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An Experimental Study of Local Scour Depth Around Bridge Abutments

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***Abstract*— The current research work presents laboratory experimental results on local scour around vertical-wall bridge abutments in uniform sediments under clear water scour conditions. The study reports an extensive experimental investigation, that was performed in an experimental model in the Technological Educational Institute of Thessaly, whose findings are used to describe the effects of various parameters on local scour depth evolution. The experimental measurements of scouring depths were obtained in the vicinity of the construction for different inflow discharges and flow duration. The expected bed erosion and the maximum scour depth at the upstream edge of the construction are satisfactorily simulated by the experimental procedure. Three different sizes of the abutment width normal to the flow direction were used in order to investigate the impact of this parameter to local scour variation.**

All experimental test case results described in this work are relevant to unsteady, two-dimensional, quasi or fully three-dimensional flow calculations for viscous flows in open channels with sediment transport. All the experimental results are graphically presented and may be used to assist in the development of new and the verification and refinement of existing river numerical simulation models for computing free-surface flows with movable beds, specifically around bridge abutments and generally on bed level variation due to sediment transport.

***Index Terms*—Bridge Abutment, Experimental Measurements, Scour Depth, Time Dependence**

I. INTRODUCTION

Bed load transport in natural rivers, as well as scouring around bridge piers and abutments in rivers, compose severe environmental problems, which demand high cost in order to be faced. 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. From the engineering view point, the accurate quantitative estimation of local scour process around hydraulic structures is necessary for the prevention of severe environmental problems and for a safe river design.

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. Melville (1992) have performed experimental measurements and analyzed the effects on scour depth of abutment length, flow depth and abutment shape and alignment. Kandasamy and Melville (1998) studied experimentally the influence of abutment length and water depth in maximum scour depth around an abutment, under conditions of initiation of bed material movement. The equilibrium scour depth at bridge abutments in compound channels for steady, uniform flow, close to the initiation of motion of the bed particles was experimentally investigated by Cardoso and Bettess (1999). Farsirotou, Dermissis and Soulis (2007) have performed laboratory measurements to simulate bed variation near a trapezoidal bridge abutment and investigated the impact of water depth and discharge on scour depths. An experimental study was conducted by Elsebaie (2013) in order to investigate the time variation of three-dimensional scour hole geometry at a circular pier in sand bottom. Salami and Pirestani (2015) experimentally investigated the effect of abutment shape on bed changes and Yorozuya and Ettema (2015) presented experimental findings conducted with common standard designs of abutments in compound channels.

The objective of this research work is to produce a data base intended as support in the development of new and the refinement of existing numerical models for computing free-surface flows with movable beds, specifically around bridge abutments. A laboratory experimental procedure was established to simulate local scour around vertical-wall abutments in uniform sediments under clear water scour conditions. The present study reports an experimental investigation on the effects of various parameters on local scour depth. The impact of flow duration, water depth and discharge on local scour variation was investigated. Moreover the effect of the ratio between the width of the abutment, normal to the flow direction, and the width of the channel, b/B, on local scour evolution was also studied.

II. EXPERIMENTAL LABORATORY SET-UP

A. *Testing flume description*

All experimental test case measurements were carried out in the existed research flume at Hydraulics Laboratory of Civil Engineering T.E. Larissa Department, Technological Educational Institute of Thessaly. The testing flume is a smooth, prismatic channel, of rectangular cross-section, 6.0m long, 0.078m wide and 0.25m deep. The flume walls were made of 10mm thick plexi-glas to facilitate visual observations.

As the object of the current experiments was a parametric investigation of local scour depth evolution around vertical-wall bridge abutments, three different sizes of abutment models were constructed using waterproof wood. Each model was placed on the plexi-glass wall of the flume,

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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 abutment was equal to 0.10m and the lengths of the abutments transverse to the flow, abutment width, b, were constructed equal to 0.036m, 0.048m and 0.051m. The ratio between the width of the abutment and the initial flow depth was larger than 1.5, for all the experimental runs, and as a result there is no interaction between the wake vortices generated at the left and the right sides of the structure (Hoffmans and Verheij (1997)). 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 inflow discharge from the pump was measured using a flow meter connected to the channel (Farsirotou et al 2014). Due to fluctuations, the time average inflow discharge in each experimental test was computed and used.

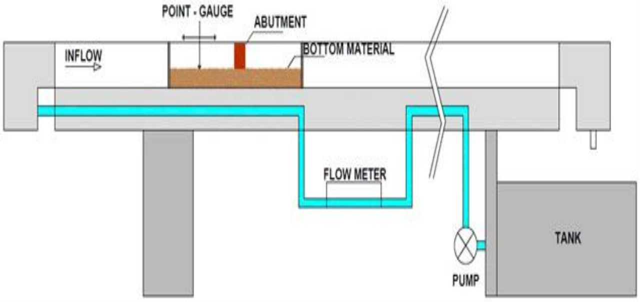


Figure 1: Schematic view of the laboratory equipment

B. *Bed sediment load*

The bottom of the tested experimental area was carefully covered with material, consisted of gravel, producing a uniform layer of sediment of 0.15 m thickness. The properties of the uniform sediments used in the experiments are given in Table 1, where d_{50} is the mean diameter of sediments. The used bed material was assumed to be uniform as the geometric standard deviation σ_g, computed by $(d_{84}/d_{16})^{0.5}$ is less than 1.4 (Dey et al (1995)). The critical shear velocity u_{*c} for the current conditions was obtained from the Shields diagram. This material selection was based on certain properties. Amongst them, the material must be light enough (density) to be transported by the acting water shearing forces under all tested flow discharges and depths, but not as light to be washed away during the required time period. This choice was made after careful consideration. The bed elevation must be clearly formed while accurate and sufficient recording of the bed level is needed. Clear water scour conditions were maintained for all the experiments. The semilogarithmic average velocity equation for a rough bed, used by Lauchlan and Meville (2001), was obtained to calculate the upstream critical velocities for sediment particles, U_c, for each experiment, as in

$$\frac{U_c}{u_{*c}} = 5.75\log\frac{h}{2d_{50}} + 6 \qquad (1)$$

Table 1. Characteristics of sediments used in the experiments.

d_{50} (m)	Specific weight	Geometric standard deviation σ_g	Critical shear velocity u_{*c} (m/s)
0.002	1.60	1.26	0.0266

C. *Experimental procedure*

Parameters that affect the variation of a channel bed level with a vertical-wall abutment projecting into the channel flow field, are:

a) the channel geometry,
b) the abutment geometry,
c) the channel bed slope in the main flow direction and in the transverse direction,
d) the initial water depth
e) the water discharge,
f) the bed material characteristics,
g) the projecting length of the abutment (abutment width)
h) the angle between the flow direction and the abutment side walls.

For the current experimental test cases the channel geometry, the abutment cross-section geometry and the angle between flow direction and abutment side-wall were held constant. The bed covering material was the same for all experimental test cases while the initial bed slope was set equal to zero. Also, there was no sediment influx into the experimental channel. Three different projecting lengths of the abutment were used equal to: 0.036m, 0.048m and 0.051m and water inflow discharges values were set equal to: 0.0004m^3/s, 0.0005m^3/s, 0.0006m^3/s, 0.0007m^3/s, 0.0008m^3/s and 0.00095m^3/s. Bed elevation measurements were performed at 6.0min, 12.0min, 18.0min and 30.0min. In order to measure the bed elevation, at any time period required, the experimental procedure must be repeated from the beginning (uniform depth of bed material). Reynolds number calculation is based on the upstream flow conditions of the experimental flume. The characteristic length is equal to 0.078m, while the kinematic viscosity takes the value of 1.0x10^{-6} m^2/s. Flow details of the currently performed experimental tests, as water inflow discharge Q, upstream Froude number Fr, upstream Reynolds number Re, initial water depth h_0 and initial flow velocity V_0, are given in Table 2. The simulated flow is subcritical throughout the tested section for all test cases as Froude number attains values less than 1.0.

After the required time duration period is reached, the bed elevation measurements data 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 two different ¨flow lines¨ presented in Fig. 2:

a) the flow line located at a constant distance of 0.005m to the streamwise face of the abutment parallel to the flow direction (¨flow line¨ 1) and
b) the flow line located at a constant distance of 0.005m to the upstream transverse face of the abutment transverse to the flow direction (¨flow line¨ 2).

All measurements along the hypothetical ¨flow line¨ 1 were obtained at successive distances of 0.02m while the measurements along the ¨flow line¨ 2 were taken at successive distances of 0.01m apart. The scanned bed variation region was included in an area extending 0.06m upstream to the abutment to 0.06m downstream to it, while in the transverse direction the length is extended along the total channel width (Fig. 2).

Table 2. Laboratory hydraulic conditions

a/a	Q (m^3/s)	Fr	Re	h_0 (m)	Vo (m/s)
1	0.0004	0.28	12500.00	0.0320	0.16
2	0.0005	0.33	14925.37	0.0335	0.19
3	0.0006	0.37	17142.86	0.0350	0.22
4	0.0007	0.38	18181.82	0.0385	0.23
5	0.0008	0.41	20000.00	0.0400	0.26
6	0.00095	0.47	22093.00	0.0430	0.28

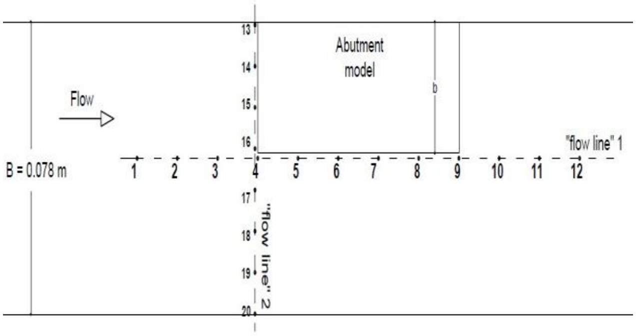
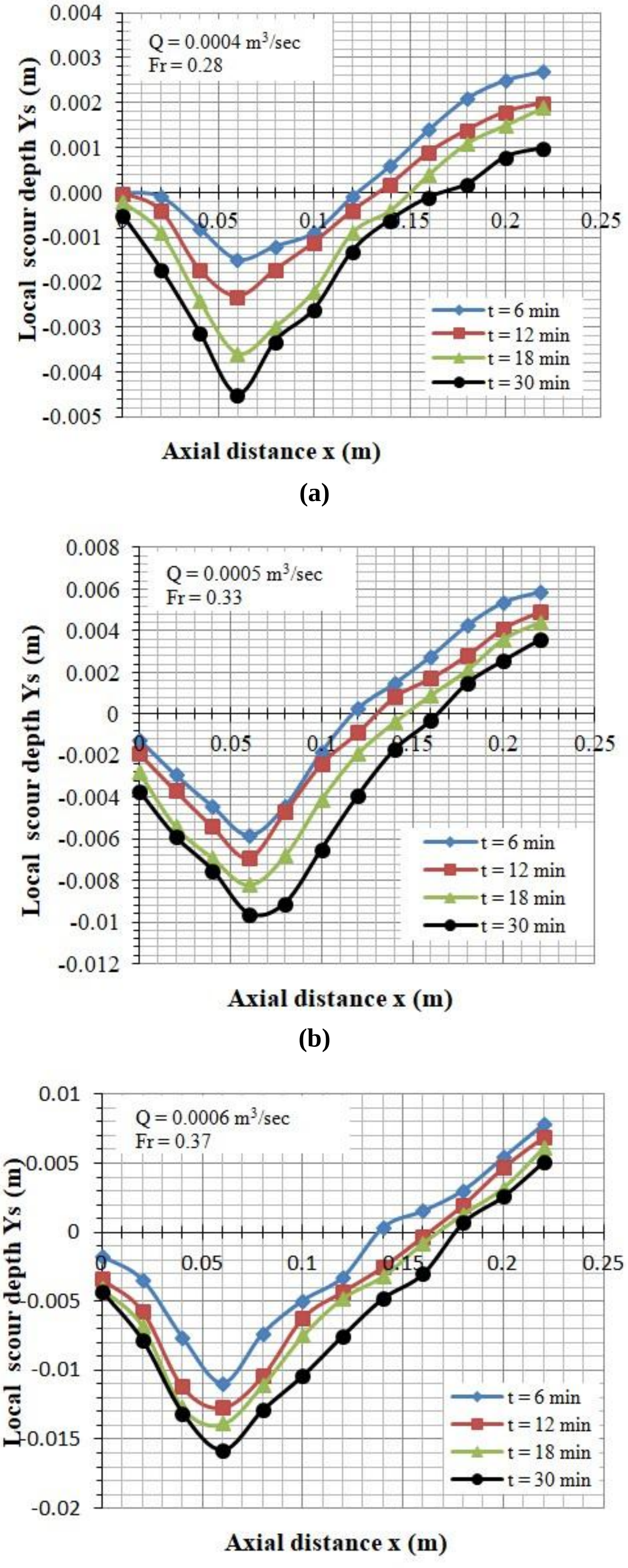


Figure 2: Measurement data locations

III. ANALYSIS OF EXPERIMENTAL RESULTS

Figures 3, 4 and 5 present the experimental local scour depths along the aforementioned ¨flow line¨ 1 under different hydraulic conditions and flow duration times for the three different width sizes of abutment models, b. Local scour depth measurements along the ¨flow line¨ 2 for the same hydraulic conditions, flow duration times and abutment's lengths, transverse to the flow, are given in Figures 6, 7 and 8, respectively. Experiments show that along the upstream to the abutment region and close to the vertical side of the abutment, erosion increases and a scour hole develops. The maximum scour depth occurs upstream of the 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 the same flow duration time, as the inflow discharge increases, scour depths also increase due to increased bed shear stresses. The maximum scour depth at the upstream edge of the abutment, Ysmax, under clear water scour conditions, is influenced by the ratio of abutment to channel width, b/B. The laboratory experimental data are used to plot the non-dimensional maximum scour depth with initial flow depth, Ysmax /h0, versus b/B in Figure 9, for each experimental time duration. 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 duration.



(a)

(b)

(c)

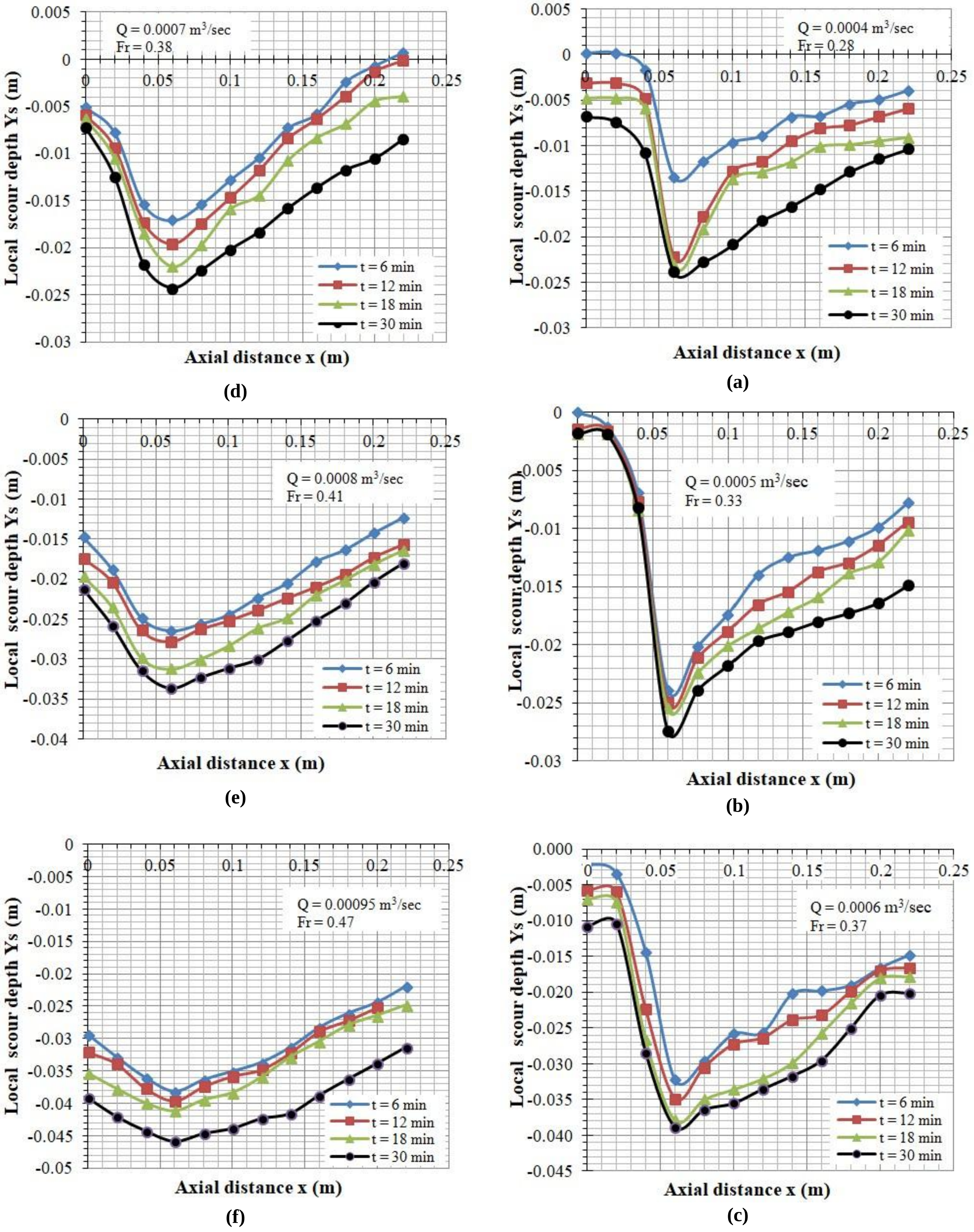
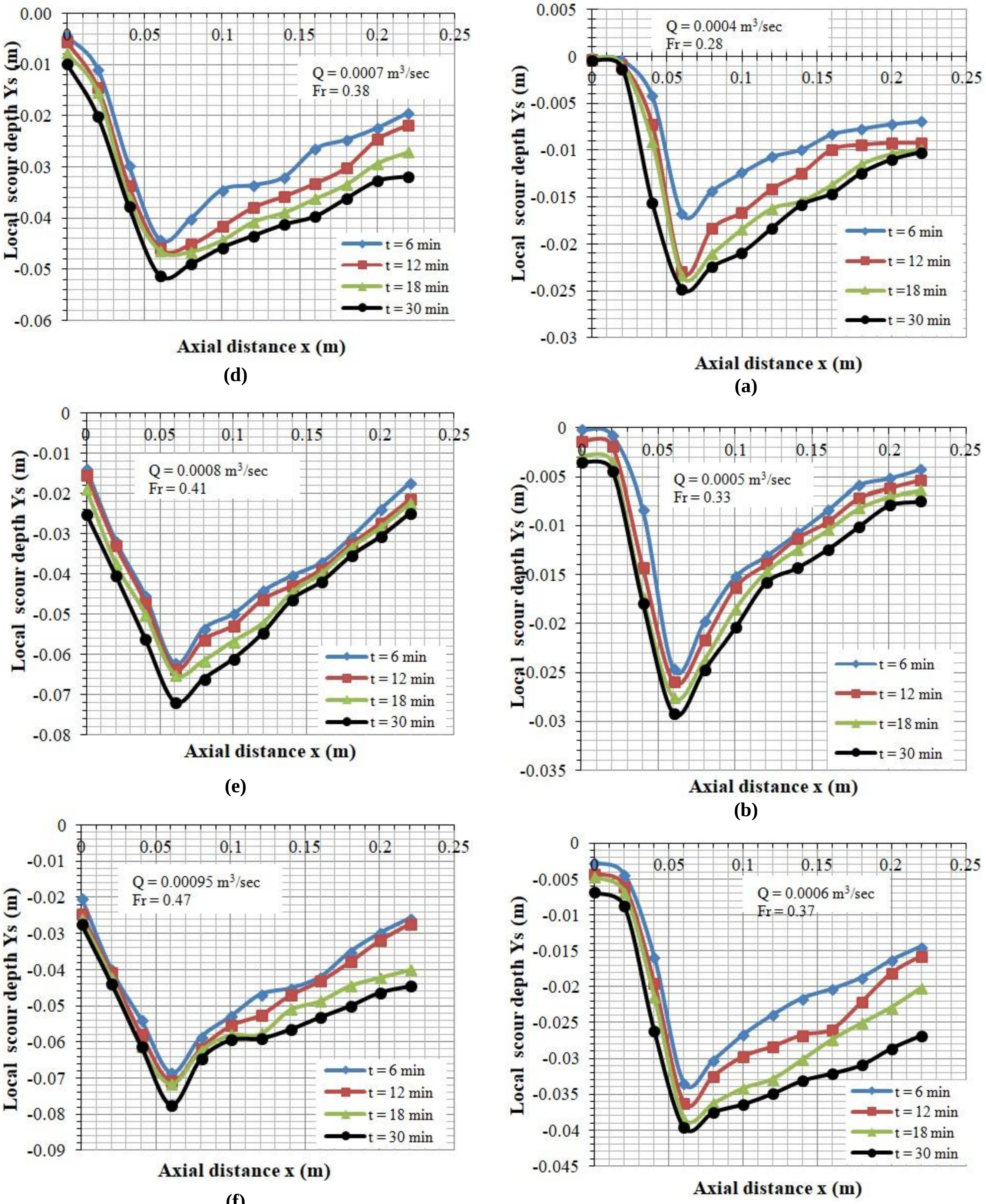


Figure 3: Experimental measurements of local scour variation at different inflow discharges along the ¨flow line¨ 1 for b=0.036



(d)

(a)

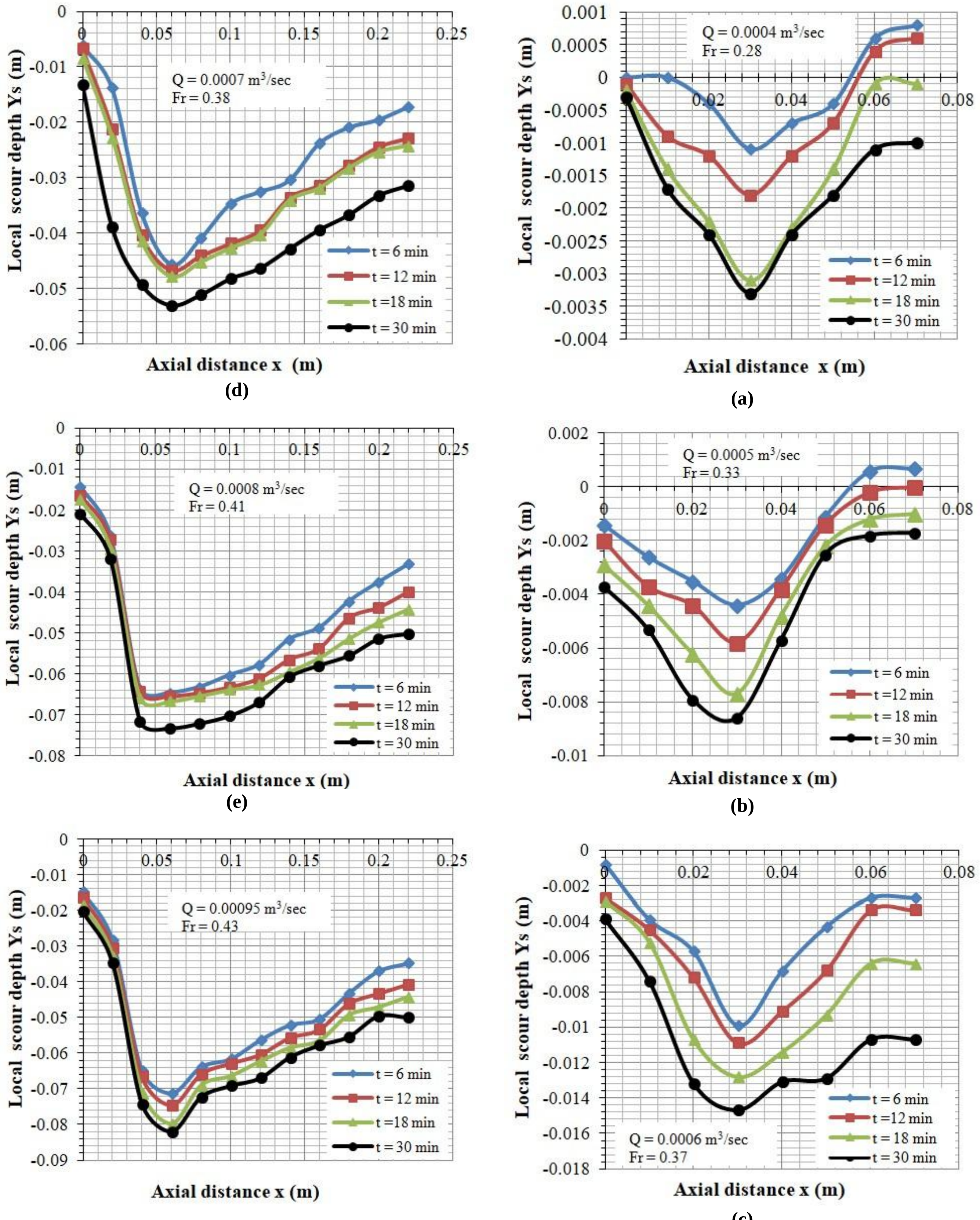
(e)

(b)

(f)

(c)

Figure 4: Experimental measurements of local scour variation at different inflow discharges along the ¨flow line¨ 1 for b=0.048

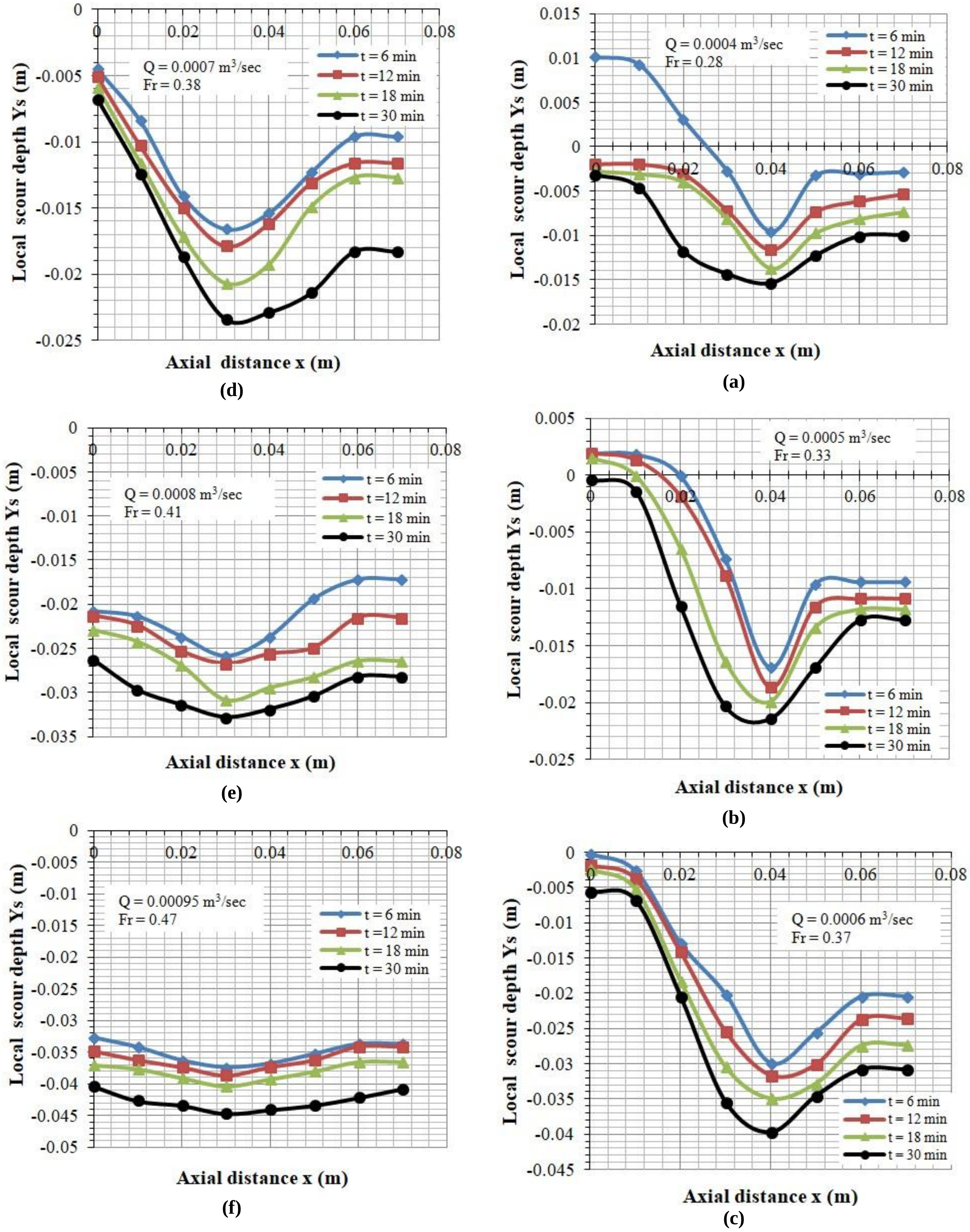


(d) (a)

(e) (b)

(f) (c)

Figure 5: Experimental measurements of local scour variation at different inflow discharges along the ¨flow line¨ 1 for b=0.051

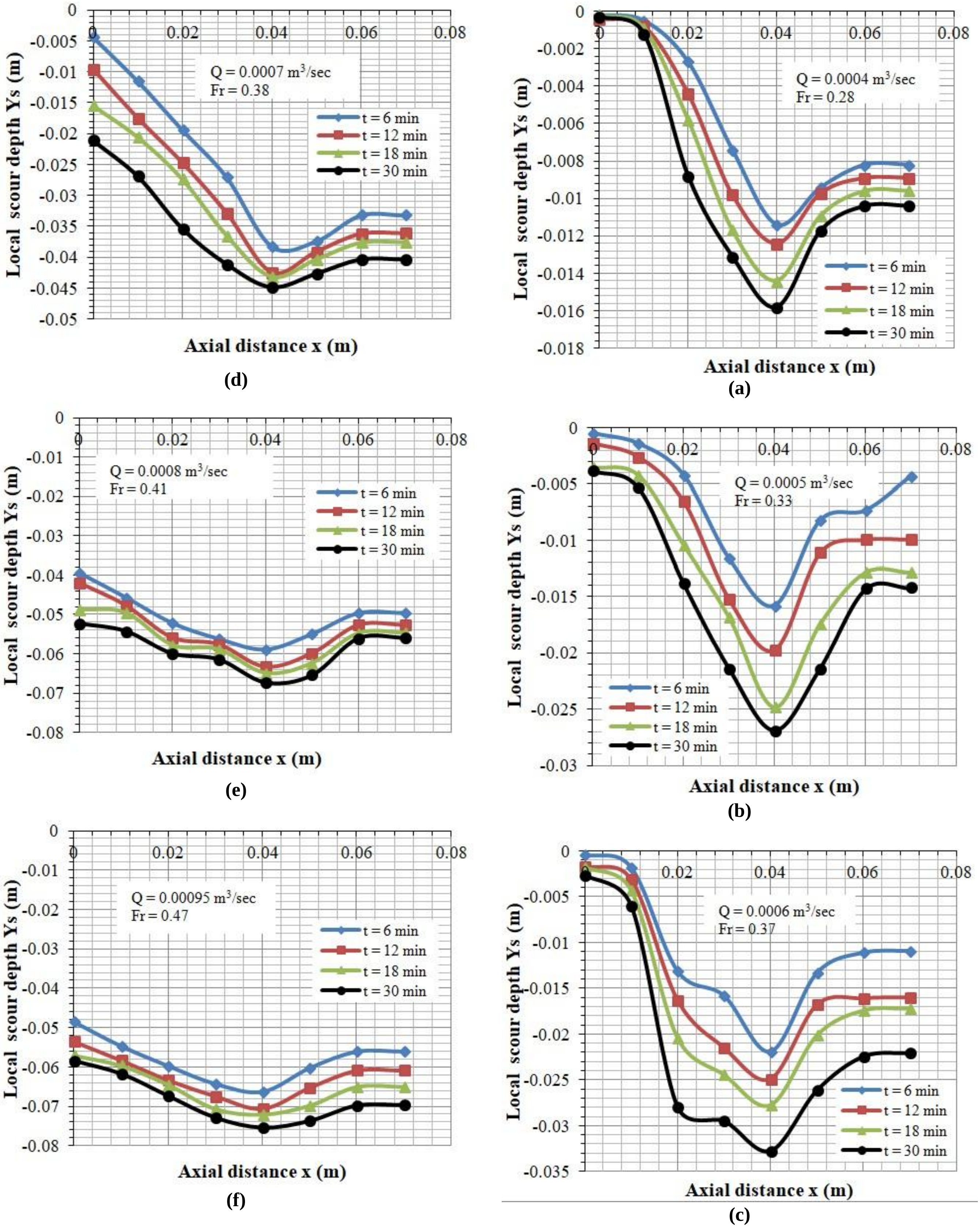


(d) (a)

(e) (b)

(f) (c)

Figure 6: Experimental measurements of local scour variation at different inflow discharges along the ¨flow line¨ 2 for b=0.036



(d)

(a)

(e)

(b)

(f)

(c)

Figure 7: Experimental measurements of local scour variation at different inflow discharges along the “flow line” 2 for b=0.048

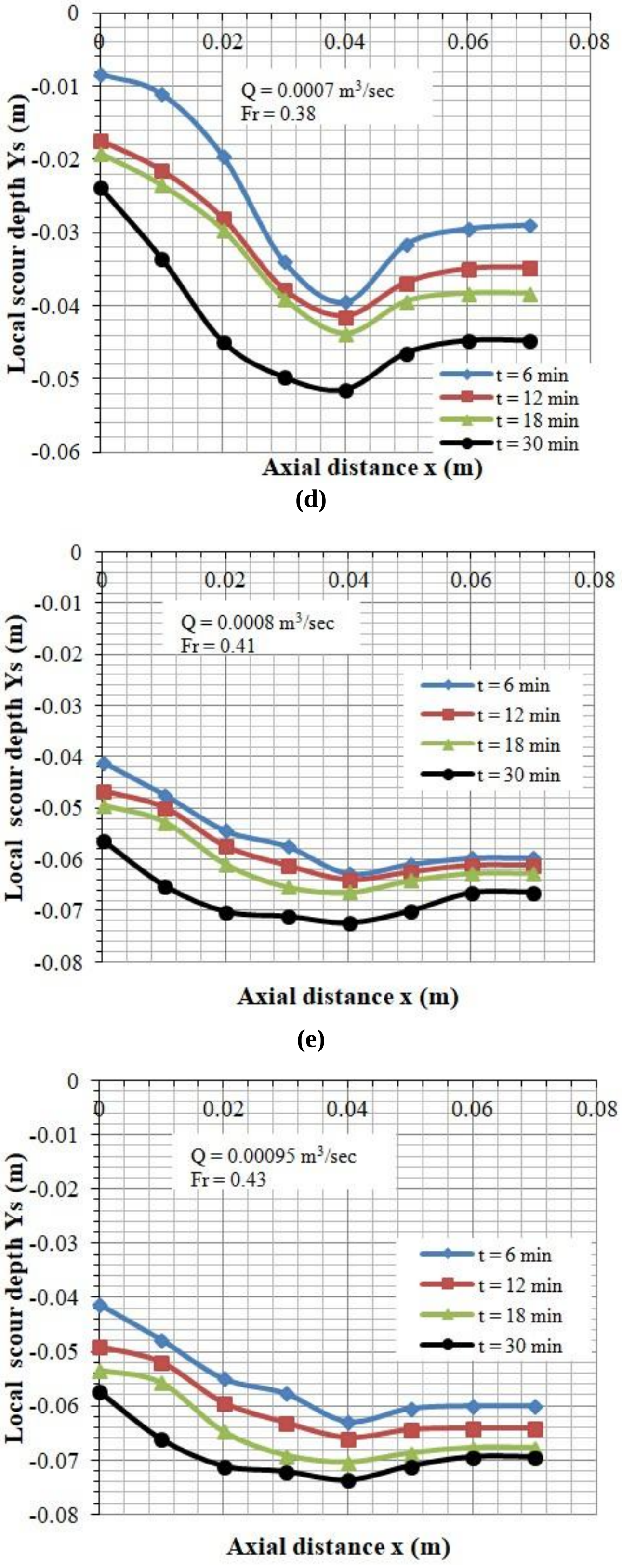


Figure 8: Experimental measurements of local scour variation at different inflow discharges along the ¨flow line¨ 2 for b=0.051

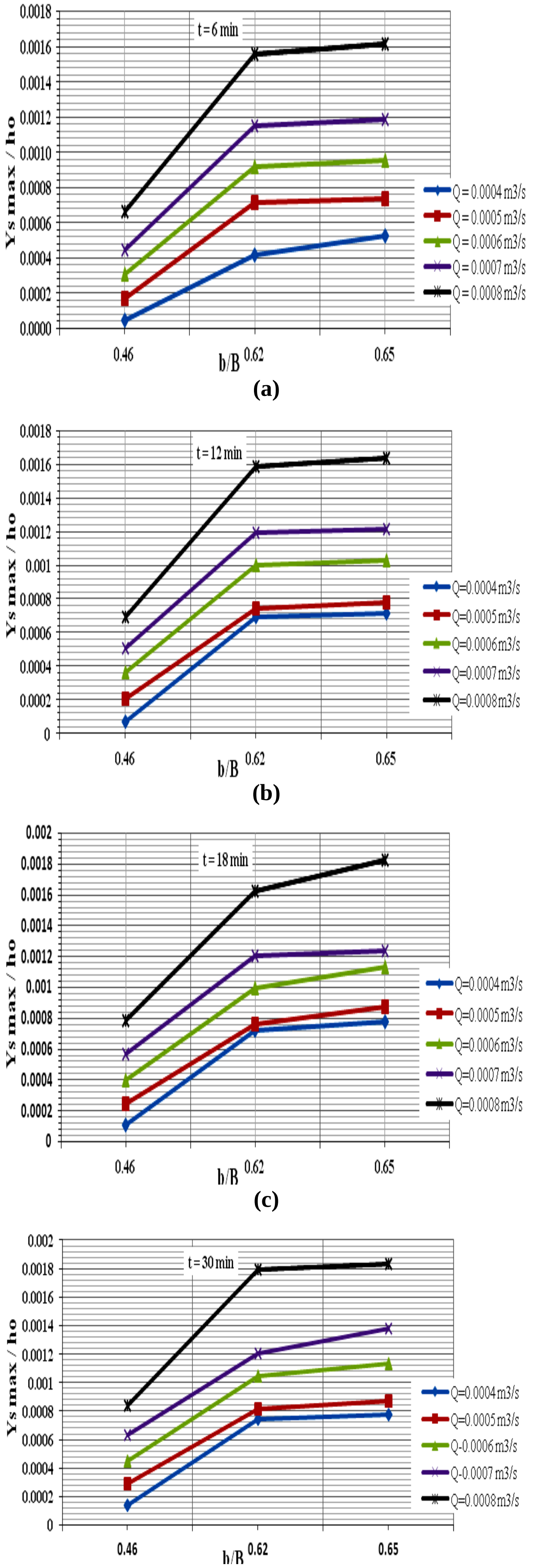


Figure 9: Variation of non-dimensional maximum scour depth with upstream flow depth, Ys_{max}/h_0, versus abutment to channel width ratio, b/B

IV. CONCLUSION

The results of laboratory experiments on local scour at vertical-wall abutments in uniform sediments under clear water scour conditions are graphically presented and can be used by other researchers to assist in the development of new and the refinement of existing codes for computing river bed morphology variations, 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 vertical-wall abutments. The experimental measurements of local scour depths were obtained at various locations near the abutments, for different inflow discharges, flow duration and abutment widths. For the same flow duration, as the inflow discharge increases, local scour depths also increase. The maximum local scour depth at the upstream edge of the abutment, under clear water scour conditions, is influenced by the abutment width and increases with increase in the abutment width, normal to the flow direction, for each experimental duration procedure.

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Research interests: hydraulics of open channels, sediment transport in natural rivers, river flood protection works, hydrology and water resource management.