Journal of Irrigation and Drainage Engineering. Submitted October 5, 2011; accepted November 20, 2012; posted ahead of print November 22, 2012. doi:10.1061/(ASCE)IR.1943-4774.0000566

Parapet wall effect on Piano Key Weirs efficiency

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ABSTRACT

Piano Key Weir is a cost effective solution for rehabilitation as well as for new dam projects with a high level of constraints (limited space, high specific flood discharge, small reservoir level variation). While the higher efficiency of the Piano Key Weir compared to standard linear weirs has already been demonstrated, its optimal geometry is still poorly defined. In order to improve the design of the complex geometry of this structure, the use of parapet walls has been tested. They consist of vertical extensions placed over the weir crest. Following a former study of the influence of the weir height on its discharge capacity, this paper presents the results of an experimental campaign dedicated to investigating the effect of parapet walls to increase weir height while reducing bottom slopes and keeping the weir height constant. These results indicate the relative influences of the alveoli bottom slopes and of the weir height on the Piano Key Weir release capacity. Comparisons with former experimental results are also provided.

KEYWORDS: Hydraulic structure, Spillway, Piano Key Weir, Parapet wall, Experimental.

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INTRODUCTION

The Piano Key Weir (PKW) is a particular shape of labyrinth weir, developed by Lempérière (Blanc and Lempérière 2001, Lempérière and Ouamane 2003), using up- and/or downstream overhangs to limit its length and enable its use directly on a concrete dam crest. The PKW proved to be a cost effective solution both for rehabilitation and for new dam projects, in which space and available reservoir segment are limited compared to the design discharge to be released.

Following Pralong et al. (2011), the "PKW-unit" can be defined as the basic structure of a PKW, composed of an inlet, two transversal walls and two halves of outlets. The main geometric parameters of a PKW are the weir height P, the unit width W_u, the number of PKW-units N_u, the lateral crest length B, the inlet and the outlet widths W_i and W_o, the up- and downstream overhang lengths B_o and B_i, and the wall thickness T_s, as defined in Fig. 1.

The use of parapet walls has been tested while optimizing the hydraulic efficiency of PKW. They consist of vertical extensions placed over the crest of a PKW (Pralong et al. 2011). Even if Leite Ribeiro et al. (2009) show that the use of parapet walls on Etroit dam increases its discharge capacity by up to 15%, the efficiency of such structures has only been studied on a single PKW configuration, with or without parapet walls changing the total weir height ratio $P/(B-B_o)$ from 0.58 to 0.65. However, in the same range of slopes, modifying the PKW height by changing the inclination of inlet and outlet bottom slopes induces similar variations in the discharge capacity (Machiels et al. 2011a). Consequently, it is not so clear yet whether a PKW with parapet walls is indeed more efficient than a standard one having the same total height. Furthermore, in most cases of PKW use, the total weir height is fixed by the normal level of the reservoir and structural considerations on the main dam body that impose

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the toe level of the weir. It is thus of primary practical interest to compare PKW geometries with the same total height.

In this paper, as a part of a global experimental study over PKW behaviour, the role of parapet walls is studied on several PKW configurations, by either increasing or keeping constant the total weir height. This double approach indicates the effect of PKW height from the one of alveoli slopes, and provides practical guidelines on the use of parapet walls.

EXPERIMENTAL SET-UP

An experimental facility made of a 7.2 m long, 1.2 m wide and 1.2 m high channel has been built to perform the scale model tests. The channel, shown on Fig. 2, is fed by two pumps delivering up to 300 l/s in an upstream stilling basin. The upstream entry of the channel is equipped with a metal grid and a synthetic membrane ensuring uniform flow conditions. Two Plexiglas plates on both channel sides allow observation of the flow patterns of the whole channel height at the location of the PKW model. Specific convergent structures reduce the channel width to the one of the tested model.

To highlight the relative influence of parapet walls and of other geometric parameters of PKW, several PVC models have been tested with and without parapet walls, providing variants characterized by either the same bottom slopes or by the same total height, while different values have been used for inlet/outlet widths ratio, developed length ratio and slopes of the keys. The characteristics of these variants are given in Table 1, where P_r represents the parapet wall height, S_i and S_o are respectively the inlet and outlet bottom slopes, L is the developed crest length and W is the PKW width.

For all tested models, a stage-discharge curve has been established by combination of discharge measurements with an electromagnetic flowmeter (accuracy of 1 l/s) and upstream water head measurements with manual limnimeter (accuracy of 1 mm) for models 1 and 2,

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and ultrasonic probes (accuracy of 0.5 mm) for models 3 to 6. For models 3 to 6, water height measurements along the centre of inlet keys have also been performed. All measurements have been performed according Webber number over 50 to avoid scale effects. For these values of Webber number, the comparison of the discharges measured on scale model and on real sized prototype validates the Froude scaling approach (Machiels et al. 2011b, Machiels 2012).

RESULTS

The comparison of specific discharges over the weir for given upstream heads between the configurations with the same key slopes, with or without parapet wall, is shown in Fig. 3 for varied W_i/W_o, L/W and P/B values.

For models 1 and 3, there is no significant influence of the parapet wall on the discharge capacity. These models have key slopes near the optimal value of 1.2 defined in a former study about inlet slope influence (Machiels et al. 2011a). This former study also highlights the low influence of the key slopes for slopes between 1 and 1.5. In this study like in the present one, the bottom slope variation is directly linked to the weir height. It can thus be assumed that, for the particular geometries studied, an optimal weir height ratio $P/(B\text{-}B_o)$ near 1.2 is observed and the stage discharge curves for varying weir height ratios between 1 and 1.5 are close. The results obtained for models 2 and 5, which have the same geometries than, respectively, models 1 and 3 except for the weir height, show on an increase in discharge capacity by respectively 20% and 15% using a parapet wall. This suggests that the use of a parapet wall is relevant when the weir height ratio is far below the optimal one.

Although models 3 and 4 have the same weir height ratio, the parapet wall has a very different effect on these two models. While there is no significant influence in the first case, an increase by 4% in the discharge capacity has been found in the later case. Models 3 and 4

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however differ in terms of inlet/outlet widths ratio W_i/W_o. Ouamane and Lempérière (2006) showed that varying W_i/W_o also modify the discharge capacity of the PKW. They recommended an optimal value of W_i/W_o near 1.5. Subsequent studies confirm this influence and provided optimal values of this ratio between 1.2 and 1.4 depending on the upstream head and other geometrical parameters (Le Doucen et al. 2009, Machiels et al. 2010). The influence of a parapet wall seems thus to be more important when the inlet/outlet widths ratio is far below the optimal one. However, the same variation of this ratio is also observed between models 5 and 6, for which the discharge capacity increases by, respectively, 15% and 10%. In this case, the use of a parapet wall is found less relevant when the W_i/W_o ratio is far below its optimal value, as the gain in specific discharge decreases. Consequently, the effect of the W_i/W_o ratio on the efficiency of a parapet wall also depends on the PKW height.

For models 2 and 5, Fig. 4 compares the discharge capacity obtained with or without parapet wall, while keeping the same total weir height.

For both configurations, the discharge capacity is only slightly influenced by the use of a parapet wall. As expected after the analysis of Fig. 3, the parapet walls enhance the PKW discharge only if they increase the total PKW height to tend to its optimal value. There is thus no direct effect on the discharge capacity of the key slopes but well of the ratio between the total weir height and the length of the keys.

Fig. 5 shows the free surface profiles in the centre of the inlet key for the 3 variants of model 5 considering low, normal and high upstream heads H of respectively 5 cm, 15 cm and 24 cm.

Comparison of free surface profiles for models 5-2 and 5-3 highlights that the use of a parapet wall, while keeping constant the total weir height, influences only the downstream part of the inlet. Indeed, the maximal difference observed between surface profiles of the two

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models remains below 0.5 cm except on the downstream crest where it reaches 1.7 cm for the intermediate and the highest upstream heads. Since these two models have similar stage-discharge curves, it may be deduced that above a threshold upstream head, the downstream part of the inlet has no more influence on the PKW discharge capacity. This observation is confirmed by the development for high heads of a control section in the inlet, upstream of the inlet apex, which controls the discharge of the downstream part of the weir, as reported by Machiels et al. (2011b).

Comparison of free surface profiles for models 5-1 and 5-2 highlights the influence of the parapet walls increasing the total weir height far from its optimal value. For an upstream water head of 24 cm, the free surface is higher (up to 1.5 cm) without parapet walls except on the downstream crest (- 3.3 cm). However for this value of the upstream head, there is no more influence of the downstream part of the inlet key due to the presence of a control section. The model with a higher free surface along the lateral crest has thus a lower discharge capacity. That means that the lateral discharge is not directly a function of the water height over the lateral crest but also of the velocity in the inlet direction. The lateral discharge capacity will be reduced due to inertia effect, related to the velocity in the direction of the inlet key. In model 5-1, even if the water head along the lateral crest is higher than in model 5-2, the velocity in the direction of the inlet key is more important due to lower water heights in the inlet key providing by a lower total weir height. This higher velocity in the direction of the inlet key decreases the lateral discharge and, in turn, the discharge capacity of the PKW.

Fig. 6 shows the free surface profiles in the centre of the inlet key for the 2 variants of model 3 considering upstream heads of 5 cm, 15 cm and 24 cm.

The influence of the parapet wall, increasing the total weir height near its optimal value, is only visible in the downstream part of the inlet. The total weir height of the model

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without parapet walls is important enough to reduce the longitudinal velocity. The height increase, induced by the parapet wall, does not modify significantly this velocity and the lateral discharge is mainly influenced by the water height over the lateral crest. Once more, even if the free surface profiles vary on the downstream part of the inlet, for the intermediate and the highest upstream heads, it does not change the PKW discharge capacity, due to the presence of a control section upstream of this zone.

CONCLUSIONS

The main influence of a parapet wall on a PKW crest is an increase of the total PKW height. The use of a parapet wall, increasing the total weir height to approach its optimal value, has been shown to increase the discharge capacity of the PKW. At the contrary, the discharge capacity does not increase when a parapet wall is placed on a PKW having already an optimal weir height. Similarly, the discharge capacity does not change for PKW having the same total height with or without parapet wall. Consequently, the main effect of the parapet walls is to increase the inlet height and, hence, to reduce the longitudinal velocity resulting in an increase of the lateral discharge. However, the height of the parapet wall has to be limited to keep the interest of upstream overhang use that limit the head losses at the inlet key entrance and so give to the PKW a better discharge capacity than a labyrinth weir with same horizontal shape.

As practical design of PKW is based on project constraints which most of the time impose the weir height (normal reservoir level, structural characteristics of the dam, …), it is more convenient and cost effective to use standard PKW, without parapet walls. However, parapet walls provide a good opportunity for future PKW rehabilitations, enabling in some cases to increase the discharge of the initial PKW by up to 20% by a limited increase of the maximal reservoir level. Parapet walls must thus be conserved and studied as safety works for future.

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ACKNOWLEDGMENTS

This research has been realised thanks to the Belgian Fund for education to Industrial and Agricultural Research (FRIA).

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LIST OF SYMBOLS

B	Lateral crest length;
B_i	Downstream overhang length;
B_o	Upstream overhang length;
L	Developed crest length;
N_u	Number of PKW-units;
P	PKW height;
P_r	Parapet wall height;
q_1	Specific discharge over PKW without parapet walls;
q_2	Specific discharge over PKW with increasing height according to parapet use;
q_3	Specific discharge over PKW with increasing height without parapet use;
S_i	Inlet key bottom slope;
S_o	Outlet key bottom slope;
T_s	Wall thickness;
W	PKW width;
W_i	Inlet key width;
W_o	Outlet key width;
W_u	PKW-unit width;
X	Horizontal coordinate along the inlet key measured from the downstream apex;

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Z	Vertical coordinate measured from the bottom of the channel.

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LIST OF TABLES

Table 1. Geometric parameters of tested models and mean gain in specific discharge with use of parapet walls

Model	Variant	*P* [m]	P_r [m]	$S_i = S_o$	$P/(B-B_o)$	W_i/W_o	*L/W*	*Gain with parapet wall*
1	1	0.525	0	1.18	1.18	1	4.15	0% (variants 1–2)
	2	0.625	0.1	1.18	1.4	1	4.15	
2	1	0.135	0	0.34	0.34	1	4.15	20% (variants 1–2)
	2	0.235	0.1	0.34	0.53	1	4.15	0% (variants 2–3)
	3	0.235	0	0.53	0.53	1	4.15	
3	1	0.4	0	1	1	1.5	5	0% (variants 1–2)
	2	0.45	0.05	1	1.125	1.5	5	
4	1	0.4	0	1	1	0.67	5	4% (variants 1–2)
	2	0.45	0.05	1	1.125	0.67	5	
5	1	0.15	0	0.375	0.375	1.5	5	15% (variants 1–2)
	2	0.2	0.05	0.375	0.5	1.5	5	0% (variants 2–3)
	3	0.2	0	0.5	0.5	1.5	5	
6	1	0.15	0	0.375	0.375	0.67	5	10% (variants 1–2)
	2	0.2	0.05	0.375	0.5	0.67	5	

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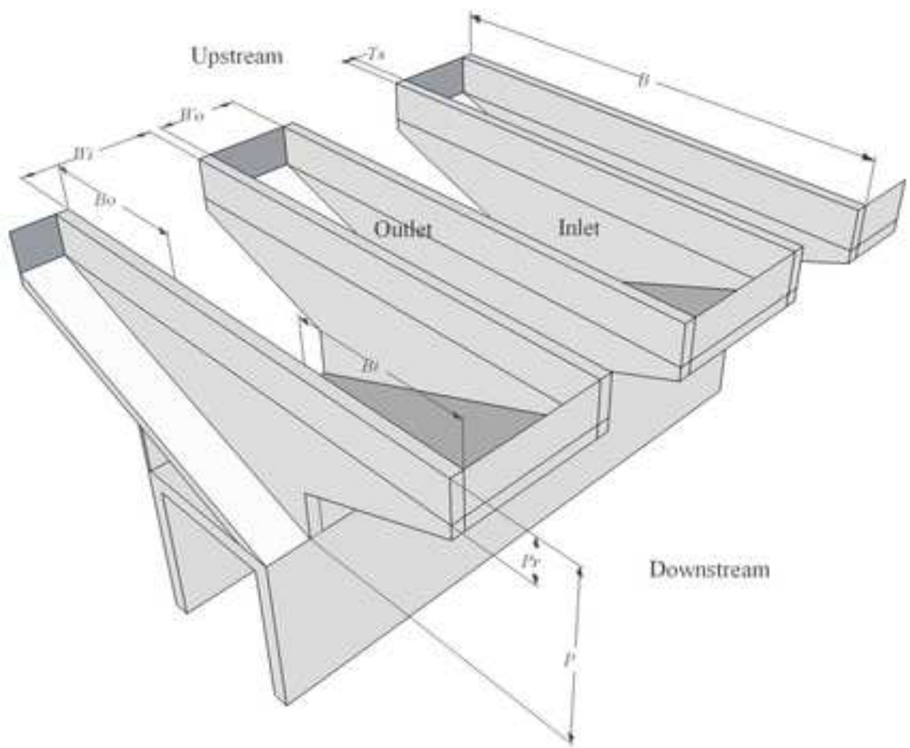

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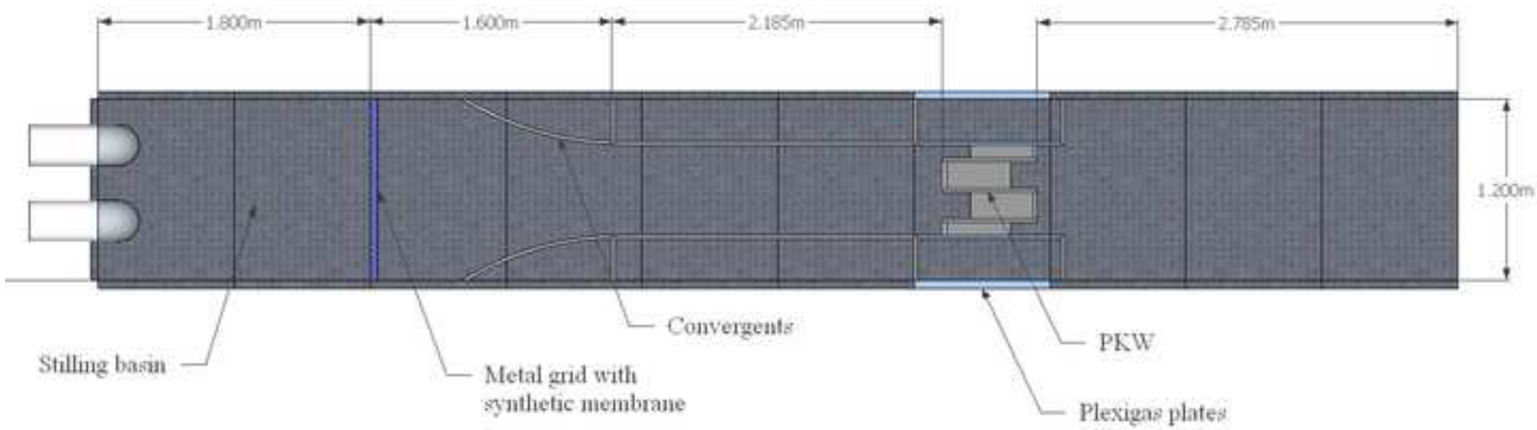

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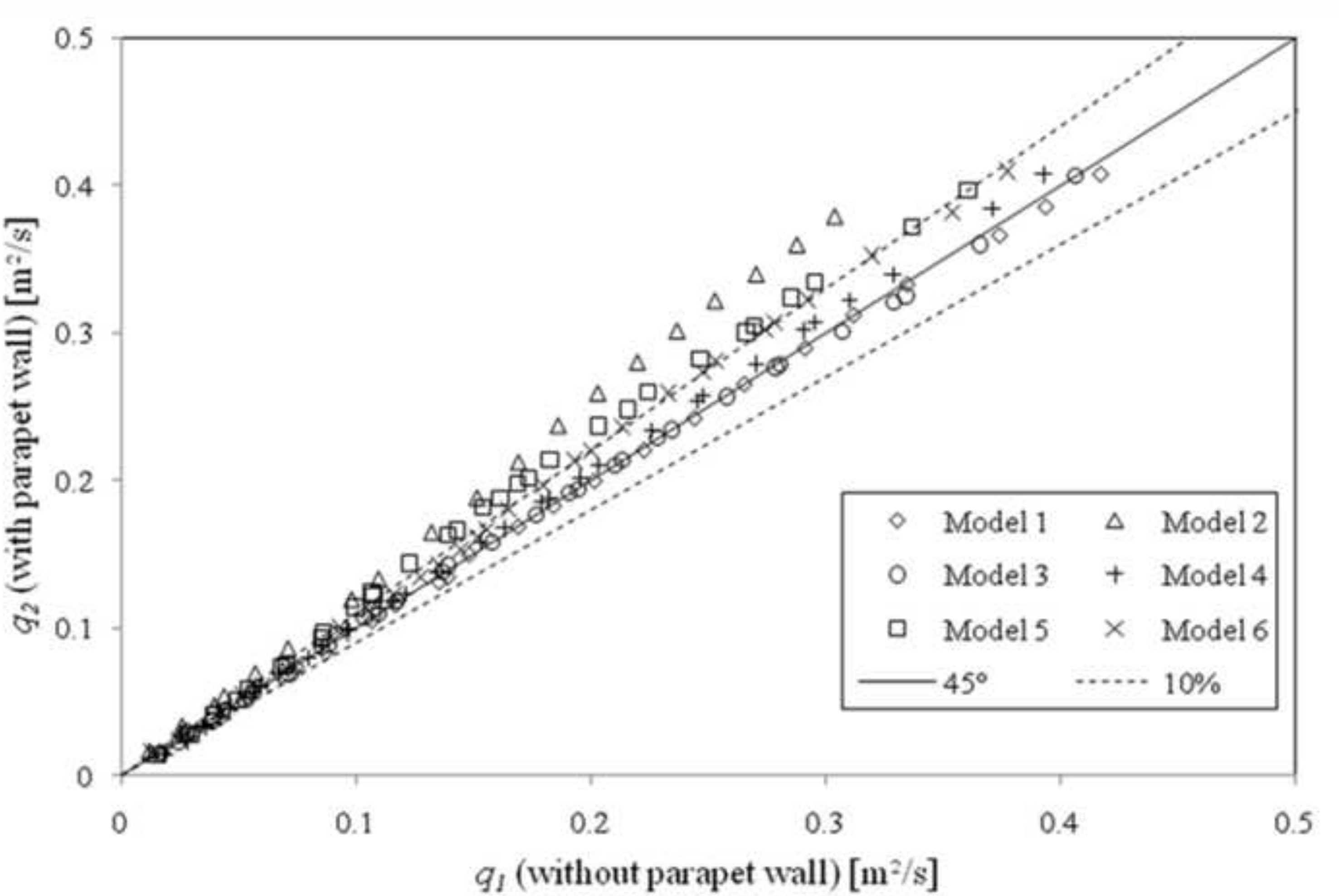

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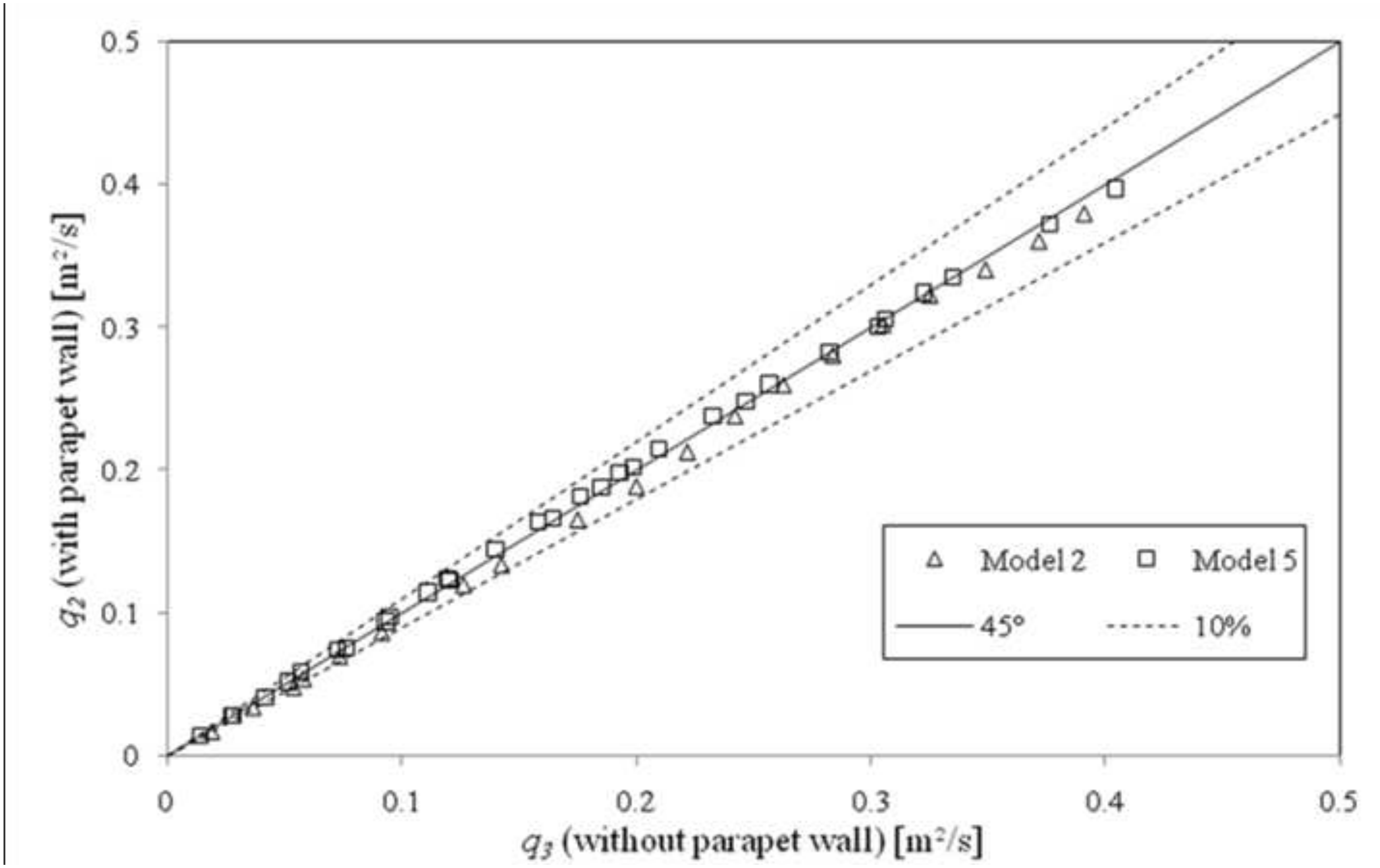

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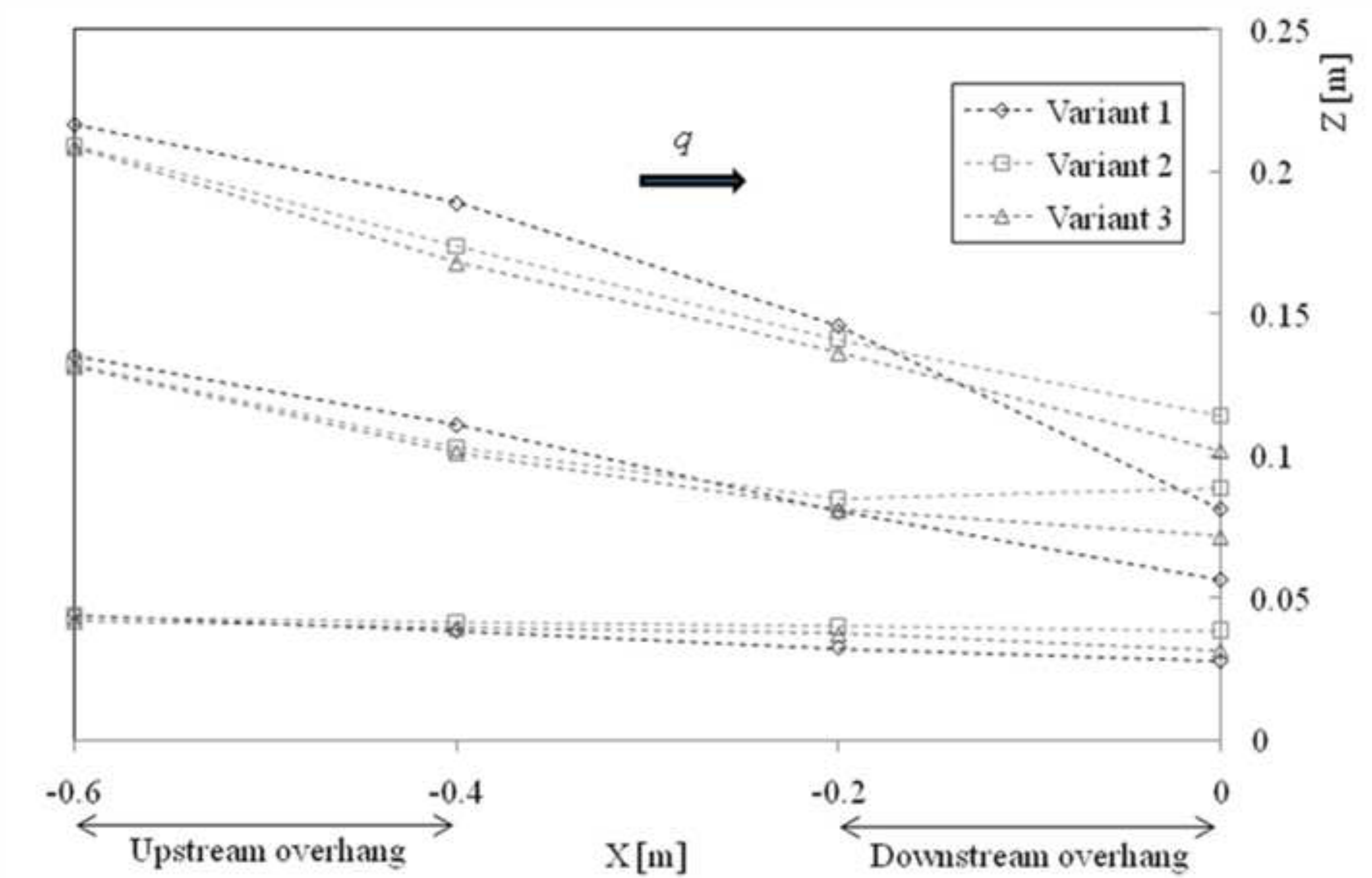

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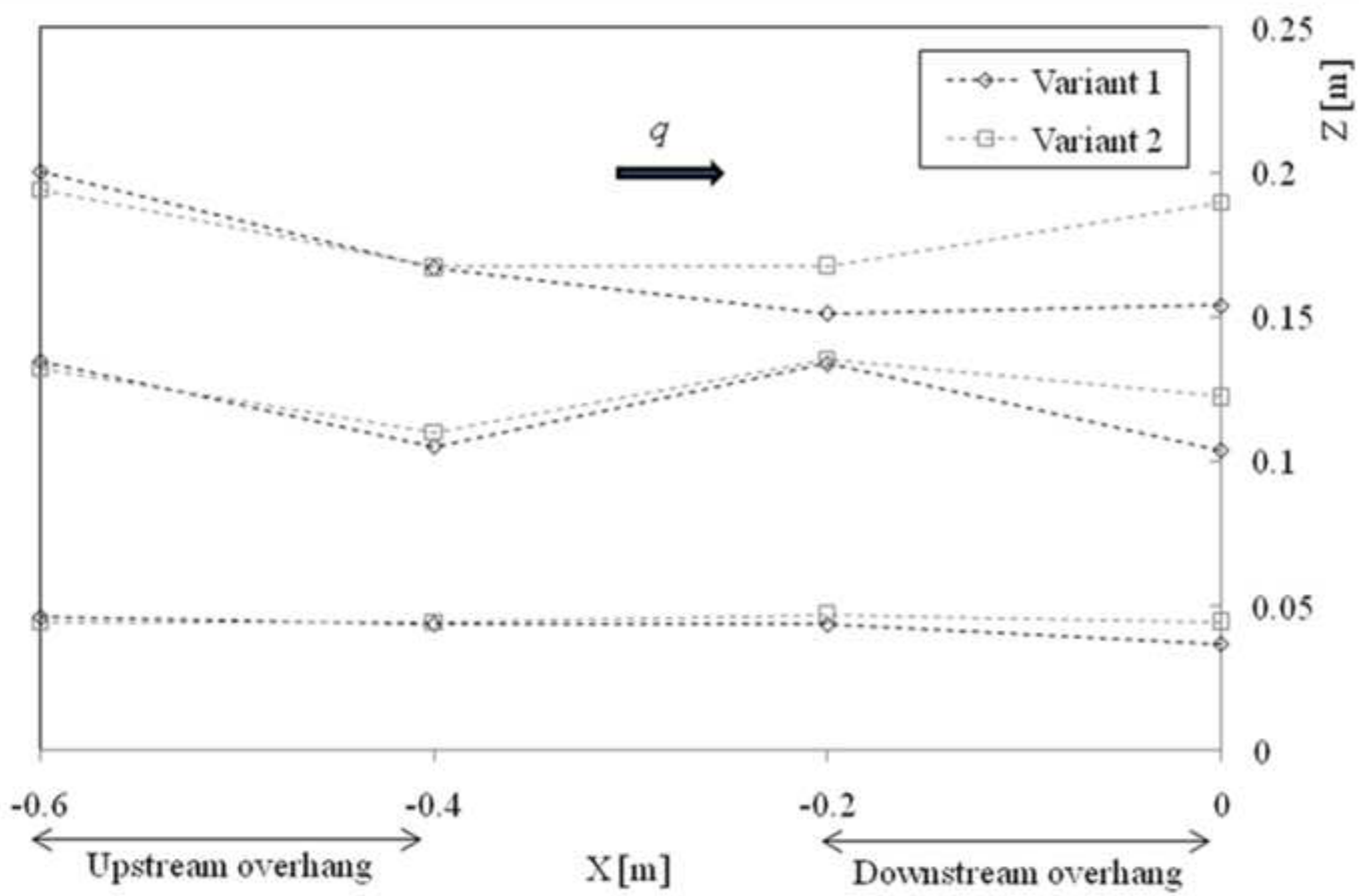

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