The global solution for profitable, safe and sustainable fish production

Anders Ytterland and Endre Kvalheim[1]

Many people, inside as well as outside the aquaculture industry, are engaged in the growth of the industry. The global potential for growth is, indeed, great. Often, access to feed and juveniles are pointed out as obstacles to achieving this potential. These are genuine challenges to be solved, but another crucial point is the presently available fish farm technology. Why is the global sea-based aquaculture industry mainly located in a few countries that have extensive fjords, bays and other shielded sea areas? If one takes into consideration that most countries place a high priority on environmental protection as well as the rights of other users of the coastal areas and that many nations, at this point, have laws regulating uses of the coastal zone, the need for new cage technology becomes obvious.

OceanGlobe represents such technology inasmuch as this newly developed system gives all countries the opportunity for safe and profitable fish farming in their respective offshore areas and, in a way, is environmentally favorable as well. It is a known fact that the global total catch from traditional fisheries already has reached an upper responsible limit of approximately 100 million tons, which is why the aquaculture industry, to an increasing degree, must meet the demand for fish and fish products. A large number of countries have accepted responsibility for this and established a distinct priority on fish farming. The European Union (EU) has, in the Common Fisheries Policy, established an objective of 8,0000-10,000 new jobs in aquaculture by 2008 (Fischler 1999), as well as an objective for a considerable reduction in the total capacity of the fisheries fleet. In addition to this, the EU has introduced a water directive that will likely hold the breeders responsible for all negative environmental effects from fish farming in the inner coastal areas. This will inflict additional costs on the traditional fish farmer (EU 2004). The USA wishes to make itself much less dependent on the import of fish and fish products by increasing fish farming and is currently revising such legislation as the Magnuson-Stevens Fishery Conservation and Management Act to reflect the new emphasis on aquaculture. For example, fish farming licenses are being considered in the entire Exclusive Economic Zone (MAFAC 2003). In countries such as Australia, Taiwan, Vietnam and South Africa, large investments are being made in the development of fish farming in their exposed seas. In all of these areas, the absence of suitable technology is an obstacle for further growth in the aquaculture industry. In the few countries, such as Norway, Chile, Canada and, to a certain extent Japan, that have access to fjords, bays or other protected fish farming locations, significant aquaculture industries have been developed during the last few decades. However, those nations are faced with great challenges related to the growth in various other sectors that has taken place in their protected coastal areas. Available localities for fish farming in those areas are decreasing and the level of conflict with respect other users of the areas continues to increase. In addition, many areas are affected by pollution from the aquaculture industry, especially in shallow and poorly flushed localities. Such areas can also lead to poor fish health and reduced product. The challenges facing aquaculturists in coastal waters have led to the establishment of research and development on offshore aquaculture in some of these countries, such as Chile and Canada.

Discussion

There have been attempts in the international aquaculture industry to develop durable and reliable construction techniques for profitable offshore fish farms. Offshore fish farming structures need to be functional in deep, open and exposed areas, within an adequate distance from the coast, so as not to interfere with the inner areas visually, physically or by polluting them. In most cases, this means a distance of 5-28 km from the coast. Attempts have often failed with respect to at least one of the points that are critical to such structures. Some operations have used the offshore oil and gas platforms as fish farming sites and have taken the approach of simply increasing the material dimensions on traditional farm designs to cope with the natural forces. This has resulted in large, heavy and rigid constructions with an extensive waterline area that often expands over several wave crests (Figure1). Fatigue has been a significant problem and, in some instances, has led to total system failure and loss of both the structure and the fish. Great relative motion between the water column and the structure is also a significant problem, leading to a high stress level on the fish and, in extreme cases, a considerable increase in injuries and death.

Most heavy and rigid structures have free hanging nets from a construction frame on the surface, which leads to considerable deformation and volume reduction in strong currents. Easy and safe access for vessels and personnel is not achieved in conjunction with most of these structures. Additionally, the working conditions are exhausting; several of the tasks require diving operations that are costly, time-consuming and present a high risk to personnel working in offshore waters.

Internationally, there have been attempts to use very flexible construction methods. To a certain extent these have been successful because the risk of fatigue has been reduced. As a result, some of the farms using such structures have had some commercial success. But with offshore fish farming, the problems are still great, because the structures, in extreme situations, can be too flexible, resulting in a drastic reduction of available volume for the fish, as well as a significant increase in stress level and injuries to the fish. However, the reduction of volume is not the only reason why these structures do not represent a possibility for safe and profitable offshore fish farming. Some attempts have been made using closed and fixed extended structures that feature only a moderate reduction of volume in strong currents. There have even been attempts with submersible structures. The problems remaining with offshore fish farming have to do primarily with very difficult accessibility and working conditions for vessels and personnel, as well as the poor maintainability and operational efficiency of the structures. These are crucial aspects regarding offshore installations. Generally, a rigid anchorage also decreases the possibility of reducing the relative motion between the water column and the structure in agitated waters (Figure 1). Most of the flexible structures have a problem with access for vessels and personnel. In addition, all necessary working operations, such as maintenance, harvesting and inspections are generally based on time-consuming and hazardous manual labor, including diving operations.

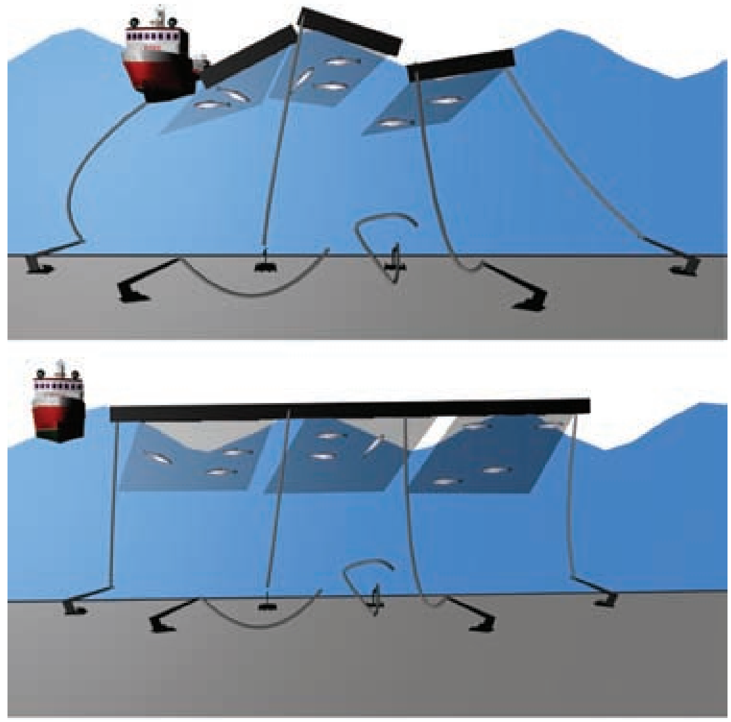


Fig. 1. System anchored flexible and rigid constructions in agitated waters.

None of the attempts to develop durable offshore structures have had any significant success internationally; a statement confirmed in both the *Farming the deep blue* report (Ryan 2004) and the *Farming the deep blue* conference in Limerick, Ireland in October 2004. However, today there is a growing demand for offshore technology in many parts of the world. This indicates that the solutions presently on the market are only considered adequate for coastal areas in close proximity to the shore or in minimally exposed localities and, thus, not for offshore operations. Whether or not these solutions have been attempts to develop sufficiently sound and safe offshore structures is difficult to determine. However, the earliest structures for protected localities were rapidly optimized for the existing conditions and controlled a major part of the market. This means that for a long period of time one has found it sensible financially to keep these early solutions and redesign them for increasingly more exposed localities.

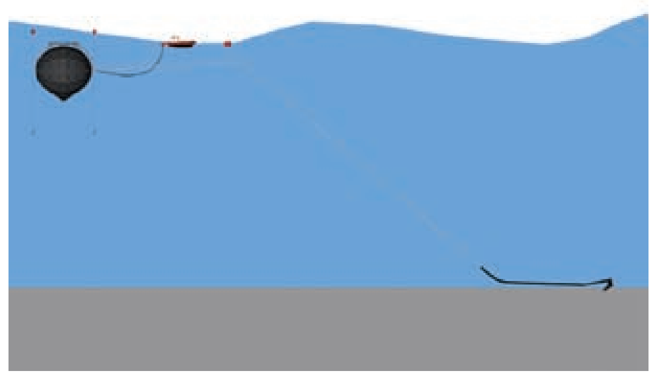


Fig. 2. Drawing showing how the OceanGlobe is sway anchored with a separate supply and control platform integrated in the anchorage.

The necessary conditions to achieve a safe, profitable and lasting offshore fish farm cannot, in any case, be considered as being either solved or not solved. They can be solved in a more or less optimal way, which also implies significant differences in structures with regard to financial and practical differences, as well as security.

But what about *OceanGlobe*? In what ways does this structure have the necessary qualities for offshore production? *OceanGlobe* is a sway anchored (single point moored) ellipsoidal,[2] closed and submersible offshore fish farming structure with a continuous center pole, a surrounding horseshoe shaped working and docking platform and a separate supply and control platform, which is an integrated part of the anchoring of the structure (Figures 2 and 3). The sway anchoring gives the structure great freedom of movement, so that it more easily moves with the forces of winds, currents and waves. The anchoring also allows the structure to move across a large area, depending on the direction of current. The frame of the patent pending net cage is built of pipes using polyethylene, while the remaining components, including the center pole and the working platform are made mainly from steel. The largest version of *OceanGlobe* has a volume of about 40,000 m^3; however, smaller versions will be available: 23,000 m^3 and 12,000 m^3. The volume in all the three sizes can be divided into two or three chambers by interior net panels. The supply and control platform is a vessel. In addition, it will be demonstrated that the construction is not only suitable for fish farming, but is also applicable for storage and transportation of wild fish and as a special cage for storage and delivery of fish at fish processing plants.

OceanGlobe has four different operational positions (Figure 4): semi-submerged, surface/iceberg, submerged and extreme-submerged. Semi-submerged is the position for inspections and maintenance operations, including harvesting, and is not a normal operating position for growout. Iceberg position is the breeding position for anadromous species; approximately 1/10 above the surface, while the submerged position is preferred for growout of most marine species. In both positions 2 and 3 (Figure 4) the rest buoyancy constitutes the working platform and separate buoys. The extreme-submerged position, which means submersion to a predetermined depth (20 m), is primarily a rescue condition for the fish in the event of extreme weather or the presence of algae blooms. For species that do not thrive in the upper layers of water, such as the cod, this position may be the normal operating position for growout. In some cases, the extreme-submerged position is an extraordinary operating condition due to depth optimizing or finding appropriate temperature layers. In this situation, the cage has significant permanent rest buoyancy in separate buoys, together with safety-buoyancy in case of total control system failure. Because the maintenance position of the structure is only relevant for inspections, maintenance/operational purposes or harvesting, the cage will be in that position for only a limited part of the time, compared to the other positions.

The philosophy behind the construction is that it should live *with* the natural forces, not fight them. The design, the composition of materials as well as the anchorage give the structure qualities consistent with this philosophy; low relative motion between the cage and the water column, low relative force influence, symmetrical distribution of forces and

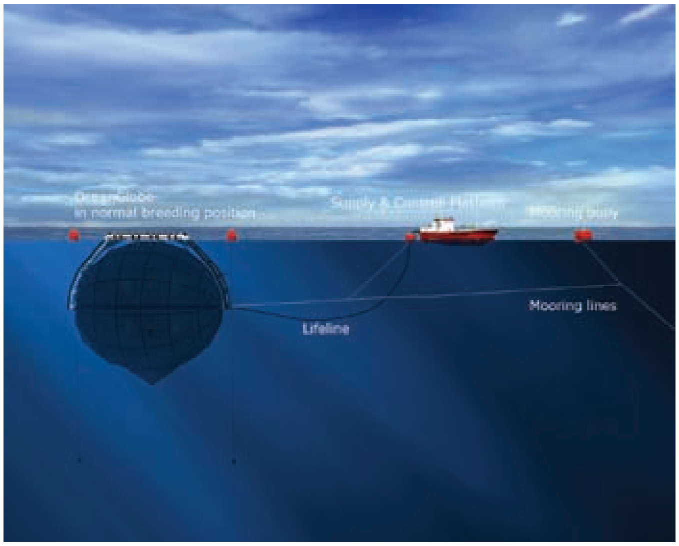


Fig. 3. A side view of OceanGlobe in submerged position, which is the normal position for breeding of most marine species.

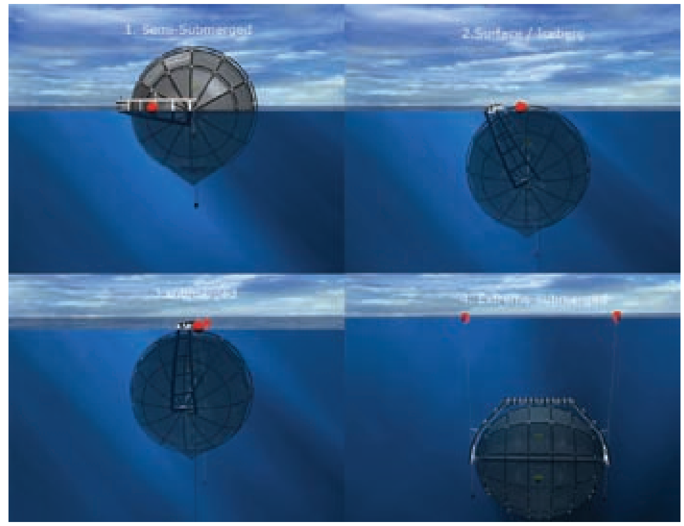
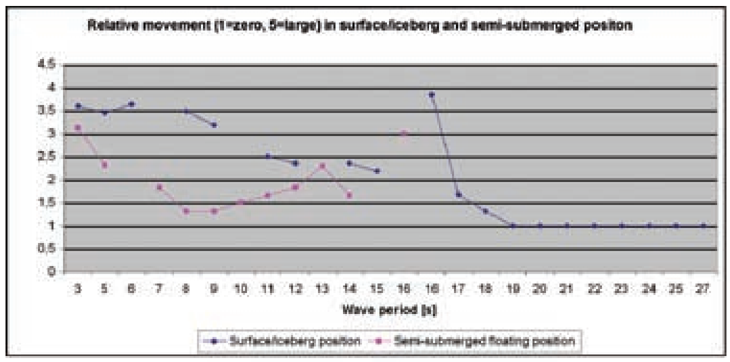


Fig. 4. A side view of OceanGlobe, showing the four different operational positions.

elimination of the fatigue problem. Figures 4 shows that the *OceanGlobe* resembles the iceberg, nature's own structure, which, incidentally, copes with extreme weather conditions in a remarkable fashion. The resemblance to the iceberg is in shape as well as the density of the framework material (about 1 g/cm[3]). The greatest resemblance, though, is the response because the relative motion between the structure and the water column is low, for the iceberg as well as for the *OceanGlobe*.

An extensive series of model experiments with four different models at Sintef's ocean laboratories (Marintek) in Trondheim and in sea on the west coast of Norway have contributed to mapping the cage's pattern of response and sea capability, forces and flow rate. The extensive experiments confirm that the above-mentioned relative motion is low and not critical in all relevant sea conditions, even in extreme ones (Figure 5). The tests also show that the measured wave forces are considerably smaller than theoretical wave forces in a given sea condition; in other words, the low relative motion between the cage and the water column reduces the relative magnitude of forces inflicted on the structure. Furthermore, several tests regarding operational tasks, strength and durability in rough seas were performed. Generally, the test results were very positive and confirmed that *OceanGlobe* had remarkable sea and strength capabilities and that operational tasks, such as submersion, elevation, rotation and harvesting functioned as expected.

Figures 6 and 7 show the response in heave[4] as a function of wave period for *OceanGlobe* in surface/iceberg position and for a typical semi-submersible oil drilling platform, respectively. There are similarities as well as differences. The natural period[5] for both structures are in the mid 20s (seconds), higher than the wave periods that generally appear in open waters. However, *OceanGlobe* has a much larger and more constant response up to the natural period than is the case of the semi-submersible platform. This is not incidental. Semi-sub-



T_p [s]	H_s [m]
3	0,5
5	1,5
6	1,75
7	2
8	2,5
9	3
10	3,5
11	4
12	4,5
13	5
14	5
15	5
16	12
16	14
17	4
18	4
19	3
20	3
21	3
22	3
23	3
24	2
25	2
27	2

Fig. 5. Observed relative motion in OceanGlobe as a function of wave period in normal and half submerged floating position. The table to the right describes wave heights corresponding to the different periods.

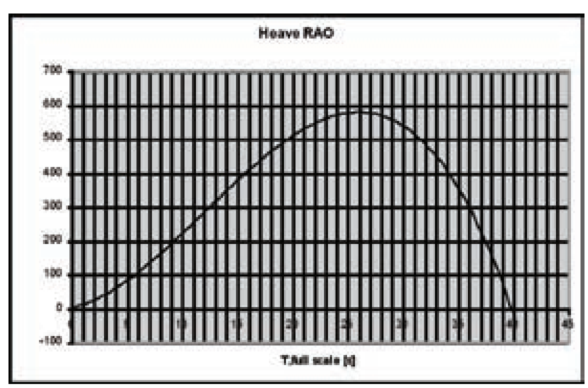


Fig. 6. RAO in heave from the OceanGlobe model testing.

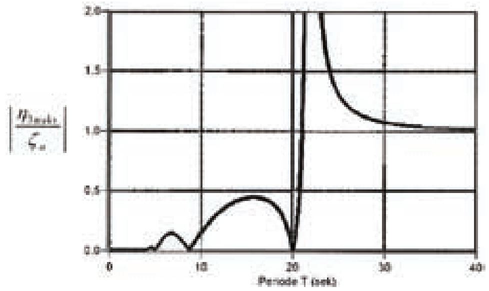


Fig. 7. Motion characteristics (transfer function) in heave for a semi-submersible platform as a function of the wave period (Pettersen 2000).

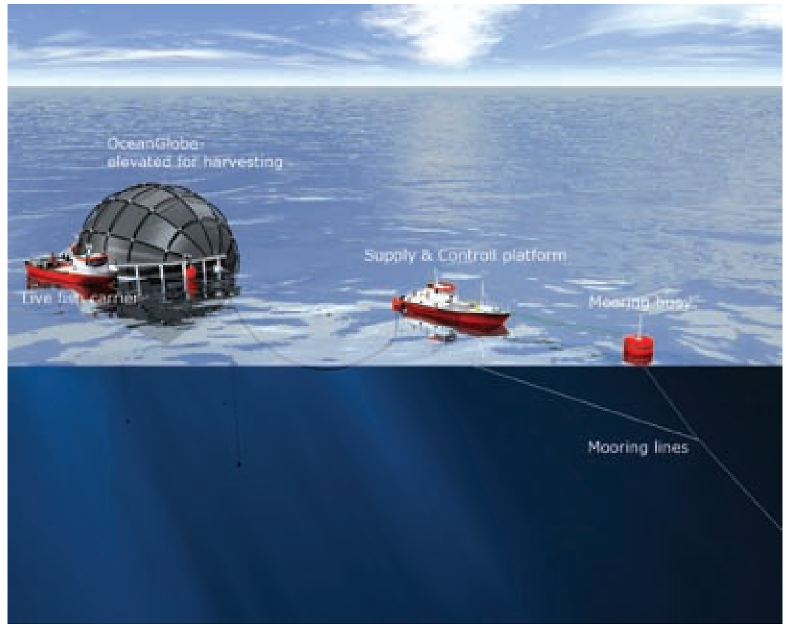


Fig. 8. OceanGlobe elevated to semi-submerged floating position for inspection, maintenance operations or harvesting.

mersible platforms are deliberately designed to have a very low response in frequently occurring sea conditions to meet the very severe requirements for drilling operations. *OceanGlobe*, on the other hand, must have a greater response to achieve a satisfactory low relative motion between the water column and the structure, so the fish are not exposed to stress or injuries. In other words, there is a distinct connection between Figures 6 and 7.

Several tests confirm that polyethylene is very resistant to fatigue (Janson 1999). Generally, the tests were discontinued after extended periods of exposure to great cyclic strain without showing that the material was fatigued. For more than 80 percent of the time, the *OceanGlobe* will be in position 2, 3 or 4 (Figure 4) and only during inspection and maintenance operations in moderate seas will the structure be elevated to a semi-submerged floating position. All steel components that are critical and have a potential for fatigue are, therefore well protected most of the time by being located in 20-70 m of water. Seen in relation to the response pattern of the structure, this means that fatigue is not a great risk for the *OceanGlobe*.

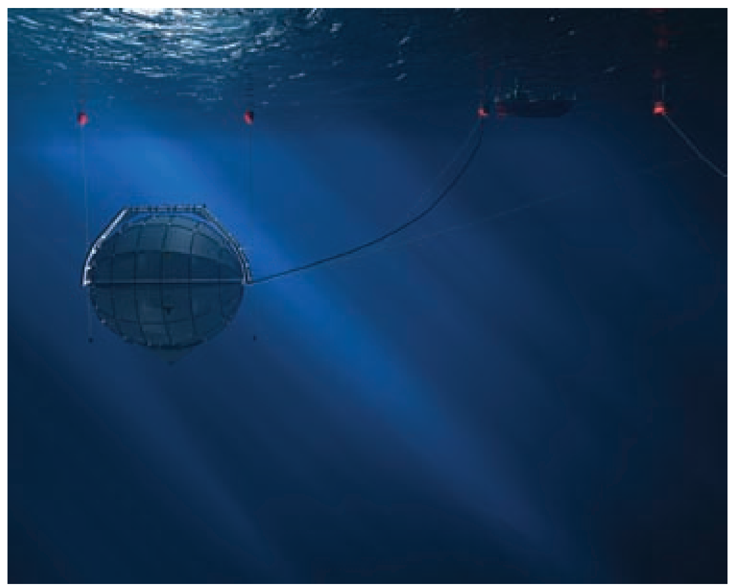


Fig. 9. OceanGlobe in extreme-submerged position.

The separate supply and control platform of the structure meets the purpose of supplying the fish cage with sufficient feed, compressed air and electrical energy. Those pass through a lifeline going from the platform to the fish cage along the mooring line. Besides the feed bin with sufficient capacity for 2-4 weeks of operation, depending on the species, the supply and control platform contains compressors and pumps for the operation of the feed and air regulatory system, as well as a regulation system for obtaining sensory data and for feed control. As mentioned previously, the *OceanGlobe* is adapted for use with vessels as supply and control platforms. Because the number of unused and unprofitable vessels of good quality has increased greatly in recent years due to the surplus capacity in the fishing fleet, and falling fishing quotas, *OceanGlobe* has been developed to utilize these secondhand vessels. Such a vessel is shown in Figures 2, 3, 8 and 9. These vessels are, in spite of their low value, in very good condition and contain much of the necessary equipment and machinery. Only minor refitting is necessary. In addition to the feed tank, live fish tanks may be installed in the cargo holds for transportation of fish to and from cages. A 60^3 tank can transport nine tons of fish.

In some locations a single vessel can be employed to supply several *OceanGlobes*. In cases where the employment of vessels is not possible or desirable, one of the newly developed offshore feed barges, which have shown good results so far, for example in Ireland, can be used. The working platform, which is mainly a robust steel pipe structure, ensures great rest buoyancy in the surface and submerged positions (positions 2 and 3). In the extreme-submerged position the platform maintains positive buoyancy, which means that the working platform is always in position above the cage. In the semi-submerged position, the *OceanGlobe* center pole contributes much of the total rest buoyancy. The chambers in the working platform are only filled by water/air during

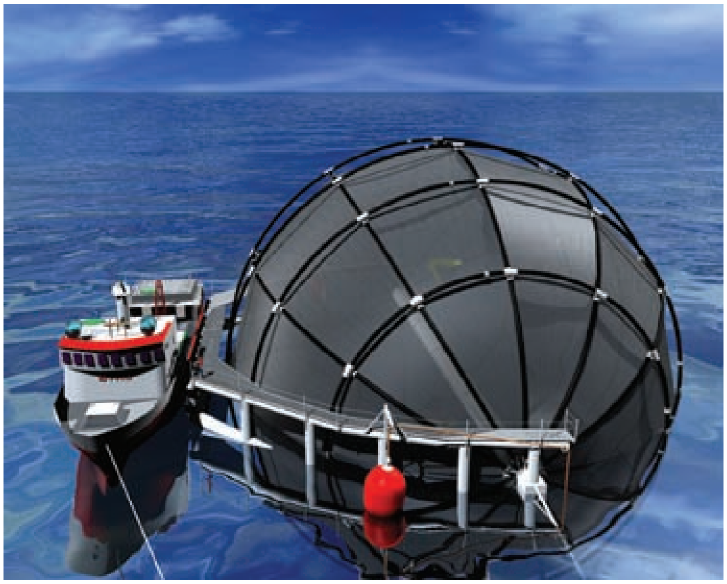


Fig. 10. The horseshoe-shaped working platform ensures that personnel have the necessary space to operate the cage in an efficient and safe way.

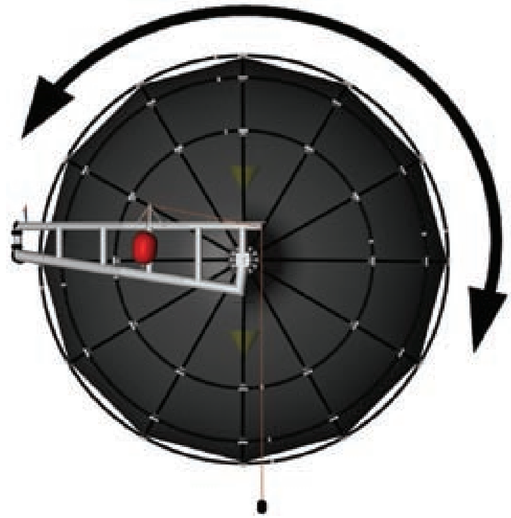


Fig. 11. Rotation of the cage inside the working and docking platform.

regulation between the submerged and extreme-submerged operational positions. *OceanGlobe* is regulated between the other positions simply by changing the ballast weight in the center pole with water and air. One of the most significant advantages of *OceanGlobe* is the unique efficient and safe working and maintenance operations, as well as easy access to the structure for vessels and personnel. When docking, vessels may use a long mooring line fastened to the supply and control platform (Figures 8 and 10), after which the vessel moves astern against the 25 m docking quay at the working platform. Operated by experienced mates pointing the nose against waves and current, with a long, flexible mooring line that absorbs a great part of the forces acting on the vessel, is a strongly preferred way of mooring in open sea. Due to this long and flexible mooring line, the relative forces and motions between vessel and quay are minimized. The fish cage can also be rotated completely inside the working platform (Figure 11), which means that all working operations can be carried out from the platform approximately 3 m above the water (Figures 10 and 12). Hence, diving operations are not necessary. The working operations include inspections, net cleaning, mortality collection, sorting and harvesting, replacement of net modules and repair or replacement of equipment and structure parts. The net that closes the cage is divided into several small net modules, each covering a few windows in the framework of the structure. For net handling and net maintenance, this is a great advantage compared to traditional systems. Dead fish are gathered in a dish at the bottom of the fish cage and are frequently and automati-

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cally pumped into a large fish crate that is integrated into the working platform. Personnel can then empty the crate from the working platform. This can be performed not just in a semi-submerged position, but also in positions 2 and 3 (Figure 4). Harvesting is carried out by dropping a wall of a closing net inside the cage, then rotating the cage so that the density of fish increases sufficiently to allow them to be pumped directly onboard into a fish carrier. The internal net module is helicoidal/screw shaped, which ensures that the fish are collected at the end of the cage. The suction shaft from the fish carrier is placed inside the fish cage by opening one of the closing net modules that has an integrated zipper for easy access. Necessary working operations, whether it is inspection, replacement of closing net modules, removal of dead fish, cleaning of the closing net or other tasks can be performed easily and safely from the working platform and also very efficiently by employing the rotational features of the cage.

By assessment of a structure's suitability for offshore breeding, circumstances relevant to the structure, fish and personnel for the operational tasks must be taken into consideration. In the model scale tests of the *OceanGlobe*, which were performed in a many sea conditions representative of the exposed areas outside the Norwegian coast, as well as for the analysis of the test results, all of the above-mentioned circumstances were taken into account. The results showed that good conditions can be maintained continuously for the fish and the fish cage, year-round. Also, good working conditions for personnel are maintained with sufficient continuity to provide an efficient and safe operation during all seasons and under all conditions. In addition, the cage is very stable in the different operational positions and is easily moved from one position to another by air and water filling. The testing also confirms that net cleaning can be performed efficiently. By elevating the structure to the semi-submerged position and exposing the fouled net to direct sunlight, the fouling will dry and fall off. In the tests, the fouling was dry after three hours, meaning that six hours may be sufficient for cleaning the entire structure. If there is no access to sunlight, one may easily flush the fouling off the netting with a high-pressure washer. Last, but not least, rotation of the cage is performed without any problems and the harvesting system functions well.

With regard to safety of the fish, it is crucial that the structure be fully submersible in the water in extreme conditions, such as storms, typhoons and algae invasions. This submersion will be accomplished automatically when the weather conditions exceed a defined limit or in exceptional situations when the cage and supply and control platform are in danger of colliding. In the latter situation, which is only possible in calm weather, the vessel may easily be reconnected and go to standby for an hour or two until the cage reaches its new position. Fish farmers who have tested submersible structures report that the fish and the structure have been spared, and no losses were registered during storms that have wrecked settlements on land and vessels in harbor, obviously as a direct consequence of the cages being

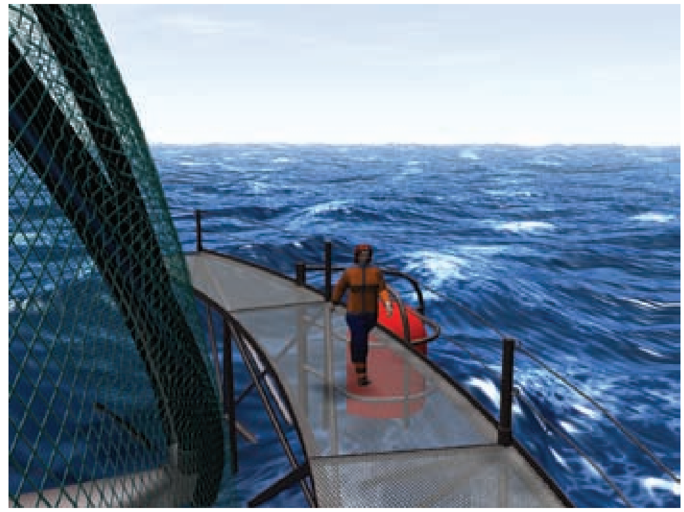

Fig. 12. A close-up which shows personnel on the working platform during quite rough weather.

submerged and, thereby, protected during the storm. In the occurrence of noxious algal blooms, the fish can be spared by lowering the structure beneath the algae zone. Recently, several fish farming companies have suffered large losses of fish from algal blooms; for example, along the east coast of the USA and in Spain. A major advantage with the *OceanGlobe* is that normal operation can be maintained in an extreme-submerged position and, thereby, the structure can be lowered for several weeks without affecting the fish. As mentioned, this operating position can be the normal growout position for deepwater species such as cod. When growing anadromous species, such as salmon and trout, the fish are able to inflate their swim bladders through an air pocket at the top of the structure, which is refilled with a portion of the air usually employed for elevation operations and removal of dead fish. The feeding system, which is an appetite regulated water flow system, based on reputable Norwegian technology, is able to maintain normal feeding in both positions 2, 3 and 4 (Figure 4). The fish are fed through two internal feeding points, and the feeding is stopped automatically when the fish no longer eat all of the feed pellets.

Research work so far, shows that fish health can be improved by submersion; for instance problems with sea lice (*Lepeopththeirus salaris*) can be reduced in salmon farming by submerging the cage to deeper and colder layers of water. In addition to the positive effects of submersion and periodic optimization of depth, internal lightning, appetite controlled feeding with two feeding points, low relative movements as well as ample access to oxygen are all factors facilitating the survival and health of the fish, thus securing a high growth rate. Model testing shows that access to oxygen is better in the *OceanGlobe* than in traditional structures in sheltered waters, even with a 50 percent reduction of current through the cage.

The sway mooring system, combined with strong currents and larger depths in offshore locations, eliminates environmental problems outside the net cage normally caused

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OceanGlobe

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by debris from waste feed and feces. Those losses, which contain nutrients, are spread over a large area because of the mooring system and, therefore, do not accumulate in large quantities on the ocean floor. Considering that major parts of the offshore areas have a low levels of nutrients, waste from the fish farm can be considered as positive fertilization of those areas.

The technical strength of the design and functionality of the *OceanGlobe* drastically reduces the probability of escape of cultured fish. Because of the way the net is stretched and fastened, the risk of damaging the net during maintenance also is minimal. If the net is damaged during maintenance, there will not be a risk of fish escaping because all operations on the net are performed above the water level. The vessel docking system reduces the risk of damaging the net in a collision with a boat or a propeller to a minimum. In 2003, approximately 20 percent of escape incidents in Norway were the result of damage to nets during maintenance by personnel and propeller collisions. In locations where predators are a considerable problem, *OceanGlobe* is adapted for mounting an extra, larger mesh predator net outside the main net. To minimize the risk of conflicts with other ships when the supply and control vessel is not present at the cage, the main buoy and cage are clearly marked by lights, flags and radar reflectors. In the future, offshore farming locations are also most likely to be marked on digital charts.

Because of the extensive model testing and calculations already performed, *OceanGlobe* may be built in accordance with international safety codes in general, and specific safety codes in particular, such as the NS9415 (NAS 2003), which is the recently inducted rules for floating fish farming cages in Norway. Comparison between *OceanGlobe* model test results and calculations by a calculation tool accredited for approval in accordance with NS9415, showed good correspondence, meaning that the calculation tool is well suited for *OceanGlobe* calculations (Berstad 2003)a. Another crucial aspect of *OceanGlobe* is easy and local assembly. Although the farm dimensions are considerable, the structure parts and equipment may be transported and assembled at local sites, also at places with poor infrastructure and no access to shipyards or other industrial areas.

Because of the design resilience and flexibility, it is also possible to employ the *OceanGlobe* for storage and transportation of wild fish. For transportation, it is important that the *OceanGlobe* have a fixed extended volume, without the risk of significant reduction of volume in strong currents. Testing has shown that structures with a free pendent or partly extended net in extreme cases of current can result in as much as 80 percent reduction of volume (ICE 1990). Model testing of *OceanGlobe* shows no visual deformation of neting or polyethylene framework when towing the cage with a velocity that corresponds to eight knots in full scale. Storage and transportation of fish opens a possibility for fishing vessels to deliver parts of their live catch to centrally situated *OceanGlobe* structures close to the fish market. This opens the possibility of delivering extra fresh or live fish in very short time, or when the prices are favorable. In this respect, the *OceanGlobe* will be especially interesting to fishing companies and food markets. At several fish processing plants, time consumption and control when harvesting the fish in storage cages are problems today. There is a great potential for cost reduction by harvesting the right amount of fish at the right time, and by reducing the time spent on such activities. In that respect, *OceanGlobe* will be very well suited.

Two additional conditions are crucial for profitablility: high operating efficency with respect to accomplishment of work operations and high growth rate of the fish. Several aspects of the design and equipment ensure a high growth rate. These include the anchorage system, seaworthiness, safety from external threats, food supply and feeding system, supply of oxygen, automatic removal of dead fish and adaptation of depth to optimal temperature**.** At the *Farming the deep blue* conference in Limerick, Ireland in October 2004 a farmer, who was operating one fairly traditional farm at an offshore site and one farm at a shielded site, claimed that the fish in the offshore site were on average 0.4 kg heavier than the fish in the shielded site during a nine month period. This means that there is a great potential for obtaining high growth rates in specially adapted and optimized offshore structures, such as *OceanGlobe*. Calculations show that the *OceanGlobe* will have a lower production cost per kg of fish compared to traditional systems marketed as offshore systems. In some cases, the payoff time of the structure can be under a year, but this depends on the species and the market price for this specific species. Additionally, the construction cost per m^3 of volume is competitive with existing structures that are being marketed as offshore or submersible, despite the fish farms being considerably simpler and with a different operational system as well as a different risk evaluation.

When it comes to the profitability assessment of the *OceanGlobe,* the following factors are especially important. The safety of the structure when it comes to loss of fish from escape, sickness, stress, injury, and algal invasions will save major expense. For *OceanGlobe* it is unnecessary to lie fallow for certain periods, which is the case for many of the traditional farms. The structure can, therefore, produce continuously as long as it is functional. The employment of unused and unprofitable fishing vessels in the *OceanGlobe* will increase the profitability for the parties owning those vessels through the reduction of costs one will achieve with this utilization.

Conclusion

The technological obstacles for fish farming in open and exposed areas at sea are solved with the *OceanGlobe*. Also, the construction will have a positive role in restructuring the fisheries and aquaculture industries, because the *OceanGlobe* also represents opportunities for the fisheries. The upcoming full-scale testing will provide the final verification of the functionality of the structure and its properties. Considering the positive results and the documentation prepared at this point, as well as the fact that much research and development money in many regions is being invested in the production of fodder and juveniles, indicates that the fish farming industry may become an exceptionally vigorous, influential and lasting industry in all regions of the world during the next decades.

Notes

[1]The *OceanGlobe* entrepreneurs and founders of Byks AS, Utviklingssjef - Chief Development Engineerl. E-mail: ytterland@byks.no. Tel.: (+47) 57848010.

[2]The shape is slight elliptic, almost globular.

[3]Largest/shortest diameter respectively.

[4]Vertical movement.

[5]The natural or built-in swinging period, where great resonance swinging may occur.

[6]Berstad (2003) also gives an overview of the NS9415 design rules.

References

Berstad, A.E. 2003. Design rules for marine fish farms in Norway. Calculation of the structural response of such flexible structures to verify structural integrity. Proceedings of OMAE 2004, 23rd International Conference on Offshore Mechanics and Arctic Engineering, 20-25 June 2004 Vancouver, Canada.

Fischler, F. 1999. Speech – The future of aquaculture in Europe, 3rd annual Conference PESCA, Santiago de Compostela, Spania.

ICE (Institution of Civil Engineers). 1990. *Engineering for offshore fish farming*. Proceedings of the Conference organized by the Institution of Civil Engineers and held in Glasgow on 17-18 Oct. 1990. Thomas Telford, London, England.

Janson, L.E. 1999. Plastics pipes for water supply and sewage disposal, 3rd edition, Borealis, Stockholm, Sweden.

MAFAC (Marine Fisheries Advisory Committee). 2003. Report by Aquaculture Subcommittee, San Diego, California, USA

NAS 2003. “Marine fish farms – requirements for design, dimensjoning, production, installation and operation”. Publisher: Standards Norway, Pronorm AS Postboks 342, Skøyen, 0213 Oslo, Norway. http://www.standard.no.

Official Journal of the European Union. 2004. C 045 E, 25.02.2003 P. 127-149, COM/2002/0581 final – COD 2002/254. http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/ce045/ce04520030225en01270149.pdf (July, 2004)

Pettersen, B. 2000. Marine hydrodynamics and constructional technology, , Institute for Marine Hydrodynamics, NTNU.

Ryan, J. 2004. Farming the deep blue. “Setting the scene” report for the Farming the deep blue conference, held in Limerick, Ireland 6.-7.October 2004. Ireland.

Calendar

February 13-16, 2006 — **Las Vegas, Nevada**
Aquaculture America 2006. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

March 5-7, 2006 — **Muscat, Oman**
The Seafood Mideast Oman, a technical and trade conference and seafood exposition, will be conducted by Infofish. Conference details can be found at www.infofish.org.

May 9-13, 2006 — **Florence, Italy**
AQUA 2006. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

May 25-27, 2006 — **Bangkok, Thailand**
The 9th Infofish World Tuna Trade Conference and Exhibition will be held at the Shangri-La Hotel. The meeting is being organized by Infofish in collaboration withy the Thailand Department of Fisheries and the Thai Food Processors’ Association. Details can be found at www.infofish.org.

August 27-30, 2006 — **Adelaide, South Australia**
The Australasian Aquaculture Conference 2006 will be held at the Adelaide Convention Centre. This is a joint exposition of the national Aquaculture Council, the Department of Primary Industries and Resources, and the South Australia and Asia-Pacific Chapter of the World Aquaculture Council. For further information contact the Australian Aquaculture Conference Manager, P.O. Box 533, Curtin, Act 2606, Australia. Tel: +61-2-6281-0383; Fax: +61-2-6281-0438 or the Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

September 6-8, 2006 — **Veracruz, Mexico**
Latin America Chapter/ISTA 2006 is the annual conference and exposition of the Latin American Chapter of WAS. Contact: Director of Conferences, Tel: +1-760-432-4270; FAX: +1-760-432-4275; Email: worldaqua@aol.com.

September 10-14, 2006 — **Lake Placid, New York USA**
The 136th annual meeting of the American Fisheries Society has the theme “Fish in the Balance.” The focus will be on the relationships among fish, habitat and humans. Complete information on registration, lodging, abstract submission and symposium proposals can be found at the AFS website: www.fisheries.org

September 17-22, 2006 — **Seattle, WA USA**
Third International Symposium on Stock Enhancement and Sea Ranching. Further details will be announced shortly on www.searanching.org.

February 26-March 2, 2007 — **San Antonio, TX USA**
Aquaculture 2007. The next triennial meeting of the World Aquaculture Society, Fish Culture Section of the American Fisheries Society and the National Shellfisheries Association will take place in San Antonio, Texas USA at the San Antonio Convention Center. For information contact Conference Manager, 2423 Fallbrook Place, Escondido, CA 92027 USA. Tel: +1-760-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

May 19-23, 2008 — **Busan, Korea**
WORLD AQUACULTURE 2008. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

February 16-19, 2009 — **Seattle, WA USA**
Aquaculture America 2009. Contact: Director of Conferences, Tel: +1-760-432-4270; FAX: +1-760-432-4275; Email: worldaqua@aol.com.