Paul W.H. Voorhaar Stress Engineering

VALIDATION OF PROGRAMME UNIT

WAVE LOADINGS ON OFFSHORE HORIZONTAL PIPELINE

Date: Za 12-Jan-2002
Time: 16:26:10

Project: IMPROVEMENTS OF FUTURE DEVELOPMENTS
Jobnr: PV2002

ABSTRACT:

This case study is the result of ongoing discussions between me and my roommate at that time: Robert van der Kooy.
Ever since the original design of the F3-FB-1P we did disagree with the way waveloadings were calculated, so we did our own research which resulted in a number of own written programmes for personal use only. This report is a translation of a report from 1995 in Dutch: SP95037.

It must become clear that the traditional method of modelling waveloadings on pipelines by using the windloading module from pipestress programmes is incorrect. Especially at the long radius bottom elbow of a riser this results in loadings that are to low and the force direction is incorrect.
The loadings should be calculated seperately and than imported into the model as nodal loadings.

Also the maximum loading does not necessarely occurs at the maximum height of the wave.
In this document wave slamming is not considered. Delta stretching of the current flow is included but will be documented in a seperate report.

The wave velocities and accelerations are calculated using the formulas of Lars Skelbreia.
The forces perpendicular to the pipeline are calculated using Morrison’s formula’s.
The total forces acting on the pipeline are calculated using the general approach of Turgut Sarpkaya.

REFERENCES:

Mechanics of Wave Forces on Offshore Structures by Turgut Sarpkaya / Michael Isaacson
Rules For Submarine Pipeline Systems by Det Norske Veritas (DNV) 1981/1982
Fifth order Gravity Wave theory by Lars Skelbreia Proc. Coastal Eng. 1961
NEN 3650 1992 Transportleidingsystemen
Report UR8 CIRIA underwater Engineering Group
Handbook of Ocean and Underwater Engineering by John J. Myers
Validatie computerprogramma SP95037 by P.W.H. Voorhaar 1995

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This case study is to verify the wave module as used in the off-shore programmes of P.W.H. Voorhaar
The wave data are adopted from the article of Lars Skelbreia for compairetive use:
water depth d = 30 ft.
wave height H = 18 2/3 ft.
wave period T = 7.72 seconds.

The results from the computer programme are imported via a file. The actual calculation of the wave velocities is not presented here. In this verification calculation delta stretching is included. A separate report is written for verification of this phenomenon.
The method used will be compaired with commonly used methods showing that these methods are mostly wrong.

Outside pipe diameter	$OD := 0.2731$
Marine growth	10 mm
Water temperature 10 ^{o}C	
Sea water density (determined by programme)	$\rho := 1026.5$
Coëfficient of Inertia	$Cm := 3.29$
Lift Coëfficient	$Cl := 0.7$
Drag Coëfficient	$Cd := 1.3$

Line under consideration is HORIZONTAL on the Z-axis with wave and current direction perpendicular to the pipeline axis. By using this general approach of an inclined cylinder the correct calculations will be performed on large radius elbows.
The direction of wave and current is taken the same in this verification for simplicity only.

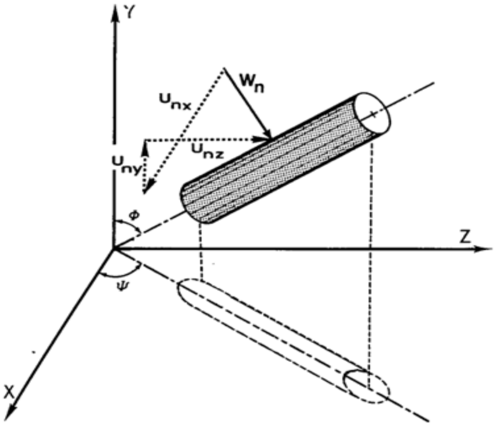

Fig. 5.9. Definition sketch for an inclined cylinder.

By the programme the horizontal and vertical velocities and accelerations are calculated for a complete wave period and over the fhe full sea water depth :

$U_{h_1} = 2.021 \quad U_{v_1} = 0 \quad u\_nx_1 = 2.021 \quad u\_ny_1 = 0$

$a_{h_1} = 0 \quad a_{v_1} = -0.269 \quad a\_nx_1 = 0 \quad a\_ny_1 = -0.269$

$U_{h_{0.5 \cdot period}} = 7.991 \quad U_{v_{0.5 \cdot period}} = -0.076 \quad u\_nx_{0.5 \cdot period} = 7.991 \quad u\_ny_{0.5 \cdot period} = -0.076$

$a_{h_{0.5 \cdot period}} = -0.125 \quad a_{v_{0.5 \cdot period}} = 7.095 \quad a\_nx_{0.5 \cdot period} = -0.125 \quad a\_ny_{0.5 \cdot period} = 7.095$

The velocity (and acceleration) perpendicular to the pipeline is calculated according Sarpkaya page. 328 METHOD 4 and COMPUTERPROGRAMME:

$$W_{n_r} := \sqrt{\left(U_{h_r}\right)^2 + \left(U_{v_r}\right)^2 - \left(e_x \cdot U_{h_r} + e_y \cdot U_{v_r}\right)^2}$$

There are several methods used to calculate the forces acting on the pipeline from the local wave velocities. Not all methods give the correct results.

METHOD 1

The velocity and acceleration are determined by adding the horizontal and vertical component vectorial.

$$W_{n2_r} := \sqrt{\left(U_{h_r}\right)^2 + \left(U_{v_r}\right)^2} \qquad a_{n2_r} := \sqrt{\left(a_{h_r}\right)^2 + \left(a_{v_r}\right)^2}$$

METHOD 2

The horizontal and vertical force are determined from the horizontal and vertical velocity and acceleration. The resultant force is calculated vectorial from these (correct) components.
This is further referred to as the JBF method: The "Jan Boere Fluitjes" method.

$$F_{h_r} := 0.5\cdot\rho\cdot OD\cdot Cd\cdot\left|U_{h_r}\right|\cdot U_{h_r} + OD^2\cdot 0.25\cdot\pi\cdot\rho\cdot Cm\cdot a_{h_r} \qquad F_{h_1} = 744.34$$

$$F_{v_r} := 0.5\cdot\rho\cdot OD\cdot Cd\cdot\left|U_{v_r}\right|\cdot U_{v_r} + OD^2\cdot 0.25\cdot\pi\cdot\rho\cdot Cm\cdot a_{v_r} \qquad F_{v_1} = -53.194$$

METHOD 3 and 4

The horizontal and vertical forces calculated according Sarpkaya:

$$F_{dx_r} := 0.5\cdot\rho\cdot OD\cdot Cd\cdot\left|W_{n_r}\right|\cdot u\_nx_r \qquad F_{ix_r} := OD^2\cdot 0.25\cdot\pi\cdot\rho\cdot Cm\cdot a\_nx_r$$

$$F_{dx_1} = 744.34 \qquad F_{ix_1} = 0$$

$$F_{dy_r} := 0.5\cdot\rho\cdot OD\cdot Cd\cdot\left|W_{n_r}\right|\cdot u\_ny_r \qquad F_{iy_r} := OD^2\cdot 0.25\cdot\pi\cdot\rho\cdot Cm\cdot a\_ny_r$$

$$F_{dy_1} = 0 \qquad F_{iy_1} = -53.194$$

METHOD 1

$$F_{r,1} := 0.5\cdot\rho\cdot OD\cdot Cd\cdot\left|W_{n2_r}\right|\cdot W_{n2_r} + OD^2\cdot 0.25\cdot\pi\cdot\rho\cdot Cm\cdot a_{n2_r}$$

No spilt-up of
Fx, Fy en Fz

METHOD 2

$$F_{r,2} := \sqrt{\left(F_{h_r}\right)^2 + \left(F_{v_r}\right)^2}$$

Jan Boere Fluitjes
method

METHOD 3

$$F_{r,3} := \sqrt{\left(F_{dx_r}\right)^2 + \left(F_{dy_r}\right)^2} + \sqrt{\left(F_{ix_r}\right)^2 + \left(F_{iy_r}\right)^2}$$

This method gives the same
result as method 1

METHOD 4

$$F_{r,4} := \sqrt{\left(F_{dx_r} + F_{ix_r}\right)^2 + \left(F_{dy_r} + F_{iy_r}\right)^2}$$

Sarpkaya and
computerprogramme of
Paul Voorhaar

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Method 1 calculates the drag and inertiaforce by adding up vectorial the horizontal and vertical velocity and the horizontal and vertical acceleration. By using this method one ignores the fact that the angle of the total velocity is NOT THE SAME as the angle of the total acceleration. This method is NOT CORRECT.

Method 2 uses the horizontal velocity to calculate the horizontal dragforce and uses the horizontal acceleration to calculate the horizontal inertia force. The addition of both forces results in the total horizontal force. In a similar way the total vertical force is determined. The velocity and accelaration ALONG the pipeline are considered to be ZERO always. The total acting force is the square root of the sum of squares.
This often used approach is NOT CORRECT.

Method 3 calculates the local velocities and accelerations PERPENDICULAR TO the pipeline and assumes a zero value ALONG the pipeline. The drag and inertia forces are added vectorial. The total force is the sum of both results. This method serves only to show what is wrong in method 1.

Method 4. The drag and inertia forces are calculated similar to method 3, however the horizontal and vertical force is determined by the summation of the LOCAL drag and inertia force. The total force is calculated by vectorial addition of the horizontal and vertical force. This method is addopted in the computer programme of Paul W.H. Voorhaar.

The direction of the velocity and acceleration is not the same during the total wave period. By DNV the dragforce is calculated with the velocity acting perpendicular to the pipeline. The inertia force is calculated with the acceleration acting perpendicular to the pipeline.
Because of this the drag and inertia force can not simply be added up over the whole period of the wave.

To check the method as described by Sarpkaya the drag and inertia forces are calculated independendly, after this the vertical and horizontal components are determined.

The horizontal dragforce can be added to the horizontal inertiaforce.
The vertical dragforce can be added to the vertical inertiaforce.

These horizontal and vertical forces can be added vectorial.
From the results we see that only the SARAPKAYA - method is correct.
Thus the **OFFSHORE WAVE LOADING COMPUTER PROGRAMME** calculates the figures correctly.

$$F_{d_{r,1}} := 0.5 \cdot \rho \cdot OD \cdot Cd \cdot \left| W_{n_r} \right| \cdot W_{n_r} \qquad F_{i_{r,1}} := OD^2 \cdot 0.25 \cdot \pi \cdot \rho \cdot Cm \cdot a_{n_r}$$

$$Fd_{hor_r} := \left(\frac{U_{h_r}}{W_{n_r}} \right) \cdot F_{d_{r,1}} \qquad Fd_{vert_r} := \left(\frac{U_{v_r}}{W_{n_r}} \right) \cdot F_{d_{r,1}}$$

$$Fi_{hor_r} := \left(\frac{a_{h_r}}{a_{n_r}} \right) \cdot F_{i_{r,1}} \qquad Fi_{vert_r} := \left(\frac{a_{v_r}}{a_{n_r}} \right) \cdot F_{i_{r,1}}$$

$$Fd_{hor_1} = 744.34 \qquad Fi_{hor_1} = 0$$

$$Fd_{vert_1} = 0 \qquad Fi_{vert_1} = -53.194$$

$$F_{r,5} := \sqrt{\left(Fd_{hor_r} + Fi_{hor_r}\right)^2 + \left(Fd_{vert_r} + Fi_{vert_r}\right)^2}$$

$F_{m_r} := M_{r,10}$ <--- Computerresult according SARAPKAYA and VOORHAAR imported from data file into a matrix called M_r.

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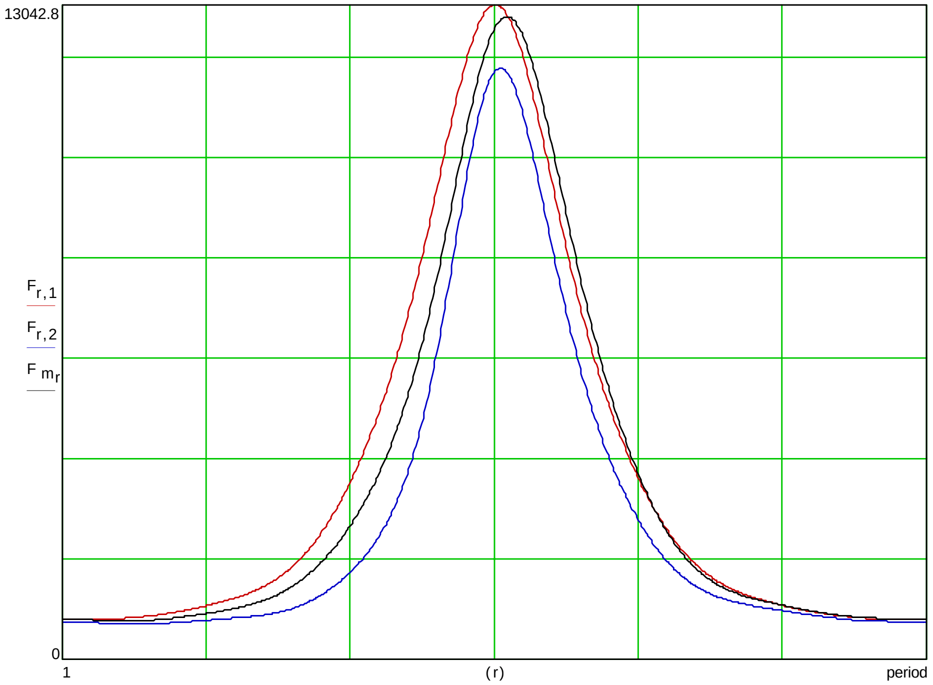
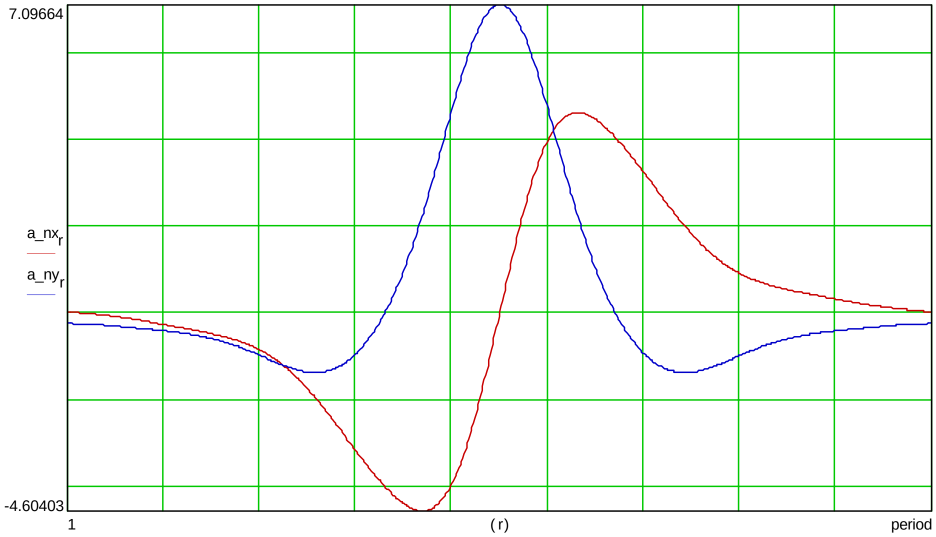


It can be clearly seen that method 2 (J.B.F.) underestimates the values over a wide range of the wave period. Only if the vertical acceleration is maximum the true values are calculated.

Method 1 is slightly conservative (red line).
The black line shows the results of the calculation method of Sarpkaya (method 4 and the computerprogramme).



Local horizontal and vertical accelerations over the wave period

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Some results showing the difference

$F_{1,i}$	i	$F_{90,i}$	i	
797.534	1	915.951	1	<-No split-up
746.238	2	722.633	2	<-J.B.F.
797.534	3	915.951	3	<-Just not enough
746.238	4	756.838	4	<-Sarpkaya
746.238	5	756.838	5	<-Voorhaar

$F_{m_1} = 801.259$

$F_{m_{90}} = 809.452$

The next graph is just to show that the velocity and the acceleration do NOT have the same angle during the wave period.

$a_r := \operatorname{atan}\left(\frac{U_{v_r}}{U_{h_r}}\right)$ angle of velocity

$b_r := \operatorname{atan}\left(\frac{a_{v_r}}{a_{h_r}}\right)$ angle of acceleration