TIDAL HARMONIC ANALYSIS AT BONGA FIELD

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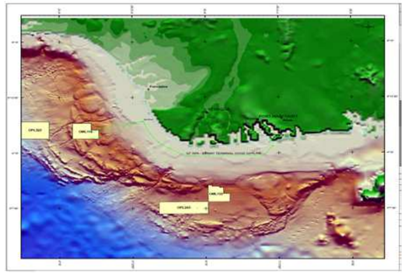
CONTENTS

INTRODUCTION

- Tide gauges used traditionally in Nigeria for water level observation.
- Need for new methods for observing tides offshore Nigeria.
- Tidal observation important in navigation, rig moves, design of engineering works and support for marine operations.

Study Area: Bonga Field

- Located in Oil Mining Lease (OML) 118. ~ 120km from Nigerian coastline.
- Area approximately 1167 km^2 .
- Average water depth of 1000m.
- Production of both crude oil and natural gas started in November 2005 through a Floating Production, Storage and Off-take (FPSO) vessel.
- Field operated by SNEPCo (55%), along with Exxon (20%), Nigerian AGIP (12.5%) and Total Petroleum (12.5%).



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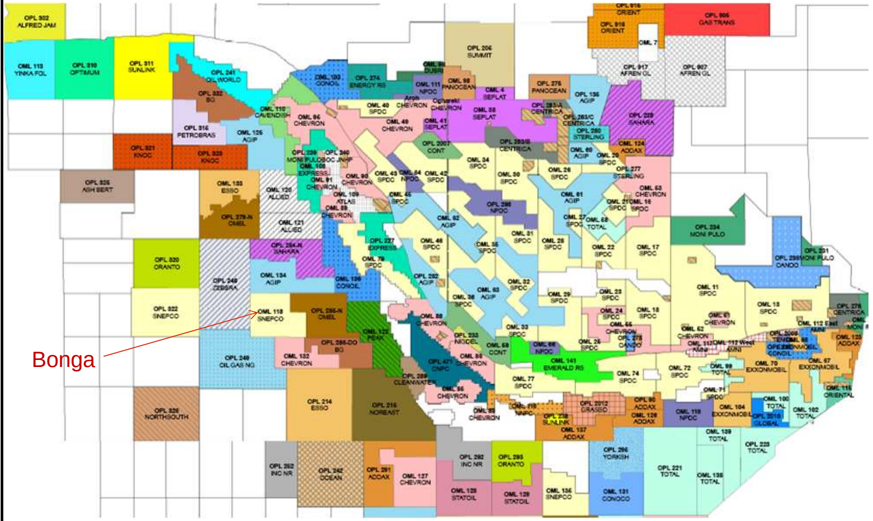


METHODOLOGY

- Data Acquisition with Water Level Recorder WLR7
- Data Validation using Median Filter
- Harmonic Analysis of Tides
- Tidal Prediction

Data aquisition with Aanderaa Water Level Recorder WLR7

High precision recording instrument for determining water level in the open sea.

Water level is determined by measuring the hydrostatic pressure with an ultra-precise quartz pressure sensor.

Capable of measuring up to 6000m water depth.

51 days hydrostatic pressure data was aquired at the Bonga Field.

Temperature and water density in Bonga were also measured.

Acquired pressure readings at the water surface and at depth were used to determine the water depth.

Conversion of Water Level Recorder WLR7 Data to Depth

Water Depth (m) = $0.001*(P_{wd} - P_{atmos})/d*g$ 1

Where

P_{wd} = Pressure at water depth (Pa)

P_{atmos} = Atmospheric Pressure (Pa)

Atmospheric pressure of Bonga = 101000 (Pascal)

d = Density of water at the actual location

Density used for Bonga = 1.03017 (Kg/m^3)

g = Gravity of the earth (9.78334 m/s^2)

The lowest water depth was taken as the chart datum, while all heights above the lowest depth were regarded as tidal observations.

Data Validation using Median Filter

The median filter was applied if the difference between two consecutive hourly water level was greater than a threshold (i.e. 0.5m).

Thus:

If Absolute (Water Level 2 - Water Level 1) > 0.5

then

Water Level 2 = (Water Level 1+ Water Level 3) / 2 (2)

Harmonic Analysis of Tides: Basic Equation

$$h(t) = S_0 + \sum_{i=1}^{n} f_i H_i \cos(\omega_i t + (v_i + u_i) - \alpha_i) \quad (3)$$

where;

n = Number of harmonic constituents
v = Phase angle at time zero
u = Nodal angle
f = Nodal factor
ω = Constituent speed
S_0 = Mean Sea Level (determined after harmonic analysis)
α = Phase Lag (Determined after harmonic analysis

Note:
Eighteen tidal constituents were used for the harmonic analysis.

The values of the nodal facors (f), phase angle at time zero (v) and nodal angle (u) were computed at the midle of the time of the observation data for all the eighteen tidal constituents using astromonic parameters computed by Stravisi, (1983).

Harmonic Analysis of Tides

The tidal harmonic and prediction model in equation 3 was expanded using the trigonometric identity as:

$h(t) = S_0 + \sum_{i=1}^{n} f_i H_i \text{Cos}(\omega_i t + (V_i + U_i)) \text{Cos} X_i + \sum_{i=1}^{n} f_i H_i \text{Sin}(\omega_i t + (V_0 + U_i)) \text{Sin} X_i$ **4**

Let $A_i = H_i \text{Cos} X_i$ **and**

$B_i = H_i \text{Sin} X_i$

The tidal harmonic and prediction model in equation 4 becomes:

$h(t) = S_0 + \sum_{i=1}^{n} (A_i f_i \text{Cos}(\omega_i t + (V_i + U_i)) + B_i f_i \text{Sin}(\omega_i t + (V_i + U_i))$ **5**

The Least Squares adjustment of equation 4 was carried out using Conjugate Gradient Method in Matlab to determine the unknown values of S_0, A1, A2.....A18 and B1, B2,.....B18. The Conjugate gradient method was used to avoid finding the inverse of the near singular matrix (i.e matrix with determinant equal to 0).

Harmonic Analysis of Tides and Tidal Prediction

The phase angle for each of the 18 constituents were computed using the following relationship:

$B_i/A_i = H_i \text{Sin}\, \alpha_i \;/\; H_i \text{Cos}\, \alpha_i = \text{Tan}\, \alpha_i$ 6

$\alpha_i = \text{Tan}^{-1} (B_i/A_i)$ 7

The amplitudes H for each of the 18 constituents was determined from the following relationship:

$B_i = H_i \text{Sin}\, \alpha_i$ 8

$H_i = B_i / \text{Sin}\, \alpha_i$ 9

Computed phase angles α_i and amplitudes H_i were put in equation 3 to predict the water level for Bonga untill December 2015

RESULTS

S/N	Parameters	Least Squares Solution (X)	Residuals from Adjustment (V=AX-L)
1	A0 or SO	0.8955061328	-3.56E-14
2	A1	-0.4934201491	-9.05E-14
3	B1	-0.0596395818	-1.10E-13
4	A2	-0.1089335765	-1.13E-15
5	B2	0.1336482689	4.01E-14
6	A3	-0.1033088931	-2.64E-14
7	B3	0.0592944342	-3.16E-13
8	A4	-0.0297730983	-4.80E-15
9	B4	-0.0266593669	-3.64E-14
10	A5	0.0924520282	1.30E-13
11	B5	-0.1013088968	2.29E-14
12	A6	0.0178565621	1.19E-13
13	B6	0.0237078003	-7.13E-13
14	A7	0.0344841015	-2.22E-14
15	B7	-0.0117571831	6.27E-14
16	A8	-0.0111300358	-5.99E-13
17	B8	-0.0229343292	5.06E-13
18	A9	0.0091126804	-3.46E-13

RESULTS (CONTINUED)

S/N	Parameters	Least Squares Solution (X)	Residuals from Adjustment (V=AX-L)
19	B9	0.0320225152	3.99E-15
20	A10	0.0001806800	2.03E-13
21	B10	0.0007702764	1.62E-13
22	A11	-0.0013186013	-9.43E-13
23	B11	-0.0015664692	-2.31E-12
24	A12	0.0066212762	-1.09E-12
25	B12	0.0055185843	-7.28E-13
26	A13	-0.0095449268	-8.98E-13
27	B13	0.0104535647	-3.89E-13
28	A14	0.0011717711	8.44E-13
29	B14	0.0023108752	6.81E-13
30	A15	-0.0034879694	2.92E-13
31	B15	0.0082143343	7.42E-13
32	A16	0.0005404965	-8.43E-13
33	B16	-0.0000773116	1.98E-13
34	A17	0.0015285740	2.25E-13
35	B17	0.0002063698	5.28E-13
36	A18	0.0016164270	-8.08E-13
37	B18	-0.0000454650	1.45E-13

RESULTS (CONTINUED)

S/N	Constituent Name	Constituent Speed (m/s)	Amplitudes (H) (m)	Nodal Factor (F)	V+U (Deg)	Phase Lag (Deg)
1	M2	28.9841042000	0.1433380234	1.0063923852	1.2854605886	186.8918952806
2	S2	30.0000000000	0.2466006241	1.0000000000	360.0000000000	129.1826711369
3	N2	28.4397295000	0.2778514447	1.0063923852	281.6303114864	150.1462078758
4	K2	30.0821373000	0.0308251429	0.9682220264	83.5240317641	221.8418364774
5	K1	15.0410686000	0.1623680664	0.9953671368	228.0175372109	312.3828149372
6	O1	13.9430356000	0.0269270663	0.9920402910	93.4467282115	53.0131767945
7	P1	14.9589314000	0.0688045195	1.0000000000	98.6537475120	341.1734450712
8	MSf	1.0158958000	0.0671200035	1.0063923852	358.7145394114	244.1126892071
9	2N2	27.8953548000	0.0320332562	1.0063923852	201.9751623842	74.1151819934
10	MO3	42.9271400000	0.0007911065	0.9983817946	94.7321888001	76.7990608860
11	MK3	44.0251729000	0.0016101879	1.0017299069	229.3029977995	229.9104510050
12	MN4	57.4238337000	0.0057122694	1.0128256329	282.9157720751	39.8099325798
13	M4	57.9682084000	0.0494229282	1.0128256329	2.5709211773	132.3985370134
14	SN4	58.4397300000	0.0023374243	1.0063923852	281.6303114864	63.1118871266
15	MS4	58.9841042000	0.0158124501	1.0063923852	1.2854605886	113.0070406986
16	2MN6	88.4079380000	-0.0001086132	1.0193000044	284.2012326637	351.8597318230
17	M6	86.9523127000	0.0002364713	1.0193000044	3.8563817659	7.6889020828
18	2MS6	87.9682080000	-0.0000578705	1.0128256329	2.5709211773	358.3888753874

Analysis of Results

The objective is to test whether μ_1 (mean of observed tide) and μ_2 (mean of the predicted tide) are the same.

H_0: $(\mu_1 - \mu_2) = 0$
H_1: $(\mu_1 - \mu_2) > 0$

The *t* statistic was used to test whether the means are different at 95% confidence level.
The number of degrees of freedom of the test statistic is

$v = n_1 + n_2 – 2 = 1224 + 1224 -2 = 2446$

The rejection region for a 95% significance level is t (computed) < $t_{\alpha,y}$ (tables)

$t_{\alpha,y}$ = t0.95,2446 = -1.645

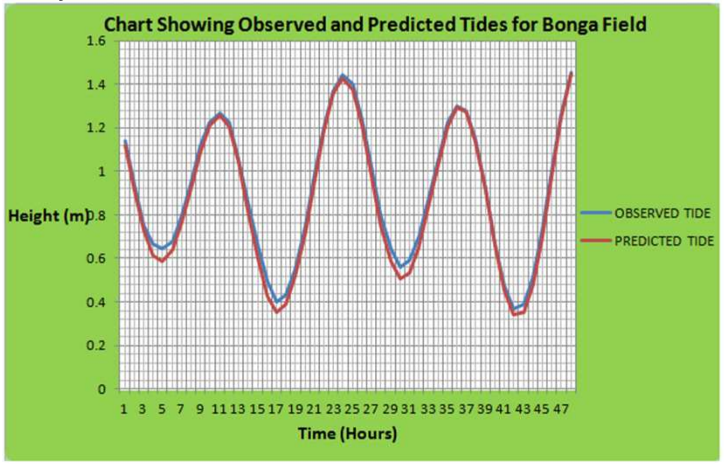
Pooled Variance S_{x1x2} =√{(1223* 0.0000000144 + 1223*0.0000000142)/2446}

t = 0.0000000143

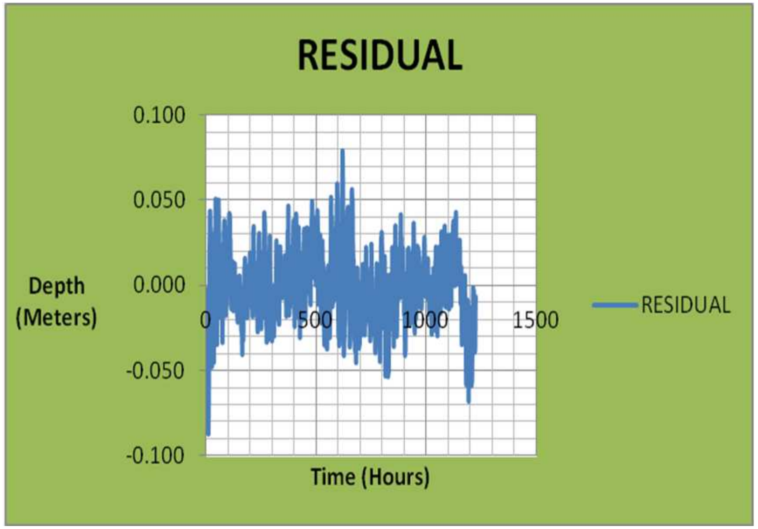
Since t > $t_{\alpha,y}$ we therefore conclude that the mean of the observed tide is equal to the mean of the predicted tide.

Analysis of Results (Continued)

The chart below shows the comparison between observed data for day 51 which was not used for harmonic analysis and predicted data for day 51.



Residuals of Observed and Predicted Tides for 50 days



CONCLUSIONS

- Detailed tidal harmonic analysis carried out 50 days water level data derived from pressure data recorded in 1,000m at Bonga field offshore Nigeria.
- Harmonic constants - amplitudes and the phase lags for eighteen tidal constituents were determined.
- Prediction from 2008 to December 2013 was made at 10 minutes intervals.
- Fifty one days hourly predictions to validate the work done.
- Statistical analysis of the predicted tides with validation data was made and the maximum deviation of the predicted tides from the validation data was 0.08m.
- The accuracy of the harmonic analysis and prediction is high despite the fact that only 50 days data was used for the analysis.

Recommendations

- Tidal data covering a period of at least one year should be collected at deep offshore locations.
- This will allow for better harmonic analysis and prediction to support marine operations in the oil and gas industry.
- Tide Gauge Stations or buoys (with satellite links) should be placed at strategic locations offshore Nigerian for further tidal studies on the Nigerian coastal waters.
- Collaboration efforts between governmental and non-governmental agencies to observe and analyse water current (using classical oceanographic equipment and satellite data) .
- Joint industry projects are recommended around the Nigerian coastal waters to better understand the hydrodynamic forces operating in the Nigerian coastal environment.

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