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# Influence of Channel Expansions on Local Scour.

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# INFLUENCE OF CHANNEL EXPANSIONS ON LOCAL SCOUR

by

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## "تأثير الاتساع فى القنوات على ظاهرة النحر المحلى"

الخلاصه : يقدم هذا البحث دراسة معملية لظاهرة النحر المحلى نتيجة الاتساع فى القنوات المكشوفة مع الاخذ فى الاعتبار نسب مختلفة للاتساع وزوايا التوسيع المتدرج فى وجود تصرفات مختلفة للسريان فوق الحرج على قاع من الرمل غير المنتظم . يشمل البحث تحليل النتائج المعملية من خلال العلاقات الخاصة بالنحر كدالة فى المتغيرات المختلفة وذلك بأستخدام نظرية التحليل البعدى وقد تم الحصول فى هذا البحث على معادلة عامة لعمق النحر الأقصى والتى يمكن استخداميا فى الحالات المشابهه لحالة الدراسة .

## ABSTRACT

Laboratory measurements have been made to study the local scour phenomenon in a sand bed that occurs in an expansion outlet in open channels. Experiments were carried out for various expansion ratios, transition angles and efflux velocities using one sand size as a bed material. Dimensional analysis to develop non-dimensional terms affecting the phenomenon were obtained based on the experimental data. An empirical formula for the maximum depth of scour is developed and could be used for similar flow conditions.

## INTRODUCTION

The equilibrium depth of scour in channels constricted by either hydraulic structures ( pier, abutment, etc. ) or change in geometric shape of channel ( transition sections ) is one of the most important problems to be considered in the design of apron and longitudinal cross section of flow. An open channel expansion may be defined as an increase in cross sectional area in the direction of flow, thereby reducing the mean velocity of flow. The flow conditions in the outlet of channel are complicated by likelihood of flow separation along the expansion if the rate of change of cross section area is too rapid.

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Many investigators have been published results on vario aspects of this problems in the past, particularly on loc erosion at various types of obstruction [ 2, 4, 7, 11 and 12 One of the situation that has attracted considerable attention the scour around bridge piers [ 7 ]. Most previous studies on t expansion topic dealt with the problem for reducing the ener loss and flow condition particularly in supercritical fl condition [ 1, 3, 5, 6 and 10 ].

In this paper, the local scour due to expansion of channe were considered. Two types were tested the abrupt and the gradu with different ratios between the width of channel before a after expansions. Measurements were made of the scour dep downstream of the expansions for constant flow depth and vario discharges.

## EXPERIMENTAL SETUP AND PROCEDURES

### Flume

The experimental investigation was performed in 5.5 m lc fixed-bed flume that has a rectangular cross section 0.25 m hi by 0.6 m wide as shown in Fig.(1). The flume test section whi starts 1.2 m from the entrance section was modified to rea different expanding ratios. The downstream end of the flume h 0.3 m wide that represent the outlet of expanding ratio. The si walls were constructed of painted wooden sheets to give a smoc surface.

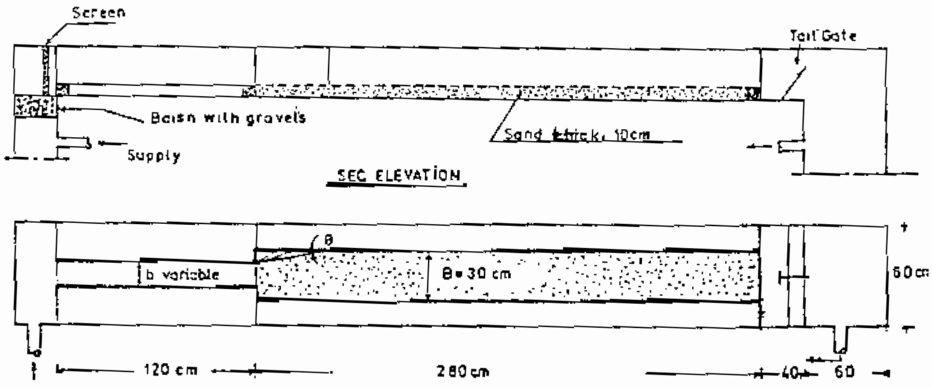


Fig.(1) Schematic Diagram of Laboratory Model.

All model expansions measured 1.2 m long had different upstream width of 0.12, 0.18 and 0.24 m to give the expanding ratios as 0.4, 0.6 and 0.8 which related to the downstream width.

## Sand Bed

The experiments have been performed using one erodible bed. Fig.(2) shows the grain size distribution curve of the sand used. A sieve analysis indicated the median grain size, $d_{50}$, is 0.46 mm with geometric standard deviation of 2.14.

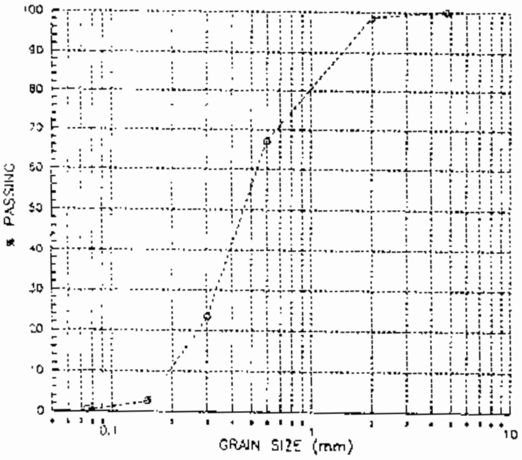


Fig.(2) Grain Size Distribution Curve.

## Expansion Models

Three expansion ratios (r= 0.4, 0.6 and 0.8) were provided in the series of tests. Different transition angles ( $\theta = 90^\circ$, $46^\circ\ 34'$, $18^\circ\ 38'$ and $9^\circ\ 28'$ ) were used with each expansion ratio.

## Test Program

The test program was designed to investigate the scour characteristics. It consisted of four series of runs with each expansion ratio model, i.e. the different transition angles. Experimental runs have been conducted considering different discharges ranging from 3.0 to 11.0 l/s with a constant water depth of 8 cm upstream the expansion. Table 1 shows the detail of the experimental data.

Table 1. Significant Test Data.

| Run No. | θ | Q l/s | Fr | $Y_e$ cm | $L_e$ cm | $L_{re}$ cm | $Y_e/Y$ |
|---|---|---|---|---|---|---|---|
| r = 0.4, α = 2.25 | | | | | | | |
| 1 | 90° | 6.42 | 0.75 | 6.6 | 20 | 90 | 0.83 |
| 2 | | 4.85 | 0.57 | 4.7 | 15 | 39 | 0.59 |
| 3 | | 3.33 | 0.36 | 3.0 | 10 | 30 | 0.38 |
| 4 | | 5.37 | 0.63 | 5.8 | 15 | 49 | 0.73 |
| 5 | | 4.10 | 0.47 | 3.7 | 10 | 38 | 0.47 |
| 6 | 46°34 | 4.33 | 0.51 | 4.2 | 15 | 36 | 0.53 |
| 7 | | 4.48 | 0.63 | 4.9 | 10 | 40 | 0.61 |
| 8 | | 4.90 | 0.70 | 5.3 | 10 | 57 | 0.66 |
| 9 | | 3.23 | 0.38 | 2.3 | 10 | 30 | 0.29 |
| 10 | | 3.90 | 0.46 | 3.8 | 10 | 32 | 0.48 |
| 11 | | 4.60 | 0.54 | 4.7 | 10 | 37 | 0.59 |
| 12 | 18°26 | 4.48 | 0.53 | 3.9 | 10 | 46 | 0.49 |
| 13 | | 3.95 | 0.47 | 2.6 | 15 | 36 | 0.33 |
| 14 | | 5.74 | 0.68 | 4.6 | 25 | 66 | 0.58 |
| 15 | | 4.70 | 0.55 | 3.4 | 20 | 47 | 0.43 |
| 16 | 9°28 | 4.77 | 0.56 | 2.3 | 15 | 33 | 0.29 |
| 17 | | 5.58 | 0.57 | 3.0 | 15 | 38 | 0.30 |
| 18 | | 5.95 | 0.70 | 3.2 | 20 | 40 | 0.40 |
| 19 | | 4.67 | 0.54 | 1.8 | 15 | 24 | 0.23 |
| 20 | | 3.80 | 0.45 | 1.6 | 10 | 20 | 0.20 |
| r = 0.6, α = 1.50 | | | | | | | |
| 21 | 90° | 6.90 | 0.54 | 4.8 | 10 | 62 | 0.60 |
| 22 | | 7.90 | 0.62 | 6.0 | 20 | 90 | 0.75 |
| 23 | | 5.40 | 0.42 | 2.2 | 10 | 40 | 0.28 |
| 24 | | 5.50 | 0.43 | 3.0 | 10 | 24 | 0.38 |
| 25 | | 6.02 | 0.47 | 2.9 | 15 | 22 | 0.36 |
| 26 | 46°34 | 6.30 | 0.49 | 3.2 | 15 | 24 | 0.40 |
| 27 | | 8.77 | 0.69 | 6.3 | 20 | 73 | 0.79 |
| 28 | | 7.45 | 0.59 | 5.9 | 15 | 70 | 0.60 |
| 29 | | 5.40 | 0.44 | 2.2 | 10 | 18 | 0.28 |
| 30 | | 7.50 | 0.59 | 4.2 | 10 | 41 | 0.52 |
| 31 | 18°26 | 8.80 | 0.68 | 4.5 | 20 | 65 | 0.56 |
| 32 | | 7.27 | 0.57 | 2.8 | 10 | 30 | 0.35 |
| 33 | | 8.50 | 0.67 | 4.5 | 30 | 70 | 0.56 |
| 34 | | 6.03 | 0.53 | 2.4 | 10 | 28 | 0.30 |
| 35 | | 6.00 | 0.47 | 2.0 | 10 | 20 | 0.25 |
| 36 | 9°28 | 7.66 | 0.60 | 2.6 | 15 | 32 | 0.33 |
| 37 | | 8.70 | 0.68 | 3.9 | 25 | 54 | 0.49 |
| 38 | | 7.75 | 0.61 | 2.8 | 15 | 37 | 0.35 |
| 39 | | 7.00 | 0.55 | 1.9 | 05 | 22 | 0.24 |
| 40 | | 6.00 | 0.47 | 1.4 | 10 | 20 | 0.17 |
| r = 0.8, α = 0.75 | | | | | | | |
| 41 | 90° | 9.44 | 0.56 | 3.6 | 15 | 43 | 0.45 |
| 42 | | 8.91 | 0.52 | 2.8 | 15 | 24 | 0.35 |
| 43 | | 8.60 | 0.51 | 3.4 | 20 | 55 | 0.42 |
| 44 | | 6.77 | 0.40 | 2.1 | 10 | 19 | 0.26 |
| 45 | | 9.96 | 0.59 | 3.9 | 20 | 75 | 0.49 |
| 46 | 46°34 | 7.14 | 0.42 | 1.7 | 10 | 15 | 0.21 |
| 47 | | 8.50 | 0.50 | 2.7 | 15 | 28 | 0.34 |
| 48 | | 9.91 | 0.58 | 3.9 | 20 | 62 | 0.49 |
| 49 | | 7.55 | 0.44 | 2.6 | 15 | 35 | 0.28 |
| 50 | | 9.44 | 0.55 | 3.6 | 15 | 60 | 0.44 |
| 51 | 18°26 | 8.60 | 0.51 | 2.1 | 10 | 25 | 0.26 |
| 52 | | 7.14 | 0.42 | 1.4 | 05 | 10 | 0.18 |
| 53 | | 9.80 | 0.58 | 3.6 | 20 | 70 | 0.45 |
| 54 | | 7.24 | 0.43 | 1.5 | 05 | 20 | 0.24 |
| 55 | | 10.93 | 0.61 | 3.9 | 20 | 70 | 0.49 |
| 56 | 9°20 | 7.66 | 0.45 | 1.8 | 10 | 18 | 0.23 |
| 57 | | 9.75 | 0.57 | 3.3 | 20 | 40 | 0.41 |
| 58 | | 9.91 | 0.52 | 3.1 | 20 | 40 | 0.35 |
| 59 | | 9.06 | 0.53 | 3.2 | 15 | 29 | 0.37 |

After the final adjustment, flow was introduced slowly at lume's upstream end. The flow rate was gradually increased until he desired discharge was achieved. The discharge and approach depth, Y, were kept constant through the test period. It should also be noted that the flow was subcritical open channel flow, and no hydraulic jump was observed in the test section during the experiments. Each test was allowed to continue for about 2.5 hr period to ensure that an equilibrium scour condition had been reached. At this time, flow to the system was halted and the gate slowly lowered to expose the local scour pattern for measurements.

A total of 59 individual tests, combining different expansion ratios with different angles and several discharges were performed in the course of this study.

## DIMENSIONAL ANALYSIS

Scour geometry depends on many variables that characterize the expansion model. These variables are the upstream width b, the downstream channel width B, the flow depth Y, the effective particle size of bed material $d_m$, tail water depth $Y_t$, approach velocity $V_o$, the density of bed material $\rho_s$, the water density $\rho$, the dynamic viscosity of water $\mu$, the angle of expansion $\theta$, and the acceleration due to gravity g. Thus if $\phi$ represents any dimension of the scour hole, then

$$\phi = f\ ( b, B, Y, V_o, Y_t, d_m, \theta, \rho_s, \rho, \mu, g) \qquad (1)$$

Applying the Buckingham Π-theorem ( Rouse, 1938 ), with Y, $V_o$, and $\rho$ as repeating variables, the following equation is arrived at:

$$\phi = f\ ( \frac{b}{Y}, \frac{B}{Y}, \frac{Y_t}{Y}, \frac{d_m}{Y}, gY\,V_o^{-2}, \theta, \frac{\upsilon}{VY}, \frac{\rho_s}{\rho} ) \qquad (2)$$

The expression $\phi$ may be represented by the relation depth of scour:

$$\frac{Y_s}{Y} = f\ ( \frac{B-b}{Y}, \frac{Y_t}{Y}, \frac{d_m}{Y}, F_r^{-2}, \theta, R_n^{-1}, \frac{\rho_s}{\rho} ) \qquad (3)$$

In all experiments conducted, the term $Y_t/Y$ influences were assumed negligible since it is nearly constant. Assuming constant relative density of bed material and the absence of viscous effects, Eq.(3) reduces to:

$$\frac{Y_s}{Y} = f\ ( \alpha, \theta, F_r^{-2} ) \qquad (4)$$

where: $\alpha = (B-b)/Y$ , $\theta$ = transition angle, $F_r = V_o\ (gY)^{-1/2}$, Froude number, and $Y_s$ = the maximum scour depth defined as the vertical distance from the original flat bed elevation to the deepest point in the stable scour profile.

## RESULTS AND ANALYSIS

### Influencing Parameters

Individual experiments were arranged according to the expansion ratios and transition angles. Table 1 gives these experimental data which represents the different expansion ratios. Generally the size of scour hole increases with time till it reaches a stable form. In most of test runs the scour holes showed symmetrical shapes and the trend of scour hole may be similar. The rate of scour was significantly rapid during the first few minutes and slow as scouring progresses with time.

As evidenced in Fig. (3) the scour depth increases with an increase in the Froude number parameter, $F_r$. This is to be expected, because a decrease in discharge implies a decrease in velocity and hence the erosive power. Fig (3) shows the transition angle $\theta$, affected the maximum depth of scour which decreases as well as decrease in the transition angle. Moreover, the scour depth was reduced when the expansion ratio was high, r=0.8.

In order to check if the scour depths are influenced by the changes in transition angles, the experimental data for relative scour depth and radial angle, $2\theta/\Pi$, with different Froude number, $F_r$, have been plotted. It is apparent from Fig (4) that the scour depth is affected by the transition angle. Generally the abrupt expansion scour was deeper than the transition expansion. The changes of scour depth in transition expansions for low ratios (r=0.4 & 0.6) are rapidly and more significant for large Froude number except for the case of high expansion ratio, r=0.8.

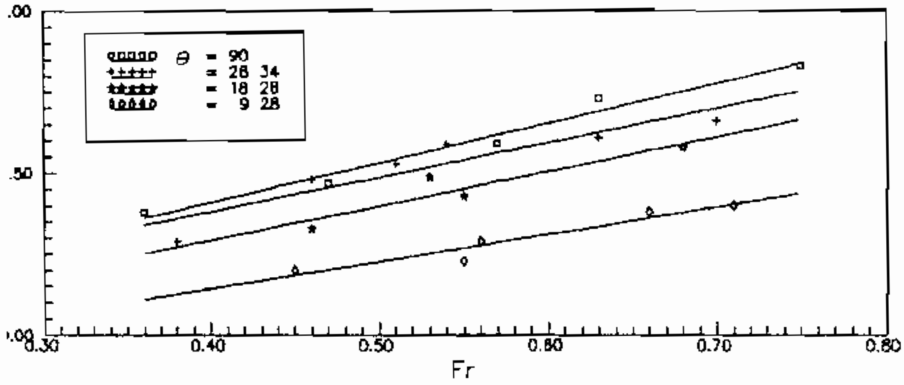
### Multilinear Regression Analysis

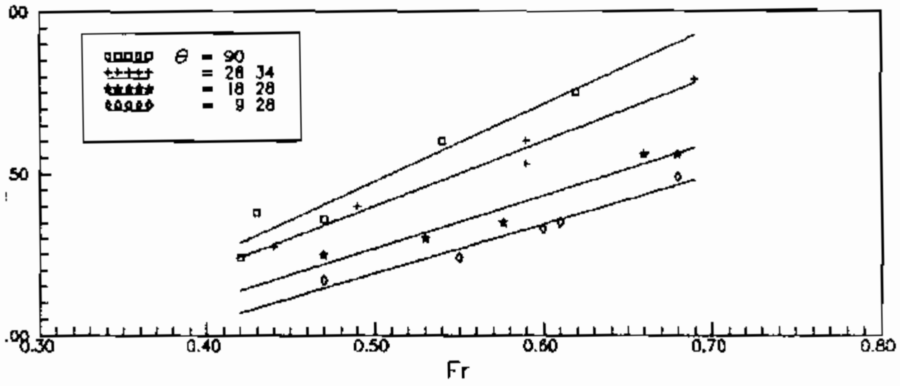
Following the procedure proposed herein the maximum scour depth at equilibrium condition $Y_s$, is expressed as a function of three parameters. The general formula is obtained as:

$$Y_s/Y = 1.616 \quad (F_r)^{1.622} \quad (\theta/\Pi)^{0.234} \quad (\alpha)^{0.178} \qquad (5)$$

where $F_r$ is Froude number, $\theta$ is transition angle, and $\alpha$ =( B-b)/Y.

This equation has a multilinear correlation coefficient of 0.977. The computed values of $Y_s/Y$ using the above equation are plotted against the corresponding experimental data as shown in Fig (5). It should be noted that this equation is valid for cases of abrupt and gradual expansions.


(a) r=0.40 & α =2.25


(b) r=0.60 & α =1.5

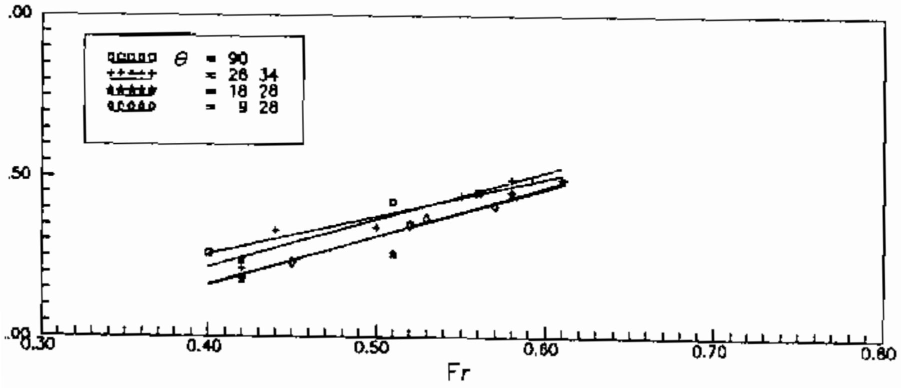
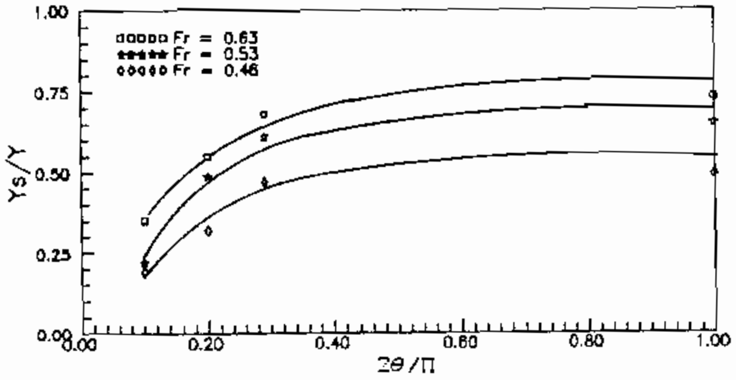
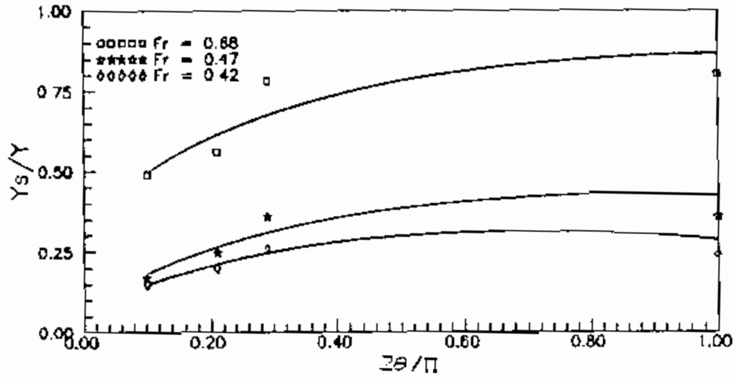

(c) r=0.80 & α =0.75

Fig.(3) Influence of Froude No. on Scour Depth.

(a) r=0.40 & α=2.25



(b) r=0.60 & α=1.5



(c) r=0.80 & α=0.75

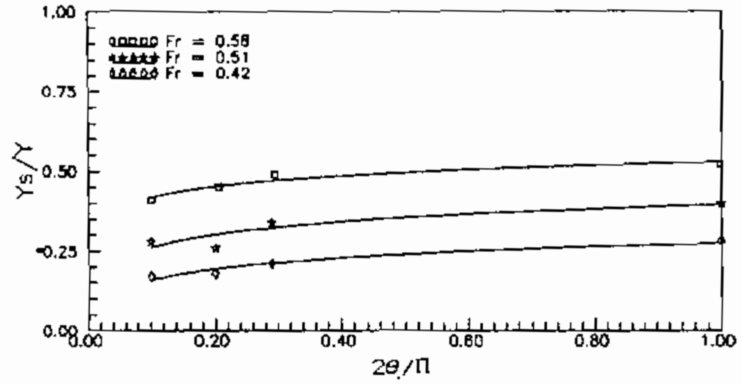


Fig. (4) Influence of Transition Angle on Scour Depth

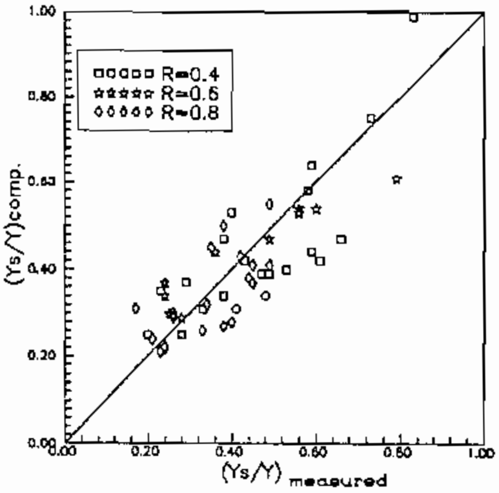


Fig (5) Comparison of Measured Scour Depth with Proposed Equation (5).

## Geometry of Scour Hole

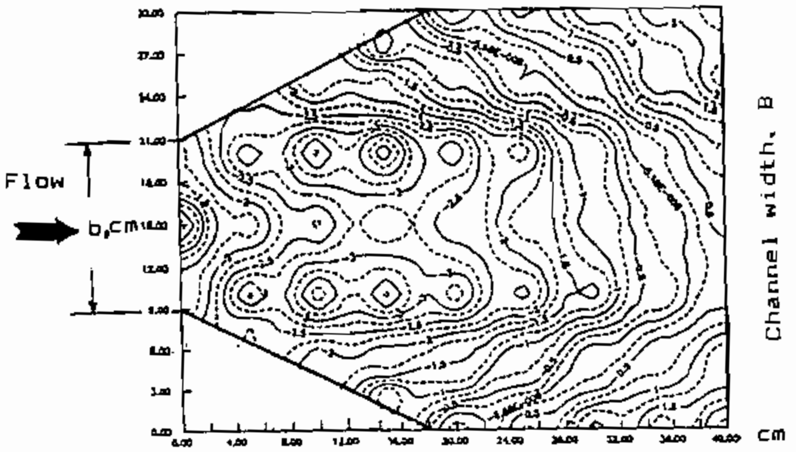
Fifty nine scour holes were observed and documented for a sand bed material. It was observed that the scour hole dimensions generally increased with time. The most of holes were generally similar in geometric configuration and few samples appearance in Fig.(6). It is found that these holes have two circular shapes around the center line of the channel for ratios of 0.4 and 0.6 and elongated to oval shapes. In case of a ratio of 0.8 the holes have circular shapes in the center of channel. This means that mean flow patterns become more symmetrical and steady with increasing an expansion ratio. It was also observed that the deepest scour point at a distance $L_s$, ranging from 0.31 to 0.34 of scour length measured from expansion outlet, $L_{Ts}$.

## CONCLUSIONS

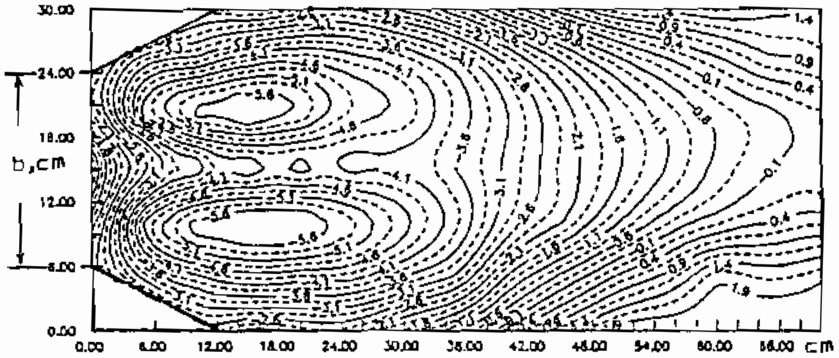
For the laboratory study carried out to get the local scour in a sand bed outlet model expansions, the following findings and observations may be summarized as follows:

1. The observed scour holes were found to be similar in geometric configuration and appearance dependent on expansion ratios and transition angles.
2. The maximum depth of local scour was found to vary with efflux velocity, transition angle and essentially increases with increase the Froude number and transition angle.

(a) Run No. 6, r=0.4 & α=2.25



(b) Run No. 28, r=0.6 & α=1.50



(c) Run No. 48, r=0.8 & α=0.75

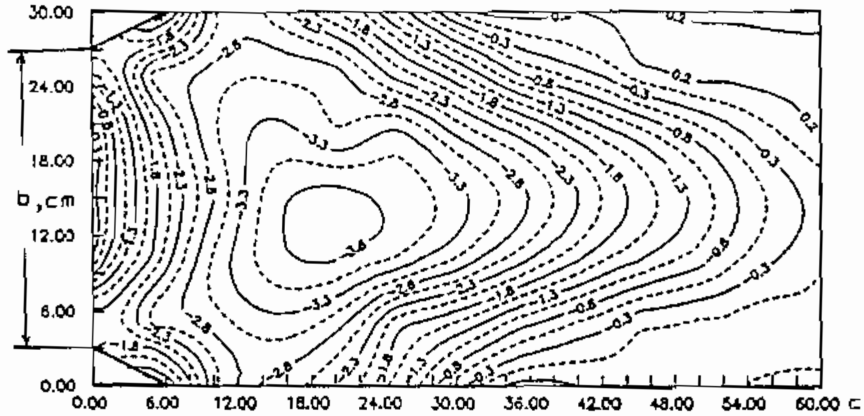


Fig.(6) Contour Map of Bed Configuration.

. The maximum scour depth occurred at approximate (0.31-0.34) of the maximum length of scour hole measured downstream from expansion outlet.

. The formula developed for estimating the scour depth may be used to get the maximum depth of scour, yet more studies are needed using various sands as bed material and a wider range of flow depths.

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## NOTATION

The following symbols are used in this paper:

$b$ = upstream width of channel,
$B$ = downstream width of channel,
$d_m$ = mean diameter of bed material,
$F_r$ = Froude Number,
$g$ = acceleration of gravity,
$L_s$ = max. length of deepest scour,
$L_{Ts}$= total length of scour measured from expansion outlet,
$r$ = $b/B$, expansion ratio,
$V_o$ = mean approach flow velocity,
$Y$ = upstream water depth,
$Y_s$ = maximum scour depth,
$Y_t$ = tail water depth,
$\alpha$ = $(B - b)/Y$,
$\mu$ = viscosity of water,
$\nu$ = kinematic viscosity,
$\theta$ = transition angle,
$\rho$ = water density, and
$\rho_s$ = density of bed material.