Flow Measurement and Instrumentation 45 (2015) 56–61

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Horizontal bottomed semi-cubic parabolic channel and best hydraulic section

Yan-Cheng Han

College of Resources and Environment, University of Jinan, P. O. Box, 250022 Jinan, China

ARTICLE INFO

Article history:
Received 3 January 2015
Received in revised form
29 March 2015
Accepted 2 April 2015
Available online 11 April 2015

Keywords:
Channel
Horizontal bottom
Semi-cubic parabolic
Best hydraulic section

ABSTRACT

This paper presents a new channel section having semi-cubic parabolic sides and horizontal bottom. The formulae for calculating the area, wetted perimeter are presented. The best hydraulic section is derived using three variables (water depth, water surface width and horizontal bottom width). Results show the ratios of the water surface width to depth, bottom width to depth and water surface width to bottom are all constant for the best hydraulic section. Explicit equations of the best hydraulic section for design are also deduced. Examples show these explicit equations are convenient for design. This type of best hydraulic section is compared with the trapezoid and classic semi-cubic parabolic sections. Results indicate that the area and wetted perimeter are less than those of trapezoid and classic semi-cubic parabolic sections for a given flow discharge. It means less lining and excavation cost is required for construction.

1. Introduction

There are various channel sections which are commonly used or studied such as the trapezoid, rectangular, semicircle, parabolic, catenary, semi-cubic parabolic, egg, circular sections etc. [1–4]. In a manner of speaking, that diversity is what makes the channel designers have more choices according to the different situations such as the hydraulic, economical, hydrogeological, seepage situations etc. Among these sections, the first two sections belong to horizontal bottomed section, and the rest sections are curve-shaped section which have curved bottom. Researchers have summarized the advantages of curved sections [1,5–9]: (1) they have less sharp angles at which cracks may appear as a result of stress concentration;(2) because the side slopes of the channel along the cross section are always less than the maximum allowable slide slope which occurs at the water surface, curved channels are physically more stable;(3) unlined canals, and irrigation furrows all tend to approximate a stable curved shape which make them been made more hydraulically stable; (4) normally, the curved channel sections have the larger flow capacity than trapezoid and rectangular section. However, curved channel sections have their shortcomings. For examples, as is usually the case, the tasks of construction lofting, trench excavating, foundation tamping and lining are more difficult to achieve for the curved section than for the trapezoid and rectangular section, which will uplift the construction costs of the curved section. Furthermore, after the channel is built, the operations (including maintenance, repairing, overhauling, cleaning, dredging etc.) of the trapezoid and rectangular sections are relatively easier than those of the curved sections. Hence, these advantages (the simpler construction technological process and easier foundation compacting, construction lofting, trench excavating, channel operations etc.) make trapezoid and rectangular sections still the most popular forms, although their hydraulic characteristics are not good as the curved channel.

A channel section having the largest flow capacity for a given section area or shortest wetted perimeter is known as the best hydraulic section. It is important in open channel design [7]. Because it can make the flow capacity largest, and the construction cost close to the minimum at the same time [10,11], it has been the focus of researches. Monadjem [12] has deduced the general equations of optimal hydraulic section using Lagrange's multiplier method, which is a directly perceived method. Guo [13] has studied the open channel optimal hydraulic section considering freeboard. Froehlich [14] has studied the optimal hydraulic section with the water width and depth constraints. Loganathan [6] has described the conditions for the optimal hydraulic parabolic section considering freeboard and limitations on velocity and canal dimensions, deduced various formulae and dimensionless parameters. Vatankhah [7] presented a new type of section called semi-regular polygon section such as semi-square, semi-hexagon and semi-octagon, presented the general solution of the best hydraulic section for this type of section. Abdulrahman [15] presented a section of a composite channel with a lower trapezoidal section and an upper rectangular section. Froehlich [16] has

E-mail address: stu_hanyc@ujn.edu.cn

http://dx.doi.org/10.1016/j.flowmeasinst.2015.04.001
0955-5986/

Notation

The following symbols have been used in this technical note

- A flow area for classic semi-cubic parabolic section (m^2);
- A_f flow area for horizontal bottomed semi-cubic parabolic section (m^2);
- A_t flow area for trapezoid section (m^2);
- a shape parameter of semi-cubic parabolic section;
- B water surface width for classic semi-cubic parabolic section (m);
- B_f water surface width for horizontal bottomed semi-cubic parabolic section (m);
- B_t water surface width for trapezoid (m);
- β_f optimal breadth–depth ratio for horizontal bottomed semi-cubic parabolic section;
- b the width of the channel bottom (m);
- C_f construction cost of horizontal bottomed semi-cubic parabolic section;
- $C_{t,\min}$ construction cost of trapezoid section per length;
- C_e cost of earthwork excavation per length;
- C_a cost of land acquisition per length;
- η_c optimal breadth–depth ratio for classic parabolic section;
- η_f optimal breadth–depth ratio for horizontal bottomed semi-cubic parabolic section;
- h flow depth (m);
- i longitudinal bed slope;
- m the slope coefficient of side face for trapezoid section;
- n roughness;
- P wetted perimeter for classic semi-cubic parabolic section (m);
- P_f wetted perimeter for horizontal bottomed semi-cubic parabolic section (m);
- P_t wetted perimeter for trapezoid (m);
- Q flow discharge (m3/s).

studied the cross-sectional dimensions of the most hydraulically efficient lined canals based on an analysis of a generalized trapezoidal shape that reduces to two standard sections with rounded bottom vertices. Raikar et al. [3] presented the deterministic models using regression analysis to compute the normal and critical depths for an egg-shaped conduit section recommended by Indian Standard Code of Practice. Bijankhan et al. [4] developed the iterative formulas to determine the normal flow depth to desired accuracy for the egg-shaped cross section.

Recently, the composite sections have received more attentions. Babaeyan-Koopaei et al. [17] have presented a section shape with the parabolic bottom and the triangular shape sides using Lagrange's multiplier method. Results show the flow capacity and economic performance of this type of section is better than trapezoid section. Das [8] has introduced a horizontal bottomed parabolic section, and studied its optimal economical section. Easa [9] further presented a section having two-segment parabolic sides and horizontal bottom.

It is known that the classic semi-cubic parabolic section has sharp bottom which influences the flow capacity and economies. For improving its performance, in this paper, a new section with horizontal bottom and semi-cubic parabolic sides are presented. It has the advantages of curved and trapezoid sections.

2. Classic semi-cubic parabolic section

The shape of the classic semi-cubic parabolic section (shown in Fig. 1) is described as

$$y = ax^{3/2} \tag{1a}$$

where, y=longitudinal coordinates; x=horizontal coordinates; a=section shape parameter, it is given by

$$a = 2\frac{h\sqrt{2}}{B^{3/2}} \tag{1b}$$

where, B = width of water surface; h=water depth.

Utilizing the concept of the definite integral and geometric meaning definitely to solve problems of area, wetted perimeter, they can be expressed as

$$A = 2\left(h\frac{B}{2} - \int_0^{B/2} y\mathrm{d}x\right) = hB - 1/10\sqrt{2}B^{5/2}a = 3/5hB \tag{2a}$$

$$P = 2\int_0^{B/2}\sqrt{(\frac{\mathrm{d}y}{\mathrm{d}x})^2 + 1}\mathrm{d}x = \frac{(18\,a^2B+16)^{3/2} - 64}{108\,a^2} = \frac{B^3}{864h^2}\left[\left(144\frac{h^2}{B^2}+16\right)^{3/2} - 64\right] \tag{2b}$$

where, A, P=area and wetted perimeter of the classic semi-cubic parabolic section.

3. Characteristics of horizontal bottomed semi-cubic parabolic section

From Fig. 1, one knows the classic semi-cubic-parabolic section has smaller and sharp bottom. To improve the capacity of flow discharge, a new type of channel section with a horizontal bottom and semi-cubic-parabolic sides is created (shown in Fig. 2). The governing equations of this composite section is defined by

$$\begin{cases} y = a(|x+\frac{b}{2}|)^{3/2} & x \le -\frac{b}{2} \\ y = 0 & -\frac{b}{2} < x < \frac{b}{2} \\ y = a(x-\frac{b}{2})^{3/2} & x \ge \frac{b}{2} \end{cases} \tag{3}$$

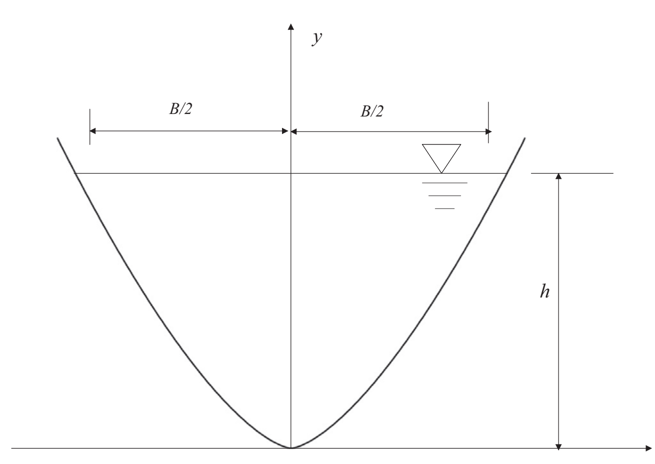

Fig. 1. Classic semi-cubic parabolic section.