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Pier Protection for the Sunshine Skyway Bridge

Protection des piliers du pont Sunshine Skyway

Schutz der Brückenpfeiler der Sunshine Skyway- Brücke

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SUMMARY
This paper summarizes the preliminary engineering and environmental studies performed for the pier protection of the replacement structure for the Sunshine Skyway bridge which collapsed in 1980.

RÉSUMÉ
L'article présente les études préliminaires de génie civil et d'environnement pour la protection de la structure destinée à remplacer le pont Sunshine Skyway, pont détruit en 1980 à la suite d'une collision.

ZUSAMMENFASSUNG
Dieser Aufsatz faßt die vorbereitenden Ingenieur- und Umwelt-Studien zusammen, die zum Schutz der Pfeiler der Neukonstruktion der 1980 gestürzten Sunshine Skyway-Brücke unternommen wurden.

1. GENERAL

On May 9, 1980 during an intense early-morning thunderstorm, the empty 40,000 dwt bulk carrier M/V Summit Venture struck one of the anchor piers of the Sunshine Skyway Bridge across Tampa Bay, Florida. The anchor pier was located 241.4 m from the centerline of the channel. A 396 m section of the southbound main span collapsed, and 35 lives were lost in vehicles which fell into the bay (see Appendix). Since that accident, southbound automobile traffic has been diverted to the parallel bridge structure which will operate under a two-lane, two-way traffic condition until the replacement bridge system is constructed.

The proposed 6.705 Km-long replacement structure (Fig. 1) presently under construction consists of a segmental concrete, single-plane, cable-stayed main span design. Figure 2 depicts 2400 m of the high level approaches and main span portion of the bridge. Estimated construction cost for the replacement bridge is approximately 115 million dollars. The new structure will increase the main span from 256.0 m to 365.8 m and the vertical navigational clearance from 45.4 m to 53.3 m.

Without some form of positive protection, however, the new bridge piers would still be vulnerable to ship collision. To investigate this vulnerability and to decide what types of protection alternatives to implement, the Florida Department of Transportation established a two-phased design process. Phase I, the Preliminary Engineering Phase, consisted of a broad-based evaluation of numerous types of pier protection alternatives, including the environmental impacts. Based on the Phase I study, a decision was made on which alternatives to implement for the project. Phase II services consist of the final design and construction document preparation of those pier protection alternatives which were selected. Because the Final Design Services are on-going at this writing, only the results and recommendations of the Preliminary Engineering Phase will be discussed below.

2. SHIP OPERATION REQUIREMENTS

Regulatory and developmental items relating to the operation of merchant vessels in Tampa Bay were studied. The existing Vessel Traffic Service (VTS) in the bay operates on a level of L_0, the lowest level of VTS under the U.S. Coast Guard's established VTS activity levels. Pilotage is required for all ships, but is not required for all barges. The study recommended that the following vessel operation procedures be implemented.

2.1 Vessel Speed Limits

Establish a vessel speed limit in the vicinity of the bridge. Since a vessel's speed exponentially affects ship impact energy, a limitation on speed will serve to limit the design collision energies. Based on a review of tidal flow velocities, ship operating characteristices, and discussions with the local bay pilots, a limit of 10 knots was recommended.

2.2 Ballast Requirements

Establish a requirement that all outbound light vessels must meet minimum ballast criteria before transiting the channel in the vicinity of the bridge. This requirement will enhance the stability and control of the

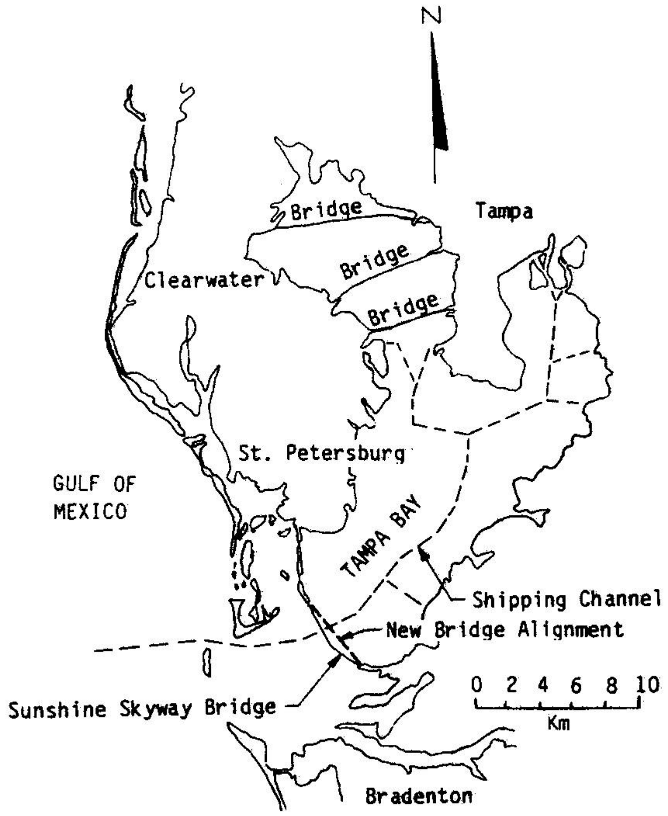


Figure 1. Project Location Map

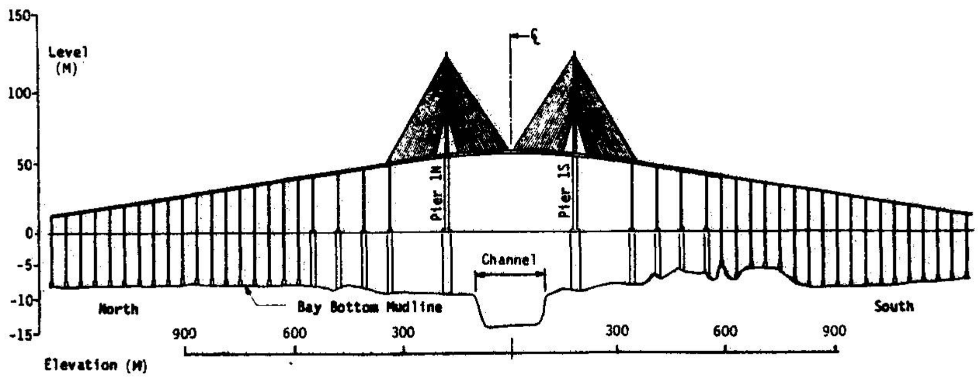


Figure 2. High Level (Main Span) Section of the new Sunshine Skyway Bridge

vessel, particularly during high wind and rough sea conditions. It is of interest to note that all historical collisions with the existing bridge involved vessels (3 ships and 7 barges) which were traveling light and without ballast. The requirement for inbound vessels to ballast is precluded because of potential adverse environmental impacts involved in deballasting polluted water within the sensitive bay environment.

2.3 Weather Requirements

Establish minimum weather conditions under which vessels can transit in the vicinity of the bridge. As a minimum, a predicted 3.2 Km visibility requirement for one hour before and after the vessel is to pass under the bridge would be established before a vessel would be allowed to leave her moorings.

3. STRUCTURAL PIER PROTECTION DEVICES

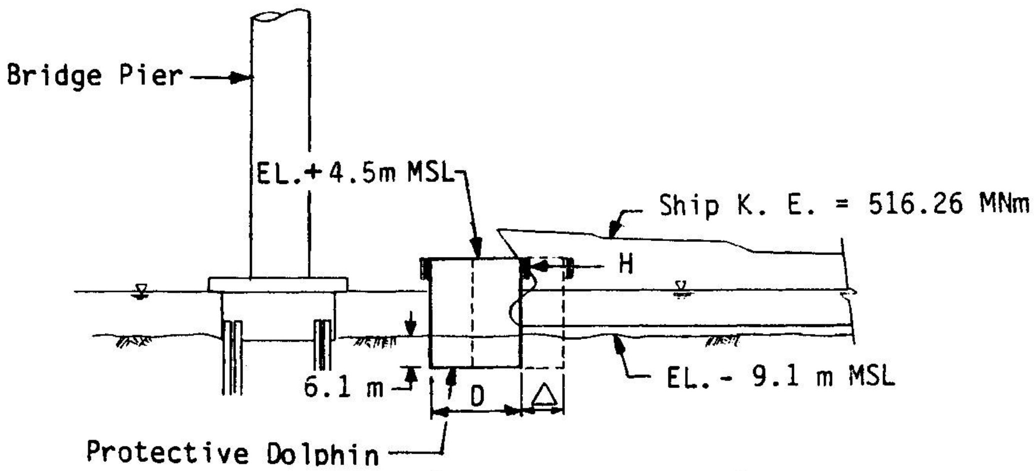
A number of pier protection systems which have been developed for other applications worldwide were considered for use on the Sunshine Skyway. Based on criteria of effectiveness, expected damage to the ship, constructibility, cost-effectiveness, maintenance, safety, and environmental impact as applied to this specific project, many of the systems were deemed unsuitable. These included cable systems, anchored ships and pontoons, sliding caissons, pile group systems, fender systems, and submerged islands. Systems which were shown to be the most desirable for the project consisted of dolphin systems and artificial islands, or a combination of both.

3.1 Dolphins

Dolphins, large-diameter circular sheet pile cells filled with material such as sand or concrete, have been successfully utilized to protect bridge piers in conditions similar to those existing at the Sunshine Skyway. Because of the existing soil conditions, the mode of dolphin failure and subsequent energy dissipation would be by sliding. The ship collision energy would be absorbed through the passive failure of the soil behind the dolphin, and through friction on the bottom of the sliding cell. The approximate length that the dolphin would slide and the duration of the impact were then calculated for the design loading conditions and the specific soils data at the project site (Fig. 3). One of the desirable characteristics of the dolphin circular shape is its tendency to redirect the vessel away from the pier under glancing-blow situations. The preliminary analysis indicated that a cluster of three 18.3 m diameter dolphins should be placed on each side of the principal bridge piers requiring protection (Fig. 4). Due to the presence of a corrosive marine environment, the steel sheet piling would require coating and cathodic protection.

3.2 Artificial Islands

Protection of bridge piers can be accomplished by constructing armored artificial islands around the piers. Several bridges in the world currently have such protection. The islands consist of a sand core which is protected against wave and current action by armored slope protection. Ship impact energy is absorbed by deformation of the island material, the rising up of the ship's weight as it slides up the island slope, and by the friction of the hull sliding against the island. The length that the vessel would penetrate into the island is primarily based on the ship geometry, island geometry, island materials, and the collision energy of the ship



Diameter (D) (M.)	Approx. Failure Load (H) (KIPS)	Approx. Stopping Distance (△) - M.
12.2	6,500	18.3
18.3	12,300	9.5
24.4	19,900	6.1
30.5	29,100	4.0

Figure 3. Ship Impact on Protective Dolphin

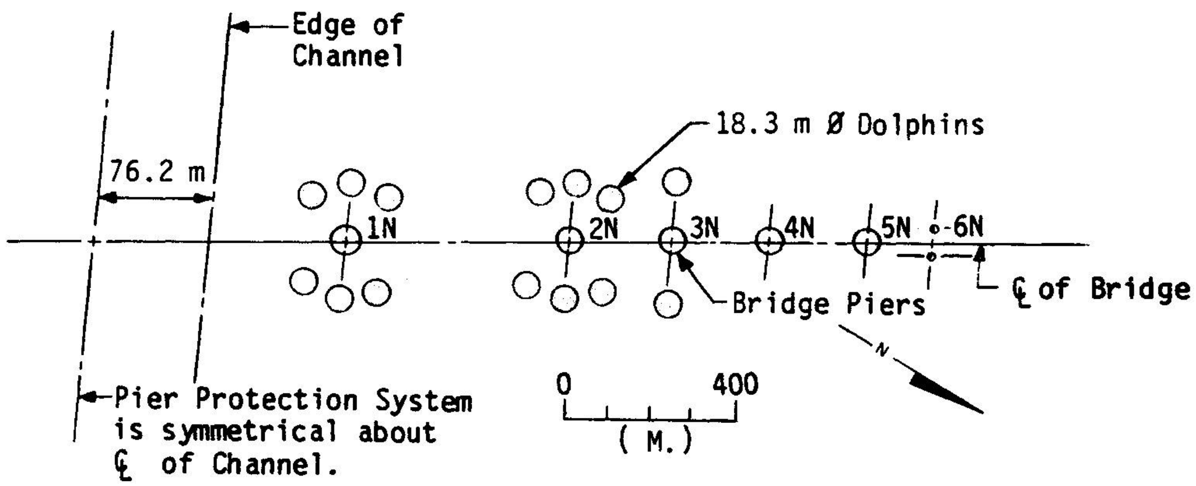
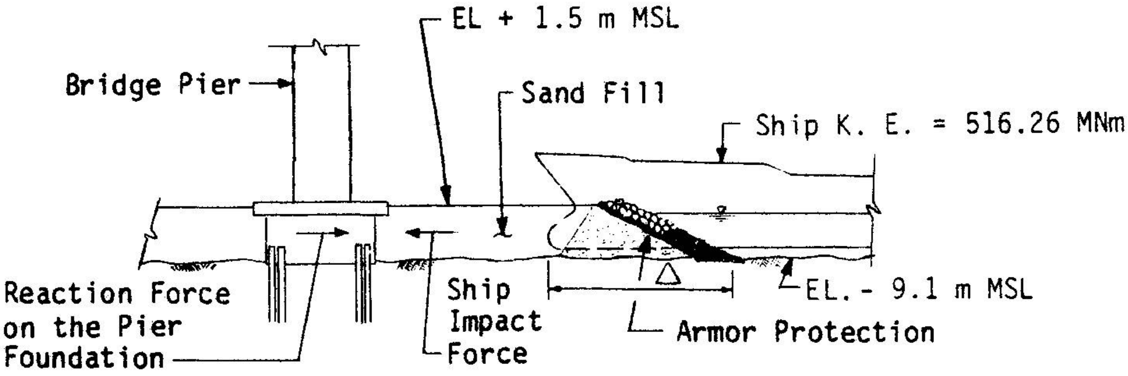


Figure 4. Plan of 6-Pier Dolphin Protection System (Piers 1-3, N & S)



Design Ships	Draft (M.)	Stopping Distance (Δ) - M. (Min.)	(Max.)
21,000 DWT (Loaded)	9.1	21.0	38.7
85,000 DWT (Ballasted)	4.7	28.4	53.3

Figure 5. Ship Impact on Protective Island

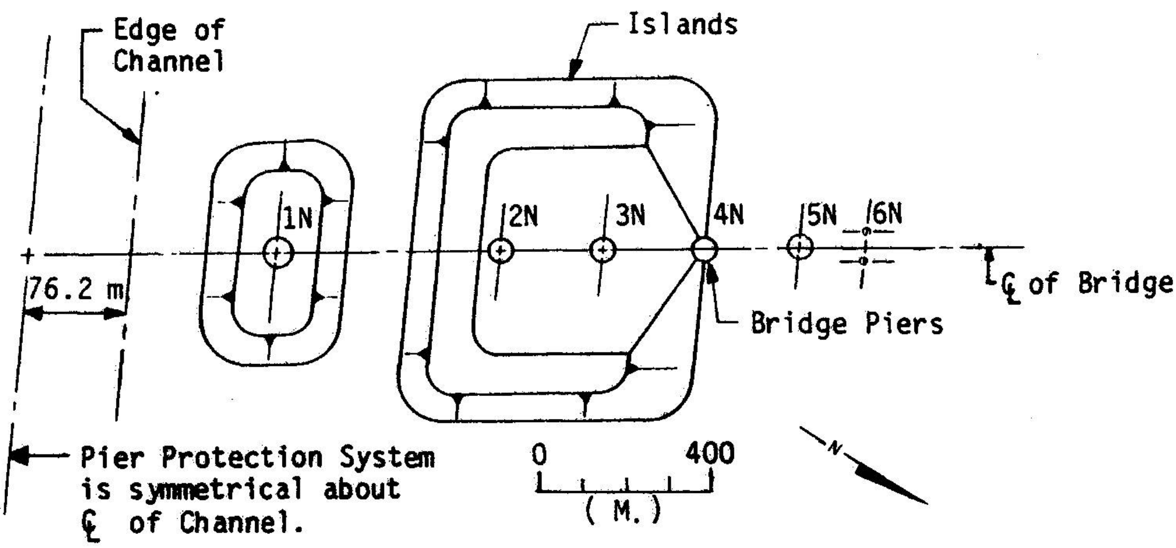


Figure 6. Plan of 6-Pier Island Protection System
(Piers 1-3, N & S)

(Fig. 5). The islands provide a high degree of ship collision protection from any direction, redirect vessels away from the piers, and stop a ship slowly, thus preventing major damage to the ship's hull. In addition, islands have a long life expectancy, are relatively maintenance free, and require only minor repairs after a ship collision. The proposed island configuration for the Skyway (Fig. 6) includes a horseshoe-shaped island, which was designed to create a positive environmental habitat in which marine life can flourish.

4. ENVIRONMENTAL IMPACTS

A preliminary environmental impact analysis was performed on the various dolphin and island alternatives under consideration. The primary focus of the study was the effect of the artifical islands on bay hydrologic patterns and on the ecology. A mathematical model was used to simulate the bay hydrologic activity and to assess the impacts of the various structural pier protection alternatives (Fig. 7). The analysis indicated that no significant changes would occur due to the dolphin alternate, and that acceptable impacts would occur due to the island alternate, providing the length of island coverage was restricted to protecting no more than six piers on each side of the channel. Extending the islands beyond this would cause excessive tidal flow velocities in the shipping channel which would adversly affect vessel operations in that area.

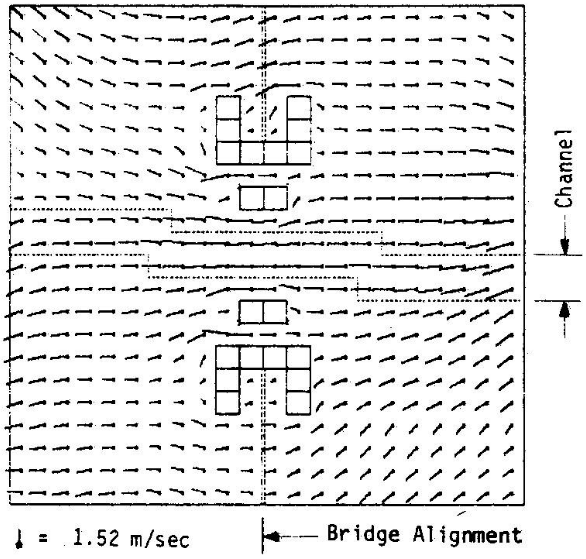


Figure 7. Typical Tidal Velocity Vectors For The 6-Pier Island Protection

5. AIDS TO NAVIGATION IMPROVEMENTS

The study recommended measures to improve the existing system of buoys and range-markers in the vicinity of the bridge. While the existing system met the minimum requirements established by the U.S. Coast Guard, it was believed that an improved system in the vicinity of the Sunshine Skyway would be of substantial benefit in providing mariners and pilots with as much navigation data as possible. The analysis indicated that 60 to 85 percent of all vessel accidents in the Bay are caused by piloting errors, with barge accidents occurring at twice the rate of ship accidents. The latter is probably a result of the lack of a requirement for all barges to utilize professional pilots.

6. ELECTRONIC NAVIGATION AID SYSTEM

In addition to assessment of the traditional aids to navigation, the study examined a variety of all-weather electronic navigation aid systems to assist a pilot in determining accurate (within 6 m) ownship position relative to the channel and the bridge. The systems studied included various types of microwave and Loran positioning systems. The system found most desirable for possible use in the Tampa Bay Harbor is based on the Loran-C signal network presently maintained by the U.S. Coast Guard. Loran-C provides ownship position information through computer processing of time-difference signals broadcast from several remote locations. Historically, the accuracy of Loran-C (usually 60 m to 800 m) has been unacceptable for precision channel navigation in restricted harbor areas. However, recent developments in the accuracy of Loran-C receivers and the development of the Loran-C survey technique have potentially alleviated this problem.

The Loran survey consists of recording time-differences at numerous positions along a shipping channel, and simultaneously computing exact ownship position referenced to a second survey system (usually a microwave system). The difference in location between the two sets of signals is the error (or the distortions) in the Loran-C grid due to the surrounding land mass. These distortions are then programmed into a small computer coupled to the Loran receiver which will then automatically compensate for the grid distortions as a vessel navigates through the channel and thus provide a pilot with accurate ownship position. To calibrate the device for daily and seasonal changes in the Loran grid, a fixed land reference station is established in the harbor area.

As part of the Skyway pier protection system, a portable, battery-powered, lightweight (less than 9.Kg) Loran-C unit as described above is being developed and tested. The unit will be carried on board a vessel by a pilot for use during the vessel's transit. The proposed unit will provide not only digital information regarding ship position and operation, but also a visual display of the vessel maneuvering within the harbor area.

7. MOTORIST WARNING SYSTEM

To protect motorists from an incident similar to the M/V Summit Venture accident, the development of a bridge warning system for both the existing and the proposed structure was undertaken. In general, the system includes vibration detectors to detect ship collisions, bridge continuity circuits to warn of a superstructure failure, weather instrumentation, closed-circuit television to monitor both ship and motorist traffic, and variable-message signs to warn motorists of bridge conditions. This warning system is recommended for the new bridge since there remains the possibility that unprotected approach piers could be struck.

In addition, the study recommended that direct VHF radio communications be established between the bay pilots and the bridge operator controlling the motorist warning system. This would enable a pilot to warn the bridge operator in the event his vessel was out of control and on a collision path with the bridge. This warning would allow the bridge operator to clear the bridge of motorist traffic prior to the potential accident.

8. THREAT ANALYSIS

The threat analysis accomplished early in the study [1] indicated that all the alternatives recommended for consideration were cost-effective. The analysis modeled the risk of vessel impacts to various bridge elements, the cost of repairing or replacing those elements damaged, the cost to the port from channel closure due to a fallen span, the cost of rerouting vehicular traffic resulting from bridge closure, and the cost of avoiding the damage by implementation of the various protection systems. The study concluded that as a minimum, the first three piers on each side of the shipping channel should have structural pier protection devices. Table 1 summarizes the cost effectiveness of the various alternatives studied.

Pier Protection Alternative	Initial Cost	Annual Maintenance	Expected Lifetime (Years)	Benefit/Cost Ratio (5% Discount)
Dolphins - 4 Piers	$17,230,000	$23,000	35	3.48
Dolphins - 6 Piers	20,022,000	26,880	35	3.32
Dolphins - 12 Piers	28,603,000	38,400	35	2.26
Islands - 4 Piers	20,440,000	7,000	50	4.59
Islands - 6 Piers	24,080,000	14,000	50	4.33
Islands - 12 Piers	34,240,000	28,000	50	3.54
Standard Navigation Improvements	1,000,000	6,000	20	17.33
Electronic Navigation System	600,000	8,000	10	6.49
Motorist Warning System	220,000	5,000	10	4.26

Table 1. Benefit/Cost Ratios for Pier Protection Alternatives

9. SUMMARY

The preliminary investigation revealed that if the new Sunshine Skyway bridge were to be unprotected, it would still be relatively vulnerable to possible ship collisions and, therefore, the implementation of adequate pier protection devices would be required. As a percentage of the overall bridge construction, the implementation of a 6-pier protection structural system, navigation improvements, electronic navigation device, and the motorist warning system represents approximately 23 percent (26 million dollars) of the total bridge cost, and 34 percent of the high level approaches and main span cost. The high cost associated with adequate protection is a result of the increased probability of catastrophic ship collision as larger and more frequent ships and barges utilize the Tampa Bay channel system.

REFERENCE

1. Knott, M. and Bonyun, D.: Threat Analysis for Ship Collisions against the Sunshine Skyway Bridge. IABSE Colloquium on Ship Collision with Bridges and Offshore Structures. Publications IABSE, 1983.

APPENDIX

Photograph of the M/V Summit Venture accident with the existing Sunshine Skyway Bridge on May 9, 1982.

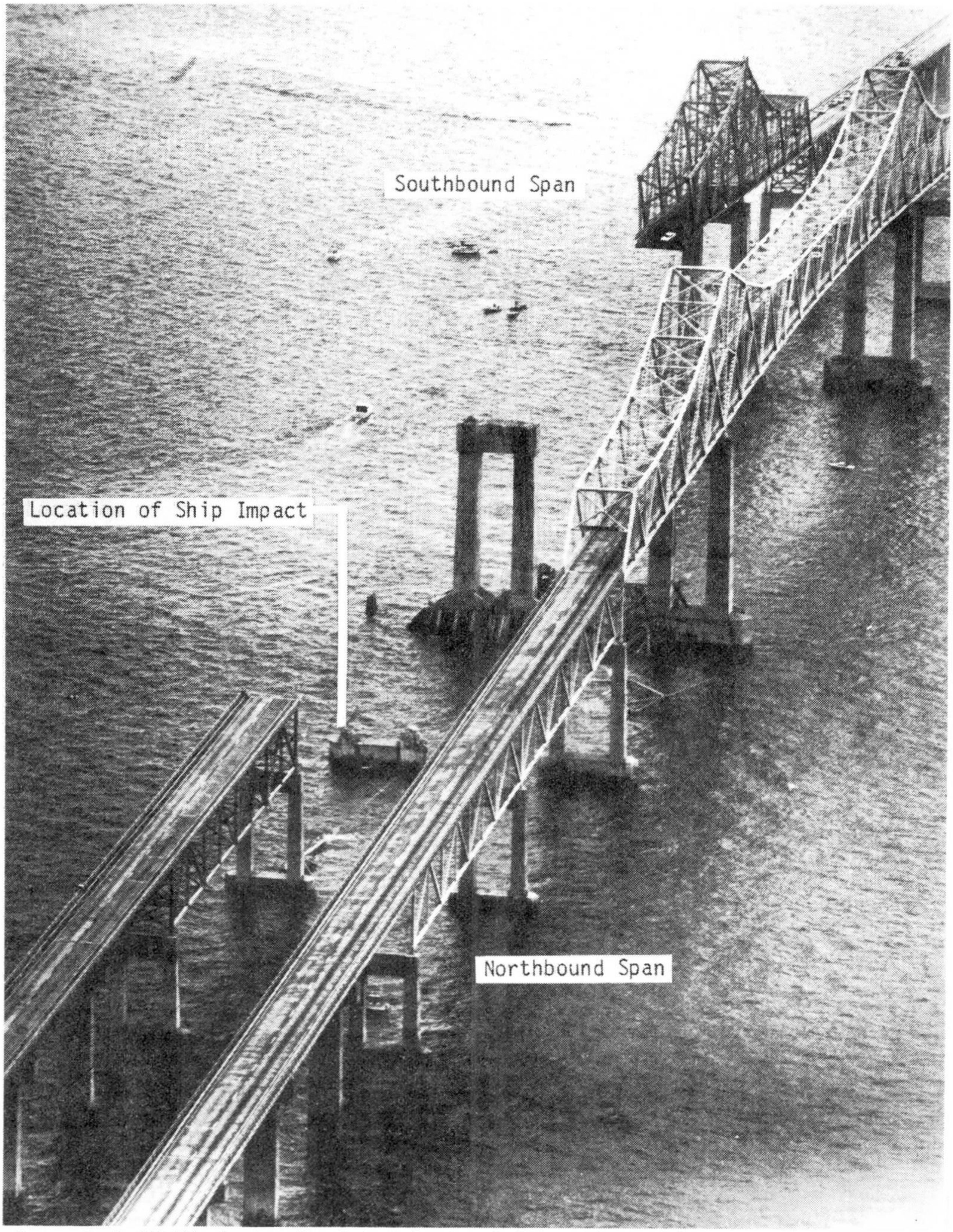


Photo: T. P. O'Neill, Courtesy Shackleford, Farrior, Stallings & Evans, P.A.

Sunshine Skyway Bridge, May 9, 1980 after being struck by the M/V Summit Venture