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Velocity Distribution with Dip-phenomenon in Conic Open Channels

Junke Guo
University of Nebraska-Lincoln

with Contributions from
Amin Mohebbi, Yuan Zhai, Jerry Chen, Kornel Kerenyi

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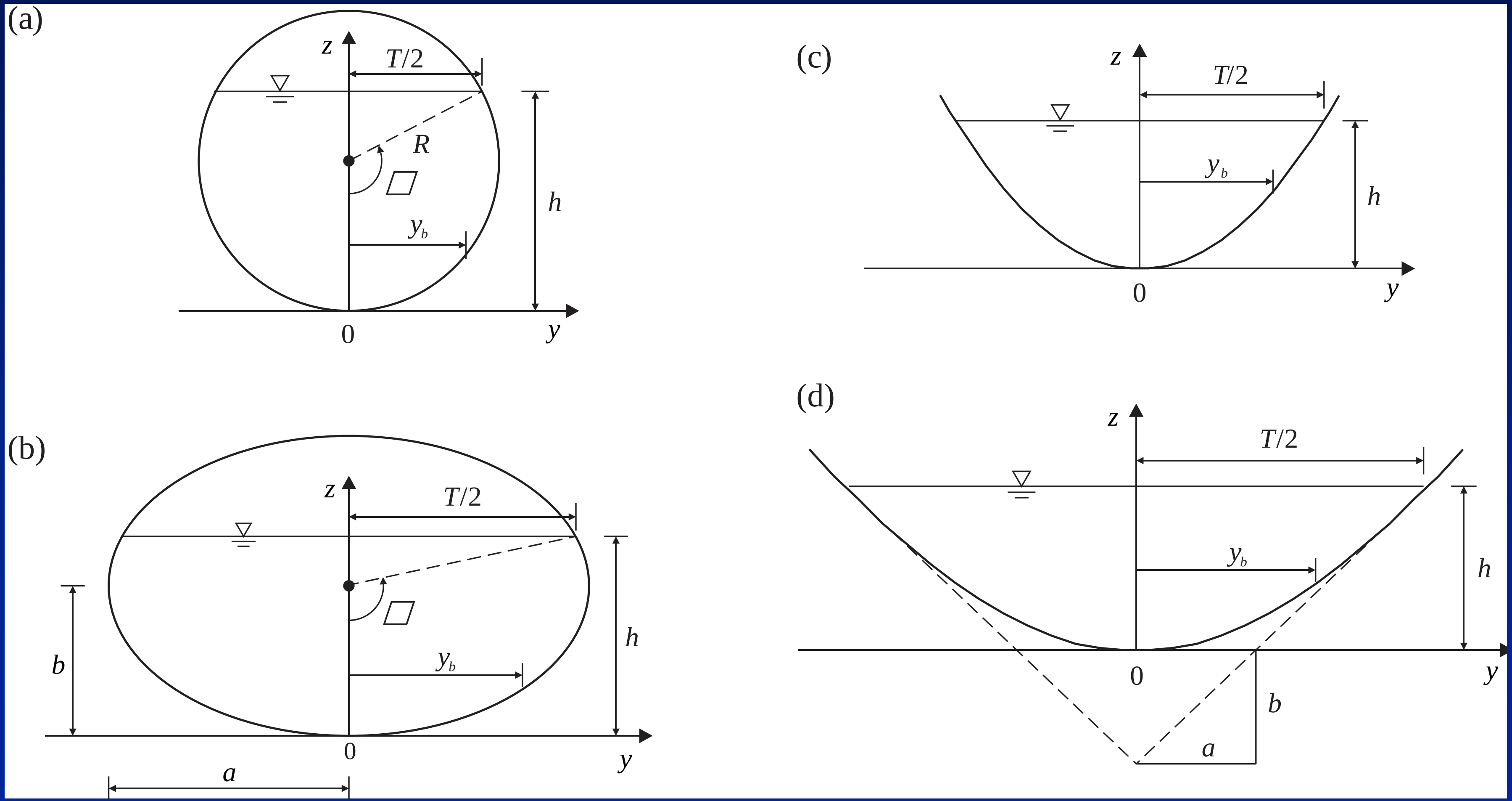
Overview

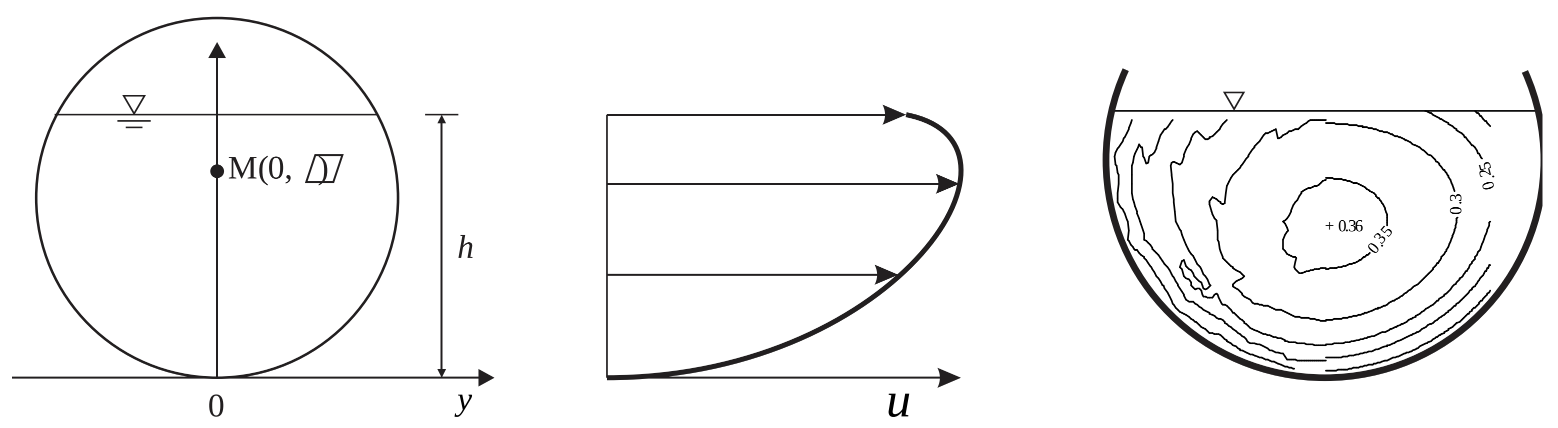
- Problem
  - How about velocity distribution in conic open channels?
  - Conic sections: highway culvert + sub-drain (circle, ellipse), stream section (parabola), trapezoidal section with sediment deposition (hyperbola)
- Motivation
  - Velocity contours are required for fish passage culvert and stage-discharge relationship
  - Maximum velocity and its position is required for self-clean sub-drain system
- Objective
  - Find the cross-sectional velocity distribution in conic channels
- Approach
  - Scientific method: Observation -> hypothesis -> test with data -> application for fish passage

Conic Sections



Hypothesis and Its Test

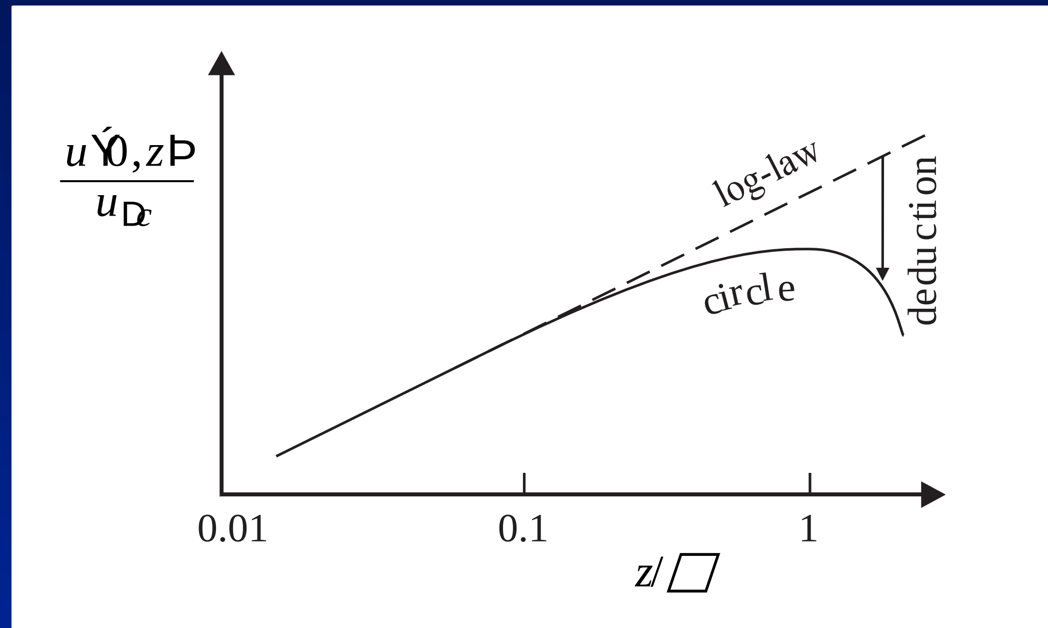
- Cross-sectional velocity distribution is described by
  - Dip (or maximum velocity) position
  - Centerline velocity distribution
  - Cross-sectional velocity distribution



(a) Dip-position (b) Centerline velocity (c) Velocity contours

Hypothesis and Its Test (cont.)

- Observation:
  - Centerline Velocity

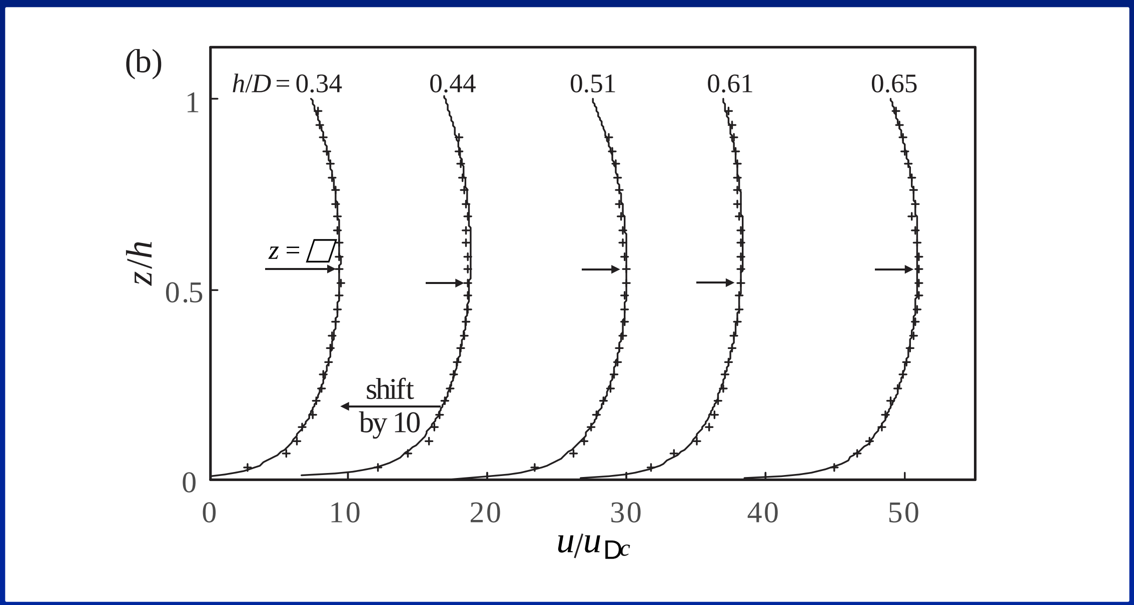


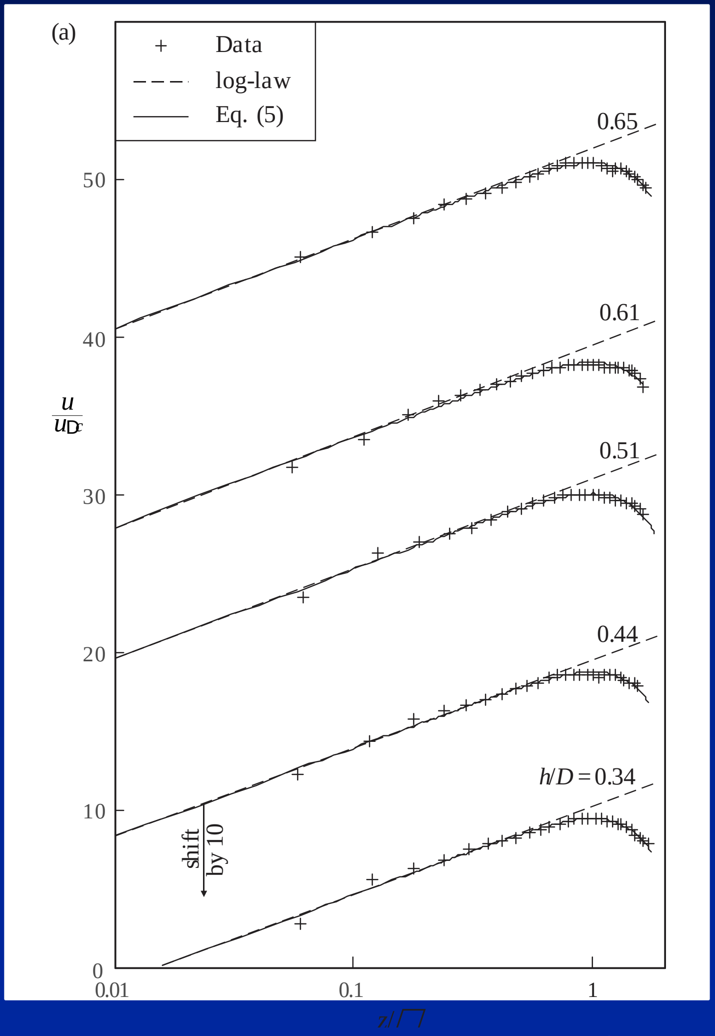
- Hypothesis: Log-cubic law

$$\frac{u(0,z)}{u_{\square b}} = \frac{1}{\square}\left[\ln\frac{z}{z_0} \;?\; \frac{1}{3}\left(\frac{z}{\square}\right)^3\right]$$

Hypothesis and Its Test (cont.)

- Test of centerline velocity



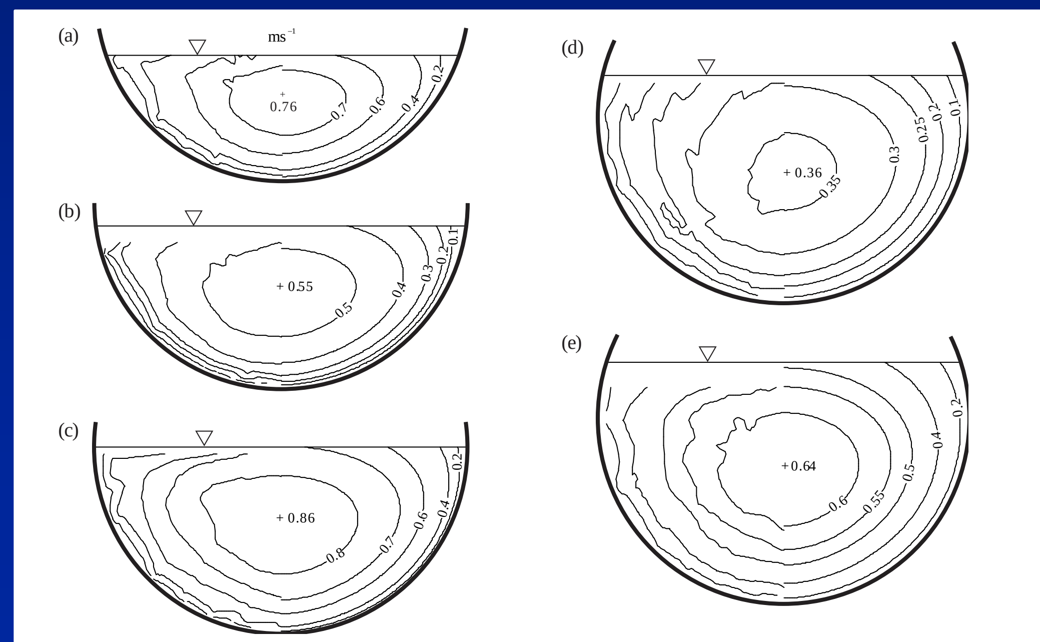


Hypothesis and Its Test (cont.)

- Hypothesis: cross-section, double log-cubic law:

$$\frac{u(0,z) - u(y,z)}{u_D} = -\frac{1}{\kappa}\left\{\ln\left(1 - \left|\frac{y}{y_b}\right|\right) + \frac{1}{3}\left[1 - \left(1 - \left|\frac{y}{y_b}\right|\right)^3\right]\right\}$$

- Test with data
  - » Clark and Kehler (2011)
  - » Left-half: data
  - » Right-half: model



Hypothesis and Its Test (cont.)

- Dip-position: Obtained by integrating the cross-sectional velocity distribution for discharge.

$$\frac{1}{\square^{3}} = \frac{3}{I_2}\left(I_1 \; ? \; \frac{A \ln z_0}{2} \; ? \; \frac{3A}{8\square} \; ? \; \frac{\square Q}{2u_{\square c}} \right)$$

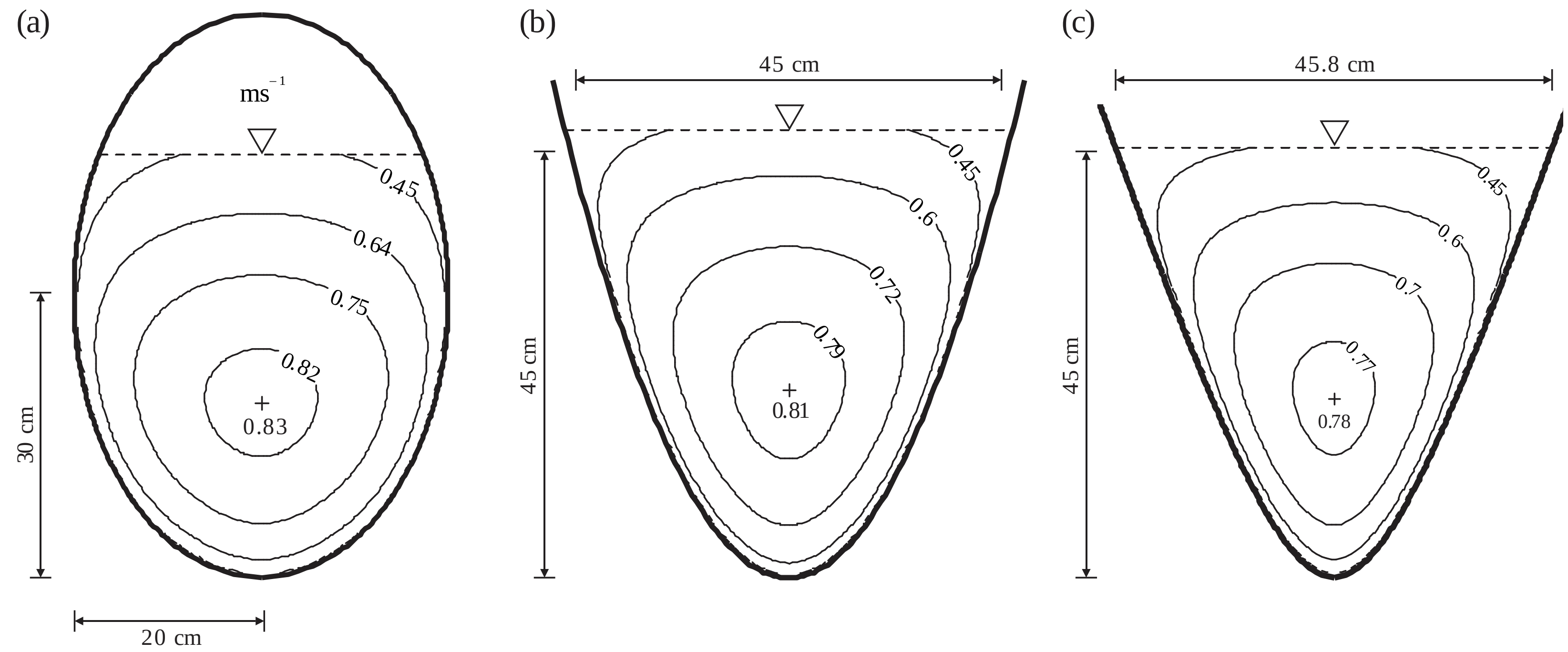
- For Clark and Kehler (2011), It is about 60% of flow depth.
  - Confirmed by data.

	Test Conditions						Fitting and computing parameters							
Test	S_f	h	h/D	Q3	V	u_*	k_s	u_*	u_{*c}	d	d /h	Error	r^2
	(-)	(m)	(-)	(m^3s^{-1})	(ms^{-1})	(ms^{-1})	(mm)	(ms^{-1})	(ms^{-1})	(m)	(-)	(-)	(-)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	0.00028	0.49	0.61	0.086	0.26	0.025	43	0.025	0.028	0.29	0.58	1.99	0.987
2	0.0011	0.35	0.44	0.086	0.40	0.045	69	0.048	0.053	0.21	0.59	2.30	0.986
3	0.0011	0.52	0.65	0.176	0.51	0.050	55	0.052	0.057	0.29	0.59	2.15	0.982
4	0.0027	0.27	0.34	0.085	0.56	0.064	64	0.069	0.076	0.17	0.61	2.75	0.982
5	0.0027	0.40	0.51	0.176	0.69	0.073	63	0.078	0.085	0.23	0.58	1.11	0.994

Applications for Fish Passage

- The proposed cross-sectional velocity distribution law can be used to find the velocity contours for fish passage.
- Detailed procedure is found in
  - » Guo, J., Mohebbi, A, Zhai, Y., Clark, S. (2014). Turbulent velocity distribution with dip-phenomenon in conic open channels. J. Hydraulic Res. (in press)
- Research need:
  - » Programs with spreadsheet, Matlab, or other math software are needed for practical engineers.

Velocity Contours for Other Conic Sections



Conclusions

- Conic cross-sectional velocity contours are described by a double log-cubic law.
- The proposed model is confirmed by data.
- It can be used to specify velocity contours for fish passage culverts.
- Research is needed for developing programs with spreadsheet, Matlab and other software for practical engineers.