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Efficiency and Economy of Automating Displacements for FPSO Pipe Stress Analysis

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Abstract

Because Floating Production, Storage, and Offloading (FPSO) modules experience significant deflections from wave motion as well as hog/ sag, on board piping must be analyzed to assure that it is suitably designed for high cycle fatigue. This is done by keeping accumulated damage to a value less than 1.0 using the Palmgren-Miner rule. In order to simplify the acceptance criteria, a method must be developed to convert allowable accumulated damage into an allowable stress range that pipe stress engineers are accustomed to evaluating. This is done by combining methods from PD5500, DVN publications and the Fatigue Handbook: Offshore Steel Structures Probabilistic Fracture Mechanics; Tapir 1985.

To consider the effects of deck bending and module sway, displacements must be calculated from the naval architects hull data for every restraint in the pipe stress analysis model. Multiple loading cases require this process to be repeated for each loading case being considered.

Most engineering companies have developed a technique for automating the computation of module and/or deck displacements. These values once computed must be entered into the pipe stress analysis software. This task normally requires 8 to 24 hours per calculation depending on size and complexity of the piping system being analyzed. Since the data has been manually entered it must also be checked, which requires another 4 to 12 hours.

If a method can be found to calculate displacements and then automatically load them into the pipe stress analysis software, significant cost savings can be realized through reduced engineering work hours. On a project requiring 100 calculations, the potential savings using a reduction of 25 hours per calculation will be 2500 hours. This will result in a cost savings of $225,000 using $90/ hour as the cost basis. Savings could range as high as $700,000 on large FPSO's.

By using the Caesar II neutral file writer to import/ export input data, it is possible to automate this process. An engineer, after entering the piping geometry into Caesar II and assigning restraints at the applicable nodes, can export a neutral file which can be read into displacement generating software (this is a company proprietary tool) where the displacements and rotations are applied to each restraint node. This enhanced neutral file can be re-imported into Caesar II ready for analysis complete with displacements and rotations. The most complex calculations can be processed in less than 30 minutes. By automating this process it may be possible to reduce FPSO pipe stress analysis time by as much as 40%.

FPSO Piping Fatigue Analysis Background:

FPSO pipe stress fatigue analysis is essentially a 6 step process:

1. Determine the allowable stress range for the piping material. This is a complex subject by itself and will not be discussed in this paper.
2. Develop the naval architectural ship/hull data into a form that can provide module displacements
3. Create a pipe stress analysis model and add restraints.
4. Add module displacements into the pipe stress analysis model.
5. Analyze the various load combinations to assure stress range compliance.
6. Deliver reports that document calculation results.

This paper will discuss steps 2, 3, and 4.

Fatigue failure has occured when a crack initially forms. Continued cyclic loading will cause small fissures to grow into thru-wall cracks resulting in loss of containment. The purpose of FPSO pipe fatigue analysis is to provide a design that avoids fatigue failure.

An FPSO normally requires 4 base loading cases be analyzed to accumulate fatigue damage:

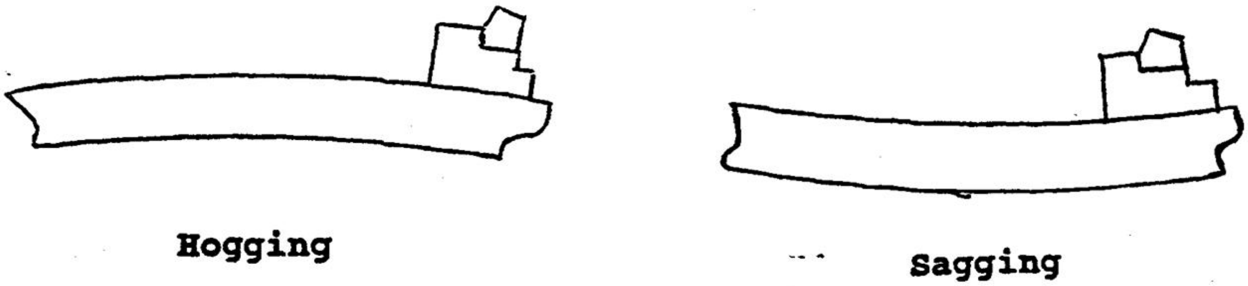
1. Extreme loading case; hurricane or peak wave
2. Thermal, sustained weight, hog/sag and wind
3. On-site wave loading
4. In-transit wave loading

An FPSO analysis varies from most other fatigue analysis problems by it’s large number of degrees of freedom (degrees of motion). This requires the engineer to calculate for each degree of freedom an associated loading or displacement that is imparted to the piping system through the restraint from the module or deck upon which the piping is supported.

Piping Engineering must perform a rigorous and repeatable analysis that can be easily checked and verified. Reports must capture the critical results of the fatigue analysis which includes damage totals for each system analyzed and locations of peak stresses. On an FPSO, every point on the piping system that is supported and restrained will experience displacements and accelerations which over time accumulate to produce damage. If done manually this process requires an enormous amount of calculations to develop the input data. The following process describes how this may be accomplished in an automated, efficient and accurate manner.

Some typical ship motions are illustrated below.

Hog and Sag from cargo loading:



Pitch and Roll - Surge and Heave - Sway and Yaw - List and Trim

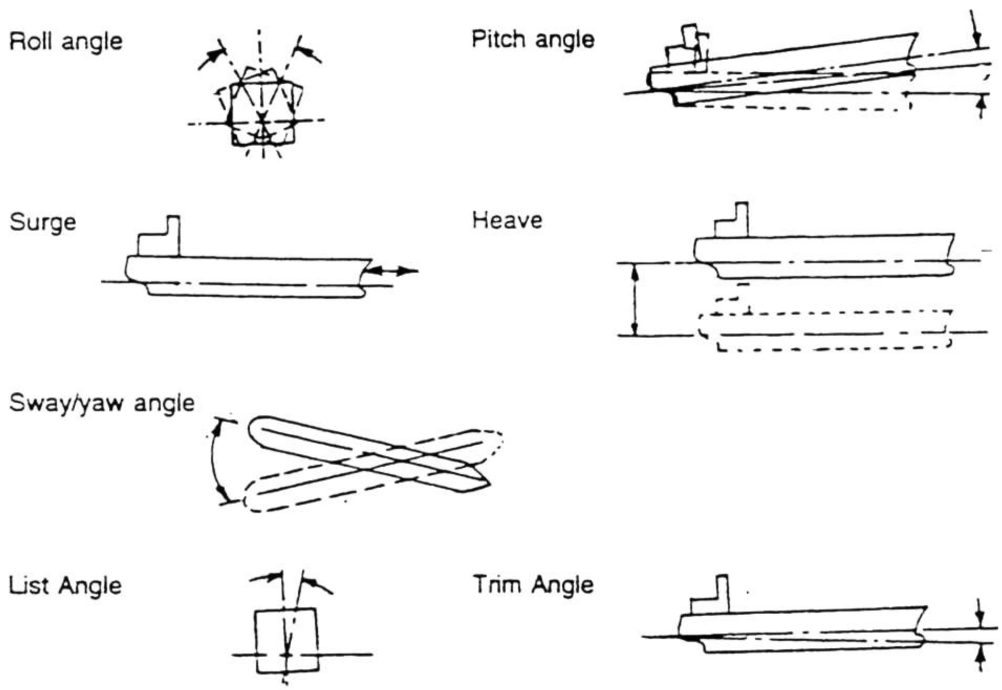


Figure 1 – Typical examples of ship motion

In addition to the induced loading from ship/ deck motion, the piping itself cycles thermally as the FPSO produces and laterally as wind blows across its surface.

The automated design process:

From the six step process decribed above, steps 2, 3, and 4 are discussed herein.

STEP 2) Develop the ship data into a form that can provide module displacements

Ship/Hull Naval Architectural Data:
Naval Architect 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 the 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	-0.0006

Figure 2 – Typical examples of Naval Architect data

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. Using the computed deck motion and structural mechanics we can compute module deflections for any point along the deck or in a module. This completes step 2.

STEP 3) Create a pipe stress model and locate restraints

This task is common for any pipe stress analysis and is performed in the same manner for any project, offshore or onshore.

Beginning with a 3D model extract or isometrics, the pipe stress engineer codes the piping geometry into the Caesar II software. The preferred restraint nodes are identified and a directional restraint(s) is applied to the node and a corresponding connect node is defined. The connect node will contain the displacement data that is to be loaded in the next step.

Below is a sample Caesar II stress Isometric, which we later add displacements to.

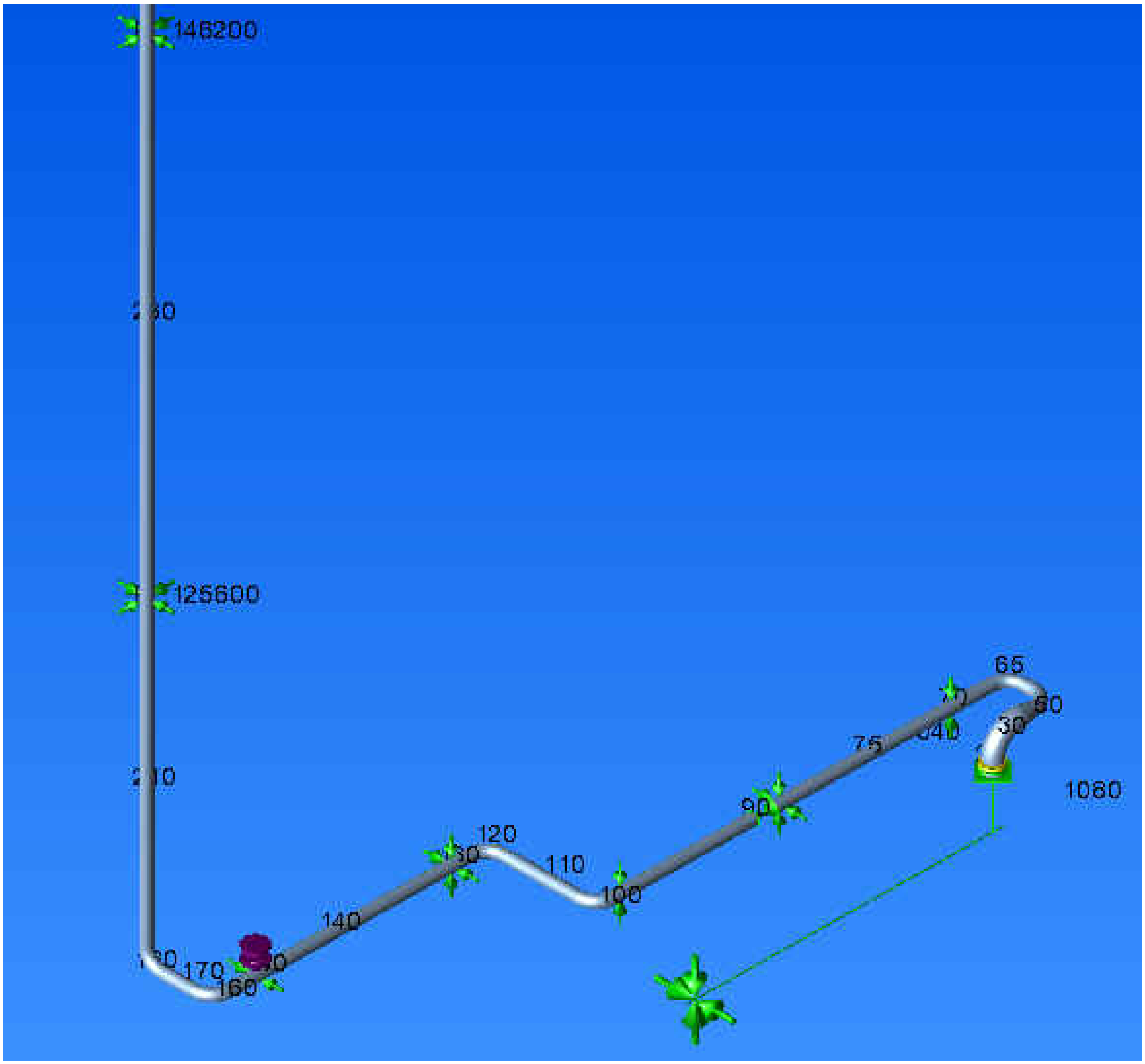


Figure 3 – Typical Caesar II input geometry

STEP 4) Add module displacements into the pipe stress analysis model.

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.

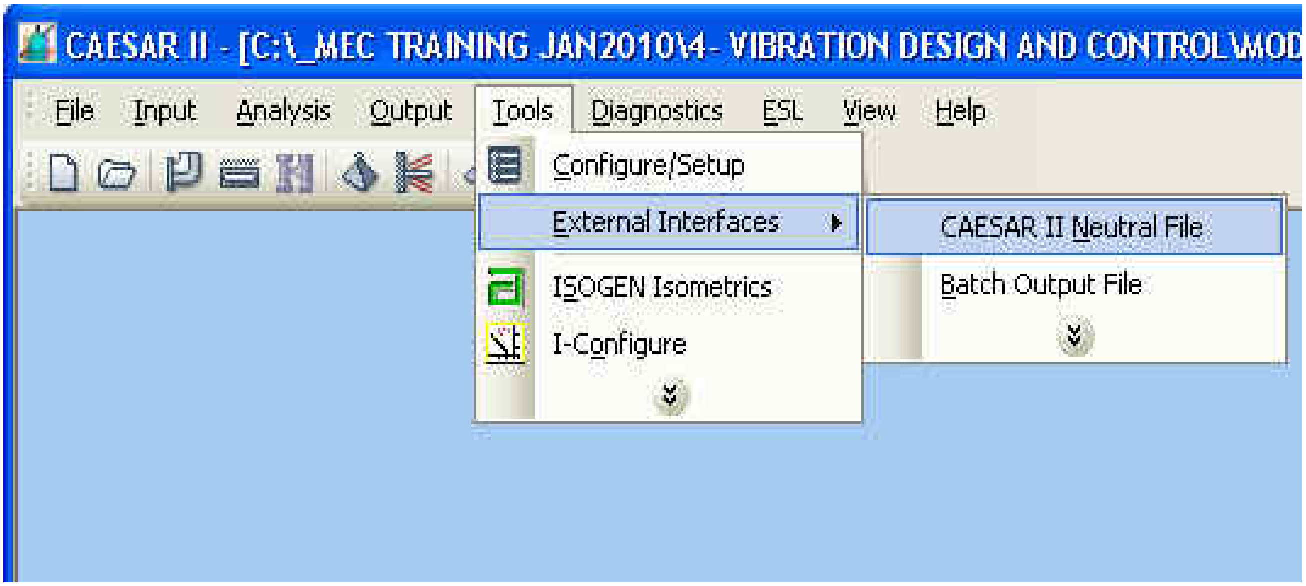
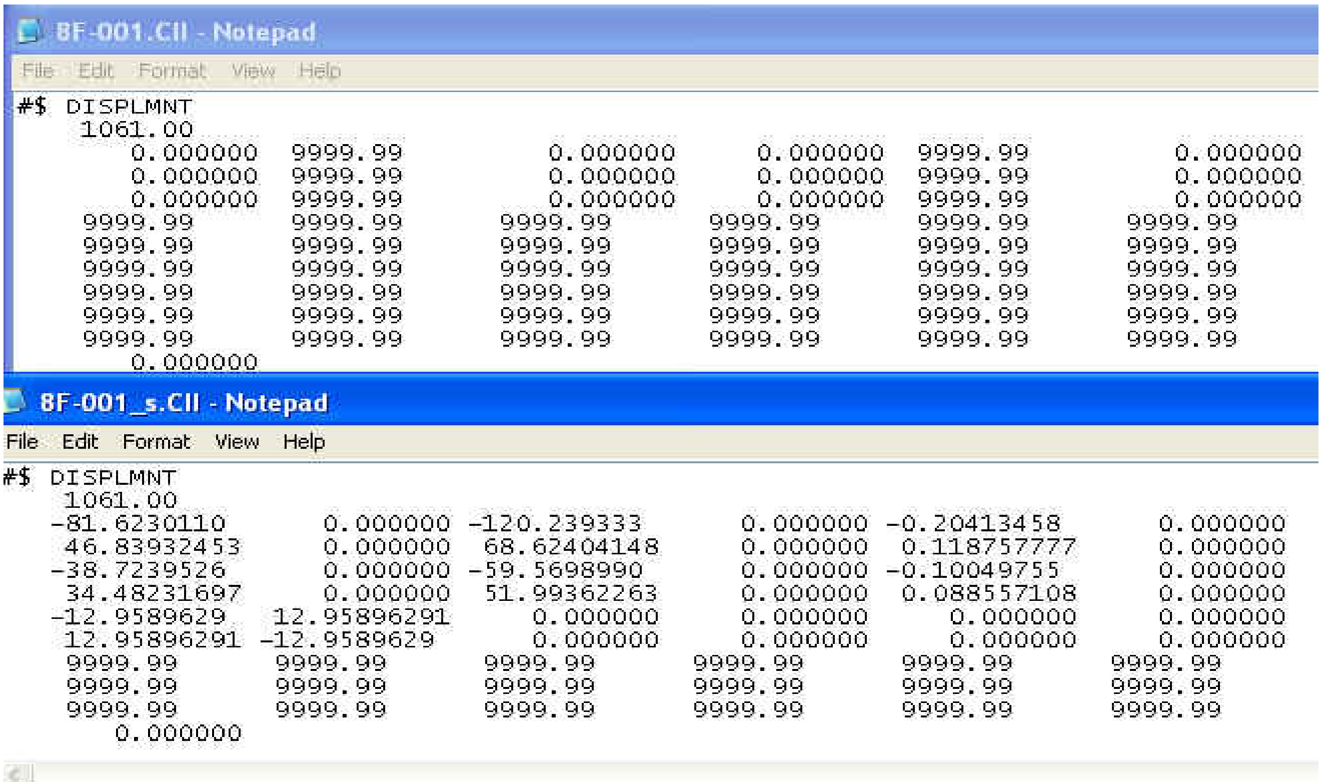


Figure 4 – Typical Caesar II interface screen

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. 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' coordinates relative to the ships origin. 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

File Edit Format View Help

```
#$ 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

File Edit Format View Help

```
#$ 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
```

Figure 5 – Typical Caesar II neutral file data

The processed file is now ready to reload into Caesar II using the same interface feature used to export the data, except the import button is selected. A sample import screen is shown below.

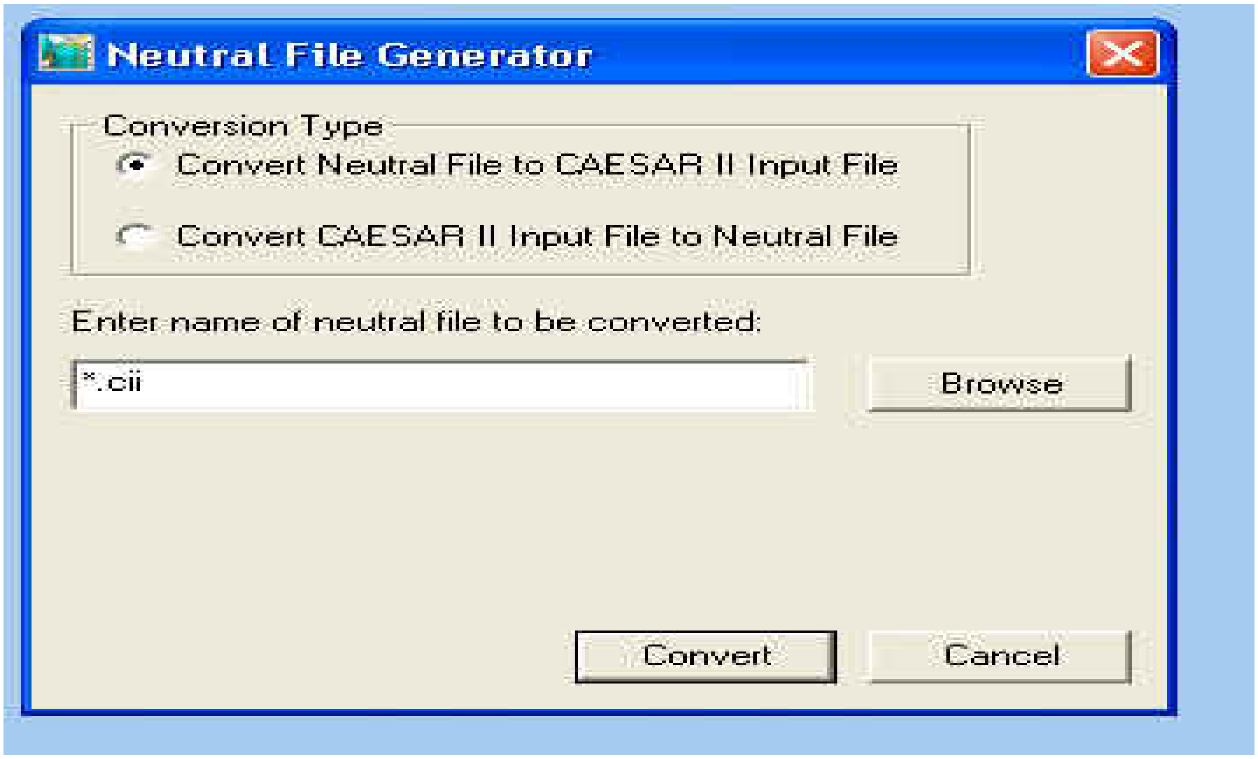


Figure 6 – Typical Caesar II neutral file import screen

This file replaces the original Caesar II input file and the analysis is ready to be run.

This procedure has many advantages.

1. Highly accurate and repeatable.
2. Eliminates the tedium of computing and entering an enormous amount of displacement data.
3. By utilizing the piping coordinates relative to the ships coordinate system the displacement generator can accomodate locations within modules by adding structural motion or flare structures which have their own displacement/deflection data in addition to the deck motion.
4. Rotational information can also be used which often decreases the amount of conservatism in the analysis and improves the accuracy of the analysis.
5. Piping engineers who do not have much experience in FPSO design have a much shorter learning curve. The Piping engineer’s focus can be on resolving stress issues rather than spending time doing input.
6. A source of potential errors and rework is minimized.