Clear-Water Experimental Scour Depths at Abutments

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***Abstract*—*Laboratory experiments on local scour process at wing wall bridge abutments were conducted for different hydraulic conditions and compared with measurements on local scour depths around vertical wall abutments, under the same flow and sediment transport conditions. The study reports an extensive experimental investigation performed in a laboratory flume in the Technological Educational Institute of Thessaly, whose findings are used to describe the effects of different hydraulic parameters on local scour depth variation in the vicinity of the constructions. Three different sizes of wing wall abutment's lengths, transverse to the flow direction, were used in order to investigate the impact of this parameter to local scour variation. The expected bed erosion and the maximum scour depth at the upstream edge of the wing wall abutments are satisfactorily simulated by the experimental procedure. All the experimental results are graphically presented and comparisons between clear-water scour depths around the vertical wall and the wing wall abutments show lower values of scour depths in the vicinity of the wing wall abutments, under the same hydraulic and sediment transport conditions and for the same abutment widths. The experimental data of clear-water scour conditions were used to determine an equation of maximum equilibrium scour depth through regression analysis. The estimated scour depths were in agreement with the experimental values for each abutment geometry.*

Keywords*—*Abutments, Laboratory experiments, Open channels, Scour depth.

I. INTRODUCTION

Realistic estimation of scour depth around bridge abutments in alluvial rivers is important for safe and economic design of their foundations. The scour hole just downstream of the head of the abutment can endanger the stability of the structure and led to the failure of the construction. The basic mechanism causing local scour at piers or abutments is the formation of vortices at their base which removes bed material from around the base of the construction. From the engineering view point, an accurate quantitative estimation of local scour process around hydraulic structures is necessary for the prevention of severe environmental problems un natural rivers.Extensive research has been conducted to determine the depth and location of the scour hole that develops around abutmentsand numerous abutment scour equations have been developed to predict this maximum scour depth [5].

Numerous experimental investigations have been performed on the study of the flow, the bed level variation and mainly the scour mechanisms in rivers and especially around bridge piers and abutments. Laboratory investigations of local scour at bridge piers and abutments were presented [7] and [6]. Development of local scour depths at vertical wall bridge abutments of varying lengths was investigated in several series of experiments of ranges of uniform sediments and clear-water flow intensities[1].Local scour experiments were performed around a trapezoidal abutment [9] and experimental measurements to simulate bed variation near a trapezoidal bridge abutment and investigation of the impact of water depth and flow discharge on scour depths were also performed [3].

The objective of this research work is to investigate local scour process around wing wall abutments and compare the experimental results of equilibrium scour depths around vertical wall and wing wall abutments, under the same hydraulic and sediment transport conditions. For this purpose, a laboratory experimental procedure was established to simulate local scour around wing wall abutmentsin uniform sediments under clear-water scour conditions. The impact of flow discharge and width of the abutment, for each abutment geometry, is also investigated and the findings are used to describe the effects of various parameters on scour depth and to determine an equation of maximum equilibrium scour depth.

II. EXPERIMENTAL LABORATORY PROCEDURE

The experiments were conducted in a 6.0m long, 0.078m wide and 0.25m deep research flume at Hydraulics Laboratory of Civil Engineering T.E. Larissa Department, Technological Educational Institute of Thessaly. As the object of the current work is the comparison of scouring procedure around vertical wall and wing wall abutments, three differentsizes of abutment models, for each geometry, were used and a parametric investigation of local scour depth evolution around the obstructions was conducted.Each abutment model was placed on the plexi-glass wall of the flume, parallel to the flow direction. The abutment projected into the main flow and was located at a distance of 2.0 m from the inlet test section. The streamwise length of each vertical wall abutment was equal to 0.10m while for the wing wall abutment it depends on the abutment width according to the angle of the abutment walls, which was equal to 80^{o}.The lengths of the abutmentstransverse to the flow, abutment width, b, were constructed equal to 0.036m, 0.045m and 0.051m.All the experiments on local scour were conducted at short abutments as the ratio of abutment width to approaching flow depth was less than unity. The bottom slopes of the tested flume, in longitudinal and transverse directions, were set equal to zero.Fig. 1 shows a schematic illustration of the total experimental set-up. The bottom of the tested experimental area was carefully covered with material, consisted of sand, producing a uniform layer of sediment of 0.15 m thickness. The used bed material had a mean diameter D_{50} of 2.0 mm, a specific weight $S_g$of 1.60 and was assumed to be uniform as the geometric standard deviation, computed by $(D_{84}/D_{16})^{0.5}$ was equal to 1.26. The experimental inflow discharges, Q, were equal to 0.0004 m^3/s, 0.0005 m^3/s, 0.0006 m^3/s, 0.0007 m^3/s, 0.0008 m^3/s and 0.00095 m^3/s.The same laboratory hydraulic conditions, bed sediment load characteristics and the experimental procedure for the simulation of local scour process around vertical wall abutments were also used for the current experimental investigation of scouring procedure around wing wall abutments.Clear-water scour conditions were maintained for all the experiments [4].In order to maintain the condition of short abutments, with respect to the flow depth upstream of the abutment, h, the ratio b/h was restricted to b/h ≤ 1 for all experiments.

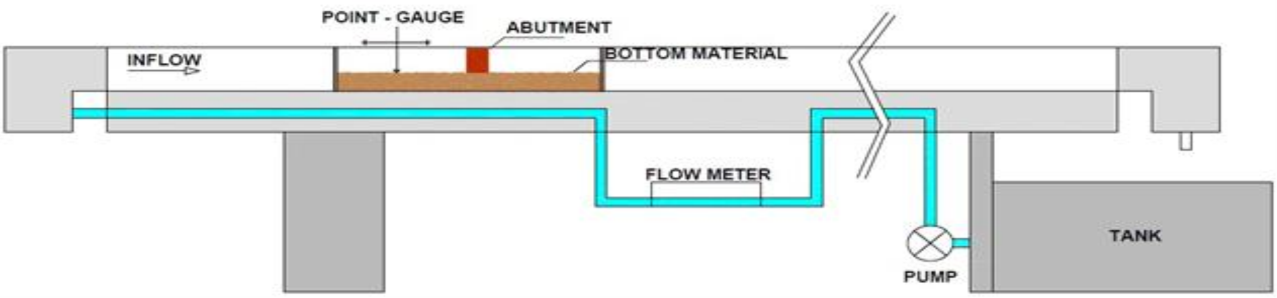


FIG. 1. SCHEMATIC VIEW OF THE LABORATORY EQUIPMENT

After the required time duration period is reached, the bed elevation measurements data, under equilibrium conditions, were recorded using a water-level gauge moving in longitudinal and in transverse directions of the flume introducing an optical error of ~0.1mm. Measurement data were obtained along the ¨flow lines¨ presented in Fig. 2. ¨Flow line¨ 1is located at a constant distance of 0.005m to the streamwise face of the abutment parallel to the flow direction.All measurements along the hypothetical ¨flow line¨ 1 were obtained at successive distances of 0.02m for the verticalwall abutments and are presented along the red ¨flow line¨ 1 while the measurements,for the wing wall abutment, along the hypothetical ¨flow line¨ 1 were obtained at successive distances of 0.02 and 0.01m and are presented along the blue ¨flow line¨ 1 in Fig. 2.

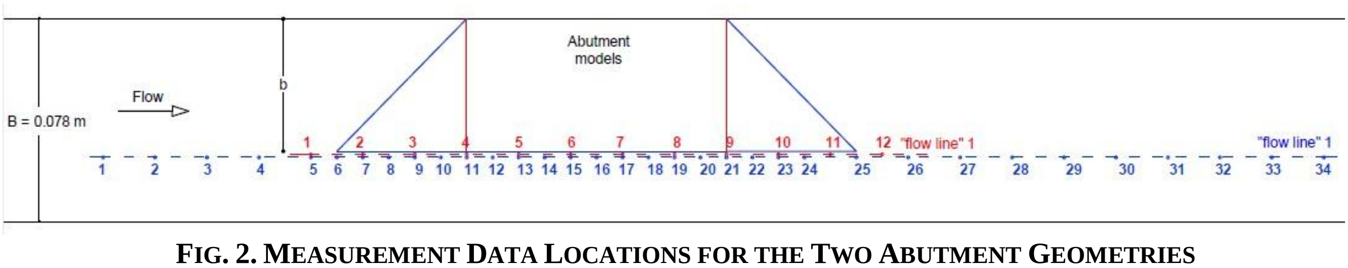
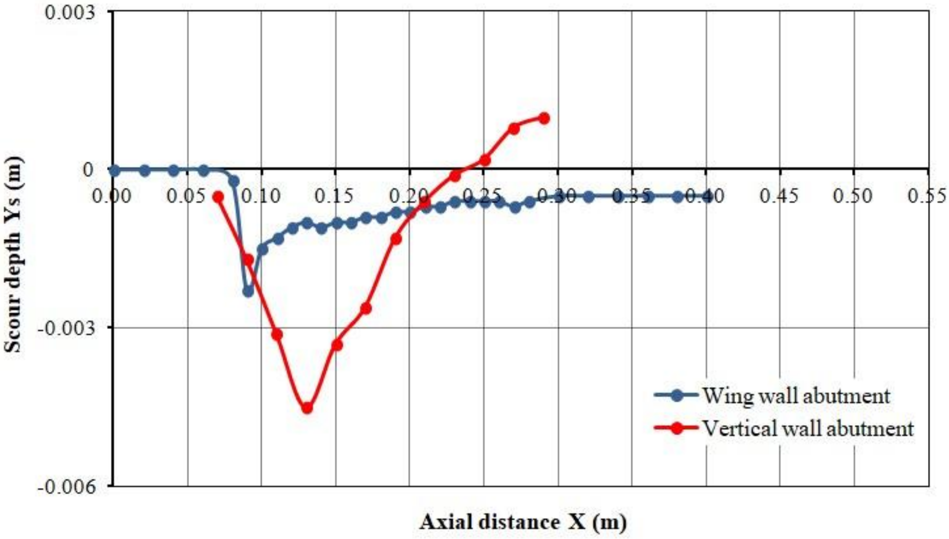


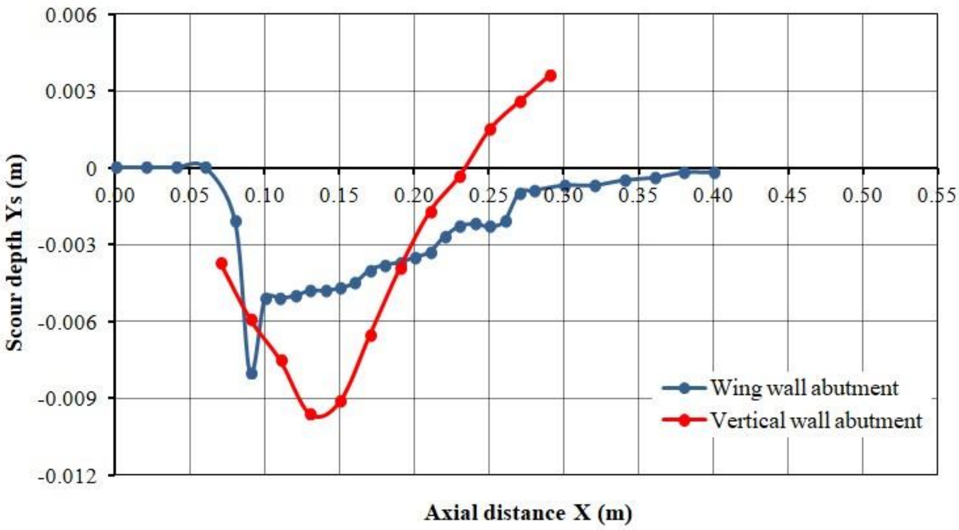
FIG. 2. MEASUREMENT DATA LOCATIONS FOR THE TWO ABUTMENT GEOMETRIES

III. ANALYSIS OF SCOURING PROCESS

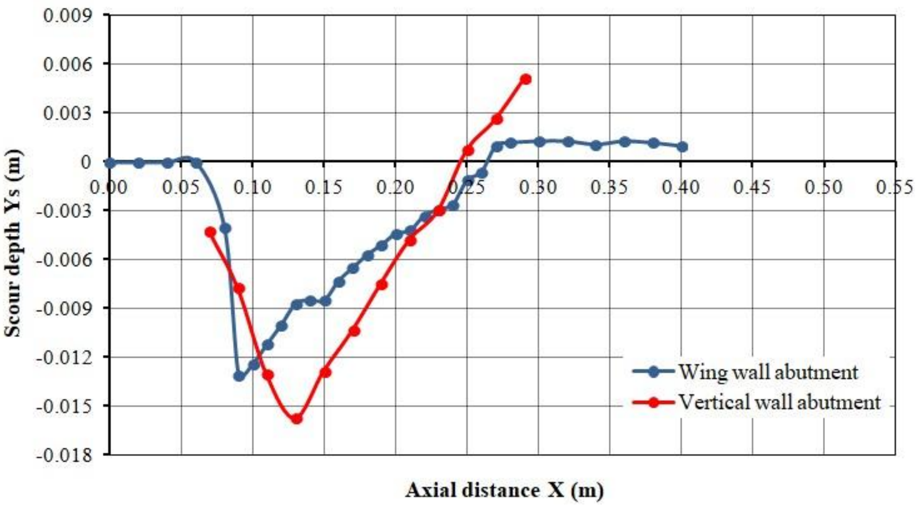
Fig. 3 presents the experimental equilibrium local scour depths along the aforementioned ¨flow line¨ 1 for the vertical wall and for the wing wall abutment, with abutment width equal to b=0.035m, under different hydraulic conditions for six different inflow discharges. Maximum local scour depth measurements along the ¨flow line¨ 1 for the same hydraulic conditions and for abutment's lengths, transverse to the flow, equal to 0.045m and 0.051m, are given in Figs 4 and 5, respectively.Experiments show that along the upstream to the abutment region and close to the upstream side of the abutment erosion increases and a scour hole develops. The maximum scour depth occurs upstream of each abutment, at the upstream corner of the construction. At the downstream side of the abutment, the previously eroded material is deposited there and the scour depth is relatively small. Analyzing the experimental measurements, it is obviously that for each abutment width the maximum depth of scour and the scour hole area are always greater in the region of the vertical wall abutments than around the wing wall abutments, for the same hydraulic conditions. Moreover, the plots demonstrate that for the same hydraulic and sediment transport conditions maximum local scour depth increases with increase in the abutment width, normal to the flow direction, for each experimental simulation.



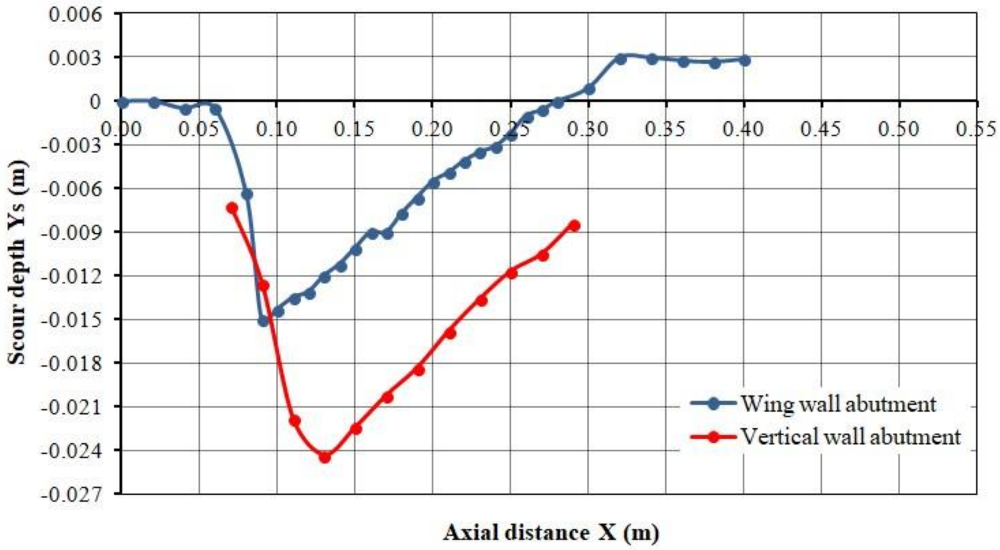
(a) Q=0.0004 m^3/s



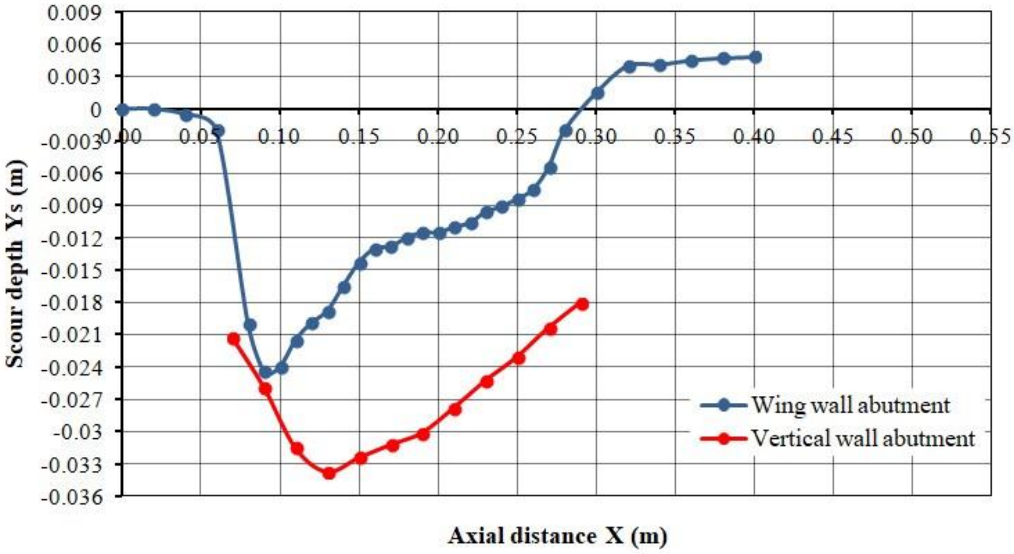
(b)Q=0.0005 m^3/s



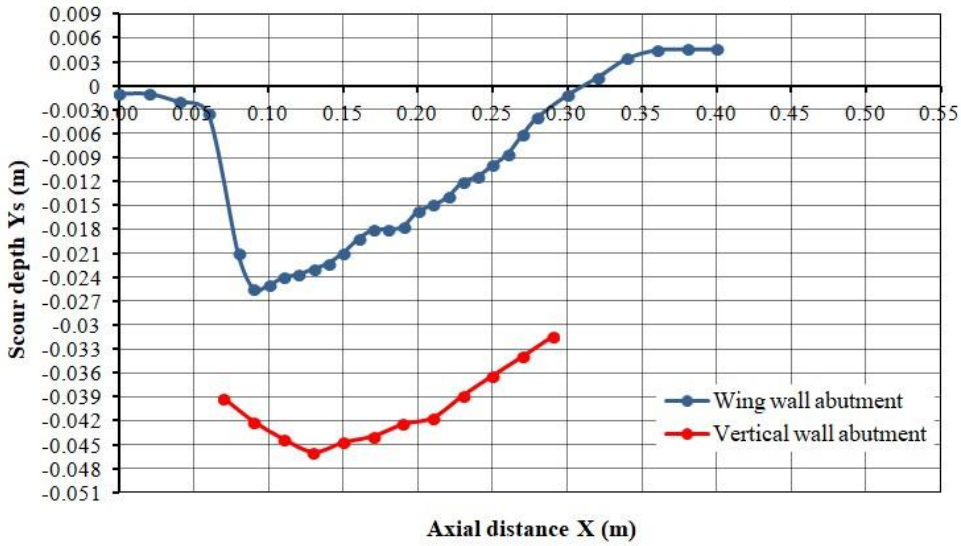
(c)Q=0.0006 m^3/s



(d)Q=0.0007 m^3/s

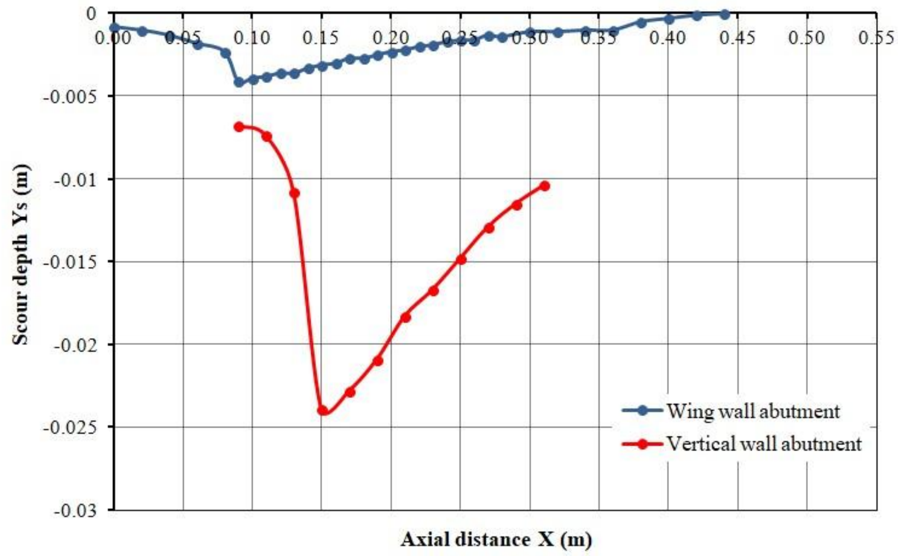


(e)Q=0.0008 m^3/s

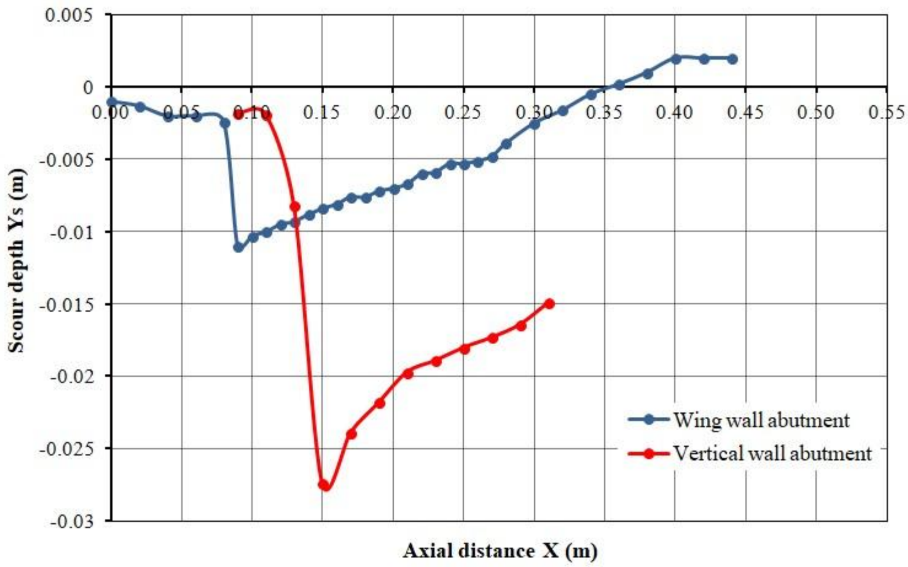


(f)Q=0.00095 m^3/s

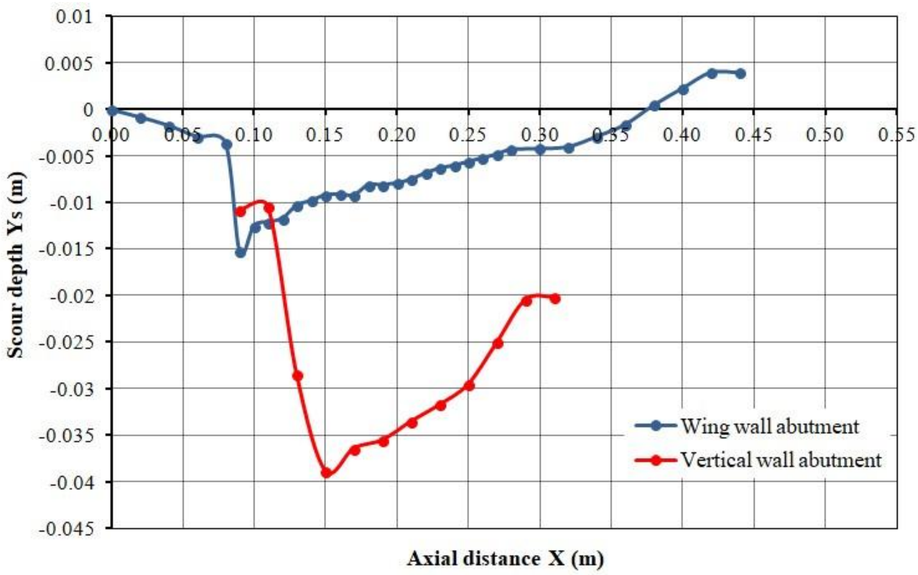
FIG. 3 COMPARISON BETWEEN MEASURED LOCAL SCOUR VARIATION ALONG THE STREAMWISE FACE OF THE ABUTMENTS, FOR B=0.036M AND DIFFERENT INFLOW DISCHARGES



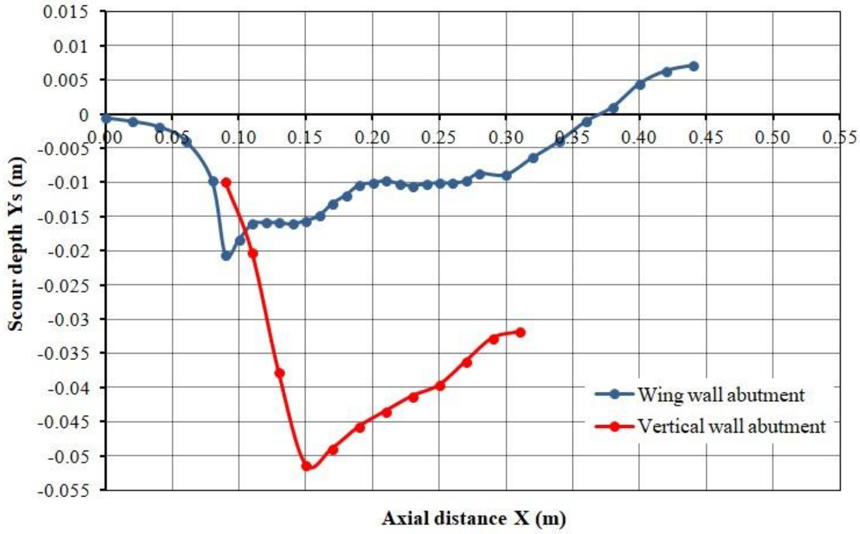
(a)Q=0.0004 m^3/s



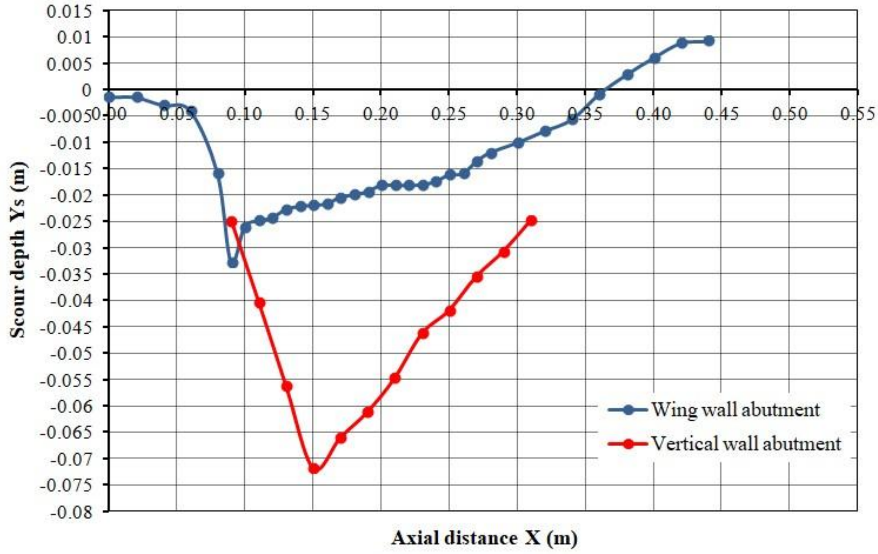
(b)Q=0.0005 m^3/s



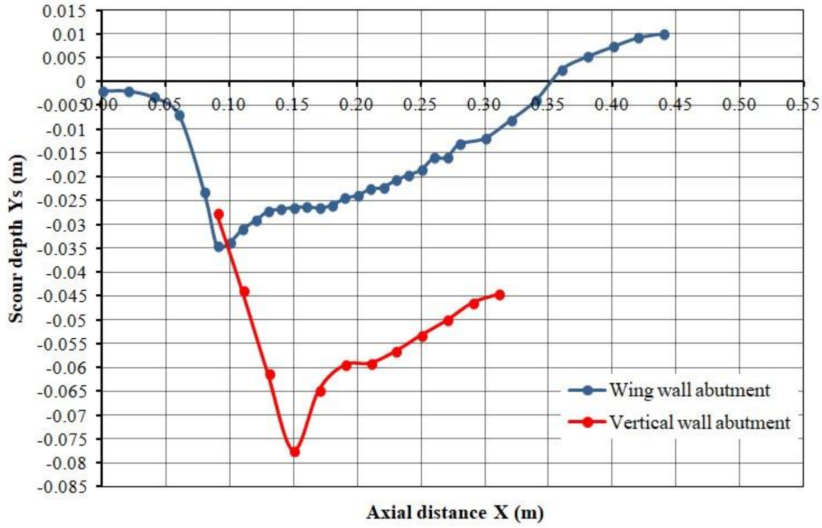
(c)Q=0.0006 m^3/s



(d)Q=0.0007 m^3/s

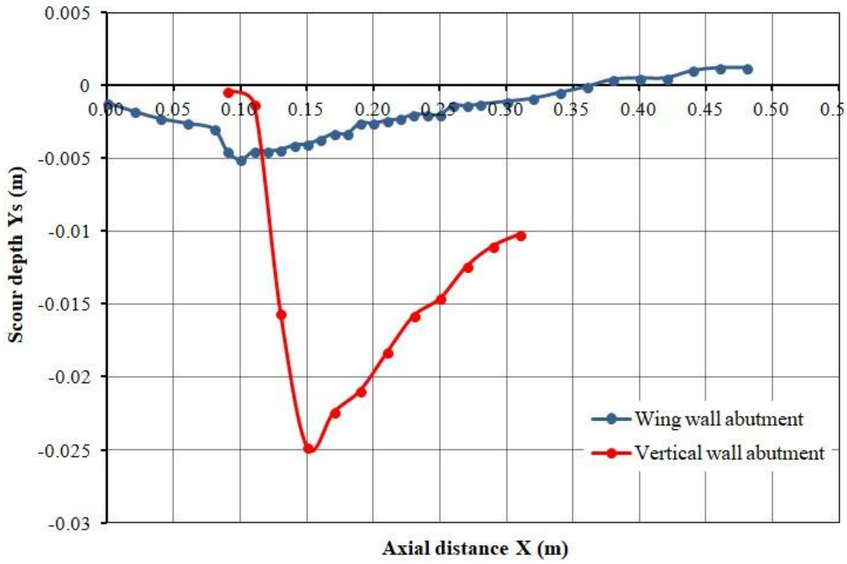


(e)Q=0.0008 m^3/s

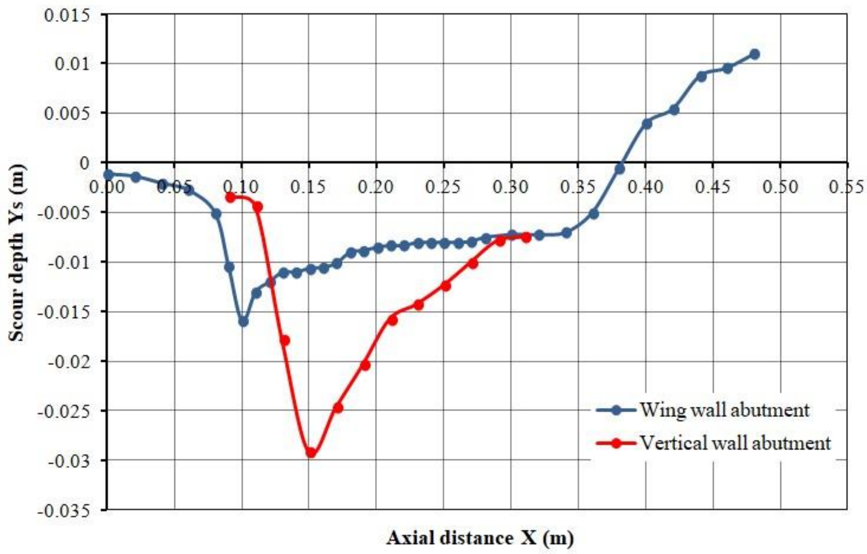


(f)Q=0.00095 m^3/s

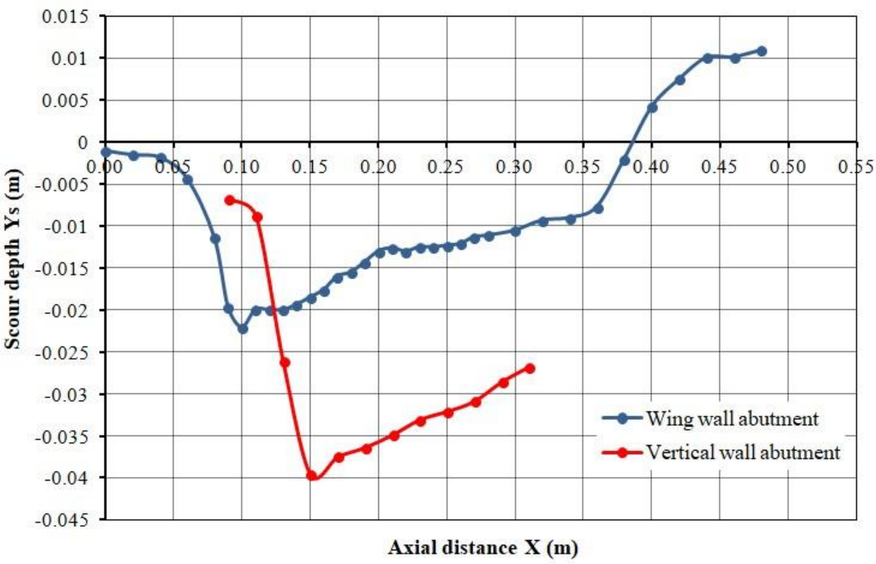
FIG. 4 COMPARISON BETWEEN MEASURED LOCAL SCOUR VARIATION ALONG THE STREAMWISE FACE OF THE ABUTMENTS, FOR B=0.045M AND DIFFERENT INFLOW DISCHARGES



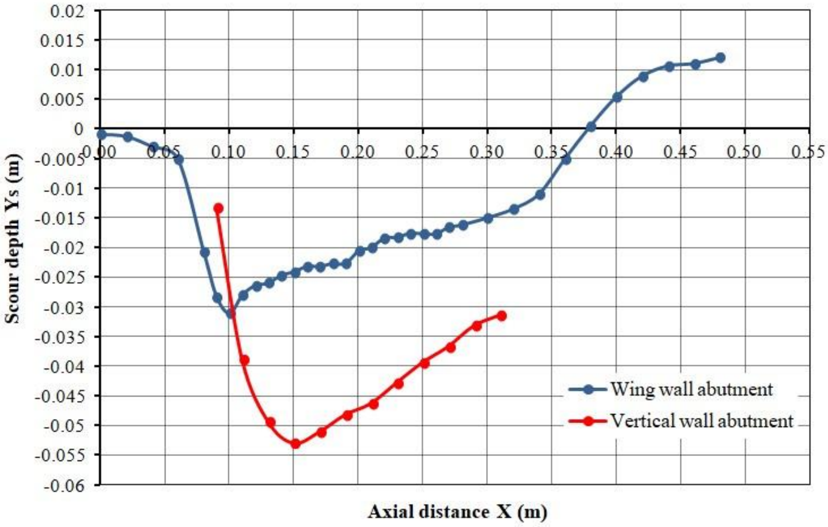
(a)Q=0.0004 m^3/s



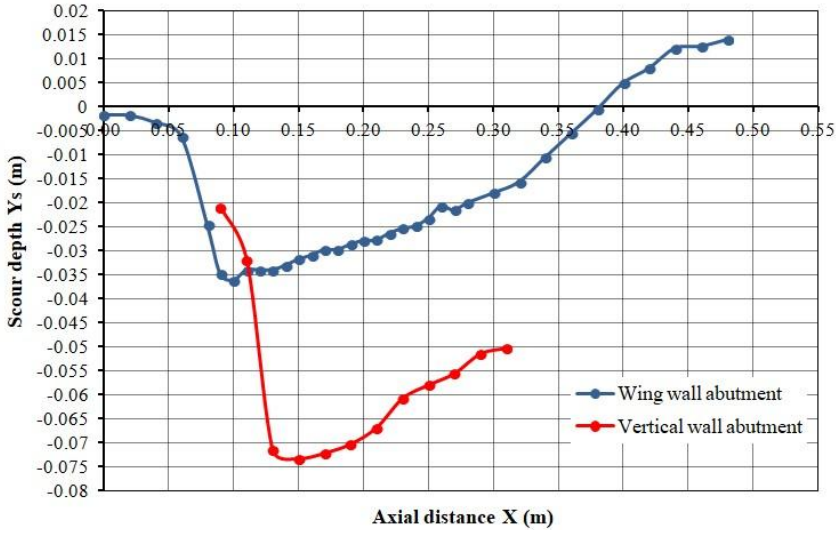
(b)Q=0.0005 m^3/s



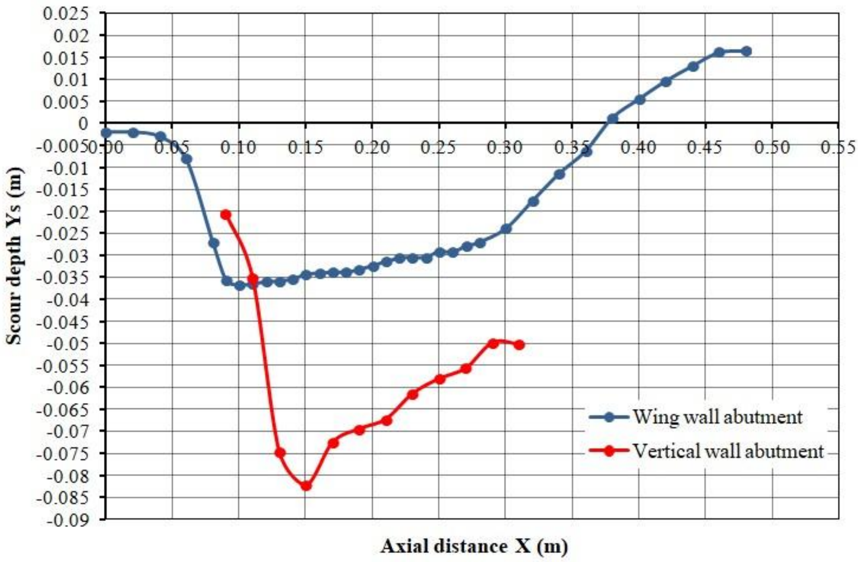
(c)Q=0.0006 m^3/s



(d)Q=0.0007 m^3/s



(e)Q=0.0008 m^3/s



(f) Q=0.00095 m^3/s

FIG. 5. COMPARISON BETWEEN MEASURED LOCAL SCOUR VARIATION ALONG THE STREAMWISE FACE OF THE ABUTMENTS, FOR B=0.051M AND DIFFERENT INFLOW DISCHARGES

IV. MAXIMUM EQUILIBRIUM SCOUR DEPTH

Dey at al [2]performed a regression analysis of their experimental data and proposed the following equation of non-dimensional maximum scour depth for different short abutments:

$$\frac{Y_{s\max}}{b} = 6.18 K_s F^{0.26} \left(\frac{h}{b}\right)^{0.18} \left(\frac{D_{50}}{b}\right)^{-0.15} \quad (1)$$

where K_s is abutment shape factor, being equal to 1 for vertical wall abutments [8] and equal to 0.82 for wing wall abutments [10], F is the Froude number according to the hydraulic conditions upstream of the abutment and h is the relative flow depth.The comparison of maximum scour depths obtained from the equation (1) with the current experimental data of vertical wall and wing wall abutments indicates that the above equation fits well with the experimental data. The value of correlation coefficient between the experimentally obtained and the computed maximum scour depths for the vertical wall abutment models is equal to 0.955 and for the wing wall abutment models is equal to 0.965 and indicates the accuracy of the experimental procedure. An extensive presentation of the hydraulic conditions used in the current parametric study is given[4]. Equation (1) indicates that the maximum scour depth increases with increase in Froude number and in flow depth.

V. CONCLUSION

The current research work presented bed level experimental measurements to produce data base intended as support in the development of new and the refinement of existing codes for computing free-surface flows with movable beds specifically around bridge abutments and generally on bed level evolution due to sediment transport. All measurements were carried out in a laboratory open channel flume and the test case geometry is formed from wing wall abutments. Experimental measurements on scour depths around the wing wall abutments were obtained at various locations near the abutments, for different inflow discharges and abutment widths, in uniform sediments, under clear-water scour conditions and were compared with available measurements on vertical wall abutments. Analyzing the experimental data it is obviously that for each abutment width the maximum scour depth and the scour hole area are always greater in the region of the vertical wall abutments than around the wing wall abutments, for the same hydraulic and sediment transport conditions. The experimental results in clear-water scour conditions have been used to determine an empirical equation of maximum equilibrium scour depth and the estimated values are in good agreement with the experimental measurements.

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