LABORATORY STUDY OF SCOUR IN LONG CONTRACTIONS

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ABSTRACT

In this investigation, scour in long contractions phenomenon was studied experimentally. For this purpose, forty laboratory experiments were carried out in a laboratory channel .Two different river sand sizes of 0.653 mm, 1.040 mm were used to conduct the experiments with standard deviations of 2.151 and 3.474 respectively. Three different ratios of contraction (B_1/B_2 =4,3 and 2) and three different angles of contraction (θ=10,15 and 20 degrees) were tested. For each case, the discharge was changed four times from 10.4 Liter/sec to 47.6 Liter/sec.

Data analysis showed that depth of scour (d_s) depends mainly on contraction ratio (B_1/B_2), densimetric particle Froude number (Fr_o) and geometric standard deviation (σ_g). Results of this study showed that there is a strong linear direct relation between the ratio of the contraction channel width and the depth of scour. Also a direct relationship was found to describe the effect of discharge on depth of scour. The results showed that there is no effect of contraction angle on the scour depth in long contractions. Also, an empirical non-dimensional relationship was obtained to determine depth ratio (Y_2/Y_1) in long contraction with correlation coefficient (R^2) = 0.9343.

The results of the present investigation were compared with those of other investigators showing a good agreement among them.

استلم في ٢٠٠٤/٣/٢٢ قبل في ٢٠٠٥/٥/١٦

- : ƕDžǭšDž (Č)

ýùlk ƘDþùƕ Ǒùk!f ljǴùödž!f Ĭ!Ž lƨƱöƪ! ƨnjljŪf Ĭ!Ž ƗöǂöǃĂƨþönj!f ƘǴTljdž!f ƗdžǴpǫ Ƙþfþƨf þl!
ǈfĂ Ü ýƕlkƪdž!f Ǒ5 Ǵdžnjdž Ǵöŋökfƨkƪf ůdžǴŽ ljǴödž! ǈdž ýƶŋ Ǵdždž lƨöƤŪf þĂlƶ!f Ǒ5 ƯĂơdž ýǂTƕ ǴNjþƨfĂdž
ýƮơö ĭŖ!f ƨơlj!f Ǵnjljdž lƨöǂ ýǂǴTdž ƚfþơǫĂ ƨǴnjljŪf ljŖNj ƗdžƯljƕ ýůƤŰf Ĭ!ǫ ĭþƌk ƘǴTljdž!f ljŖNj Ɨdžǵpǫ
Ɣƕƪƕ ƨnjlj!f ƨƶpĂ ƻǴ5ư ǈdž þfĂdž!f ǁƨơk NIljƕ ƨƮƤk!f Ɣƕƪƕ ƨơlj!f Ĭ!ǫ ƨǴTöĂ .ƨnjlj!f ƨƶpĂ ƻǴ5ư Ǒ5
þùljŽ Ǵdžnjdž ůdžǴŽ ƨơlj!! ǈƨfĂkdž!f ƽdžƶ!f ƨƕkƶöĂ Üƨ ƮƤk!f ƨǴƪdž ýĂƱƕ ǴƕǃǴƺ ƨơlj!f ýĂƱ þþơköĂ ǈǴöƨŋ!f
ǁù!Ŗ Ĭdžƪùöǂ ǴNjƨöƺĂ DžƯfĂlj!fĂ ƘfƨfþnjǃfĂ ƘǴdžǴŽþ!fĂ ƨĂƪŋ!Ǵǂ ƗöǂöǃĂƨþönj!f ƘǴTljdž! Σƪ Ūf Džödž Ʈk
ƨƮùƤk!f ǈĂùǂöĂ (Rectangular Long Contraction) ýùùùƱldž!f ýùùöƱkƪdž ýöĂƱ!fƨƮƤk!Ǵƕ
þơfĂ ĭĂǴƪö ĂD ƨƕǂf (B_1) ƨƮƤkdž!fƨöƺ Ǹƶŋ!f ƯƨŽ Ĭ!f (L)ƨƮƤk!f ýĂƱ Ɨƕƪlj ǈĂǂk ǴdžþljŽ ůöĂƱ

$$\left(1 \le \frac{L}{B_1}\right)$$ ƯơŬ (1) ýǂT!f (Komura,1966) .

- : ƕšǴƑƨǁƐ lƑƨƐþǭǁƐ (č)

Ǒù5 ǈƨfĂùkdž!f ƨùơlj!f ƽdžùùùŽ Σƨþ ǈdž ýĂD (Straub,1934) ƔĂfƨkƪ Ɨùơǃƕ!f þƶö
ƨùùùƮƤk ýöĂƱ ǈùùöƕ DžfĂŽŪf (1940-1934) ýưĂĂ Ɨ!þǴƶdž!f ƗökŰf :

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{\frac{6}{7}}\left[\frac{\tau_c}{2\tau_1}+\sqrt{\left(\frac{\tau_c}{2\tau_1}\right)^2+\left(1-\frac{\tau_c}{\tau_1}\right)\frac{B_1}{B_2}}\right]^{\frac{-3}{7}} \qquad (1)$$

: ǈD Ŗǫ

Y_1 Ü B_1 = ƯƨƶǃfĂ ƽdžƶ!f ýƱldž!! ƔƨklǷ!f Ĭ!Ž Ǒ!fĂk!f (Dž).
Y_2 Ü B_2 = ƯƨƶǃfĂ ƽdžƶ!f Ǒ5 ýƱldž!f ƨƮƤkdž!f Ĭ!Ž Ǒ!fĂk!f (Dž).
τ_1 = þnjŋ f l!f ƔƨklǷ!f ýƱldž!f Ǒ5 DžƤǴkdž!f (DžǃLJkĂölj/Ď).
τ_c = þnjŋ f l!f ƜƨơǃfĂ (DžǃLJkĂölj/Ď) .

Ơƕƪùk ($\tau_1 >> \tau_c$) Ɨùöơ (Live Bed Scour)ƨùƶl!f ƘǴƕǴƪƨ ýdžơ ýllj ƨöƛkƕ ƨơlj!f Ɨ!Ǵơ Ǒ5Ă
: ǑkŬǴǂ (1) Ɨ!þǴƶdž!f

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{\frac{9}{14}} \qquad (2)$$

Ɨùþůƶ!f Ĭ!ǫ Ǒƕƪöƪdž!fƨnjlj ǈdž ýƱldž! Ɨöǁlơ!f ƘǴƪǴöl!f ǈdž (Griffith,1939) Ɨ5öƨǂ Džǃ!Ǵƶ!f ýƮĂk Ǵdžǂ
:ƗökŰf

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{0.637} \qquad (d')$$

Ɨù!Ǵơ Ǒù5 ƨùùƮƤkdž!f ýƱldž!f Ǒ5 ƨơlj!f ƽdžŽ ƔǴƪơ! Ɨ!þǴƶdž (Laursen Ü1958b) ǈƪƨŰ ϴƨùkþf
: ƘǴƕǴƪƨ!f ýdžơ ýllj ƨƛf ƨơlj!f

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{\frac{6}{7}\left(\frac{2+a}{3+a}\right)}\times\left(\frac{n_2}{n_1}\right)^{\frac{6}{7}\left(\frac{a}{a+3}\right)} \qquad (Đ)$$

: ǈD Ŗǫ

n_1 = ǁljljǴdž ýdžǴƶdž ƗljĂƮƤ! ƨƶl!f Ǒ5 ýƱldž ƔƨklǷ!f .
n_2 = ǁljljǴdž ýdžǴƶdž ƗljĂƮƤ! ƨƶl!f Ǒ5 ýƱldž!f ƨƮƤkdž!f.
(a) = ƘƕǴƛ ýƛdžö ƨöƛk ƗŽƨƪ! lþƶ! ƳfĂljD ƗǂƮƤdž ƗǂƨơǃƗ ýllj ƘǴƕǴƪƨ!f þdžkƶöĂ Ĭ!Ž ƗùŽƨƪ þùnjŋ
(V_*) ƗŽƨƪĂ ƪĂlƱ ƗƕöƕƨƶǃfĂ (ω) ƨƶl!f ǑkŬǴǂĂ :-
$V_*/\omega < 1/2$ ǈƌ5 Ɨdžöp $a = 1/4$ ǈĂǂk Ɨǂƨơ!fĂ Ǒ5 ýdžơ ƨƶl!f.

. ƨǁǄǚ!ƒ ýǚơ!ƒ Ư ƶǃǍ ƧƶƖ!ƒ ýǚơ Ŏ5 ǇǍŧƙ Ŧŧ Ƨơ!ƒǍ 1=a Ŧǚǒp ǇǛ5 $1 = V_*/\omega$

. ýǚǴŧ!ǃ ƨǁǄǚ!ƒ ýǚơ!ƒ Ŏ5 Ŧŧ Ƨơ!ƒǍ 2.25= a Ŧǚǒp ǇǛ5 $2 < V_*/\omega$

: ǑƙǕƒ ýŧT!ǃ ($n_2 = n_1$) ǁǉǴǚ ýǚǴƶǚ ĭǍǴ ƙ Ŧ!Ǵơ Ŏ5 (4) Ŧ!þǴƶǚ!ƒ ǑǃƮƙǍ

$$\frac{Y_2}{Y_1} = \left(\frac{B_1}{B_2}\right)^{0.593}$$ (Č,Ďđ = a Ŧǚǒp Ŧ!Ǵơ Ŏ5) ……………………………… (5)

$$\frac{Y_2}{Y_1} = \left(\frac{B_1}{B_2}\right)^{0.694}$$ (Ď,Ďđ = a Ŧǚǒp Ŧ!Ǵơ Ŏ5) ………………………………(6)

ǇǴùǚ!ƒ Ŧùȵǒƙǉ ýùǒǍƱ!ƒ ƧƮƤƙ!ƒ Ŏ5 Ƨơǉù!ƒ (Laursen,1963) ǛǴƵ Ŏ5 ǇƮƧǗ ƩƧþ

ƒ ùp þùǌȵ Ĭù!ǫ ǴǒǍǴƮǚ ǛƤǴƙǚ!ƒ ƒ Ɩ!ƒ þǌȵ ƧǃƙƵƒǍ ǇǴǒƧȵ!ƒ ƻƮǍ! ǁǉǴǚ Ŧ!þǴƶǚ ǛƒþƤƙƮƒǍ Ŏ5ǴƮ!ƒ

: Ŧ!þǴƶǚ!ƒ ǇǚǍ (τ_o') Ŧùùǃǒǃơ!ƒ

$$\tau_o' = 17.2 \frac{{v_1}^2 {D_{50}}^{\frac{1}{3}}}{{y_1}^{\frac{1}{3}}} \quad \text{……………………………………………………(7)}$$

: ǇǛ Ʀǫ

(ǴǍ/Ǜ) ƔƧƙƖǚ!ƒ yƱƖǚ!ƒ Ŏ5 ǇǴǒƧȵ!ƒ ŦƵƧƮ = v_1

((Ǜ) ǛƶǇǛ ƖþǴǚ!ƒ ǇǚǍ %50) ƘǴǃǴƮƧ!ƒƧƱp ýþƶǚ =D_{50}

. (Ǜ) ƔƧƙƖǚ!ƒ yƱƖǚ Ŏ5 ǇǴǒƧȵ!ƒ ƨǚƵ = y_1

.(^{2}Ǜ / ǇƙǍǒǉ) Ŧùùǃǒǃơ!ƒ ƒ p þǌȵ = τ_o'

ǑǃǍùƮƧ ƖǴǉƖ!ƒ ƧƶpǍ (ƖǴǉƖ!ƒ ƨǚƵ ĭǍǴƮǒ Ŏŧǒ!ǍƧþǌǉ!ƒ ƧƱƖ!ƒ ƻƮǉ) Ŧưǒ ƧƵ ƖǴǉƖ!ƒ ǇǛ ǇƮƧǗ Ư ƧƙƼǍ

:ŦǒƙǕƒ Ŧ!þǴƶǚ!ƒ ǇǚǍ ƔƮơǒ (τ_c) ǛƧơ!ƒ ƒ Ɩ!ƒ þǌȵǍ Ü ŦŧƮǴǚƙǚ Ƨǒƺ þƒǍǚ ĬǁƵ ĭǍƙơǒ

$$\tau_c = 0.628 \times D_{50} \quad \text{……………………………………………………………(8)}$$

: ǇƨƒǍƙǚ!ƒ Ƨơǉ!ƒ ƨǚƵ ƔǴƮơ! ŦǒƙǕƒ ŦpǚƵ!ƒ ǇƮƧǗ þȵǍ

$$\frac{Y_2}{Y_1} = \frac{ds}{Y_1} + 1 = \left(\frac{\tau_o'}{\tau_c}\right)^{\frac{3}{7}} \times \left(\frac{B_1}{B_2}\right)^{\frac{6}{7}} \quad \text{……………………………………………(9)}$$

: Ǉƒ Ʀƒ

. ýǒǍƱ!ƒ ƧƮƤƙ!ƒ Ŏ5 Ƨơǉ!ƒ ƨǚƵ = ds

ƧùƶƖ!ƒ ƖþǴǚ! ŦǉǍŧǚ!ƒ ƘǴǃǴƮƧ!ƒ Ǜȵơ! ĭƧǴǒƶǚ!ƒ ƻƒƧơǉǕƒ ƧǒǍƙ (Komura,1966) ƒƧǍǒǚǍŧ ƩƧþ Ǵǚŧ

ýùƖǉ ƧǍƒ ƧơǉǛ! ŦǒƙǕƒ Ŧ!þǴƶǚ!ƒ ĬǁƵ ýƮơǍ ýǒǍƱ!ƒ ƧƮƤƙ!ƒ Ŏ5 Ƨơǉ!ƒ ƨǚƵ ĬǁƵ ƘǴǃǴƮƧ!ƒ Ǜȵơ Ƨǒƺ ƙǍ

: ƘǴǃǴƮƧ!ƒ

$$\frac{Y_2}{Y_1} = 1.45 \times (Fr_1)^{\frac{1}{5}} \times \left(\frac{B_1}{B_2}\right)^{\frac{2}{3}} \times (\sigma_g)^{\frac{-1}{5}} \quad \text{………………………………………(10)}$$

: ǇǛ Ʀǫ

ƔƧƙƖǚ!ƒ yƱƖǚ!ƒ Ŏ5 (Froude number) þǍƧ5 ǛpƧ = Fr_1

ƧƶƖ!ƒ ƖþǴǚ! ĭƧǴǒƶǚ!ƒ ƻƒƧơǉǗƒ = σ_g

: Ŏ5ǴƮ!ƒ ǇǴǚ!ƒ ŦȵǒƙǉƧơǉǛ! ŦǒƙǕƒ Ŧ!þǴƶǚ!ƒ ĬǁƵ ƒƧǍǒǚǍŧ ýƮơǍ

$$\frac{Y_2}{Y_1} = 1.60 \times (Fr_1)^{\frac{1}{5}} \times \left(\frac{B_1}{B_2}\right)^{\frac{2}{3}} \times (\sigma_g)^{\frac{1}{2}} \quad \text{………………………………………(11)}$$

Laursen and) ǇǍƙùƮƧƨǁƮǍ ǇùƮƧǗ ýùƀp Ǉùǚ (4) Ŧù!þǴƶǚ!ƒ ƧǒǍùƱƙ Ǜùƙ

ýùǚơ ýùƖǉ ƧùƒƒýǒǍƱ!ƒ ƧƮƤƙ!ƒ Ŏ5 Ƨơǉ!ƒ ƔǴƮơ! yƮǍƒ ŦpǚƵ ĬǁƵ ǔƮơǍ (Silverstone,1976

ƔùǒƧƖƙ ǇǚǍ ŦȵƙǴǉ!ƒ (K_1/K_2) ŦǃƮǉ!ƒǍ ƒ Ɩ!ƒ þǌȵ ƔǒƧƖƙ ǇǚǍ ŦȵƙǴǉ!ƒ (k_2/k_1) ŦǃƮǉ!ƒ Ŧ5Ǵưǃ ƘǴǃǴƮƧ!ƒ

: Ŏŧǒ!ǍƧþǌǉ!ƒ ƧƱƖ!ƒ ƻƮǉ

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{\frac{6}{7}\left(\frac{a+2}{a+3}\right)}\times\left(\frac{n_2}{n_1}\right)^{\frac{6}{7}\left(\frac{a}{a+3}\right)}\times\left(\frac{k_2}{k_1}\right)^{\frac{6}{7}\left(\frac{1}{a+3}\right)}\times\left(\frac{K_1}{K_2}\right)^{\left(\frac{a}{a+3}\right)} \quad \text{……………………….(1Ď)}$$

ƧƬùƤƙ!ƒ Ŏù5 Ƨùơǉ!ƒ ǏǁƵ ǂƵƧǀ!ƒ ƧŏƛƛƘ ýĂơ ǂǀƒƧþ (Alawi,1981) ǐĂűƵ ǂơǴ!ƒ ăƧȠ Ǵǆǂ ǂùȠŏƙǉ Ƨùơǉ!ƒ ƩƧþĂ ǂǂǀǴǆƙǆ!ƒ Ƨŏƺ ǂŏǆĂǀƧ!ƒ ǇǴùƶŏǀ!ƒ Ŏ5 ƧĂǀȠǀ! ǂŏƧƒƒþ!ƒ ƘǴǆǴƵþ!ƒ þǉƵĂ ýŏĂƱ!ƒ ǴùƱƵǫ ǇĂþ ǇùǂǀĂ ǖƧùơ!ƒ ƾĂ5Ă ǖƧơ!ƒ Ƙơƙ ǇǴŏƧȠǀ! ƘǴǴǀƧ!ƒ ýǆơ ýǀǉ Ƨƛƒ Ƨơǉ!ƒĂ Ŏ5ǴƬ!ƒ ǴǆǄ!ƒ ýùŏĂƱ!ƒ ƧƬƤƙ!ƒ Ŏ5 Ƨơǉ!ƒ ǂǀƒƧþ! ƘǴǆǋǴǀǆ!ƒ ƲƶǀƘ (Alawi,1985) ǂơǴ!ƒ ƩƼǉ ǊþþĂ ǂǆǴƵ ǂ!þǴƶǆ ǂƵƧǀù!ƒ ǂǀǀùǉ ĂǊ (τ_o'/τ_c) ƒ ù!ƒ þȵȠ ǂǀǀǉĂ ǂƵƧǀ!ƒĂ ýŏǆ!ƒ ǀþǴŏƨǀ ýǀƙ (Y_2/Y_1) ǂǀǀǉ!ƒ Ǉƒ ǴǌǉǆĂ .(V_*/ω)

:Ŏǁŏ ǴǆǂĂ ǂ!þǴƶǆ!ƒ ǏǁƵ (m) ƘǀǴƛ ýǴƤþǀ ((č) ǂ!þǴƶǆ) ƔĂƒƧƙǀ ǂ!þǴƶǆ (Gill,1981) ýȠ ƧĂƱ

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{\frac{6}{7}}\times\left[\frac{\tau_c}{\tau_1}+\left(1-\frac{\tau_c}{\tau_1}\right)\times\left(\frac{B_1}{B_2}\right)^{\frac{1}{m}}\right]^{\frac{-3}{7}} \quad \text{……………………………………….(čď)}$$

ƠùǀƬùƙ (čď) ǂù!þǴƶǆ!ƒ ǇǴù5 $\left(\tau_1=\tau_o{}'\right)$ ƲƧƼǀĂ $\left(\frac{\tau_1}{\tau_c}\le 1\right)$ ǴǆþǉƵ Ŏ5ǴƬ!ƒ ǴǆǄ!ƒ Ƨơǉ ǂ!Ǵơ Ŏ5Ă

ǏùǁƵǊ ýȠ ǊþƤƙǀƒ $\left(\frac{\tau_c}{\tau_1}\to 0\right)$ ǴǆþǉƵ ƘǴǴǀƧ!ƒ ýǆơ ýǀǉ Ƨƛƒ Ƨơǉǀ!Ă . ((ě) ǂ!þǴƶǆ) ǇǀƧŬ ǂ!þǴƶǆǂ

Ƨùƙŏǀ -ƧŏǴǆ ǂ!þǴƶǆ Ŏ5 Ǵǆǂ ǂǆŏþ ýþǂ (m=1.5)Ă ǇĂƒƧǀ – ǇŏǴƙƬǉǊ ǂ!þǴƶǆ Ŏ5 Ǵǆǂ (m=3) ƘǀǴƛ! ǂǆŏþ :ǉǴǉþǊ ýǂƬ!ǴǀĂ (čď) ǂ!þǴƶǆǀ! ǇŏƙȝŏƬ ǏǁƵ ýȠ ýƬơ5

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{0.714} \quad \text{……………………………………………………………………..(14)}$$

$$\frac{Y_2}{Y_1}=\left(\frac{B_1}{B_2}\right)^{0.571} \quad \text{………………………………………………………………………(15)}$$

.ƔĂƒƧƙǀù! (Ď) ǂ!þǴƶǆ!Ǵǂ ƠǀƬƙ (čď) ǂ!þǴƶǆ!ƒ ǇǴ5 (m=0.25) ƘǀǴƛ!ƒ ǂǆŏþ ýþƶǆ ƦƤƒ þǉƵĂ ýùƬĂƙĂ ýŏĂƱƧƬùƤƙ Ŏù5 ǇƨƒĂƙǆ!ƒ Ƨơǉ!ƒ (Lim and Cheng,1998) ǁǉǴŏȠĂ Ǌŏ! ƩƧþ :ǂŏƙŬƒ ǂ!þǴƶǆ!ƒ Ǐ!ǫ ǂŏƲǴŏƧ!ƒ ƘǴþǀƙŬƒ ǂƱǴǀĂǀ

$$\left(\frac{Y_2}{Y_1}\right)=\left(\frac{B_1}{B_2}\right)^{0.75} \quad \text{…………………………………..…………………………(16)}$$

-: ăǭyǴǁƐ üǐǂƟǂǁƐ (Ď)

: ǂŏƙŬƒ ƘƒƧŏȝƙǆ!ƒ ǏǁƵ þǆƙƶƙ ýŏĂƱ!ƒ ƧƬƤƙ!ƒ Ŏ5 ǇƨƒĂƙǆ!ƒ Ƨơǉ!ƒ ǀƧǋǴǓ Ǉǫ

ƲƧƵ Ü (Y_2) ƧƬƤƙǆ!ƒ ǴƨȠ!ƒ Ŏ5 ǇǴŏƧȠ!ƒ ƾǆƵ Ü (Y_1) ƧƬƤƙǆ!ƒ Ƨŏƺ ǴƨȠ!ƒ Ŏ5 ǇǴŏƧȠ!ƒ ƾǆƵ Ŏù5 ǀǴùǉǀ!ƒ ƲƧƵ Ü (v_1) ƔƧƙǀǆ!ƒ ýƱǀǆ!ƒ Ŏ5 ǇǴŏƧȠ!ƒ ǂƵƧǀ Ü (B_1) ƧƬƤƙǆ!ƒ Ƨŏƺ ǴƨȠ!ƒ Ŏ5 ǀǴǉǀ!ƒ Ü (ρ_w) ǴùŏǆŦ!ƒ ǂ5ǴƛǂÜ (D_{50}) ƧƶǀŦ!ƒ þƒĂǆ ƧƱþ ýþƶǆ Ü (g) ŎƲƧŬƒ ýŏȠƶƙ!ƒ Ü (B_2) ƧƬƤƙǆ!ƒ ǴƨȠ!ƒ ǏƧǴùŏƶǆ!ƒ ƻƒƧơǉŬƒ Ü (θ) ƧƬƤƙ!ƒ ǊþǀǆŦǂŏĂƒƨ Ü (μ) ǴǆǀǀǀŦ ǂŏǂŏƧơƙ!ƒ ǂȠĂƨǀ!ƒ Ü (ρ_s) ƔǴǀ!ƒ þƒĂǆ ǂ5ǴƛǂÜ : ŎƙŬƒ ýǂƬ!Ǵǀ ǂǆǴƶ!ƒ ǂþűƶ!ƒ ǂƺǴŏƬ ǇǂǆŏĂ . (σ_g) ƔǴǀ!ƒ þƒĂǆ!

$$Y_2 = f\,(Y_1 , B_1 , B_2, v_1 , g , D_{50} , \rho_w , \Delta\rho_s , \mu , \theta , \sigma_g) \quad \text{……………...……………..(17)}$$

: ŎƙŬƒ Ăơǉ!ƒ ǏǁƵ (17) ǂþűƶ!ƒ ǂƺǴŏƬ Ǉǂǆŏ (ǏǴǀ ǂŏƧǓǉ) ǐþƶǀ!ƒ ýŏǁơƙ!ƒ ǂǀŏƧƱ ǊƒþƤƙǀǴǀĂ

$$\frac{Y_2}{Y_1}=f\left(\frac{B_1}{B_2},Fr_{\circ},\sigma_g,\theta,\mathrm{Re}\right) \quad \text{…………………………………...………(18)}$$

: ǇǊ Ʀǫ

$$Fr_{\circ} = \left(\frac{v_1}{\sqrt{g \frac{\Delta\rho_s}{\rho_w} D_{50}}} \right)$$

$$\mathrm{Re} = \left(\frac{v_1 Y_1 \rho_w}{\mu} \right)$$

$\Delta\rho_s = (\rho_s - \rho_w)$.

$$ds = Y_2 - Y_1 + \frac{v_2^{\,2}}{2g} - \frac{v_1^{\,2}}{2g} + H_L \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19)$$

$$\frac{v_1^{\,2}}{2g}$$

$$\frac{v_2^{\,2}}{2g}$$

H_L

(19)

$$ds = Y_2 - Y_1 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(20)$$

ŎŀŀĮĜùŋ ƠùƼƱďž ýďžƵ Ďžǩ ƧŀǩƪďžƧōƧƮǩ ĬƖƵ ýĂƮơǃĂ .ŊĮďž ŎŋĜŋƨǃƒ Ĉƨŋǃƒ ĬƖƵ ƘŀƛďžŎƱŀĮ ƩĜōŀďž .ŀĜĮǃƒ ŁōƒþŀŎ5 (Ďžƪ ďĐ× Ďžƪ ďĐ) þĜžŀďŀ

ǈōŋŖĂùďžĮǃ! ŎǃƤĮďžǃƒ ýōǃơǩǃƒĂ Ƨžp þƒĂďžǂ ŁǃŋþƧŋĮĮ ǈďž ǈōŖĂƤďž ýďžƧǃƒ ǈďž ǈōŋŖĂďžĮ ĎžƒþƤǩƪƒ Ďžǩ

ĭĂĜƪùō (A) ƜŖĂùďžĮǃ! ŎùƪĜōŀǃƒ ĭƧĜùōžďžǃƒ ƧƒƧùơĮǕƒĂ ƧùƱŀǃƒ ýþùžďžĂ (ď) ýǂƬùǃƒ Ŏ5 ƠưĂďž

ŎǃƒĂùǩǃƒ ĬùƖƵ (ď,ĐēĐ)Ă (Ďžŀďž č,ČĐČ) ĭĂĜƪō (B) ƜŖĂďžĮǃĂ ŎǃƒĂǩǃƒ ĬƖƵ (Ď,čđč)Ă (Ďžŀďž Č,Ēďđ)

ŎžƱŀďž ŁōĂƒƨĂ ŁŀĂǃƱďžǃƒ ƧƮƤǩǃƒ ŁŀƪĮ ƘōƛǩďžōǈĜŀ ŁōƧŀǩƤďžǃƒ ƔƧĜŋǩǃƒ ĈƒƧŋƹ ŁǃōƧƱ ƒ ƤǃǩǩĂ .ĜưōĐ

ƩĜùōŀďž ŁƱĜùƪĂŀ ƧùžŀǃƒƔōƪĜĮďž ƩĜōp Ďžǩō ĎžƛĭĂǩƪďž ýǂƬŀ ŀĜĮǃƒŎ5 ýďžƧǃƒ ƫƧƽŀĂ ƜĂƧƤǃƒĂ ýĂƤþǃƒ

ƔĂǃƱďžǃƒ ƧōƧƮǩǃƒ ĬƖƵ ƘŀƛōŎǂ ƐƱŀŀ ŀƧƱōƪǃƒ ĎžĜďžƮ ƠǩƽōĂ ĈĜďžǃƒ ƨōŋĵŋǩ ŁƤưďž ýōƺƬǩ Ďžǩō Ďžƛƫďžžǃƒ

ǈōùơ! ŀĜùĮŀǃƒ Ŏù5 ǈĜōƧŋǃƒ ŁŀƒƧďž ĎžǩǩĂ ǈōŀĂǃƱďžǃƒ ĈĜďžǃƒ ƫďžƵĂ ƧōƧƮǩǃƒ ƧƒƧďžǕ ĎžǂơǩǃƒŁŀƒĂŀ Ơǩƽǩ Ďžƛ

ƠƱƪ ƘĜƪĜōp ŖƤƋǩ ýþǕƒ ĬƖƵ ýōƺƬǩǃƒ ǈďž ƘĜƵĜƪ Łǩƪ þžŀĂ ĈĜďžǃƒ ƠƱƪ ăĂǩƪďž ƧƒƧŀǩƪƒ ĬƖƵ ýĂƮơǃƒ

ĜùōǃĂƱ ƧơĮǃƒ ƘĜƪĜōp ŖƤƒ ĜŊþžŀ ĎžǩōĂ ƧơĮǃƒ ŀƧƽơ ǈďž ĈĜďžǃƒ ýƨŀōĂ ŀĜĮǃƒ ǈƵ ĈĜďžǃƒ ýƱp Ďžǩō ĜŊþžŀĂ ĈĜďžǃƒ

ŎĮĜǃƒ ƜŖĂďžĮǃĜŀ ýďžƧǃƒ ýþŀǩƪō Ďžƛ ýďžƧǃƒ ƜŖĂďžĮ Ʃƽĭ! ŁƽǃǩƤďž ƧōƧĜƮǩ ŁžŀƧǕ Łōǃďžžǃƒ ƧƧǂǩĂ . ĜōưƧƵĂ

ƧĜùŀǩƤǕƒ ŁùōǃďžƵ þĜžǩĂ ŁǩĜƛ ƜĂƧƤǃƒ ŁōĂƒƨ ĈĜŀĂ ýĂƤþǃƒ ŁōĂƒƨ ƧōōƺǩĎžǩō ĜŊþžŀĂ ƧĜǩƤǕƒ ŁōǃďžƵ þĜžǩĂ

ǈǂďžōĂ Ü ýďžĜǂǃĜŀ ĮǕƵƒ ƘĜōǃďžžǃƒ þĜžǩĂ ăƧƤĐ ŁŀƪĮ Ĭǃƒ (B1/B2) ƧƮƤǩǃƒ ŁŀƪĮ ƧōōƺǩĎžǩō ĜŊþžŀĂ ýďžĜǂǃĜŀ

.ŁŀƧŋǩ ǈōžŀƧĐ ĈƒƧŋƹ ǈōŀō Łōơ (č) ýĂþŋǃƒ Ŏ5 ƔƧĜŋǩǃƒ ŊďžĜĮƧŀ ƒ ōƤǃǩ

ŀĭþĜŁĮĎžǁƐ ƒþƑƜŁƐ ƛĎžƑďžþĜ : (Č) üŊĮƜ

(Q) ƧōƧƮǩǃƒ ĜǩƒƧǩ!	ƧƮƤǩǃƒ ĎžþŀĂ ŁōĂƒƨ ŁŋƧþ (θ)	ƧƮƤǩǃƒ ŁŀƪĮ (B1/B2)	ýďžƧǃƒ ƧƱp ýþžďž D50 (Ďžŀďž)	ŁŀƧŋǩǃƒ ĎžpƧ
Đē,Ē-čČ,Đ	čČ	Đ	Č,Ēđď	Đ-č
Đē,Ē-čČ,Đ	čČ	Đ	č,ČĐČ	Ě-đ
Đē,Ē-čČ,Đ	čđ	Đ	Č,Ēđď	čĎ-ě
Đē,Ē-čČ,Đ	čđ	Đ	č,ČĐČ	čĒ-čď
Đē,Ē-čČ,Đ	ĎČ	Đ	Č,Ēđď	ĎČ-čē
Đē,Ē-čČ,Đ	ĎČ	Đ	č,ČĐČ	ĎĐ-Ďč
Đē,Ē-čČ,Đ	ĎČ	ď	Č,Ēđď	ĎĚ-Ďđ
Đē,Ē-čČ,Đ	ĎČ	ď	č,ČĐČ	ďĎ-Ďě
Đē,Ē-čČ,Đ	ĎČ	Ď	Č,Ēđď	ďĒ-ďď
Đē,Ē-čČ,Đ	ĎČ	Ď	č,ČĐČ	ĐČ-ďē

-: ƛƏƑŁŀǁƐ üĭǂƟŁ (Đ)

þƟŀǁƐ 5ĎžƳ ĂǂƳ þƮƜŁƐ ŀĜƨďž þĭŀĐŁ (Č-Đ)

ƠưùǩƒĂ (B1/B2) ƧƮùƤǩǃƒ ŁŀƪĮ ĮþĜōƨŀ þƒþƨō (ds) ƧơĮǃƒ ƫďžƵ ǈĜŀ ƠưǩƒŊƑĜǩĮǃƒ ýōǃơǩ ǈďž

ƧùơĮǃƒ ƫùďžƵ ĬùƖƵ ƧƮùƤǩǃƒ ŁŀƪĮ ƧōƛƛƧƮĂ! ŁþǕƵ ýư5ƒ ŎŊĮ ŁōþƧƱǃƒ ŁōƱƤǃ! ŁþǕžǃƒ ǈĐ ĜưōĐ

:ŎǩǕĐǂĂ

$$ds = a_1 + b_1 \times \left(\frac{B_1}{B_2} \right) \quad (21)$$

: ǈĐ Ŗǫ

(Ďžƪ) ƧơĮǃƒ ƫďžƵ = ds

ƘǕďžĜžďž = b1, a1

ƧōƛǩǈĜơưĂō (đ)Ă (Đ) ǈōǃǂƬǃƒĂ (R^2) ƱĜǩƧǕƒ ýďžĜžďžĂ (b_1, a_1) ƘǕďžĜžďžǃƒ Ďžōp (Ď)ýĂþŋǃƒ ƠưĂōĂ

ŎơĂùō Ĝžďžďž (0.75)Ă (č) ǈōŀ ƱĜǩƧǕƒ ýďžĜžďž ƟĂƒƧǩōĂ ýďžƧǃƒ ŎŋŖĂďžĮ! ƧơĮǃƒ ƫďžƵ ĬƖƵ ƧƮƤǩǃƒ ŁŀƪĮ

(Lim and ǈùďž ýùǂ ǁù!Ŗ ǈōùŀ Ĝùďžǂ Ă ƧƮùƤǩǃƒ ŁŀƪĮĂ ƧơĮǃƒ ƫďžƵ ǈōŀ ŁōĂp ŁōþƧƱ ŁpǕƵ þĂŋĂŀ

. (Raudkivi,1998)Ă Cheng,1998)

(čČ) ŀǁĮƑƳĎžǂǁ (R^2) ǗƑĜŁþǗƐ üĎžƑƳĎžŊ (b_1, a_1) ǀǘĎžƑƳĎžǁƐ !ĭ5 (č) üŊĮƜ

ƻǒƧƮƙ!ƒ (ǤƛǺ /Ƨƙ!)	(ǅǙǖǆ 0.653 = D_{50}) A ǶƦǍǅǖǚ!ƒ			(ǅǙǖǆ 1.04 = D_{50}) B ǶƦǍǅǖǚ!ƒ		
	a_1	b_1	R^2	a_1	b_1	R^2
47.573	-3.3500	5.440	0.9997	-6.0683	5.225	Č,ěěěě
36.271	-3.1467	4.250	0.9948	-9.6433	5.020	0.9816
22.676	-2.7500	2.890	0.9624	-5.8533	2.940	0.9998
10.398	-1.3367	1.250	0.9979	-2.4617	1.055	0.7500

þƟǖǚƐ ƼǅǏƳ ǍǂƳ ƺǐþƬǂǚƐ þǐƙƉǂ (č-Đ)

ƻƮǍ! ǂþǘƵ ýưƼƒ ǑǸǰ ǂǒƱƤ!ƒ ǂþǘƶ!ƒ ǇƒǍ ƻǒƧƮƙ!ƒ ǉþǤǒƨǘ þƒþƨǒ ƧơǙǚ!ƒ ƽǅƵ ǇǬ ǊƑǤƙǚ!ƒ ýǒǖơƙ ƠưǍ
:ǑƙǛƉǂǍ ƧǒǺǅƙ!ƒ

$$ds = a_2 + b_2 \times Q \ldots\ldots(22)$$

:ǇǬ Ʀǫ

(ǅƪ) ƧơǙǚ!ƒ ƽǅƵ = ds

ƘǗǅǤƶǅ = b_2 , a_2

(ǤƛǺ /Ƨƙ!) ƻǒƧƮƙ!ƒ =Q

ǇǛǒǘ ƱǤǘƘƧǛƒ ýǅǤƶǅ ƟǍƒƧƙǒǍ (ď) ýǍþƞ!ƒ Ǒƽ ǂơưǍǅ ƱǤǘƘƧǛƒ ýǅǤƶǅǍ (b_2, a_2) ƘǗǅǤƶǅ!ƒ ǅǒǷ ǇƒǍ (7)Ǎ (6) ýǤǂǛƮǛƒ Ǒǜƽ ǇǒǘǅǤǅǂǍ ǂơưƒǍ ǂǒþƧƱ ǂþǘƵ þǍƞǍǘ ǑơǍǒ ǤǅǅǅǅǤ (0.9786)Ǎ (0.9828) ƧƮƤƙ!ƒ ǅþǙǅ ǤǒƒǍƨ ƻǚƙƤǅ!Ǎ (B_1/B_2=4) ƧƮƤƙ ǂǘƪǚ! ƧơǙǚ!ƒ ƽǅƵǍ ƻǒƧƮƙ!ƒ ǇǒǘǍ ǂþǘƵ!ƒ ǂǒơ (8)Ǎ
. ǅþƤƙƪǅ!ƒ ýǅƧ!ƒ ǑƞƦǍǅǚ!Ǎ (ǂƞƧþ ĎČ Ǎ čđǍ čČ=θ)

(22) ǘǙǚǟǅǐǂǙ **(R^2)** ǛƒǤǂþǛƐ ǜǅǐǅǐǒǅǐ **(b_2, a_2)** ǀǘǅǐǅǐǚƐ !ǐƼ **(3)** ǜǒǜǚǛ

الحالة	(ملم 0.653 = D_{50}) A النموذج			(ملم 1.04 = D_{50}) B النموذج		
B_1/B_2	a_2	b_2	R^2	a_2	b_2	R^2
4	-0.0033	٠,٣٧٥٨	٠,٩٧٨٦	-2.1182	0.3420	0.9828

þƟǖǚƐ ƼǅǏƳ ǍǂƳ þƬǛǂǚƐ !ǛƽǅǏ ǘǐǜǚƦ þǐƙƉǂ (Ď-Đ)

ǅƺƧ!ǤǜǙ ƧǒƺǘǑ ǅ! ƧơǙǚ!ƒ ƽǅƵ ǇǤƽ (ǂƞƧþ ĎČ Ǎ čđǍ čČ=θ) ƧƮƤƙ!ƒ ǅþǙǅ ǂǒǍƒƨ ƧǒǒƺǑ ǅƺƧ
ǑƞƦǍǜǅǚ! ƻƧƮƙ!ƒ ƩǖǙ ǂǓơǗǅ ǅǘ þƿǍ ƧƮƤƙ!ƒ ýƤþǅ þǚƵ ǂǒǍǚǤǺ!ƒ ƘƒƧǤǒƙ!ƒǍ ƘǤǘƒƧƱưǛƒ ǉþǤǒƨ ǇǅǏ
ǅþǜǙǅ ǂǜǒǍƒƨ ƧǒǺǅƙ ǅþƵ ǚƧǍþǘ ǇǒǘƗ ǏƦ!ƒǍ (Gill,1981) ǊƑǤƙǚ ýǅ ǤǜǙǏƒǍƙ ƳƧǤƞƙ!ƒ ƘƧǜǙƯ þǙ!Ǎ ýǅƧ!ƒ
.ýǒǍƱ!ƒ ƧƮƤƙ!ƒ Ǒƽ ƧơǙǚ!ƒ ƽǅƵ ǏǙƵ ƧƮƤƙ!ƒ

ǅǐǐǐþǛǛƐ ƼǅǏƳ ǘǤƨǅ ǍǂƳ ǂþƟǚƐ ƫ ƽǚƐ ǟǜǛǛ ǍǚƐ !ǛǂǅǏƐ ƫ ƽǚƐ ǟǜǛǛ ǘǤƨǅ þǐƙƉǂ (ď-Đ)

ǂǅƪǜǙǘ ǤǜǛǜǚƵ ýǍƮǜơ!ƒ ǇǛǂǅǒ (τ_c) ǛƧơ!ƒ ƒ !!ƒ þǛǛ ǏǃƱ (τ_o') ǅǐƤǤǅ!ƒ ƒ !!ƒ þǛǛ ǂǘƪǚ
: ǑƙǛƉǂǍ (Ě) ǂ!þǤǅ!ƒ ǏǙƵ (ē) ǂ!þǤǅ!ƒ

$$\left(\frac{\tau_{\circ}'}{\tau_c}\right)_L = 0.02739 \times \left(\frac{v_1^{\,2}}{Y_1^{\frac{1}{3}} D_{50}^{\frac{2}{3}}}\right) \ldots\ldots(23)$$

:Ǉƒ Ʀƒ

$\left(\dfrac{\tau_{\circ}'}{\tau_c}\right)_L$ = ǂǘƪǚ þǛǛ !! ƒ ǤƨǛǚ! ƧǒƺǅƤƮƧ!ƒ þǛǘǂ! ƧƪǇǑ (Laursen) [illegible] (Y_2/Y_1) [illegible] (τ_o'/τ_c) [illegible] (B) [illegible] (A) [illegible]

$$\frac{\tau_o'}{\tau_c} = a_3 + b_3 \times \left(\frac{Y_2}{Y_1}\right) \qquad (24)$$

[illegible] B [illegible] A [illegible] (4) [illegible] $(b_3,\ a_3)$ [illegible]

(24) [illegible] **(R^2)** [illegible] **(b_3, a_3)** [illegible] **(4)** [illegible]

[illegible]		[illegible] A (D_{50} = 0.653 [illegible])			[illegible] B (D_{50} = 1.04 [illegible])		
B_1/B_2	θ°	a_3	b_3	R^2	a_3	b_3	R^2
4	20	-1.2281	1.6223	0.9853	-1.0241	1.6449	0.9858
3	20	-1.3944	1.4904	0.9958	-1.0233	1.3366	0.9854
2	20	-1.2651	1.1905	0.9979	-1.0243	1.1552	0.9856

[illegible]

[illegible] (10) [illegible] (9) [illegible]

[illegible] **(Y_2/Y_1)**

[illegible] (SPSS-10.01) [illegible] (Y_2/Y_1) [illegible] (Re) [illegible] (θ) [illegible]

$$\frac{Y_2}{Y_1} = 0.618 \times \left(\frac{\left(\frac{B_1}{B_2}\right)^{0.527} \times (Fr_o)^{0.489}}{(\sigma_g)^{0.238}} \right) \qquad (25)$$

[illegible] (R^2=0.9434) [illegible] (Y_2/Y_1) [illegible]

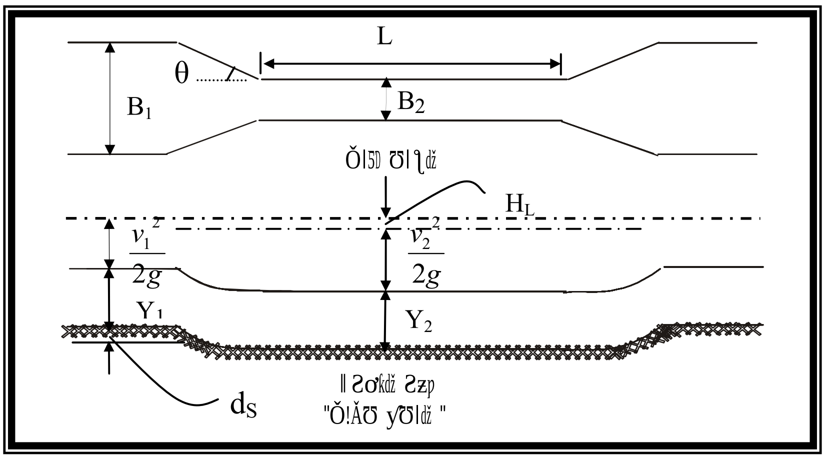
[illegible] (Y_2/Y_1) [illegible] (Y_2) [illegible] (Fr_o) [illegible] (Fr_1) [illegible] (σ_g) [illegible] (D_{50}) [illegible] (B_1/B_2) [illegible] (D_{50}) [illegible] (τ_o' / τ_c) [illegible] (B_1/B_2) [illegible].

[illegible]

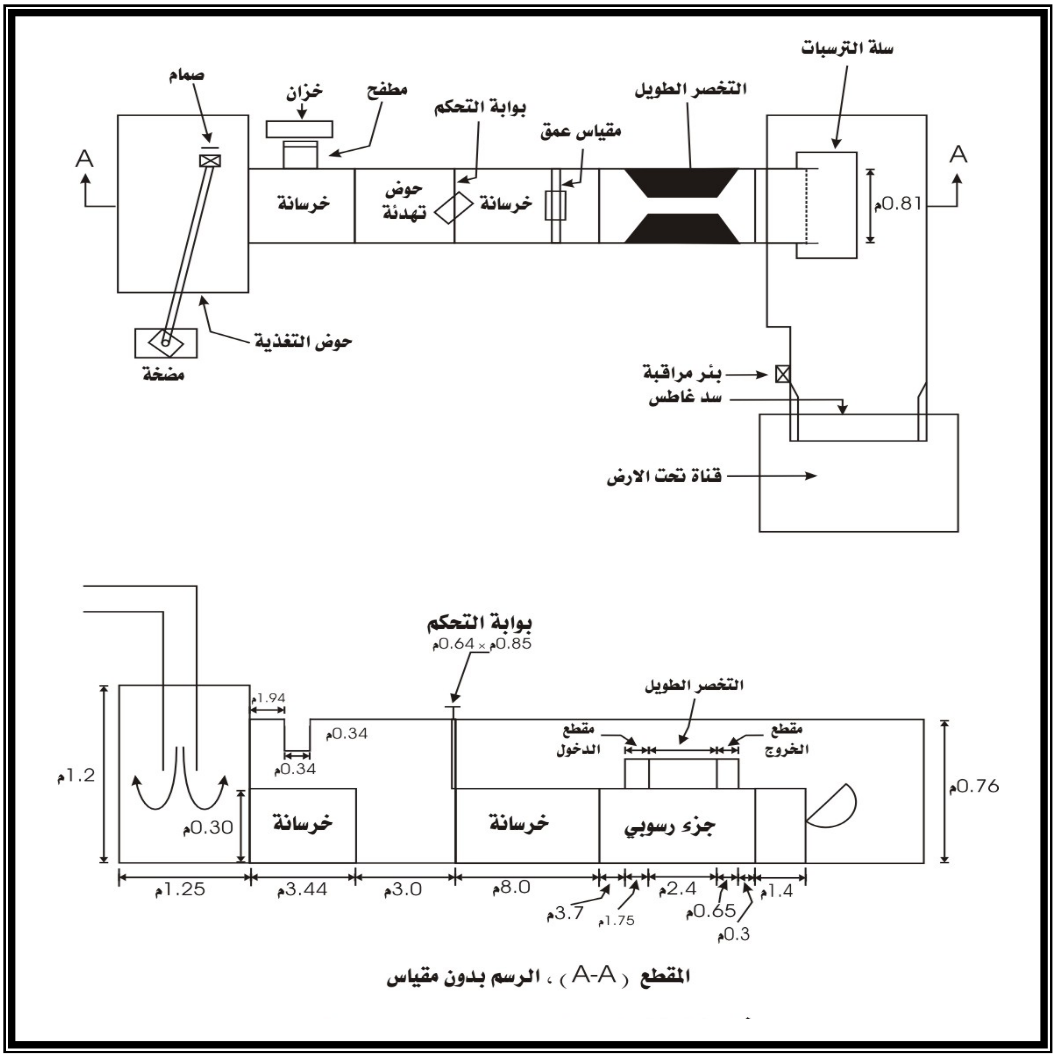
- [illegible] (B_1/B_2) [illegible] (ds) [illegible] (R^2) [illegible] (21) [illegible].
- [illegible] (Q) [illegible] (R^2) [illegible].
- [illegible] (θ) [illegible].
- [illegible] (τ_o' / τ_c) [illegible] (Y_2/Y_1) [illegible].
- [illegible] (Y_2/Y_1) [illegible] (σ_g) [illegible] (Fr_o) [illegible] (B_1/B_2) [illegible] ($R^2 = 0.9434$) [illegible].
- [illegible] (d_s) [illegible] ($ds = Y_2 - Y_1$) [illegible].

þœŁTDžllɛ (Ē)

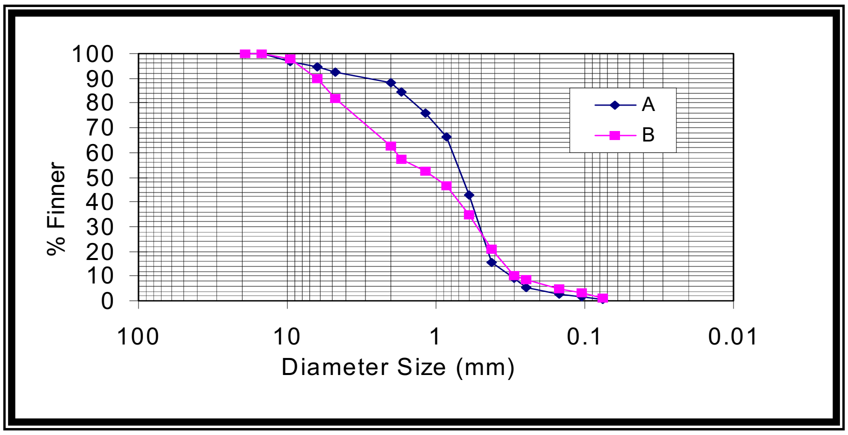
1. Alawi A.J., (1981) " Effect of Velocity on Scour ", M.Sc. Thesis, Dept. of Civil Engineering, University of Arizona, Arizona, U.S.A.
2. Alawi A.J., (1985) " Some Contribution to the Study of Scour in Long Contractions " Ph.D. Thesis, Dept. of Civil Engineering, University of Arizona, Arizona, U.S.A.
3. Das B.P., (1973) " Bed Scour at End – Dump Channel Constrictions", Journal of Hydraulics Division, ASCE, Vol. No. HY9, December.
4. Gill M.A., (1972) " Bed Erosion of Sand Beds Around Spur - Dikes ", Journal of Hydraulics Division, Vol. 98, No. HY9, September.
5. Gill M.A., (1981) " Bed Erosion in Rectangular Long Contraction", Journal of Hydraulics Division, Vol. 107, No. HY3, March.
6. Griffith W. M. (1939) "A Theory of Silt Transportation." Transactions, American Society of Civil Engineers, Vol. 104,1939.
7. Komura S., (1966) " Equilibrium Depth of Scour in Long Constrictions", Journal of Hydraulics Division, ASCE, Vol.92, No.HY5, September.
8. Laursen E. M. (1958b) " The Total Sediment Load of Streams" Bulletin No. 8, Iowa Highway Research Board, August.
9. Laursen E. M. (1963) " An Analysis of Relief Bridge Scour". Journal of Hydraulics Division, ASCE, Vol. 89, No., HY3, May.
10. Lim S.Y. and Cheng N.S., (1998) " Scouring in Long Contractions ", Journal of Irrigation and Drainage Engineering, September/October.
11. Lim S.Y., (1993) "Clear Water Scour in Long Contractions ", Proceeding Institution of Civil Engineering - Water, Maritime & Energy, Vol.101, 93-98.
12. Raudkivi A.J., (1998) " Loose Boundary Hydraulics ", A.A. Balkema Publishers, Rotterdam, Netherlands.
13. Silverstone E. and Laursen E. M. (1967) "Patterns of Scour and Fill in Pool – Rapid Rivers." Proceedings, 3rd Federal Inter – agency Sediment Conference, Denver.
14. Straub L.G., (1934) " Effect of Channel Contraction Works upon Regime of Movable Bed Streams " Transaction, American Geophysical, Union, Part II.



ŭĭŊĵƲľľ þTŒŀľľ : (1) ŭl ĩ



hubŽqŒIł ƨDŽŀĿ hıĭþĞŀŒqDŽŀĿ ƔFťsŀĿ : (č) üĿŀʅ



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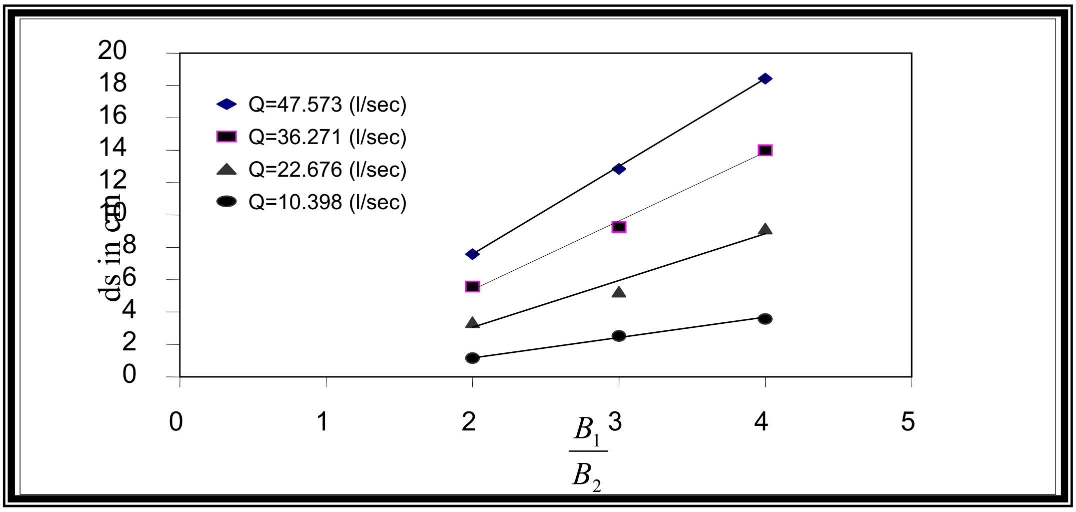
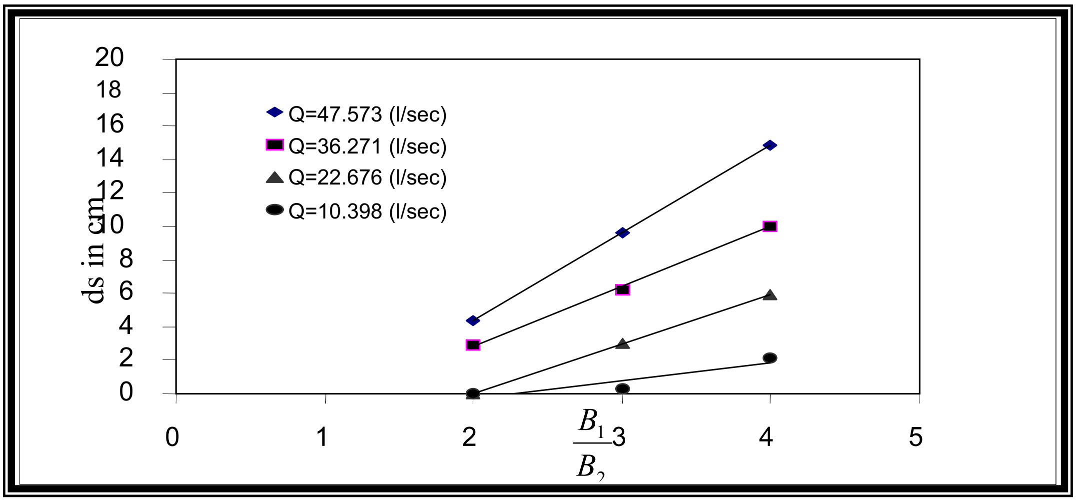
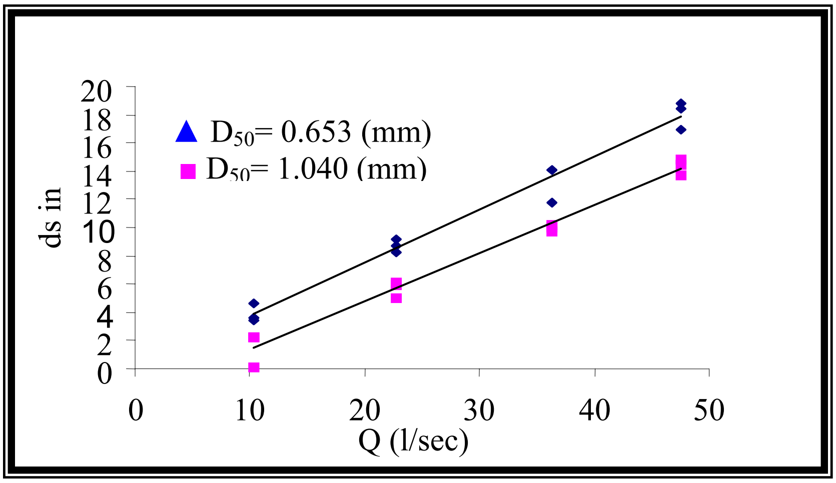


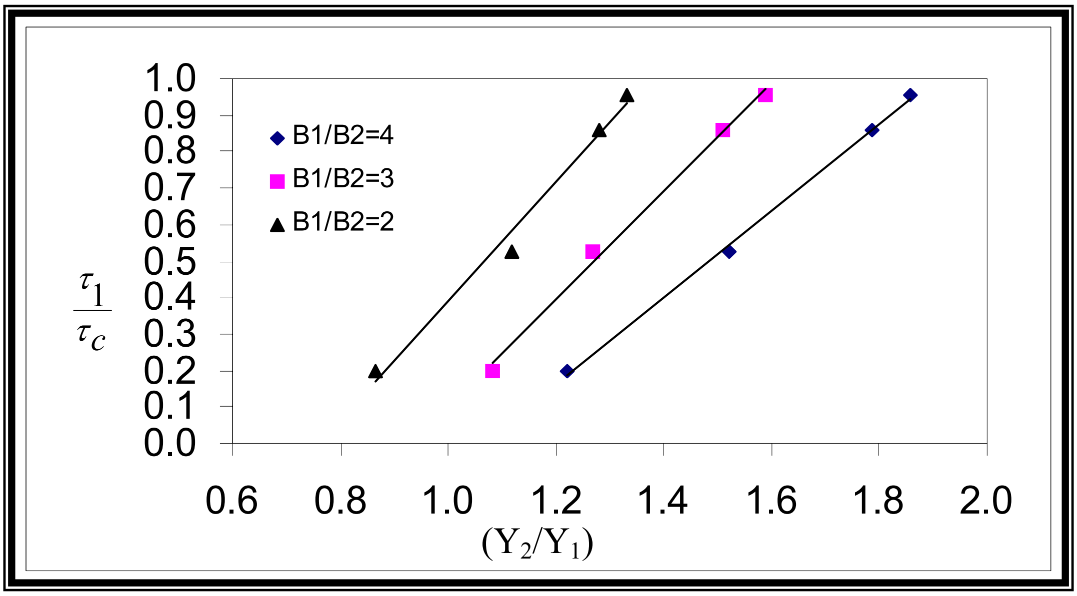
شكل (4) : العلاقة بين عمق النحر ونسبة التخصرللنموذج A



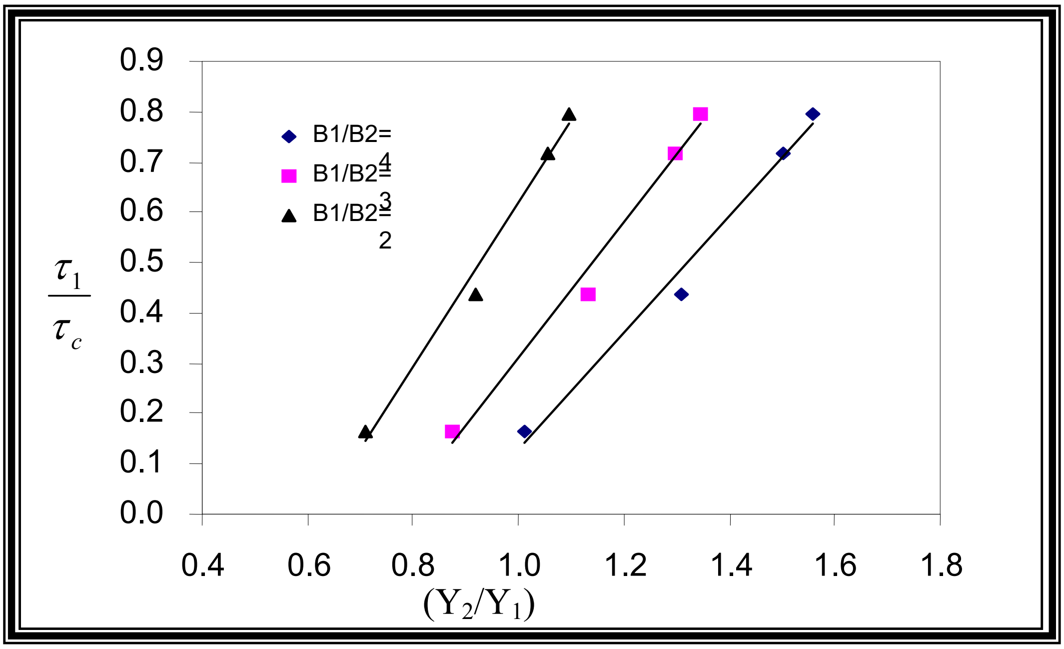
شكل (5) : العلاقة بين عمق النحر ونسبة التخصر للنموذج B



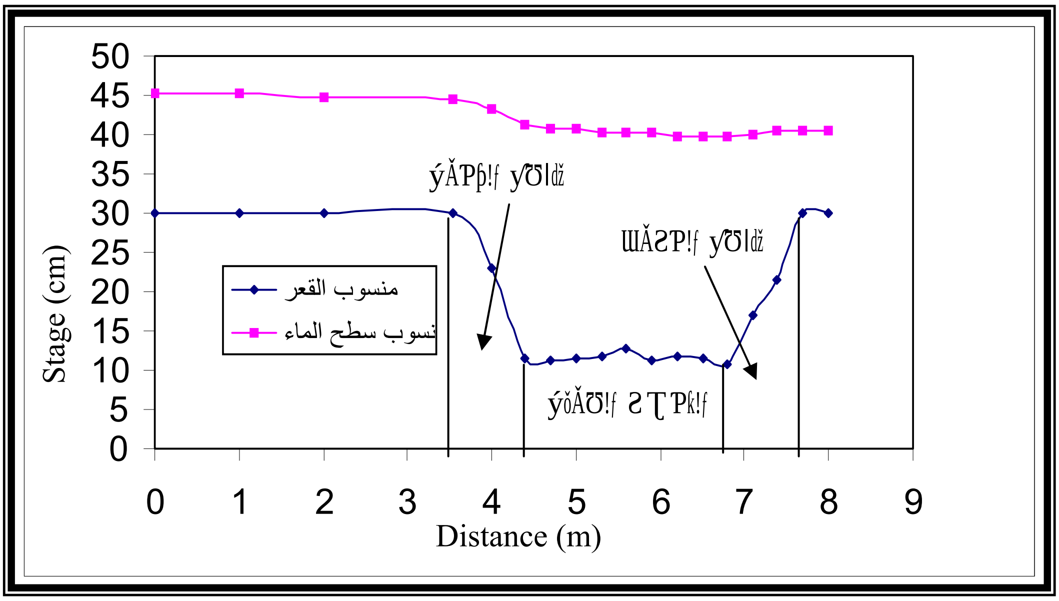
$(\theta=10^\circ,15^\circ, 20^\circ)$ﻟ $(B_1/B_2=4)$ ƒDžqǿY þΘǚlE 5ĎŽYNj ƹĭþTIlE DžǏG hƽűýllE (đ) ül l



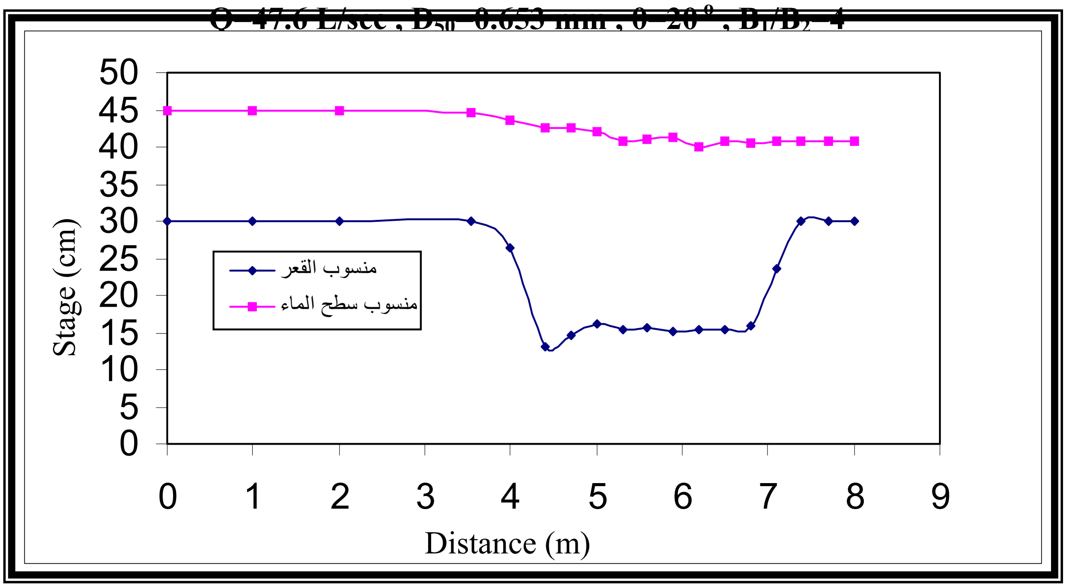
A ł PNjDŽǚǂǁ ţ şǁƐ ǫNJШ ħǴƨǚNj ƅƑDŽǁƐ ƼDŽY ħǴƨǚ DžǏǴ ħƼǘyǁƐ (Ē) üǀ ʅ



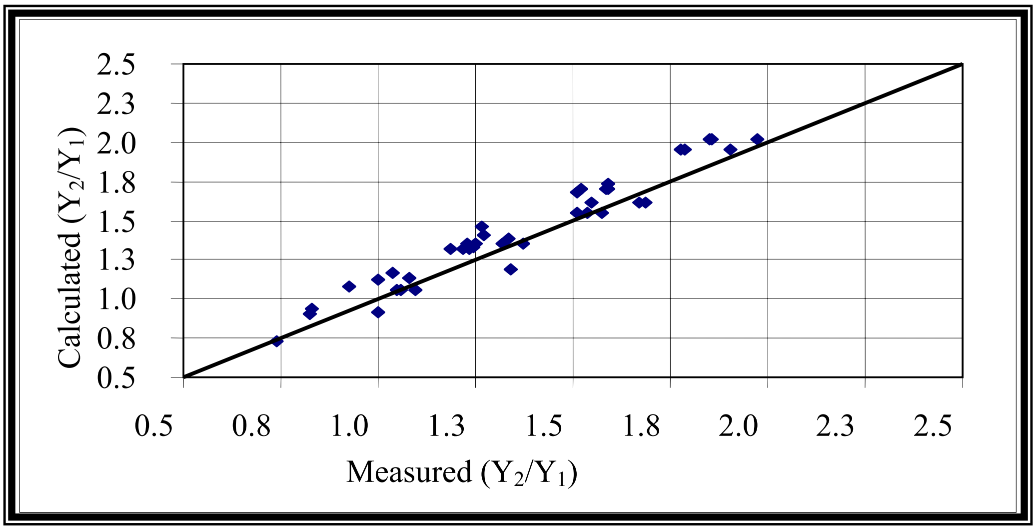
B ł PNjDŽǚǂǁ ţ şǁƐ ǫNJШ ħǴƨǚNj ƅƑDŽǁƐ ƼDŽY ħǴƨǚ DžǏǴ ħƼǘyǁƐ (ē) üǀ ʅ



A üĎǏþǁǁ ƗƤǇĎǏǁǁ þyŝǁǁǇ ƀƒĎǏǁǁ ηƯƨ ƒǇjƨǁǁĎǏ : (Ĕ) üǀƪ
Q=47.6 L/sec , D_{50}=0.653 mm , θ=20 °, B_1/B_2=4



B üĎǏþǁǁ ƗƤǇĎǏǁǁ þyŝǁǁǇ ƀƒĎǏǁǁ ηƯƨ ƒǇjƨǁǁĎǏ : (Čċ) üǀƪ
Q=47.6 L/sec, D_{50}=0.1.04 mm, θ=20 °, B_1/B_2=4



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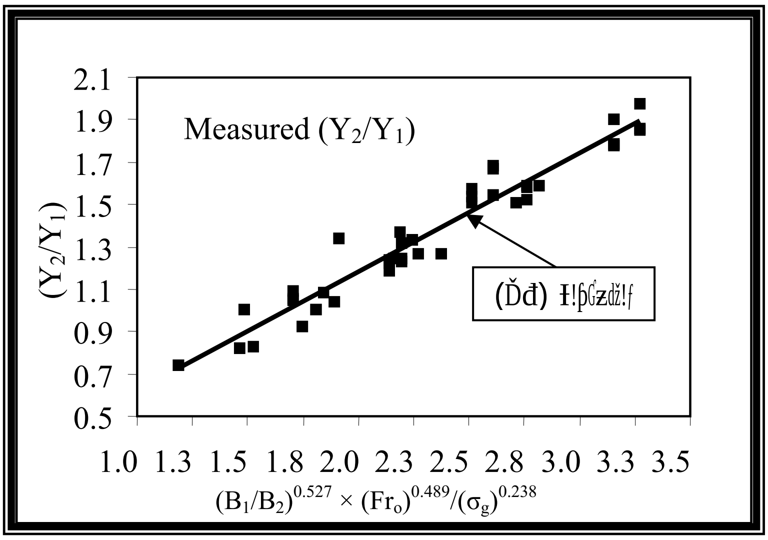
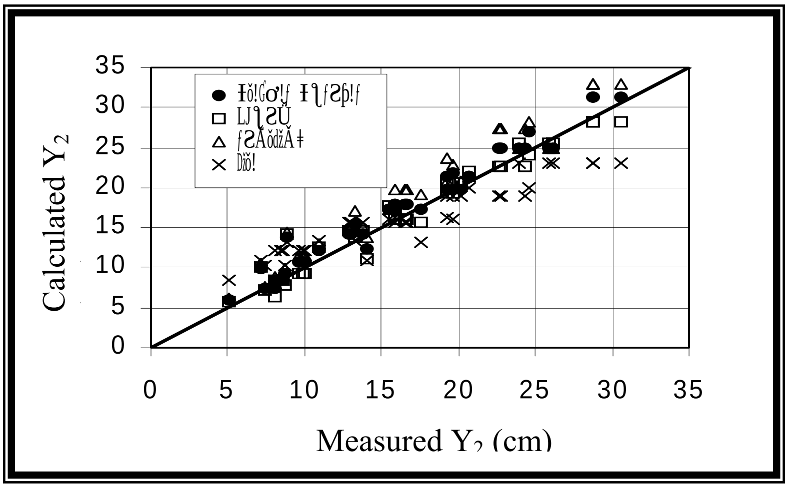


(čĐ) ƕllqƑyĎžllɛ ĎžĎž ƒǋƨƟĎžllɛ ƱĎž ƑïþƓƗƣþĎž Ƨ ƑsĎžllɛ ƼĎžyƞɛ ƒ ƨǚ !Ïƽ ƕǚþƑsĎž : (**12**) ül ľ



ĎžïþƢƆ ĎžïƙƟƑƓ ƛəƑƗǚǋ ƕïƖƑƟllɛ ƕƨƐþqllɛ ƛəƑƗǚ ĎžïƓ ƕǚþƑsĎžllɛ : (**13**) ül ľ