Investigating the effect of ocean waves on gravity based offshore platform using finite element analysis software ANSYS

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ABSTRACT: Finite element analysis (FEA) technology has become a very important tool for evaluating the structural integrity of massive and gigantic structures of which offshore platforms is an example.

Modeling of offshore platforms has been challenging due to the complexity of structural designs and the large volume of elements used in the model.

Gravity Base Structures (GBS) was applied to remote fields in deep and harsh waters in the central and northern part of the North Sea.

This paper reviews design approaches and requirements for offshore platforms, and specifically investigated the effect of ocean waves and presents several considerations in modeling the structural performance of offshore platforms using finite element analysis software ANSYS,. A numerical example with a generic GBS (gravity based structures) offshore platform is included to demonstrate the use of the proposed modeling approach.

Results are obtained from analysis done which varies the frequencies of wave to obtain the different Froude-krylov and diffraction forces obtained by the incidence of the wave on the platforms

Keywords: Finite Element Analysis (FEA), Gravity Based Structure (GBS), Impact, Simulation-based Design, Wave Load, Wind Load

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INTRODUCTION

The development of the offshore oil industry has led to numerous installations of offshore platforms. The major use of these platforms is in the drilling for oil and gas beneath the seafloor. Other usage includes, but is not limited to, military applications, navigational aid to ships andgenerating power from the sea.

Load Calculation in Offshore

The loads that strongly affect offshore structures can be classified into the following categories;

1. Permanent (dead) loads.
2. Operating (live) loads.
3. Environmental loads.
4. Construction-installation loads.
5. Accidental loads.

Whilst the design of buildings onshore is usually influenced mainly by the permanent and operating loads, the design of offshore structures is dominated by environmental loads, especially waves.

Environmental loads are those caused byenvironmental phenomena such as wind, waves, currents, tides, ice and marine growth. Their characteristic parameters, defining design load values, are determined in special studies on the basis of available data. (He, S. H., and Hong, X. F. (2003))

Wave Forces on Structural Members

Structures exposed to waves experience substantial force much higher than wind loadings. These force result from the dynamic pressure and the water particle motions. Two different cases can be distinguished:

1. Large volume bodies, termed hydrodynamic compact structures, influence the wave field by diffraction and reflection. The forces on these bodies have to be determined by costly numerical calculations based on diffraction theory.
2. Slender, hydro dynamically transparent structures have no significant influence on the wave field. This force can be calculated in a straight-forward manner with Morison's equation. As a rule, Morison's equation may be applied when D/L <0.2, where D is the member diameter and L is the wave length.

The gravity based offshore structures can usually be regarded as a large body hence the wave forces on the submerged members can therefore be calculated by diffraction theory using panel distribution methods.(Muga, B.J. 2003)

Airy Wave Theories

All wave theories obey some form of waveequation in which the dependent variable depends on physical phenomena and boundary conditions (Al- Salehy, 2002). In general, the wave equation and the boundary conditions may be linear or non-linear.

Assumptions

The main theoretical assumptions and limitations of linear potential theory employed in ANSYS Aqwa are listed below:

- The body or bodies have zero or very small forward speed.
- The fluid is in viscid and incompressible, and the fluid flow is irrotational.
- The incident regular wave train is of small amplitude compared to its length (small slope).
- The motions are to the first order and hence must be of small amplitude. All body motions are harmonic. (ANSYS Software User Manual. Copy Right 7, 1997.)

Diffraction Theory

If an incident wave system encounters a body, a diffracted wave system will be induced by the presence of the body. The disturbed flow pattern causes a pressure distribution on the body and will therefore introduce a hydrodynamic force(the diffraction force). The diffracted wave system can be calculated by applying Green's second theorem and using the known incident wave potential. A method to calculate the two-dimensional potentials, describing the diffraction problem, was first presented by Frank (1967), and is generally known as the “Frank Close-Fit” method. Another method, based on Lewis conformal mapping coefficients, is given by Keil (1974). (Iraninejad, B. 1988)

Governing Equations

According to the ANSYS AQWA theory manual, the governing equation used for the analysis of the offshore structures is obtained from the basic potential theory.

Below are the details of the analysis.

In the fixed reference axes (FRA), the water surface elevation at position X and Y can be expressed in complex value form as

$$\text{Ƒ} = a_w e^{i[-\omega t + k(X\cos\aleph + Y\cos\aleph) + \alpha]} ---- \qquad \textit{(1)}$$

where a_w = *is the wave amplitude,*
ω = *is the wave frequency (in rad/s)*
K = *is the wave number,*
$\aleph$= *is the wave propagating direction, and*
α = *is the wave phase.*

Assuming ideal, irrotational fluid, the flow can be represented by a velocity potential satisfying the Laplace equation in the whole fluid domain, the linear free surface condition, and horizontal impermeable bottom condition

In finite depth water, the velocity potential at the location X = (X, Y, Z)

$$\Phi_I(X,t) = \varphi_I(X)\, e - i\omega t$$

$$= -\frac{iga_w \cosh[k(Z+d)]}{\omega \cosh(kd)} e^{i[-wt + k(X\cos\aleph + Y\sin\aleph) + \alpha]} \quad \dots (2)$$

Where d = *water depth and* g = *gravitational acceleration.*

Employing the linear free surface condition, the relationship between the wave frequency and the wave number (the linear dispersion relationship) is represented by

$$V = \frac{\omega^2}{g} = k\tanh(kd) \dots\dots \textbf{(3)}$$

The wave length and wave period are

$$\lambda = \frac{2\pi}{K} \quad \dots\dots\dots\dots\dots \quad \dots\dots\dots.. (4)$$

$$T = \frac{2\pi}{\omega} \quad \dots\dots\dots\dots\dots \dots\dots\dots (5)$$

Using the Bernoulli equation and only taking account the linear term, the fluid pressure is

$$P(X,t) = -\frac{\rho g a_w \cosh[k(Z+d)]}{\cosh(kd)} e^{i[-\omega t + k(X\cos\aleph + Y\sin\aleph) + \alpha]} \rho g Z \dots. \textbf{(6)}$$

Where ρ *is the water density*

The wave celerity is

$$C = \frac{\lambda}{T} = \frac{gT}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right) \dots\dots\dots\dots\dots \qquad \textbf{(7)}$$

Taking the partial derivative of the velocity potential, the fluid particle velocity is

$$V(u,v,w) = \frac{a_w \omega \cosh[k(Z+d)]}{\sinh(kd)} e^{i[-\omega t + k(X\cos\aleph + Y\sin\aleph) + \alpha]}$$

$$(\cos\aleph, \sin\aleph, -i\tanh\{k[Z+d]\} \dots.. \textbf{(8)}$$

When the wave particle velocity at the crest equals the wave celerity, the wave becomes unstable and begins to break. The limiting condition for wave breaking in any water depth is given by:

$$\left(\frac{2a_w}{\lambda}\right) max = \frac{1}{7}\tanh(kd) \dots\dots\dots \textbf{(9)}$$

In infinite depth water (d), the wave elevation keeps the same form as Equation 9, but velocity potential is further simplified as

$$\Phi_I(X,t) =$$

$$\varphi_I(X) e - iwt - \frac{iga_w}{\omega} e^{i[-\omega t + k(X\cos\aleph + Y\sin\aleph) + \alpha] + kZ} \quad .(10)$$

The linear dispersion relation is expressed as

$$\boldsymbol{\omega^2 = gk} \quad \text{...............} \; \textbf{(11)}$$

The fluid pressure

$$\boldsymbol{p(X,t) = -\rho g a_w e^{i[-\omega t + k(X\cos\aleph + Y\sin\aleph) + \alpha] + KZ} - \rho g Z} \quad \text{...............} \; \textbf{(12)}$$

The wave celerity and fluid particle velocity are expressed as

$$\boldsymbol{C == \frac{gT}{2\pi},} \quad \text{....................} \; \textbf{(13)}$$

$$\mathbf{V} = \boldsymbol{a_w \omega e^{i[-\omega t + k(X\cos\aleph + Y\sin\aleph) + \alpha] + kZ}\ (Cos\aleph\, , Sin\aleph\, , -i)} \ldots \textbf{(14)}$$

Since the first order potential theory of diffraction and radiation waves is used here for radiation and diffraction analysis, the linear superposition theorem may be used to formulate the velocity potential within the fluid domain.

The fluid flow field surrounding a floating body by a velocity potential is defined by

$$\boldsymbol{\Phi(X,t) = a_w \varphi(X)} \quad \text{....................} \; \textbf{(15)}$$

Where $\boldsymbol{a_w}$ is the incident wave amplitude and ωis the wave frequency

In Equation, the isolated space dependent term v may be separated into contributions from the radiation waves due to six basic modes of body motion, the incident wave and the diffracted or scattered wave. The potential functions are complex but the resultant physical quantities such as fluid pressure and body motions in time domain analysis will be obtained by considering the real part only.

Adopting the conventional notation of the six rigid body motions in sea keeping theory, Floating Rigid Motions three translational and three rotational motions of the body's center of gravity are excited by an incident regular wave with unit amplitude:

$$\boldsymbol{x_j = u_j, (j = 1, 3)} \quad \text{............} \; \textbf{(16)}$$

$$\boldsymbol{x_j = \theta_{j-3}\, , (j = 4, 6)} \; \text{.........} \; \textbf{(17)}$$

The potential due to incident, diffraction, and radiation waves may therefore be written as:

$$\boldsymbol{\Phi(X)e^{-iwt} = [(\varphi_1 + \varphi_d) + \sum\ \Phi_{rj}\, x_j]e^{-iwt}} \ldots \textbf{(18)}$$

Where

$\boldsymbol{\varphi_1}$*is the first order incident wave potential with unit wave amplitude,*

$\boldsymbol{\varphi_d}$*is the corresponding diffraction wave potential,*

$\boldsymbol{\Phi_{rj}}$ *is the radiation wave potential due to the j-th motion with unit motion amplitude.*

In finite depth water, the linear incident wave potential $\boldsymbol{\varphi_1}$at a point X =(X,Y,Z) in Equation 18 has been given in Equation 15 , but as a special case of unit amplitude$\boldsymbol{a_w = 1}$

When the wave velocity potentials are known, the first order hydrodynamic pressure distribution may be calculated by using the linearized Bernoulli's equation

$$\boldsymbol{p^{(1)} = -\rho \frac{\mathrm{d}\Phi(X,t)}{\mathrm{d}t} = i\omega\rho\varphi(X)e^{-iwt}}. \; (19)$$

From the pressure distribution, the various fluid forces may be calculated by integrating the pressure over the wetted surface of the body. To have a general form for the forces and moments acting on the body, we extend the notation of unit normal vector of hull surface previously introduced above into 6 components corresponding to the six basic rigid body motions, such as

$$(\boldsymbol{n_1}, \boldsymbol{n_2}, \boldsymbol{n_3}) = \boldsymbol{n} \ldots\ldots\ldots\ldots\ldots\ldots \quad (20)$$

$$(\boldsymbol{n_4}, \boldsymbol{n_4}, \boldsymbol{n_5}) = \boldsymbol{r} \; \boldsymbol{X} \; \boldsymbol{n} \ldots\ldots\ldots\ldots \quad (21)$$

Where

$$\boldsymbol{r} = \boldsymbol{X} - \boldsymbol{X_g} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

is the position vector of a point on the hull surface with respect to the center of gravity in the fixed reference axes (FRA).

Employing this notation, the first order hydrodynamic force and moment components can be expressed in a generalized form:

$$\boldsymbol{F_j e^{-iwt}} = -\int_{S_0} \boldsymbol{P^{(1)} n_j ds} = [-\boldsymbol{i\omega\rho} \int_{s_0} \boldsymbol{\varphi(X)\, n_j ds}]\boldsymbol{e^{iwt}} \ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

Where

$\boldsymbol{s_0}$*Is the mean wetted surface of body?*

From Equation 3.23, the total first order hydrodynamic force can be written as

$$\boldsymbol{F_J} = [(\boldsymbol{F_{Ij}} + \boldsymbol{F_{dj}}) + \textstyle\sum_{k=1}^{6} \boldsymbol{F_{rjk} X_K}]. \quad (24)$$

Where j=1, 6 of which the j-th Froude-Krylov force due to incident wave is

$$\boldsymbol{F_{Ij}} = -\boldsymbol{i\omega\rho} \int_{s_0} \boldsymbol{\varphi_I(X)\, n_j ds} \ldots.. \quad (25)$$

The j-th diffracting force due to diffraction wave is

$$\boldsymbol{F_{dj}} = -\boldsymbol{i\omega\rho} \int_{s_0} \boldsymbol{\varphi_d(X)\, n_j ds} \ldots\ldots \quad (26)$$

Thej-th radiation force due to the radiation wave induced by the k-th unit amplitude body rigid motion is

$$\boldsymbol{F_{rjk}} = -\boldsymbol{i\omega\rho} \int_{s_0} \boldsymbol{\varphi_{rk}(X)\, n_j ds} \ldots\ldots. \quad (27)$$

Structure Description

To study the action of wave forces on the dynamic behavior of the offshore platform model shown in Fig. (1), the following wave parameters have been considered:

Wave height = 21 m,
Wave period = 12 sec,
Wave length = 225 m,
Water depth = 100 m,
Water density = 1025 kg/m3.

For the above figures, using the above stated equations these are the obtained results:

Wave Length = 223.22 m
Wave Number = 0.0281 rad/m
Radian Wave Frequency = 0.5236 rad/s
Wave Celerity = 18.60 m/s
Group Velocity = 9.68 m/s
Horizontal Velocity = 5.54 m/s
Vertical Velocity = 5.50 m/s
Horizontal Acceleration = 2.90 m/s2
Vertical Acceleration = 2.88 m/s2
Horizontal Displacement = 10.58 m
Vertical Displacement = 10.50 m
Dynamic Pressure = 105.68 kPa
Static Pressure = 0.00 kPa

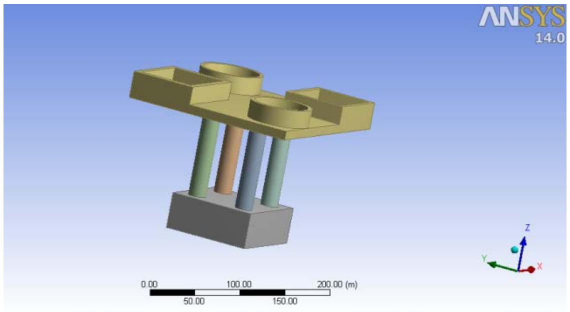


Fig 1. Model of the gravity based offshore platform to be simulated by ANSYS

METHODOLOGY

Hydrodynamic forces acting on gravity based offshore structure was simulated using ANSYS AQWA for a range of frequencies form 0.03 Hz to 0.38 Hz and also for the wave direction -180 to 180. The results for the total wave forces on the gravity based offshore platform which is essentially the wave exciting forces which comprises both the Froude-Krylov and the diffracting forces were obtained both for the range of frequencies and the range of directions simulated for

In order to investigate the effects of ocean wave on gravity based offshore platform, a simplified model of the platform has been considered in this project. Also the wave theory used to evaluate the velocity and acceleration of the water particles is the Airy wave theory (linear) and for the sake of comparison, different values of the frequencies and wave impact directions are used to evaluate the velocity and acceleration of the water particles;

Since the D/L > 0.2, (where D is the member diameter (in this case the concrete column) and L is the wave length).The Morison's equation is not applicable and as such the diffraction theory is used.

Diameter of the cylinder = 110m

Total length of the platform = 200m

Total weight assumed = 40,000 tonnes

Wave length assumed = 223m

Therefore the structure could be referred to as to as large volume body and as such the forces on its members can only be obtained by numerical calculations based on the diffraction theory.

Large volume bodies, termed hydrodynamic compact structures, influence the wave field by diffraction and reflection.

Hence the forces on these bodies which have was determined by costly numerical calculations based on diffraction theory was obtained at different frequencies and directions using ANSYS AQWA.

The loads resulting from using the airy theories with the basic potential theory are applied on the platform and the resulting bending moments, axial forces and displacement variations with time of the platform (at a point on the top of the platform and near the sea bed on the platform) were plotted to and reported

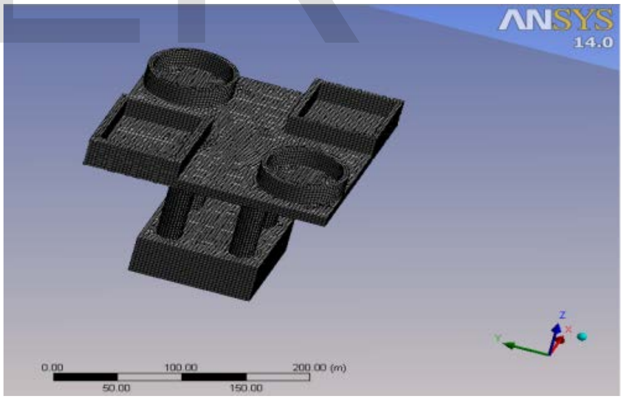


Fig 2. Meshed model

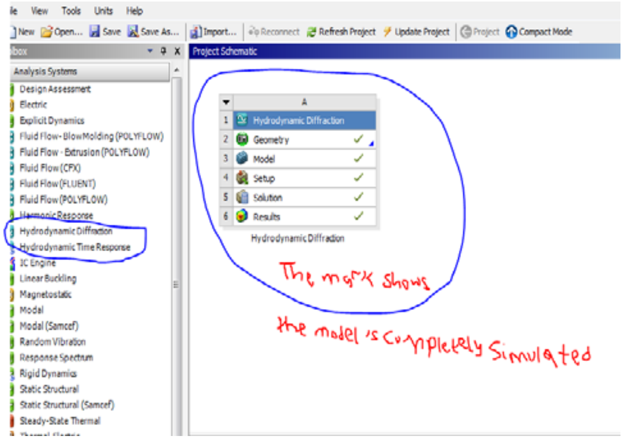


Fig 3: completed analysis from ANSYS

CONCLUSION

This research compared the results of wave exciting forces applied to a model of gravity based offshore platform expressed by natural frequency and directions results.

Therefore, the following concluding remarks can be drawn:

1. The overall response of the structure (offshore structure) is sensitive to the frequency of the wave applied as stipulated in the governing equations. Wave characteristics represented by wave theories used in the present work have a smaller effect on behavior and response of the offshore platform.
2. Due to the resistance of the platform to the flow, water increased near the upstream of platform, and to the highest when arrived at the platform, on the other hand, water two sides concentration, the kinetic energy increased, and the water drop down.
3. The analysis results suggest that under gravity loads, the example generic platform shows uniform settlement on the seabed, which is a typical required feature of GBS platforms.

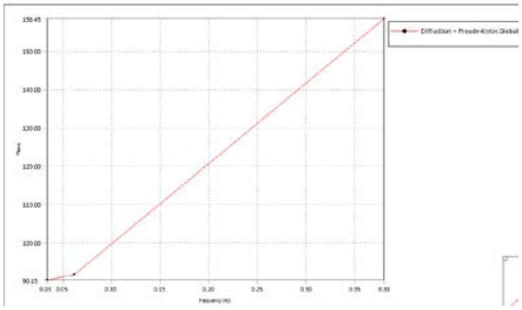


Fig4: Diffraction+Froude-krylov (Phase angle vs frequency)

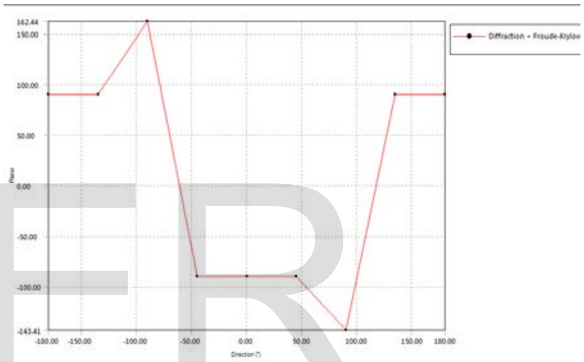


Fig5:Diffraction+Froude-krylov(Phase angle vs Direction)

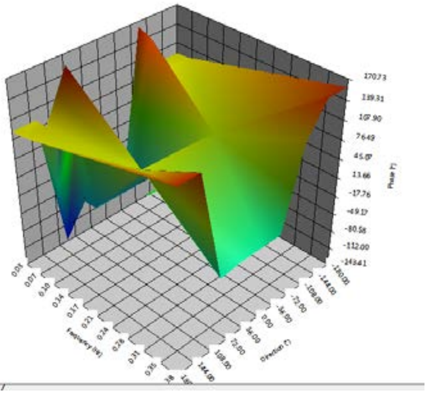


Fig6::Diffraction+Froude-krylov(Phase angle vs. frequency& Direction)

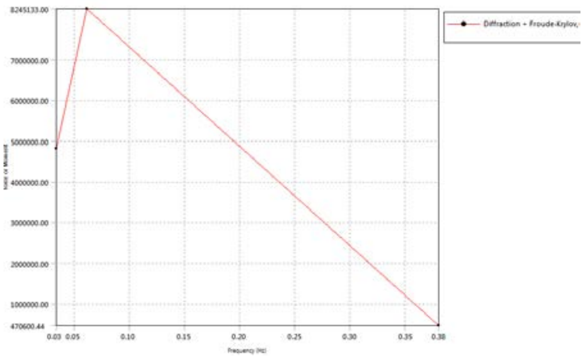


Fig7: Diffraction+Froude-krylov(moment vs frequency)

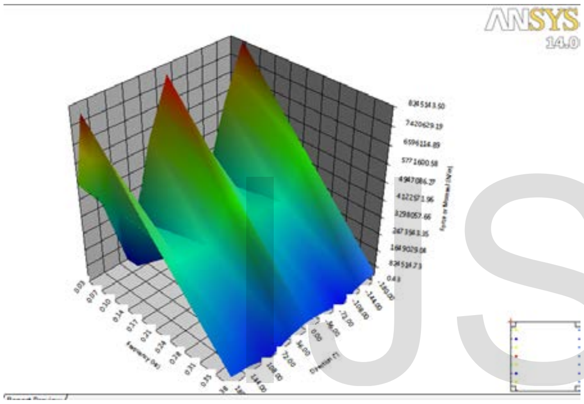
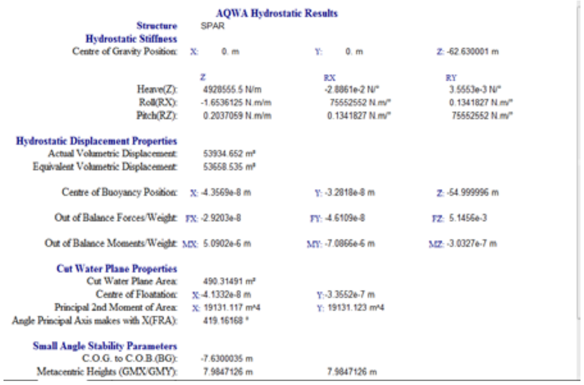


Fig8: Diffraction + Froudekrylov(force/moment vs. frequency& direction)



AQWA Hydrostatic Results

Structure	SPAR		
Hydrostatic Stiffness			
Centre of Gravity Position:	X: 0. m	Y: 0. m	Z: -62.630001 m
	Z	RX	RY
Heave(Z):	4928555.5 N/m	-2.8861e-2 N/°	3.5553e-3 N/°
Roll(RX):	-1.6536125 N.m/m	75552552 N.m/°	0.1341827 N.m/°
Pitch(RZ):	0.2037059 N.m/m	0.1341827 N.m/°	75552552 N.m/°
Hydrostatic Displacement Properties			
Actual Volumetric Displacement:	53934.652 m³		
Equivalent Volumetric Displacement:	53658.535 m³		
Centre of Buoyancy Position:	X: -4.3569e-8 m	Y: -3.2818e-8 m	Z: -54.999996 m
Out of Balance Forces/Weight:	FX: -2.9203e-8	FY: -4.6109e-8	FZ: 5.1456e-3
Out of Balance Moments/Weight:	MX: 5.0902e-6 m	MY: -7.0866e-6 m	MZ: -3.0327e-7 m
Cut Water Plane Properties			
Cut Water Plane Area:	490.31491 m²		
Centre of Floatation:	X:-4.1332e-8 m	Y:-3.3552e-7 m	
Principal 2nd Moment of Area:	X: 19131.117 m^4	Y: 19131.123 m^4	
Angle Principal Axis makes with X(FRA):	419.16168 °		
Small Angle Stability Parameters			
C.O.G. to C.O.B.(BG):	-7.6300035 m		
Metacentric Heights (GMX/GMY):	7.9847126 m	7.9847126 m	

Fig 9: Hydrostatic result

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