Boundary study of seepage around two consecutive hydraulic structures

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Constructing a downstream subsidiary weir at the downstream of a hydraulic structure is one of the solutions that help to maintain the acting heading up within the allowable limits. The main objective of this study is to draw the limit of the structures width at which the two dimensional study is considered accurate and accordingly when it is a must to perform a three dimensional study. There are two other secondary objectives for the study which are investigating the importance of locating the subsidiary weir in minimizing the dangerous seepage effects on the main structure, and illustrating the seepage characteristics around the two consecutive hydraulic structures. The concerned seepage characteristics are; the uplift forces, and the velocity gradients. Also the location of the stagnation line of the velocities, through the middle stream zone between the two structures, is determined. The study was done using the finite element technique by the help of a computer program (SWICHA version 5.05). The research states the value of the structure width at which the two dimensional study performs accurately. The results also show that using the proposed downstream subsidiary weir proved to be effective in reducing the uplift forces on the main structure, while it increases the velocity gradients.

يناقش البحث أحد الوسائل المستخدمه للحفاظ على قيمة الضاغط المؤثر على منشأ هيدروليكى قائم وهى إنشاء منشأ مساعد خلف المنشأ الأصلى. الهدف الرئيسى للبحث هو تحديد متى يمكن الإكتفاء بحل المسأله بشكل ثنائى الأبعاد وبالتبعيه متى يلزم حلها بشكل ثلاثى الأبعاد.كما أن هناك أهداف أخرى ثانويه للبحث، وهى التحقق من جدوى وضع المنشأ المساعد فى تقليل آثار التسرب السلبيه على المنشأ الأساسى و أيضا دراسة خواص التسرب حول المنشأين معا. أخذت الدراسة خواص التسرب الآتيه فى الاعتبار: ضغوط الرفع، والميول الهيدروليكية للسرعات. تم تنفيذ هذه الدراسة باستخدام تقنية العناصر المحددة بالاستعانة ببرنامج حاسب آلى جاهز (SWICHA version 5.05). أظهرت الدراسه فارقاً ملحوظاً بين حل مسألة منشأين هيدروليكيين متعاقبين بشكل ثلاثى الأبعاد وماقد تم سابقا من دراسات لنفس المسألة بشكل ثنائى الأبعاد وبالتالى تم توضيح الحدود التى تبين متى يمكن دراسة المسألة الحالية بشكل ثلاثى أودراستها بشكل ثنائى الأبعاد، كما بينت الدراسه مدى مساهمة المنشأ الخلفى ، بإعتباره منشأ مساعد، فى تقليل تأثير قوى الرفع على المنشأ الأمامى الأساسى ولكنه فى الوقت ذاته أدى إلى زياده قيم ميول السرعات بين المنشاين وخلف المنشأ المساعد.

Keywords: Seepage characteristics, Two and three dimensional models, Two consecutive structures, Subsidiary weir

1. Introduction

Several benefits are gained by locating a subsidiary weir at the downstream of an existing structure. One of the benefits is retaining a portion of the total reserved head on the main structure in order to minimize the seepage effects [1] acting on it. In Egypt, the existing Nile barrages were designed for certain effective heads. After the operation of the Aswan High Dam, the sediment load in the water at the downstream of the dam almost vanished [7]. Due to this change in the hydraulic conditions, a longitudinal degradation along the Nile occurred. Such lowering in the bed levels at the downstream sides of these barrages caused an increase of the effective head which negatively affected its stability. A subsidiary weir is proposed to be constructed at the downstream side of each barrage to retain the excess head instead of the barrage.

Nasr R.I. (1984) [7] discussed the idea of constructing subsidiary weirs at the downstream side of the existing Nile barrages to secure the stability of those barrages to overcome the noticeable increase in the effective acting head. The aim of this study was to investigate the effect of constructing a subsidiary weir on the net uplift pressure

underneath both the existing barrage and the subsidiary weir. The study was performed using conformal mapping technique. The problem of two consecutive structures was discussed by Nasr R.I. (1987) [8] who found formulas to calculate the seepage parameters for the two structures. Salem A.A. and Ghazaw Y. (2001) [10] investigated the problem of constructing subsidiary glacis weirs at the downstream of Nile barrages to secure their stability against the increase of the effective acting head. The problem was solved using the conformal mapping technique by the help of a designed computer program.
Generally, several researches handled this problem or similar problems, using two dimensional modes, 2D, by several techniques [2, 3, and 9]. It is clear that no attention was paid to study the problem of two consecutive structures in the 3D mode.

2. Physical model description

The problem of two consecutive hydraulic structures with a separating distance is investigated. Each structure is assumed having a flat horizontal floor without any sheetpiles or sudden drops. The two structures are separated by a distance of length L_f as shown in fig. 1. The upstream, US, structure has a horizontal floor with a length of, L_1, and a width of, B. The downstream, DS, structure has a horizontal floor with a length of, L_2, and the same US structure width, B. The two structures are embedded in the pervious stratum, with a depth, t. Both structures are located, for simplicity, in a rectangular shaped channel of width, b. The total head acting on the upstream side is, is H_t while the acting head on the downstream side is, H_d. An effective head of, H_1, is acting on the US structure, while an effective head of, H_2, is acting on the DS structure. lateral extended width for the two structures is, r. The horizontal length of the pervious stratum around the structures is, W. The pervious stratum underneath the two structures is of depth, D.

3. Computer program

SWICHA, version (5.05), is the 3D computer program used to solve the problem under investigation. The main technique of the program is the finite element technique [5, 11]. The program was developed by GeoTrans. Inc., Sterling, Virginia, USA [6]. The program is capable of handling the following subjects:

1. Groundwater flow in single or multiple aquifer systems;
2. Transport of single species solute in fully-saturated porous media;
3. Coupled processes of groundwater flow and density-dependent solute transport in coastal aquifer systems; and
4. Groundwater flow underneath and around hydraulic structures.

4. Cases of study

The cases are summarized in table 1.
The cases listed in table 1 are solved and the results are used to make the analysis.

5. Analysis of results

5.1. Total uplift pressures distribution

For constant values of L_f/L_1=1.0, L_2/L_1=1.0, H_2/H_1=1.0, and D/L_1=2.0, the effect of the relative structures width (B/L_1) is studied. The studied values of B/L_1 are 0.25, 0.50, 1.00, 1.50, 2.0, and 3.0, respectively.

The uplift pressure values underneath the two floors are put in the form of contours for various values of relative structures widths (B/L_1), see fig. 2. It can be concluded that the increase of the structures width increases the uplift pressures on the US structure while decreases the pressures on the DS structure.

Table 1

(B/L_1)	(L_f/L_1)	(L_2/L_1)	D/L_1	(H_2/H_1)
0.25, 0.50, 1.0,1.50, 2.0, and 3.0	1.0	1.0	2.0	1.0

- r = t = 0.1* L_1, W=6* L_1

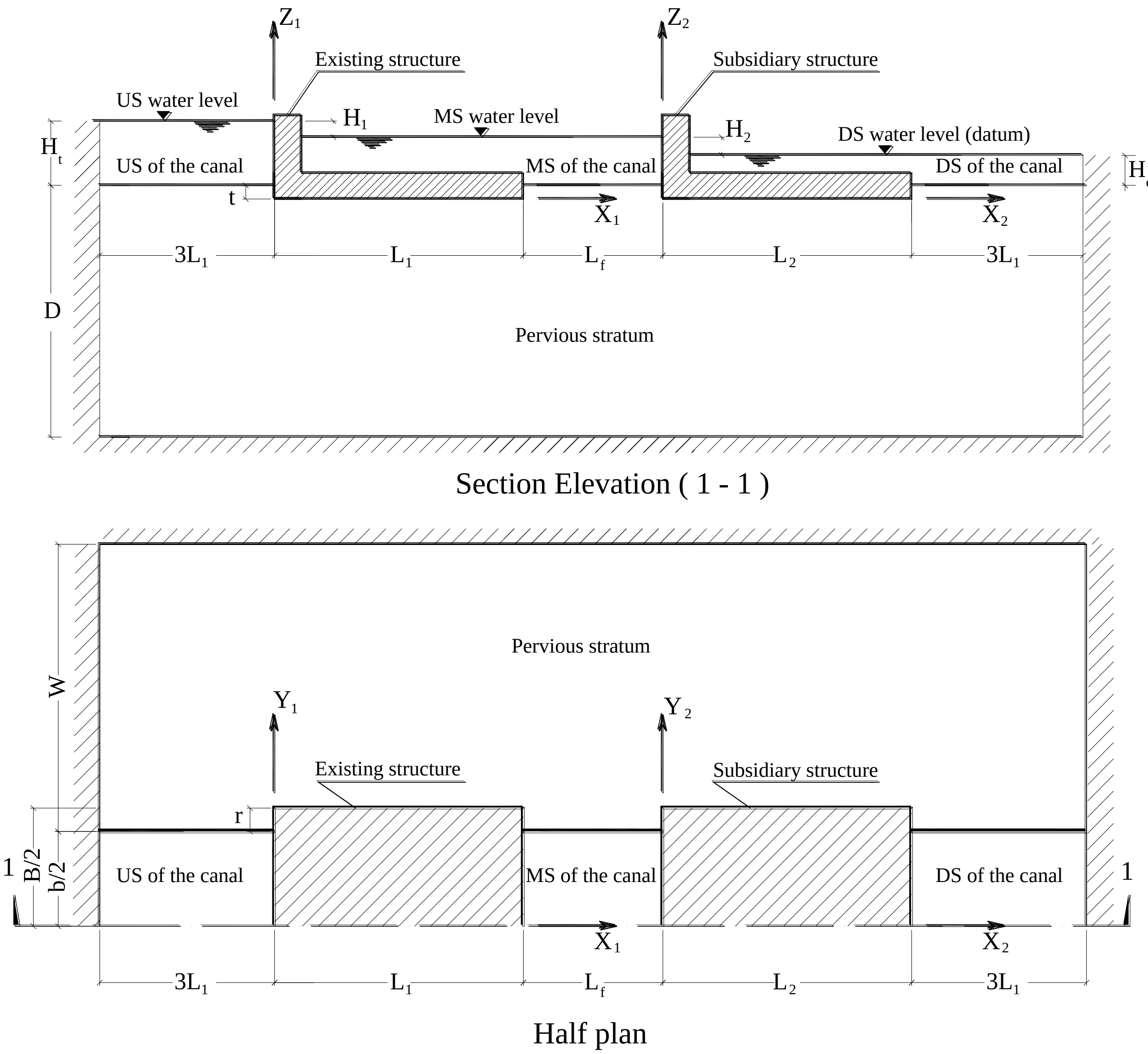
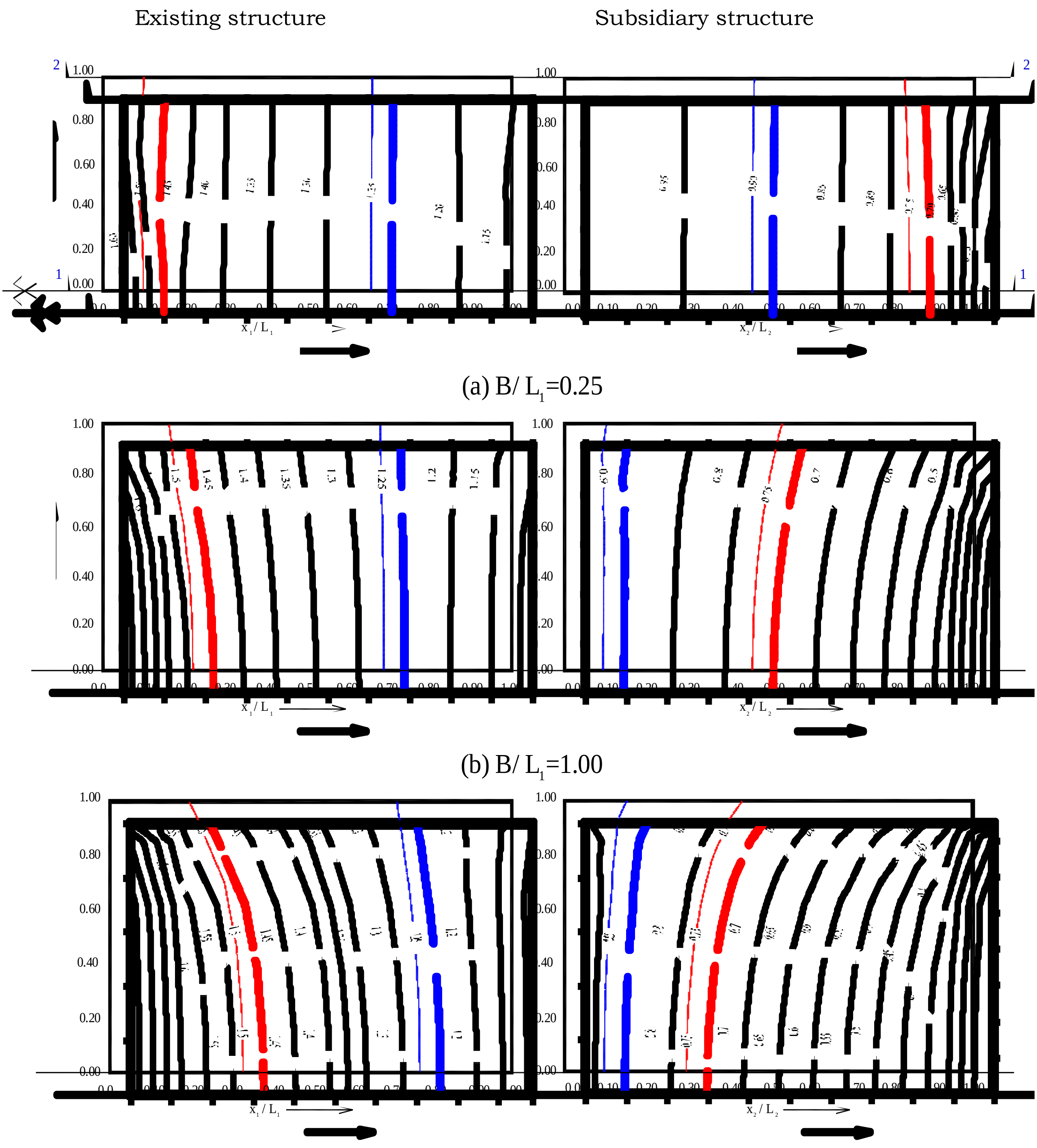


Fig. 1. Physical model.

5.2. Relative net uplift pressures

Referring to fig. 3, two sections are considered in the calculation of the net uplift pressures. For the same values used in the total uplift pressure distribution, the effect of the structures width (B/L_1) is studied. Fig. 4 shows the net uplift pressure distribution underneath the subsurface contour of both the US and the DS structures at sections (1, and 3), respectively. It is clear that the larger the structures width, the more are the net uplift pressures for the US floor and the less are the net uplift pressures for the DS structure.



(a) B/ L_1=0.25

(b) B/ L_1=1.00

(c) B/ L_1=3.00

Fig. 2. Effect of relative width [B/L1] on the total uplift pressure distribution
For L_f/L_1=1.0, L_2/L_1=1.0, H2/H1=1.0, D/L_1=2.0.

Generally, the net uplift values at section (1-1) for the US structure are larger than those at section (2-2), i.e. the uplift pressure decreases towards the side edge of the structure. On the other hand, for the DS structure, the net uplift values at section (1-1) are slightly smaller than the net uplift values at section (2-2). Also one can conclude that the closer the section to the side edges, the closer are the values of the relative net uplift pressures for the various cases.

At section (1-1) and section (2-2); For the US existing structure, the values of the relative net uplift pressure at the rear edge of the floor are almost equal except for the case of B/L1 =0.25. For the DS subsidiary structure, the values of the relative net uplift pressure at the front edge of the floor are almost equal except for the case of B/L1 =0.25 and 0.50. As an example, the results of comparison between cases of B/L1 =0.50 and 3.00, are arranged in table 2.

Fig. 5 shows the variation of percentage difference of net uplift pressure at x/L1= 0.0, 0.50, and1.0 for the US and the DS structure at section (1-1) and (2-2), comparing with case of single structure.

Generally, from the previous analysis, it is obvious that when B/L1 ≥3.00, the problem could be investigated in the 2D mode with a slight difference from the 3D solution.

Table 2

	Section (1-1)				Section (2-2)			
	US Existing structure		DS Subsidiary structure		US Existing structure		DS Subsidiary structure	
	Front edge	Rear edge	Front edge	Rear edge	Front edge	Rear edge	Front edge	Rear edge
Value for B/L1=0.50	0.74	0.085	0.97	0.34	0.62	0.12	0.96	0.53
Value for B/L1=3.00	0.83	0.09	0.92	0.18	0.66	0.12	0.91	0.40
Percentage difference	+13.0%	+3.5 %	-5.2%	-48.1 %	+7.1%	0.0 %	-5.3%	-22.7 %
Maximum percentage difference	30.8 % at x/L_1=0.375		-48.1 % at x/L_1=1.00		11.2 % at x/L_1=0.375		-22.7 % at x/L_1=1.00	

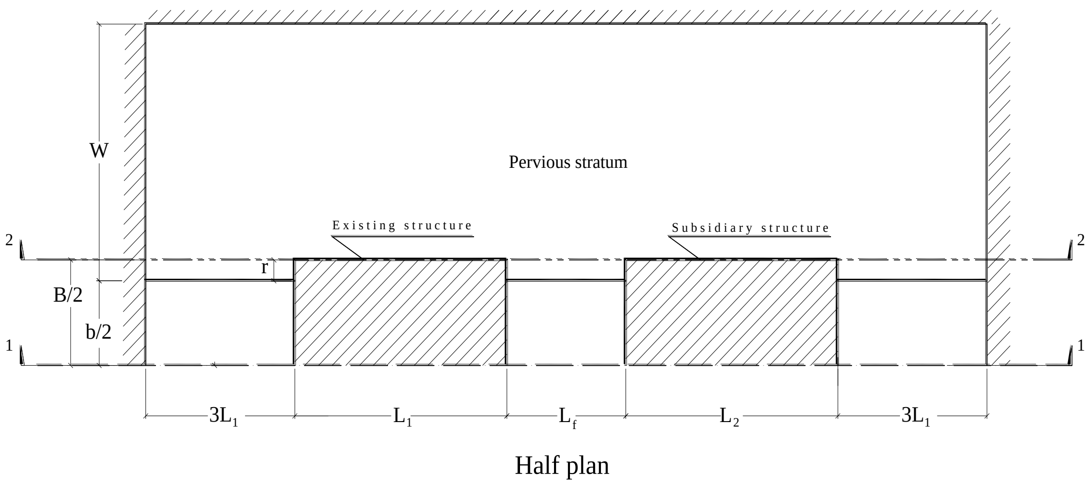


Fig. 3. Position of the concerned net uplift pressure sections.

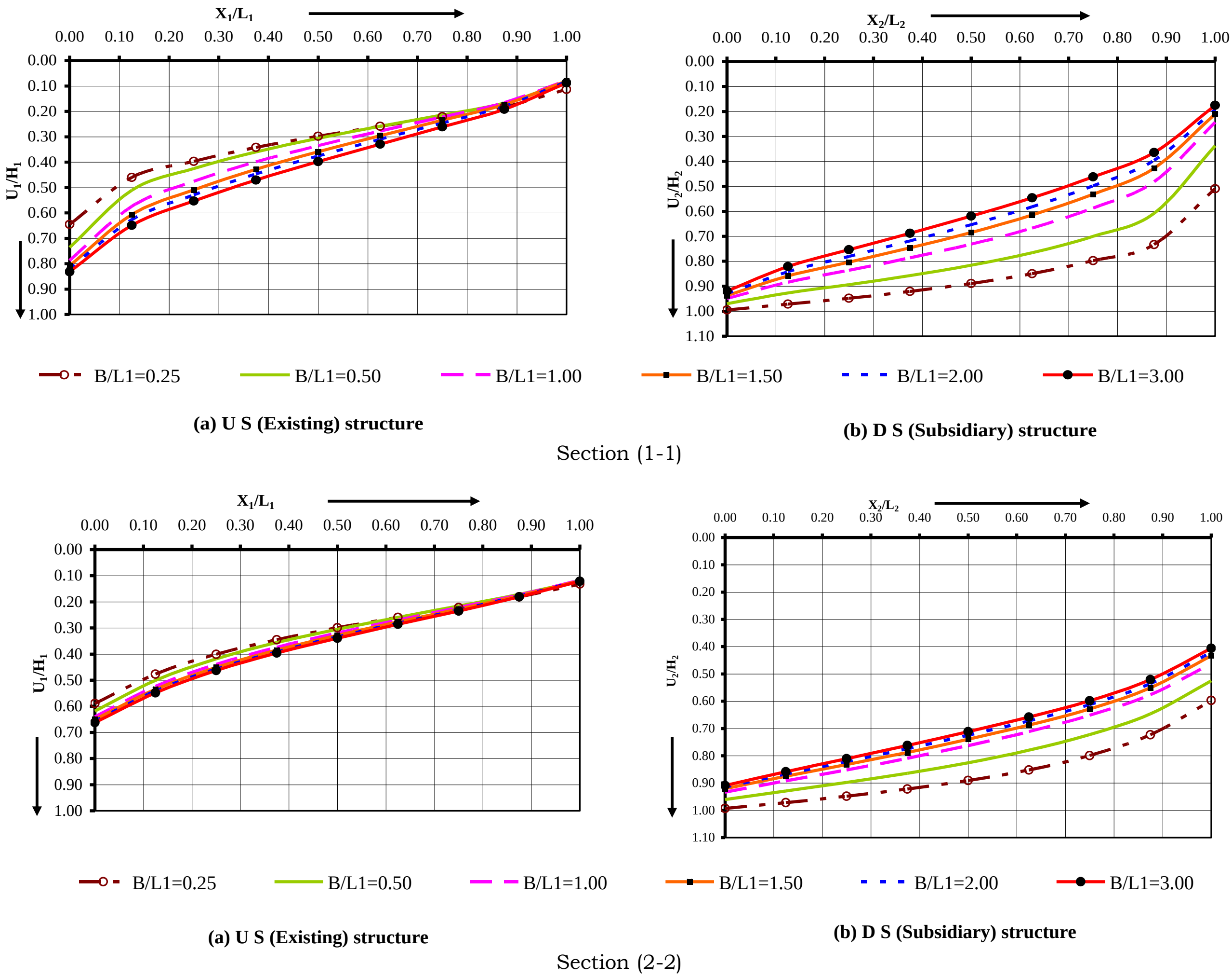


Fig. 4. Effect of relative width [B/L1] on the relative net uplift pressure [U/H],
For Lf/L1=1.0, L2/L1=1.0, H2/H1=1.0, D/L1=2.0.

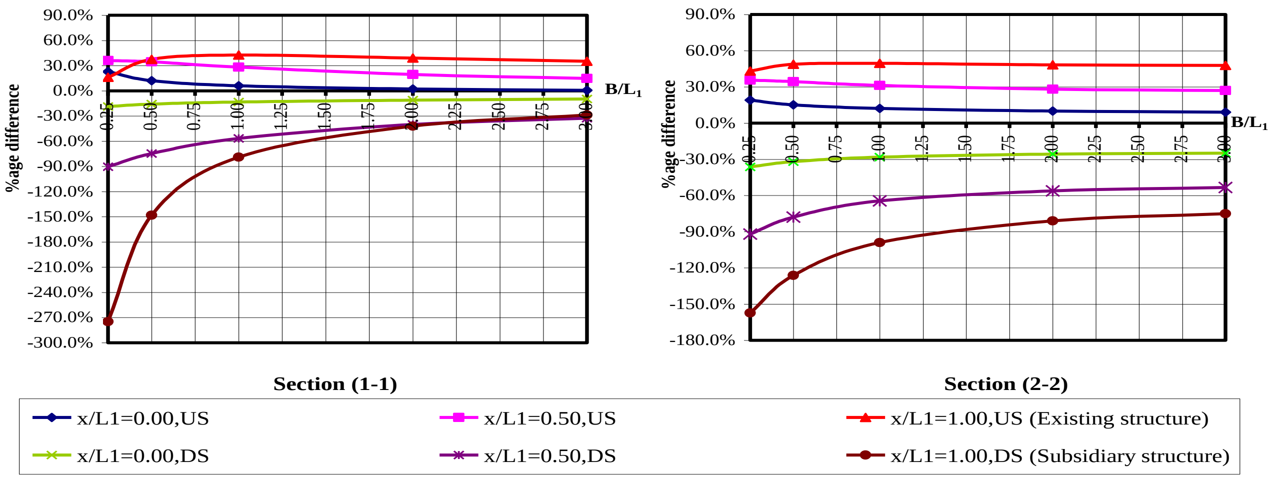


Fig. 5. Variation of uplift pressure percentage along the existing and subsidiary structures.

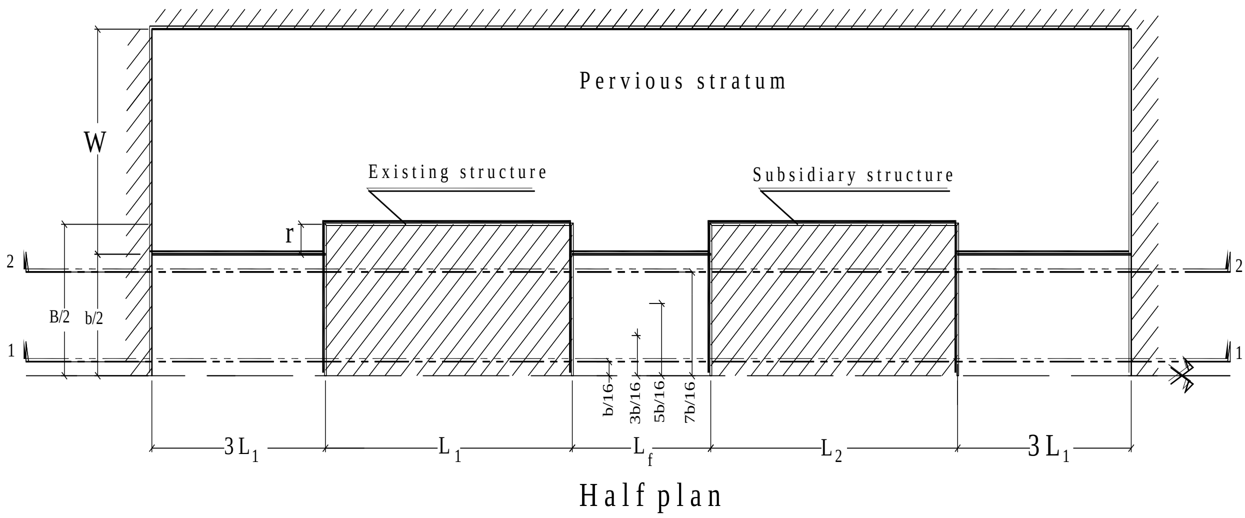


Fig. 6. Velocity gradient sections.

5.3. Velocity gradients

Referring to fig. 6, two sections are considered. The analysis is illustrated in terms of graphs for the different cases of pervious stratum depth (D) as shown in fig. 7.

5.3.1. MS velocity gradients

With the help of fig. 7, it can be seen that the case of B/L1=0.25 is an extreme case as it does not include a stagnation point, i.e. no negative velocity gradient exists, either at section (1-1) or at section (2-2). For B/L1≥ 1.00, the relative velocity gradient values at the MS can be considered constant. For section (1-1), the maximum relative positive velocity gradient value equals to 0.96, for the case of B/L_1=0.25, at the beginning of the MS face. The maximum relative negative velocity gradient equals to 0.59 at the end of the MS face for B/L_1=3.00.

For section (2-2), it is nearly the same as for section (1-1), especially for the low values of B/L_1, as the maximum relative positive velocity gradient value is also for B/L_1=0.25 at the beginning of the MS face and it is equal to 0.97 which is 1% larger than the value at section (1-1) i.e. the velocity gradients does not change towards the edge of the structure as the structures width is relatively small. The maximum relative negative velocity gradient is 6.80% less than that at section (1-1), at the end of the MS face for the case of B/L_1=3.00.

5.5. DS velocity gradients

Fig. 7 shows that the case of B/L_1=0.25 appears again as an extreme case as the values of relative velocity gradients are larger than the closest case by about 70% at section (1-1) and 40% at section (2-2). Generally, the wider the structures, the less are the velocity gradients at the DS. For section (1-1) the maximum relative exit gradient value at B/L_1=0.25 is equal to 4.39 while it is 1.23 for B/L_1=3.00, which means a large difference of 256.91%. For section (2-2), the values are 4.47 and 1.83 for the cases of B/L_1=0.25 and 3.00, respectively, indicating a difference of about 144.26%. The relative exit gradient values for case of B/L_1≥ 1.00 are close, submitting the same note at the MS zone.

Finally, one can conclude that if B/L_1< 1.00, the stability of the foundation material, either at the MS or at the DS, decreases sharply as the values of the velocity gradients are increased rapidly.

6. Conclusions

Based on the forgoing analysis, the following conclusions could be drawn:

1. The problem of two consecutive hydraulic structures can be studied in 2D mode instead of 3D mode at B/L_1≥3.00.
2. <u>As B/L_1 increases</u>:

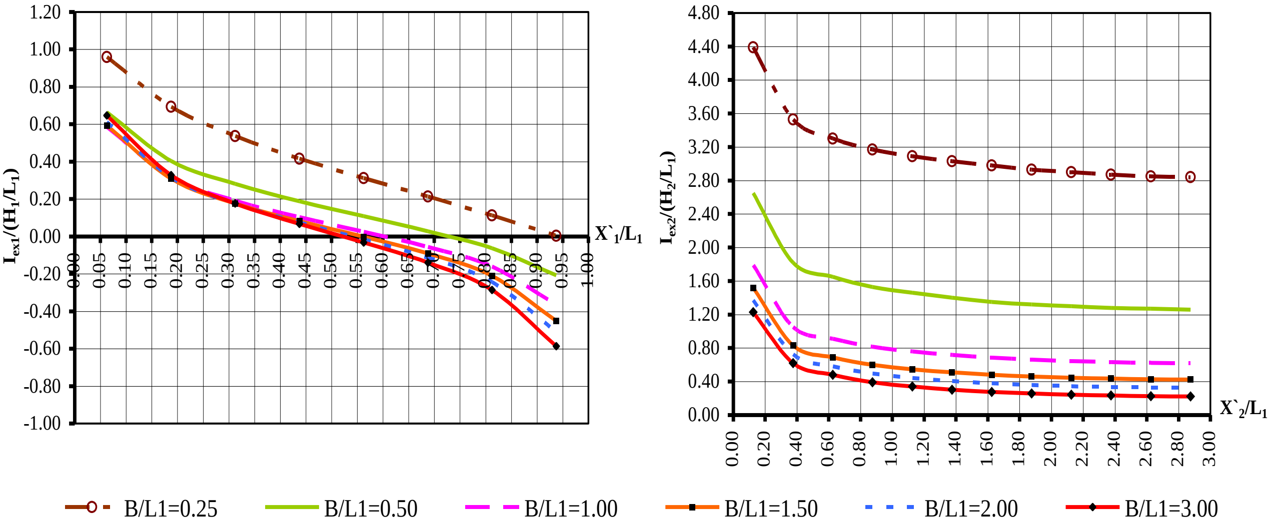
a) Uplift forces increase along the existing structure and decrease along the subsidiary structure.
b) Velocity gradients decrease at both the MS and DS zones.
3. The 2D study gives greater uplift pressure values than the 3D study for the existing structure, and the opposite occurs for the subsidiary weir.
4. The velocity direction at the DS zone is upward, while the MS zone is combined of source and sink.
5. The velocity values at canal sides are greater than those at the centerline by approximately 30%.
6. For $B/L_1<1.00$, the velocity gradients at both MS and DS zones are much larger than the other conditions and accordingly the foundation materials stability sharply decreases 6.

Notations

B	Structure width,
B	Canal bed width,
D	Depth of the pervious stratum,
H	Head producing flow,
H_1	Effective water head on the upstream structure,
H_2	Effective water head on the downstream structure,
H_d	Total acting water head at the downstream of the hydraulic system,
Ht	Total acting water head on the two structures,
Iex	Velocity gradient,
L	Total length of the hydraulic structure floor,
L_1	Length of upstream structure,
L_2	Length of downstream structure,
L_f	Separating distance between the two structures,
r	Lateral extended distance of the structures,
t	Vertical penetration distance of the structures floors,
u	Uplift pressure,
W	Lateral thickness of the pervious stratum,
X,Y,Z	Horizontal , vertical, and perpendicular on plane Cartesian directions, used in uplift pressure calculations,
X',Y',Z'	Horizontal , vertical, and perpendicular on plane Cartesian directions, used in velocity gradient calculations,
x	A certain horizontal length in uplift pressure calculations,
x'	A certain horizontal length in velocity gradients calculations,
y	A certain vertical length in uplift pressure calculations, and
y'	A certain vertical length in velocity gradients calculations.

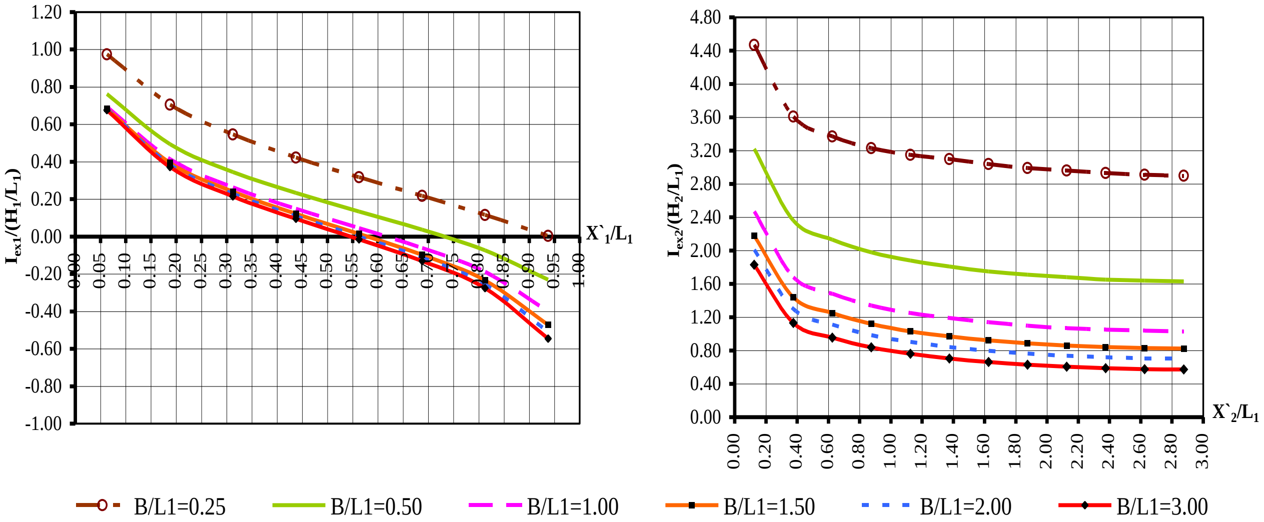
Appreviations

2D	Two dimensional model,
3D	Three dimensional model,
DS	Downstream,
DSWL	Downstream water level,
MS	Middlestream,
MSWL	Middlestream water level,
SWICHA	Finite element program to simulate fluid flow into porous stratum,
US	Upstream, and
USWL	Upstream water level.



(a) M S zone **(b) D S zone**

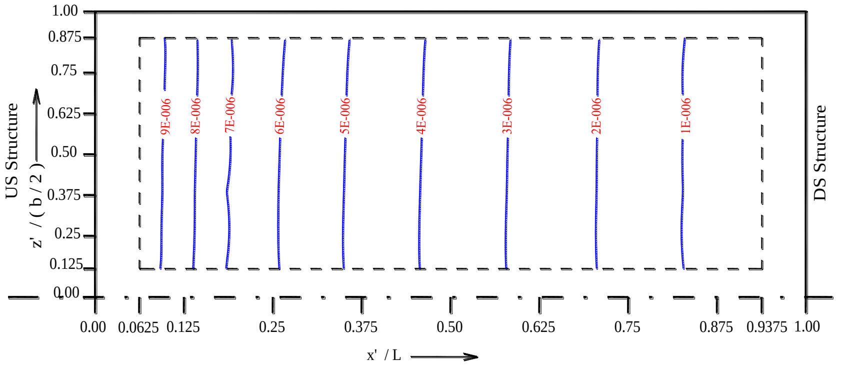
Section (1-1)



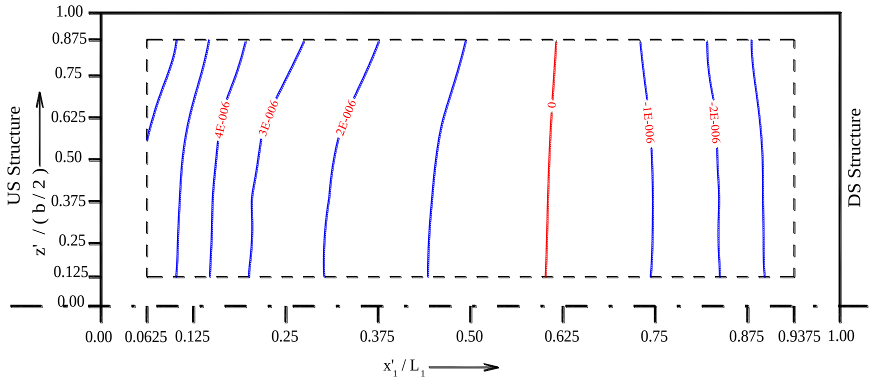
(a) M S zone **(b) D S zone**

Section (2-2)

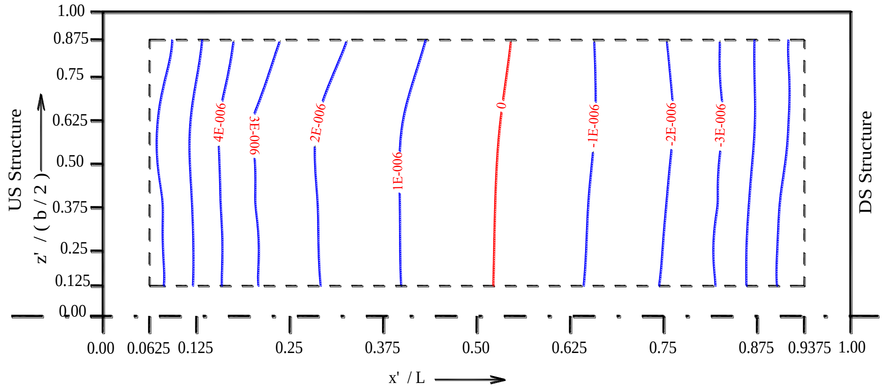
Fig. 7. Effect of relative width [B/L1] on the relative velocity gradients [Iex/H/L1],
For Lf/L1=1.0, L2/L1=1.0, H2/H1=1.0, D/L1=2.0.



(a) B/L1=0.25



(b) B/L1=1.00



(c) B/L1=3.00

Fig. 8. Effect of relative structures width [B/L1] on the velocity distribution at MS zone for Lf/L1=1.0, L2/L1=1.0, H2/H1=1.0, D/L1=2.0.

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