Longitudinal Vs Transversely Framed Structures For Large Displacement Motor Yachts

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1.0 Introduction

The selection of a structural framing system in any vessel must be made from a consideration of weight, production matters, suitability to resist global loads and vibration. Vessels can principally be either transversely or longitudinally framed although hybrid systems are also in use. However the choice of which framing system is best can be the cause of considerable debate between designers and builders with the advantages and disadvantages of each system often being debated but rarely quantified.

This paper explores the structural design of an 80m displacement motor yacht utilising both transversely and longitudinally framed systems, with the aim of quantifying the weight, structural benefits, and production differences between the two. In the development of the basic structural design, rule minimum local scantlings are considered and then suitably increased to account for practical constraints, production aspects and global loads.

Following analysis of the results the Authors have assessed a hybrid framing system which is considered to combine most of the advantages of other systems.

2.0 General Background

The majority of large steel motors yachts are transversely framed featuring heavy shell plate with transverse frames of typically 600 to 800mm pitch. A limited number use longitudinal framing systems with transverse frames typically spaced at 1200mm to 2400mm pitch and closely spaced longitudinal stringers.

Historically, early iron and steel vessels were built with transverse faming as this was the tried and tested configuration used for wooden ship building. The structural design requirements used for wooden ships were copied over to iron ships, featuring very heavy keel structures and relatively light decks. As ships got larger the limitations of thin transversely framed decks were observed and understood, although the industry was slow to adapt. One notable exception to this was the 'Great Eastern' (1858) which was a very early example of a scientifically designed ship. Isambard Kingdom Brunel, a civil engineer, used beam theory in the structural design of this vessel which was based on a cellular system of longitudinal framing. With a tonnage five times greater than any other vessel of the time, this remarkable ship boasted many other innovative features and despite her lack of commercial success, the structure performed well throughout her 31 year life.

Although the technical benefits of longitudinal framing were known in the 19th Century it was not until the British naval architect Joseph Isherwood introduced his longitudinal framing method in 1906, that interest was revived. His system used longitudinal stiffeners and deep transverse web frames in the same way that modern arrangements do. The benefit was primarily a lighter structure, which for commercial vessels equated to increased deadweight for a given displacement, and hence a more profitable ship. This was particularly true for oil tankers where the increased web frame depth did not affect cargo stowage volume. The first ship using this system, the tanker 'Paul Paix', was built in 1908 to Lloyd's Register class. By 1918 over 1000 ships had been built using the Isherwood framing system. [1]

Early designs had problems with longitudinal end connections. In an effort to reduce collars, which were expensive and problematic in riveted construction, longitudinal stiffeners were terminated and bracketed at every bulkhead. This led to cracking around the rivets on the brackets and the system did not really gain widespread popularity until the advent of all welded construction.

Transverse framing systems feature closely spaced frames, typically at 600mm pitch spanning between tank top and deck. These frames are often Holland Profile [HP] sections bent to the correct moulded line shape. With such a framing system the principal longitudinal material is the shell and deck plating.

1: Arnott, D. Design & Construction of Steel Merchant Ships (SNAME)

Longitudinal framing systems feature widely spaced transverse web frames, typically between 1200mm and 2400mm depending on vessel size, with closely spaced longitudinal stringers. All transverse frames are typically of identical scantlings and longitudinals are spaced to optimise the selected local shell thickness, leading to an effective structure with little structural redundancy.

A graphical example of both systems is presented in Figure 1.

There are advantages and disadvantages to both systems but the fundamental difference from a structural design viewpoint is related to the ability of the stiffened plate to carry in-plane loads. Longitudinal bending of the hull girder, due to the buoyancy and weight distribution of the vessel, as well as the action of the waves, will induce stresses in the fore and aft direction. Thin shell plate is susceptible to buckling, and due to the orientation of the stiffeners, a transversely framed panel will have approximately a quarter of the strength of a longitudinally framed panel of the same size and thickness. As a result, transversely framed vessels tend to have to have thicker plating, particularly on the decks, in order to have adequate buckling capacity to resist hull girder loads.

As the size of a vessel increases the significance of hull girder loads increases dramatically; Lloyd’s generally require global strength calculations for all steel hulled yachts over 50m. Currently small vessels are generally transversely framed, and larger vessels, when global loads become significant, are generally longitudinally framed. The transition occurs between 50m and 90m dependent on vessel type and usage.

Hybrid or combination framing employs both transverse and longitudinal framing within the same section. Typically this would entail longitudinally framing for some or all of the decks, with the remainder of the structure being transversely framed.

When selecting a framing system for a new design there is often debate between designers and builders as to the best system, particularly as builders may have historically only used one system or the other. In general the designer is seeking to optimise structural effectiveness and eliminate redundant structure whilst the builder is seeking to minimize construction complexity and time. As steel is relatively cheap the builder may often accept a structure with redundant material if it simplifies the structure and makes it easier and quicker to build.

It is often claimed that a longitudinally framed structure is more time consuming to construct due to (perceived) large amounts of welding of the longitudinals to the shell as well as bracketing or collaring of longitudinals at bulkheads. However this must be offset against the high number of transverse frames found in a transverse system.

Additionally weight is often cited as the reason for selecting one system or the other. Whilst the majority accept that a longitudinally framed structure will be lighter a minority will still argue the reverse. It is of interest to note that the vast majority of high speed light weight vessels, where weight is critical, feature longitudinally framed structures.

Due to the strict noise and vibration limits found in a typical yacht build specification, vibration control is a major issue on these vessels. As a result the structural design can be driven by stiffness requirements rather than strength requirements. This is particularly true for deck structures which will generally exceed class scantlings. The relative merits of different framing systems are analysed and discussed later from a vibration perspective.

It is the aim of the Authors to try and quantify some of these issues in this paper.

3.0 Methodology

A basis design has been adopted. This is a typical 80m monohull and is described in further detail in the following section. It is assumed that the vessel features a steel hull and main deck and aluminium superstructure. In the development of the structure for this paper it is assumed that the aluminium structure does not contribute significantly to the vessel's global strength. This has consequently been ignored and is customary in the experience of the Authors.

Lloyd's Register of Shipping Special Service Craft (SSC) Rules have been used as the design standard because:-

- These rules are based on a first principles approach (albeit with empirically based scantling multipliers) which is useful when comparing designs.
- The SSC Rules are in common use in the large yacht sector. At the time of writing it was reported that Lloyd's Register's market share of new yacht build projects greater than 50m in length is 86%[2].

The methodology adopted for the development of structure is presented in Figure 2. The design approach is based on the derivation of scantlings to meet local design loads which are then increased as necessary to comply firstly with a set of defined practical constraints and secondly, failure modes control based on global loads and buckling criteria. Additionally, vibration aspects concerned with deck response to excitation at propeller blade passing frequencies have been considered and are discussed.

A transverse framing system with a frame spacing of 600mm has been developed. For the longitudinal framing system a pitch of both 1800mm and 2400mm has been considered. Under the SSC Rules the frame pitch must be 'generally' limited to 2000mm or less. The higher value of 2400mm was investigated in order to explore the benefits that would be offered from a pitch more reflective of larger vessels (>85m & 3000 GRT). All frame pitches investigated are multiples of 600mm for practical reasons.

Comparative results are presented for structural weight, length of welding and number of structural parts within a length of parallel mid body between bulkheads.

4.0 Basis of Design

The work presented is based on a typical 80m displacement motor yacht of normal proportion and form. This size of modern, high volume yacht (circa 80 – 85m LOA) typically represents the length associated with the 3000 GRT limit applicable to the MCA Large Commercial Yacht Code (LY2) and consequently is (generally) the limit for the application of SSC Rules. Above 3000 GRT the LY2 Code is no longer applicable and a popular option is to build the vessel as a SOLAS passenger ship. This usually dictates a change in class society rules. Continuing with the Lloyd's example this would mean using the LR Passenger Ship Rules rather than the SSC Rules – the implications of doing so are discussed later in the paper. Additionally in this size regime global loads will have more influence on the scantlings.

The principal characteristics and mid ship section geometry are presented in Figure 3. The candidate geometry has a double bottom with a tank top height of 1700mm above base, an inner deck (5350mm AB), and main deck (8350mm AB). Primary girders are spaced at 2.4m and 4.8m off centreline with a span of 9.6m between bulkheads.

Mild steel has been considered throughout with the use of HP and fabricated steel sections.

5.0 Local Scantling Design & Practical Constraints

Minimum scantlings were calculated using local loads and minimum plate thicknesses . The scantlings of a section based purely on this approach produce a very light structure. However, the level of complexity and lack of robustness of the structure make it impractical for yacht applications. As a result, some practical constraints based on achievable construction practices have then been applied. These constrains are summarised as follows;

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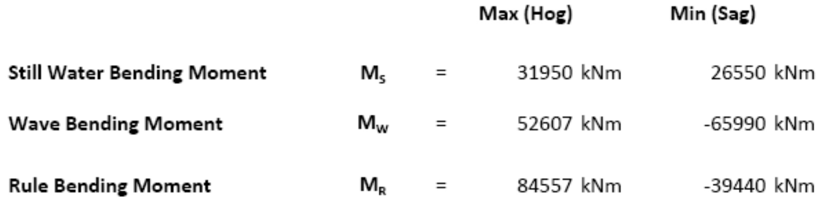
2. – Lloyd's Register Passenger Ship Focus, September 2008

- To limit weld distortion a minimum practical plate thickness of 6mm on decks was applied.
- Plate thickness kept to a full mm, i.e. no half thickness plates.
- Maximum girth distance of 2.8 m between plate seams.
- Construction unit seams typically 100 mm above tank top, deck etc; plate thickness changes occur here if applicable.
- Minimum girder depth of 450mm to allow penetrations for HVAC; The routing of services, particularly the large diameter HVAC ducting in deck heads, can be very challenging on large yachts. In reality there will not be enough ‘tween deck height to be able to run HVAC services under the girders, so the girders must be deep enough to accommodate penetrations of around 250 – 300 mm. A practical solution is to make the girder structure as deep as the general arrangement allows, leaving enough space under girder structure for linings, shallow cable trays and minor pipe work. This suggests that a girder depth of 450-500 mm is the minimum practical depth.
- For a practically laid out structure all stiffener pitch values were generally a function of 600mm.
- For fairness and robustness a minimum shell thickness of 8mm on hull sides and 11mm on hull bottom.

With the application of the above constraints the scantlings increased somewhat over the design for pure rule minimum scantlings.

6.0 Application of Global Loads

Wave bending moments were derived from the SSC Rules. An estimate of still water bending moment was made based on statistical data from a number of similarly sized yachts. Values utilised are presented below.



			Max (Hog)	**Min (Sag)**
Still Water Bending Moment	M_S	=	31950 kNm	26550 kNm
Wave Bending Moment	M_W	=	52607 kNm	-65990 kNm
Rule Bending Moment	M_R	=	84557 kNm	-39440 kNm

Section modulus calculations were performed on each of the sections with the practical constraints applied so that an assessment of the global strength for each could be made.

In reality there would not generally be a fully intact section in the midships region. Openings for stairwells, atriums, large hull side windows, shell doors and bilge wells would normally be removed from the section calculation - the remaining effective material is often slightly sobering. These vessels should pass global strength requirements using intact section properties with ease, and it is recommended that a good reserve on global strength is maintained in any design to account for late changes to openings and still water bending moment. Often the hull openings and structural discontinuities are so extensive that hull girder strength can only be verified using FEA.

In the case of this study, having a non-fully-intact section is true for both the longitudinally and transversely framed sections so from a comparative view would appear not to matter. However it would mask the true effect and influence of the global loads if ignored. Therefore the average stresses that were derived from the global bending moment/section modulus calculations were factored by 25% to account for loss of effective structure.

Once the global average stresses were derived, each section was assessed for buckling. Failure mode calculations were carried out on all critical parts of each section in accordance with the SSC Rules. Several areas required an increase in scantlings to pass the requirements. These are summarised in the tables below.

Longitudinally Framed Sections

Structure Component	**Cause of increase**	**Before**	**After**
Main Deck Stiffeners	Stiffener buckling (global loads)	60x6 OBP	80x5 OBP
Main Deck Frames	Consequence of stiffener depth change	140x7 OBP	180x6/60x6 T
Lower Deck Stiffeners	Stiffener buckling (global loads)	60x4 OBP	80x5 OBP
Lower Deck Frames	Consequence of stiffener depth change	140x7 OBP	180x6/60x6 T
Double Bottom Side Girders	Plate buckling (global loads)	8mm Plate	9mm Plate

Transverse Framed Section

Structure Component	**Cause of increase**	**Before**	**After**
Main Deck Plate	Plate buckling (global loads)	6mm Plate	8mm Plate
Upper Topside Shell Plate	Plate buckling (global loads)	8mm Plate	9mm Plate
Main Deck Frames	Stiffener buckling (global loads)	80x5 OBP	120x6 OBP
Lower Deck Frames	Stiffener buckling (global loads)	60x4 OBP	80x5 OBP
Double Bottom Side Girders	Plate buckling (global loads)	8mm Plate	9mm Plate

It can be seen that the transversely framed structure generally requires greater scantling increases in the shell than the longitudinally framed structure. This is due to its inferior ability to resist globally induced buckling loads.

The designs of the final midship sections are presented in Figure 4 (transversely framed), 5 (longitudinally framed at 1800mm) and 6 (longitudinally framed at 2400m). It should be noted that decks are designed to local load criteria only and do not include the increases in scantlings required to meet vibration criteria.

7.0 Results

Results are presented to compare the following factors;

- Weight
- Number of structural parts, joint length and length of welding

Additionally a number of secondary factors are discussed in general terms which may influence the choice of framing system.

7.1 Weight

The weight of each framing system has been calculated from the midship sections that have been produced. Calculations are for a 9.6m length of parallel mid-body containing one watertight bulkhead. Weights are presented at all 3 stages of the section development process to demonstrate the differences in weight between rule minimum structure, addition of practical constraints and influence of global loads. The results are presented in the table below;

Frame System	**Longitudinal**	**Longitudinal**	**Transverse**
Frame Spacing	1800mm	2400mm	600mm
Weight - Minimum Scantlings	6.732 t/m	6.903 t/m	7.686 t/m
Weight - Design Constraints Applied	8.149 t/m	8.345 t/m	8.492 t/m
Weight - Global Strength Requirements	8.256 t/m	8.457 t/m	8.846 t/m

The results illustrate that the lightest structure is produced by the longitudinally framed structures, in particular the 1800mm frame pitch. The transversely framed structure is some 7% heavier.

It can be seen that in general the application of practical constraints to the rule minimum structure adds around 10% to the transversely framed structure and 20% to the longitudinally framed system. This difference is due mainly to the fact that the longitudinally framed structures can be optimised to rule minimum scantlings by adjustment of the stiffener pitch. This is not possible on the transversely framed structure where the frame spacing drives the shell thickness. Consequently, the selection of 8mm and 11mm minimum (practical) shell thicknesses limits the extent to which the longitudinally framed system can be optimised.

Additionally the influence of the global loads can be seen to be more significant on the transversely framed structure. The longitudinally framed structures require a 1% increase in weight to meet global strength requirements whilst the transversely framed structure requires a 4% increase in weight. This is due to the large increase in the deck and shell scantlings required to resist buckling.

Yachts unusually represent very high value tonnage and this will need to be considered when assessing the significance of saving weight as a cost saving measure. In order to put this into perspective, for a yacht typical of the design used in this paper, the hull structure is probably 40% of the final weight of the vessel, but only represents around 12% of the cost.

7.2 Number of Parts, Joint & Weld Length

The cost of steelwork fabrication is often compared by using the measure ‘man-hours per tonne’. Although useful in cost estimating for similar ships it can be misleading when comparing construction methods. A longitudinally framed vessel might take a little longer to build, but because it is lighter will appear costly in terms of man-hours per tonne relative to the transversely framed system.

In an attempt to make a relative comparison and quantify the labour involved in the assembly of all the framing systems, an estimate of the number of structural parts, joint lengths and weld lengths have been made.

Additionally, it is generally perceived that transversely framed vessels are easier to build. This is due to:

- Less welding.
- Fewer orthogonal welded connections (i.e. longitudinal to transverse web frame connection).
- Fewer cut parts.
- Weld shrinkage is easier to predict as welds are predominately in one plane.

In quantifying the number of parts and weld length the Authors have attempted to make an objective assessment of the above perceptions. This has required some simplifying assumptions to be made. For example it should be noted that no detailed optimised welding schedule has been undertaken. Consequently weld specifications have been made based on past projects of similar size and type.

The table below illustrates the results;

Frame System	**Longitudinal**	**Longitudinal**	**Transverse**
Frame Spacing	1.8m	2.4m	0.6m
Length of joint per 9.6m span	2938m	2724m	2704m
Length of weld per 9.6m span	4527m	4199m	4662m
Number of Parts per 9.6m of ship	817	761	931

It can be seen that the length of welding required for each system is approximately the same but marginally higher for the transversely framed system whilst the number of parts is significantly lower for the longitudinally framed system.

7.3 Secondary Factors to Consider

A comparison between midship sections cannot be limited to a weight comparison and quantified production aspects, and so the Authors have addressed a number of secondary factors below. Whilst those discussed are not exhaustive they highlight areas where further consideration may be required before selecting a framing system.

7.3.1 Hull-form Geometry

In commercial ships with a parallel mid-body it is relatively easy to fabricate a longitudinally framed mid-body section, since the longitudinals have an easy run in areas of equal girth. The flat of side and flat of bottom areas can be fabricated in a panel hall on a flat floor using semi-automated welding of the stiffeners to the plate. In the bow and stern areas, where the girth measurement decreases rapidly, the longitudinals will tend to run out and require more complex bending to get them to take the form required. Hence it is usual practice to adopt the transverse framing system in the fore and aft regions.

Yachts typically have relatively low block hulls, and their fine form and lack of parallel mid-body makes longitudinal framing appear less attractive, although it is by no means impossible to achieve.

7.3.2 Minimum Plate thickness

The practical limits for minimum plate thickness are dependent on the skill and welding processes of the yard, the need to have a surface robust enough to hold filler and to generally be stiff enough to avoid vibration problems in service. All of these factors tend to drive minimum plate thicknesses beyond the rule minimums.

It is suggested that for most yards, using plate thicknesses less than 5-6 mm will start to be problematic. The ability to optimise longitudinally framed structure can therefore be somewhat limited as the large shell and deck areas are where the most significant weight savings can be made.

7.3.3 Fairness of Form

Yacht builders seek to achieve very high levels of fairness and finish in both transverse and longitudinally framed hulls. Weld shrinkage and distortion will be different for the two arrangements and consequently the amount of fairing compound needing to be applied will be different. However in the Authors experience neither method shows a clear advantage in this area.

7.3.4 Routing of services

As previously discussed [ref. Section 5] the routing of services, particularly large diameter horizontal HVAC ducting in deck heads, can be very challenging on these vessels. This can drive the scantlings of the structure, particularly on longitudinally framed decks, well above those required from a pure strength perspective.

Vertical service routing is also often problematic and one advantage of a transversely framed side shell is the ability to route larger services vertically within the hull side linings which are unhindered by longitudinal stiffeners and consequently offer more room.

7.3.5 Vibration Considerations

Large yachts generally have strict noise and vibration limits; usually in excess of ISO 6954 and Class Notation requirements. In order to keep below these vibration limits it is important that deck structures do not resonate at frequencies close to major excitation frequencies. Since this problem will only emerge during measurement trials of the finished vessel, it is necessary to design the deck structures with these requirements in mind.

The major low frequency source is the propeller at blade rate passing frequency (BPF). This is dependent on number of blades and shaft rate, but a cruise speed blade passing frequency of 10-15 Hz is not uncommon. In order to ensure that the decks do not resonate at any point in the speed range, the design approach with least risk is to ensure that the first mode frequency of every deck panel is in excess of BPF. Generally this will not dictate the plate thickness required, but will dictate the selection of deck secondary and primary structure to ensure natural frequencies in excess of BPF are achieved.

A frequency analysis of the lower deck panel with both framing configurations was undertaken, including a typical outfit weight. The analysis was limited to a single deck field rather than an entire deck, and as such, the boundary conditions are not wholly representative but are sufficient for comparative purposes. The table below presents the natural frequencies of the two framing systems.

Mode Shape	**Resonant Natural Frequency (Hz)**	
	Longitudinal	Transverse
1	13.891	12.644
2	14.240	12.653
3	15.540	12.798
4	18.123	12.843
5	21.636	13.177
6	23.984	13.500
7	24.040	14.386
8	24.054	14.457
9	24.200	15.357
10	24.386	15.373
11	24.405	15.856
12	24.496	16.118

For the model analysed the comparative deck mass was 9.94 tonnes for the longitudinally framed deck and 9.39 tonnes for the transversely framed deck. Plots of the first mode shape of excitation are presented in Figures 7 & 8.

The results can be summarised as follows:

- The longitudinal framing example has a higher natural frequency despite its increased mass, and so is a stiffer structure.
- Both examples fall below the typical frequency required for risk adverse vibration design on this size of vessel. The frequency could be increased by using internal pillars and partitions to reduce span lengths or by considerably increasing scantlings in large pillar free areas. This reflects current practice.
- There are a greater number of modes below 15 Hz on the transverse framing example, suggesting raising the natural frequency of this deck would be more problematic.

It can be concluded that longitudinally framed decks are advantageous with respect to vibration control.

7.3.6 Side Shell Framing

The side shell is one area where transverse framing can offer advantages. The deep web frames required for longitudinal framing can impact on the accommodation, reducing internal space, and increasing recess depths in way of hull windows etc. In addition, since the transverse hull side frames only have to support a modest plate area, it is easier to incorporate and manage late design changes in window and port light positions which seems an inevitable part of the stylist's GA development.

7.3.7 Risk management

All builders will have their favoured methods of construction, including the selection of a framing system. Weight estimation, costing and yard standard details will all be based around their normal construction methods. As steel cutting is often an early contract milestone there is usually little time to develop alternative structural arrangements. Consequently changing current practice is frequently viewed as increasing commercial risk without significant technical benefit.

7.3.8 Progressive Failure

There is one hidden benefit of longitudinal framing which should be borne in mind, and that is the reserve factor over progressive failure. With transversely framed decks the only longitudinally effective material is the deck plate and girders. Should the upper deck exceed its buckling stress only the girders are left to carry the in-plane loads. With longitudinally framed decks the longitudinally effective material also includes the secondary stiffeners. The stiffeners have a buckling capacity far higher than the plating (which is in any case improved over the transversely orientated plate by a factor of 4) and so should the deck plate exceed its buckling stress the longitudinals and girders will generally be able to carry the in-plane load and prevent progressive failure. Although this is not usually considered in design, this additional reserve makes it easier for the structural designer to accommodate some of the more extreme whims of the stylist knowing that should the design loads be exceeded, the section will still remain intact.

8.0 Hybrid Section Development

Giving due consideration to the results achieved, a hybrid framing system is often adopted by the Authors (and others). This combines longitudinally framed decks with a transversely framed side shell and double bottom. At vessel lengths much beyond 85m a longitudinally framed double bottom will also be required.

The geometry of the Hybrid System is presented in Figure 9. The hybrid section weight is 8.648 t/m (for comparative purposes with Section 7.1).

9.0 Impact of Length & Class Society

Current market trends are for ever larger yacht structures and the debate on framing systems changes as size increases. Global loads on the hull girder will increase proportional to the beam, and to the square of the length of the vessel.

$$\text{Bending Moment} \propto L^2 B$$

As a yacht gets longer it will increase in beam but not significantly in depth, and hull section modulus will increase roughly proportionally to the beam. Hence hull girder stress will increase approximately in proportion to L^2. This would result in a 100 m vessel seeing a 50% stress increase over its 80 m cousin. Hull girder strength issues rapidly dominate the design of the 100 m + size range, and there clearly comes a size of vessel where transverse framing is no longer a viable option.

As discussed in section 4.0 the regulatory framework changes above 3000 GRT which generally drives the design towards the use of more empirically based 'traditional' ship rules. When faced with this option it is useful to realise the impact that this will make to the structural design of the yacht.

The fundamental differences between the SSC Rules and (LR) Passenger Ship Rules can be summarised as follows:

- Corrosion margins. SSC Rules are net scantling rules (no corrosion margin). Ship Rules include a corrosion margin, which is not generally required for highly maintained yacht structures. The exact value is not transparent, but generally scantlings will be heavier for that reason.
- Minimum plate thicknesses are increased.

- Standard frame spacing. Ship Rules provide a standard frame spacing based on vessel length, which there is no benefit in reducing. This will dictate shell thickness.
- Global Loads are increased. Pt 4 Ch 2 increases the sagging wave bending moment on ships with large bow and stern flare, probably by 20% on a typical yacht hull form.
- Minimum Hull Section Modulus requirement. Regardless of still water bending moment, the vessel needs to satisfy this additional global strength requirement.
- Bow and stern strengthening. Ship Rules have specific requirements to strengthen against slamming, which are in considerable excess of the SSC Rules.
- Ship Rules require a minimum plate buckling capacity of 40 N/mm^2, which effectively means 8mm minimum deck thickness for transversely framed vessels.
- Ship Rules do not permit the critical buckling stress of plates to be exceeded, regardless of the stability of the structure as a whole. This further increases global strength requirements on the design.
- Ship Rules on aluminium structures is based on a steel equivalence and requires special consideration to apply sensibly to a yacht superstructure.

It is suggested that these differences could add approximately 20% to the steel weight of an 80-90 m vessel, although a detailed comparison is beyond the scope of this paper.

10.0 Conclusions

A comparative analysis of both longitudinally and transversely framed structures has been made with specific reference to large yacht yachts.

It has been illustrated that longitudinally framed structures will be lighter, have fewer parts and involve less welding than a transversely framed structure. The longitudinal framing system is easier to optimise for weight and the vibration characteristics of longitudinally framed decks have been shown to be superior.

From consideration of practical construction constraints as well noise and vibration considerations it has been illustrated that, for large yachts, achieving a structure which is close to rule minimum scantlings, is difficult to achieve. Consequently the adoption of a longitudinal framing system can be of limited benefit for yacht sizes which are not dominated by global load considerations, as surface fairness, robustness and noise and vibration requirements penalise the ability to build a very light longitudinally framed structure.

A hybrid framing system has been presented which employs a transversely framed side and bottom structure in conjunction with longitudinally framed decks, and is shown to be a good compromise between weight and practical limitations on these types of vessel.

The influence of increasing the vessel length has been discussed both from a perspective of applicable classification society rules and it has been suggested that the application of more traditionally based ship rules could add approximately 20% to structural weight. Additionally the influence of size on global load requirements has been illustrated and it is suggested that for vessels of 100m and above the use of longitudinally framed bottom structures becomes mandatory to efficiently meet buckling criteria.

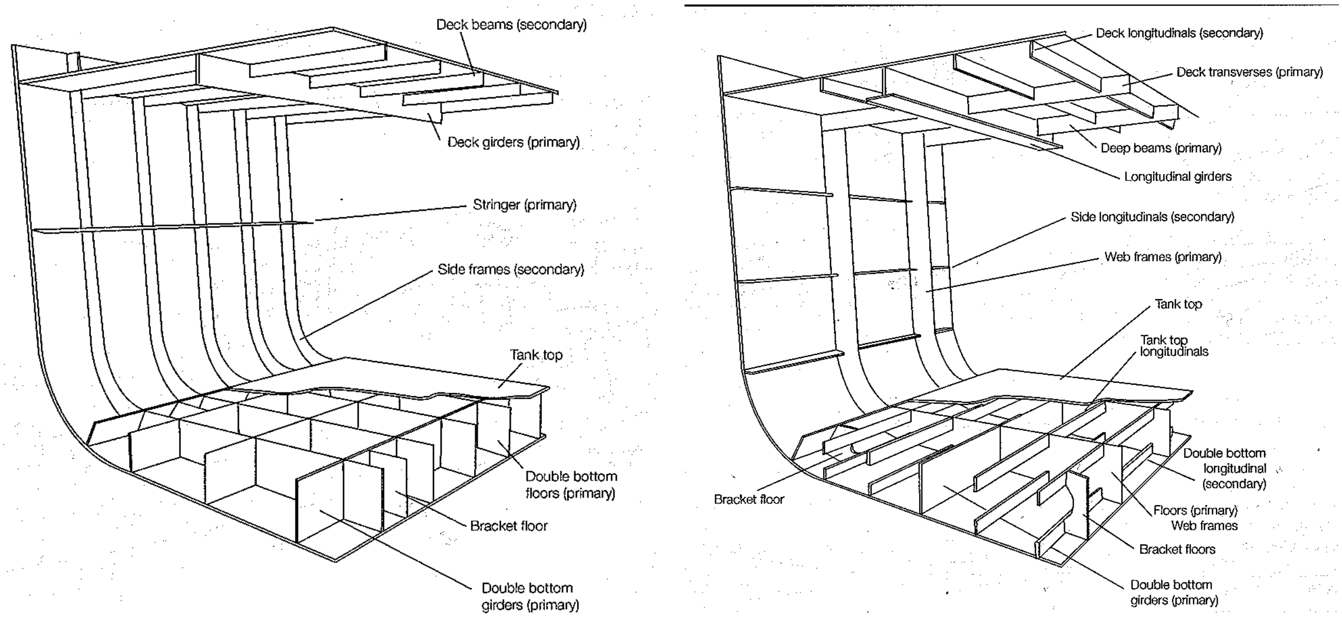


Figure 1 – Transverse (Left) and Longitudinal (Right) Framing
(Images supplied courtesy of the Lloyd's Register Group)

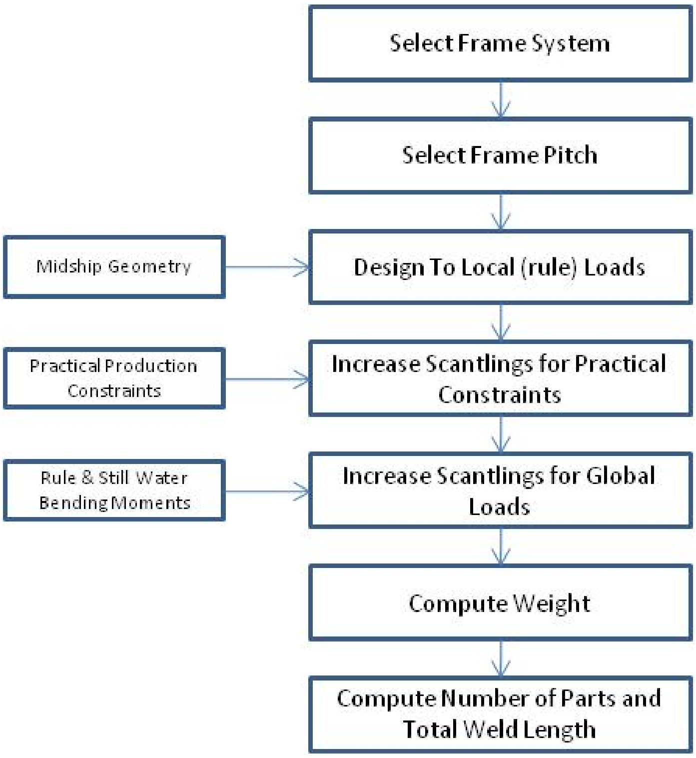
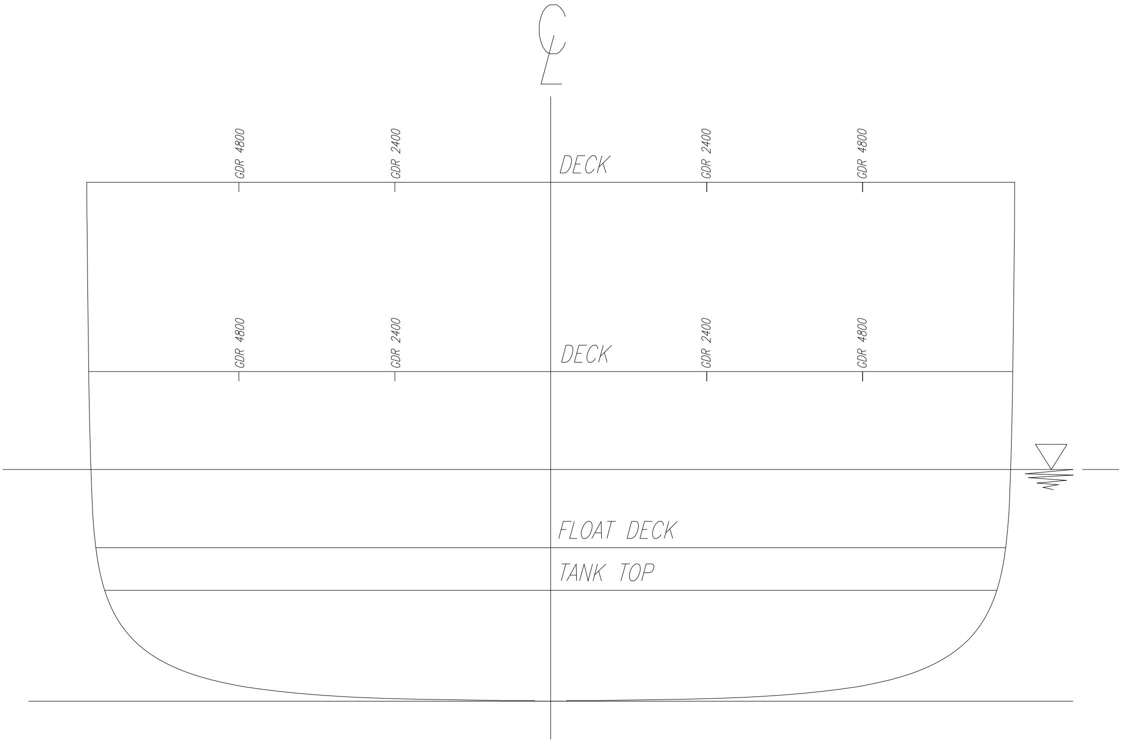


Figure 2 – Design Methodology



Principal Dimensions		
Length Overall	80.00	m
Length Waterline (Design)	71.40	m
Length between Perps	71.40	m
Waterline Beam	14.00	m
Displacement (Design Draught)	2000	tonnes
Design Draught	3.55	m
Service Speed	14	knots
Max Speed	16	knots

Figure 3 – Midship Geometry and Principal Characteristics

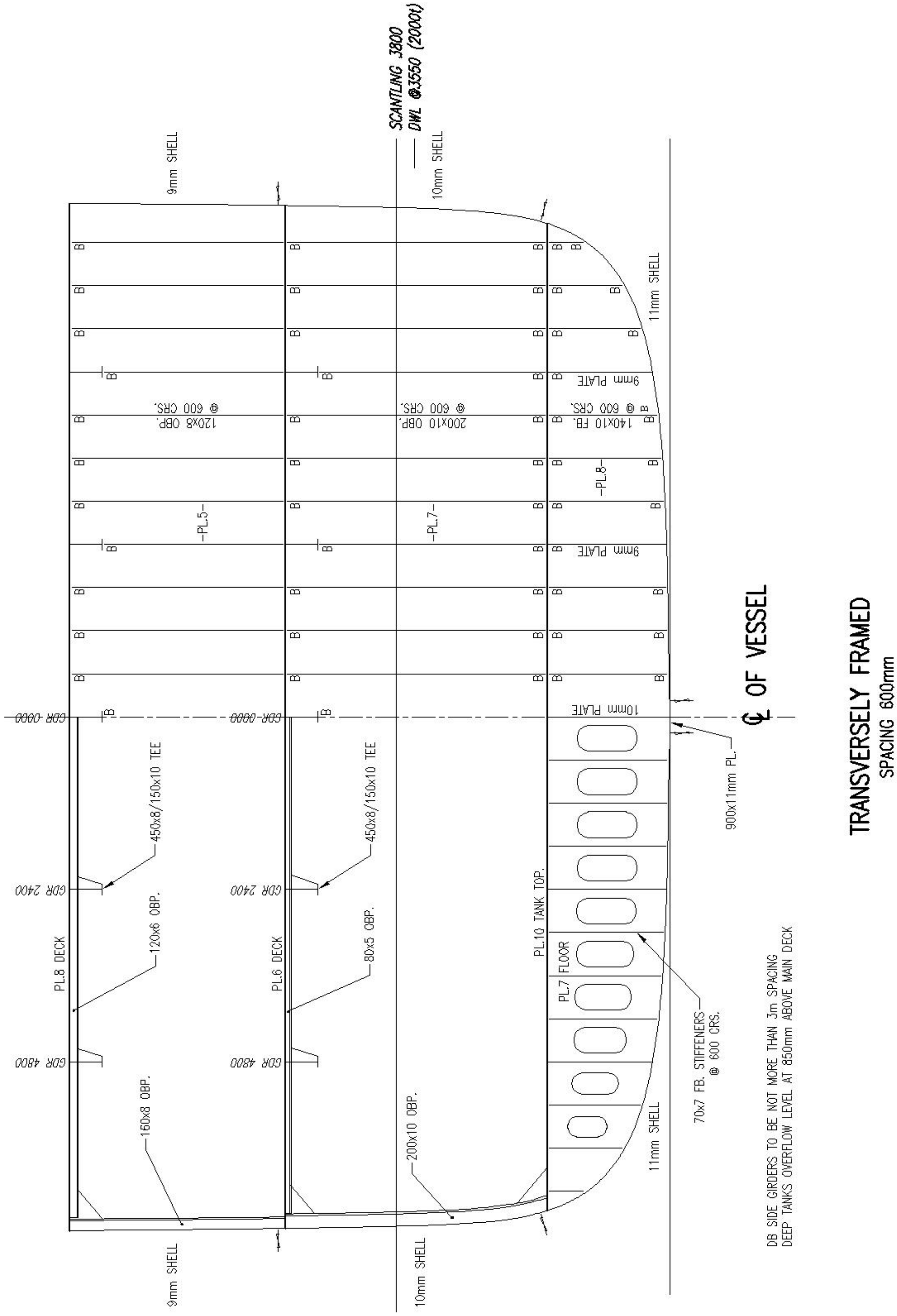


Figure 4 – Transversely Framed Structure

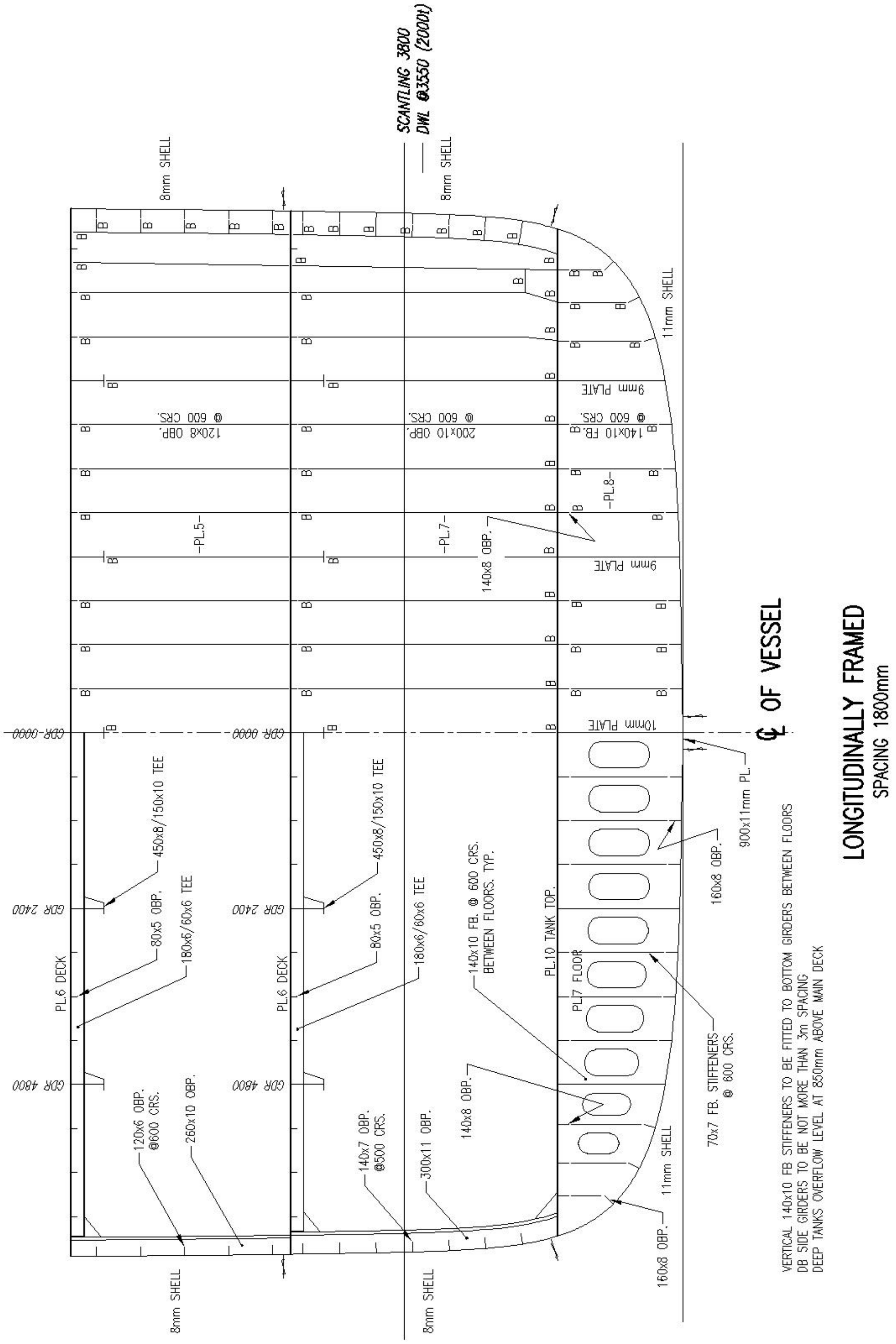


Figure 5 – Longitudinally (1.8m Pitch) Framed Structure

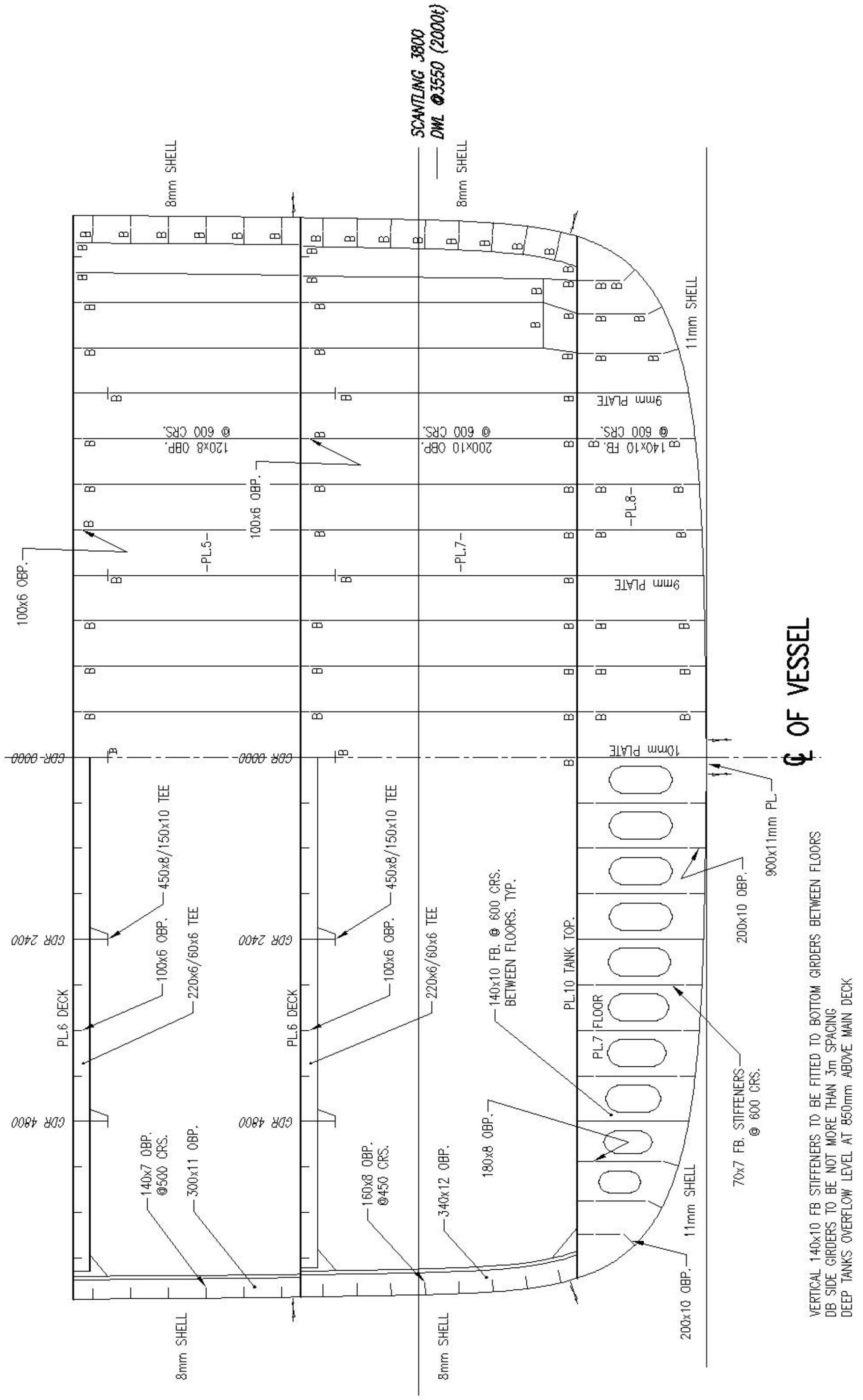


Figure 6 – Longitudinally (2.4m Pitch) Framed Structure

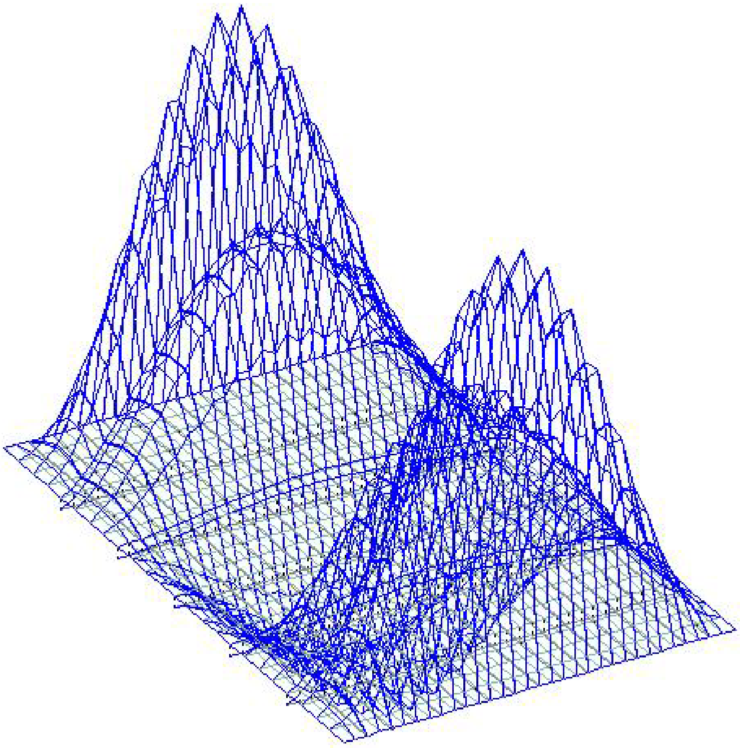


Figure 7 - Transverse Framing Mode Shape 1: 12.64 Hz

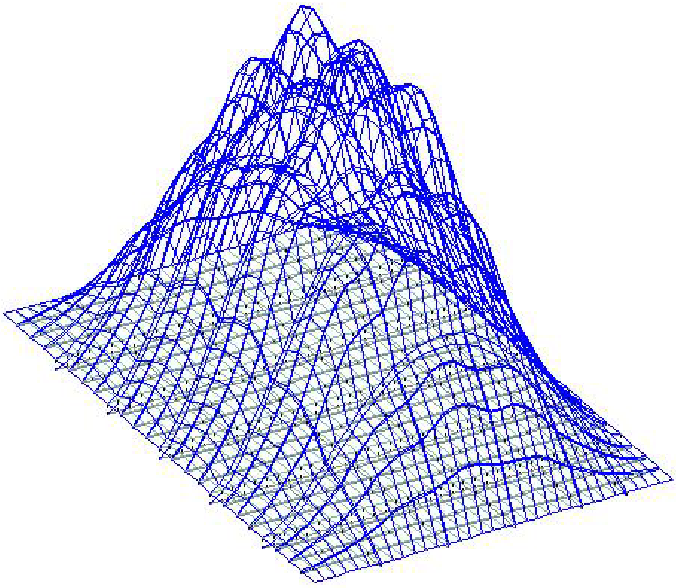


Figure 8 - Longitudinal Framing Mode Shape 1: 13.89 Hz

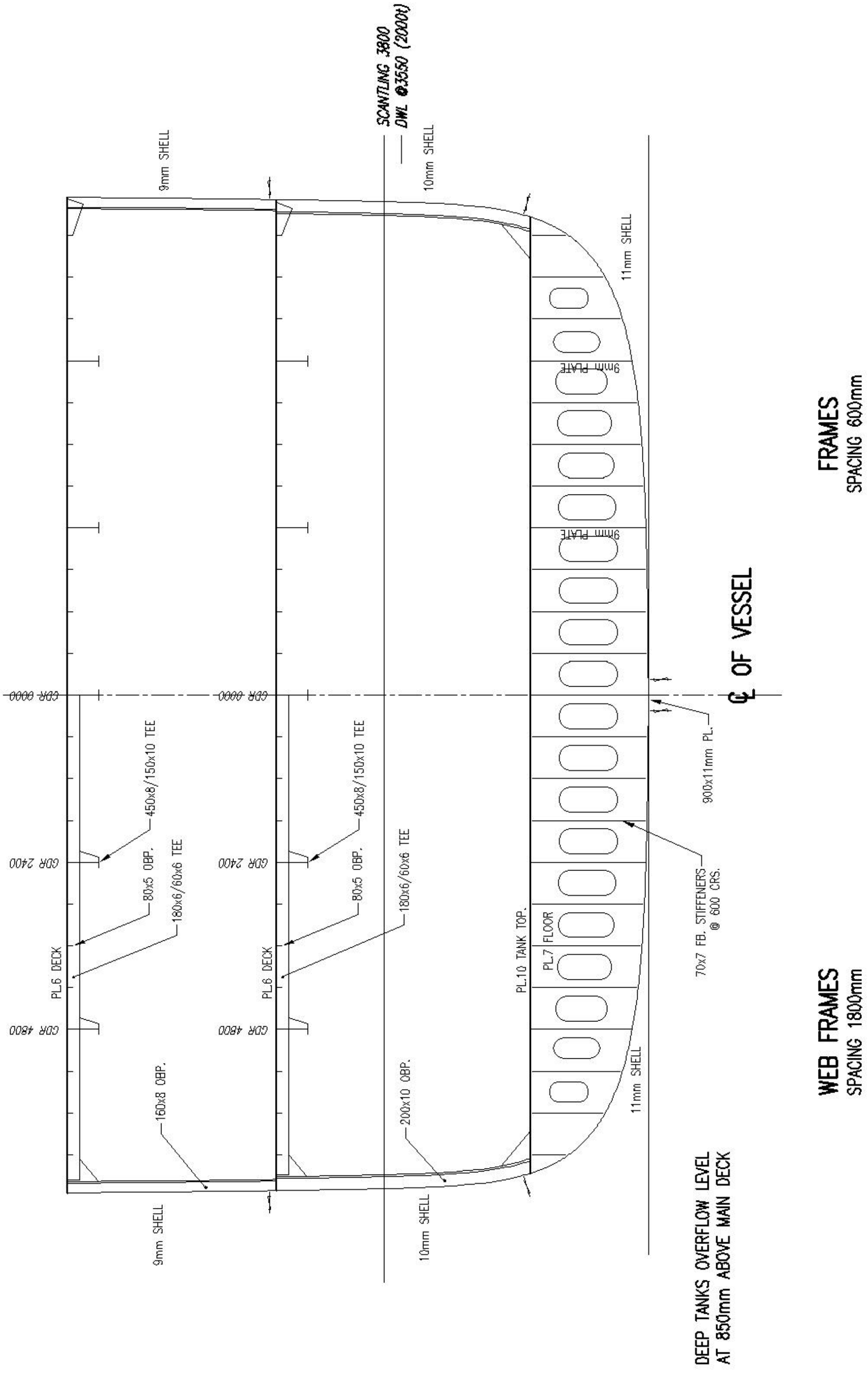


Figure 9 – Hybrid System Structure