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Tools to Support Design of Coanda-Effect Screens for Debris Exclusion and Fish Protection

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Hydraulics Laboratory Technical Memorandum PAP-1193

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14. ABSTRACT
Coanda-effect screens exclude coarse and fine debris from a variety of water intakes, including small hydropower installations, irrigation diversions, and stormwater runoff facilities. High velocity supercritical flow passes over an inclined wedge-wire screen panel with specially tilted wires that shear thin layers of water from the bottom of the water column and through the screen. The screens have high capacity and are hydraulically self-cleaning, making them well suited to remote sites without electrical power. The flow conditions vary significantly over a typical screen. Previous testing has indicated that screen capacities are affected by gravitational, surface tension, and viscous forces, but the range of tested flow conditions has been limited compared to the potential applications. In this study, small sections of prototype screen materials were tested in a variable-slope flume. Screen discharge coefficients were calculated from the test data and related to the Froude and Weber numbers of the flow. Tests conducted over a range of water temperatures showed that screen performance is independent of fluid viscosity but depends strongly on surface tension. Several screen materials were tested, and the performance of all screens could be modeled with relations having a common functional form. Individual screens exhibited unique performance characteristics, but nine of the thirteen tested screens performed similarly, and their performance was effectively modeled as a group.

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Acknowledgements

This research was sponsored by the Science and Technology Program, Bureau of Reclamation. Christopher Shupe of the Hydraulics Laboratory conducted most of the recent laboratory testing. The Coanda-effect screen design software was originally written as a stand-alone Visual Basic 4.0 application by the lead author of this report, and was ported to Microsoft Excel (Visual Basic for Applications) in 2014 by Mr. Clarence Prestwich, Irrigation/Drainage Engineer with USDA-NRCS West National Technology Support Center, Portland, OR. The lead author revised the Excel version during this project to incorporate the newest findings from recent laboratory testing.

Cover Photo

The C-Ditch headworks screen on the Needle Rock Project near Delta, Colorado was constructed in 2014 as part of the Basin Wide Salinity Control Program (Reclamation/Joshua Dunham).

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Peer Review

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Executive Summary

Coanda-effect screens have been used worldwide since the 1980s for high capacity screening of organic debris, trash, sediment, and aquatic organisms from a variety of water intakes, including small hydropower installations, water diversions, fish exclusion structures, and stormwater facilities (Finch & Strong 1983; Strong & Ott 1988; Esmond 2012; Nøvik et al. 2014; May 2015). Research begun in the late 1990s (Wahl 2001) by the Bureau of Reclamation (Reclamation) established the first experimentally based methods for predicting the discharge through screens for design purposes. Reclamation applications of Coanda-effect screens have included small and large structures used to remove fine debris from systems transitioning from open-channel delivery and flood irrigation to pressurized pipe systems serving sprinkler- or drip-based irrigation. The cover photo on this report shows a screen installed at the C-Ditch headworks on the Needle Rock Project near Delta, Colorado. This structure enabled a conversion from open-channel to closed-conduit deliveries that was beneficial for the Basin Wide Salinity Control Program.

A typical Coanda-effect screen structure is shown schematically in Figure 1 (Wahl 2001). The screen panel is installed downstream from the crest of an overflow weir so that high-velocity flow passes across the screen surface. An acceleration plate leads the flow tangentially onto the screen. The screen panel is fabricated from stainless steel *wedge wire*, often used in fish screens and well screens, with the individual wires oriented perpendicular to the flow direction, and slot sizes that are in the range of about 0.5 to 2 mm (0.02 to 0.08 inches). Coanda-effect screens use a unique type of wedge wire panel in which each individual wire is tilted a few degrees downstream on its axis so that the leading edges of the wires form a series of water-shearing offsets projecting into the flow. The Coanda effect causes flow to attach to the top surface of each wire so that the flow in the immediate vicinity of the wires is parallel to the wire surfaces instead of the overall screen surface. At the trailing edge of each wire the flow detaches cleanly from the wire and strikes the upstream face of the next downstream wire, which turns the flow and discharges it through the open slot between the wires. Figure 2 shows a small sample of a Coanda-effect screen panel.

In a typical installation, flow conditions over the full length of a screen panel vary considerably, since the flow is accelerating down the screen face. Reclamation's early research (late 1990s) considered a range of flow rates and velocities but was limited to one fixed slope for the screen, 37° from horizontal. This work indicated that screen capacity was related to the slot width, screen porosity, wire tilt angle, and three dimensionless numbers related to the ratios of important forces affecting the flow: the Froude number (inertial-to-gravitational forces), the Reynolds number (inertial-to-viscous forces), and the Weber number (inertial-to-surface tension forces). Results of these early studies were published in the *Journal of Hydraulic Engineering* (Wahl 2001).

In 2012 Reclamation used private funding to test a series of screens being considered for a Canadian hydropower project. The lab facility constructed for this project enabled screens to be tested at a wide range of incline angles. Subsequent S&T funded research expanded the range of flow conditions used for screen testing and new screen discharge equations were developed (Wahl 2013). Additional testing conducted since 2016 has expanded the range of flow conditions further to include relatively flat slopes, and this work showed that the previous methods for mathematically modeling the discharge capacity of the screens were very inaccurate in some flow conditions (±30% errors). A significant lingering question from the early testing was whether the screen capacity was really affected by both viscous and surface tension forces (Reynolds and Weber numbers), since it was impossible to independently vary only one parameter at a time (both vary primarily as a function of the flow velocity).

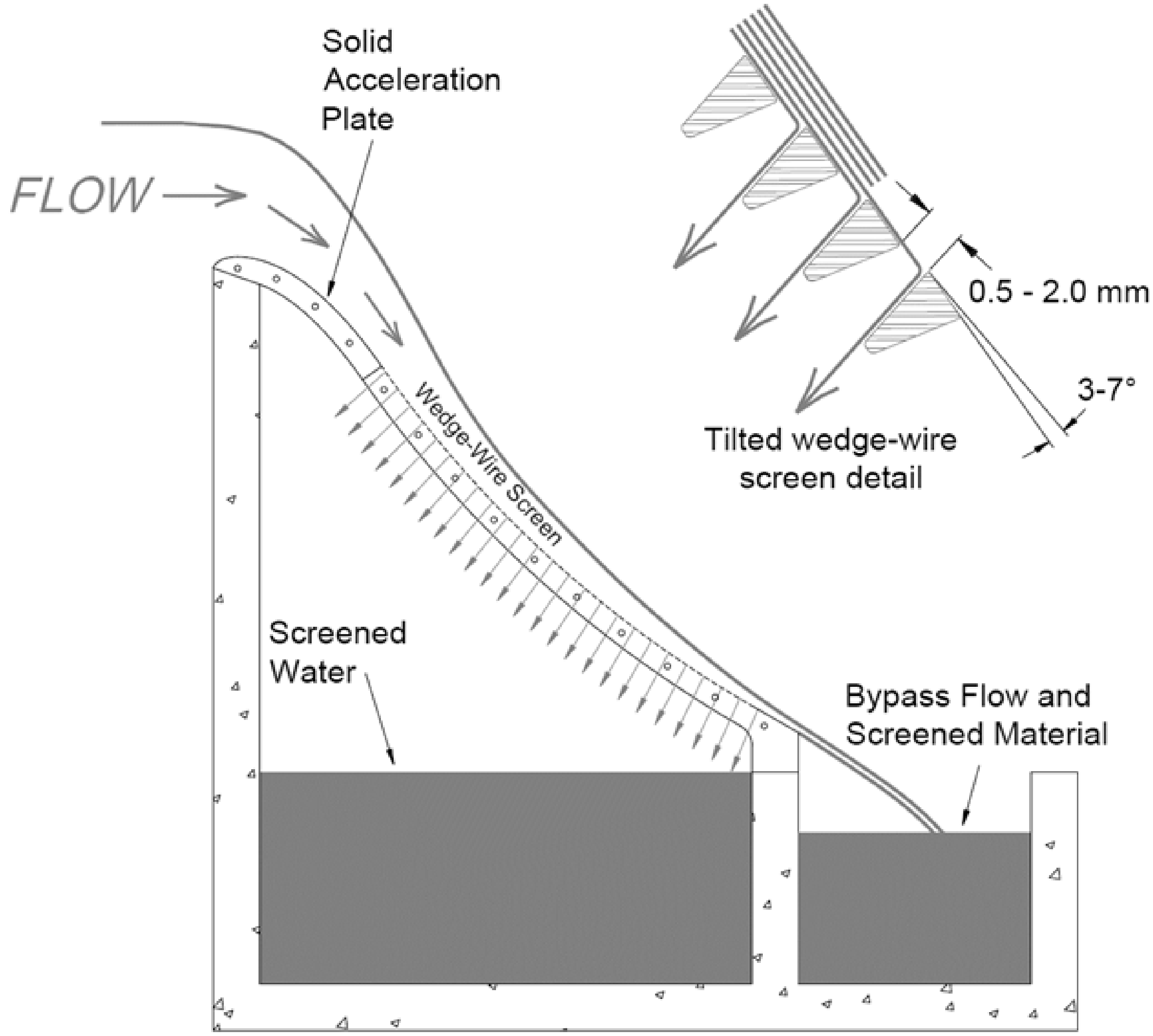

Figure 1. — Features and typical arrangement of a Coanda-effect screen structure.

Figure 2. — Sample section of a Coanda-effect screen panel. The slot size is 0.5 mm.

The latest project funded during 2019 and 2020 used testing conducted over a range of water temperatures (approx. 37-70°F) to increase the fluid viscosity and Reynolds number by about 65% while holding the Weber number almost constant. This testing showed definitively that the screen performance is primarily affected by surface tension, not viscosity. With this knowledge, greatly improved discharge equations were developed using the data accumulated since 2012. The new methods reduce the uncertainty of predicted flow rates by a factor of 3 or more compared to the previous methods (Wahl 2001; Wahl 2013). These findings have been summarized in a new technical paper submitted in July 2020 to a refereed journal. This paper is presently under review by the journal.

Following completion of the draft journal article, the new discharge equations developed in this project were incorporated into an updated version of a computer program developed previously by Reclamation to compute the discharge capacity of Coanda-effect screen structures. This program is implemented in a Microsoft Excel spreadsheet that will be made available through the web site of Reclamation's Technical Service Center (TSC). The software can estimate the discharge through a screen and that bypassed off the screen, or the length of wetted flow in cases where all flow passes through before reaching the toe of the screen. The software can quickly analyze a range of flow conditions to create a rating curve for a structure, or in a batch mode of operation the software can analyze the behavior of multiple structures and flow conditions in a single run. The software uses default screen performance parameters developed from the aggregated analysis of the multiple screen materials tested during this project. Custom screen performance parameters can also be entered when test results are available for a specific screen material.

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Metric Conversions

Provide metric equivalents for non-metric units used in the text:

Unit	Metric Equivalent
1 inch	25.4 mm
°F (temperature measurement)	(°F–32) × (5/9) = °C

Appendix A

A manuscript containing pertinent data and results titled "Surface Tension Effects on the Discharge Capacity of Coanda-Effect Screens" has been finalized and submitted to a refereed journal. The principal investigator of this work will update this section to include the submitted manuscript once the journal peer review process has been completed and information is ready for public dissemination. After completion of this task the "Interim" designation will be removed from this report.