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REPORT

ON

WORLD CLASS SHIPBUILDING STEEL DESIGN, PROCUREMENT, AND PRODUCTION BEST PRACTICES

Prepared

For

AMERICAN IRON AND STEEL INSTITUTE

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16. Abstract

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The purpose of the report is to provide a world wide summary of shipbuilding and steel industry practice, both to inform and to form the basis for identifying potential areas of joint research that would result in U.S. shipbuilders becoming internationally competitive, which in turn would increase the demand for steel.

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EXECUTIVE SUMMARY

The world shipbuilding industry is truly global with significant movement of shipbuilding centers over the past thirty years. Both Japan and Korea build 100 percent of their domestic commercial fleets. This provides a stable base on which to build an effective commercial ship export capability.

The U.S. shipbuilding industry is the third largest in the world, behind China and Russia, based on the number of employees. However, Japan, with half the number of employees annually delivers 10 times the number of ships delivered by the U.S. The obvious difference is that Japan is building mostly commercial ships whereas the U.S. is mainly building military ships.

While the U.S. focused on military ships, its international competitors focused on commercial ships developing and introducing new ship types and new shipbuilding processes that completely redefined the marine industry. This has led to a significant capability gap between the U.S. and its competitors in product range, cost, delivery, and performance.

This has caused the U.S. government and shipyards to refocus their plans. First, based on the actual, budgeted, military-shipbuilding requirements, the level of workforce in U.S. shipyards, which was about 90,000 in 1990, will fall to about 30,000 in 2000. However, the U.S. Navy forecasts that they will need a shipbuilding workforce of about 80,000 to meet their needs in 2006. This is the so-called Bow Wave problem, where there are no ships required for a number of years and then there is a demand for many.

A number of U.S. shipyards are actively seeking international and domestic commercial shipbuilding orders. Along with this is the desire, forced by the need for lowest cost, to develop international supplier relationships for much of the equipment that is used to construct a commercial ship. This includes steel products that are being used by world-class competitors that are not available from U.S. steel mills, such as long leg angles and bulb plates.

During the past twenty years, the methods of analysis used by ship designers have changed significantly. These changes have been based on better understanding of the marine environment, better understanding of materials, and ultimately the development and reduction in cost of computer hardware and software. This has led to more rational basis for ship design. However there are still many aspects of ship structural design that can not yet be based on pure analysis. Consequently, ship structural design still requires empirical experience and judgment.

Structural steel is about 40% of the material cost for a typical commercial ship. On the other hand it accounts for only about 15% of the material cost of a combatant vessel.

Typical steel throughput in U.S. shipyards is 50,000 tons per year, whereas in Japan it is 200,000 tons and Korea from 500,000 to over 1 million tons.

If the influence of the customer (shipbuilders) on the supplier (steel mills) depends on the size of demand, then in the U.S. and some European countries, where the percentage of the total domestic steel supply used by the shipbuilders is less that 1 percent, there is negligible influence. On the other hand the shipbuilding demand in Japan and Korea is a significant share of the steel mills supply and they can influence the steel producing industry.

There are attempts to introduce electronic ordering of steel, but these efforts at electronic commerce will meet with limited success, as they can have an adverse effect on shipyard cash flow and financing costs. For example, Bethlehem Steel offers a service by which cash transaction is automatic at the time of receipt at the shipyard. Although there is a benefit to the steel producer, this would require more finance charges by the shipyard and thus greater cost to the owner.

The basic use of steel for shipbuilding is very similar around the world. This is also true for the range of structural-design approaches. The decision to use the different structural-design approaches depends more on the size of the shipyard and the skill level of its design staff than ship type or the country of build.

U.S. shipyards have adapted the hull-block-construction approach to suit each of the military ship types. However, shipyards such as Bath Iron Works (BIW) and Ingalls, which build the same ship (DDG51) approach it differently with regard to block breakdown, size, and erection method. This is mainly because BIW still builds its ships on the traditional inclined slipway whereas Ingalls builds on a level land facility on a transfer system.

The recent return by some U.S. shipyards to commercial shipbuilding has resulted in new equipment and changes in their processes for steel construction. This has mainly been in the area of robotic shape-preparation lines and larger size and more modern panel lines.

A major area where U.S. shipyards could improve their practice with corresponding productivity improvement is Quality Control (QC). QC in U.S. shipyards is still basically an end-of-process control involving large teams of quality inspectors. Although some U.S. shipyards have tried to introduce Accuracy Control, it is not done at the worker level and thus only gains any marginal benefits. At the moment most U.S. shipyards still leave stock or green excess material on their blocks, which has to be cut off after the blocks are aligned. It also requires an additional movement of the block after the excess is removed to bring the blocks together.

Shipbuilding welding practices in all countries are similar, with Japan manual stick welding the least. Manual stick welding is being replaced in most shipyards as the alternative welding methods offer superior performance as well as better conditions for operators.

Material handling for steel in shipyards is also similar throughout the world, with the more modern shipyards incorporating more automation of the early preparation processes. This is mainly through conveyors and tracks, but some autonomous track vehicles (ATV) are being introduced, such as in one of the recently refurbished shipyards in Germany where cut and marked plate is transported to the various processing lines by Automatic Transport Vehicles (ATVs). Extensive use is made of conveyors, multi-wheeled transporters with lift capacities up to 400 tons, whirley cranes up to 500 tons, and gantry cranes up to 1200 tons.

If the United States could increase its share of the international commercial shipbuilding to 3 percent of the current annual demand, the steel usage by U.S. shipbuilders in total would only increase from the current 250,000 tons to just over 500,000 tons. To do this they would need to produce over twenty ocean-going commercial ships each year, something they have not done since the end of World War II.

U.S. shipbuilders while recognizing the need to increase commercial work, have no apparent approach involving radical change, to reach international competitiveness. Current improvement efforts are incremental with marginal benefit. Areas for consideration by which improvements could be made include:

- Adoption of enhanced welding techniques.
- Use of statistical process control methods by workers to improve accuracy and eliminate stock.
- Just-in-time (JIT) ordering practices.

In cooperation with the North American steel industry considerations include:

- A cooperative effort of shipbuilders, steel industry and researchers, to jointly develop industry leading steel technology, including new steel shapes that maximize ship design strength for minimum cost.
- Joint marketing of North American steel and shipbuilding quality and value.
- EDI initiatives

Representatives of the U.S. steel industry should become members on the various National Shipbuilding Research Program panels that focus on their products, such as SP-3 Coatings and Surface Preparation, SP-4 Design/Production Integration, and SP-7 Welding.

CONTENTS

1.0 INTRODUCTION

The steel industry, through its association, American Iron and Steel Institute (AISI), is actively seeking ways to work with the U.S. shipbuilding industry to assist it in reaching its goals for international commercial shipbuilding and to benefit the steel industry as well. The activity to date has been reported back to both industries by the AISI (1 & 2)*. With this in mind, a deliberate attempt has been made not to repeat the information already reported by the AISI to its members.

With this condition clearly stated, this report is another step in the move to accomplishing the joint development of a plan to reach the goals.

1.1 World Shipbuilding Industry

The world shipbuilding industry is truly global and has had significant movement of shipbuilding centers over the past thirty years. The position of the world's largest shipbuilding country shifted from Britain to Sweden to Spain and then to Japan, where it has remained for over twenty years. Korea developed its shipbuilding capability from the ground up and in just over twenty years is challenging Japan as the world-leading producer of commercial ships. Meanwhile China is building up its capability and Russia is attempting to regain some of its past capability. These movements occurred while the market expanded to a record of 134 million Gross Tons in 1974, only to shrink drastically to 21 million Gross Tons in 1981, as a result of the first oil price shock. It expanded again to 45 million gross tons in 1995. In 1996 the world order book for commercial ships, over 1000 GT, was 2,655 ships totaling 48.5 million Gross Tons.

This is still only a fraction of the market of the profitable times of twenty years ago. Prices for new commercial ships are set by Korea's prices, and they have been 20 to 30 percent below the average European shipyard cost for the last decade. This necessitates construction subsidies to maintain shipbuilding in a number of countries. At recent international meetings of shipbuilders the number one goal is to raise new ship prices, but in an overcapacity market, it is difficult, if not impossible to accomplish this.

The scale of foreign shipbuilding in many countries, such as Japan, Korea, Germany, and Denmark, is directly tied to national trading and maritime policy considerations that have a much higher national economic priority than the defense-oriented policy considerations driving the U.S. shipbuilding industry. Economic viability of many economic sectors is directly affected by a prosperous maritime community in these countries, while in the U.S. there is far less dependence on the maritime community to do this. Interestingly, both Japan and Korea build 100 percent of their domestic commercial fleets. This provides a stable base on which to build an effective commercial-ship export capability.

1.2 U.S. Shipbuilding Industry

The U.S. shipbuilding industry is the third largest in the world, behind China and Russia, based on the number of employees. However, Japan, with half the number of employees annually delivers ten times the number of ships delivered by the U.S. The obvious difference is that Japan is building mostly commercial ships whereas the U.S. is mainly building military ships. In fact, until a few years

* See SECTION 7.0 - REFERENCES

ago, there were no ocean-going commercial ships being built in the U.S. for over a decade.

There were two main causes for this. First was the elimination of the Construct Differential Subsidy by President Reagan in 1980. Second was President Reagan's desire for a 600-ship navy. Without the subsidy, U.S. shipyards were not competitive and with the military ship build-up they had no need to be. While the U.S. focused on military ships, its international competitors focused on commercial ships and developed and introduced new ship types and new shipbuilding processes that completely redefined the marine industry. This has led to a significant capability gap between the U.S. and its competitors in product range, cost, delivery, and performance. The U.S. remains significantly ahead of the rest of the world in military ship performance, due to the heavy funding of those product development and deployment costs by the U.S. government. However the U.S. has not been able to translate this lead into viable commercial ship products, nor a sufficient business base that could produce cost effective commercial ships or support effective marine equipment and material suppliers.

Unfortunately, all good things come to an end. In this case the "peace dividend" resulted in a drastic reduction in the demand for military ships. This has resulted in some of the large and many of the small shipyards closing. The demand for steel by the U.S. shipyards decreased over this time because military ships use less steel than correspondingly sized commercial ships, and commercial ships are generally larger than military ships.

This has caused the U.S. government and shipyards to refocus their plans. First, based on the actual, budgeted, military shipbuilding requirements, the level of workforce in U.S. shipyards, which was about 90,000 in 1990, will fall to about 30,000 in 2000. However, the U.S. Navy forecasts that they will need a shipbuilding workforce of about 80,000 to meet their needs in 2006. This is the result of the so-called Bow Wave problem, wherein the U.S./ Navy will need to start replacing many of its existing ships, starting in the year 2006.

The U.S. government's long term solution is for the U.S. shipyards to capture enough of the international commercial shipbuilding market to fill the hollow to maintain the U.S. shipbuilding employee base at a sufficient level to be ready to meet the demands in 2006. However, this is impractical, as the employment hollow is more than the current Japanese shipbuilding employment level.

The Oil Pollution Act of 1990 (OPA 90) addresses both oil pollution and clean-up. A key requirement of the law is in Section 4115, which mandates that tankers constructed after June 30, 1995 be equipped with double hulls. OPA 90 also requires that all oil tankers entering U.S. waters must have double hulls by the year 2005. This is seen as an opportunity for U.S. shipyards to obtain commercial work as the existing world tanker fleet serving the U.S. is upgraded and the tankers in the U.S. domestic trade are replaced.

In 1993 the President proposed a plan "Strengthening American Shipyards: A Plan For Competing In The International Market," which was passed by Congress. It is known as the President's Five-part Plan.

It focused on:

1. Ensuring fair international competition
2. Improving commercial competitiveness with MARITECH
3. Eliminating unnecessary government regulation
4. Financing ship sales through Title XI Loan Guarantees
5. Assisting international marketing

The plan has had some success in obtaining international orders, mainly because of the availability of the Title XI loan Guarantee to foreign ship owners, with both Newport News and Atlantic Marine winning commercial orders from foreign ship owners. These orders were at prices close to world market prices and it is known that both shipyards have lost money on the ships completed thus far. Avondale has been successful in winning commercial ship orders but they were for U.S. Jones Act trade, thus not internationally competed.

Most U.S. shipyards are presently actively seeking international and domestic commercial shipbuilding orders. Along with this is the desire, forced by the need for lowest cost, to develop international supplier relationships for much of the equipment that is used to construct a commercial ship. This includes steel, especially for steel products that are being used by world-class competitors that are not available from U.S. steel mills.

There is currently a boom in the offshore, marine-construction industry. The offshore supply-vessel fleet is being rebuilt as economic forces are driving renewed oil production mainly in the Gulf of Mexico. This surge in vessel construction is cyclical and is expected to last for the next few years.

U.S. shipbuilding has been focused on military vessels for the last twenty years. The structure of military vessels is significantly different owing to the demands of their mission and service. Many of these design requirements have little or no counterpart in the design of a commercial vessel. However, there is some carryover, as the methods for design of complex structures for military service can be applied in effective design of commercial vessels.

There is a general trend toward more extensive design analysis. This is being made practical by the availability of inexpensive computing power and software. As a result there is a trend toward lighter vessels in order to reduce construction cost both in terms of material and labor.

Due to the Buy American policies for Military and Jones Act ships, ships for these services will be designed using domestically produced shapes and plates. There have been some exceptions such as the cases where vessels have been procured overseas for Sealift services. In these cases, foreign content has been allowed, mainly to match existing structural materials.

There is an interest on the part of the Navy and some vessel owners in the use of composite materials. These are seeing use in decorative vessel features as well as in the vessel piping and for reduced weight and radar observability.

1.3 European Shipbuilding Industry

A trend in European yards is toward both designing lighter commercial vessels through improved structural design methods and designing to support automation. Odense Steel Shipyard, a highly automated shipbuilder, has recently delivered very large (6000 TEU) container ships to their parent company, Maersk Lines. These ships were designed for larger capacity and for automated fabrication and assembly.

European commercial shipbuilding concentrates on high value ships such as cruise ships, refrigerated ships, LNG/LPG carriers, chemical tankers, refrigerated ships, service ships such as dredgers and offshore support ships, and ferries. European shipyards have all but opted out of the tanker and bulk carrier fields except for some Spanish shipyards and Harland Wolf shipyard in Northern Ireland.

The shipyards can be classed into three groups. The large group employs over 2000 production workers and delivers up to twenty ships per year with close to 500,000 tons of steel used annually. The medium shipyards employ between 800 to 1500 production workers and deliver 4 to 10 ships per year with annual steel usage of 200,000 tons. Finally, there is the small shipyards with 500 or fewer employees building smaller ships with annual steel usage from 40,000 to 100,000 tons.

Most European maritime countries have significant military shipbuilding programs but not at the U.S. level. They also have a significant foreign military sales involvement. Except for Germany, the building of military ships is performed in dedicated shipyards. That is, the military and commercial shipbuilding is not performed in the same facility.

The German government has invested billions of dollars into upgrading shipyards in former East Germany while existing shipyards in the FRD are closing. The refurbished shipyards are well equipped with the most up-to-date steel processing equipment including highly automated processing lines and robotics. The refurbishing of the shipyards provide two opportunities for Germany. The first is the potential to build commercial ships. The second is that this spate of refurbished shipyards has enabled a German shipyard equipment manufacturer to develop and grow to become the leading shipyard equipment manufacturer worldwide.

1.4 Japanese Shipbuilding Industry

The increased capacity of Korean shipbuilding companies has created a great deal of competitive pressure on the Japanese shipbuilding industry. In response, Japanese ship designers are making efforts to innovate in structural design. This competitive pressure in the shipbuilding market will be further exacerbated when, sooner or later, the People's Republic of China (PRC) becomes a major force in the shipbuilding world. To help them maintain their competitive position, Japan is purchasing steel and structural assemblies from Korea. For example, Japanese shipbuilders are actually taking advantage of lower costs in Korea by purchasing subassemblies and blocks, such as deckhouses as shown in Figure 1, from Korean shipbuilders. There is still a quality issue, which shows up in the overall life cycle of the ship. One U.S. owner has expressed the opinion that his company would be willing to pay a premium over the Korean price to have a ship built in Japan.

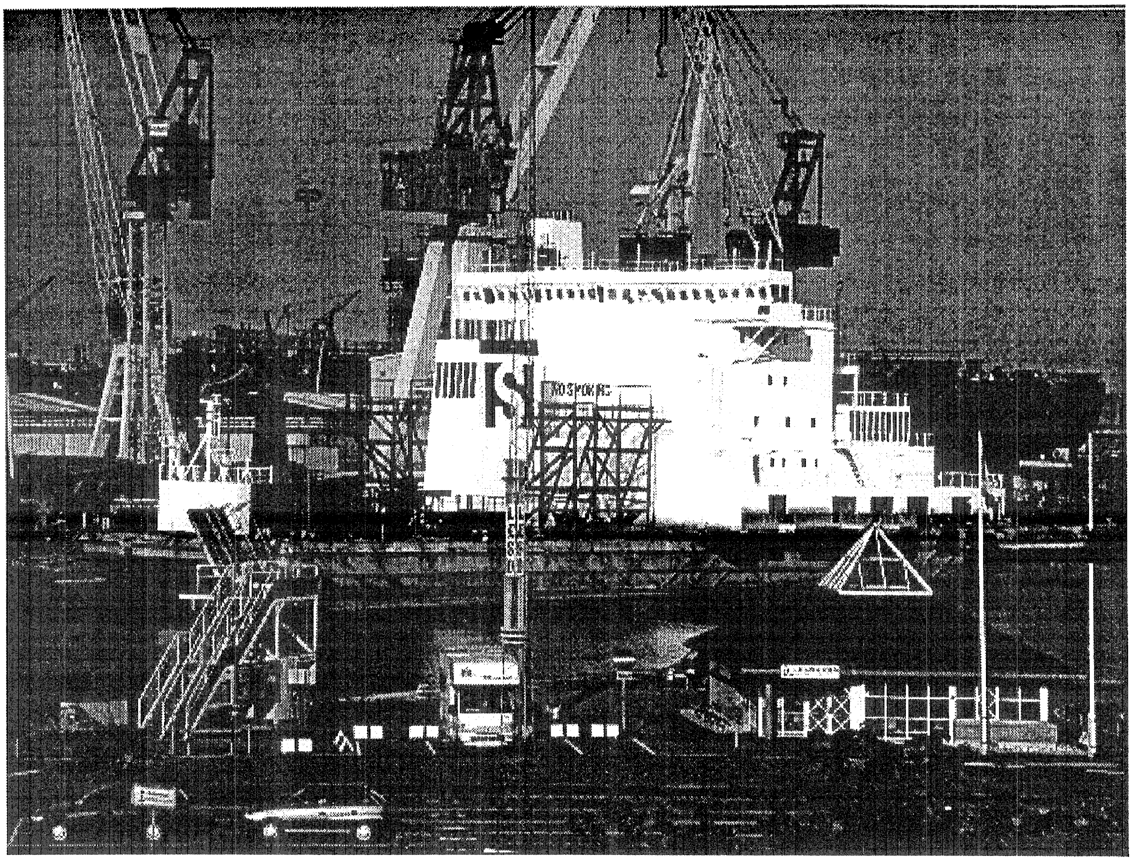

Figure 1: Deck house being delivered to a shipyard by barge

Japanese shipbuilders do not have large production work forces in each yard, although, because they usually each own a number of shipyards, they do have high total employee levels. While maximum employment in an individual shipyard was around 2,500 about ten years ago, this has reduced due to industry cut back, scarcity of workers and, fortunately, significant continuous productivity improvement over these years. Today typical Japanese shipyards have 800 to 1,200 production workers and build from 6 to 10 ships per year with an annual steel throughput of about 250,000 tons.

Japanese shipyards still build bulk carriers, tankers and container ships. However they have almost lost the bulk carrier market to Korea.

Japan has a very effective Ship Research Association, which undertakes the development of new approaches that will dramatically improve the performance of the Japanese shipbuilders. Such a project was the recently completed nine-year Computer-Integrated Manufacturing (CIM) study. The Japanese Shipbuilders Association sets the goal and the Research Association performs the work.

Japan builds military surface ships up to destroyer size and diesel submarines. They are currently building a Landing Ship Dock ship similar to the U.S. LSD's to carry the U.S. built Air Cushion Landing Craft (LCAC). This will be their largest military ship.

The Japanese are building the CONGO class destroyer, which is their version of the U.S. DDG51, in that it carries the same weapon and communication and control systems. Interestingly the Japanese destroyer is deliberately designed to be larger than the U.S. DDG51, which results in greater steel weight. However, the greater space, especially tween deck height makes it easier to design and install distributive systems. Thus the greater material cost for more steel is more than offset by the reduction in labor cost.

1.5 Korean Shipbuilding Industry

Korea is striving to become the world shipbuilding leader. They reached that position a few years ago based on total deadweight of ships delivered, but Japan still was first in number of ships delivered. Since then Japan has regained the lead in both categories. However, Korea definitely sees itself becoming the world leader in a few years, with China becoming second and Japan falling to third.

One of the researchers, who recently visited Korea, reports that the Korean shipbuilding facilities are excellent, but the level of use of robotics is still significantly behind Japan and some European shipbuilders. This makes sense as Korea has no labor shortage and labor cost is still low compared with Japan. However, labor costs are increasing and continuing labor unrest and management-worker relationship are a problem.

Korean ship designers appear to use more traditional structural design methods rather than design by analysis, but they are catching up in this regard very quickly. Because Korean shipbuilders are very large they tend to have their own research departments and cooperation between them is almost non-existent. Certain government and university groups are trying to change this to provide a research basis for their groups and also to foster cooperation.

Korea has a significant military shipbuilding effort, but it is kept quiet. Daewoo is the major military shipbuilder, producing amphibious assault ships, destroyers, frigates, patrol craft, and submarines. Daewoo has a separate military shipbuilding facility that employs about 1,000 production workers.

Korea has four major, commercial shipbuilding companies, Daewoo and Samsung on the island of Koje in the South, Hyundai in the Southeast and Halla on the West Coast. Korean shipbuilding grew from almost nothing in the late 1970's to challenging Japan for world delivery leadership in twenty years. Today they build about a third of all the world's commercial ships based on total deadweight delivered annually. Collectively, the Korean shipyards use over 3 million tons of steel per year, which is supplied from the Korean steel mills.

Hyundai is the largest shipbuilder with 16,000 production workers who build about sixty ships (maybe eight to twelve different designs) per year, using 1.2 million tons of steel plate. Daewoo is next in size with 7,000 production workers who deliver about twenty-five ships per year using 500,000 tons of steel plate per year. At any time Daewoo can have up to fifteen ships under construction. To support these 7,000 production workers Daewoo, has a management and administrative staff of 850 and engineering staff of 2,300. The engineers also work on military contracts. Daewoo currently takes nine months to design a new ship. They are working on using information technology to reduce it to six months. They currently take an average of eleven months from start of fabrication to delivery. Daewoo, has made significant productivity improvement over the years as can be seen from the fact that ten years ago they had 25,000 production workers. Today they have 7,000 and deliver more ships each year.

1.6 World Steel Production and Consumption

World steel production is approximately 825 million tons per year. This is still below the peak in supply in 1989. The United States produced just over million tons of steel in 1996, imported about 4 percent and exported just below 3 percent. China was the world's largest steel producer in 1996 at 110 million tons.

1.7 World Steel Usage in Shipbuilding

Steel usage by world shipbuilding is about 10 million tons per year. This is less than 1 percent of world steel production. So, even on a worldwide basis shipbuilding only uses a very small fraction of the output from the steel industry. In certain countries, such as Japan and Korea, the percentage is higher, but still only 3 percent. In comparison, U.S. shipbuilding uses only ¼ % of the U.S. steel production and 2 percent of the world shipbuilding steel usage. By either measure, the U.S. shipbuilding industry is clearly not in a position currently to greatly influence the world or U.S. steel industry. On the other hand, if U.S. shipbuilders could capture 3 percent of the commercial shipbuilding market, it would increase the U.S. shipbuilding demand for steel by 300,000 tons or double the current U.S. steel usage.

2.0 STRUCTURAL DESIGN

2.1 Structural Design Practices

Ship structures are determined by the ship's mission and intended service. These determine a ship's size, complexity and the function of structural components. There are inherent uncertainties in the loads imposed on ship structure because of the random nature of the loads imposed by the marine environment. Unlike a fixed, land-based structure, a ship derives its entire support from the buoyancy provided by a fluid, which transmits these loads to the hull structure.

During the past twenty years, the methods of analysis used by ship designers have changed significantly. These changes have been based on better understanding of the marine environment, better understanding of materials, and ultimately the development and reduction in cost of computer hardware and software. This has led to a more rational basis for ship design, however there are still many aspects of ship structural design that cannot yet be based on pure analysis. Consequently, ship structural design still requires empirical experience and judgment.

There is a tradeoff in the use of material and complex structures. Typically, a complex structure requires more labor and fabrication than a simpler structure, which uses more material. There is also a tradeoff between using more complex structure and the lighter weight of the vessel, as a lighter ship can carry more cargo for a given volume, requires less power and therefore fuel to operate. A lighter ship thus provides more revenue for lower operating costs. The simple structure, heavier ship, offsets this benefit by lower construction man hours and thus labor cost. Figure 2 is an example of the relationships among construction attributes and owner attributes in a design and their relative impacts. Note that this example is for illustration only and not for use in forecasting or otherwise determining actual costs.

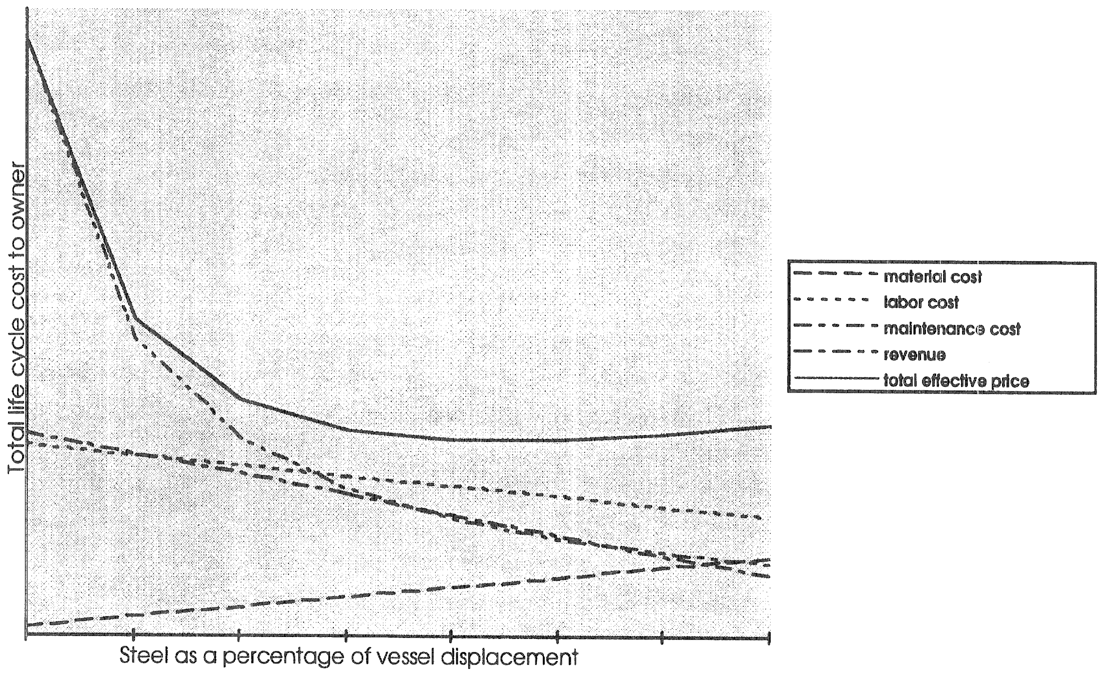

Figure 2: Illustration of relationships between vessel steel weight and life cycle costs

2.1.1 U.S.A.

2.1.1.1 Military

The U.S. Navy has its own manual that details its approach for the design ofship structures. It is based on many years of experience with lightweight structures that have a capability to sustain both sea loads due to the natural environment and shock loads due to explosions. To obtain lightweight structures, military ships are usually longitudinally framed. The U.S. Navy prefers symmetrical sections for the longitudinals and other stiffeners. These sections are generally not used in commercial applications and are only required for military ships. They therefore, provide no growth opportunities for the U.S. steel mills. In military ship structural design the welding requirements are based on joint location/importance and they are designated by joint efficiency. For example a 100 percent joint efficiency would require back gouging and full penetration.

Another difference in military ship structural design, relative to commercial design is the detail at connections of web frames and bulkheads to longitudinals. Military ships require full collars or double chocks at the shell, even in non- watertight web frames. It is obvious that more fitting and welding is required for the military ship detail. This is because of the lighter scantlings and the need for shock hardening.

Military ships use some high-strength steels, usually between 5 and 10 percent of the total steel weight for the ship, again driven by desire for minimum weight. High-strength steels require preheating before welding and extra care in handling, including prohibition of temporary attachments.

A recent military development, that could have application to commercial ships, is the "advanced double hull" concept (3). This could also be called the sectionless hull, in that it basically eliminates all traditional framing and uses widely spaced plate girders in conjunction with thicker shell and inner skin plating. A lot of basic research has been carried out for this concept and the Japanese have already built one series of ships with a similar concept.

2.1.1.2 Commercial

Commercial ships are designed to the requirements of one of the many classification societies. In the United States, the American Bureau of Shipping is the one that is normally used. The classification societies have all made significant progress in computer-based design in the past five years, and most large commercial shipyards use the latest computer systems available from the classification society to develop the structural design for a new ship. While the newer computer-based design approaches use structural design theory and tools such as finite element analysis and fatigue analysis, they are still heavily influenced by results from operational experience of successful designs over many years.

The major differences in commercial ship structural design, relative to military ships, are in framing, welding, weight, and extent of high-strength steel usage. Many ships are still transversely framed and the connection details are simpler and often driven by production considerations. Welding size selection is simpler. While structural weight is important, it is not the driving force in commercial ship design. Instead, the structural design is driven by what is competitive in both labor and material cost. Finally, the use of high strength steel (HTS) is much less than in military ships, although the application of Thermal Mechanically Controlled Process steel (TM or TMCP) and High-Strength Low

Alloy steel (HSLA), may reverse this trend, as it provides higher strength without the need for pre-heating and many of the other constraints of HTS.

2.1.2 Europe

2.1.2.1 Military

The trend is to seek affordable military ships by using as many commercial design approaches, including structural design and commercial equipment to the greatest extent practical. This can be seen in the joint effort between Vickers Shipbuilders, a military shipbuilder, and Kvaerner Govan, a commercial shipbuilder. For the new British Royal Navy "through deck" carrier, Govan built the hull with basic outfitting, and the ship was then towed 200 miles to the Vickers facility to be completed. Other joint ventures have been between countries combining to design and build military ships such as mine-hunters, destroyers and frigates, but only the mine-hunters have been successfully brought to actual construction.

Warship structural design is predominately longitudinally framed single hull with an interest in applying commercial ship design, structural experience to simplify details and reduce cost.

2.1.2.2 Commercial

A trend in European yards is toward both designing lighter vessels and designing to support automation. Odense Steel Shipyard has recently delivered very large (6000 TEU) container ships to their parent company, Maersk Lines. These ships were designed for larger capacity and for automated fabrication and assembly.

The large and medium shipyards utilize the latest structural design tools, including those provided by classification societies' new computer-based design systems, such as Lloyds Register's SHIPRIGHT.

The trend in structural design is toward tighter tolerances to suit robotic welding. The single-skin tanker has given way to double-hull tankers and the single-skin sided bulk carrier has given way to double-skin sides.

2.1.3 Japan

2.1.3.1 Military

It was not possible to obtain any information on the structural details of Japanese military ships, but based on personal interviews, it is believed that they make more use of commercially available structural rolled sections.

2.1.3.2 Commercial

The structural design of commercial ships in Japan is driven by the need to suit robotic assembly and welding. On the other hand, they do not seem to be designed for production in many other regards, compared with European designs. For example, they still used formed faceplates around web frames rather than a combination of straight face plates and stiffened brackets.

Robotics require close tolerances, and this drives the shipyards to fabricate their own built up sections, so they can control dimension tolerance to within 1mm. Where possible, they still make extensive use of bulb plates.

There is a trend among Japanese ship designers to use more design by analysis methods rather than design by rule. Japanese ship designers have been quick to adopt new structural-analysis technologies and research into load-estimation methods. These technologies are being used in conjunction with improvements in computer hardware and software.

These trends are based on the results of operational experience with "second-generation" Very Large Crude Carriers (VLCC) which developed cracks in the ship's longitudinal framing. It was determined that the high tensile steel widely used in the ship structure did not offer sufficient fatigue strength. As a result, certain areas for research and development have been defined. In particular these are:

- highly accurate methods for estimating change in cargo load due to high waves
- detailed structural analysis methods that enable evaluation of sections of stress concentration due to waves
- highly efficient methods for precisely evaluating fatigue strength
- a rational maintenance inspection system that is tied to part materials integrity or the propagation span of fatigue-fracture development
- Development of structures to prevent the leakage of oil

Also driving adoption of design by analysis methods is the ability to innovate in structural systems for lower-cost production processes. For example, Japanese ship designers have been able to use these tools to develop innovative structural systems. An example is the double-hulled EPOCH MARK-II (product oil tanker), developed and constructed by Hitachi Zosen of Japan. This particular structural system consists of a double bottom, double side shell, a double deck, and double-skin transverse bulkheads. The longitudinal girders are arranged in the double hull and there are no transverse girders. The only transverse structures are the bulkheads. This arrangement eliminates the traditional grillage structures made up from longitudinal sections and deep web frames. The result is suited to automated fabrication and use of robotic systems in construction.

2.1.4 Korea

2.1.4.1 Military

It was not possible to obtain any information on the structural details of Korean military ships.

2.1.4.2 Commercial

The structural design of commercial ships in Korea is currently not as analytical as that in Japan, but in resulting structural arrangements are very similar. The Korean designers are also quickly acquiring the skills and tools required to perform computer-based design.

2.2 Steel Grade Application

A survey was undertaken to determine the usage of various steel grades for a number of domestic and foreign shipbuilders. Twenty survey questionnaires were sent out and only three responses were received, one domestic, one Canadian, and one German. None of them had significant steel throughput (less than 20,000 tons per year). Interestingly all purchase preprimed steel.

2.2.1 U.S.A.

2.2.1.1 Military

Relevant military standards are:

- MIL S 22698
- MIL S 16113
- MIL S 16216 (HY80, HY100)
- MIL S 24371 (HY130)

Typical application of high strength steels is toward reduction of weight for a given mission requirement. For example, high-strength steel is used for blast protection or the use of HY steels in submarine pressure hulls. In these cases, using mild steel would require thicker plate or deeper stiffeners, impinging on space constraints and performance. That is, the heavier the vessel the more power required or the more stability required, causing the need for a wider vessel and a resulting impact on powering and ancillary systems.

Stainless steel has its place in some applications in military ships. Typically, CRES is used structurally in gas turbine casings and for nonstructural use in galley spaces, food handling spaces, and sanitary spaces. Stainless sheet steel is used in the HVAC and joiner paneling. Stainless steel piping is used throughout for fuel and the dry part of firemain systems.

Shipyards doing military work have been looking at alternatives to the special HY grades of steel. These efforts have been driven by the higher welding and process time required for these materials. Material cost for HSLA-100 steel is not considered significantly different from HY-100 steel at roughly $20 less per ton. However, one estimate of the labor savings range is between $500 and $3,000 per metric ton.

The Navy has expressed interest in the use of HSLA steels in order to achieve the estimated cost savings. To this end, the MANTECH Program has sponsored a research and development project to test the functional benefits of HSLA steel. This project makes use of commercially available HSLA-65 steel to replace high-strength steel (HTS) currently used in naval ship construction. For example the current aircraft carriers being built at Newport News Shipbuilding uses over 10,000 tons of HSLA steel, 10,000 tons of HY steel, 13,000 tons of HTS, and only 5,000 tons of mild steel. Because of the higher yield strength of HSLA-65 (65 ksi) versus HSS (51 ksi) there is an opportunity to reduce vessel weight. However, there is concern that the HSLA steels are more expensive than HTS and may have a negative impact on production costs.

2.2.1.2 Commercial

The grade of plate steel used in commercial ship construction is generally guided by the requirements of the cognizant classification society. Commercial ships use mild steel grades equivalent to ASTM Grade A36. Steel shapes are generally of the same grade as the plate to which they will be attached. By far the most frequently used steel grade for shapes is ABS Grade A.

Castings are used in areas of the ship requiring heavy structural members and these parts of a ship's hull having complex shapes. These are typically in the rudder horn, the stern frame, the ship stem, mooring bits, and similar components. Steel used in ship structural castings are to an ABS Grade, which is substantially similar to ASTM A27 Grade 60-30. This material is readily weldable and has structural properties that are approximately those of ordinary steel. Some shipyards have replaced stern frame, rudder horn and stem castings with weldments. Decisions during design of hull shape can assist in making such welded structures easier and cost effective.

Hull steel forgings are produced in a variety of grades depending on the required mechanical properties, but are typically made of materials comparable to ASTM A668 Grade BH. Materials are usually low carbon steel to a maximum content of 0.35 percent and annealed or normalized to ABS requirements.

High strength steels are used in applications where relatively small deck areas are available for longitudinal strength considerations or where there are strength to weight concerns. Container ships, which have large hatch, deck cut outs, make use of high strength steels as do VLCCs. However, the application of higher strength steels is infrequent because of the greater cost associated with procurement and construction.

Stainless steel is used for tank structure containing chemicals. Typically nonstructural use is for galley spaces, food handling spaces, and sanitary spaces, as in military ships. Various gauges of stainless sheet steel is used in the HVAC and joiner paneling.

Steel piping is used throughout commercial ships, for fuel and firemain systems. There are some applications where steel pipe has been replaced by fiberglass pipe, for example, ballast system piping. This application is based on the corrosion resistance and lower maintenance costs over the operational lifetime of the ship.

Over the last decade, there have been a number of efforts to use HSLA steels in commercial applications. These applications have been for special applications such as ship's and oil well drilling equipment, which will see service in the polar climates. In these cases ASTM A710 steel was used where yield strengths of 100 ksi were required. These applications met the owner's need for weight and strength, while reducing related production costs by a range estimated to be between 40 to 75 percent from alternative steel grades. As in the military application of HSLA steel grades, there was no material cost savings between HSLA and alternative steel grades.

2.2.2 Europe

2.2.2.1 Military

No information was available.

2.2.2.2 Commercial

As in the United States, application of steel grades are determined by the classification society. Major societies in Europe are Lloyd's, Det Norske Veritas, and Germanischer Lloyd's. Requirements are similar to those of ABS. However, there is a move toward more analytical approaches to structural design.

2.2.3 Japan

2.2.3.1 Military

No information on military steel usage was available.

2.2.3.2 Commercial

Table 1 below shows a comparison of Japanese and American steel grades. Classification societies allow the effective equivalence of steel grades.

Japanese shipbuilders are moving toward the use of lighter structures and thinner plates particularly for superstructure. This has introduced quality problems because of large deformations of thin plates during welding. The associated cost of more expensive processes to control distortion and rework has been challenging to Japanese shipyards building cruise passenger ships.

Japanese Standards	American Standards	General Application
JIS G 3101 SS34	ASTM A36	General Structure
SS41	A529	
SS50	A570	
JIS G 3106 SM41	ASTM A36	Welded Structure
SM50	A440	
	A529	
	A570	
JIS G 3131 SPHC	ASTM A569	Sheet & Strip
SPHD	A621	
	A662	
JIS G 3132 SPHT1		Pipes and Tubes
SPHT2		
SPHT3		
SPHT4		

Table 1: Comparison of Japanese and American Grading Standards

2.3 Profile Type Application

2.3.1 U.S.A.

2.3.1.1 Military

The U.S. Navy requires that profiles used for the major stiffening of structure in their ships be of symmetrical section. That is tee-shaped profiles. It appears that some relaxation of this requirement is currently acceptable, at least for the non-combatant military ships.

The traditional method to produce tee-shapes is to deflange I beams. Bath Iron Works has compared this practice to fabricating tee-shapes from plate. These findings are reported in a the NSRP Report, Number 0446 (4), which states:

"Another benefit is that the accuracy can be controlled to give the desired tolerances for robotic welding."

2.3.1.2 Commercial

U.S. Shipbuilders recognize that the substitution of special structural steel shapes for standard shapes has potential for increasing productivity. The use of special shapes, such as long-leg angles and bulb flats, in ships is common throughout the rest of the world. In the United States, except where shipbuilders have resorted to fabricating shapes, standard angles, tee-shapes and channels that frequently need further processing are the norms.

2.3.2 Foreign

2.3.2.1 Military

No information was available.

2.3.2.2 Commercial

Foreign commercial shipbuilders make extensive use of bulb plates and long-leg angles. For large ships the shipyards manufacture many of the required profiles.

3.0 STEEL PROCUREMENT

Structural steel is about 40 percentof the material cost for a typical commercial ship. On the other hand it accounts for only about 15% of the material cost of a military vessel.

3.1 Ordering Practices

3.1.1 U.S.A.

US shipbuilders have long had the practice of buying steel as early as possible after contract award. A large part of this is due to the lead-time and volume requirements associated with the types and sizes of steel used in the construction of a ship. This uniqueness and relatively small quantities of shipbuilding materials drives large up-front purchases rather than staged purchases or just-in-time material procurement practices.

U.S. shipbuilders are also encouraged in this practice by the current government payment arrangements. In this situation, US shipyards are paid through progress payments that match expenditures. As material is ordered and received, the shipyard bills its customer accordingly. The shipyard is not expending large amounts of working capital on inventory, but those costs are accruing to the customer in his financing costs. This is in contrast to the normal worldwide practice of paying10 percent of the price at contract award, 10 percent of the price at keel laying, 10 percent at launch, and the balance on delivery to the owner. In today's competitive business it is becoming the normal practice to only pay 10 percent at contract signing and pay the remainder when the ship is delivered to the owner. In both of these cases, the shipyard is responsible for the financing of materials and work-in-progress.

3.1.1.1 Military

Ordering is done as early as possible as steel is a long lead-time item, particularly if there is any amount of special steels, such as HY steel. However, military-ship delivery schedules are usually so long that steel is not the critical long-lead item.

There is typically a U.S. content or Buy American requirement for military ships, so they will be designed using domestic produced shapes and plate.

The larger shipyards order on the basis of quantity discounts and availability. Smaller shipyards often order through steel-product distributors because their ordering quantities are too small for steel mills.

3.1.1.2 Commercial

If the ship is being built under the Jones Act there is a US content requirement for steel. However, there is no U.S. content requirements for ships built with Title XI mortgage guarantee. This means that shipbuilders can purchase steel on the world market. One deterrent to this, is that because most U.S. shipbuilders still design to the Imperial system, using foreign, metric-sized material becomes a nuisance.

Most often, the steels used are more common grades and typically more available. However, the steel has to be certified by ABS at the steel mill. Depending on the ship size and quantity of steel ABS may accept equivalent ASTM grades for the steel.

Where possible, shipyards order on the basis of quantity discounts and availability. Delivery is of more significance for commercial ships as the delivery schedule is as short as possible and steel cannot be the critical item.

There are attempts to introduce electronic ordering of steel, but these efforts at electronic commerce will meet with limited success as they can have an adverse effect on shipyard cash flow and financing costs. For example, Bethlehem Steel offers a service by which cash transaction is automatic at the time of receipt at the shipyard. Although there is a benefit to the steel producer, this would require more finance charges by the shipyard and thus greater cost to the owner.

3.1.2 Europe

European shipbuilders purchase steel from any country. Some shipyards in Germany are using EDI for steel procurement. Bremer Vulcan was using EDI before its demise. Although steel is ordered as a lot, deliveries are just in time, typically on a weekly basis.

3.1.3 Japan and Korea

No information was obtained on Japanese and Korean ordering practice.

3.2 Inbound Logistics and Inventory Practices

3.2.1 U.S.A.

Delivery of steel products to shipyards is typically by rail or truck with very limited water delivery.

When the steel is delivered by rail it generally comes right to the plate and shape stockyard. Some shipyards with robotic shape-processing lines store the shapes in magazines, which automatically feed the shapes to the processing line.

3.2.2 Europe

Many shipyards in Europe receive their steel deliveries by sea. This is because of the extensive waterway system and availability of short sea ships. Many small shipyards are receiving fabricated parts from structural service centers. Just-in-time delivery has eliminated the need for large steel stockyards as shown by the small amount of steel that can be seen in Figure 3.

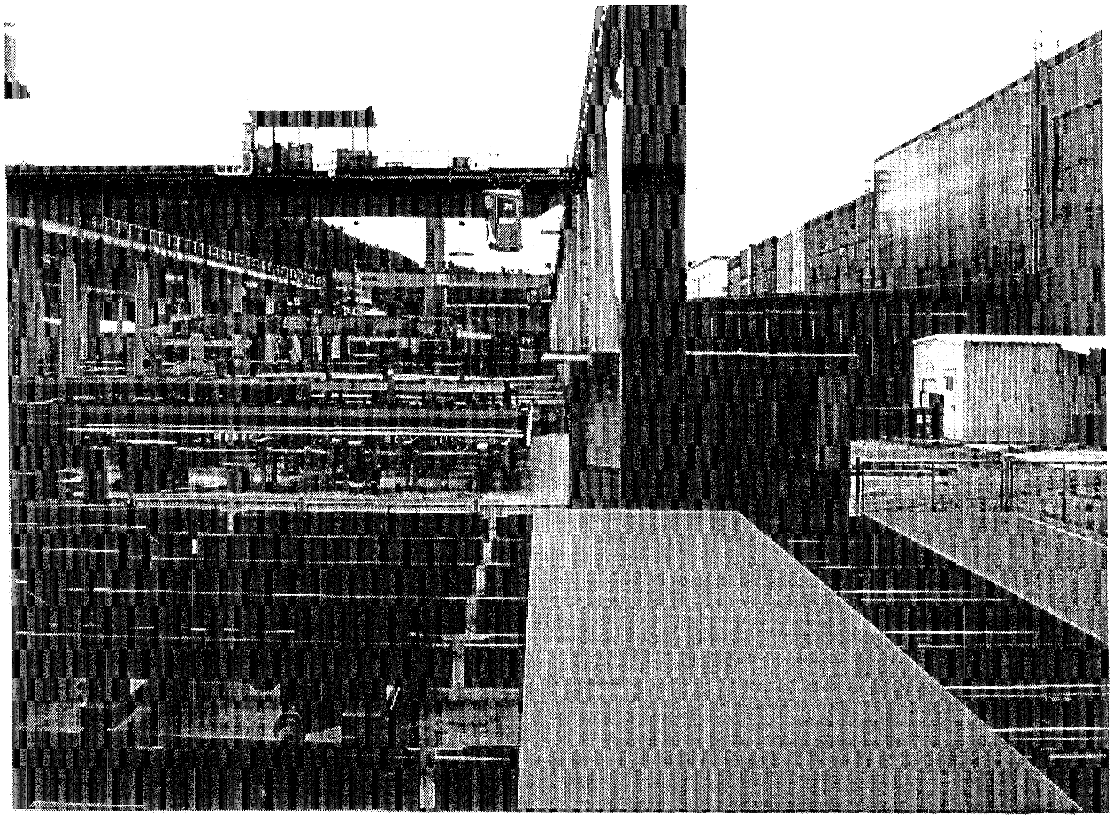

Figure 3: Plate stockyard showing the impact of JIT delivery

3.2.3 Japan

Some Japanese shipyards are located next to a steel mill, so delivery is directly by rail or road, but most receive their steel by sea. Because of the large steel throughput and deliveries by sea, the steel stockyards are quite large.

Japanese shipbuilders have long enjoyed a strong relationship with the Japanese steel mills. However, recently Japanese shipbuilders have been purchasing steel outside of Japan. Although there is a cost advantage in doing so, the Japanese are discovering problems with quality and performance from these sources. This has prompted cooperative action on the part of Japanese shipbuilders to work with foreign suppliers to improve performance and product quality.

3.2.4 Korea

Korean shipyards receive steel by both rail and sea. Steel stockyards are enormous because of the very high throughput (50,000 to 100,000 tons per week).

4.0 STEEL PRODUCTION

4.1 Steel Preparation and Construction Practices

4.1.1 U.S.A.

4.1.1.1 Military

Most of the ships built over the past Fifteen years in the United States have been for the military. Therefore the larger, shipyard, steel-preparation practices have been developed for military ships. The facilities and equipment are therefore selected for their application to military ships. Shipyards such as Avondale and NASSCO, which build noncombatant military ships, are more similar to the commercial shipbuilders of the world.

The basic steel-preparation practices are similar in all shipyards and are the same as for commercial ships. The steel is delivered to the shipyard and stored in separate stockyards for plate and shapes. Some shipyards are now using automated "magazine" storage for their shapes. The steel plate and shapes are blasted and primed.

The plate then goes through a series of processes including burning and marking, by numerical controlled (NC) machines as shown in Figure 4.

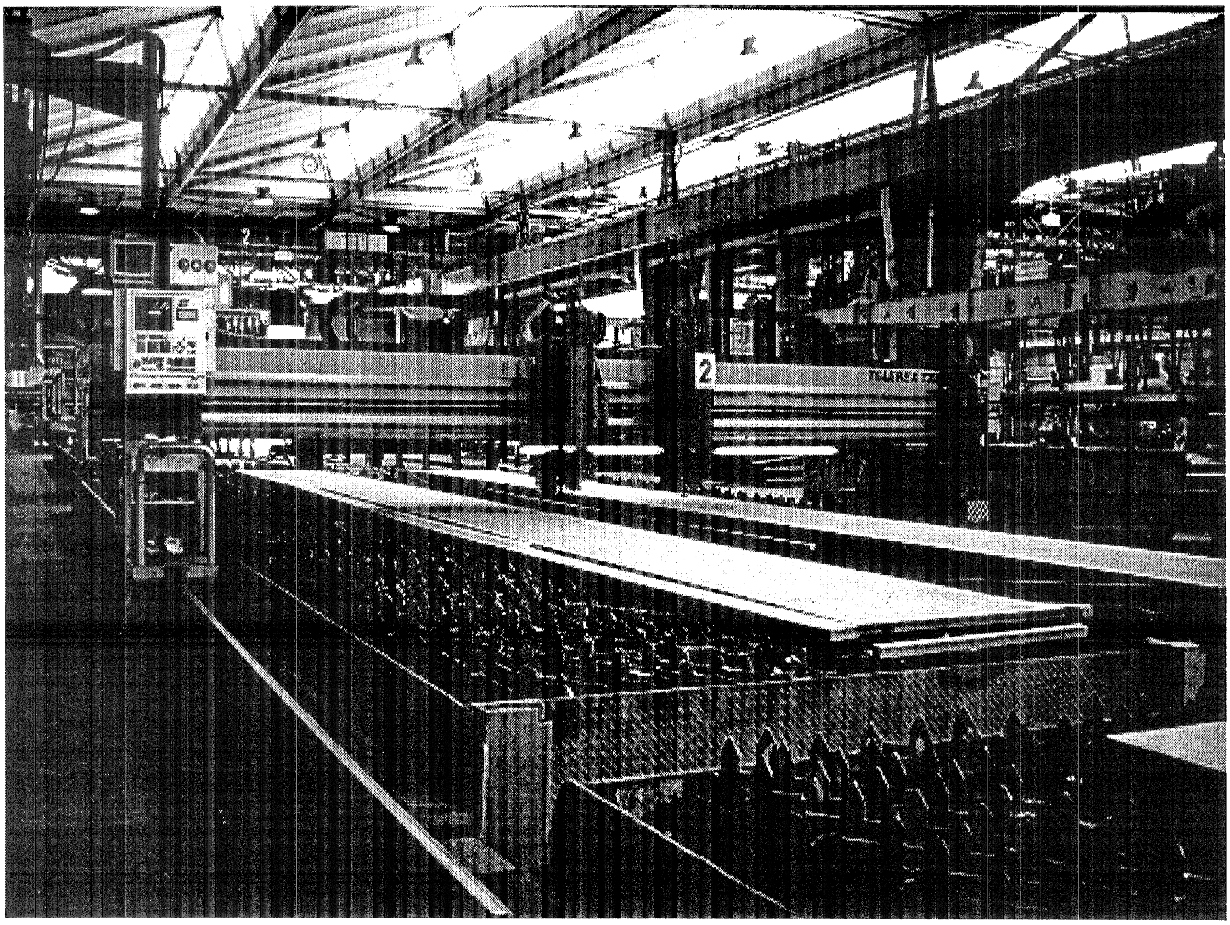

Figure 4: Burning and marking machine

Plates that have no forming requirements move on to subassembly and panel line fabrication as shown in Figures 5 and 6. Plates with curvature are processed through forming and rolling in plate rolls such as shown in Figure 7, and line heating for plates with extreme curvature, and then moved to assembly fabrication. They all come together in constructing the blocks as shown in Figure 8.

Military ships use thinner plate and smaller-shapes than correspondingly sized commercial ships. This presents a distortion problem, which in turn requires special distortion control processes. The method used to remove distortion in ordinary steel is heating and quick cooling. The distortion problem is exacerbated by the use of high-strength steels, which cannot be faired by heating and quick cooling.

The shipyards have adapted the hull-block-construction approach to suit each of the military ship types. However, shipyards such as Bath Iron Works (BIW) and Ingalls, which build the same ship (DDG51), approach it differently with regard to block breakdown, size and erection method. This is mainly because BIW still builds their ships on the traditional inclined slipway whereas Ingalls builds on a level land facility on a transfer system and move the blocks in a parallel progression until the reach the block joining station, where they are moved together by the same transfer system, but at 90 degrees to the original parallel movement. BIW has more blocks to erect and they are split vertically. That is to make up the depth of the hull, BIW may use up to three blocks. Ingalls construct "ring" blocks which go from the keel to the main deck and side to side of the ship.

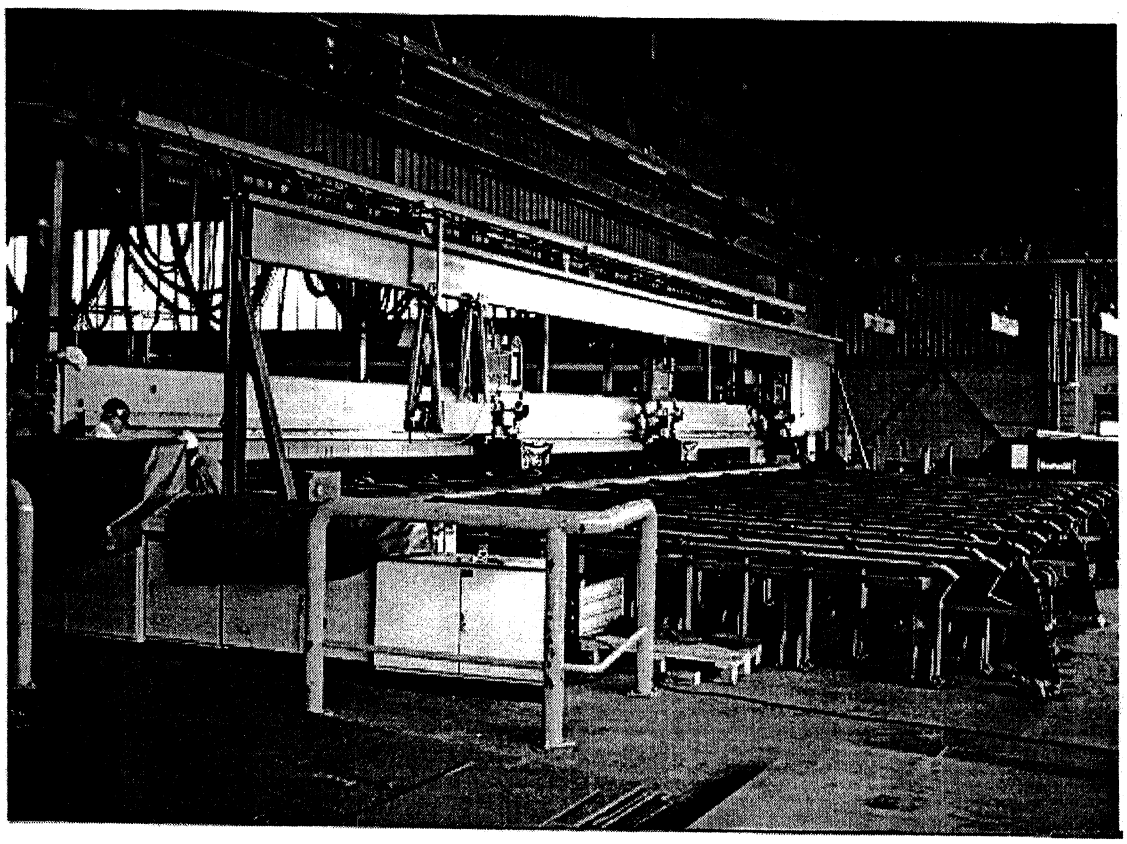

Figure 5: Panel line load station

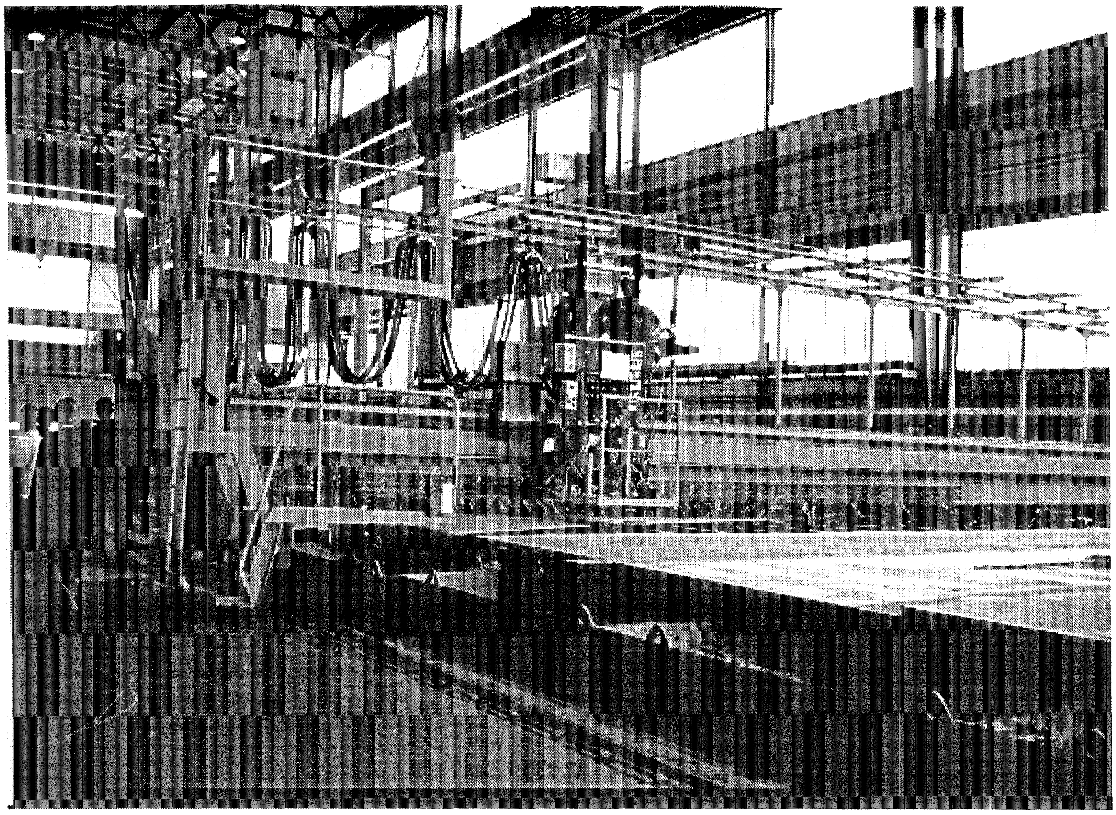

Figure 6: Reverse side butt welder

4.1.1.2 Commercial

The recent return by some U.S. shipyards to commercial shipbuilding has resulted in new equipment and changes in their processes for steel construction. This has mainly been in the area of robotic shape-preparation lines and larger size and more modern panel lines. Avondale installed a new "ship factory" in which all the processing through block construction is performed.

Newport News Shipbuilding installed new panel lines, but did not complete their plans to install a block line. NASSCO is currently deciding the supplier for its new panel line. At this time these shipyards are still reviewing the best way to build the different types of blocks. This can have a significant impact on the design of the panel lines. Although it has been around for some time, one decision that has to be made is whether or not to use one-sided welding on the panel line. Most shipyards have decided to use one-sided welding.

At the moment most U.S. shipyards still leave "stock or green" excess material on their blocks, which has to be cut off after the blocks are aligned. It also requires an additional movement of the block after the excess is removed to bring the blocks together.

The types of commercial ships being built in the U.S. are such that they all utilize double hulls. This presents a number of block-assembly issues that result in different shipyards selecting different approaches to the block construction. The issue of type of slot for longitudinals was referred to earlier. A shipyard can choose to slot the shell longitudinals and chock the inner-hull longitudinals so that the inner hull can be easily installed, but this limits application of robotics for the final welding of the inner-hull plating and longitudinals to the web frames. Kawasaki Heavy Industries in Japan has developed a unique approach to this issue which will be discussed in the section for Japan.

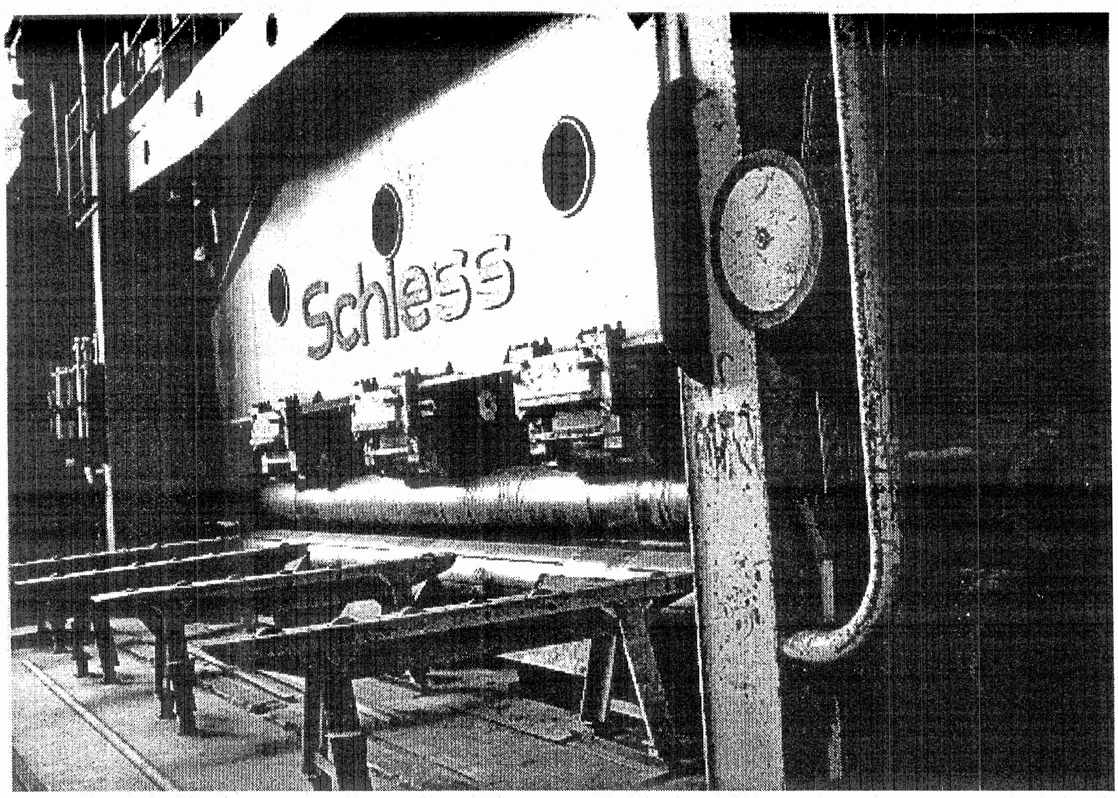

Figure 7: Plate rolls

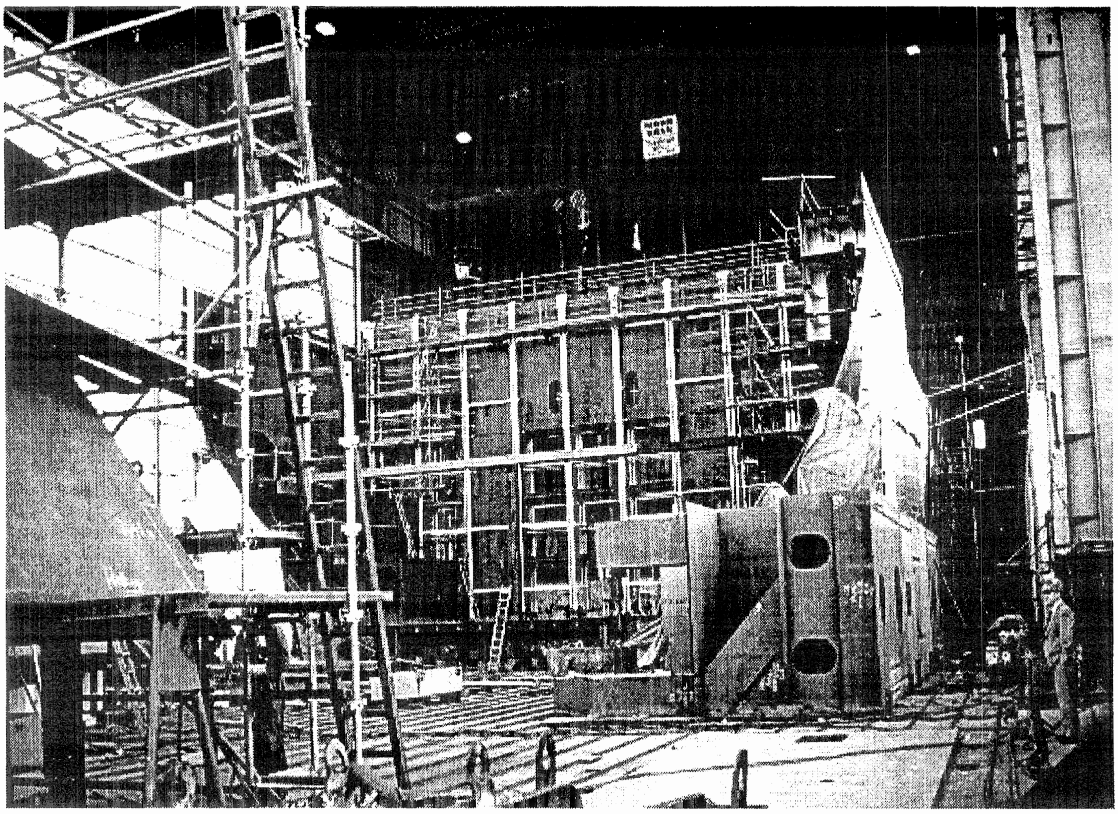

Figure 8: Ring grand block

4.1.2 Europe

The preparation of steel in Europe is the same as for U.S. The most significant difference is the Just-In-Time (JIT) delivery of steel to the shipyards. One German shipyard gets weekly deliveries of steel from a Norwegian steel mill. Other differences include not priming the steel because it is processed within days of receipt and the block in which it is incorporated will also be completed and painted in days or at the most weeks under cover. Holland has been at the forefront of the cut-steel service concept. The service center can work from the structural drawings and provide "kits" of steel parts, both plate and shapes, cut and shaped as required for each assembly or block. Smaller shipyards use this service.

4.1.2.1 Military

In Europe the position regarding military shipbuilding is reversed relative to U.S. The shipbuilding practices are driven by commercial shipbuilding approaches and they are adapted to military ships. In some countries there is complete separation between military shipbuilders and commercial shipbuilders, which allows each to optimize their shipbuilding approach to suit their products.

4.1.2.2 Commercial

There is a considerable technology range for steel construction practices, from simple panel lines and fixed workstations for block construction to fully automated panel lines and robotic assemblers and welders. The best known high end shipbuilder is Odense Steel Shipyard, but the recently refurbished East German shipyards are applying significant automation and robotics to the steel construction process.

4.1.3 Japan

Japanese steel shipbuilding practices are completely dominated by commercial shipbuilding. Military ships are built in shipyards that specialize in small, high-work content ships. Steel preparation is no different from U.S. practice except that because of the steel throughput they will have separate blast and prime facilities for plate and shapes.

Structural construction practices are decided by the Japanese shipbuilder's continual drive to reduce man-hours. They have halved them every ten years and are now attempting to get the man-hours down to 10 percent of the cost of the ship. As steel is the largest component of these man-hours it is obviously being given the major focus. Steel construction is highly automated and the use of robotics is normal. Work organization is highly effective, work is brought to the workers at the right place and time. A unique success of the Japanese shipbuilders is the integration of new approaches with old equipment and processes into a seamless operation.

The Japanese have analyzed the steel construction processes in great detail and are able to select the best for their facility and the ship types they build. They have processed over time from the traditional sequence of block assembly of:

join plates–position stiffeners–weld stiffeners–position web frames/floors–weld web frames/floors
to some variation of:
join plates-position web frames/floors-thread stiffeners through slots-robotic weld out block

Kawasaki Heavy Industries' approach to constructing large double-hull blocks is interesting and shows the thought that must be applied to make a shipbuilder world competitive today. They effectively build the block as two single-skin assemblies with the web frames/floors split down the middle and complete all the longitudinal/plate/web frame welding robotically while the block is open. They then place the single-skin assemblies together and complete three horizontal butt welds instead of the many skin-plate-to-web frame and longitudinal connection welds.

4.1.4 Korea

Korean steel construction practices are similar to the Japanese but with only a fraction of the robotics. As the shipyards have large steel throughput, each shipyard has multiple blast and prime facilities, multiple burning machines, and a number of panel lines. The assembly techniques for blocks are world average. The Korean shipbuilders make extensive use of line heating for plate shaping and seem to be as good as the Japanese in this practice.

While some shipyards that have very large (1 million ton) building docks build more than one ship in the dock at a time, it is a standard practice in Korea where up to eight ships are built in the large building docks at the same time. Blocks constructed in the steel shops are joined into Grand Blocks at the head or the side of the building dock and lifted into the dock by the large gantry cranes. This requires steel assemblies and blocks for many ships (up to eighteen at Daewoo and twenty-five at Hyundai) to be constructed at the same time.

4.2 Welding Practices

In general, welding accounts for 20 to 30 percent of total production labor hours or about 10 percent of the total cost of a commercial ship. In large Japanese yards nearly 90 percent of total welding length may be automated or in some way mechanized. This is in contrast to major European yards in which 50 to 60 percent of welding is automated or semiautomated, and 50 to 60 percent of welding in small yards being done manually.

On average, throughout the world, only 20 percent of a welder's time actually spent welding, and the remaining 80 percent is typically spent in welding support (i.e. hook-up, slag clean up, settings, getting weld metal, etc.). However, some of the better European yards have nearly reached Japanese efficiencies. Table 2 shows welding processes in Europe and Japan

There are a number of technical problems in the move toward automation in welding ship structures. Among these are:

- Large, heavy structure creates handling problems
- Variety of welds required
- Small quantities of production structures
- Assembling accuracy (distortion, edge preparation)
- Severe environmental conditions

In order to increase the amount of automated welding, there is a range of considerations. Among these are the need to design in such a way as to accommodate automation and robotics. Production considerations include improved accuracy of intermediate work components and developing faster welding technologies. Another consideration is the development of user-friendly robotic controlling equipment.

Other areas in which productivity and efficiency can be gained are in work to minimize of strain and deformation after cutting and welding. Related to this is control of distortion due to welding. These problems manifest in increased work processes (straightening, adjusting curvatures, extra fit-up) or rework (cutting excess material, adding material, recutting parts). Improving the speed and quality of edge preparation for welding and improving fit-up tolerances play a role in reducing shipbuilding costs and improving product quality (e.g. less built-in stress, better fatigue life, etc.).

Many of the above issues may be shipyard induced due to inferior cutting or other manufacturing methods. Improvement in these processes can improve accuracy in intermediate components, which is critical to increasing automation in welding. As most robotic or automatic welding systems cannot compensate for large variances in weld gap, there would be some benefit in the development of more flexible and robust welding equipment and processes.

Recognizing these problems, shipyards have identified areas in which improvements to process and equipment need to take place. Shipyards are focusing on adopting improved semiautomatic welding technologies, adopting welding technologies that are easier to use both in process and set-up, and increasing the use of CAD/CAM capabilities (taking CAD information into cutting and edge preparation processes). Shipyards are also focusing on developing or adopting lower cost mechanization, more modern plate cutting technologies (such as laser cutting), and using more efficient welding technologies such as laser welding, electron beam welding, or making better use of one-sided welding technologies.

Table 2
Typical Shipbuilding Welding Processes

Production Stage	Location	Size	Weld Type / Method	Automation	Comments
Panel Line	Japan	1st Tier	Panel Butts: 1) One sided flux cored sub-arc w/ Cu backing 2) One sided flux cored sub-arc w/ glass fibre or ceramic backing Stiffener / Profile Attachment: 1) Flux cored arc (FCAW)	Panel Butts: Fully automated high speed sub arc machines Stiffeners: Gantry mounted robotic dual head fillet welding machines	Stiffener Gantry: Oscillating heads, low hydrogen content wire, and low speed to combat porosity
Panel Line	Japan	2nd / 3rd Tier	1) Two sided sub arc 2) Two sided flux cored arc 3) Combination of 1 & 2	Semi-automatic sub arc machines Semi auto tractors for sttiffeners	
Panel Line	Europe	1st Tier	1) One sided flux cored sub-arc w/ Cu backing 2) Modified series arc system (Square and edge prepared butt welds)	Fully automated high speed sub arc machines Gantry mounted robotic fillet welding machines (stiffener attachment)	Tilting jigs for curved plate Automatic ultrasonic inspection
Panel Line	Europe	2nd / 3rd Tier	1) Two sided sub arc 2) Two sided flux cored arc 3) Combination of 1 & 2	Semi-automatic sub arc machines Semi-automatic tractors for stiffener attachment	
Subassembly Stage	Japan	1st Tier	Flux cored arc (FCAW) fillet welds Flux cored sub arc	Twin torch gantry mounted NC robotic welders	Separate gantries for line and curved welds
Subassembly Stage	Europe	1st Tier	Flux cored arc (FCAW) fillet welds Flux cored sub arc	Gantry mounted robotic fillet welding machines	

Table 2 (continued)
Typical Shipbuilding Welding Processes

Production Stage	Location	Size	Weld Type / Method	Automation	Comments
Assembly Stage	Japan	1st Tier	1) One sided Flux cored sub arc w/ Cu backing for joints 2) Flux cored arc for fillet welds	1) Magnetically fixed semi-automatic sub arc machines 2) Multi axis, articulated robots for fillet welds	Also automated filling & cold reforming equpment
	Europe	1st Tier	High energy Metal Inert Gas welds (MIG) for vertical butts Flux cored arc for fillets	Gantry mounted robots (fillet welds) MIG welding towers (vertical butts)	
Block Stage	Japan	1st Tier	Flux cored sub arc for horizontal joints Tractor type flux cored arc for fillet welds CO2 shielded flux cored arc for vertical joints	Portable robots and welding machines (Semi-automatic)	
	Europe	1st Tier	Flux cored sub arc (horizontal joints) Metal Inert Gas (vertical butts) Fulux cored arc (fillets)	Portable welding machines (semi automatic)	
Erection Stage	Japan	1st Tier	One sided sub arc welds Electroslag arc welds Electrogas arc welds Gas metal arc welds	Portable sub arc machines Semi automatic tractors	
	Europe	1st Tier	One sided sub arc welds Metal Inert Gas welds	Portable welding machines (semi automatic)	

4.3 Quality Control Practices

4.3.1 U.S.A.

Quality Control in the U.S. shipbuilding industry is still basically end-of-process control involving large teams of quality inspectors. These inspectors are from the shipbuilder, the classification society, and sometimes the owner. The use of statistical process control and involvement by the workers at the different workstations is only slowly being introduced.

Typical quality control of steel consists of checking part dimensions and marking, visual, and nondestructive testing (NDT) of welds and distortion of the finished structure. Quality control inspectors do not usually get involved with checking the dimensional accuracy of assemblies and blocks to ensure easy fit up. This task is performed by Shipwrights.

The difference between quality control and dimensional control is generally not well understood and because of this, U.S. shipbuilders are unable to construct blocks without leaving excess material to cut off as the blocks are aligned and fitted together. This is one of the most important areas that U.S. shipbuilders need to improve to become more productive. It is also more difficult for the thinner and lighter structures of military ships.

4.3.2 Europe

European shipbuilders have better dimensional control than those in the United States. Some state they use accuracy control, which is the application of statistical process control to shipbuilding, but they are really only using a portion of it, as they the workers do not apply it at the different workstations. They have accuracy control departments, which in itself, is contrary to the real concept.

4.3.3 Japan

Japanese shipbuilders follow the general Japanese quality control concept that quality is everyone's business and therefore they employ the concept of self-checking. They make extensive use of worker applied statistical process control, and this along with dimensional control, enables them to construct blocks without any excess "cut in" material on them. This obviously saves time and effort.

The final quality control function still is performed by teams of inspectors, but the effort is significantly less and the time shorter.

4.3.4 Korea

No information on quality control was available.

5.0 MATERIAL HANDLING PRACTICES

5.1 U.S.A.

Within the steel-processing shops, steel is handle by overhead cranes with magnetic lifters and/or clamps, conveyors, special pallets, and flat bed trailers. As the steel parts are built up into assemblies and blocks they are transported by flatbed trailers and the multiwheeled hydraulic transporters. Movement of the block onto the erection berth is mostly by crane.

5.2 Europe

Many shipyards use remotely controlled and some automatic collection systems of cranes and conveyors to move the steel from stockyard to the blast prime and cutting stations. One shipyard in Germany uses ATVs to move the steel from the cutting station to the different processing lines. Then the steel is moved along the processing lines from one station to the next until blocks emerge from the ends of the lines. They are then moved to the clean and paint halls by transporters, which are also used to move the painted blocks to the building berth where they are lifted into position by cranes as shown in Figure 9.

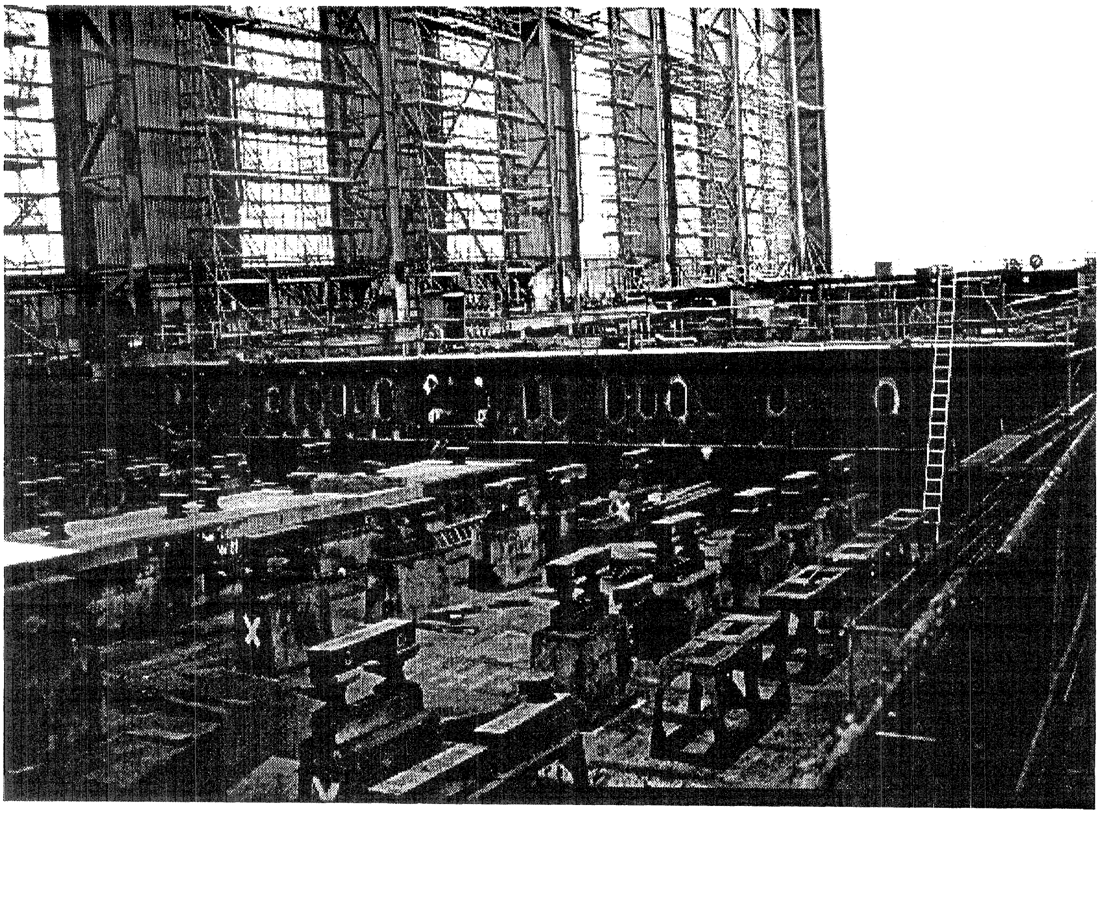

Figure 9: Double bottom block in building berth

There are two notable exceptions in the way the blocks are moved onto the building berth. The Kvaerner Govan system transports the blocks to an inclined slipway at the same position in the middle of the berth. The blocks are landed on special sliding ways and slid up and down the berth until the last midship block is positioned and the forward and after portions of the already erected ship joined to it. The Bremer Vulcan system used a system of level land track and dollies to move the very large ship blocks out of the block construction and outfitting hall to alongside the head of the dock. The block is moved transversely on to an elevator, which lowers it to the bottom of the building dock. A matching track and dolly system moves the blocks along the bottom of the dock to their final position. The obvious advantage of both of these systems is that they can erect blocks on the building berth up to 3,000 tons in weight without large cranes. A not so obvious advantage is that the need for heavy lifting fittings, built into the block structure is eliminated.

The most recent trend in Europe is the "compact shipyard" where travel distance is minimized.

5.3 Japan and Korea

Transport of steel throughout the steel construction process is similar to Europe but all the Japanese shipyards have large gantry cranes to lift the grand blocks into the building docks. The new shipyards in Korea are enormous with great distances to be traveled by the steel products as they are processed and erected in the building docks.

6.0 SUMMARY AND CONCLUSIONS

The basic use of steel for shipbuilding is very similar around the world. This is also true for the range of structural design approaches. The decision to use the different structural design approaches depends more on the size of the shipyard and the skill level of its design staff than ship type or the country of build.

If the influence of the customer (shipbuilders) on the supplier (steel mills) depends on the size of demand, then in the U.S. and some European countries, where the percentage of the total domestic steel supply used by the shipbuilders is less that 1 percent, there is negligible influence.

On the other hand the shipbuilding demand in Japan and Korea is a significant share of the steel mills' supply, and they can influence the steel-producing industry.

Typical steel throughput in U.S. shipyards is 50,000 tons per year, whereas in Japan it is 200,000 tons, and in Korea it is rom 500,000 to over 1 million tons.

The shipbuilding steel preparation practices are very similar with only the quantity of steel being processed differing. Most shipbuilding countries are still struggling with weld through primers, but some, through the use of JIT steel deliveries and short in-process time, are eliminating the pre-fabrication priming, especially if the final coating of the structure requires blasting to bare metal after block construction.

In-bound logistics will continue to be a determining factor in sourcing domestic materials. The constraint on transportation cost imposed by Jones Act compliance will make rail more cost effective, and the timeliness of over-the-road trucking for small lots will offset the higher costs.

The steel construction practices are again similar in what needs to be done, but differ considerable in how it is done. This is significantly influenced by the use of robotics. The different construction approaches obviously have different work content and it is through the relentless and continuous removal of non value-added work that the Japanese lead in this area.

Shipbuilding welding practices in all countries are similar, with Japan using manual stick welding the least. Most shipyards are replacing manual stick welding as the alternative welding methods offer superior performance as well as better conditions for operators.

Material handling for steel in shipyards is also similar throughout the world, with the more modern shipyards incorporating more automation of the early preparation processes. This is mainly through conveyors and tracks, but some autonomous track vehicles (ATV) are being introduced, such as in one of the recently refurbished shipyards in Germany, where cut and marked plate is transported to the various processing lines by ATVs.

A major area where U.S. shipyards could improve their practice with corresponding productivity improvement is Quality Control (QC). QC in U.S. shipyards is still basically an end-of-process control involving large teams of quality inspectors. Although some U.S. shipyards have tried to introduce Accuracy Control, it is not done at the worker level and thus only gains any marginal benefits.

If the United States could increase its share of the international commercial shipbuilding to 3 percent of the current annual demand, the steel usage by U.S. shipbuilders in total would only increase from the current 250,000 tons to just over 500,000 tons. To do this they would need to produce over twenty ocean-going commercial ships each year, something they have not done since the end of World War II.

U.S. shipbuilders while recognizing the need to increase commercial work, have no apparent approach involving radical change, to reach international competitiveness. Current improvement efforts are incremental with marginal benefit. Areas for consideration by which improvements could be made include:

- Adoption of enhanced welding techniques.
- Use of statistical process control methods by workers to improve accuracy and eliminate stock.
- Just-in-time (JIT) ordering practices.

In cooperation with the North American steel industry considerations include:

- A cooperative effort of shipbuilders, steel industry and researchers, to jointly develop industry leading steel technology, including new steel shapes that maximize ship design strength for minimum cost.
- Joint marketing of North American steel and shipbuilding quality and value.
- EDI initiatives

Representatives of the U.S. steel industry should become members on the various National Shipbuilding Research Program panels that focus on their products, such as SP-3 Coatings and Surface Preparation, SP-4 Design/Production Integration, and SP-7 Welding.

7.0 REFERENCES

1. "The Shipbuilding Industry – Market Issues," AISI January 23, 1996

2. Steelmaker/Shipbuilder Meeting – Report of Meeting, May 1,1996, AISI

3. "Mid-term Sealift Ship Technology Development Program," by J. Carey Filling, et al, SNAME Annual meeting 1996

4. Tee-beam Manufacturing Analysis, by Paul Blomquist, Bath Iron Works, NSRP Report No. 0446, Released 5/1/95.