Mechanical Design Considerations
Of the Irrigation Tunnel

Purpose

The purpose of this document is to give a brief synopsis of the information gathered from various sources. These sources are available in Appendix C. The information below concerns a portion of the Irrigation tunnel works; primarily from the tunnel plug to the hollow-jet valves. Also included is information learn by speaking with a Rodney Hunt representative.

Unlined tunnel

A 1964, Bureau of Reclamation report by E. E. Gonzales gives a brief description of the tunnel, "The irrigation outlet works consist of a 34 foot diameter modified horseshoe-shaped tunnel on the left side of the canyon… a Rotovalve chamber located in the tunnel, approximately 2,000 feet downstream from the intake gate structure, and a hollow-jet control valve house located at the discharge end of the outlets 450ft downstream from the rotovalves…. The unlined but grouted irrigation outlet tunnel runs through limestone, and is plugged with a keyed concrete plug 75 feet long. Except for expansion joints located immediately upstream from the rotovalves, the outlet pipes are embedded in 18 inches of concrete from the tunnel plug to the hollow-jet valve house"

The thickness of concrete in the tunnel arch in the rotovalve chamber is a nominal 1 meter. Length of the valve chamber tunnel is approximately 450 feet. From photos taken it appears as though the equipment access to the tunnel is from the left side of the valve house. See photos in Appendix A.

Tunnel Plug

As mentioned earlier the plug is 75 feet long, notched and poured in 2 pieces. The downstream end of the tunnel plug forms the back wall of the rotovalve chamber.

The conduits

Three 84 inch conduits are set into the tunnel plug. The flow is throttled by a hollow-jet valve and a rotovalve provides emergency closer.

The weekly Progress Report during construction for week ending Friday, October 30, 1953 indicates that conduit #2 was primed with Kooper's Bitumastic No. 70-B and that hot enamel would be applied once the primer had dried. The week ending report for November 13, 1953, indicates however that enameling of conduit #2 was omitted due to application difficulties and that in conduit #3 "practically all of the previously applied enamel has been scowered off. By the January 1954, "It was decided to postpone enamel painting of the conduits indefinitely…"

In May of 1964, Gonzales reports that the rotovalves were closed one at a time and the conduit inspected. Evidence in two of the pipes showed signs of paint similar to CA-50. All paint in conduit #1 was gone except for a patch near the rotovalve 15 ft long and full circumference. Conduit #2 had a similar section of paint 6 ft long, but near the hollow-jet valve. Conduit #3 had no signs of paint. In regards to the condition of the conduits, Gonzales reports:

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> "The inside surface of the outlets showed no evidence of rusting, cavitation or erosion. A slight roughness of tiny pimples and small irregular depressions no larger than one-eighth inch across could be detected by sight, but roughness could not be felt by hand. The roughness looked like concrete crosshatching on a drawing. By scraping the pipe surface with a sharp screwdriver, a slight amount of black substance could be collected on the point. This could have been the remains of the paint or perhaps a deposit of some kind. The outlet pipes are in excellent condition and it is questionable if painting will be required in the near future."

Gonzales did not dewater the irrigation tunnel, and so was only able to inspect the downstream face of the plug. Apparently the same paint was used as that in the conduits and was missing in areas up to 6" in diameter. The areas with missing paint were described as "rusting quite badly". He recommended that the portion of the rotovalve plug exposed to water on the downstream side should be cleaned and painted with a water resistant paint such as CA-50. He also recommended the upstream side should be painted when the tunnel is dewatered.

The Engineering Report from week ending February 19, 1954 mentions that the exposed sections of conduit in the dresser coupling pit were painted with #50 cold tar enamel.

<u>The RotoValves</u>

These three valves were manufactured by S. Morgan Smith Company, which is now owned by Rodney Hunt. The valves were purchase by Morrison-Knudsen Afghanistan Incorporated under purchase order number 11.5031. The Operations and Maintenance Instructions list the three (3) – 84" diameter Rotovalve of steel construction, 125# standard A.S.A flanges, 115 psi working pressure, for water service. Special assembly. No controls or special equipment. Serial nos. VB-1844, VB-1845, VB-1846.

Gonzales describes the control system for the rotovalves as consisting of a sump tank, two electrically driven oil pumps rated for 30 gallons per minute at 500 pounds per square inch, and a control panel with pushbuttons and hydraulic selector valves.

The motive force for the mechanism to move the plug consists of two cylinders. The lift cylinder is 12 inches in diameter. The rotation cylinder is 20 inches in diameter. See the Rotovalve Operation & Maintenance.pdf in Appendix C for further descriptions of the rotovalve operator and descriptions of the oil pressure system and controls.

The valves were fabricated in pieces and assembled in place at the end of the tunnel. The following descriptions and weight are taken from the *Assembly Procedure & Clearance Dwg – 84" Dia -115 psi Hydraulically Operated Rotovalve*:

Component / Feature	Number of components	Approximate Weight (lbs)
Lower Head	2 Halves	20,000
Body	4 Quarters	40,000
Plug	2 Halves of Plug, Top and Bottom Trunions	35,000
Shaft	1	5,000
Upper Head	2 Halves	25,000
Mechanism Yoke	1	15,000
Entire Valve	14	160,000

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The installation order of the rotovalves in the conduits is: conduit #2—conduit #3—conduit #1. Rotovalve #3 was installed in conduit #1; it is noted in the Engineering reports that the rubber seal groove on the vertical face of the bottom head was omitted in fabrication. This groove was chipped out on-site. Engineering Report for week ending December 31, 1953 mentions that as soon as Rotovalve #3 was put into service a small leak was noticed in the vertical joint of the top head. This leak was sealed by drilling into the joint down as far as the rubber seal and injecting #50 bitumastic tar with a grease gun.

An overhead 16 ton crane was used to set the valve components. The inside stiffener plates of the 16 ton Yale hoist were slightly trimmed to allow the trolley to travel around the curves of the monorail tracks. The plug must be disassembled in pieces, because it weighs too much for the hoist handle in a single pick.

There is a single reference to the rotovalve fabrication being delayed a year and half because of the "war effort" contributions by the S. Morgan Smith Company. The hollow-jet valves had been installed for a couple of years before the rotovalve were fabricated and shipped. Installation of the rotovalves was then complicated by the need to maintain water flow through the Irrigation tunnel, except for short outages. During installation of the rotovalves the flow would be switched between the conduits as needed. The following is found in the Construction Progress Report for week ending Friday, November 20, 1953, gives a description of a 4 day process of transitioning the installation work from conduit # 2 to conduit #3.

> "With tunnel dewatered, bulkhead on #3 conduit was fastened in place in preparation for installation of second roto-valve in this line. The first roto-valve in closed position was tied into upstream #2 conduit by means of a single flanged section of 84 inch conduit and Dressler coupling. This change over was completed at 2 AM Nov. 14th. With manholes fastened down, jetvalve No. 1 was closed and leaving jetvalve No. 2 open. Latching device was lowered to wheel gate and gate raised 9 inches."…"With approx. 47 lbs/sq. in. water pressure against upstream end of Rotovalve the water leakage was nill around the plug on the downstream end."

The longest shut down of the river for the installation of the rotovalves found in the construction reports was for 7 days, during which the reservoir rose 1.80 meters.

As a side note, there are several entries in the Construction Progress Reports which mention considerable delays due to broken wrenches for the Rotovalve assembly and the need for the machine shop to make more slugging wrenches.

The construction progress reports mention that 129 cubic meters of structural concrete and 80 cubic meters of porous concrete were placed in the valve block. The top slab around the rotovalves was placed with 21.6 cubic meters of concrete. The top slab grad is approximately 1 below the Upper head – Body joint of the rotovalves.

I inquired with Rodney Hunt concerning the 84 inch Rotovalves that are currently installed at Kajaki. The RH representative was able to locate the original job order to provide a little more information on the valves, see Kajaki-84-inch-RV.pdf in Appendix C. A cast valve would weigh 80-90 tons depending on the

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actuator configuration chosen. Due to transportation issues the valves where designed and fabricated to be broken down into sections. The sections where shipped to Kajaki where they were assembled in place and imbedded in the concrete. This differs from the normal fabrication method of casting.

It was indicated that the RH factory, in Orange Massachusetts, currently does not have the ability to refurbish the valve, even if it could be brought back to the factory. The representative indicated that minor repairs to the valve seat may be possible in the field. Minor repairs would be small grooves or nicks in the seat. This would require the in-field welding of monel overlay and then hand grinding the seats. A minor repair requires that the worker doing the hand grinding have reference points fairly close together in order to estimate the surface of the repair. Example: A 1/8 inch groove is likely repairable, a 1 inch groove might be repairable, larger than 1 inch grooves or general abrasions would prove too difficult to estimate the surface of the seat to repair. Major repairs would consist of generalized abrasion or other large area defects. Major repairs in the field would be difficult at best and may not be possible. Work on the trunnion bushing should be possible in the field but does have its challenges. The trunnion bushings at the top and bottom of the valve are shrink fit and will require cooling with liquid Nitrogen or CO2 to remove.

The cost estimates for new Rotovalve is $3-4 million per valve. Lead time would include the following: 10 to 12 weeks for submittals, at least 20 weeks for engineering, and an unknown fabrication time of at least 52 weeks. The time estimate is then at least 84 weeks. The RH representative indicated that a more accurate estimate will require some preliminary engineering work. The representative mentioned that typically a valve refurbishment (like new condition) cost between 60 -70 percent of a new valve.

The following is a brief list of the major items from Rodney Hunt's specification for remanufacturing smaller Rotovalves at the factory:

> The monel seating surfaces shall be removed (by machining) from the body and plug.
> The bushings and sleeves shall be removed from the head body and plug.
> The plug, head, mechanism housing, and body shall be blast cleaned to near white metal and inspected for cracks and other damage.
> The monel seat surfaces on the body and plug shall be replaced and machined to new valve tolerances.
> The plug sleeves, body, and head bushings shall be replaced.
> New bushings and sleeves shall have an interference fit and shall be staked with set screws. (Note: this will require cooling with liquid Nitrogen or CO2 to remove and precautions to deal with the gases will be needed.)
> The operating shaft and lift nut shall be replaced.
> The new operating shaft shall be stainless steel with minimum yield strength of 125,000 psi.
> The operating mechanism components shall be inspected and any worn or damaged components shall be replaced with new components.
> The guide rods for the crosshead shall be replaced with new stainless steel rods.
> The hydraulic cylinder will be replaced with a new cylinder.

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The interior of the valve will be painted with two coats of a high solids epoxy suitable for potable water.
The valve exterior and interior of the valve mechanism and mechanism components will be painted with two coats of high solids epoxy.

It is assumed that the refurbishment of the three rotovalves is the corrective maintenance required to extend the service life to period of 50 years.

The Jet Valves

Each hollow-jet valve has an approximate discharge capacity of 2100 cubic feet per sec when operating fully open at 100 feet of head. The current valves are hydraulically operated and mechanically positioned by an electrically driven, Cutler Hammer, Type TN-3-Y Valve Operating Unit, Bulletin 817, Publication No. 8431.

The hollow-jet valves have had trouble since installation. During the installation of the rotovalves (Nov. 1953) an inspection of hollow jet valve #3 showed that considerable damage had been done to the knife edges of the splitters; one edge had been flattened to a depth of about 1". Gonzales indicates that "All valves are cavitated extensively in the body and on the splitters. One valve has severe cavitation damage on the needle." It is mentioned that the cavitated area should be repaired by filling with stainless steel weld metal. In addition to the cavitation troubles the rubber seals would not stay in place. Mention is made that during the rotovalve installations the hollow-jet valve seal were missing in two of the valves and partial gone in the third. The seals were replaced but in 1964 when Gonzales inspected the valves the seals were all but missing again. He recommended that, "Since it is not necessary to close the hollow-jet valve tight, cavitation will be minimized if the rubber gaskets are eliminated and the gasket grooves filled with weld metal and overlayed with one-fourth inch of stainless steel."

A drawing of the hollow-jet valve installation can be found in Gonzales report; it is labeled as Drawing No. 3 and shows the Valve house with the valves and some pertinent elevations. The centerline of the hollow-jet valves is EL. 965.00 meters.

The hollow jet valves have lost the ability to move without being under hydraulic head. Gonzales describes the operation of the hollow-jet valves as follows.

> "The hollow-jet valve controls will function satisfactorily with pressure in the outlet pipes, but only when a skilled operator is at the controls. Synchronization of the needle travel and speed of the pilot valve screw is dependent on the pilot valve which is a built-in feature of the hollow-jet valve. The oil pump motor and the gear unit motor are started by a common pushbutton, but the gear unit motor has a time delay relay to give the pump motor time to-get up to speed before the valve actually starts moving. Oil is bypassed while the pump is getting up to speed. The operator has to press the start button and run across the room to close the bypass valve by the time the delay relay starts gear unit.
>
> The operator has no indication as to when to close the bypass valve except by instinct gained from experience. The gear unit is equipped with interlocked limit switches, which stop both motors at the open and close limits of the hollow-jet valve travel, and with a thrust switch that stops both motors if the pilot screw should bind when the needle

> travels too fast or too slow. If the operator does not close the bypass valve to start the needle moving at the exact moment the gear unit motor starts, tile thrust switch shuts off the control system and the operator has to start the cycle over again. Once the hollow-jet valve control has been properly set for the opening or closing cycle, the valve will complete the cycle without further adjustment. The operators are skilled and can always operate the hollow-jet valves satisfactorily with the present control system providing there is water pressure in the outlet pipes."

A Rodney Hunt representative gave an estimated cost for replacement of hollow-jet valve at about $850K each. Hollow-jet valve of this size have separate hoods. The hood would ship in four pieces while the valve could ship in one piece. Valve seats are repairable in the field. The lead times are estimated as follows: submittals (10-12 weeks), manufacture (36-40 weeks).

Some care must be given in selecting the replacements for the hollow-jet valves. The size of the discharge chamber will limit the size of the hood that can be installed.

The consensus of the PDT is to move away from a hollow-jet valve that is hydraulically operated to one that is electro-mechanical driven. This will remove the potential for an oil leak into the water should the seals fail. Also, it should be considered that the local water supply is a pipe stuck into the outlet of hollow-jet valve #1.

<u>Decision formation</u>

The following is taken from an email dated 2/21/2012 from Jim Calnon in regards to the rotovalves.

> The real issue is what we don't know. These valves are relatively complicated machines. The plug is conical, and might possibly have valve seats on the downstream side only, or it might have seats on both sides. The plug has to lift vertically before it can rotate, and there are mechanical limit devices that regulate the vertical motion. Once lifted, the plug is rotated by the hydraulic power system. Both the vertical lift and the plug rotation are required in order for the valve to operate. The valve seats are Monel, which is a fairly soft Nickel alloy. They are likely to have some age-related wear. We would be completely dependent on the contractor to determine if they need repair or not. We don't know the condition of the plug and valve bodies, and the degree of corrosion they have suffered. Many unknowns. Relatively large risk of finding an unforeseen problem that is a show-stopper.
>
> We would have to agree that we are limiting scope, and accepting that the valves will be re-assembled with known deficiencies, as long as those deficiencies do not stop the valves from adequately working. We also recognize that as the valves are disassembled, we will be discovering a few unforeseen problems that must be repaired before the valves can be put back together again. (We will likely be manufacturing sleeves for worn out bushings, performing weld-repair on corrosion pits, re-threading stripped out holes, drilling out studs and replacing with thru-bolts, machining new actuator cams, and so on.)
>
> I agree that the valves do not need to seal drip tight; in fact new valves will not seal drip tight. There is an acceptable leakage rate for new valves in the AWWA standard. However, they need to seal well enough to permit normal maintenance activities in the pipeline downstream of these valves.

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So in essence, we are talking about reducing the base scope to only replacing the hydraulic power unit, control valves, limit switches, mechanical limits and stops, hydraulic cylinders, trunnion bushings, trunnion greasing system, and repainting the interior of the rotovalves. The seal repair would be optional, and would need to be as directed by the COR, unknown quantity. I don't know what contract mechanisms are available for dealing with unknown quantities, but you could potentially have CLINs for optional blocks of on-site machining labor, and optional CLINs for miscellaneous materials. Exercise as many of the optional blocks as are required to complete the necessary seal repairs.

Jim Calnon, PE
Chief, Mechanical Design Section
USACE Portland District

The following is taken from an email date 2/17/2012 from Robert van der Borg in regards to the rotovalves.

Team,

During our conference call it was confirmed that 2 of the 3 roto valves work. It sounded like the third one may work but needs some attention. If this is the case then refurbish instead of replace. I got the impression during the call that the object of the irrigation system program is to bring the equipment to a sound operating condition (it should last another 20+ years).

Now comes the approach to refurbish. We have to define "operating valves," the ability to significantly close off the flow of water. The reason I use significantly is because a minor amount of leakage is not detrimental any downstream equipment so the seats would need limited attention. This would mean that, an inspection of the seats and to what level of scoring is seen, then we make repairs. The seat repairs could be an optional item. A plan is submitted.

The only other point of observation would be the bearings the plug rides on/against, another option item.

If we have operating valves (the plugs turn and close the water passage) the primary attention turns to the actuator and hydraulic system. From my experience in Afghanistan there has been very limited O&M of the hydraulic system. If we were to do a wholesale replacement of the hydraulic pumps and piping and refurb the actuator we would have a very satisfactory valve. My guess is that the problem with the valve that doesn't work properly is the hydraulic system not the seats.

I am proposing we run calculated risks in our approach to get to sound operating equipment.

Thanks,
Robert van der Borg, PMP
PM for FCRPS

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Conduit Inspections

The safest way to inspect the conduits is with the tunnel dewatered. Such an inspection would still require pumping out the conduit, and all other confined space entry requirements. However, it is

possible to inspect that portion of the conduit downstream of the rotovalves with water in the tunnel if the requirements of ER 1110-2-8157 are met. In summary, the regulations requires that a Structural Engineer of record perform the following

(1) Take responsibility for the valve as a Hydraulic Steel Structure (HSS) **AND** determine through inspection that the inspection may be done safely. Presumably, this would mean that the inspection determines the structural components are not in danger of fracture.
(2) Deduce that the existing roto valve with conical valve plug goes not qualify as a HSS **AND** that it is still safe to perform the inspection. The later is probably true, however it will be the responsibility of the engineer of record to decide.

Publication Number: **ER 1110-2-8157**
Title: **Engineering and Design - Responsibility for Hydraulic Steel Structures**
Proponent: **CECW-ED**

There is a historical precedence for an inspection of the conduit with water in the tunnel, i.e., USBR inspection circa 1964 for which documentation is available. It is not known what regulations were in effect during that era, however it is absolutely clear that any inspections on the conduit with water in the tunnel in modern times shall meet ER 1110-2-8157. A copy of this regulation should be attached to the RFP for this project.

There is a manhole downstream of the rotovalves sump shown in photo 110317-O-61229S-126.JPG. Once the conduits and tunnel are dewatered, then the conduit may be accessed via the manhole. If the roto valve is opened, then there is access through the hole in the valve plug. There must be an air vent in the tunnel or at the intake structure, however none can be located on the available drawings. Based on historical documentation it takes approximately 3 days to dewater the tunnel and a half day to dewater the tunnel.

<u>Alternate Means of Watering the Irrigation Tunnel</u>

The Hoist Load Curves shown on Drawing 15-F-B for lifting the roller gate off of the sill with unbalanced head to have a maximum load of 300kips. The “Cracked” position for filling the tunnel is 6 inches. Once the tunnel fills and the head differential across the gate equalizes the hoist load reduces to the weight of the gate for the remainder of the lift. The dry weight of the roller gate is approximately 42 kips. The maximum load of 300 kips would require a 150 ton crane or a 120 ton crane overloaded by 125% (maximum engineered lift). Using an alternate means of watering up the irrigation tunnel avoids the possible need to do the 300 kip lift. A possible means of watering the tunnel is to install lever operated globe valve(s) on the roller gate itself. The size and number of these valves will need to be determined; the main determining factor is the space constraints of the roller gate. The valve locations would likely be located in the central “compartments” of the gate. The Keckley Company is a manufacturer of such valves. From the general catalog cuts it appears as though the 6” and 8” valves could fit and larger valves such as the 10” or 12” would require modifications or perhaps alternative configurations to be installed. Obviously the larger the valve the faster the water will fill the tunnel.

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Other possible alternative means of watering up the tunnel could include: using a pump/siphon system to feed water down through the air vents, or installing a crossover line between the power house pen stock and the station service unit penstock (or one of the 84” conduits if accessible). The crossover line has the added benefit of also providing a simple connection point for the local water supply design work.

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