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EXPERIENCE WITH CAVITATION IN HIGH PRESSURE SLIDE GATES

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ABSTRACT

High pressure slide gates have been used for many years in a variety of applications, usually for controlling flow through the outlet works of dams. The Bureau of Reclamation has many years of experience in the design and operation of high pressure slide gates. Design modifications based on operating experience and laboratory research studies have been aimed at improving discharge characteristics, modifying downpull and uplift forces, and controlling cavitation damage. While most of these problems have been successfully addressed, cavitation damage sometimes occurs while operating this type of gate.

This paper will discuss the historical use of high pressure slide gates by Reclamation and the cavitation potential of the different designs. Several prototype examples where damage has occurred will be reviewed. Field modifications to the downstream gate frame which mitigate cavitation damage will be discussed. Current laboratory studies and future research needs will be covered.

INTRODUCTION

The Bureau of Reclamation has installed and operated high pressure slide gates since 1906. Yet, through all the years of operating experience and increased knowledge of the cavitation phenomena, current slide gate designs still occasionally exhibit damage. With a few exceptions, most of the gate and valve installations before the construction of Hoover Dam (1931-1936) were considered relatively low head (<150 ft). Due to the lack of knowledge about cavitation and the damage which could result, slide gates which operated satisfactorily under low head conditions were used in high head installations. Usually this resulted in massive damage, needing costly repairs and maintenance or modifications [Gaylord, 1923]. In some cases, the

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gates were abandoned after years of repeated damage. Reclamation has basically had two major designs of high pressure slide gates over the years. Before 1940, the standard design had a wide seating area and slot, with a curved leading edge on the gate leaf, figure 1a. After many years of operation, this style gate was abandoned as a regulating gate due to continual cavitation damage. During the 1940's, the standard design was modified to include a much narrower seating area and slot with a 45° leading edge on the leaf, figure 1b.

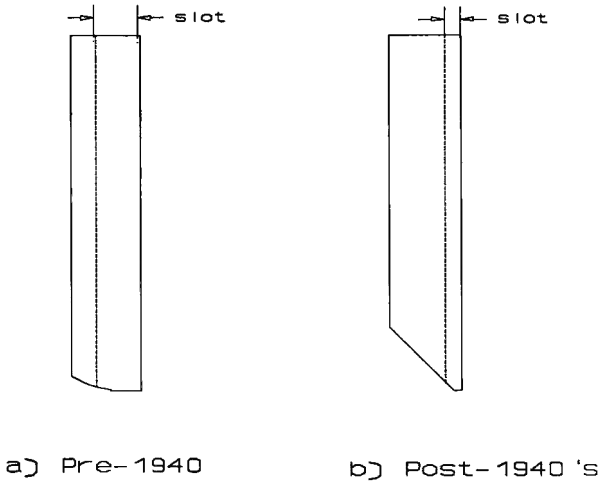

Figure 1: High pressure slide gates used by the Bureau of Reclamation.

EVOLUTION OF THE STANDARD DESIGN

The current design of high pressure slide gates within the Bureau of Reclamation has evolved through hydraulic model tests and via experience gained from operation of prototype structures. Before 1940, flat bottom slide gate designs were used due to their ease of construction. Wide gate slots were used to provide sufficient structural leaf strength. The relatively flat bottom was found to cause cavitation damage to the bottom of the gate leaf. Wide flat bottom leafs are subject to a short tube effect as the spring point of the flow generally forms near the upstream edge of the gate leaf. Wide gate slots allowed flow to impinge on the downstream corners of the slot. This resulted in cavitation damage to the walls and floor of the downstream gate body. Cavitation damage occurred on many of the flat bottom gate structures. Structures such as Rye Patch Dam and Caballo Dam experienced severe cavitation damage at heads well below 100 feet. A history of cavitation and poor flow distribution at the exit of the standard slide gate resulted in hydraulic model studies of slide gates for Cedar Bluff and Medicine Creek Dams in the early 1950's. These structures used slide gates to regulate flow discharging into hydraulic jump stilling basins.

Cedar Bluff [Simmons, 1950] and Medicine Creek [Wagner, 1951] model tests investigated flow pattern effects due to the shape of the upstream gate leaf face, slot width, gate slot flow deflectors and shape of the downstream gate frame. The studies resulted in the standard slide gate design being changed as follows:

1. The upstream face of the gate leaf was changed from a convex to a flat surface.

2. The standard gate slot width was reduced by about 45%.

3. Wedge-shaped slot deflectors were placed immediately upstream of the gate slot to force a flow contraction in front of the slot.

4. The crown of the downstream gate frame was sloped upward from the gate slot to the downstream end of the gate frame. An air vent was placed in the crown immediately downstream of the slot to prevent low pressures along the crown.

5. When using a slide gate to discharge into a stilling basin chute the sidewalls of the downstream gate frame were flared to improve the flow distribution at partial gate openings.

The flat bottom leaf shape was maintained, possibly due to the ease and low cost of construction. Hydraulic model tests conducted by Lowe [Lowe, 1943] on coaster gates for Shasta dam recommended the gate bottom be changed from a flat arrangement to that of a 45° slope from the upstream to the downstream surface. The sharply sloping bottom moved the spring point to near the downstream edge of the gate leaf and reduced the low pressures on the gate bottom. This reduced the downpull and the potential for cavitation damage to the gate leaf. Although the sloping bottom provided the best flow conditions, the design was considered difficult to construct.

In 1954 a slide gate was designed for Palisades Dam. A research study was conducted by Simmons [Simmons, 1954] to develop a regulating slide gate capable of discharging into a stilling basin chute at heads up to 240 feet. The high heads required the standard slide gate design be improved to further reduce the cavitation potential on the leaf and downstream gate frame. The study resulted in the adoption of several additional features to the standard high pressure slide gate. Simmons concluded:

1. A steep sloping gate leaf bottom reduces possible cavitation damage to the leaf and provides a smooth jet surface. A slope of 45° was chosen as a compromise between hydraulic and structural needs.

2. Gate slots should be designed as narrow as possible. The thickness of the gate leaf which is required based on bending should be reduced at the edges to that required to withstand the shear load in the slots.

3. The downstream slot corners should be offset outward 0.5 inch followed by converging walls to return to the upstream throat dimensions. Flow deflectors upstream of the slot were not used.

As noted by Ball [Ball, 1958], the Palisades outlets were tested for about 30 days at small openings at heads near 200 feet. No cavitation damage was apparent on the gate, although damage occurred to the concrete immediately downstream of the gate. Ball attributed the concrete damage to offsets in the concrete at the junction with the downstream gate frame.

Since the development of the Palisades style standard high pressure slide gate, numerous slide gates have been installed on Reclamation projects. Many have operated without cavitation damage, however, extensive damage has occurred on several gates for reasons which are unclear. A review of selected case histories points to significant improvements in high pressure slide gate design from the days of the flat bottomed gate but falls short of showing that a cavitation damage-free slide gate design has been developed.

CASE STUDIES

Vallecito Dam

Vallecito Dam is a zoned earthfill structure, 162 ft high and located on the Pine River, 18 miles northeast of Durango, Colorado. The dam was constructed between 1938 and 1941. Typical of designs of pre-1940, flat bottomed slide gates were used to regulate releases from the outlet works. Two 5 ft by 5 ft gates control the flow through a twin-section concrete conduit. The first repair of cavitation damage was done in 1962. At the time, minor cavitation damage to the gate leaf and downstream frame was patched with an epoxy material. In 1984, an inspection of the gate leaf revealed significant cavitation damage, typical of that experienced previously with this type of gate leaf geometry [Rood, 1984]. In addition to the usual damage to the slots and downstream gate frame, the gate leaf showed extensive damage to the curved portion of the leading edge. Permanent repair to a leaf with this much damage is nearly impossible. In addition, the repair is a temporary fix since the gates will cavitate again if used to control at small openings. At Vallecito, the gate leaf and seats were replaced with the current standard design (45°) leaf. The gate has operated without damage since replacement in 1985.

Joe's Valley Dam

Joe's Valley Dam is a zoned earthfill embankment, with a structural height of 187 ft. It is located on Selly Creek about 12 miles northwest of Orangeville, Utah. Construction was completed in 1961. The outlet works features two 2.25 ft by 2.25 ft high pressure slide gates of the current Reclamation standard design. An underwater examination revealed severe cavitation damage downstream of the two

regulating gates [Buchheim et.al., 1981]. The repair was a new approach. In addition to patching the voids with epoxy, two stainless steel bars were attached to the downstream gate frame along the side seats just downstream from the gate slot. These bars are designed such that air can flow down the side walls behind them, reducing the chance of cavitation damage. The *orifice* bars make the slide gate similar to a jet flow gate in concept. Allowing the jet emanating from the gate to spring free from the sidewalls. The coefficient of discharge for the modified gate is lower than that of the standard high pressure slide gate design.

Glen Canyon Dam Left Diversion Tunnel Plug

Glen Canyon Dam is a concrete arch dam, 710 ft high and located 15 miles upstream from Lees Ferry on the Colorado River. During construction, water passed through three 7 ft by 10.5 ft high pressure slide gates, located in the left diversion tunnel. During 1965, these gates (45° leaf) were used for free discharge of over 2 million acre-ft at nearly 350 ft of head [Kohler & Ball, 1969]. The cavitation damage which occurred is considered minor. The majority of the damage in the gate areas could be attributed to misalignments in construction joints. There was some damage due to gate and gate slot geometry on the upstream sloping surface of the leaf and the gate frame downstream from the gate slot. Neither the stainless or Monel clad surfaces on the gate leaf or slot areas were damaged.

CONCLUSIONS

There has been little additional work to modify the standard high pressure slide gate design since the Palisades study of the mid 1950's. Reclamation still occasionally experiences cavitation damage to installations with the standard design, even at heads as low as 100 ft. Generally the damage is limited to the downstream gate frame just downstream of the gate slot and occurs at partial gate openings. Due to recurring operation and maintenance problems, Reclamation is involved in a new research program aimed at eliminating cavitation damage from all its high pressure slide gate installations.

CURRENT STUDIES AND FUTURE RESEARCH NEEDS

The Research program will include studies to modify existing slide gate facilities which would mitigate cavitation damage. These tests will include model studies of the present standard design with the objective: "to develop a retrofit modification to the gate leaf or frame which would eliminate or greatly reduce cavitation damage." First to be studied are the *orifice* type bars discussed earlier which have been installed at Joe's Valley and Ridgeway Dam. These studies are currently underway with results expected to be available by early 1990.

Future research will build upon Reclamations' 85 years of experience in design and operation of high pressure slide gates. Research will

clarify the causes of damage experienced on many installations of the current design.

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