2nd International Workshop on

Labyrinth and Piano Key Weirs – PKW 2013

Estimation of A-type Piano Key Weir rating curve

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….and in
Switzerland

Advantages of PKW

As compared to Labyrinth weirs

- small structural footprint: well suited for spillway rehabilitation on gravity dams for example
- improved hydraulic efficiency (discharge): gain up to 20% compared to labyrinth weirs

Hydraulic design supported by physical models, as few design criteria available

First comprehensive experimental studies

Extensive parametric research studies conducted by

- Kabiri-Samani and Javaheri (2012), *J. Hydraulic Res.* 50(1)
- Leite Ribeiro, Pfister, Boillat and Schleiss (2012), *J. Hydraulic Res.* 50(4)
- Machiels (2012), PhD *Thesis*, Liège

First general design equations related to rating curves are now available!

Do they provide similar results?

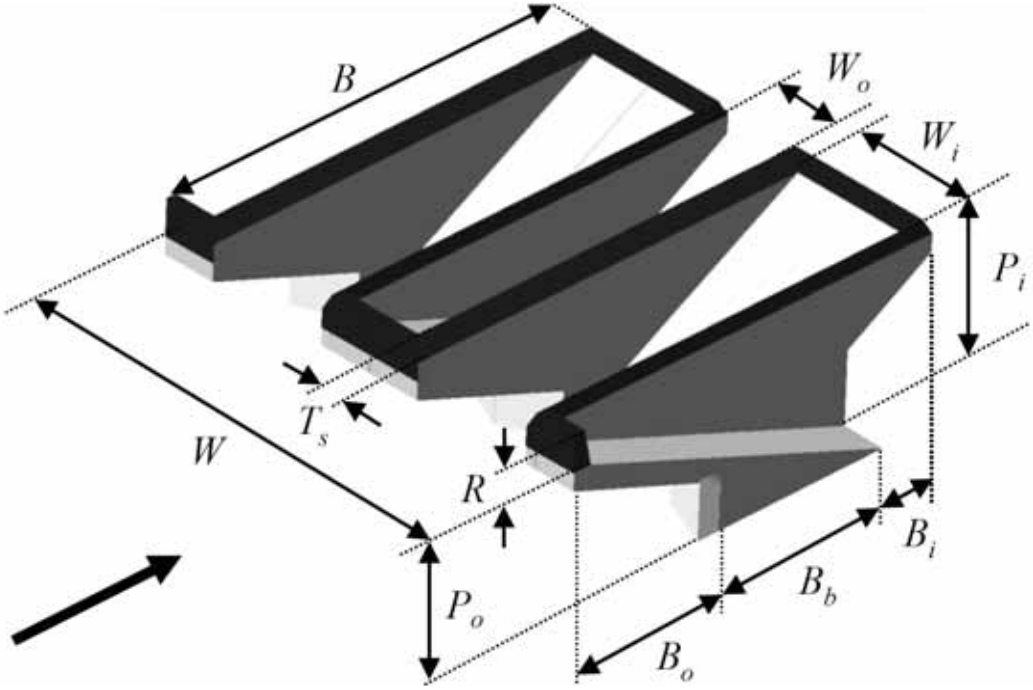
<u>Goal of the presentation:</u>

- Brief presentation of individual equations
- Comparison on virtual prototype respecting common range of application

First comprehensive studies

Application range – tested range of parameter

	L/W	H/P	W_i/W_o	B/P	B_i/B, B_o/B
Kabiri-S. & Javaheri	2.5-7.0	0.1-0.6	0.33-1.22	1.0-2.5	0.00-0.26
Leite Ribeiro et al.	3.0-7.0	0.1-2.8	0.50-2.00	1.5-4.6	0.20-0.40
Machiels	4.2-5.0	0.1-5.0	0.50-2.00	1.0-6.0	0.29-0.33



Kabiri-Samani and Javaheri (2012)

- 12 m long and 0.4 m wide channel
- Totally 600 tests resulting in 3000 data
- PKW types A, B, and C
- Specific discharges between 25 and 175 l/sm
- Genetic algorithm
- Free overfall and submerged set-ups
- Based on Poleni
- **Sharp, narrow crest**

For free overfall:

$$C_d = \left[0.212 \left(\frac{H}{P} \right)^{-0.675} \left(\frac{L}{W} \right)^{0.377} \left(\frac{W_i}{W_o} \right)^{0.426} \left(\frac{B}{P} \right)^{0.306} \exp\left(1.504 \frac{B_o}{B} + 0.093 \frac{B_i}{B} \right) \right] + 0.606$$

Leite Ribeiro, Pfister, Boillat and Schleiss (2012)

- 3 m long and 0.5 m wide channel
- 380 tests considering 49 different PKW geometries
- PKW types A
- Specific discharges between 26 and 440 l/sm
- Physically-based data analysis
- Free overfall conditions exclusively
- **Cylindrical, half round crest**

- Based on discharge increase ratio (relative to sharp-crested weir discharge)

$$r = \frac{Q_{PKW}}{Q_S} = \frac{Q_{PKW}}{0.42 W \sqrt{2g} H^{1.5}}$$

Leite Ribeiro, Pfister, Boillat and Schleiss (2012)

Prediction of *r*

$$r = 1 + 0.24\left(\frac{(L-W)P_i}{WH}\right)^{0.9} \cdot (wpba)$$

Individual correction factors

ratio inlet/outlet key width

$$w = \left(\frac{W_i}{W_o}\right)^{0.05}$$

ratio inlet/outletkey heights

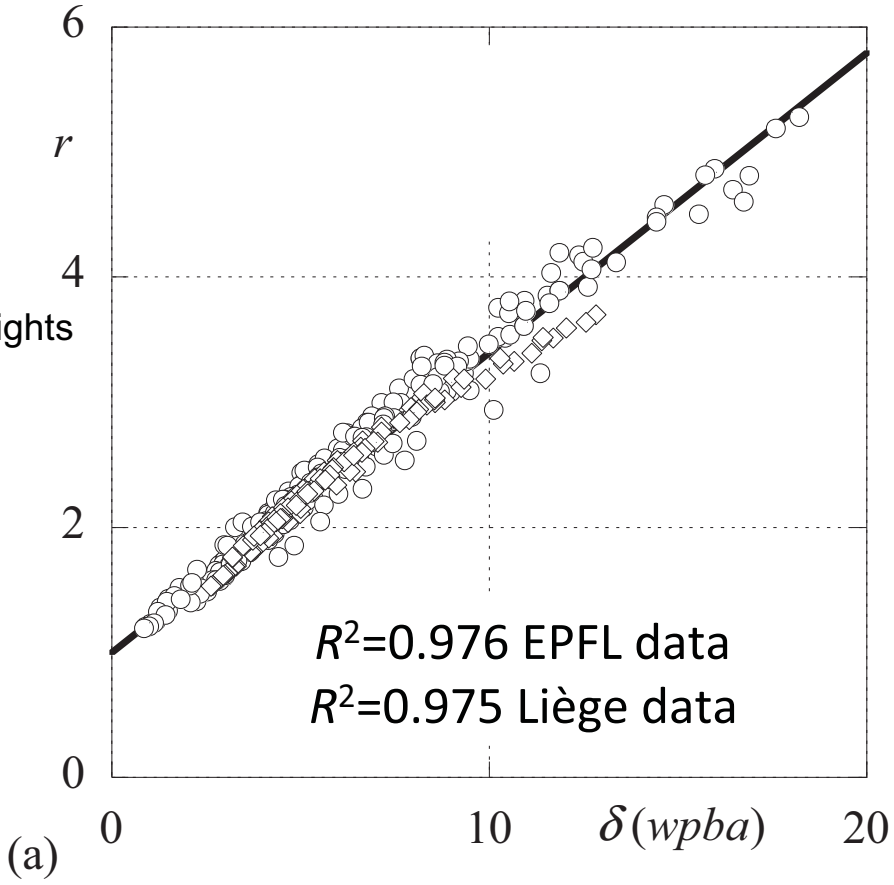
$$p = \left(\frac{P_o}{P_i}\right)^{0.25}$$

Ratio inlet key overhangs/base length

$$a = 1 + \left(\frac{R_o}{P_o}\right)^2$$

Relative parapet wall height

$$b = \left(0.3 + \frac{B_o + B_i}{B}\right)^{-0.50}$$



Machiels (2012)

- 7.2 m long and 0.3 m wide channel
- specific discharges between 13 and 400 l/sm
- Physical approach
- Free overfall conditions exclusively
- **Broad-crested weir top**

PKW discharge as sum of specific discharges:

Downstream(d) + upstream(u) + side crests(s)

$$q = \frac{Q_{PKW}}{W} = q_u \frac{W_o}{W_u} + q_d \frac{W_i}{W_u} + q_s \frac{2B}{W_u} K_{Wi} \; K_{Wo}$$

Plus some 13 equations specifying the parameter

Comparison of design formulas

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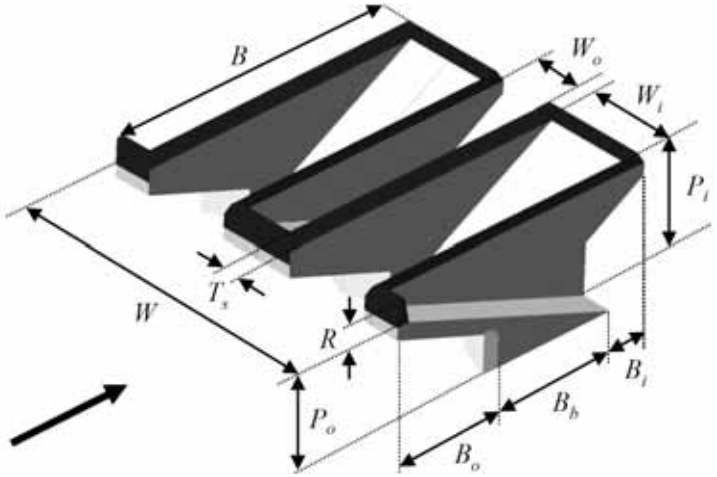
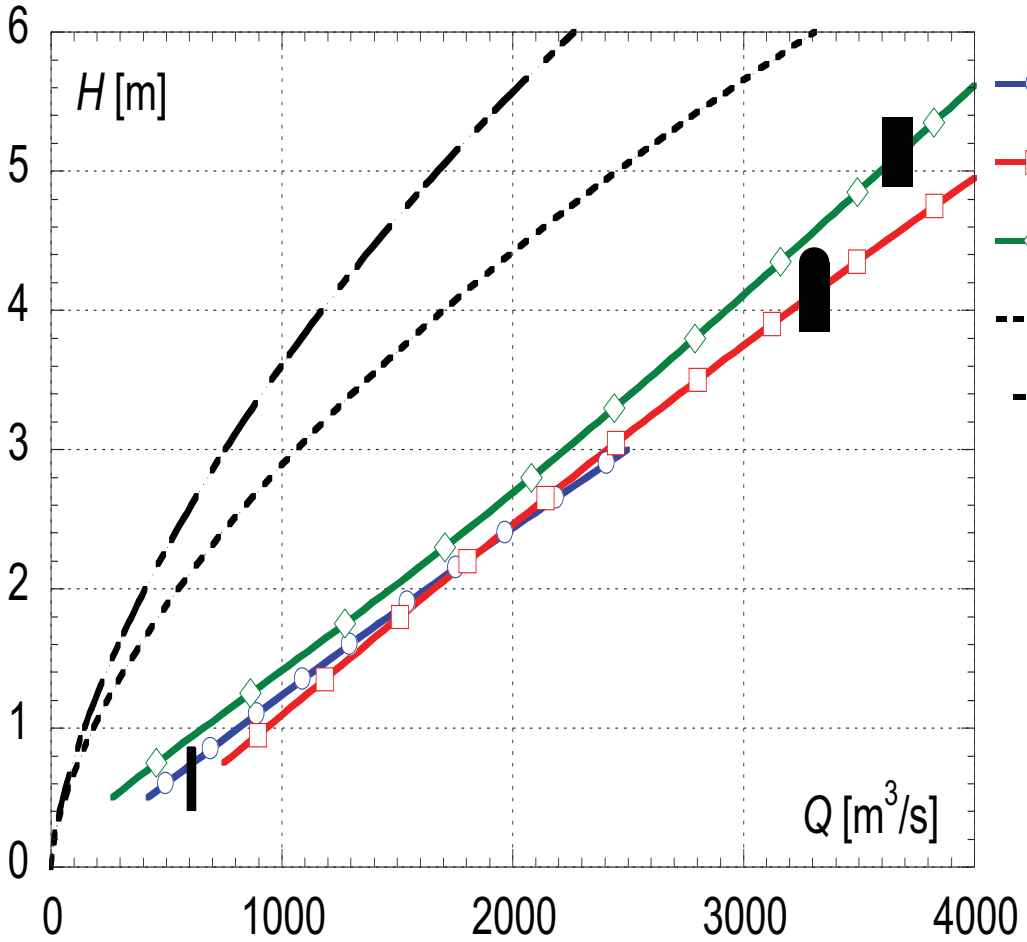
Virtual prototype respecting common application range

- RCC Dam, W=100 m wide spillway, dam height P_d=30 m,
- symmetrical A-type PKW, B=8.00 m, P=P_i=P_o=5.00, T_s=0.35 m, R=0 m (no parapet walls), W_i=1.80 m, W_o=1.50 m as, and B_i=B_o=2.00 m
- Ogee (standard) crest with H_D=5.00 m for Q_D=2'500 m^3/s
- Weir crest type according model tests used for formulas



Comparison of design formulas



PKW [Kabiri-Samani & Javaheri, 8]
PKW [Leite Ribeiro et al., 9]
PKW [Machiels, 10]
Ogee [Vischer & Hager, 11]
Broad-crested weir [Hager & Schwalt, 12]

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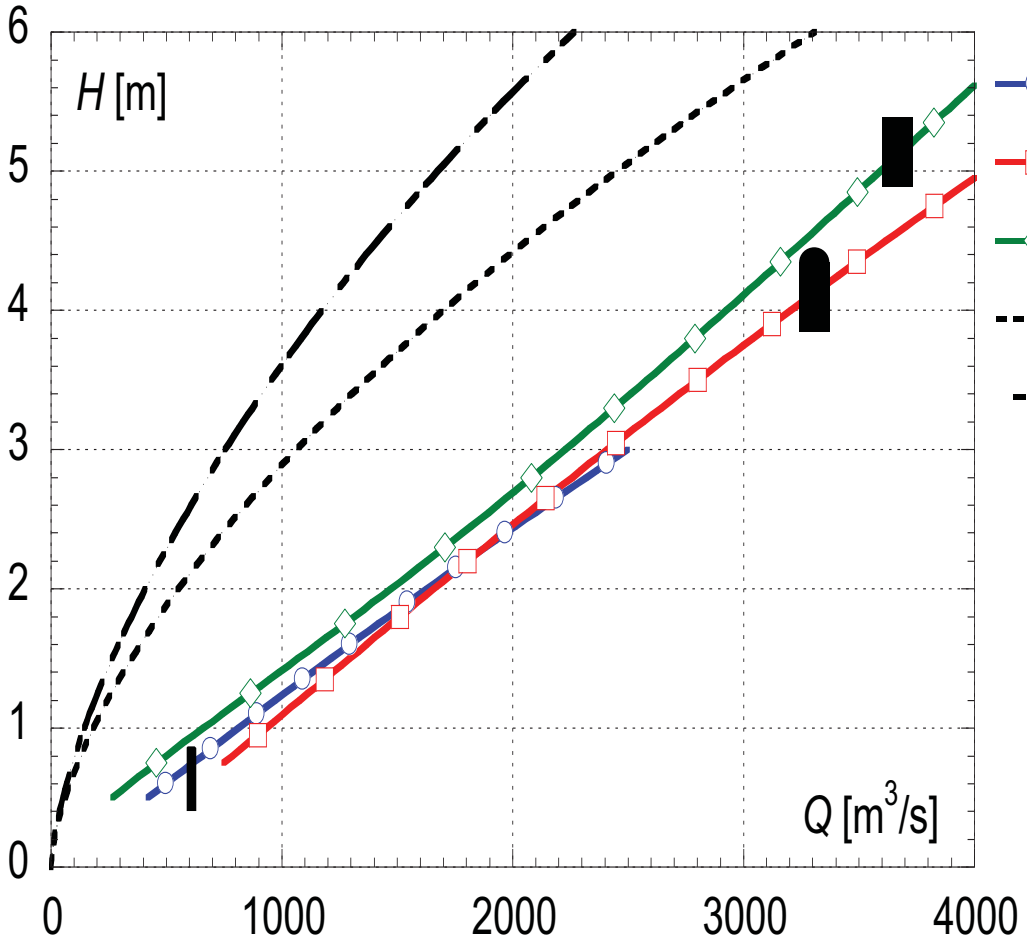

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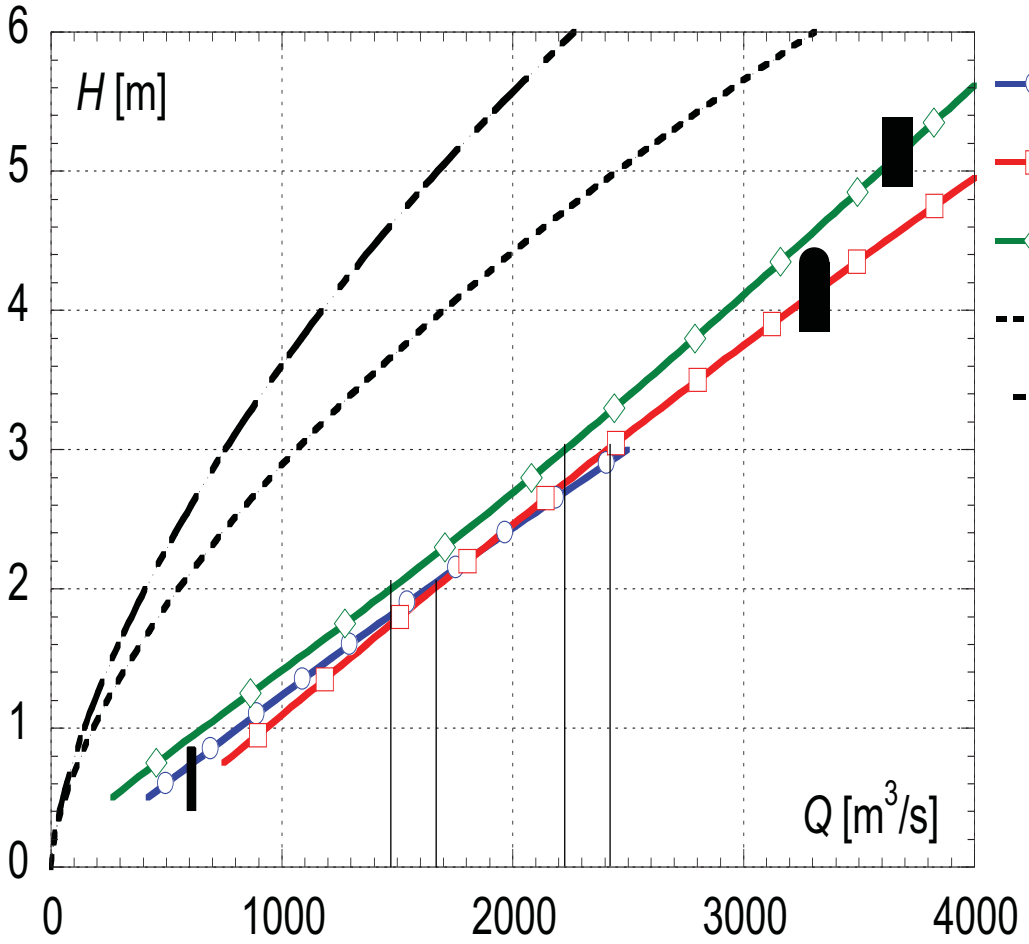

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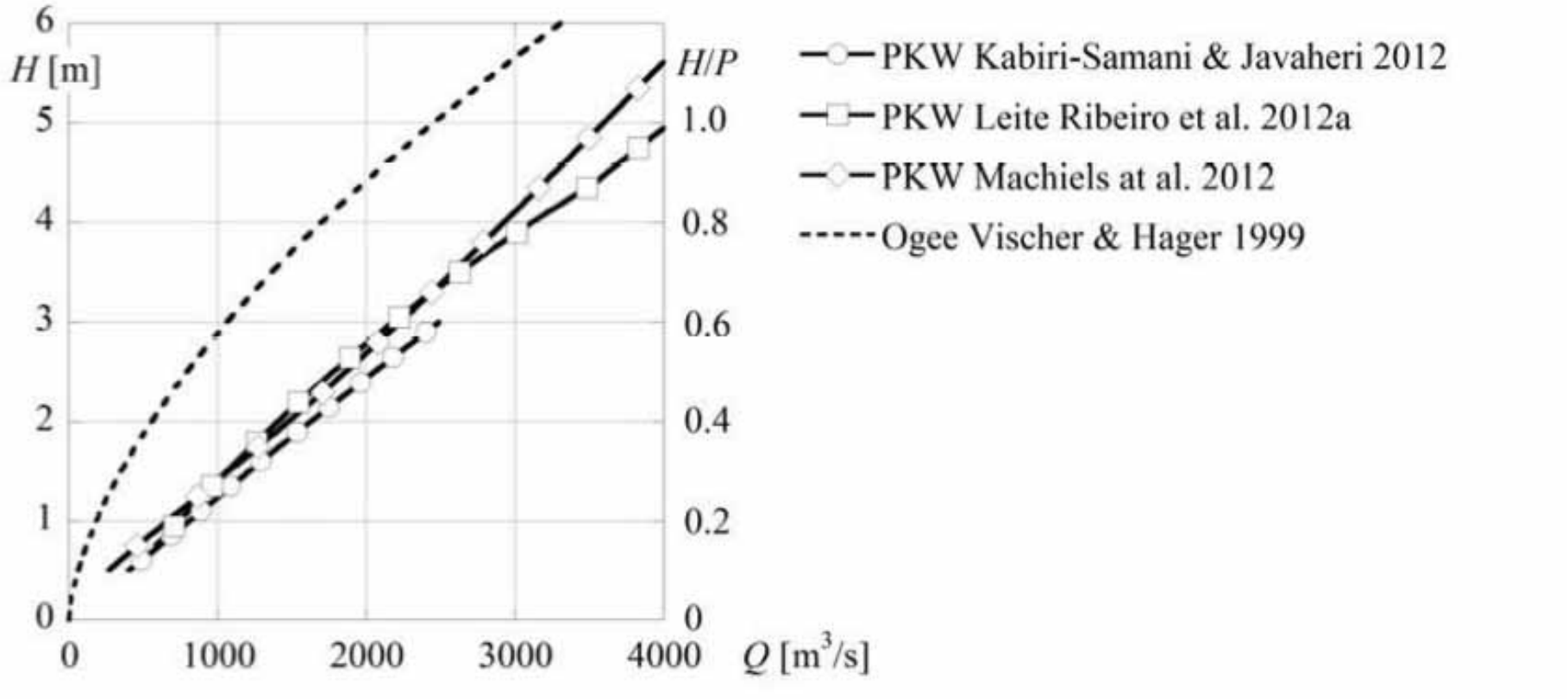
Broad-crested weir [Hager & Schwalt,

Difference in discharge estimation about 200 m^3/s between H = 2 m and 3 m

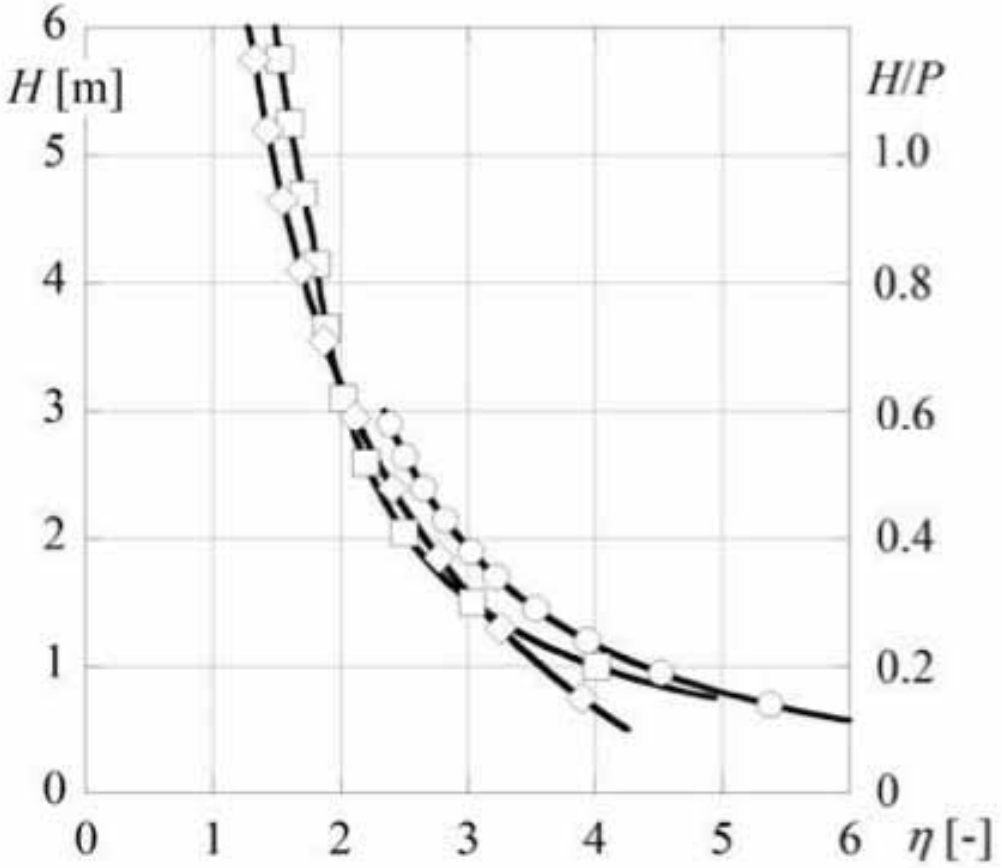
Comparison of design formulas

C_d for broad-crested weir as function of H (Hager & Schwalt, 1994), with T_s=0.35 m

C_d for cylindrical weir as a function of H (Castro-Orgaz 2012), with T_s=0.35 m



Comparison of design formulas



$$\eta = \frac{Q_{PKW}}{Q_{Ogee}}$$

Conclusions

- Three general design equations related to PKWs so far published
- They give quite similar discharges for certain head; differences mainly duo to crest shape; can be corrected
- Recommendation for design:
  - Use several formulas to obtain range of possible discharge efficiency
  - Use the formula which which has an application range close to the prototype and which uses similar crest shape

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Thank you for your attention

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