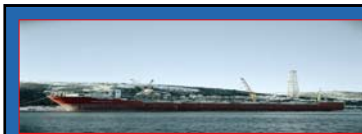

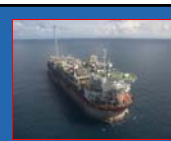


Efficiency and Economy of Automating Displacements for FPSO Pipe Stress Analysis.

Bob Robleto & Jim Williams


Pipe Stress Considerations on an FPSO

Because Floating Production, Storage, and Offloading (FPSO) modules experience significant deflections from wave motion and deck bending. On board piping must be analyzed to assure that it is suitably designed for high cycle fatigue. This is done using the Palmgren-Miner rule by keeping accumulated damage to a value less than 1.0 from deflections occurring during transportation from ship yard to final mooring, hog and sag due to cargo transfer, thermal displacements due to operation, wind, and wave loading.

In order to simplify the acceptance criteria, it is very beneficial to convert accumulated damage into an allowable stress range so that pipe stress engineers can evaluate fatigue in a manner similar to ASME B31.3 stress range. This is not discussed in detail here, but can be done using methods from PD5500, DVN publications and the Fatigue Handbook: Offshore Steel Structures Probabilistic Fracture Mechanics; Tapir 1985.

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Pipe Stress Considerations on an FPSO

Fatigue allowable - example. This will eventually be replaced by ASME B31.3 App W methods.

3. On-site Wave Case

For t ≤ 22mm,

$$Sr_{3,100} = \left(\frac{E}{2.09\times10^5} \times \sqrt[m]{\frac{(\ln N_3)^{(m/h)}}{\Gamma\left(1+\frac{m}{h}\right)} \times \frac{A\times D_3}{N_3}} \right) \div \left(\frac{\ln(N_3)}{\ln(5\times N_3)} \right)^{1/h}$$

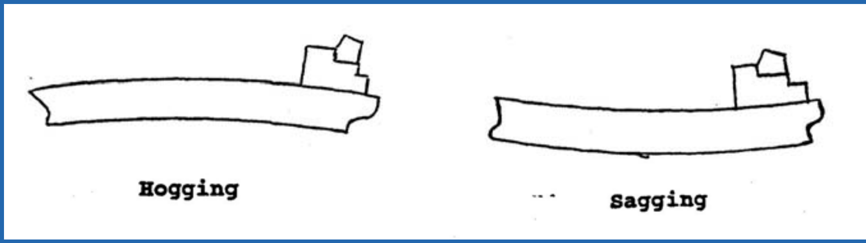
For t > 22mm,

$$Sr_{3,100} = \left(\frac{E}{2.09\times10^5} \times \sqrt[m]{\frac{(\ln N_3)^{(m/h)}}{\Gamma\left(1+\frac{m}{h}\right)} \times \frac{A\times D_3}{N_3}} \times \left(\frac{22}{t}\right)^{\frac{1}{4}} \right) \div \left(\frac{\ln(N_3)}{\ln(5\times N_3)} \right)^{1/h}$$

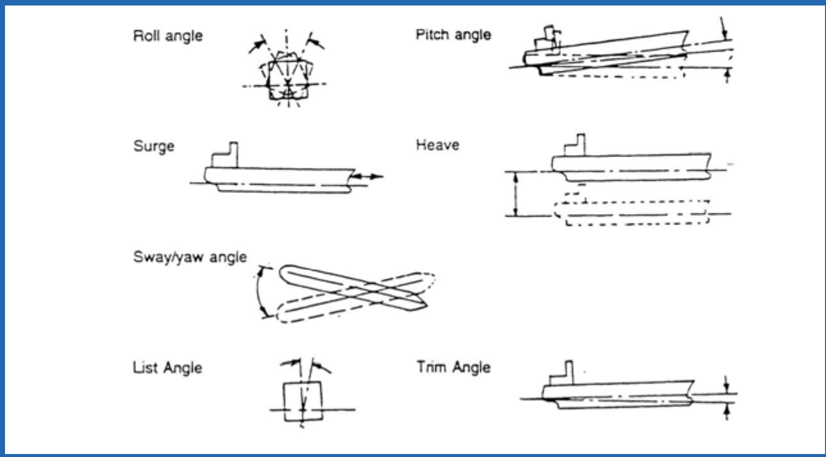
Damage Ratio	D3 =	0.89		
Overall Length of FPSO	L =	325	m	
Total Number of Cycles in 100 Years	N3 =	1.16E+08	Cycles	(from Metocean Data)
Negative Inverse Slope	m =	3		
Weibull Shape Distribution Parameter	h =	0.904		
Gamma Function	G =	9.097		
Graph Constant	A =	3.52E+11	MPa	
Allowable Stress Range for 20 Years	Sr3, 20 =	164.260	MPa	
Allowable Stress Range for 100 Years wav	r3, 100 =	**180.087**	MPa	
Equivalent Effective Stress Range Factor	k1 =	**0.075**		

Ship Motion – Hog & Sag

To consider the effects of deck bending and module sway hull deflection data is used to compute displacements at restraint points in the pipe stress analysis model. Multiple loading cases require this process to be repeated for each loading case being considered. Following are illustrations of the ship motions that are analyzed.



Ship Motion – wave action
pitch & roll; surge & heave; sway & yaw; list and trim



Pipe Stress Considerations on an FPSO

An FPSO analysis normally requires 7 loading cases to accumulate fatigue damage:

1. Thermal
2. Sustained weight & pressure
3. Hog/sag
4. Wind
5. On-site wave loading
6. In-transit wave loading
7. Extreme loading case; hurricane or peak wave

Utilize Hull Data to Compute Module Displacements

Hull Data is used as the starting point for obtaining the displacements for the loading conditions to be analyzed. This data is usually in tabular form containing hull displacements and associated moments for low cycle events such as loading and unloading and high cycle events where the displacements of the hull are at a maximum or minimum for a 100 year storm. Below is a sample excerpt from a table in a naval architects report.

N.A from base line		15.74	m							
On-site	Static	Ballast	Hogging	C.3101						
x Loc	0	5	10	15	20	25	30	35	40	45
EI	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14
M	2698175	30523020	1.1E+08	2.27E+08	3.6E+08	4.92E+08	6.06E+08	6.89E+08	7.33E+08	7.65E+08
y'	0	-2.3E-07	-1.2E-06	-3.5E-06	-7.5E-06	-1.3E-05	-2.1E-05	-3E-05	-3.9E-05	-4.9E-05
y	0	-5.7E-07	-4.1E-06	-1.6E-05	-4.3E-05	-9.5E-05	-0.00018	-0.00031	-0.00048	-0.0007
z from neutral axies		16.76								
x disp	0	3.79E-06	1.98E-05	5.82E-05	0.000125	0.000222	0.000347	0.000495	0.000657	0.000828
On-site	Dynamic	Ballast	Hogging	C.3101						
x Loc	0	5	10	15	20	25	30	35	40	45
EI	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14
M	-2E+08	-9E+07	20078965	1.3E+08	2.4E+08	3.5E+08	5.22E+08	6.94E+08	9.09E+08	1.14E+09
y'	0	1.97E-06	2.44E-06	1.42E-06	-1.1E-06	-5.1E-06	-1.1E-05	-1.9E-05	-3E-05	-4.4E-05
y	0	4.92E-06	1.6E-05	2.56E-05	2.65E-05	1.1E-05	-2.9E-05	-0.00011	-0.00023	-0.00041
z from neutral axies		16.76								
x disp	0	-3.3E-05	-4.1E-05	-2.4E-05	1.83E-05	8.56E-05	0.000185	0.000324	0.000506	0.00074
On-site	Static	MidC	Sagging	D.5308						
x Loc	0	5	10	15	20	25	30	35	40	45
EI	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14	3.67E+14
M	1170539	46616178	1.23E+08	1.57E+08	1.24E+08	7519038	-2.3E+08	-6.1E+08	-1.1E+09	-1.5E+09
y'	0	-3.3E-07	-1.5E-06	-3.4E-06	-5.3E-06	-6.2E-06	-4.7E-06	1.02E-06	1.24E-05	3E-05
y	0	-8.1E-07	-5.3E-06	-1.7E-05	-3.9E-05	-6.8E-05	-9.5E-05	-0.0001	-7.1E-05	3.54E-05
z from neutral axies		16.76								
x disp	0	5.45E-06	2.48E-05	5.67E-05	8.87E-05	0.000104	7.84E-05	-1.7E-05	-0.00021	-0.0005

Utilize Hull Data to Compute Module Displacements

This data can be curve fit to provide deck deflections and rotations along the length of the vessel using Roark's beam formula.

$$EI\left(\frac{d^2 y_c}{dx^2}\right) = M$$

Using simple boundary conditions, integration constants can be computed and subsequent integration provides slopes and deflections at any point on the deck. This results in much smoother data steps than table lookups and interpolations can provide.

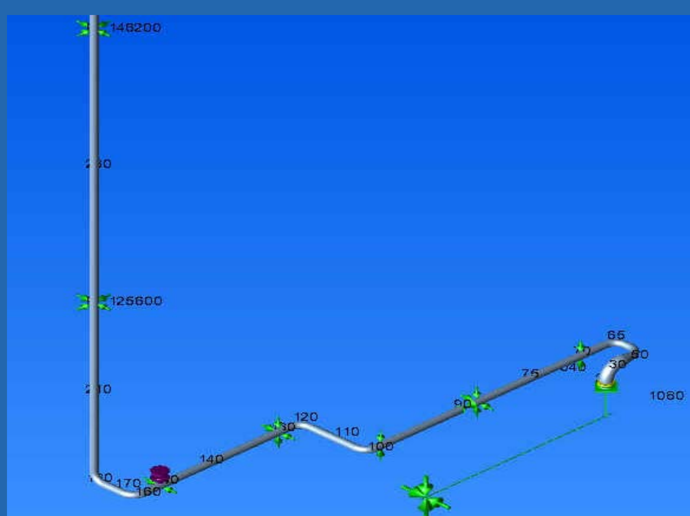
Using the computed deck motion and structural mechanics we can compute module deflections for any point along the deck or in a module.

Create a Pipe Stress Model and Locate Restraints

The Pipe Stress engineer must first create a Caesar II input file. This can be done most efficiently using a PDMS to Caesar interface to automatically create a Caesar II neutral file for import or it can be entered manually from a 3D model extract or isometrics.

The preferred restraint nodes are identified and directional restraints are applied to the node with a corresponding connect node. The connect node will contain the displacement data that is computed by the displacement generator.

Sample Caesar II Stress Isometric

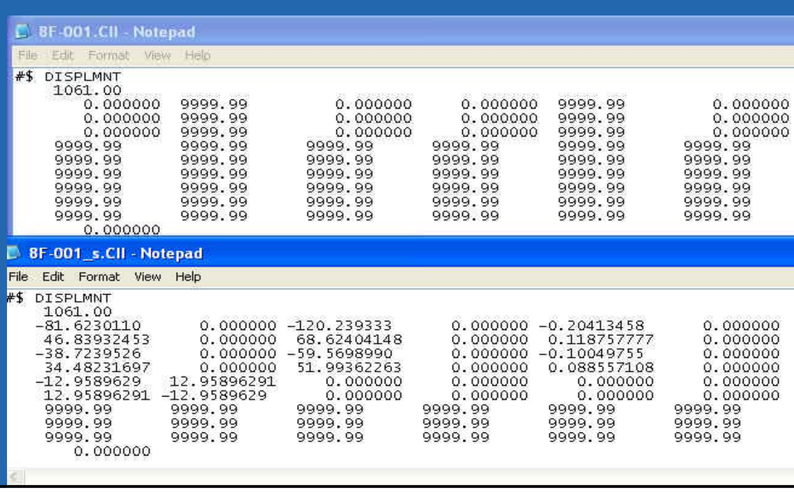


Export the Caesar II Geometry

After the Caesar II model is complete and back checked it's time to export the neutral file. This is done using the external interface feature in the Caesar II menu as shown below.

Sample Neutral File

The neutral file is a text file echo of the input. The original geometry with the restraints is used to create the input neutral file. A sample displacement section of a neutral file before and after processing is shown below. In this format 9999.99 represents a blank field.



8F-001.CII - Notepad

```
#$ DISPLMNT
  1061.00
     0.000000   9999.99          0.000000     0.000000   9999.99          0.000000
     0.000000   9999.99          0.000000     0.000000   9999.99          0.000000
     0.000000   9999.99          0.000000     0.000000   9999.99          0.000000
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
     0.000000
```

8F-001_s.CII - Notepad

```
#$ DISPLMNT
  1061.00
 -81.6230110      0.000000 -120.239333      0.000000 -0.20413458      0.000000
  46.83932453     0.000000   68.62404148    0.000000  0.118757777     0.000000
 -38.7239526      0.000000  -59.5698990     0.000000 -0.10049755      0.000000
  34.48231697     0.000000   51.99362263    0.000000  0.088557108     0.000000
 -12.9589629   12.95896291     0.000000     0.000000    0.000000      0.000000
  12.95896291 -12.9589629      0.000000     0.000000    0.000000      0.000000
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
  9999.99       9999.99       9999.99      9999.99       9999.99       9999.99
     0.000000
```

Generating Displacements at Restraints

The next step is to process the neutral file using an EXCEL macro that reads the file and replaces the blank displacements on the connect nodes with actual module deflections based on the restraints' three dimensional coordinates relative to the ships origin.

B	C
Location of DNA file should be in same directory as neutral file!	C:_Piping Presentation\2010 OTC conference\OTC_DNA.txt
Job Description	*Primary*
Project Name:	*FPSO Topsides*
Problem No:	*S7-011*
Analyst:	*R Robleto*
Path:	*C:_Piping Presentation\2010 OTC conference*
Name Input Neutral File:	*S7-011*
Node Number of known location	*430*
North coordinate	*351850*
East coordinate	*127592*
elevation	*102821*
Probable Storm Period	*100*

Caesar II Automated Input

Generating Displacements at Restraints

Enter the calculation number, node, and ship coordinates to enable the displacement generator to compute displacements.

FPSO TOPSIDES

PENDING

resume

Document No.	
Calculation No.	S7-011

Flip Module Motion

CAESAR II Node No.	PDMS Longitudinal Coordinate (mm)	PDMS Vertical Coordinates (mm)	PDMS Lateral Coordinate (mm)	Restraint Elevation	Type Module	Location Module Name	Longitudinal Stiffness Ht/defl	Lateral Stiffness Ht/defl	Module Motion : P=Yes N=No	D1 = On-site Static Sagging DX (mm)	D1 DZ (mm)	D1 RY (deg)	D2 = On-site Static Hogging DX (mm)	D2 DZ (mm)	D2 RY (deg)
13120	351010	100045	127233	100000	H	S7G	NA	NA	P						
13110	351850	100045	127853	100000	H	S7G	NA	NA	P						
321	359197	104430	128359	106000	M	S8G	300	300	N						
381	364997	104430	128069	106000	M	S8G	300	300	N						
401	369997	104430	128069	106000	M	S8G	300	300	N						
461	373497	104200	127500	106000	M	S8G	300	300	N						
841	370377	111813	127122	114000	M	S8G	300	300	N						
721	378041	111813	127322	114000	M	S8G	300	300	N						
581	373228	105511	126100	106000	M	S8G	300	300	N						

Generating Displacements at Restraints

After the file is loaded and the analyst is satisfied that it's correct he processes the file to compute displacements.

FPSO TOPSIDES

Final

Document No.

Calculation No. S7-011

Microsoft Excel

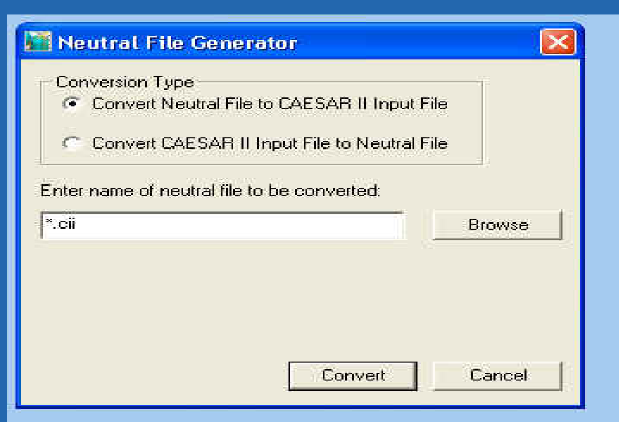
New Neutral files are complete!

OK

CAESAR II Node No.	PDMS Longitudinal Coordinate (mm)	PDMS Vertical Coordinates (mm)	PDMS Lateral Coordinate (mm)	Restraint Elevation	Type Module	Location Module Name	Longitudinal Stiffness Ht/defl	[illegible] Stiffness Ht/defl	[illegible]e Motion : P=Yes N=No	[illegible]atic Sagging DX (mm)	DZ (mm)	RY (deg)	D2 = On-site Static Hogging DX (mm)	DZ (mm)	RY (deg)
13120	351010	100045	127233	100000	H	S7G	NA	NA	P	-35.10	-250.16	-0.15865	23.25	150.25	0.10725
13110	351850	100045	127853	100000	H	S7G	NA	NA	P	-35.39	-247.88	-0.15991	23.37	148.70	0.10775
321	359197	104430	128359	106000	M	S8G	300	300	N	-68.40	-227.41	-0.18370	43.94	134.85	0.11500
381	364997	104430	128069	106000	M	S8G	300	300	N	-68.43	-208.81	-0.18370	43.93	123.21	0.11500
401	369997	104430	128069	106000	M	S8G	300	300	N	-68.46	-192.78	-0.18370	43.91	113.17	0.11500
461	373497	104200	127500	106000	M	S8G	300	300	N	-68.48	-181.56	-0.18370	43.91	106.15	0.11500
841	370377	111813	127122	114000	M	S8G	300	300	N	-94.11	-191.60	-0.18370	59.97	112.40	0.11500
721	378041	111813	127322	114000	M	S8G	300	300	N	-94.15	-167.03	-0.18370	59.96	97.01	0.11500
581	373228	105511	126100	106000	M	S8G	300	300	N	-68.48	-182.42	-0.18370	43.91	106.69	0.11500

Re-import Neutral File into Caesar II for Analysis

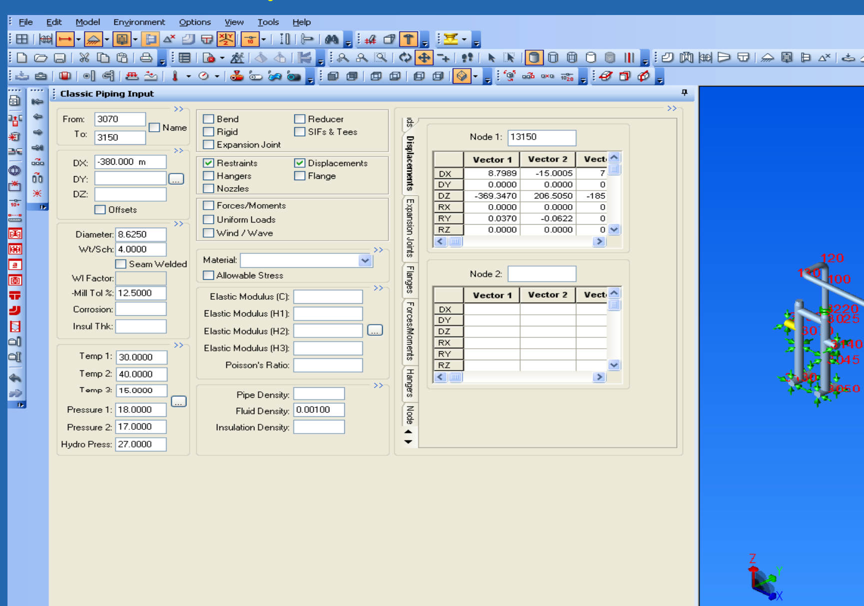
The next step is to re-import the neutral file into Caesar II for analysis. This is done using the Caesar II import utility. This new file complete with displacements replaces the previously exported file.



Re-import Neutral File into Caesar II for Analysis

Following is an example of a converted Caesar II file with imported displacements.

Re-imported Neutral File



Summary

By applying a significant amount of automation substantial schedule time and cost savings can be achieved by the pipe stress group for both engineering contractor and owner.

Questions?