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DYNAMIC FORCES AND LIMITING SEA STATES FOR INSTALLATION OF GRP PROTECTION COVERS

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ABSTRACT

This paper describes a study aimed at finding and demonstrating a feasible method to reduce the uncertainties in calculation of dynamic forces and limiting sea states for installation of protection covers produced from glass fiber reinforced polyester (GRP). Uncertainties arise in the choice of hydrodynamic coefficients and the applied analysis method e.g. the Simplified Method, as suggested in DNV-OS-H206, versus time-domain simulations. The maximum limiting sea state for water entry and lowering through the splash zone has been assessed stepwise by use of alternative methods. Firstly, the hydrodynamic force coefficients for a fully submerged, selected GRP cover were estimated manually, by use of simplified data in DNVGL-"Recommended practice for modelling and analysis of marine operations", DNVGL-RP-H103. The estimated hydrodynamic added mass was compared with the potential theory solution obtained by use of WAMIT. WAMIT calculations are also performed to obtain added mass and potential damping for the cover with different draughts at the selected installation angle. Viscous damping and added mass will be dependent on amplitude of oscillation and is studied by CFD simulations. A fully submerged cover is oscillated harmonically with different amplitudes at a selected period. The obtained added mass and damping coefficients were used in a numerical model including installation ship, lifting gear and GRP cover, in the non-linear time domain simulation program SIMO. The lowering through the splash zone were finally performed in some selected wave conditions to illustrate how a realistic limiting sea-state for the lowering through the splash zone may be estimated.

INTRODUCTION

GRP has its advantages as material for protection of subsea units for production of oil and gas (durable, high impact absorption capacity, low weight). However, the installation of GRP protection covers is particularly weather sensitive due to the low weight and large area. Hydrodynamic forces can exceed the submerged weight even in low sea states, resulting in slack lifting wires followed by hard snatch loads. In order to increase the limiting wave height, in which the risk for snatch loads is acceptably low, the weight of the covers is often increased by attachment of steel blocks. In addition the covers are often lowered through the wave zone at a steep angle. During wet-storing, retrieval and final installation the cover can be handled in horizontal position by use of an active heave compensated crane minimizing the vertical motion and thus the vertical dynamic forces.

This paper focus on finding hydrodynamic coefficients for a representative GRP cover and applying them in a time-domain simulation tool, SIMO [1]. Both manually estimations of the coefficients by use of data published in DNVGL-RP-H103 [2] and numerical simulations with WAMIT [3] and CFD [4] are used to find the coefficients. How a realistic limiting sea state then may be found from time domain simulations is illustrated.

The intention of the Simplified Method is, as stated in DNV-OS-H206 [5], to provide a basic, albeit conservative, estimate of the forces acting on a lifted object. The method is based on the following simplifying assumptions:

- The lifted object is relatively small compared with the wave length.
- The vertical motions of the object follows the crane tip motion plus winch speed. No other motion components are considered.

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[1] Earlier MARINTEK, SINTEF Ocean from 1st January 2017 through a merger internally in the SINTEF Group

- Only vertical forces are considered.
- The dynamic forces on the object does not influence on the ship motions.

In this way, the Simplified Method will generally give conservative estimates for the limiting sea state of an operation.

NOMENCLATURE

a – length of short side of plate
b – length of long side of plate
k – factor dependent on b/a
D – characteristic length
Re – Reynolds number [6]
KC – Keulegan-Carpenter number [6]
A_{11} – added mass in horizontal direction
A_{22} – added mass in transverse direction
A_{33} – added mass in vertical direction
B_{11} – damping in horizontal direction
B_{22} – damping in transverse direction
B_{33} – damping in vertical direction
ρ - density of water 1025 kg/m^3
COG – center of gravity
L – length of cover
Z – amplitude of oscillation
T – period of oscillation
F_X – total force on structure in horizontal direction
F_Z – total force on structure in vertical direction
B_1 – linear damping
B_2 – quadratic damping
Hs – significant wave height
Tp – wave peak period
t – time
a_n - added mass in direction normal to the roof
V_n - relative velocity normal to the cover roof
V_z - relative velocity in vertical direction
v – relative velocity
F_{sz} - vertical force component
α – tilting angle of roof during deployment
F_D – characteristic hydrodynamic drag force
F_{slam} – characteristic slamming impact force
F_M – characteristic hydrodynamic mass force
F_B – characteristic varying buoyancy force
A – projected area of submerged part of object
C_d - drag coefficient
v_r - relative velocity
M – mass of structure
A_z - added mass
V – volume of structure
a_c – vertical crane acceleration
a_w - wave particle acceleration
z_r - relative amplitude
H – height
SWL – Safe Working Load

PROBLEM DESCRIPTION

The GRP cover is shown in FIGURE 1. It has the following main dimensions:

Length:	11.5 m	
Total breadth:	8.25 m	(flange included)
Breadth:	6.62 m	(flange excluded)
Height:	4.4 m	
Height (lower end):	1.66 m	
Mass in air (ballast included):	11910 kg	
Volume fully submerged:	3.65 m^3	
Longitudinal COG:	6.91 m	
Vertical COG:	1.43 m	

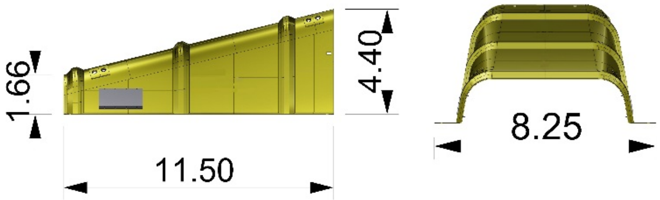

FIGURE 1. **GRP COVER DIMENSIONS**

The lifting equipment is shown in FIGURE 2 and consists of, from the top:

- the main lifting wire
- main hook with mass 12 t
- a double sling from the hook to a masterlink
- a master link (which is omitted in the SIMO model)
- two slings from the masterlink to the spreader bar
- a spreaderbar with mass 2 t
- two slings from the spreaderbar to the GRP cover

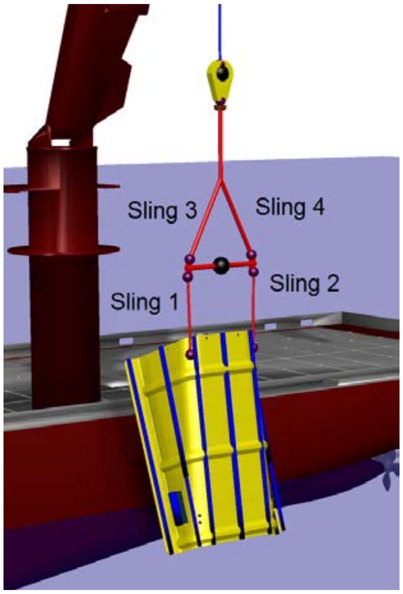

FIGURE 2. **SIMO MODEL OF LIFTING GEAR AND GRP COVER.**

Polyester slings with safe working load (SWL) 15 t and an elongation equal to 5% at the SWL is assumed for the lifting gear. The installation is to be performed with the GRP cover hanging with an initial angle of the bottom flange equal to 68 degrees to the horizontal, as shown in FIGURE 3.

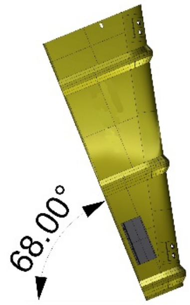

FIGURE 3. INSTALLATION ANGLE GRP COVER.

The installation vessel used in the analysis is a typical crane vessel with length 138 m, breadth 27 m and draught 6.4 m. The natural roll period is equal to 14.5 s. In the numerical model the vessel is kept in position by use of a horizontal mooring system consisting of four lines with stiffness and damping values to simulate a typical DP system.

MANUAL ESTIMATION OF ADDED MASS

A general formula for added mass on a rectangular plate is taken from DNVGL-RP-H103 [2]:

$$A = \rho\cdot\pi/4\cdot a^2\cdot b\cdot k \tag{1}$$

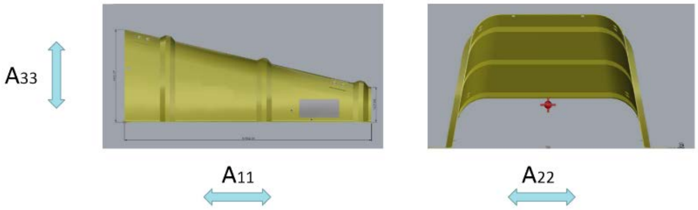

FIGURE 4. DEFINITIONS OF DIRECTIONS FOR FULLY SUBMERGED GRP COVER

In longitudinal direction, it is assumed that the added mass is equal to the added mass of a flat plate with area equal to the projected area normal to the flow:

$a = 4.4 - 1.66 = 2.74\text{m}$
$b = 6.62\text{m}$
$b/a = 2.42 \rightarrow k = 0.8$
$A_{11} = \rho\cdot\pi/4\cdot 2.74^2\cdot 6.62\cdot 0.8 = \underline{32\text{ t}}$

In transverse direction it is assumed that the outside contribution to A_{22} may be considered as one half ellipsoid cylinder, with half axis lengths equal to the width of the flange, $(8.25-6.62)/2 = 0.815$ m, and average height of the cover, $0.5\cdot(4.4+1.6) = 3$ m.

$A_{22}o = \rho\cdot\pi\cdot 3\cdot 0.815\cdot 11.5/2 = 47\text{t}$

Inside contribution is uncertain, due to the long distance between the vertical side walls. Two alternative estimates are considered:

a) Volume completely filled:
$A_{22}ia = \rho\cdot 3\cdot 6.62\cdot 11.5 = 234\text{ t}$

b) ¼ cylinder inside each wall (k=0.75):
$A_{22}ib = \rho\cdot\pi\cdot 32\cdot 11.5\cdot 0.75/2 = 125\text{ t}$

Resulting estimate alternatives:
a) $A_{22}a = 234 + 47 = \underline{281\text{ t}}$
b) $A_{22}b = 125 + 47 = \underline{175\text{ t}}$

In vertical direction added mass is simply assumed as equal to the value for a rectangular plate with area equal to the projected area of the cover:

$a = 8.25\text{ m}$
$b = 11.5\text{ m}$
$b/a = 1.39 \rightarrow k = 0.67$
$A_{33} = \rho\cdot\pi/4\cdot 8.252^2\cdot 11.5\cdot 0.67 = \underline{422\text{ t}}$

CALCULATION OF HYDRODYNAMIC COEFFICIENTS BY USE OF POTENTIAL THEORY

Hydrodynamic calculations by use of WAMIT are performed to obtain added mass and potential damping coefficients for the GRP cover.

Fully submerged cover

The calculations are performed for infinite water depth and the cover is located in horizontal position, as shown in FIGURE 4, at 300 m depth to avoid effects from the free surface. For this depth, the added mass is independent of period for the wave periods of interest. Four different panel models are investigated:

- Simplified model of the cover with thickness of the model equal to the material thickness 0.02 m. 1208x2 panels.
- Simplified model of the cover with a thickness of the model equal to the height of the corrugations on the roof, 20 cm. 1208x2 panels.
- Simplified model with zero thickness of the panel model. The dipole option in WAMIT is used for solution. 570x2 panels.
- Complex model of the cover with zero thickness of the panel model including the corrugations. The dipole option in WAMIT is used for solution. 676x2 panels.

The simplified model with thickness equal to 0.02 m, which is equal to the material thickness is shown to the left in FIGURE 5. The complex model with zero thickness is shown to the right.

The results show that the simplified geometry panel model with small thickness and the simplified model with zero thickness (dipole option) gives almost the same results for all coefficients. This show that the traditionally panel solution in WAMIT and the dipole solution with zero thickness of the model gives similar results. For longitudinal and vertical added mass the results for the simplified geometry with thickness 0.2 m and the complex geometry gives similar results. This indicates that the corrugation on the roof will have some influence on the added mass in these directions. But, generally the difference between the results for the different panel models are small. Based on this observation, the results with the complex geometry panel model with zero thickness (dipole option) has been used for further analysis.

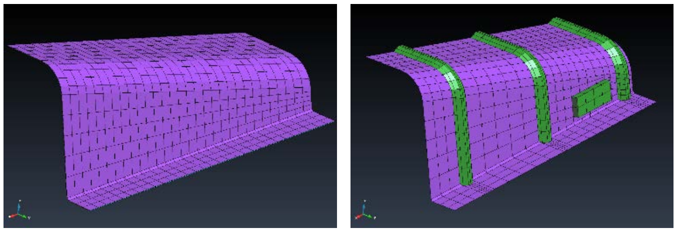

FIGURE 5. **PANEL MODELS IN WAMIT. LEFT: SIMPLIFIED MODEL WITH THICKNESS 0.02 m. RIGHT: COMPLEX MODEL WITH NO THICKNESS.**

From the WAMIT calculations with the complex model of the GRP cover, the following added mass values for fully submerged cover in horizontal position are obtained:

Horizontal longitudinal added mass: A_{11} = 19.5 t
Horizontal transverse added mass: A_{22} = 217 t
Vertical added mass: A_{33} = 444 t

The directions are defined in FIGURE 4.

Partly submerged cover

The depth dependency of the added mass and damping coefficients of the GRP cover are input parameters in the SIMO model. How the coefficients varied with depth are studied with WAMIT calculations where panel models with different draughts are used. The cover is "hanging" with an angle 68 degrees to the horizontal, as shown in FIGURE 3. Note that relative to the cover, the coordinate system is different from the fully submerged case. A_{11} and B_{11} is the added mass and damping in global horizontal direction, A_{22} and B_{22} the added mass and damping in global horizontal direction (transverse to the cover) and A_{33} and B_{33} added mass and damping in global vertical direction, as illustrated in FIGURE 6.

Added mass for different draughts for a period equal to 8 s are shown in FIGURE 7 and the potential damping in FIGURE 8.

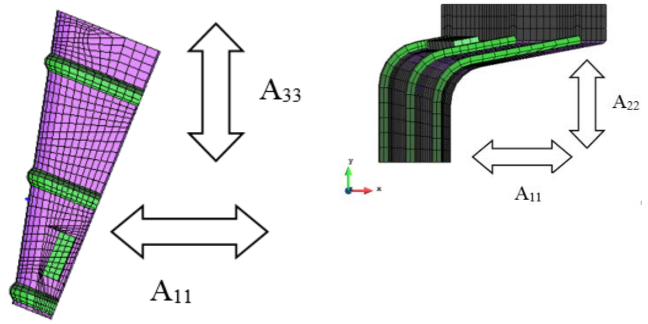

FIGURE 6. **DEFINITION OF DIRECTION OF MOTION FOR COVER IN AND CLOSE TO THE FREE SURFACE. SEEN FROM THE SIDE (LEFT). SEEN FROM THE TOP (RIGHT).**

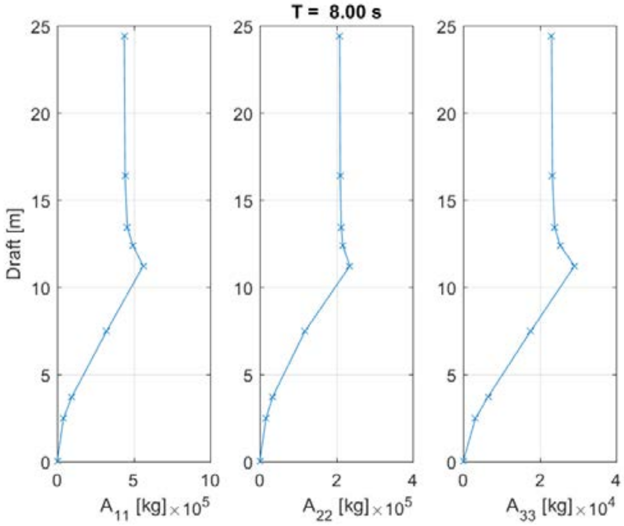

FIGURE 7. **CHANGE OF ADDED MASS WITH DRAUGHT FOR WAVE PERIOD T = 8 s.**

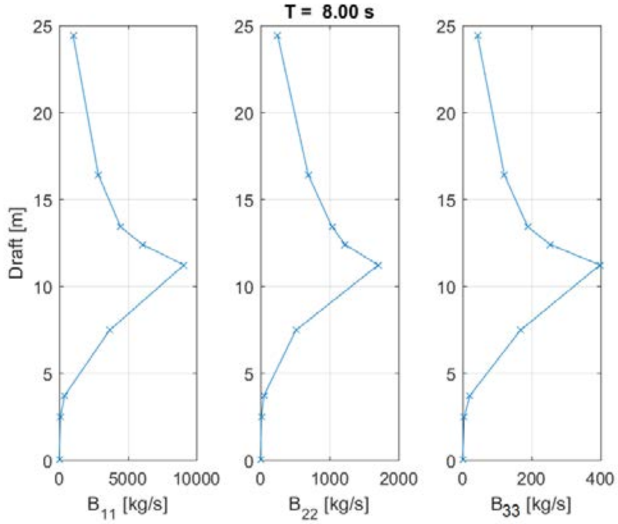

FIGURE 8. **CHANGE OF POTENTIAL DAMPING WITH DRAUGHT FOR WAVE PERIOD T = 8 s.**

As expected, we can see an increase of the coefficients with increasing draught until the GRP cover is fully submerged at 12 m. Then the coefficients begin decreasing and converges towards the values with no free surface.

The fully submerged added mass values for T = 8 s are as follows when the cover has an angle of 68 degrees:

A_{11} = 440 t
A_{22} = 210 t
A_{33} = 23 t

The directions are defined in FIGURE 6.

CALCULATION OF HYDRODYNAMIC COEFFICIENTS BY USE OF CFD

Calculations of added mass and damping for fully submerged GRP cover are performed with the CFD-software STAR-CCM+ from CD-adapco version 11 that solve Navier-Stokes equations with appropriate turbulence models using Reynolds averaging.

The simulations are performed without free surface and the momentum equations solved for only one fluid whose properties are equivalent with water.

The solution domain is split into a finite number of control volumes; here Cartesian grid with local refinement is used, except near solid walls where ten prism layers are created. The outer surface of the prism layer cuts the surrounding Cartesian cells, creating trimmed cells, which can have an arbitrary polyhedral topology. Discretization of the governing equations involves approximation of surface and volume integrals, interpolation to compute variable values at locations other than cell centroids (where the unknowns are stored), and numerical differentiation. All approximations used are of second order (midpoint rule approximation for integrals, linear interpolation and central differences). Discretization leads to one algebraic equation per control volume for each differential equation solved; upon application of appropriate boundary and initial conditions, algebraic equation systems are solved to obtain variable values at cell centers. A segregated iterative procedure is used, in which the three momentum equations, the pressure-correction equation and the equation for volume fraction of water are solved in turn; the process is repeated several times within each time step in order to update non-linear terms and account for inter-equation coupling. Under-relaxation is used to control the update of variables, which is required due to non-linearity of equations. Under-relaxation factors used in this study were 0.2 for pressure and 0.9 for velocities and volume fraction of water (default). The turbulence model SST – k-Omega was used in all simulations with its default parameters.

The computational domain uses the global right-handed coordinate system where the z-axis is positive upwards. In the lowering simulations, the xy-plane is on the still water level. The extents of the mesh domain is 200 m x 200 m x 100 m in the x, y, and z-directions with a total number of cells equal to 14315570. A cut of the volume mesh through the centerline of the cover is shown in FIGURE 9. The oscillation of the cover is modelled by moving the whole volume mesh and keep the boundary conditions fixed. In estimation of the coefficients three cycles of oscillation with steady state flow is used.

The cover is oscillated in surge, sway and heave with harmonic oscillations with three different velocities of oscillation; 0.5 m/s, 1.0 m/s and 2.0 m/s. The period of oscillation is 8.5 s and the corresponding amplitudes, Reynolds numbers and KC numbers are given in TABLE 1. The definitions of the directions is shown in FIGURE 4. A snap shot of the pressure distribution on the cover for oscillations in heave is shown in FIGURE 10.

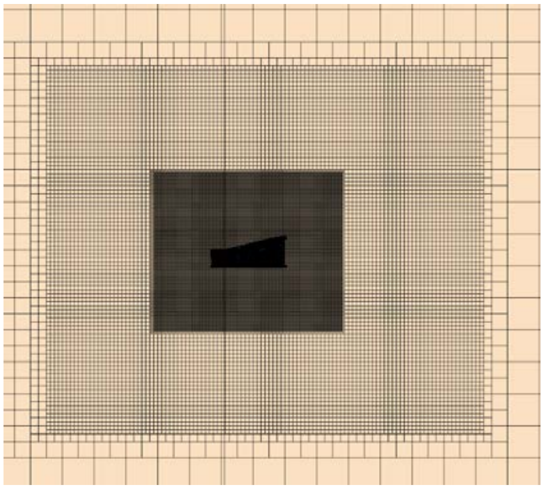

FIGURE 9. VOLUME MESH FOR CFD CALCULATIONS.

TABLE 1. REYNOLDS NUMBER AND KC NUMBERS FOR OSCILLATION OF FULLY SUBMERGED COVER.

Motion direction/ Characteristic length	Velocity	0.5 m/s	1.0 m/s	2.0 m/s
	Amplitude	0.676 m	1.353 m	2.706 m
Longitudinal (11)/ D = 11.5 m	Re	5.7e+06	1.2e+07	2.3e+07
	KC	0.37	0.74	1.48
Transverse (22)/ D = 8.25 m	Re	4.1e+06	8.2e+06	1.6e+07
	KC	0.52	1.03	2.06
Vertical (33)/ D = 4.4 m	Re	2.2e+06	4.4e+06	8.8e+06
	KC	0.97	1.93	3.86

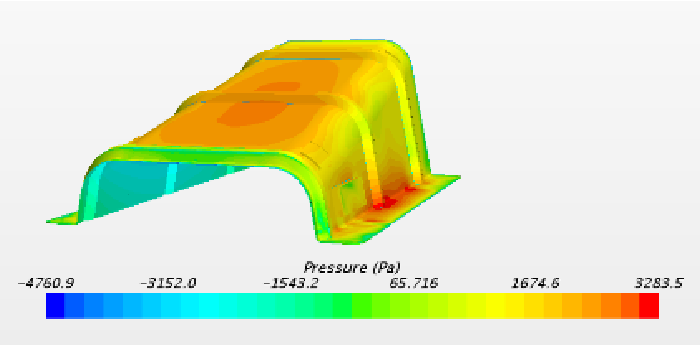

FIGURE 10 SNAP SHOT OF DYNAMIC PRESSURE (Pa) ON THE COVER FOR VERTICAL OSCILLATIONS WITH VELOCITY 1 m/s.

Validation of CFD setup

Hydrodynamic coefficients from model test results are not available for the GRP cover. The goodness of the CFD mesh and setup is therefore studied by performing simulations with the same numerical setup for two flat plates above each other and comparing the results with model test results from decay and forced oscillation tests. The reason for choosing the two plate tests for comparison was that both plates and cover consist of thin plates and have sharp edges. The plates are oscillated harmonically with amplitudes 0.73, 0.97 and 1.25 m and period 6.4 s. Corresponding Reynolds- and KC-numbers are given in TABLE 2 and is of the same order of magnitude as in the GRP case.

TABLE 2 REYNOLDS NUMBERS AND KC NUMBERS FOR THE TWO PLATE CASE.

Motion direction/ Characteristic length	Velocity	0.78 m/s	0.95 m/s	1.23 m/s
	Amplitude	0.79 m	0.97 m	1.25 m
Vertical (33)/ D = 6 m	Re	4.7e+06	5.7e+07	7.3e+07
	KC	0.83	1.01	1.31

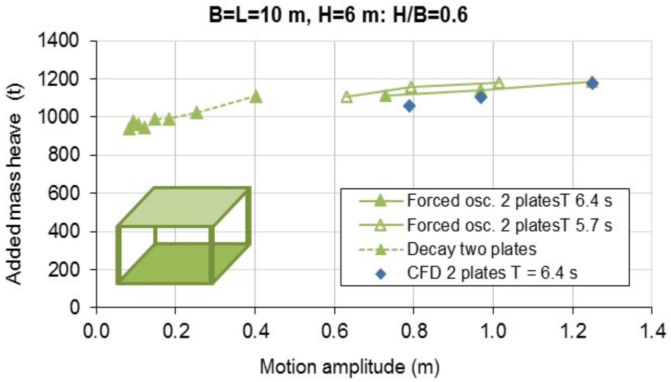

FIGURE 11. ADDED MASS IN VERTICAL DIRECTION FOR TWO RECTANGULAR PLATES ABOVE ECH OTHER.

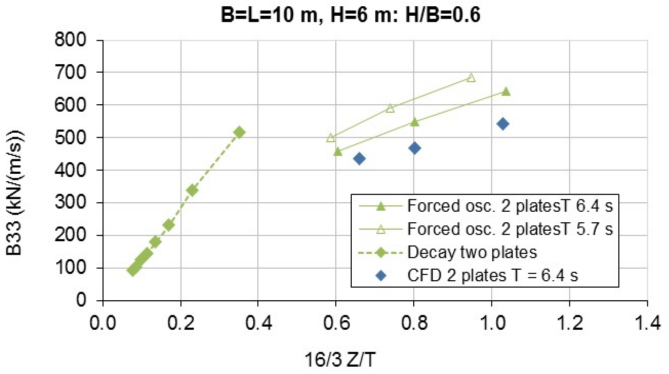

FIGURE 12. DAMPING IN VERTICAL DIRECTION FOR TWO RECTANGULAR PLATES ABOVE ECH OTHER.

It is seen that the added mass from CFD and forced oscillation tests with the same amplitude and period are the same with a difference less than 5%. The damping from the CFD calculations is somewhat lower, with a difference of 15% for the largest amplitude and 4% for the smallest. The reason for this may be that the model in the tests was equipped with some shackles, lifting wires and ballast plates attached with tape that are not present in the CFD model.

HYDRODYNAMIC COEFFICIENTS

The added mass coefficients obtained from manual estimations, WAMIT and STAR-CCM+ calculations are compared in FIGURE 13, FIGURE 14 and FIGURE 15.

The CFD results are plotted for the amplitude of motion used in the simulations. The potential theory solutions from WAMIT are linear and, strictly speaking, only valid for infinite motions. The WAMIT results are therefore plotted for amplitude equal to zero. As expected, the WAMIT and CFD results forms a nearly straight line when plotted as function of amplitude. It is seen that the results . The results from the manual estimations are not given for a specific amplitude, but plotted for zero amplitude for the comparison.

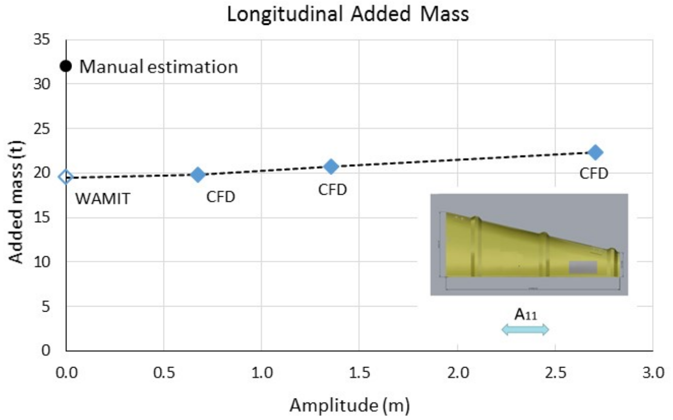

FIGURE 13 ESTIMATED AND CALCULATED ADDED MASS FOR GRP COVER IN LONGITUDINAL (A11) DIRECTION.

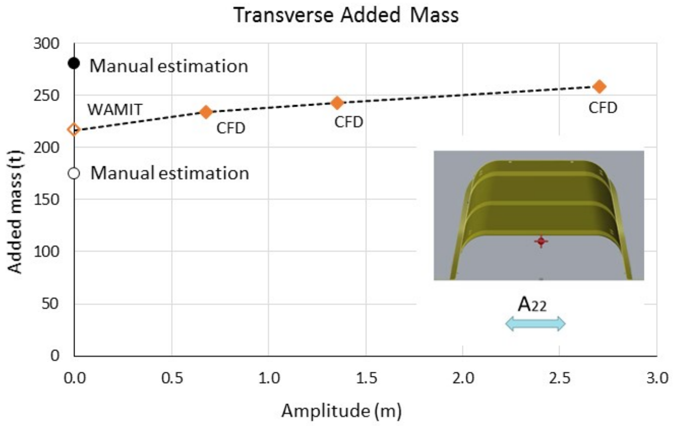

FIGURE 14 ESTIMATED AND CALCULATED ADDED MASS FOR GRP COVER IN TRANSVERSE (A22) DIRECTION.

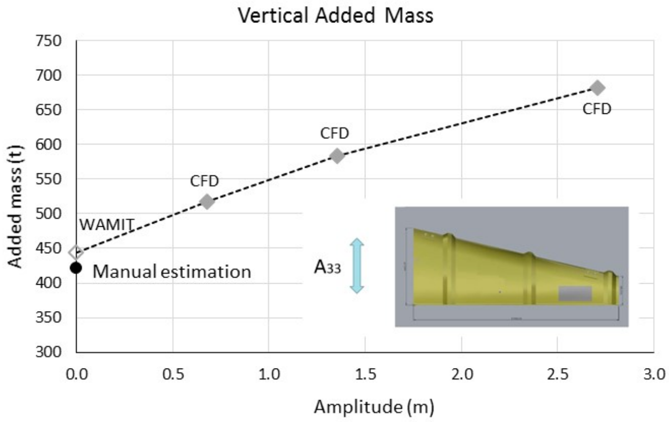

FIGURE 15. ESTIMATED AND CALCULATED ADDED MASS FOR GRP COVER IN VERTICAL (A33) DIRECTION.

The damping is shown in FIGURE 16. A linear fit between the obtained damping values give the following values for linear and quadratic damping constants:

TABLE 3 LINEAR AND QUADRATIC DAMPING FOR SUBMERGED COVER.

	B$_1$ (kN/(m/s)	B$_2$ (kN/(m/s)^2)
Longitudinal (11)	2.4	6.6
Transverse (22)	2.0	69.0
Vertical (33)	89.1	156.9

The damping force on the structure is then given by:

$$F_D = B_1 \cdot v + B_2 \cdot v\,|v| \tag{1}$$

where v is the relative velocity between the cover and the waves.

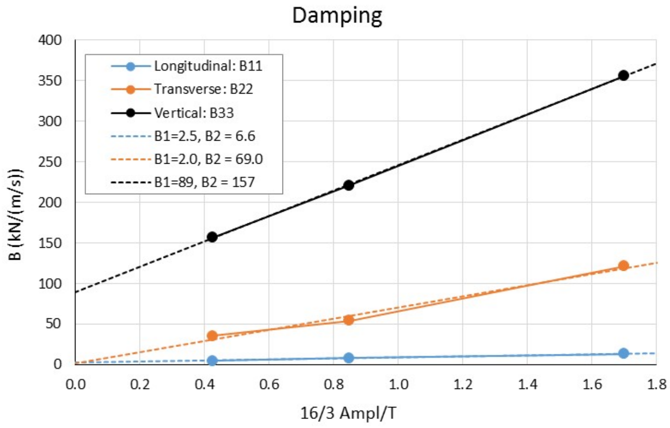

FIGURE 16. DAMPING FOR GRP COVER CALCULATED BY CFD. RESULTS FOR DIFFERENT AMPLITUDES OF OSCILLATION WITH PERIOD 8.5 s TOGETHER WITH LINER AND QUADRATIC DAMPING ESTIMATED FROM THE RESULTS.

NUMERICAL SIMO MODEL OF GRP COVER

The distributed hydrodynamic properties of the GRP cover is modelled by use of the "Slender element" model in SIMO [1], shown as blue Morison elements on the cover in FIGURE 2. Eleven elements are used to model the cover. Two elements are representing the "skirts" on each side of the cover, four representing the side walls, three representing the roof and two small elements representing the ballast. Mass, volume and hydrodynamic added mass and damping are distributed along the elements to obtain a correct mass matrix, volume and total added mass and damping.

The values of the added mass per unit length of the elements are distributed in such a way that the depth dependency of the total added mass for the cover hanging with an angle of 68 degrees to the horizontal correspond to the ones given in FIGURE 7.

Modelled in this way, with the center axis of the elements longitudinal to the cover, the depth dependency of the coefficients will be taken care of when the model is lowered through the surface and an increasing part of the elements is submerged. Slamming forces will not be included in this way of modelling. See discussion below.

INSTALLATION SIMULATIONS

Simulations of the lowering are performed for head sea (180 deg) condition. Short crested sea with cosine spreading from 90 to 270 degrees. The exponent in the cosine spreading function is equal to 2 and the number of directions 11. JONSWAP wave spectrum with Hs = 2.0 m, 2.5 m and 3.0 m, Tp = 8 s is used. 40 lowerings with different seed numbers are performed for each condition. Cosine series is used for representation of the waves to take care of the change of the wave particle motion with depth. The sea-state shown is chosen as an example to illustrate the method. For a more complete installation analysis more combinations of peak periods, wave heights and directions should be considered.

Due to the small mass of the cover and spreader bar compared with the hook mass and stiffness in the crane wire and lifting gear a time step equal to 0.001 s had to be used in the simulation. No tag or tugger wires are used in the simulations and, as expected, the cover experienced large rotations when lifted in air. The motions in air will be increased further if the cover is exposed to wind. When the cover is submerged the motion of the hook increases and will contribute to the sling forces.

To the left in FIGURE 17 it is seen how the cover is rotating and moving in air. To the right it is seen how the hook is getting a pendulum motion when the cover is submerged.

A typical lowering sequence is shown in FIGURE 18. The winch starts to run at time equal to 200 s with a speed of 0.2 m/s. The GRP cover reaches the water surface around t = 210 s and is fully submerged at t = 270 s. The winch stops at time equal to 400 s.

The time series of sling forces and lifting wire forces for a case with slack slings are shown in FIGURE 19 to FIGURE 21. It is seen that the maximum forces occur when the cover is nearly fully submerged.

Maximum and minimum sling forces from the numerical simulation of 40 lowerings in Hs = 3.0 m Tp = 8 s at different wave seeds are plotted in the Gumbel plots in FIGURE 22 to FIGURE 25.

Sling1 and Sling2 are the two slings between the spreaderbar and the cover. Sling3 and Sling4 are located above the spreaderbar, between the spreaderbar and the master link. The force in Sling3 and Sling4 therefore includes the weight of the spreaderbar.

It is seen that when lowering in Hs = 3.0 m Tp = 8 s four occurrences of slack in Sling1 or Sling2 were observed for 40 seed numbers. 20 seed numbers gave two occurrences of slack. Maximum force in the slings after slack is 12 t, which is below the Safe Working Load of 15 t for the slings.

The instances of slack slings will change the behavior of the dynamic system. Therefore, the lower part of the observations in in FIGURE 22 to FIGURE 25 should be disregarded when the statistics of extreme forces is studied. When fitting a straight line to the tail of the maxima points, the 90% percentile can be assessed as:

Lower slings (no. 1 and 2):	88 kN
Upper slings (no. 3 and 4):	107 kN

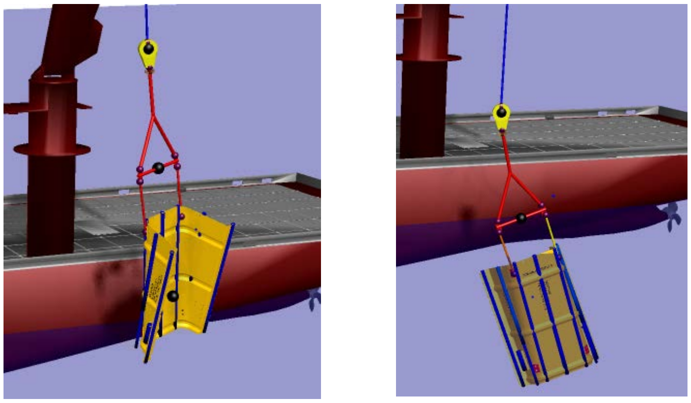

FIGURE 17. SNAP SHOTS FROM LOWERING IN Tp = 8 s Hs = 3 m, SEED NUMBER 3. LEFT: ROTATION OF THE COVER WHEN STILL IN AIR. RIGHT: MOTIONS OF THE HOOK WHEN COVER IS SUBMERGED.

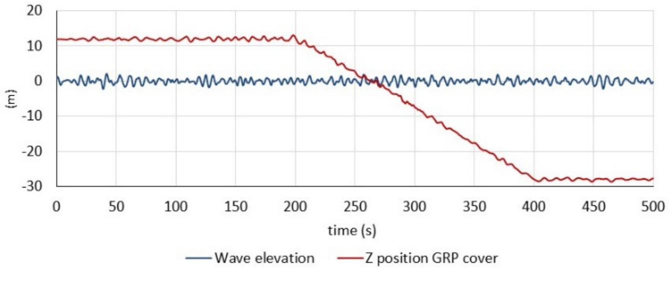

FIGURE 18. WAVE ELEVATION AND VERTICAL POSITION OF GRP COVER FOR Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.

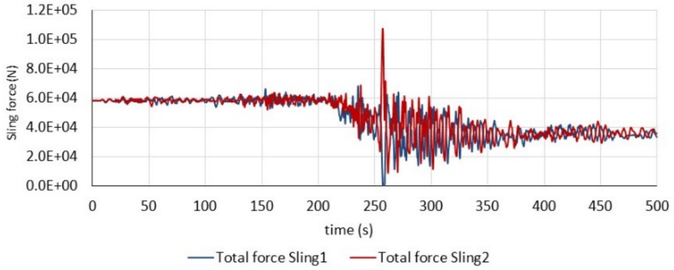

FIGURE 19. EXAMPLE OF FORCES IN Sling1 AND Sling2 IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.

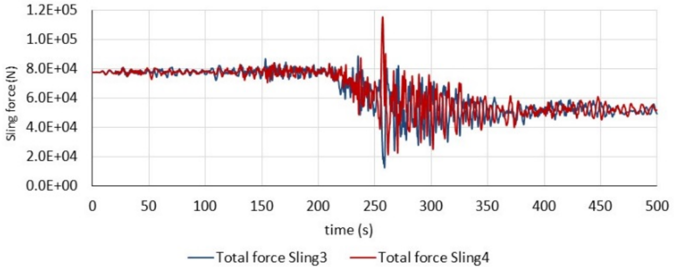

FIGURE 20. EXAMPLE OF FORCES IN Sling3 AND Sling4 IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.

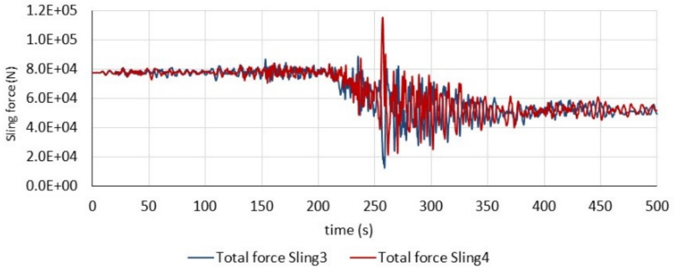

FIGURE 21. EXAMPLE OF FORCES IN CRANE WIRE AND HOOK WIRE IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.

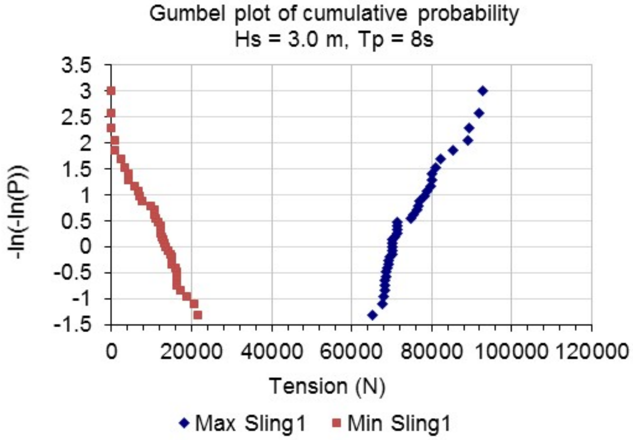

FIGURE 22. GUMBEL PLOT OF MINIMUM AND MAXIMUM FORCE IN Sling1 FOR 40 LOWERING IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.

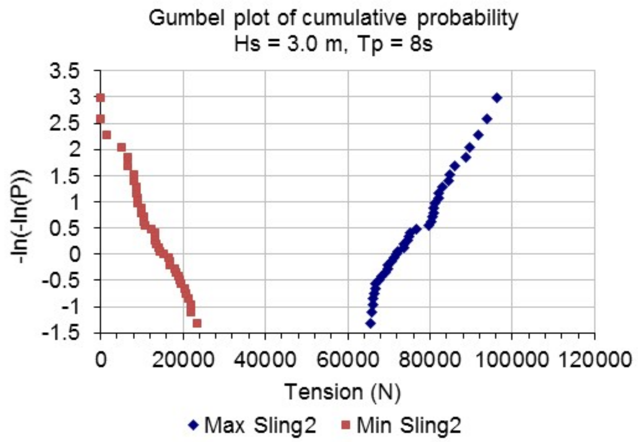

FIGURE 23. **GUMBEL PLOT OF MINIMUM AND MAXIMUM FORCE IN Sling2 FOR 40 LOWERING IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.**

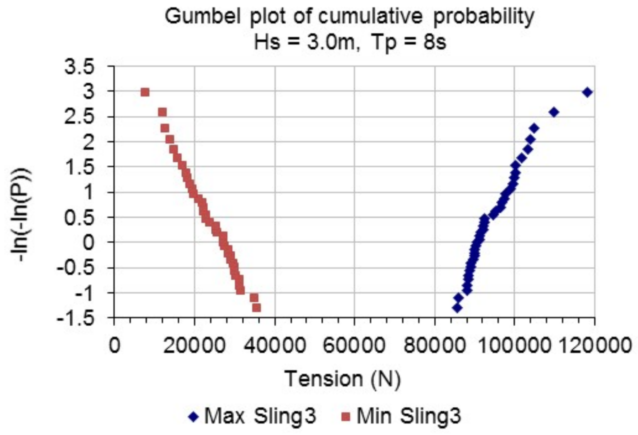

FIGURE 24. **GUMBEL PLOT OF MINIMUM AND MAXIMUM FORCE IN Sling3 FOR 40 LOWERING IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.**

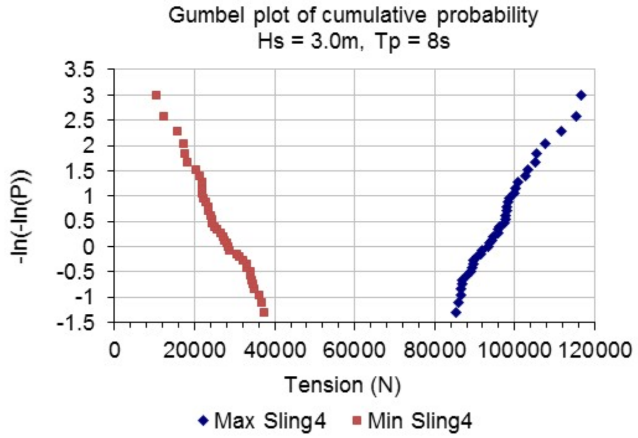

FIGURE 25. **GUMBEL PLOT OF MINIMUM AND MAXIMUM FORCE IN Sling4 FOR 40 LOWERING IN Hs = 3.0 m Tp = 8 s, SHORTCRESTED HEAD SEA.**

SLAMMING

A slamming force term has not been included in the SIMO model for this deployment case. The slamming term during deployment with tilting angle α, can be expressed by:

$$F_{sn} = v_n \cdot \frac{\partial a_n}{\partial t} = v_n \cdot v_z \cdot \frac{\partial a_n}{\partial z} \qquad (2)$$

where a_n is the added mass in direction normal to the roof, found from A_{33}, FIGURE 15. V_n is the relative velocity normal to the cover roof, V_z the relative velocity in vertical direction and $F_{sz} = F_{sn} * \cos\alpha$ is the vertical force component.

The characteristic vertical velocity in Hs = 3 m and Tp = 8 s is approximately 2.8 m/s, which gives a vertical slamming force component around 15 kN for a tilting angle of the roof of the cover relative to the horizontal α=80 degrees, which is relatively small compared to the calculated dynamic force during water entry.

It is seen from FIGURE 19 and FIGURE 20 that the largest forces on the cover occur when the cover is fully submerged (around 270 s). Eventually slamming events will therefore not occur at the same time as the maximum forces.

SIMPLIFIED METHOD

A simplified method for assessment of the hydrodynamic force and the limiting sea states for a deployment operation is given in Section 4 of DNVGL RP H-103 [2]. The total hydrodynamic force is here given as:

$$F_{HYD} = \sqrt{(F_D + F_S)^2 + (F_M - F_B)^2} \qquad (3)$$

where the drag force

$$F_D = \frac{1}{2}\rho c_d A \cdot v_r^2 \qquad (4)$$

and the slamming force F_S = 0 (considered only for horizontal members). The mass force:

$$F_M = \sqrt{[(M + A_z)a_c]^2 + [(\rho V + A_z)a_w]^2} \qquad (5)$$

and the varying buoyancy force:

$$F_B = \rho g V \cdot \frac{z_r}{H} \qquad (6)$$

The required minimum margin against slack wire is 10% of the submerged weight (which is approximately 80 kN).

An assessment is made for a sea state with Hs = 3 m and Tp = 8 s. The zero-crossing period (used in the calculations) will be approximately Tz = 6.3s (wave frequency around 1 rad/s). The characteristic wave amplitude will be 0.9*Hs = 0.9*3.0=2.7m. The characteristic velocity and acceleration will have the same numerical value.

The vertical crane top motion has been taken from the RAO curves for heave, pitch and roll motion, for a typical installation vessel with length 140m to be 0.76 m.

An assessment based on the manually estimated added mass in longitudinal direction and a drag coefficient equal to 1.0, gives F_{HYD} = 123 kN. The limiting sea state, assessed by linear scaling from 123 to 0.9*80 kN, gives Hs(lim) = 1.75m for Tp = 8s. Use of the above damping and mass values calculated by CFD increases the limiting sea state to Hs(lim) = 2.0 - 2.5m.

The Simplified Method also contain a recommended alternative assessment of wave kinematics independent of wave period. This recommendation assumes steeper waves than used above, and will give approximately 14% reduction of the limiting sea states, to 1.5 – 2.1m.

SUMMARY AND CONCLUSIONS

To obtain hydrodynamic coefficients for a GRP cover during installation the following studies are performed:

- Manual estimation of the added mass coefficients for fully submerged cover.
- WAMIT calculation of added mass coefficients for fully submerged cover.
- Comparison between the results from WAMIT and the manual estimations.
- To obtain information about the depth dependency of the coefficients, WAMIT calculations are performed for different draughts of the GRP cover in the free surface positioned with the angle to be used during installation, (68 degrees to the horizontal).
- CFD calculations (StarCCM+) are performed for fully submerged cover to obtain added mass and damping, included viscosity. The cover is oscillated harmonically with a period equal to 8.5 s for the velocities 0.5 m/s, 1m/s and 2 m/s in surge, sway and heave.

A SIMO model of the GRP cover based on the slender element model in SIMO is then prepared. The total added mass and damping for the submerged structure are assessed based on the WAMIT and CFD calculations for fully submerged structure. The depth dependency of the coefficients is estimated by use of the WAMIT calculations at different draughts.

SIMO simulations of the lowering is performed for Hs = 2.0 m, 2.5 m and 3.0 m with Tp = 8.0 s. Short crested head sea is assumed with a $\cos^2$ spreading function with 11 direction. A lowering speed of 0.2 m/s is applied. Since no tag or tugger lines are used to control the motions in the simulations, the simulations gave large motions and rotations of the cover when still in air. After reaching the water the motions of the cover calmed down and the motions of the hook increased with a pendulum motion.

The largest force variations in the slings occur just after the cover is fully submerged. A few incidences of slack occur for Hs 2.5 m and 3 m for Tp = 8 s, but without dramatic snatch loads afterwards. Therefore, it is concluded that for Tp = 8 s, installation may be performed in Hs up to 2.5 to 3 m if the motions during lift in air is controlled. Other peak periods should be examined before final conclusions about general weather conditions can be drawn.

The time domain simulations indicate that deployment in Tp = 8 s is feasible in sea states up to Hs = 3 m. Based on manually estimated hydrodynamic data for the cover the Simplified Method described in DNVGL RP H-103 [2] gives a limiting Hs in the range 1.50 - 1.75m. This illustrates how a more accurate method like time domain simulations may be cost saving when it comes to time used on waiting for acceptable weather conditions for the installation operation.

ACKNOWLEDGMENTS

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