Revisit of a 1970s semi-submersible pipe layer

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Introduction

The start of offshore drilling is took place in 1947. Since then many novel floating structures were conceptualised, designed, built, put in operation and finally scrapped again. When these structures are called *ships*, as does the present author, this meant an unprecedented rapid and all-encompassing development in naval architecture. The impact of this development was not restricted to mobile offshore units only, but in fact had an indelible influence on the design of all types of ships. All of this took place in a time frame spanning just one or two human generations. Documenting this history still can be based upon living memories and does not need to be restricted to paper information sources.

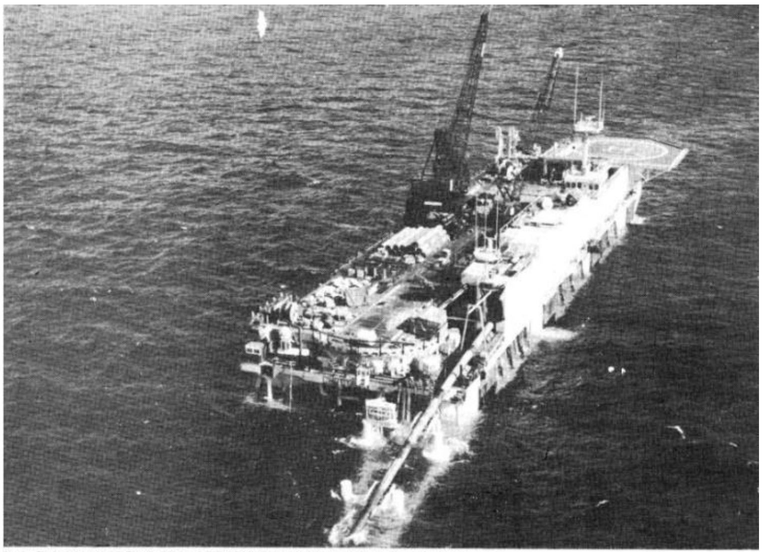
In the early 1970s Gusto Shipyard of Schiedam, Holland, designed and built the then new generation semi-submersible pipelay barge *Viking Piper* (Fig. 1).

Figure 1 Viking Piper at delivery (GustoMSC)

The design basis had to be set by the yard itself as hardly any rules or accepted standards did exist. Today, some 40 years later, the vessel still is in operation, now named *Castoro 7*, and cherished by her present owners SAIPEM as *one of the world's most efficient semi-submersible pipelay barges*. This proofs the value of the original design principles and the quality of the fabrication work then performed. Concentrating on structure and strength this paper describes the original design approach [1] and compares it with the way in which this would be performed today.

Background

In the 1960s gas and later oil was found in the North Sea. Constructing production platforms, laying pipes and other offshore activities were originally performed using equipment from the Gulf of Mexico (GoM) where such work already followed an established pattern. Soon it became clear that the environmental conditions in the North Sea were so much more harsh that many days were lost in down-time. Simple crane and pipelay barges were not suitable in this new environment. In 1968 Santa Fe from the USA designed a semi-submersible crane/pipelay barge which was built in Holland at the van der Giessen/de Noord yard (Fig. 2).



Santa Fe International Corp's Choctaw II, which has recently set a North Sea pipelaying record.
http://www.kombuispraat.com/viewtopic.php?f=1&t=694&start=1120

Figure 2 Choctaw II

Although new in its concept this vessel in several respects still possessed characteristics of the GoM lay barges (combined crane and pipelay capabilities, pipelay located at vessel side, hinged stinger, single joint pipelay). It was not the success its designers had hoped for, because at semisubmersible draft its stability was insufficient for heavy lifting operations.
In 1972 a group of offshore entrepreneurs and investors, mainly from the Netherlands, supposed that a new generation of pipelayer would be needed for North Sea conditions. IHC Holland recently had acquired RJBA (R J Brown and Associates), a specialist company in pipelay engineering and studies. Its founder, Bob Brown, came up with the idea of the 3GLB (3rd generation lay barge) semi-submersible. Together with the recently formed R&D department of Gusto Shipyard, another IHC Holland subsidiary, a feasibility study for such a large vessel was performed. The positive outcome led to the decision to build the vessel (the later-named *Viking Piper*, *VP*) and the order thereto was given to Gusto in November 1972.

State-of-the-art in semi-submersible design

Semi-submersibles for drilling were built in the USA since the early 1960s. Late 1960s in Holland RDM built the *SEDCO 135D* and the *Sedneth I* and, as already mentioned, GNK the *Choctaw II*. All were of American design. Notwithstanding the vicinity to those building yards the background to such designs was not known to Gusto other than through a small number of papers presented at the OTC, Offshore Technology Conference in Houston. Even the total loss only a few years before of the semi-submersible *Ocean Prince* in the Humber Wash off the English coast was completely unknown in those days without internet and all todays offshore related magazines (Fig. 3).

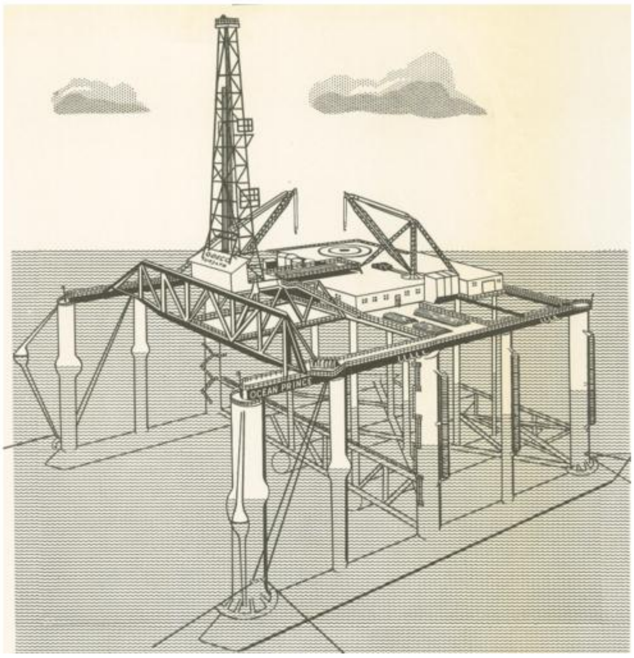


Figure 3 Ocean Prince (www.veritas-assoc.com/Ocean%20Prince1.htm)

The only knowledge available in the yard was the experience in designing other (offshore) vessels such as jack-ups and drillships. And of course what was taught about ships and engineering mechanics at university. Gusto used opportunities to train their young engineers. Thus the author by coincidence was send to a one-week introductory course in offshore engineering given at the University of Berkeley. Although given before the *VP*-contract, it showed similarities and differences between ship strength courses and structural strength of offshore units. Splitting loads and racking were not normally considered for ships, but governing in semi-submersibles. This fresh knowledge even in its condensed form, assisted tremendously in the further design of *VP*.

The classification society involved, Bureau Veritas, as well had very limited experience with semi-submersibles and certainly no rules. Actually the number of published design rules in existence was very small, mainly a small booklet published by ABS.

Both yard and class, who performed the early global structural analysis of the vessel with a finite plate element analysis, had no other choice than to use an approach from first principles. Only where applicable existing rules could be used such as for instance in determination of the thickness of plates subjected to lateral water pressure. When a plate would perform a global and a local strength role, those were analysed separately and not in combination (as often is done today).

Assembly method

Then: *VP* dimensions were much larger than the Gusto slipways. This alone already meant that the vessel had to be assembled afloat. In the feasibility and conceptual design stage the

assembly method had not explicitly been taken into account. Setting large blocks using floating sheerlegs was assumed, but this was not translated into design consequences.
Once the construction contract was signed that assembly method was one of the first things to be tackled. The 2000 tons maximum block weight anticipated required too many floating sheerlegs to make that system practical. Instead it was decided to set the blocks with a dedicated jack-up. After lifting the sections the partly assembled vessel was floated underneath and the blocks put down (Fig. 4).

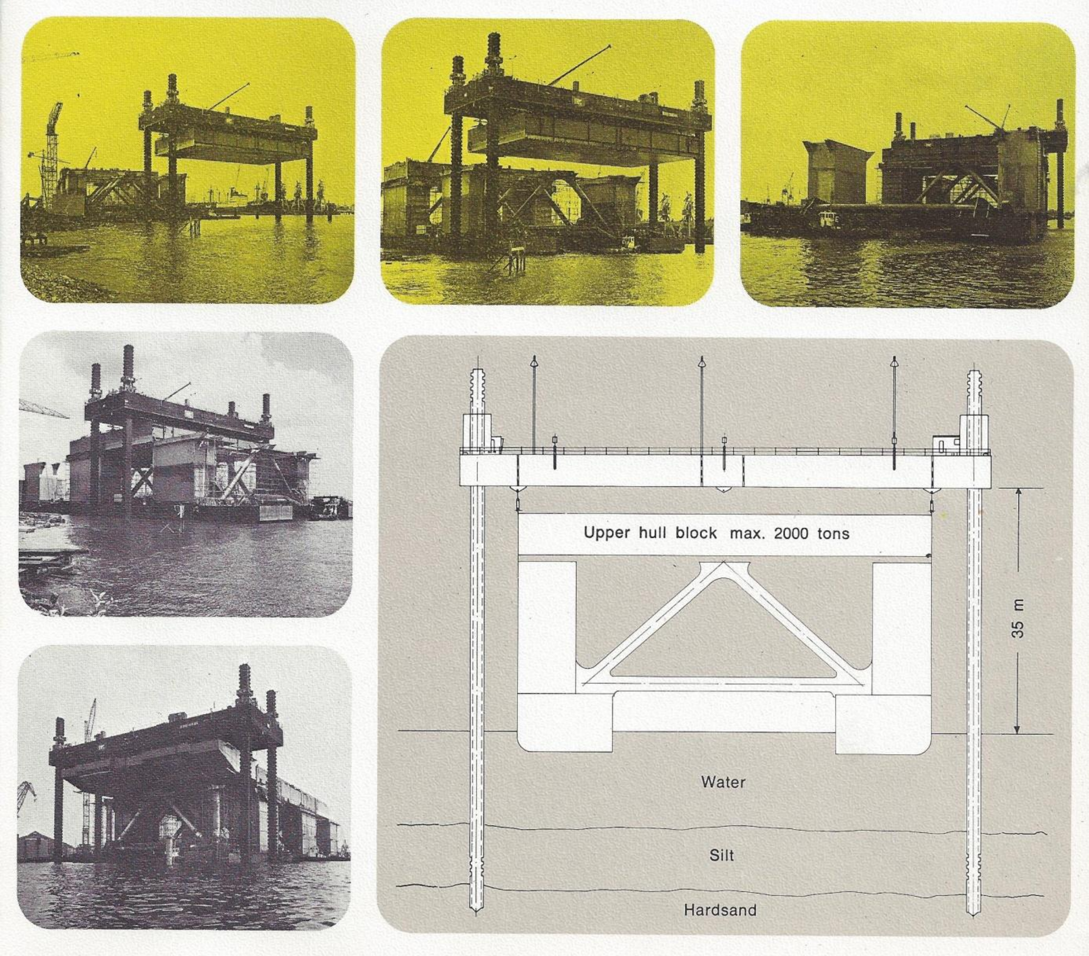


Figure 4 Assembly method *Viking Piper* (GustoMSC)

When opting for this construction method it was assumed that later it would be possible to cut the jack-up in two, add legs and sell them as two individual jack-ups for civil construction. Such platforms were much in demand and the commercial optimism in this sense fortunately proved to be true.
This assembly method was found to be quite efficient. But of course, practical problems were experienced. One of earliest tasks was positioning the two floats relative to each other and connecting them with the first set of braces (see later). Notwithstanding all the measurements taken (such as hose water levels) it was (later) found that the floats had a slight trim relative to each other. This translated in the deck blocks being somewhat rotated in the horizontal plane. The underdeck girders for the deck crane rails consequently could not be aligned properly. Doublers on the girder webs had to be installed in order to properly support the crane rails.

Today a vessel like this probably would be built in a large drydock making assembly much easier. And even if assembled afloat, may much more capable equipment exists today than in those days. Still, the elevating platform idea was good given the circumstances then.

The bracing system

Semi-submersibles consist of a number of elements such as floats, columns and work areas tied together by a space frame generally consisting of tubulars. The *Ocean Prince* is a typical example thereof (Fig. 3).

The concept of *VP* was based upon the same idea: large blocks supported by a space frame (Fig. 4). Not visible in this sketch a longitudinal horizontal member was foreseen at point A between two cross-sections as shown at the ends of the columns (not between the brace systems in between columns).

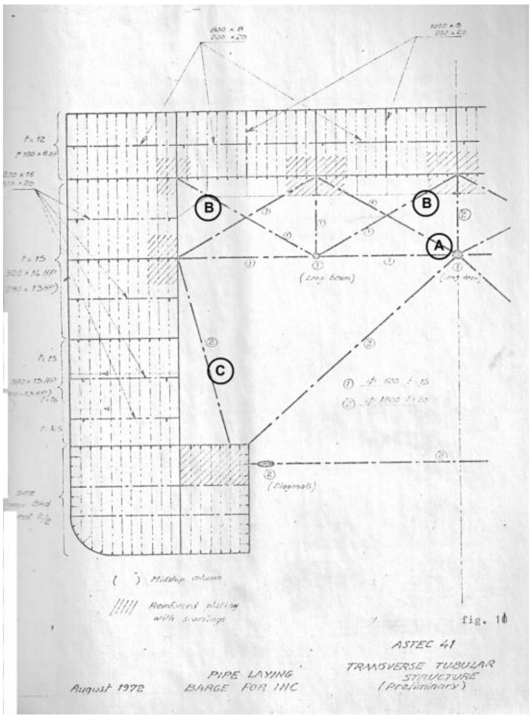


Figure 5 Bracing system in feasibility stage (GustoMSC)

At contract signing the diagonal braces B and C already were omitted resulting in a contract brace system as shown in Fig. 6.

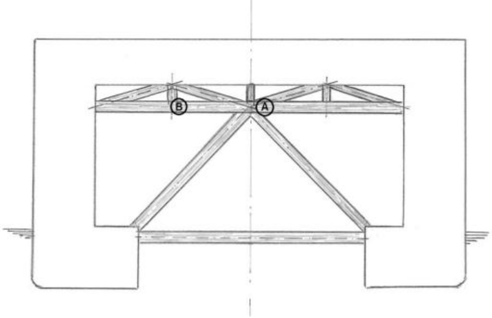


Figure 6 sketch of brace system at contract signing

During preparation of the preliminary design the longitudinal member at point A of Figure 6 was left out. Considering the force equilibrium at nodal point B in Figure 6 it was concluded that the vertical member at that point necessarily had to be a zero-member and thus could be left out. Thereafter it was concluded that at point A any vertical force from the large diagonal braces would probably be transmitted to the upper pontoon directly through the vertical member at A rather than through the shorter diagonal members at that point. Those members thus were left out. As no role was seen for the horizontal member through A and B that could be left out as well. The result was a transverse brace lay-out as shown in Figure 7.

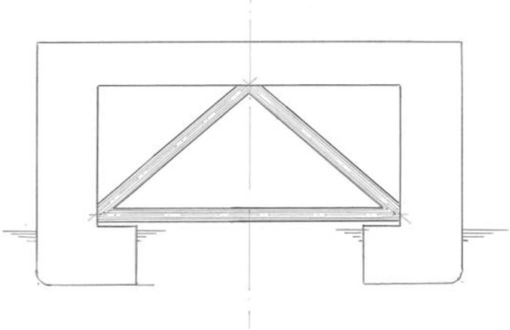


Figure 7 Final transverse brace lay-out

On the other hand it was felt that raising the lower horizontal member connecting the two floats offered some advantages. First it would mean that during tow (at a design draught some 0.25 meters less than the depth of the floats) the braces could be above the still water line. This would reduce the resistance during transit. Secondly by doing so all bracing members between two columns could be pre-assembled and lifted by the dedicated jack-up *Assembler I* as one unit (Fig. 8) making assembly of the vessel easier.

Figure 8 Setting a brace assembly (GustoMSC)

During the feasibility study the horizontal braces were laid out as in Figure 9.

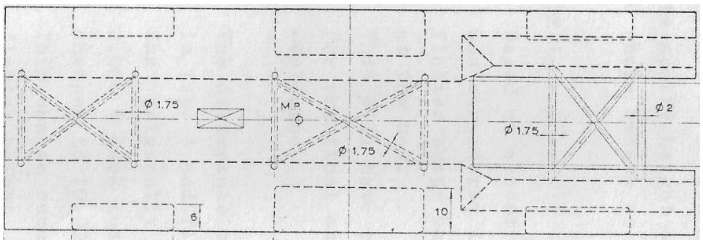


Figure 9 Lay-out horizontal braces in feasibility study (GustoMSC)

In the preliminary design stage it was suggested to replace the horizontal X-braces with K-braces. This would make the braces more efficient (a better angle for accommodating any horizontal shear force between the two floats) and result in less complex nodal points. This was rejected by client and management "because everybody knows X's are more efficient than K's". In combination with the transverse brace lay-out of Figure 7 the diagonal horizontal braces were laid-out as in Figure 10. Note that raising the lowermost braces made the horizontal diagonal braces less efficient due to their direction.

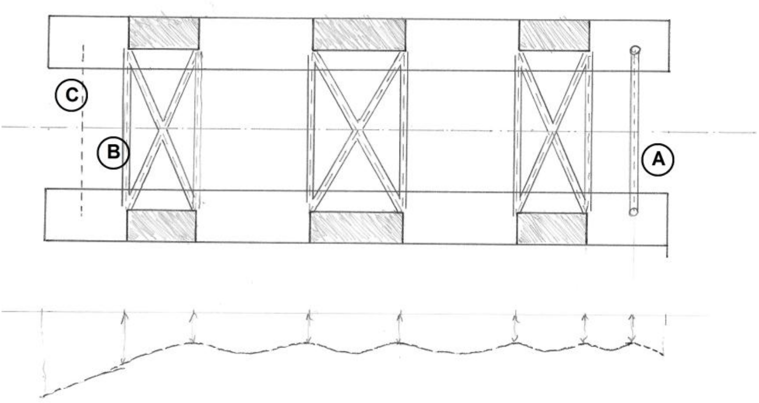


Figure 10 Necessity for additional transverse brace at stern

Because in the final stages of the feasibility study the work deck had been sifted forward relative to the floats an additional set of vertical braces and a horizontal one were installed at frame 204 (position A in Figure 10; see also Figure 1). At the aft end of the vessel brace B was the last one. The finite element analysis made by Bureau Veritas showed that in a splitting load condition the force in this latter brace was about double of that in all other braces. The transverse deformation of the float in that situation was as sketched in Figure 10. This indicated the necessity to add an extra horizontal brace at the stern of the vessel (position C in Fig. 10). Figure 11 shows the final lay-out. Note that the additional brace is located above the float leading a rather special attachment node.

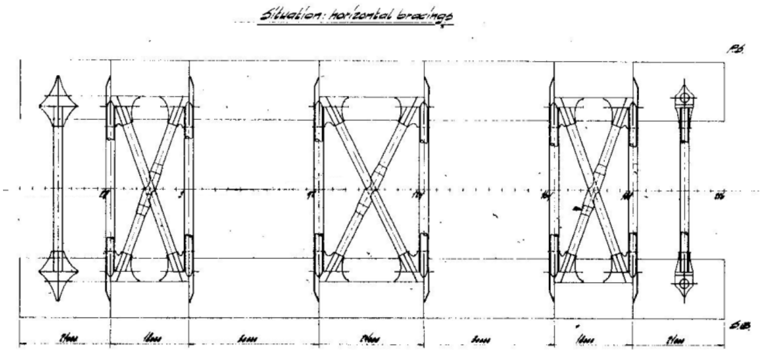


Figure 11 Final lay-out horizontal braces (GustoMSC)

Today most likely the vessel would have only transverse horizontal braces. That system was developed by Gusto when designing the semi-submersible crane vessels *Balder* and *Hermod* (Figure 12) and later *Micoperi 7000* (now *SAIPEM 7000*). MSC used the system on the *Smit Semi 1* and *2*. Both vertical and horizontal diagonal braces can be done without. The system was developed by Gusto as a further development along the line of thinking originating with *Viking Piper*. It may be seen as an optimum trade-off between integrated box-structures and braces. Today this transverse-braces-only system is quite common in semisub design.

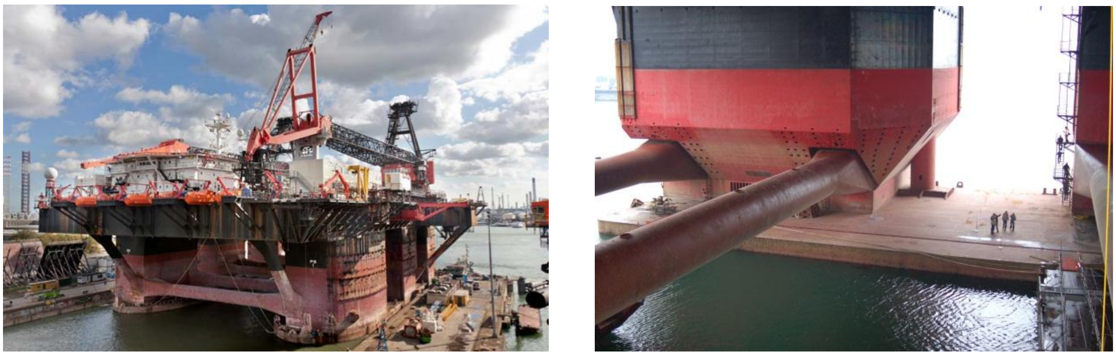


Figure 12 Transverse braces only on Balder (left; keppelverolme.nl) and Hermod (right; Bart Boon)

Steel type

Of course the vessel was constructed from normal strength steel grade A. The only exception are the braces and their nodal points. Because in the 1970s some fatigue problems showed up in nodal points of fixed North Sea platforms it was decided to minimise the risk of fatigue. Normal strength steel thus was selected and the best quality of steel available, which meant that grade E was selected both for the brace tubes as well as for the plates in the nodal points. Those steels came from different suppliers.

All welds of the braces and the nodes were fully penetrated as this again was supposed to minimise the risk of fatigue. It was chosen to let the plate material be continuous and the tube material discontinuous (Figure 13). Unfortunately this “best” plate material was found to possess very limited through thickness properties. Extensive lamellar tearing was the result. Proper repair meant gouging out and nearly replacing all plate material in between the tubular material by weld material. Further buttering was applied. And all nodes were heat treated in large protection tents. The latter measure was considered by the specialists to be hardly effective, but management decided that “we must show the client that we did everything within our possession to obtain the best quality possible”. Certainly in a costly way finally very good quality for the nodes was achieved.

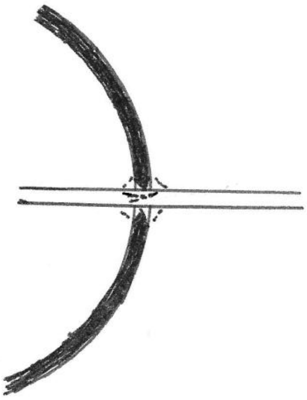


Figure 13 Lamellar tearing under full penetration weld in brace nodes

Note that in this particular case making the tubular material rather than the plate material continuous probably would have been beneficial. But this is due to the coincidental material properties only. Moreover using fillet welds or partial weld penetration would have reduced the risk of lamellar tearing albeit at an increased risk of fatigue starting from the weld root (which in this case with welds mainly transferring in-line shear loads probably would have been minimal).

Today because of better steel fabrication the risk of lamellar tearing has decreased significantly. Special steel with through-thickness properties, Z-steel, is readily available. That steel contains very little sulphur and phosphor by vacuum-degassing during production. Classification societies give rules for fabrication, testing and marking of such materials. Their application is generally restricted to “structural details subject to strains in the through thickness direction in order to minimize the possibility of lamellar tearing during fabrication” [2]. Many designers interpret this as meaning that Z-steel must be used when there are significant tensile (operational) stresses through the thickness of a plate. The effect of weld shrinkage during fabrication is often underestimated. The material today is better, but it is doubtful whether the design efforts to avoid lamellar tearing are much better than in the 1970s.

Brace nodal points

As today also in the 1970s nodal joints of fixed platforms often consisted of tubulars joined together with or without local reinforcements. The larger diameters of braces in semi-submersibles often quite different in size (for instance columns and braces) meant that the nodes nearly always consisted of a combination of plates (brackets and gussets) and tubes. The actual structure sometimes was concealed inside the visible part of the tubulars and in other cases visible from the outside.

Given the assembly method of *VP* with units of connected braces (such as in Figure 8) it was clear that it would be beneficial to have the entire nodal points outside the column structure. According to the contract brace lay-out the centre lines of the transverse braces were in line with the end shells of the columns. This automatically led to the choice of large brackets at the centre of the brace tubes. In order to make load transfer to the columns more smooth, it was considered beneficial to have horizontal brackets at the brace tube centre lines as well. General engineering knowledge indicated that very gradual transition from the tube structure to the brackets would make the unavoidable stress concentration as small as possible (Figure 14). For the same reason the end of the brace tubes as well was foreseen with long bracket-like transitions.

This principle was also applied at the top boxes connecting the braces to the upper pontoon (Figure 15). Even the additional brace at frame 12 was connected to the float in the same way. For the latter it may be wondered whether for instance the horizontal brackets at some 1.5 meters above the float deck fulfilled any function. This was done as well during the design. However, as there was no way to quickly analyse this (see the finite element analysis described hereafter) it was decided that adhering to the same principle in the design was the most secure way to go.

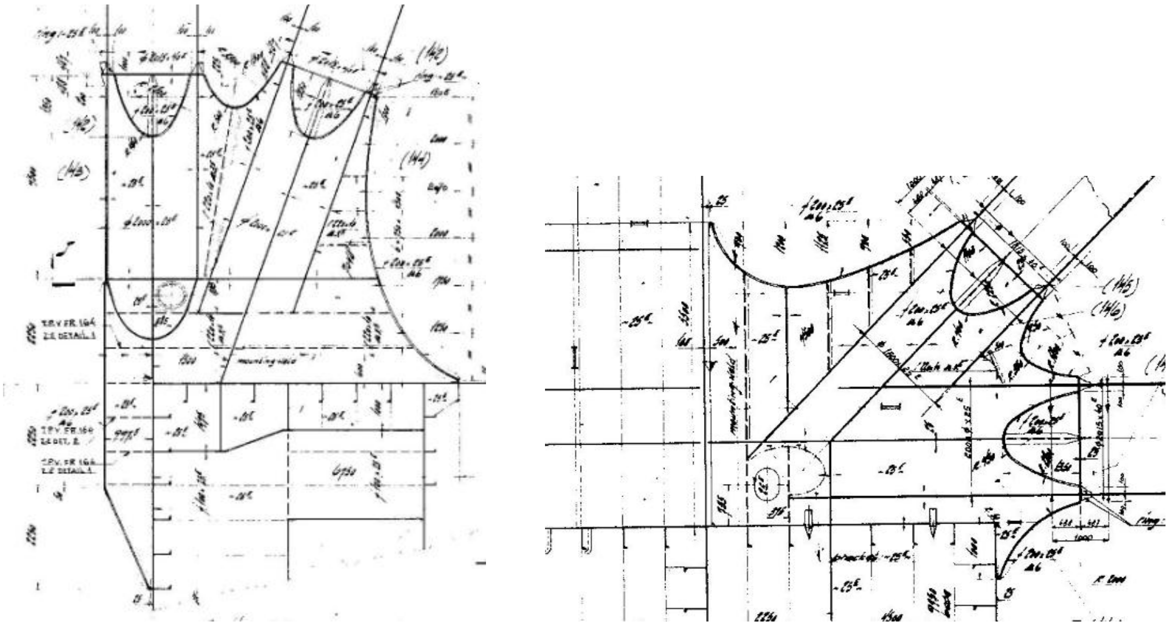


Figure 14 Horizontal section over brace centre lines (GustoMSC)

Figure 15 Brace top box in 2012 (Bart Boon)

After the concept design for the brace nodes was made, it was decided that it would be worthwhile to analyse one detail using finite elements. This was quite new in those days and had to be performed by an outside company, i.e. KSEPL (Shell) in Rijswijk, Holland. A very detailed analysis confirmed the original design ideas. The analysis was very time consuming and could be made for one node only. Under the assumption that the nominal stress in the brace tubes would be near the allowable, the target of the finite element analysis was to keep any stress concentration factor below 1.3. The calculated stresses as such were not directly assessed. Note that the smallest elements in the FEM analysis had dimensions in the order of magnitude of 0.05 meters.

The other nodes had to be based upon the assumption that similar stress concentration factors would apply. It was found that notwithstanding the extreme gradual introduction of the brackets, still some serious stress concentration occurred at the bracket toes. As this meant high stresses at a point of a non-stiffened round plate (a fundamental horror to shipbuilders in view of fatigue initiation) it was decided to provide ring stiffeners on the outside and on the inside of the tubes at the bracket toes. Further FEM analysis still showed quite high stresses, now in bending of those rings. Providing very small triangular brackets in line with the large brackets too away practical all those stresses. Of course those small brackets again ended on an unstiffened plate, but this was considered acceptable in view of their only 15 mm thickness and the fact that they were fillet welded rather than the full penetration of all other welds. The fact that today there is not the slightest indication of any fatigue cracking at these points (Figure 16) shows how effective the original design was.

Figure 16 Nodal points on Castoro 7 in 2012 (Bart Boon)

The other type of nodal point is the crossing of the two horizontal diagonal braces. The basis for its design was continuity of material. From a practical fabrication point of view this was considered to be impossible with the two braces having the same diameter.
Today probably no longer nodes would be designed with such an amount of external brackets. A transition from tubular to square as in Figure 12 is the more likely design. Yet with the same boundary conditions as during the construction of the *VP* a similar nodal point still might be a very good solution. Easy to use finite element analysis methods allow a much better optimisation and adaptation of designs in different locations. This probably would result in some less structural elements and smaller scantlings. However, optimising for a required fatigue life might easily lead to a solution which accepts higher stress concentrations than the minimisation of those that was strived for in the original *VP* design. As a consequence a modern design may quite possibly have a shorter fatigue life than the *VP* nodes.

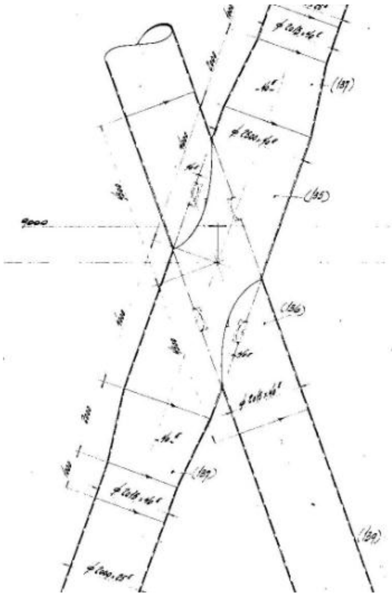


Figure 17 Node at crossing horizontal diagonal braces (GustoMSC)

Giving one of the braces a larger diameter connected to the original diameter by conical transitions solved this fabrication problem. Providing locally 40 mm instead of 25 mm thickness reduced all stress concentrations to an very acceptable level.

Column and float corners

The choice of position and shape of the columns was based upon transparency of the vessel side view in order to minimise wave excitation and at the same time optimisation of vessel stability in order to maximise the allowable pipe load on the deck. These considerations led to rectangular columns sitting on the outside of the floats (Figure 18).

Figure 18 Columns set using floating sheerlegs (GustoMSC)

This configuration at the same time made it easy to achieve structural continuity by aligning column shell with float shell and with longitudinal and transverse bulkheads in the floats. The orthogonal stiffening system more or less automatically led to squarer corners for the columns and floats. At that time this was completely new for semi-submersibles. Most had completely round columns and often floats or at least corners with large radii. The arrangement of *Viking Piper* obviously not only offered optimal structural alignment, but at the same time was most fabrication cost efficient.

From client side objections to this solution were made, in particular because they were afraid of corrosion fatigue in such corners. Although such sharp corners underwater indeed were not very common in the offshore industry or shipbuilding, some special vessel types, such as dredgers, had shown that the detail performed completely satisfactory. Actual behaviour of the *VP* after four decades proved this assumption to be completely correct (see Figure 16 left to the far right of the photo).

Another special feature of *VP* was the lack of any brackets in the transition of columns to floats (Figure 1). Again it was felt that this was justified in view of the good structural continuity at this point. Although it was recognised that some stress concentration might be caused in for instance the plane of the outer float and column shell, it was also expected that any bracket in the corner would make the stress transfer between column transverse shell and bulkhead in the floats would be made less effective by such bracket. Note that at the upper end of the columns large box-type brackets are provided in the transition to the upper deck structure. Partly it was recognised that the upper pontoon would be more flexible than the floats in view of their smaller depth (5.9 meters as opposed to 8.25 meters). The advantage of providing brackets for that reason was considered to be somewhat more at the top column end than at the lower end. But the main reason to provide these box brackets was supporting during fabrication the deck blocks in between the columns for as long as those blocks were not yet rigidly welded to the blocks above the columns. Figure 18 illustrates this situation.

Objections to this arrangement were raised. It was actually stated that such transition should look like the transition of a bough to a tree trunk; “that is the natural stress flow and thus will provide the most smooth transition”. *VP* designers rejected this strongly with the argument that in trees this concerns the transition of a full 3-D structure, not that of a thin plate arrangement where continuity requirements led to quite different solutions from that found in nature.

Lack of any fatigue cracks at these transitions after nearly forty years proves the correctness of the assumptions made then.

Today extensive finite element analyses replace the partly intuitive understanding of structural behaviour that was the basis of the designs in former days. Rectangular columns and floats are well accepted now. Some rounding of the corners is often applied in view of diminishing somewhat the hydrodynamic forces exerted, safeguarding ropes and wires that now and then may run around the corners and reducing somewhat the risk of damage in case of small collisions (both to the semi-submersible as well as to the colliding vessel). The actual transition itself is often fully based upon rectangular structural elements. As a consequence transition pieces must be provided between the part with the square and the part with the rounded corner (Figure 19). Note in Figure 19 the horizontal transverse braces only. Two between the columns means that some amount of redundancy is provided which is a new requirement in many cases and something that was not taken into account forty years ago.

Figure 19 DSS21 Maersk Developer (GustoMSC)

Conclusions

In the 1970s Gusto yard designed and built the semi-submersible pipe lay barge *Viking Piper*. Using common sense and a first principles approach it was possible to develop a vessel that even after 40 years of operation performs completely satisfactory. Modern computer analyses might have optimised the design as far as weight is concerned without altering fundamentally the safety of the vessel.

Acknowledgements

The late Bart Jan Groeneveld was project manager during the design of *Viking Piper* and the author gratefully acknowledges the intensive cooperation with him in those days. But also several other former colleagues gave their input in writing this paper.

References

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[2] ABS: Rules for Materials and Welding, Part 2, 2012