International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Two-Dimensional Verification Model for Buoyancy Using Explicit Code

Mohamed Abdalla Almheriegh*

Assistant Professor, Department of civil Engineering Faculty of Engineering - Tripoli University P O Box 82677, Tripoli, Libya

Email: malmherigh@gmail.com

Abstract

Results attained from an advanced finite element analysis code such as the explicit LS-DYNA3D code need be verified on small models before we can jump to the final judgment about its validity. This paper outlines the creation of a simple 2-D model for the purpose of assuring such validity; the work is intended to check the capability of ‘ALE’ (Arbitrary Lagrangian Eulerian) powerful feature in the named code to model fluids elements i.e. air or water. Code results are validated against hand calculation and Fast Fourier Transform ‘FFT’ and have shown good agreement in terms of; element stresses, nodal forces and kinetic energy dissipation.

Keywords: verification of floating wind converter analysis; 2-D analysis of floating wind energy turbine; modeling of floating wind energy turbine by LS-DYNA3D code; 2-D floating wind converter for LS-DYNA3D code modeling; the use of Fast Fourier Transform (FFT) approach.

1. Introduction

The ‘ALE’ (Arbitrary Lagrangian Eulerian) feature available in LS-DYNA3D has been used for many fluid-structure interaction problems, mainly for transient impact analyses where severe mesh deformation of the Lagrangian material presents a problem [5,6,7].

---

* Corresponding author.

To date though there appears to be little information specifically on modelling buoyancy effects and subsequent dynamics. Although we are not expecting the mesh to deform in this case, it could provide the appropriate buoyancy and sought fluid material effects. This could however be at the expense of increased elements and solution runtime, so model complexity will need to be monitored carefully. Typically, if using 'ALE', the turbine will have to float in a fluid 'half-space' of a size which will best represent the effects of the pseudo-infinite sea. The boundaries will need careful consideration, and perhaps employ non-reflecting (energy absorbing) representation. It is this representation which will be employed in this work and a study of buoyancy conducted for verification purposes.

2. The Model

The model is shown in Figure 1 and consists of a floating two-dimensional box Figure 2, of one solid element thickness floating under its own body force and buoyancy force exerted by water shown in Figure 3. Above this is the air part shown in Figure 4.

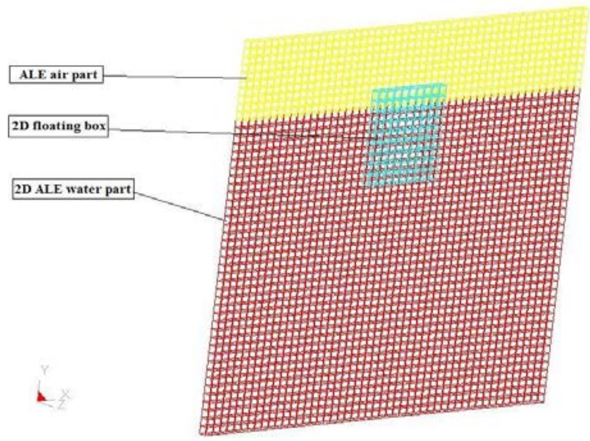


Figure 1: The 2D model, all parts

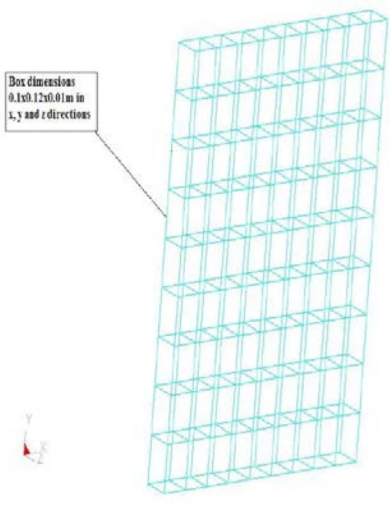


Figure 2: 2D-floating box

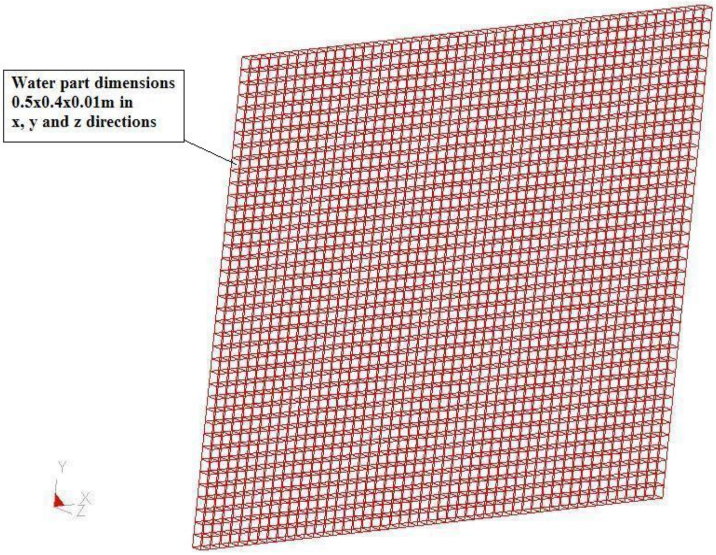


Figure 3: 2D-ALE water part

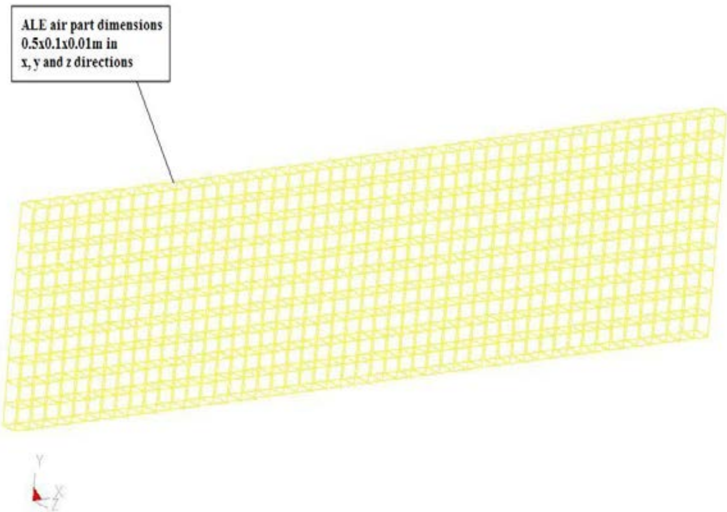


Figure 4: 2D-ALE air part

3. Analytical results of the 2D model

In the next phase the twelve cases reported in Table 1 were run using LS-DYNA3D code. The different buoyancy positions were based on different densities and the model were allowed to float till sufficient submerged height is achieved.

The assumed position(s) of this float in eight configurations of interest are shown in the following Figures 5 through Figure 12. The results are discussed in Section 3 & 4 of this paper.

Table 1: Stability positions for buoyant small 2-D box

Case	h m	γ kg/m^3	$\Theta_{theoritical}$ degree	metacentric height mm	stability condition
1	0.010	087.980	0.00	26.055	stable
2	0.013	113.600	0.00	9.3090	stable
3	0.016	136.900	0.00	0.0080	stable
4	0.027	228.070	44.9	-15.440	unstable
5	0.040	341.670	53.7	-19.167	unstable
6	0.053	455.271	56.5	-17.715	unstable
7	0.067	569.729	56.5	-14.156	unstable
8	0.080	683.333	53.7	-9.5830	unstable
9	0.093	796.938	44.9	-4.4180	unstable
10	0.100	854.170	32.4	-1.6670	unstable
11	0.104	888.100	0.00	0.00100	stable
12	0.105	900.000	0.00	0.59100	stable

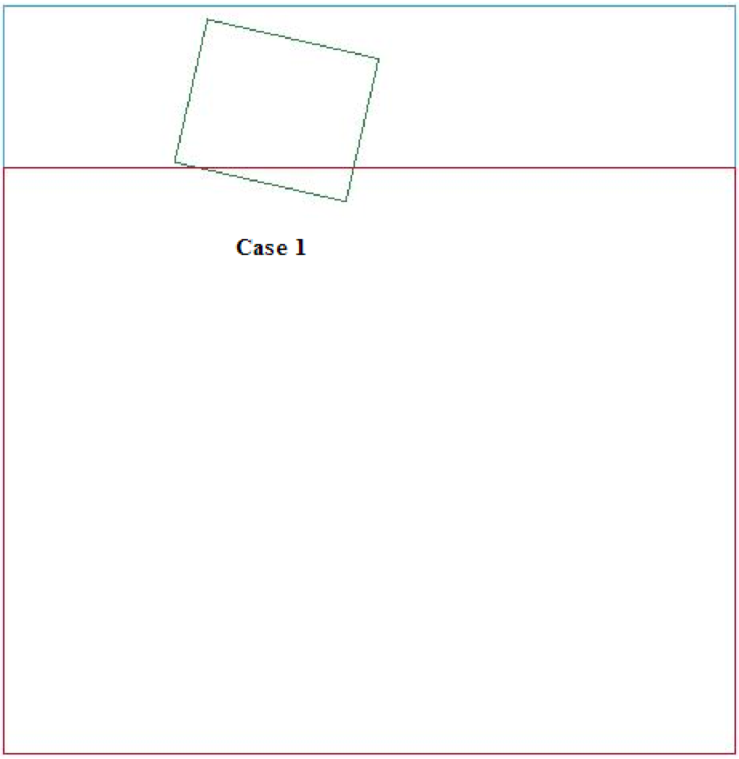


Figure 5: Code estimated position of the float Case 1

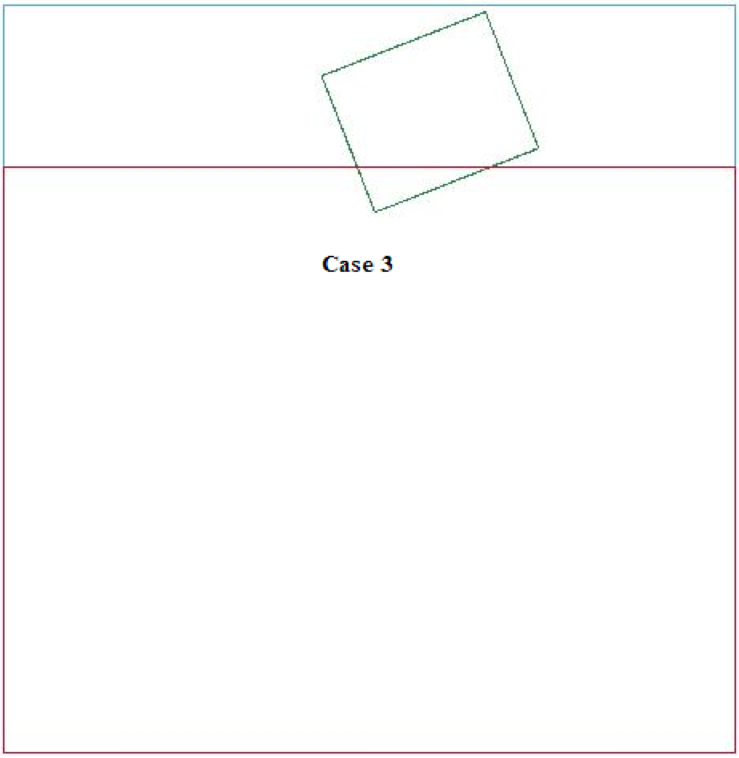


Figure 6: Code estimated position of the float Case 3

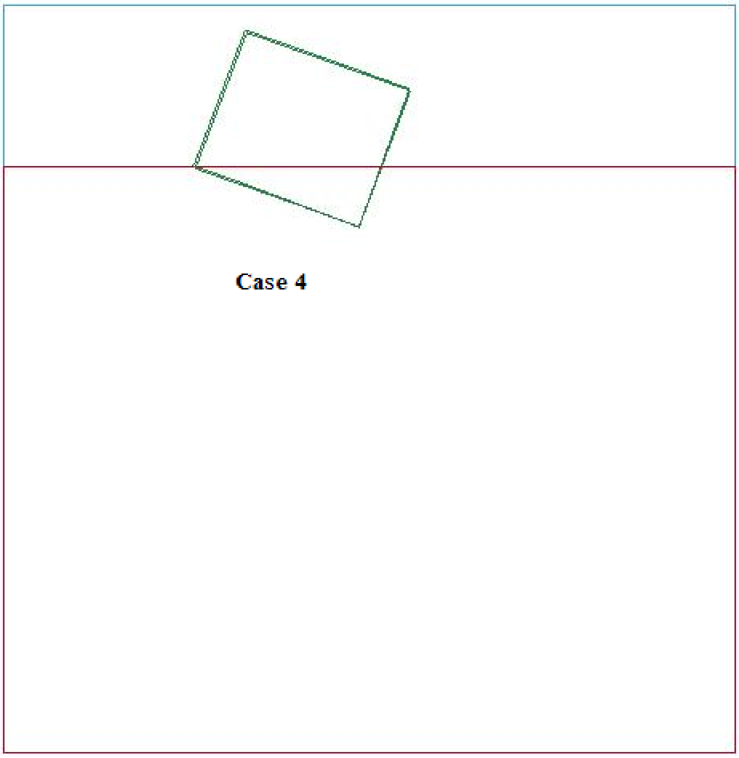


Figure 7: Code estimated position of the float Case 4

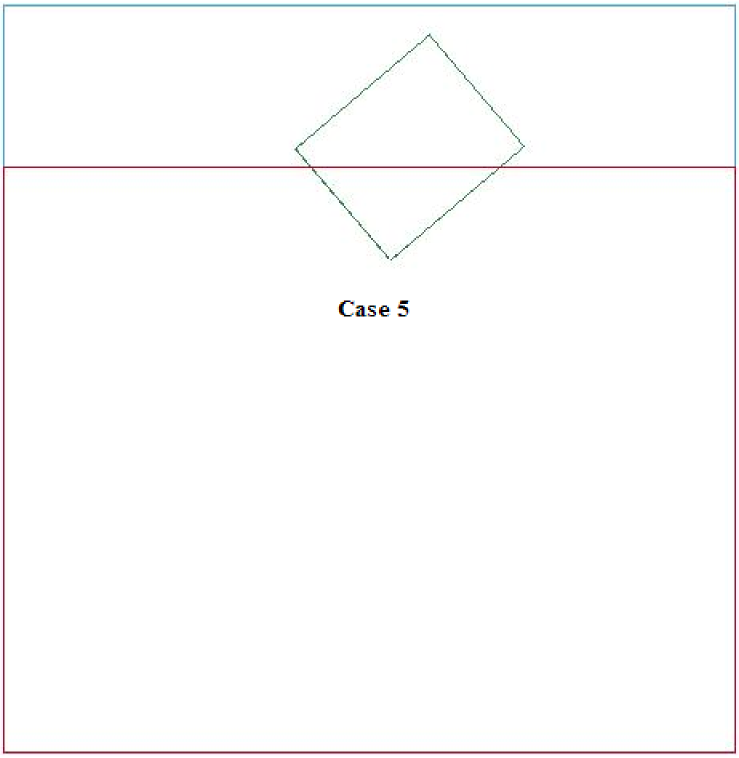


Figure 8: Code estimated position of the float Case 5

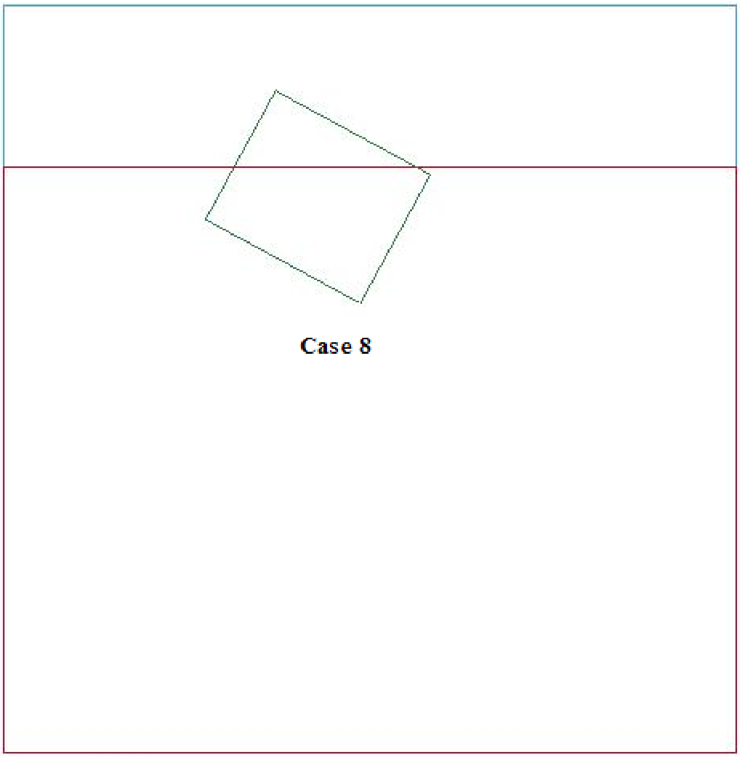


Figure 9: Code estimated position of the float Case 8

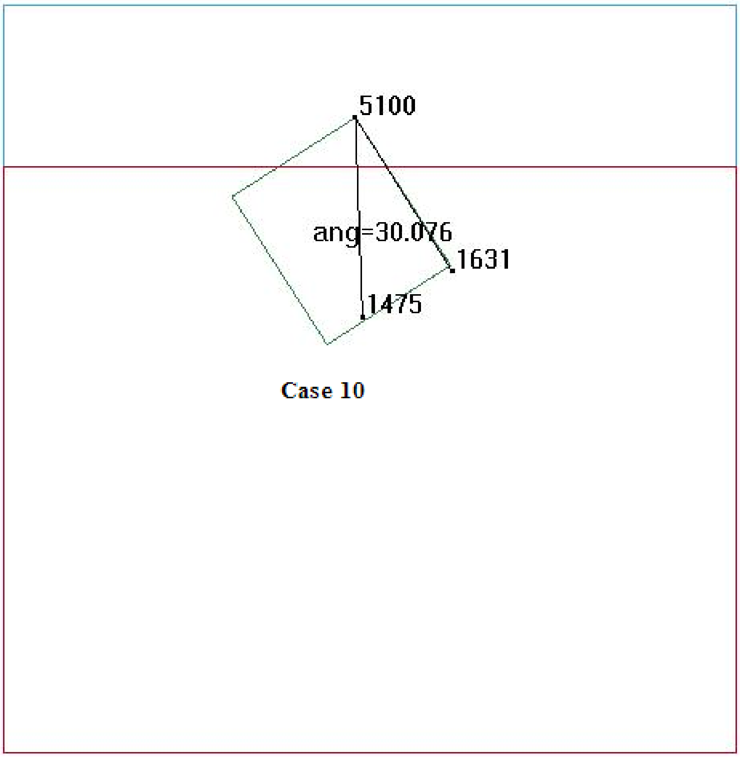


Figure 10: Code estimated position of the float Case 10

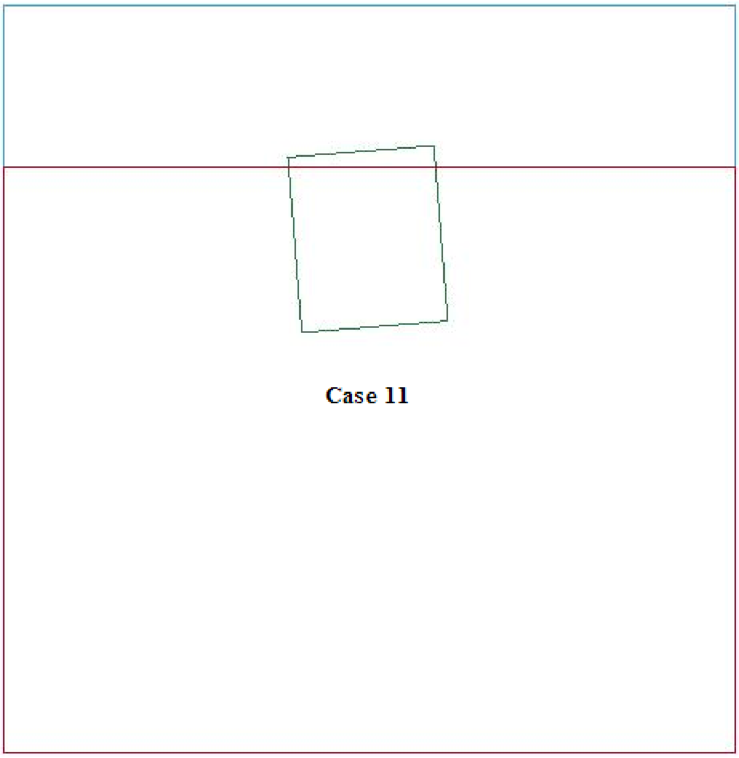


Figure 11: Code estimated position of the float Case 11

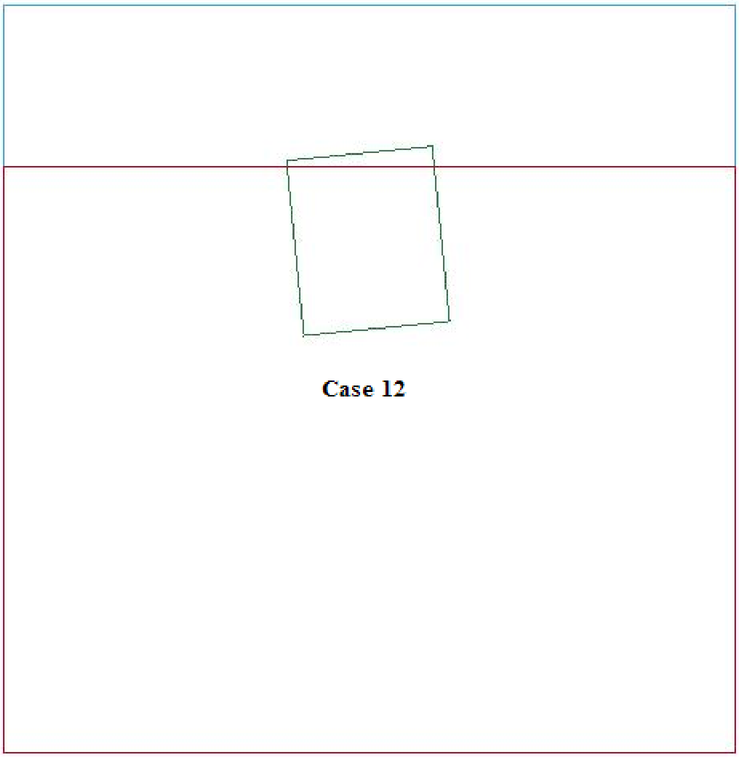


Figure 12: Code estimated position of the float Case 1

4. Further Verification and Validation

Further verification and validation process need be carried out as follows;

Bigger; verification models must be created in a successive manner starting with the lower parts and running them to insure the expected behaviour, once assured the next part is added and checked. By this, assurance of materials, section properties, restraints and boundary conditions is achieved.

At least three small characteristic models need be created and are intended to provide confidence in the behaviour of the full-scale model. To start with, a visual inspection of the floating body in the postprocessor attached to LS-DYNA3D package will provide a first check of the required behaviour, the body should be seen to ‘bob’ in the water until it equilibrates. Further verification is carried as follows:

a) Element pressures and stresses as well as nodal forces for selected regions of the structure were verified against hand calculated values and a good match should be achieved.

b) The kinetic energy should die out which is indication of attaining the system stability.

c) Energy ratio (total energy divided by initial energy) should ideally be equal to unity, hence the closer to this value the better.

d) Linear stresses and strains in the cable elements are studied and compared to the expected values to assure the desired behaviour of the cables.

e) The database function (*database_fsi) to be used in conjunction with ‘constrained Lagrange in solid’ function is created as “ASCII” file in ‘d3plot’ it is very useful in confirming that the uplift force calculated by the code matches with the total weight of the floating body. Stresses and average pressure are also useful tools for verification, the existence of these files and the correlation of their values is good indication that the coupling (contact) between ‘ALE’ elements and Lagrangian solid elements is achieved properly.

Based on the verification and assured reliability of results, such results will be screened, presented in a useful format and can be used for constructive judgement for the structural performance of the model.

Analytical verification is done using the time history values of the analysis as follows:

The density of the floating box is chosen according to the buoyancy principle.

Total weight of the box = weight of the displaced water by the submerged volume of this box ‘Case 12’ in Table 1.

= (0. 1 x 0.105 x 0.01) x 1025 = 0.1076 kg.

Total buoyancy upward lift force = 0.1076 x 9.81 = 1.056 N this will produce stress on the lower face of the box as follows:

$$\sigma_{yy} = \frac{1.056}{0.1 \times 0.01} = 1055.8 \text{ Pa}$$

These values are in conformance with the uplift y-force and bottom stress at the box lower face shown in Figure 13 and Figure 14 respectively.

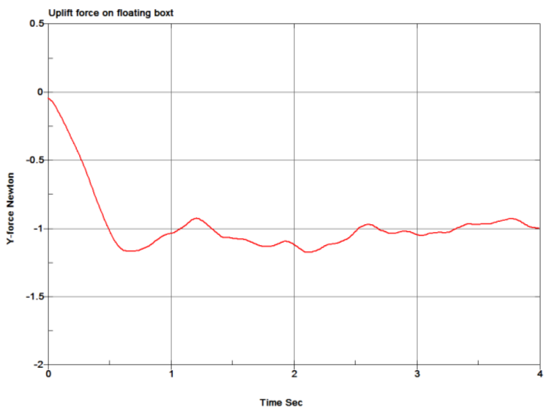


Figure 13: Uplift force under floating box

Choosing bottom side element in the z-side of the floating box with the centre of this element at depth of 0.0984m from free water surface giving a hydrostatic side pressure of:

P_{water}= 0.0984 x 1025 x 9.81 = 989 Pa, this value is conforming to the mean value of the code calculated pressure for the same element shown in Figure 15.

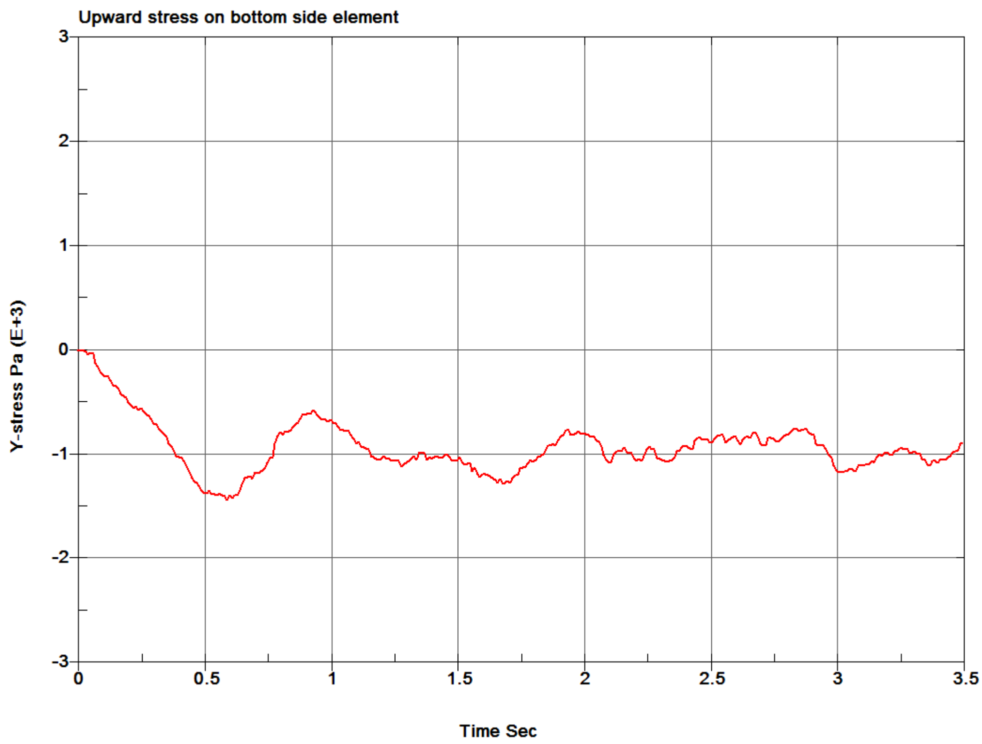


Figure 14: Bottom stress under lower side element of the box

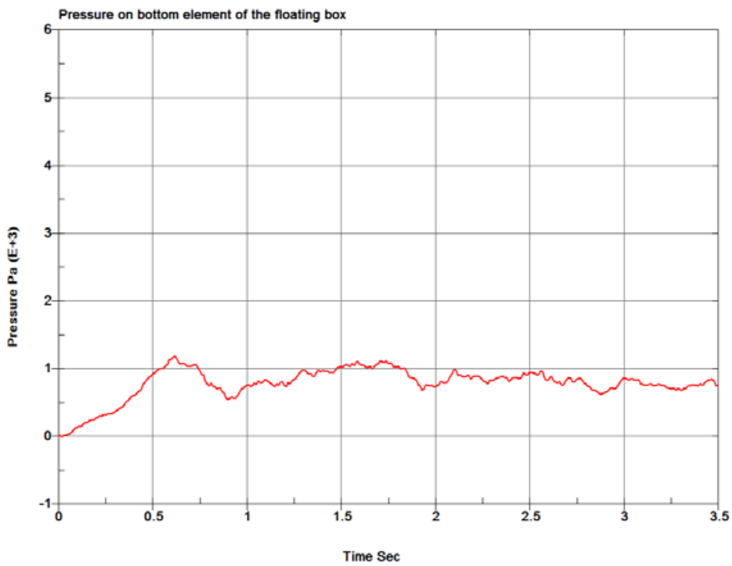


Figure 15: Pressure on lower bottom element of the box

For the same element, the z-direction forces for the four surrounding element nodes as calculated by the code are:

F_1=F_2 = 0.023 N for the bottom edge of the element where the contribution of these two forces = 0.5 x 0.023 x 2 = 0.023 N, while the two top edge forces of the element face are:

F_3=F_4 = 0.017 N, these two will contribute a force = 2 x 0.25 x 0.017 = 0.0085 N, therefore the force in z-direction on the element = 0.0085 + 0.023 = 0.0315 N and hence z-stress on this element = 0.0315/0.0133 x 0.0111 = 213 Pa, this value is close enough to the value calculated by the code shown in Figure 16.

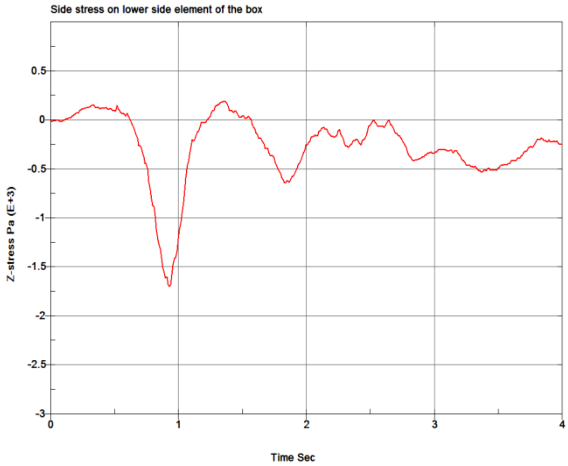


Figure 16: Side stress on lower bottom element of the box

To a certain extent, the animation and results of this simple model proves the expected action of the floating model as well as the behaviour of the ALE formulation the float bounces and was bobbing till equilibrates, thus suggesting that the algorithms adopted are capable of modelling buoyancy action.

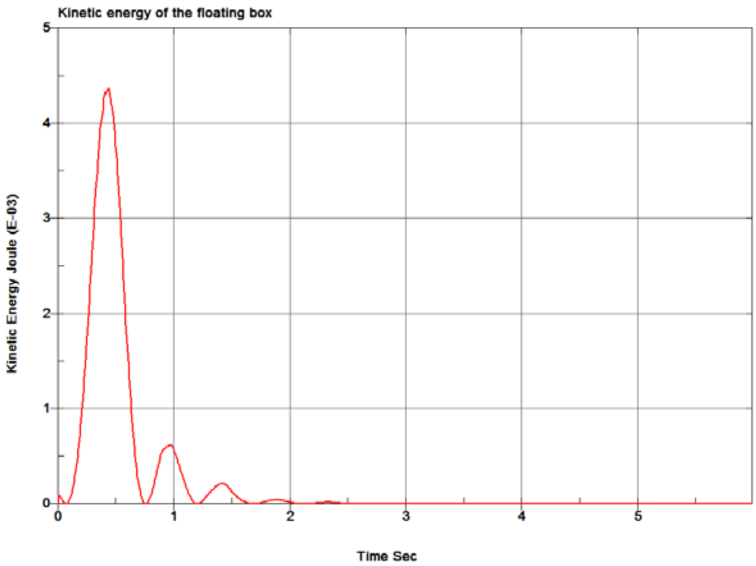


Figure 17: Kinetic energy of the floating box

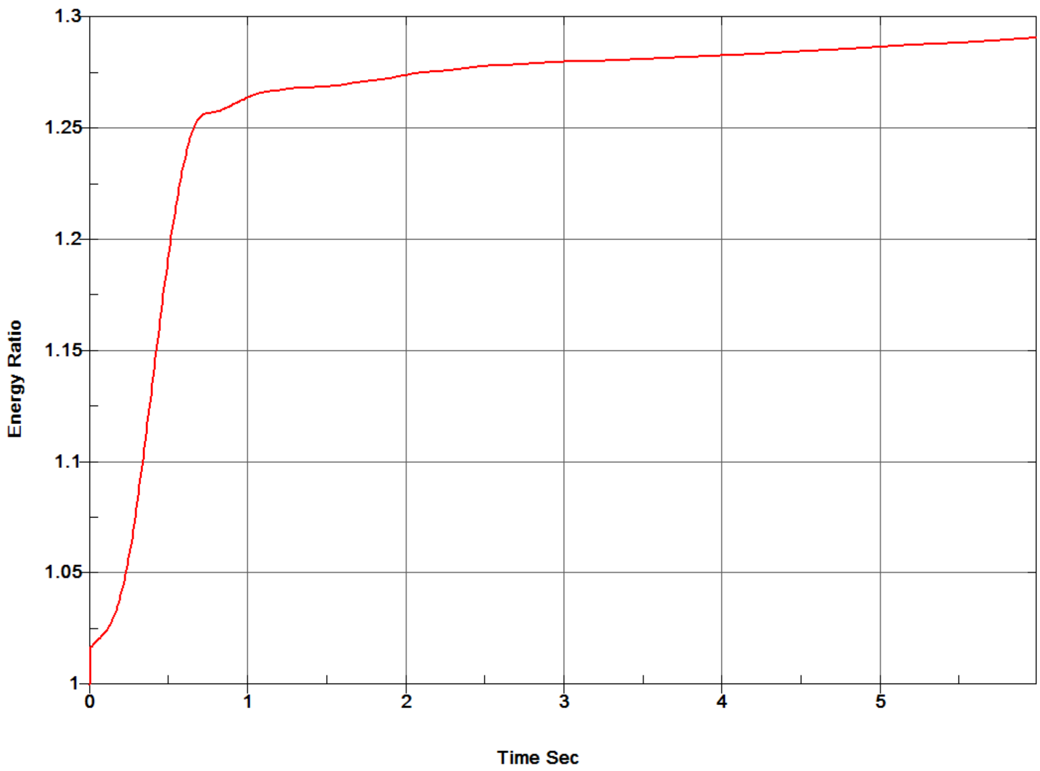


Figure 18: Energy ratio for the floating box

Looking to the kinetic energy, Figure 17 and energy ratio, Figure 18 of this system, the energy ratio is close to the unity value while the kinetic energy is dissipating to zero value. Both values are within good converging values of a stable system.

5. Discussions of the results of the 2D model

❖ Analysis of Buoyancy of 2D Model

For the cases of stability of (Table 1) where the density is low compared with that of the water, the block is theoretically stable. Its geometry is such that it starts with its longer axis vertical, and statics dictates that it should remain so. In reality this configuration is actually highly unstable as it is analogous to a ‘tall’ block resting on an extremely flexible foundation. The block would be expected to tilt over and come to ‘rest’ in a position with its long axis horizontal, i.e. the centre of gravity ends up in its lowest position to minimise the potential energy within the rigid body. This effect was observed in the LS-DYNA3D model for Cases 1 and 3 (Figures 5 and 6). These show a ‘snapshot’ in time where the body would be approaching its equilibrium state, although the time required for this to occur would be considerably larger than the analysis run time used (this was not possible to run the models for longer than 5 seconds due to practical implications). In reality, if more time could be realised, the float would be expected to oscillate through its equilibrium state and the results from LS-DYNA3D suggests that this would indeed be the case.

For the models where an equilibrium state of listing is expected (Cases 4, 5, 8, and 10 Figures 7, 8, 9 and 10 respectively), the models do indeed show angles of list of the order of that predicted by ‘hand’ calculation. The simplistic geometrical approach adopted by the ‘hand’ calculation does not account for submergence of part of the top surface of the float, so comparison of the angles of list with the behaviour from the finite element model may be misleading. However, the angles of list observed are of the correct order and the behaviour is as expected using engineering judgement.

For the cases where the float has a large density compared with that of the water, the float will theoretically sit low and vertical in the water. Cases 11 and 12 shown in Figures 11 and 12 respectively demonstrate that this is indeed the case, with only a small angle of list evident from the LS-DYNA3D modelling.

This investigation has also highlighted the differences between the pseudo-static hand calculation approach and the dynamic behaviour demonstrated by LS-DYNA3D. It is likely that behaviour is captured more realistically under dynamic action than the static calculation can predict without adopting a more complex calculation approach.

These results give confidence that the effects of buoyancy are being modelled sufficiently correct for the purposes of transient load events.

❖ Presence of High Frequency 'Noise'

With a large number of stress/time history plots, it was evident that higher frequency components/oscillations are corrupting the results. The average 'form' of most of the plots conforms to that expected from theoretical hand calculation and expected behaviour. Within LS-DYNA3D, the filtering functions were used in all cases to remove this high frequency component and effectively smooth the data. Filtering frequencies above 1000Hz was adequate in most cases to produce smoothed data plots.

The immediate concern was to investigate the source of the noise and to whether its effects could be influencing the global behaviour of the floating body. There are two likely sources for the high frequency noise which need to be considered, [3], [4]:

1. Internal reflection of waves from the boundaries of the structure.
2. High frequency oscillations generated by the fluid/structure coupling.

The most likely culprit for the spurious oscillations is the fluid/structure coupling. The effects of each of these causes is considered in turn

(i) Boundary Reflections

The external boundaries of the model are represented with non-reflecting (energy absorbing) boundaries therefore it is hoped that these should minimise reflection of generated waves. However there are internal boundaries within the float model and these are ideal for causing reflection of waves. For example, if we consider the speed of sound in the air/water/solid mediums, the frequency at which waves are returned to their source can be easily calculated from the model geometry. Invariably these frequencies are in excess of 1000Hz (generally 2000Hz to 4000Hz) and are not expected to cause any unwanted effects on the global behaviour.

(ii) Fluid/Structure Coupling

High frequency contact oscillations for penalty coupling are well documented. Contact 'chatter' often occurs as the contacting boundaries adjust themselves relative to each other once penetration initiates. In LS-DYNA3D this problem has been witnessed in many contact models and methods for its mitigation are also well documented, [1,2]. To mitigate these effects the data may simply be filtered using the built-in functions of the coupling keyword. Alternatively damping across the penalty force may be specified to smooth the response and aid convergence. LS-DYNA3D command 'CTYPE=4' was specified for the models in hand, which sets the contact algorithm to penalty coupling without erosion. However, the optimum value of this damping may be the subject of parametric studies as this may affect the global behaviour of the model if the wrong values are used as already discussed under the damping bullet in literature, [2,8]. So, the value chosen for the float model was the program default option, which is possibly (conservatively) low.

To investigate this further, spectral analysis was carried out using the Fast Fourier Transform (FFT) approach on data from a particular stress/time history plot extracted from the 2D float model. The frequency analysis of results was carried out on data before and after filtering was carried out in the post-processing program, [2].

It should be noted that the sampling rate of the numerical data dumped from LS-DYNA3D during its runs was 0.001 second. Hence this sampling rate can only capture frequencies up to 1000Hz when the time history trace is analysed. Runs were repeated with a higher frequency of data dumps to enable a smaller sampling rate of data, but unfortunately this caused premature termination due to machine specific criteria. Hence the FFT frequency analysis is only valid up to 1000Hz:

The plots in the following 'MathCAD' templates shown afterward illustrate that before filtering there is noise at around 50Hz and 150Hz. Reflection is unlikely to have caused this noise as it will be found at higher frequencies if present. However multiple reflections may manifest at lower frequencies so this cannot be ruled out entirely.

The frequency of contact 'chatter' is harder to ascertain, and may well be causing noise at these frequency levels. Hence the frequency analysis is inconclusive as to the source of the high frequency noise. In terms of the global behaviour, the filtered data oscillates at a significantly lower frequency about the expected values of stress, and the high frequency content is successfully removed.

So, in conclusion there is a high degree of confidence that the source of the noise will not significantly affect the results and that the filtering process of the post-processor is adequate for smoothing and presenting the data.

Original unfiltered data from Figure 14.

Frequency Analysis using Fast Fourier Transform

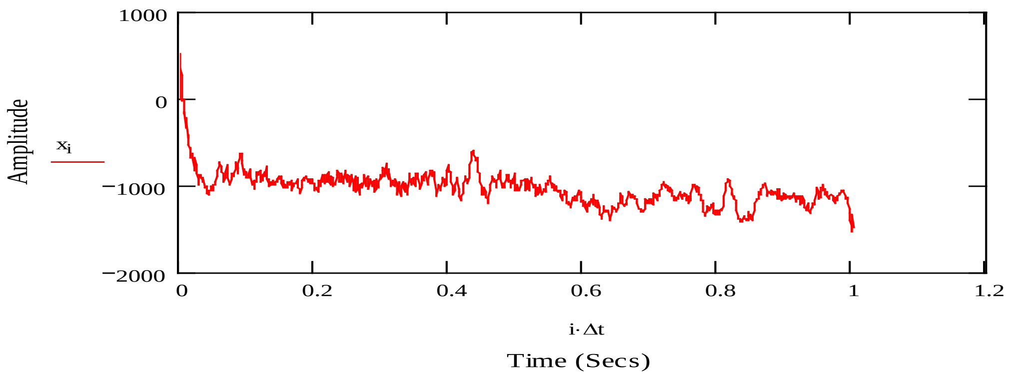
TEST := READPRN("c:\FFT\noise.txt")

Number of records on file $i := 0..\,1001$

Amplitude of data $x_i := TEST_{i,1}$

$\Delta t := 0.001 \cdot sec$ $\max(\overrightarrow{|x|}) = 1.53 \times 10^3$

Waveform in Time

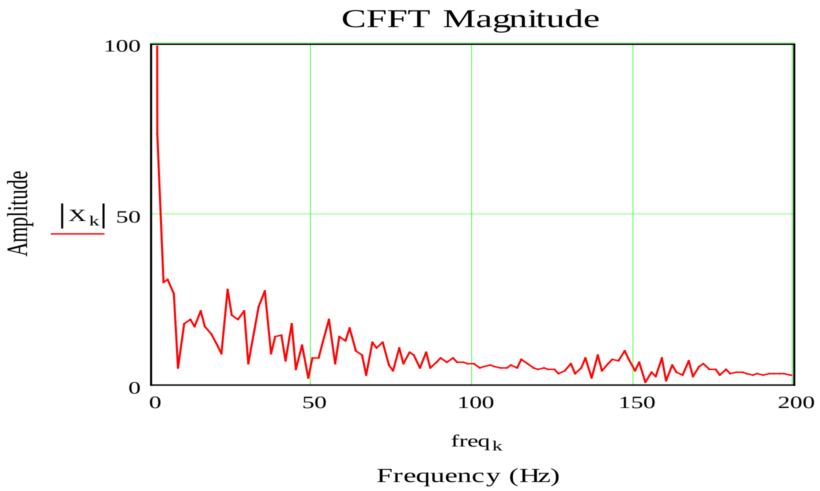


Frequency Analysis

Number of Samples $N := 600$ $k := 0..\,N-1$

Sample Rate: $T := 0.001$ Frequencies $f_s := \frac{1}{T}$ $freq_k := \frac{k}{N} \cdot f_s$

$X := CFFT(x)$



Same data from Figure 14 but filtered

Frequency Analysis using Fast Fourier Transform

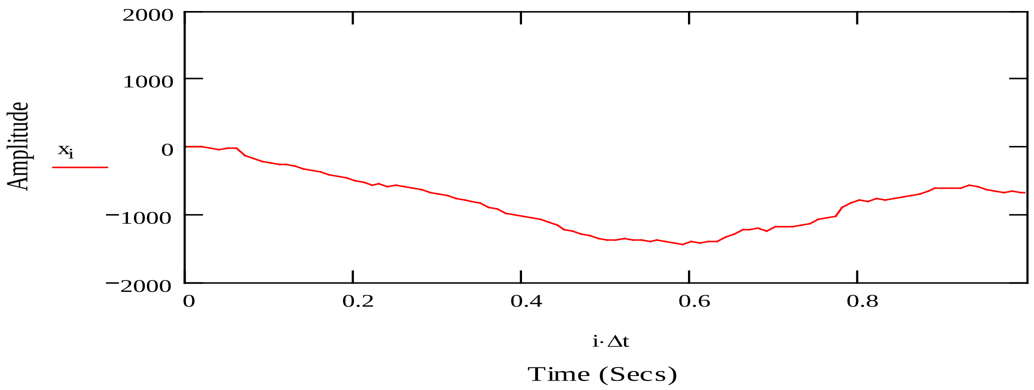
TEST := READPRN("c:\FFT\fig4-7.txt")

Number of records on file $i := 0..600$

Amplitude of data $x_i := TEST_{i,1}$

$\Delta t := 0.01 \cdot sec$ $max(\overrightarrow{|x|}) = 1.76 \times 10^3$

Waveform in Time

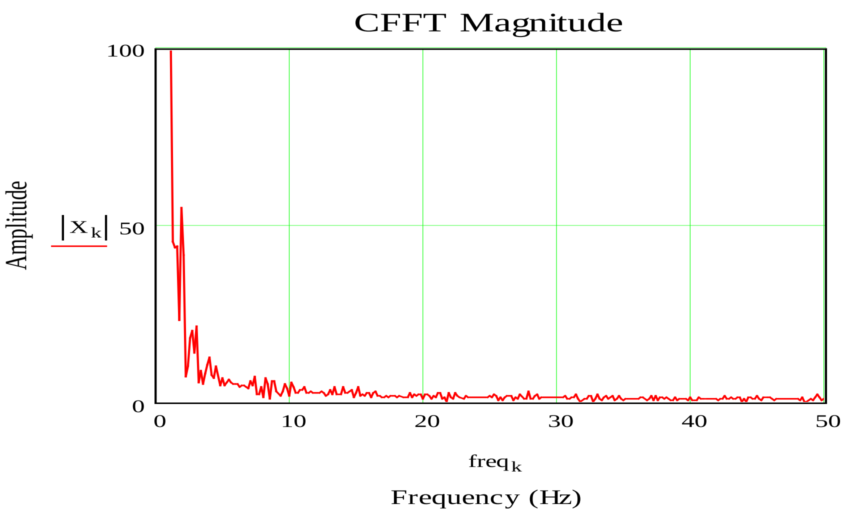


Frequency Analysis

Number of Samples $N := 600$ $k := 0..N-1$

Sample Rate: $T := 0.01$ Frequencies $f_s := \frac{1}{T}$ $freq_k := \frac{k}{N} \cdot f_s$

$X := CFFT(x)$



References

[1] N. Aquelet and M Souli, "Damping effect in fluid-structure interaction: application to slamming problem" http://www.univ-lille1.fr/gdr-ifs/cv/aquelet/damp3.pdf, 05/2005

[2] Mohamed A Almherigh, "Evaluation of Finite Element Techniques Applied to Floating Offshore Wind Turbine" Ph. D thesis, The University of Salford, Salford, UK, 2006.

[3] Patel M H "Dynamics of Offshore Structures" Butterworth 1989.

[4] Various editors "Advanced Offshore Engineering" Benthham press 10/ 1994

[5] Jhon O Halliquist "LS-DYNA Theoretical Manual" May 1998 Livermore Software Technology Corporation, online PDF file LSTC website.

[6] LSTC "LS-DYNA Keywords User's Manual" April 2003, Version 970 Livermore Technology Corporation, PDF online, LSTC website. http://www.lstc.com/ , July 2003.

[7] LSTC "LS-DYNA Keyword User's Manual Volume II (Material Models, References and Application)" March 2001, version 960 Livermore Software Technology Corporation, PDF file online, LSTC website. http://www.lstc.com/, January 2003.

[8] Peter S Tromans and Luc Vanderscuren "Response Based Design of Floaters" http://www.info.ogp.org.uk/metocean/floatingSystems/presentations/Tromans, June 2003.