AN INTEGRATED SYSTEM FOR THE DERIVATION OF SEA-GOING FORCES AND ITS APPLICATION TO THE TRANSPORTATION OF WARSHIP HULL BLOCKS

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SUMMARY

When engineering the transportation of large indivisible units by sea it is important that we have an accurate system of obtaining the forces experienced by the unit to allow the design of effective and efficient sea-fastenings.

The company formed a Knowledge Transfer Partnership with the Universities of Glasgow and Strathclyde. Over a two year period we developed a complete system for the calculation of sea-going forces. The system includes a database of wave statistics for common sea-routes, and key software files for frequently used barges. By utilising both the database and the files, the company can carry out various types of motion and structural analysis; from a simple deterministic design-wave height calculation, to a long term probabilistic analysis based on a given sea-route.

The company has applied the system to a commercial project; using information supplied by the client in conjunction with our own files we ran a simulation to get unitised results. Utilising the design wave specified by the Warranty Surveyor and the aforementioned validated response information accelerations were derived from this wave and then fed into a Finite Element model as part of the sea-fastening design process.

In conjunction with this study a model test was also carried out to ensure the validity of the computed results. The tests included a beam seas test at zero forward speed and a head seas test at a given forward speed. The physical test results closely matched the computed results for the same conditions.

NOMENCLATURE

$f(\mu_\omega)$ = Spreading Function
H = Wave Height (m)
m_0 = Area under Response Curve
$R(s)$ =Variance of response s
$RAO_s(\omega_e, \mu_\omega)$ = Response Amplitude Operator of Response s
$S(\omega,\omega_e)$ = Sea Spectra in terms of ω or ω_e.
$S_\sigma(\omega_e)$ = Spreaded Sea Spectra in terms of ω_e.
z = Heave Motion
ϕ = Roll Motion
θ = Pitch Motion
μ = Angle between barge direction and dominant wave
μ_w = Angle between component wave and dominant wave direction
ω = Wave Frequency (s^{-1})
ω_e = Wave Encounter Frequency (s^{-1})
ω_T = Mean Wave Frequency (s^{-1})

1. INTRODUCTION

The derivation of short term motion response of a loaded vessel or barge to ascertain seafastening loads is by no means a recent development. Nor is the use of seagoing motions as input to a finite element model of cargo to assess impact of these accelerations on the cargo as a whole.

However the combined use of these two analyses is an increasingly common feature in the preparatory work required when planning complex moves of abnormal and heavy lift cargoes.

This paper intends to outline the work we have carried out with the Universities of Glasgow and Strathclyde in developing a robust and streamlined system for this work and also demonstrate the benefits found when applying this to the movement of the hull sections for the new Type 45 destroyer between Portsmouth and Glasgow.

The paper will finish with an outline of future development of the system and what advances in analytical methods can offer to the practical experiences of lifting and moving cargoes of this nature.

2. RESEARCH PROGRAMME

2.1 OVERVIEW

The project aim was defined as thus;

"Improvement of working standards relating to the assessment of forces experienced by cargoes during sea transit and then applying this new methodology to the working practices of the company"

The project began with the construction of three databases to serve as an information base for the programme. These were ocean routes, barges and regulations. The next stage was to develop the analysis. This began with the selection of suitable software for the basic motion analysis. The barge database then had to be updated to include the necessary software files for the selected barges. Using these files a test case was run. From the results, basic accelerations could be calculated from the design wave height and period. (Deterministic analysis) The next step was statistical analysis which required creating spectrums and encounter spectrums. The result of this work was a developed numerical procedure for the calculation of accelerations both deterministic and statistical. This same procedure can also be applied to structural response. Once the numerical system was in place the results had to be tested and calibrated. This was done against model results and existing data. Then a software application was designed that would allow us to implement this system. The final stage was integrating the new system into existing work practices.

2.2 DATABASE CREATION

This was the first stage of the research; to have comprehensive databases so that the user of the system would have all the information he required to hand. We identified key ocean routes that may be used in the offshore industry. Examples of these routes are:

- Great Britain to Gulf of Mexico
- Great Britain to South America
- Great Britain to West Africa
- Coastal routes around Britain
- Britain to Mainland Europe

This list is obviously not exhaustive and new routes can be added to the database as and when required. Once a route had been identified we work out the zones that the routes go through and using data from [1] we create a combined scatter diagram for the route. These scatter diagrams will be used for long term analysis.

The second database we created was to store transportation barges that may be used for deliveries. Each barge is listed with all the information required to determine barge suitability for a certain job such as main dimensions, deadweight capacity and maximum draughts. This database would be added to later to include the pertinent software files required for each barge, namely a geometry file and a mass file. This effectively gives us 'off the shelf' solutions with models from the majority of key barge owners in Europe.

The final database is mainly informative. It contains summaries on a selection of classification society's rules on calculating forces on sea-going cargo. This was used to define target levels of reliability and as a general reference throughout the programme to ensure compliance with the rules.

2.3 DEVELOPMENT

This stage forms the most important part of the research. In this stage we developed a numerical procedure for the calculation of forces in supporting structures. To supply motion data for the post processing we had to purchase motion analysis software. After extensive review the DNV program WASIM was selected. Data created from this program is used as input to the post processing procedures that calculate motions and forces.

With the software in place we knew the format of the input files and could start adding to our barge database. For the purposes of testing the software and developing the system we created a generic test barge. This barge was a simple swim ended barge symmetrical about mid-ships. Motion analysis was carried out for this barge with a test weight and the resulting RAOs used for the rest of the analysis.

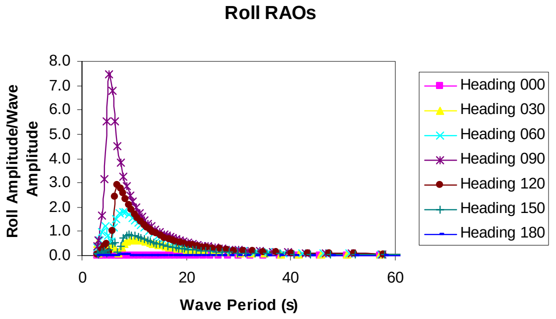


Figure 1: Roll Response Amplitude Operators for Test Barge

From these RAO's we can get simple accelerations and therefore forces by simple multiplication. By working to a design wave period and height we can calculate the motion due to that particular wave.

$$RAO_{roll}(radm^{-1}s^{-2}) \times \frac{H_{design}}{2}(m) = RollAcceleration(rads^{-2})$$

In the above case we are calculating roll acceleration but the equation is the same for displacements and velocities in all six degrees of freedom.

This form of analysis is very basic so the next stage was to take it further and carry out a statistical analysis. For the purposes of the test case we utilised the ISSC form of the Pierson-Moskowitz spectrum [2] which is defined below.

$$S(\omega) = 0.11 \times H^2 \times \omega_T^{-1} \times (\frac{\omega}{\omega_T})^{-5} \times \exp[-0.44 \times (\frac{\omega}{\omega_T})^{-4}]$$

This spectrum can then be converted to an encounter spectrum using the equation below. [3]

$$S(\omega_e) = S(\omega) \times \frac{1}{(1-(\frac{4 \times \omega_e \times V}{g}) \times \cos\mu)^{0.5}}$$

The response of a motion, *s*, is modelled on a Gaussian zero mean stationary stochastic process described by the variance *R*.

$$R(s)=\int_{0}^{\infty}[RAO_s(\omega_e,\mu)]\times S(\omega_e).d\omega_e$$

From this variance we can calculate significant responses.

The above produces significant motions based a 2-dimensional (or long crested) sea. However in reality a sea has three dimensions, in that the incoming waves will change in speed and height as well as direction. Therefore in order to model the seaway more accurately we must multiply in a spreading function. [4]

$$S_\sigma(\omega_e)=S(\omega_e)\times f(\mu_w)$$

where $f(\mu_w)=\frac{2}{\pi}\cos^2\mu_w$ for $\mu_w\le\frac{\pi}{2}$ and

$f(\mu_w)=0$ for $\mu_w\ge\frac{\pi}{2}$

Integrating the product of the encounter spectrum and the RAO for the response, over the spreading angle, results in one response spectrum that takes into account all the component waves.

$$m_0(s)=\int_{-\pi/2}^{\pi/2}\int_{0}^{\infty}[S_\sigma(\omega_e,\mu_w)]\times[RAO_s(\omega_e,\mu_w)]$$

The two figures below show the effect that this spreading function has on the significant accelerations in roll.

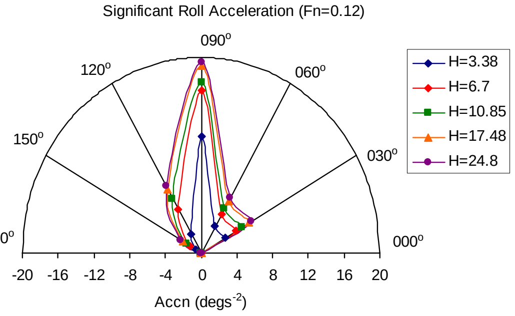


Figure 2: Significant Roll Accelerations in 2D Seas

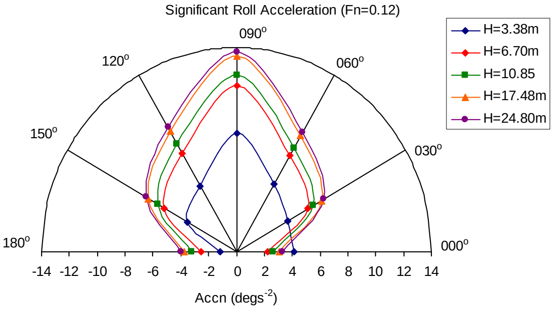


Figure 3: Significant Roll Accelerations in 3D Seas

The principles above can be applied to bending moment RAO's and similar graphs can be calculated for the bending moments at mid-ships.

2.4 CALIBRATION AND VALIDATION

Calibration was carried out in two ways. Firstly the results were compared to existing results for similar style of barge. As the results are given in a unitised fashion it is acceptable to compare results between barges with different dimensions. The second comparison was with a model test. (see Section 3)

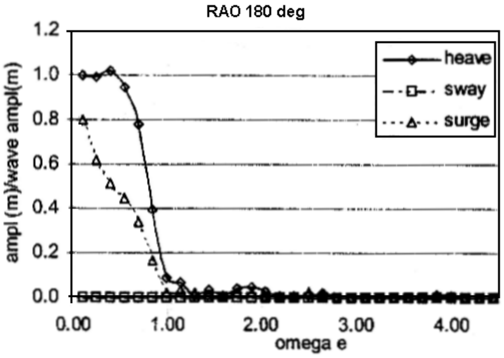


Figure 4: External Translational RAOs at 180 degrees

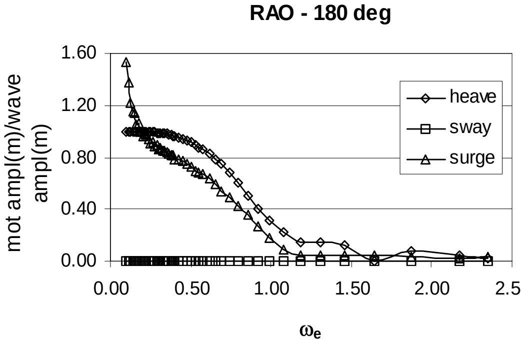


Figure 5:Test Barge Translational RAOs at 180 degrees

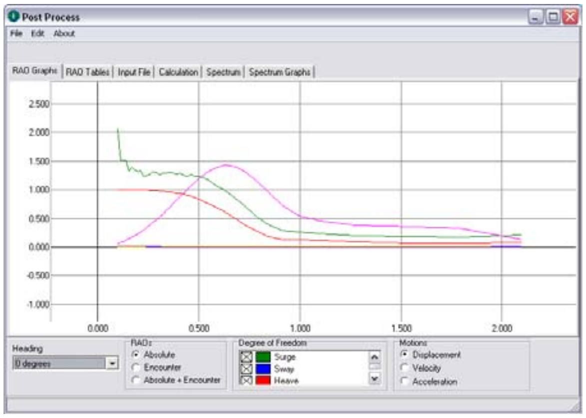
The two results seem to compare quite favourably. This, coupled with the comparison with model test, indicated that the software was modelling the barge accurately.

2.5 IMPLEMENTATION

In this stage of the programme it was decided to code an application that would carry out the post processing automatically, in order to eliminate errors that can occur when utilising spreadsheets or similar software. The application has the following features:

- Error checking of input file
- Ability to carry out deterministic and statistical analysis
- Selection of sea spectrums
- Graphical and tabular display of RAOs and responses

- Calculation of forces from accelerations at any given point



Heading: 0 degrees

RAOs: ● Absolute

Degree of Freedom: ☒ Surge ☒ Sway ☒ Heave

Motions: ● Displacement

Figure 6: Application Screen-shot

The application allows users to calculate forces for support structures quickly and efficiently. Alternatively, as discussed in section 3, the accelerations can be used for input into a Finite Element Analysis.

When the application was completed, a set of manuals and tutorials were created that would be made available to the staff in the integration stage of the programme.

2.6 INTEGRATION

Once the system was tried and tested, we had to integrate it into the company's work practices. The first stage of this was a thorough audit of the filing system, reviewing the necessary files to be uploaded to the company server and recommending work practices involved with the day to day use of the system.

Issues covered in the audit included which files to delete and which to keep after a run of the commercial software. This was to prevent wasting computer storage spacewith redundant files. The audit also covered quick error checks that the user can make to determine the validity of the commercial output. Finally, the audit made recommendations about the logging and reporting of any runs that are carried out to allow easier transitions between employees on a particular job.

Using the recommendations found is this audit, the necessary files were transferred and a set of working instructions were included in the manual for the system.

With the system in place, and the manuals/tutorials available to the staff, the company is now ready to utilise the system for upcoming jobs and offer it as a stand alone service.

3. MOVEMENT OF BOW SECTION (BLOCK E/F)

Following on from the work done with the local universities we then proceeded to implement the system in the movement of the Bow section of the new Type45 destroyer from VT's new construction facility in Portsmouth to the integration yard at BAE Systems, Glasgow.

3.1 MOTION RESPONSE ANALYSIS

The movement was carried out using VT's non-standard launch barge which has unusual design features specific to its role as a launch barge in Portsmouth, one of which is a 1.00m deep tunnel which runs along its length on the centre line.

Principle dimension are:

Length o.a.	90.00m
Breadth o.a.	23.00m
Depth o.a.	5.00m
Lightship	1323 Te
Max. Disp.	6628 Te
Max Draught	3.92m

Figure 7: VT Barge

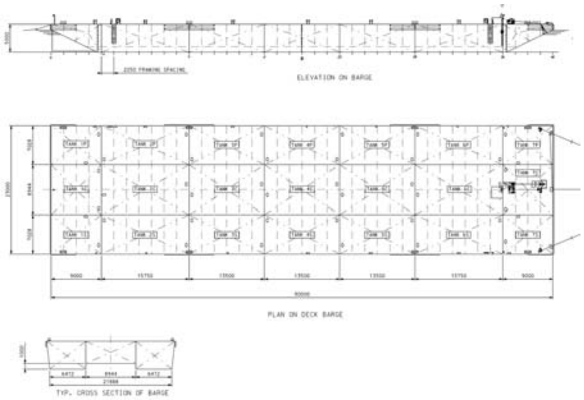


Figure 8: VT Barge GA

This model was built in the hydrodynamic package and a series of RAO's were created. These were to be validated against tank tests, which were carried out at the Denny Tank in Dumbarton.

The following tests were carried out at the test tank;

- Roll Decay Test
- Beam Sea Tests (Zero Speed)
- Head Seas Tests (Forward Speed)

A roll decay test was carried to allow the calculation of roll damping coefficients. The linear coefficient is required as input to the software. An accurate value of this coefficient will therefore lead to a more accurate assessment of the motions in roll.

During the beam sea tests the model was allowed to drift freely and the response amplitude operators were calculated using a system of motion capture cameras. The results were compared with the un-damped values and the damped values from WASIM. The figure for the roll damping was calculated from the table of results from the roll decay test. The results are given as non-linear and to calculate the linear value we must use an iterative approach. We guess the expected roll amplitude and find the corresponding damping ratio from the table and then carry out a run using this value. Using the roll amplitude gained from this run we can interpolate to find a new roll damping ratio. This process as repeated until the two values converged. The effect of the damping ratio can be seen in Figure 9.

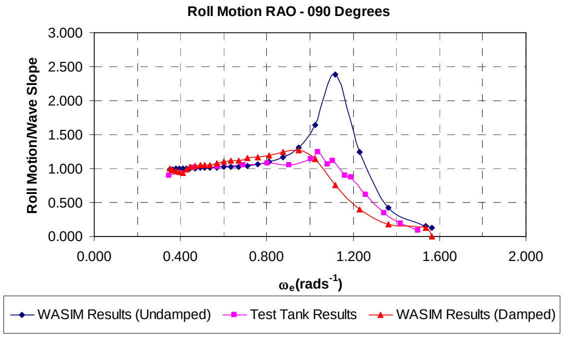


Figure 9: Roll Motion in Beam Seas

The head seas test was carried out by attaching the model to the test carriage and pulling it along at the scaled down equivalent of a velocity of 6 knots. The model was free to move in heave, pitch and roll. The vertical motions were measured at the bow and CG by way of linear variable transducers and the pitch and heave values calculated from these using simple geometry.

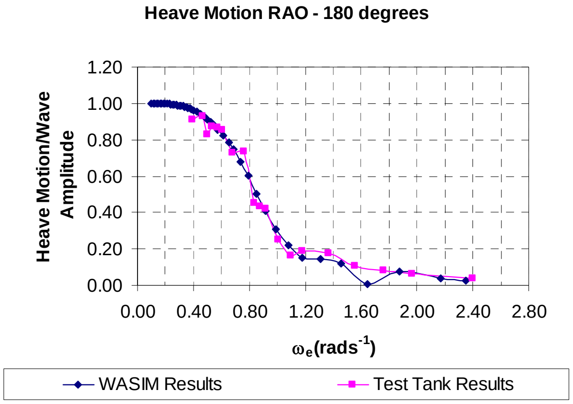


Figure 10: Heave Motion in Head Seas

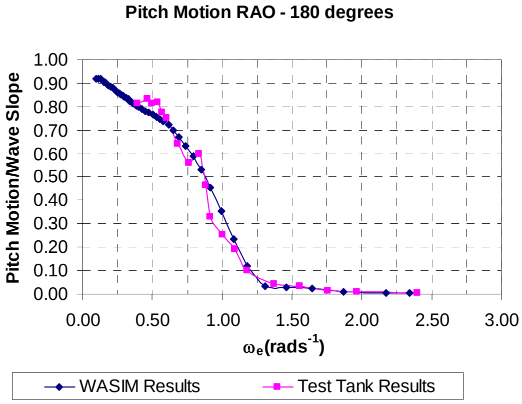


Figure 11: Pitch Motions in Head Seas

Figures 9~11 show excellent correlation between the numerical and physical tests and the use of the numerical model for further assessments was approved by the Warranty Surveyor.

Design accelerations represent the barges response to the specified weather criteria, over a range of headings in a given load and ballast condition and are therefore the load cases against which the sea fastenings are designed.

Accelerations were obtained for a set of 7 headings, relative to the weather, ranging from directly astern to directly ahead in 30° increments. It was assumed the ship block was sufficiently symmetric, both in terms of its internal geometry and outfit weight, that results with the weather over the Port and Starboard side of the barge would essentially be mirror of one another.

For each heading results were obtained from the motion response model in the form of a linear acceleration in each principle direction, a rotational acceleration about each of the principle axes and a maximum angle of heel and pitch. The centre about which the barge rotates was also found.

3.2 FINITE ELEMENT MODEL

The purpose of the finite element model in the project was to convert the design accelerations, into load carried by each roll brace and the vertical reaction into each barge frame.

From the motion response model we obtained the accelerations necessary to represent the barge's motion in the finite – element model, with each heading relative to the weather being considered as a separate load case. In each load case the condition with both positive and negative heave was considered. Some work was therefore required to correct the linear accelerations from the motion response analysis to give the actual accelerations seen by the hull block, allowing for the "downhill" effects of the roll and pitch angles. To achieve this result the heave acceleration for example was split to find the components acting, vertically, transversely and longitudinally. This approach allows a single geometric model to be used to solve all the load cases. For the purpose of the analysis it was assumed the maximum acceleration occurs at the maximum angle of heel. The analysis therefore considers the situation were the hull block experiences all the applied accelerations at the same time.

An initial study was carried out to review the sizing and placement of all principle structural members which included the pro-forma design of all transportation beams, high and low level roll braces and deck grillages. Using the detail from this initial assessment in conjunction with scantling drawings of the Type 45 hull itself a non-linear Finite Element model was created which accurately represented all external and internal principle structure including framing, bulkhead/deck construction and longitudinal stringers in the side shell.

This level of detail was achieved to allow the model to be further used in the internal stress validation of the hull block itself.

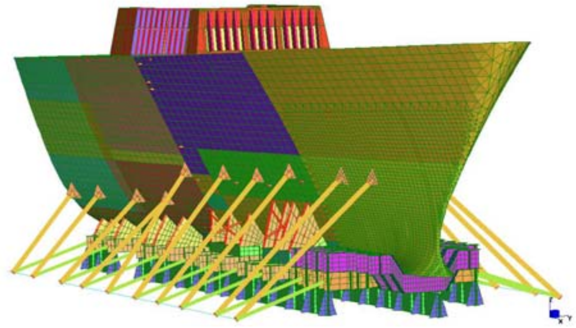


Figure 12: FE Model of Bow Section, Seafastening and Grillages

For validation of the FE model a series of checks were carried out on both the geometry and gravity load cases. Calculated and measured weights of the block were compared with non-linear gravity runs and results were as follows:

Source	Calculated Weight (Te)
Hull Design Model	1021
FE Model	960.35
As Weighed	969.80

Table 1: Actual and Calculated Hull Block Weights, including transport supports.

To account for the high level of outfit expected on the block at sailaway, client supplied weight control sheets were interrogated and all outfit was split down by category and location and then smeared over deck areas that corresponded to relevant seat locations of major outfit components as non-structural masses. In this way the rotational inertia of the model and centre of gravity (VCG, TCG and LCG) were preserved in the numerical model, all of which play an important role in the reaction of the cargo to seagoing forces whilst in transit.

The detail design of the supporting structure can be broken into two principle groups namely the Hull Attachments (transportation beams and hull poppets / attachments) and the Deck Structure (grillages).

Due the design and build philosophy behind the construction of the block, emphasis was placed upon the minimising of any hull attachments which may damage sensitive coatings inside the hull. For this reason, we used existing launch attachments wherever possible and modified/added to these for the transportation attachments; for example, launch poppets were retrofitted with additional box sections which allowed them to be directly fitted to our transportation beams. Also, gusset locations were jointly agreed with the client yard to allow them to be retrofitted as support stays during block construction and unit assembly.

The deck grillages allowed the disparity between frame spacing on the cargo and the barge to be spanned and also allowed the self elevating trailers to self unload to the barge following loadout. The heights and properties of these had to be compatible with, the trailer capabilities, the build height in the fabrication shed and the increased depth of the fwd launch beams.

Figure 13: Hydraulic Self-Elevating Trailers during loadout

As the barge structure spanned by the grillages represented both transverse frames and bulkheads, an assessment of the stiffness of each crossing point was made with the supports under the grillage accurately modelled as springs with appropriate properties. This allowed for an accurate assessment of areas where high local stiffness resulted in high loads imposed through the grillages. It is worth noting that in the past, this type of assessment has led to disproportionately strong local deck points being avoided to prevent overstressing of under deck elements.

Accurately modelling the stiffness of the barge deck was required to obtain the correct load distribution between the barge frames and bulkheads. The approach taken in this project was to treat assessing the stiffness of the barge deck as a separate problem in its own right and then use the results of this analysis to help form the freedom case for the main model.

To assess the stiffness of the barge deck a pair of finite element models of a barge frame and bulkhead were produced. A series of loads were then applied to each model at the intersection with the centreline grillage beam, side grillage beams and roll braces. From these results the deck stiffness at each point was obtained.

The stiffness values were then applied to the main model as a nodal stiffness, below the support grillages.

Due to the limitations in welding to the cargo the stiffest load path through the keel of the block and into the centre line grillage was principally a bearing contact only. To accurately assess any potential load shedding in negative heave cases these were modelled as non-linear contact elements and the results post-processed accordingly.

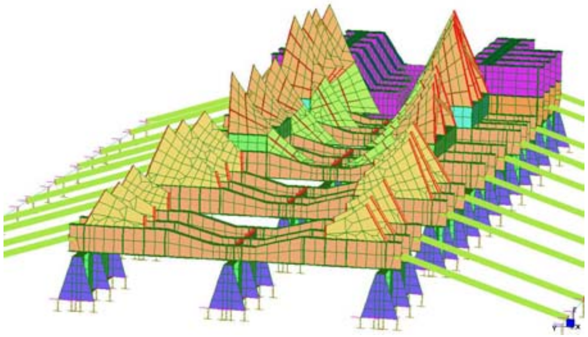


Figure 14: Transportation Beam and Grillage Detail

4. FUTURE DEVELOPMENT

The method used in this case study is fairly rudimentary; however the expertise is there to carry out more in depth analysis. As mentioned the system is capable of statistical analysis, utilising a variety of spectrums to calculate significant motions and structural responses. Leading on from that is the ability to carry out probabilistic analysis, which is required for long term calculations when the transportation crosses many ocean zones.

There is now the ability to take a sea route, cargo and barge, and input the resultant statistical or deterministic results directly into an FE model which can accurately assess not only the forces in the sea-fastenings but also the forces acting on the deck and cargo as well as the wave action on the ship or barge as a whole. Given the trend of larger indivisible loads we feel this style of integrated numerical approach will become increasingly important within the industry.

5. CONCLUSIONS

Two years of collaboration with the Universities has led to the company furthering their understanding of motion analysis. It has also enabled us to create a system that allows us to accurately predict the forces experienced by large cargoes, their seafastenings and even the whole structure of the transportation vessel itself at sea using tried and tested results from commercial hydrodynamics software. With this input being fed into our non-linear FE package the holistic view of the entire system this offers will be paramount in offering both increases in safety, satisfaction in the residual structural strength of the transportation vessel and reducing the levels of redundant seafastening wherever possible with these savings passed on to the client.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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