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Siphon-Spillway Models Tested Against Prototypes

Series of laboratory studies on siphon models indicates full-scale characteristics can be predicted—Data on priming and discharge—Conclusions on relation of models to prototype

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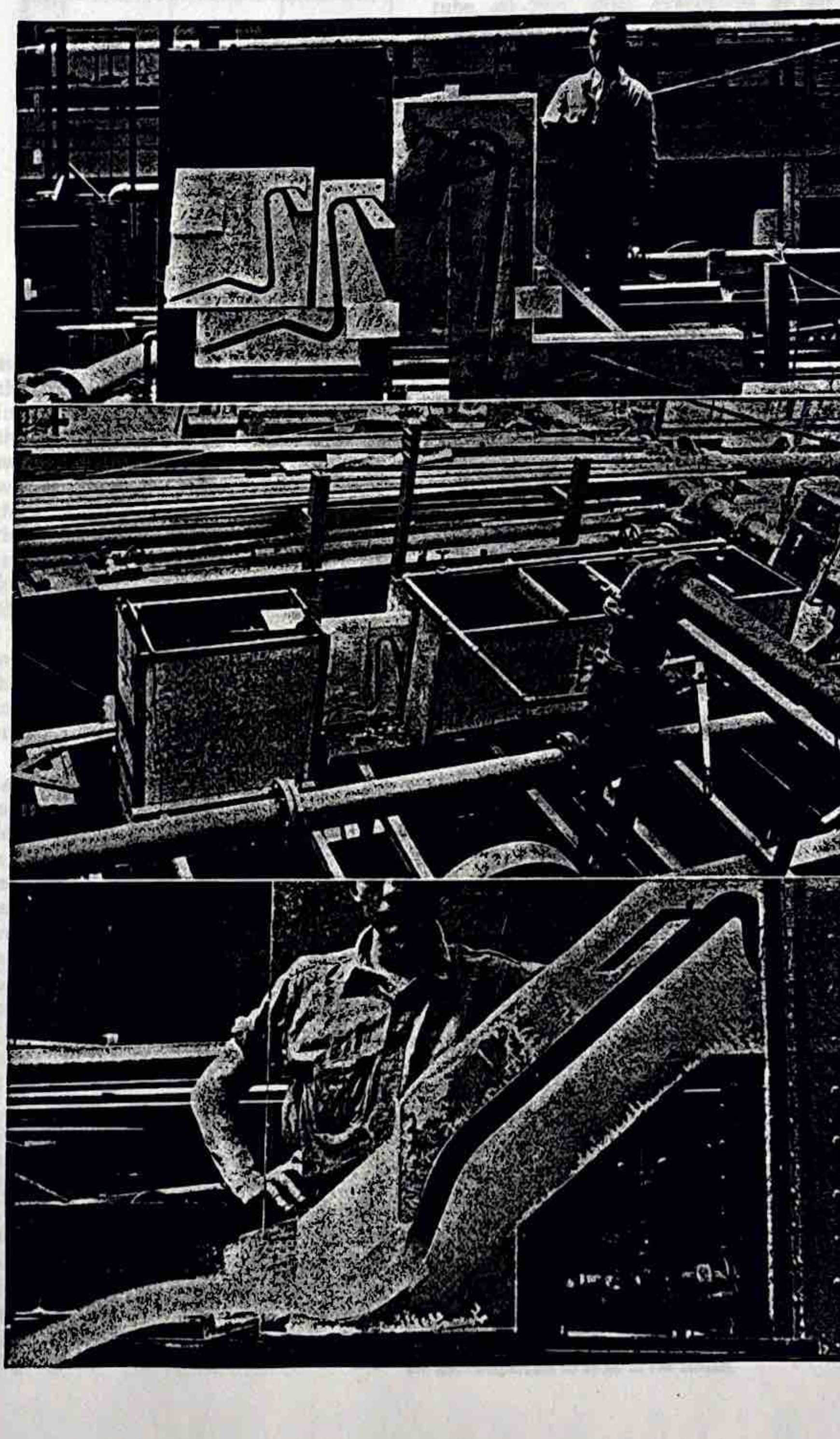
SUPPLEMENTING the data published recently on field tests of actual siphon-spillway installations (*ENR*, May 5, 1932, p. 649), the following article presents valuable material on laboratory studies of siphon models. Unusual significance attaches to these experiments because the models copied prototypes on which comprehensive field tests had been made. This permitted interpretation of results both as to reliability of tests and possibility of using models to determine operating characteristics of new installations. The following article, extending the material contained in the previous one, brings the subject of siphon spillways up to date. This valuable feature of hydraulic design, which has too long been subject to vague uncertainties, is receiving the attention required to make it available for more general and reliable use. The author recently was awarded the Freeman scholarship for hydraulic study abroad. —EDITOR.

FUNDAMENTAL relations between siphon-spillway models and prototypes and data on operating characteristics of both resulted from graduate research studies made in the hydraulic laboratory of the University of California. The original problem was to determine how completely a siphon model could be relied on to provide a true representation of the action of the prototype, and only siphons were selected that had been accurately field-tested. Extending the study, tests were made to determine the model-scale relation for coefficients and other factors not susceptible of field experiments.

Description of the Originals—The originals selected were tube No. 7 of the siphons at the Leaburg hydro-electric plant, city of Eugene, Ore., and tube No. 1 of the siphon in the Bear River feeder to the Tiger Creek flume of the Pacific Gas and Electric Co. on the Mokelumne River, Calif.

The Leaburg siphon has an outlet leg inclined backward toward the dam, and a water seal. The tube is rectangular in cross-section, uniform in width but varying in depth, with a throat area of 3.43 sq.ft. and an outlet area of 4.44 sq.ft. The difference in elevation between center of the outlet and the bottom of the throat is 28.9 ft. Priming occurred with a head of 0.2 ft. over the throat. The measured discharge was 119 sec.-ft., giving a coefficient of discharge of 0.62 based on outlet area.

The Bear River siphon has an outlet leg sloping away from the intake and was originally built without a water seal. A sealing basin was added later to insure priming. The siphon tube is of constant rectangular cross-section from throat to outlet, with an area of 12.5 sq.ft. It is equipped with a priming weir, which allows a screen of water to fall across the tube at a point just beyond the throat bend. With the water seal its maximum discharge was 312.6 sec.-ft. The difference in elevation between top of the outlet and the bottom of the throat is 25.7 ft. Priming occurred with a head of 0.2 ft. over the crest. The coefficient of discharge based upon outlet area was 0.61 with the water seal. This siphon and the



Use of three scales of models (upper view) confirms relation with prototype and provides data on effect of scale reduction. Built of treated sugar-pine lumber, the models were equipped with a glass side attached by shellac.

Set-up of model (center view) provided for measuring quantities of flow, heads, rate of rise and effect of air leakage on coefficient.

Lower view shows a typical test run of which hundreds were made to duplicate field tests on prototypes and to study additional problems.

tests made on it were described in detail in *Engineering News-Record*, May 5, 1932, p. 649.

Operation of models

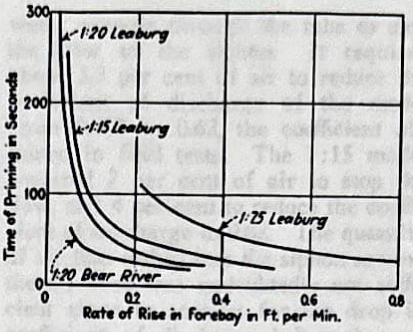
Models of the Leaburg siphon were built to scales of 1:20, 1:15 and 1:7.5, and the Bear River siphon was reproduced to scales of 1:20 and 1:10. The models were built of sugar-pine lumber treated with three or more coats of spar varnish and, except in one case, finished with white cement paint. Each model had one glass side attached to the wood with shellac.

With heads comparable to those during field tests, the Leaburg models showed consistently higher coefficients of discharge (see table) than did the prototype. Due to the large operating head, the diverging vertical leg of the prototype did not flow full, and it also sucked in some air at the air vent during field tests. Two models on the scale of 1:20, identical except that one was painted with cement paint, while the other had a smooth varnished surface, showed no difference in coefficient of discharge. One of the models, laid in a horizontal position and tested with the same range of operating heads as when in the vertical position, showed no noticeable difference in discharge. One of these models, when cut off at the bottom of the vertical leg, showed an increase in discharge coefficient from 0.685 to 0.705 for ordinary operating heads.

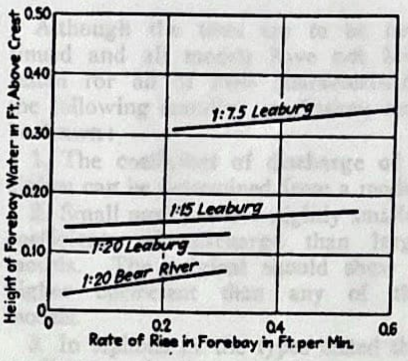
With the outlet submerged, the 1:20 model showed no decrease in discharge coefficient until the operating head was reduced to about two-thirds of that with free discharge. The 1:15 model showed no decrease until the head was reduced to about one-half of that with free discharge. Results indicate that the coefficient for the two model siphons began to decrease at about the same value of Reynolds' number, which is a figure expressing the relation of velocity times diameter divided by kinematic viscosity.

The Bear River model, 1:20 scale and with a water seal, showed a coefficient of 0.58. Without the water seal the model showed a coefficient of 0.59. With no water seal but with an obstruction in the outlet leg to facilitate priming, the coefficient was 0.58. With no water seal and with the priming weir intake blocked, the coefficient of discharge was also 0.58. Apparently the turbulence produced by the water entering from the priming weir during full flow is almost enough to offset the benefit of the larger entrance area that it provides.

Model Priming Tests—For each model of the Leaburg siphon the time of priming varied inversely as the rate of rise in the forebay. For the same rate of rise applied to all sizes the smallest siphon primed quickest. The ratio of the time of priming for any



Relation of rate of rise to time for priming models, showing effect of difference in the scale.



Effect of rate of rise on head to prime siphon models.

two models was directly proportional to the ratio of the first power of their linear dimensions, if the rate of rise in the forebay was the same. This is due, no doubt, to the compression of the air within the tube by the rising water in the forebay. With this compression the models all required forebay water levels above the top of the throat before priming occurred. When enough air was admitted to the throat through a rubber tube during the priming to maintain atmospheric pressure within the siphon until the evacuation of air commenced at the outlet, the time of priming was considerably shortened.

The head necessary to prime the Leaburg models was larger for rapid rates of rise in the forebay than for slow rates, although the actual variation in head for different rates of rise for any model was small. The curves of head required to prime plotted against the rate of rise of forebay water were approximately straight lines and were parallel for all three models. With the same rate of rise applied to all three sizes of model, the head to prime was directly proportional to the first power of the scale ratio.

A small rubber tube was admitted to the throat of the 1:7.5 model, so that atmospheric pressure was maintained within the siphon until the evacuation of air began at the outlet. This became so rapid that, in spite of the air sucked in through the tube, the siphon primed. Under these conditions priming occurred with less than one-third the head above the crest required when compression was present. With the compression thus relieved, the forebay water did not rise to the height of the top of the throat during the priming.

Comparing models and prototypes

The original Leaburg siphon primes more quickly and with a lower proportionate forebay elevation than did the models when compression was allowed. This was probably because of the air leakage in the original around the plate covering the air vent. Apparently no compression developed in the siphon, because air could escape during the rise of water in the inlet and for some time after first overflow. The leaks were small enough, as in the case of the model in which the throat was connected with the outside by a rubber tube, so that, after evacuation of air began at the outlet, air was carried out more rapidly than it could be supplied through the leaks. The model tests indicate that the original would have required a forebay water level above the top of the throat to prime the siphon had it not been for the leaks at the air vent.

This experiment also indicates that the submergence of outlet in the water seal should not be as great as in the Leaburg siphon. With less submergence less compression would be possible, and the models would prime more quickly and at lower heads. The tests point to the advisability of equipping a siphon that has a submerged outlet with a low-pressure air valve. Such a valve would eliminate compression in the tube and would close as soon as the pressure began to drop below atmospheric.

The time of priming could be reduced, perhaps at the expense of a decrease in the efficiency of the siphon, if the upper surface of the barrel at the lower end of the vertical leg curved more sharply. The air carried into the sealing basin by the water splashing down from above cannot pass around a large-radius curve and escape until the flow becomes considerable. With a sharp edge or small-radius curve, much air would escape when the flow is small.

Priming tests were made on models of the Bear River siphon under conditions similar to those imposed on the prototype (*ENR*, May 5, 1932, p. 649).

COMPARISON OF OPERATING CHARACTERISTICS OF SIPHON-SPILLWAY MODELS AND PROTOTYPES

	Coefficient of Discharge	Priming Head, Ft.	Time to Prime, Sec.	Per Cent of Air to Break Siphon
Rate of Rise = 0.3 ft. per min.				
Leaburg				
Prototype..	0.62*	0.2*	*	*
1:7.5 model	0.715	0.32	75	..
1:15 model.	0.695	0.16	40	7
1:20 model.	0.685	0.13	30	6
Bear River				
Prototype..	0.61	0.2	..	..
1:10 model.	0.61	....	..	..
1:20 model.	0.58	0.07	20	..

*Discharge and priming characteristics of original are not comparable to those of the models.

As the siphon was originally constructed the 1:20 model would not prime. It flowed full only as far as the priming weir, even with a considerable elevation of forebay water above the top of the throat. When the siphon was flowing full only as far as the priming weir, if the entrance of the channel leading to the weir were suddenly blocked, the remainder of the tube filled with water. When an obstruction was placed on the lower side of the outlet leg to represent the 2x8-in. plank across the leg of the original, the siphon primed. With a water seal that submerged the outlet somewhat more than that added to the original, but with no obstruction in the tube, the siphon primed. With a water seal identical with that of the original, the siphon would not prime. The sealing basin flushed clean, allowing air to back up the outlet leg before full priming occurred.

The 1:20 model primed more quickly for rapid rates of rise than for slow rates. At no time did the forebay water level rise to an elevation above the top of the throat. A change in the rate of rise in the forebay produced little change in the head required to prime. A comparison with tests on the original shows that a proportionately greater head was required to prime the model than the prototype.

The 1:20 and 1:15 models of the Leaburg siphon were each fitted with a tank to collect air as it escaped at the outlet. The 1:20 model required 5 per cent of air by volume at atmospheric pressure in proportion to the water passing through the tube to stop the flow of the siphon. It required about 3.3 per cent of air to reduce the coefficient of discharge of the model from 0.685 to 0.62, the coefficient obtained in field tests. The 1:15 model required 7 per cent of air to stop the flow, and 4 per cent to reduce the coefficient of discharge to 0.62. The quantity of air that leaked into the siphon around the air vent was undoubtedly not sufficient alone to account for the drop in coefficient of discharge below that of the model.

Conclusions

Although the tests are to be continued and all models have not been tested for all of their characteristics, the following tentative conclusions may be drawn:

1. The coefficient of discharge of a siphon can be determined from a model.

2. Small models show slightly smaller coefficients of discharge than large models. The original should show a higher coefficient than any of the models.

3. In siphons of the types tested the coefficient of discharge is constant throughout the range of operating heads usually required by field conditions.

4. The break in the curve of coefficient of discharge plotted against operating head seems to occur for models of the same siphon to several scales at a constant value of Reynolds' number. Model and original should therefore be compared only when both are above some critical value of Reynolds' number.

5. Models of the same siphon to several scales may show a correlation of results of tests of time and head to prime. Results of tests on one siphon need not necessarily apply to one of a different design.

6. The quantity of air necessary to stop the siphon may be determined by a model. It should give an indication of the necessary size of air vent. Results of tests for a particular design would probably not apply to another except in a general way.

7. The outlet of a siphon with a water seal should be submerged as little as possible, or compression resulting in the tube will cause an increase of both the time and head necessary for priming.

8. The value of a priming weir is questionable.

9. A sharp curve at the upper edge of the tube where it enters the water seal will facilitate quick priming.

10. A siphon, when flowing full, shows the same discharge characteristics as a short tube under the same operating head.

11. There is probably a limit to the scale reduction of the model for reliable results.

The research has been carried out as graduate thesis work in the college of civil engineering, University of California, by the author, assisted by Charles R. Sexton under the direction of B. A. Etcheverry, chairman of the department of irrigation engineering. Morrough P. O'Brien, associate professor of mechanical engineering, is in charge of work in the hydraulic laboratory.