# TEMPE TOWN LAKE PROJECT
# RUBBER DAM DESIGN/CONSTRUCTION/OPERATION/REPAIR

*By John Livingston, PE/CH2M HILL, Basil Boyd, Jr., RG/City of Tempe, Dave Allard, PE/CH2M HILL, and Chuck Pedri, PE/CH2M HILL*

## Abstract

The Rio Salado Town Lake Project includes features that provide recreation and aesthetic benefits to the formerly dry Salt River located on the north side of Tempe Arizona. Two inflatable rubber dams and associated shoreline trails, bike paths, rest areas and boat ramps provide recreation opportunities to local and out of town visitors. The initial vision of restoring the river channel began at Arizona State University School of Architecture in 1966. Feasibility studies began in 1992 and construction occurred between 1997-99. This $42 million project designed by CH2M HILL includes an 800-foot long rubber dam consisting of 4 separate 16-foot high rubber bladders separated by reinforced concrete piers. As one of the largest applications of inflatable rubber dams in the United States, this dam sets on a 30 feet thick foundation of reinforced concrete and roller compacted concrete. Two miles up the lake a second rubber dam 6-feet high is set on a concrete foundation. Town Lake covers approximately 220 acres and is partially surrounded by a soil-bentonite slurry cutoff wall to reduce seepage losses. Recovery wells located outside the reservoir return seepage water to the lake. Operational since 1999, the lake is functioning as planned. Pedestrian trails supported by retaining walls and soil cement slope protection are landscaped to blend in with surrounding features.

Repairs to the rubber bladders were conducted by the dam manufacturer in September, 2002. These repairs, which required deflating two of the bladders, were possible without emptying the lake by using a cofferdam system included in the original design.

## Background

The City of Tempe contains the Salt River channel which is normally dry due to storage by a series of six storage reservoirs and one diversion dam constructed between 1909 and 1946 to supply water and power to the communities and farm areas along the Salt River. The river channel bisects the City from east to west and is dry except under flood flow conditions. This dry channel has been neglected for many years and is the site of extensive aggregate mining and illegal dumping. In 1966, the Arizona State University College of Architecture, located in Tempe, conceived the idea of turning this neglected riverbed into a recreation area. The idea sat dormant for many years until the Rio Salado (Spanish for Salt River) Commission was formed in the late 1970's. The Commission's first task was to evaluate whether or not intermittent flooding from over 800 square miles of uncontrolled drainage areas would adversely affect the Project. The Tempe section of the Salt River was stabilized in 1989-1990 with cement-soil alluvium

(CSA) on the banks and as grade control structures on the river bed. Wire gabions were used on the slopes above the CSA -covered fill to accommodate the 100+ year flood.

The major storage reservoir on the Salt River, Theodore Roosevelt Dam, was modified in 1996 and included both additional water conservation storage and flood control space. These modifications contributed to a reduction in the potential of flooding frequency on the lower Salt River. This in turn helped lead the decision for the Rio Salado Project to include a commercial, residential and recreational development that would greatly enhance this portion of the City of Tempe while accommodating the flood cycle from the Salt and Verde River watersheds. The concept of a Town Lake, which would be the focal recreational component of the Rio Salado Project and which could also accommodate the flood cycle, was therefore born. The proposed lake was to be located downstream of the confluence of Indian Bend Wash with its uncontrolled 80+ square mile watershed and the Salt River.

In 1991, an engineering feasibility study was begun by CH2M HILL of Tempe, Arizona to study the lake concept and determine the major facilities needed for its implementation. The major design issues were:

- Major facilities in the river bed would need to survive the 100-year flood flow of 215,000 cubic feet per second (cfs) with an average velocity of 12.5 feet per second. Under this condition, general scour is estimated at 2 feet, with local scour near bridge piers and energy dissipater aprons estimated at greater than 10 feet.

- Any development in the river channel must not reduce the capacity of the channel to less than the 100-year flood with 3 feet of freeboard.

- Fifteen stormwater outfalls discharge into this reach of the river. Since urban stormwater could have an adverse impact on the lake water quality, it should be eliminated, reduced, or treated. The “first flush” describes the tendency for most pollutants in urban areas to be washed off impervious surfaces during the first part of a storm event. The first flush is defined as twice the average storm runoff.

- An extensive hydrogeological investigation (including 11 soil borings, 35 test pits, 47 piezometers and 5 test wells) indicated that the proposed lake is bisected by a north-south fault. West of the fault the geology consists of a thin sand and gravel layer above consolidated rock (at a depth of about 30 feet). East of the fault, the geology consists of relatively thick sand and gravel layers with interspersed finer-grained materials with consolidated rock not encountered until a depth of about 200 feet. The coarse sand and gravel materials would result in very high rates of reservoir leakage.

- The upstream half of Town Lake is bounded on the north and south by the U.S. EPA Indian Bend Wash Superfund Site. Groundwater modeling was required to determine the lake’s impact on the groundwater contaminant plumes emanating from within the Superfund site.

- The study and subsequent design report concluded that despite these issues, a 2-mile long lake approximately 1,000 feet wide could be developed in the river bed. The 220 acre lake would be located just north of the rejuvenated downtown district and would include the following components:

- A 16-foot high air-filled rubber dam at the downstream end that would be lowered as necessary during flooding events to allow storm waters to pass, but still maintain the lake's desired water level. At the 100-year flow, the rubber dam would be fully deflated to a height of 3 inches. When the stormwater flows recede, the dam would be re-inflated to capture the tail water of the storm and refill the lake

- A 5-foot high air-filled rubber dam at the upper end of the lake to maintain a minimum depth for water quality and to separate the lake from river nuisance flows. Flows coming down the Salt River would impound and infiltrate behind the upstream dam. A bypass pumping and piping system will be constructed to capture and divert unwanted waters from upstream of the dam to downstream of the lake.

- Operations buildings would be located at both the upstream and downstream dams to provide space and shelter for the compressors and electrical equipment required to inflate and deflate the dams.

- A constructed shoreline to provide flood protection, an aesthetic edge treatment, pedestrian access, emergency egress from the lake, and boat docking and ramp facilities for the lake. Floating docks will be attached at the shoreline marinas to accommodate small sail boats and paddle boats.

- A seepage control system including soil-bentonite slurry cutoff walls down to bedrock on the downstream half of the lake and a pump and recovery system on the upstream half of the lake. The walls would be keyed into relatively shallow bedrock in the downstream part of the lake. Because of the depth to bedrock in the upper half of the lake, recovery wells were selected to capture infiltration and return the well discharge to the lake.

- A water delivery system from the Salt River Project canal system to fill the lake and provide a water source for replacing evaporation and seepage losses.

- A storm drain bypass system to prevent the City storm drain system's "first-flush" pollutants from entering the lake and degrading its quality. The diversion piping system was to be up to 108 inches in diameter and designed to bypass all or a portion of the flows from several major outfalls to other outfalls either upstream or downstream of the lake.

Figure 1. Looking at Town Lake toward the 16-foot-diameter Downstream Dam

Construction of the Town Lake project began in July 1997 and was completed in June of 1999. On November 6, 1999, Tempe officially put in service Town Lake as the first project in Arizona to include rubber dams. The dams not only maintain a minimum water level vital to the lake's water quality, but also control flooding in a way unique to this type of dam.

The following paragraphs discuss the issues considered during the design process for the rubber dams and foundations, any problems encountered during construction, and the routine operation and monitoring required after construction. Also discussed is the required repair of one of the rubber dam bladders.

## Design

The major features involved in the design included a 5-foot high rubber dam, 16-foot high rubber dam, soil-bentonite slurry wall and peripheral storm water pipelines, pump stations and control buildings. Only the 16-foot high dam and slurry walls will be covered in this paper.

### *Cut-off Walls*

Subsurface investigated on the project site indicated a significant geologic feature at approximately 1000 feet west of Rural Road (north-south major arterial street), about the midpoint of the lake,. To the west of this location Alluvium consisting of sand, gravel and cobbles (SGC) overlies consolidated bedrock at a maximum depth of 50-feet. East of this location the alluvium extends to a depth of over 200 feet inferring a high-angle north-south trending fault. Hydraulic groundwater modeling was conducted to evaluate several combinations of cut-off walls, recovery wells and lake linings. The most cost effective alternative was a cut-off wall to the west of the inferred fault, where the bedrock was relatively shallow and a series of ten groundwater recovery wells east of the fault. The alignment of the cut-off walls was along the north and south side of the lake just inside the bank protection. The bottom of the sloping bank protection was toed into the river alluvium to a maximum depth of 12 feet. This, in addition to concerns about settlement of the hard banking surface during construction, required the cutoff wall to be constructed up to 30 feet from the edge of the river bottom. To control seepage between the cut-off wall and the hard banking a geosynthetic clay lining was placed between the two features. The lining was placed 5 feet below the river bed and covered with large armor stone to protect it during river flow events. A cross section of the slurry wall is shown in Figure 2.

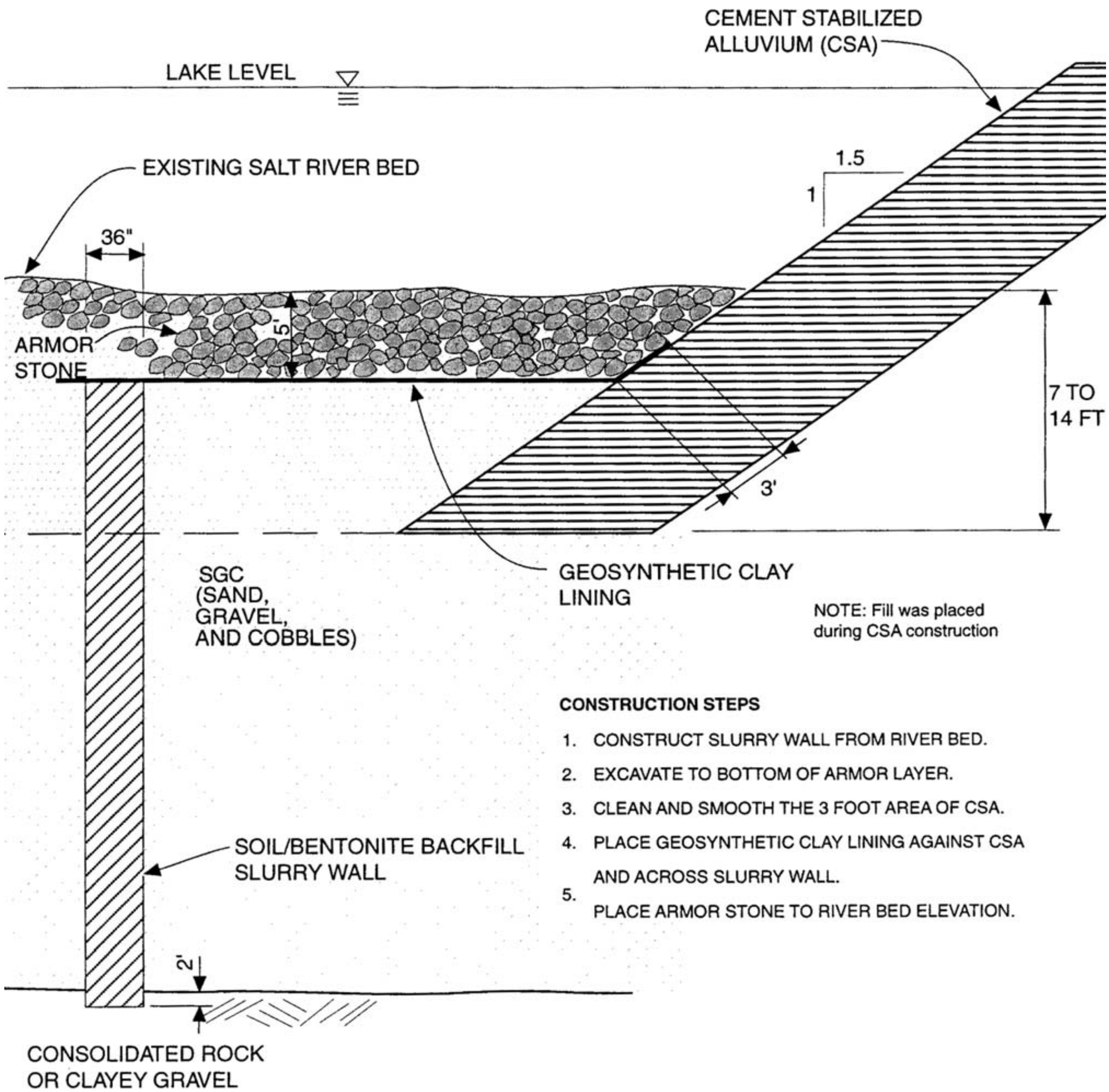


Figure 2. Cut-off Wall Section

The infiltration requirements of the project dictated the cut-off wall meet a permeability of $1X10^{-6}$ cm/sec. Backfill mix design was conducted using constant head permeability test in a 9-inch permeameter. The test results showed river alluvium crushed to less than 2-1/2–inches with 10 percent fines and 8 percent bentonite would meet the project goal. Mix design test by the cut-off wall contractor indicated they could meet the project permeability requirements without the additional fines.

The cut-off walls were constructed using bentonite slurry displacement methods. In this method a trench is excavated ahead of the cut-off wall. The trench is stabilized by using a bentonite and water slurry. A test of the slurry infiltration was conducted during site exploration. The tests consisted of excavation of two 3-foot wide by 4-foot deep trenches. The trenches were backfilled with a slurry mix of 20 pounds bentonite 50 gallons water and 5 percent by slurry weight sand. The unit weight of the slurry was approximately 9 pounds per gallon with a Marsh funnel reading of 42 seconds. The slurry was placed in the trench and the surface monitored for 40 minutes. The surface drop averaged about 2-inches over the length of the test. Stability analysis required the slurry have a minimum density of 80 pcf. The maximum density was limited to 110 pcf to allow successful placement of the backfill mix. A minimum Marsh funnel viscosity of 40 seconds and filtrate loss of 25 cubic centimeters were specified based on case study information.

During project design, concerns were raised over the strength of the soil/ bentonite wall in front of the downstream dam. To increase the wall strength, a soil/ cement/bentonite cut-off wall was specified for the section directly in front of the downstream dam. The mix design required that the soil/cement/bentonite mix achieve a 28 day compressive strength of between 10 and 50 psi while maintaining the $1X10^{-6}$ cm/sec permeability requirement.

***Rubber Dam***

The Salt River channel is composed of alluvium consisting of clayey gravel with cobbles and is layered with increasingly pervious sand and gravel layers toward the surface. (Note: The depth to bedrock varies, the channel is incised into bedrock on the west side but on the east side it sits on older alluvial deposits not related to the Salt River) To prevent the channel from being eroded during high river flows, previous construction work had placed cement stabilized alluvium on the shoreline embankments to prevent lateral erosion and large grade control structures of similar material across the channel at approximately 1 mile intervals. These grade control structures were constructed by excavating a wide trench with scrapers perpendicular to the channel and backfilling it with a mixture of sand, gravel and cement placed similar to roller compacted concrete.

To minimize the foundation costs for the dam, and to locate the dam within the correct reach of the river, one of the grade control structures was explored and found to be suitable for a partial cutoff and foundation. The river width at this location was about 900 feet. Rubber dams were selected as most effective and able to lay down during high river flows to prevent overtopping of the shoreline protection. The rubber dams are bladders made of layers of rubber and yarn reinforcement similar to a belted tire. They are made by creating a large rectangular sheet of material and assembled onsite. To optimize the layout and allow for repairs at the downstream damsite, it was decided to utilize four bladders with a maximum length of 228 feet and diameter of 16.3 feet when fully inflated. The bladders would be connected to three piers in the river and two abutments.

At approximately 16-feet high, the rubber bladders at the downstream (west) end of the lake are the world's largest by volume and the tallest in North America as of 1999**.** A cross section of the downstream dam is shown on Figure 3. The words dam, rubber bladder, and rubber dam refer to the elements or combination of elements that provide a hydraulic barrier across the entire river channel.

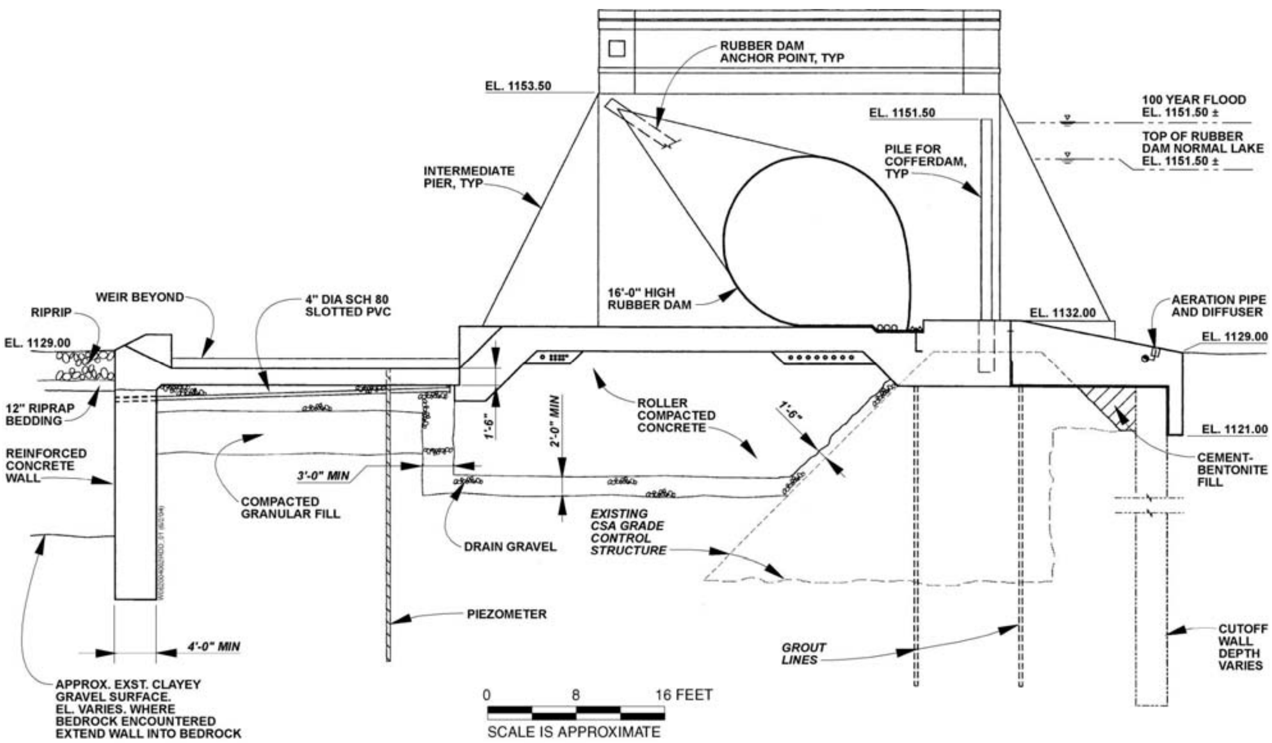


Figure 3. Downstream Dam Cross Section

To create a suitable foundation for the rubber dam, the alluvium downstream of the grade control structure was removed to a depth of 12 feet below the top of the grade control structure and replaced with roller compacted concrete. This composite foundation served as the subgrade for the 2.5-feet thick reinforced concrete slab on which the piers and rubber bladders were anchored. To decrease the permeability of the grade control structure and potential underlying bedded native alluvium, two rows of grout holes were designed. In addition, a 3-feet-thick soil-bentonite cutoff wall was placed in front of the dam to connect to the cutoff walls extending upstream. An 18-inch reinforced concrete energy dissipation slab is connected to the main dam foundation to collect minor flows coming over the dam and allow for pumping them back into the reservoir. Finally a 4-foot thick reinforced concrete slurry wall to a depth of 24 feet serves as protection from scour during high river flows.

Inflation of the rubber bladders is accomplished with air pipes embedded in the concrete foundation and connected to each bladder separately. A control building located on the north(right) abutment, contains air compressors and controls to inflate and maintain the bladders at an operating pressure of about six to eight pounds per square inch (psi). Each bladder can be controlled separately and are automated to deflate at a predetermined lake elevation or pressure. During storm events, the bladders are deflated as necessary to maintain a maximum water elevation as the storm waters are allowed to pass. As flows approach the “100-year discharge,” the dam can deflate to a height of about three inches. As the storm wave in the river passes the bladders are reinflated to capture “free” water and allow for immediate return to normal operation. Time for inflation and deflation is from 30 to 60 minutes.

Management of seepage under the dam was accomplished by use of drainage blankets that flow by gravity out the downstream slurry wall and into the river channel. Vibrating wire piezometers set a various levels under the energy dissipation slab are remotely read to check the competency of the various cutoff features. All phases of the project were reviewed by the Arizona Department of Water Resources including the field exploration, design and construction observation of the foundation elements.

## Construction

Construction of the Town Lake facilities began in December 1997. The overall project was divided into four contract packages: A) Recovery Wells and Stormwater Piping, B) Cut-off Walls, C) Shoreline improvements, and D) Dam Facilities**.** The prime contractor for the cut-off walls was GeoCon, Inc. of Sacramento CA. The prime contractor for the dam facilities was Ogden Construction from Salt Lake City, Utah. The rubber dam bladders and control equipment were pre-purchased by the City from Bridgestone Corporation.

The cut-off wall construction began in September, 1997 with excavation of the armor stone trench to get to the top of wall elevation. The material from this excavation was crushed on-site and placed near the trench for use in the backfill mix. Slurry was mixed in a slurry pond using a high shear mixer, then pumped to the work location through HDPE pipe. The majority of the trench was excavated using a Cat 375 excavator with a standard stick and rock bucket. Backfill was mixed near the trench site using a case 690 excavator and Cat D8 dozer as shown in Figure 4. A custom made long stick (60 foot) was used for the deeper excavations to the east.

Figure 4. Slurry wall construction at toe of shoreline CSA

The contractor started on the south shoreline and worked west to the down stream dam location. They did the same along the north side alignment. The contractor then completed the cement/bentonite wall along the front of the downstream dam. The contractor complete the project including geosynthetic clay lining and armor stone placement by the end of December, 1997. This 3 month construction schedule required a second shift for some of the wall construction.

The construction of the dam facilities began in January, 1998 after completion of the cut-off walls. The contractor essentially took over the river bottom both upstream and downstream of the dam. Grouting of the foundation consisted of drilling two rows of holes on a 10-foot spacing. Alternate holes were drilled and grouted first. Closure holes included some that fractured with grout coming to the ground surface. The existing grade control structure took little grout in most areas.

Encapsulation of the upstream soil-bentonite slurry wall by the reinforced concrete apron slab proved very difficult as the strength of the slurry wall was low and trimming and preservation of the fragile bentonite mix were time consuming and time dependent. The upstream edge of the grade control structure also had to be trimmed and a strip of geosynthetic clay liner set between the new apron slab and the underlying cutoff features to prevent seepage along the interface of the grade control structure apron and the reinforced concrete slab.

Roller compacted concrete placement proceeded smoothly once the dewatering system was fully functional. The design mix for the RCC was 150 to 300 lb/cy cement, 100 to 150 lb/cy fly ash, 170 to 200 lb/cy water, and the balance 2-inch minus crushed alluvium from site excavations. Mix design strength was 1,800 psi at 28 days. The downstream reinforced concrete slurry wall was also difficult as this was the first done by the contractor and the panel connection proved time consuming and difficult to control. Like most dam projects the foundation elements were the most difficult. Concrete work in large mass placements went smoothly during moderate temperatures but high temperatures required large amounts of water, water blankets and coordination.

Figure 5. Rubber bladder being positioned on dam foundation

The rubber dam bladders are installed by laying out a flat sheet of the material as shown on Figure 5. Anchor bolts had been cast in the reinforced concrete slab. The sheet is placed over the anchor bolts after holes have been punched at the correct frequency. The sheet is then pulled over itself and the top is aligned, punched, and put over the bolts. A top plate is set over the bolts and nuts torqued. The sloping ends of the bladders are also anchored to the concrete in a similar way. Air piping is attached to the bladder near the anchor plate.

## Operations and Routine Monitoring

Town Lake is operated for the City by the Salt River Project (SRP). All of the automated systems including the blowers for the rubber bladder dams are monitored remotely at the SRP control center. The reservoir water level is maintained near elevation 1,148.00 feet above mean sea level by the automatic control functions and instrumentation at the dam, which either inflates or deflates the bladders. There are two backup control systems including manual override controls at the control house located on the north abutment and automatic mechanical deflation controls that are designed to deflate the dam when the water level reaches elevation 1,150.

The City inspects and monitors of the dams and reports annually to the Arizona Department of Water Resources (ADWR). This monitoring consists of the following:

- Piezometer data
- Horizontal and vertical movement surveys
- Crack mapping
- Visual inspections reports

***Piezometers***

There are 20 piezometers at the downstream dam and 3 at the upstream dam. The upstream dam piezometers are read manually once per month. The downstream dam piezometers are outfitted with pressure transducers. These piezometers are vibrating wire pressure transducer-type piezometers that report to a digital data logger in the downstream dam operations building. The data logger records the readings from the pressure transducers once per day at 12:00 midnight. The raw data is downloaded at the end of each month and imported to a Microsoft Excel spreadsheet that converts the pressure reading to feet of water above the transducer and then to an elevation.

The piezometers at the downstream dam are located in four rows parallel to the stream flow with five piezometers in each column. The downstream piezometers are installed at three different depths as follows:

- Moving in the downstream direction, each row has one piezometer at approximately 25 feet and 15 feet below the dam foundation apron.
- Two piezometers near the upstream side of the recycle pump channel at depths of approximately 22 feet and 5 feet below the recycle pump channel slab.
- One piezometer near the downstream side of the recycle pump channel at a depth of approximately 5 feet.

In 2001 water movement was detected between some piezometers through the transducer cable conduits. These conduits were sealed to isolate each piezometer. It was also observed that the grout seal around several of the piezometers was no longer completely intact and these were repaired to prevent migration of the gravel drain material from beneath the slab.

### *Movement Surveys*

During construction in 1998 permanent survey control monuments were placed on the downstream dam piers and abutments. Horizontal and vertical surveys have been conducted quarterly since January 2000. These surveys so far have not indicated significant horizontal or vertical movement.

### *Crack Monitoring*

All cracks at the downstream dam are mapped annually by a registered surveyor. These surveys have identified only hairline cracking and minor spalling.

### *Visual Inspections*

The City conducts visual inspections of the upstream and downstream dams monthly. These inspections include examination of the reservoir, instrumentation, piers, abutments, foundations, aprons, and bladders. Features checked include crack changes, spalling, displacement, seepage, erosion and any changes from the previous inspection.

## Rubber Dam Repairs

On September 9, 2002, Tempe and SRP staff discovered an air leak on the downstream side of the downstream rubber dam, span No. 3 (the spans are numbered from right to left looking downstream). The manufacturer, Bridgestone Corporation, responded and discovered a 12-inch long tear in the right abutment looking upstream which needed immediate repair and determined that the repair process required deflation of the span No. 3 rubber bladder. To maintain the lake full during the repair process required installation of a cofferdam on the upstream side of the damaged span such that minimal water would be lost during the repair. Fortunately the City of Tempe had prepared for just such a repair situation by incorporating the necessary coffer dam structural components into the dam foundation with prefabricated portable panels and beams stored at a nearby SRP facility. Installing the cofferdam required divers to remove the cap from each of the 21 soldier pile sockets located near the upstream edge of the dam foundation. Divers teamed up with a 60 ton hydraulic crane to install the 23.5 feet long soldier piles and the steel panels that fit between the piles.

There are two primary methods to repair damage to a rubber dam bladder:

- For minor damage a cold vulcanization approach will usually suffice consisting of removing the damaged outer cover and fabric, buffing the remaining layer and installing new materials (fabric and cover rubber) using the appropriate adhesives.

- For major damage a step-repair process is usually required consisting of a hot vulcanization process. This method requires removal of all damaged fabric layers in multiple “steps.” Each layer is then buffed and replaced in-kind with “raw”, un-vulcanized rubber and fabric. The damaged area must then be placed under a uniform pressure between heating platens and cured at a specific temperature and duration.

Bridgestone determined that the 12-inch tear was categorized as major damage near a joint, and sent personnel from Japan to perform the repair. Span No. 3 was first removed from the anchoring bolts in the foundation and then opened up to expose the damaged area. The damaged section on the exterior side of the bladder was repaired first, followed by the damaged section on the interior side. The repair procedure consisted of the following:

- Lay the bladder out flat with the exterior side up
- Cut out the damaged sections of each of the 5 layers on the exterior side of the bladder
- Dry and buff the area
- Apply the new materials for each of the 5 layers
- Heat vulcanize the new materials
- Turn over the bladder with the interior side up
- Cut out the damaged sections for the outermost layers on the interior side of the bladder
- Dry and buff the area
- Apply the new materials
- Heat vulcanize the new materials
- Reposition the fabric over the anchor plates and bolts
- Assemble the top plate and anchor bolts
- Inflate the bladder
- Check for leaks
- Remove the cofferdam

During the course of the span No. 3 repair, Bridgestone took the opportunity to inspect the remainder of the dam using divers, both below and above the water surface. Several instances of minor damage was found on each bladder which was repaired. The inspection also found a ½” X 8” hole in the exterior cover of span No. 1, that was attributed to delamination of the outermost reinforcing layer. This hole also required the same procedure used for span No. 3. Following removal of the cofferdam from span No. 1 to span No. 3, the same repair procedure discussed previously was repeated. Following completion of all minor repairs and air leak testing the entire dam was put back in service.

## Conclusions

Rubber dams have been used worldwide to allow the full channel cross section to be used during high flow events, to increase the height of existing concrete dams and to provide flexibility in discharge rates by partially deflating the dam. For the Tempe

Town Lake project, the high flows and high velocity of the river made selection of an inflatable dam system consistent with site and operational conditions. Variability in foundation conditions caused multiple seepage control barriers to be provided for this rather short dam. With its high visibility to the public visual features included special treatments to concrete walls along the shoreline, to the piers at the ends of the rubber bladders and the dam control building.


## Acknowledgements

The authors would like to acknowledge the City of Tempe, Arizona for their insight and dedication to completing this project.