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USING THE BOUNDARY ELEMENTS APPROACH TO SOLVE THE PROBLEMS OF LIQUID FILTRATION VIA THE DAM

The work deals with the method and programs to calculate the liquid filtration via the dam, with allowing for the events of their possible damage. On the base of the boundary elements approach the method to calculate the flow of a liquid via the dam in the presence of a watertight fitting member was conducted. Using the numeric test, the free boundary position at the liquid filtration via the dam with the defected upper and lower basins was received and provisional analysis with the outcomes, received in the event of the defect of the upper dam basin only, was conducted. The primary free surface position has been determined arbitrarily. The boundary elements disposition drawing for the soil unit at the stream with the free area via the barrage with the defected upper (at the top) and lower barrage basins has been developed with allowing for reaching the optimal computing time. The boundary elements disposition drawing for the soil unit at the stream with the free area via the barrage with the defected upper (in the middle) and lower dam basins has been developed for the same considerations. The application was created in Delphi 7 visual programming environment. The main calculated outcomes were compared for the potential at the stream with the free area via the barrage with the defected only upper basin made earlier and for the barrage with the defected upper and lower basins. The outcomes show that in the event with the upper dam basin defect there is more wetting of the soil than in the event with the defect of both dam basins. It can be explained by the fact that the liquid stream at the defect lower dam basin will be faster and wetting of the soil will be less. The results of submitted paper can be useful in engineering practice for designing the soil dams.

Key words: liquid filtration, dam, barrage, defected basin, wetting, boundary elements approach.

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Бөгет арқылы сұйықтықтарды сүзу есептерін шешу үшін шекаралық элементтер әдісін қолдану

Жұмыста ықтимал зақымдану жағдайларын ескере отырып, дамба арқылы судың сүзілуін есептеу әдісі мен бағдарламасы қарастырылған. Шекаралық элементтер әдісіне сүйене отырып, су өткізбейтін шекаралық элемент болған кезде бөгет арқылы сұйықтықтың сүзілуін есептеу әдісі ұсынылады. Сандық эксперимент арқылы жоғарғы және төменгі бьефтердің зақымдалуымен дамба арқылы сұйықтықты сүзу кезінде бос шекараның жағдайы алынды және дамбаның тек жоғарғы бьефі зақымданған жағдайда алынған нәтижелермен салыстырмалы талдау жүргізілді. Бос беттің бастапқы орны ерікті түрде анықталды. Оңтайлы есептеу уақытына қол жеткізуді ескере отырып, жоғарғы және төменгі бьефтерді зақымдай отырып, дамба арқылы еркін беті бар сұйықтықты сүзуге арналған шекаралық элементтердің орналасу графиктері салынды. Дәл осындай себептер бойынша бөгеттің ортасында және төменгі бьефінде зақым басталған жағдайда бөгет арқылы еркін беті бар сұйықтықты сүзу үшін шекаралық элементтердің орналасу кестесі жасалды. Delphi 7 визуалды бағдарламалау ортасында бағдарламалық жасақтама жасалды. Алынған нәтижелерден дамбаның тек жоғарғы бьефінің бөгеті зақымданған жағдайда, дамбаның екі бьефінің зақымдануына қарағанда, топырақтың көбірек суланауы байқалады. Бұл дамбаның сынуы мен төменгі бьефі болған кезде су ағыны тезірек жүреді және топырақтың суланауы аз болады. ұсынылған жұмыстың нәтижелері жер бөгеттерін жобалау кезінде инженерлік тәжірибеде пайдалы болуы мүмкін.

Түйін сөздер: сұйықтықты сүзу, дамба, бөгет, қоршау, зақымдалған бассейн, сулау, шекаралық элементтер әдісі.

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**Применение метода граничных элементов
для решения задач фильтрации жидкостей через дамбу**

В работе рассмотрены методика и программа расчета фильтрации воды через дамбу с учетом случаев возможного повреждения. На основе метода граничных элементов предложен метод для расчета фильтрации жидкости через дамбу при наличии водонепроницаемого граничного элемента. Путем численного эксперимента получено положение свободной границы при фильтрации жидкости через дамбу с повреждением верхнего и нижнего бьефов и проведен сравнительный анализ с результатами, полученными в случае повреждения только верхнего бьефа дамбы. Первичное положение свободной поверхности было определено произвольно. Построены графики расположения граничных элементов для фильтрации жидкости со свободной поверхностью через дамбу с повреждением верхнего и нижнего бьефов с учетом достижения оптимального расчетного времени. По тем же соображениям был построен график расположения граничных элементов для фильтрации жидкости со свободной поверхностью через дамбу в случае начала повреждения в центре и нижнего бьефа дамбы. Разработано программное обеспечение в среде визуального программирования Delphi 7. Из полученных результатов видно, что в случае, когда произошло повреждение дамбы только верхнего бьефа дамбы происходит большее смачивание грунта, чем в случае с повреждением обоих бьефов дамбы. Это объясняется тем, что когда происходит облом и нижнего бьефа дамбы поток воды будет идти быстрее и смачиваемость грунта будет меньше. Результаты представленной работы могут быть полезны в инженерной практике при проектировании грунтовых плотин.

Ключевые слова: фильтрация жидкости, дамба, заграждение, поврежденный бассейн, смачивание, метод граничных элементов.

1 Introduction

The liquid filtration via ground barrages plays very significant role in the National economy [1,2]. The data presents that more than half of all casualties caused by destruction of ground barrages occur owing to the liquid filtration.

Thus, when planning and developing the ground barrages it is necessary to conduct filtering calculation, in the course of which the depression bend position in the edifice corpus should be determined; to determine filtering stream gradients and rate of filtering speeds [3,4]; to determine the filtering expenditure via the barrage corpus and its base. Currently there are many suggestions for the filtering calculation techniques via the ground dams [5].

Nevertheless, analysis of situation, when the barrage sequence defects are probable, is of great significance [6,7]. it is more common that the most wash upper and lower dam basins are defected.

The work is aimed at creation of the method and programs to calculate the liquid filtration via the dam, with allowing for the events of their possible damage, and developing the method to calculate the flow of a liquid via the dam in the presence of a watertight fitting member.

2 Problem setting

Let us consider the problem of liquid filtration via the dam with waterproof embedded elements.

The considered medium is smooth and isotropic, then the problem is resulted in the Laplace equation $\Delta u = 0$ regarding the speed potential u with boundary conditions: $q = 0$ on the impermeable boundary(because the bottom is solid $(u_n) = 0$) i.e. on the surface layer of soil and rocks (AF surface in Figure 1); $u = const$ on ABC and EF surfaces of the spongy medium;

$u = x_2$ on DE filtration surface where the liquid goes via the soil and flows downward; $u = x_2$ and $q = 0$ on the free surface (CM and LD). KL is an inset element. Among other things, the exact position of the free area is unknown, and determining it is a part of the process to solve the problem.

The boundary conditions in the problem of liquid filtration via the dam:

$$ABC : u = H_c; \ : q = 0, u = x_2; LD : q = 0, u = x_2;$$

$$DE : u = x_2; EF : u = HE; AF : q = 0; ML : q = 0, u = x_2.$$
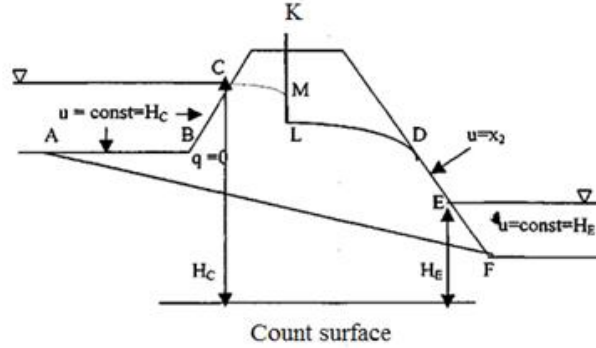

Figure 1 – The boundary conditions in the problem of liquid filtration via the dam

To numerically calculate the problem, the primary free area position is set arbitrarily, and moreover, in all parts of its accepted condition $q = 0$ [8]. Found for each nodular point of the free area value of the potential is correlated with the liquid surface height if the difference between them is more than the maximal admissible error, this difference is added with the algebraic approach to the height of the surface at the respective nodular point and a new iteration is performed. If necessary, the potential values at the internal points are determined after identifying the real free surface position.

3 Mathematical model and results of numerical calculation

The division into boundary elements in the problem of liquid filtration via the dam is shown in Figure 2. Position scheme of boundary elements for the soil unit in liquid filtration via the dam is as follows:

$$j = 1, 6 : q_j = 0; \ j = 7, 9 : u_j = 0, 1; \ j = 10, 20 : q_j = 0, \ u_j = x_2; \ j = 21, 24 : u_j = 0, 5.$$

The division into boundary elements in the problem of liquid filtration via the dam is shown in Figure 2. The heights' upstream and downstream are 0.5 and 0.1 m respectively, regarding the surface of reference. The boundary conditions are of the following form: $u = 0, 5$ on the surface facing the flow (node 21-24), $q = 0$ on the bottom (impermeable) surfaces (nodes 1-6); $u = 0, 1$ on the surface directed downstream (sites 7-9), and $q = 0$ on the free surface (10-20 nodes). At the primary stage of calculations, the free surface shape was chosen arbitrarily flat and equally arbitrarily identified position of the surface. The ultimate free surface position will be received by iterations. The problem is solved by the boundary elements approach.
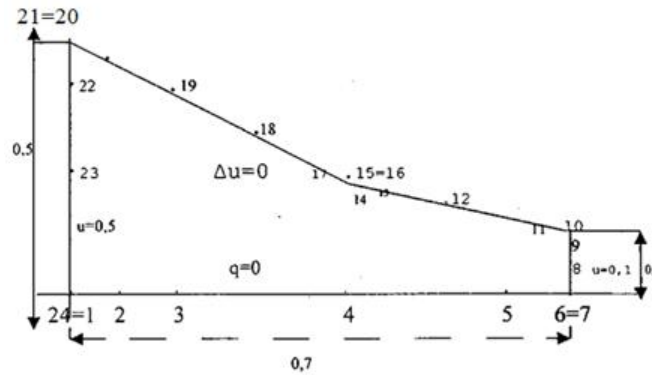
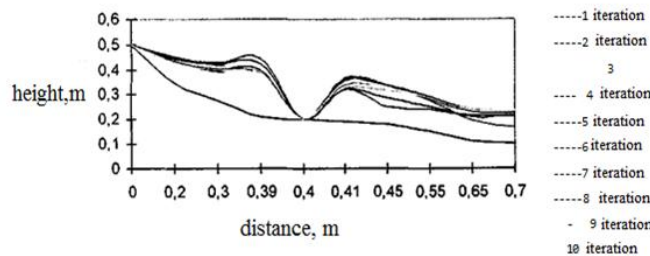**Figure** 2   –   The scheme of position of boundary elements

Figure 3   –   The preliminary estimated results of the problem of filtration of a liquid via a
dam with a waterproof embedded parts

Figure 3 shows the estimated results of the problem of filtration of a liquid via a dam with a waterproof embedded parts.The position of the free area was found after the 11th iteration [7,8].

During the numerical calculation of the problem, the primary free surface position is determined arbitrarily, and, among other things, in all points of this surface $q = 0$ convention is accepted [9]. The potential value,which was determined for each nodal point of the free surface, is correlated with the liquid surface height [10].If inequality among them is more than the maximal admissible error, this inequality will be algebraically compiled with the area height in the relevant nodular point and new iteration will be conducted [11–13].

Figure 4 presents the boundary elements division in the issue on the stream with the free area via the unit from spongy material. The upper and lower basins heights form 0,5 and 0,1 accordingly concerning the reference area.

The ultimate free area position was received after the 6th iteration.

Consider in more detail the filtration problem via the edifice with defect in the spongy medium entrance (Figure 5), where ABCK section is a fragment of the barrage (defected area of the barrage). Respectively the boundary circumstances for the issue of the liquid current via the barrage will be unequal.

Arrangement of the boundary elements for the ground block at the current with the free area via the barrage with the defect in its top point is in Figure 6, with the defect in its middle point is in Figure 7.

Let's regard in details the issue on the filtering via the barrage with the defected upper and
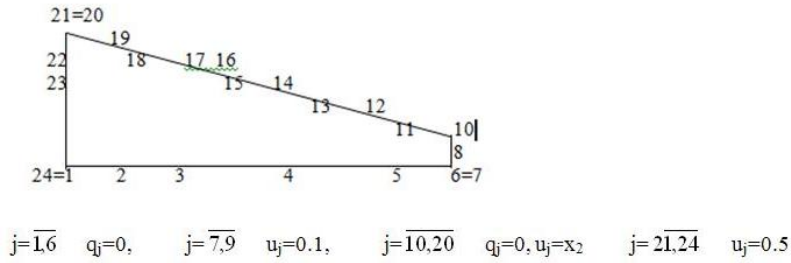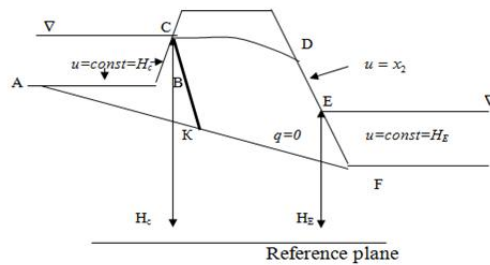
$$j=\overline{1{,}6} \quad q_j=0, \qquad j=\overline{7{,}9} \quad u_j=0.1, \qquad j=\overline{10{,}20} \quad q_j=0, u_j=x_2 \qquad j=\overline{21{,}24} \quad u_j=0.5$$

Figure 4   –   The boundary elements arrangement drawing for the soil unit

ABC: u=H_c, AK: u=H_c, CD: $u = x_2, q=0$, DE: $u = x_2$, EF: =H_E, KF: $q=0$

Figure 5   –   Boundary conditions in the issue of the liquid current
via the barrage with the defect

$$j=\overline{1{,}3} \; u_j=0.5, \;\; j=\overline{4{,}6} \; q_j=0, \; j=\overline{7{,}9} \; u_j=0.1, \; j=\overline{10{,}20} \;\; q_j=0, u_j=x_2 \; j=\overline{21{,}24} \; u_j=0.5$$

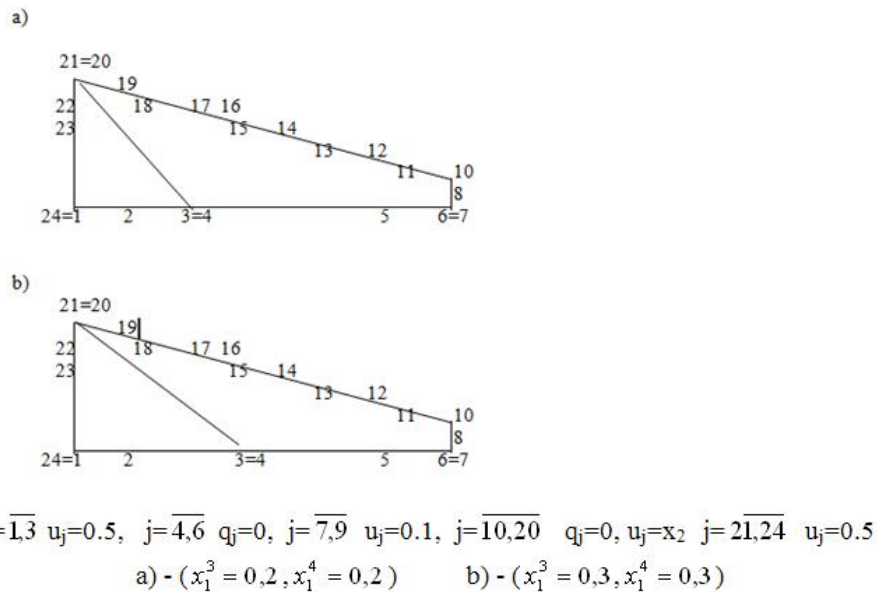a) - ($x_1^3 = 0{,}2 , x_1^4 = 0{,}2$)   b) - ($x_1^3 = 0{,}3 , x_1^4 = 0{,}3$)

Figure 6   –   Arrangement of the boundary elements for the earth block with the damage
(beginning of the damage at the top of the dam)

$j=\overline{1,3}$ u_j=0.5, $j=\overline{4,6}$ q_j=0, $j=\overline{7,9}$ u_j=0.1, $j=\overline{10,20}$ q_j=0, u_j=x_2 $j=\overline{21,22}$ u_j=0.5

$j=\overline{23,24}$ u_j=0.3

1) - ($x_1^3 = 0,3, x_1^4 = 0,3$)   2) - ($x_1^3 = 0,4, x_1^4 = 0,4$)   3) - ($x_1^3 = 0,5, x_1^4 = 0,5$)
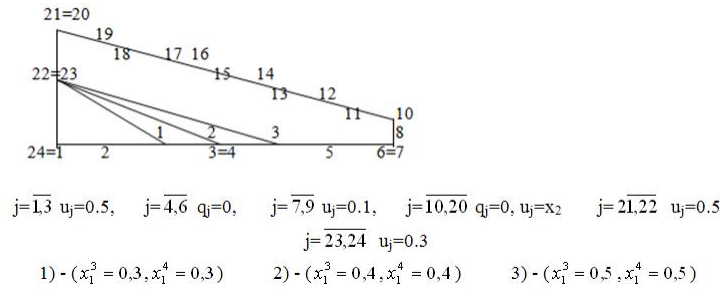
Figure 7   –   Arrangement of the boundary elements for the earth block with the damage
(beginning of the damage – middle point of the dam)

lower basins of the spongy medium, where ABCK, LEF sections are the upper and lower dam basins' fragments accordingly. Thus, the boundary conditions for the issue on the liquid stream via the barrage will be different (Figure 8).
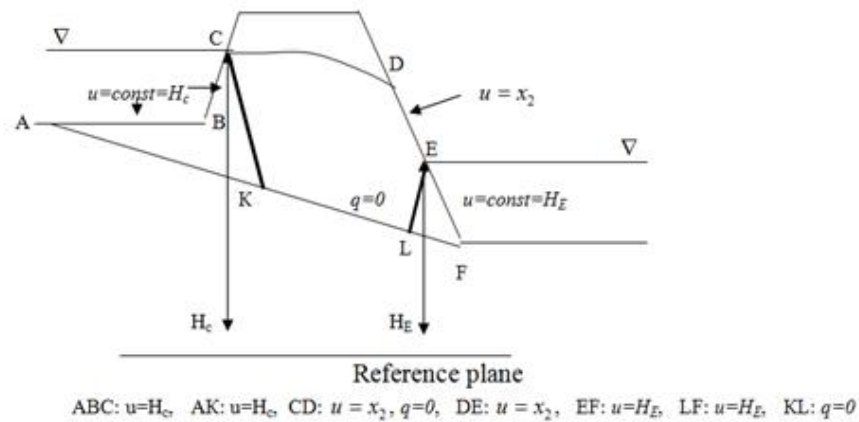

ABC: $u=H_c$, AK: $u=H_c$, CD: $u = x_2$, $q=0$, DE: $u = x_2$, EF: $u=H_E$, LF: $u=H_E$, KL: $q=0$

Figure 8   –   The boundary conditions in the issue on the liquid stream via the barrage with the defected basins

The boundary elements disposition drawing for the soil unit at the stream with the free area via the barrage with the defected upper (at the top) and lower barrage basins is presented in Figure 9. The boundary elements disposition drawing for the soil unit at the stream with the free area via the barrage with the defected upper (in the middle) and lower dam basins is presented in Figure 10.

The application was created in Delphi 7 visual programming environment. The program comprises all necessary data and resolutions of the issue. Figures 11 and 12 show corresponding betwixt the calculated outcomes for the potential at the stream with the free area via the barrage with the defected only upper basin made earlier and the barrage with the defected upper and lower basins.

Lines nomenclatures for Figures 11 and 12 are as follows:
_____ an event of the undefected dam;
.... an event with the defected upper dam basin ($x_1^3 = 0,3; x_1^4 = 0,3$);

$$j=\overline{1,3}\ u_j{=}0.5,\ \ j{=}\overline{4,6}\ q_j{=}0,\ \ j{=}\overline{7,9}\ u_j{=}0.1,\ \ j{=}\overline{10,12}\ u_j{=}0.1,\ \ j{=}\overline{13,20}\ q_j{=}0,\ u_j{=}x_2\ \ \ j{=}\overline{21,24}\ u_j{=}0.5$$

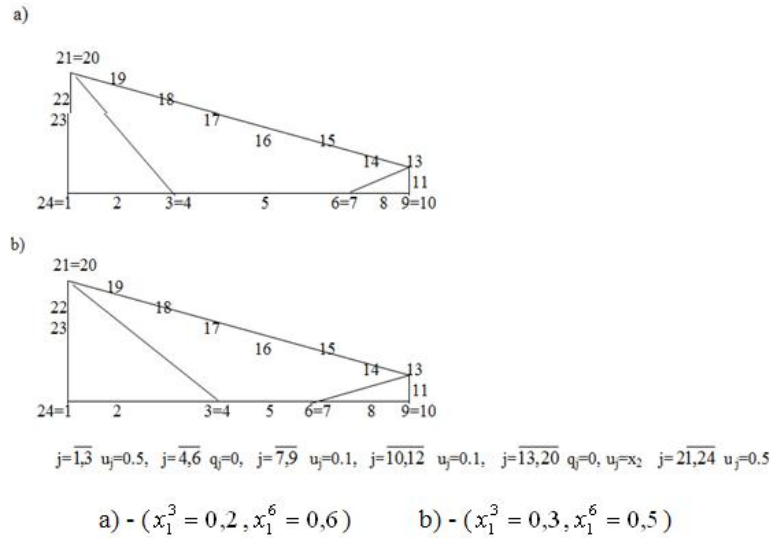$$a) - (x_1^3 = 0,2\,,x_1^6 = 0,6\,) \qquad b) - (x_1^3 = 0,3\,,x_1^6 = 0,5\,)$$

Figure 9 – The boundary elements disposition draw for the soil unit with the defected basins (beginning of the defect at the barrage top)

$$j=\overline{1,3}\ u_j{=}0.5,\ \ j{=}\overline{4,6}\ q_j{=}0,\ \ j{=}\overline{7,9}\ u_j{=}0.1,\ \ j{=}\overline{10,12}\ u_j{=}0.1,\ \ j{=}\overline{13,20}\ q_j{=}0,\ u_j{=}x_2;$$
$$j=\overline{21,22}\ u_j{=}0.5\ j{=}\overline{23,24}\ u_j{=}0.5$$

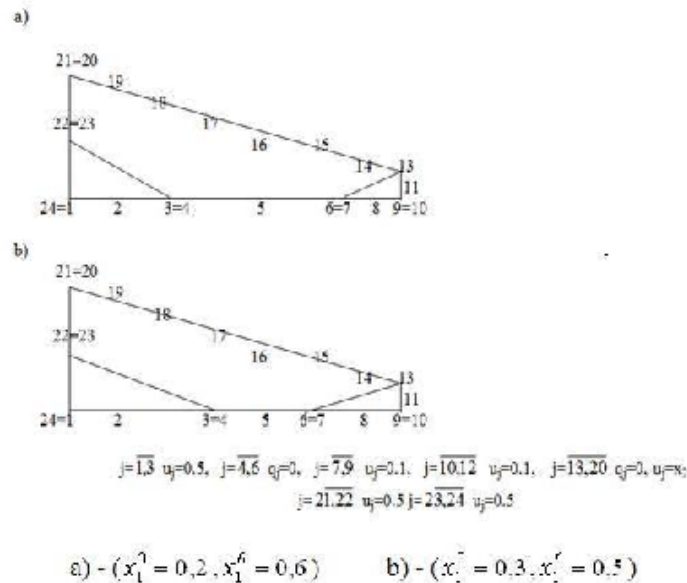$$a) - (x_1^3 = 0,2\,,x_1^6 = 0,6\,) \qquad b) - (x_1^3 = 0,3\,,x_1^6 = 0,5\,)$$

Figure 10 – The boundary elements disposition draw for the soil unit with the defected basins (beginning of the defect in the barrage middle)

- - - - - - - - . an event with the defected upper dam basin $(x_1^3 = 0,4; x_1^4 = 0,4)$;

- - - - - - - - . an event with the defected lower and upper dam basins $(x_1^3 = 0,2; x_1^6 = 0,6)$;

$-\cdot\cdot-\cdot\cdot$ an event with the defected lower and upper dam basins $(x_1^3 = 0,3; x_1^6 = 0,5)$.

The outcomes of the modeling and computer test present potential of considerable effect of the barrage washout areas on the wetted barrage capacity and, adequately, on the filtrate consuming even at concerning small defect sizes [14].
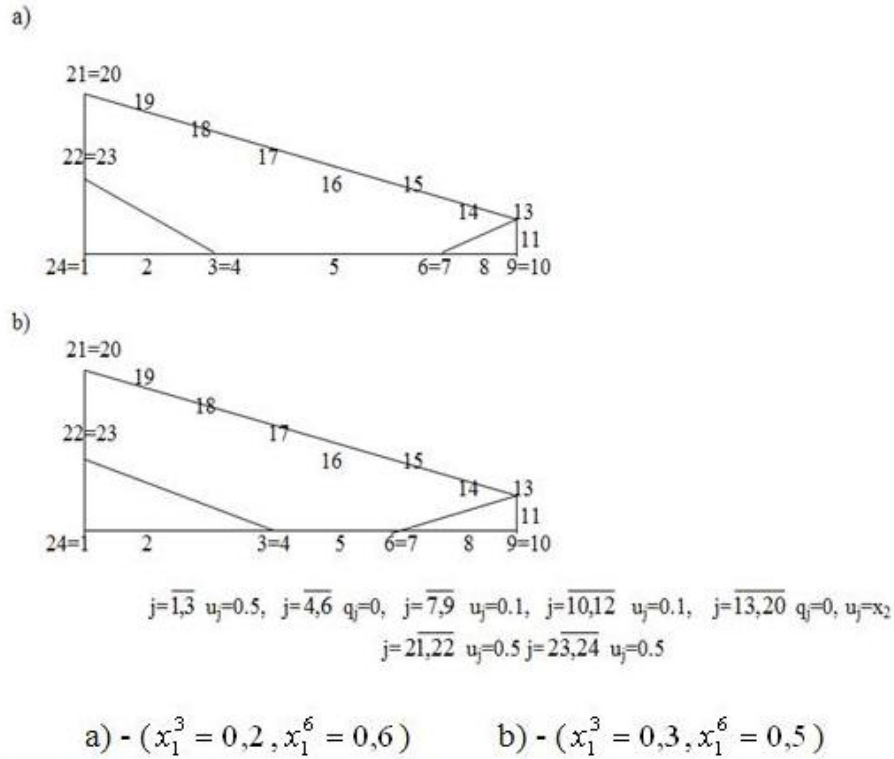
a)

b)

$$j=\overline{1,3}\ u_j=0.5,\ \ j=\overline{4,6}\ q_j=0,\ \ j=\overline{7,9}\ u_j=0.1,\ \ j=\overline{10,12}\ u_j=0.1,\ \ j=\overline{13,20}\ q_j=0,\ u_j=x_2$$

$$j=\overline{21,22}\ u_j=0.5\ j=\overline{23,24}\ u_j=0.5$$

$$a) - (x_1^3 = 0,2, x_1^6 = 0,6)\qquad b) - (x_1^3 = 0,3, x_1^6 = 0,5)$$

Figure 11 – Corresponding of the calculated outcomes for the potential at the stream with the free area via the barrage with the defect in the upper basin top only and via the barrage with the defect in the upper and lower basins top
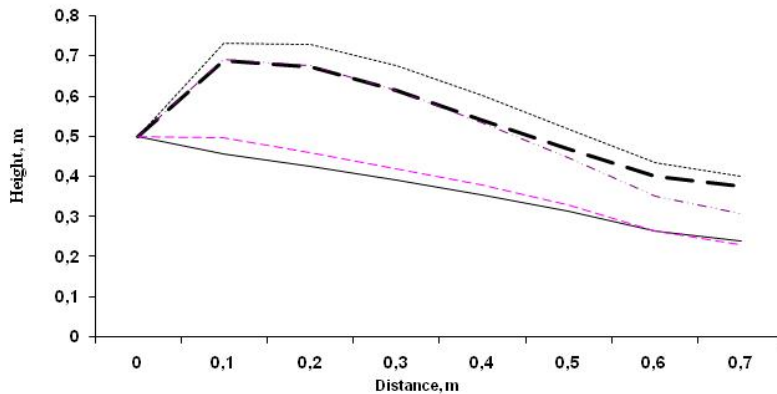

Figure 12 – Corresponding of the calculated outcomes for the potential at the stream with the free area via the barrage with the defect in the upper basin middle only and the barrage with the defect in the upper and lower basins middle

4 Conclusion

Using the numeric test, the free boundary position at the liquid filtration via the dam with the defected upper and lower basins was received and provisional analysis for comparing with the outcomes, received in the event of the defect of the upper dam basin only, was conducted. The outcomes show that in the event with the upper dam basin defect there is more wetting of the soil than in the event with the defect of both dam basins. It can be explained by the fact that the liquid stream at the defect lower dam basin will be faster and wetting of the soil will be less [15].

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