Report on Check Valve Testing
Performed at Utah Water Research Laboratory
For Southern California Edison Co.
During The Week of March 31, 1986

Herb Rockhold

The week of March 31, 1986, Dr. Paul Tullis and associates of Utah State University performed a series of tests on a 10" Atwood-Morrill check valve at the Utah Water Research Laboratory (UWRL) in Logan, Utah for Southern California Edison Co. (SCE) operators of the San Onofre Unit One Nuclear Station. This report is a summary of the tests performed and does not intend to draw any conclusions since the data obtained from the tests was retained by Dr. Tullis and will be published in a report by him for SCE.

The check valve test configuration for the first test had the 10" Atwood-Morrill check valve located in a straight run of horizontal 10" pipe with greater than 10 pipe diameters of straight pipe upstream and greater than 5 diameters of straight pipe downstream of the check valve. The water at $\approx 5.5^{o}$C was supplied to the test assembly by a reservoir initially at about 10.5 psi to supply low flow, and by a centrifugal pump rated at 1500 gpm at 70 feet of head driven by a 100 horsepower motor for the higher flowrates. The flowrates through the check valve was measured by weighing the quantity of water passed through the valve in specific time intervals. The flowrates were also measured with a flow orifice, however, this was expected to be inaccurate at low flowrates. The check valve was equipped with an accelerometer located on the valve body located approximatley where the valve disk would make contact. The accelerometer was coupled to an acoustic amplifier feeding a speaker to provide relatively clear audible monitoring of the check valve internal moving parts. The check valve noise was also monitored with a simple stethoscope.

At flowrates up to 2600 gpm equivalent plant flows (corrected for water density, velocity, etc., to produce the same forces on the check valve disk that would be experienced at plant operating conditions) the noise level was primarily background flow and pump noise. Near 2600 gpm equivalent plant flow gentle tapping of the valve disc against the valve body was distinctly heard and this gentle tapping continued up to approximately 3000 gpm equivalent plant flow. Flowrates greater than 3000 gpm equivalent plant flow produced very little if any distinguishable tapping attributable to valve disc to body contact. This test was performed to simulate the plant conditions for the check valves to be located in the feedwater headers inside the containment at SONGS-1. This test tends to indicate little or no problems can be expected from these check valve due to flow induced vibrations resulting from location in the pipe.

The second test performed at the UWRL on the 10" Atwood-Morrill check valve involved locating the check valve downstream of the feedwater regulating valve as installed at the SONGS-1 facility. The check valve was located approximately 86 inches downstream of the feedwater regulating valve in a straight run of 10 inch pipe with greater than 5 pipe diameters of straight 10 inch pipe downstream of the check. The feedwater regulating valve is a Fisher 8 inch spool type, double seated, balanced plug valve located 52 inches downstream of a 10 inch $90^{o}$ elbow. The flow through the test assembly was provided by a centrifugal pump rated at 4500 gpm at 140 feet of head driven by a 200 horsepower motor with the flowrate controlled by a combination of the pump discharge pressure regulating valve and a flow control ball valve located approximately twenty feet downstream of the check valve. This flow control configuration was utilized to minimize the cavitation in the feedwater regulating valve which was set at ≈60% open to correspond with the setting during 94% power operation of the SONGS-1 plant. The flowrate through the test assembly was measured by a flow orifice and a catch tank with level instrumentation. Differential pressure across the check valve was also monitored. At approximately 2300 gpm equivalent plant flow distinct valve disc tapping began and continued through the maximum flowrates obtained during this test (approximately 6000 gpm). The tapping of the disc on the valve body was distinct however, Dr. Tullis and Bill Rahmeyer of Utah State and Edgar Bottom of Atwood-Morrill felt the magnitude and frequency of tapping at all flowrates would not be detrimental to the valve or significantly reduce its service life.

The third test performed on the 10" Atwood-Morrill check valve was intended to simulate the conditions that the B main feedwater pump discharge check is exposed to at SONGS-1. This test configuration involves a scaling factor of approximately 10/12 since the actual plant check valve is a 12 inch check of the same design as the 10 inch check utilized in the lab. Additionally, since the actual plant conditions utilize a multi-stage centrifugal feedwater pump just upstream of the check, the lab test configuration utilized a short radius 8 inch elbow and two 8 inch by 10 inch reducers to simulate the turbulence produced by the feedwater pump.

The test configuration was established with an orifice plate with the center hole 10.0 inches in diameter (slightly larger than pipe inside diameter) located in a vertical run of 10 inch pipe 16 inches above an 8 inch to 10 inch reducer. The 8 inch outlet of this reducer was welded to a short radius 8 inch elbow and this was then welded directly to another 8 inch to 10 inch reducer. Flow then traveled through a short, approximately 12 inch, section of straight 10 inch pipe into a long radius 10 inch elbow into another short section of straight 10 inch pipe then into the check valve. Flow from the check valve immediatley entered a 10 inch T with the straight thru outlet welded closed with a flat plate, therefore the flow turned 90$^{o}$ down out of the T directly into another long radius 10 inch elbow. From this point the flow traveled a long straight run of 10 inch pipe (greater than 10 pipe diameters) to a ball type flow control valve and into the instrumented tank for flowrate measurement.

Once flow was established in the test assembly and increased to approximately 3600 gpm equivalent plant flow, there was no noticeable noise attributable directly to the check valve. At equivalent plant flows of 3653 and 5321 gpm gentle tapping of the check valve was detected however, the magnitude was low at about one to two taps per second. At an equivalent plant flow of 6283 gpm very little tapping was noticed (about once per 10 seconds). When reducing flow to approximatley 4900 gpm near continuous tapping was noticed (about 4 to 5 Hz) of relatively low amplitude.

After performance of the previous testing the flow was stopped and the orifice plate was changed to an orifice plate with 33 one inch holes drilled thru the 1 inch thick aluminum disc with the inlet side of the holes radiused 1/4" to provide reasonable smooth flow upstream of the pump simulator device. Again various flow rates were established through the test assembly and light tapping began at approximately 3762 gpm and continued until a maximum of 6005 gpm was established. Although the tapping continued throughout this flowrate range the tapping was less severe than that noticed in the configuration with the check valve located just downstream of the feedwater regulating valve. The temperature of the test water was measured at 6.5$^{o}$C.

This series of tests indicates the check valves located downstream of the feedwater regulating valve and at the feedwater pump discharge are in a severe turbulence region in the system and are never firmly backseated during plant operation.

During the test with the check valve located downstream of the feedwater regulating valve it was noticed that the sound of the check valve disc tapping against the valve body appeared to be comming from a spot approximately 10 to 12 inches downstream of the actual contact area. This tends to explain the opinion of the SCE staff that the noise during the July 1985 event was comming from the downstream block valve rather than the check valve that was later found failed during the November, 1985 water hammer event investigation.

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Dear Chuck,

This is the review of the final Report "Performance Tests on the Feed Water Check Valves for the San Onofre Unit 1 Nuclear Power Plant, Phase A" by J. Paul Tullis and William J. Rahmeyer dated April 1986.

I have no disagreements with their measurements or interpretation of them. Because the tests were run in low pressure, low temperature water and applied to high temperature, high pressure water, some extrapolation of the test results is needed. Let me touch on two issues that must be extrapolated, the maximum tapping velocity, and the cavitation limits.

A small extrapolation of the tapping velocity measured is necessary because the water density in the test is higher than in the application. Equation (3) of the report does this and I agree with the use of this equation in this problem. It is just what I would have done. Used with a modest safety factor, say 1.2, these test can be used to set the minimum velocity at which these values are allowed to run during steady operation. In later work, they might want to correct the buoyant force of the gate for the different water density but that is a trivial improvement. In any case, the valves should not be installed with less than 6 L/D's to the nearest upstream disturbance.

The other extrapolation was for the cavitation index. This is given as equation 4. This is a commonly accepted formulation for extrapolating cavitation data taken at one condition to another. (See Streeter, V.L., "Handbook of Fluid Dynamics," First edition, McGraw-Hill, 1961, pp. 12-17.) The value at which cavitation occurs can be greater than the value calculated for this valve 1.34, and is a function of geometry. Though I see no reason for alarm, it would be good, in subsequent tests, to see if there is any cavitation. I, frankly, find it hard to believe any valve manufacturer would design a valve that would cavitate under design conditions. It would greatly reduce the life of the valve. The cavitation index of 1.34 is large enough so that there may be no cavitation at all.

The fact that this valve failed only when operated at less than design velocity for a year after apparently operating for years at the design velocity makes me think that cavitation is no problem. The valve should cavitate most at its maximum velocity. If it worked for years at full load I fail to see how cavitation could cause problems at part load. In the phase two tests, however, I think finding the cavitation limits for this system of flow control valve an new check valve is a worthwhile goal. I think this problem can be laid to rest once and for all. My guess is that you will never have cavitation in the operating range for the valve.

They could take this valve into the cavitating range by increasing the water temperature or, perhaps, decreasing the back pressure. I would like to see one of those things done.

There is one item that I would like to raise that might be settled in the phase two experiments. The description of the tapping in this report makes it hard for me to believe that it could cause the damage that led to the valve's failing. Whether the severe damage in the San Onofre installation was due to the check valves closeness to other fittings or the design of the check valves themselves is not clear. I'd like to see that settled. I would also like to see some damage measurements made so that an inspection schedule can be set up and approximate times at which the valves can be run at less than design velocity determine.

Let me now summarize my findings.

1) The tests and extrapolation procedures used to define the allowable conditions for the Atwood and Morrill swing check valves are both satisfactory.

2) I would like to see the flow limits presented in this report checked against the minimum velocity formula in Chiu and Kalsi report to see what an allowable safety factor for the Chiu and Kalsi formula is. This would help you evaluate other installations.

3) I would like to see the cavitation limits determined for this flow control valve-check valve installation. I suspect you have no cavitation under normal operating conditions, and this is no problem. One measurement would show this.

4) I would like to see some kind of deformation or wear measurement made so that the life of the valves when they are tapping could be estimated. I'm not sure how to do this but using a soft stop, made of lead perhaps, would give accelerated wear and allow use to estimate the life. Probably penetration hardness is the scaling parameter. This would tell us how often to inspect the valves and how long, during startup for instance, we could run at reduced velocity.

If you have any questions, I'd be glad to talk to you. Enclosed is an invoice for the time I spent on this review.

Sincerely,

Peter Griffith

Peter Griffith
Consultant

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