THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
74 Trinity Place, New York, N.Y., 10006
Paper to be presented at the Ship Structure Symposium
Washington, D.C., October 6-8, 1975

Structural Developments: Inland Waterway Towboats and Barges

James O. Gundlach, Visitor, Canal Barge Company, Inc., New Orleans, La.

ABSTRACT

The harsh, exacting environment of the inland waterways requires a continual search for safer, more efficient and more reliable equipment and methods. While traditional research and development efforts have accounted for much of the progress thus far, parallel headway has been made by innovative operators seeking higher levels of productivity and reliability.

Many improvements have occurred in the past and many are yet to come, but this goal can be reached far more expeditiously by free and easy exchange of information between designers, builders and operators. It is incumbent upon designers and builders to follow their creations into the rivers and canals to view them in service, looking for flaws and weaknesses. It is equally important that we operators share experiences and ideas, not only with one another, but with the design and building community, as well. With an open and receptive exchange of information we can effectively utilize real-world operations as a research and development environment for future growth.

INTRODUCTION

Developments or improvements in any system usually come as the result of research and development efforts or through innovations based on field experience. In the past one hundred and fifty years river equipment in the United States has experienced many technological advancements which came by way of the former. By contrast, this report deals with several refinements, most of which are the products of the latter. Canal Barge Company is an operating barge line and not a research and development enterprise. But we, like so many others, have made significant developments by an inquisitive and analytical search for better utilization of the equipment we operate. The credo which guides us is simply stated: when solving a problem, find and cure the cause; treat just not the symptom.

What are the incentives that prod us to solutions? Obviously, increased productivity and safety of the equipment is dominant, but this goal is reached by a dual path. Surely higher operating performance characteristics, i.e., speed and tonnage, improve productivity. But just as important in this quest is the minimization of equipment idleness forced on the operator by needed maintenance and repairs. Fortunately, sizeable gains have been made in both areas, with classic research and development accounting for most of the performance improvements and field developments generating most of the increased utilization through better "maintain-ability."

From a "structures" point-of-view why is the matter of "maintain-ability" significant enough to warrant consideration here? Are not structures, properly designed in the first place and adequately cared for and protected during their lives, expected to be relatively free of maintenance and repairs? Perhaps this is true of ocean-living equipment, but it certainly has not been the case with river-bound equipment. Why is this? Have river designs been inadequate? Are the American Bureau of Shipping rules deficient? Are the U. S. Coast Guard regulations insufficient? The answer to these questions is, "No." The current rules and regulations produce river equipment designs quite adequate to perform their expected tasks safely and efficiently. Why then the need for improvisations? For one, competition spurs us to achieve higher levels of efficiency and lower operating costs. Unforeseen operating requirements similarly dictate a need for change in equipment characteristics. And of no small importance is the economic pressure to create equipment capable of withstanding the countless impacts and abrasions during a full lifetime of river service.

Technology has brought the inland waterway industry to its present high degree of proficiency. It has not been sheer luck, or accidental, or only the product of trial-and-error experiences that has carried us from the flatboats and keelboats of the eighteenth century, past the steamboat and packet boat era, and through the development of the diesel-powered towboats and specialized barges of today. This progress has been the result of systematic development based on sound technology, and nothing less.

Of utmost importance in any discourse on river equipment technology is the understanding of their unique service conditions and operating requirements. Quite often we operators find marine researchers, boat and barge designers, and our regulatory agencies do not fully understand the uniqueness of the rivers and canals. In fact one might generalize by saying the only thing common to river and ocean equipment is that both float in water and transport freight. Beyond that there is little commonality. Ships are built, sail the oceans for decades, and barring grounding and collisions, the only things they touch, save water, are piers when docking (and usually these with the aid of tugs). Conversely towboats and barges are built, and from that moment to retirement theirs is a life of repeated impacts, groundings and abrasions.

On the other hand, ships must endure the ravaging effects of stormy weather at sea, while river equipment seldom is exposed to any severe wave action. Obviously, the basic hull strength required of ships is far greater than that of river boats and barges. By the same token ships need very little localized stiffening, added strength or abrasion protection, while on river equipment these are absolutely essential.

TOWBOAT DEVELOPMENTS

Increased Power: Todays towboats are refinements of those which came on the scene in the decade prior to World War II. The diesel engine prompted the shift from steam, and with it came improved reverse-reduction gears and clutches. With a relatively low-weight and compact power train available towboats have progressed steadily from a few hundred horsepower to the 10,000 horsepower brutes now in service. But the changes have not all been in increased power. There is hardly a system on a boat that has not been improved many times in the recent past. But what changes have occurred in boats' structures?

One readily apparent change has been the capability of increased horsepower with no increase in overall boat size. In fact, some modern higher powered boats are smaller than their lower powered predecessors.

Packing more power into a towing vessel implies the need for greater hull rigidity. But as power levels have increased, the propellers have grown in diameter up to about 10 feet. With typical water depths in the range of 9 feet, the propellers must be recessed into "tunnels" under the stern. These tunnels have the effect of reducing hull depths in this critical location which, unless compensated for, would lessen rather than increase the rigidity. One common correction has been to raise the deck near the stern, thereby returning the vital section modulus by deepening the hull. Another is to utilize the structure of the deck house in this area to provide the additional stiffness required. A third method has been to modify and enlarge the structural members of the hull, especially those in the after parts of the vessel.

To those who have not experienced a high-horsepower towboat in service, when the vessel is moving ahead at full speed and suddenly the propellers are reversed with the "flanking" (or reverse) rudders turned to one side and the steering rudders to the other, the violent vibrations then encountered are difficult to describe adequately. It has been said this is perhaps the most tortuous maneuver one can ask of any boat, and yet it is a common occurrence with almost all river towboats. Since this maneuver is an operational necessity it is likewise necessary the hull structure be designed and built to accomodate it. This has been achieved in part by the same techniques outlined before, but, as the entire vessel is subjected to the violent shaking, the structure throughout has had to be strengthened and stiffened. Hull plate thicknesses have been increased; bulkheads, trusses, and frames are made continuous through intersecting bulkheads; and machinery foundations made heavier and a part of the hull structure where possible.

Kort Nozzles: From a structural viewpoint, the most complex portion of many towboats, especially the higher powered ones, are the Kort nozzles enshrouding the propellers. These devices enhance the thrust production under load significantly and are quite common on vessels in excess of 4000 horsepower. But, the advantages of the nozzles did not come cheaply. Early nozzles were high maintenance items. Inadequate internal framing, insufficient welding, thin shell plating and weak hull attachments combined to produce nozzles needing frequent repairs. Rather quickly, designers and builders modified and strengthened this critical structure to a point where now one can usually expect nozzles to perform for years with little or no repairs. One significant change, which surely has been of great importance here, has been to eliminate from the nozzles the pintle pins and gudgeon plates commonly used to support both the steering and flanking rudders. The violent and turbulent forces imposed on the boat's rudders would be transmitted directly into the nozzles through the pintle pins, and thereby imposed continual high-energy vibrations into their structure. It is no wonder early nozzles with rudder bearings attached were such problems.

Skin Coolers: One novel use of the Kort nozzle that has been tried, albeit unsuccessfully, is that of a skin cooler for engine cooling water. Notwithstanding the problem of keeping the nozzle watertight, it would be an ideal cooler. The high external water velocities would produce heat transfer coefficients sufficient to reject any engine's requirements. But even today it is practically impossible to depend on the nozzle as a watertight vessel, and so it has been abandoned as a cooler.

Kort nozzles are not the only location found to be undesirable for the placement of skin coolers, however. Not too many years ago, it was a very common practice to place the skin coolers on the bottom of towboats. These were of two basic types. One was an internal cooler with the hull's bottom plate forming the exterior side of the cooler. The other was an external cooler affixed to the outside of the bottom plate. In either case the location has proved to be very undesirable, especially after a few years of service. The abrasive action of rubbing the river bottoms in shallow water thins the plate, ultimately resulting in failures and leaks. Even a small skin cooler leak must be repaired promptly and this is another point of contention with bottom coolers: when repairs must be made, they are very difficult and expensive. The repairs require overhead welding while the welder is usually in a prone position. To complicate the problem, the very docking of the boat frequently damages bottom coolers. Large towboats weigh several hundred tons, and may be supported on but a few blocks. The loading on the hull in way of the blocks is sufficient to distort and upset the plate. Should it be weakened due to reduced thickness from abrasion, the docking load can, and has, caused plate failures which are usually found only after the boat is returned to the water.

An obvious solution to the cooler location problem is to place them elsewhere. This is now easily accomplished by mounting the coolers on the hull sides. To provide the surface area needed one must use a separate extruded tubular exchanger or a formed plate or channel-type cooler. Either choice is acceptable, but each type must be given some protection from impacts and rubbing along lock walls and docks. If repairs should be necessary, however, they are relatively easy and accessible.

Retractable Pilot-House: To one unfamiliar with inland river towboats, the sight of a retractable pilot-house boat must give a strange impression. Here is a vessel, its deck house confined to a single level, with only its pilot-house extended atop a hydraulic ram, sometimes approaching an elevation of 40 feet above water level. If not blessed with the beauty of the swan, surely these boats have its style and grace. Only they can lower their "heads" to pass low fixed bridges which would halt most of their fixed pilot-house counterparts. The upper reach of the Illinois River near Chicago has several of these bridges, but as most of you are aware many of the rivers we ply experience some extraordinary changes in water levels. It is not at all a rarity, therefore, for high fixed pilot-house boats to find otherwise passable bridges on the Ohio River and others temporarily blocking passage because they are too near the water surface.

Some might ask then, why not build only "retractables?" A good question, but many boats are built to ply only the Mississippi River, and of that, only below St. Louis, Missouri or even Cairo, Illinois at the confluence with the Ohio River. This part of the Mississippi has no bridge which would impede even the highest fixed pilot-house boat of today. These limited-route boats though generally are the highest powered vessels. But what of the great number of other boats which may see service on any navigable stream? Would not the retractable design be the most versatile and functional? In my opinion, any towboat built to see unrestricted service should be of this type, simply because a retractable pilot-house towboat can do anything a fixed pilot-house boat can, but the reverse statement cannot be made.

If retractables are a desirable design, do they present any unusual structural problems? Yes, some, but not overwhelming ones. Basically, their hulls are much like any other, the only difference being in the supports for the lifting ram and guides. Perhaps the biggest structural difference is in the deck house. Since the retractable has only a single level house, its contribution to overall hull rigidity would be less, if compensations are not made for extra stiffness.

Towing Knees: Another noteworthy field-conceived improvement in towboat structure is in the towing knees. These triangular shaped appendages on the bow decks of all towboats provide the boat's contact surface when pushing barges. Obviously, they must be of great strength and they are. From a strength point-of-view, I think all builders have solved this problem. But the towknee is more than a pushing surface. When pushing barges whose decks are higher than the foredeck of the towboat, the towknees also serve as stairways. Most all are equipped with steps up their rear sloping surfaces. The problem thus created is if the barge deck is lower than the top of the towknee, crewmen must climb to the top and then step or jump down to the barge. Ideally the empty barge deck would be even with the top of the towknees, while loaded barge decks would be flush with the foredeck of the boat. Unfortunately, the wide variance in barges often places their deck at an intermediate level, forcing one to either climb up or down. With rigging or other heavy loads in hand this presents a hazard. The solution: construct the knees with an additional sloping surface with steps from the top, extending inboard, adjacent to the headlog down to the deck. Then, providing the knees are at least as high as the highest barge decks, no matter what deck elevation is encountered thereafter one can step across safely and comfortably.

BARGE DEVELOPMENTS

General Considerations: The concept of barging as we know it today began almost 150 years ago when wooden keelboats were lashed to steamboats. Over twenty years passed however before the first steamboat was built and operated expressly as a towboat for barges. However, another twenty years were to pass before barges in numbers became a common sight. The technology of barge design moved ahead in the latter part of the 19th century and the first 30 years of this century, but with the completion of the Ohio River improvement project in 1929, this industry spurted ahead to a new level of activity. Other rivers were then improved and the barge business continued to expand and it is still growing today.

This growth in size should not overshadow the technical growth in barge designs brought on by the wide variety of commodities shipped. Structurally, the barges of today are highly developed, and though some might wish them to be stronger, more damage resistant and less vulnerable to spilling their cargoes, it should be acknowledged they are the safest vehicles for bulk commodities in use. Yet each one of those desirable goals is sought by every barge operator, and as everyone knows we now can make barges stronger and more damage resistant. But to do so almost always implies more displacement (light) and less cargo weight to be carried. In the extreme we can produce structures that would be practically impenetrable, but this is economic foolishness. No, we must search for compromises in these attempts at improving barge structures. And it should be emphasized strongly that a structure which appeals to one operation may be unacceptable to another. Certain situations may allow for barges to be removed temporarily from service for repairs, but when in service demand maximum cargo tonnages aboard. Others may allow almost no downtime, but can tolerate small reductions in cargo tonnage. The point here is that it is not possible to generalize and make blanket statements on what is the "best" design for all.

In our operation, we have only tank barges, many of which are highly specialized. Their capital requirements are naturally much higher than typical dry-cargo hopper barges. Since the capital cost of a barge is a prime factor in determining allowable downtine, we have found it prudent to incorporate several features in our barges which add to their weight (and reduce cargo tonnages) in order to avoid costly premature idleness and repairs later.

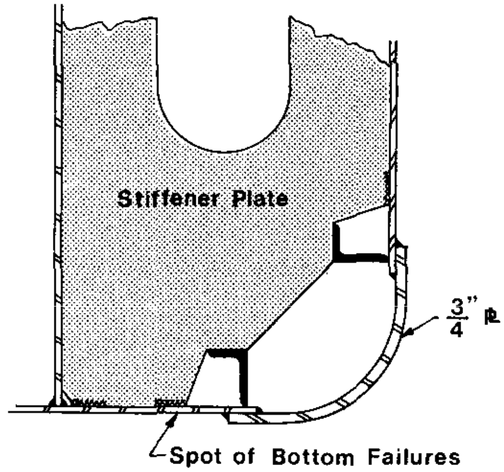
Bilge Knuckle Modifications: One item found to contribute significantly to hull maintenance in our scope of operations was the bilge knuckle wearing thin prematurely due to abrasion. That this area is one of high wear should come as no surprise. If one imagines a barge of rectangular cross-section floating in a stream whose bottom profile is somewhat elliptical in shape, the point of contact, should a grounding occur, is at the knuckles. Surely, not all river beds are elliptical in shape, but the wear patterns we see indicate the knuckles rub the bottom more than does the flat section in between. Our solution to this is to add a wearing allowance to the plate thickness required by the ABS rules. In a barge measuring 250 feet long, the required thickness is about 3/8 inch. Our standard practice is to use 3/4 inch, so we have an additional 3/8 inch wear allowance. In this barge we sacrifice about 10 tons of cargo capacity because of this, but we know these knuckles will give at least 20 years of almost trouble-free service, whereas the required 3/8 inch knuckle will usually require major repairs or replacement after eight to ten years service, depending on routes travelled.

A feature we include in the use of the extra-thick knuckles is a lap-joint attachment to the side plate and bottom plate rather than the customary buttweld connection. The advantage of the lap, with the knuckle outside both bottom and side plates, is it acts as a continuous 3/4 inch thick rubbing strip protecting the adjacent plating.

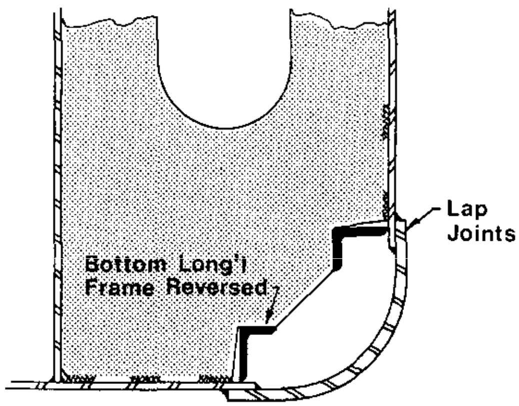
Reduction of Hard-Spots: Another practice adopted in the design of bilge knuckles is to eliminate "hard-spots" as much as possible. Hard spots are those areas where a strong transverse or vertical member attaches directly to the side or bottom plating. If such a frame or member is attached to the knuckle it surely will create a spot for concentrated wear. When the knuckles impact severely with the bottom they flex inward, often taking a permanent deformation. But at the point of reinforcement behind the knuckle, it will usually prevent or reduce the deformation. This causes the "hard-spots" to protrude out from the surrounding plate. From this time on these spots will wear thin much faster than the plate around them.

The use of the thicker knuckles also did create a minor problem in the adjacent hull structure of some barges. In double-sided or double-skin barges employing transverse wing tank stiffener plates in lieu of built-up trusses, it was found a minor impact from the side on the stiff, thick knuckle would pull the thinner bottom plate away from the stiffener plate if this plate was not welded to the bottom plate at the lap joint. (See Figure 1)

Early designs faced the toe of the outer bottom longitudinal frame inboard. With this frame placed directly over the lap joint, the notch cut in the stiffener plate to allow passage of this frame caused the bottom plate to first contact the stiffener plate several inches away from the lap. Upon impact at the knuckle its stiffness caused the adjacent bottom plate to flex downward. If even a moderate impact occurred the bottom plate might tear away from the stiffener plate and fracture itself in the process thus creating a leak. The solution here is fortunately simple. We have found by only reversing the alignment of the outer bottom longitudinal so its toe faces outward (rather than inward), the stiffener plate can be attached easily to the bottom plate in way of the lap joint. The bottom plate then does not have the flexibility to bend and tear. The forces imposed on the vulnerable weld attachment are more parallel with the weldment rather than across it, (as in the earlier method) and the unit stresses are reduced porportionally.



EARLY DESIGN



LATER DESIGN

BILGE KNUCKLE DESIGNS

FIGURE 1

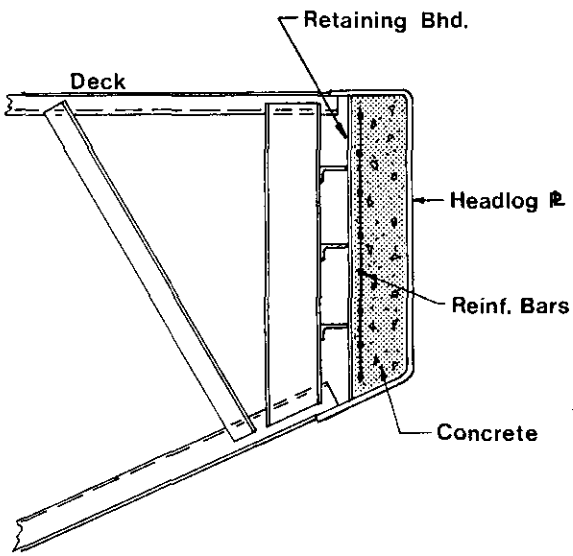
The problem just described surely must appear to a designer or builder as trifling, but to the operator it can be a major and very expensive nuisance. We view this problem as an example of the lack of understanding by designers of the unique character of the river environment mentioned before. Unfortunately this character is not always apparent on the drawing board. It is only fully revealed in the harsh world of barges banging into each other, smacking and sliding along lock walls, landing against docks and piers, smashing into ice up to two feet thick, and rubbing shallow river bottoms.

Another subtle improvement we have made in double-side or double-skin barge designs is to reduce to a minimun members which may, if impacts or collisions occur, cause a penetration of the cargo tank bulkhead. Even if the outer hull should remain tight, cargo spilled into a wing void can be a costly problem. Some designers feel the wing tank transverse framing, stiffener plates and bulkheads should be stiff and stout in the transverse direction. Certainly, there must be transverse strength, but to make inflexible structures will only lead to wing bulkhead failures. In our experience, we would much prefer to replace a bent or buckled plate or frame in a "clean" wing tank than to repair a fractured cargo bulkhead which had deposited its product into the void.

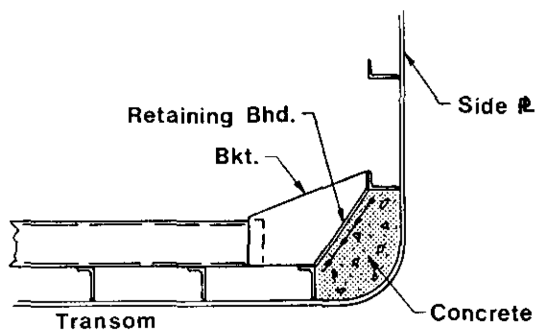
The varieties of frame and bracket arrangements are many, but the designer and builder should be mindful of these potential problems when piecing together a hull structure. Remember, it is usually better in low to moderate pacts to let the structure flex and deform if it must, rather than be extremely stiff, especially in concentrated spots.

Longitudinal vs. Transverse Framing: A discussion of river barge hull structures would not be complete without comparing the two basic framing methods, for double-skin designs, longitudinal versus transverse. Our fleet has several of each, and in our opinion the longitudinally framed barge is the better choice. Recall, the service of a typical river barge consists of much rubbing against fixed objects, and most of this rubbing is in the longitudinal direction. Therefore, a longitudinally framed barge creates fewer "hard-spots" as the frames adjacent to the hull plate can flex and yield smoothly with the plate, usually remaining free of sharp curves. Transverse framing conversely creates "hard-spots" where the frames attach to the hull plate. While these structures are strong, the hull plate frequently and quickly takes on the appearance of a washboard. With only the "high-spots" making contact when rubbing the bottom or lock walls, it is easy to understand why the hull plate wears thin before its time.

In most barges, two areas frequently damaged, although usually of a minor nature, are the headlogs of rake ends and the vertical corners on square end transoms. The headlogs most vulnerable are those pushed against by the towboats. In our operations where we push only integrated unit tows, it is the trail barge headlog which is most susceptible to damage. The damages to these areas usually result from the repeated impacts (low energy) sustained when barges are assembled in tow at docks, locks and in fleets. In most cases, brittle failures occur as the structure is hit repeatedly. Because the impacts ordinarily are "point" blows, that is the contact area is small, the local stresses become quite high. As we analyzed this problem, it was concluded the only long-term solution would be to distribute the impact force over a wider area where more of the structure could absorb it. Having tried thick contact plates (up to 2" thick), with only moderate success, it was decided to use reinforced concrete, poured into a void one feet thick adjacent to trail barge headlogs, and in the immediate space inside each vertical corner on square ends. There is no framing in the areas filled with the concrete. It has been relocated inside the bulkhead retaining the concrete. To many of you, the addition of concrete to the structure of a cargo-carrying vessel may seem strange. But if the early results of this experiment are indicative of the future, we think ours will have been a wise choice. (See Figure 2)



HEADLOG SECTION



VERTICAL CORNER SECTION

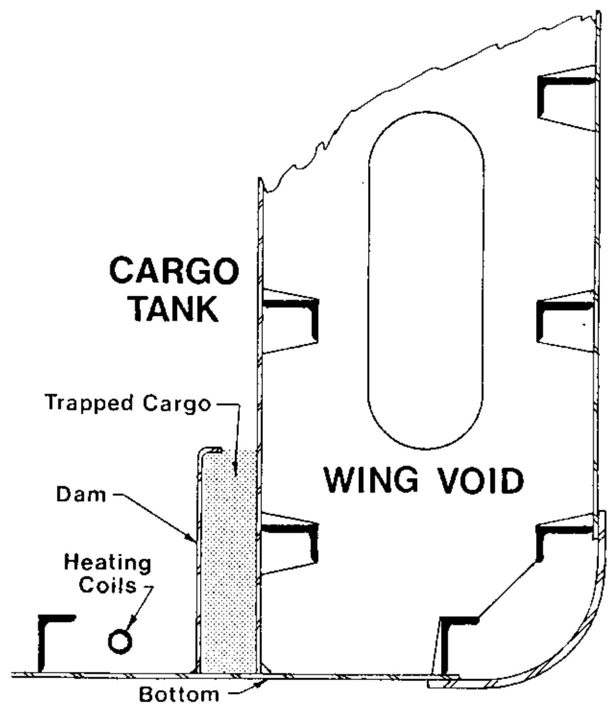
CONCRETE REINFORCEMENT

FIGURE 2

So much for structural improvements to enhance the serviceability of barges. No doubt there are many others deserving recognition, but I should like to turn my attention to a subject of particular interest to many barge operators today. Most of you are probably aware there are several cargoes commonly shipped which are heated, either enroute or prior to loading and discharge. A few, like liquid sulphur, command much attention and are usually carried only in very specialized barges having independent cargo tanks, free to expand under the high operating temperature (275°F). Others like residual fuel oil, coal tar, waxes and asphalts have not attracted much technical attention, but I hope this will change, especially the ones requiring higher temperatures. Fuel oil and coal tar normally are heated to no more than 150°F and 125°F is more common, but waxes require about 200°F and asphatls, while unloaded at about 250°F, may be loaded at near 400°F. Since these products, especially asphalt, are fairly low-revenue cargoes, most barge companies have not seen fit to carry them in expensive and sophisticated barges. In short, the towing rates have prohibited using the type equipment the conditions warrant. If this situation continues, is there a way to redesign the lower cost barges (double-sides and double-skin) to accomodate the temperatures and not be prone to tank failures from the high stresses developed?

The double-skin barge gives the most protection from cargo spills into the water, but with the carriage of asphalt in these barges if the cargo tank should allow the product to leak into the innerbottom, the repair consequences are enormous. And since the temperature differential between the cargo tank and the outer hull may be as much as 350°F, this calamity is a real possibility.

The double-sided barge offers an interesting prospect with this service. The possibility of product leaking into the wing voids certainly exists, but if it should, it is much easier to remove than from the innerbottom of a double-skin barge. What can be done to prevent this from happening though? As we view it, the most likely zone for wing bulkhead failures in double-sided designs is near the connection with the bottom plate. The bottom plate is cooled by the river, while the hot product may raise the bulkhead's temperatures to almost 400°F. It seems logical then this is where to expect trouble. It appears there is no practical method of constructing this bulkhead to allow flexibility along this critical juncture. One idea which seems to have some promise here is to prohibit the lower portion of these longitudinal bulkheads from exposure to the high loading temperatures. We feel one practical way to accompolish this is to construct a "dam" a few inches inboard of the bulkhead and parallel to it. During the first loading the product would spill over into the isolated area and be trapped indefinitely. As the barge is unloaded this small amount of cargo would remain in place. During subsequent unloadings it will act as an insulator to reduce the temperature on the lower part of the bulkhead proper. Surely, the bulkhead will receive heat by conduction through the plate itself and even convection of the product trapped behind the dam, but if this notion will reduce the temperature in the danger zone sufficiently, the stresses may become tolerable. To my knowledge this idea has never been attempted in practice and before it is, I think some research is required. Should it prove to be a workable solution it will have gone a long way toward solving one of the puzzles of today's barge operations. (See Figure 3)



WING BULKHEAD DESIGN

CARGO INSULATING LOWER PART

FIGURE 3

CONCLUSION

I have alluded to many technical developments in our area of the marine transportation field. Much of what has been discussed has been the result of innovations based on operational experiences. Not discussed in detail, but certainly deserving acknowledgement, is the vast amount of fruitful research spanning more than a century which has developed the inland waterway towing industry into the safe, efficient and reliable system we have today. But we cannot stop here. To do so is to move backwards. We need to continue our efforts to improve reliability to make our operations more safe, and to make better use of the resources available to us. These goals can only be achieved if all of us, the research community, the designers and builders and we operators coordinate our efforts and work together. The opportunity to have presented some of our thoughts and ideas today is a fine example of this much needed spirit of cooperation. We thank you for allowing us to contribute.