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A STUDY OF SCOUR AROUND AL-KUFA BRIDGE PIERS

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Abstract

Bridge pier scouring is a significant problem in the safety estimation of bridges. This research is carried out to study the local scour around the piers of Al-Kufa bridge ,and to estimate the effect of the spacing between the piers on the depth of equilibrium scour .

Dimensional analysis technique was used ,and from the collected data filed measurements ,an empirical formula was derived .I has been found that the predicated scour depth from the formula compares well with the observed values .

It was found that no mutual influence on maximum scour depth occurs for spacing ratio in Al-Kufa bridge piers , and the scour depth in the middle pier is greater than the others .

The study showed that the piers of Al-Kufa bridge is safe against scouring in the present time , However the scour around the piers should be main laned when the hydraulic conditions is change in the location of the bridge.

Keywords : scour , bridge piers , dimensional analysis , Froude number

دراسة الانجراف حول دعامات جسر الكوفة

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الخلاصة

يعتبر الانجراف حول دعامات الجسور من المسائل المهمة لتخمين سلامة و أمان الجسور لذلك أصبح من الضروري دراسة الانجراف ألموقعي حول الدعامات كلما كان ذلك ضروريا في الجسور المنفذة وخاصة القديمة منها .
في هذا البحث تم دراسة الانجراف ألموقعي حول دعامات جسر الكوفة ومدى تأثير المسافة بين الدعامات على عمق الانجراف المتوازن حول تلك الدعامات .
لقد استخدمت وسيلة التحليل ألبعدي في الحصول على العوامل المؤثرة على الانجراف ألموقعي وتم جمع القياسات الحقلية للحصول على صيغة وضعية لتحقيق الانجراف حول دعامات جسر الكوفة مستقبلا وقد تبين من خلال اختبار تلك الصيغة للمعلومات الحقلية الأخرى بأنها ذات نتائج جيدة.
ومن خلال النتائج التي تم الحصول عليها تبين إن المسافات بين دعامات جسر الكوفة غير مؤثرة على عمق الانجراف إضافة إلى ذلك فقد أظهرت الدراسة على إن أعظم عمق انجراف يحدث حول الدعامة الوسطى للجسر مقارنة بالدعامات الأخرى.
لقد بينت الدراسة بان دعامات جسر الكوفة في حالة أمينة ضد الانجراف في الوقت الحالي ومن الضروري إجراء القياسات الحقلية للانجراف عند حدوث تغير في الظروف الهيدروليكية لموقع الجسر .

Notations

b	Pier diameter
d_{50}	Median sediment size
d_s	Depth of scour
g	Gravitational acceleration
y	Flow depth
k_s	Pier shape factor
k_θ	Pier alignment factor
R^2	Determination coefficient
s	Spacing between piers center to center
v	Flow velocity
F_r	Froude number
ρ	Fluid (water) density
ρ_s	Sediment density

1-Introduction

"Man who overlooks the water under bridge will find the bridge under water". This anonymous citation highlights the detrimental effects that river flow can have on the stability of piers that support a bridge founded in river . The main cause of concern in stability of bridges founded in river beds is the lowering of river bed level caused by river flow around piers and is termed "local scour ". Combined effects of turbulent boundary layer , time- dependent flow pattern , and sediment transport mechanism in and around the scour hole make the phenomenon extremely complex [(1)].

To avoid a failure in the bridge ,the pier foundation is to be constructed to a depth deeper than the maximum possible scour depth in its life time , and the old bridges must be evaluated from time to time to estimate the maximum scour depth around piers to avoid the failure.

Over the past half century , numerous studies have been conducted and numerous equations have been developed to predict bridge pier scour . Most of these equations were developed using laboratory data and sometimes tested using limited field data .

Investigating the sophisticated manner of influencing variables of local scour around piers is still needed .

The present study aims at performing an extensive field investigation on the local scour around Al-Kufa bridge piers in Al-Najef city , and using the field data to derive a formula to predict the maximum scour depth around the piers .

2-Local scour problem around piers

Local scour around bridge piers is caused by obstruction and separation of the flow with attendant generation of a system of velocities . There is a stagnation line on the front of the pier with decreasing pressure downward due to the lower velocities near the bed . This causes a down flow directed toward the bed near the front of the obstruction that separates and rolls up into a horseshoe vortex wrapped around the base of the pier [(8)].

In addition , there are wake vortices in the separation zone .This system of vortices fluidizes the bed and carries the sediment out of the separation zone to create a highly localized scour hole adjacent to obstruction .Figure 1 shows the flow pattern around bridge piers .

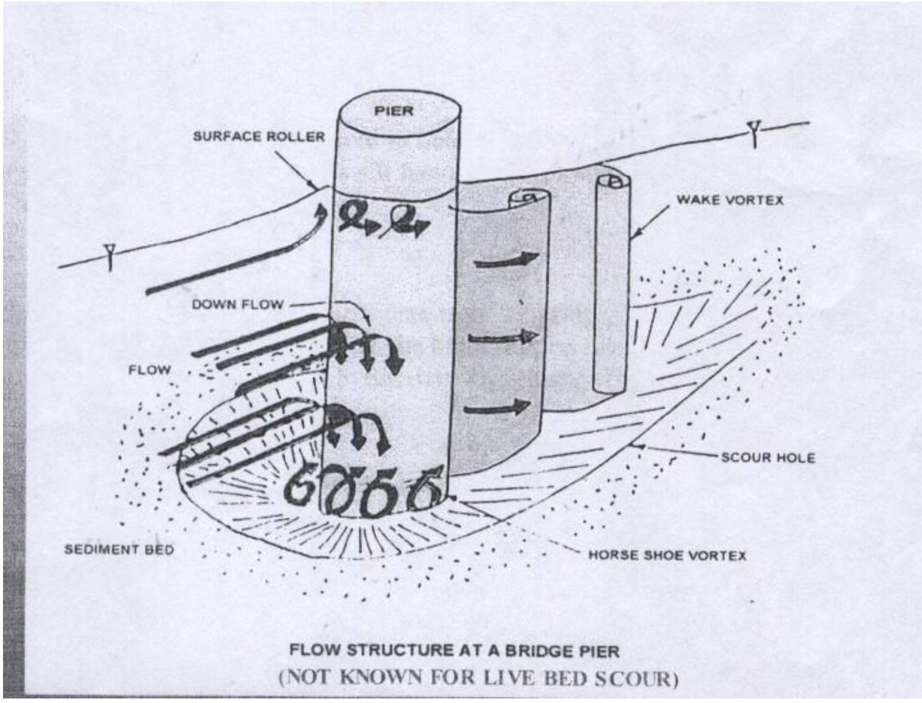


Fig. 1. Schematic representation of scour around bridge pier

3-Bridge Contraction Scour

The acceleration of the flow caused by a bridge contraction can lead to scour in the bridge opening that extends across the entire contracted channel . The contraction can arise from a narrowing of the main channel as well as blockage of flow on the flood plain .

The type of contraction scour can be either clear water or live bed . In clear water scour [9] the velocities and shear stresses in the approach cross – section upstream of the bridge are insufficient to initiate sediment motion , so no sediment transport is coming into the contracted area . In this case , scour continues in the contracted section until the enlargement of the cross – section is such that the velocity approaches the critical velocity and no addition sediment can be transported out of the contraction . This is the equilibrium condition that is approached asymptotically in time [10] Live –bed scour , on the other hand , occurs when sediment is being transported into the contraction from upstream scour continues until the sediment discharge out of the contracted section is equal to the sediment discharge into the section from upstream , at which time equilibrium conditions have been reached .

4- Dimensional analysis of the problem

The dimensional analysis technique was utilized by using the Buckingham π – theorem in order to formulate the field data which can be used to predict scour depth around bridge piers .

Scour depth at pier is a function of pier geometry , flow variable , fluid properties and sediment properties :

$d_s = f_1 (k_s , k_\Theta , b , v_1 , y_1 , g , \rho , \mu , (\rho_s - \rho) , d_{50} ,\sigma_g)$ ……. (1)

In which d_s = depth of scour around piers ; k_s = pier shape factor = 1.0
For cylindrical piers (5) ; k_Θ = pier alignment factor ; b = pier width ; v_1 = approach velocity ; y_1 = approach depth ; g = gravitational acceleration ; ρ = fluid (water) density ; ρ_s = sediment density ; μ = fluid viscosity , d_{50} = median sediment size ; and σ_g = geometric standard deviation of sediment size distribution .
Choosing ρ , v_1 , and b as repeating variables and carrying out dimensional analysis results in

$\frac{ds}{b} = f_2 \left[k_s , k_\Theta , \frac{y1}{b} , \frac{ds}{\sqrt{gy1}} , \frac{\rho v b}{\mu} , \frac{\rho - \rho_s}{\rho} , \frac{y1}{d50} , \sigma_g \right]$ ……. (2)

Combining the Froude number $\frac{ds}{\sqrt{gy1}}$ with $\frac{\rho - \rho s}{\rho}$ and $\frac{y1}{d50}$

$\frac{y1}{d50}$ can be replaced by $\frac{b}{d50}$ with these substitutions and neglecting viscous effects the result is :

$\frac{ds}{b} = f_3 \left[k_s , k_\Theta , \frac{y1}{b} , \frac{ds}{\sqrt{gy1}} , \frac{V1}{Vc} , \frac{b}{d50} , \sigma_g \right]$ ……. (3)

k_s = pier shape factor = 1 for round pier and
k_Θ = skewness factor is constant for the study position (4,5)

Different field measurements at Al-Kufa bridge piers were conducted to reduce the effect of parameters on the maximum depth of local scour , and to drived a new formula to predict the scour around these piers .

5- Al-Kufa bridge

Al-kufa bridge was built during the period 1972-1975 . It consists of four openings separated by three piers with a total length of 166 m , The width of each pier is two meters and the space between each pier equal 46 m the abutment of the bridge is built out of the section of the river , plate 1 shows Al-Kufa bridge .

Plate 1. Al – Kufa bridge at Al-Najaf city

6- Field works

Field works were made during the research from 1/9/2008 – 15/12/2008

6-1 Cross section measurements

The cross section of the river near Al-kufa bridge was observed by taking reference point on the left side with respect to the water flow direction . From the reference point , the whole width of the channel was divided into several part , then the depth for each part was measured , the approximated shape of the channel is a trapezoidal as shown in Fig 2 .

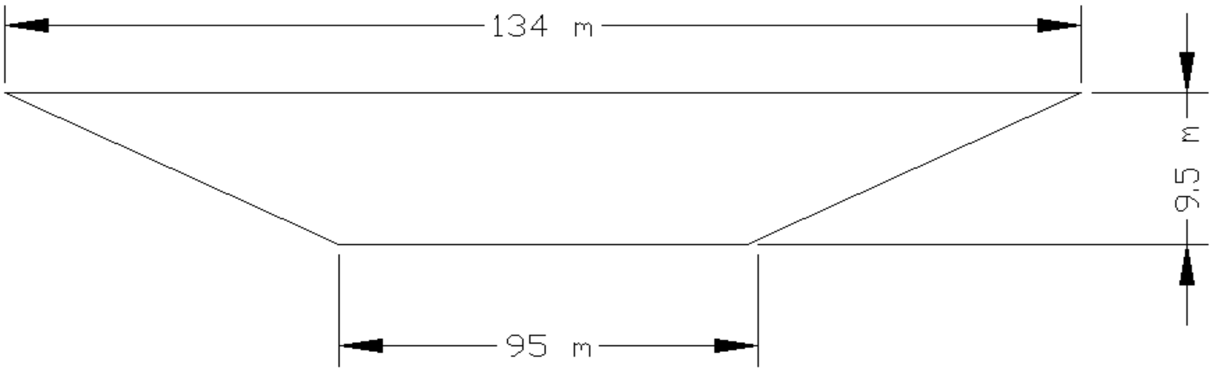


Fig. 2. Observed cross section of the river near Al – Kufa bridge

6-2 Discharge measurement

A current meter at depth (0.2 and 0.8m) at each part was used to measure the velocities in the cannel (plate 2) and the depth of flow as shown in plate 3 , Consequently the discharge were calculated from average velocity times cross section area at different time of the study , the results are shown in Table 2.

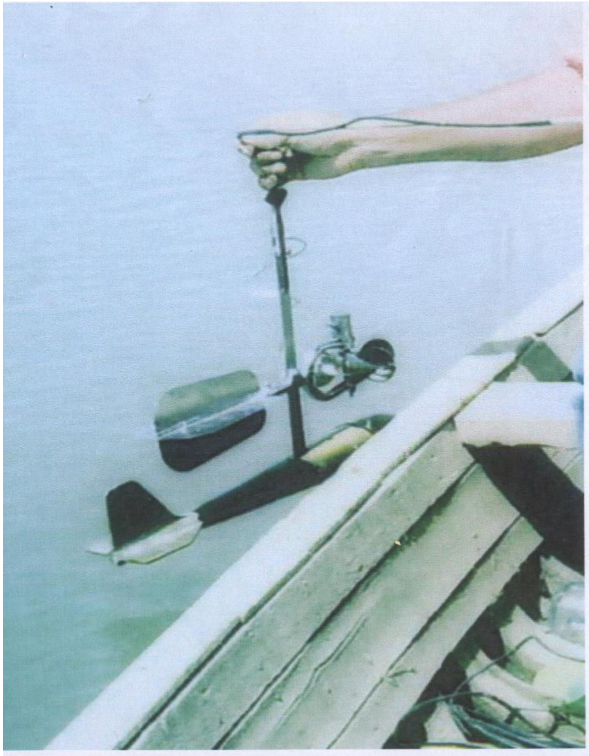


Plate 2. Velocity computations using current meter in Al-Kufa river

Plate 3 . measurement of flow depth in Al-Kufa river

6-3 Bed material sampling

Five samples from the bed material were taken from the section near the piers , at location 0.15 , 0.3 , 0.45 , 0.6 and 0.75 the width of the river in the cross section in order to conduct the grain size analysis . These samples finally mixed well to reduce the error of measurement and get a homogenous sample .

The sampler which is used to measure the bed material is shown in Fig. 3a,b,c .

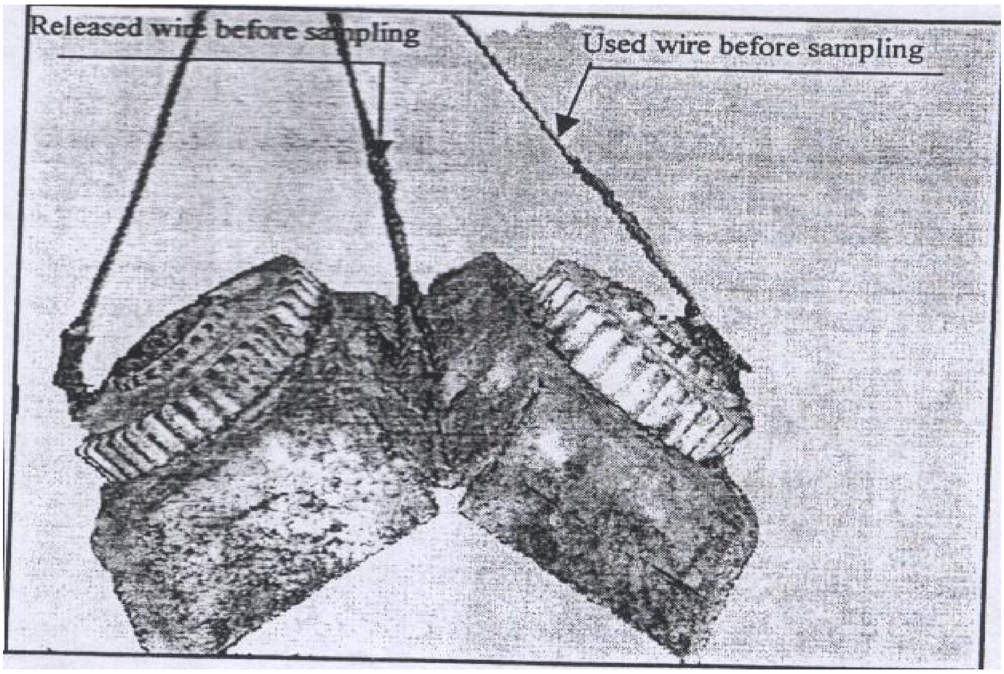


Fig 3a. The bed material sampler before sampling

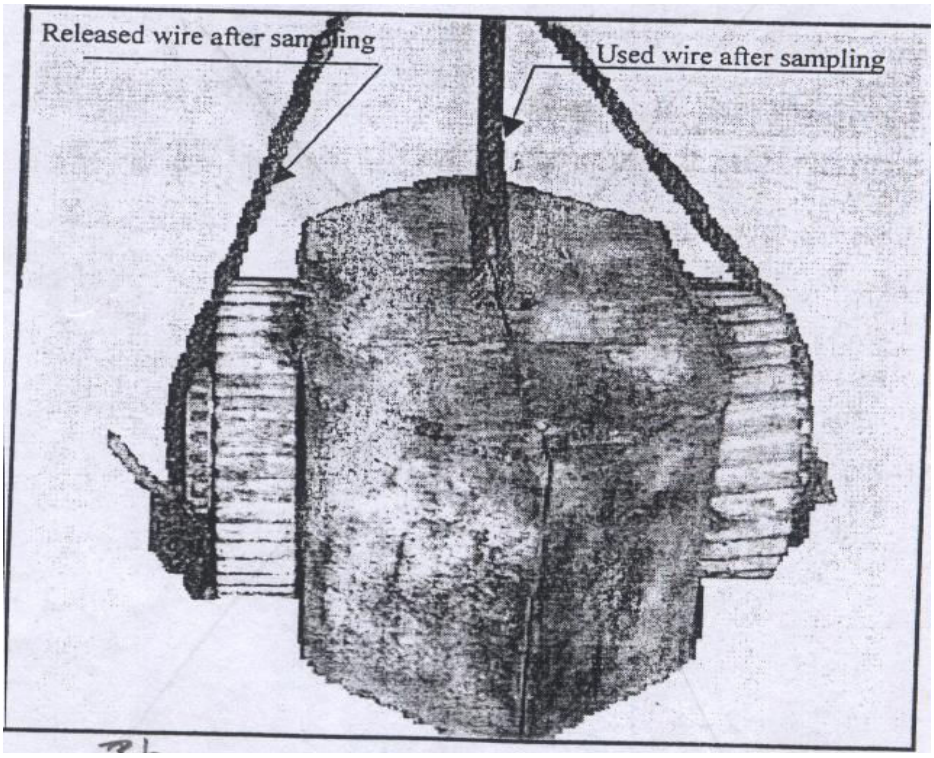


Fig 3b. The bed material sampler after sampling

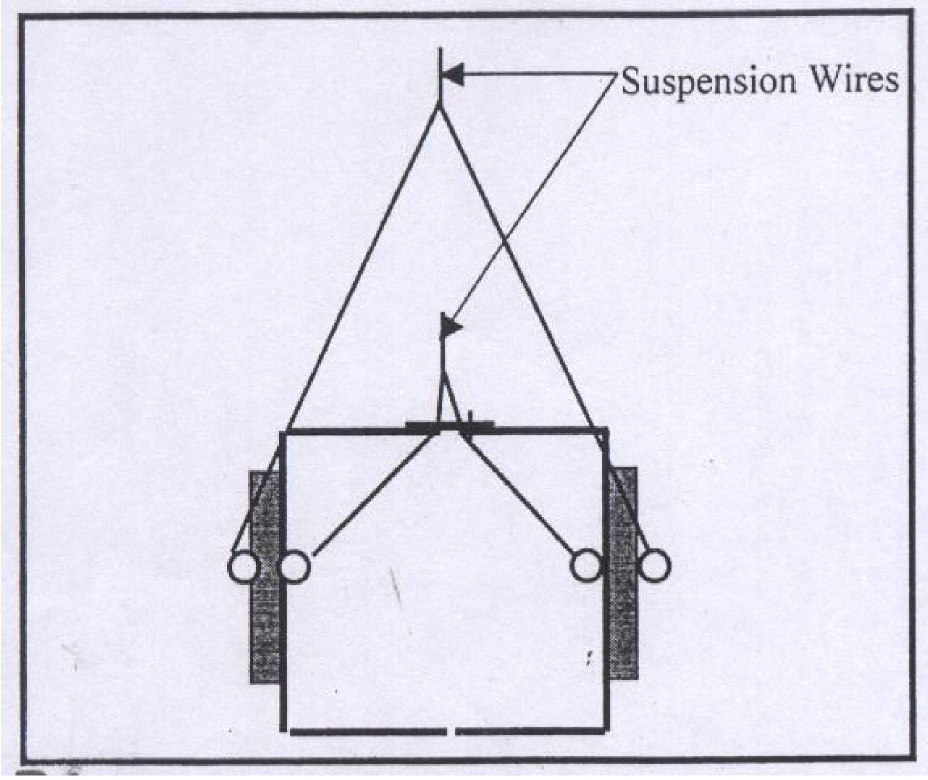


Fig 3c. Sketch of the bed material sampler after sampling

7- Laboratory measurements

It involves collecting of laboratory data including measurements of

A- specific gravity

B- Mechanical analysis of the bed sample from which the size distribution curve can be constructed.

7 –1 Specific gravity determination

The specific gravity is defined as the dry weight of the material within unit volume , the procedure that followed to obtain specific gravity of bed material was according to Bowel´s .

The calculations showed that the specific gravity of the section near Al – Kufa bridge is equal to 2.73.

7 – 2 Grain size analysis

The process of obtaining the size distribution which is essentially the separation of sample into a number of size classes , is known as the mechanical analysis . The results of such analysis of sediment are usually presented as cumulative size – frequency curve .

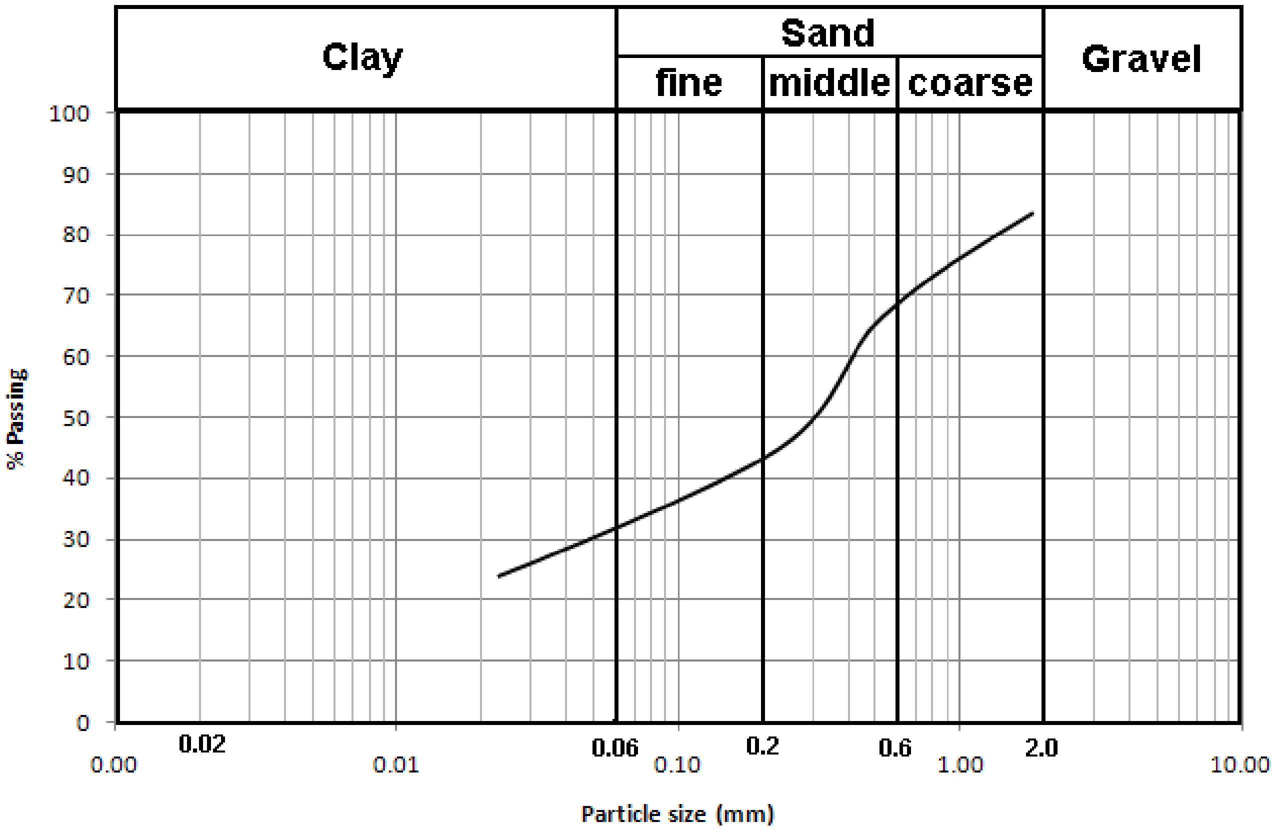
7 – 2 – 1 Sieve analysis

The most reliable and most easily duplicable method of performing the sieve analysis is to take an oven – dried sample , break it as fine as possible , then washed on the NO. 200 sieve , oven dry it , and sieve the residue through a set of sieves .

The weight of sediment kept in every sieve was recorded for the section near Al – Kufa bridge .

Fig 4. shows the grain size distribution of the bed material .

Fig 4 . Grain size distribution curve of bed material



8- Local scour around AL-Kufa bridge piers

AL-Kufa bridge has three piers , each two meters width at a rounded shape .

The scour around each piers is estimated in this research at different time as shown in Table 2.

Table 2 . Hydraulic measurements of AL-Kufa bridge piers

Date	Avg. water depth (m)	Avg. cross section area (m^2)	Avg. of velocity m/sec	Avg. of discharge m^3/sec	Scour depth (m)around piers from the left		
					Pier 1	Pier 2	Pier 3
1/9/2008	3.9	328.73	0.7	230.11	1.4	1.8	1.2
15/9/2008	3.5	293.47	0.67	196.62	1.2	1.7	1.1
30/9/2008	3.2	267.26	0.66	176.39	1.1	1.8	1.1
15/10/2008	3.3	275.98	0.71	195.94	1.0	1.65	1.0
30/10/2008	3.2	267.26	0.72	192.43	1.1	1.73	1.2
14/11/2008	3.1	258.57	0.68	175.83	0.9	1.8	1.1
30/11/2008	3.8	319.88	0.7	223.92	1.2	1.7	1.2
15/12/2008	4.0	321.1	0.67	215.14	1.3	1.9	1.2

9-Development of a new formula

According to eq.3 ,the best fit relationship when used the measurements data given by:

$$\frac{ds}{b}=0.29\left(\frac{y_1}{b}\right)^{0.51} Fr_1^{\,0.19}\left(\frac{b}{d_{50}}\right)^{0.1} \quad \ldots\ldots\ldots(4)$$

In which :

ds = max. scour depth around pier (m)

b = pier width (m)

y_1= depth upstream of the pier (m)

Fr_1=froude number of approach flow (upstream)

d_{50}= median grain size

In order to illustrate the scatter in the other data .

A plot of the calculated scour depth using eq. (4) versus the observed scour depth are presented in fig (5) a good coefficient of determination (R^2) of 0.92 is obtained .

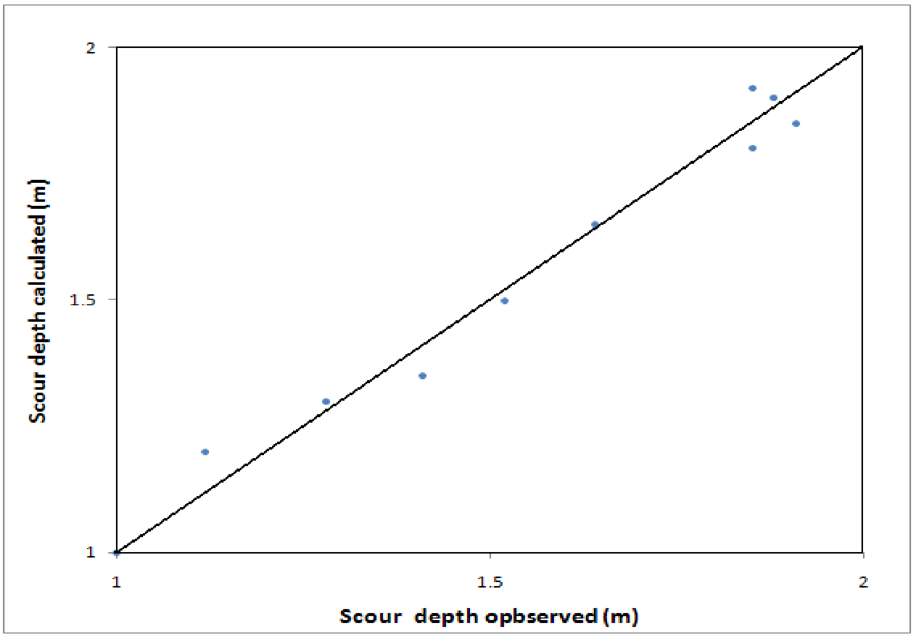


Fig 5.Computed versus observed scour depth at AL-kufa bridge piers

10- Discussion

The regime of stream bed may be in live , i.e. , the scour hole which is formed around a bridge piers is continually supplied with sediment by the approach flow.

In practice ,the bridge piers may take several situation , such that the shape of pier may be other than circular , the pier skewed relative to flow direction(this situation occurs , in practice , when the layout of bridge is not perpendicular to river banks and \ or the variation occurs in river morphology) and effects of neighboring piers.

In this study , Al- kufa bridge piers, the shapes of piers were circular , so that the shape factor is one, and the piers are perpendicular to the stream . It has been mentioned that the scour depth increases as pier is aligned in skewness with flow and the rate of scour continually increases with the length of a piers [7] .

When a bridge pier is allocated across a river , the scour which is formed around any pier may be affected by the action of morphological aspects of flow around neighboring piers , This effect will increase with decreasing the space between neighboring piers due to increasing the inter locking of eddies in their action around each pier , many investigators find that no mutual influence on maximum scour depth occurs for spacing ratio (spacing center to center (s) / width of pier (b)) greater than 8 , such that ,in Al-Kufa bridge piers (s/b =48/2 = 24) greater than 8 ,therefore ; the spacing ratio of piers no effect of the local scour around the piers .

It was found in this study that the scour depth in the middle pier is greater than of the others (first and third pier)

11-Conclusions

In this study , the following conclusions can be drawn :

1-The maximum scour depth occurs at the nose of the piers of Al-Kufa bridge .

2- The maximum depth of scour is significantly affected by Froude number (velocity and depth of flow) and median grain size (d_{50}) of the bed material of river .

3- It was found that there is no effect of spacing between piers because the spacing ratio is equal to 24.

4- An empirical formula ,for the maximum depth of scour was developed using the dimensional analysis technique ,it give a good determination coefficient .

5-The reduction of scour around Al –Kufa bridge piers is the main aims , the classical one is to use ripraps and some suitable protection devices may be used such as , small piles placed a head of the main pier with different arrangements .

6-The study showed that the piers of Al-Kufa bridges is safe against scouring because the depth of the equilibrium scour is less than the depth of foundation of the bridge .The scouring around the piers should be evaluated from time to time because the local scour could be a major cause of bridge failures which the hydraulic conditions may change .

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