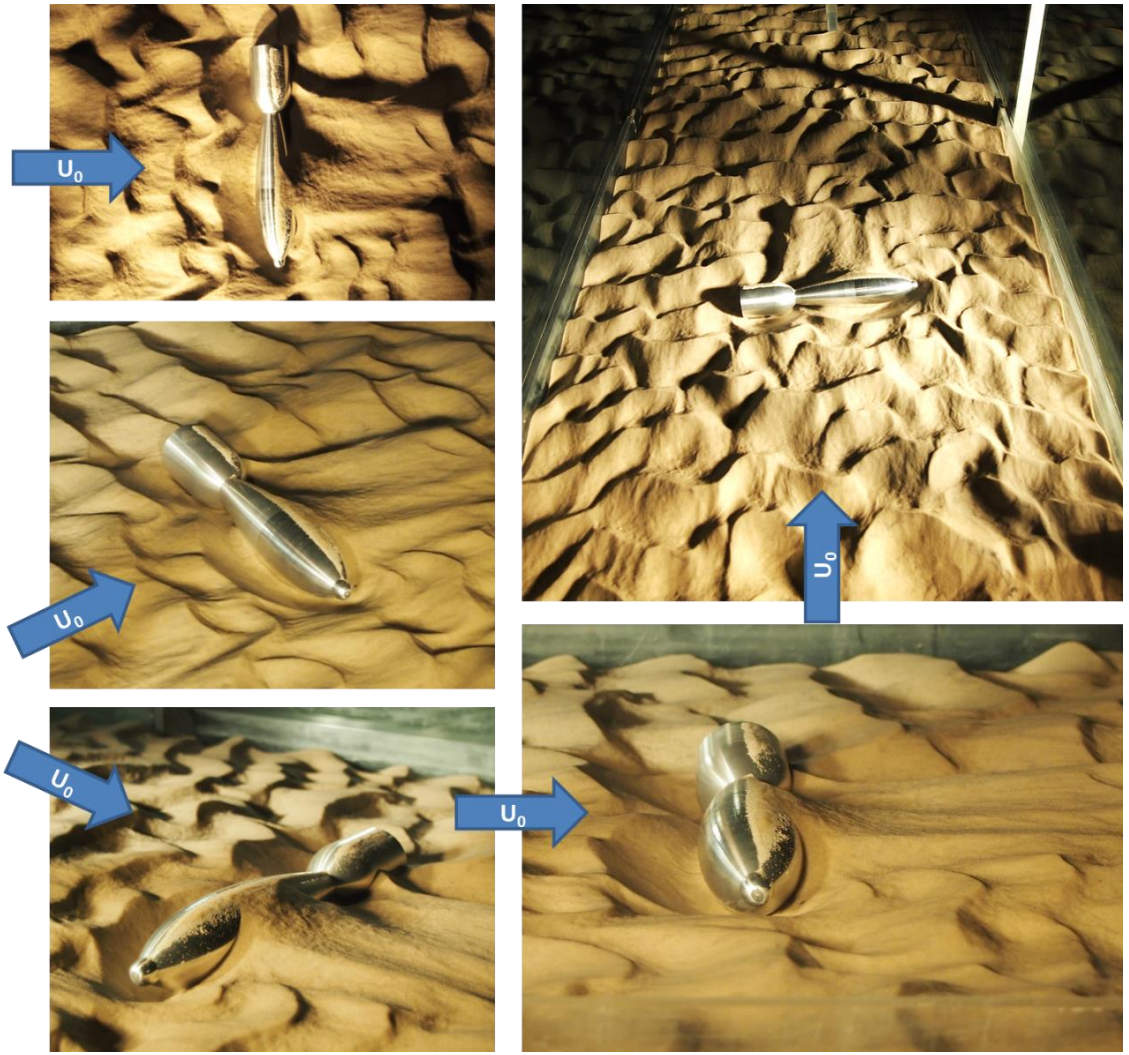
Current-Induced Mobilisation

British 250lb General Purpose Bomb (reduced weight)

Measured Bottom profile and vortex model



Water-channel experiments in Rostock

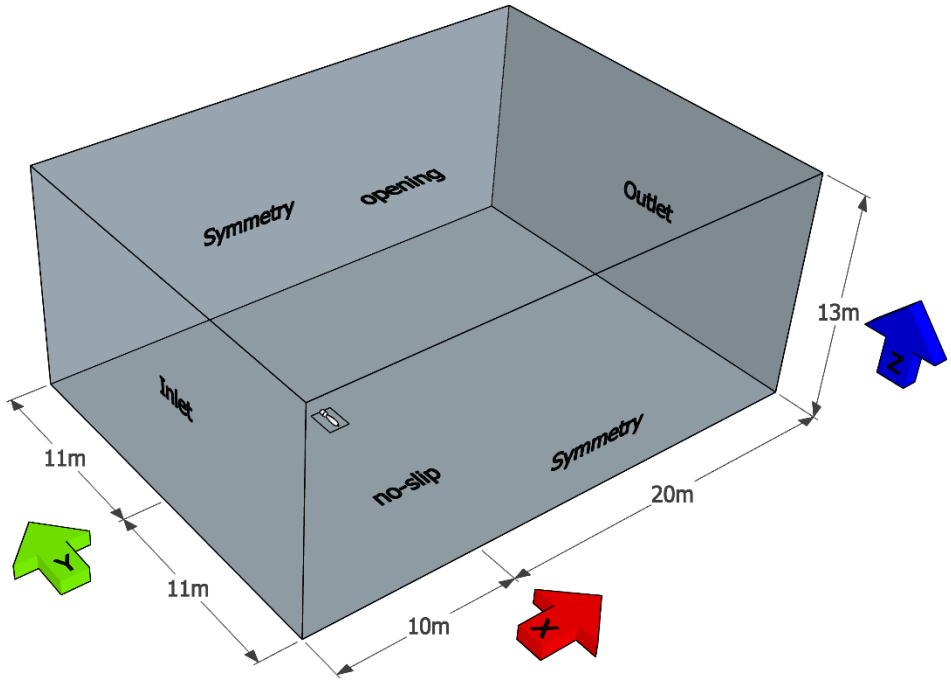


British 250lb General Purpose Bomb (scale 1:5)

Water-channel experiments at HR Wallingford

British 250lb General Purpose Bomb (scale 1:1)

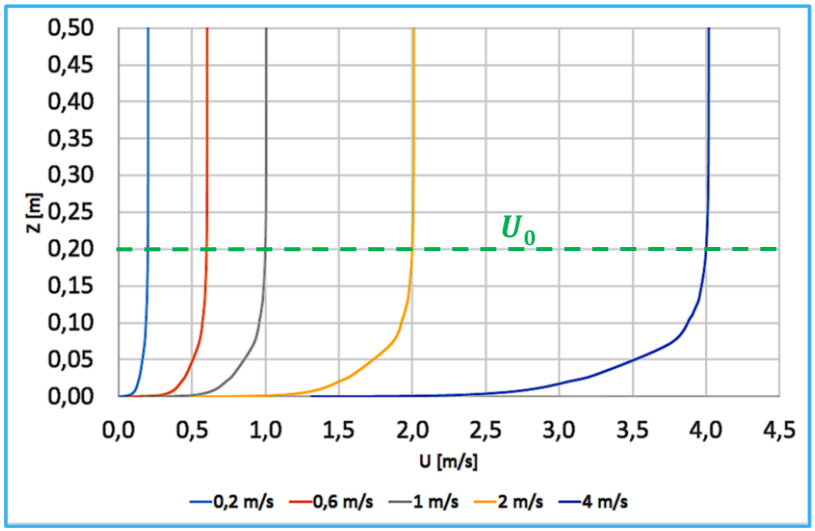
Numerical Simulations with CFD



- RANS/URANS with SST-turbulence model
- 6-10 million finite volume elements

- Water temperature : 8°C
- Smooth walls

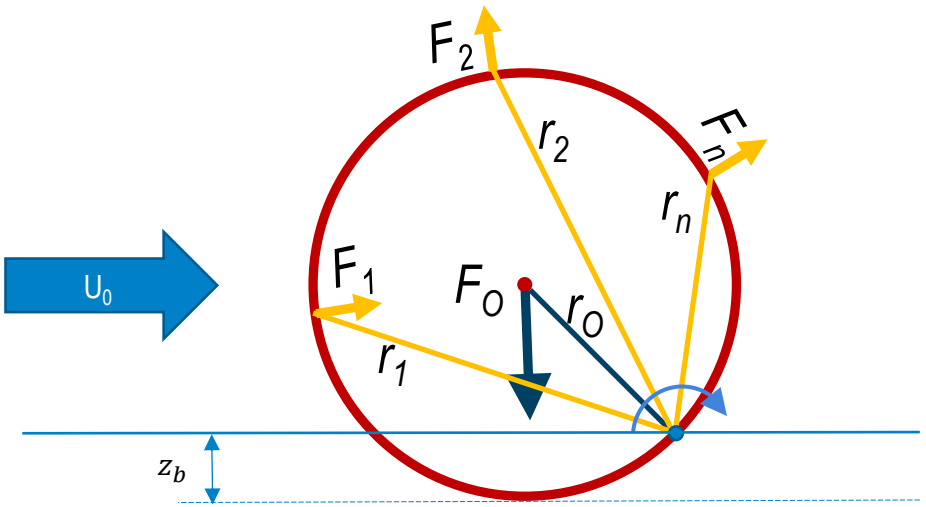
- Boundary layer profil at object place :



Burial [%] : (5 ; 15 ; 30 ; 50)
Velocity U_0 [m/s] : (0,2 ; 0,6 ; 1,0 ; 2,0 ; 4,0)

4 burial depths × 5 velocitys × 4 objects → **80 simulations**
+ simulations with scour

Force/Moment-Model



F_n	pressure force	
F_g	weight force	$F_O = F_g - F_b$
F_b	buoyancy force	

$$M_{DL} = \sum_n {}^{\perp}F_n \,.\, r_n$$

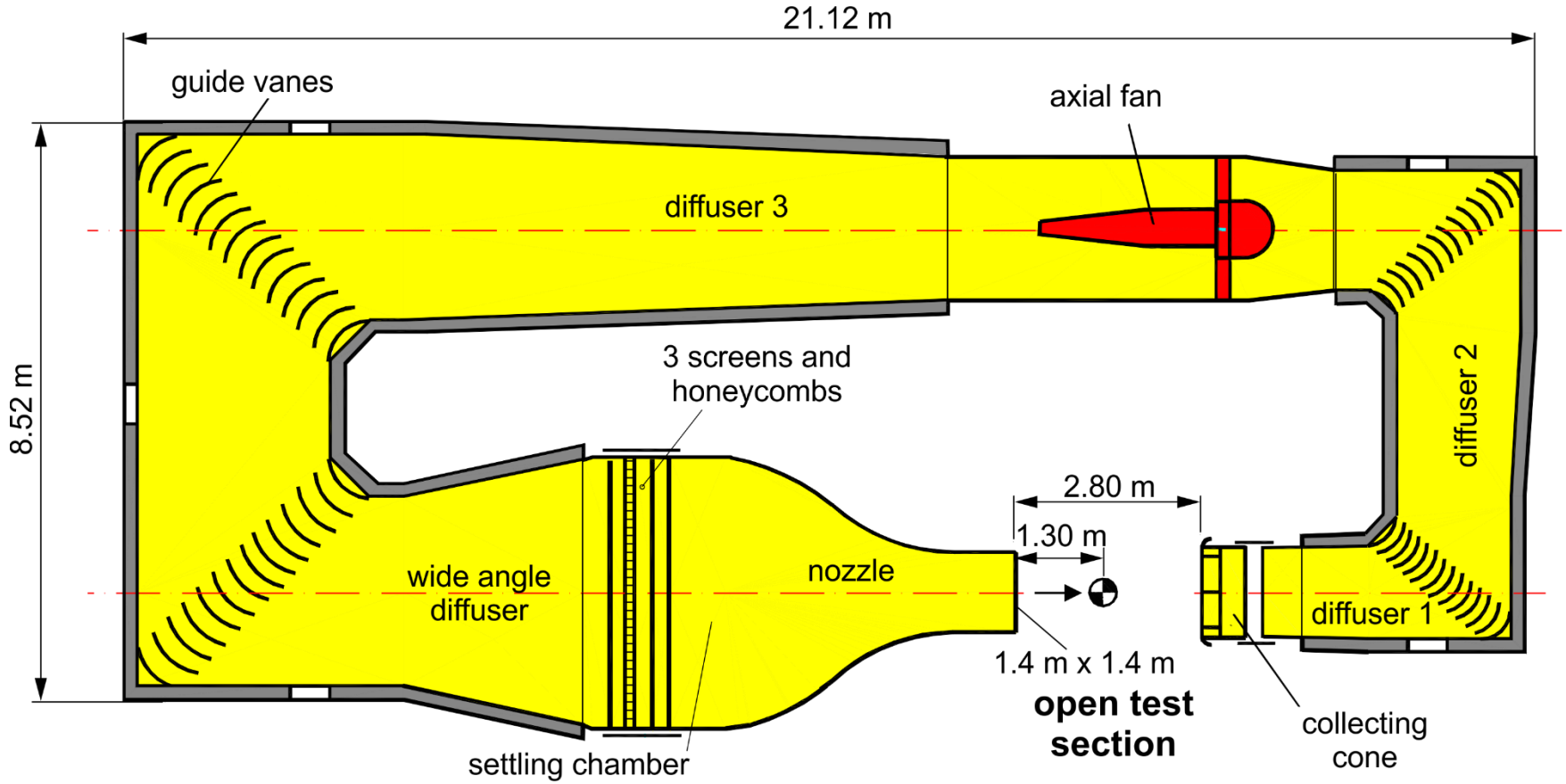
$$M_O = {}^{\perp}F_O \cdot rO$$

$$\boldsymbol{M}\text{–Coefficient} = \frac{\boldsymbol{M_{DL}}}{\boldsymbol{M_O}}$$

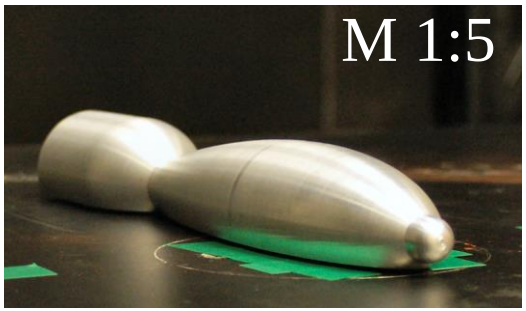
M–Coefficient $> 1 \rightarrow$ Motion possible

${}^{\perp}F$: force normal to lever

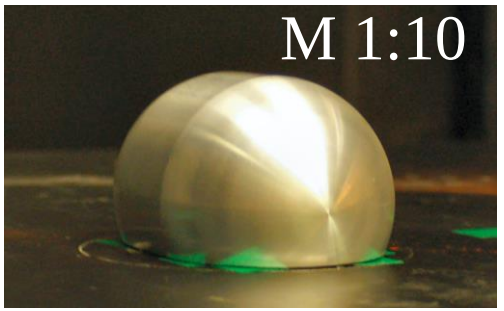
Wind tunnel



Experimental setup



British 250lb Bomb



German Mine GU

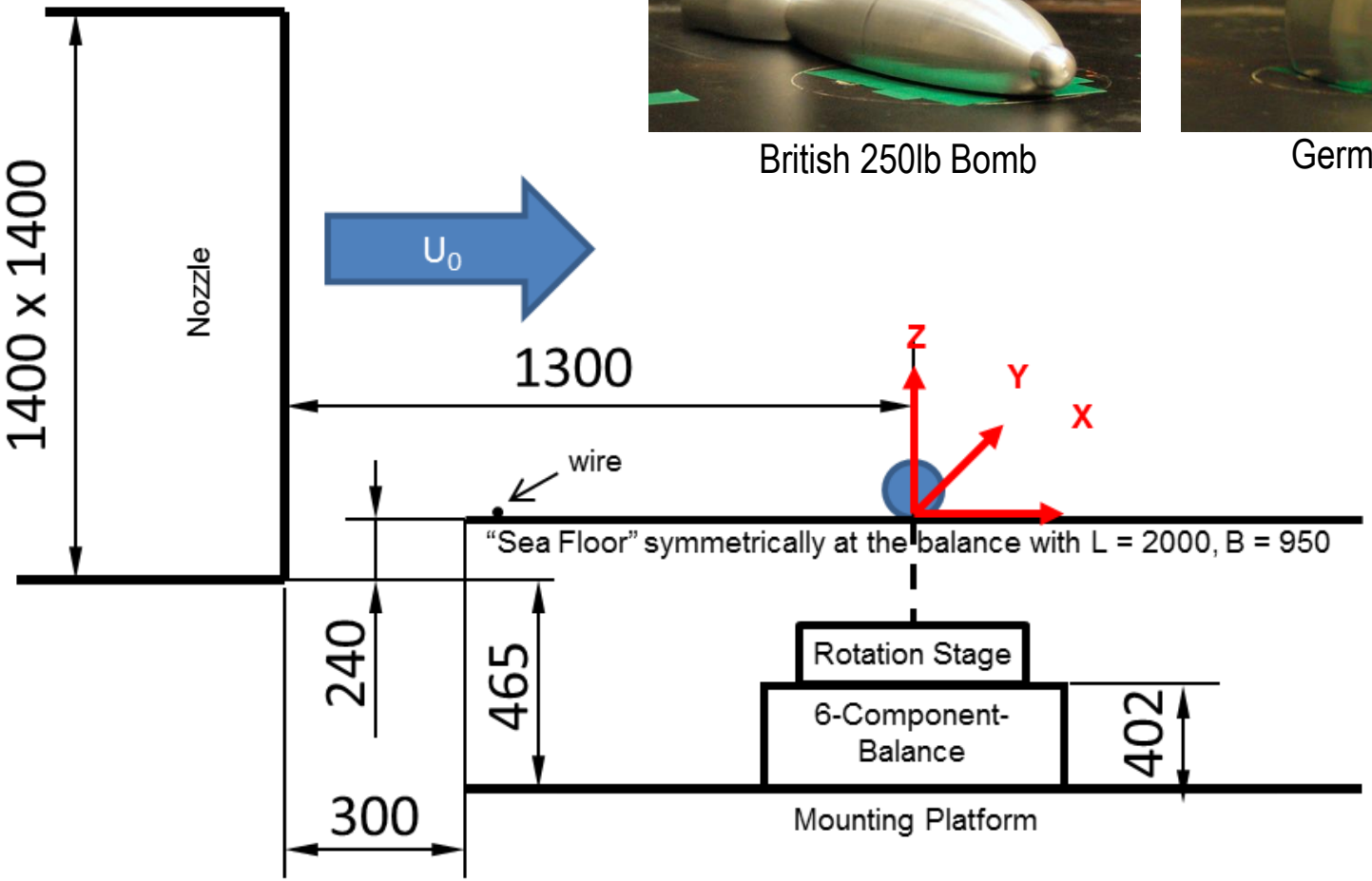
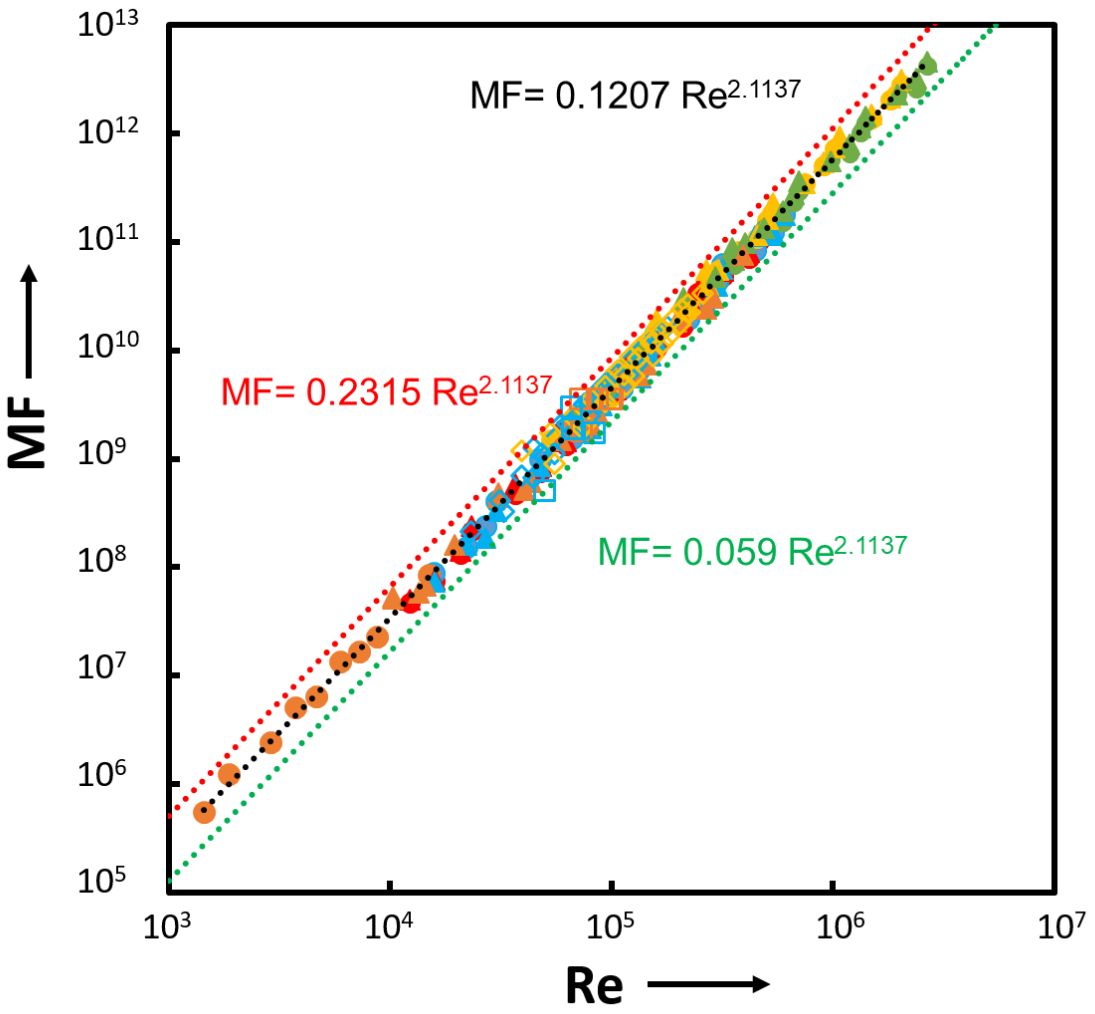


Abb. inkl. HR Wallingford



numerical simulations

- Mark 1 (1:1)
- B250 (1:1)
- Mine GU (1:1)
- Mine GY (1:1)
- Cylinder (1:10)
- Mark 1 with scour (1:1)
- B250 with scour (1:1)
- Mine GU with scour (1:1)
- Mine GY with scour (1:1)
- Cylinder with scour(1:1)

experiments

- B250 wind (1:5)
- Mine GU wind (1:10)
- Cylinder water (1:2)
- B250 water(1:1)

287 points

Equation

$$\mathrm{MF} = \frac{M_{DL}}{\mathrm{L}\cdot\cos\alpha} \cdot \frac{\rho_w}{\mu^2} = aRe^b$$

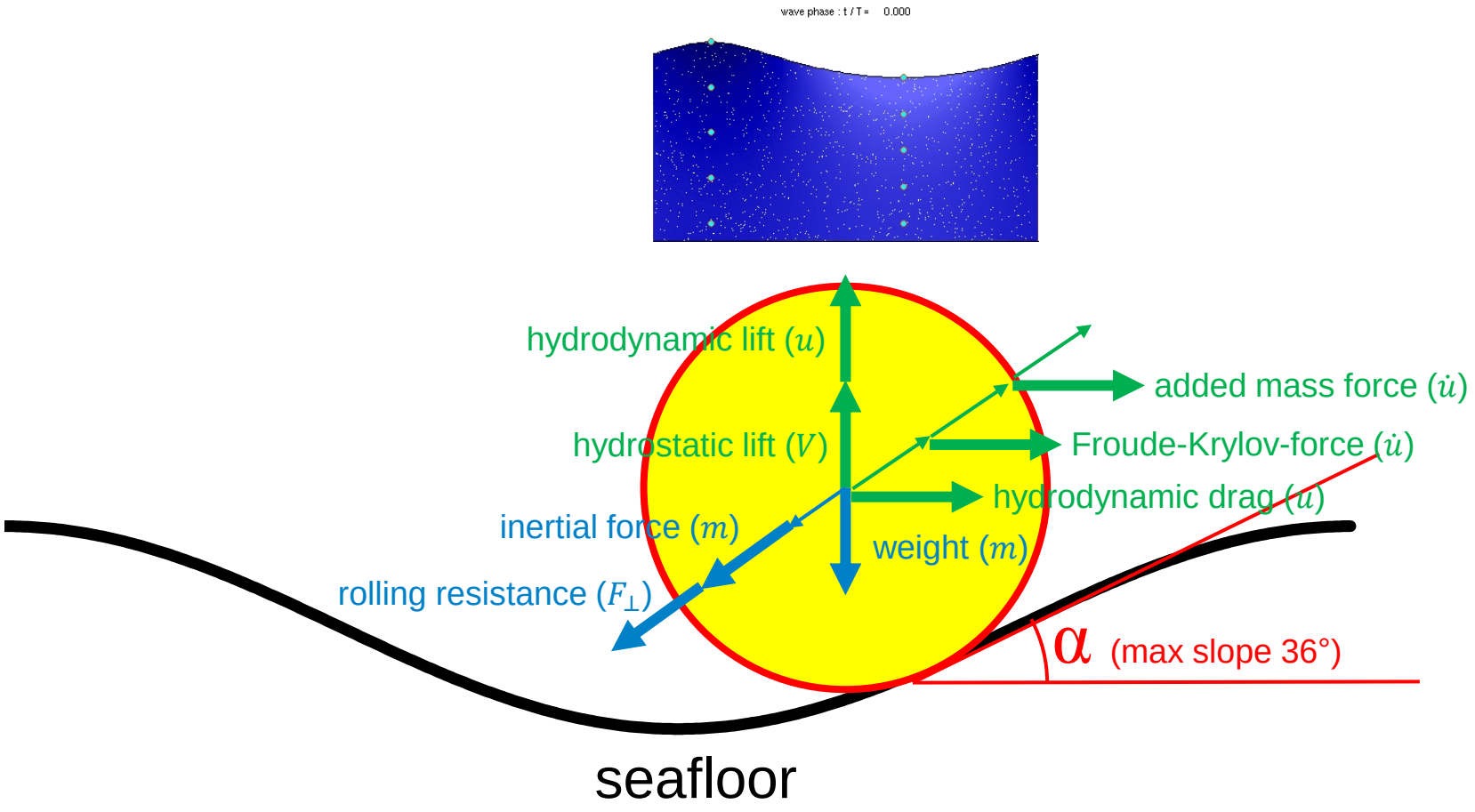
$$a = 0.2315 \qquad b = 2.1137$$

$$U_{crit} = \sqrt[b]{\frac{\rho_w g D_{avg} V(\rho_{obj} - \rho_w)}{2a\mu^2 L}} \cdot \frac{\mu}{\rho_w(1 - z_b)D_{avg}}$$

@ 50% burial and z = 1 m

British 250lb General Purpose Bomb:	U_{crit} = 1,9 m/s
British Depth Bomb Mark 1:	U_{crit} = 1,3 m/s
German Mine Type GU:	U_{crit} = 2,1 m/s
German Mine Type GY:	U_{crit} = 2,3 m/s

Wave-Induced Loads



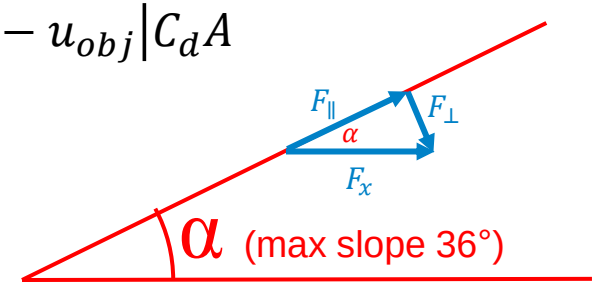
Morison-Equation

horizontal component

$$m\dot{u}_{obj} = \underbrace{\rho V_{obj}\dot{u}}_{\text{Froude-Krylov}} + \underbrace{\rho C_a V_{obj}(\dot{u} - \dot{u}_{obj})}_{\text{hydrodynamic mass force}} + \underbrace{\frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_d A}_{\text{hydrodynamic drag}}$$

$\rho C_a V_{obj}$: added/hydrodynamic mass

$$(m + \rho C_a V_{obj})\dot{u}_{obj} = \rho V_{obj}\dot{u}(1 + C_a) + \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_d A$$



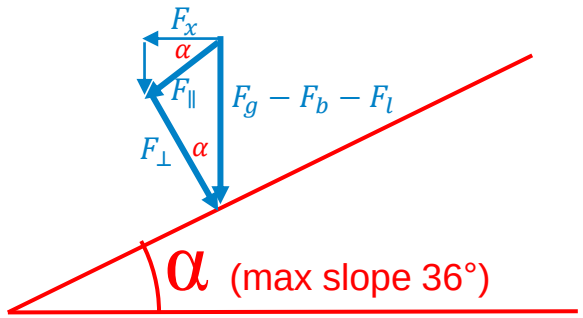
$C_r \cos\alpha\, F_{\perp}$: rolling resistance

$$(m + \rho C_a V_{obj})\dot{u}_{obj} = [1 + C_r \cos\alpha]\left[\rho V_{obj}\dot{u}(1 + C_a) + \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_d A\right]$$

Horizontal loads

$$F_x = \cos\alpha\, F_{\parallel}$$
$$= \cos\alpha \sin\alpha \left(F_g - F_b - F_l\right)$$

: weight – buoyancy – hydrodynamic lift



$$F_g - F_b - F_l = (m - \rho V_{obj})g - \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_l A$$

$$(m + \rho C_a V_{obj})\dot{u}_{obj}$$
$$= [1 + C_r \cos\alpha]\left[\rho V_{obj}\dot{u}(1 + C_a)\right.$$
$$+ \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_d A + \cos\alpha \sin\alpha \left\{(m - \rho V)g\right.$$
$$\left.\left. - \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_l A \right\}\right]$$

$$\dot{u}_{obj} = \frac{[1 + C_r \vec{e}_{\perp} \cos\alpha]\left[\rho V_{obj}\dot{u}(1 + C_a) + \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_d A + \cos\alpha \sin\alpha \left\{(m - \rho V)g - \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_l A \right\}\right]}{(m + \rho C_a V_{obj})}$$

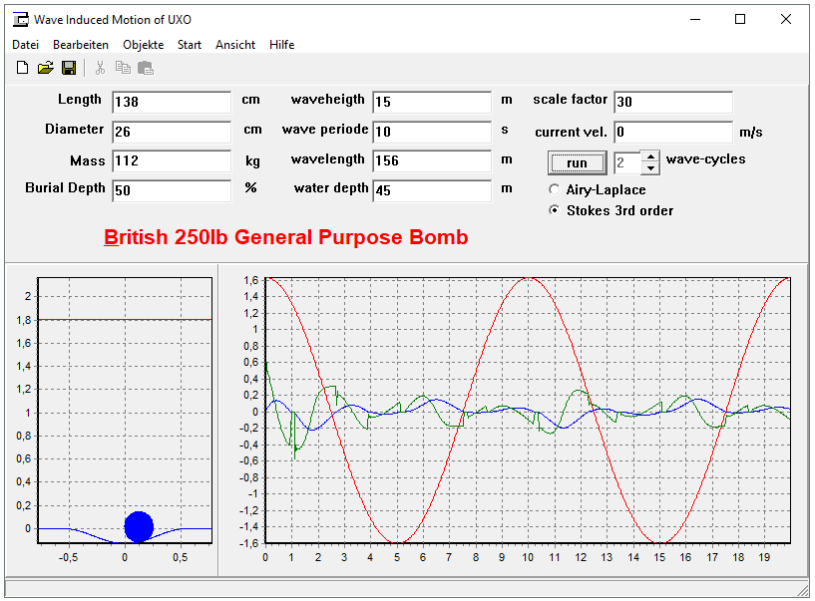
Stokes 3rd order, shallow water

$$\dot{u}_{obj} = \frac{[1 + C_r \vec{e}_\perp \cos\alpha]\left[\rho V_{obj}\dot{u}(1 + C_a) + \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_d A + \cos\alpha \sin\alpha \left\{(m - \rho V)g - \frac{\rho}{2}(u - u_{obj})|u - u_{obj}|C_l A\right\}\right]}{(m + \rho C_a V_{obj})}$$

$$u = c\left[ka\frac{\cosh[k(z+h)]}{\sinh(kh)}\cos\varphi + \frac{3}{4}k^2a^2\frac{\cosh[2k(z+h)]}{\sinh^4(kh)}\cos(2\varphi) + \frac{3}{64}k^3a^3\frac{11 - 2\cosh(kh)}{\sinh^7(kh)}\cosh[3k(z+h)]\cos(3\varphi)\right]$$

$$\dot{u} = c\left[a\frac{\cosh[k(z+h)]}{\sinh(kh)}\sin\varphi + \frac{3}{2}k^2\omega a^2\frac{\cosh[2k(z+h)]}{\sinh^4(kh)}\sin(2\varphi) + \frac{9}{64}k^3\omega a^3\frac{11 - 2\cosh(2kh)}{\sinh^7(kh)}\cosh[3k(z+h)]\sinh(3\varphi)\right]$$

plus vertical component =>



Part 2: Chris Jenkins

Part 2