# Analysis of Ship Structures

A discussion paper on the use of structural analysis
software for the design of ship structures

MULTIFRAME

*Structural engineering software that works the way you do*

formation DESIGN SYSTEMS

July 2005

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## 1. Introduction

In recent years the world has seen a dramatic improvement in computer technology with regard to both hardware and software. These improvements have made it possible for engineering designers to access software and analysis capabilities that were once reserved only for those who specialised in numerical analysis.

This paper is aimed at the designer of ship structures who wishes to enhance and improve the way they work by introducing this new technology into their range of design tools. As an introduction to the subject of structural analysis, we will look at how the technology has changed, how it can be used in the ship design process, and how it can and must change the way that shipyards and ship designers work. The aim is to give the reader a basic understanding of the subject that can be built upon with some further in depth study. While aimed at shipbuilding, the principles presented can be applied to any industry or any other form of structural design.

This is intended to be a discussion paper rather than a technical paper, however some introductory aspects of computerised analysis will be discussed. After reading this paper a designer should be able to select software that is best suited to their needs and confidently develop a simple analysis model and verify the results. It should also provide some basic grounding for further study.

### About the Authors

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## 2. Recent History

In order to better understand the reasons behind the way ship designers work these days, it helps to look into the past to see how the current design methods have evolved.

As little as ten years ago, a 486 desktop computer with only 4MB of RAM was very expensive and was considered leading technology. DOS was the primary operating system for desktop computers and user friendly analysis software was unheard of. Computer analysis of structures was the specialty of dedicated analysis engineers who would spend countless hours building an optimised model so that it would be able to solve over night. Small shipyards and design offices could not afford the type of super computer that was required to solve complex models, nor could they afford the specialist engineers who knew how to use them. Because of this limited technology, ship designers mostly relied on simple spreadsheets and even hand calculations when designing ship's structures. Considering that this technology was not commercially viable for most shipyards and design offices, the classification societies developed a set of rules that could be programmed into a spreadsheet and these were the basis for most design decisions. In general terms, detailed structural analysis was not required for ships less than 50m in length.

In such a short period of time technology has certainly advanced. Desktop computers are very fast and very affordable. Analysis software is also very affordable and much more user friendly. This has enabled designers to make use of computerised structural analysis even though they are not specialists in this field. The specialists still have a role in today's engineering world, but instead of simple linear static analysis, the studies they undertake have become extremely complex. Finite element modelling and beam analysis have now become an affordable part of a designers tool kit. However in spite of these massive improvements in technology, some shipyards and designers have continued with the old working methods choosing to perform computerised structural analysis only when class societies insist, which generally is still only when a ship's length exceeds 50m.

In times when costs are rising and litigation is becoming more common, shipyards and designers can no longer afford to ignore the capabilities of today's technology.

## 3. Classification Societies

The role of the classification society in ship construction is to protect the ship owner, its crew, passengers, and cargo by ensuring that ship designs meet minimum standards for its intended operation. These standards are based on their experience and research.

When considering ship's structures, the class society rules are generally very good for determining the required structural scantlings based on a strength requirement. They have very detailed formulas for calculating loads, and beam sizes based on section modulus and shear area considerations. Where they are weaker is in assessing deflection and vibration criteria. This is generally left to the designer as the rules do not have comprehensive formulas for these. A long and slender beam can have a relatively high deflection before its bending stress limit is reached. This can be detrimental for a ships system if a pipe or internal fitout is attached to this beam that can experience large deflections. Similarly a beam that vibrates excessively can cause major problems in service.

As the rules cover many aspects of ship design including structural strength, machinery, electrical and safety systems, it would be unreasonable to expect them to comprehensively cover all types of ship designs and operating conditions. When considering the vast number of variables in determining a ship's characteristics, such as length, speed, displacement etc, it is a credit to the class societies that the rules are reasonably reliable. Having said that, and with no disrespect intended, the fact that some ships with full class certificates still have cracking problems today shows that meeting the rule requirements is not enough to ensure an adequate design solution. The rules are an excellent starting point, but that is all that they should be considered as – a starting point for sound engineering analysis.

Many class societies have developed their own software to assist their plan approval surveyors assess a design. As part of their service, they generally offer the software free of charge to shipyards and designers. While this is generally appreciated by the designers there are some limitations when using their software.

Firstly the software is developed to assist with checking designs that have been presented to them for assessment. While very good for this, they can lack some of the desirable features required by a designer who is progressing through a design loop looking to optimise a structure.

Secondly they tend to only be able to calculate simple two dimensional structures as this is the basis of the rule formulas. It is however beneficial for designers to be able to analyse a 3D structural model in detail. In addition they are also usually limited only to stress calculations and do not consider deflection or vibration.

Finally, each class society has its own software and most shipyards and designers deal with many class societies. This means that if designers were to rely on this free software, they would need to learn and master the different packages offered by the different class societies.

It should also be noted that there are differences in the rules for different class societies. For example one will give a lower sea pressure than the other for exactly the same design, so which one is correct? Maybe one is too conservative in some areas and not conservative enough in other areas. This fact adds weight to the argument that the rules should be considered only as a starting point for further analysis.

## 4. Designer Responsibilities

As mentioned earlier, the world is becoming more and more litigious. Thankfully many of the problems with ships structures in service are limited to minor cracking in superstructures, and in machinery spaces such as jet rooms with high vibration levels. However should an unfortunate incident arise where a person is seriously injured or killed, a shipyard or designer may have difficulty defending a claim made against them if it can be shown that they did not apply sound engineering analysis to the design. Now that the technology is readily affordable, the risks associated with potential litigation should be seriously considered.

The designer must also take responsibility for ensuring that they understand how to use these tools correctly. The analysis specialists have an in depth understanding of the mathematics behind the various beam and element types. The risk for a designer who is not a specialist is that they may select the wrong element or load or boundary condition for the problem. An example of this is using shell elements to model a beam. Shell elements are designed to behave like a piece of plate, and beam elements are designed to behave like beams. So you can see that building a beam structure out of elements that are designed to behave like plates may not give accurate results in some cases. While in some instances it can be done with reasonable accuracy, this is largely dependant on the mesh density. However even with a suitable mesh density, the results may still not be as accurate as those generated by a beam element. So choose your elements based on what you are looking for. If you are investigating the bending stress of a ship’s frame then it is probably best to use a beam element. If you are interested in the shear stress distribution throughout the bottom plate, then use shell elements. If you do decide to model a beam structure using plate elements, it is recommended that you also make a beam model and cross check the results.

Considering the above it would be wise for the designer that chooses to undertake structural modelling to familiarise themselves with the basics of how the elements are designed to perform and what, if any, limitations they have.

## 5. Commercial Considerations

Computers and software are continuing to become more affordable while the cost of labour continues to rise. It is critical for long term survival that manufacturing companies minimise labour requirements by integrating technology into their business and this is also applicable in the shipbuilding environment. The implementation of new technology can reduce labour requirements in both the design office and the workshop. Efficiency gains in the design process can reduce design and drafting labour requirements. The delivery of higher quality drawings and information to the workshop floor can increase efficiency and reduce re-work and warranty burdens, hence reducing labour requirements. If the use of improved design technology can reduce the labour requirements of your company by just one person, it will probably pay for itself.

The above view is one based on labour requirements but let's now assess the numbers when considering warranty risk. An accountant will determine the cost of analysis by considering many associated costs such as the cost of wages, overheads, a portion of the software cost and maintenance, just to name a few.

To perform a detailed global analysis of a 45m ship would take two designers approximately three weeks. Considering typical wages for designers and making some allowance for overheads and other costs let's assume that the cost of the analysis is $20,000. This is a relatively small cost for a multi million dollar project.

Now let's assume that the analysis was not done and consider the cost of repairing a crack in a super structure. To start the analysis would now have to be done. There is no point just re-welding the cracked area, it will only crack again. The fact that it has cracked usually means that there is a design fault in the area. So we are already up for $20,000 to do the analysis that was not done. However in addition the shipyard now has to fly at least two tradespeople to the vessel, pay for hotel accommodation, travel allowances, taxi fares, equipment hire, and the purchase of materials. To repair the cracked area, interior fitout will usually need to be removed and will probably be damaged in the process. The vessel operator has been inconvenienced and the shipyard's reputation has been damaged.

Considering that most of the $20,000 cost will be incurred anyway, because the designers are getting paid no matter what they do, it makes commercial sense to minimise the risk of warranty problems by performing detailed analysis in all cases.

## 6. Three Types of Ship Structures

A ship's structure can be broken down into three key areas, plate fields, simple beam structures and complex beam structures.

### Plate Fields

Plate fields are assessed from a local and global perspective. For example bottom plating can be assessed with local sea pressure loads applied to the plate field bounded by transverse framing and longitudinal stiffeners. An assessment of stress, deflection, vibration and buckling can be made from local considerations. However when the ship is bending due to global forces, then the bottom plate will be subjected to global stresses and deflections. This is an analysis that is best performed using Finite Element Modelling.

### Simple Beams

Simple beam structures are those that can be analysed using one dimensional analysis and local loads. An example is a deck beam between two longitudinal girders. The beam is simply analysed as a one dimensional fixed ended beam with a uniform pressure load. Beam analysis software or a spread sheet would be used in this case to analyse for stress, deflection and vibration.

### Complex Beam Structures

Complex beam structures are two or three dimensional structures subjected to simple or combined loading. An example of this is a superstructure comprised of side frames, deck frames, longitudinal girders and compression posts that is being subjected to deck pressure and sea pressure simultaneously. This type of analysis is best suited to beam modelling software and would be assessed for stress, deflection and vibration.

## 7. Three Methods of Analysis

Here we will explain the three methods of analysis that can be used and explain when each type of analysis should be used.

### Spreadsheets

The evolution of the spreadsheet over the past 10 years has been quite dramatic. They now come with many built in functions and are very user friendly. Spreadsheets are most commonly used for the first set of local calculations to the class society rules. They can also be used for simple one dimensional beam calculations as the formulas are quite straightforward and easy to write in a spreadsheet format.

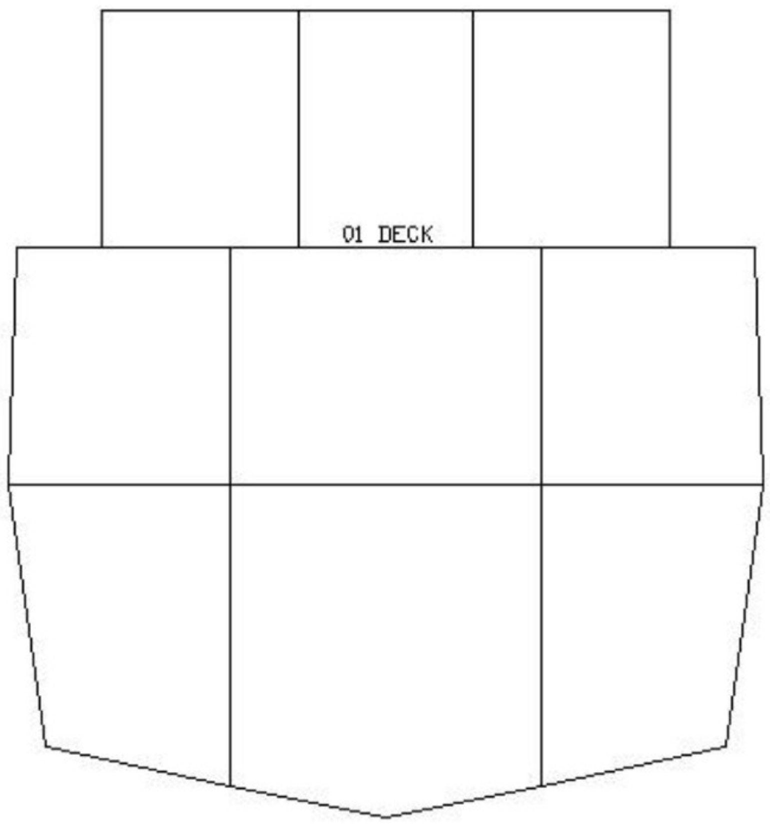
There are two main problems with using spreadsheets. Firstly they are difficult to debug and modify as the formulas use cell references instead of symbols. When if statement logic is needed to perform the calculations, they can be very difficult to debug or modify when the rules change. The second and most concerning in a large office is that they are easy to copy and modify. The temptation for designers to 'customise' a spreadsheet that already exists is sometimes too tempting. A well meaning designer can easily modify a spreadsheet and unintentionally introduce an error into it. Passwords can be used to lock them but they are very easy to get around these days.

An alternative would be to use the software issued by the class societies, or use a programming language to write a program that can not be modified and is modular for easy debugging and modification. This can however be very time consuming so most designers use spreadsheets. In this case you should consider putting procedures in place to ensure that they are not tampered with.

### Beam Modelling

When considering a one dimensional beam such as a fixed ended beam with a uniformly distributed load, the decision between using a spreadsheet or a beam modelling program is really one of personal choice. The time taken to use the spreadsheet or build a small beam model will slightly favour the spreadsheet. Many designers however prefer to build a beam model using dedicated beam analysis software such as Multiframe. The reason for this is that spreadsheets are usually limited to giving maximum stress and deflection values however with beam modelling software, you get much more than maximum stress and deflection. You get the stress and deflection at any point along the beam, a visual display of how the beam will behave, reaction moments and forces at the ends of the beams (which are useful for weld calculations). Also with the press of a button, you can calculate the modal frequencies of the beam.

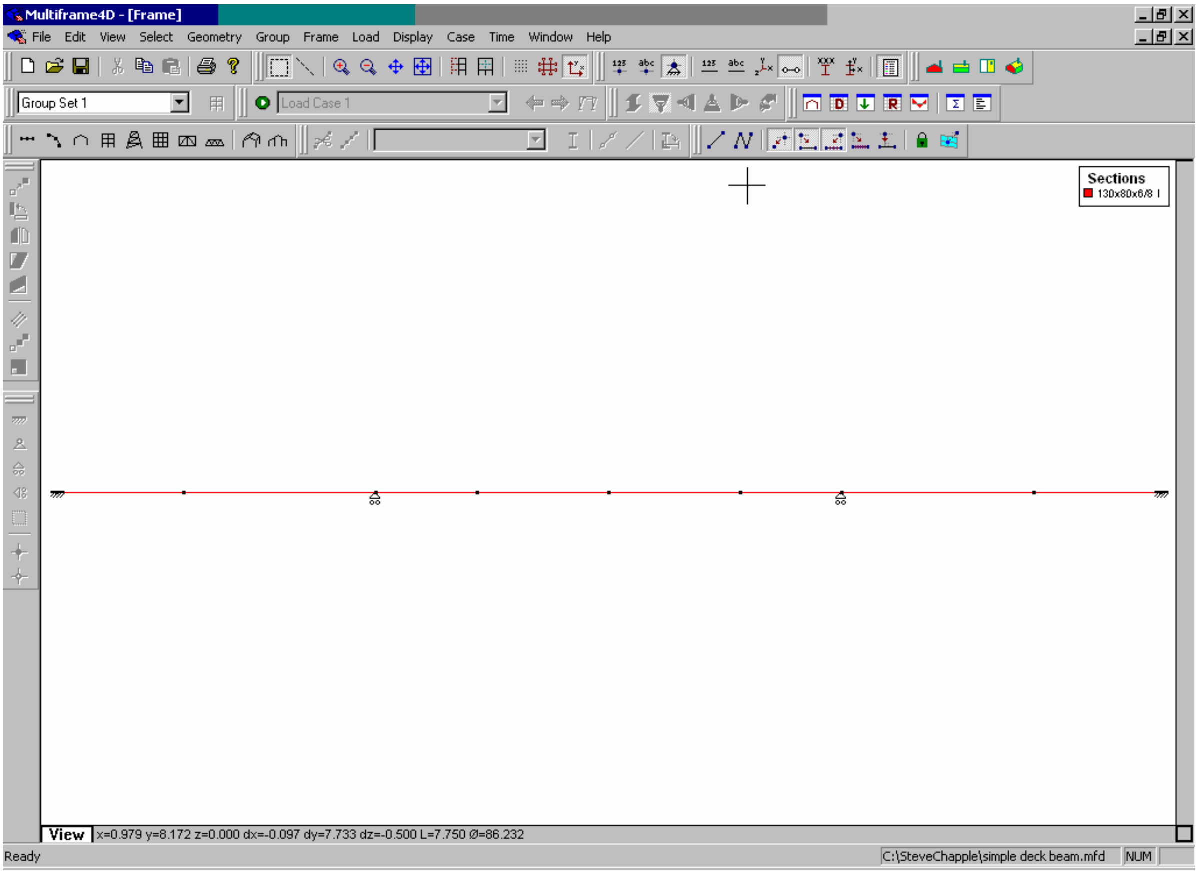
However when it comes to two or three dimensional models, or a one dimensional model with a complex load condition, beam modelling software is by far your best choice. For example consider the 01 Deck beam of the midship section shown below.



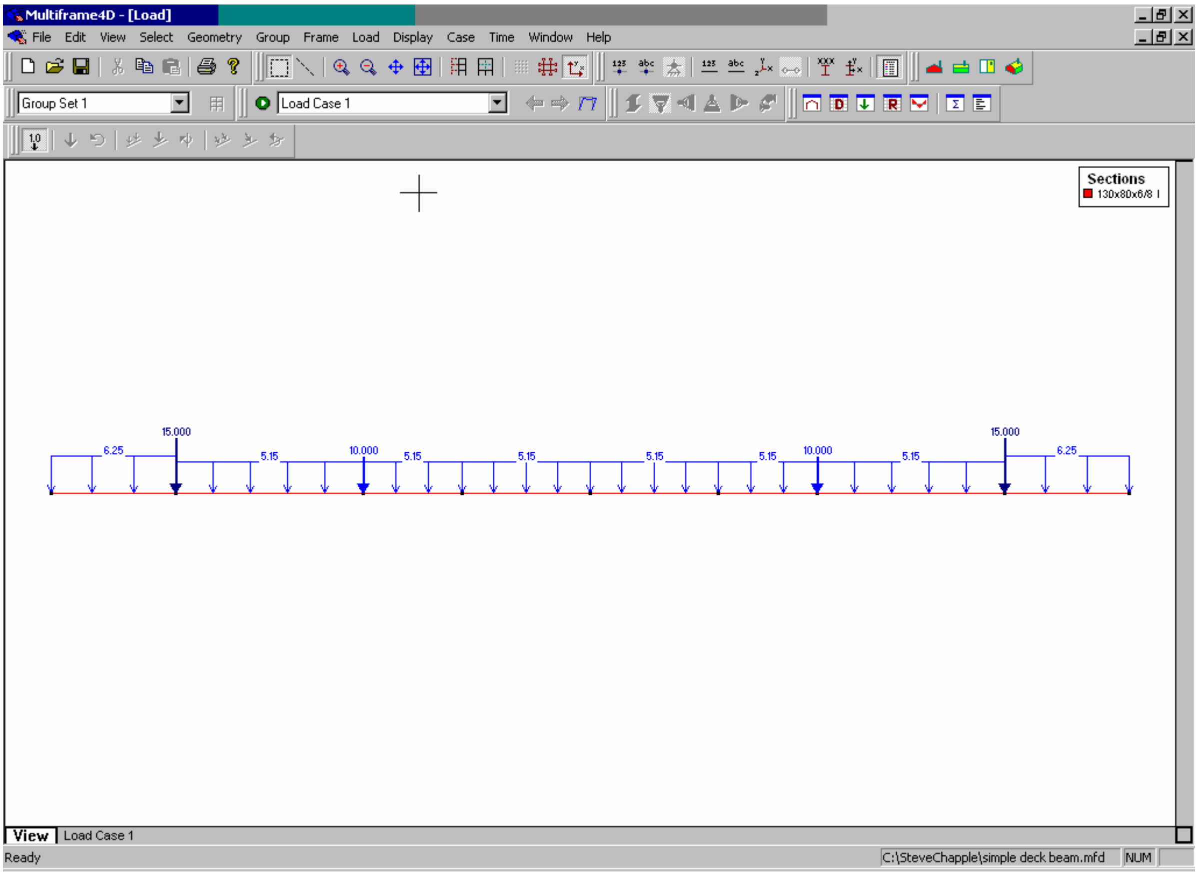

At first glance it looks quite simple however once you look deeper it is actually a complex calculation.

Firstly the beam has different rule pressure values for inside and outside. Then there is the offset between the upper and lower pillars. The load distributed from the roof must also be included as point loads at the pillar base and cabin side locations. Additionally the pillar under the deck also means that part of the beam has its vertical deflection restricted so this must be approximated by a simple support making the beam statically indeterminate. It is possible to manually calculate this beam problem however it will require that a very lengthy set of calculations be made, which then need to be independently checked.

We will now look at two alternative methods of analysis using Multiframe. The first is to build a one dimensional model of the beam and apply the loads as point loads and distributed loads. This is a valid analysis however you must still manually calculate, and check, the magnitude of the point loads being placed on the beam from the roof.

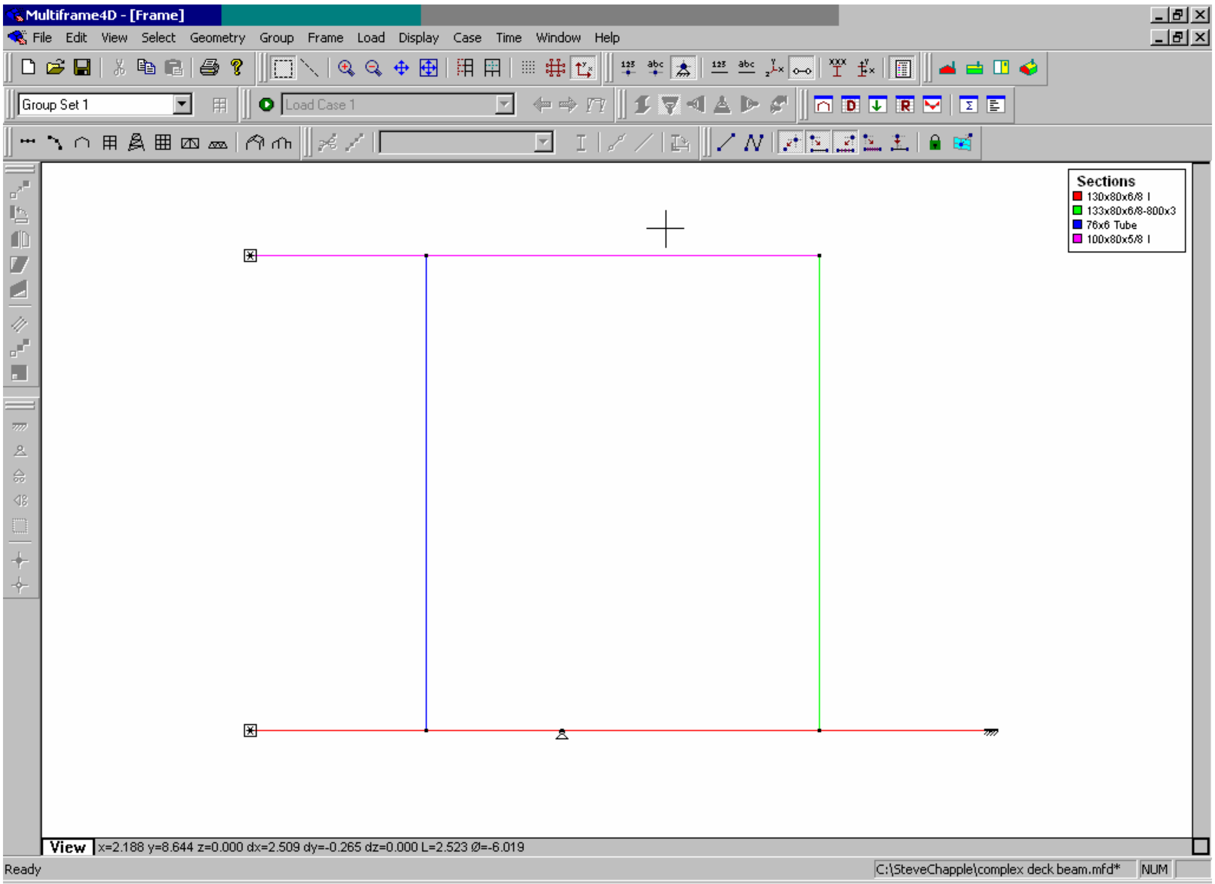



Note The Restraints For The Compression Posts



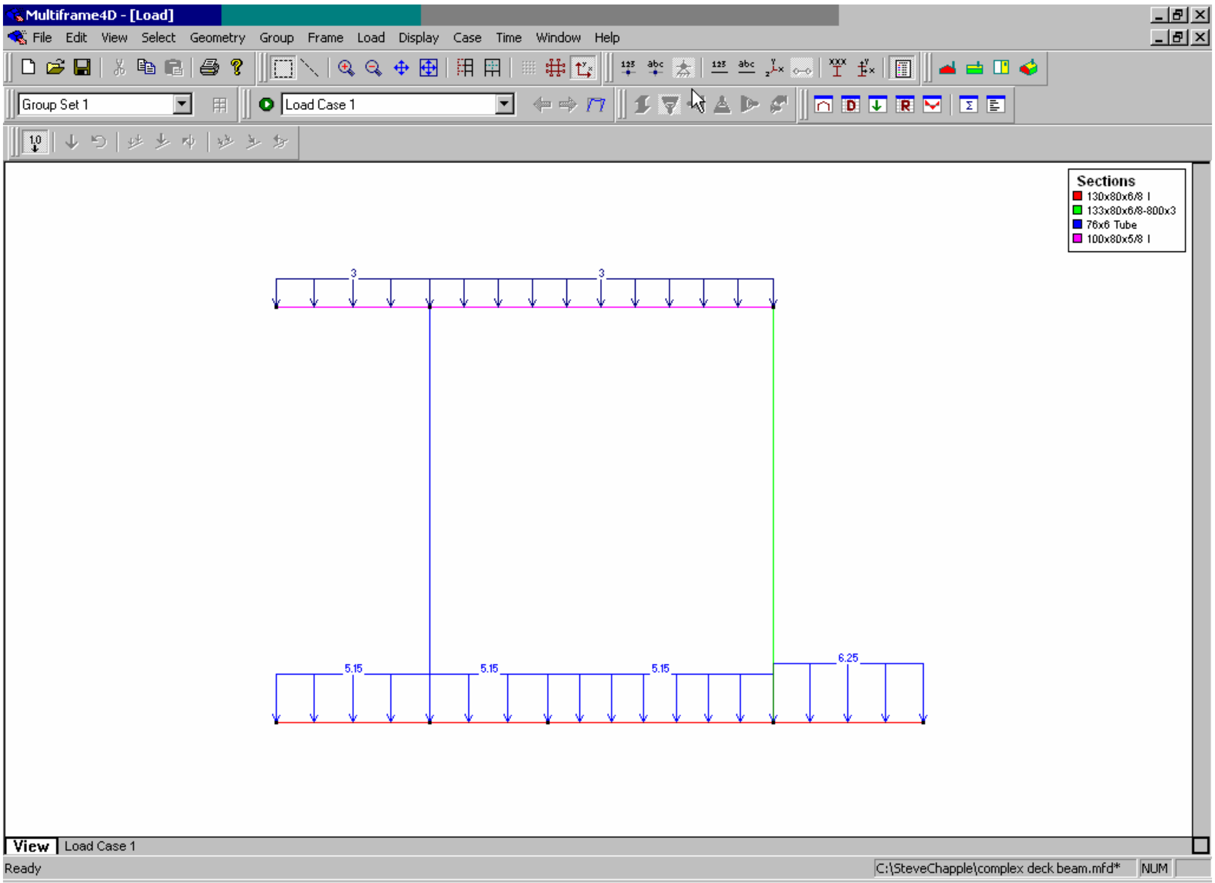

Note The Point Loads Used To Approximate The Transfer of Roof Loads

A simpler and even faster method is to make a two dimensional model of the structure and include the roof structure. This is much faster than manually calculating the distribution of the roof loads and you get the added bonus that the model also analyses the roof structure at the same time.

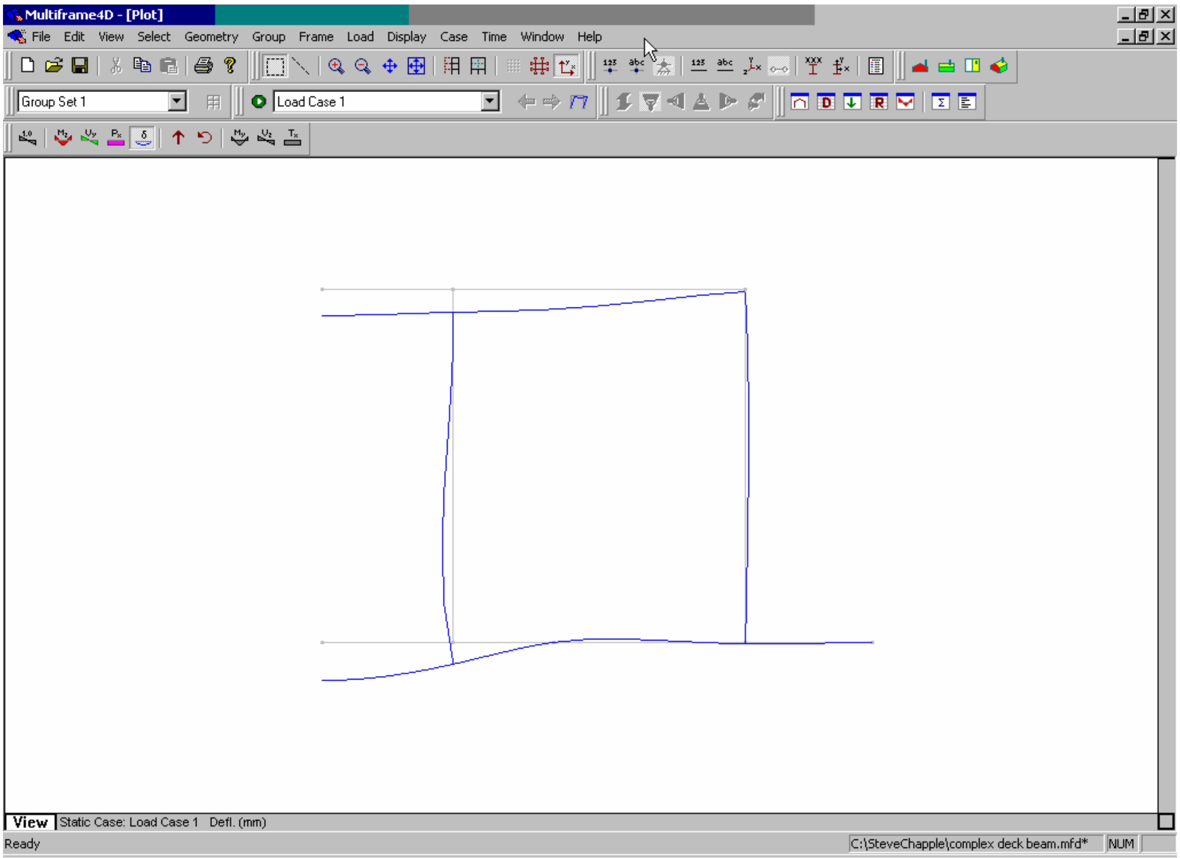


It Can Be Faster And More Accurate To Model The Entire Structure

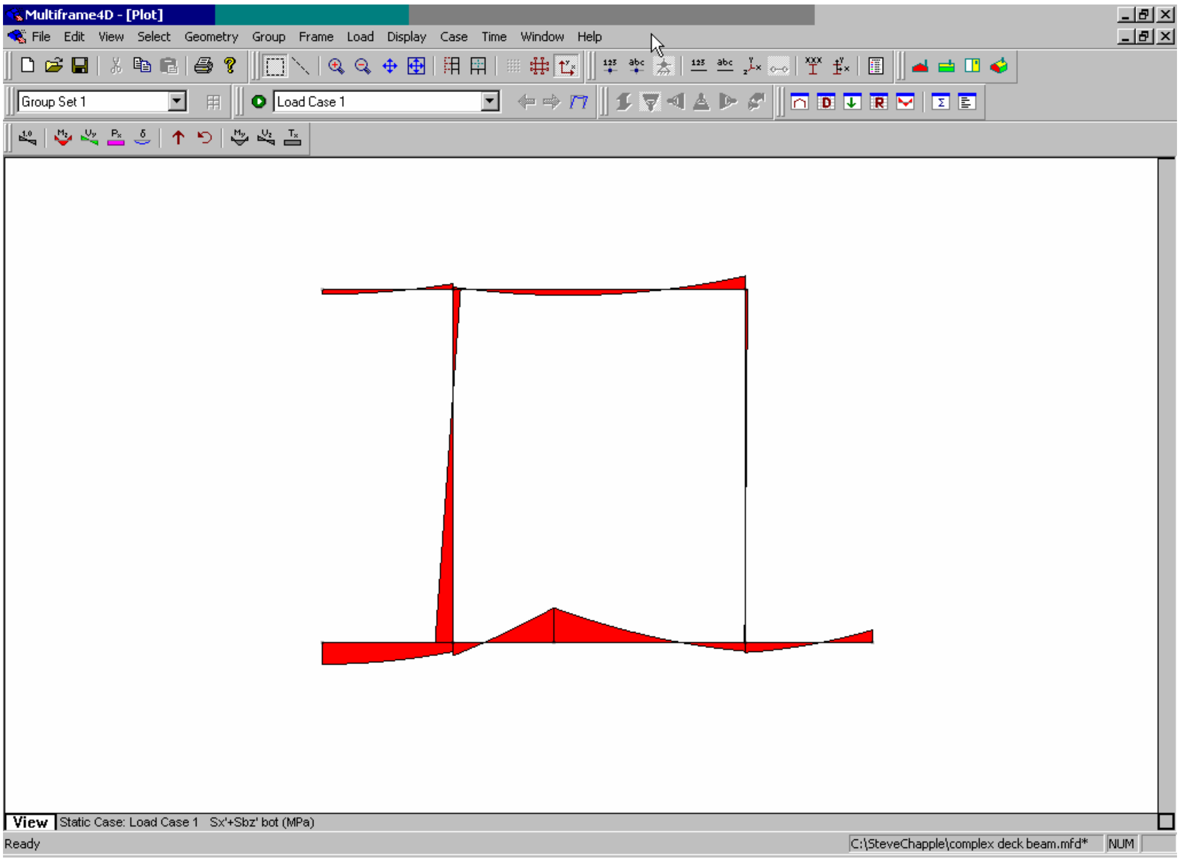
Note also that only half of the structure has been modelled. This makes building the model even faster and will be discussed in more detail later. This could also be done if using the one dimensional model above.




Point Loads Do Not Need To Be Calculated




Deflection Plot




Stress Plot

## Finite Element Modelling

Since the beams in a ship are usually welded directly to the shell plate, you must include the shell plate in your beam properties when using beam modelling for ship structures (how to do this will be discussed later). The results will give an indication of the stress in the plate however due to the mathematics behind a beam element, the analysis will not consider the fact that adjacent plate fields are connected. Therefore to get a true indication of shell plate stresses and deflections, you must use finite element modelling, especially when considering longitudinal stresses.

Finite element programs are quite capable of analysing beam structures however they are primarily designed to analyse solids and shells. Using a dedicated beam modelling program to model beam structures is generally faster than FEA as they have all the tools and commands dedicated to beam structures. Also if your office has FEA and beam modelling software, one designer can start developing the global FEA model while another is already analysing the beam structures. If you tried to use only an FEA package then you would most likely slow the design process. This consideration will have to be made based on the size and needs of you organisation.

## 8. Four Types of Analysis Output

There are generally four types of output that are relevant to ship structural design. These are stress, deflection, modal frequency and forced dynamic response.

### Stress

Both finite element and beam analysis programs output all the stress values that need to be considered, these being bending stress, axial stress, shear stress and combined stress such as bending and axial combined. Remember though that a beam model does not consider the shear stress between adjacent panels. You should check that the maximum allowable stresses have not been exceeded when the rule loads have been applied. This is in order to pass the classification society rules however you should remember that this is only the beginning. Since different class society rules will give different pressures for the same ship, we can not assume that the loads or the results are exact. They are an indication only – a good indication – but not an exact figure. For example when considering a global model and looking at the stress in the plate, all you can really be sure of is relative changes in stress. Consider that your model shows a background stress of 40MPa in the superstructure side. As the loads are not exact, you can not be sure of the accuracy of that figure. If however a stress concentration near an opening in that same superstructure is displayed showing that the stress is 80MPa in that area, again you can not be sure of the exact magnitude but you can be confident that there is a stress concentration factor of 2 present in that area. You must then consider that the stress may be higher (or lower) and design that area for the worst case scenario. It doesn't cost much more to add some brackets or heavier plate inserts while the ship is being constructed. As discussed earlier, it will however be a significant cost if you have to do it once the ship is in service.

### Deflection

The classification society rules generally do not concern themselves with deflection. If a deck beam deflects 5mm or 10mm, they really don't care as long as it doesn't fail. Therefore this is an area where the designer must look beyond the rules and consider if the deflections are acceptable. Ask yourself what is attached to the beam and does it matter if it deflects. In most cases it won't matter however there are some cases where it will be a cause for concern.

Consider a long slender beam that can have a relatively large deflection. If the beam has stiff brackets at its ends, there is a good chance that the beam will eventually crack at the toe of the bracket. Either make your beam stiffer or design the bracket to give a little.

Then there are the non-structural items. For example if a pipe hanger is attached to the beam, consider whether or not the pipe can tolerate the deflections expected. Internal fitout such as wall linings are usually made from stiff, brittle materials that can not tolerate large deflections. Consider how your linings are attached to the ship's structure and what deflections will be forced upon them. You may need to either re-design your structure or mount the linings differently.

### Modal Analysis

Modal responses, otherwise known as natural frequencies, are very important and again are generally not addressed by the class society rules. The natural frequency of a beam or plate is simply the frequency that it will vibrate at with very little excitation force required, or more simply, the frequency that it 'likes' to vibrate at. The phenomenon of resonance occurs when a beam or plate is excited at or near its natural frequency, resulting in excessive vibration. This will cause the generation of structure bound noise and drastically reduces the fatigue life of the member. In extreme cases it can result in catastrophic failure. To properly consider this you must first identify all of the major forcing frequencies in the ship. Examples are out of balance forces of engines, compressors, shaft rotational speed, and propeller blade pass frequency. Once these forcing frequencies have been identified, both local and global structures should be checked to ensure that their natural frequencies do not coincide with the forcing frequencies. This area is not adequately addressed by the classification society rules but should be considered a fundamental component of good engineering design practises.

### Forced Dynamic Response

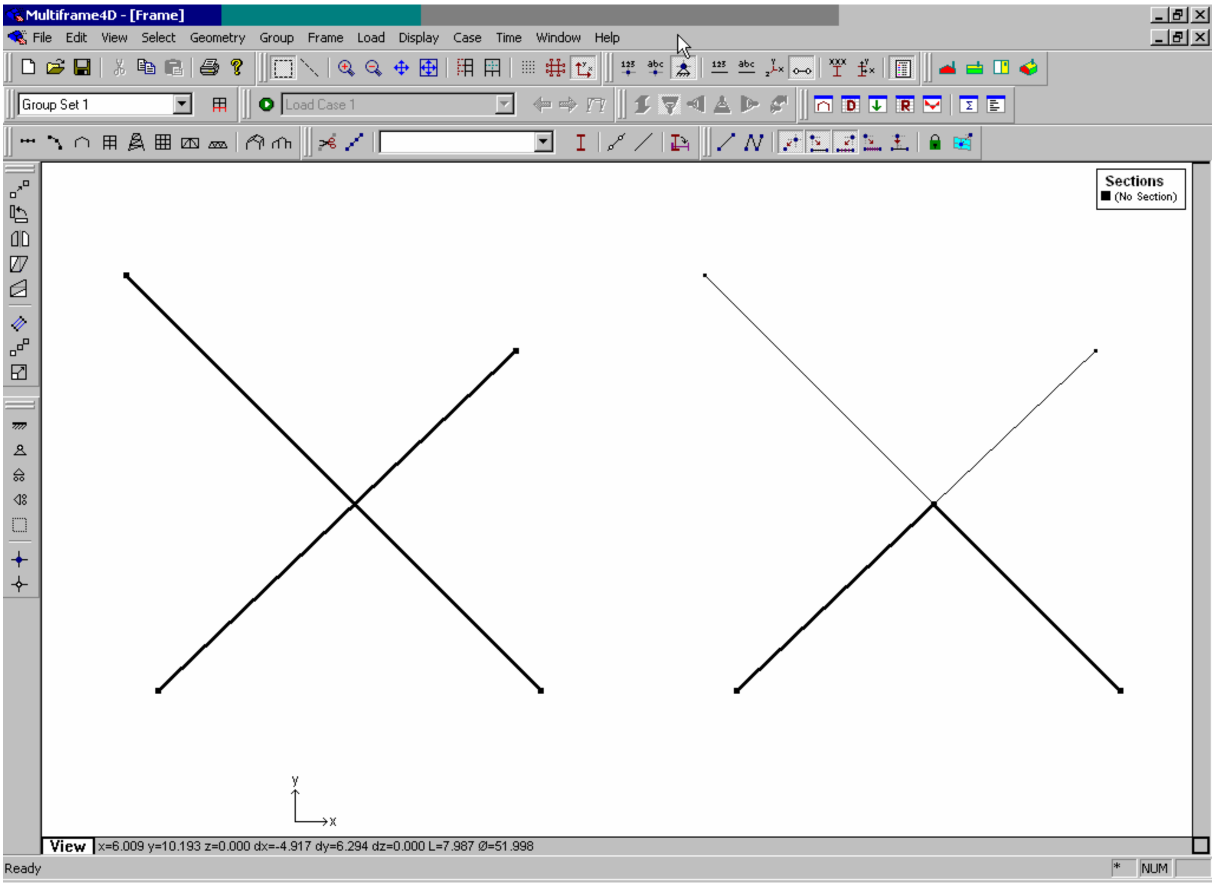
This is similar to modal response however the forcing frequency is not coincident with the structure's natural frequency. A structure will however vibrate to some degree when influenced by external cyclical forces but the resulting vibrations are not as violent as those experienced at resonance. It is however important to consider the forced response of a structure for noise and vibration control. An example is modelling an engine bed that is subjected to the cyclical dynamic forces associated with engine out of balance mass. The response of the structure will have a bearing on both fatigue life and noise and vibration transmission. Once again this area is not adequately addressed by the classification society rules.

## 9. Geometry Creation

Today's software makes the task of creating the geometry of your model easier than ever before. The old systems used to generate the nodes and elements directly, which would then also become your geometry. If you deleted your nodes or elements you lost everything. This made it very difficult to modify a model once it was built. Today's' software is geometry based. That is you draw your geometry using points, curves & surfaces and then apply your nodes and element properties to the geometry. If you delete your nodes or elements, the geometry still exists. This makes it very easy to modify your model.

To model a ship's structure it is often necessary to make some assumptions. For example slight curvature in a bottom shell can usually be ignored and be approximated by a straight line. Small chines between bottom and side plates are also often ignored. You need to consider what results you are looking for. For example if you are looking for stress concentrations in the superstructure of a global model, the omission of the chine structure should not impact your results.

Even though a model is built in a graphical environment, it solves in a purely mathematical environment. You must therefore ensure that all of the structural members are connected by common nodes. Two lines that intersect may look graphically as if they are intersecting and connected, but if they don't share a common node, then they will not be mathematically connected. This is of vital importance for both beam models and FEA models. An example of this is illustrated below.



The Beams On The Left Are Not Mathematically Connected, The Addition Of Nodes To BOTH Members Connects Them Mathematically (Right).

In the picture above, the beams on the left appear to be intersecting however this is not the case. We have highlighted the beams and you can see nodes at the ends of each beam. There is no node at the intersection point. For beams to be mathematically connected, they must share common nodes. By subdividing both beams as shown on the right, we have created four beams. Note that each beam has an end node at the point of intersection. We have highlighted only two beams to illustrate this. These beams are mathematically connected since all four share a common node at the point of intersection.

## 10. Application of Loads

When considering how your model should be loaded the first step is to consult the classification society rules. They all have very good sections dedicated to calculating the loads expected for various locations on the ship. You can either use their software for this or write a set of spreadsheets using their formulas. One important point to consider is that different class societies have different formulas and hence the same ship assessed using one set of rules will have a different set of load values when assessed with an alternative set of rules. This inherently means that the loads can not be considered as 100% accurate. They should only be considered as a guide and your own judgement will be required to determine if they are too conservative or not. You must use them when assessing the structure for compliance with the rules, however once you move beyond the rules and start making independent calculations, the designer must then use their own judgement as to how realistic the rules are. In some cases the rule values may be too high and in others they may be too low. While you must use the rule values for your strength calculations, you can usually use the actual loads when considering deflection and vibration. For example, consider the rule loads used when checking the deflection of a deck beam of a passenger ferry. The rule value used for determining whether or not an internal deck meets the rule strength requirements is in the order of $5kN/m^2$ or approx. $510kg/m^2$. When you consider the self weight of the structure and the actual passenger distribution, this load value may in some areas of the ship be too high. On the other hand the deck structure in a galley may be subjected to loads greater than the rule value due to the weight of the equipment. So you can see that you should give consideration to the layout and function of the ship so you can be sure that the load values being used in your design process are realistic for the structure being assessed.

Now consider a case when a sea pressure load may be too high. The rule value for the pressure applied to a deckhouse roof is in the order of $3kN/m^2$ which is approx. $305kg/m^2$. In assessing the deflection of your roof beams you will need to consider if $305kg/m^2$ is a realistic load. In cases where the deck house is a considerable distance from the water line, the rule load will be too high, and if used, can give larger deflection results than can be expected in reality.

Once you have decided on which values to use, applying them to you model is quite straight forward. Simply select the member to be loaded, assign the load value and select the orientation of the load with reference to either a global coordinate system or a local member coordinate system.

## 11. Selection of Boundary Conditions

Many designers find the application of boundary conditions quite daunting but be assured that it is very simple. All you have to do is consider how the structure will be restrained and constrain the degrees of freedom to make the model behave in a realistic manner. There are only six degrees of freedom to consider, 3 translation (tx,ty,tz) and three rotation, - the rotation about each axis (rx,ry,rz). Since most ship structures are welded, the majority of boundary conditions will be fixed, ie all 6 degrees of freedom constrained. Consider a deck beam welded to a longitudinal girder. It can not translate in any direction and it can not rotate in any direction. Simply restrain all 6 degrees of freedom to represent this.

The other sort of boundary condition to consider is the symmetry boundary condition. The use of these evolved many years ago when solve times were long and software was not so user friendly. If you could model half of your structure and get an accurate result using symmetrical boundary conditions, you would halve the size of your model and significantly reduce the time to build and solve it. These days this is not so important. You can build half of the model and use a mirror command to generate the other half. As for the model now being twice as large, the fast solve times given by today's technology no longer make this an issue. Some designers still prefer to use symmetrical boundary conditions simply because it results in less clutter on the screen. To apply them just think of how the structure behaves on its plane of symmetry when under load. For example consider a beam with a uniform load. The centre of the span is the plane of symmetry, so just think about what is happening at this point. For the 3 dimensional case, the centre point has translated in the negative y direction, but not in the x or z direction. Next consider rotation. It has not rotated about any axis. Therefore your symmetry boundary condition is to restrain all degrees of freedom except translation in the y direction.

Another important Point to consider is that boundary conditions can cause a stress concentration in the model. To allow for this extend your model past the point of interest. This way the boundary conditions are applied away from your point of interest and are less likely to influence the results.

## 12. Model Verification

Once you have built and solved your model the next consideration is to assess how accurate and valid the analysis is. We have all heard of the phrase 'garbage in - garbage out' and this applies to structural analysis. The computer will in most cases solve a model even if its load conditions, boundary conditions, or geometry are incorrect. There are four items to verify in your model, geometry, loads, boundary conditions, and comparative calculations. These must be checked before you can have confidence in your results.

### Geometry

The graphical nature if today's software makes this task very easy. First use layers or different colours when constructing your model and later isolate the members by layer or colour for viewing to check that all the members properties are correct. For example if you isolate the deck beam layer, you will very easily see if a beam is missing or if it has the wrong properties assigned to it. Next use a render command to give a rendered display of the model. This will give a visual display of beam orientation and size. Once the model has been solved, use the animate command to view the model deflecting. This will show any nodes that are not properly connected and will also give an indication to whether the model is behaving as expected.

As mentioned earlier, the topic of connected nodes is very important. Your model can look as though the elements and beam members are connected, however if they don't share a common node, then they are not mathematically connected and your model will not solve correctly. Using the animated view will highlight this if it has occurred.

### Loads

The first step in checking that your model is correctly loaded is to use the graphical display to check the orientation and magnitude of the loads. Once this has been done and the model solved, the next step is to sum the moments and reaction forces to ensure that the total load is correct. Again use the animated display to check that deflections are not excessive and that the model members are deflecting in the correct direction.

### Boundary Conditions

These are best viewed graphically after the model has been solved. Use the deflection plot and animation display to visually check that he model has been restrained property. If the model won't solve, there is probably a global translation or rotation that has not been restrained. Check your constraints and make sure that the model is globally restrained.

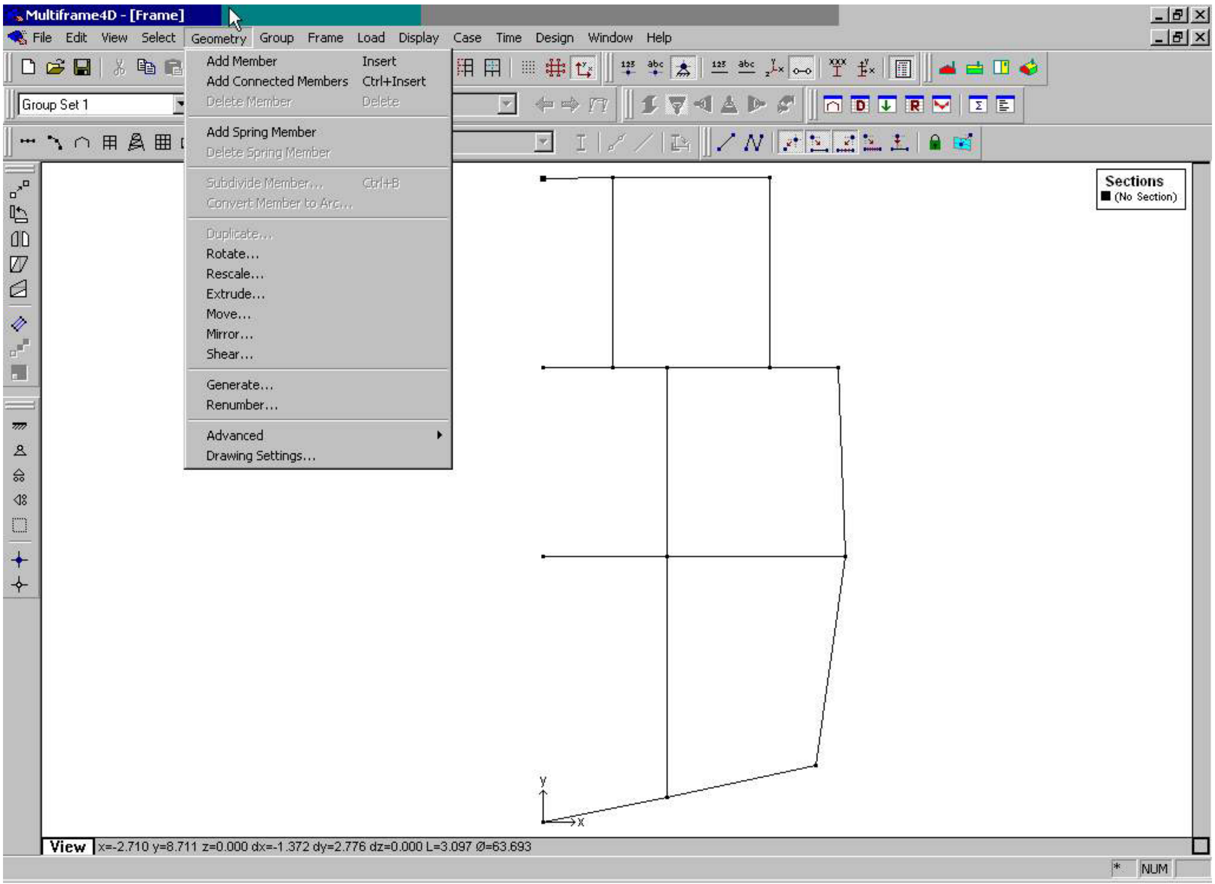
### Comparative Calculations

The final step is to select parts of your model that can be approximated by simple beam or plate theory and perform some random manual calculations to check that the stress values given by your model are reasonably close to those calculated manually.

## 13. Beam Modelling Examples using Multiframe

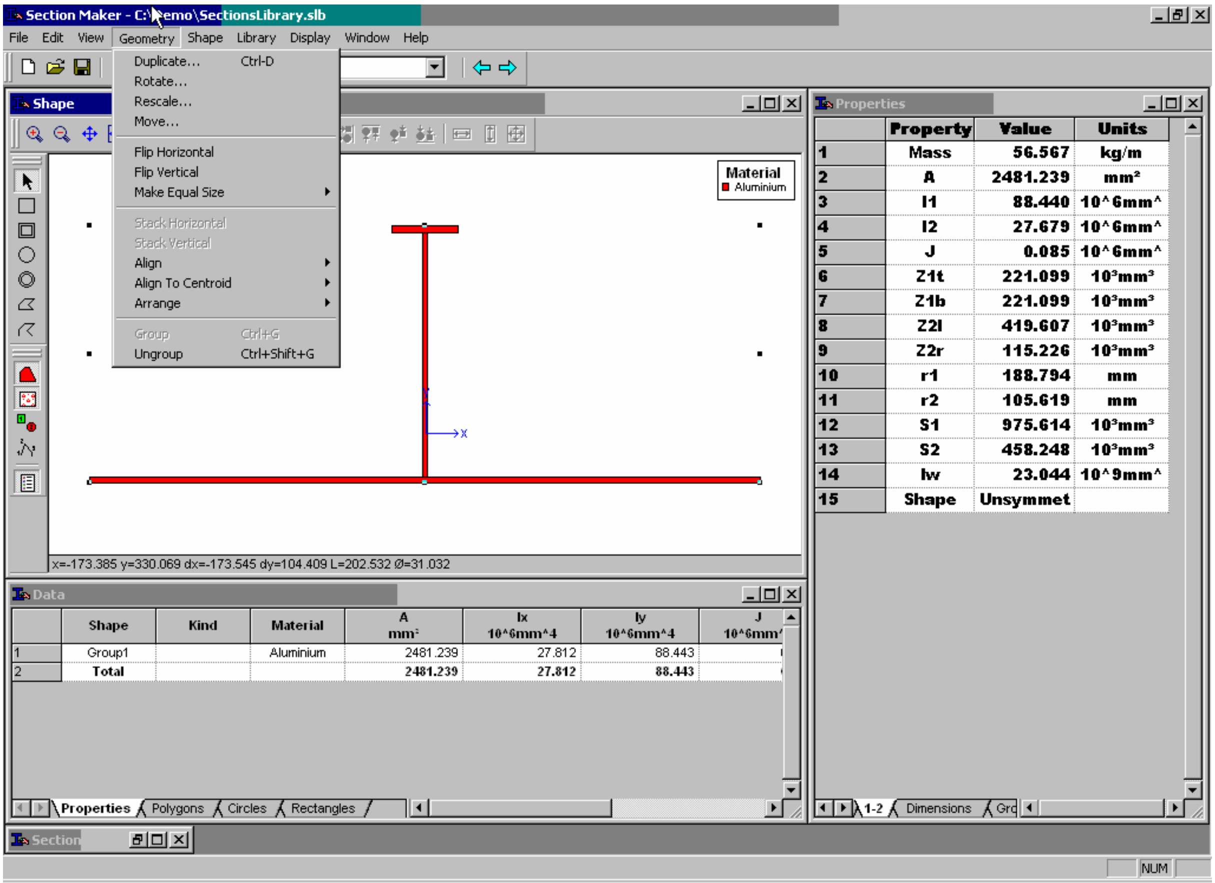
To clarify the preceding sections we will now analyse a typical midship section using Multiframe. First we will investigate the effects of a local slamming load on one frame.

Generate a midship section using the commands in the Geometry menu. Nodes are located at major points including longitudinal girder locations. Apply the constraints to the nodes to simulate the expected real restraints. In this example we will use a half model to illustrate the use of symmetrical restraints.



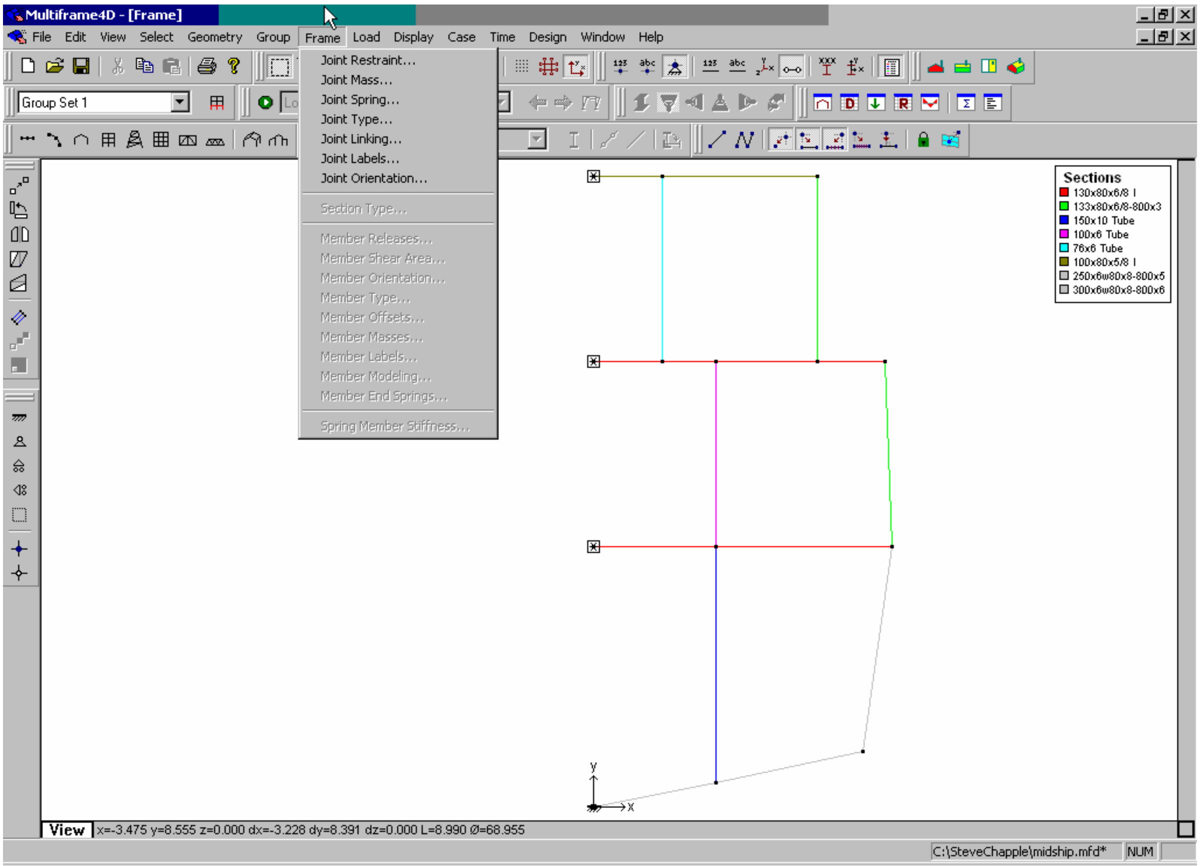
Midship Section With Significant Nodal Points

Next using Section Maker, create the beam sections for the structure. Remember that the shell plate is welded to the frame sections so this must be included. In the example we are using a 'T' section welded to the shell plate. The shell plate width used in creating the section is obtained from the effective flange calculation found in the classification society rules. Once the shape has been built, assign the material property to the section and use the align to centroid command to correctly locate the centroid of the complete built up section.

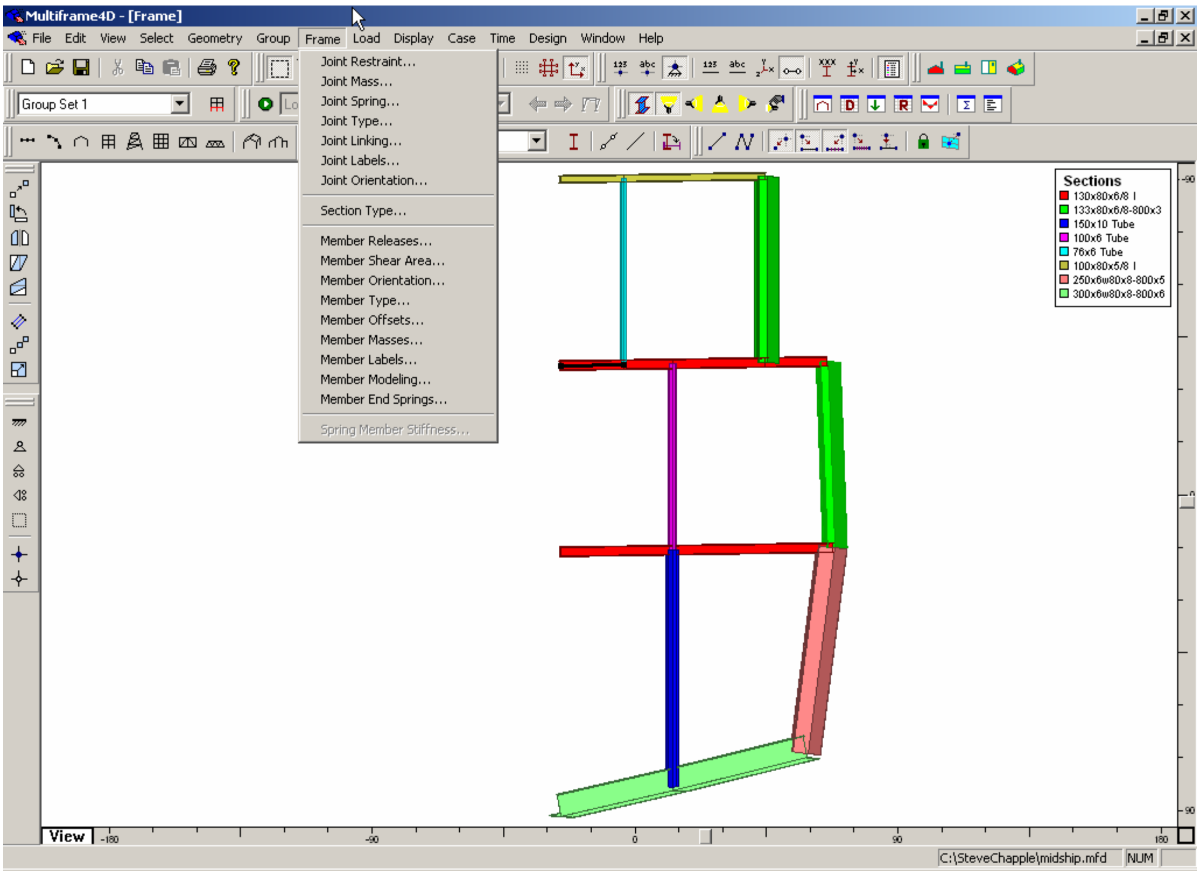



Section Maker Screen Shot Showing Built Up Frame Section

Now you can assign your beam properties to each beam in the model. This is done by selecting the member (or members) and then selecting the section from the sections library. The beam colours will help you verify that the beam properties have been assigned correctly. Check the isometric view in rendered mode to verify that the beam sections are correctly orientated. If they are not orientated correctly, select the incorrect member and use the Member Orientation command found in the Frame menu to change its orientation.

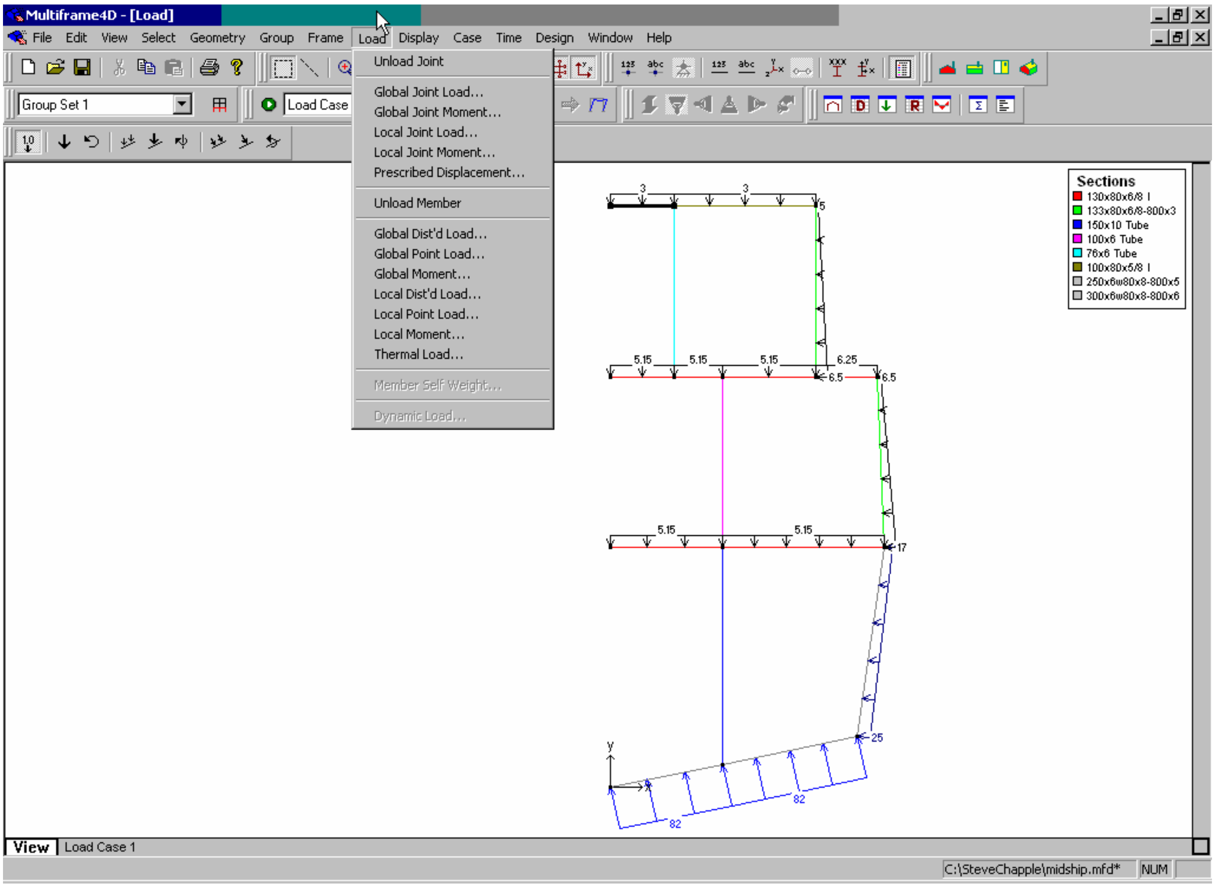



Beam Properties And Node Restraints Have Been Assigned



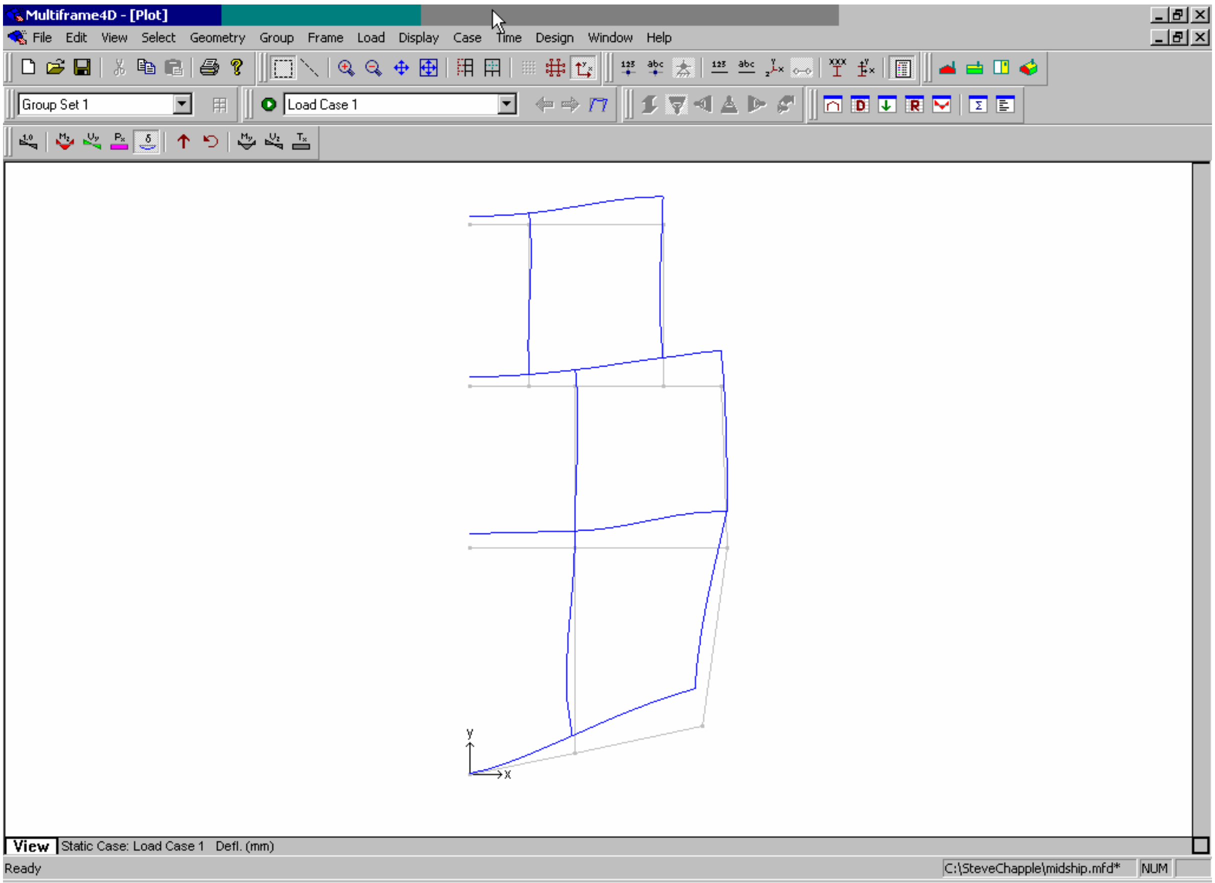

Rendering Assists In Verifying Beam Orientation

Next switch to the load window to load the model. The load values are obtained from the classification society rules. You can apply the loads to the members or to the nodal points using commands found in the Load menu. Since we are using rule pressures we will apply a pressure load to the frame members.



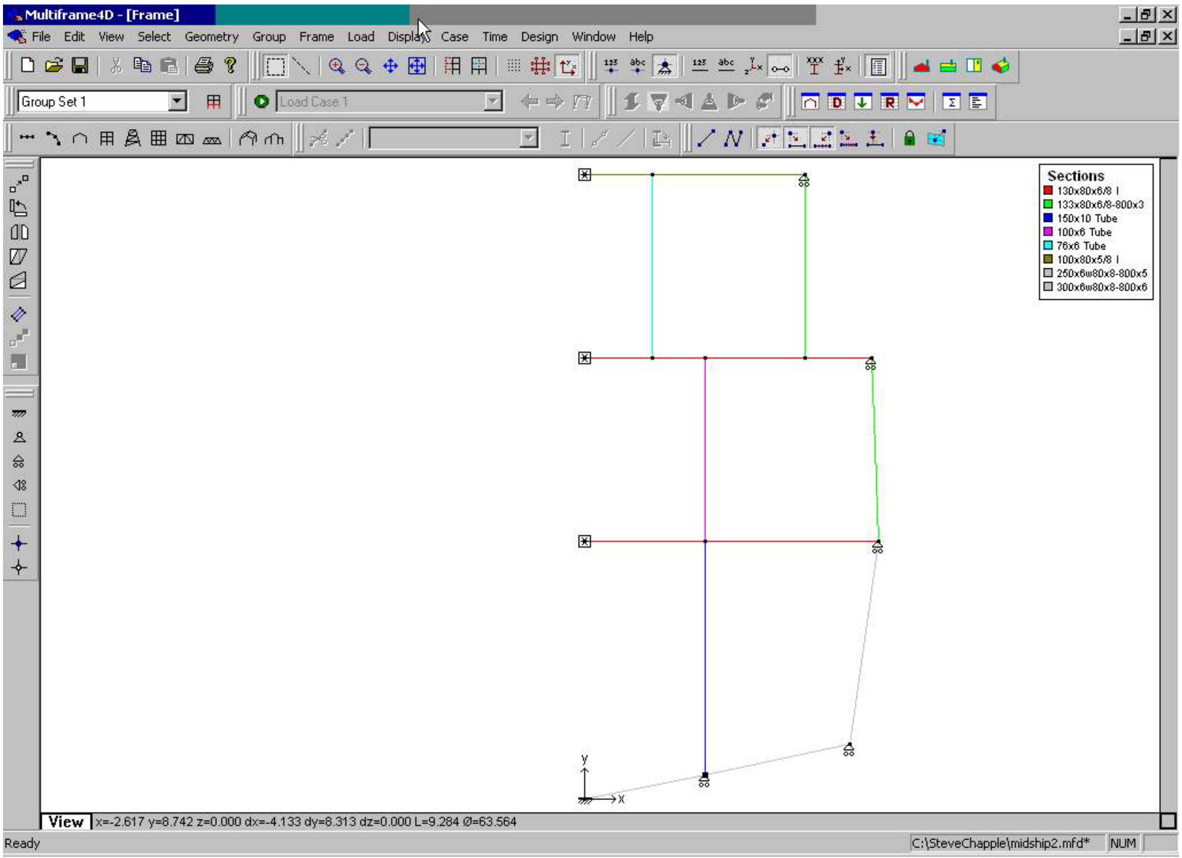
It Is Easy To Visually Check Your Load Values & Orientation

Once the loads have been applied, analyse the model and use the plot view to view the results. Start your verification with the deflection and animation plots.

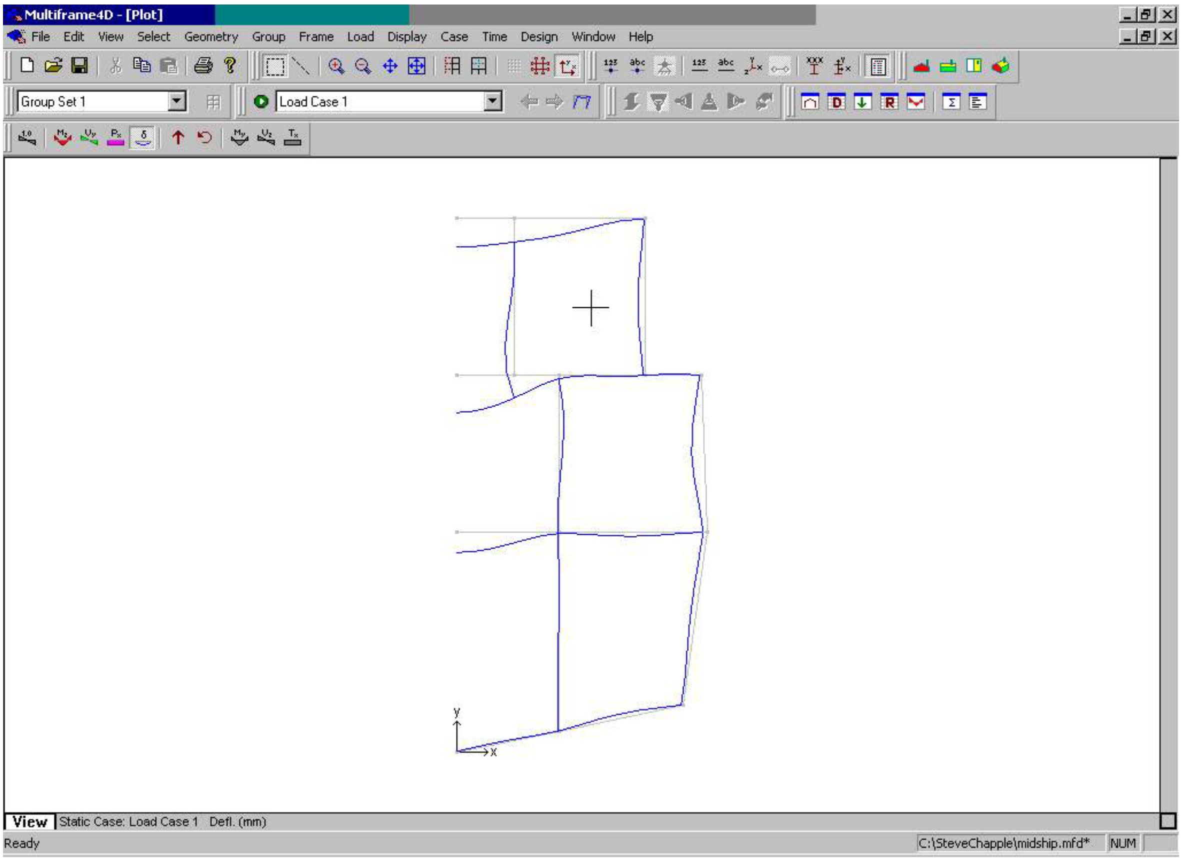



The Deflection Plot is Vital for Verifying The Model

Straight away we can see a problem with the deflection plot. See how the node at the deck edge has moved up significantly. This is because as discussed earlier, the shear connection of adjacent plate fields is not considered in the mathematics of a beam model. There is little chance that a local slamming load will cause the deck edge to move. The hull and superstructure sides are extremely stiff so the plate would have to shear in order for the deck edge to move up. Also notice how the hull girder node has moved significantly. This is unlikely in reality. To fix this add a boundary condition to the deck edges and hull girder node to restrain the vertical movement. Now solve the model again.

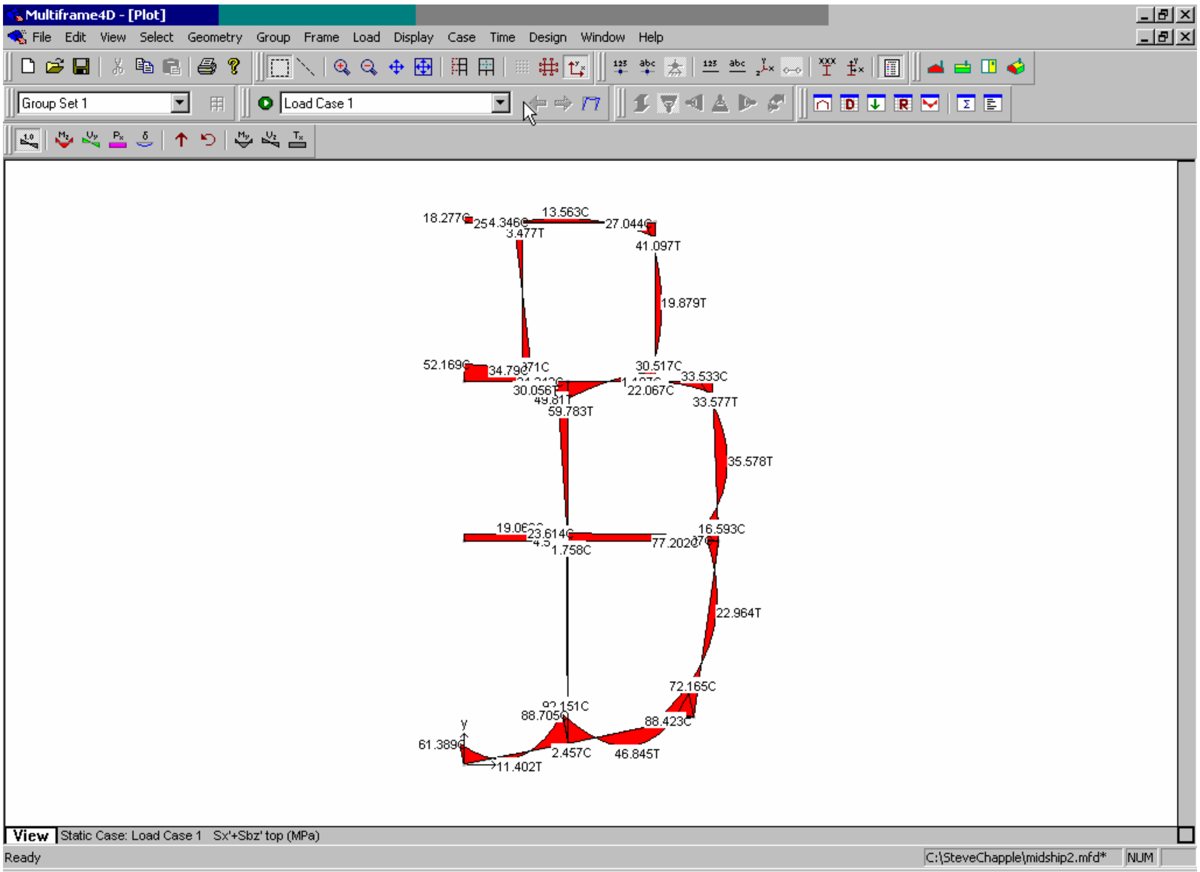



New Boundary Conditions Added

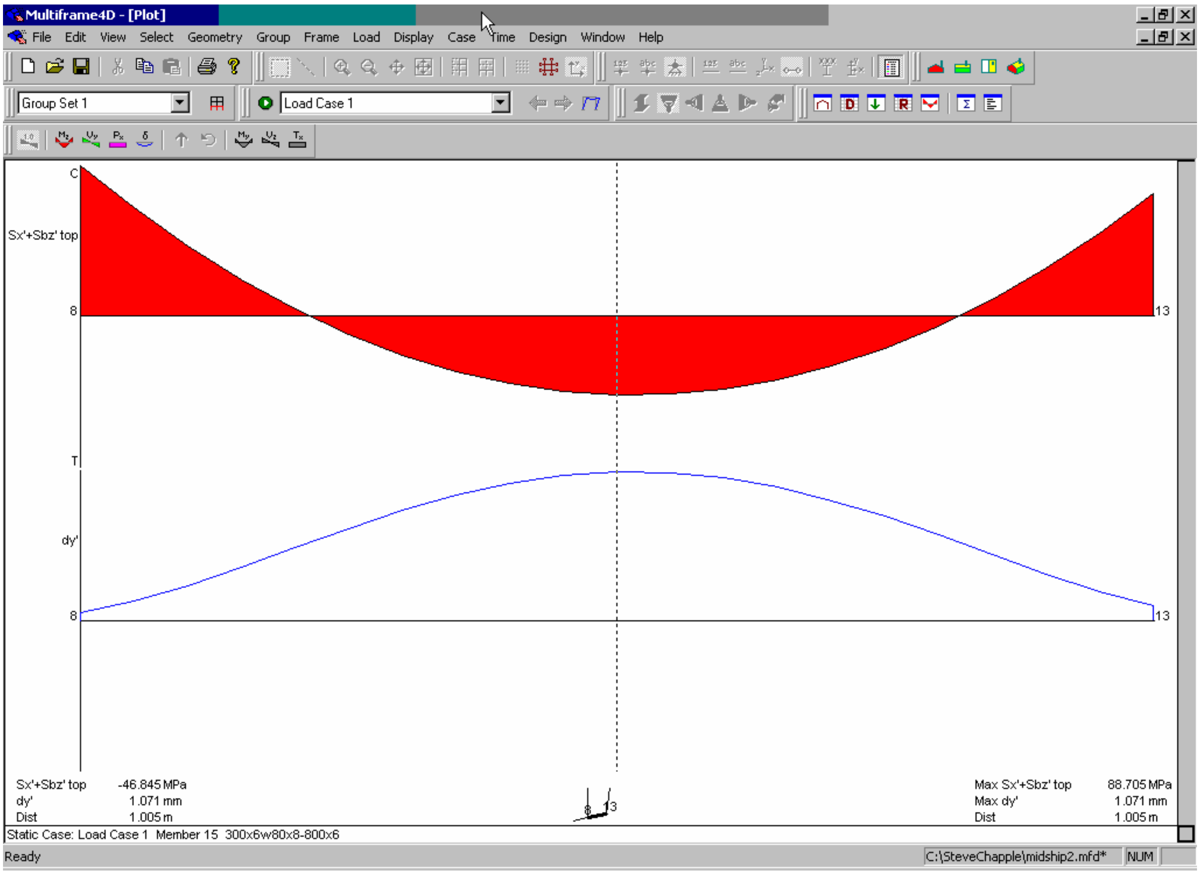



Now The Deflection Plot Looks Realistic

You can see that the model deflection now looks more realistic. Once all the other aspects of the model have been properly verified, you can view various stress plots for each member and have confidence in the results.

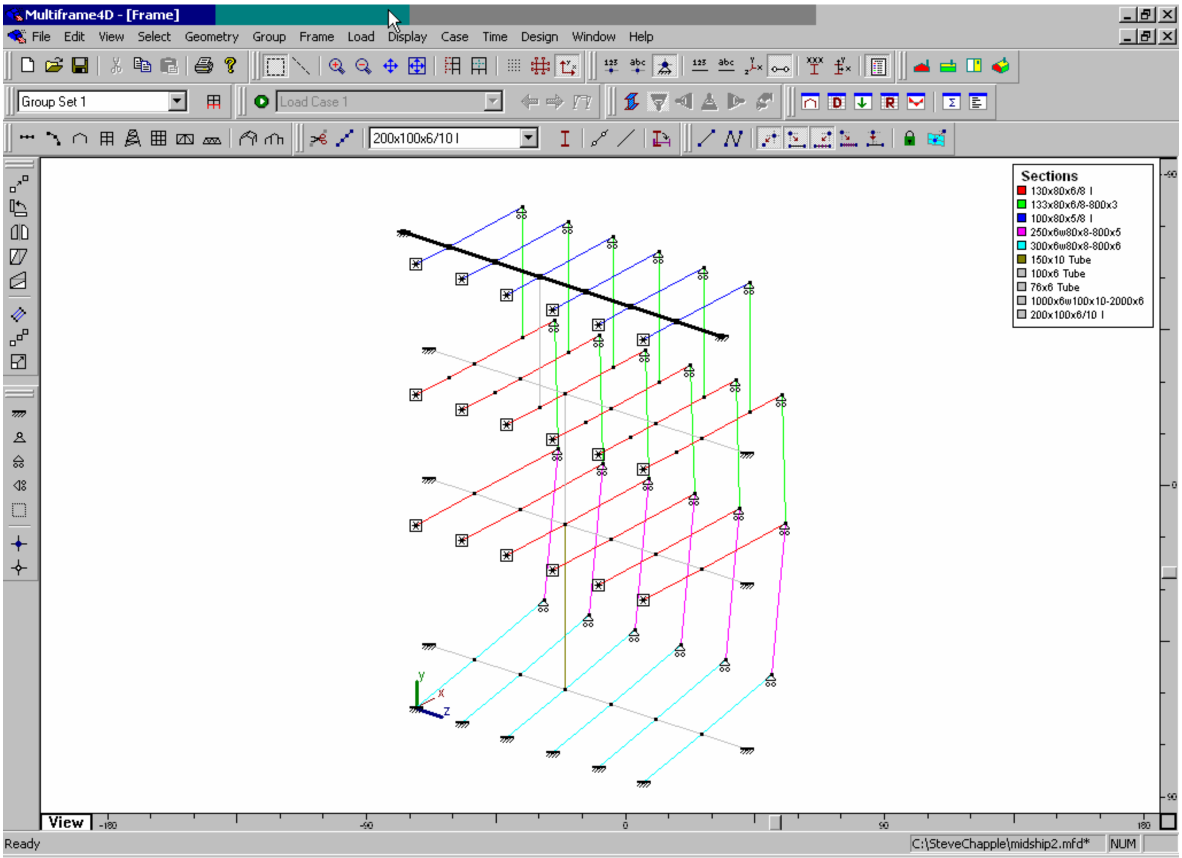


Global Stress Plot With Plot Values Displayed

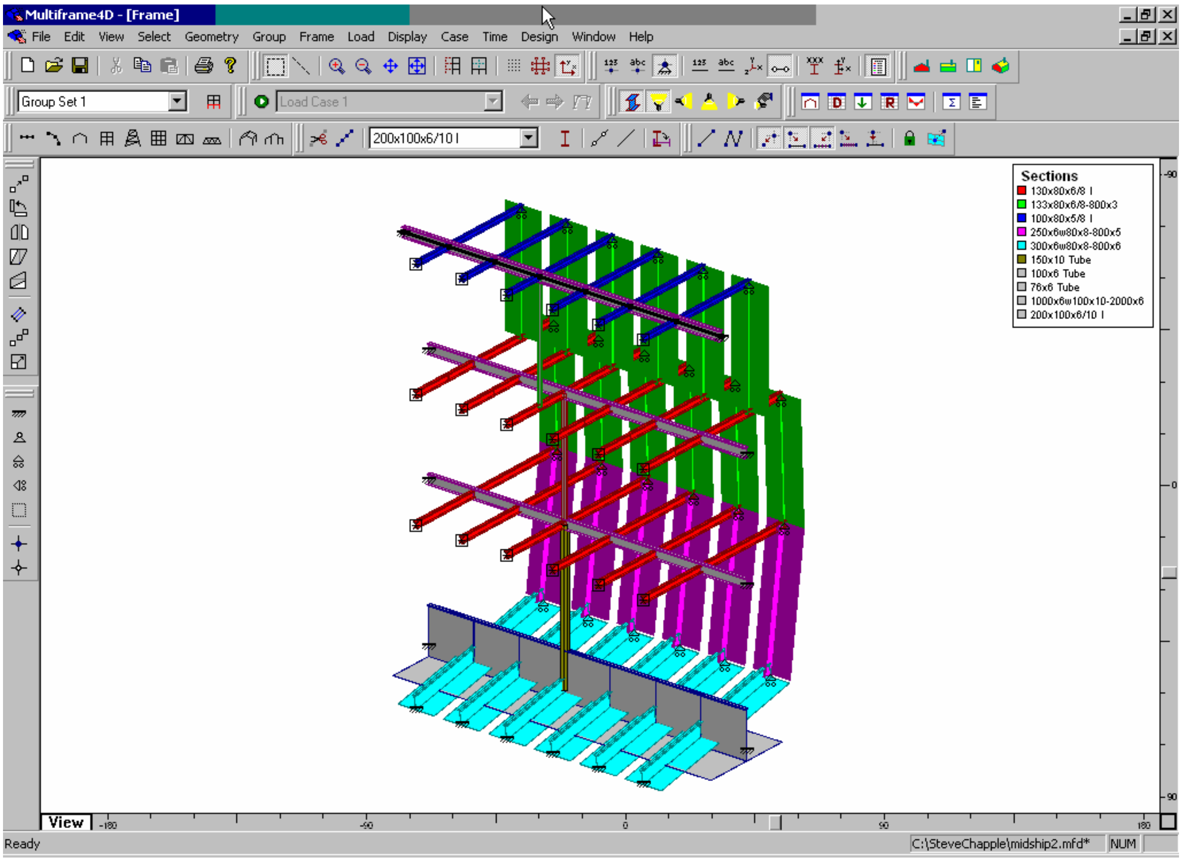


Stress & Deflection Plot of Outer Bottom Frame

One of the assumptions made in this 2D model is that the longitudinal girder stiffness can be approximated by a vertical boundary constraint as it is much stiffer than the transverse frame. This assumption may be valid for hull girders but this may not be valid for deck girders that are typically smaller. The best way to test this is to create a 3D model and actually include the girders in the model. This is very simple in Multiframe, just use the Duplicate command. Then assign beam properties to the lines representing the girders. It is best to model one whole compartment, bulkhead to bulkhead, and use fixed boundary conditions to simulate the end conditions at the bulkhead.

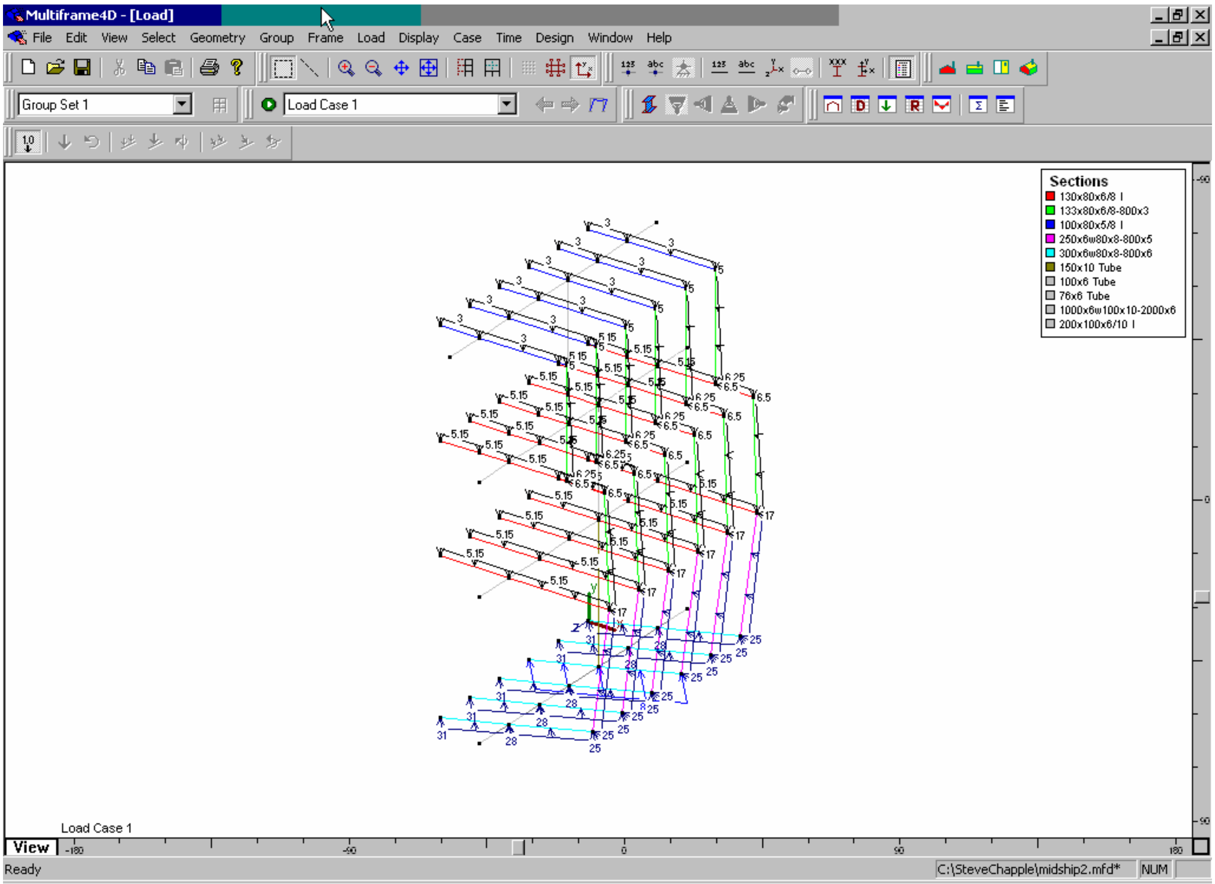



3D Geometry Created Using The Duplicate Command

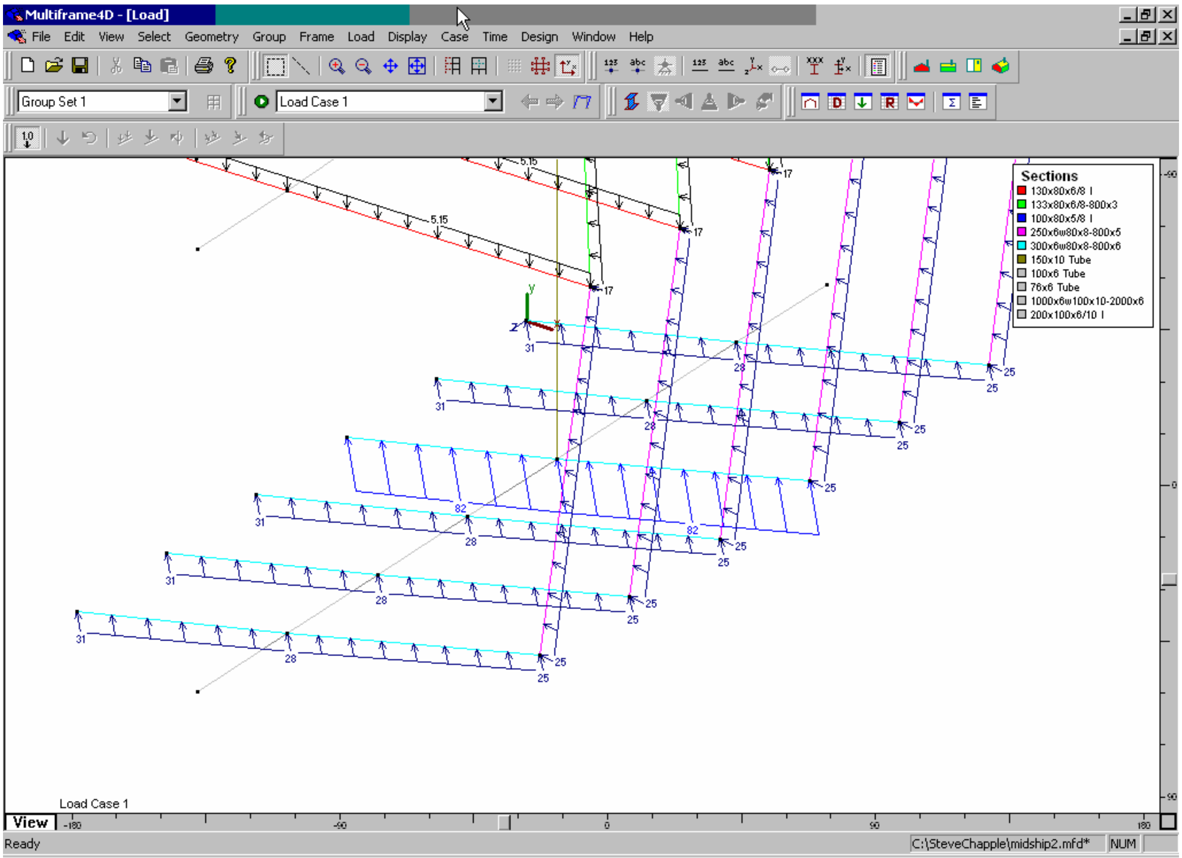



Rendered 3D View

We now have a more accurate model of the structure. Since the deck loads are assumed constant across the deck, we have loaded each deck beam. We have also loaded each hull frame with a sea pressure load, but placed a slamming load on only the one frame of interest. It is very easy to develop this type of model and the advantage to the designer is that you can literally see how the structure interacts.

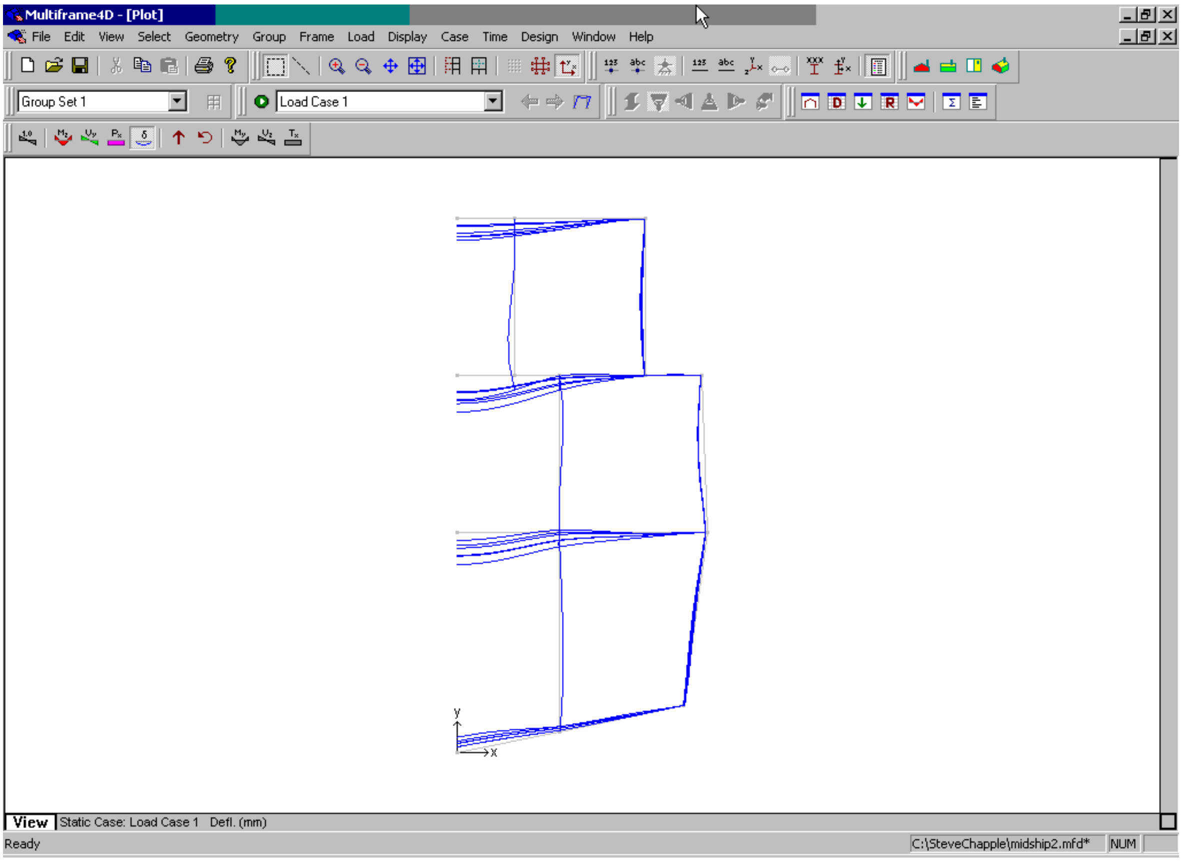


All Sections Loaded

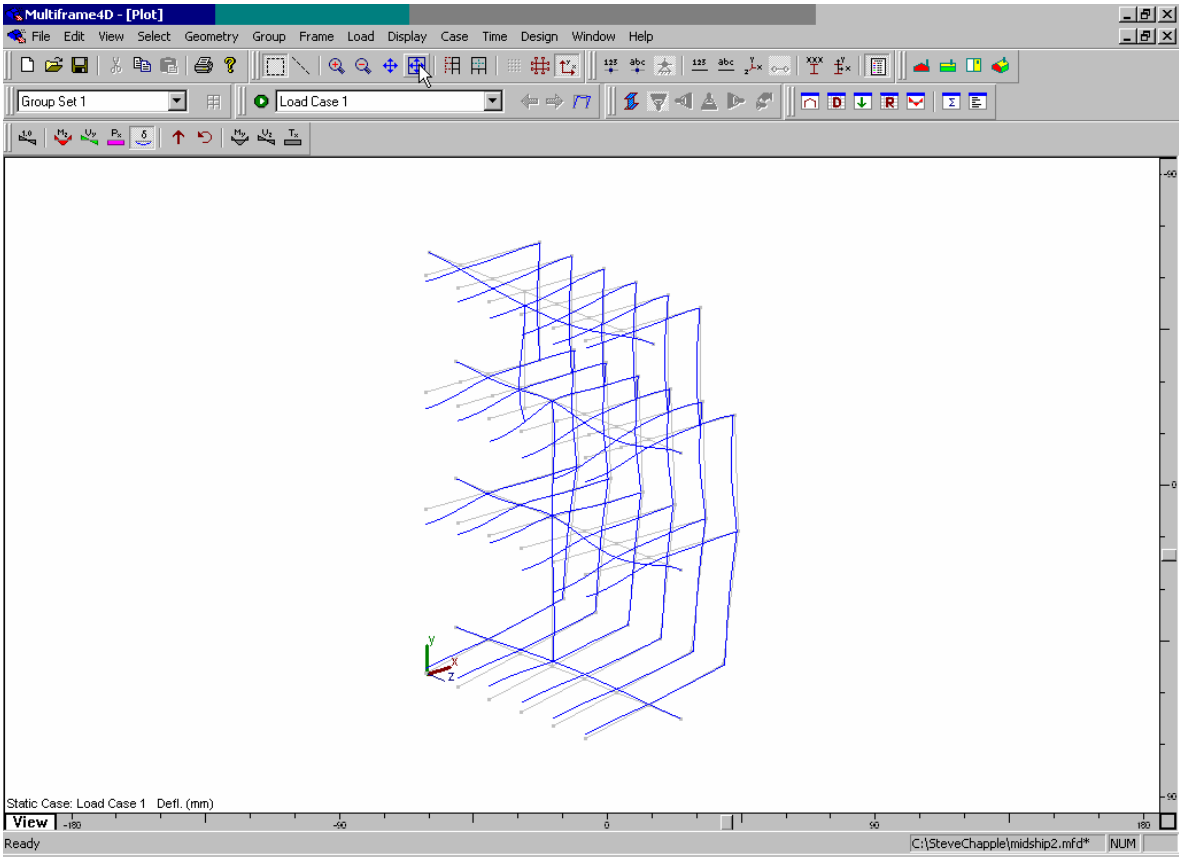



Note Only One Frame With a Slamming Load and Sea Pressure For The Others

Again the first step is to check the deflection and animation plots. Notice how the girder has not deflected very much even though it is now restrained only at the ends. This is because it is significantly stiffer than the frames. This result validates the use of the restraint in the 2D model.

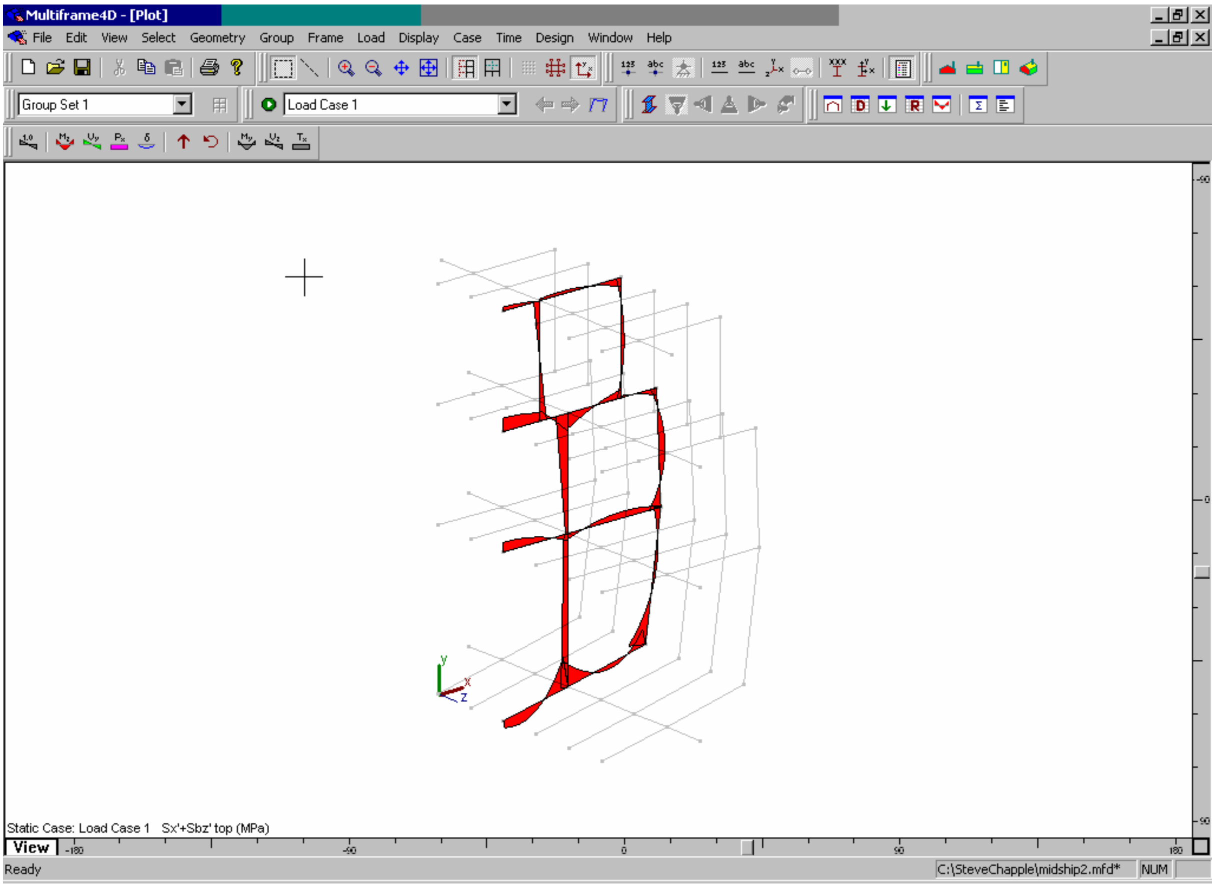



2D Deflection Plot



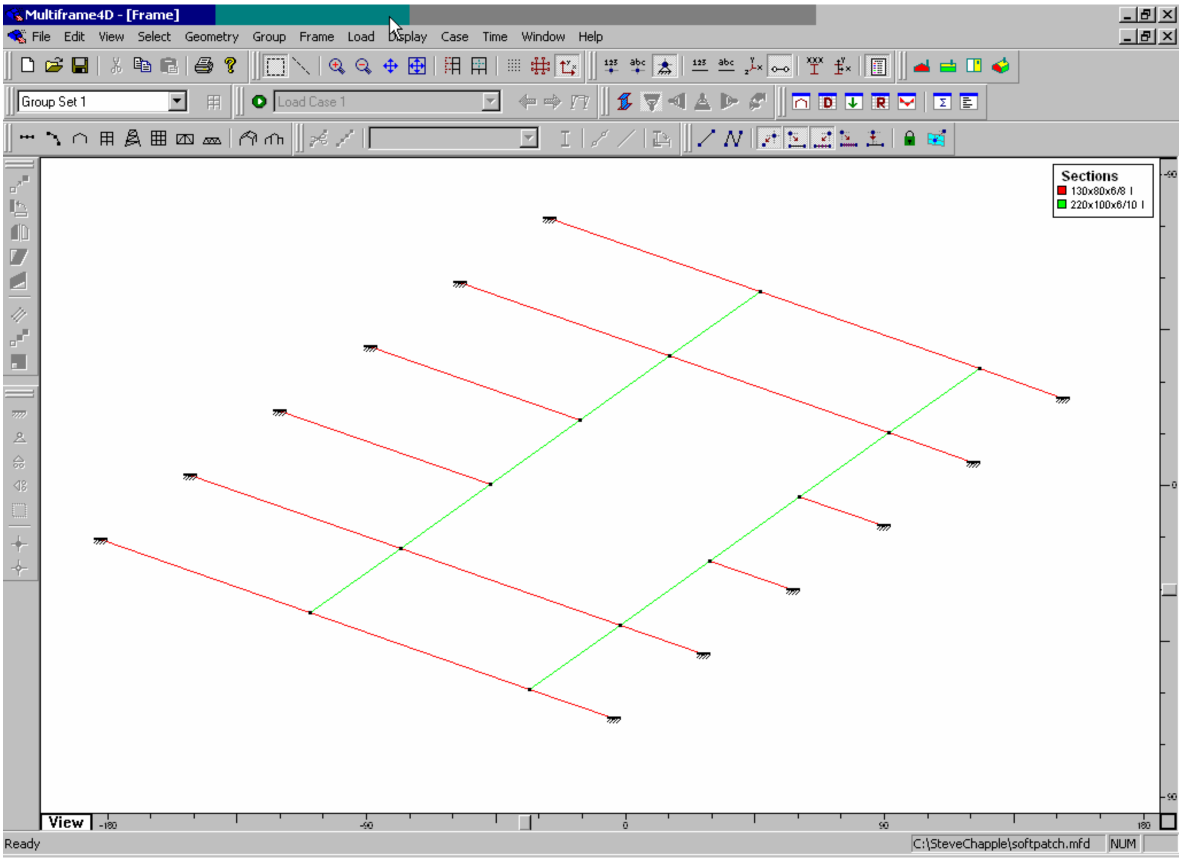

3D Deflection Plot

You can view the stress plot with or without the plot values turned on and you can also use the clipping command to turn off the display for some frames making the results easier to view. In this example we are investigating the effects of slamming loads so the frames with sea pressure loads have been clipped.

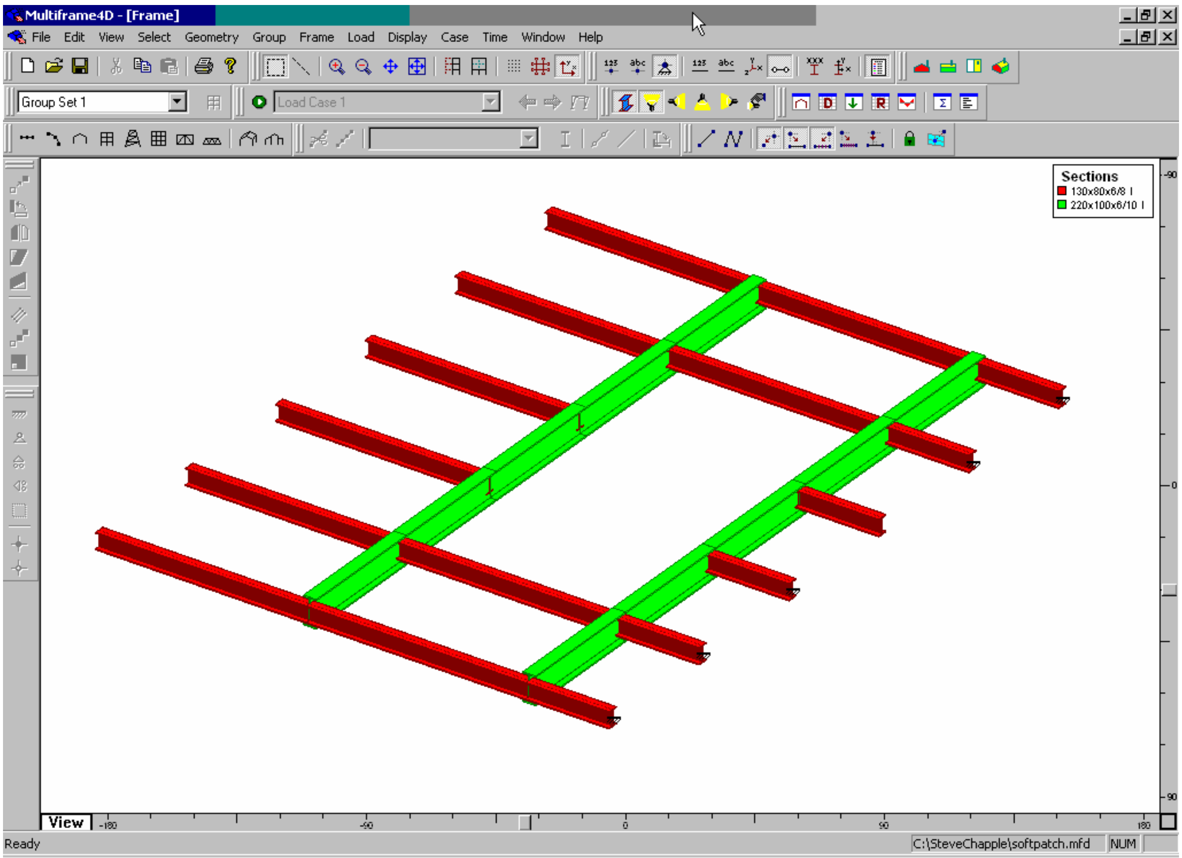



Use Clipping To Make Your Plots Easy To Read

Lets now consider a model of a deck opening such as an engine soft patch. This would be difficult to calculate using hand calculations or spreadsheets but when using Multiframe, we can quickly build a model of the structure, apply the deck loads and see how the structure behaves. There is no need to model the hull in this case as we are only interested in how the deck beams behave.

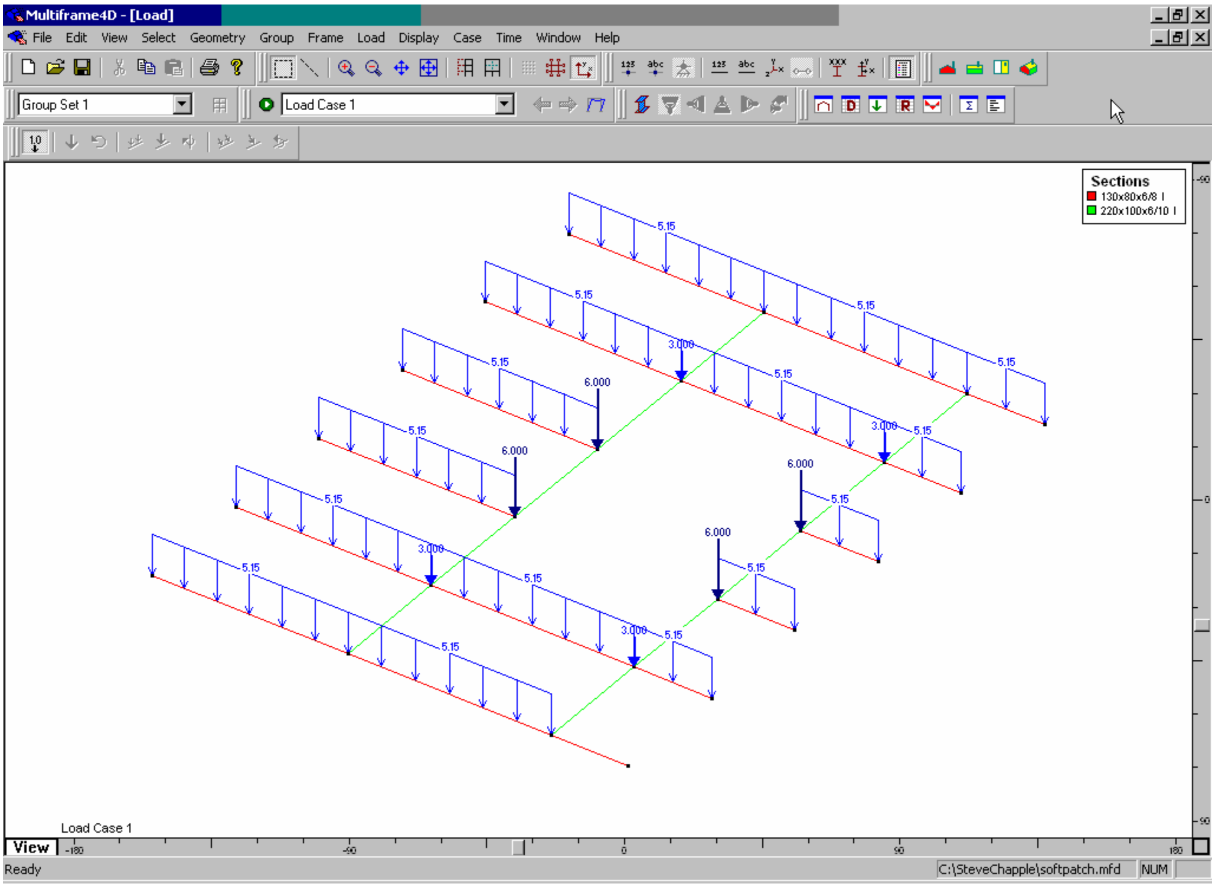


Softpatch Geometry

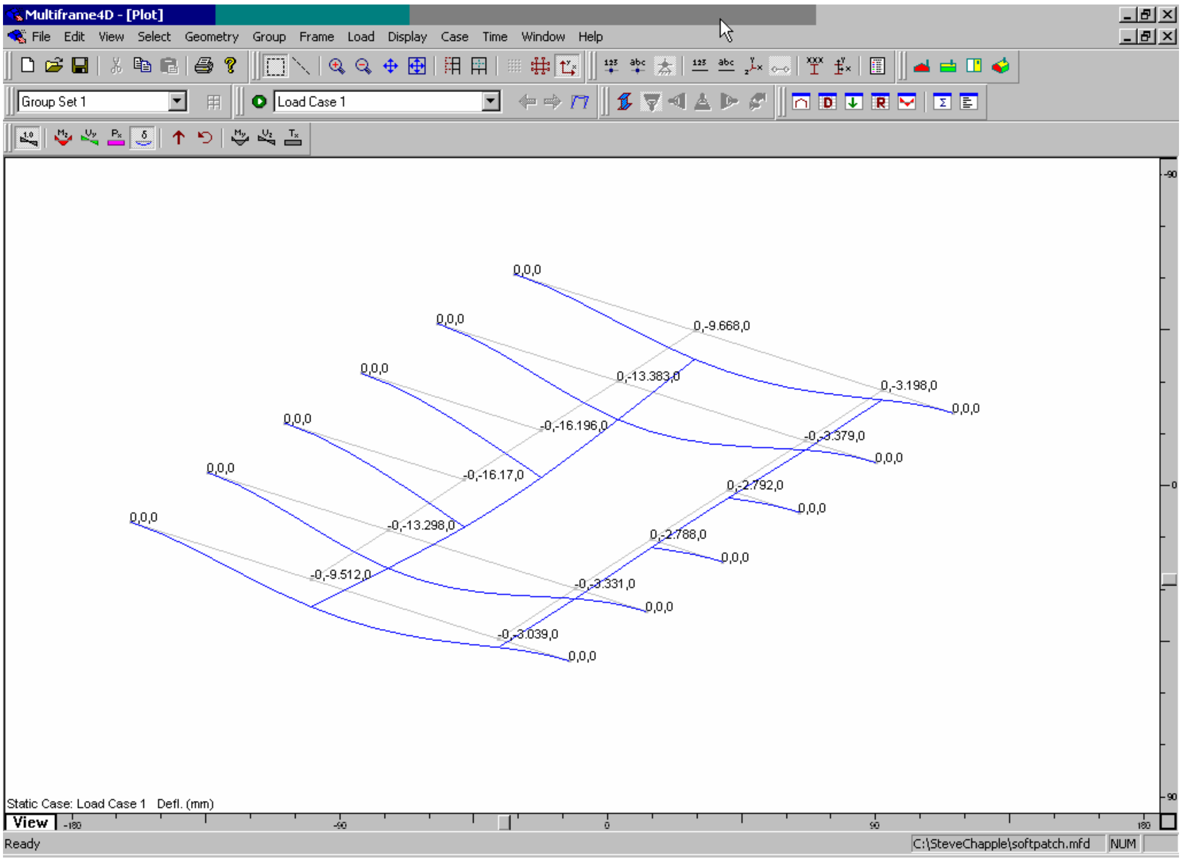


Check Member Orientation

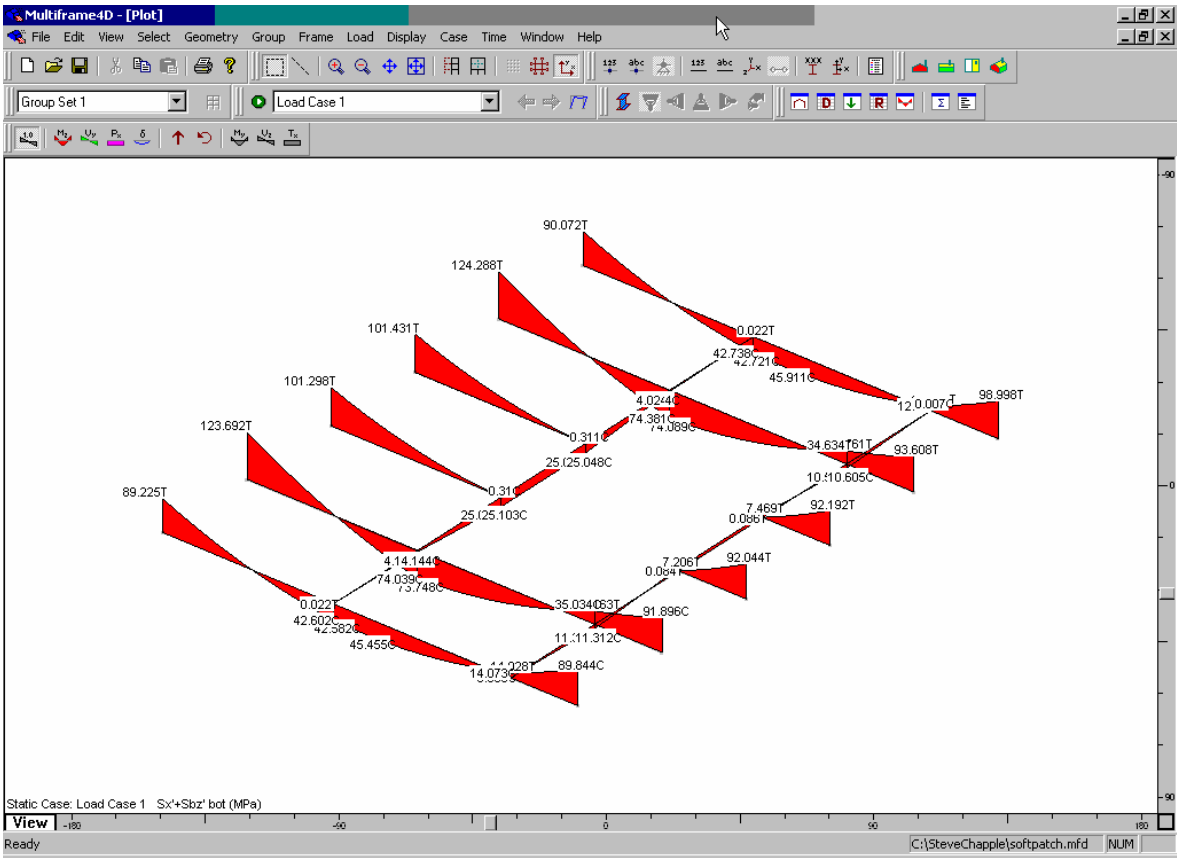
When loading a model such as this we must account for the loads transferred from the softpatch lid to the surrounding structure. Since the lid is not incorporated in the model, we calculate the total pressure over the area of the lid and apply point loads to approximate the load distribution to the frames.



Apply Deck Pressure Loads

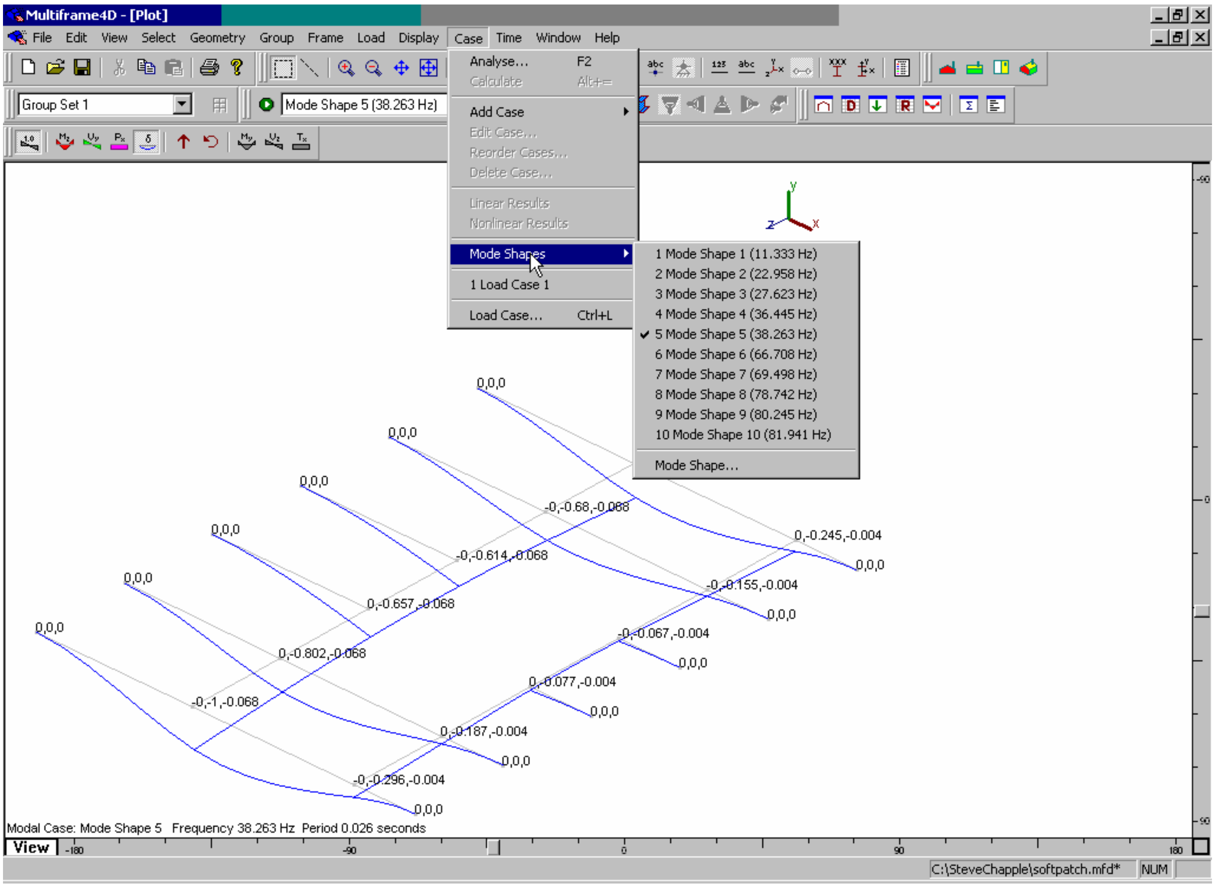


Check That Deflection Plot Looks Correct



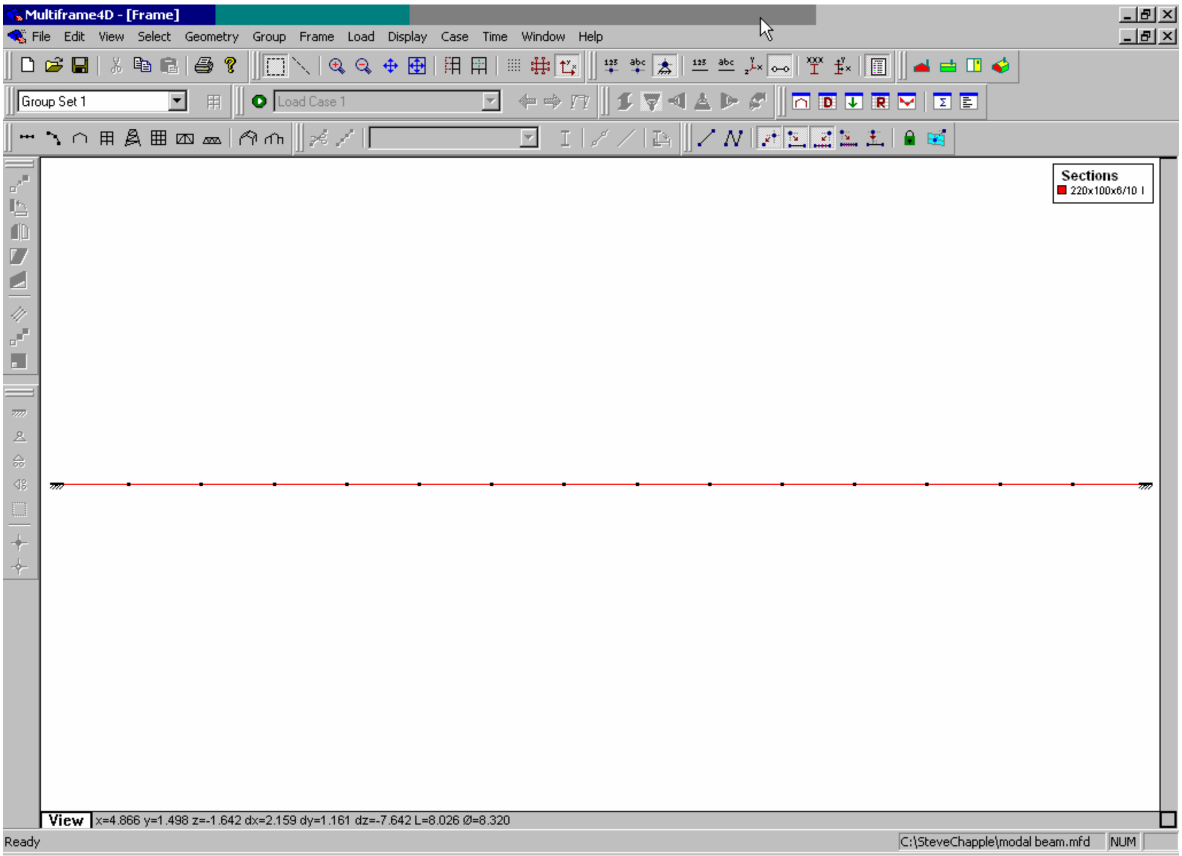
Stress Results For All Members Can Be Viewed At Once

By selecting modal analysis in your calculation preferences you can simultaneously calculate the model frequencies for the structure and display the modal values and shapes in the plot window.

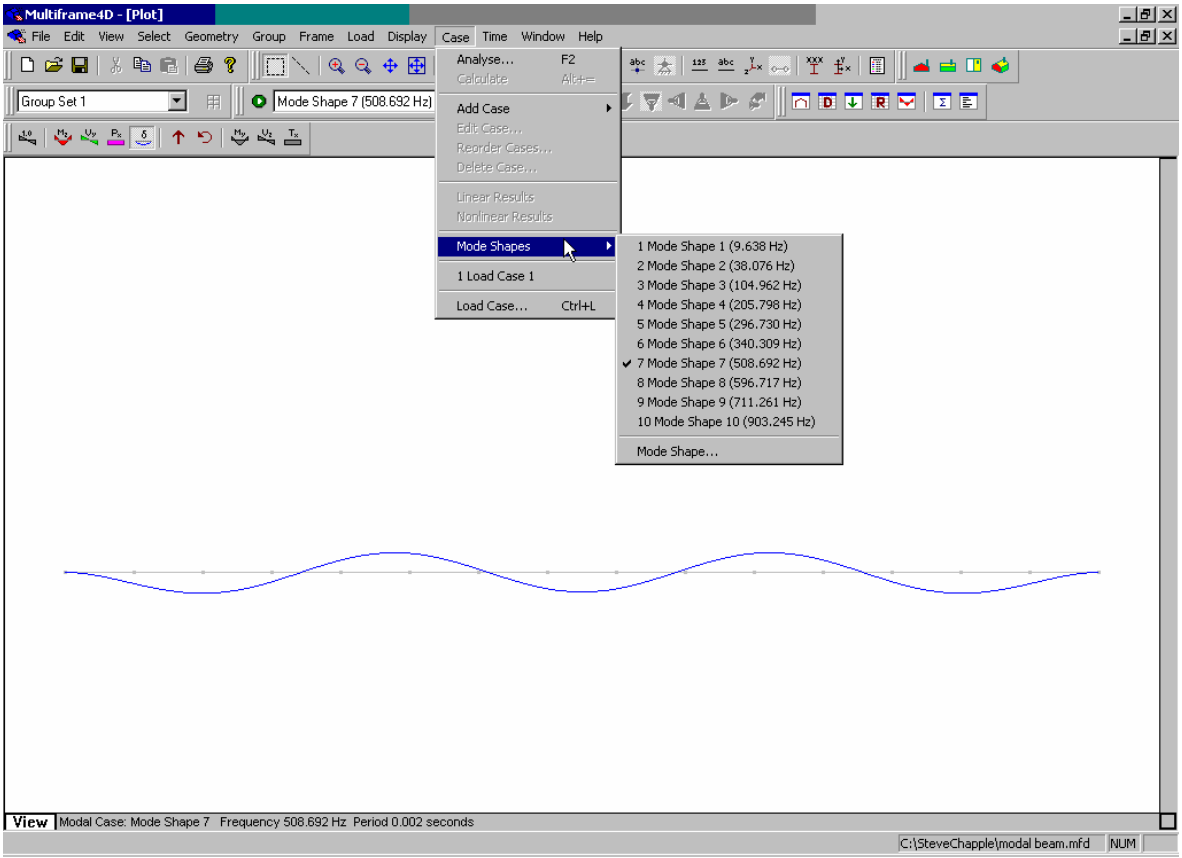



Softpatch Modal Results

You can also perform a modal analysis for a single beam, for example a deck beam between two longitudinal girders. In this case you must subdivide the beam to give it more nodal points so that the software can calculate the modal shapes correctly.




Note Additional Nodes Along The Beam




Mode Shape Display

## 14. Automating The Design Process

While building models using Multiframe is very simple and quick, it can be made even easier with the use of macros. The use of macros is becoming more and more popular since Microsoft introduced Visual Basic for Applications (VBA). VBA comes as standard with most Office applications and many software developers such as Formation Design Systems are now also including VBA with their applications. VBA is based on the standard visual basic programming language but has specific commands and functions relevant to the application that it is being supplied with. It is also fully compatible with stand alone Visual Basic. As is the case with Visual Basic, VBA is very easy for someone with a basic understanding of programming to learn.

The possibilities of incorporating some simple macros into your design process are limited only by your imagination. When used in the structural analysis area, the programming complexity is generally limited to only using loops and if…then statements. All you need to do is develop a flow diagram in plain English of how the work process should be performed and then convert it to VBA code modules.

Here is an example of how you could use VBA to build a model of a ship's hull using Multiframe. Lets assume that you have an offsets table for the hull in MS Excel.

1. Use an Excel VBA macro to loop through the data and send the coordinates of the keel, bottom girder point, chine, deck edge, deck girder and deck centre line to a text file. This requires only a loop and some if..then logic to select the points.
2. In Multiframe, use you Multiframe VBA macro to read in the points from the text file and create the geometry of the ships hull. You would have already saved considerable time and could stop here and proceed manually, or with some more thought, you could use VBA to go much further. (Note that you can also combine steps 1 & 2 to have Multiframe read directly from Excel but it may be easier for the beginner to separate these steps).
3. While the model is being built, you could have VBA assign beam properties to the model based on where they are, eg deck beam, hull side etc.
4. If you develop some modules based on the class society rules, you can also have VBA calculate and apply the loads to your model based on height above waterline and location along the vessel's length.
5. Once the model has solved you could also use VBA to create views and reports and send them to MS Word.

In essence, if you can do it manually, then you can probably write some code to automate it. While there is some time to be spent in developing your code, once it is done it can be used repeatedly.

One point to remember is that you should not be too concerned with writing the most efficient code. While programming purists may disagree, the point to using macros is to increase your efficiency, not to prove that you can write perfect code. Macros are usually very small and given the speed of computers today, you will not see any noticeable difference if you spend extra time striving to write the most efficient code. It is more important to make your code easy to follow and have it well commented so that it can be de-bugged and modified in the future.

If your software doesn't use VBA, it will probably have its own macro language that can be used for similar automation. Some of these have a macro recorder that will build a basis for the code by recording key strokes.

The value of automating tasks should not be underestimated as it saves time and also ensures consistency by eliminating human error.

## 15. Selecting Your Software

The change in technology has also changed how software should be evaluated. Ten years ago the major consideration was processing speed and even today software developers still quote solving speed as a performance benchmark. The reason for this is that models used to take many hours to solve and it was common to start the solution process just before leaving the office so that it could run over night. While the model was solving, the computer could not be used and the design process stopped until it was complete. This made solve times critically important. But once again technology has changed this. A beam model will now solve in a matter of seconds and a global FEA model can solve in as little as five minutes. The most time consuming part of the analysis is now building the model and reporting the results. So the most important considerations when evaluating software are user friendliness and customer support. We would suggest that you look for the following qualities.

### Logical Menu Layout

The menus should be set out so that building a model follows a logical sequence and that the commands are in the menus where you would intuitively expect them to be. This reduces the time needed for learning how to use the software. The ability to create short cut keys is also beneficial.

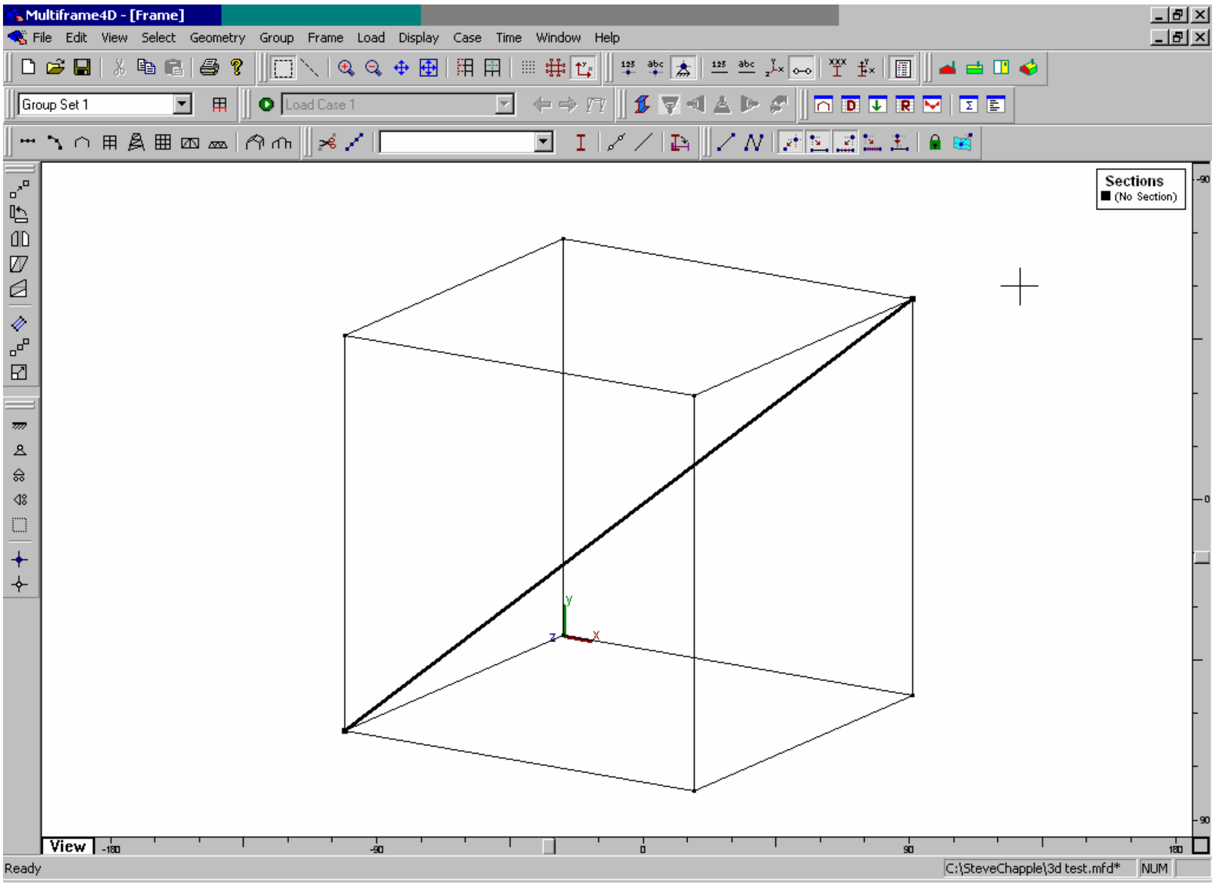
### Graphics

This is important for both building the model and viewing the results. When building the model you should be able to render and rotate it easily so that you can visually check the orientation of the model components. For viewing results, the model should display good colour contrast and again be able to be rotated for viewing from different angles.

### 3D Geometry Based Modelling

The software should allow you to build your model from basic geometry such as points, lines & surfaces, and then apply a mesh or beam members. You should be able to remove or change your beam and element properties without losing your base geometry. Most software has this ability now but some still do not so be sure to check for this feature.

Also make sure that the modeller uses true 3D commands. Some packages that claim to be 3D are not truly 3D. They rely upon the geometry being drawn on a 2D work plane and then extruding it in the third dimension. This can lead to problems when modelling ships, especially when using Finite Element Modelling. You must be able to create and select points, curves and surfaces in 3D space, either by typing coordinates or picking with the mouse. A simple test for this is to ask your software vendor to draw a 3D cube and then draw a line from one corner to the opposite corner. A true 3D package will easily do this just by picking the points with the mouse. If your vendor starts trying to create a work plane in line with the two corners then it is not true 3D.




A Simple Test For 3D Capabilities

## Editing Commands

Most software has good editing commands but you should check that they are suited to the types of models that you will be building. The most commonly used are extruding, breaking at intersections, moving & copying.

## Layer Commands

The ability to assign components to different layers or groups is very useful for checking your model geometry and also for viewing results.

## Libraries

Your software must have the ability to create libraries of standard components that can easily be recalled for use at any stage of the model development, and for future, unrelated models.

## Macro Language

The software should have the ability to be programmed for automating repetitive tasks. Given the widespread use of VBA amongst a variety of different software applications, this would be the recommended preference. If it has its own unique language then it should be simple to learn and use, and preferably have a key stroke recorder that will write the code as you build a model. With minor modifications, the recorded code than then be made suitable for general use.

## Training and Support

There should be good quality training and support available, however if the software is user friendly then you should not need to attend lengthy training courses. The software should be user friendly enough so that once some people in your organisation are trained, they can quickly bring others up to speed. This is important, as you don't want to be paying for training courses every time a new designer joins your team. It is also important that your software vendor understands the basics of your business. I once had a software vendor demonstrate his software by drawing a toilet bowl. His point was to show how it could develop and display complex compound curvature. Once he had finished his presentation I asked him to draw something that looked like a ship's hull – he couldn't do it. Clearly he would not have been able to train us in the use of his product in the shipbuilding industry. So make sure that the training offered suits your application.

## 16. Future Trends

Shipyards and design offices that embrace the current technology will find that they are doubling up on drawings. Typically ship construction drawings are drawn in 2D. Since the introduction of CAD, the drawings have not really changed all that much. While the CAD system has replaced the pens used in manual drafting, the format of the final drawing is the same – a two dimensional representation of the structure.

So we have the situation where the drafting team is drawing the structure in 2D, and the designers are making models of the same structure in 3D, hence the doubling up of drawings. Software developers have recognised this and we are now seeing the development of 3D CAD systems that have basic analysis capabilities. While these packages are good in principal, they have the shortfall that only one task can be done at a time. The system is either performing analysis or being used for drafting. Additionally only one person can use it at any one time so either one person has to become proficient in both drafting and analysis, or the software has to be shared amongst at least two people. Depending on the size and type of your organisation, this may or may not be acceptable.

An alternative solution is to have separate analysis and drafting software that are compatible. Usually the design task is completed before drafting commences so the optimum solution would be to pass the 3D information from the analysis model to the CAD system where it can be detailed in 3D. Once detailed in 3D, there is not much point producing 2D drawings. It makes sense to give the workshop 3D drawings so they can see what the structure is going to look like.

By adding the power of using macros to working in this way some enormous benefits are possible. These include more control over standard procedures, increased drawing accuracy, less re-work in both the design office and the workshop, increased efficiency, a reduction in construction times and possibly even a reduction in staffing requirements.

Working in this way will take a huge shift in attitudes and will mean that working methods will have to significantly change, however the shipyards and designers that have already embraced these changes are reporting significant improvements in efficiency and quality.

## 17. Summary

We have discussed how technology has progressed over the past ten years and there is no reason to think that it will not continue to change at the same rate. Computers and software are more affordable than ever and are so user friendly that almost any engineer or naval architect can use them.

We now live in a world that is becoming more competitive, seeing an increase in litigation, demanding shorter construction times, demanding higher quality ships, and is facing rising costs each year. We can reasonably expect these demands to keep increasing over time. The proper use of technology can address all of these issues and ensure that a shipyard or design office remains competitive while minimising the risk of litigation.

Hopefully by now you can see that structural analysis using modelling software is accessible to all these days. By combining sound engineering principles with some common sense, almost anyone can make good use of this tool.

The steps are simple
1. Perform local calculations to class society rules to give you a starting point.
2. Analyse a beam model of the ship's frame work to verify the beam sizes.
3. Analyse a global finite element model of the ship to verify the plate thicknesses.
4. Use macros to automate repetitive and mundane tasks.
5. Pass the information to a 3D CAD system.
6. Produce accurate and meaningful drawings for the workshop.

By investing in the technology that is now available, a shipyard or design office should be able to offset the associated costs against gains in efficiency and a reduction in warranty claims. If the introduction of technology results in your organisation being able to operate with less people, it will most likely pay for itself.

Technology will continue to improve whether we embrace it or ignore it. To remain competitive it would be wise to embrace it and make it work for you.

## 18. Recommended Reading

Ship Structural Design : A Rationally Based, Computer Aided, Optimization Approach; Owen Hughes, Wiley. This book focuses on the theory behind the design of ship structures using structural modelling techniques. It has a good mix of theory and practical application.

Building Better Products With Finite Element Analysis; Vince Adams & Abraham Askenazi, Onword Press. This is a great book that explains the practical use of FEA. It focuses on how to create & analyse a model but does include some theory.