

## CONSIDERATIONS IN THE DEVELOPMENT OF AN EARLY WARNING VESSEL/BRIDGE COLLISION SYSTEM

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### Overview

Highway and railway bridges spanning navigable waterways face the real possibility of being accidentally struck by large ocean-going vessels or large barge trains. In many cases, these accidents can result in serious damage to the bridges, blockage of the waterways, economic losses to communities served by the bridges and waterways, and loss of property and life.

Two basic types of systems might be used to help prevent ships from striking bridge supports. The fender system is sometimes deployed around vulnerable bridge supports, but this approach is not always practical nor cost effective. Moreover, the fender system is not always effective in preventing damage to ships and bridge structures. Since it provides no warning to alert the ship crew that the ship is on a collision course, the fender system can at best only reduce the damage; it is a brute-force, last-ditch protection device.

An electronic warning system is a viable alternative or complement to the fender system. The electronic system could continuously monitor the ship position relative to a safe corridor for passage under the bridge and issue an immediate warning of any deviation from a safe-passage course. The system could also issue warnings to the bridge tender and people on the bridge when a collision is determined to be unavoidable. An advanced design concept of such a system was developed by the Georgia Institute of Technology Engineering Experiment Station (GIT/EES) during a recent study.

Equipment failure and human negligence are the primary causes of accidental damage to bridges by ships, but any system designed to prevent such accidents must also consider other factors; e.g., bridge-waterway configuration, ship navigation characteristics and the effects of wind and tide conditions, system reliability, and liability for accidents attributed to system failure. These design considerations led to selection of a system that uses a shore-based radar and shore-based displays as the most practical concept for an electronic collision avoidance/warning system. The radar would determine the ship's position, and the displays would inform the ship's pilot of the ship's position relative to a safe-passage

corridor. The system would continuously assess the potential for collision during the various stages of the ship's passage. Ship speed and trajectory would be monitored as the ship approached the bridge; this information could be displayed for use by the ship crew in navigating the channel. When the ship approached closer to the bridge and entered a critical maneuver zone, the system would continue displaying the ship position while performing trajectory calculations to determine the possibility of a collision with the bridge. Should the system determine that a collision is possible (given the ship's handling characteristics and position in the channel, tide and wind conditions, and distance from the bridge), an alarm would be sounded to alert the ship crew, the bridge tender, and those on the bridge. Safety systems such as gates could be activated to keep additional traffic off the endangered bridge span.

Although the design concept was developed for the protection of highway bridges, it could be easily adapted for the protection of railway bridges.

### Design Considerations

#### Effects of Ship/Bridge Collisions

Human lives, property, and income are often affected by ship/bridge collisions. The GIT/EES became involved in the design and development of ship/bridge collision warning systems shortly after the freighter African Neptune rammed the Sidney Lanier Bridge near Brunswick, Georgia, on 7 November 1972. Ten people were killed when an entire bridge span was severed from its support system and dumped into the river. The bridge was closed to vehicle traffic for seven months while repairs were being made to the damaged parts of the bridge span. This was not an isolated incident.

A similar accident occurred during January 1975 when the freighter Illawarra struck the Tasman Bridge spanning the Derwent River at Hobart on the Australian island of Tasmania. The collision collapsed an entire bridge span, sinking the vessel and killing at least six persons. Four of the dead were motorists who plunged from the broken span into the river.

Since 1955, the Lake Pontchartrain Causeway in Louisiana has been damaged by waterway traffic 13 times. Nine persons were killed in these accidents.

On 13 September 1976, one motorist was killed and two were injured when the tugboat Leander, Jr. lashed to several barges collapsed a span of the Highway 51 bridge near Pass Manchac, Louisiana, after colliding with the structure.

On 24 February 1977, the sulphur carrier Marine Floridian smashed into the Benjamin Harrison lift bridge, dumping vehicles into the James River near Hopewell, Virginia. The river channel was closed to shipping traffic for 20 days, and the bridge was closed to vehicle traffic until the latter quarter of 1978.

These (and many more documented ship/bridge collisions) accidents indicate a definite need for a collision avoidance/warning system.

#### Cause of Ship/Bridge Collisions

Equipment failure and human negligence are the primary causes of ship/bridge collisions. Human error caused the collision of the African Neptune with the Sidney Lanier Bridge. During the approach to the bridge, the harbor pilot ordered 20-degrees left rudder. The helmsman mistakenly put the rudder 20-degrees to the right. The mistake was noticed too late for compensating actions to prevent the collision.

Eight of the accidents involving the Lake Pontchartrain Causeway Bridge were caused by human negligence; five were caused by equipment failure. All but one of the accidents caused by negligence occurred at night or under twilight conditions. One accident occurred when the helmsman passed out, another occurred when the helmsman fell asleep.

#### Mitigation of Losses

A study of ship/bridge collision reports indicates that suitable warning could substantially reduce accidental losses, particularly human lives. Newspaper accounts of the Sidney Lanier Bridge accident credit three boys with saving the lives of several persons. The boy's cars were stopped with other traffic on the bridge waiting for the African Neptune to pass through the lift. One of the boys realized that the ship was on a collision course with the bridge even before the ship began to sound its whistle as a warning. The boys began beating on the windows of other cars and shouting warnings of the impending collision. Several motorists left their cars and ran with the boys to safety; others, perhaps thinking the boys were joking, rolled up their windows and locked their doors.

Analysis of other similar accident reports revealed several common factors which must be considered in designing a warning system. It appears that when human factors cause a collision the ship crew either can not or does not sound a warning in time for all persons on the bridge to reach safety. In the case where a warning was sounded, few motorists associated the warning whistle with danger. In most accidents, the ships were well outside of a narrowly-defined approach corridor sometimes minutes before the collisions.

These analyses indicate that a warning system designed to prevent or reduce the potential for losses due to ship/bridge collisions should:

1. Notify the ship crew of the ship position relative to the channel centerline.

2. Sense when a ship is on a non-correctible collision course with the bridge.

3. Warn the bridge tender and motorists of the impending collision and give instructions on where to seek safety.

4. Actuate gates and other barriers to prohibit vehicles from entering onto the endangered bridge span.

5. Record the track of the ship as it navigates the waterway for later analysis and court evidence.

#### Bridge-Waterway Configuration

The bridge-waterway configuration affects the need for and the design of a collision avoidance/warning system. Wide waterways offering a straight approach to the bridge reduce the changes of ship/bridge collisions, but these are not always practical. The Sidney Lanier Bridge chosen by the GIT/EES for development of the electronic warning system concept represents a more dangerous configuration, particularly for ships sailing from Brunswick Harbor. Ships approaching the bridge from the south-east (i.e., sailing up the Turtle (Brunswick) River) make a straight approach to the bridge for a distance of approximately 3.3 km (1.8 nmi); very little maneuvering is done by ships approaching from this direction since only minor course corrections are normally required.

The critical part of navigating the channel occurs between the Sidney Lanier Bridge and the Brunswick Port Authority docks. Approximately 457m (1500 feet) north-northeast of the bridge, the channel forms a Y intersection. The right fork goes to the dock area; the left fork continues up-river. The angle formed by the intersection of the river and dock area channel is about 50 degrees. Thus, all large vessels entering or leaving the Brunswick dock area must negotiate a 50-degree turn over a distance of less than approximately four ship lengths. It is during the performance of this maneuver by outbound ships that almost all problems occur that lead to potential collisions with the bridge.

#### Ship Navigation Characteristics

Ship navigation characteristics and the effects of wind and tide conditions combine with the bridge-waterway configuration to increase the possibility of a ship/bridge collision. Large ships, by virtue of their size, are not highly maneuverable. Each ship has a design turning radius that cannot be reduced at will. The turning performance is further degraded when the current vectors of the surrounding water are aligned with the thrust vectors of the ship (ebb tide). Wind can combine with current vectors to further degrade a ship's maneuvering ability.

The rudder size of large ships requires the use of hydraulic systems to relay steering commands to the rudder. This can account for a delay of up to 15 seconds in the ship's response to a steering command. The effectiveness of the rudder is also affected by ship speed; the faster the ship moves, the more effect the rudder has for any given degree of rudder offset.

For ships such as those leaving the Brunswick Harbor, these characteristics pose a paradox. The ship must maintain speed for maximum rudder effectiveness while making the critical turn; yet, the speed cannot be so great that the ship cannot be stopped should the ship fail to navigate for proper alignment with the bridge opening. The range of speed that must be maintained to ensure the proper balance between ship maneuverability and safety is

very narrow. Any system designed to help in avoiding ship/bridge collisions should, therefore, have the capability of displaying the ship's true speed to the pilot.

#### Operational Requirements

The electronic system must function in adverse weather and must provide position information to the ship pilot without distracting the pilot. The use of the radar aboard the ships was rejected as an element in the warning system because the operational performance of shipboard radars varies significantly and requires that the local pilot become familiar with each particular ship radar peculiarities. In addition, it was determined that the pilot should have a system that he can depend on and learn to use skillfully. This requirement dictates that the system must be a permanent fixture having known performance standards. Furthermore, the system should not require that the pilot rig the system for each ship. Thus, the primary requirements are for a shore-based radar system and shore-based displays.

#### System Concept

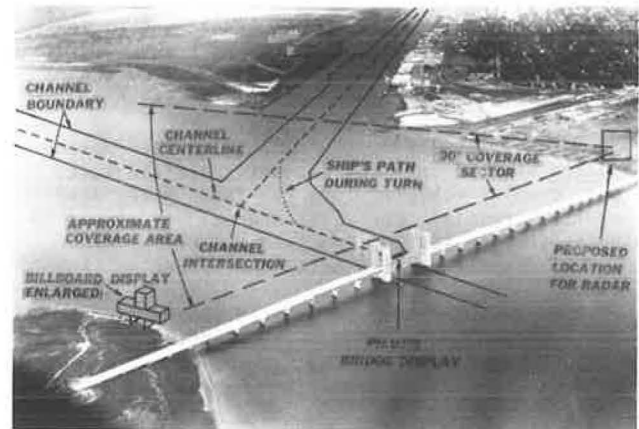
The system concept developed for protection of the Sidney Lanier Bridge is based on the use of a shore-based radar to determine the ship's position and shore-based displays to inform the ship's pilot and the bridge tender of the ship's position relative to a safe-passage corridor. The system concept is illustrated in Figure 1.

The radar would be located so that it would have a clear view of the entire river channel from the mouth of the Brunswick dock area to the bridge, and the antenna would be operated in a sector scan mode to provide an angular coverage of approximately 90 degrees. The radar would track the ship as it left the Brunswick dock area until it reached the bridge. The radar would supply information concerning the location of the ship bow and stern (i.e., orientation of the ship in the channel).

The pilot's display would be a billboard system to provide a heads-up indication of ship speed and distance from channel centerline. The Sidney Lanier Bridge system would require the use of two pilot's displays; one located on the bank and one located on the bridge. Two displays would be used because it is important that the pilot look down the center of the ship bow during turning maneuvers. The pilot would use the shore-based display while emerging from the dock area until reaching a point halfway through the 50-degree mid-river turn. Halfway through the mid-river 50-degree turn, the pilot's field of view would shift to a point near the center of the bridge. At this point, the pilot would use the display mounted in the center of the bridge.

The display system used by the bridge tender would be a miniature version of the pilot's display system and would be mounted on a panel in the bridge control room. Thus, the bridge tender would have access to the same information as the ship pilot. It was reasoned that the bridge tender would eventually learn the proper channel position for the ship as a function of distance from the bridge. The ability of the bridge tender to use his display to warn of a collision would not be left to chance. The radar signal processor would automatically sound an alarm when the ship posed a danger to the bridge. This danger criteria would be computed on the basis

Figure 1. System concept for Sidney Lanier Bridge.



of the ships location in the channel, heading, speed, size, and interactions with tide, current and wind conditions. A second alarm would be sounded if the ship reached a point where collision were imminent. A plan of action could be developed to warn motorists and the pilot, given the two levels of warning available to the bridge tender. This warning would be in verbal form given to motorists (by loudspeaker or other communication device) with instructions on the evasive action to be taken. The evasive action tape recording message would be selected by the radar signal processor.

#### Conclusions

Highway and railway bridges are vulnerable to damage by ships. The consequences of ship/bridge collisions can be far reaching, including the loss of human life. The primary causes of accidental ship/bridge collisions are equipment failure and human negligence. Therefore, an electronic system that reduces the chances of or the losses from such accidents should be given serious consideration.

The system concept developed by the GIT/EES for protection of the Sidney Lanier Bridge represents a near worst case condition. The concept can be readily adapted to provide protection of less vulnerable bridges.

An automated detection and warning system may be a cost-effective alternative to fenders for protection of certain bridges. The system could in many cases provide a warning to motorist much earlier than a ships crew. It could also provide a warning message tailored to get an optimum response as well as provide accurate data for post accident inquiry boards. Ships crews could be given information to improve their navigation and thus decrease the probability of collision. The same system could operate safety barriers to close traffic lanes after collision.

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