A CONTINUOUSLY OPERABLE HYDRAULIC MODEL OF SELECTIVE WITHDRAWAL FROM A STRATIFIED RESERVOIR

ROBERT ETTEMA [1], MARIAN MUSTE [1], JACOB ODGAARD [1]
PATRICK RYAN [2], FREDERICK LOCHER [2] and SCOTT TU [3]

[1] Faculty, IIHR-Hydroscience and Engineering,
The University of Iowa. Iowa City, IA 52242
(Tel: +319-384-0596, Fax: +319-335-5660, e-mail: robert-ettema@uiowa.edu)
[2] Engineers, Bechtel Corp., 50 Beale Street, San Francisco, CA 94105
(Tel: +415-768-7788; Fax: +415-768-4955; e-mail: pryan@bechtel.com)
[3] Engineer, Pacific Gas & Electric Co., 3400 Crow Canyon Rd, San Ramon. CA 945835
(Tel: +925-866-5804, e-mail: SST3@pge.com)

This paper describes a large hydraulic model used to determine the influence of design modifications intended to enable an existing water intake to selectively withdraw colder water from the lower depths of a thermally stratified reservoir. A particularly useful feature of the model was that it could be operated so as to facilitate practically continuous testing of selective withdrawal over a range of withdrawal rates and for various structural modifications of the intake.

The hydraulic model was about 300m^2 in plan area and held about 120m^3 of water. A model of this magnitude was feasible because of the availability of large volumes of water (cold, temperate, and warm) with which to establish and maintain water-temperature profiles in the hydraulic model, and attain a steady outflow temperature for a range of outflow rates. A 165m^3 ice tank and a 150m^3 heated sump provided the cold and warm water used for the model, which was plumbed with an elaborate system of water-feed lines to continuously feed cold, temperate, or warm water so as to maintain the simulated temperature profile of reservoir water

The model had to be vertically distorted to encompass a sufficient area of the reservoir with adequate model depth, and its outflow thus required careful calibration and validation. A straightforward, though challenging, method of calibration and validation was used. It entailed experiments with a pair of testboxes that simulated simplified geometries of the intake and the lake bathymetry surrounding it. One testbox simulated a vertically distorted intake, whereas the other simulated an equivalent undistorted intake. Prior studies of selective withdrawal do not explain how vertical distortion may affect model results.

The calibration and validation method illuminated the importance of simulating flow vorticity (at least in approximate terms) when replicating the withdrawal performance of a vertically distorted hydraulic model of an intake in a thermally stratified reservoir, and led to a simple relationship for vorticity scaling of flow in a vertically distorted model. The relationship requires increasing the outflow rate from the distorted model by way of a calibration factor estimated as

$$\alpha = \overline{\omega}_r / \omega_{r(Lr=Xr)} = (X_r^{-0.5} + Y_r^{-0.5})/2X_r^{-0.5} = 0.5[1 + (X_r/Y_r)^{0.5}] \quad (1)$$

in which $\overline{\omega}_r$ is an average of the vorticity scales for corresponding undistorted models built at horizontal- and vertical length scales X_r and Y_r, respectively; usually $X_r > Y_r$. Also, $\omega_{r(Lr=Xr)}$ is the vorticity scale for a model built at undistorted scale $L_r = X_r$. Here, ω_r

= (vorticity in prototype)/(vorticity in model). In accordance with Eq. (1), the usual similitude criterion based on densimetric-Froude number –

$$(F_D)_r = \left[\frac{U}{\sqrt{g(\Delta\rho/\rho_0)Y}} \right]_r = 1 \qquad (2)$$

should be adjusted to

$$F_{Dr} = 1/\alpha. \qquad (3)$$

In Eq. (2), subscript r signifies scale ratio; U is flow velocity; Y is flow depth; g is gravity acceleration; with ρ_0 and $\Delta\rho$ being water density and density increment, respectively.

Tests with the model showed that a skimming curtain suitably placed around the intake could reduce withdrawal temperature substantially. Other potential modifications investigated included a hooded-inlet pipe extending (to varying lengths) from the intake out on to the reservoir bed, and sundry excavations near the intake. Tests with the hydraulic model showed that a curtain, augmented by minor excavation, held best promise for enabling the intake to release colder water.

In closing, the study showed that a vertically distorted hydraulic model could be used successfully to simulate the outflow performance of a water intake in a thermally stratified reservoir. Calibration and validation tests conducted with a simplified pair of distorted and equivalent undistorted, testbox replications of the intake indicate that an important modeling consideration for three-dimensional flow fields is similitude of flow vorticity near the intake.