SPILLWAY GATE VIBRATIONS ON ARKANSAS RIVER DAMS, ARKANSAS AND OKLAHOMA

Hydraulic Model Investigation

by

G. A. Pickering

June 1971

Sponsored by U. S. Army Engineer Districts, Little Rock and Tulsa

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

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FOREWORD

The model investigation reported herein was authorized by the Office, Chief of Engineers, on 1 August 1969 at the request of the U. S. Army Engineer District, Little Rock. The studies were conducted in the Hydraulics Division of the U. S. Army Engineer Waterways Experiment Station during the period October 1969 to June 1970 under the general supervision of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. T. E. Murphy, Chief of the Structures Branch. The tests were conducted by Messrs. H. H. Allen, Curtis Dent, and G. A. Pickering under the direct supervision of Mr. J. L. Grace, Jr., Chief of the Spillways and Conduits Section. This report was prepared by Mr. Pickering.

During the course of the model investigation, Messrs. Ed Madden, Chester Berryhill, and Tasso Schmidgall of the Southwestern Division and Messrs. J. K. Stanley, M. G. Wilbur, and Roland Dubuisson of the Little Rock District visited the Waterways Experiment Station to discuss test results and to correlate these results with design studies in the District Office.

Directors of the Waterways Experiment Station during the conduct of the study and the preparation and publication of this report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.
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**CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT**

British units of measurement used in this report can be converted to metric units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>2.54</td>
<td>centimeters</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>miles (U. S. statute)</td>
<td>1.609344</td>
<td>kilometers</td>
</tr>
</tbody>
</table>
SUMMARY

The Arkansas River navigation project has 17 individual lock and dam projects. Vibration of the tainter gates has been reported at several of these dams, the major causes of the gate vibrations being the gate lip and bottom seal designs.

A 1:12-scale model that reproduced one 60-ft-wide gate bay and the adjacent half bays was used to investigate the gate vibrations. The central gate reproduced the prototype with respect to size, shape, and weight, whereas the adjacent gates were only schematic. Prototype water-surface elevations and flow conditions were accurately reproduced in the model.

The vibrations of the prototype gates that were attributable to the gate lip geometry were reproduced in the model for similar flow conditions. Revisions in the shape of the gate lip were made that successfully eliminated the vibrations.

The vibrations of the prototype gates that were attributable to the fluttering of the rubber seal were not exactly reproduced in the model for similar flow conditions because of the inability to reproduce the elastic and geometric properties of the rubber seal. However, it was determined in the model that there would be no vibrations for any flow conditions with the rubber seal and backing plate removed. Removal of the seal is considered feasible for the prototype because none of the Arkansas project prototype structures that used this type of seal have power-generating units and thus some leakage under the gates is allowable.
Fig. 1. Vicinity map
PART I: INTRODUCTION

Project Description

1. The Arkansas River navigation project has 17 individual lock and dam projects as shown in fig. 1. Except for Lock and Dam 1, which is located in the Arkansas Post Canal, each project has a spillway with tainter gates to maintain navigation pool levels and regulate river discharges. The spillway sections of these dams consist of low sills, surmounted by 60-ft-wide* tainter gates located within the main channel of the river. Details of the spillway for a typical structure are shown in plate 1. Four of the projects (Locks and Dams 10, 12, 15, and 16) will provide power reservoirs. The dams at these projects have 50-ft-wide tainter gates. All of the projects were completed and in operation by December 1970.

Tainter Gate Designs

2. Vertical-ribbed tainter gates are used at each project. A typical gate showing pertinent dimensions is shown in plate 2. Table 1 summarizes the specific gate dimensions at each project.

3. Four types of gate lip and bottom seal designs were used on the 16 projects with gated spillways. These designs are shown in plate 3. The type A lip designs were used on the spillway gates at Locks and Dams 2, 3, 10, and 15, the first projects to be designed. The bottom seal is made with a flexibly mounted rubber J-bulb. The type B lip design was used on the gates at Locks and Dams 4, 5, 6, and 7. This design was

* A table of factors for converting British units of measurement to metric units is presented on page vii.
developed after fluttering of the gates had been experienced with the type A design of Lock and Dam 10. The bottom plate was angled up to provide a sharp control point at partial gate openings, and the bottom J-bulb seal was rigidly mounted to the bottom of the gate. The type C design was used on the gates at Locks and Dams 8, 9, 13, and 14. It was developed to provide a sharp breakpoint for flows under the gate at all gate openings and did not have a rubber seal on the bottom. The sharp breakpoint provided an additional safeguard against vibration tendencies. The type D design was used at Locks and Dams 12, 16, 17, and 18 and is the same as the type C design except for a rigidly mounted rubber bar seal on the downstream plate.

Prototype Gate Vibrations

4. With the spillways at 12 projects in operation, vibration problems have been encountered with the gates at Locks and Dams 2-6 and 10.* Operating personnel detected vibrations by hearing humming, fluttering or roaring noises, by feeling vibrations in the spillway walkway, and by observing the oscillating movement of the gate members and, in the more severe cases, a ripply wave pattern that developed on the upper pool surface just upstream from the skin plate. Field investigations of the gates at Locks and Dams 2-6 revealed a number of cracks in the structural members and welded connections of the gates that were determined to be fatigue failures resulting from severe gate vibrations.

Purpose of Model Study

5. Since it was not possible to determine analytically how to modify the gates to eliminate the vibrations, either model or prototype testing was required. With either of these methods a trial-and-error procedure

is necessary to arrive at suitable designs. It was decided that model testing would be preferable to prototype testing, since the flow conditions could easily be controlled and flow conditions existing underneath the gate could be observed. Also, a number of different designs could be built and tested for a relatively low cost.

6. Specifically, the purpose of the model study was to verify the effectiveness of completed and proposed gate lip modifications in eliminating the gate vibrations.
PART II: THE MODEL

Description

7. The model (fig. 2), constructed in a 12-ft-wide flume to an undistorted scale of 1:12, reproduced 300 ft of the approach area, one 60-ft-wide gate bay as well as two adjacent half bays, two 10-ft-wide piers, the stilling basin, and 120 ft of the exit area. The approach and exit areas were molded in cement mortar. The spillway weir, schematic gates for the half bays, and gate piers were fabricated of sheet metal. The test gate (fig. 3) was constructed of brass and reproduced the prototype with respect to size, shape, and weight; however, no attempt was made to reproduce the elastic properties of the gate. The stilling basin and its elements were modeled of wood and treated with a waterproofing compound to prevent expansion. A section of the gate piers next to the test gate was constructed of plastic so that mirrors could be used to observe flow conditions underneath the gate.

Fig. 2. The 1:12-scale model
Model Appurtenances

8. Water used in the operation of the model was supplied by pumps. Steel rails set to grade along the sides of the flume provided a reference plane for measuring devices. Water-surface elevations were measured by means of point gages. The upper pool elevations were regulated with a flap gate at the upper end of the model, and the tailwater elevations were regulated by a gate at the downstream end of the flume.

Scale Relations

9. The accepted equations of hydraulic similitude, based on Froude's law, were used to express mathematical relations between dimensions and hydraulic quantities of model and prototype. General relations for transference of model data to prototype equivalents are as follows:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Ratio</th>
<th>Scale Relations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>$L_r$</td>
<td>1:12</td>
</tr>
<tr>
<td>Area</td>
<td>$A_r = L_r^2$</td>
<td>1:144</td>
</tr>
<tr>
<td>Velocity</td>
<td>$V_r = L_r^{1/2}$</td>
<td>1:3.464</td>
</tr>
<tr>
<td>Discharge</td>
<td>$Q_r = L_r^{5/2}$</td>
<td>1:498.816</td>
</tr>
</tbody>
</table>
PART III: TESTS AND RESULTS

Lock and Dam 4 Gate

10. The original test gate was constructed to simulate one of the gates at Lock and Dam 4. The details of this gate are shown in plate 4. The gate lip and seal were of the type B design shown in plate 3. A refrigeration seal was used to simulate the prototype rubber J-bulb seal. The gate was supported with a high degree of freedom in the suspension system, and the side seals were not reproduced on the model gate as they would tend to damp vibrations.

11. Initial tests with the Lock and Dam 4 lip design and bottom seal revealed that vibration of the model gate could not be detected with conditions simulating those in which vibration of the prototype gate was observed (upper pool el 196.0* and lower pool el 188.0 to 190.0). However, with lower tailwater elevations such that free flow conditions existed, vibration of the model gate was both visible and audible, provided an upper pool approximately 9 ft above the lip of the gate was maintained with gate openings ranging from 2 to 10 ft. The skin plate, top of the gate, and top girder vibrated in the same manner as those reported from observations of the prototype. Variations in the elasticity of the cables supporting the gate did not affect vibration of the model gate with the above conditions.

12. Slight alterations in the position of the model seal were made in an effort to determine whether more pronounced seal flutter would occur under submerged flow conditions. Also, tests were conducted with the bottom seal fabricated from several different types of rubber and from metal. The model gate did not vibrate under submerged flow conditions with any of these seals; also, the model gate did not vibrate with the bottom seal and seal bracket removed.

Locks and Dams 2 and 3 Gate

13. The model was revised to reproduce the gate lip shape of Lock

* All elevations (el) cited herein are in feet referred to mean sea level.
and Dam 3, and the bottom seal used in the model was one of the rubber seals tested with the Lock and Dam 4 gate lip. The gate lip and seal were of the type A design shown in plate 3. The model gate vibrated quite noticeably under flow conditions similar to those at which vibration of the prototype gates was observed. Table 2 shows the range of gate openings at which vibration occurred and the gate openings at which vibration appeared the most severe for various tailwater conditions. Under no flow conditions did vibrations occur at a gate opening greater than 3.0 ft.

14. With the bottom seal and seal bracket removed from the gate lip, the ranges of gate openings at which the gate vibrated were shifted slightly and the severity of vibration seemed to be somewhat reduced; however, vibration was still quite noticeable.

15. Several schemes for altering the gate lip to eliminate vibration tendencies of the gates were proposed by the Little Rock District Office. These schemes are shown in plate 5. Since cost estimates for revising the prototype gates favored scheme 4, it was tested first in the model. This scheme was successful in eliminating the vibration that had previously occurred with the Locks and Dams 2 and 3 design. Tests with the full range of flow conditions and gate openings expected in the prototype revealed no vibration of the gates. Thus, the other schemes were not tested in the model.

**Lock and Dam 12 (Ozark) Gate**

16. Although vibrations of the prototype gates at Lock and Dam 12 (Ozark) had not been reported, gates with similar gate lip and seal configurations at Barkley Dam* were reported to vibrate at small gate openings. Details of both the Ozark and Barkley lip and seal designs are shown in plate 6.

17. The model gate lip was revised to reproduce that at Ozark Lock and Dam. The model gate of this design did not vibrate for any gate.

opening or flow condition. The Barkley gate lip, configuration, and seal were then reproduced in the model, and this gate did not vibrate in the model either.

**Lock and Dam 15 (Kerr) Gate**

18. The Robert S. Kerr gate lip and seal design was very similar to the original design at Lock and Dam 3 (type A, plate 3). The model gate used to test the Lock and Dam 3 design was only 28 ft high (prototype); and, with the small gate openings (0.8 to 3.0 ft) at which vibration occurred, heads on the crest of about 30 ft were the maximum that could be tested. Thus, it was not certain that vibration of the Kerr gates would occur with the 43-ft head on the crest that will be present with the normal pool elevation. Therefore, the model gate was revised to reproduce the Kerr gate in height and lip shape (fig. 4). Also, the trunnions were relocated to the elevation of those at Kerr Dam.

![Fig. 4. Robert S. Kerr gate](image)
19. Tests conducted with the Kerr gate indicated that the gate will vibrate with gate openings of 1.0 ft or less with certain pool and tailwater conditions. However, the model gate did not vibrate with the upper pool at el 460.0 (normal navigation pool) at any gate opening. The ranges of pool and tailwater elevations for which the model gate vibrated are shown in plate 7.
PART IV: DISCUSSION

20. Vibration of the tainter gates has been reported at several of the dams on the Arkansas River navigation project. The major cause of the gate vibrations was found to be the gate lip and bottom seal design. The gate-lip induced vibrations were caused either by the shifting of the flow control point between the skin-plate lip and other gate bottom members or between the rubber seal and the backing plate,* or by the flexibility of the rubber seals which causes them to flutter when subjected to instabilities of pressure and/or flow.

21. Vibrations of gates with the type A lips with or without seals occurred at small gate openings, generally between 0 and 3 ft. Vibrations occurred over a wide range of tailwater elevations or gate submergences but none occurred under free flow conditions. Vibrations of gates with this type lip were caused by the shifting of the flow control point and could be reproduced in the model; thus, by revising the shape of the gate lip in the model the vibrations were eliminated.

22. Vibrations of gates with the type B lips occurred over a wide range of gate openings and tailwater conditions. Vibrations of gates with this type lip were caused by the fluttering of the rubber seal or flow instability between the seal and backing plates; and vibrations of the prototype gates could not be reproduced in the model since the elastic and geometric properties of the seal could not be reproduced. Thus, it was concluded that the 1:12-scale model gives questionable results when vibration of the gates is caused by flutter of a rubber seal. However, none of the prototype structures that used this type of seal have power-generating units (some leakage allowable); and the vibrations of the gates were eliminated by removing the rubber seal and backing plate.

23. None of the projects where the types C and D lip designs are used on the gates have reported vibration of the gates. The model gate did

not vibrate with the type D gate lip. The type C lip design was not tested in the model since it had a sharp lip without a rubber seal, and it was obvious that vibration would not occur with this design.

24. In the future when model studies are required to test the design of gate lips with rubber seals, it is recommended that narrow sections of the lower portion of the gates be studied at a 1:1 scale. This would allow the use of the prototype seal and eliminate the uncertainty involved in modeling both the elasticity and geometry of rubber seals. The model should be constructed to simulate actual prototype pressures on the upstream and downstream sides of the gate so that pressures along the lip can be measured and flow conditions underneath the actual gate geometry can be observed.
### Table 1

#### Spillway Gate Information

<table>
<thead>
<tr>
<th>Lock and Dam No.</th>
<th>No. of Gates</th>
<th>No. of Girders</th>
<th>Elevations* of Upper Pool</th>
<th>Lower Pool</th>
<th>Gate Sill</th>
<th>Gate Trunnion</th>
<th>Gate Dimensions, ft</th>
<th>Water Depth,** ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>3</td>
<td>162.0</td>
<td>Varies</td>
<td>134.0</td>
<td>162.0</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>2</td>
<td>182.0</td>
<td>162.0</td>
<td>158.0</td>
<td>184.0</td>
<td>60</td>
<td>32</td>
</tr>
<tr>
<td>4 (Low sill)</td>
<td>9</td>
<td>2</td>
<td>196.0</td>
<td>182.0</td>
<td>169.0</td>
<td>196.0</td>
<td>60</td>
<td>35</td>
</tr>
<tr>
<td>5 (High sill)</td>
<td>8</td>
<td>2</td>
<td>196.0</td>
<td>182.0</td>
<td>174.0</td>
<td>196.0</td>
<td>60</td>
<td>33</td>
</tr>
<tr>
<td>6 (Terry)</td>
<td>17</td>
<td>2</td>
<td>213.0</td>
<td>196.0</td>
<td>183.0</td>
<td>215.0</td>
<td>60</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>3</td>
<td>231.0</td>
<td>213.0</td>
<td>206.0</td>
<td>232.0</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>2</td>
<td>249.0</td>
<td>231.0</td>
<td>218.0</td>
<td>248.0</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>3</td>
<td>265.0</td>
<td>249.0</td>
<td>242.0</td>
<td>267.0</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>10 (Dardanelle)</td>
<td>20</td>
<td>3</td>
<td>287.0</td>
<td>265.0</td>
<td>253.0</td>
<td>288.0</td>
<td>60</td>
<td>46</td>
</tr>
<tr>
<td>12 (Ozark)</td>
<td>15</td>
<td>3</td>
<td>328.0</td>
<td>287.0</td>
<td>299.4</td>
<td>313.5</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>13 (Mayo)</td>
<td>15</td>
<td>3</td>
<td>372.0</td>
<td>338.0</td>
<td>327.0</td>
<td>360.0</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>14 (Kerr)</td>
<td>18</td>
<td>3</td>
<td>412.0</td>
<td>392.0</td>
<td>392.0</td>
<td>417.0</td>
<td>60</td>
<td>32</td>
</tr>
<tr>
<td>16 (Webbers Falls)</td>
<td>12</td>
<td>3</td>
<td>460.0</td>
<td>412.0</td>
<td>416.8</td>
<td>434.5</td>
<td>50</td>
<td>44</td>
</tr>
</tbody>
</table>

**Arkansas River**

| 17 | 3 | 2 | 411.0 | 490.0 | 485.0 | 512.5 | 60 | 37 | 27.0 | 27.5 | 26 | 5 |
| 18 | 3 | 2 | 532.0 | 511.0 | 506.0 | 533.5 | 60 | 37 | 27.0 | 27.5 | 26 | 5 |

**Verdigris River**

Note: Letter symbols used for gate dimensions and water depths are graphically defined in plate 2.

* All elevations are in feet referred to mean sea level.

** Relative to gate sill elevation.
Table 2
Gate Vibration with Lock and Dam 3 Lip Design

<table>
<thead>
<tr>
<th>Pool El*</th>
<th>TW El</th>
<th>Range of Gate Opening, ft, at Which Vibration Occurred</th>
<th>Gate Opening, ft, at Which Most Severe Vibration Occurred</th>
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</thead>
<tbody>
<tr>
<td>182.0</td>
<td>178.5</td>
<td>No vibration</td>
<td>--</td>
</tr>
<tr>
<td>182.0</td>
<td>176.0</td>
<td>0.2 to 1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>182.0</td>
<td>174.0</td>
<td>0.3 to 1.6</td>
<td>0.7</td>
</tr>
<tr>
<td>182.0</td>
<td>172.0</td>
<td>0.3 to 1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>182.0</td>
<td>169.0</td>
<td>0.4 to 2.8</td>
<td>1.6</td>
</tr>
<tr>
<td>182.0</td>
<td>Free flow</td>
<td>No vibration</td>
<td>--</td>
</tr>
</tbody>
</table>

* All elevations are in feet referred to mean sea level.
DETAILS OF TYPICAL SPILLWAY

PLATE 1
BASIC GATE INFORMATION
L & D 2 AND 3

L & D 10

L & D 15

TYPE A

L & D 4, 5, 6, AND 7

L & D 8, 9, 13, AND 14

L & D 12, 16, 17, AND 18

TYPE B

TYPE C

TYPE D

GATE LIP DESIGNS
PLATE 4

SECTION A-A

SCALE

SECTION C-C

ELEVATION

DETAIL OF LIFTING LUG

SECTION D-D

GATE DETAILS

LOCK AND DAM 4
TAINTER GATE LIP MODIFICATION
LOCK AND DAM 3
BOTTOM LIP AND SEAL DETAILS
OZARK AND BARKLEY GATES
NORMAL NAVIGATION POOL

NO VIBRATION

VIBRATION WITH GATE OPENINGS 1.0 FT OR LESS

NO VIBRATION

POOL ELEVATION, FT MSL

TAILWATER ELEVATION, FT MSL

GATE VIBRATION RANGE
LOCK AND DAM 15 (KERR)

PLATE 7
The Arkansas River navigation project has 17 individual lock and dam projects. Vibration of the tainter gates has been reported at several of these dams, the major causes of the gate vibrations being the gate lip and bottom seal designs. A 1:12-scale model that reproduced one 60-ft-wide gate bay and the adjacent half bays was used to investigate the gate vibrations. The central gate reproduced the prototype with respect to size, shape, and weight, whereas the adjacent gates were only schematic. Prototype water-surface elevations and flow conditions were accurately reproduced in the model. The vibrations of the prototype gates that were attributable to the gate lip geometry were reproduced in the model for similar flow conditions. Revisions in the shape of the gate lip were made that successfully eliminated the vibrations. The vibrations of the prototype gates that were attributable to the fluttering of the rubber seal were not exactly reproduced in the model for similar flow conditions because of the inability to reproduce the elastic and geometric properties of the rubber seal. However, it was determined in the model that there would be no vibrations for any flow conditions with the rubber seal and backing plate removed. Removal of the seal is considered feasible for the prototype because none of the Arkansas project prototype structures that used this type of seal have power-generating units and thus some leakage under the gates is allowable.
<table>
<thead>
<tr>
<th>KEY WORDS</th>
<th>LINK A</th>
<th>LINK B</th>
<th>LINK C</th>
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<tbody>
<tr>
<td>Arkansas River Navigation Project</td>
<td></td>
<td></td>
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<td>Gates (Hydraulic Structures)</td>
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<td>Hydraulic models</td>
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<tr>
<td>Vibration</td>
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