Polski Rejestr Statków

Safety of fishing vessels

dr Monika Warmowska

Stability criteria and standards for fishing vessels

The main reasons underlying stability problems and safety standardization of smaller vessels involve :

- Generally unfavourable relations between stability capability and the magnitude of external heeling moments (waves, wind);
- Water trapped on deck;
- Change of centre of gravity causing dramatic change of stability;
- Inadequate stability criteria and standards – based on static stability in calm water, and not on real dynamic behavior in waves.

Stability criteria and standards for fishing vessels – PRS's long term project

Theoretical analyses of physical phenomena

Development of mathematical models and computer software

Carrying out the model tests verifying the theories and software

Performing systematic numerical simulations

Statistical analyses of real accidents vs. "safe" ships

Development of rational criteria preventing capsize

Development of safety standard

Stability criteria and standards for fishing vessels – PRS's long term project

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Modelling of smaller vessel’s motion

The model of simulation of smaller vessel’s motion consists of models describing:

- irregular wave rounding the vessel,
- forces and moments acting on the vessel and determining equations of vessel’s motion,
- phenomena of water inflow and outflow on vessel’s deck,
- motion of water over the deck,
- forces and moments caused by water trapped on deck.

Modelling of irregular wave

Elevation of irregular wave is a sum of harmonic wave components' elevations:

$$\zeta(x, y, z, t) = \sum_i \zeta_i (x, y, z) \cos(\omega_i t + \varepsilon_i)$$

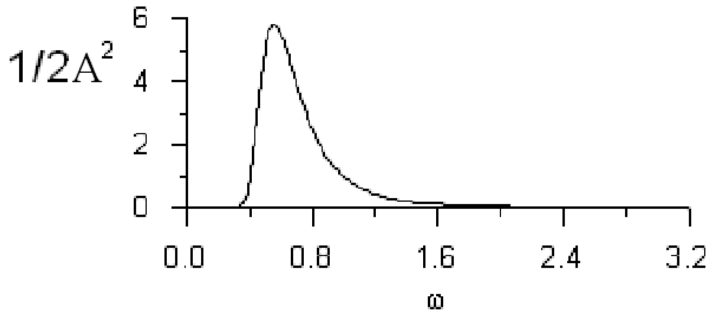
Where

ζ_i is the amplitude of harmonic wave with a frequency ω_i.

Both parameters are defined by wave spectrum:

e.g. *Pierson – Moskowitz* wave spectrum for North Atlantic:

$$A(\omega) = \frac{4H_s^2\pi^3}{T_z^3\omega^5} \exp\left[-\frac{16\pi^3}{T_z\,\omega^4}\right]$$



H_s – significant wave – height,

T_z – averaged zero – up crossing period,

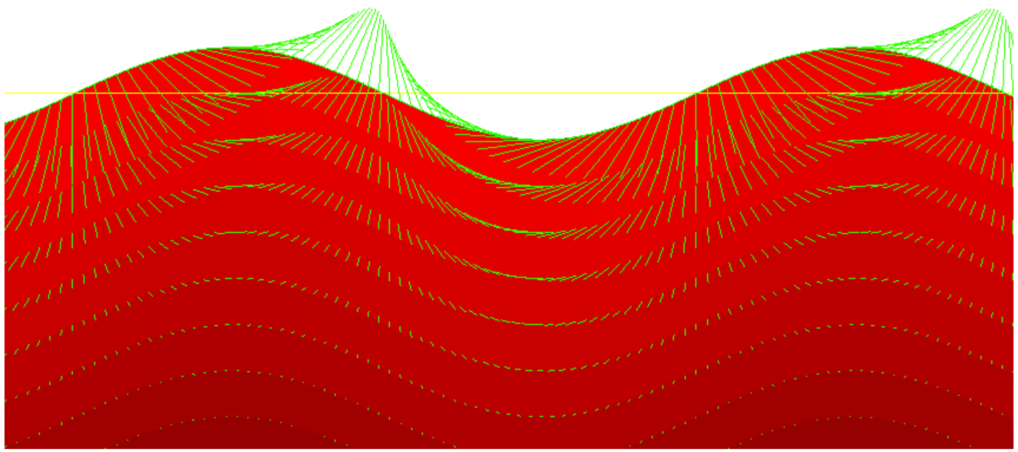
ε_i is a stochastic parameter.

Modelling of irregular wave

Linear Theory

Velocity potential of harmonic wave is defined as follows:

$$\phi(t) = \frac{r_0}{\omega} e^{kz} \sin(kx - \omega t).$$



Assumption

A small elevation of free surface

Modelling of harmonic wave component

Linear Theory

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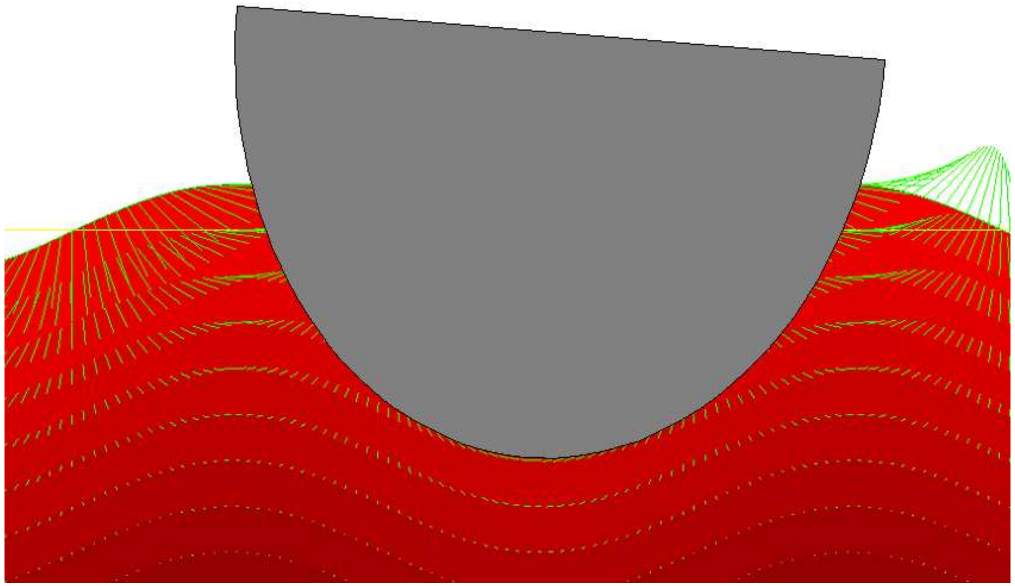

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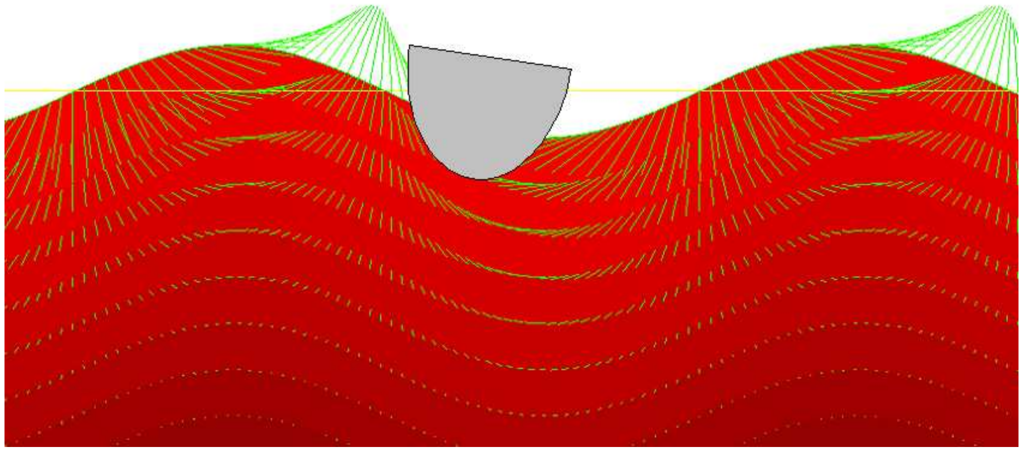

Assumption

A small elevation of free surface

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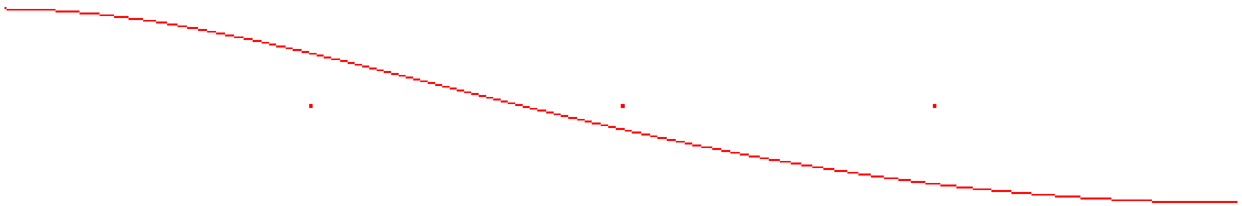
Modelling of harmonic wave component

Motion around average position of water's particle

Position of water's particle is defined by equations:

$$
\begin{aligned}
x(t) &= x_0 - r_0 e^{kz_0} \sin(kx_0 - \omega t),\\
y(t) &= y_0,\\
z(t) &= z_0 + r_0 e^{kz_0} \cos(kx_0 - \omega t),
\end{aligned}
$$



where (x_0, y_0, z_0) is an average position of this particle,

r_0 is the amplitude of harmonic component of irregular wave,

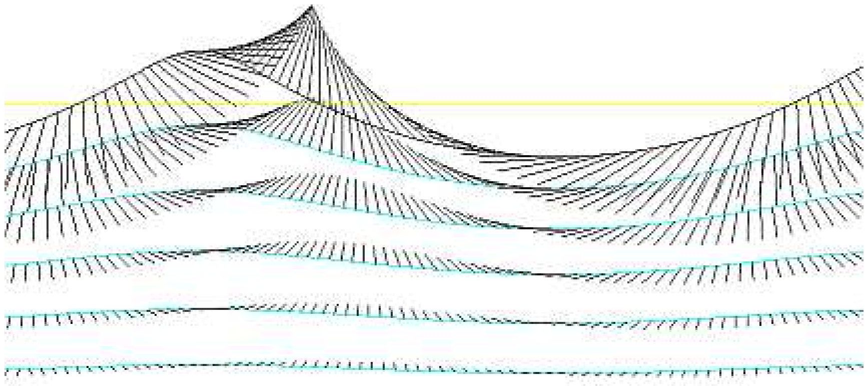
k is a wave number, ω is a wave frequency.

Modelling of harmonic wave component

Motion around average position of water's particle

Velocity field is calculated form equations (also for particles near free surface of water):

$$u_x(t) = \omega r_0 e^{kz_0} \cos(kx_0 - \omega t),$$
$$u_y(t) = 0,$$
$$u_z(t) = \omega r_0 e^{kz_0} \sin(kx_0 - \omega t)$$



where (x_0, y_0, z_0) is an average position of this particle,

r_0 is the amplitude of harmonic component of irregular wave,

k is a wave number,

ω is a wave frequency.

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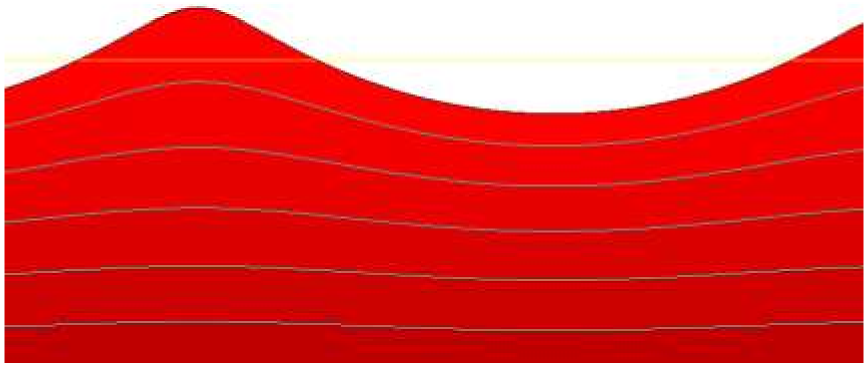
Modelling of harmonic wave component

Motion around average position of water's particle

Pressure field calculated form equations:

$$p(x,y,z,t) = p_a - \rho g z_0$$



where (x_0,y_0,z_0) is an average position of this particle,

$$z_0 = z(t) - r_0 e^{kz_0} \cos(kx_0 - \omega t)$$

r_0 is the amplitude of harmonic component of irregular wave.

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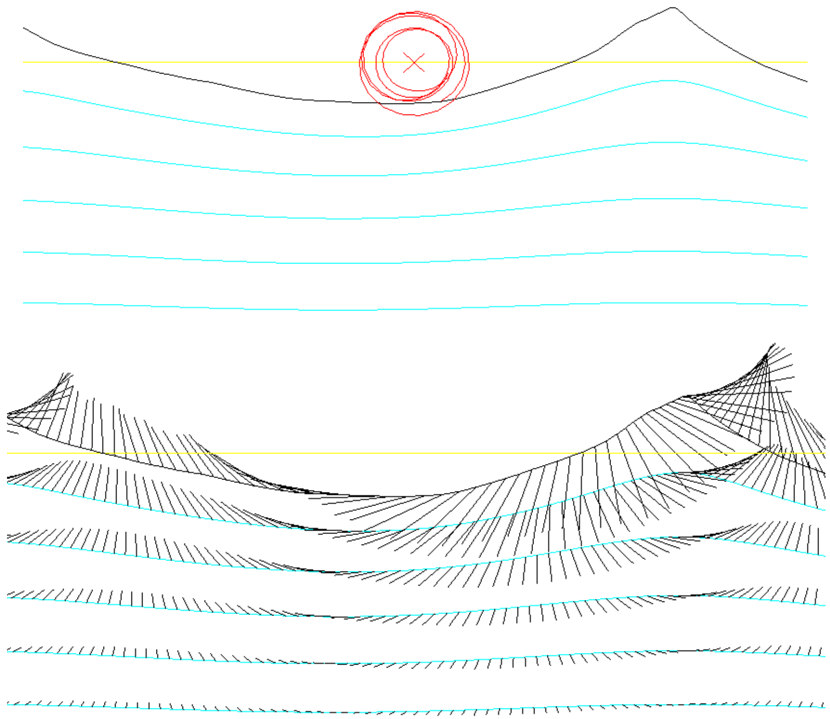
Modelling of irregular wave around vessel

Irregular wave is modelled as a sum of harmonic waves

lp.	w [rad/s]	r0 [m]	eps [rad]
1	0.25919	0.01098	2.97684
2	0.51839	0.02095	2.92991
3	0.77758	0.04324	3.04594
4	1.03677	0.04903	3.05436
5	1.29597	0.19743	2.53691
6	1.55516	1.59948	5.51299
7	1.81435	0.35981	5.28492
8	2.07354	0.23741	4.62165
9	2.33274	0.11671	6.19782
10	2.59193	0.09689	3.38105
11	2.85112	0.10264	1.89439
12	3.11032	0.07792	0.08787
13	3.36951	0.03913	5.43628
14	3.62870	0.01175	2.88475
15	3.88790	0.04255	5.98528
16	4.14709	0.00628	4.99486



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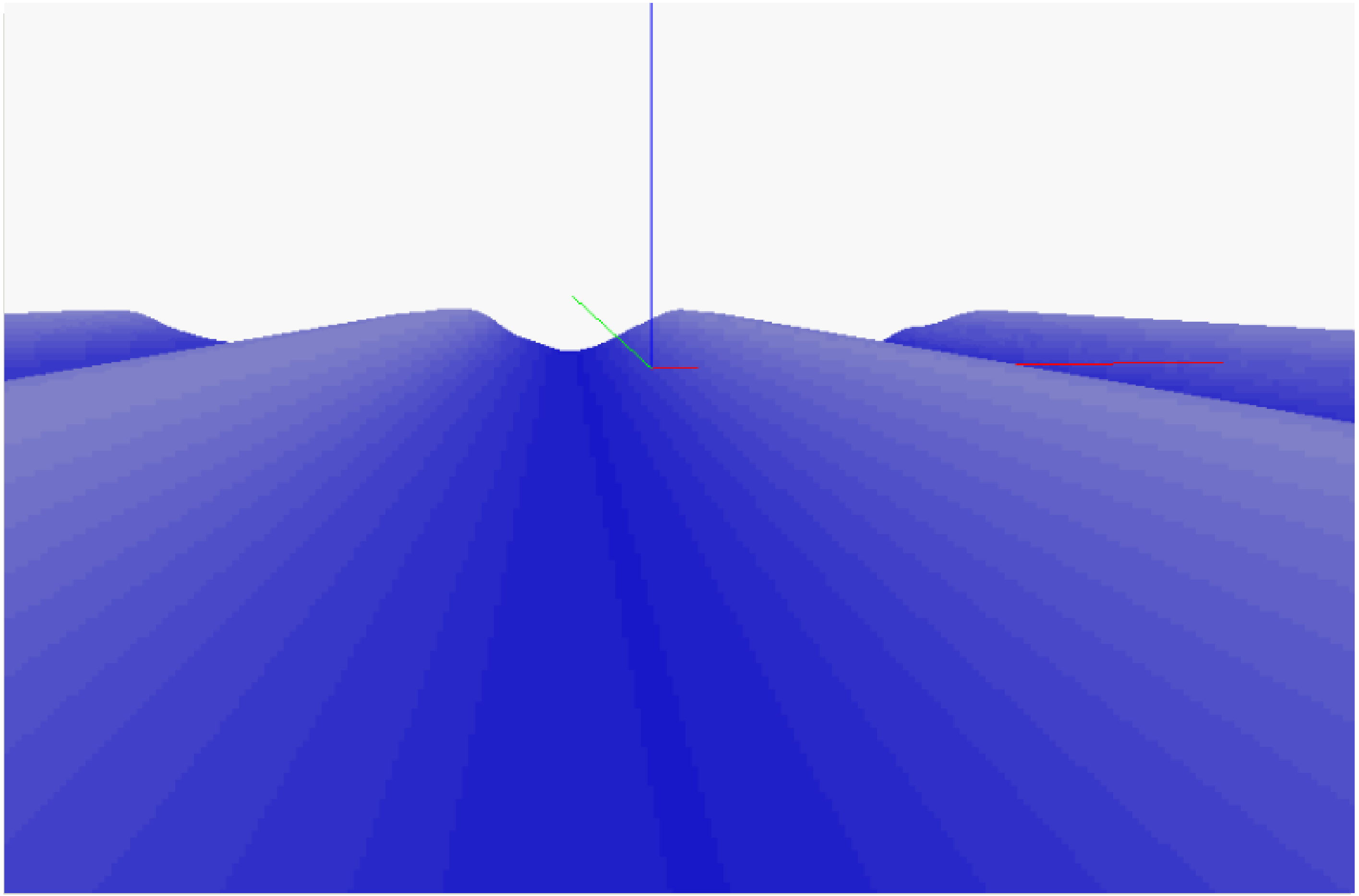
Modelling of irregular wave around vessel



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Equations of vessel motion

$$m[\dot{\mathbf{v}}_Q(t)+\mathbf{\Omega}(t)\times\mathbf{v}_Q(t)]=\mathbf{F}_W(t)+\mathbf{F}_D(t)+\mathbf{F}_R(t)+\mathbf{F}_T(t)+\mathbf{F}_A(t)+m\mathbf{D}_\Omega^{-1}\,\mathrm{G},$$

$$\dot{\mathbf{L}}(t)+\mathbf{\Omega}(t)\times\mathbf{L}(t)=\mathbf{M}_{QW}(t)+\mathbf{M}_{QD}(t)+\mathbf{M}_{QR}(t)+\mathbf{M}_{QT}(t)+\mathbf{M}_{QA}(t),$$

$$\dot{\mathbf{R}}_{UQ}(t)=\mathbf{v}_Q(t)-\mathbf{\Omega}(t)\times\mathbf{R}_{UQ}(t),$$

$$(\dot{\varphi}(t),\dot{\theta}(t),\dot{\psi}(t))^T=\mathbf{D}_\Omega^{-1}\mathbf{\Omega}(t)$$

The forces acting on the vessel can be split into:

- Froude – Krilov forces – $\mathbf{F}_W$;
- diffraction – $\mathbf{F}_D$;
- radiation forces – $\mathbf{F}_R$;
- rudder forces – $\mathbf{F}_T$;
- **forces generated by water moving on deck - $\mathbf{F}_A$;**
- others.

Equations of vessel motion

The *Froude-Krylov forces* are obtained by integrating the pressure caused by irregular waves, undisturbed by the presence of the ship, over the actual wetted ship surface.

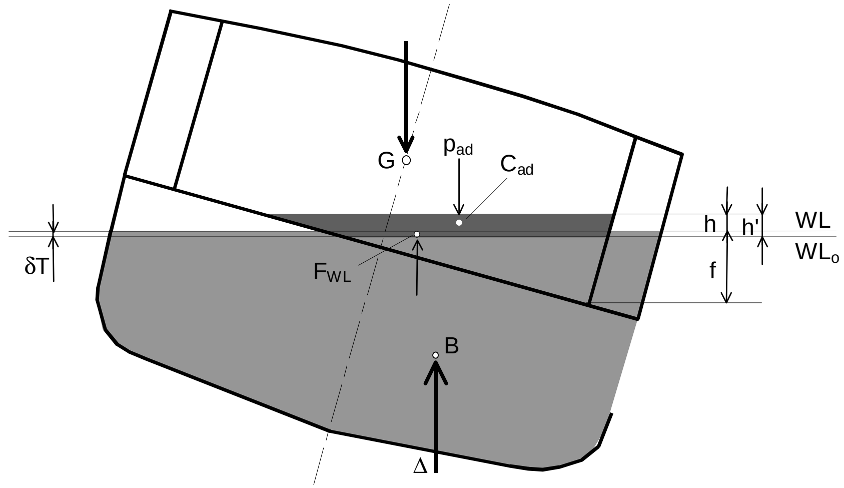
The *diffraction forces* are determined as a superposition of diffraction forces caused by the harmonic components of the irregular wave. It is assumed that the vessel is in its mean position.

The *radiation forces* are determined by added masses for infinite frequency and by the so-called memory functions given in the form of convolution.

The *forces caused by water trapped on deck* are obtained by integrating the pressure generated by moving water in relation to deck.

Forces generated by water flow on deck of damaged vessel – simplified method

To determine forces generated by water moving on the deck of a damaged vessel (e.g. after collision), a simplified model is used.



Water which flows in and out of the ship in time through the damaged hole is assumed to have a free surface in form of a horizontal plane.

Pressure generated by moving water on deck of damaged vessel – simplified method

The position of water trapped on deck is determined by the actual position of the vessel deck and the water free surface in the given time instant.

The pressure generated on deck is described by the following formula:

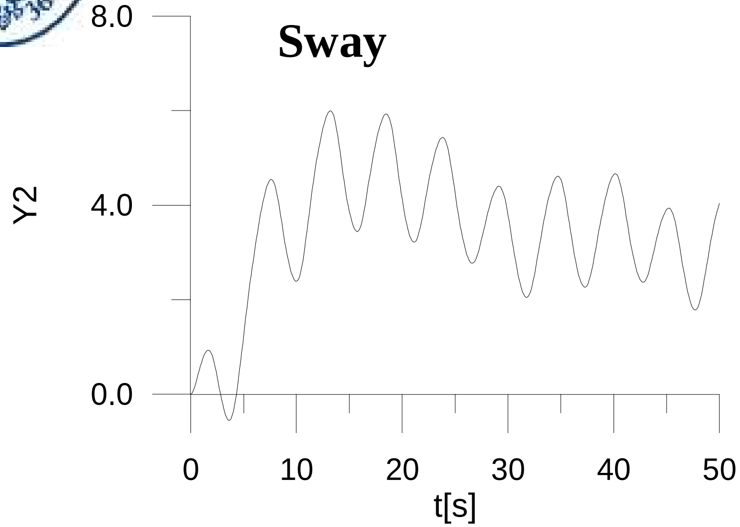
$$p_d = \rho \frac{dh}{dt} v_V + \rho (g + a_V) h$$

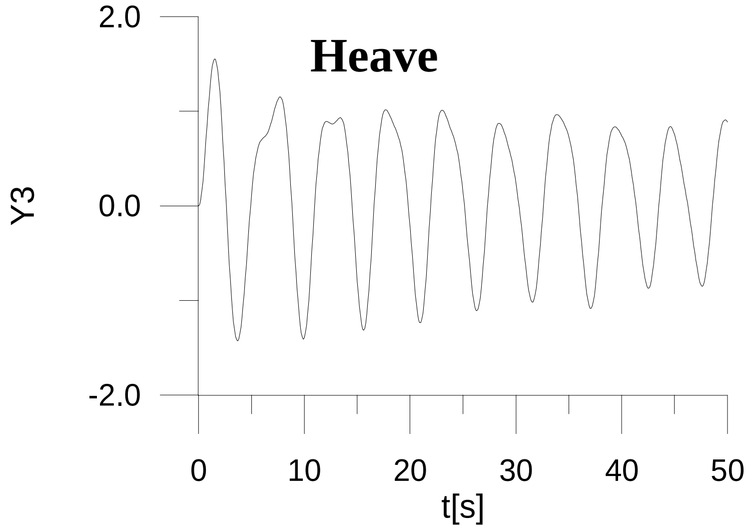
h – vertical distance from free surface to the point of the deck,

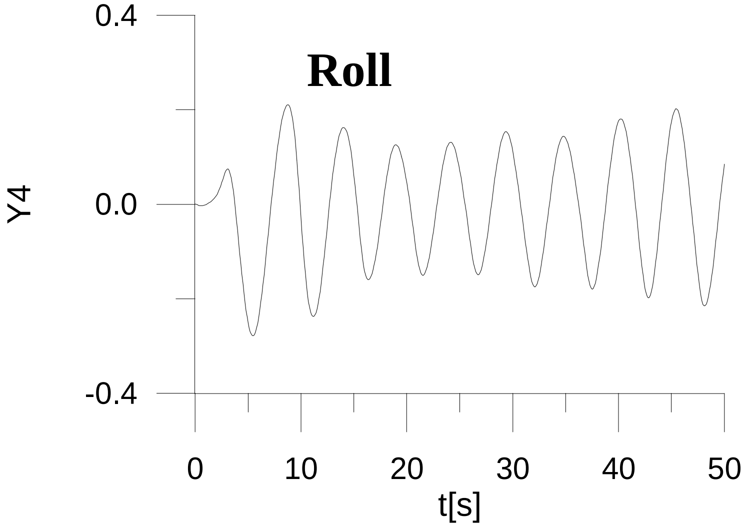
v_V – water velocity field,

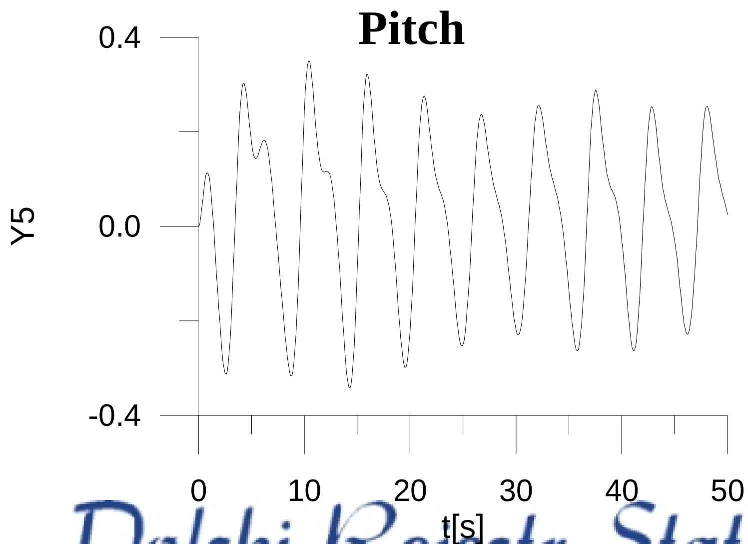
a_V – water acceleration caused by ship's motion.

Ship’s motion in irregular waves
Time history









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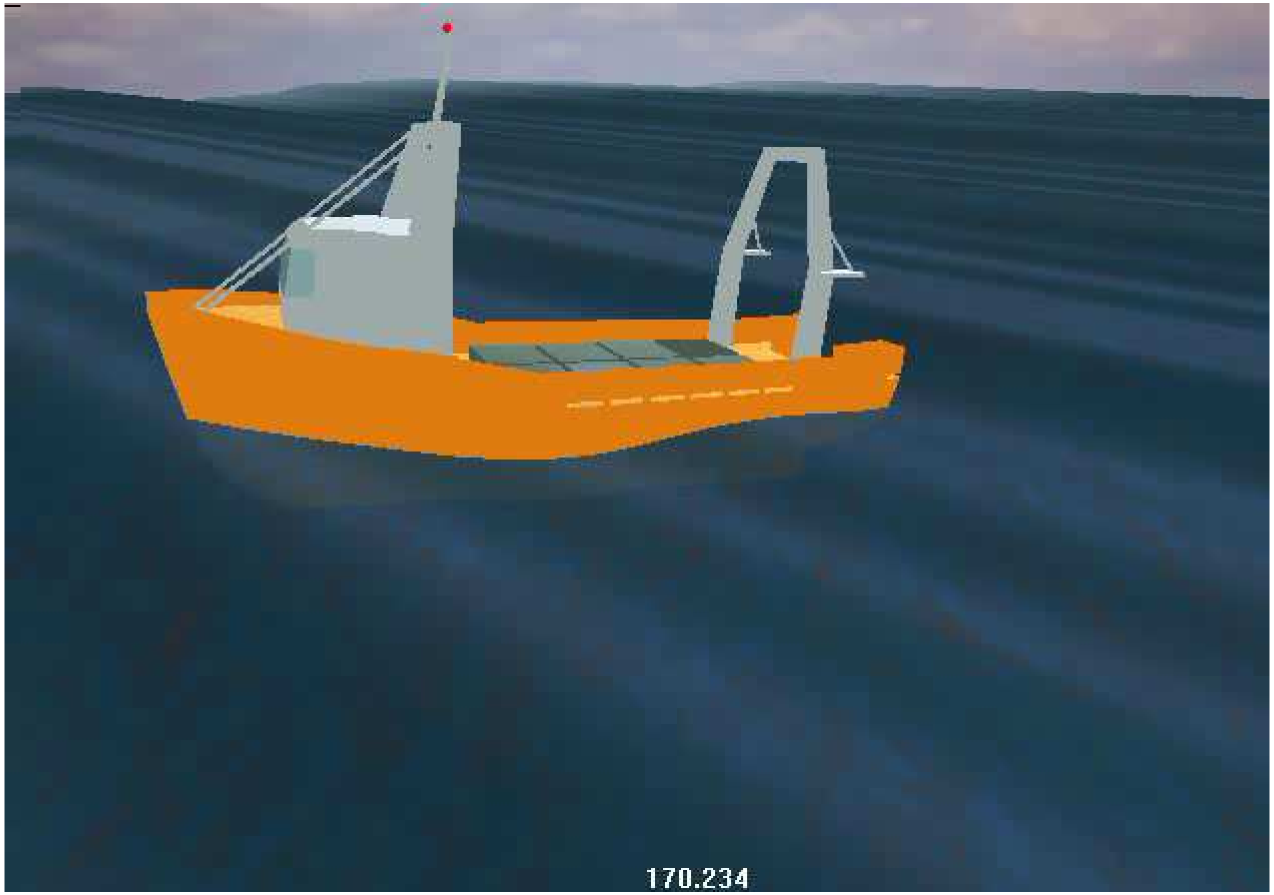
Simulation of fishing vessel

A.Laskowski, J.Jankowski 2006



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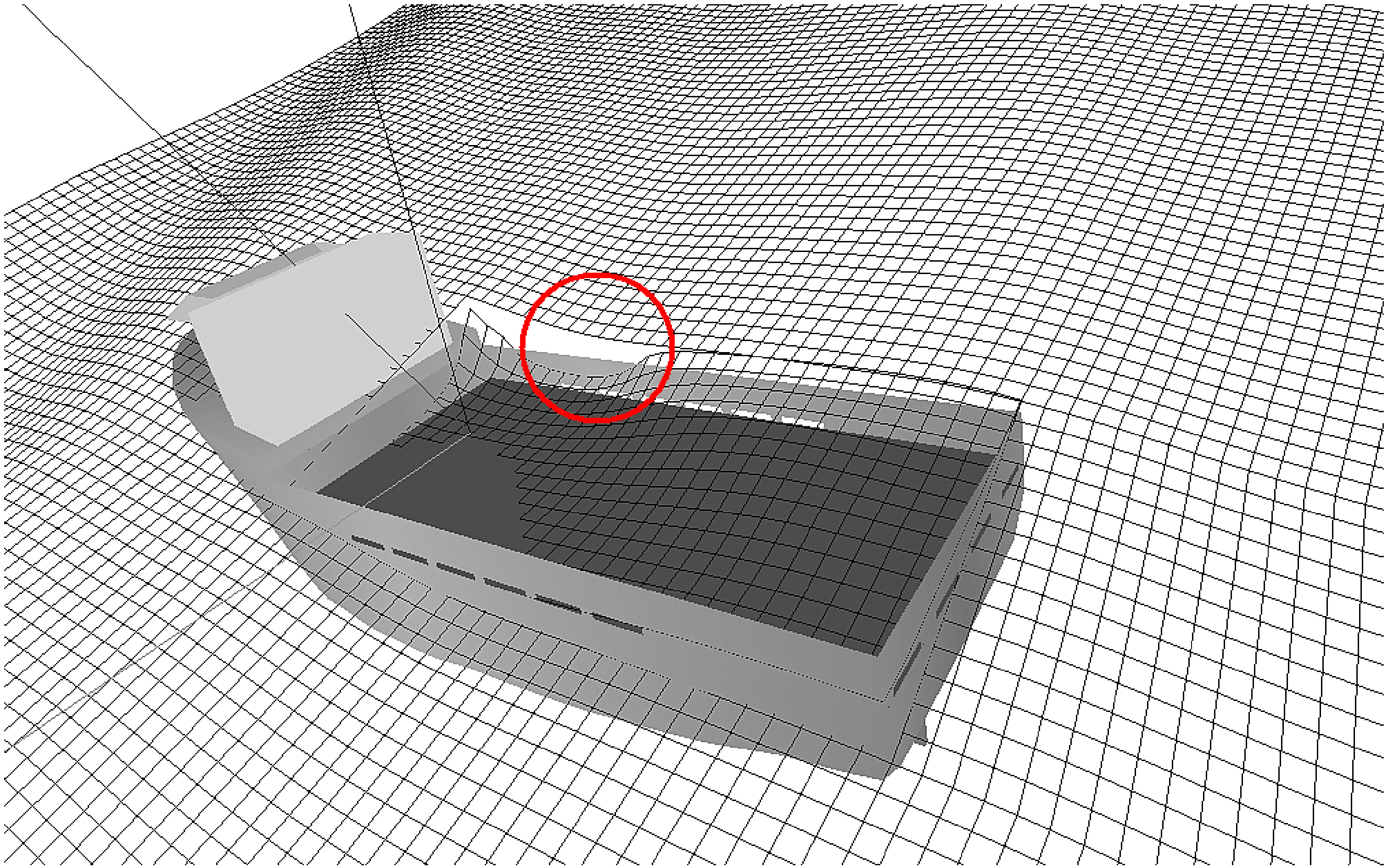
Problem of water moving on deck of smaller vessel

The phenomenon can be divided into the following stages:

- inflow of water over upper edge of bulwark,
- flow of sea water over the submerged vessel deck,
- dynamic water motion on deck, and
- inflow and outflow of water from deck through openings in the bulwark.

Boundary conditions
Flow over bulwark



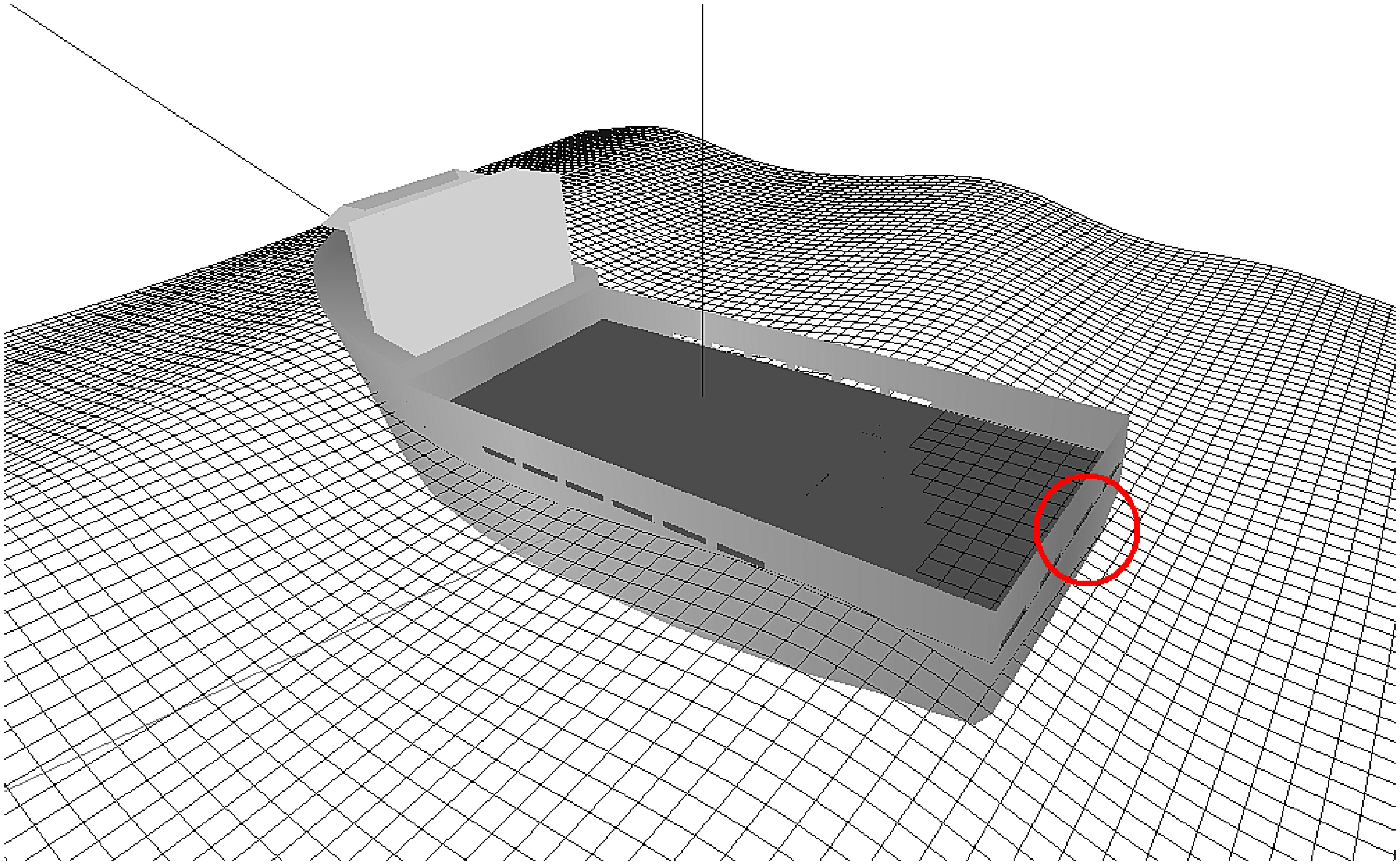
Boundary conditions
Water ingress on ship deck

It is assumed that the flow rate of water volume over the bulwark can be approximated by the flow over a weir. The general formula for the flow rate is:

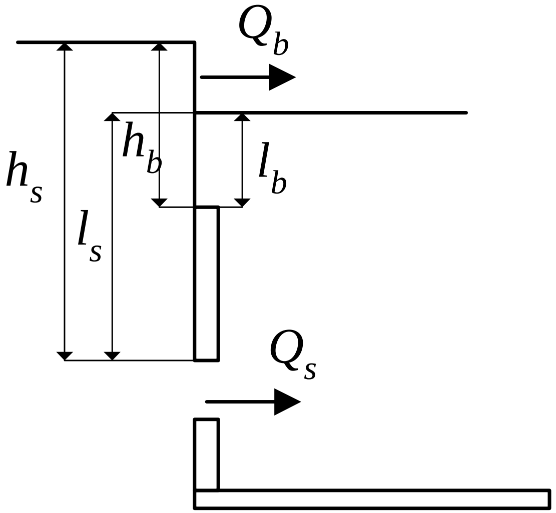
$$q = (signH)cb\sqrt{2g}\left(\frac{2}{3}|H|^{\frac{3}{2}} + d|H|^{\frac{1}{2}}\right)$$

where
q – the changes of water's mass on deck,
c – the correction coefficient for non-stationary flow,
b – the width of the orifice or the fragment of bulwark above which the deck is flooded,
H – the vertical distance between the wave profile and the free surface on the deck,
d –the instantaneous elevation of wave profile above the deck edge.

Boundary conditions
Flow through openings



Boundary conditions
Flow trough openings of bulwark



Flow *through the openings of bulwark* depends on the pressure difference across it:

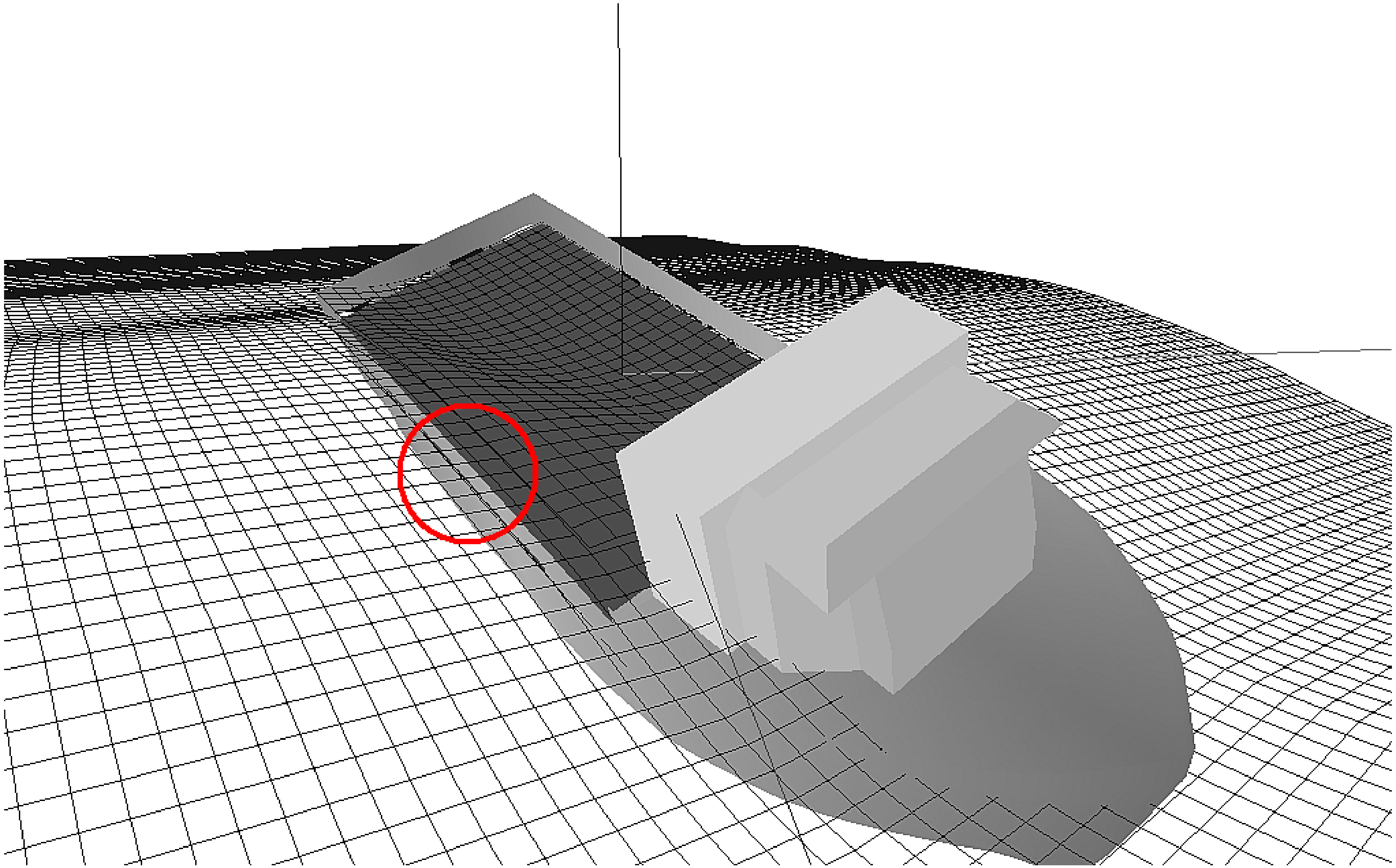
$$Q_S = sign(h_s - l_s) C_S A_S \sqrt{2g(h_s - l_s)}$$

$$C_S = 0.6$$

$(h_s - l_s)$ – the vertical distance between the wave profile and the free surface on the deck,

A_s – the area of the opening.

Boundary conditions
Deck submerged in water

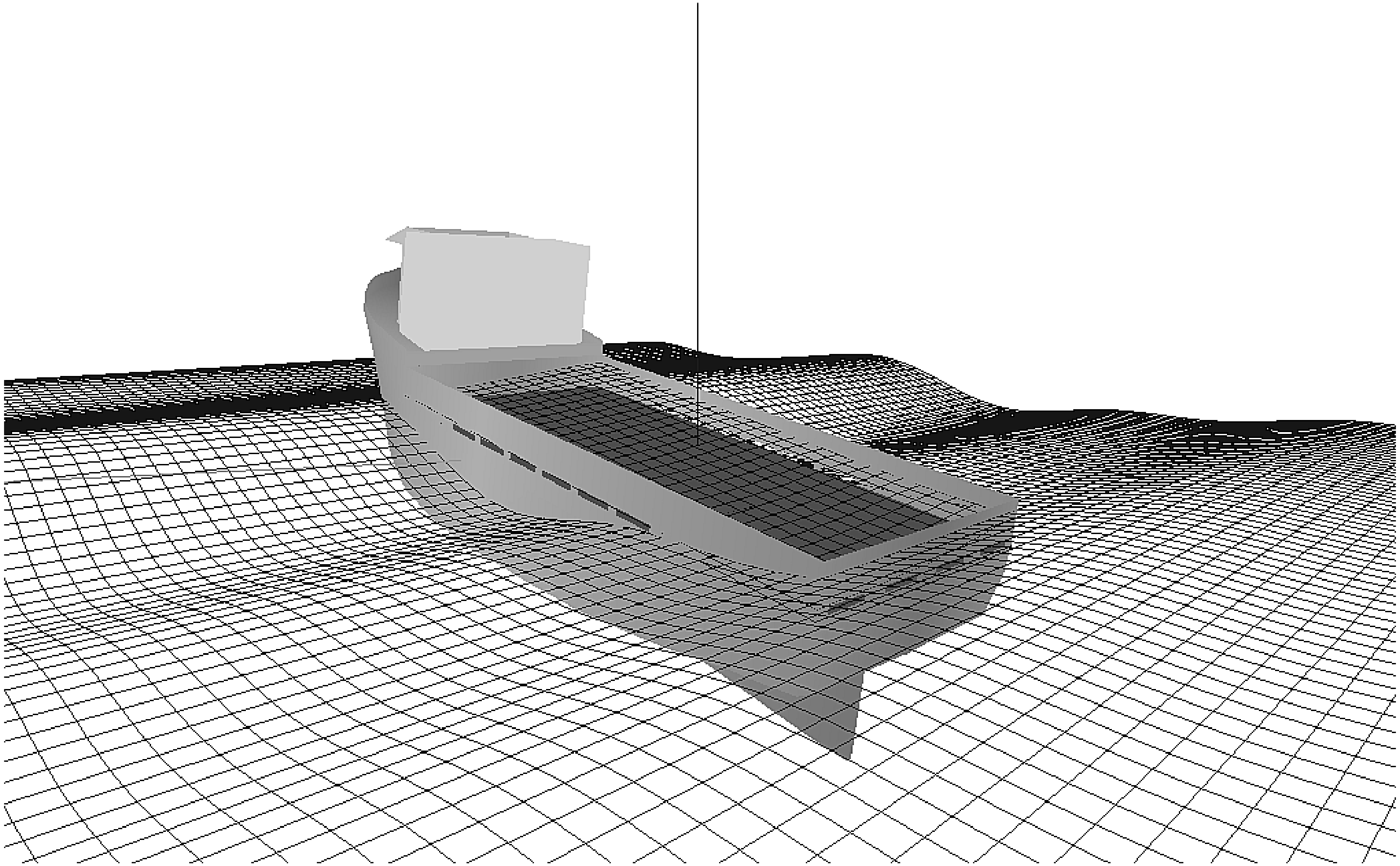


Boundary conditions
Flow trough openings of bulwark

It is assumed that the velocity field around the ship is the velocity of the undisturbed ocean wave.

In the case of the deck submerged in the wave, the water particle velocity over the deck is calculated taking into account the velocity around the ship.

Water moving on deck



Model of water moving on deck
Shallow water problem

Assumptions:

– There are small changes of vertical velocity u_z in time;

– Horizontal velocities u_x and u_y **do not** depend on the vertical coordinate z.

Algorithm

The shallow water problem is solved in four steps, determining:

1. domain Ω occupied by water**,**
2. pressure field,
3. horizontal velocities u_x , u_y,
4. vertical velocity u_z**.**

Shallow water problem - algorithm

1. The elevation of the free surface S_F is described by the following equations:

$$\left(\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt}\right) = \left(u_x, u_y, u_z\right) \quad (x, y, z) \in S_F.$$

2. The pressure p_d caused by water on deck depends on inertial forces f_z and height h of water elevation over the point (x,y,z_d):

$$p_d(t, x,y,z_d) \cong p_a + \rho \int_{z_d + h(t,x,y,z_d)}^{z_d} f_z(t, x,y,s)ds, \quad (x(t),y(t),z_d(t)) \in \Omega(t).$$

3. The horizontal components of water particles velocity are obtained from Euler equations.
4. The vertical component u_z of velocity **u** is obtained from the equation of mass conservation:

$$u_z(t, x(t), y(t), z(t)) = \left(-\frac{\partial u_x}{\partial x}(t, x(t), y(t)) - \frac{\partial u_y}{\partial y}(t, x(t), y(t)) + q\right)(z(t) - z_d(t))$$

where q represents the changes of water mass.

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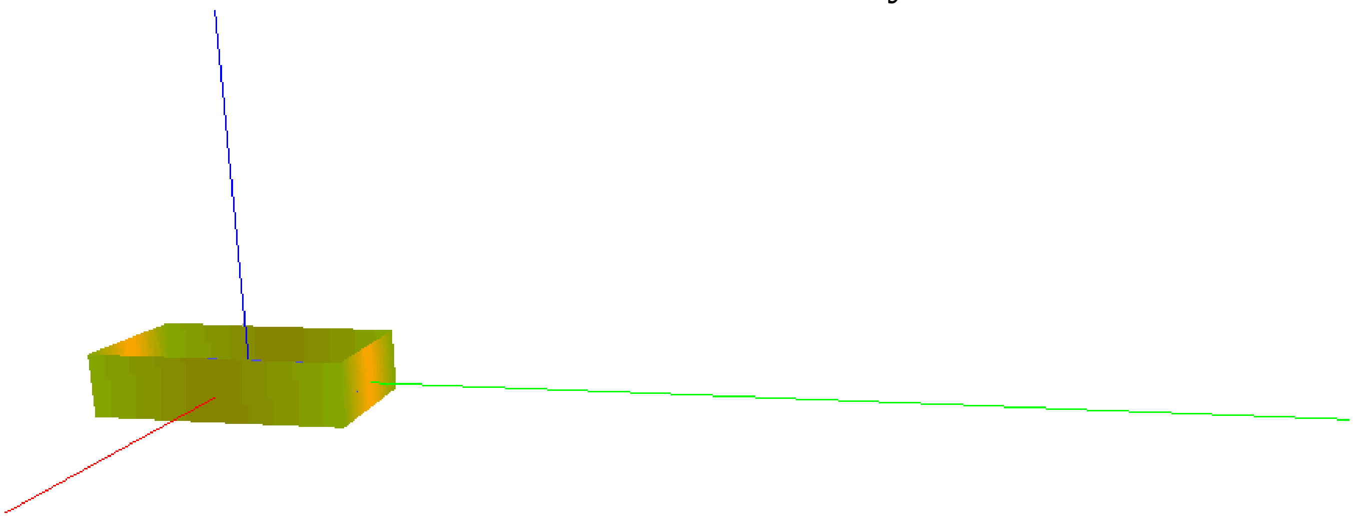
Validation of methods applied
Shallow water problem

Simulations of tank moving horizontally with constant acceleration a_x=1m/s^2

GLOBAL coordinate system

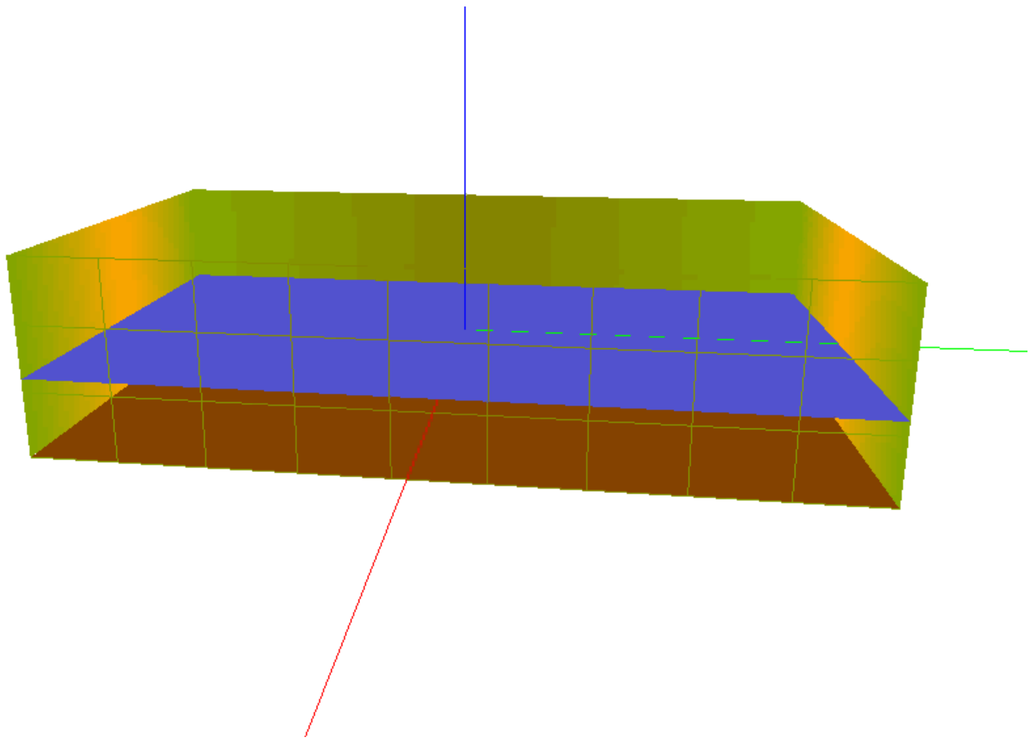


The free surface is going to incline at the angle $\alpha = -5{,}82°$ ($tg(\alpha) = -1/9{,}81$).

Validation of methods applied
Tank moving horizontally

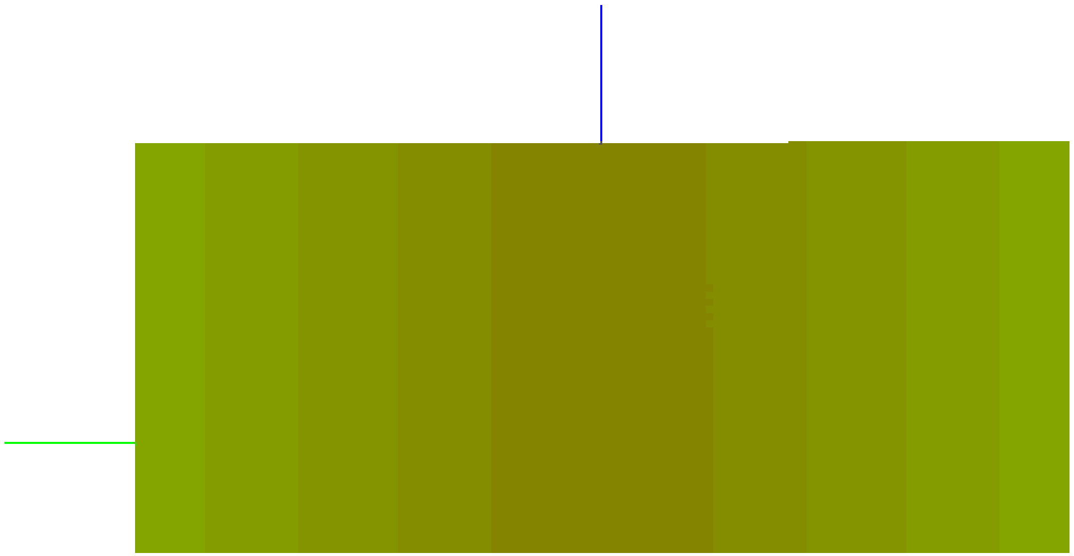
Simulations of tank moving horizontally with constant acceleration a_x=1m/s^2

LOCAL coordinate system



Validation of methods applied
Simulation of constant water mass motion on deck

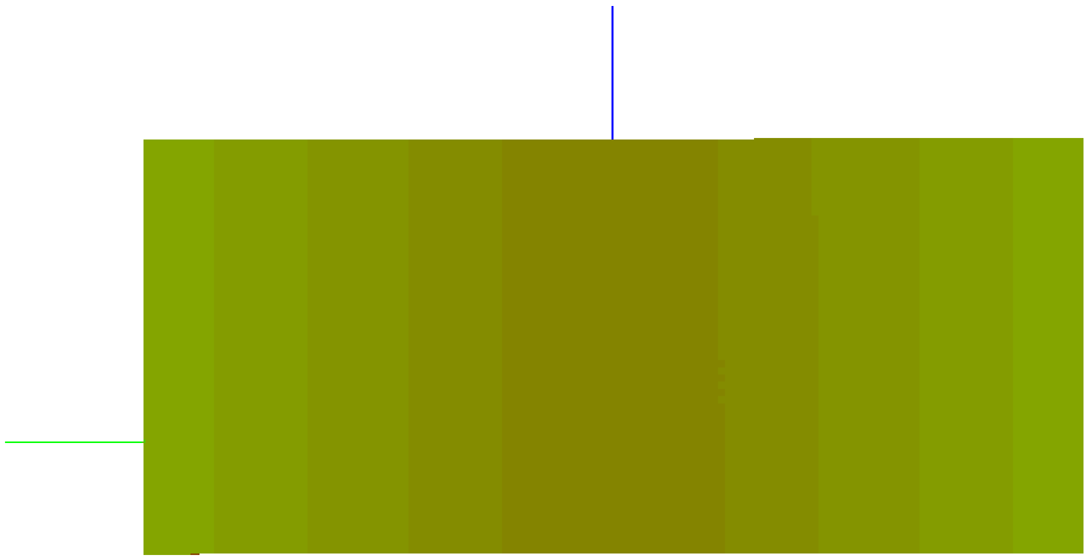
Simulations of water motion in tank for various rolling frequencies



The frequency of tank motion is equal to one and half of first natural frequency, the bore can be clearly observed.

Validation of methods applied
Simulation of constant water mass motion on deck

Simulations of water motion in tank for various rolling frequencies



The frequency is equal to second natural frequency, the wave is a superposition of two waves: coming and reflected.

Validation of methods applied
Simulation of constant water mass motion on deck

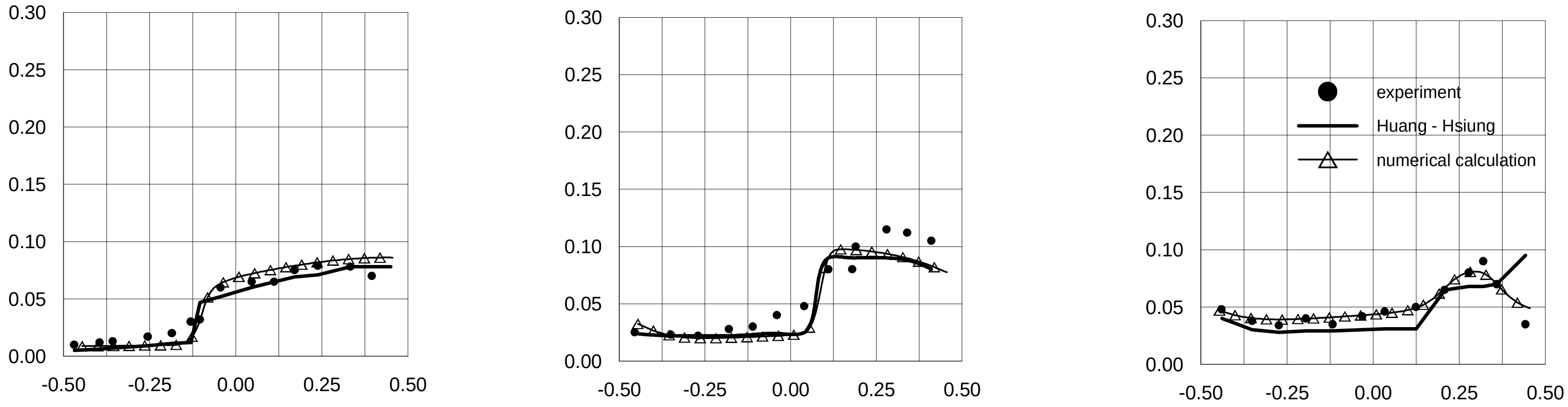
Simulations of water motion in tank for various rolling frequencies

The wave generated by coupled sway and pitch motion.

Validation of methods applied
Simulation of constant water mass motion on deck

Water motion on deck moving with a harmonic acceleration

Results were compared with:
– Numerical results obtained by Huang Z.-J. and Hsiung C. and
– Results measured by Adee and Caglayan during the experiment.

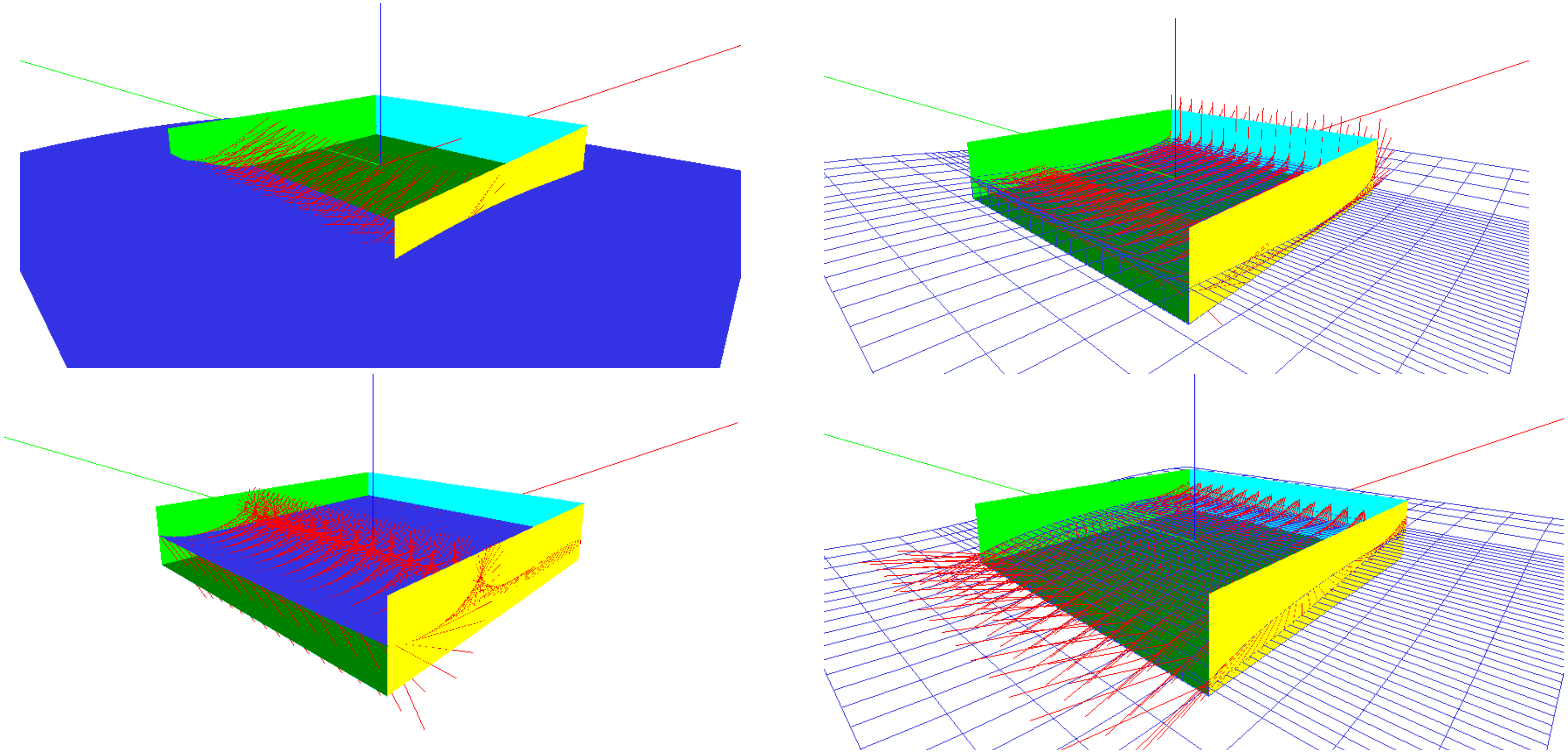


Validation of methods applied
Inflow and outflow of wave on deck at rest

The dimensions of the rectangular deck are: 20m x 20m x 4m.

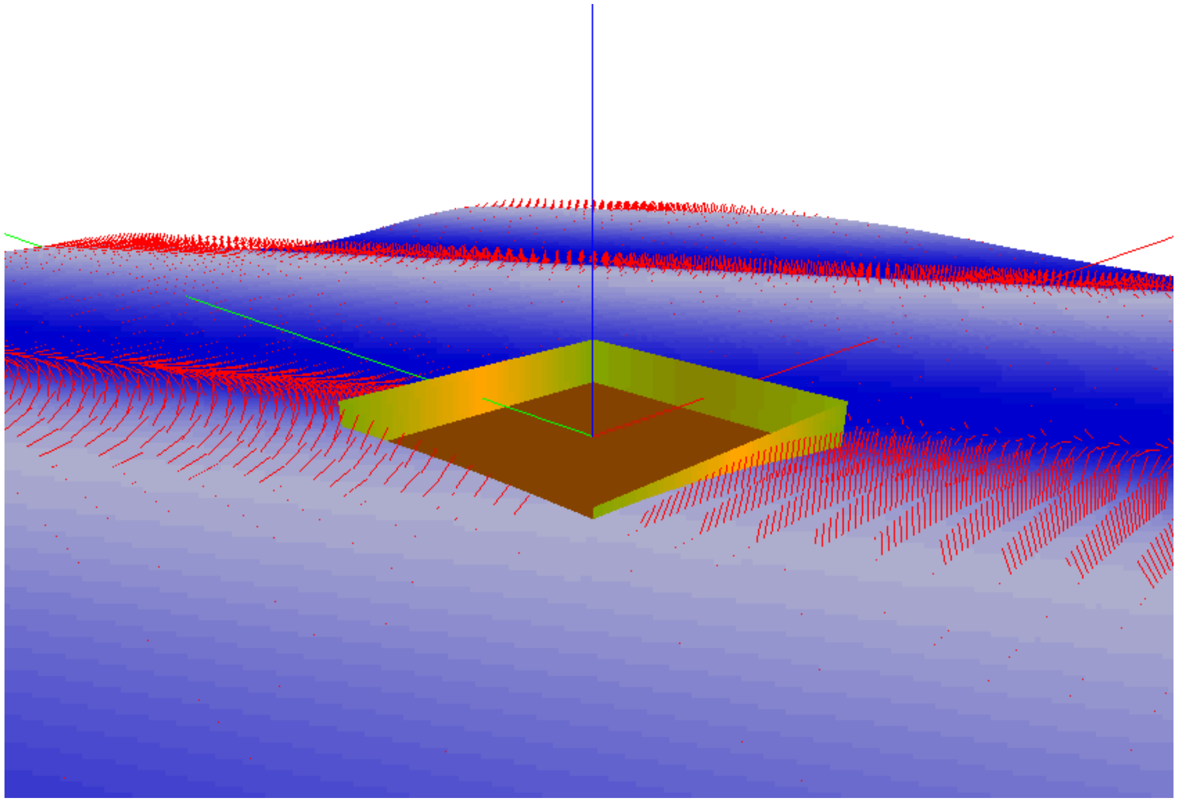
The deck is situated 1.3m below water line.

The sea wave is harmonic with amplitude A=1m and period T= 6s.



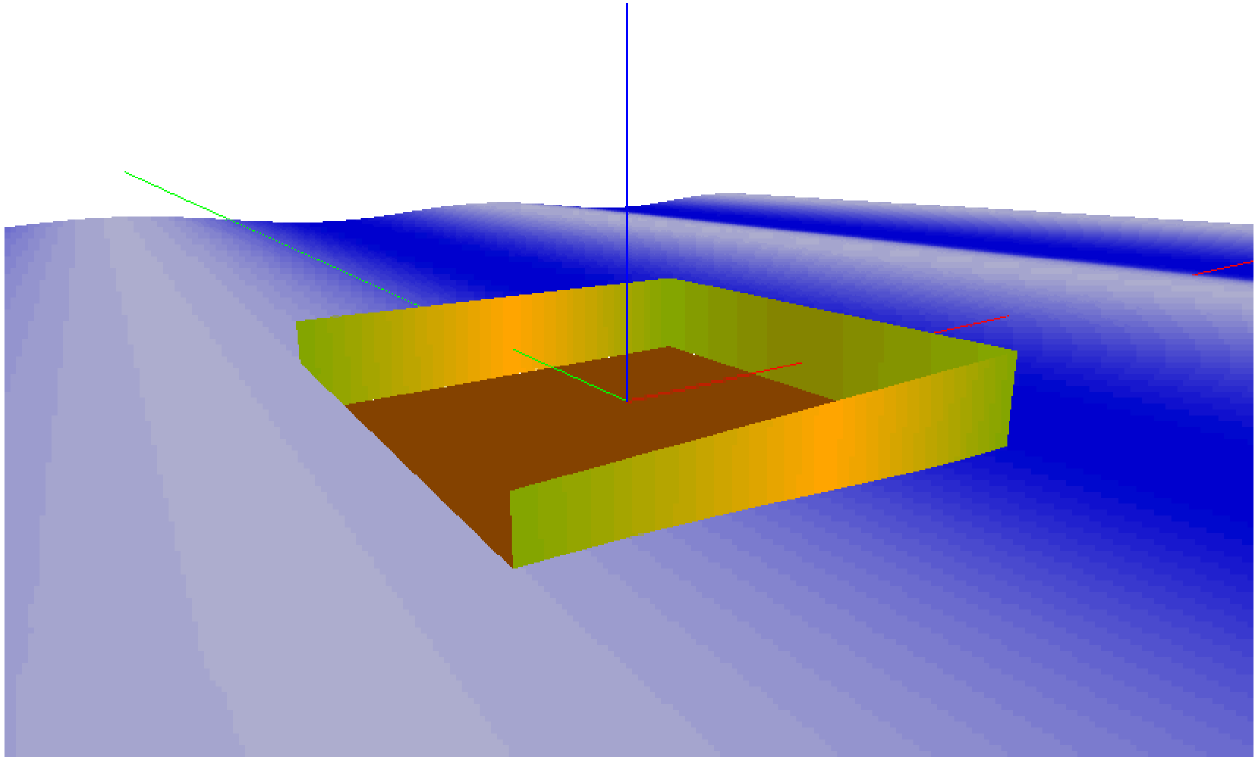
Validation of methods applied
Inflow and outflow of wave on deck at rest

The inflow of wave on the deck at rest is determined by the sea wave velocity field T_z=6s, H_s=4m, β= 30°.



Validation of methods applied
Inflow and outflow of wave on deck at rest

The inflow of wave on the deck at rest is determined by the sea wave velocity field T_z=6s, H_s=4m, β = 0°.



Simulation of water flow on moving vessel

A program simulating water flow on moving vessel's deck has been developing at Polish Register of Shipping.

The program is based on shallow water problem.

The vessel is moving on irregular wave.

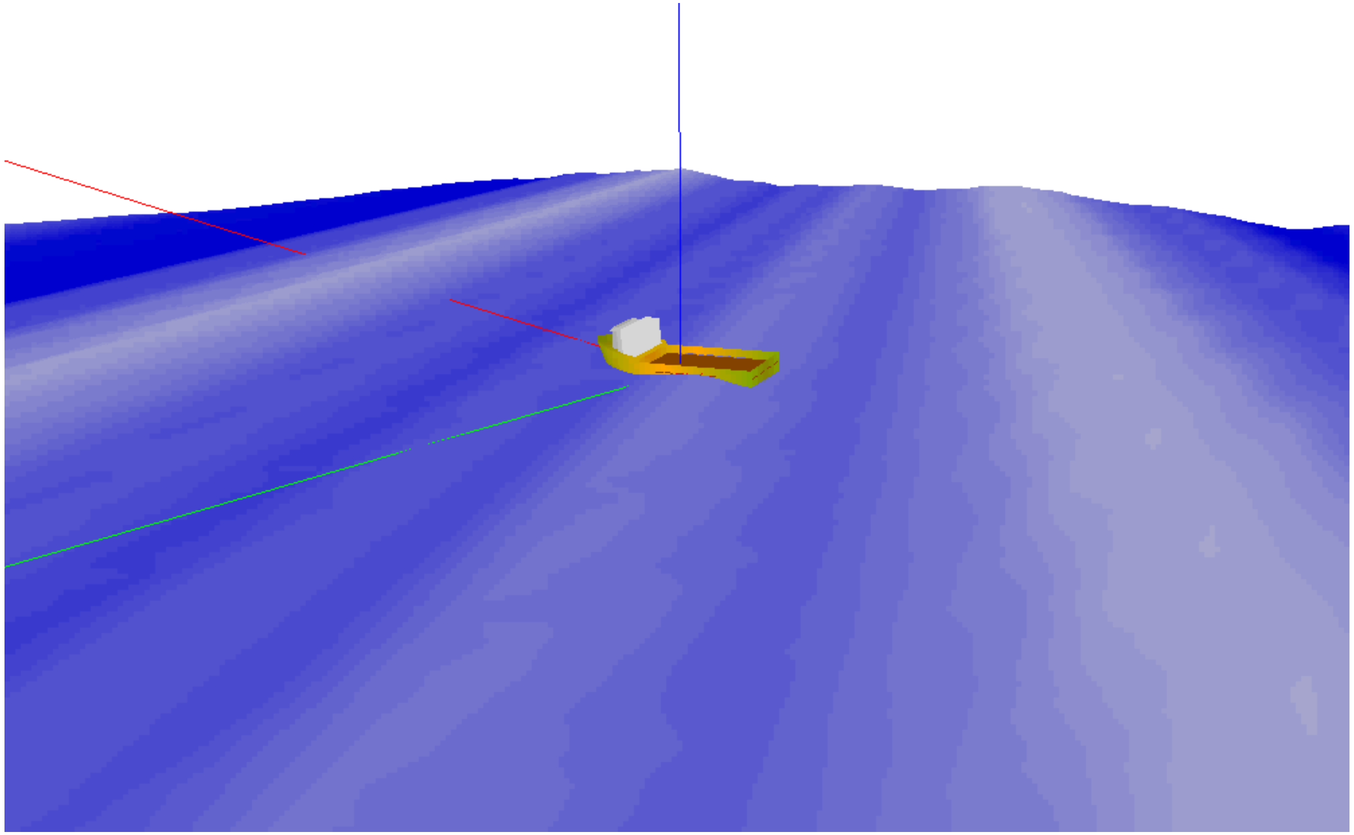
The mass of water over deck caused by flow over bulwark is changing.

The mass of water over deck caused by inflow (and outflow) through openings of the bulwark is taken into account.

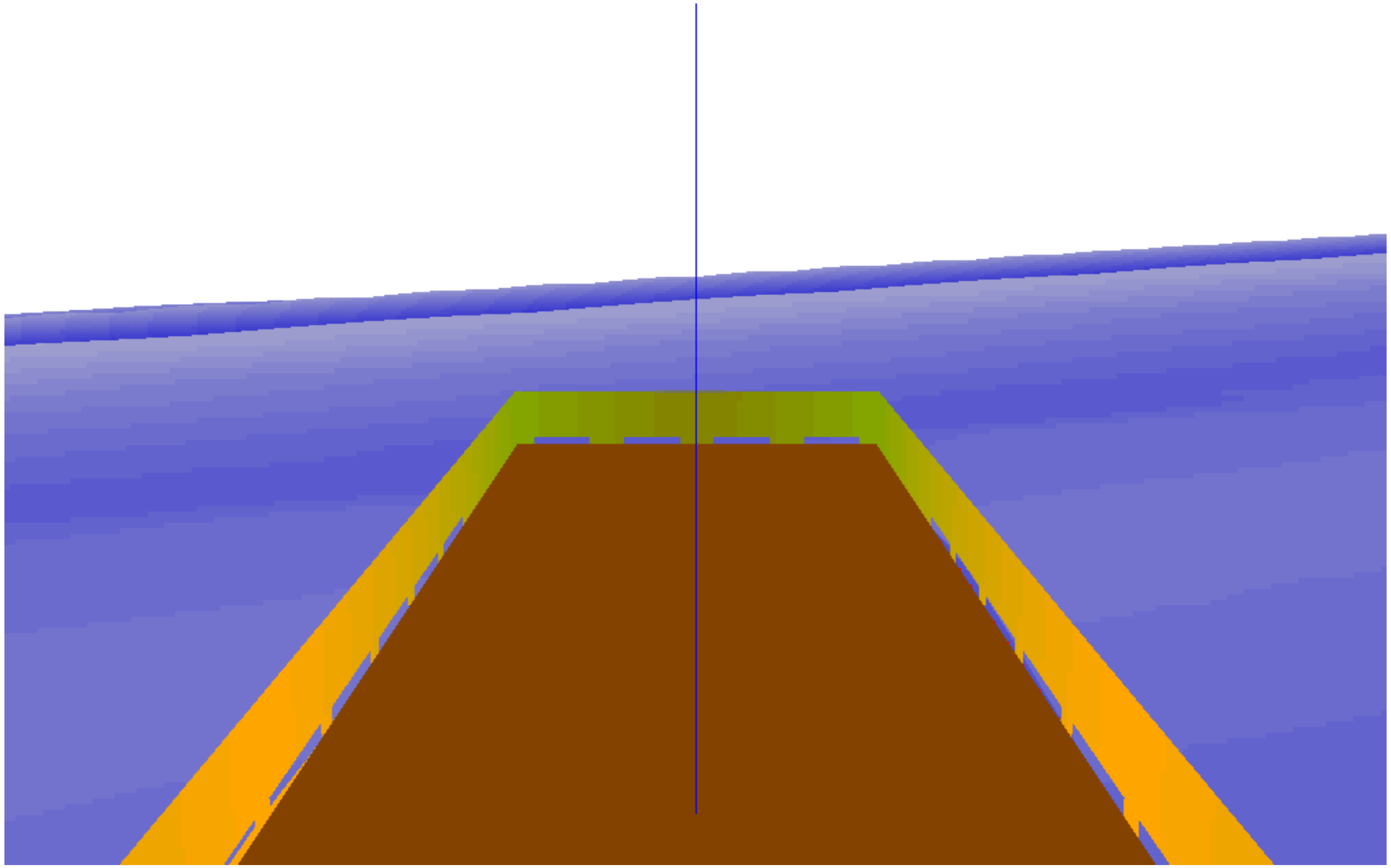
The sea water velocity influences the water velocity over the deck .

Program simulating motion of vessel in irregular wave

Simulation of water motion on deck of vessel moving in irregular waves (T_z=8s, H_s=6m, β=30°)

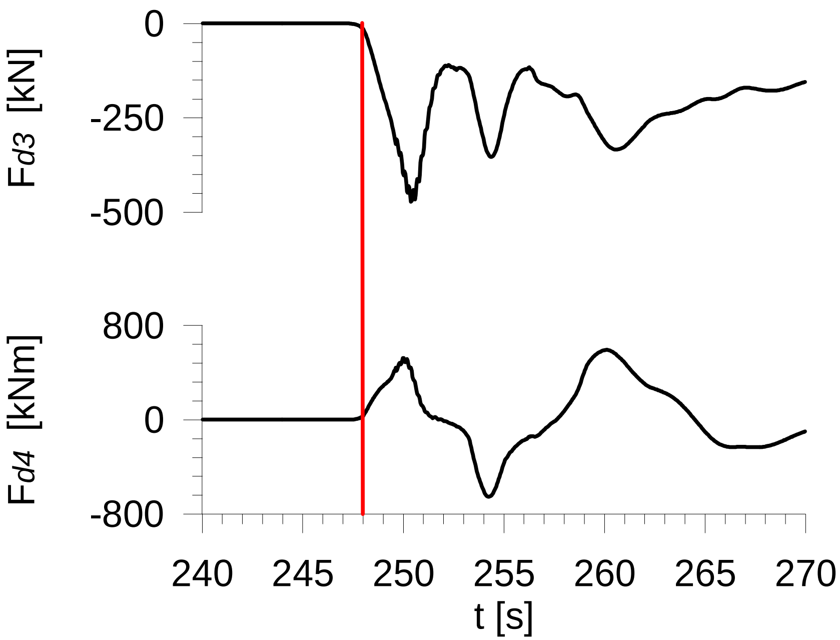


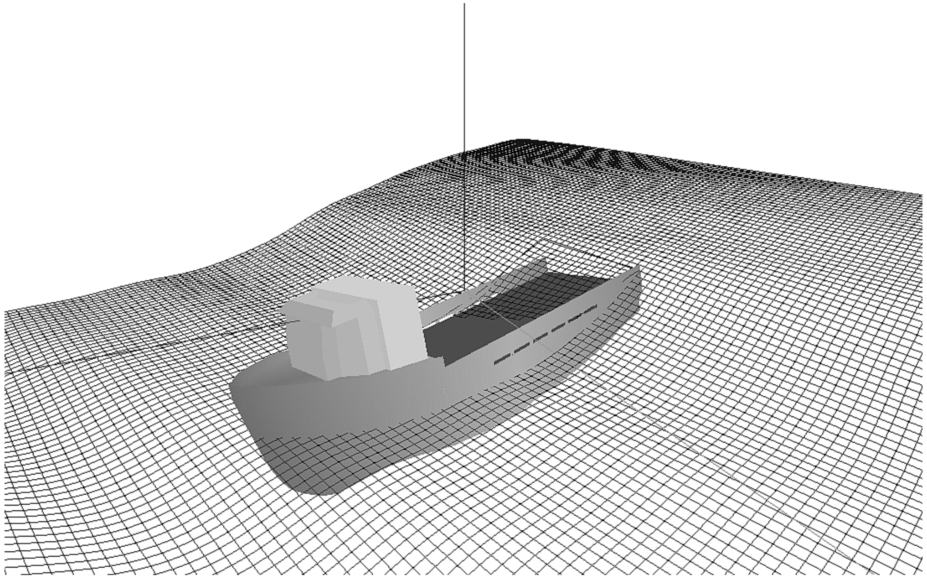
Program simulating motion of vessel in irregular wave



The same simulation displayed with reference system fixed to the ship

Forces and moments generated by water on deck

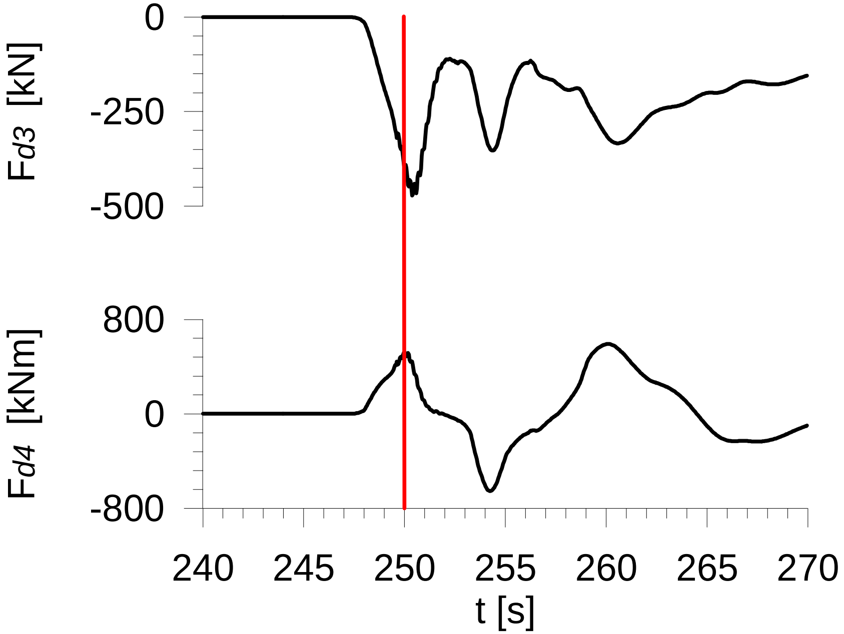


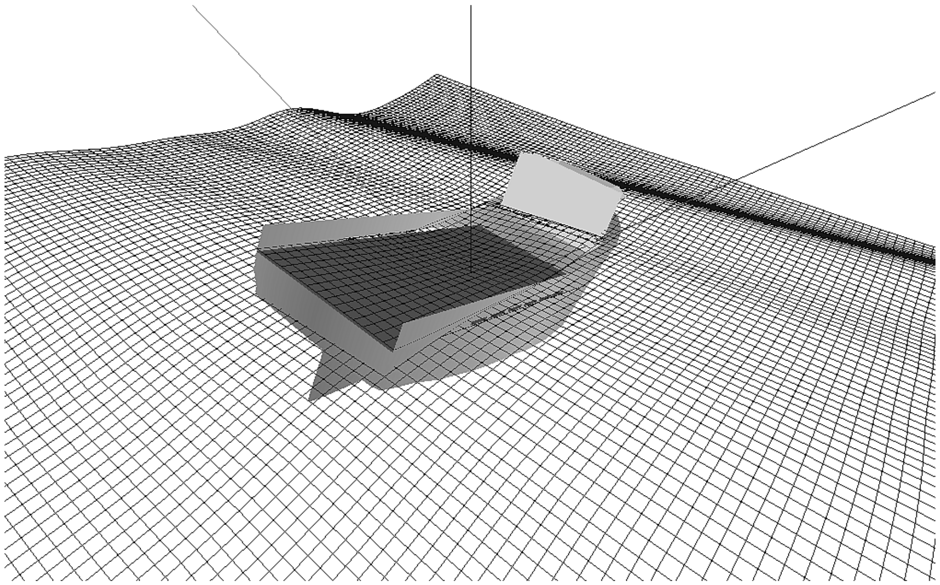


Inflow of wave water on deck, t=248s

The irregular wave: H_s=6m, T_z=8s, u=6m/s, β=30°

Forces and moments generated by water on deck

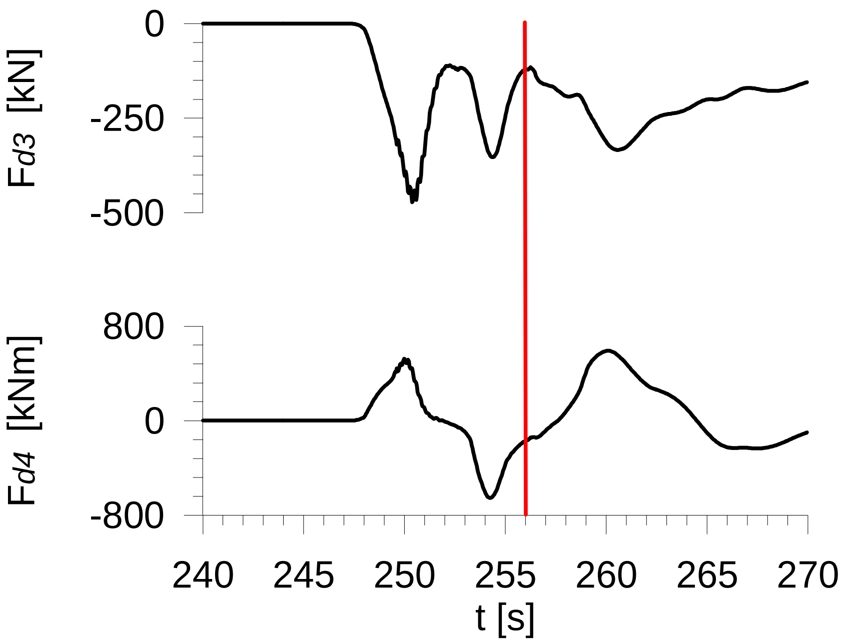


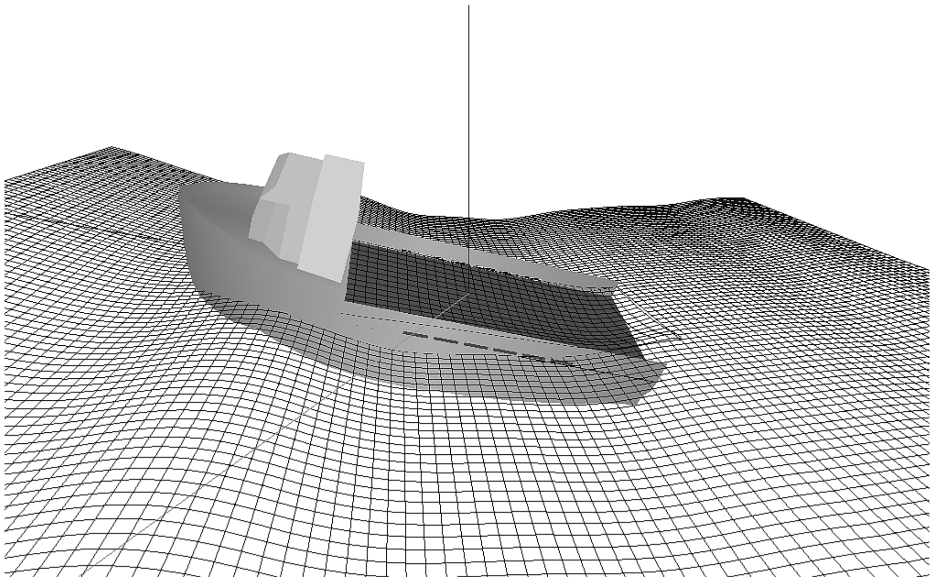


Water over the deck, *t*=250s

The irregular wave: H_s=6m, T_z=8s, u=6m/s, β=30°

Forces and moments generated by water on deck

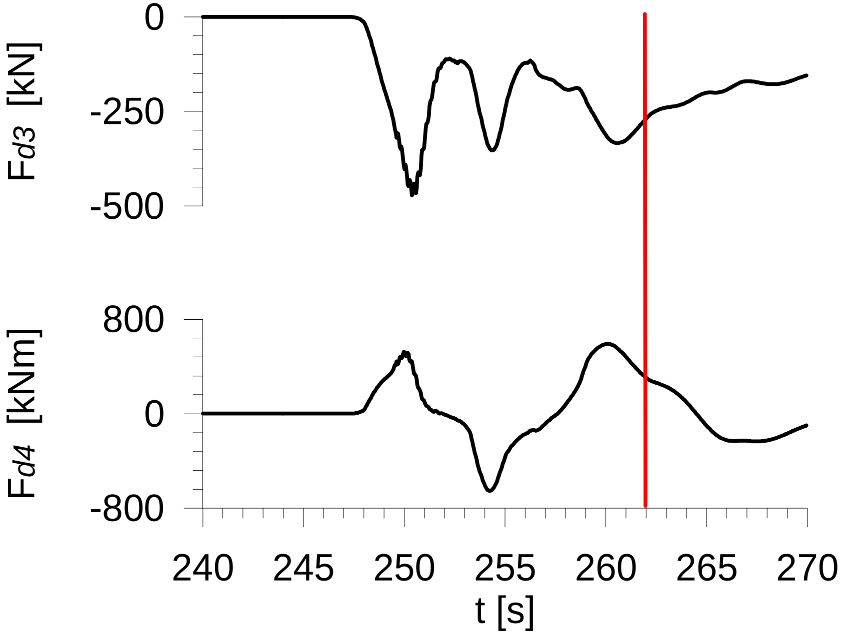


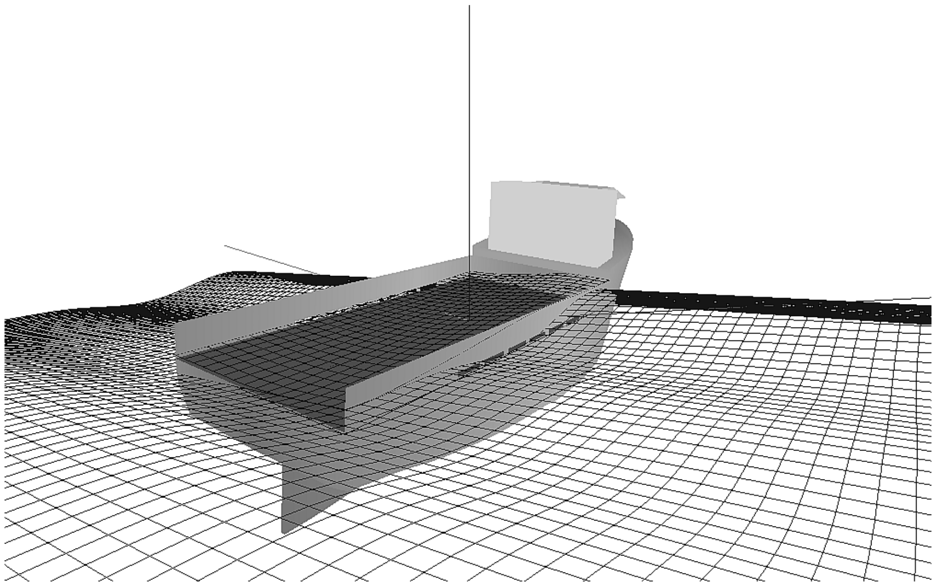


The relation between wave surface and water surface on deck at t=256s

The irregular wave: H_s=6m, T_z=8s, u=6m/s, β=30°

Forces and moments generated by water on deck





Outflow of water from deck, t=262s

The irregular wave: H_s=6m, T_z=8s, u=6m/s, β=30°

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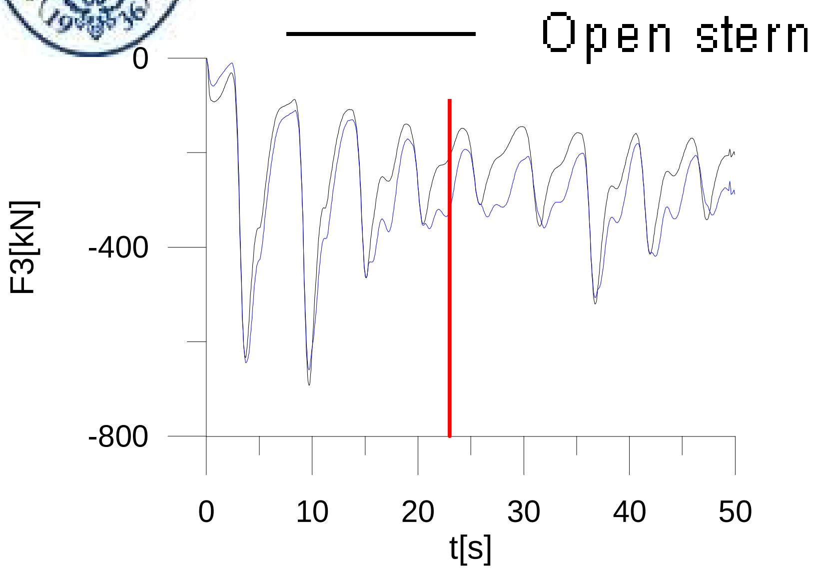
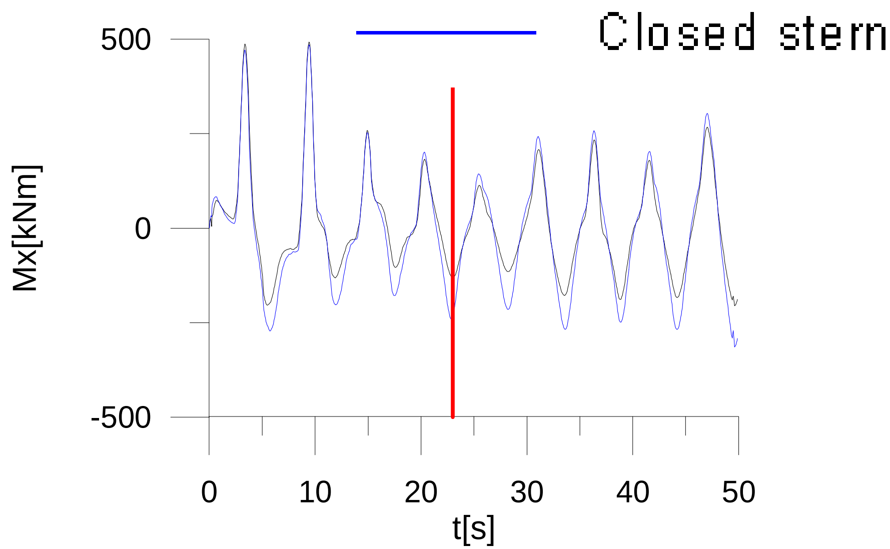
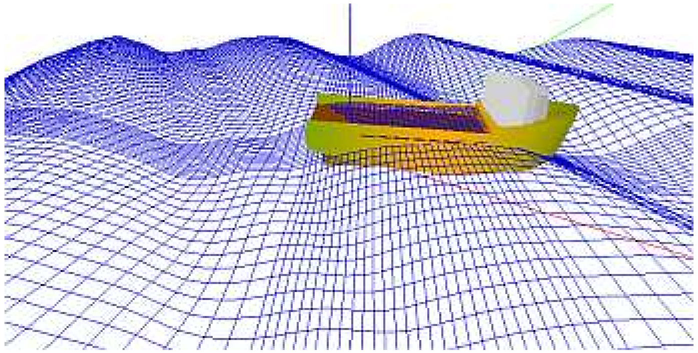
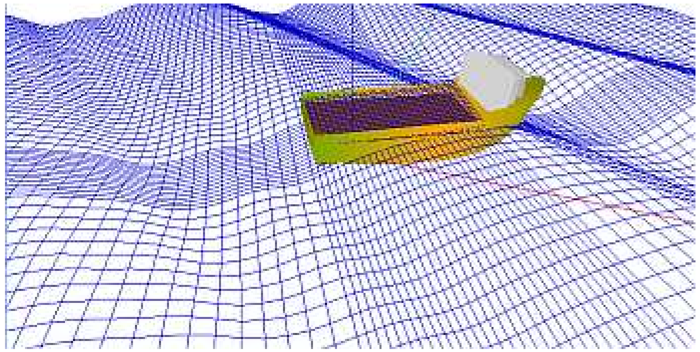
Simulation of water motion on deck









The irregular wave: H_s=6m, T_z=4s, u=0m/s, β=60°

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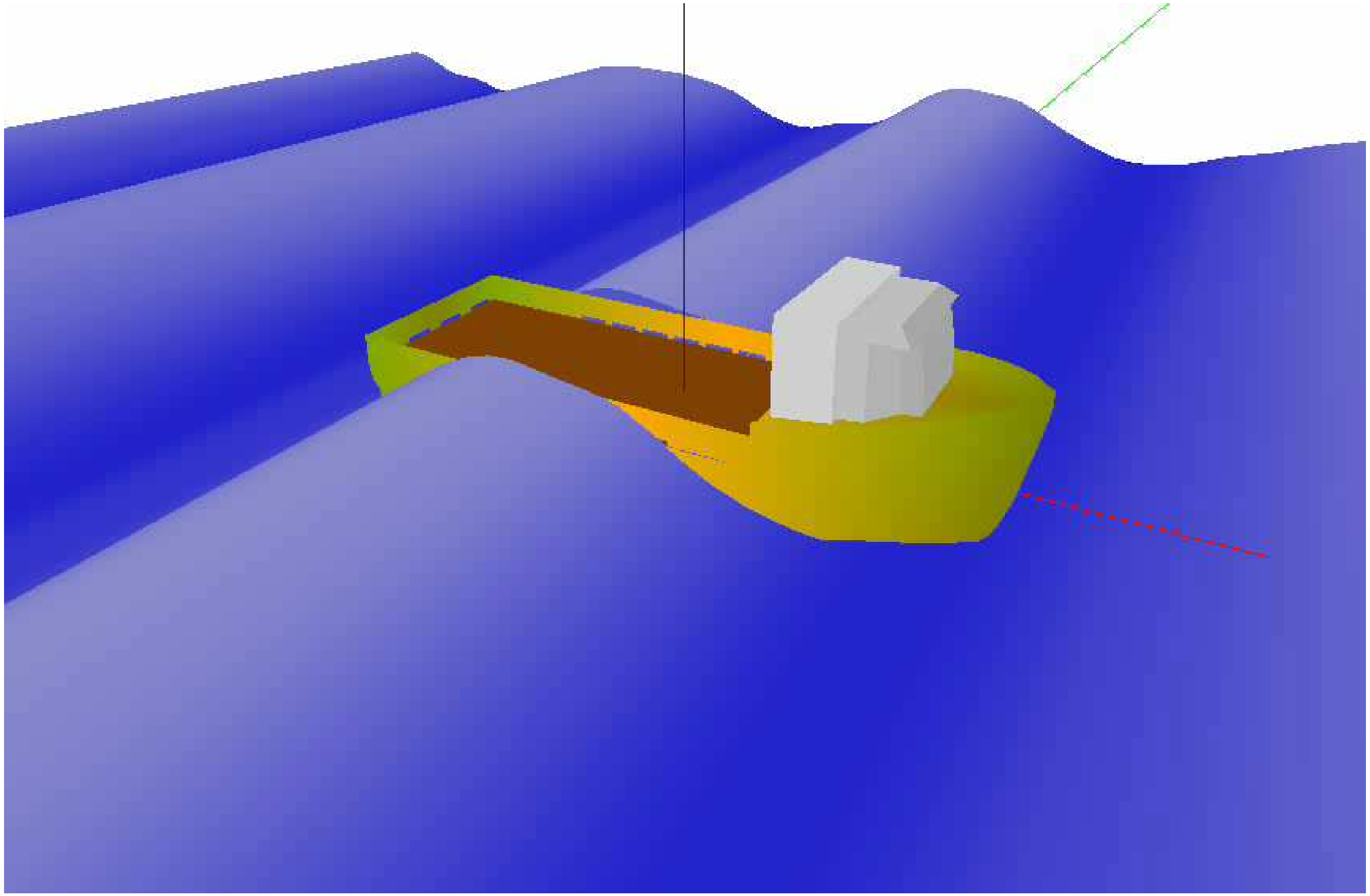
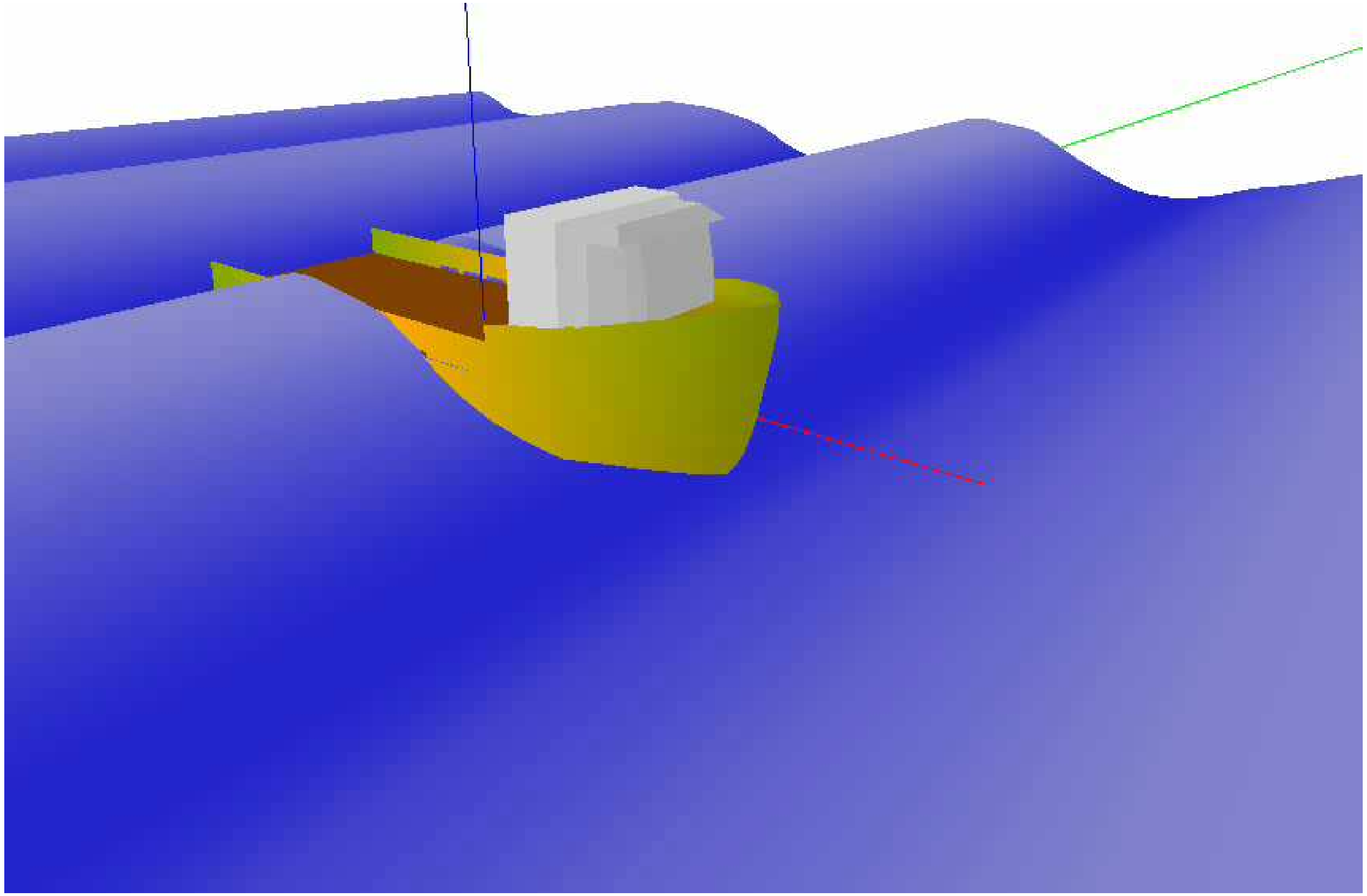
Simulation of closed stern vessel motion



The irregular wave: H_s=6m, T_z=4s, u=6m/s, β=0°

Simulation of open stern vessel motion



The irregular wave: H_s=6m, T_z=4s, u=6m/s, β=0°

Conclusions

Models of vessel’s motion should be improvement.

The next steps:

- accounting for diffraction of the free surface shape,
- accounting for the influence of velocity field in water on deck on velocity field in water around the vessel,
- performing model tests to verify the mathematical models and software,
- performing systematic numerical simulations to identify the essential elements affecting the vessel’s dynamic stability such as the extreme waves for a given vessel.

Simulation of fishing vessel

A.Laskowski, J.Jankowski 2006