RESEARCH

Report No. UT-09.19

# A-JACKS AND AQUAWRAP INSTALLATIONS IN UTAH

## SCOUR REVETMENT PERFORMANCE EVALUATION

**Experimental Feature Final Report**

**Prepared For:**

Utah Department of Transportation
Research Division

**Submitted By:**

Utah Department of Transportation
Research Division

**Authored By:**

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Jessica Andrews,
Michael Fazio, P.E.,

**December 2009**

UDOT
CONNECTING COMMUNITIES
Utah Department of Transportation - Research Division
4501 South 2700 West, Box 148410 - Salt Lake City, Utah 84114-8410

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## DISCLAIMER

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## EXECUTIVE SUMMARY

This is a performance evaluation report for A-Jacks, an articulated concrete block designed to protect bridge elements exposed to the river scouring forces, and for Aquawrap, a glass fiber reinforced polymer designed to protect and strengthen bridge elements. The materials and methods were installed more than five years ago to protect the Colorado River Bridge at Moab, Utah and the Green River Bridge at Green River, Utah from further scour and abrasion damage. The uses of proprietary materials were allowed as an "Experimental Feature" in accordance with Federal Highway Administration (FHWA) Guidelines. This report includes the description of performance measures, data acquisition, data, data analysis, conclusions and recommendations. According to the UDOT Research Division who correlated the performance review of the experimental features in this report, both A-Jacks and Aquawrap performed well and are recommended for use according to manufacture's specifications and guidelines and for the intended uses.

## 1.0 INTRODUCTION

Both the Colorado and Green Rivers in Utah are snowmelt dominated systems with annual peak discharges typically occurring in late spring. These flow events generally begin in May, peak in the beginning of June, and recede to base flow conditions by July. Structures located within these types of environments sustain large magnitude flows[1].

According to the evaluation of all Utah State bridges over water in 1995, the Utah Department of Transportation (UDOT) had close to 90 bridges that were considered scour critical. Two of these bridges, SR-19 over Green River in Green River, Utah and US 191 over the Colorado River near Moab, Utah, presented unique challenges for scour revetment. An underwater inspection of both bridges showed the foundations were critically exposed, with the river currents undermining the stability of the bridges.



Figure 1: Location Map and Tamarisk

The SR-19 Green River Bridge and the US 191 Colorado Bridge were constructed in the 1950's. At that time, tamarisk, an invasive riparian shrub, appeared along the Colorado and Green Rivers. Originally, tamarisk was brought in to act as an erosion control measure. However, the spread of tamarisk and the loss of the original native cottonwood trees combined with extensive flow regulations have lead to dramatic changes in the landscape. Channels that have been traditionally wide and shallow have begun to narrow and cut deeper into the earth. The US Bureau of Land Management in cooperation with local and state agencies is mitigating the spreading of tamarisk along affected Utah rivers through Tamarisk Control Projects.

## 1.1 SR-19 Green River Bridge

The SR-19 Bridge has nine spans crossing the Green River's wide bed. For the last ten years, the Green River split into two parts due to low flows. An island formed upstream of the bridge and most of the flow went to the west side, within the first two spans of the river. The force of the river eroded the bed materials between the two spans down to the bridge foundations. Traditional methods of restoring original waterways have required large dredging operations. In this case, the Green River supports threatened and endangered fish species, making the traditional methods unattractive.

In 1991, scour started to develop around some of the bridge Piers. Debris accumulated around the abutments. By 1993, high water flows created a channel that directed the current into the 3rd pier, further developing a scour issue. These conditions continued to worsen. In 1999, UDOT contracted Han-Padron Associates to conduct an underwater inspection. Overall, the bridge substructure was found in satisfactory condition. The bridge exhibited minor structural deficiencies in the submerged portions of the Piers and localized scour at the Piers. The footing at pier 2 was exposed. The waterway was in fair condition due to the poor channel alignment and the extent of the localized scour at the structure. As a result of these findings, UDOT adjusted the substructure rating to a 6.

Over time, the scour along the west abutment continued to develop. The aggradation near the center of the channel caused the flow through the span to hit the Piers at an angle, increasing scour. The aggradation also caused two sand bars to develop containing moderate to heavy vegetation.


Figure 2: SR-19 Green River Sand Bars, Google Image 2006

In 2003, UDOT installed A-Jacks as scour countermeasures at the west abutment and at the 2nd pier, making them more secure. The countermeasures experienced several high flows since they were installed. H. W. Lochner, Inc. conducted an underwater inspection in November of 2004. While other Piers still exhibited previously mentioned cracking, scaling and spalling problems, the protected areas had no additional damage. The A-Jacks properly protected the west end covering the structural elements affected by the intense river flow.


Figure 3: SR-19 Green River Bridge Pier Labeling

The Green River Bridge conditions have remained the same since the most recent inspection of the bridge in 2007. The channel flows mainly to the west, the structural elements look good and no further scour problems have been observed. However, the sedimentary islands have been substantially reduced since the installation of the A-Jacks.

## 1.2 US 191 Colorado River Bridge

The US 191 Bridge has eight spans, covering 604 ft across the Colorado River. This bridge has had complications similar to the SR-19 Green River Bridge. Water cascading down from the Rocky Mountains and toward the Grand Canyon along the Colorado River picks up significant force before it enters the downstream areas in Utah where bridges and scour become an issue. The Colorado River also supports threatened and endangered fish species, once again making the traditional methods of scour mitigation unattractive.

In 1991, cracking was noted along the waterline on the bridge Piers. The center pier cap experienced the most amount of cracking with delamination and exposed rebar.


Figure 4: US 191 Colorado River Bridge Location Map, Google Image 2006

The bed of the Colorado River has been reduced by the tamarisk growing along the banks. In 1993, tamarisk began choking off the waterway on the South end of the bridge, thus increasing the stream power on the bridge pier. This allowed sediment to collect within the confines of the tamarisk, which eventually developed into a substantial sand bar. The channel was then forced to concentrate on the north end of the bridge, cutting deeper into the riverbed. The original scour protection around the Piers was all but removed, leaving the structure exposed to erosion. By 1997, the north abutment was undermined several inches.

UDOT contracted Han-Padron Associates in 1999 to conduct an underwater inspection of the bridge. The general condition of the concrete of the pier columns, footings and seals had not particularly changed since the 1994 inspection. The cracking in the columns above the waterline was possibly caused by run-off from the deck through the deck joints. The cracking in the footings appeared to be nonstructural in nature and did not seem to have an impact on the integrity of the Piers. However, they provided an avenue through which water and potentially harmful substances could enter the concrete and lead to more serious problems. The cracking and voids in the seals did not warrant repair, but needed to be monitored.


Figure 5: US 191 Colorado River Bridge during construction, April 2009. Notice the dramatic changes in the river bed width from the time of the original bridge construction up until now.

The underwater inspection did reveal increased localized and general scour. The northern side of the channel bottom exhibited as much as 5 ft of degradation. In the northern quarter of the waterway, 100 ft upstream of the bridge, the channel had deepened approximately 3 ft. Similarly, 100 ft downstream of the bridge, the river had carved out an additional 4 ft. The channel bottom is comprised of rocks and boulders, making it difficult to define localized scour swales at the Piers. However, the size of the undermined area at Pier 6 was conclusively larger than what was measured at the previous underwater inspection.

Figure 6: US 191 Colorado River Bridge Facing West, 2003

By 2001, the tamarisk had invaded much of the southern bank, making it impossible for UDOT crews to inspect the bridge south of Pier 4. Two years later, the column footings for Piers 5 through 8 were exposed. Piers 1 through 4 were no longer in the waterway. The bent cap for Pier 5 exhibited heavy cracking and spalling with exposed rebar.

In 2003, Aquawrap, a fiberglass wrapping, was placed around Piers 5, 6, 7 and 8. The top two tiers of the footings for Piers 6 and 7 as well as Bent 5 were also wrapped. A-Jacks were placed at the footings of Piers 6 and 7.


Figure 7: US 191 Colorado River Bridge Facing North, 2009

In 2004, H.W. Lochner Inc. was contracted to do an underwater inspection to assess the condition of Piers 5 though 8 after the mitigation measures were installed. The report determined that the undermining issues at Pier 6 had been corrected. The severe cracking along Bent 5 was no longer evident. Cracking was visible at the footing of Pier 5 and Pier 8 where the Aquawrap had not been applied.

By this time, the sand bar along the south edge of the waterway had become well-established with heavy vegetation. A small sand bar had also developed in the downstream channel. The north bank of the river had continued to erode away.

The addition of the scour countermeasures had caused a build-up of sediment behind the Piers, further protecting the existing foundations.

## 1.3 A-Jacks Design

UDOT Central Hydraulics studied several options available for protecting bridge elements from further scour damage. The engineers determined to use a relatively new product known as A-Jacks. A-Jacks have never been applied in Utah for this purpose before. Just as the name infers, this articulated block looks like a giant jack. They are assembled in place into groups of 64 or more and tied with steel or acrylic ties. Once they are assembled together, they form a large mat that is difficult to displace. They are then laid at the base of the structure to protect the surface below from further erosion.


Figure 8: A-Jacks Module, 2002

"Just like the riprap they replace, these units all still function as individual, randomly placed elements, and need to be evaluated using discrete and separate element design approaches. Scour resistance for these traditional concrete armor units was limited to adjustments in size, weight and geometry of the individual units[2]."

Figure 9: A-Jacks Installed in the Snake River, Idaho

"A-Jacks are different in that a number of them can be interlocked and banded together into modules, creating units that have a large mass flexible enough to conform with a curved channel bottom. The A-Jacks module, and not the individual elements making up the module, becomes the discrete element being evaluated[2]."

The typical sized module has a mass of over one ton and greater roughness than riprap, which promises enhanced scour resistance. This enhanced scour resistance is dependent on the degree of interlock (carefully stacked instead of randomly placed) and also on an assessment of reliability and constructability[2].

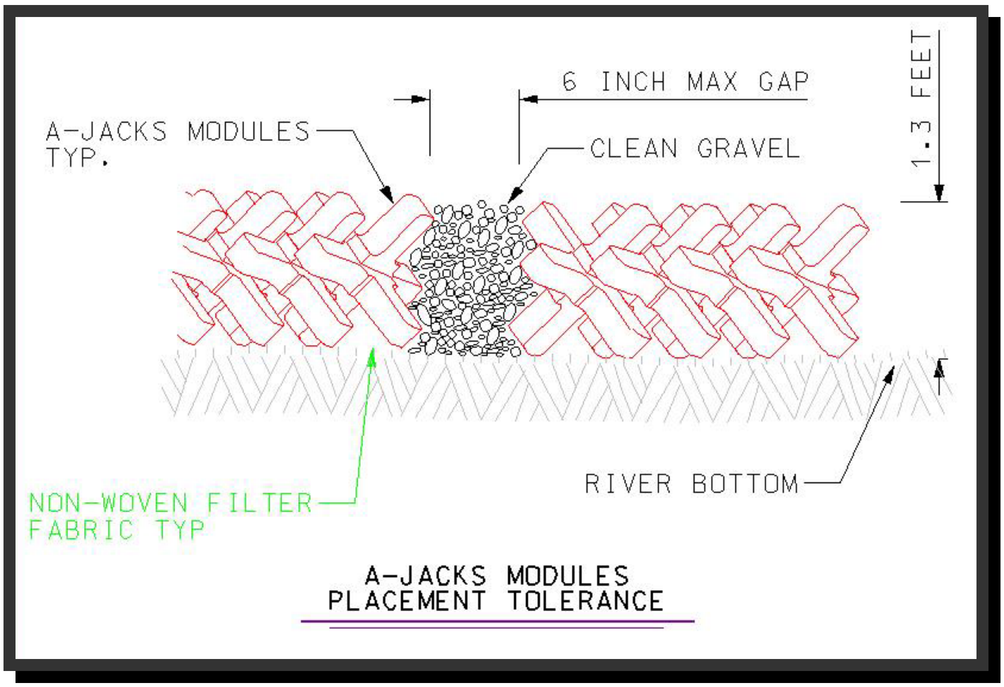


Figure 10: A-Jacks Design

Unlike the rock rip-rap they replace, A-Jacks modules can be installed with little or minimal excavation required. A-Jacks are easily manufactured near bridges where rock rip-rap is not always available. According to HEC-22, A-Jacks are considered a permanent protection from scour and are also easier to install than rock rip-rap.

The 7x6x7x6x7 24-inch A-Jacks armor units for scour protection were placed around Abutment 1 and Pier 2 at the Green River Bridge and at Pier 6 and Pier 7 at the Colorado River Bridge. This module had sufficient resistance to overturning at flows greater than the 100 year flow. A total of 2,886 A-Jacks were installed around the Green River Bridge pier and 1,677 A-Jacks were installed around the abutment. Bridge Replacement funds covered the cost of the improvements for scour protection. Federal and State research funds have covered the cost to monitor and complete the research report.

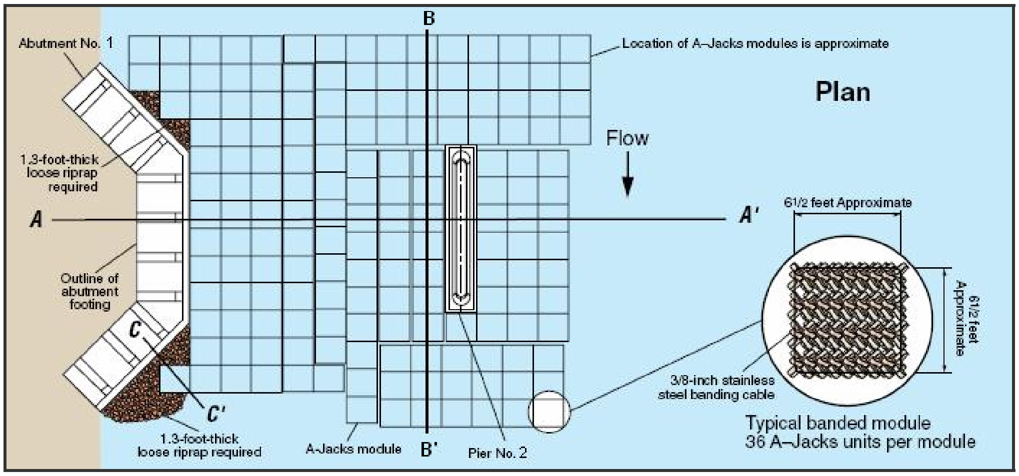


Figure 11: Plan View of Green River Installation[1]

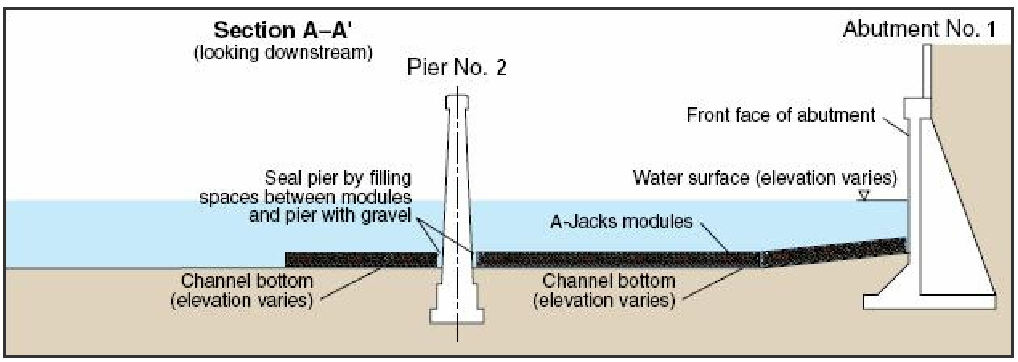


Figure 12: Cross Section A-A' of Green River Installation[1]

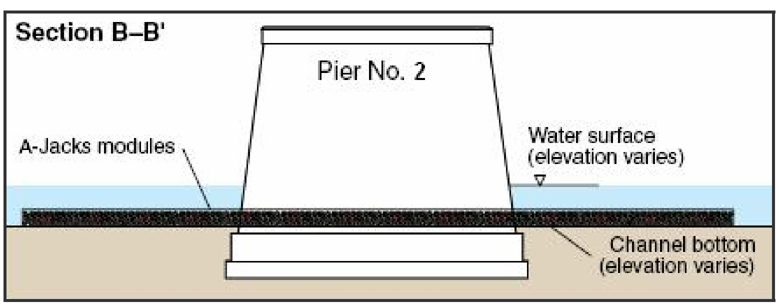


Figure 13: Cross Section B-B' of Green River Installation[1]

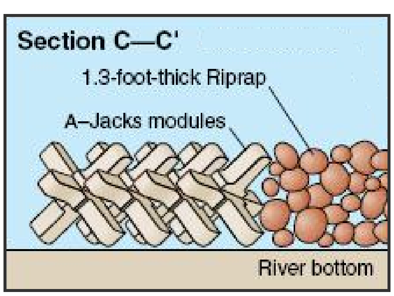

Figure 14: Cross Section C-C' of Green River Installation[1]

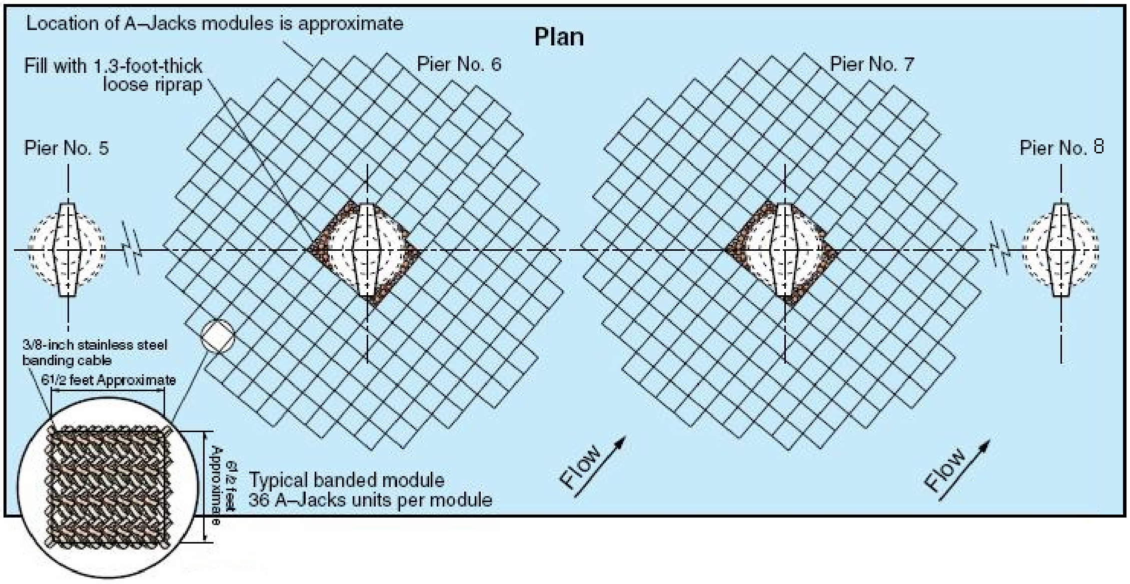

Figure 15: Plan View of Colorado River Installation[1]

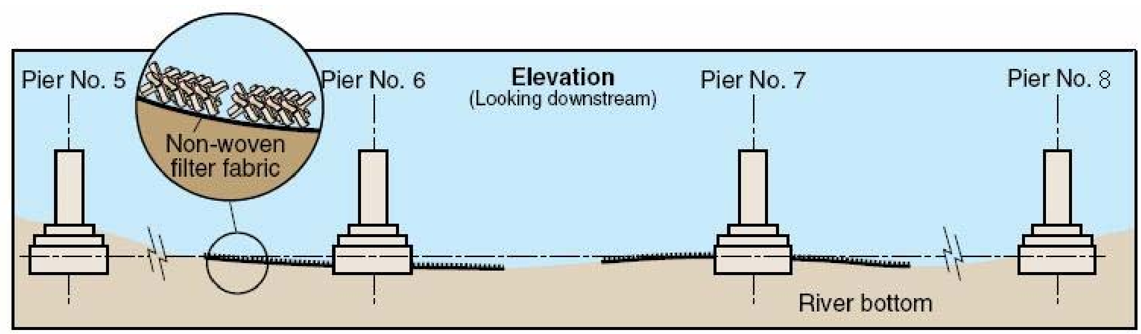


Figure 16: Cross Section View of Colorado River Installation[1]

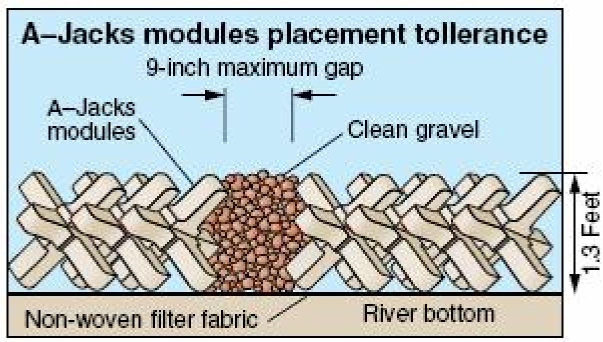


Figure 17: Close Up View of A-Jacks Design at the Colorado River Installation[1]

## 1.4 Aquawrap Design

Steel reinforced concrete bridge Piers are especially subject to damage along the waterline. The damage to the concrete is often caused by wave impacts, debris collisions and typical spalling on the concrete surfaces. Oxygen and water penetration can also cause reinforcing steel to corrode over long term exposure. Once the reinforcing steel has begun to falter, the concrete will tend to crack when it expands and contracts[3].

There are a few techniques that have been used to protect and repair submerged structure members at the waterline. Spalled concrete can simply be patched when the structural integrity has not been compromised. However, plain patching may not be sufficient especially in areas subject to freeze thaw. In most spall repairs that are patched, the varying temperatures cause "insufficient bonding to the base concrete, resulting in premature failure of the patch[3]." For both structural and cosmetic issues, steel or composite forms can be used to encapsulate the concrete or the pier can be wrapped with ambient cured fiber reinforced composite (FRP)[4]. Encapsulation systems can be very complicated and sometimes require coffer dams to complete the installation. Conventional composite systems using FRP need to be field saturated, which means the work must be done by trained technicians. The fumes from the resin used in FRP can be harmful. Since this type of repair work can only be performed in a dry environment, coffer dams are a must to complete the application[3]. This increases both the overall cost and project completion time.

Aquawrap is a relatively low-cost composite system used to repair and reinforce, among other things, existing structures. Furnished factory-impregnated with the proprietary 22-77 resin system, Aquawrap is odorless and non-flammable. Aquawrap is ready to apply, right out of the bag and cures by way of a chemical reaction with field-applied water. When cured, it is a very durable, high strength material that is impervious to fuels, most chemicals and solvents. It permanently bonds to a wide variety of surfaces such as metals, composites, concrete, plastics and wood[5].

Aquawrap has several advantages to ease the installation process. First and foremost, there is no hazardous waste and no mess to clean up after the application[5]. This characteristic was vital for this project because the Colorado River provides a habitat for many threatened and endangered species. Aquawrap can be applied in cold and wet conditions, and even underwater. This was particularly necessary when installing the Aquawrap around two of the pier footings.

Dr. Larry Cercone, material scientist, who at the time of the project design was working for Air Logistic, prepared the design for wrapping the columns. The columns wrap design considered carbon and glass fiber. Glass fibers were selected because the wrap wasn't providing additional strength to the columns but protection from weathering. Dr. Cercone assisted UDOT by preparing specifications and plans for the FRP installation.

The design required the installation of two layers of 24 oz. and one layer of 11 oz. woven FRP on the bent cap and three layers of 24 oz. one layer of 11 oz. woven FRP.

The Aquawrap installation needed to be well planned because once exposed to the humidity it will begin to cure and will gel within about 1 hour. Aquawrap requires no other special handling or application procedures. The installation required the use of gloves, safety glasses, disposable overcoats and other personal protection equipment. . This resin is also slightly irritating to sensitive people; it will give off a small amount of carbon dioxide vapor while curing[5].

Aquawrap was installed around several of the Colorado River Bridge Piers to protect them from further damage from the abrasive action of sand loaded discharges and weathering. This was the first time Fiber Reinforced Polymer (FRP) materials have been used to protect bridge element from the river abrasion, in US.

Figure 18: Colorado River Bridge Aquawrap Installation, 2003

## 1.5 SR-19 Green River Bridge Design Variables

The average slope of the Green River at the SR-19 Bridge is 0.0004 ft/ft. The bed materials consist of moderately sized gravels, sands and silts. The contributing drainage basin of the Green River above SR-19 is roughly 41,000 square miles. USGS has maintained the stream flow gage station 09315000 at Green River, Utah for 104 years. According to USGS data, the average annual peak discharge of the Green River dropped to 22,000 cfs after the Flaming Gorge Reservoir was completed in 1962[1]. The design flow for a 100-year flood event, Q100, is 49,098 cfs and for a 500-year flood event, Q500, is 56,336 cfs.

The Green River near SR-19 in Green River, Utah, is split by vegetated sand bars, most of the river flowing on the right next to the river banks, passing through the two bridge spans separated by pier number two. This has been a main contributing factor to the erosion of Pier 2 and the abutment.

## 1.6 US 191 Colorado River Bridge Design Variables

The average slope of the Colorado River at the US 191 Bridge is 0.0002 ft/ft. The bed materials range from coarse gravels to silts. The contributing drainage basin of the Colorado River above US 191 is roughly 24,500 square miles. USGS has maintained the stream flow gage station 09180500 near Cisco, Utah for 86 years. According to USGS data, the average annual peak discharge dropped to 29,400 cfs after 1950 when upstream flow regulations were put into place.

The US 191 Colorado Bridge is located at the entrance to Moab, Utah, one of the few locations within the Colorado Plateau where the river is not confined laterally by bedrock. The majority of the Colorado River passes through only four of the eight spans of the US 191 Bridge. This has contributed, in part, to the scour located on Piers 6 and 7.

# 2.0 FIELD INSTALLATION

## 2.1 A-Jack Installation

The A-Jack is a proprietary product that was installed as an experimental feature, according to federal requirements. UDOT designed the A-Jacks to accomplish three primary tasks: to armor the streambed, to dissipate energy near the substrate around the Piers, and to promote sediment deposition onto and between the A-Jacks modules.

Figure 19: A-Jacks Stockpiled at the Colorado River Bridge

Both the Green River Bridge and the Colorado River Bridge locations have deep flows, live current and turbid flow that block the view of the channel bottom. These less than ideal conditions greatly handicapped the placement of the A-Jacks. After consulting with Dr. Thornton of Colorado State University, the requirement to place a fabric was removed, because of the granular material existing at the bottom of both rivers.

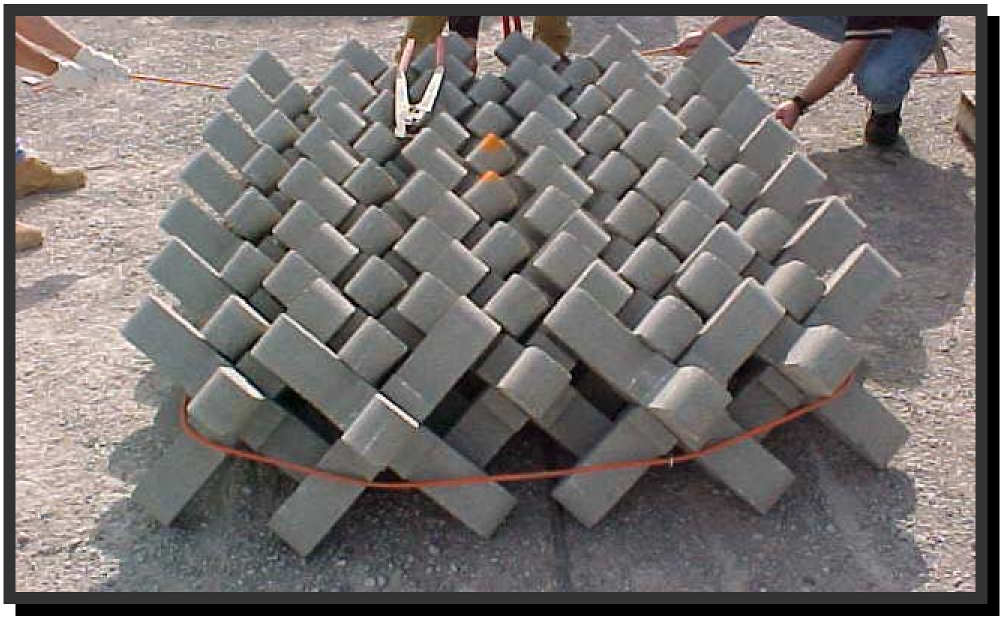

Figure 20: A-Jacks Fitted Together at the Colorado River Bridge

Figure 21: Frame Used to Lift the A-Jacks Module as a Distributed Load at Colorado River Bridge

Figure 22: Frame Used to Lift the A-Jacks Module as a Distributed Load at Green River Bridge

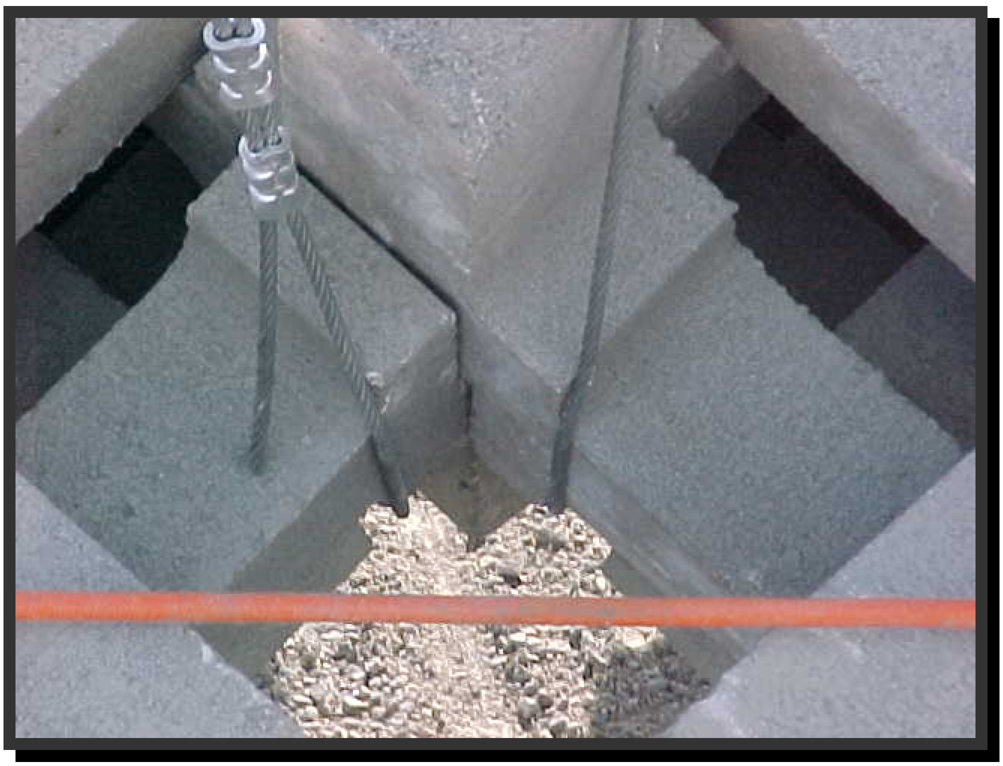

Figure 23: Close Up of A-Jacks at the Colorado River Bridge

Figure 24: Placement of A-Jacks at the Green River Bridge

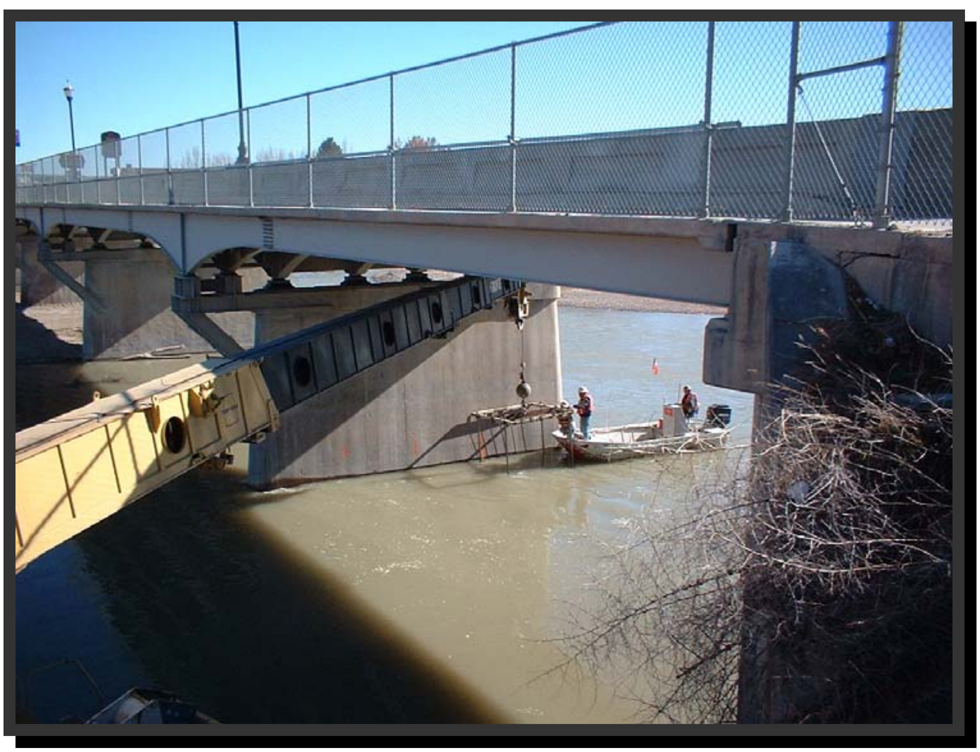

Figure 25: Paint marks on the bridge pier were used to align the A-Jacks modules along the foundation. A small motor boat was used to nudge the modules into the correct placement.

Figure 26: Green River Bridge A-Jacks Placement

In both locations (Green River at Green River and Colorado River at Moab), the contractors had professional scuba divers in the rivers guiding the installation of the bundled A-Jacks. At Green River, the contractor designed and fabricated a crate to mount the bundle so it could be lifted up by a crane and placed in the river. The murky rivers allowed only placement by fill. The contractor had to be careful not to release the bundles in the wrong location by touch. Each bundle was assembled on the river's shore, where the contractor had mobilized their operation. Once the A-Jacks bundle was completely assembled with a tie cable, the contractor would secure it on the crate, lifting and lowering it in place following the directions from the scuba tech in the river. The bundles and crate designed by the contractor repairing the Colorado River Bridge were twice as large as those being used to repair the Green River Bridge.

The Green River installation was also challenging because the crane could not reach behind the first pier. The installation at Green River was completed in about one week, and at the Colorado River in a week and a half.

## 2.2 Aquawrap Installation

Aquawrap, a fiberglass wrapping, was placed around Piers 5, 6, 7 and 8 of the Colorado River Bridge. The top two tiers of the footings for Piers 6 and 7 as well as Bent 5 were also wrapped.

Figure 27: Aquawrap installation at the Colorado River Bridge, 2003

Figure 28: Colorado River Bridge Bent 5 Aquawrap Installation, 2003

Aquawrap is available in several different fabric materials and weaves. Figure 29 shows a close-up view of the texture used in this application.

Figure 29: Close-up view of Aquawrap not sticking to the surface below, 2003

To prepare for the wrap installation, the manufacturer had two training sessions for the contractor and the inspectors. The designers and inspector were invited and attended the training that included some theory but was mostly practical. Dr. Cercone used a sonotube as a column. He wrapped the FRP by spraying the tube with water using a spray bottle. The installation was simple. With the assistance of an inspector, he wrapped the tube in a few minutes. This wrap began hardening around the tube almost immediately. The product seemed promising.

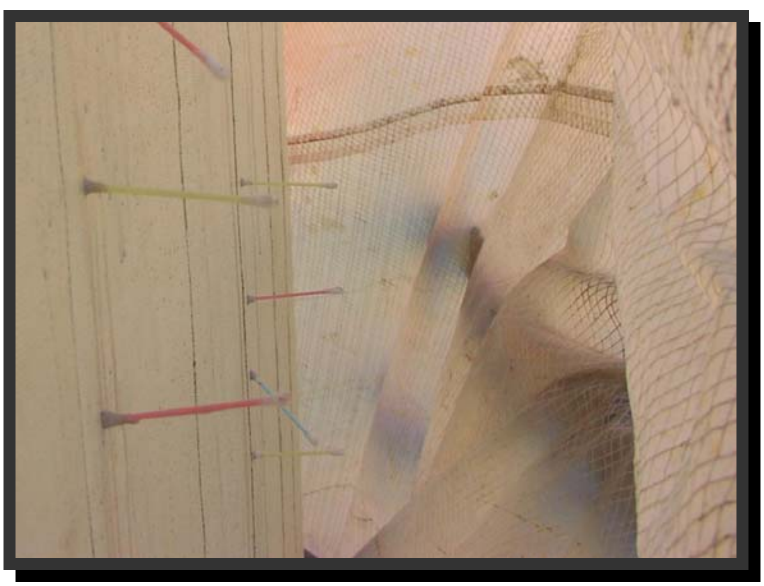

Figure 30: Aquawrap Q-tip Installation where epoxy was injected, 2003

Figure 31: Aquawrap oozage, 2003

Before beginning the underwater installation, the scuba team inspected the bridge columns' foundation. The inspection revealed very large holes and a very irregular surface in the foundation. The underwater report prepared by Lochner didn't mention this condition. In light of the information received by the contractor's scuba team, UDOT decided not to wrap the foundation because the wrap would not adhere properly to the surface of the foundation and would have required subsequent repairs. UDOT requested the contractor to wrap other two columns instead of the foundation.

Bubbles formed under the second and third wrapping layer during the first part of the operation, which slowed down the operation. The contractor had to fill the air bubbles with epoxy to prevent any weakening of the wrapping layers. In some locations, the wrap experienced excessive bleeding (noticeable in Figure 31). This required the contractor to constantly clean the surface. Some presoaked bundles had to be rejected because they had hardened while in the package. The contractor had been behind schedule and some material that had been delivered on time to the project had reached its shelf life or had been exposed to the local weather. In rare occasions the wrap did not adhere properly to the surface below and additional epoxy had to be used.

The contractor repaired the bent caps delamination before the wrapping operation. UDOT inspectors assessed delaminated locations on the bent caps using the sound a hammer or chains make to recognize hollow parts in the caps and marked these with spray paint. After assembling scaffolding, the contractor removed the compromised sections of concrete on the bents and patched them with structural vertical patching compounds according to UDOT specifications. After the patches were properly cured, the contractor placed the wrap according to the patterns described on the plans.

Despite the installation challenges, the wrap has performed well to this point, protecting the bents and bent caps from weathering.

The wrapping operation lasted about three weeks.

## 3.0 RESEARCH METHODOLOGY

The experimental features installed with these projects were evaluated using topographical survey and visually. The A-Jacks installations were surveyed to assess any movements of the installation to verify the installations would not be removed by the river currents, but that would protect the structure as intended. Duration and integrity of the installation were not assessed.

To measure any movements of the A-Jacks installation, the USGS surveyed the installation after placement using Doppler acoustic radar, which provided a three-dimensional record of the location of the A-Jacks. USGS resurveyed the installation for the following three years to verify movements.

The Aquawrap installation was documented by pictures. The durability of the installation can be verified by assessing the condition at later dates.

# 4.0 DATA COLLECTION

## 4.1 Five-Year Underwater Inspections

According to law, a team of professional engineers and technical expert divers inspected the submerged portion of the bridges' structure in 1999 and 2004 after the repairs were completed.

The underwater inspectors visually and physically examined the entire surface of the Piers, giving more attention to areas where they found significant deterioration or apparent distress.
As part of the inspection, the team collected data on the channel and river bed near the bridge and river banks, which included the the type of the channel bottom material present, scour conditions, presence or absence of riprap, location of foundation undermining and the presence of debris.

The underwater inspectors collected bathymetry data using sonar and fathometer.ft Using a lead line, and using a pole mounted fathometer, they were able to get more detailed data around submerged structural elements. (A fathometer is an instrument used to measure the depth of water. "It works by sending a sound down through the water to be echoed back from the bottom[6]." Engineers can back-calculate the total depth of water using the time it takes for the sound to return and the known speed at which the sound travels through water.)

Appendix A includes a summary of the findings from each underwater bridge inspection at each site.

## 4.2 USGS Spring Runoff ADCP and DGPS Underwater Inspections

"The key to the overall success and evaluation of both the Green River Bridge and the Colorado River Bridge was the ability to monitor the initial placement, as well as any movement or loss of A-Jacks modules after they have experienced a number of flood events. This was a difficult task given that it is impossible to directly observe objects at the bottom of these deep and naturally turbid waters[2]."

From 2003 to 2005, "UDOT enlisted the help of the United States Geological Survey (USGS) to help overcome the observation and monitoring problems found at these scour mitigation sites. Using a sophisticated acoustic Doppler technique with real-time global positional, coupled with side scan sonar imaging techniques, the USGS was able to see through the turbid water and chart the channel bottom. These twin technological advancements provided interpretive tools to UDOT roughly analogous to aerial photographs overlain by traditional contour mapping. This allowed UDOT engineers to evaluate both the initial placement of the A-Jacks modules and the initial channel bathymetry [the three-dimensional study of underwater depth], specifically during peak runoff periods[2]."

Figure 32: Preparing for an ADCP Bridge Inspection, 2003

The Acoustic Doppler Current Profiler (ADCP) is a sound navigation system, or sonar, that produces a record of water current velocities for a range of depths. The ADCP used in this application has four acoustic transducers that transform sound into electrical energy for a frequency range between 1 and 30 kHz. The transducers were each oriented 20 degrees from the center of the ADCP. Transducers work in water similar to how directional loudspeakers work in the air. These transducers are aimed such that the sound pulse travels through the water in different, but known direction. As the sound energy leaves and arrives at the transducer face, it is shifted in frequency by the relative velocity of the water. This is known as the Doppler Effect. That sound energy is returned or echoed by moving particles in the water. The sound may also be shifted in frequency if there is relative velocity of water to water particles. Velocities are calculated by determining the shift in frequency of sound waves returned by moving particles within the water. By repetitive sampling of the return echo, and by "gating" the return date in time, the ADCP can produce a "profile" of water currents over a range of depths[7].

According to R.D. Instruments in 2003, the depths measured by the ADCP are accepted to be accurate to within 1 percent of the true depth. There are a number of factors that affect accuracy, resolution and profile range when using an ADCP. Most notable are: absorption, spreading, speed of sound in water, bandwidth of the sound energy, signal strength of the transmitted pulse and echo, size of the transducers, beam width of the energy pulse traveling through the water, frequency, and a host of limitations associated with the signal processing techniques and hardware, including clock/oscillator accuracy[7].

The ADCP has an internal compass, which, when properly calibrated and assigned the proper magnetic variation/declination, allows velocity vector components to be collected in a true world coordinate system[1].

Figure 33: Green River ADCP Bridge Inspection, 2003

Figure 34: Colorado River ADCP Bridge Inspection, 2003

The Differential Global Positioning System (DGPS) is an enhancement to the Global Positioning System (GPS) that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by satellite systems and the known fixed positions[7].

"For this study, measured water velocities were calculated by using the bottom track feature of the ADCP. This feature operates under the assumption that the channel bed is stationary. Bottom tracking treats any shift in frequency associated with the streambed to the velocity of the ADCP, often termed the boat velocity. In the presence of a moving bed in the streamwise direction, measured water velocities are negatively biased. Use of a DGPS to obtain the boat velocity can alleviate this bias. However, due to the corruption of DGPS signals near structures, such as bridges, and the processing software used, water-velocity data presented in this report were computed by using bottom tracking and as a result may be less than true water velocity by a factor equal to the streamwise bed velocity. Comparable DGPS and bottom-tacking data acquired at the Colorado River Bridge in 2005 indicates that the true water velocity at a discharge of 28,000 cfs may be as much as 0.40 ft/s greater than that presented in this report. Data from the largest observed discharge at the Green River Bridge, 27,000 cfs, indicates that the true water velocity may be as much as 0.30 ft/s greater than that presented in this report. The DGPS was used to spatially register all measured depths and velocities. Corrupted location DGPS data was manually adjusted using the logged bottom-tracking vector coordinates[1]."

"A digital data-collection grid was developed for each bridge site and utilized for the 2004 and 2005 data-collection surveys. This grid was navigated in realtime using a handheld GPS interfaced with a personal digital assistant (PDA)[1]."

The raw data was then analyzed to create an interpolated elevation dataset and combined with a digital elevation model to produce a three-dimensional simulated view of both bridges such as the image below.

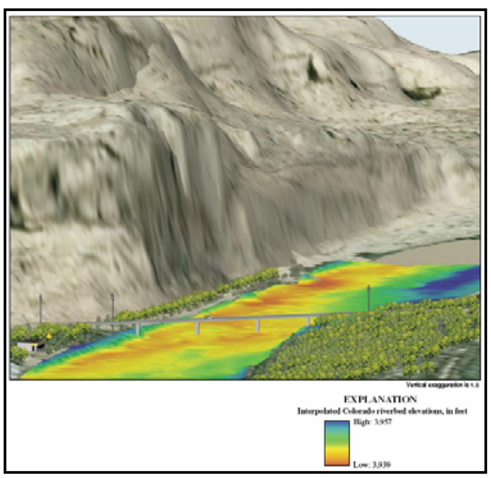


Figure 35: Three-dimensional view of the Colorado River Bridge, USGS 2005

## 5.0 DATA EVALUATION / ANALYSIS

The comparisons of the interpolated riverbed topography at the Green River Bridge showed that the riverbed has remained stable since the installation of the scour countermeasures. These comparisons also revealed an increase in bed elevation related to the A-Jacks installations at the Colorado River Bridge. "Comparisons of the velocity datasets developed during the study were not made because the data acquisition surveys were made at different discharges[1]."

Comparisons of regular underwater inspections and bridge inspections show that the Green River Bridge conditions have remained the same since the most recent inspection of the bridge in 2007. The channel flows mainly to the west, the structural elements look good and no further scour problems have been observed. The islands have been substantially reduced since the installation of the A-Jacks. The A-Jacks installations at the Colorado River Bridge, as well as the Green River Bridge in a lesser extent, increased the aggradation behind the Piers, further protecting the existing foundations. The sand bar along the south end of the Green River Bridge is now well established with heavy vegetation, and the north bank of the river has continued to erode away as the river continues its meandering pattern. The severe cracking on Bent 5 of the Colorado River Bridge no longer exists, and the Aquawrap applied to the bridge Piers appears to be in good condition.

### 5.1 Green River Bridge Site Visit, April 2009

Representatives from UDOT Research, Hydraulics and Structures conducted an additional site survey in April 2009. The sand bars at the Green River Bridge have been significantly reduced since the installation of the A-Jacks, especially upstream of the bridge.


Figure 36: Green River Bridge sand bars looking upstream (North)


Figure 37: Green River Bridge sand bars looking downstream (Pre-installations)

As the river merges together downstream of the bridge, there is a noticeable elevation change between the east and west channels.


Figure 38: Green River Bridge elevation change from the East channel to the West channel (Pre)

The downstream islands have not been affected nearly as much as the upstream islands. However, as the river erodes away islands 1 and 2, the river will have a greater access to wear down islands 3 and 4. See Figure 2 for the island locations.


Figure 39: Green River Bridge Sand Bars looking South (Pre-installation

### 5.2 Colorado River Bridge Site Visit, April 2009

Representatives from UDOT Research, Hydraulics and Structures conducted an additional site survey of the Colorado River Bridge site in April 2009. The tamarisk now occupies most of the south bank.

Figure 40: Colorado River Bridge and Tamarisk, 2009

The once developing sand bar on the south end of the bridge has now become the newly defined river bank, nearly covering Piers 1 through 4.

Figure 41: Pier 4 on the Colorado River Bridge, 2009

The Aquawrap on Piers 5 through 8 is still in good condition. The following pictures were taken before peak runoff season.

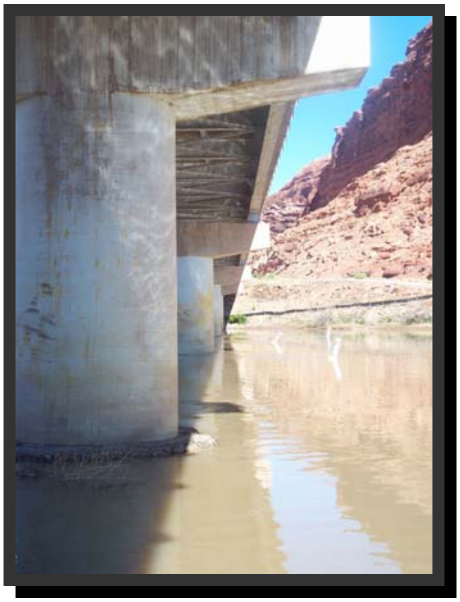

Figure 42: Colorado River Bridge Piers 5-8, 2009

Figure 43: Colorado River Bridge Bent 5, 2009

Figure 44: New Colorado River Bridge Alignment, 2009

A new 4-lane bridge is currently under construction to replace the existing 2-lane Colorado River Bridge. The final alignment will run between the temporary bridge on the left and over the existing bridge on the right. Demolition of the existing bridge is scheduled for February, 2010.

## 6.0 CONCLUSIONS

The installation of the experimental features, A-Jacks and Aquawrap, provided invaluable information. The A-Jack, a concrete armoring unit, when assembled together with other units, forms a protective blanket over the river bed where they are applied that reduces the scour and erosion. The cost of protecting a bridge with A-Jacks is more expensive than using the traditional rip-rap, however over the life of the installation, the A-Jacks last longer than rip-rap, reducing the need for repeated installations. A-Jacks installation require more preparation work to clear and level the surface where they have to be installed, and they require assembly. The assembly is time consuming and costly. Laborers have to put together the units and set them in a bundle tied by a steel or nylon rope.

The A-Jacks performed as designed. They provided scour protection for the river bed where they were installed. In Green River, the A-Jacks installation increased the river bed roughness and reduced the conveyance area, forcing the river flow to move easterly reducing the area of the existing sediment bars. At the Colorado River Bridge, this installation provided the same protection, increasing the aggradation near the Piers.

The Aquawrap is performing well despite the installation difficulties that were encountered. The application prevented further weathering of the bents and bent cap of the Colorado River Bridge. The application effectively extended the life of the bridge structures where they were applied, providing an extra impermeable layer that protected the structure from frost, erosion and corrosion damage potential.

The Aquawrap is relatively easy to install but needs a temperature controlled storage for the bundles to protect them from early curing of the resins. The installers were frustrated by the oozing of the fibers and sometimes the quick set. The installers experienced more problems on the flat areas than over the curved columns' areas. In all, this is a good product, but requires care that sometimes is not available at remote areas.

### 6.1 recommendations and implementation

The UDOT Research division and Central Hydraulics section recommend both products according to intended use and according to proper design and standards as provided by UDOT and the manufacturer.

## 7.0 REFERENCES

1. U.S. Geological Survey (USGS) and Utah Department of Transportation (UDOT), Hydraulic and Geomorphic Monitoring of Experimental Bridge Scour Mitigation at Selected Bridges in Utah, 2003-05, Scientific Investigations Report 2006-5033
2. Site Solutions Magazine, A-Jacks used in experimental installations, by Denis Stuhff, Utah Department of Transportation (UDOT)
3. Society for the Advancement of Material and Process Engineering (SAMPE), Vol. 39, No. 3, May/June 2003
4. Highway Bridge Pier Column Repair Using Aquawrap 22-77 Glass Composite System, Air Logistics Corporation Report No. 073101, 2001
5. www.airlog.com, Aquawrap Brochure
6. http://reference.howstuffworks.com
7. http://en.wikipedia.org

# APPENDIX A

## Underwater Inspection Summary

The tables below summarize the underwater bridge inspections conducted by Han-Padron in 1999 for both the Green River and the Colorado River Bridge.

| Substructure Unit | Condition Rating | Remarks |
|---|---|---|
| Abutment 1 | 6 | • Light scaling in wingwalls and breastwall<br>• Two full-height vertical cracks, the largest up to 1/16 in. wide in the breastwall |
| Pier 2 | 6 | • Heavy debris at upstream nose<br>• Localized scour swale approximately 2 – 3 ft. deep<br>• Footing vertical exposure of 1.4 ft. (estimated) |
| Pier 3 | 6 | • Seaming along horizontal cold joint<br>• Localized scour swale up to 5 ft. deep |
| Pier 4 | 7 | • Minor pattern cracking in shaft concrete<br>• Localized scour swale up to 1.5 ft. deep |
| Pier 5 | 7 | • Minor scaling and seaming in shaft concrete<br>• Heavy debris at upstream nose<br>• Localized scour swale up to 2.5 ft. deep |
| Pier 6 | 7 | • Seaming and minor spalls in shaft concrete<br>• Localized scour swale up to 3 ft. deep |
| Pier 7 | 6 | • Scaling, vertical and diagonal cracking in shaft concrete<br>• Undercutting at the shaft footing juncture at the pier’s north nose<br>• Localized scour swale up to 4 ft. deep |

Table 1: Green River Underwater Bridge Inspection, 1999

| Substructure Unit | Condition Rating | Remarks |
|---|---|---|
| Pier 5 | 5 | • Soft concrete exhibited over most of the footing face with some delamination also present<br>• Cracking, 1/32 in. to ½ in. wide, in the top of footing<br>• Top edge of footing exhibits random voids up to 4 in. deep |
| Pier 6 | 5 | • Increase in localized scour: undermining of footing seal has grown in opening height, length and penetration<br>• Random voids up to 5 in. deep in seal concrete<br>• Cracks up to ½ in. wide in seal concrete, some of which extend into lower step of footing<br>• Cracking up to 1/16 in. wide in the footing |
| Pier 7 | 6 | • Increase in localized scour: vertical exposure height of seal has increased<br>• Vertical cracks up to ¼ in. wide in seal concrete<br>• Random voids up to 3 in. deep in seal concrete<br>• Random cracking up to 1/32 in. wide in footing |
| Pier 8 | 6 | • Random cracking up to 1/16 in. wide in footing<br>• Spalls, typically less than 2 in. deep, in the top edges of footing |

Table 2: Colorado River Underwater Bridge Inspection, 1999

The table below gives a description of the condition ratings used by Han-Padron in the 1999 Underwater Inspection Report.

| Code | DESCRIPTION |
|---|---|
| N | NOT APPLICABLE |
| 9 | EXCELLENT CONDITION |
| 8 | VERY GOOD CONDITION – no problems noted. |
| 7 | GOOD CONDITION – some minor problems. |
| 6 | SATISFACTORY CONDITION – structural elements show some minor deterioration. |
| 5 | FAIR CONDITION – all primary structural elements are sound but may have minor section loss, cracking, spalling or scour. |
| 4 | POOR CONDITION – advanced section loss, deterioration, spalling or scour. |
| 3 | SERIOUS CONDITION – loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present. |
| 2 | CRITICAL CONDITION – advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken. |
| 1 | “IMMINENT” FAILURE CONDITION – major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service. |
| 0 | FAILED CONDITION – out of service, beyond corrective action. |

Table 3: Underwater Inspection Report Condition Rating Descriptions

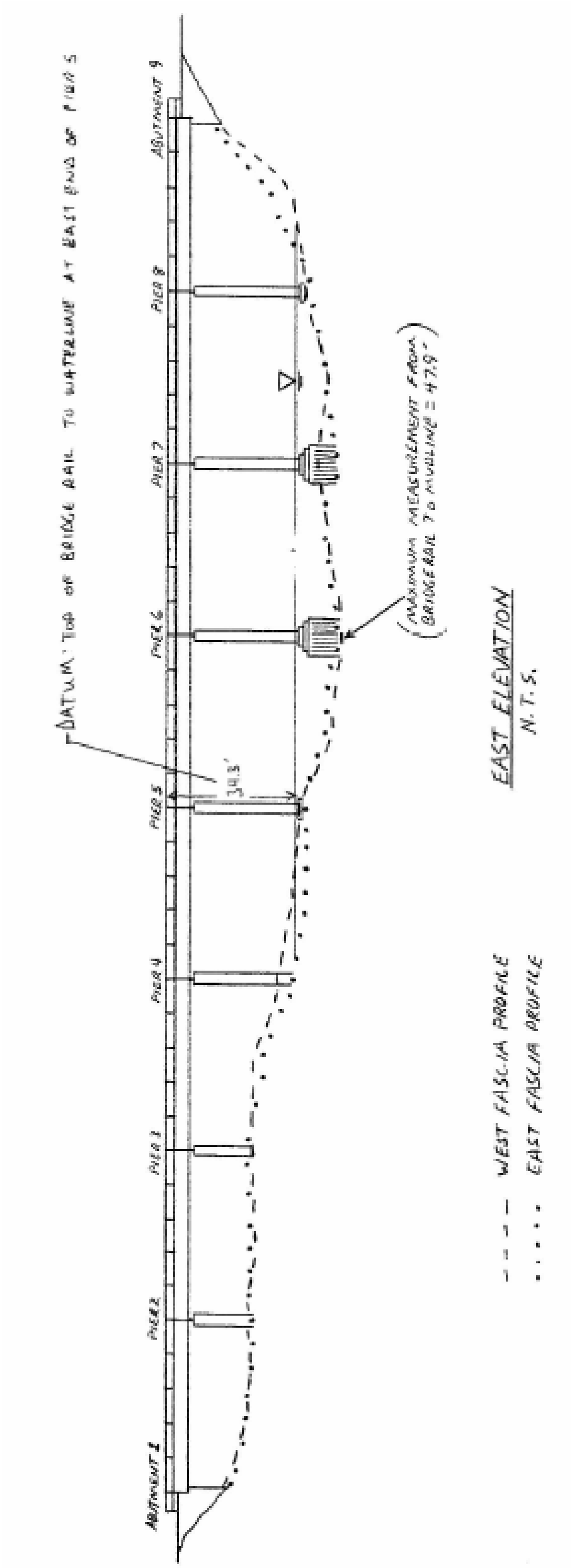


Figure 36: Green River Bridge Profile, 1999

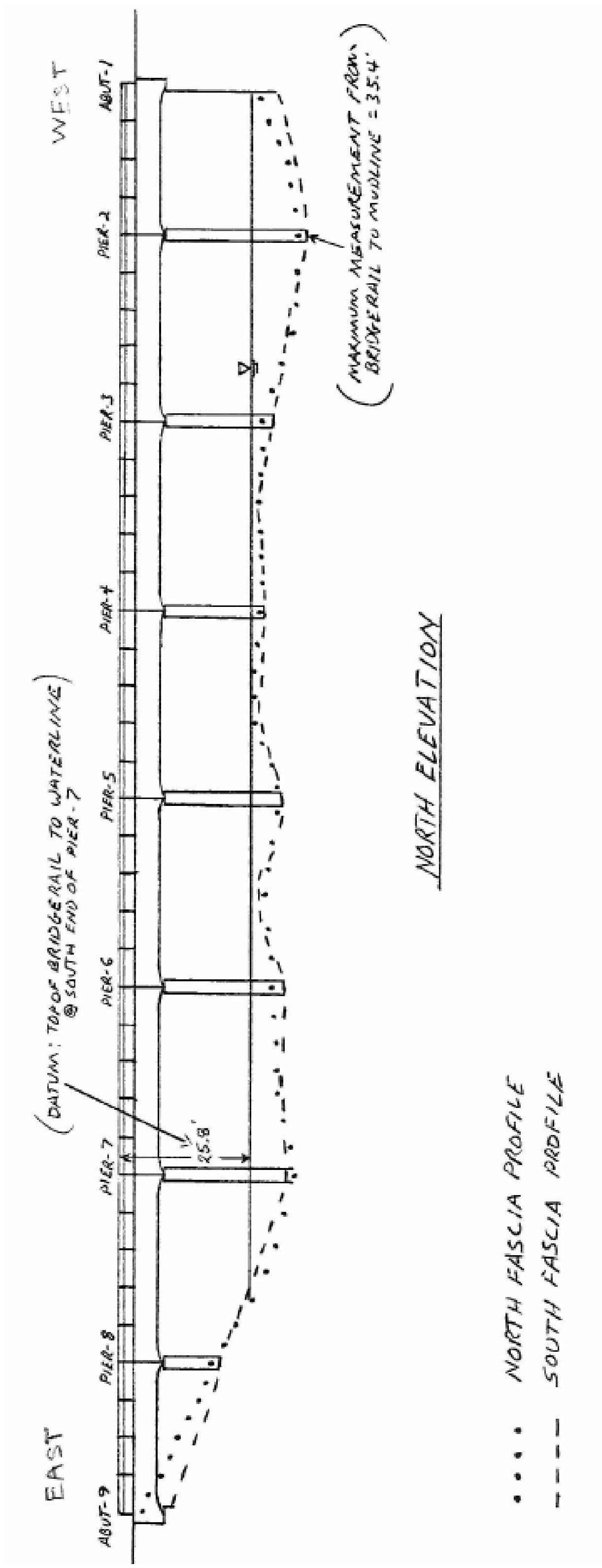


Figure 37: Colorado River Bridge Profile, 1999

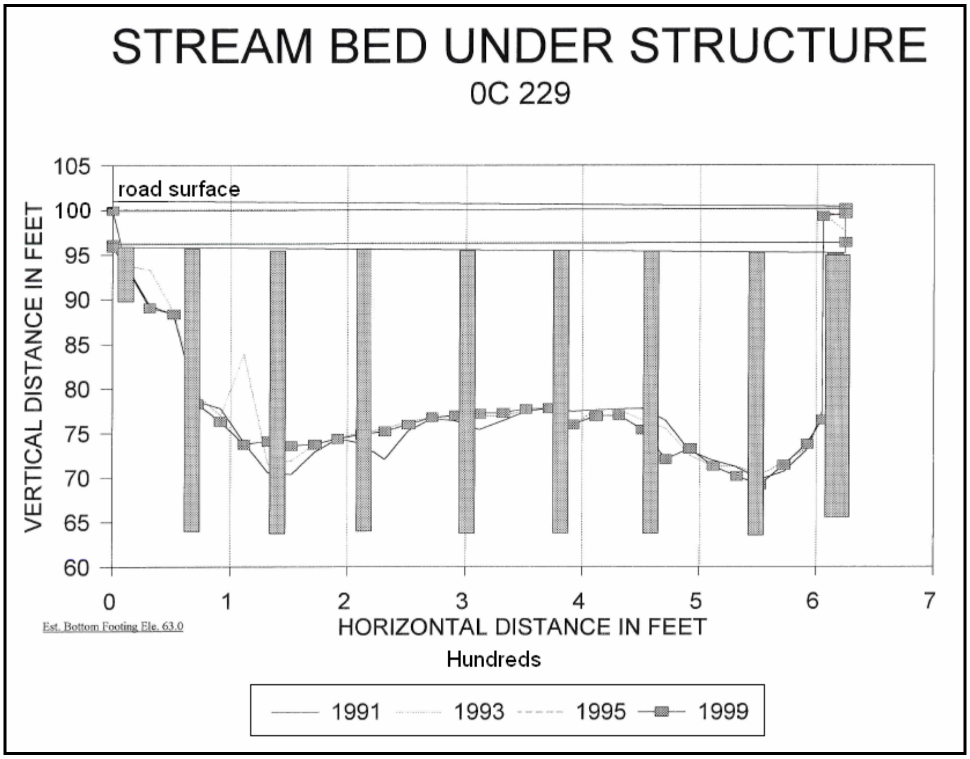


Figure 38: Underwater Inspection Report, Green River Bridge Profile, 1991 through 1999

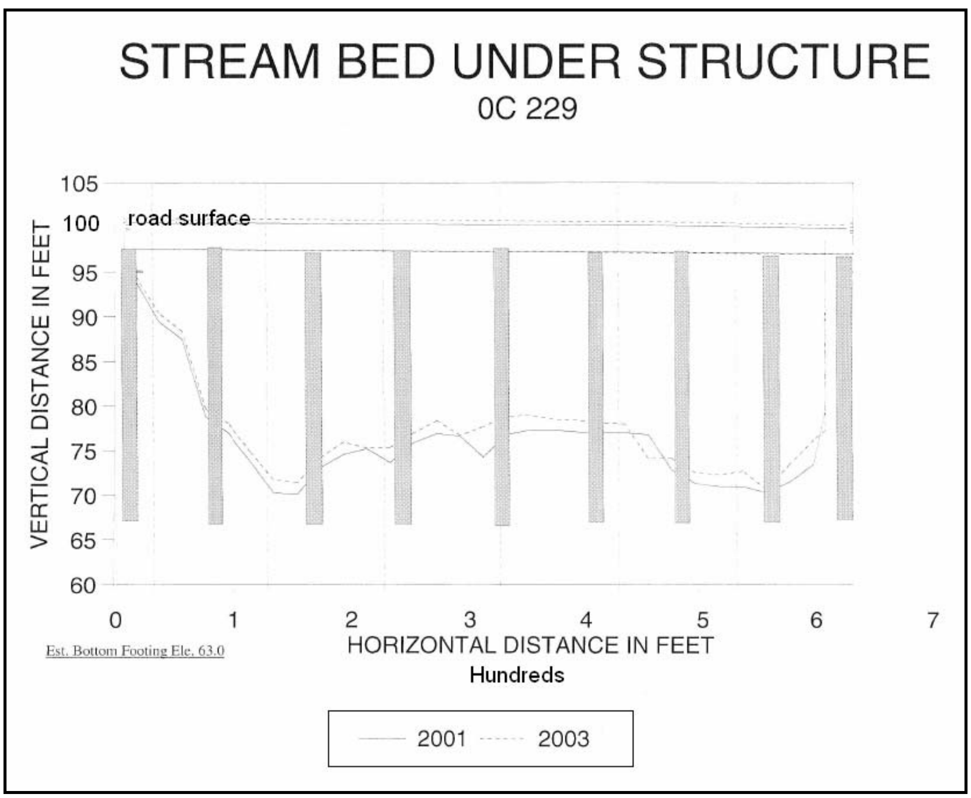


Figure 39: Underwater Inspection Report, Green River Bridge Profile, 2001 to 2003

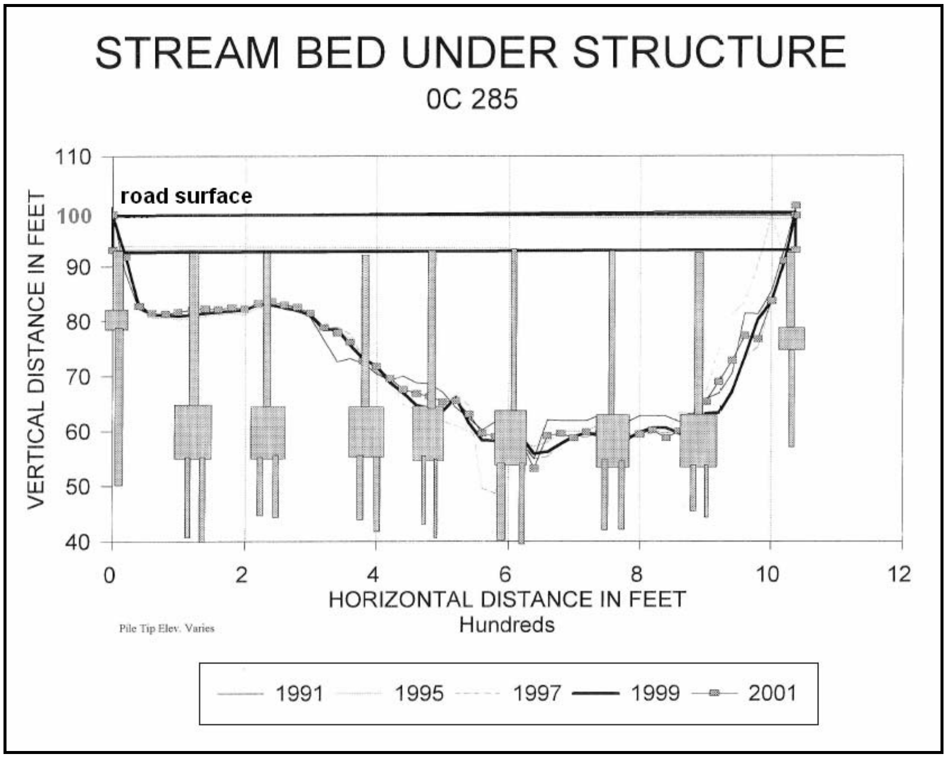


Figure 40: Underwater Inspection Report, Colorado Bridge Profile, 1991 through 2001

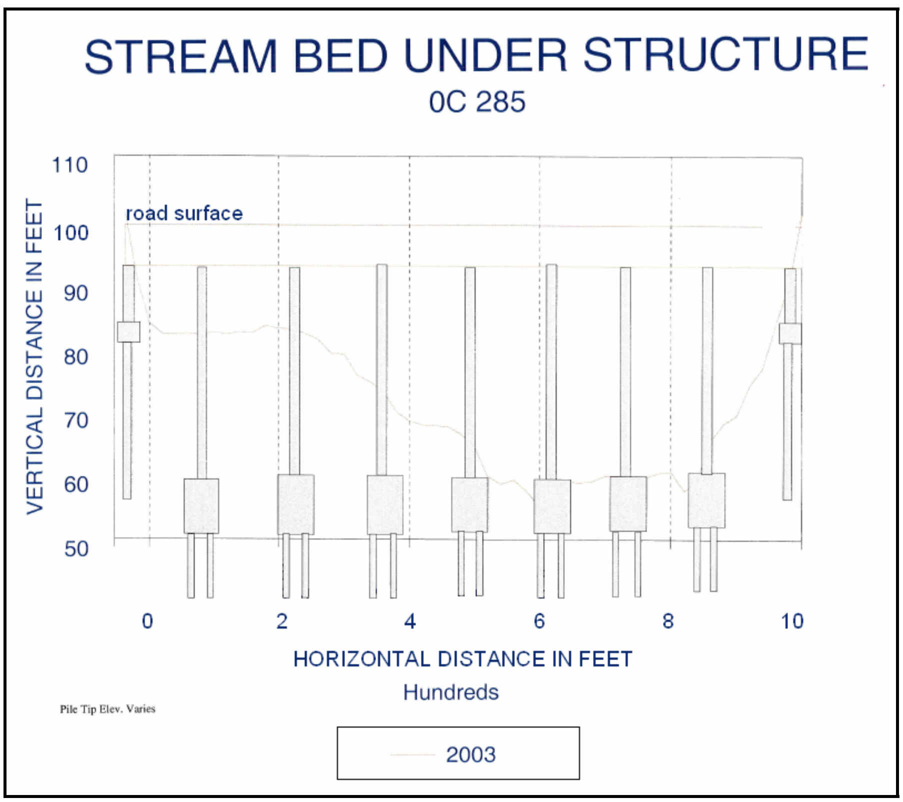


Figure 41: Underwater Inspection Report, Colorado River Bridge Profile, 2003

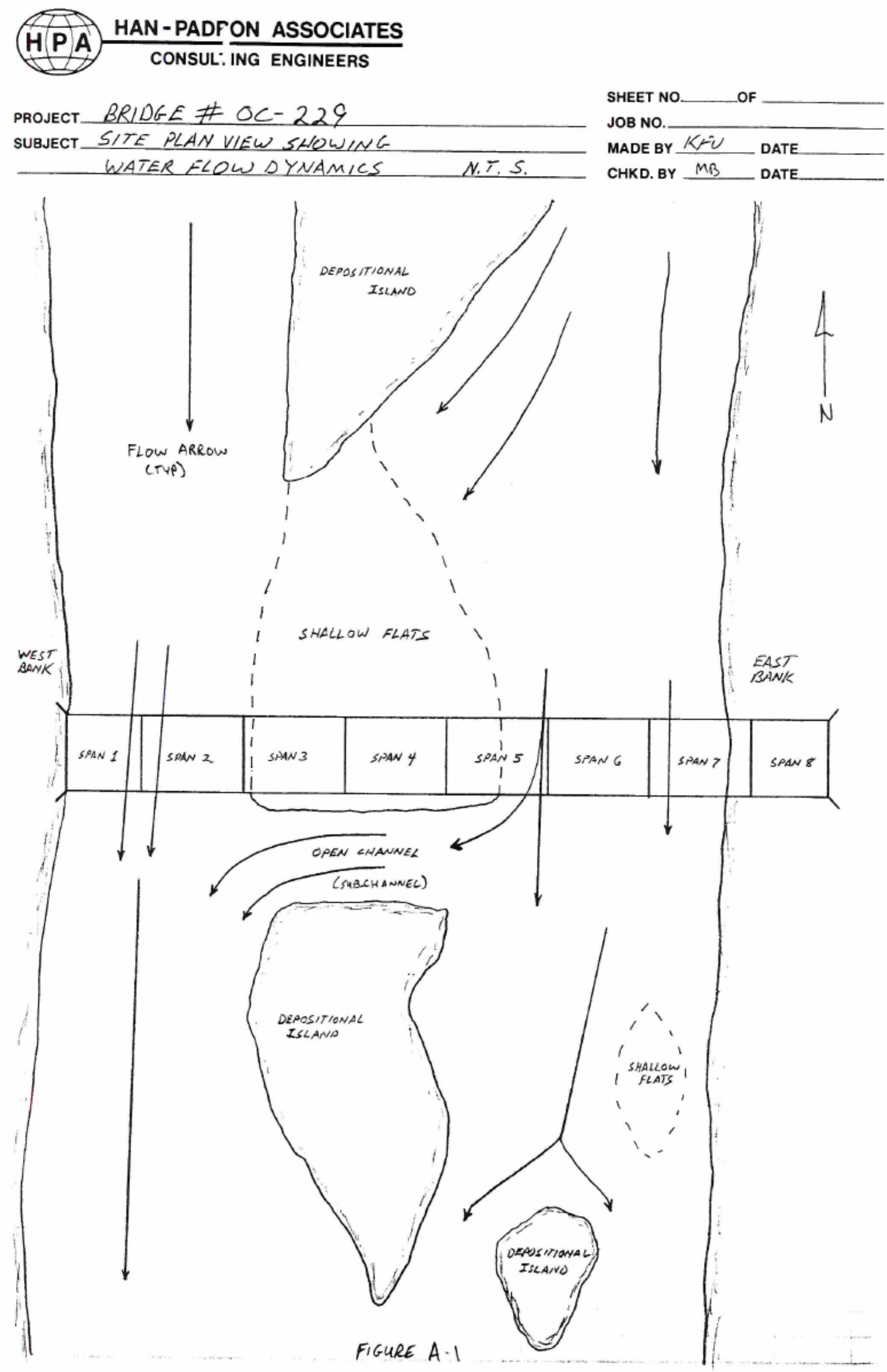


Figure 42: Underwater Inspection Report Plan View of Green River Bridge, 1999