SH-100 BRIDGE

OVER THE ARKANSAS RIVER
MUSKOGEE & SEQUOYAH COUNTIES, OKLAHOMA

VESSEL COLLISION RISK ASSESSMENT

For

STATE OF OKLAHOMA
DEPARTMENT OF TRANSPORTATION

By

Modjeski and Masters, Inc.
New Orleans, Louisiana

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SH-100 BRIDGE

TABLE OF CONTENTS

APPENDIX A – SITE VISIT REPORT

APPENDIX B – BRIDGE DATA

APPENDIX C – HISTORICAL ACCIDENT DATA

- C1 BRIDGE COLLISION INCIDENT STUDIES
- C2 DATA ON SERIOUS BRIDGE COLLISIONS
- C3 USCG ACCIDENT ANALYSIS: ACCIDENTS ON THE MCCLELLAN-KERR ARKANSAS RIVER NAVIGATION SYSTEM FROM 1991 TO 2001
- C4 USCG ACCIDENT ANALYSIS: SUMMARY OF ACCIDENTS ON THE MCCLELLAN-KERR ARKANSAS RIVER NAVIGATION SYSTEM FROM 1991 TO 2001

APPENDIX D – VESSEL TRAFFIC DATA

- D1 U.S. ARMY CORPS OF ENGINEERS PUBLICATIONS "WATERBORNE COMMERCE OF THE UNITED STATES" (WCUS) FOR THE YEARS 1977 THROUGH 2001
- D2 PAST THE POINT ANALYSIS CONDUCTED BY THE U.S. ARMY CORPS OF ENGINEERS WATERBORNE COMMERCE STATISTICS CENTER (WCSC) AT OUR REQUEST FOR THE YEAR 2000
- D3 LPMS LOCK STATISTIC SUMMARY REPORTS FOR THE YEARS 1995 THROUGH 1999
- D4 SPECIAL ANALYSIS CONDUCTED BY THE U.S. ARMY CORPS OF ENGINEERS NAVIGATION CENTER LOCK PERFORMANCE MONITORING SYSTEM (LPMS) AT OUR REQUEST FOR THE YEAR 2001

APPENDIX E – VULNERABILITY ANALYSIS DATA

- E1 HISTORICAL PROBABILITY OF ABERRANCY BASE RATE COMPUTATIONS
- E2 RISK ANALYSIS CALCULATIONS
- E3 RISK ANALYSIS CALCULATIONS WITH PROPOSED PROTECTION MEASURES

1. INTRODUCTION

1.1 Authority

This study was authorized by the Oklahoma Department of Transportation under Project No. IMY-0040-6(292)290, JP No. 20029(09), EC-696B2, with notice to proceed on July 9, 2002.

1.2 Scope of Work

The objective of this study was to evaluate the risk of vessel collision for the state owned bridge crossings over the McClellan-Kerr Arkansas River Navigation System in Oklahoma and, if necessary, make recommendations that can reduce the likelihood and consequences of vessel collision. The scope of work included the following tasks:

1. Review vessel collision related bridge characteristics, such as horizontal and vertical geometry, number size and location of bridge piers, cross sections and reinforcing details.
2. Collect information on waterway characteristics such as channel layout, river bottom elevations, river stages and discharge and current velocities.
3. Collect information on the vessel and traffic characteristics, including vessel types, number of vessels by type and size, loading conditions, transit speeds and history of accidents.
4. Determine pier capacities, evaluate the risk of vessel collision with the bridge piers and assess annual frequencies of collapse.
5. Recommend possible prevention and protection measures, if needed.

1.3 Approach

The study follows the guidelines provided in the "AASHTO Guide Specification and Commentary for Vessel Collision Design for Highway Bridges," 1991 Edition (AASHTO Guide 1991). The data collection involved the use of numerous sources of information including federal and state agencies, organizations, individuals and various publications. The data collected was first evaluated for consistency among the several sources and then analyzed and reduced to a format suitable for risk analysis. The pier capacities were determined for several limit states based on both linear and non linear analyses. The risk of vessel collision was evaluated in accordance with Method II of the AASHTO Guide. Calculation spreadsheets were created to allow for easy evaluation of the effects of changes in the input data and possible future use in the design of bridges over the McClellan-Kerr Arkansas River Navigation System.

The report presents findings of the evaluation of the risk of vessel collision with the bridge piers, as per Method II of the AASHTO Guide. These findings are intended to provide the Oklahoma Department of Transportation with the information necessary for selecting the most appropriate prevention and/or protection measures or for performing further analysis using the Method III of the AASHTO Guide.

2. BRIDGE CHARACTERISTICS

2.1 Location, Type, Size, and Geometry

The SH-100 Bridge is located in Muskogee and Sequoyah Counties, near Webbers Falls, Oklahoma, as shown in Figure 2.1-1. It crosses the Arkansas River portion of the McClellan-Kerr Arkansas River Navigation System, at river mile 363.1, between the Webbers Falls Lock & Dam (upstream) and the Robert S. Kerr Lock & Dam (downstream), within the Kerr Lake Conservation Pool. The navigation distance from the bridge to the Webbers Falls Lock & Dam is 3.5 river miles, and the distance to the Robert S. Kerr Lock & Dam is 26.9 river miles. The SH-100 Bridge is located 2.8 miles upstream from the I-40 Bridge.

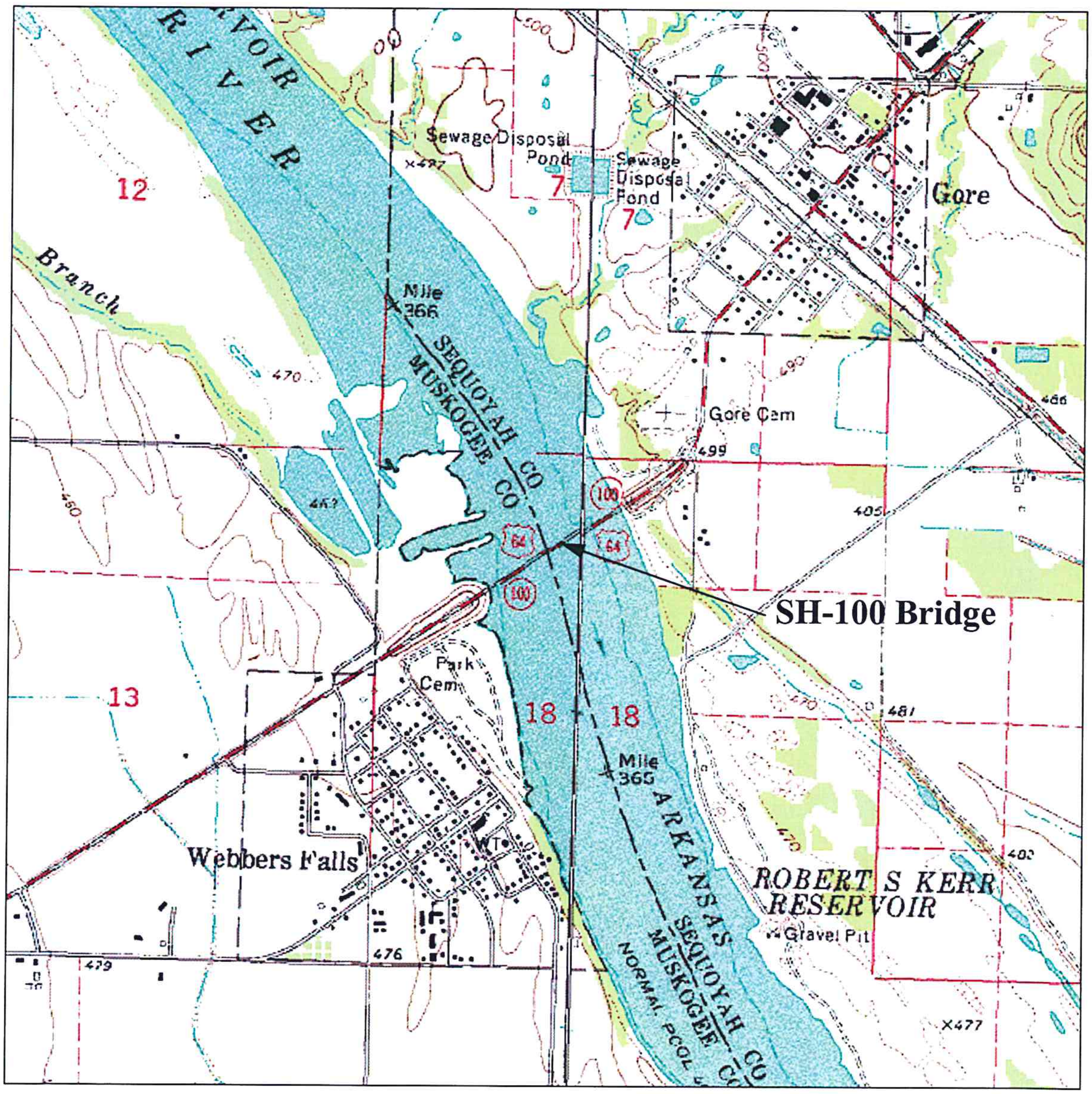


Figure 2.1-1: Bridge Location

The bridge is 1,928.25 feet long and consists of 15 composite steel plate girder spans on concrete piers (see Figure 2.1-2). The main span is 334 feet long over the navigation channel. The construction of the bridge was completed in 1967.

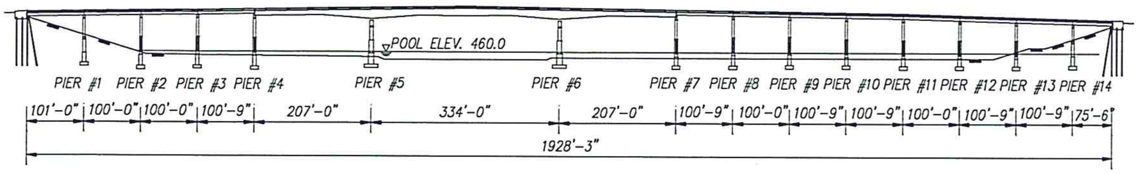


Figure 2.1-2: Bridge Elevation

A vertical clearance of 52.0 feet from the 2% flowline elevation (EL. +470.5) and 62.5 feet from the pool elevation (EL. +460.0) is provided in the 300 foot wide navigation channel. Figure 2.1-3 shows an elevation view of the channel span with the available navigation clearances. Additional site and bridge information is included in Appendix A.

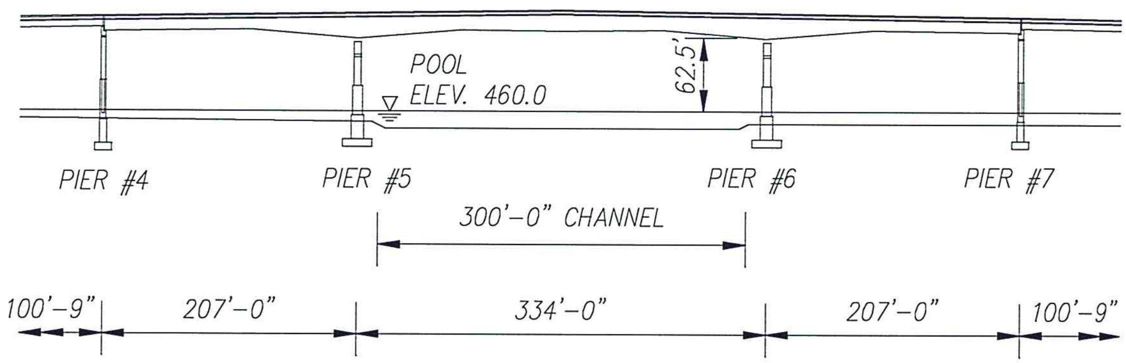


Figure 2.1-3: Elevation View of the Navigation Channel of the Bridge

2.2 Design Criteria

The bridge design was completed in 1966 prior to the development of criteria for vessel collision design. Two dolphins on the upstream side of the bridge were provided in the original design to protect the piers adjacent to the navigation channel.

2.3 Piers, Footing Depth and Soil Information

The piers exposed to vessel access include Piers 2 through 13. Piers 1 thru 4 and 7 thru 13 are two column concrete piers with a concrete web wall, as shown in Figure 2.3-1. The upper portion of the pier consists of two 4 foot diameter columns and a 5 foot deep pier cap. The middle portion of the pier has two 5 foot diameter columns with a 2 foot thick web wall, followed by two 6 foot diameter columns. The 6 foot diameter columns rest on spread footings which are 12 or 14 feet long, 8 feet wide and 5 feet deep. The spread footings are typically founded between Elevation 430 and 440 within a layer of hard shale.

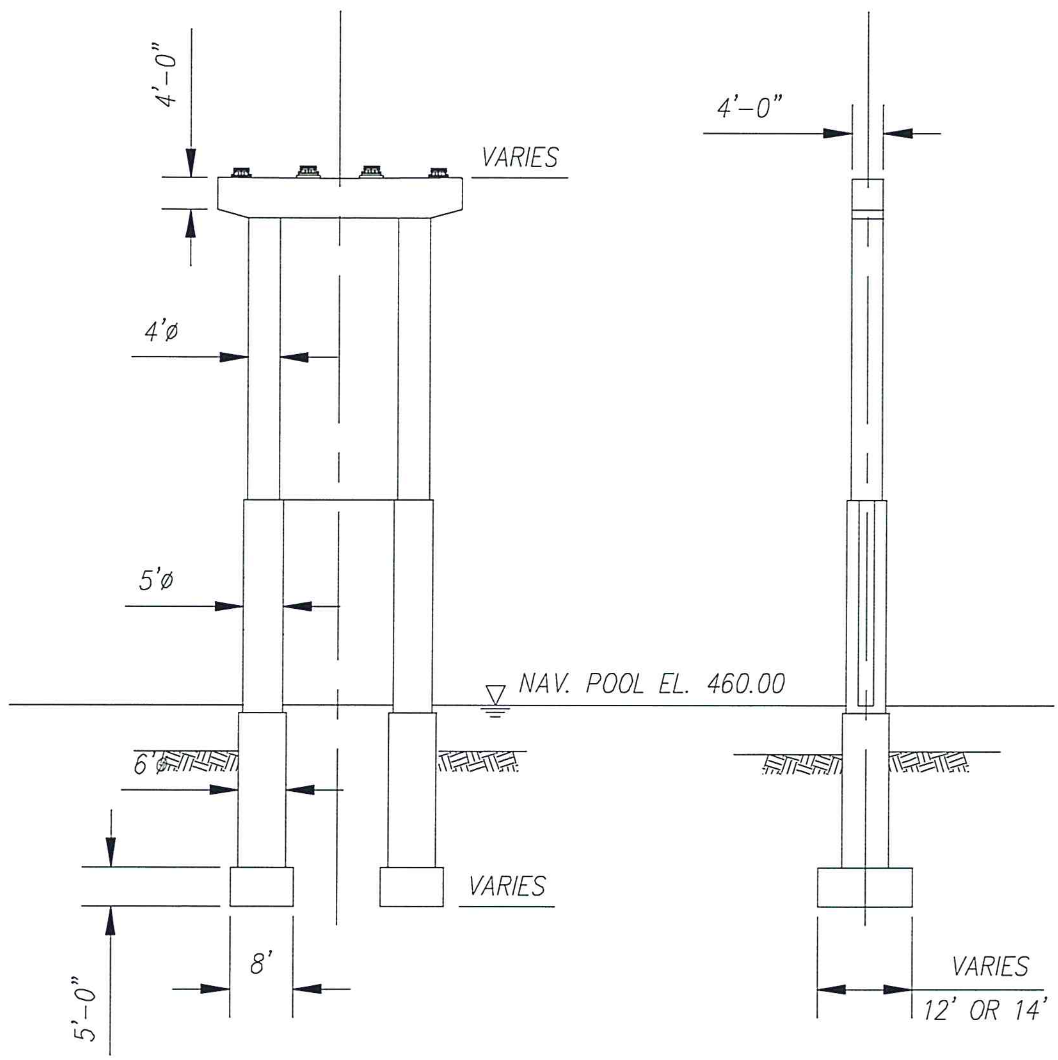


Figure 2.3-1: Piers 2 thru 4 and 7 thru 13

Piers 5 and 6, which are adjacent to the navigation channel, are solid concrete piers, resting on spread footings, as shown in Figure 2.3-2. The spread footings, which are 31 feet long, 21 feet wide and 6 feet deep, are founded at Elevation 433 within a layer of hard shale.

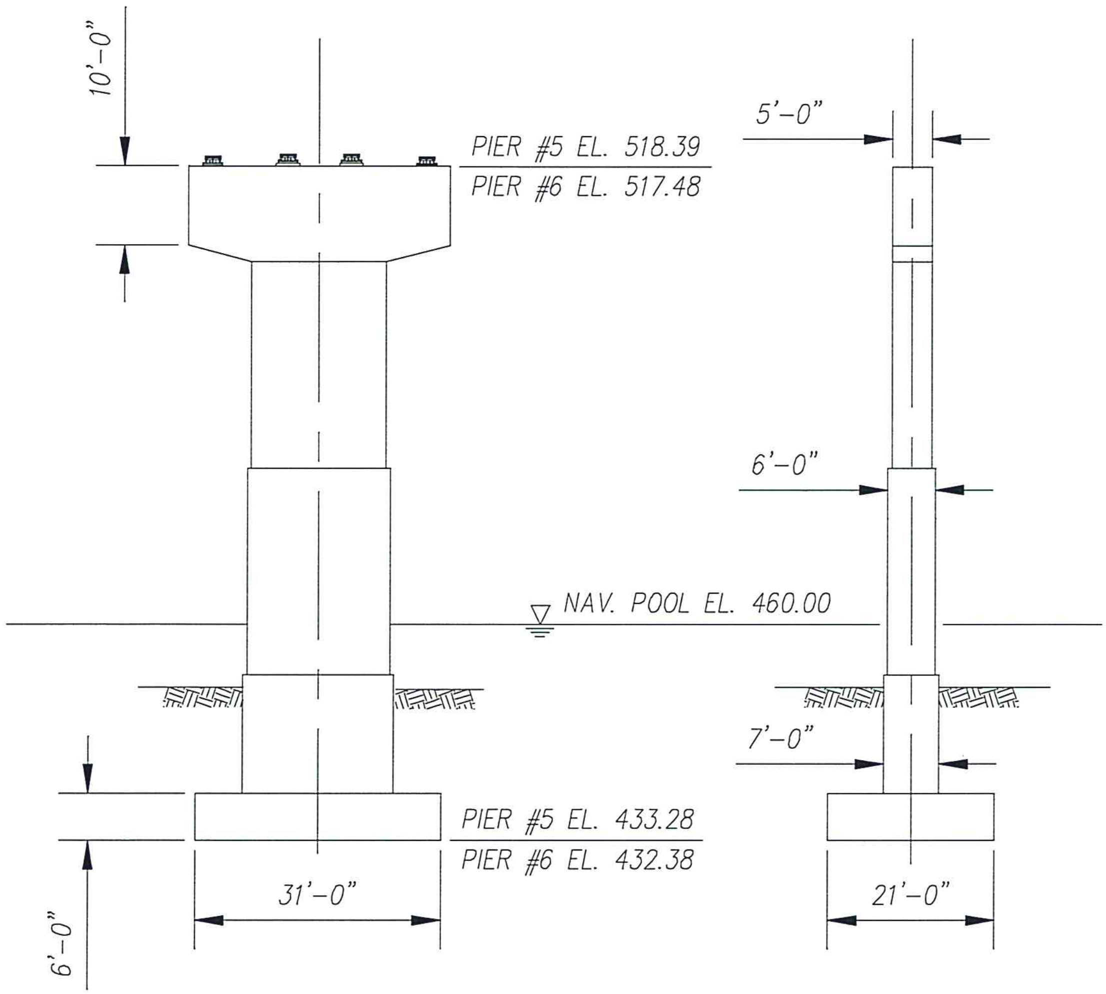


Figure 2.3-2: Piers 5 and 6

2.4 Existing Protection

Two 40 foot diameter steel sheet pile dolphins are located directly upstream from the channel piers (Piers 5 and 6) as shown in Figure 2.4-1.

Figure 2.4-1: Sheet Pile Dolphins at Piers 5 and 6

3. RISK FACTORS AND HISTORICAL ACCIDENT DATA

3.1 General

The risk of vessel collision with a bridge reflects both the likelihood of a collision and its consequences. The factors involved are related to the following events: 1) an approaching vessel becomes aberrant and strays off course in the vicinity of a bridge, 2) the aberrant vessel is on a collision course with one of the bridge piers, and 3) the pier impact results in serious bridge damage or collapse. These factors are affected by the waterway and navigation conditions, the vessel characteristics, and the bridge location, geometry and strength characteristics.

Data on the history of marine accidents in a given waterway region can provide information on how likely it is for a vessel to lose control while approaching a bridge crossing and potentially strike it. In addition, it can help identify collision prevention measures. Loss of vessel control can result in groundings, collisions with other vessels or collisions with fixed structures. Note that in the maritime industry the term collision is only used to refer to impact between two vessels, while the term allision (or ramming) is used for impact of a vessel with a fixed structure (e.g. a ship with a bridge pier, lock or docked vessel).

The main causes of marine accidents can generally be grouped into mechanical failure, human error and environmental conditions categories. The role of the environmental conditions in an accident is somewhat subjective since in many cases adverse environmental conditions can be regarded as merely influencing factors to the human error category. Other influencing factors include waterway conditions, bridge characteristics, and vessel traffic and navigation conditions.

3.2 Bridge Collision Incident Studies

The increased frequency of barge tow accidents at bridges in the early 1970's and the increase in the volume of hazardous materials being transported by water led to several U.S. Coast Guard investigations of the causes and the relative importance of the various factors involved. The rise in the number of vessel accidents was attributable to the relatively large increase in the waterborne traffic and the size of the barge tows. For example, the waterborne commerce increased by about six times from the 1950's to the 1970's.

A summary of previous vessel incident studies is included in Appendix C1. These studies indicate that the majority of the bridge collision accidents reported occurred on only a few of the waterways and mainly at certain locations, which usually have little margin of navigation error. By evaluating the statistical data of all of the incidents, it was found that the most common cases include a bridge near a bend during high water periods, a movable bridge with a narrow span opening or several bridge crossings next to each other. The majority of the causes of bridge collisions were related to human performance and only a small percentage to mechanical failure. At most locations the accidents were frequent and the damage was not significant.

However, a closer review of only the more serious and rare accidents indicates that they have mainly occurred at unexpected locations and that the general findings based on the statistics of all reported incidents are not representative. For example, an analysis of the serious collision accidents worldwide (INCOM 2001) has found that the navigation difficulty, the weather conditions and sharp bends in the waterway were of minor importance. Thus, when evaluating a certain waterway segment or bridge crossing, a distinction needs to be made between the likelihood of frequent and minor bridge collisions at locations with little margin of error and the likelihood of rare but serious collisions at unexpected locations.

3.3 Data on Serious Bridge Collisions

In order to evaluate the nature and the causes of serious bridge collisions that may occur at normal navigation sites, historical accident data on significant accidents that have occurred in the past has been compiled (see Appendix C2). A review of the data suggests that the serious collisions with fixed spans tended to group into two cases. In one case, the vessel pilot or operator was not aware that he was out of the navigation channel or the navigable waterway, and, in the other, the vessel operator fell asleep or was incapacitated.

3.4 Marine Incidents on the Verdigris and Arkansas River

In order to assess the likelihood of vessel aberrancy on the McClellan-Kerr Arkansas River Navigation System in Oklahoma, a special search and analysis of vessel incidents involving collisions, allisions, loss of vessel control and groundings in the Verdigris and Arkansas rivers from 1991 through 2001was conducted as part of this study.

The vessel incident information was obtained primarily from the available volumes of the *United States Waterway Data* CDs. These CDs, which are published annually by the U.S. Army Corps of Engineers, contain files that are a compilation of U.S. waterway data from multiple sources, including the Navigation Data Center, the Bureau of the Census, and the U.S. Coast Guard. One section of data that is available on the CD is the U.S. Coast Guard Marine Casualty and Pollution Investigations. The data in these files are extracted from the Marine Safety Information System (MSIS) database, which is a database of marine casualty and pollution investigation reports conducted by U.S. Coast Guard investigators. The CDs that were obtained provided incident information for the following calendar years: 1993, 1994, 1996, 1997, 1998, 1999, 2000 and 2001.

To supplement these reports, a query was made in the U.S. Department of Transportation, Bureau of Transportation Statistics database, TranStats. Because the TranStats reports do not include the location of the incident on the river or river mile, a special request was made to the U.S. Coast Guard, under the Freedom of Information

Act, to search their main database and retrieve the river mile points for the incomplete records. The data provided to the U.S. Coast Guard included the incident date, case number, USCG activity number, vessel name and accident type. A listing of the reported accidents on the McClellan-Kerr Arkansas River Navigation System is included in Appendix C3.

The search of vessel incidents identified 11 allisions, 61 groundings, 2 collisions and 20 loss of vessel control cases. This represents an average of about 9 reported aberrant vessel incidents per year on the Verdigris and Arkansas River. The allisions reported involved four bridges in Arkansas (I-430 Bridge, I-30 Bridge and two railroad bridges) and several lock & dam structures in Arkansas. The majority of the groundings reported also occurred in Arkansas mainly in areas that had locks, facilities or sharp bends in the waterway. Vessel grounding locations in Oklahoma include MI 311.5, about 3 miles upstream from the US-64 Bridge in Fort Smith, MI 386, about 6.5 miles downstream form the US-62 Bridge, Muskogee, MI 393, 0.5 miles upstream from the US-62 Bridge, Muskogee, MI 393.3 at a terminal just upstream of US-62 Bridge, Muskogee, and MI 394.5, about 2 miles upstream from the US-62 Bridge, Muskogee. None of the vessel incidents reported were very serious.

Figures 3.4-1 and 3.4-2 show the number, type and location of these incidents by river mile. Figure 3.4-1 contains incident data for the entire system, with a line representing the Arkansas-Oklahoma border that has been added to differentiate the two sections. It shows a significant decrease in the number of incidents that occurred in Oklahoma compared to Arkansas. Figure 3.4-2 concentrates on the Oklahoma portion of the waterway, with additional lines symbolizing bridge locations.

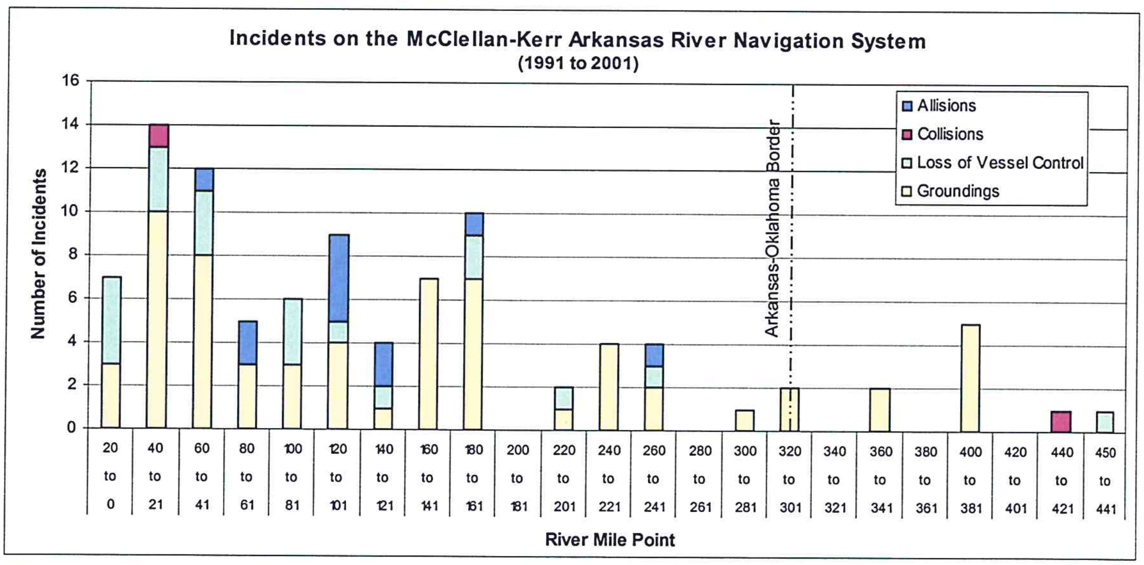


Figure 3.4-1: USCG Accident Analysis (1991 to 2001): Incidents on the McClellan-Kerr Arkansas River Navigation System by River Mile Range

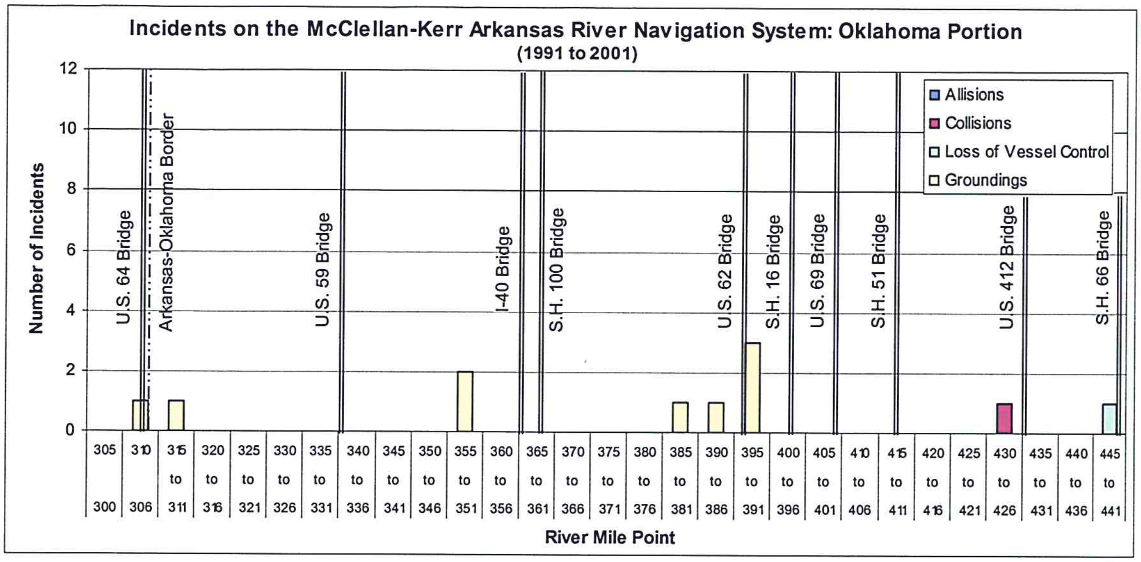


Figure 3.4-2: USCG Accident Analysis (1991 to 2001): Incidents on the McClellan-Kerr Arkansas River Navigation System by River Mile Range: Oklahoma Portion

The results of the analysis of the accident data are summarized in Tables 3.4.1 and 3.4.2 and Figures 3.4-1 through 3.4-4. Table 3.4.1 provides a distribution of the accidents by type and state, and Figure 3.4.3.a illustrates the percentages of accident types over the entire McClellan-Kerr Arkansas River Navigation System. The data shows that groundings are clearly the most prevalent accident type, both for the entire system and for each state individually. Collisions are the least frequent, with only one incident in each state for the period of review. Most notably, during this period, there were no reported allisions with bridges on the Oklahoma portion of the waterway, although Arkansas had 4 incidents. Additional accident information is included in Appendix C4.

Table 3.4-1: USCG Accident Analysis (1991 to 2001): Accident Type by State for the McClellan-Kerr Arkansas River Navigation System

	Accident Type					
State	**Allision w/ Lock**	**Allision w/ Bridge**	**Grounding**	**Collision**	**Loss of Vessel Control**	**Total**
Arkansas	7	4	55	1	19	86
Oklahoma	0	0	8	1	1	10
Total System	7	4	63	2	20	96

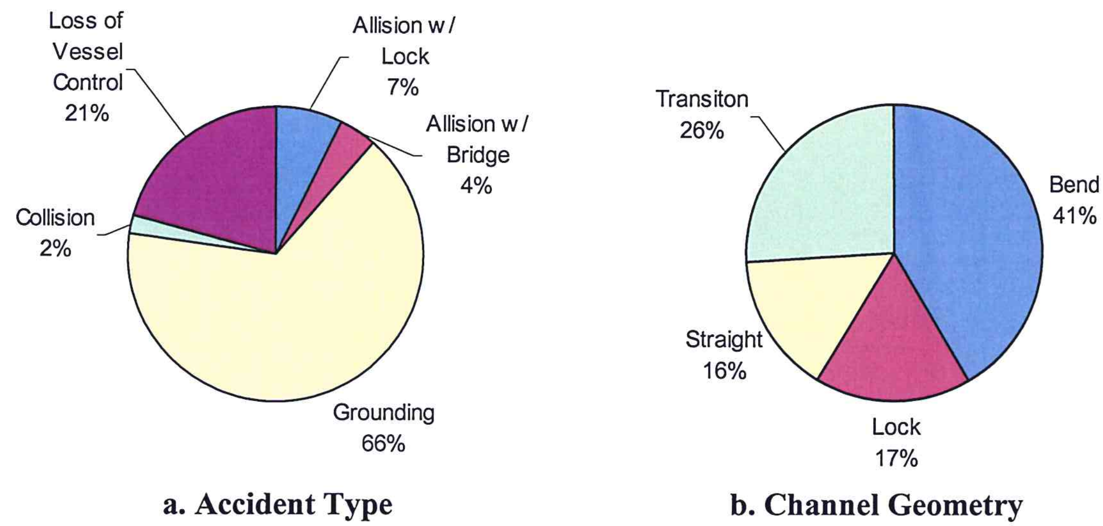


Figure 3.4-3: USCG Accident Analysis (1991 to 2001) for the McClellan-Kerr Arkansas River Navigation System

Table 3.4.2 groups the accident data by channel characteristics at the accident site and state, and Figure 3.4.3.b illustrates the percentages of accidents by channel conditions at the accident sites over the entire McClellan-Kerr Arkansas River Navigation System.

Table 3.4-2: USCG Accident Analysis (1991 to 2001): Channel Geometry at Accident Site by State for the McClellan-Kerr Arkansas River Navigation System

	Channel Geometry				
State	Bend	Lock	Straight	Transition	Total
Arkansas	34	16	15	24	89
Oklahoma	6	0	0	1	7
Total System	40	16	15	25	96

The accident data on the Verdigris and the Arkansas River generally confirms the tendency for accidents to cluster at certain locations along the waterway, as found in previous studies. Many of the accidents occurred at lock & dam structures, which are not representative of the conditions at bridge crossings. The data also suggests a tendency for some towing vessels to be more involved in accidents than others, which may be an area for further study of risk reduction measures. Relative to other waterways the frequency of accidents on the McClellan-Kerr Arkansas River Navigation System River is quite low and even lower in the Oklahoma portion. For example, the frequency of bridge allisions on the Arkansas River during the time period 1992 through 2001 is about 15 to 20 times lower than the frequency of bridge allisions on the Mississippi River System estimated in the U.S. Coast Guard-American Waterway Operators Bridge Allision Work Group (2003) study.

3.5 Marine Incidents near the Bridge Site

From 1991 through 2001, there were no accidents reported within a ten mile range of the SH-100 Bridge.

4. WATERWAY CHARACTERISTICS AND ENVIRONMENTAL CONDITIONS

Adverse waterway characteristics and environmental conditions have a direct influence on the navigation conditions and the probability of vessel aberrancy. Accident statistics indicate that adverse waterway and environmental conditions such as awkward channel alignment, poor visibility conditions (fog or rainstorms), strong currents, and wind squalls are common influencing factors in vessel collision accidents.

4.1 Sources of Information

The waterway characteristics for the McClellan-Kerr Arkansas River Navigation System (MCKARNS) were determined based on information from several sources that include:

- U.S. Army Corps of Engineers (USACE) McClellan-Kerr Arkansas River Navigation System Navigation Charts
- U.S. Army Corps of Engineers (USACE) McClellan-Kerr Arkansas River Navigation System Lock & Dam Gages
- United States Geologic Survey (USGS) Gage Stations on the McClellan-Kerr Arkansas River Navigation System
- Ports of Catoosa and Muskogee
- Discussions with the U.S. Army Corps of Engineers (USACE) Hydraulics Division Navigation Engineering Support

4.2 Channel Layout and Geometry

The McClellan-Kerr Arkansas River Navigation System (MCKARNS) is maintained as a 9 foot deep draft navigation channel. The river at the SH-100 Bridge is approximately 1,500 feet wide, and the navigation channel is 300 feet wide.

The passage of the River and Harbors Act by Congress on July 24, 1946 authorized the building of the McClellan-Kerr Arkansas River Navigation System. This authorization provided for construction of a 9 foot deep channel from the Mississippi River to Catoosa, Oklahoma, a distance of 450 miles. In addition to accommodating navigation, the project was to incorporate a design mix of hydropower facilities, flood control capabilities and recreational purposes. The MCKARNS, which begins at the junction of the White River and the Mississippi River, flows 10 miles up the White River, then 10 miles up the man made Arkansas Post Canal, and into the Arkansas River. It continues up the Arkansas River to Muskogee, Oklahoma, where it transfers onto the Verdigris River for the remaining 50 miles before reaching the head of navigation at the Tulsa Port of Catoosa. Construction of the navigation system began in 1957 and was completed in 1970. On January 5, 1971, an Act of Congress (PL 91-469), designated the official name of the waterway as the McClellan-Kerr Arkansas River Navigation System (MCKARNS).

Authorized by Congress, the Little Rock and Tulsa Districts of the U.S. Army Corps of Engineers are currently conducting a feasibility study on the MCKARNS to improve navigation capabilities and reduce the flooding of adjacent lands. Phase I of the study will evaluate the flow management on the system and propose alternatives. Proposed alternatives may include deepening the navigation channel from 9 feet to 12 feet through dredging, deepening the channel from 9 to 12 feet by raising the pool elevations, and channel widening. Phase II will consider all of the environmental and socioeconomic aspects of the alternatives proposed in Phase I. The Phase I report is scheduled for completion in April 2004, and the Phase II report is scheduled for completion in March 2005.

The SH-100 Bridge is located on the Arkansas River section of the MCKARNS, at river mile 363.1. There are gradual bends in the channel on both the upstream and downstream sides of the bridge. A 39° bend is located approximately 6,520 feet on the upstream side of the bridge, and a 17° bend is located approximately 1,780 feet on the downstream side of the bridge. The bridge is aligned slightly skewed relative to the channel as shown in Figures 4.2-1 and 4.2-2. Figure 4.2-1 is an aerial view of the bridge and waterway, and Figure 4.2-2 is a USACE Navigation Chart. A larger scale version of the USACE Navigation Chart is included in Appendix B.

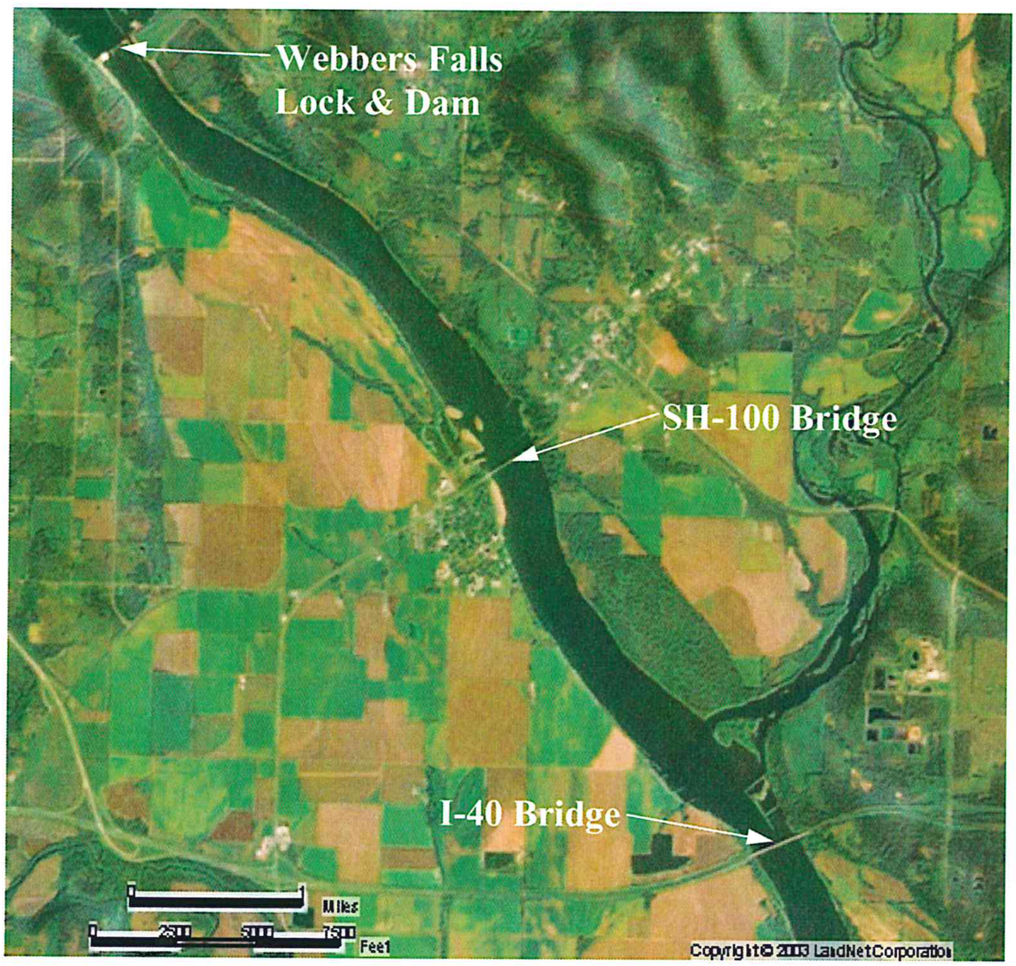


Figure 4.2-1: Aerial Photo of Bridge Vicinity (1:75,000)

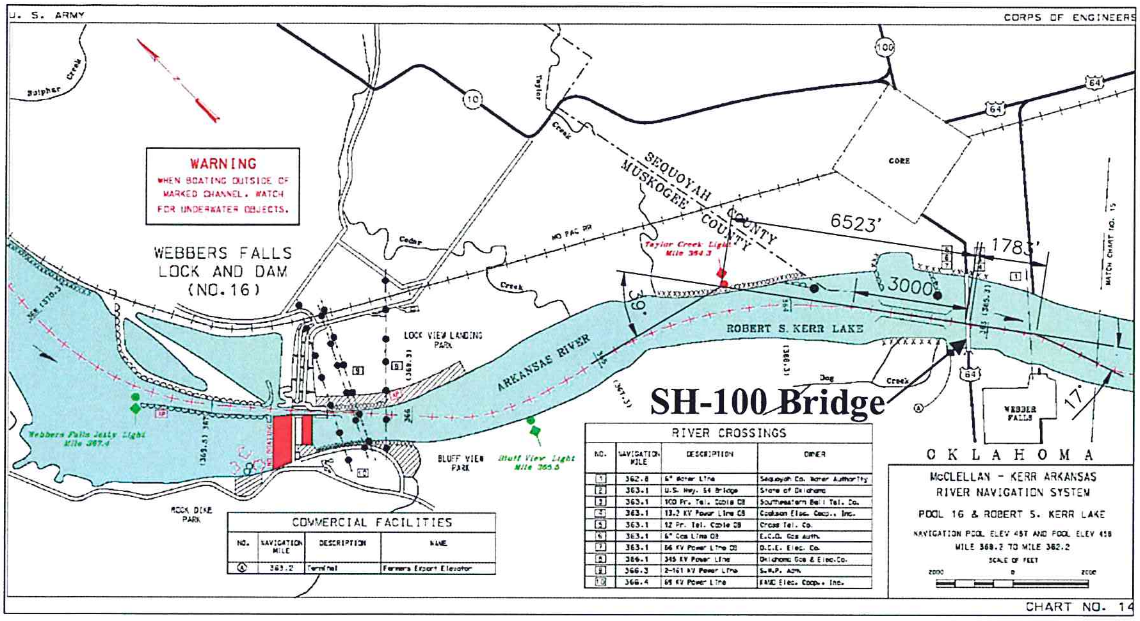


Figure 4.2-2: Navigation Chart Showing Channel Bends (USACE)

4.3 Water Depth and Fluctuations

Except for extreme events, water levels on the McClellan-Kerr Arkansas River Navigation System vary little since they are controlled by the 17 lock and dam structures. Figure 4.3-1 shows a representative hydrograph of the pool elevation readings at the Robert S. Kerr Lock and Dam, located at river mile 336.2. It also includes the 2% flowline, used to represent the flood event water level at the bridge, and the navigation pool elevation. Figure 4.3-1 illustrates that the river elevation does not very much and is about 11 feet lower than the 2% flowline.

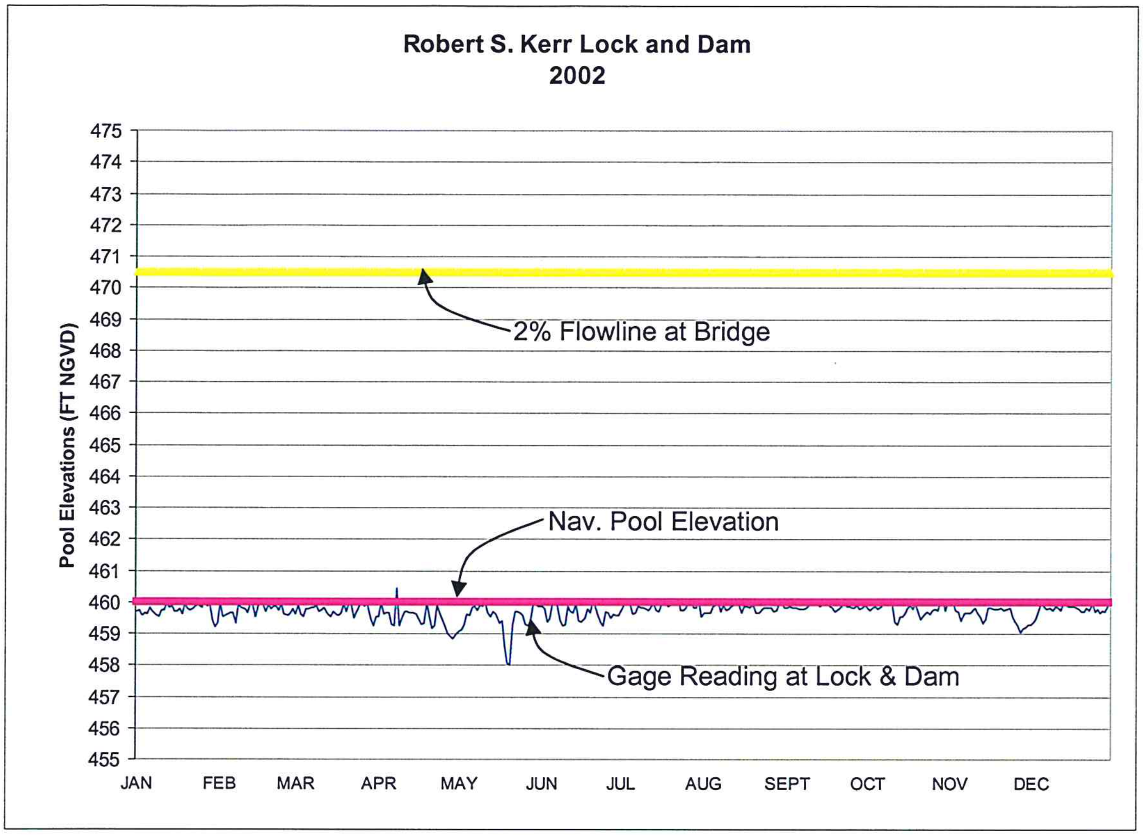


Figure 4.3-1: Pool Elevations at the Robert S. Kerr Lock and Dam for 2002

The reason for the large difference in elevation between the 2% flowline and the navigation pool is that the lock and dam structures on the waterway are not used to control flood events. As the flood event occurs, the flow is constricted at the dam, and this causes the river profile to rise upstream of the dam as the water "backs up". The further upstream from the dam a bridge is, the greater the difference will be in the 2% flowline from the navigation pool. When a flood does occur, the navigation system is closed in advance of the water levels reaching the lock machinery. The last flood event that forced a closure of the locks and dams on the system occurred in 1990.

The United States Geological Survey (USGS) operated a stream gaging station near the bridge site on the Arkansas River, near Muskogee, Oklahoma. Figure 4.3-2 shows the daily discharge readings for this station, from October 1, 1925 to September 30, 1970. The daily discharge readings from the Muskogee gage show that the daily discharge has rarely exceeded 100,000 cubic feet per second since the early 1960's.

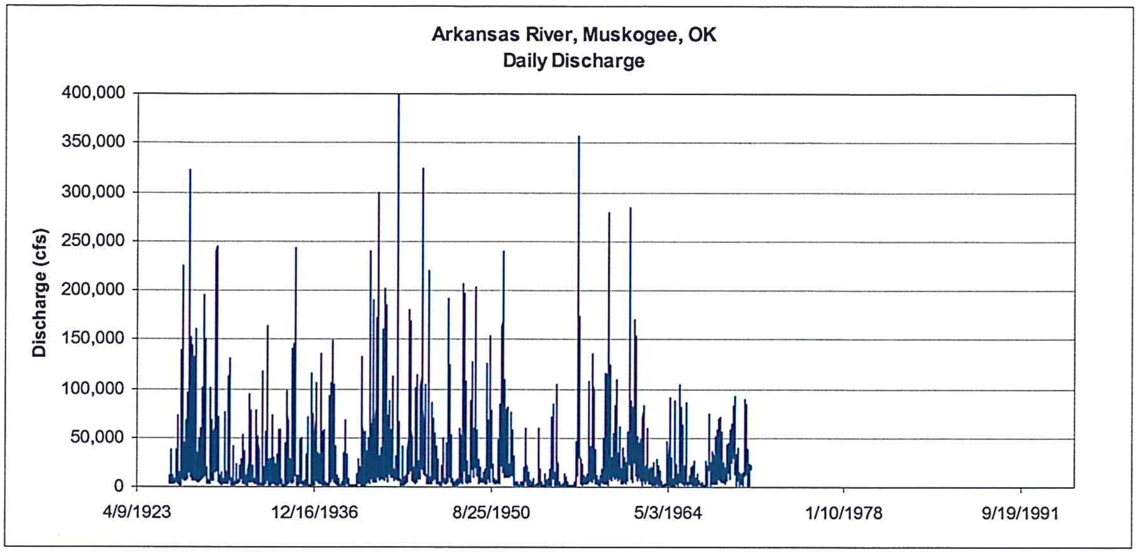


Figure 4.3-2: Daily Discharge Readings at Muskogee, OK from 1925 to 1970

Monthly mean discharge readings were computed for the entire period of record, from 1925 to 1970, as shown in Figures 4.3-3.

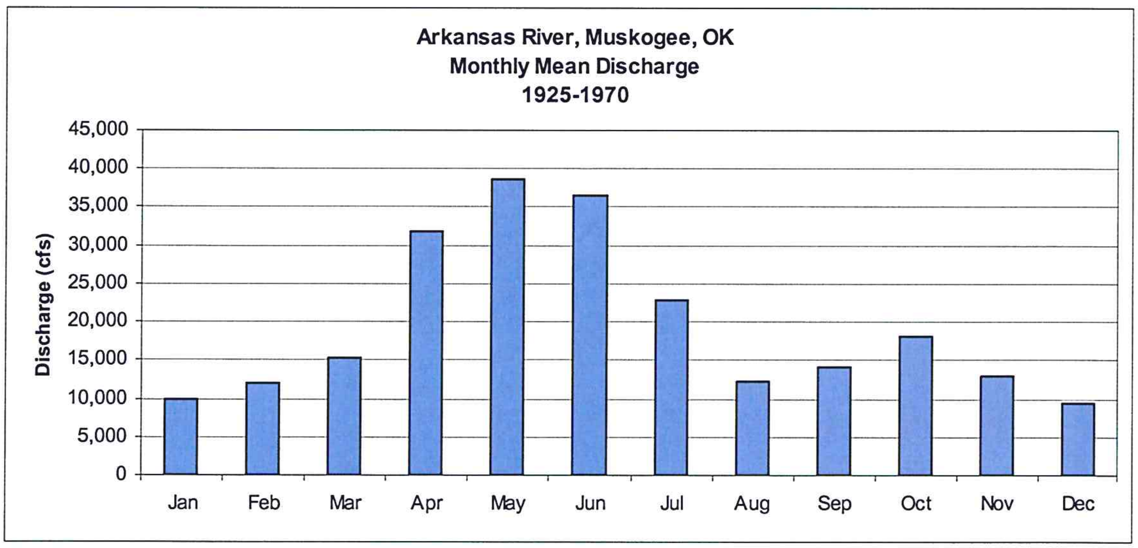


Figure 4.3-3: Mean Monthly Discharge Readings at Muskogee, OK from 1925 to 1970

4.4 Current Direction and Velocities

The channel geometry at the site is illustrated in Figures 4.2-1 and 4.2-2. The river flow is slightly skewed relative to the bridge. Cross currents can occur in the vicinity. The current velocity varies from very low to as high as 6 feet per second during a high water event, but the average velocity is below about 2.5 feet per second.

The United States Geological Survey (USGS) operates a real-time stream gaging station downstream from the bridge site on the Arkansas River, at Fort Smith, Arkansas. Figure 4.4-1 shows the range of velocities and corresponding river stages from October 14, 2003 to November 14, 2003, and Figure 4.4-2 shows the range of velocities and corresponding discharges recorded between 1997 and 2003.

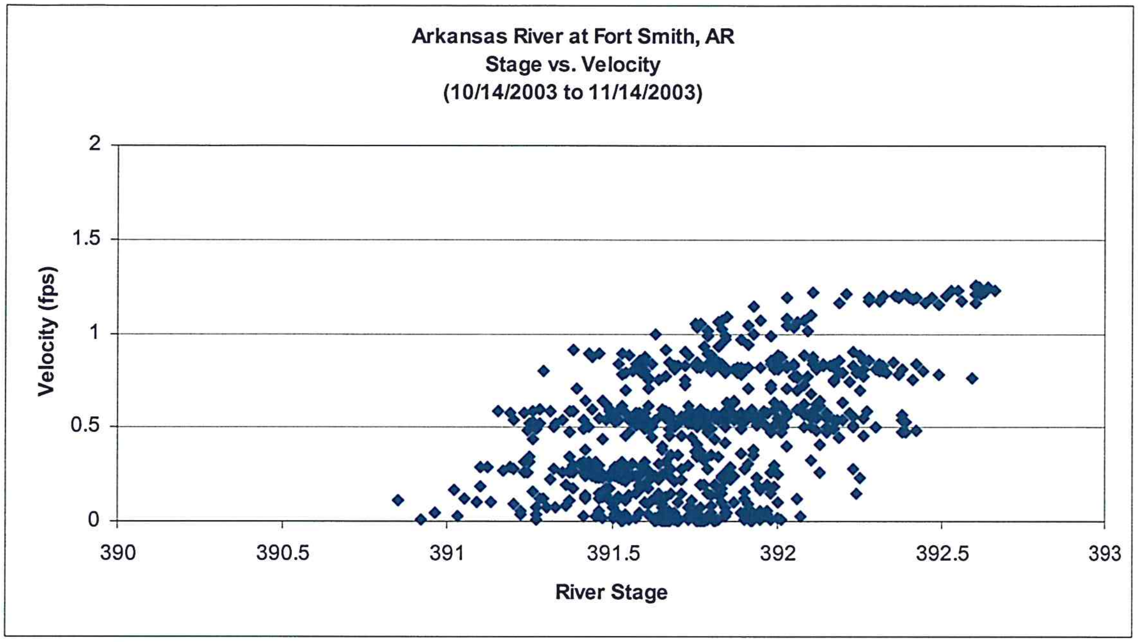


Figure 4.4-1: Stage vs. Velocity on the Arkansas River at Fort Smith, AR

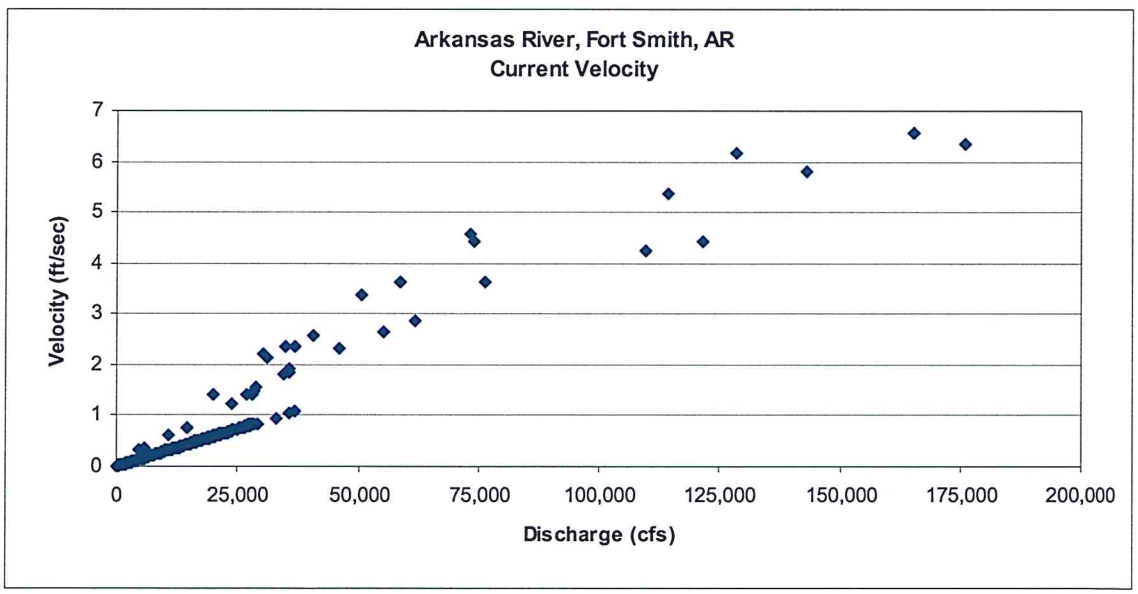


Figure 4.4-2: Discharge vs. Velocity on the Arkansas River at Fort Smith, AR

For reference, Figure 4.4-3 illustrates the frequency of the current velocity at various gaging stations along the Verdigris River and the Arkansas River.

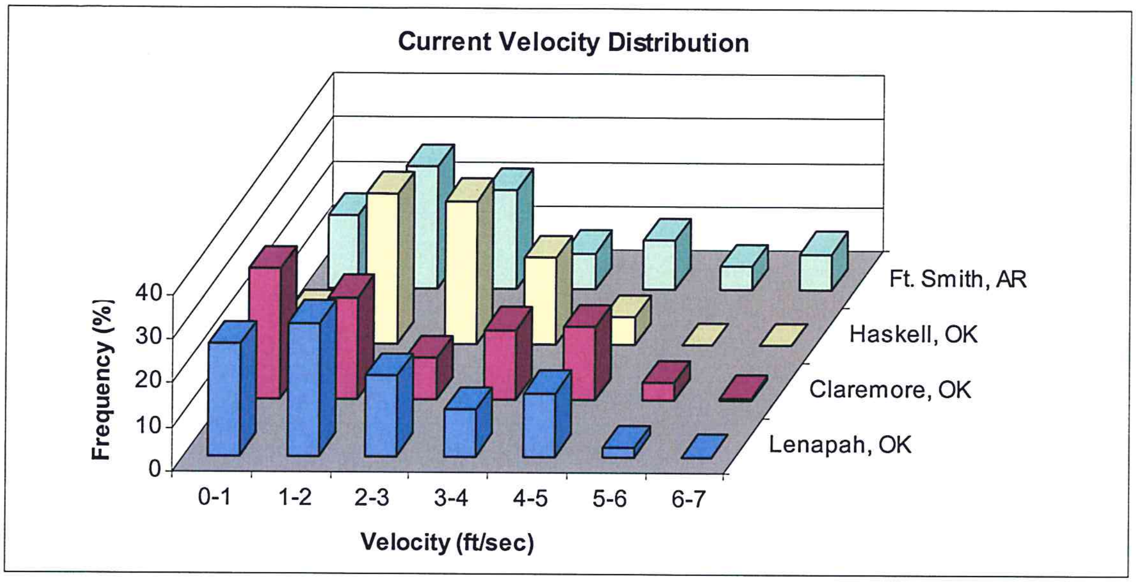


Figure 4.4-3: Current Velocity Distributions At Verdigris River and Arkansas River Gaging Stations

4.5 Weather Conditions

The climate in the region is humid subtropical. Annual precipitation for the area is 42.2 inches. Since 1888, the maximum monthly rainfall of 18.18 inches occurred during September 1971. The maximum rainfall in one day over the same period was 9.27 inches, and it occurred on May 26, 1984. The average annual snowfall is 9.2 inches, and the average wind velocity is 10.2 miles per hour. Dozens of tornadoes occur in the state annually, especially during the months of April and May.

5. VESSEL AND TRAFFIC CHARACTERISTICS

5.1 Sources of Information

The bridge crosses the McClellan-Kerr Arkansas River Navigation System (MKARNS), which is an important barge traffic route. MKARNS construction began in 1957 and was completed in 1970. The 445 mile long system of 17 locks and dams allows vessel traffic to overcome the 420 foot difference in elevation from the beginning to the end.

The vessel traffic through the bridge was determined based on information from several sources that include:

- U.S. Army Corps of Engineers (USACE) publications "Waterborne Commerce of the United States" (WCUS) for the years 1977 through 2001
- Past-the-point analysis conducted by the U.S. Army Corps of Engineers Waterborne Commerce Statistics Center (WCSC) at our request for the year 2000
- LPMS Lock Statistic Summary Reports for the years 1995 through 1999
- Special analysis conducted by the U.S. Army Corps of Engineers Navigation Center Lock Performance Monitoring System (LPMS) at our request for the year 2001
- Ports of Catoosa and Muskogee
- Interviews with lock operators

The WCUS publications contain information on commodities, tonnage and vessel trip and draft data for the whole McClellan-Kerr Arkansas River navigation system. It is an important source of information since it includes historical data that can show trends and help with making projections for future traffic.

The WCSC can conduct special past-the-point analyses to obtain vessel traffic data at a particular river mile along the navigation system, for the more recent years. The type of vessel data that can be generated by WCSC is similar to the data included in the WCUS publications. The information in both of these sources is based on reports of vessel movements made by the barge companies to the U.S. Army Corps of Engineers. The vessel traffic data generated by the past-the-point analysis includes the following fields:

Direction	Upbound (also north/eastbound) or Downbound (also south/westbound)
Traffic Type	Domestic or Foreign
Vessel Type	Range of 1-6 (types 1 & 2: ships, type 3: tugboats, types 4 & 5: barges and type 6: others)
Draft	Draft of actual movement in feet
Trips	Number of trips

The LPMS Lock Statistic Summary Reports include summary data of the barge movements through each lock, while a special analysis conducted by the U.S. Army Corps of Engineers Navigation Center LPMS can generate comprehensive and detailed data on vessels that went through a particular lock and in a given year. The LPMS data is based on more accurate information recorded directly by the U.S. Army Corps of Engineers. The vessel traffic data generated by the LPMS analysis includes the following fields:

Flotilla No.	Identification number for the barge tow	
Direction	Upbound (also north/eastbound) or Downbound (also south/westbound)	
Num Loaded	Number of loaded barges in the tow	
Num Empty	Number of empty barges in the tow	
Draft	Max draft barge tow of actual movement in feet and inches	
Num Barges	Total number of barges in the tow	
Barge Type	Type of barge (i.e. covered hopper, liquid/cargo (tank) barge)	
Dimensions:	Barge Width	Barge Length
	A – Under 28 feet	A – Under 100 feet
	B – 28 to 36 feet	B – 100 to 174 feet
	C – 37 to 41 feet	D – 195 to 199 feet
	D – 42 to 49 feet	E – 200 to 259 feet
	E – 50 to 54 feet	F – 260 to 289 feet
	F – Over 54 feet	G – 290 to 300 feet
	Z - None	H – Over 300 feet
		Z – None

The various sources of information were used to complement and independently verify the vessel traffic data used.

5.2 Commodities and Vessel Types

Information on the commodities transported on the McClellan-Kerr Arkansas River navigation system was obtained from the WCUS publications and from the ports of Catoosa and Muskogee. The most common shipments consist of dry bulk movements (grain, coal, metallic ores and concentrates, sulfur, nonmetallic minerals and cement products), liquid bulk commodities (refined petroleum products, and agricultural and industrial chemicals) and general cargo. Figure 5.2-1 shows the distribution by tonnage of the major commodities transported on the McClellan-Kerr Arkansas River navigation system in 2001. Additional commodity information is included in Appendix D.

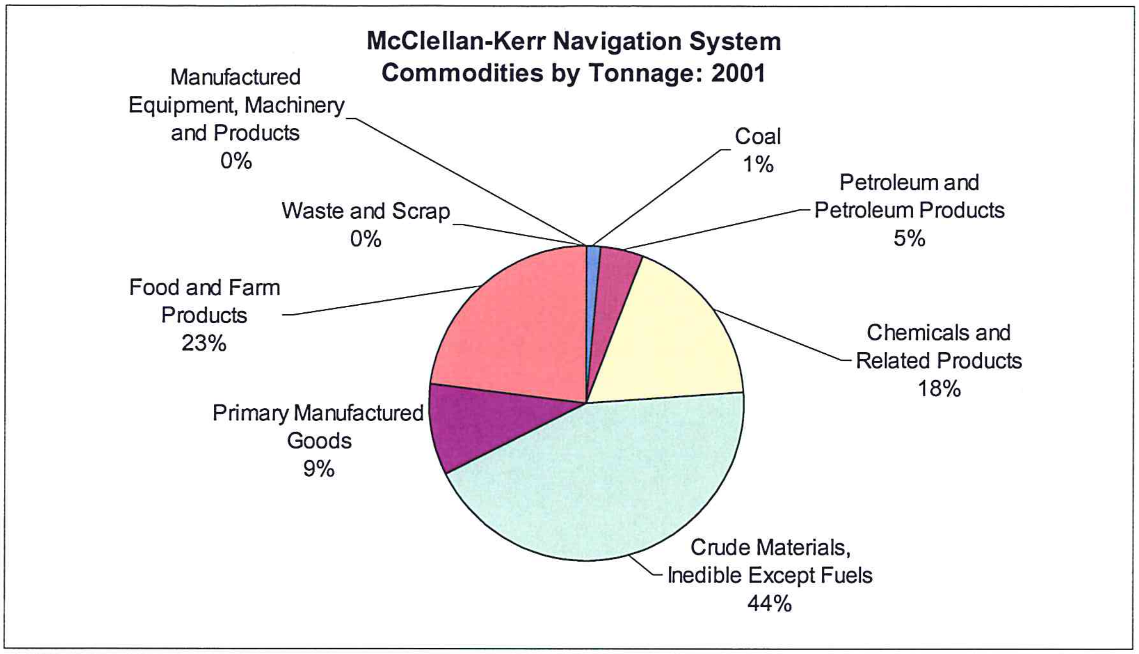


Figure 5.2-1: Commodity Distribution by Tonnage in 2001

In 2001, crude materials represented 44% of the total tonnage, and food and farm products accounted for 23% of the total traffic. Chemicals, petroleum and related products were about 23% of the total traffic.

The vessel types on the McClellan-Kerr Arkansas River navigation system include mainly hopper and tanker barge tows. A view of a typical hopper barge tow is shown in Figure 5.2-2, and a view of a typical tanker barge tow is shown in Figure 5.2-3.

Figure 5.2-2: Typical Hopper Barge Tow (USACE)

Figure 5.2-3: Typical Tanker Barge Tow (USACE)

Hopper barges are typically 35 feet wide, 195 feet long and 12 feet deep and have a cargo capacity of about 1,700 tons. Large tanker barges are commonly 53 feet wide, 290 feet long and 12 feet deep, and have a cargo capacity of about 3,700 tons. Thus, a typical tanker barge can carry over twice the tonnage of a hopper barge. The draft of both barge types can vary from 2 to 9 feet depending on their loading condition.

The size of the barge tows on the McClellan-Kerr Arkansas River navigation system is affected by the size of the locks in the system. All lock chambers are 110 feet wide and 600 feet long and can accommodate only 8 hopper barges or 3 tanker barges in one lockage, as illustrated in Figure 5.2-4. It is not uncommon, however, for large tows to use a double lockage in which the tow is broken apart before the lockage and then assembled again. In general, the hopper barge tows include 4 to 6 barges and the tanker barge tows 2 to 4 barges per tow. The largest hopper tows can include as many as 12 barges and the largest tanker tows include about 5 barges per tow.

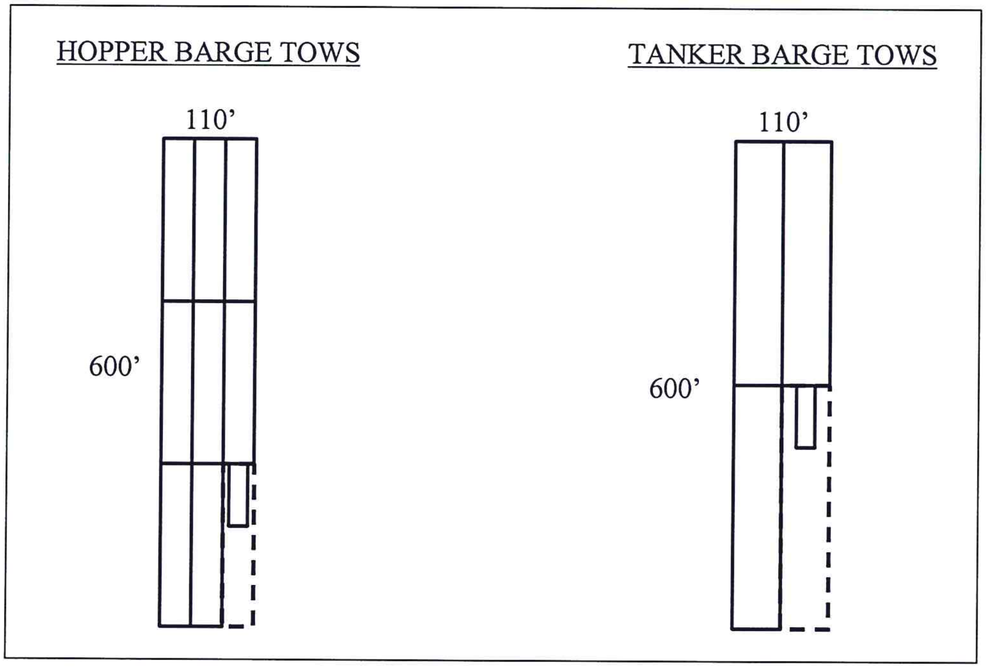


Figure 5.2-4: Limit of Hopper and Tanker Barge Tows in One Lockage

Figure 5.2-5 shows a tanker barge tow entering the Choteau Lock, and Figure 5.2-6 shows a typical hopper barge tow leaving the Newt Graham Lock.

Figure 5.2-5: Tanker Barge Tow Entering the Choteau Lock (USACE)

Figure 5.2-6: Hopper Barge Tow Leaving the Newt Graham Lock (USACE)

5.3 Historical Traffic Data

5.3.1 Tonnage Data

Most of the historical information on the traffic on the McClellan-Kerr Arkansas River navigation system was obtained from the WCUS publications. Figure 5.3-1 shows the yearly tonnage of shipments transported on the McClellan-Kerr Arkansas navigation system since 1968. The volume of traffic in the late 1960's and early 1970's was quite low. However, the tonnage steadily increased until 1978, when it started to level off. In the early 1990's the traffic increased again, but then remained relatively constant from 1995 through 2001.

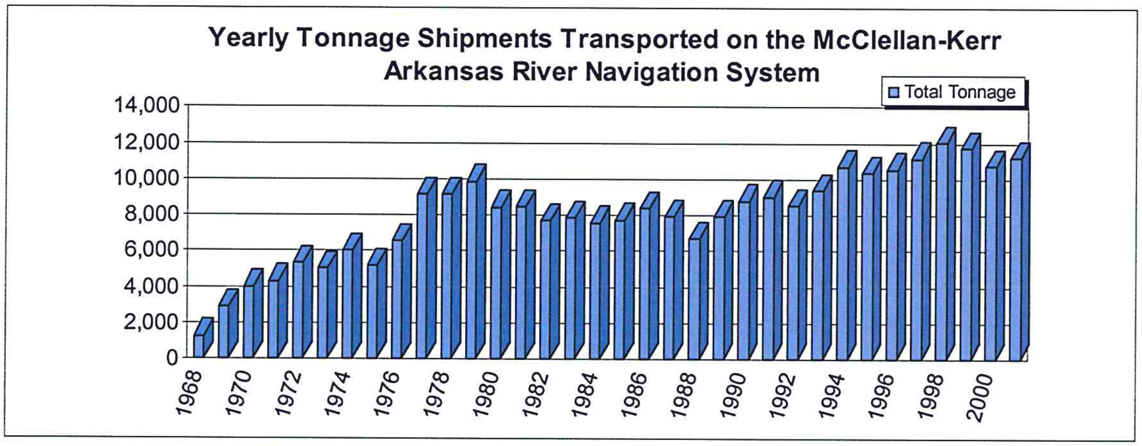


Figure 5.3-1: Yearly Tonnage Transported on the McClellan-Kerr Arkansas River Navigation System Traffic

5.3.2 Commodity Data

Historical data on the commodities transported on the McClellan-Kerr Arkansas River navigation system is included in Figures 5.3-2. Commodity groups have fluctuated to some extent, with some showing discernable trends. For example, the petroleum and petroleum products group has decreased by about 75% from 1977 to 1990, but chemicals and related products has increased by 240% during the same time period. In general, the percentage of each commodity has not changed much during the period from 1994 to 2001, which is considered to be representative of the present traffic (see Figure 5.3-2).

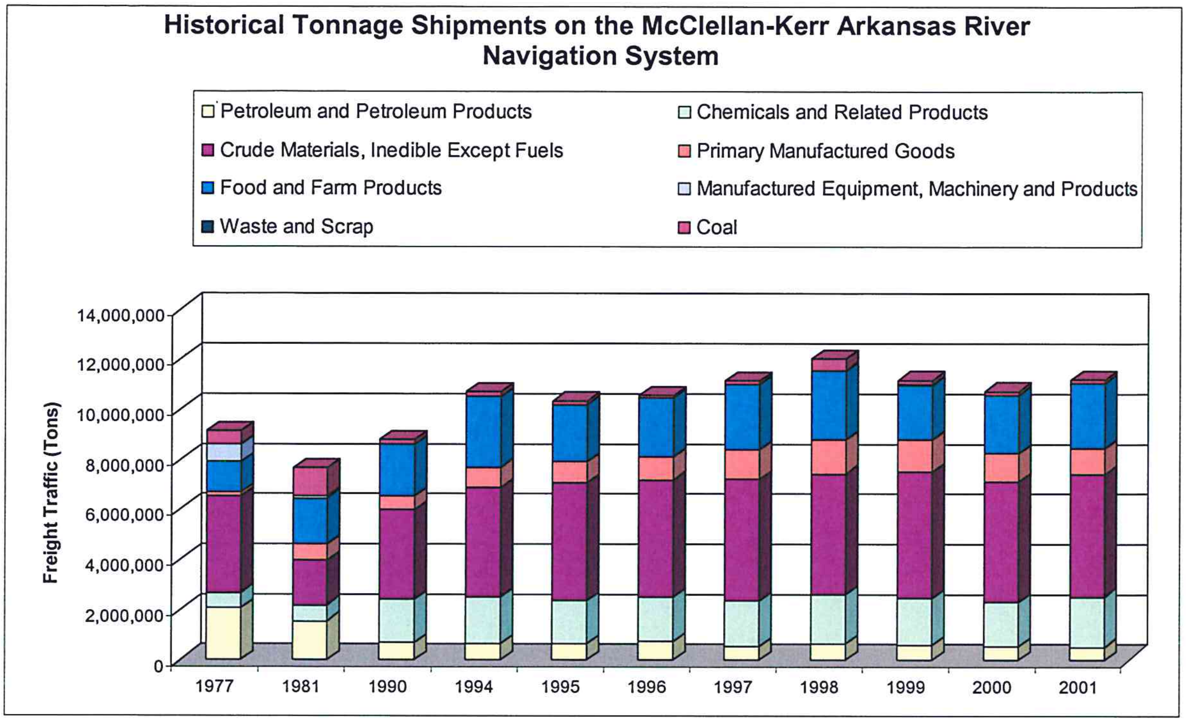


Figure 5.3-2: Historical Commodity Distribution by Tonnage

5.3.3 Vessel Trip Data

Historical data on the number of barge trips by type on the McClellan-Kerr Arkansas River navigation system is included in Figures 5.3-3 and 5.3-4. The yearly number of hopper barge trips since 1977 has fluctuated over time, but in general it has remained relatively constant. However, the yearly number of tanker barge trips since 1977 has steadily declined. Additional historical trip data is located in Appendix D.

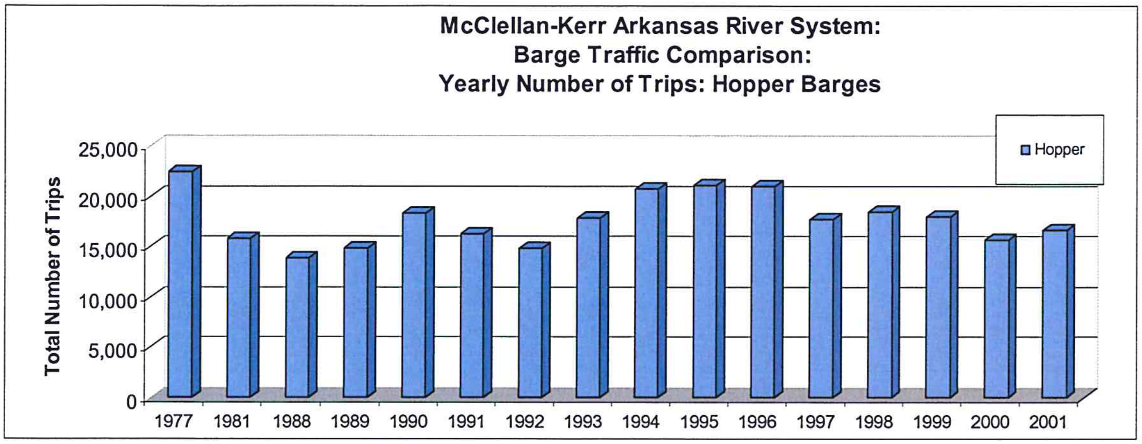


Figure 5.3-3: Yearly Number of Hopper Barge Trips on the McClellan-Kerr Arkansas River Navigation System

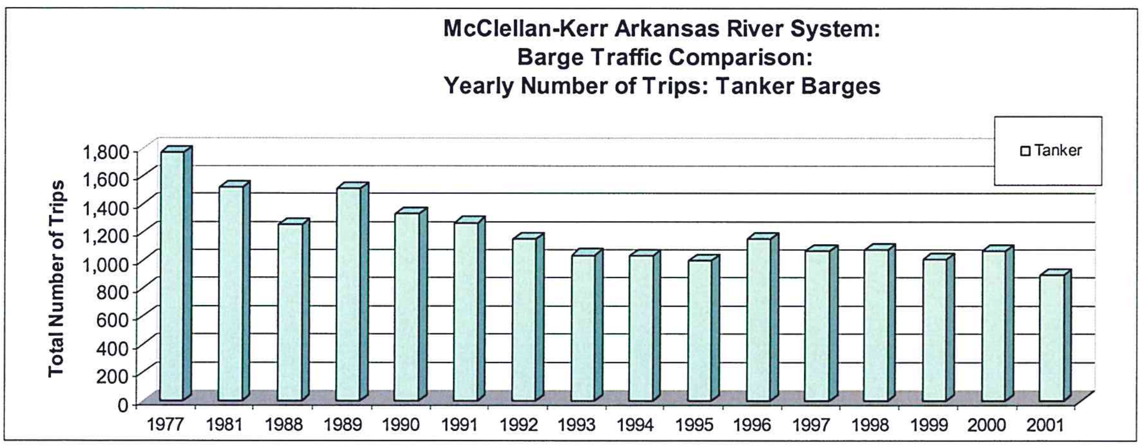


Figure 5.3-4: Yearly Number of Tanker Barge Trips on the McClellan-Kerr Arkansas River Navigation System

5.3.4 Vessel Draft Distribution

Historical data on the actual draft of barges was obtained from the U.S. Army Corps of Engineers Waterborne Commerce of the United States (WCUS) publications. Barge draft distributions were evaluated for the following years: 1977, 1981, 1990, 1994, 2000 and 2001. Figure 5.3-5 shows the barge draft distribution for the year 2001 based on the data reported for the entire McClellan-Kerr Arkansas River Navigation System in the U.S. Army Corps of Engineers Waterborne Commerce Statistics Center Report: Part 2 - Waterways and Harbors on the Gulf Coast, Mississippi River System and Antilles. Most of the tanker barges had a draft of either 2 feet (i.e. empty) or 8 or 9 feet (i.e. loaded), while many of the hopper barges had drafts in between (i.e. partially loaded). Additional barge draft distributions are included in Appendix D.

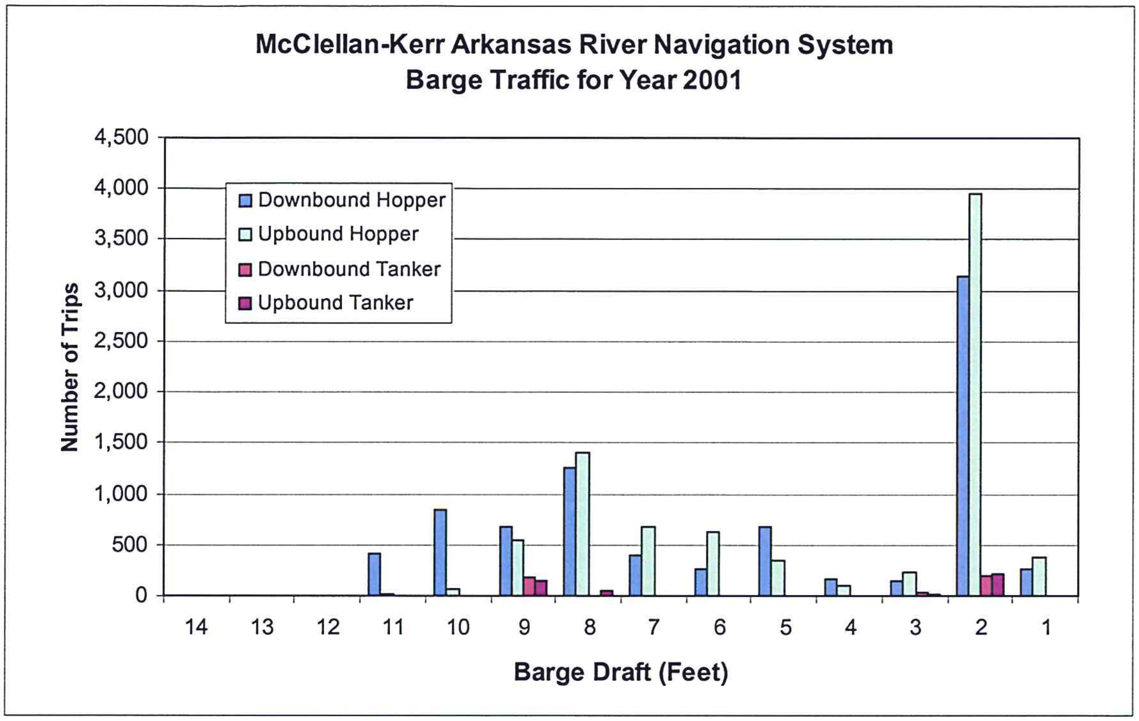


Figure 5.3-5: Barge Draft Distributions in 2001 for the McClellan-Kerr Arkansas River Navigation System

Figures 5.3-6, 5.3-7 and 5.3-8 show a comparison between the percentages of barges traveling within a specified draft range for selected years between 1977 and 2001. The distribution of the percentage of barges with a draft of 3 feet or less and 8 feet or more has varied some over the years, but, as a whole, it did not change much, especially since 1994. In 1994, there was a reduction in the percentage of hopper barges with a draft of over 8 feet, but an increase in the percentage of barges with a draft of 4 to 7 feet. Otherwise, the distribution of the percentage of barges traveling with a draft of 4 to 7 feet has generally decreased, for all directions and barge types. This decrease indicates a better utilization of vessels and that, for analysis purposes, most barge traffic can be classified as either empty or loaded.

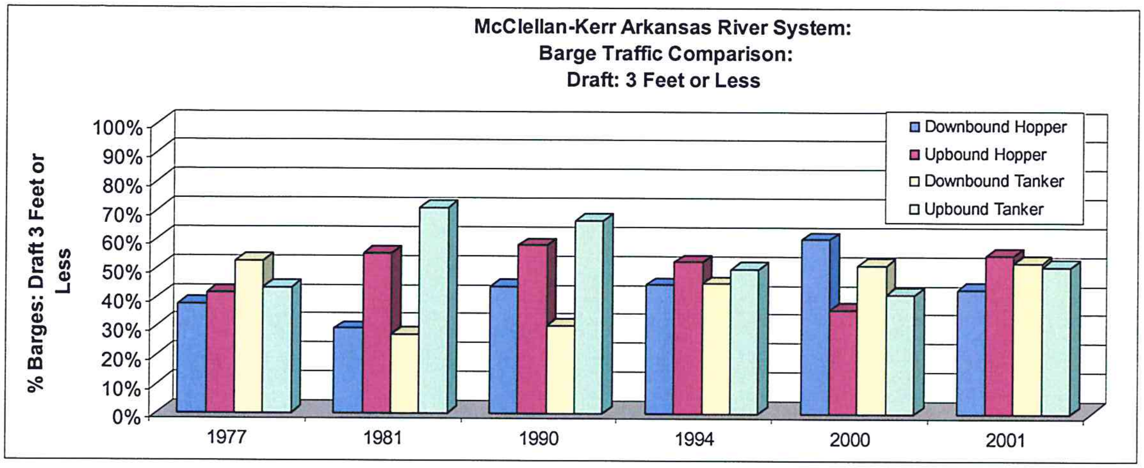


Figure 5.3-6: Historical Comparison between Barges with a Draft of 3 Feet or Less

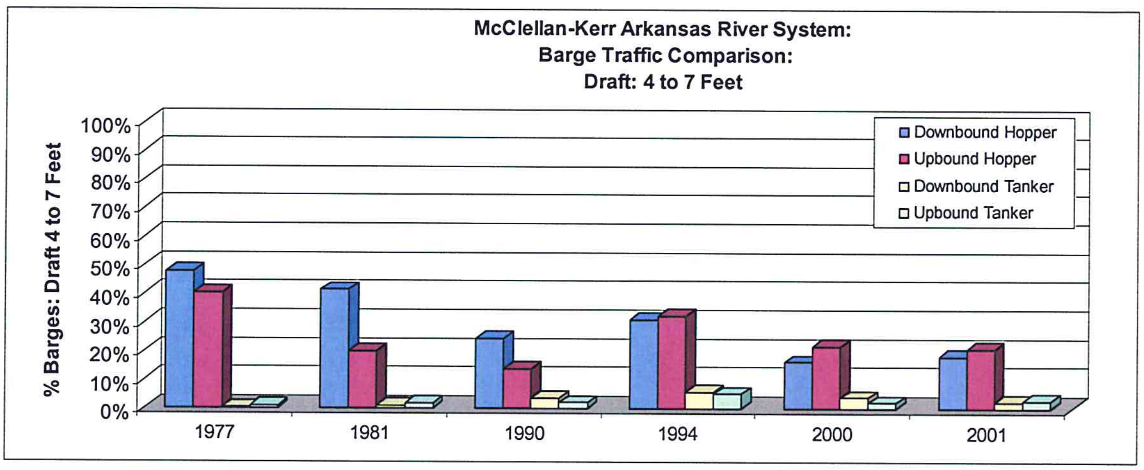


Figure 5.3-7: Historical Comparison between Barges with a Draft of 4 to 7 Feet

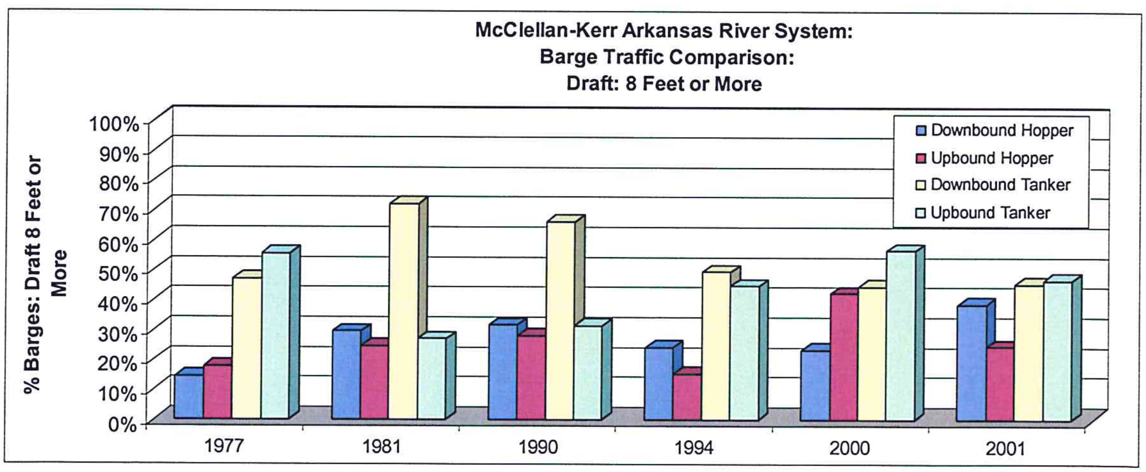


Figure 5.3-8: Historical Comparison between Barges with a Draft of 8 Feet or More

5.4 Present Traffic Characteristics

Most of the information on the characteristics of the present vessel traffic passing through the bridge was generated from the results of analyses conducted by the Lock Performance Monitoring System (LPMS) and by the Waterborne Commerce Statistics Center (WCSC). Additional information on the vessel characteristics was obtained from interviews with lock operators.

5.4.1 Data from the Lock Performance Monitoring System (LPMS) Analysis

The McClellan-Kerr Arkansas River navigation system locks are operated and maintained by the U.S. Army Corps of Engineers. The lock operators make detailed recordings of the barge passages through the lock, including the barge dimensions and their loading condition. Since the Webbers Falls Lock is located 3.5 river miles upstream of the SH-100 Bridge, the vessel traffic data through the lock is considered to be comparable to that at the bridge site. Figures 5.4-1 shows an aerial view of the Webbers Falls Lock.

Figure 5.4-1: Photo of Lock at Webbers Falls (USACE)

5.4.2 Data from the Waterborne Commerce Statistics Center (WCSC) Past-the-point Analysis

The Waterborne Commerce Statistics Center (WCSC) data is compiled from Vessel Operator Forms, as reported by the vessel operating companies. All domestic waterborne commercial movements are required to be reported to the WCSC under federal law.

The past-the-point analysis performed queries the WCSC database and reports all vessel movements passing Arkansas River mile point 363.1, at the bridge site.

5.4.3 Vessel Size Distribution

The distribution of the barge traffic per direction of traffic was established based on their type as generated by the Lock Performance Monitoring System (LPMS) analysis. The barge categories used to reduce the data are:

Dry Cargo/Standard Hopper	breadth < 42 feet
Tanker/Oversize Tanker	42 feet ≤ breadth ≤ 60 feet
Other/Special Deck	breadth > 60 feet

The barge type distribution determined for the Webbers Falls lock is illustrated in Figure 5.4-2. The majority of the barges are hopper barges, and there are no records of large special deck barge passages. The number of dry cargo hopper barge passages is over nine times larger than the number of tanker barges.

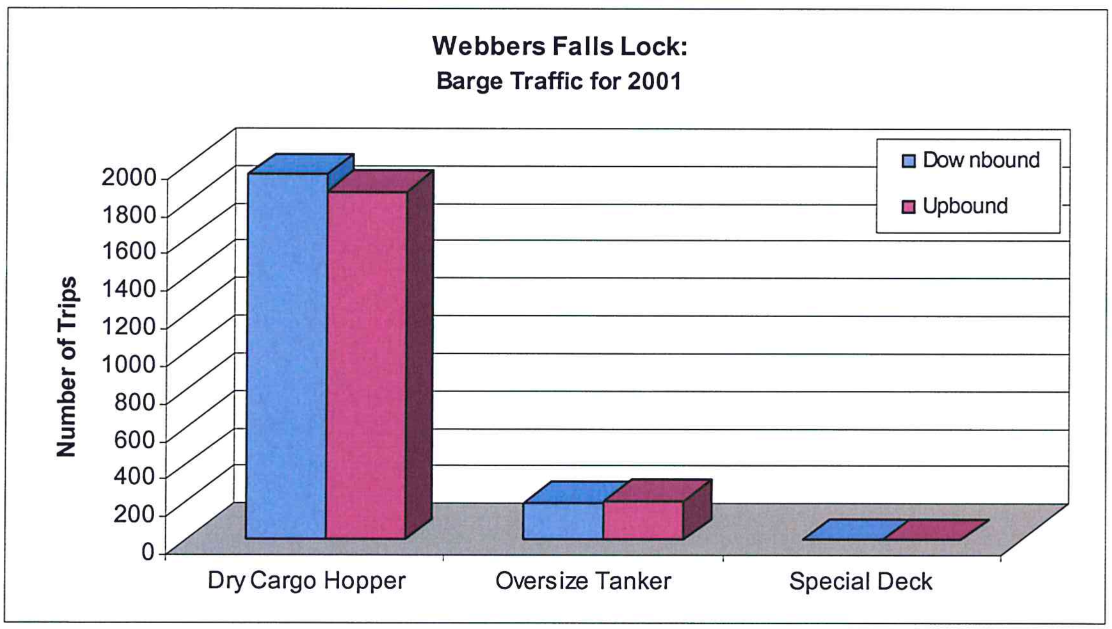


Figure 5.4-2: Barge Type Distribution at Webbers Falls Lock

The barge tow characteristics were determined from the LPMS analysis data reports that include both the number of barges per tow and the barge type, for the year 2001. The tows were first classified as either hopper or tanker barge tows, and then they were separated by direction of traffic. The tows were further sorted by the number of barges per tow, and the number of trips for each tow size was determined. Figure 5.4-3 shows the tow size distribution for the hopper barge tows in each direction. It indicates that the hopper barge tows range in size from one to twelve barges per tow, with a six to eight barge tows being the most common.

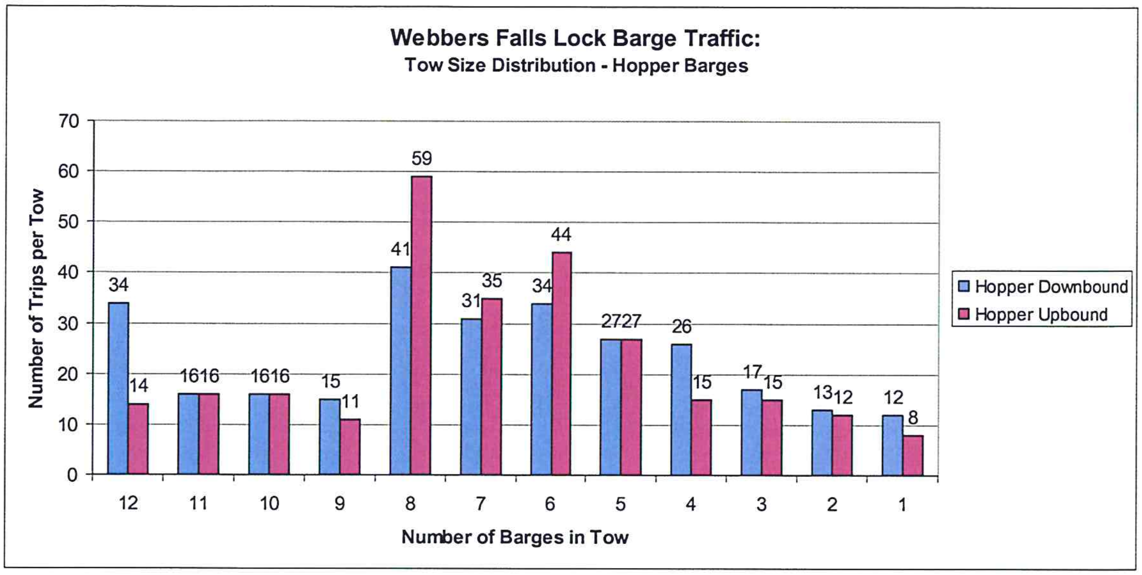


Figure 5.4-3: Tow Size Distribution for Hopper Barge Tows at Webbers Falls Lock for 2001

Figure 5.4-4 shows the tow size distribution for the tanker barge tows. The tanker barge tows range in size from one to five barges per tow, with a two or four barge tows being the most common. Additional vessel distribution data is located in Appendix D.

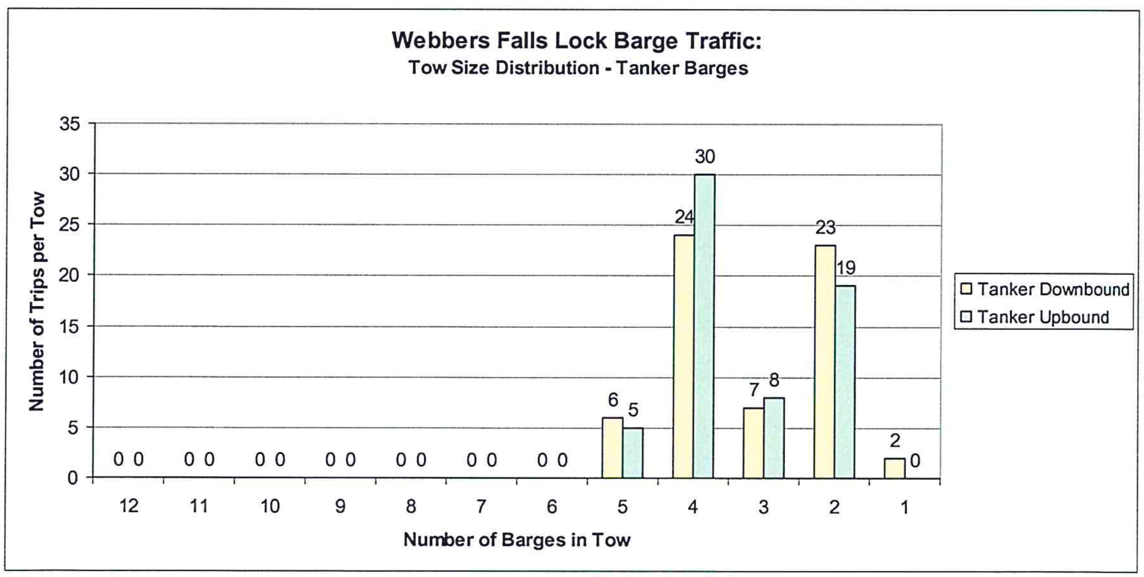


Figure 5.4-5: Tow Size Distribution for Tanker Barge Tows at Webbers Falls Lock for 2001

5.4.4 Vessel Loading Conditions

The LPMS data directly reports the number of loaded and empty barges per tow. Table 5.4-1 shows the barge traffic categories and the corresponding percentages of loaded and empty barges in 2001. The historical vessel draft distribution (see section 5.3.3) indicates that the loading conditions of the barge tows have not changed much over the years, especially during the more recent years.

Table 5.4-1: Barge Traffic: Loaded vs. Empty

Barge	Downbound		Upbound	
	% Loaded	% Empty	% Loaded	% Empty
Dry Cargo Hopper	68%	32%	85%	15%
Oversize Tanker	88%	12%	27%	73%

5.5 Projection of Future Traffic

There are no long term projections of significant changes in traffic on the McClellan-Kerr Arkansas River navigation system. Therefore, it is assumed that the increasing trend in the volume of traffic between 1980 and 2001 will also continue during the next 20 years, and that the type and makeup of traffic will remain relatively constant. Since from 1980 to 2001 the total tonnage has increased by 32% (see Figure 5.3-1), a 30% increase in the number of barge tow trips was also projected for the year 2020.

5.6 Evaluation Vessel Groups

The vessel traffic data collected was evaluated and then reduced to a format suitable for bridge risk analysis. The barge types considered in the substructure assessment include standard hopper and oversize tanker. From the barge tow size distributions shown in Figures 5.4-3 and 5.4-4, the barge tows were grouped into the following categories: Hopper 1, Hopper 2, Hopper 3, Tanker 1, Tanker 2, and Tanker 3. Figure 5.6-1 illustrates the tow size for each of the barge groups and the number of barges per tow that they represent.

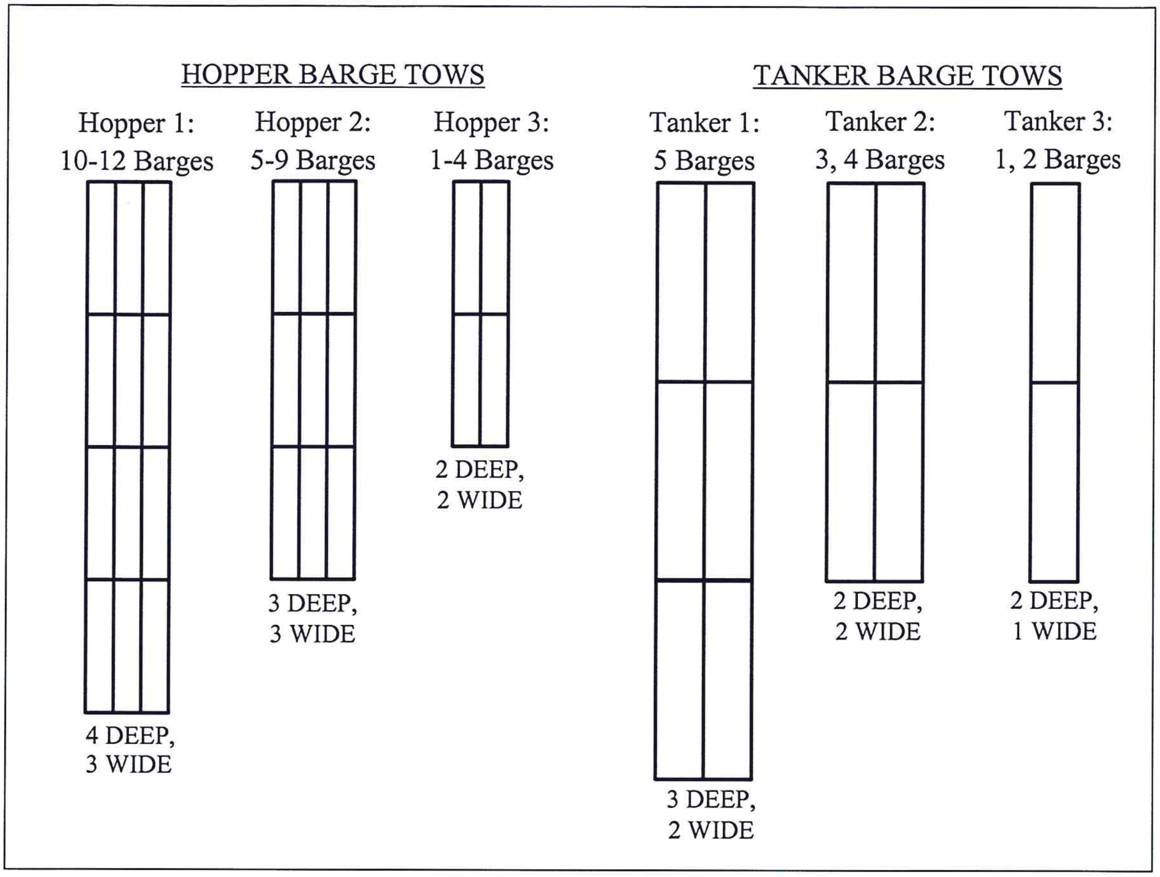


Figure 5.6-1: Evaluation Vessel Groups

The typical barge characteristics listed in the AASHTO Guide Specification for each barge type and a 90 foot long towboat with an estimated displacement of 300 tonnes were assumed. The tow characteristics used are defined in Table 5.6-1.

Table 5.6-1: Representative Barge Tows

Barge	Length (Feet)	Width (Feet)	Loaded Draft (Feet)	Light Draft (Feet)	Max. Capacity (tons)	Length of Towboat (Feet)
Hopper 1	4x195	3x35	9	2	20,400	90
Hopper 2	3x195	3x35	9	2	15,300	90
Hopper 3	2x195	3x35	9	2	6,800	90
Tanker 1	3x290	2x53	9	2	18,500	90
Tanker 2	2x290	2x53	9	2	14,800	90
Tanker 3	2x290	1x53	9	2	7,400	90

In order to obtain the evaluation vessel group trip distributions, the number of trips for each tow size in a group was first determined. For example, in order to obtain the Hopper 1-Downbound group trips, the values shown in Figure 5.4-3 for the 10, 11, and 12 barge tow sizes were combined. Classification of each tow size into one of the evaluation vessel groups results in the vessel trip distribution shown in Table 5.6-2. The total number of trips per evaluation vessel group was further divided by the percentage of vessels traveling loaded or empty, using the data in Table 5.4-1.

Table 5.5-2: Evaluation Vessel Group Trip Distribution (Present Traffic)

Barge	Total Trips		Loaded		Empty	
	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound
Hopper 1	66	46	45	39	21	7
Hopper 2	148	176	101	150	47	26
Hopper 3	68	50	46	43	22	7
Tanker 1	6	5	5	1	1	4
Tanker 2	31	38	27	10	4	28
Tanker 3	25	19	22	5	3	14

5.7 Navigation Regulations

Navigation regulations on the McClellan-Kerr Arkansas River Navigation System are included in 33 Code of Federal Regulations 162.9 *White River, Arkansas Post Canal, Arkansas River, and Verdigris River between Mississippi River, Ark., and Catoosa, Okla.; use, administration, and navigation.* The regulations apply to the waterways, bridges, wharves and other structures listed in this section, and to vessels and rafts. The following regulations in 33 CFR 162.9 are specific to vessels passing through a bridge:

- (3) (ii) When approaching and passing through a bridge, all vessels and rafts, regardless of size, shall control their speed so as to insure that no damage will be done to the bridge or its fenders.
- (3) (iii) Within the last mile of approach to unattended, normally open automatic, movable span bridge, the factor of river flow velocity, of vessel (and tow) velocity, and of vessel power and crew capability are never to be permitted to

result in a condition whereby the movement of vessel (and tow) cannot be completely halted or reversed within a 3-minute period.

The Corps of Engineers also has specific regulations on the McClellan-Kerr Arkansas River Navigation System, which are listed in 33 Code of Federal Regulations 207.275 *McClellan-Kerr Arkansas River navigation system; use, administration, and navigation.* These regulations mainly apply to locks, wharves and other Corps of Engineers structures.

According to 33 Code of Federal Regulations 165.817 the Arkansas River from Mile 118.2 to 125.4, Little Rock, Arkansas is a regulated navigation area (RNA). A regulated navigation area is a water area within a defined boundary for which regulations for vessels navigating within the area have been established. The regulations on the Arkansas River RNA go into effect during periods of high velocity flow, defined as the flow rate of 70,000 cfs or more at the Murray Lock and Dam at mile 125.4. They include restrictions on vessels meetings, passings, anchoring or stopping and special communications and operating procedures for passing through the movable bridges in this area.

6. MARINE TERMINALS, WHARVES, AND DOCKS

Facilities located in the vicinity of the bridge can affect vessel navigation. Facilities in the region can increase the traffic density and decrease the width of the river available for navigation. Vessel operations at these facilities may interfere with the main river traffic.

The facility located near the bridge site is listed in Table 6.1-1. It is identified in Figure 6.1-1, corresponding with the labeling system listed below in Table 6.1-1. A larger scale version of Figure 6.1-1 is included in Appendix B.

Table 6.1-1: Marine Terminals, Wharves, and Docks near the Bridge Site

Facility	Navigation Mile	Location	Type
A. *Farmers Export Elevator*	363.2	Right Bank	Terminal

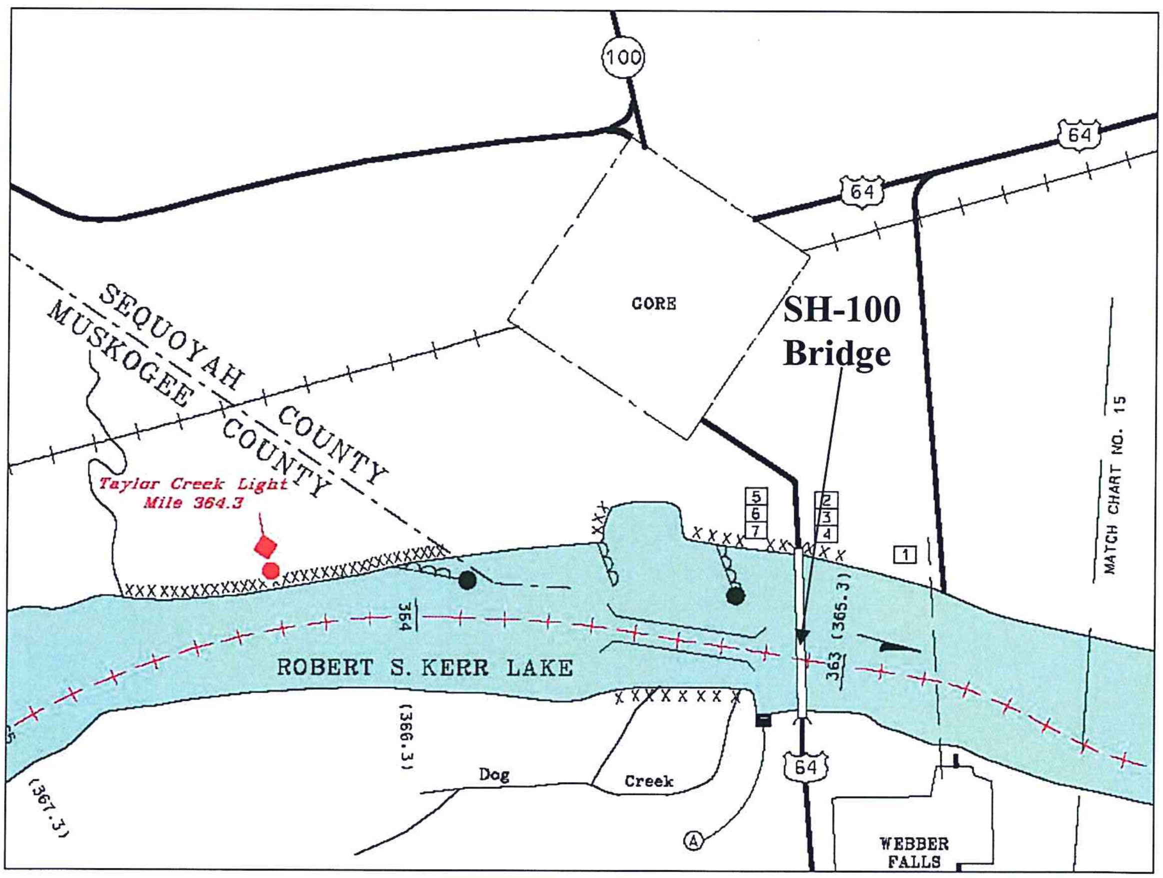


Figure 6.1-1: Close-up View of Navigation Chart Showing Facilities Near the Bridge Site (USACE)

7. VULNERABILITY ANALYSIS

7.1 Assessment Methodology

The bridge substructure risk assessment procedure follows the guidelines of Method II of the "AASHTO Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges." Method II is a probability based, risk analysis procedure. An idealized mathematical model describing the bridge and the vessel traffic transiting through the bridge is used to estimate the probability of substructure collapse. Vessel, bridge, and waterway characteristics data are used to determine the probability of vessel aberrancy, geometric probability, and probability of collapse. These probabilities lead to the computation of annual frequencies of collapse. Substructure risk evaluations were made for both the present traffic and traffic projected for the year 2020 so that changes in the projection year and the future traffic growth could be readily assessed. Detailed calculations for the vulnerability analysis of the bridge can be found in Appendix E.

7.2 Evaluation Vessels and Vessel Access to Bridge Piers

Several representative barge tow categories were used as evaluation vessel groups. They include three hopper and three tanker barge tow categories (see Section 5.6). Geometric probabilities and probabilities of collapse are calculated for each barge tow category for both the upstream and the downstream directions. The directions of traffic were separated in analysis because of the different channel, barge loading and pier access conditions. The total number of barge tow trips considered is 678 a year, and the projected annual traffic for year 2020 is 881 trips.

The piers exposed to vessel access include piers 2 through 13. The rest of the piers are on land, and they are not likely to be hit by barges even during high water events. Average river bed elevations are based on information obtained from the Oklahoma Department of Transportation as-built plans for the SH-100 Bridge.

For each pier, the number of trips considered was reduced based on the access of a given evaluation vessel group to the pier. Two types of vessel traffic reduction factors were used for each direction of traffic (upstream or downstream) and direction of impact (longitudinal or transverse to channel). They include water depth access factors and pier protection access factors (see Appendix E2). The water depth access factors take into account the actual vessel draft in relation to the water depth, and the pier protection access factors take into account the existence of pier protection, an adjacent bridge, or other barriers that limit vessel access to the piers.

7.3 Probability of Aberrancy

7.3.1 General

The probability of aberrancy (PA) is a value related to the statistical probability that a vessel will stray off course and threaten the bridge. Vessel aberrancy is usually a result of pilot error, adverse environmental conditions, or mechanical failure. The AASHTO Guide (AASHTO 1991) recommends two methods of determining PA. As stated in Section 4.8.3.2, "the most accurate method of determining PA for a particular bridge site is based on historical data on vessel collisions, rammings, and groundings in the waterway, and the number of vessels transiting the waterway during the period of accident reporting." In lieu of the aforementioned method, PA can be estimated based on the AASHTO Guide, formula 4.8.3.2-1. In this study, PA was determined based on both the AASHTO formula and the historical accident data methods.

7.3.2 Probability of Aberrancy Based on AASHTO Formula

According to the AASHTO Guide formula, the probability of aberrancy is determined by taking a base rate probability (BR) and multiplying it by a series of correction factors that account for bridge location (R_B), water current (R_C), cross-currents (R_{XC}), and vessel traffic density (R_D). Thus, PA is calculated as follows:

$$PA = (BR)(R_B)(R_C)(R_{XC})(R_D)$$

The aberrancy base rate, BR, recommended for barge tows is 1.2×10^{-4}, and the guidelines for calculating the correction factors are given in the AASHTO Guide, Section 4.8.3.2.

The SH-100 Bridge is located on the Arkansas River section of the MCKARNS, at river mile 363.1. There are gradual bends in the channel on both the upstream and downstream sides of the bridge. A 39° bend is located approximately 6,520 feet on the upstream side of the bridge, and a 17° bend is located approximately 1,780 feet on the downstream side of the bridge. Although the current flow is usually controlled, the current velocity varies from very low to as high as 3 knots during a high water event. The yearly mean current velocity of 1.5 knots was assumed for the downstream direction at this location (see AASHTO Guide, Section 3.7), and a current velocity of 2.5 knots was assumed to be representative of the current component parallel to an aberrant vessel path (see AASHTO Guide, Section 4.8.3.2). The river flow is slightly skewed relative to the bridge. Cross currents can occur in the vicinity, and a cross-current velocity of 0.5 knots was used for both directions. Since barge tows rarely meet or pass each other under the bridge, a low vessel traffic density factor was used in the analysis.

The above information on the local influencing conditions was used to calculate the series of correction factors that account for bridge location (R_B), water current (R_C), cross-currents (R_{XC}), and vessel traffic density (R_D) (see Appendix E2).

7.3.3 Probability of Aberrancy Based on Historical Accident Data

Historical accident data was obtained from a special search and analysis of vessel incidents involving collisions, allisions, loss of vessel control and groundings in the Verdigris and Arkansas rivers from 1991 through 2001, as discussed in Section 3.4.

Because of their distinct characteristics, the data was analyzed separately for the Oklahoma and Arkansas portions of the waterway.

The approach used (INCOM 2001; Larsen 1983) assumes the existence of a general, constant probability that a vessel will stray off course because of human errors and/or mechanical conditions under favorable conditions. This probability is referred to as the causation probability (A) in Larsen (1983), the basic aberrance probability (BAP) in INCOM (2001) and the base rate probability (BR) in AASHTO (1991). When combined with the probability of local influencing factors, this basic probability can be modified to reflect the local probability of aberrancy.

In this study the base rate of the probability of aberrancy is determined by summing up the individual base rate, $BR_{accident\ type}$, for each of the incident types, using the following expressions:

$$BR = \Sigma\, BR_{accident\ type}$$

$$BR_{accident\ type} = \frac{N_{incidents}}{N_{years} L_{waterway} T} \frac{L_{vicinity}}{F_{PG}}$$

where

$BR_{accident\ type}$	= Base rate of probability of aberrancy for each type of incident
$N_{incidents}$	= Number of recorded incidents by type in a known period
N_{years}	= Number of years of record for incidents
$L_{waterway}$	= Total length of waterway over which incidents were recorded
T	= Average number of trips made by the vessels types under consideration in the waterway annually
$L_{vicinity}$	= Influencing length of waterway to be considered as within the vicinity of the bridge
F_{PG}	= Adjustment factor due to the geometric probability of a collision between an aberrant vessel and a bridge pier or span or another vessel

Since the reported information spanned from 1991 to 2001, N_{years} equals 11. $L_{waterway}$ is 136.2 miles for the Oklahoma portion and 308.6 miles for the Arkansas portion. $L_{vicinity}$ was conservatively taken as 2.0 miles for both the Oklahoma portion and the Arkansas portion. The $L_{vicinity}$ values used in INCOM (2001) range from 1 to 1.3 miles.

The average number of trips made by the vessels types under consideration in the waterway annually, T, was obtained from detailed database files that contain the U.S. Army Corps of Engineers Monthly Summary Statistics collected within the Lock Performance Monitoring System. The only vessels considered were the barge tows. The locks used to obtain the barge tow trip data include the Newt Graham Lock, the James W. Trimble Lock, and the Norrell Lock. For the Oklahoma portion, the annual number of barge tows was averaged using tow data from the Newt Graham Lock and the James W. Trimble Lock statistics for 1995 and 1999. For the Arkansas portion, the annual number of barge tows was averaged using tow data from the James W. Trimble Lock and the Norrell Lock statistics for 1995 and 1999. Thus, $T_{Oklahoma}$ was estimated as 784 barge tows annually, and $T_{Arkansas}$ as 1,225 barge tows annually.

The number of vessel trips that is often used to estimate the frequency of incidents is based on the U.S. Army Corps of Engineers Waterborne Commerce Statistics data. This data includes the number of individual trips within a waterway or a section of a waterway, which is generally larger than the actual number of vessel passages at a given location. The vessel trip data based on the Lock Performance Monitoring System that was used is closer to the actual number of trips at a given location.

The adjustment factor due to the geometric probability, F_{PG}, varies depending on the local conditions and the accident type. As discussed in INCOM (2001), it may be assumed that, on average, one out of three loss of vessel control events can result in an allision, and one out of five loss of vessel control events can result in a collision. Subsequently, we may use $F_{PG\ allisions}$ equals 0.33, $F_{PG\ collisions}$ equals 0.2, and $F_{PG\ Loss\ of\ Vessel\ Control}$ equals 1. For groundings, the grounding model developed by Kristiansen (1983) was used. Based on this model, the geometric probability of grounding over a distance, L, along the waterway can be calculated as follows:

$$PG_{groundings} = 1 - \frac{2W}{\pi L}$$

where

$PG_{groundings}$	= Geometric probability of grounding over a distance, L, along the waterway
W	= Width of the waterway
L	= Length of waterway considered

Two allisions were conservatively added to the accident period considered (1991-2001) to account for three allisions that are known to have occurred in Oklahoma between 1983 and 2004. In 1983, maintenance records for the I-40 Bridge indicate that an unknown vessel struck a channel pier. In 2002, the I-40 Bridge collapsed as the result of an allision, and one unknown allision was reported at a nearby bridge. The rate of allisions was calculated by counting 3 allisions from 1983 to 2004 (21 years) and adjusting for the study period of 11 years. This resulted in about 2 additional allisions.

The contributions of the various accident types to the historical probability of aberrancy base rates are shown in Table 7.3.3.1 for the Oklahoma portion and in Table 7.3.3.2 for the Arkansas portion of the waterway. The historical probability of aberrancy base rate was found to be 3.8×10^{-5} for Oklahoma and 5.1×10^{-5} for Arkansas. These rates are smaller than the BR value of 1.2×10^{-4} calculated based on the AASHTO formula by about 3.2 times for Oklahoma and 2.4 times for Arkansas. The computation spreadsheets used are included in Appendix E1.

Table 7.3.3.1: Historical Base Rate of Probability of Aberrancy for the Oklahoma Portion of the McClellan-Kerr Arkansas River Navigation System

Accident Type	$N_{incidents}$	F_{PG}	$BR_{accident\ type}$
Allisions	2	0.3	1.0×10^{-5}
Groundings	8	0.8	1.7×10^{-5}
Collisions	1	0.2	8.5×10^{-6}
Loss of Vessel Control	1	1.0	1.7×10^{-6}
		$\Sigma\ BR_{accident\ type}$	$\mathbf{3.8 \times 10^{-5}}$

Table 7.3.3.2: Historical Base Rate of Probability of Aberrancy for the Arkansas Portion of the McClellan-Kerr Arkansas River Navigation System

Accident Type	$N_{incidents}$	F_{PG}	$BR_{accident\ type}$
Allisions	4	0.3	5.8×10^{-6}
Groundings	55	0.8	3.4×10^{-5}
Collisions	1	0.2	2.4×10^{-6}
Loss of Vessel Control	19	1.0	9.1×10^{-6}
		$\Sigma\ BR_{accident\ type}$	$\mathbf{5.1 \times 10^{-5}}$

To obtain the probability of aberrancy, *PA*, the historical base rate probability may be multiplied by a series of correction factors that account for bridge location (R_B), water current (R_C), cross-currents (R_{XC}), and vessel traffic density (R_D), in the same manner as in the AASHTO formula method. Using similar local influencing factors as described in Section 7.3.2, the barge tow probability of aberrancy was computed as 7.0×10^{-5} for the downstream traffic and 8.0×10^{-5} the upstream traffic (see Appendix E2).

7.4 Geometric Probability

The geometric probability (PG) is defined as the conditional probability that a vessel will hit a bridge pier given that it has lost control (it is aberrant) in the vicinity of the bridge. The probability is calculated statistically using a normal distribution for the location of the aberrant vessel across the waterway. The PG represents the area in the normal distribution within the zone of impact. One standard deviation of the distribution is assumed as the length overall (LOA) of the evaluation vessel group. The geometric probability depends on the size of the pier, the skew of the pier relative to the channel and the width of the barge tow. Wider tows have a higher likelihood of contacting part of the substructure. It also depends on the location of the shore line relative to a given pier, which could prevent some barge tows from reaching the pier. Different geometric probabilities are calculated for each barge tow category.

7.5 Vessel Impact Speed and Collision Forces

The vessel collision forces were computed using an operating speed of 12.5 feet per second for the downstream traffic and 9.5 feet per second for the upstream traffic. The operating speed reflects typical vessel transit speeds within the navigable channel limits in the vicinity of the bridge under normal environmental circumstances.

Vessel impact loads were determined for each barge tow category for both the longitudinal and the transverse directions and for the actual loading condition, according to the AASHTO Guide, Section C3.12. For impacts applied in a direction parallel to the alignment of the centerline of the navigable channel, 100% of the impact force is used. For perpendicular impacts, 50 % of the impact force is used.

7.6 Substructure Capacities

7.6.1 General

Since vessel collisions with bridges are extreme events with a low probability of occurrence, the capacity limit states used in bridge design are generally based on structural survival criteria (AASHTO 1991; AASHTO 1994). Damage or local collapse of substructure and superstructure elements is permitted to occur provided that the structure maintains its integrity, hazards to traffic are minimized and repairs can be made in a relatively short period of time.

The evaluation of the bridge member capacities is mainly based on the AASHTO (1994) ultimate state design criteria with resistance coefficients equal to 1.0. Because of the similarity between the limit states criteria for vessel collision and seismic design, guidelines for evaluating seismic resistance were also considered (AASHTO 1991; FEMA 2000; Priestly 1996).

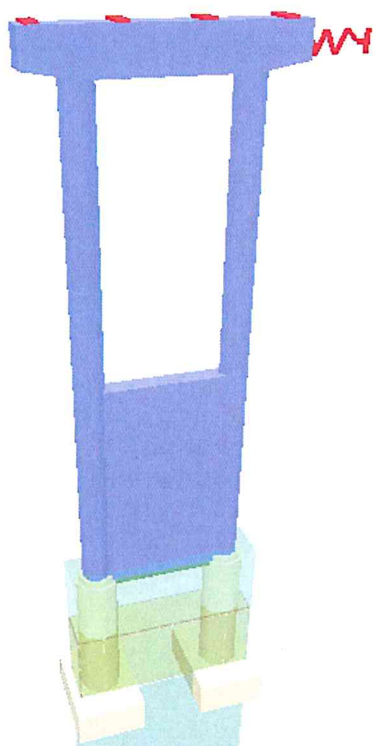
The computer programs used include FB-Pier, SAP2000 and Response-2000.

7.6.2 FB-Pier

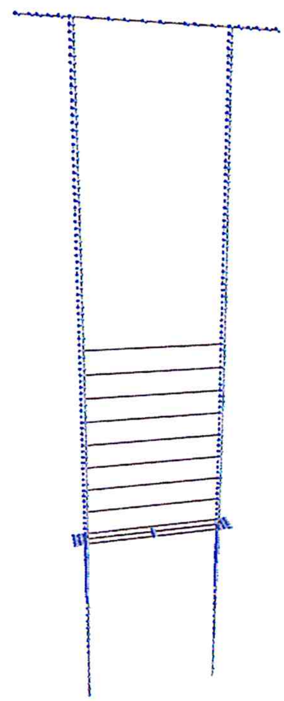
The FB-Pier (Florida Pier) program was developed by the Florida Bridge Software Institute (BSI 2002), specifically for vessel collision design of bridge piers. The FB-Pier program has the ability to analyze both the foundation and the pier structure at the same time. The analysis couples a standard finite element analysis with a nonlinear static soil model for the axial and lateral loading of the pier. The finite element model for the pier is generated by the program based on the geometry and design parameters of the pier. Pier piles and columns can be modeled with a nonlinear material behavior using discrete element formulation to account for plastic hinge formations. The capability of considering both the nonlinear behavior of soil and the structure geometric and material nonlinearities is important for evaluating failure conditions.

The FP-Pier can model substructures that include pile or drilled shaft foundations, pile caps, pier columns and pier caps. The soil-structure interaction is modeled using vertical lateral and torsional nonlinear springs for the foundation soil. The pile cap is modeled with combined plate and beam finite elements and its response is controlled by its thickness, modulus of elasticity and strength properties. The effects of the superstructure may be included using equivalent linear springs connected to the pier cap.

For the SH-100 Bridge, separate FB-Pier models were created for the side piers and for the channel piers. The side pier models are illustrated in Figure 7.6.2-1, which shows a solid representation and a deflected wire frame of the Pier 4 model. A combination of pile cap plate elements and several beam elements was used to model the web wall.



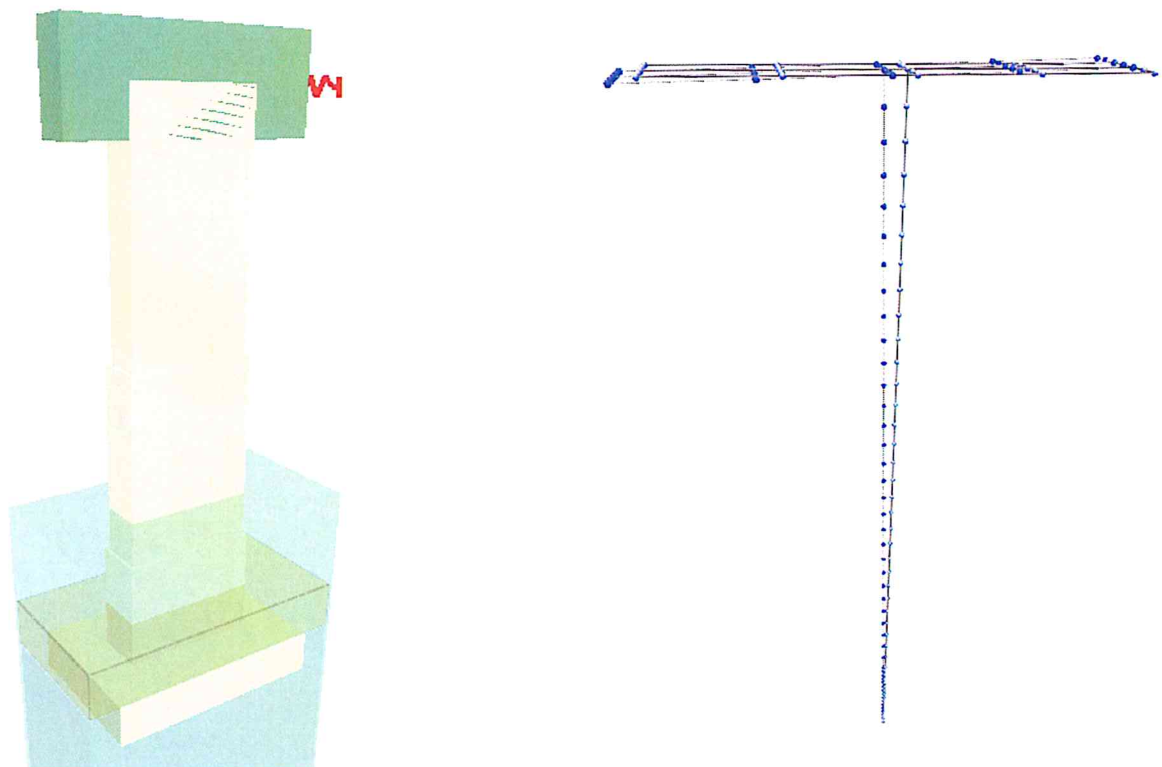
a. Solid Representation



b. Deflected Wire Frame

Figure 7.6.2-1: FB-Pier Finite Element Model for Rebuilt Side Piers

The analysis model used for the channel piers is shown in Figure 7.6.2-2, which includes a solid representation and a deflected wire frame of the Pier 5 model.



a. **Solid Representation** b. **Deflected Wire Frame**

Figure 7.6.2-2: FB-Pier Finite Element Model for Channel Piers

The footings are cast against the shale rock layer. Since the program only accounts for the side resistance of the footing, additional sensitivity analyses were performed for varying rotational stiffness properties at the tip of the footing to account for the contribution of the bottom of the footing. The analyses were bounded by upper and lower bound assumptions of the foundation stiffness, which was calculated based on FEMA 356 guidelines (see Section 7.6.5). The program was used to calculate deflections, member loads and demand capacity ratios for bending, based on both linear and non linear analyses. Shear capacity was checked separately.

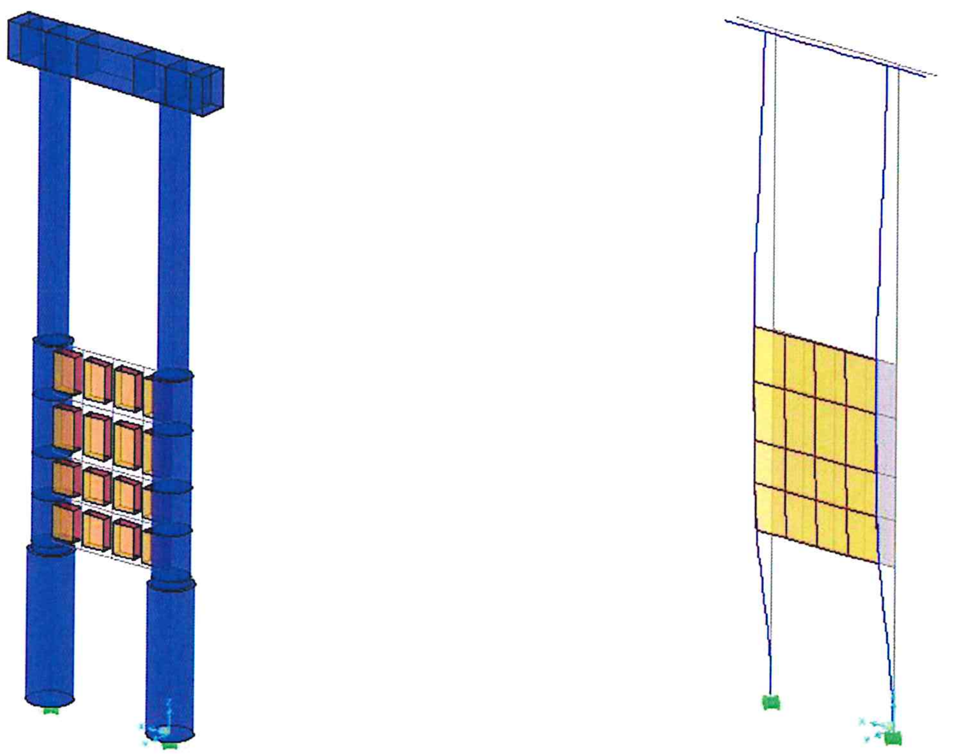
7.6.3 SAP2000

The computer program **SAP2000** (SAP2000 2002) is a general purpose structural analysis program. Its capabilities include linear static and dynamic analysis, and static nonlinear analysis for material and geometric effects. One of the features of the program that includes integrated concrete design can calculate moment capacity ratios for columns when the amount of longitudinal reinforcing steel is specified.

The structural analyses used to determine member loads, displacements and column capacity ratios included both linear analysis and nonlinear analysis with P-delta effects included.

Beam elements were used for the columns and caps, and shell elements were used for the web wall. The modeling of the foundation included a case of full fixity and a case using equivalent springs at the bottom of the pier to model the foundation stiffness. The modeling of the superstructure included two cases; a case that assumes no contribution from the superstructure in distributing loads to the other piers and a case in which equivalent linear springs at the top of the pier were used to model the effects of the superstructure.

Separate SAP2000 models were used for side piers and for the channel piers. The side pier models are illustrated in Figure 7.6.3-1, which shows a solid representation and a deflected wire frame of the Pier 2 model.

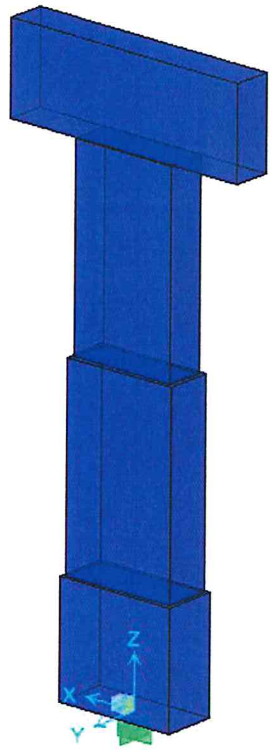


a. Solid Representation **b. Deflected Wire Frame**

Figure 7.6.3-1: SAP2000 Finite Element Model for Side Piers

The analysis model used for the channel piers is shown in Figure 7.6.3-2, which includes a solid representation and a deflected wire frame of the Pier 5 model.

The results of the SAP2000 analysis were also used to verify the FB-Pier analysis results.



a. Solid Representation **b. Deflected Wire Frame**

Figure 7.6.3-2: SAP2000 Finite Element Model for Channel Piers

7.6.4 Response-2000

Response-2000 (Benz 2001) is a non-linear sectional analysis program for the analysis of reinforced concrete elements subjected to combined shear and moment based on the Modified Compression Field Theory (MCFT) (Vecchio 1986; Collins 1978). The MCFT is capable of giving more accurate predictions of the shear response of existing reinforced and prestressed concrete bridge members with and without shear reinforcement. The program satisfies the AASHTO LRFD design criteria, and it is a good complement to the FB-Pier program, which does not include a shear capacity check.

Capacities were calculated at the base of the pier for moment only and at a shear critical location at a distance of about 0.75 times the width of the pier above the base for combined shear and moment.

Examples of the analysis results are shown in Figure 7.6.4-1 and 7.6.4-2. Figure 7.6.4-1 is an illustration of the cross section and moment-curvature data from the sectional analysis of the 6 foot diameter concrete columns. Figure 7.6.4-2 is an illustration of the Pier 5 cross section and shear-shear strain data from the strong direction sectional anaylsis of the section above the base for combined moment and shear.

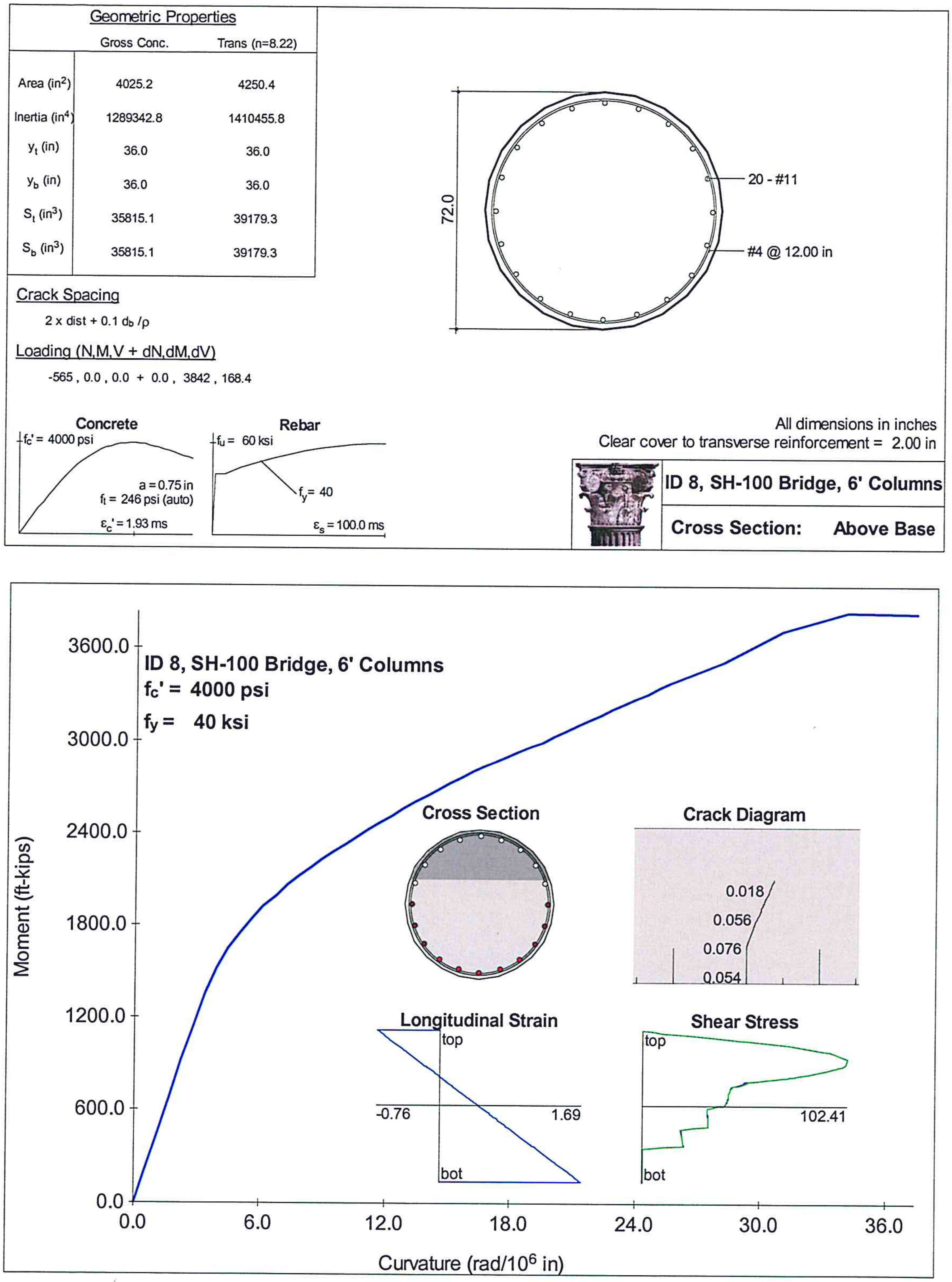
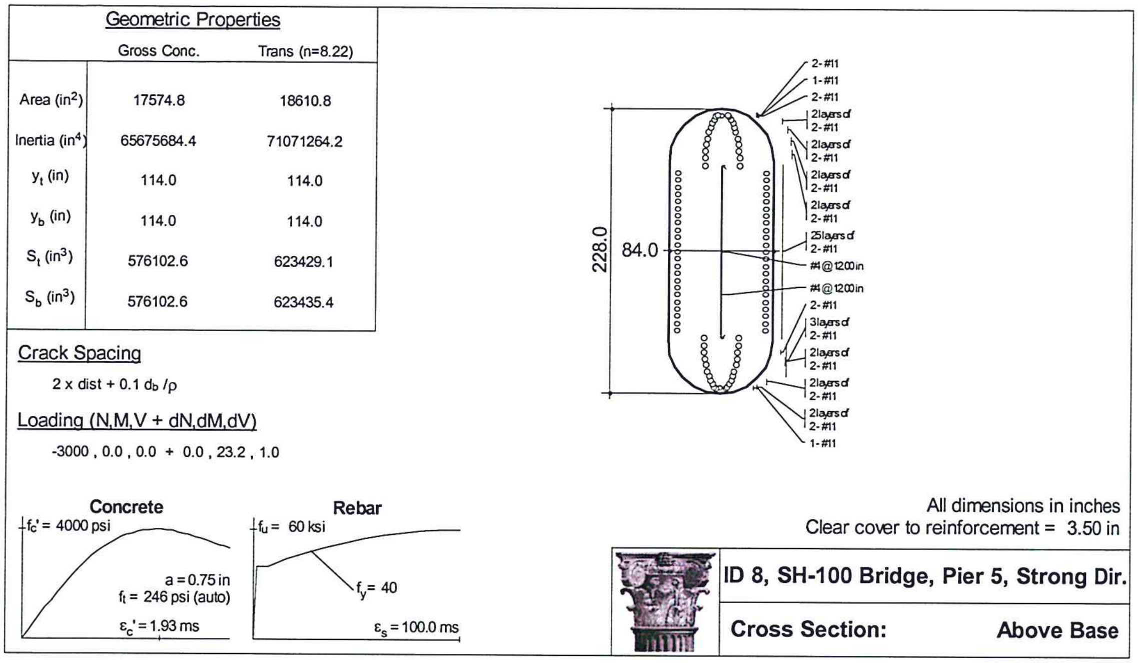


Figure 7.6.4-1: Response-2000 Sectional Analysis – 6' Column Cross Section and and Moment-Curvature Data for Weak Direction, Section Above Base for Moment and Shear



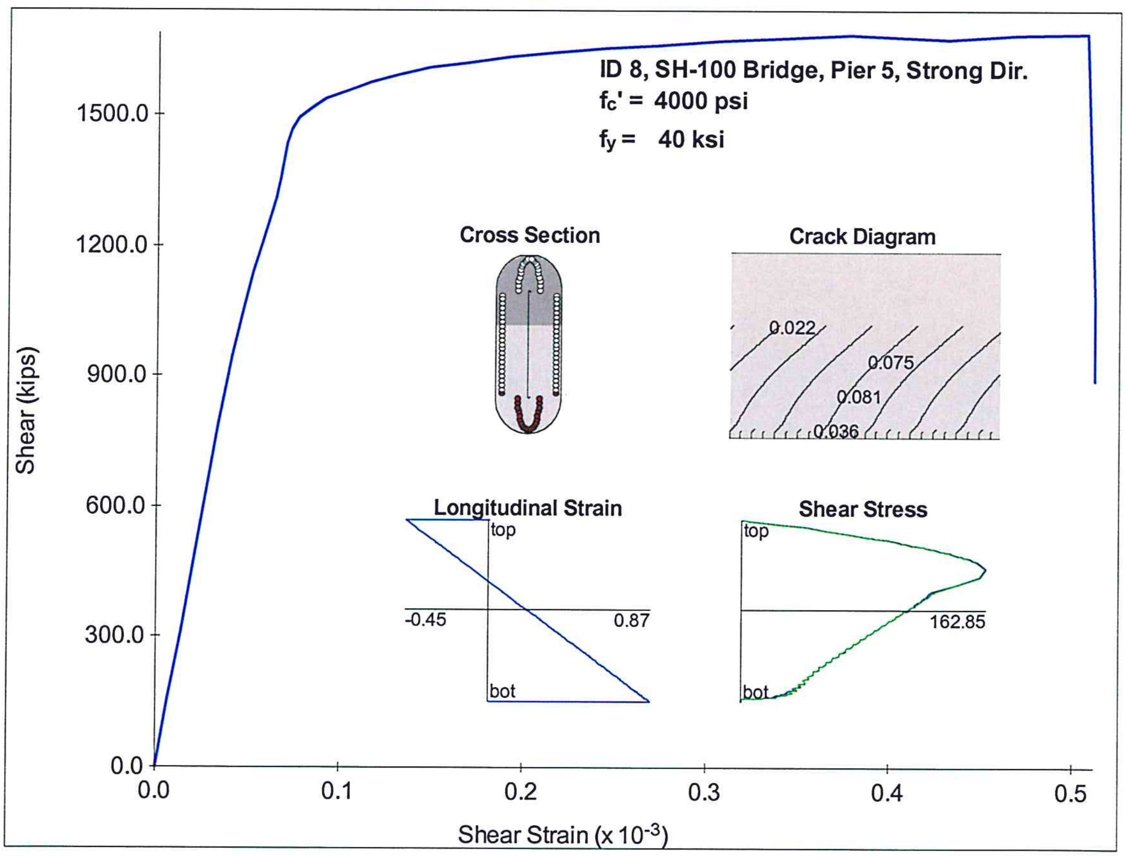


Figure 7.6.4-2: Response-2000 Sectional Analysis – Pier 5 Cross Section and Shear-Shear Strain Data for Strong Direction, Section Above Base for Moment and Shear

7.6.5 FEMA 356

Because FB-Pier does not account for the rotational stiffness of the base of the footing, foundation strength and stiffness characteristics were also determined based on the guidelines provided in FEMA 356 (2000). The approach used in FEMA 356 is based on spring stiffness solutions applicable to rigid foundations on the surface of, or partially or fully embedded in, a homogeneous halfspace.

7.6.6 Analysis Approach

The piers were first analyzed using a 3-D model in FB-Pier that includes soil structure interaction. The analysis results were then verified using an independent 3-D model in SAP2000. Both the FB-Pier and the SAP analyses performed included linear and nonlinear analyses of the pier structure with geometric nonlinearity for P-delta effects. In both models equivalent springs were used at the top of the pier to model the participation of the superstructure, where applicable. Springs were also used at the base of the pier in some cases to evaluate the effects of the foundation stiffness. The stiffness of the springs was determined based on FB-Pier soil structure analysis results and also based on spring stiffness elastic solutions applicable to rigid foundations partially or fully embedded in a homogeneous halfspace provided in FEMA 356 (2000). Moment and combined moment and shear capacities were checked using Response-2000 analysis.

7.6.7 Summary of Pier Capacity Data

The global, nominal pier capacities obtained are presented in Table 7.6-1, in terms of controlling maximum lateral concentrated forces applied at the 2% flowline. The longitudinal direction refers to loading parallel to the channel, while the transverse direction refers to loading perpendicular to the channel. The material properties used include a concrete compressive strength (f'c) of 4,000 psi and steel yield strength (f_y) of 40 ksi for the reinforcing steel.

Table 7.6-1: Nominal Substructure Capacities (kips)

Pier	Parallel to Channel		Perpendicular to Channel	
	Lower Level	Upper Level	Lower Level	Upper Level
2	505	650	350	350
3	540	790	355	400
4	540	730	300	305
5	1,690	2,250	780	815
6	1,690	2,225	780	815
7	500	655	275	285
8	530	750	365	390
9	530	670	350	370
10	515	610	270	290
11	545	775	380	410
12	550	570	340	350
13	570	705	285	315

Where applicable, the capacity of the reinforcing bars lap splices was verified based on a rational assessment procedure (Priestly et. al. 1996), which was developed by the University of California, San Diego and confirmed by full scale tests conducted between 1992 and 1994.

7.7 Design Water Elevation

The water level along with the loading condition of a vessel influence the location of the vessel impact loads, the accessibility of vessels to piers outside the navigation channel, and the susceptibility of the superstructure to vessel hits. The design impact force is applied as a concentrated force on the substructure at the mean high water level (or the 2% flowline) for overall capacity checks, and as a vertical line load distributed along the ship's bow depth with the ship in relation to the mean high water level for localized collision forces.

The 2% flowline established for the bridge site is quite conservative. It is about 11 feet higher than the pool elevation (see Section 4.3).

7.8 Probability of Collapse

The probability of collapse (PC) once a bridge substructure element has been struck by an aberrant vessel is a function of many variables, including vessel size, type, forepeak ballast and shape, speed, direction of impact, and mass. It is also dependent on the ultimate lateral strength of the pier, span, or element to resist collision impact loads. The PC is determined based on the ratio of the structural capacity (H) to the static impact force (P).

7.9 Annual Frequencies of Collapse

Annual frequencies (AF) of collapse were determined for each bridge substructure element exposed to vessel impact in both the parallel and perpendicular directions for different barge tow types and configurations. The general expression used is as follows:

$$AF=(N)(PA)(PG)(PC)$$

where

N = annual number of vessels classified by type, size, and loading condition which can strike the bridge element

The summation of all substructure element frequencies of collapse in the controlling impact direction for both upstream and downstream traffic represents the annual frequency of collapse for the entire substructure. The annual frequencies of collapse for the substructure are shown in Figure 7.9-1 and summarized in Table 7.9-1. Figure 7.9-1 shows that most of the contribution to the annual frequency of collapse comes from the side piers closer to the navigation channel. The risk analysis spreadsheets are included in Appendix E2. The main variables governing the risk of vessel collision have been used as input parameters to the spreadsheets to allow for sensitivity analysis and future changes in parameters, if needed.

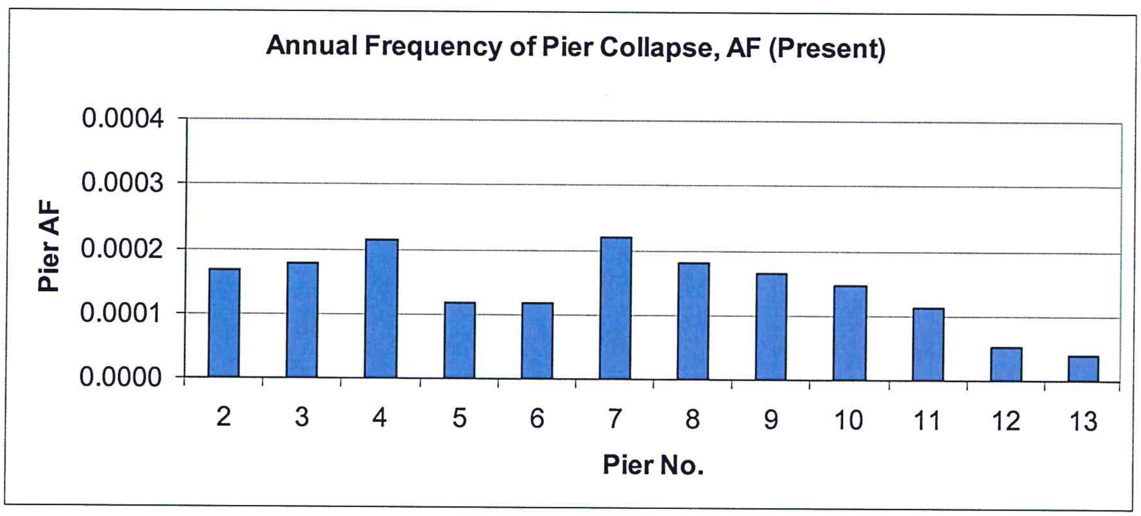


Figure 7.9-1: Annual Frequency of Collapse by Pier

Table 7.9-1: Annual Frequency of Substructure Collapse

Pier	Controlling Case	Controlling Case (2020)
2	0.00017	0.00022
3	0.00018	0.00023
4	0.00021	0.00028
5	0.00012	0.00015
6	0.00012	0.00015
7	0.00022	0.00029
8	0.00018	0.00024
9	0.00016	0.00021
10	0.00015	0.00019
11	0.00011	0.00014
12	0.00005	0.00007
13	0.00004	0.00005
Total:	**0.00171**	**0.00222**

The annual frequency of collapse (AF) for the entire substructure based on the present vessel traffic and the upper level of substructure capacities was computed as 0.00171, and the projected annual frequency of collapse for the year 2020 was estimated to be 0.00222.

The controlling case is governed by impacts perpendicular to the channel for both the new side piers and the channel piers. However, the annual frequency of collapse values based on all impacts parallel to the channel are only about 1.2 times lower.

The acceptable annual frequency of collapse for design is 0.001 for "regular" bridges and 0.0001 for "critical" bridges.

7.10 Bridge Classification Criteria

The classification of a bridge with respect to vessel collision has to be made by the bridge owner. Based on the *AASHTO Guide Specification and Commentary for Vessel Collision Design of Highway Bridges*, the main factors that need to be considered when determining the classification of a bridge with respect to vessel collision include:

- *Need for civil defense, police, fire department, or public heath agencies to respond to an emergency, which might exist on the opposite side of the waterway. Bridges that provide the only continuous transportation route for such emergency situations should be classified as critical.*

  The I-40 Bridge, located 2.8 miles downstream from the SH-100 Bridge, can provide an emergency route across the waterway.

- *Social/Survival importance in an emergency or disaster situation.*

  The SH-100 Bridge is important for an emergency or disaster situation. However, the I-40 Bridge can provide an alternate emergency route across the waterway.

- *Role as an important link in the defense highway network. Bridges that are part of the Security/Defense roadway network should be classified as critical.*

  The SH-100 Bridge is not part of the Strategic Highway Network (STRAHNET) system. This system is a network of public highways designated by the Federal Highway Administration in partnership with DOD, which provides access, continuity, and emergency transportation of personnel and equipment in times of peace and war.

- *Availability of alternate detour routes.*

  Available detour routes exist, such as the I-40 Bridge.

The factors contributing to the bridge classification criteria are consistent with a regular bridge classification. Note that these factors are subject to change and may need to be reevaluated as such.

8. PREVENTION AND PROTECTION ALTERNATIVES

8.1 General

Vessel collision with a bridge involves a sequence of events (vessel becomes aberrant, aberrant vessel actually strikes a bridge element and the bridge element hit actually fails). Measures that can reduce the likelihood of vessel aberrancy and the likelihood that an aberrant vessel reaches a vulnerable bridge element can be used to prevent collisions, and bridge protection and motorist warning measures can be used to mitigate the consequences of a collision if it occurs.

8.2 Prevention Measures

8.2.1 Causes of Accidents

Marine accident studies have found the human element as the predominant factor in vessel incidents. Therefore identifying measures for preventing human errors and measures for increasing the chances for evasive actions is of utmost importance. Human errors generally include piloting errors, such as incorrect decisions, improperly performed actions or improper lack of action, and other operation errors such as miscommunications between pilot and bridge crew, insufficient horsepower or tow configuration and assembly problems. Main factors that were found to contribute to human errors in the entire maritime industry include fatigue, inadequate pilot-bridge crew coordination, and inadequate technical knowledge, especially of radar (U.S. Coast Guard 1995).

Studies of bridge collision accidents also found that the majority of the causes of accidents are related to human performance. However, while the contributing factors to the more frequent accidents at difficult navigation sites are generally consistent with those in the entire maritime industry, the causes of the rare accidents at normal navigation sites were found to center around two main cases; cases in which the vessel operator was not aware that he was out of the navigation channel and cases in which the vessel operator fell asleep or was incapacitated (see Section 3.3).

8.2.2 General Collision Prevention Measures

General measures for preventing human error during bridge transits were identified in U.S. Coast Guard-American Waterway Operators (2003) study. They include:

- Development of navigation best practices for transiting bridges vulnerable to collision.
- Training of operators in the application of navigation best practices.
- Requiring route familiarization, posting, or check-ride before an operator is permitted to navigate under a vulnerable bridge.
- Improving Coast Guard-industry information sharing on near misses.

- Requiring the implementation of Crew Endurance Management Systems (CEMS) throughout the towing industry as a means of improving decision making fitness.

8.2.3 Site Specific Collision Prevention Measures

Site specific measures that have been used or recommended in the past to reduce the likelihood of collisions at locations that have experienced frequent accidents or at locations where a bridge analysis has shown high risk levels include:

- Adding aids to navigation (33 CFR 118.100-118.140), such as:
  - Retroreflective panels on bridge piers (to better identify a hazardous pier, provide a back up for bridge lights or to mark bridge piers or channel sides not required to have bridge lighting).
  - Daymarks and lateral lighting on bridges (to mark the margins of navigation channels through bridges).
  - Radar reflectors (used to mark the location of the edge of the navigation channel or bridge channel piers).
  - Racons (to mark the centerline of the channel).
  - Fog signals (for waterways where the visibility is frequently reduced due to fog or other causes).
  - Painting bridge piers (when they are poorly visible against a dark background).
- Establishing a Regulated Navigation Area (RNA). A regulated navigation area may be established on the initiative of any authorized Coast Guard official, as set forth in 33 CFR 165: Regulated Navigation Areas and Limited Access Areas. Restrictions to vessel operations in the RNA can include regulating a vessel's operating speed, meetings, passings, anchoring or stopping. They can also include precautions such as power to tow size ratios and watch requirements for high water or other certain conditions. For example, 33 CFR Sec. 165.817 defines the Arkansas River from Mile 118.2 to 125.4 (Little Rock, Arkansas) as a regulated navigation area, as described in Section 5.7.
- Passing State legislature to regulate navigational safety in a specific area. Such local regulations could require special equipment for use with collision avoidance warning systems or establishing a prohibited navigation zone. For example, the Louisiana Legislature passed La. Acts (1988) No. 552 on July 14, 1988. This law requires that vessels of a certain size or greater be equipped with Loran C Equipment, for use with the Lake Pontchartrain Collision Aviodance Warning. It also establishes a "prohibited zone" paralleling each side of the entire length of the bridge.

Cost effective measures for reducing the likelihood of accidents at normal navigation sites may include installation of a Racon device to help vessel operators identify the navigation channel, and taking steps for identifying and implementing measures that could increase the likelihood of evasive actions in case vessel operators fall asleep or become incapacitated in the vicinity of the bridge.

A Racon device is an aid to navigation installed on the bridge superstructure at the centerline of the navigation span (33 CFR 118.120). It is used to identify the location of the centerline of the navigation channel on the radar screen of the vessel. Racons include a transmitter receiver device associated with a fixed navigational mark which when triggered by a radar, automatically returns a distinctive signal on the display of the triggering radar, providing range, bearing and identification information. Racons and their identifiable marks are normally indicated on navigation charts and the Coast Guard Light List. The U.S. Coast Guard operates approximately 80 Racons. Several more are operated by states or private organizations such as offshore installations, major bridges in California and over the Hudson River in New York State.

Advantages of using a Racon device on the bridge include:

- Assistance in initial approach to a bridge and shaping up for safe passage through the navigation channel span of the bridge.
- Assistance in restricted visibility.
- Improvement in radar navigation, especially in narrow channels and multiple pier bridge crossings.
- Supplement to the visual aids to navigation during good visibility.
- Increased awareness of the bridge crossing and the location of its navigation channel during navigation.
- Increased awareness of a special bridge crossing during the review of navigation charts and Coast Guard Light Lists, which include information on Racons.

Identifying measures that could increase the probability of successful evasive actions requires further evaluation mainly within the maritime industry, and their implementation will require coordination between towing industry organizations, U.S. Coast Guard, U.S. Army Corps of Engineers, State agencies and legislature. Possible measures could include dead man's switches, motion sensor in the pilothouse to detect if the pilot ceases to move for a programmable period of time, or requiring a second person to be present in the pilothouse when passing through this bridge.

Yearly reviews of U.S. Coast Guard vessel casualty data for prevalent trends in types and locations of incidents, conditions of the towboat and barge tow involved, and the courses of incidents can also help identify accident prevention measures.

8.3 Physical Protection

8.3.1 General

The main objective of bridge protection measures is to minimize consequences of bridge collision. Bridge protection measures that may be considered at existing bridges that were determined to be at risk of vessel collision include pier strengthening, pier mounted protection or independent pier protection.

Since it is often impossible to provide 100% protection to an exiting bridge, cost benefit criteria is an important aspect in the selection of the protection system. Factors that need to be considered include the bridge type and size, the vessel types, the pier capacity and the governing failure modes. It may be economically feasible to strengthen a pier if the local capacity of a slender element above water governs, but much more difficult to strengthen a pier if the overall foundation capacity of a pier in deep water controls. AASHTO (1991) recognizes the high costs that could be involved in the protection of existing bridges and provides a Method III type analysis option, which is based on cost benefit of risk reduction criteria.

8.3.2 Site Specific Protection Measures

The selection of the type and extent of physical protection measures depends on a number of factors that include:

- The calculated versus the acceptable annual frequency of collapse for the bridge substructure.
- The degree of implementation of the general and site-specific collision prevention measures described in Sections 8.2.2 and 8.2.3.
- The effects of the protection measures on the river flow and the potential for increased scour.
- The cost-effectiveness of risk reduction of the protection measures.

The most conventional type of protection consists of sheet pile dolphins 40 to 50 feet in diameter. However, the use of sheet pile dolphins for the side piers could have an adverse effect on the river flow due to their size and the relatively close spacing between the side piers (see Figure 8.3.2).

A less conventional type of protection structure that could be more appropriate for the bridge site consists of individual 12-foot drilled shafts, strategically placed to reduce barge tow access (both straight-on and at an angle with the channel) to the higher risk piers. The actual number and location of the drilled shafts will depend on the factors listed above. For example, if no collision prevention measures are implemented, the extent of protection will mainly depend on the number of drilled shafts needed to achieve the acceptable annual frequency of collapse for the bridge substructure.

As a result of the high impact loads that can be applied in certain collision cases, plastic deformation and crushing of the drilled shafts can be considered to be acceptable. Energy will be dissipated through their damage, and barges will be slowed down and diverted. Thus, the drilled shafts may require repair or replacement after a serious collision. The use of appropriate reinforcing details, which could include H-pile sections, could effectively increase the moment and shear capacity of the drilled shafts and minimize their damage.

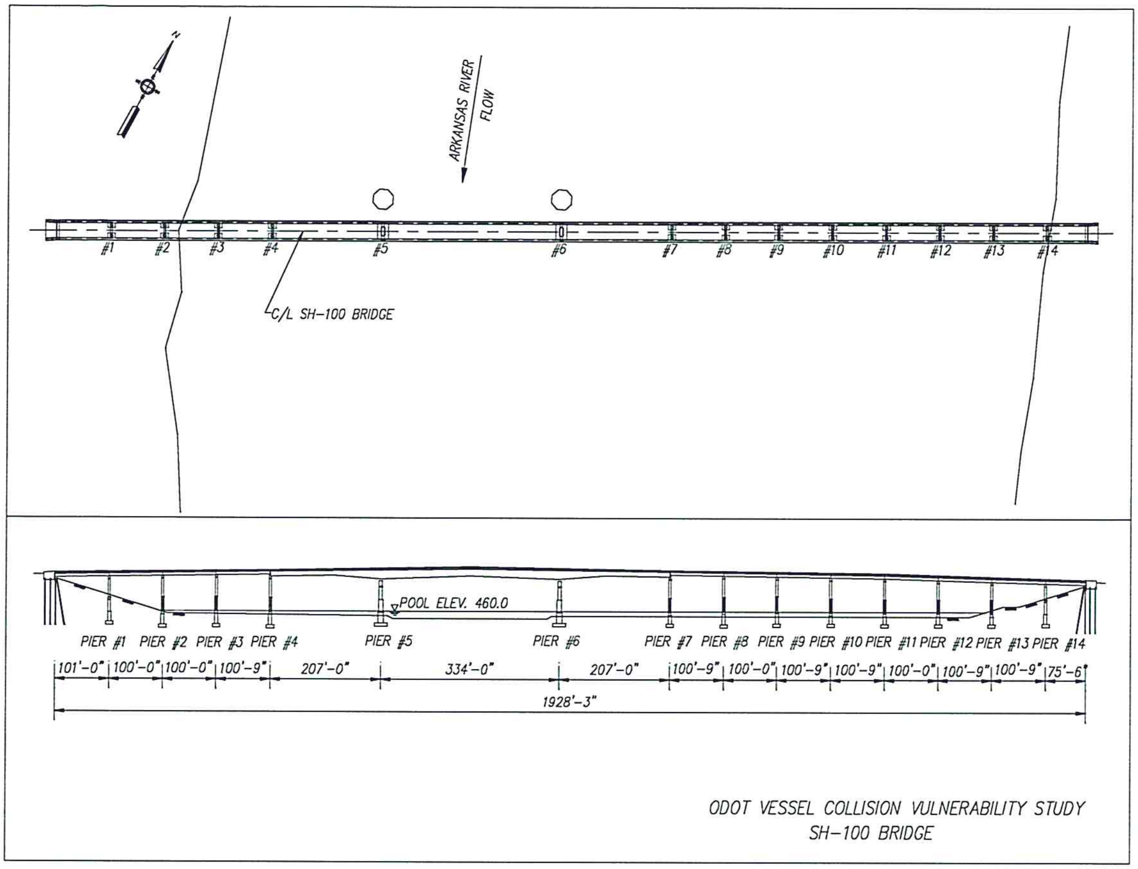


Figure 8.3.2-1: Bridge Plan and Elevation View

If no collision prevention measures are to be implemented, the specific collision protection layout recommended for the bridge crossing is shown in Figure 8.3.2-2. By strategically placing individual concrete drilled shafts to reduce barge tow access to the higher risk piers, the annual frequency of collapse would be reduced to acceptable value for "regular" bridges (0.001) as defined by AASHTO (1991).

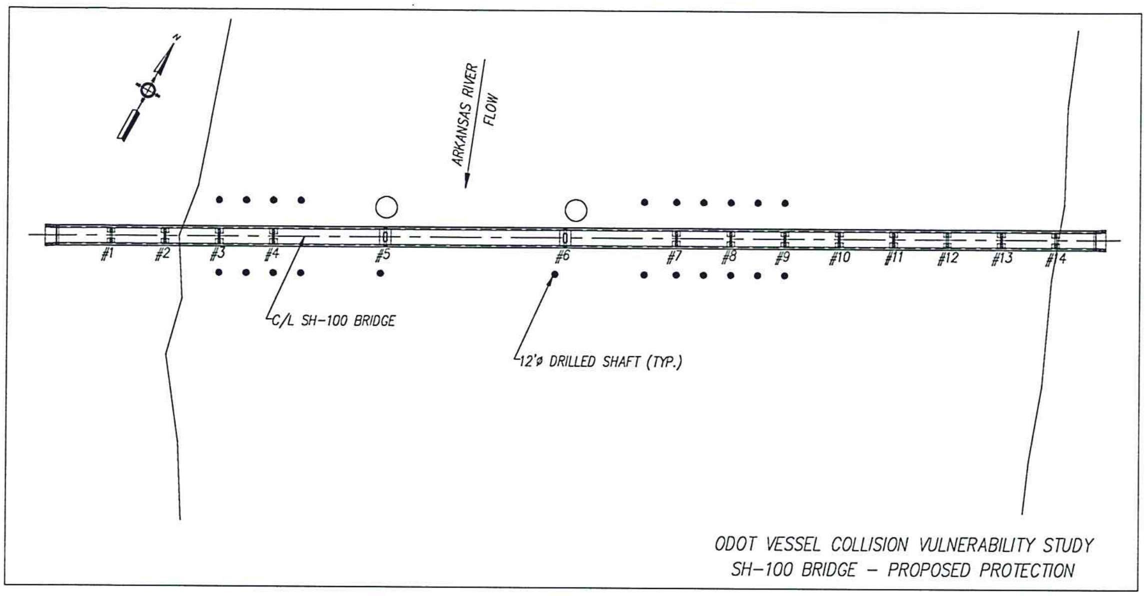


Figure 8.3.2-2: Bridge Plan View with Proposed Pier Protection

8.4 Motorist Warning Systems

Bridge user warning systems include collision hazard detection measures and bridge traffic control measures. The collision hazard detection options may include vessel impact vibration detectors, continuity circuits or VHF radio link. Bridge traffic control measures may include variable message signs, flashing beacons or movable gates.

It should be noted, however, that many if these systems tend to be complex and of uncertain reliability for infrequent operation over long periods of time. In addition, there is a need for further investments and development, and for the establishment of a track record. So far, the use of bridge user warning systems has been limited.

9. SUMMARY OF RESULTS AND CONCLUSIONS

The SH-100 Bridge is located at river mile 363.1 on the Arkansas River section of the McClellan-Kerr Arkansas River Navigation System (MCKARNS). The McClellan-Kerr Arkansas River Navigation System (MCKARNS) is a 445 mile long system of 17 locks and dams, which allows vessel traffic to overcome the 420 foot difference in elevation from the beginning to the end.

The bridge is 1,928.25 feet long, and it consists of 15 composite steel plate girder spans on concrete piers. The navigation span is 334 feet long, and the adjacent spans range from 100 feet to 207 feet. Two 40-foot diameter steel sheet pile dolphins are located directly upstream from the channel piers. A vertical clearance of 52.0 feet from the 2% flow line elevation (EL. +470.5) and 62.5 feet from the pool elevation (EL. +460.0) is provided in the 300-foot wide navigation channel.

The river at the bridge site is approximately 1,500 feet wide, and the water depth in the navigation channel is about 14 feet relative to the navigation pool elevation. The bridge is aligned slightly skewed relative to the channel. A 39° bend in the channel is located approximately 6,520 feet on the upstream side of the bridge, and a 17° bend in the channel is located approximately 1,780 feet on the downstream side of the bridge. Except for extreme events, water levels on the McClellan-Kerr Arkansas River Navigation System vary little. The average velocity is below about 2.5 feet per second, and cross currents can occur in the vicinity. Only one facility was identified near the bridge site.

The commercial vessel types on the McClellan-Kerr Arkansas River Navigation System include mainly hopper and tanker barge tows. The size of the barge tows on the McClellan-Kerr Arkansas River Navigation System is affected by the size of the locks in the system. The hopper barge tows range in size from one to twelve barges per tow, with a six to eight barge tows being the most common. The tanker barge tows range in size from one to five barges per tow, with a two or four barge tows being the most common. Vessel traffic is relatively low, with an average of one barge tow per day in each direction. Vessels do not typically pass each other under the bridge.

Overall, the SH-100 Bridge is relatively easy to navigate through. Except for possible cross currents, no serious hazards to navigation were identified.

Relative to other waterways, the frequency of accidents on the McClellan-Kerr Arkansas River Navigation System River is quite low, especially in the Oklahoma portion. The historical probability of vessel aberrancy base rate was found to be $3.8\text{x}10^{-5}$ for the Oklahoma portion of the McClellan-Kerr Arkansas River Navigation System. This rate is about 3.2 times lower than the probability of aberrancy base rate value of $1.2\text{x}10^{-4}$ in the AASHTO Guide formula. During the time period between 1991 and 2001, there were no accidents reported near the SH-100 Bridge.

The annual frequency of collapse for the entire substructure based on the present vessel traffic was computed as 0.00171, and the projected annual frequency of collapse for the year 2020 was estimated as 0.00222. These values do not satisfy the acceptable annual frequency of collapse for "regular" bridges (0.001).

To reduce the annual frequency of collapse, collision prevention and/or protection measures may be used. Possible collision prevention measures include installation of a Racon device to help vessel operators identify the navigation channel, and taking steps for identifying and implementing measures that could increase the likelihood of evasive actions in case vessel operators fall asleep or become incapacitated in the vicinity of the bridge. Possible collision protection measures include individual concrete drilled shafts strategically placed to reduce barge tow access (both straight-on and at an angle with the channel) to the higher risk piers. The extent of the protection will depend on the degree of implementation of the general and site specific collision measures selected.

The proposed collision protection measures consist of individual concrete drilled shafts strategically placed to reduce barge tow access to the higher risk piers. Including the proposed pier protection measures in the calculations, the annual frequency of collapse for the entire substructure based on the present vessel traffic is reduced to 0.00073, and the projected annual frequency of collapse for the year 2020 is estimated as 0.00094. These values satisfy the acceptable annual frequency of collapse for "regular" bridges (0.001), but not for "critical" bridges (0.0001).

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APPENDIX A

SITE VISIT REPORT

APPENDIX A
Site Visit Report
Bridge ID 8, SH-100

The site visit for the SH-100 Bridge took place on Saturday, May 17, 2003. It began at approximately 12:15 p.m.

BRIDGE LOCATION

- Located on SH-100 in Webbers Falls, Oklahoma.
- See Figure A1.

CHANNEL GEOMETRY

- The bridge crosses the Arkansas River section of the McClellan-Kerr Arkansas River Navigation System, and is skewed relative to the channel.
- There are gradual bends in the channel on both the north and south sides of the bridge.
- See Figures A1 and A2.

WATER DEPTH FLUCTUATIONS

- Controlled by Lock & Dam.

WATER EDGE WITH RESPECT TO PIERS

- Pier 2 is approximately 50' off of the west bank.
- Pier 13 is approximately 25' off of the east bank.
- See Figures A5 and A8.

WATER VELOCITY

- Medium at the time of the visit.

CROSS CURRENTS

- Yes.

CONNECTION OF SUPERSTRUCTURE TO PIERS

- Steel rocker type bearings for the expansion joints at Abutment 1, Pier 1, 4, 6, 7, 10, 13 and 14.
- Steel key type bearings for the fixed joints at Piers 2, 3, 8, 9, 11, 12 and Abutment 2.
- Steel pin type bearings for the fixed joint at Pier 5.

EXISTING PIER PROTECTION

- 40'-0" diameter dolphins on the upstream side of Piers 5 and 6.
- See Figures A4, A5, A7 and A9.

DAMAGES / REPAIRS DUE TO PAST VESSEL COLLISIONS

- None noted.

CHANGES TO AS-BUILT PLANS

- None noted.

BARGES BLOCKING SIDE SPANS OR BOATS TIED TO THE BRIDGE

- None noted.

VESSEL CHARACTERISTICS

- Mostly barge tows and smaller pleasure craft.

PORTS, WHARVES, AND INDUSTRIES

A. Consolidated Grain & Barge Company
   - Located approximately 500' upstream from bridge on the west bank.
   - See Figures A12, A13, and A14.
B. Boat Launch
   - Located approximately 500' upstream from bridge on the east bank.
   - See Figure A16.
C. Sequoyah Company Water Authority
   - Located approximately 1,600' downstream from bridge on the east bank.
   - See Figure A15.

OTHER BRIDGE CROSSINGS OR OBSTRUCTIONS TO VESSEL PASSAGE

D. "Peninsulas"
   - Located approximately 900' upstream and 2,300' upstream from bridge, both extending from the west bank.
   - See Figures A17, A18 and A19.
E. "Island"
   - Located approximately 750' upstream from bridge
   - See Figure A10.
F. I-40 Bridge
   - Located approximately 2.8 river miles downstream from SH-100 Bridge.
   - See Figure A2.

LOCKS

G. Webbers Falls Lock
   - Located approximately 3.5 miles upstream of the SH-100 Bridge.
   - See Figure A20.

COMMENTS

- None noted.

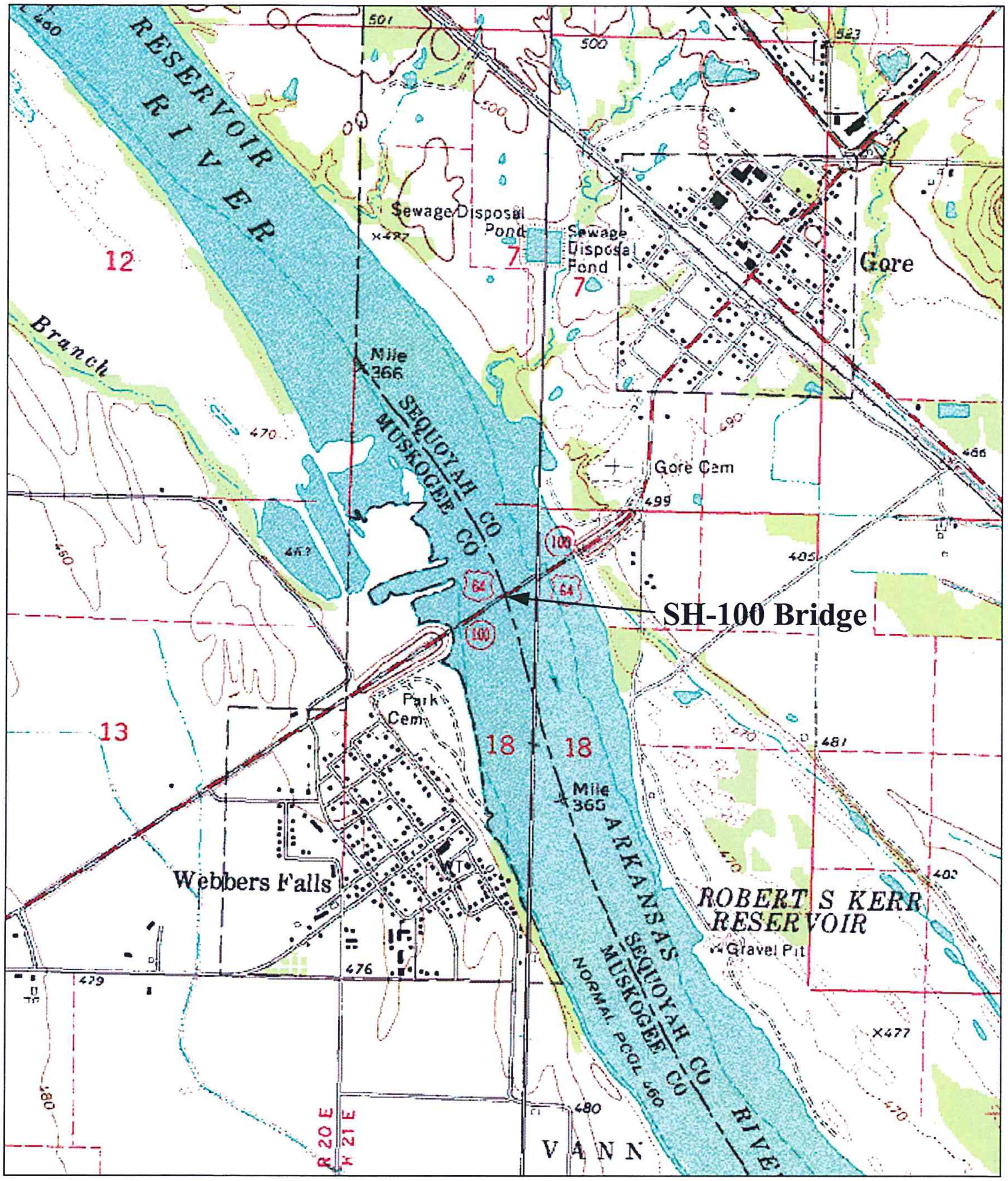

Figure A1: Location Map

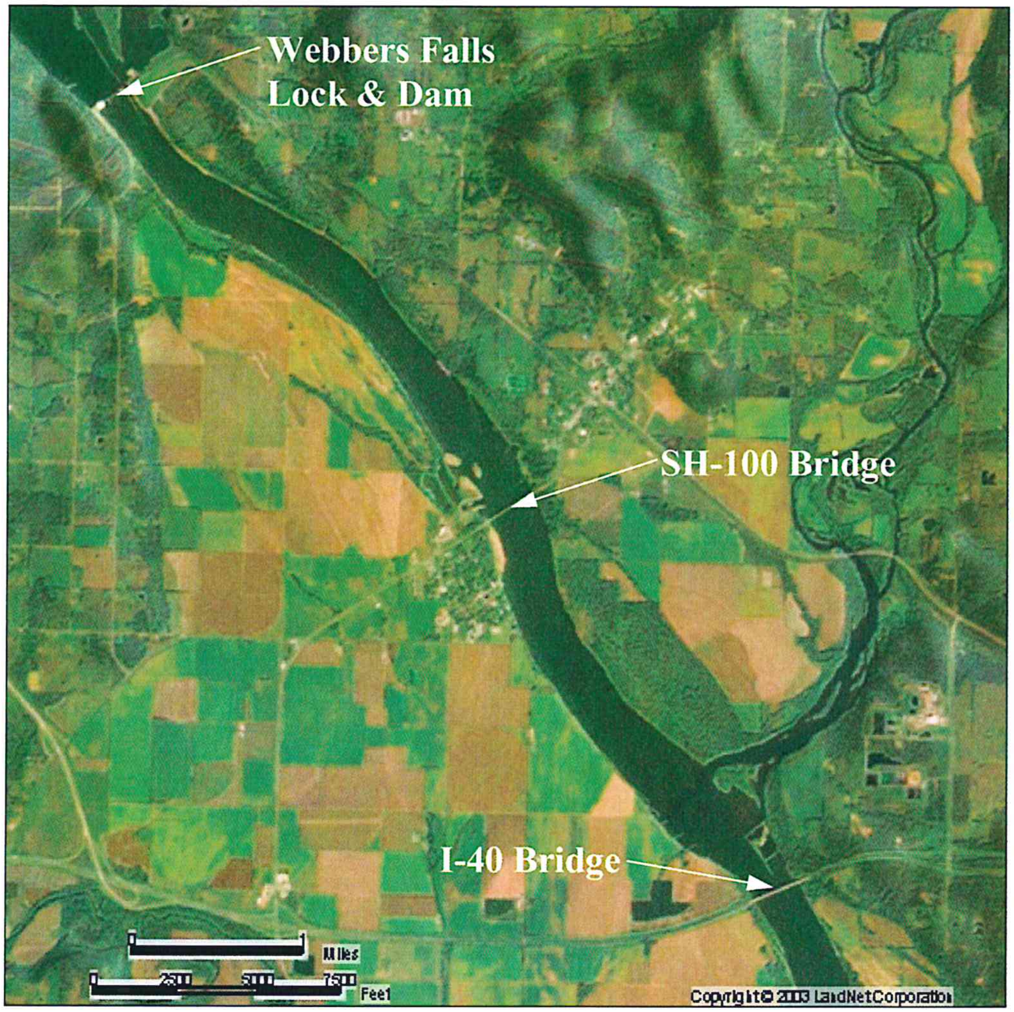

Figure A2: Aerial Photo of Bridge Vicinity (1:75,000)

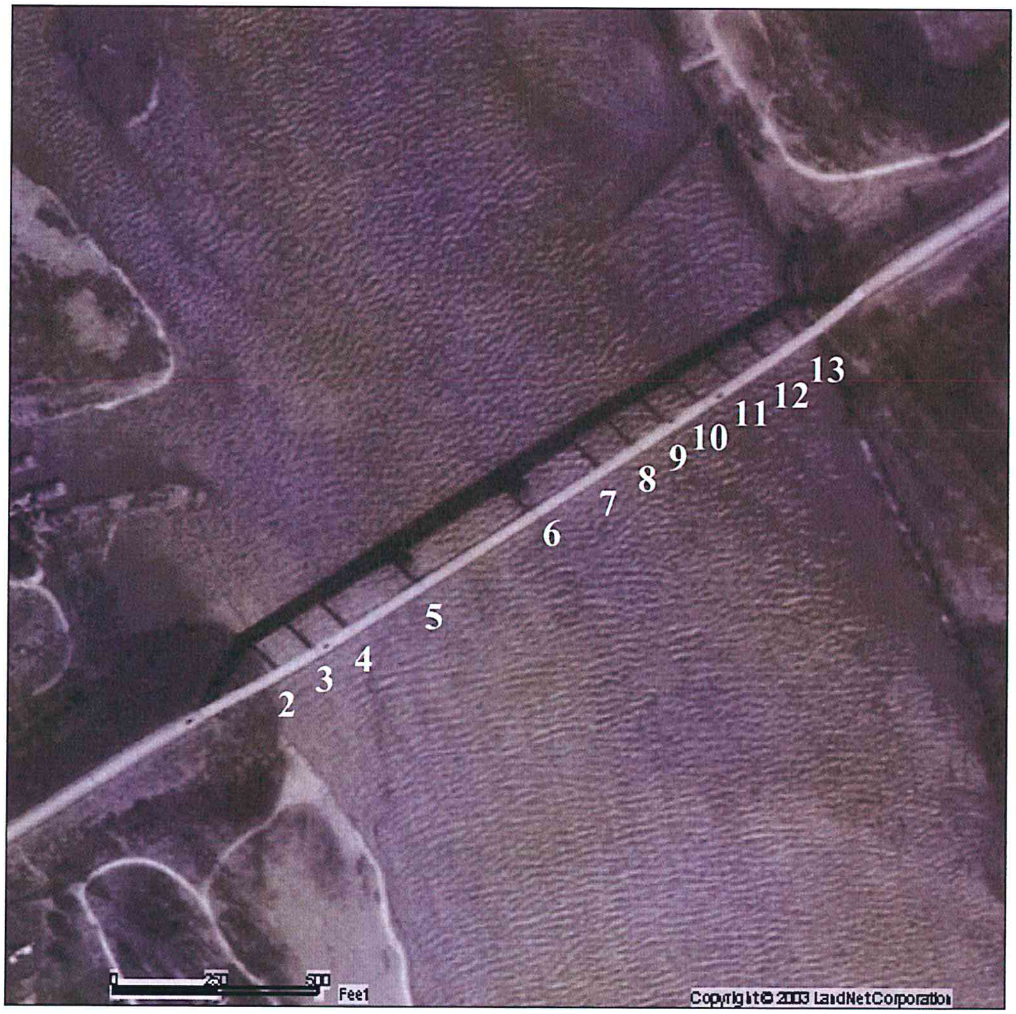

Figure A3: Close-up Aerial Photo of Bridge Crossing (1:6,000)

Figure A4: **General view of upstream side of the SH-100 Bridge, taken from east bank.**

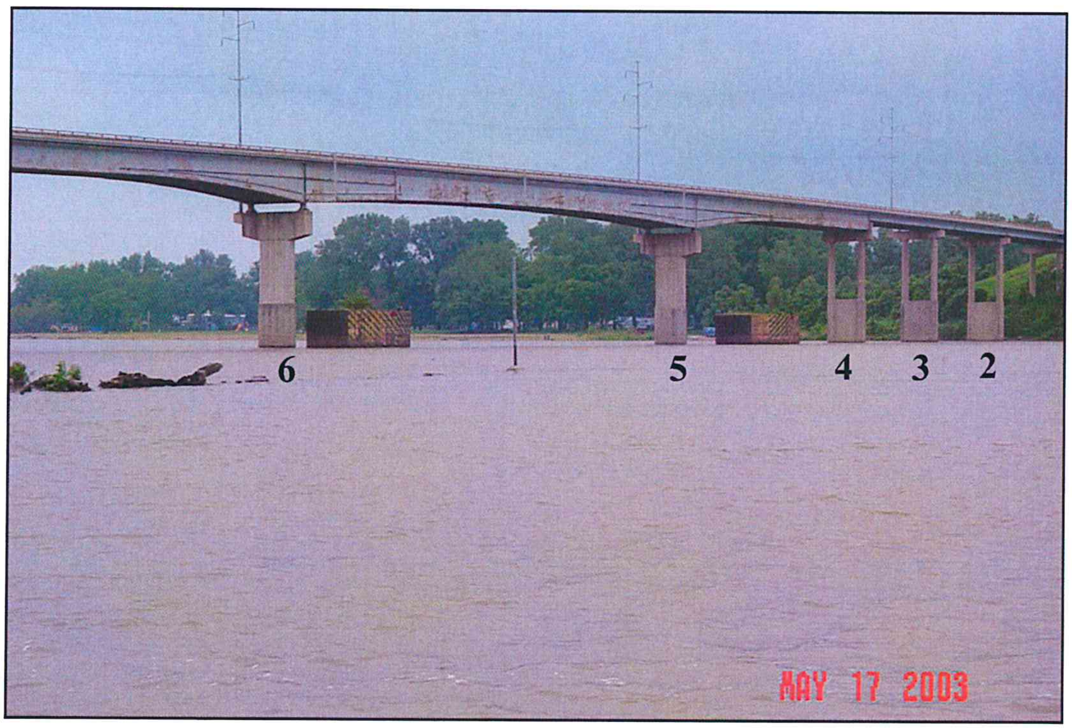

Figure A5: **Upstream side of channel span and pier protection at Pier 6 and Pier 5.**

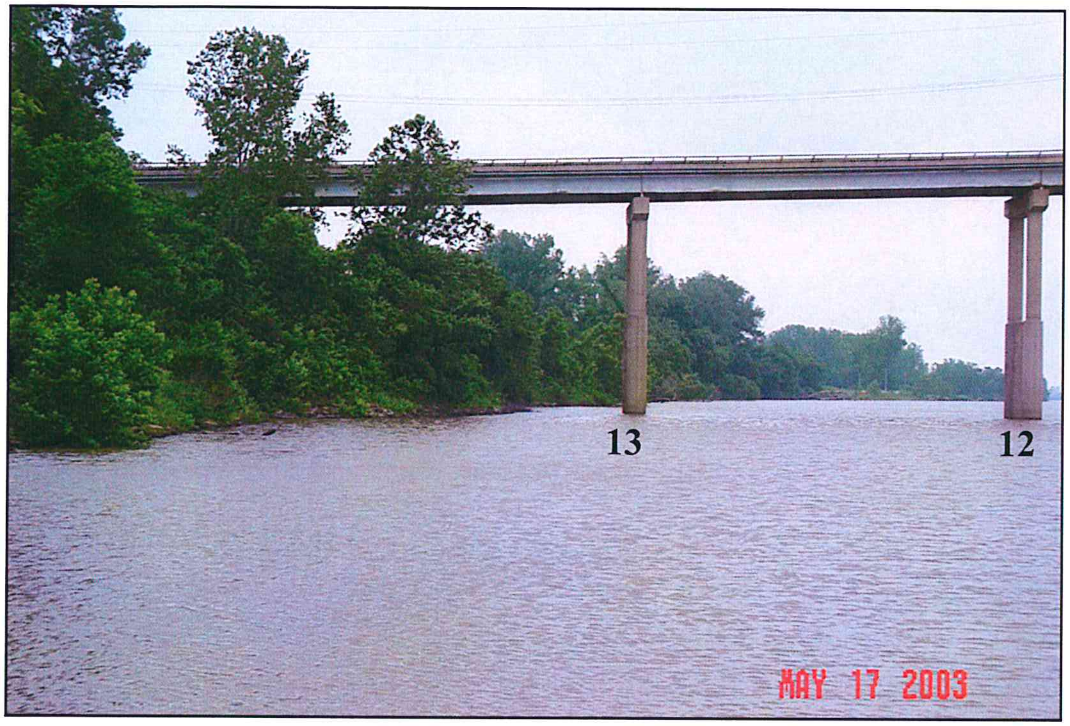

Figure A6: **Water edge with respect to Pier 13 near the east bank, taken from upstream side.**

Figure A7: **Upstream side of the SH-100 Bridge and existing dolphins, facing east bank.**

Figure A8: **General view of downstream side of the SH-100 Bridge, taken from west bank.**

Figure A9: **Downstream side of the SH-100 Bridge, facing east bank.**

Figure A10: **General channel view upstream, taken from middle of channel span. Note "island" near west bank.**

Figure A11: **General channel view downstream, taken from middle of channel span.**

Figure A12: Consolidated Grain & Barge Company, upstream from the SH-100 Bridge on the west bank.

Figure A13: Consolidated Grain & Barge Company, upstream from the SH-100 Bridge on the west bank.

Figure A14: **Waterway entrance for Consolidated Grain & Barge Company located upstream from the SH-100 Bridge on the west bank.**

Figure A15: **Sequoyah Company Water Authority with docked barges located downstream from the SH-100 Bridge on the east bank.**

Figure A16: Summers Ferry Park and boat launch located upstream from the SH-100 Bridge on the east bank.

Figure A17: Vegetation and rock "peninsula" located upstream from the SH-100 Bridge on the east bank.

Figure A18: Vegetation and rock "peninsula" located upstream from the SH-100 Bridge on the east bank.

Figure A19: Second vegetation and rock "peninsula" located further upstream from the SH-100 Bridge on the east bank.

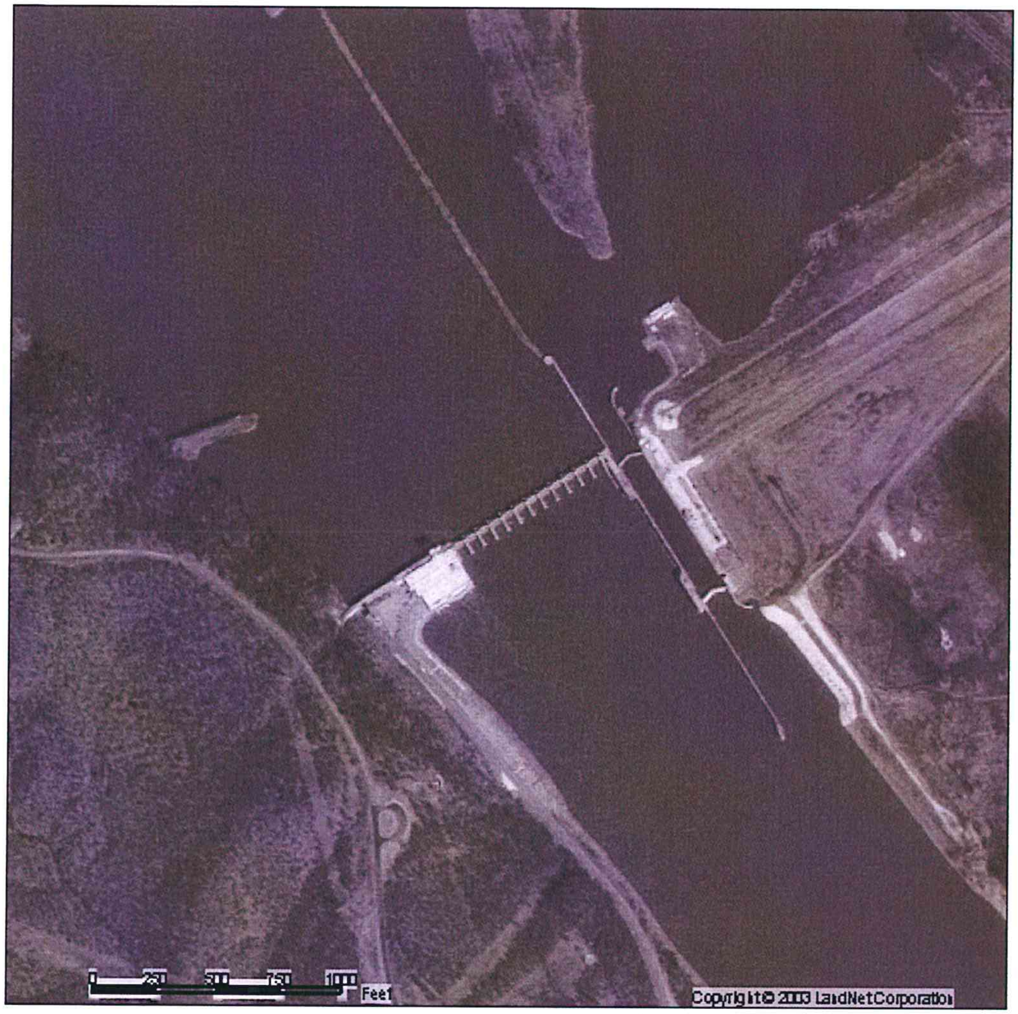

Figure A21: Aerial photo of Webbers Falls Lock, located 3.5 river miles upstream of the SH-100 Bridge. (1:10,000)

APPENDIX A'
Second Site Visit Report
SH-100 Bridge

A second site visit for the SH-100 Bridge took place on Thursday, December 9, 2004. It began at approximately 12:30 p.m. The river stage at the time of the site visit was estimated to be about 461.4.

The SH-100 Bridge crossing was found in need of protection, and the objective of this site visit was to verify the information needed for the design of the protection system. The focus of the site visit was the area upstream and downstream of the bridge and the location of the shoreline relative to the side piers. Some additional photos that complement the previous site visit photos were also taken.

The water edge on the west bank at the time of the visit was between Pier 1 and Pier 2. The water edge on the east bank at the time of the visit was between Pier 13 and Pier 14.

- See Figures A'3 through A'5.

The current velocity at the time of the visit was very low.

- See Figure A'2.

There were no visible power lines in the area upstream and downstream close to the bridge crossing.

- See Figures A'8 and A'9.

There were utility warning signs on the west bank upstream from the bridge.

- See Figures A'10.

Figure A'1: General view of downstream side of SH-100 Bridge taken from the west bank.

Figure A'2: View of downstream side of channel span taken form the west bank.

Figure A'3: View of downstream side of west side spans taken from the west bank.

Figure A'4: View of upstream side of west side spans taken from the west bank.

Figure A'5: View of upstream side of SH-100 Bridge crossing taken from the west bank.

Figure A'6: View of upstream side of SH-100 Bridge crossing taken from the east bank.

Figure A'7: View of waterway on the downstream side of the bridge crossing taken from the west bank.

Figure A'8: View of waterway on the upstream side of the bridge taken form the west bank.

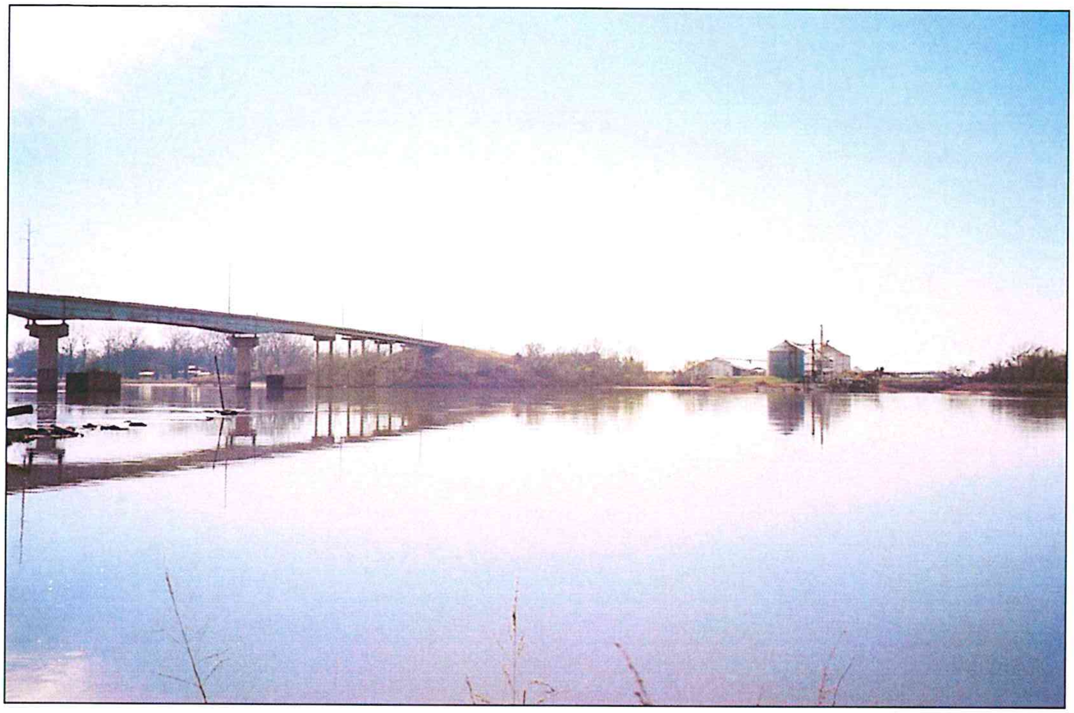

Figure A'9: View of waterway on the upstream side of the bridge taken from the east bank.

Figure A'10: Utility signs on the west bank upstream from the bridge.