RECLAMATION

Managing Water in the West

TR-2015-03

Travel to Trenton Dam, Nebraska

Trenton Dam – Canal outlet works instrumentation installation and vibration testing

Date(s) of Travel: April 30 – May 1, 2015

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

BUREAU OF RECLAMATION
Technical Service Center
Denver, Colorado

TRAVEL REPORT

Code: 86-68460 Date: May 29, 2015

To: R. Einhellig, Manager - Hydraulic Investigations and Laboratory Services Group

From: J. Kubitschek, Hydraulic Engineer; B. Heiner, Hydraulic Engineer; J. Mortensen, Hydraulic Engineer - Hydraulic Investigations and Laboratory Services Group

Subject: Trenton Dam - Canal outlet works instrumentation installation and vibration testing.

Travel period: April 30 – May 1, 2015

2. Places or offices visited: Trenton Dam, NE

3. Purpose of trip: At the request of Reclamation's Nebraska-Kansas Area Office (POC – Mark Rouse) via Reclamation's, Technical Service Center - Mechanical Equipment Group (POC - John Shisler), Reclamation's Technical Service Center - Hydraulic Investigations and Laboratory Services Group was asked to provide support for assessing excessive vibration recently observed during operation of the canal outlet works at Trenton Dam. It was proposed that data be acquired during operational testing to support decision making for future corrective actions (as needed).

Trenton Dam is located on the Republican River near Trenton, NE. The dam is a 100-ft-high earthfill structure that forms Swanson Lake and is comprised of a radial gated spillway section with a river outlet works on the left abutment and canal outlet works on the right abutment. The canal outlet works consist of a conventional submerged intake structure with trash racks, a concrete intake conduit, an emergency gate, a 56-in-I.D. welded steel conduit with ¼-in wall thickness connected from the emergency gate to a downstream regulating gate, and a stilling well.

Operators recently observed low frequency vibration after initial operation of the outlet works in preparation for the upcoming irrigation season. NKAO personnel indicated that the outlet works conduit was filled and operated normally for a period of time (several minutes or more) after which the regulating gate was closed. The initial closure was accompanied by a banging sound. Operators entered the outlet works tunnel to inspect and observed a resonant vibration of the outlet works pipe. The regulating gate was then opened slightly and the vibration stopped. However, when the regulating gate was closed again, the vibration reoccurred. Video of the pipe motion was obtained, the emergency gate was closed, and the pipe unwatered. The 30-second video clip provided by NKAO shows the relatively large amplitude, low frequency (slightly > 1

Hz) mode of vibration with no apparent damping for the duration of the video. At the time of the occurrence, the reservoir elevation was low (below approximately El. 2734.5 ft). The regulating gate and piping were inspected following unwatering. Minor free play in the regulating gate was noted and the pipe expansion joint apparently showed some recent movement, both of which are considered common.

NKAO staff also indicated that similar vibration had been noted as “pipe breathing” in the operating logs at the end of the 1999 irrigation season. Furthermore, it was indicated that the seam weld at the location shown in the recent video began leaking in 2013 and was subsequently weld repaired, though there were no documented observations of vibration at that time.

4. Synopsis of trip: Kubitschek, Heiner, and Mortensen departed Denver, CO around 6:15am (MDT) on April 30, 2015 and arrived at Trenton Dam around 11:30am (CDT). The team met Mark Rouse (Civil Engineer - NKAO) and Charlie Mack (Facilities, Equipment, and Services Tech – Trenton Dam). We discussed the recent observations (documented in the video clip provided by NKAO). We then discussed the proposed test plan for attempting to reproduce the vibration and obtain relevant data. The team inspected the exterior of the piping and proceeded to install accelerometers, strain gauges, and an external mount ultrasonic flowmeter.

Eight (8) uniaxial accelerometers were mounted on the weld repaired section of piping, 3-1/2 in. off the axial seam weld, using magnetic bases (Figure 1). Accelerometer No. 1 was positioned 1-3/4 in. upstream of the downstream-most ring support in the outlet works tunnel (Figure 2), with the remaining 7 accelerometers located equidistant upstream on 2 ft 6-3/16 in. centers covering ½ of the pipe length between ring supports. Four (4) additional low frequency tri-axial accelerometers were mounted at various locations along the canal outlet works piping well upstream of the test location.

Four (4) uniaxial strain gauges were installed near the weld seam at the location of the 2013 weld repair. Three (3) of the strain gauges were oriented in the circumferential (hoop) direction and the remaining strain gauge was oriented in the axial direction (Figure 3).

An external mount ultrasonic flowmeter was installed using ratchet straps on the same pipe section at a location upstream of accelerometer #8 (Figure 4). The installation was completed around 5:30pm (CDT) after which the team traveled to McCook, NE east of Trenton Dam to stay overnight.

We arrived at Trenton Dam on May 1, 2015 around 6:30am (CDT) and met Mark Rouse, Carl Koenig (Supervisory Civil Engineer, NKAO), and Charlie Mack. The data acquisition systems were setup, instrumentation operational checks were performed, and video monitoring equip was positioned in preparation for operational testing. Mark Rouse led a safety briefing (JHA) to advise all participants on safety-related issues and to discuss operating conditions, hazards, emergency procedures, and emergency contact information.

Figure 1. - Accelerometers mounted using magnetic bases (view looking upstream).

Figure 2. Accelerometer #1 located just upstream of downstream-most ring support.

Figure 3. Strain gages located near seam-weld repair for longitudinal and hoop stress measurements.

Figure 4. Ultrasonic flowmeter located upstream of accelerometers (view looking downstream).

With the emergency gate closed, the 56-in. diameter steel pipe portion of the outlet works was filled by closing the regulating gate and then opening the air vent and emergency gate bypass fill line in the emergency gate chamber. Once the pipe was full, the emergency gate was opened. Strain gage data were acquired during filling. Testing commenced with opening the regulating gate a small amount for a brief period of time followed by closing the gate. No abnormal pipe vibrations were observed during this initial test. The second test involved opening the regulating gate 1.5 ft which resulted in a measured outlet works discharge of approximately 188 ft^3/s. The regulating gate was then closed and seated. No abnormal pipe vibration was observed during this test. A third test, duplicating the second test, failed to produce any abnormal vibrations. It was then decided that the regulating gate should be opened a small amount followed by closure and seating multiple times in succession. Again no abnormal conditions were observed. The final test involved opening the regulating gate to 2.5 ft (which produced a discharge of approximately 240 ft^3/s), maintaining that gate position for several minutes, followed by closing and seating the gate. No abnormal pipe vibrations were observed during this final test.

After discussion with NKAO staff it was decided that the instrumentation could be left in place should excessive vibrations be observed in the next few weeks. Data acquisition and computer equipment were disconnected for transport back to Denver. The team departed Trenton Dam around 11:15am (CDT) and returned to Denver, CO.

5. Conclusions: The previously observed abnormal “breathing-mode” vibration could not be reproduced and no excessive vibrations were apparent during operational testing. Although it was not confirmed, the intermittent abnormal vibration may be due to a critical combination of low head (low pressure in the pipe) and incomplete gate seating. It is plausible that under low reservoir elevations the pressure differential across the regulating gate could lead to poor sealing resulting in a cyclic leak-seal feedback response. It is also conceivable that the local “flat spot” deformation near the weld repair could be a source of or contribute to resonant self-excitation. The mechanism in that case might involve a "spring-back" response at some critical internal pressure which could produce pressure fluctuations and result in excitation at the natural frequency.

The video provided prior to the site visit appears to show relatively large shell deflections in the form of an azimuthal mode (possibly n=2) with a period slightly less than 1 second (or a frequency in the range of 1-2 Hz). From Blevins (1979), for a 56-in. cylindrical shell with a ¼-in wall thickness (actual pipe wall thicknesses of 0.235-0.037 in were measured using an ultrasonic thickness gauge), the n=2 mode natural frequency can be estimated as approximately 2.2 Hz (using $E = 30x10^6$ psi, $\rho = 0.284$ lbm/in^3, and $\nu = 0.29$). This theoretical estimate assumes an infinitely long cylinder with no apparent consideration for added mass of a water-filled pipe which would be expected to lower the natural frequency. Furthermore, pipe deformations near the longitudinal seam welds likely influence mode shapes and corresponding natural frequencies. In any case, the "breathing mode" frequency based on the video observations appears to be near the estimated natural frequency for the n=2 azimuthal mode.

While the recently observed vibration apparently occurs rarely (i.e., only one other observation noted in 1999 per NKAO staff), the 2013 weld leak, which is likely related, would suggest that sufficiently large fluctuating stresses have occurred frequently enough to produce weld (fatigue) damage. Such conditions should be avoided until the source of vibration can be identified and eliminated or other corrective actions can be implemented.

Strain gage data acquired during testing are plotted as hoop and axial stresses (using $E = 30x10^6$ psi) in Figure 5. All gages were zeroed prior to water up. The initial peak in stresses during pressurization was due to adjustments in the vent valve during filling. Other changes in the time series data reflect operational changes that reduced static pressure via changes in regulating gate settings which produce changes in outlet works discharge. The results show large changes in hoop stresses in the vicinity of the weld repair. Theoretical calculations for a perfectly round cylinder indicate hoop stresses should be on the order of 3,000 psi given the reservoir head during testing.

It should be noted that uncertainty is introduced by unknown residual stresses in the vicinity of the welds. It is conceivable (though not likely) that residual stresses could be in compression for the unpressurized state. If that were the case, the stresses in tension would be less than these results indicate. However, given the past weld repair, a conservative approach is warranted and additional testing is needed to confirm the large stresses measured during this testing. Confirmation could be accomplished installing strain gages away from the weld for the weld repair section of pipe and comparing measurements from that section with strain gage measurements at similar locations on another section of pipe that is in "good" condition.

Although measured changes in stress are considered large, observations during this testing did not indicate excessive vibrations. However, close monitoring of the outlet works is recommended (especially during shutdowns) and if the previously observed resonant vibration occurs in the future, action (including closure of the emergency gate as necessary) should be taken to immediately eliminate it. A description of how the outlet works was operated at the time of the observations along with parameters (i.e., gate position and discharge prior to closure, reservoir water surface elevation, canal water surface elevation, etc…) should also be documented.

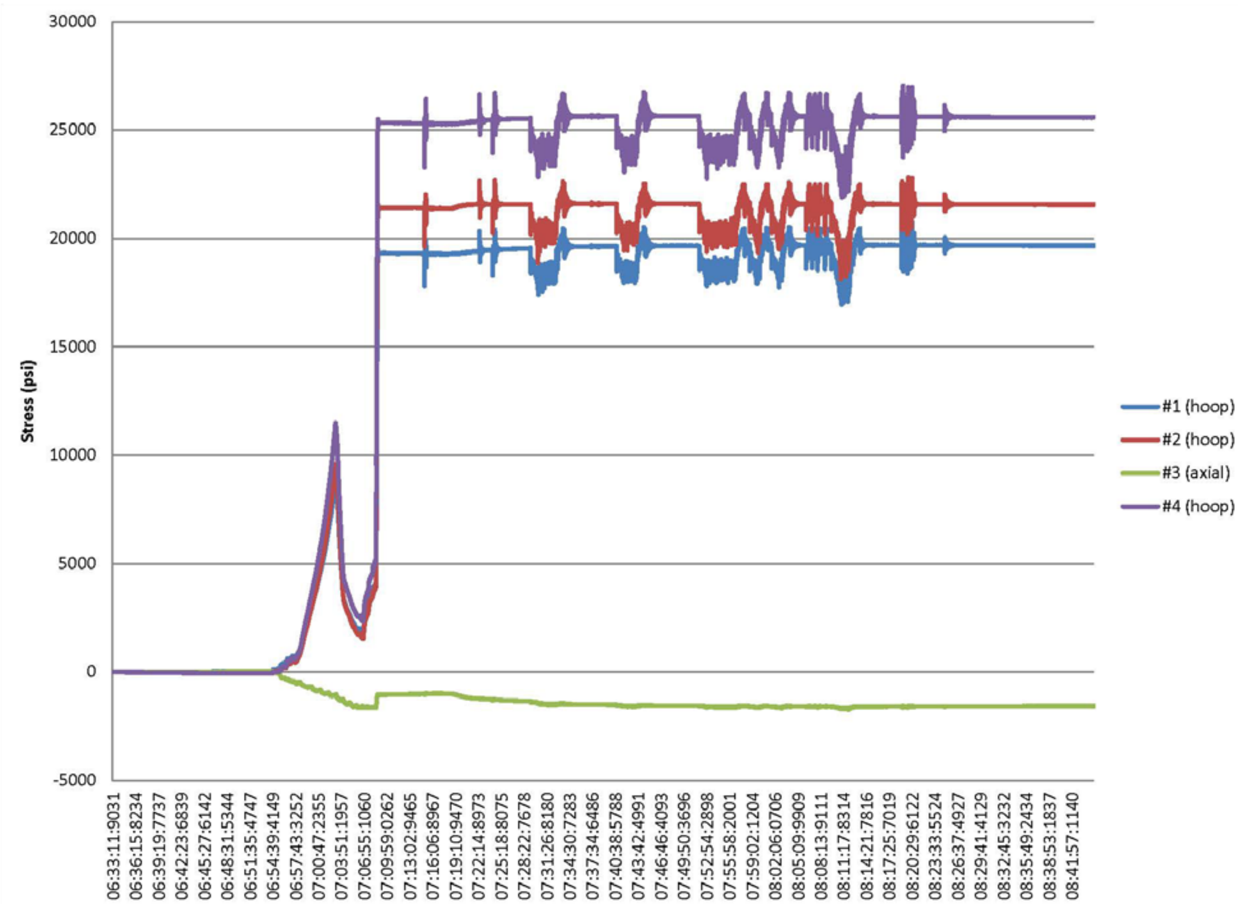

Figure 5. Hoop and axial stresses measured near weld repair.

6. Action correspondence initiated or required: Further testing to confirm large stresses near the longitudinal weld repair. This would involve installing additional strain gages at locations away from the weld repair and on another section pipe for comparison.

7. Client feedback received:

cc: Koenig (NK-Koenig ckoenig@usbr.gov), Rouse (NK-Rouse mrouse@usbr.gov), McStraw (86-68410 wmcstraw@usbr.gov), Frisz (86-68420 rfrisz@usbr.gov), Shisler (86-68410 jshisler@usbr.gov)

bc:

SIGNATURES AND SURNAMES FOR:

Travel to: Trenton Dam, NE

Date or Dates of Travel: 30 Apr – 1 May 2015

Names and Codes of Travelers: Kubitschek (86-68460), Heiner (86-68460), Mortensen (86-68460)

Travelers

Signature | 5/26/2015 Date

Signature | 5/26/2015 Date

Signature | 5/26/2015 Date

Noted and Dated by:

Signature | Manager, 86-6840 Title | 5/26/2015 Date