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History of Floating Bridges in the State of Washington

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INTRODUCTION

Floating bridges are not new. In fact, they are one of the earliest types of bridge for spanning wide waterways. This is not to say that there is nothing new about floating bridges. As I will try to illustrate in this presentation, there have been a series of interesting applications of this concept throughout history around the world, a concentration of concrete floating bridges in Washington State in the past 50 years, and others are planned or being considered in several countries.

In Washington State we now have four concrete floating bridges, each over a mile in length, making us the floating bridge capitol of the world. The first one, built in 1940, crosses Lake Washington at Mercer Island and is now called the Lacey V. Murrow Bridge. The next one was built at Hood Canal on Puget Sound in 1961, followed closely by the Evergreen Point Bridge across Lake Washington in 1963. Now we have added the Third Lake Washington Bridge which, along with the Lacey V. Murrow Bridge, will carry Interstate 90 and transit system traffic.

To a bridge engineer, a floating bridge presents a challenging assignment because it involves technology that he does not ordinarily use. He must become familiar with naval architecture and the behavior of moored ships. The sciences of oceanography and meteorology are suddenly of great importance. The dynamic response of the structure to wave-loading may be far more significant than the traffic the bridge will carry. Floating bridges must handle large motions in all directions. Therefore, the anchorage system and the connections with fixed portions of the bridge become critical. All of these things make the floating bridge unique in

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the bridge engineer's world. The fact that very few have been built in modern times means that each one is a special case, and has a story of its own. I don't have time to tell all of the fascinating history of floating bridges, so I have selected a few that I think are interesting.

Before describing Washington State bridges further, I would like to review briefly some of the other floating bridges throughout history.

ANCIENT BRIDGES

The earliest recorded floating bridges were built by the Persian kings in their military escapades into southern Europe. The most dramatic early floating bridge episode was in 480 B.C., when Xerxes' Army needed to cross the Hellespont. First, Egyptian engineers built two floating bridges of boats, but unfortunately, both of these were quickly destroyed by a storm. This angered Xerxes so he beheaded the engineers and then ordered that the water be lashed 300 times to punish it, as well. He somehow found new engineers who built a better bridge, this time with nearly 700 ships anchored fore and aft in two lines. Over each line of ships were placed six large cables; made of flax and papyrus. On top of these main cables were placed wood planks held in place by a second layer of cables above. Then a roadway with parapets was built on top of the planks using brush and earth. It is variously recorded that from 300,000 to 2½ million troops crossed this bridge. The design was further sophisticated by having, in three places, gaps between the boats, to allow small craft to pass through. This bridge seems to have been well designed and it did serve the initial purpose well. Can you imagine this in 480 B.C.?

MORE RECENT BRIDGES

A long-time floating bridge site is the Golden Horn at Istanbul, Turkey. There have been bridges here for centuries, the early ones of wood and later ones of steel.

Features developed by the designers of these bridges, over the years, include openings for the passage of small boats, a movable span for passage of larger vessels, a cable anchorage system, continuity over several pontoons by using a steel framed superstructure, and a two-level bridge to accommodate a variety of users.

At present, two floating bridges at the Golden Horn are still in service, although the oldest one, built in 1912 is being replaced by a fixed bridge with a bascule opening.

Although various floating bridges were built in America within the last century or two, one that I found quite impressive was the Prairie du Chien bridge across the Mississippi River in Wisconsin. This was a movable wood pontoon railroad bridge first built by John Lawler in 1874, but the design was actually done by a German immigrant named Michael Spettel. He developed a design which accommodated a seasonal change in water elevation of over 20 feet by raising and lowering the elevation of the railroad tracks on the 408' long pontoon swing span by using a system of variable height support blocks under the floor beams. This bridge was rebuilt several times and operated continuously for many years by the Chicago-Milwaukee.

OTHER FLOATING BRIDGES

Aside from strictly military use of temporary floating bridge equipment, there is a civilian type of bridge that has been used both for temporary and permanent installations in many places around the world. A commercial company builds and sells a modern version of this type of bridge. One example is this road bridge across a wide river in Guyana, South America, which even has a drawspan unit for ship passage. These bridges use steel pontoon units, and bailey bridge type superstructures with articulated connections.

THE FIRST CONCRETE BRIDGES

The first floating bridge in this state is now called the Lacey V. Murrow Bridge, and with good reason. Lacey Murrow graduated from Washington State College and started his engineering career with our Highway Department. He rapidly rose through the ranks to become the Director at the age of only 28. During his term from 1933 until 1942, the crossing of Lake Washington became a major feature in the transportation system in this state. Back in the 20's, some ideas came forth for crossing Lake Washington. The high cost of conventional fixed bridges in the deep water and soft bottom was the major problem. A floating bridge of timber barges or surplus ships was at one time proposed and an engineer was sent to the Golden Horn in Turkey to see what had been built there, so the idea of a floating bridge across Lake Washington gained some momentum.

During this period, a young Seattle engineer, Homer Hadley, suggested that a concrete pontoon bridge might be feasible. He had worked during World War I for a Philadelphia firm designing concrete barges. His

suggestion was that hollow concrete barges connected rigidly end-to-end could be made into a bridge using the top-side as a roadway. He had some difficulty in selling this concept, but he persisted and when, in 1937, the Legislature established the Washington State Toll Bridge Authority he took his idea to Lacey Murrow who, as Director of Highways, also served on that board.

There were two routes being considered at that time for a crossing, and the one that was generally favored crossed from Seward Park to Mercer Island. This route was shorter across the water and a more conventional fixed bridge could conceivably be built.

Lacey Murrow decided to choose the other route calling for a longer bridge, and also adopted Homer Hadley's suggestion of a concrete floating bridge. The route more directly connected the center of the population of Seattle with the Snoqualmie Pass Highway to the east, thus it better served the regional transportation needs as well as opening up the east side of Lake Washington to development. The selection of a floating bridge was based primarily on the fact that it would cost considerably less than even the fixed bridge on a shorter route. So, Homer Hadley should be given credit for suggesting this type of bridge and promoting concrete as the best bridge material. Lacey Murrow had the courage to make a controversial decision in the face of skepticism and ridicule by various factions. Indeed, when the bridge opened on July 3, 1940, certain wags wore life jackets to show their lack of faith.

Another name that immediately comes up when one reviews the floating bridges in this state is Charles E. Andrew. He graduated from the University of Illinois in 1906 and his first job was that of an engineer on the longest railroad bridge in the world. It seems he was destined to be involved in major bridge projects, many of them controversial.

In 1921 he was hired by the State of Washington as the Chief Bridge Engineer for the Highway Department. The California Highway Department hired him away in 1927, and while in California, Mr. Andrew became the Principle Bridge Engineer in charge of the San Francisco/Oakland Bay bridge.

He came back to the State of Washington in 1939 - this time as Chairman of the Consulting Board on proposed Lake Washington Floating Bridge.

The Consultant Board reviewed the concept and determined that a floating bridge was indeed feasible, safe and of such a nature that the public would use it. Charley's engineers had to determine what physical force would have to be met to make the bridge stable. I understand that the engineers actually anchored a barge on the lake and had a tugboat pass by making as large waves as it could so that the designers could learn more about wave forces.

The first Lake Washington Bridge became a total success with the motoring public and the bonds were paid off in only nine years; much sooner than had been predicted.

Charles Andrew successfully dealt with the challenges of developing the first concrete floating bridge. He also went on to oversee the development of the Hood Canal and Evergreen Point Bridges.

OTHER CONCRETE BRIDGES

The Hobart Bridge

Shortly after the Lake Washington bridge, a separate but somewhat similar project in Australia was designed and built. This was the curved bridge across the Derwent River at Hobart in Tasmania. It was assembled first in two long segments, then joined at the center by a hinge. In the shape of an arch with the convex face upstream the structure had inherent resistance to the river current. The total floating length was 3,168 feet and the cross-section was similar to but smaller than the Lake Washington design. Credit for the design goes to the Public Works Department of Tasmania. The bridge was built in 1943, suffered some storm damage problems and eventually was replaced by a high level bridge in 1965.

With the use of the arch shape to resist lateral forces, no transverse anchorage system was needed. This concept has served as a model for proposed crossings where water depth precludes the use of anchors.

The Lake Okanogan Bridge

In 1957, a concrete floating bridge was built across Lake Okanogan at Kelowna in south central British Columbia. Its floating length is 2,100 feet and its design is very similar to the Lake Washington Bridge. This may be due to the fact that Charles Andrew was an advisor to the Canadian design firm of Swan and Wooster. The bridge has functioned well and remains in service today. Built for two lanes, the province is planning to widen to four lanes by adding cantilever wings.

The Original Hood Canal Bridge

Next in sequence comes the Hood Canal Bridge across an arm of Puget Sound in Washington State. This is an inland sea with a tidal range of 18 feet, and storm conditions more severe than Lake Washington. Designed in the late 1950's as a toll bridge under Charles Andrew's direction, the initial design suffered damage during construction. He had patterned the design after the successful Lake Washington Bridge, but elevated the roadway on a viaduct above the pontoons, some 20 feet above water to avoid salt spray on the vehicles. Crossing deeper water than Lake Washington, with a significant tidal current and a 600 foot drawspan opening for naval vessels added to the complexities of this design. During storms it is common for seas to break over the lower deck and flood the top surface of the pontoons. This splash zone salt water exposure required special precautions to protect the electrical and mechanical equipment.

The bridge was redesigned during construction by the engineering firm of HNTB. They added some external tendons inside the pontoons to further prestress the concrete. The bridge opened to traffic in 1961 and served reasonably well, although it frequently required repair in the drawspan elements.

The Evergreen Point Bridge

In the meantime, the second Lake Washington bridge was built at Evergreen Point, some four miles north of the first bridge. It opened to traffic in 1963. The design was essentially the same as the original Lake Washington bridge, but used partial prestressing in addition to mild steel reinforcement. The location is more severe than the first bridge, having a

larger open water fetch, so the storm action has caused some operational problems and structural damage. With some retrofitting in the drawspan area, the structure is now quite reliable, and if it were only wider to handle more traffic, would be even more successful. Built as a toll facility, it also paid off the bonds quickly.

The Replacement Hood Canal Bridge

A storm on February 13, 1979, totally destroyed the entire western half of the Hood Canal Bridge. The structure took on water and broke up in domino fashion, sinking to the bottom of the canal. This was one of the more dramatic moments in the history of floating bridges, and we were glad that Xerxes was not our boss.

The exact cause and sequence of failure were a subject of some controversy, but it was quite clear that to be totally reliable, a much stronger bridge was needed. The replacement bridge is a fully post-tensioned structure designed by a joint xventure of Parsons Brinckerhoff and Raymond Technical Services. Reopening of traffic was accomplished in 1982 with a bridge fully designed to withstand stresses from dynamic response to wave loading. This is the first bridge to have been sized to meet this design criteria, and it did require substantially more structural capacity.

The Third Lake Washington Bridge

The newest bridge, called the Third Lake Washington Bridge, is still under construction. Since it will be described in detail by the presentations following mine, I will not try to cover that project except to include it in some comparisons that I have prepared.

COMPARISONS

All of the concrete floating bridges in Washington are basically of the same configuration. The pontoon structure is a series of concrete barges of cellular construction, sometimes using precast elements joined rigidly end to end to form a continuous beam. The chart compares the basic cross sections of these bridges. You can see that the Lacey Murrow Bridge and the Evergreen Point are very similar. The Third Lake Washington Bridge is the only one with cantilever wings to create a wider roadway surface. The second Hood Canal Bridge pontoons are wider and deeper than the first bridge giving it 2 to 3 times the bending capacity.

While the earlier designs at Lake Washington have far less capacity than the new Hood Canal Bridge, their less severe environment protect them from being as critical during storms. We feel comfortable in continuing to use these bridges, although their reliability to withstand extreme events is not as good as we would like to have.

The Lacey V. Murrow Bridge will be refurbished and modified as part of the I-90 project. The fact that a 50-year old concrete bridge of such unique design remains suitable to use as part of a brand new interstate is a testament to the original designers and builders, and to the durability of concrete as a bridge material.

The remaining east half of the Hood Canal Bridge has been rehabilitated and made as reliable as is possible. Although it does not meet the strength criteria we used for the new west half, it is more protected by geographical features.

A comparison of lengths show that Evergreen Point is the longest of these bridges, and therefore, is the longest floating bridge in the world. All of the bridges in Washington are well over a mile in length, much longer than the Lake Okanogan Bridge.

Two types of drawspans to provide for navigation have been used in these bridges. The Lacey V. Murrow Bridge had a drawspan which required a curved roadway or "bulge" for traffic to bypass the drawspan well. This proved dangerous when traffic volumes became heavy, so the drawspan was removed in 1981, when a higher level bridge east of Mercer Island was built to allow larger vessel navigation to use that channel.

The Evergreen Point Bridge drawspan has the other configuration, which we call a lift/draw, and results in a safer straight roadway. The Hood Canal Bridge now has one of each of these types. The remaining east half of the original bridge has the bulge type of draw, while the new west half has the lift/draw design.

These drawspan features have been the most difficult parts of the floating bridges to maintain. They are more vulnerable to storm damage, and are sensitive to marine exposure, especially at Hood Canal. Fortunately, the new Third Lake Washington Bridge does not require a navigation opening.

Cost comparisons are always interesting. The data shows that we have a considerable investment in floating bridges, with a total present worth of nearly \$400 million in Washington State. Since the bridges are of different lengths and sizes, a unit cost comparison is more realistic.

This shows that when converted to a 1987 base, the Lake Washington bridges are consistent, and in fact, decreasing in cost over time. The Hood Canal bridge is much more costly on a square foot basis, largely because it is a two-lane facility where the others are four or more lanes. On a cost per cubic yard basis, the new west half is about the same as the original, showing that the cost increase with the new west half is due to its much more sturdy design.

When compared to fixed long-span bridges or tunnels as alternate structure types for crossing wide, deep waterways, floating bridges generally show a cost of less than half of the closest competition.

FUTURE BRIDGES

Over the years we have been contacted by engineers in many countries who are considering a floating bridge and want to learn from our experience.

Most likely, the next concrete floating bridges will be in Norway, where their interest and studies have been going on for many years. They are now in final design of two bridges; one at Solhus, and the other at Bergsoysund. Both of these will use the curved arch-like concept because the water depth and bottom shape in these fiords make submerged anchorage impractical. I understand that one of these bridges will be under construction in 1988.

It seems likely that the floating bridge, one of the earliest types used to cross wide waterways, will be used even more in the future, and undoubtedly will remain a challenge to the engineers that design and build them.