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FACULTY OF TECHNOLOGY

ICENTE'23

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Sakir TASDEMIR

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7TH INTERNATIONAL CONFERENCE ON ENGINEERING TECHNOLOGIES

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PREFACE

International Conference on Engineering Technologies (ICENTE'23) was organized in Konya, Turkey on 23-25 November 2023.

The main objective of ICENTE'23 is to present the latest research and results of scientists related to Biomedical, Computer, Electrics & Electronics, Mechanical, Mechatronics, Metallurgy & Materials and Civil Engineering fields. This conference provides opportunities for the delegates from different areas in order to exchange new ideas and application experiences, to establish business or research relations and to find global partners for future collaborations.

All paper submissions have been double blind and peer reviewed and evaluated based on originality, technical and/or research content/depth, correctness, relevance to conference, contributions, and readability. Selected papers presented in the conference that match with the topics of the journals will be published in the following journals:

- Artificial Intelligence Studies (AIS)
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- New Trends in Computer Sciences
- Open Journal of Nano (OJN)
- Selcuk University Journal of Engineering Sciences (SUJES)
- Intelligent Methods in Engineering Sciences (IMIENS)

At this conference, there are 177 paper submissions. Each paper proposal was evaluated by two reviewers. and finally, 115 papers were presented at the conference from 6 different countries with 58 local and foreign universities and organizations participating,

In particular, we would like to thank Prof. Dr. Metin AKSOY, Rector of Selcuk University, conference scientific committee, session chairs, invited speakers, referees, technical team, participants, and all our colleagues who have contributed. They have made a crucial contribution to the success of this conference. Our thanks also go to our colleagues in our conference office.

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CONTENTS

USING MATLAB TOOLBOXES IN BIOMEDICAL IMAGE PROCESSING **YASIN NUHOGLU,YAHIA ADWAN,AYTEN ATASOY**	1
PERFORMANCE EVALUATION OF GRAPH CUT AND SNAKE ALGORITHMS ON SKIN LESION SEGMENTATION **SEVDA GUL,GOKCEN CETINEL**	5
ANALYSIS OF THE WING STRUCTURE OF THE COENONYMPHA PAMPHILIUS BUTTERFLY SPECIES USING ATOMIC FORCE MICROSCOPY **RASHID DALLAEV,STEFAN ŢĂLU,TATIANA PISARENKO,VLADIMIR HOLCMAN**	9
THE EYE STRUCTURE OF THE COENONYMPHA PAMPHILIUS BUTTERFLY SPECIES STUDIED BY ATOMIC FORCE MICROSCOPY **RASHID DALLAEV,STEFAN ŢĂLU,TATIANA PISARENKO,PETR SADOVSKY,DINARA SOBOLA**	14
IMPLEMENTATION OF A SECURE VOTING SYSTEM USING BLOCKCHAIN **OMAR AHMED SALAD,AHMET SENOL**	19
BREAKDOWN PREDICTION WITH MACHINE LEARNING METHODS **AZHAR MURZAEVA,SEVINC ILHAN OMURCA,BERK OZSOY,KADIR YUNUS KOC,ENES DENIZ,MUHAMMMED GUNDOGDU**	27
A SOFTWARE PACKAGE TO COMPUTE EQUIVALENT WATER THICKNESS CHANGES DIRECTLY FROM GRACE GGMS ESKAD **EMEL ZERAY OZTURK,RAMAZAN ALPAY ABBAK**	31
A LOCATION BASED AUGMENTED REALITY APPLICATION WITH MACHINE LEARNING METHODS **KUBRA KAPICI,ALI OZTURK**	35
LANE TRACKING AND COLLISION AVOIDANCE USING DEEP LEARNING IN AUTONOMOUS VEHICLES **CEMRE BELEMIR SAFAK,ALI OZTURK**	40
TURKISH AND ENGLISH DATASETS IN PARAPHRASE GENERATION TASK WITH BART MODEL **HILAL TEKGOZ,SEVINC ILHAN OMURCA**	45
DETECTING DDOS ATTACKS WITH DEEP LEARNING METHODS **SABAHAT SUMEYYE GUCLU,ALI OZTURK**	49
A NON GEOMETRICAL FEATURE IMPACT COMPARISON FOR REMOTE SENSING IMAGE CLASSIFICATION **ALI SAGLAM**	54
A COMPARISON OF THREE FAST GRAPH BASED SEGMENTATION ALGORITHMS ON 3D POINT CLOUDS **ALI SAGLAM,NURDAN AKHAN BAYKAN**	58
DETERMINATION OF DIABETIC RETINOPATHY GRADES USING A DEEP LEARNING BASED CLASSIFICATION **NUR SENA OZTEKIN,ALI SAGLAM**	63
A DISTRIBUTED ALGORITHM FOR BACKBONE CONSTRUCTION IN THREE DIMENSIONAL WNSNS **OMER GULEC**	67
DEVELOPING A DESKTOP APPLICATION FOR REAL TIME DETECTION OF ACROMEGALY FROM FACIAL IMAGES WITH ARTIFICIAL INTELLIGENCE **MEHMET OZEL,NURETTIN DOGAN,RUKIYE KARAKIS,MUHAMMED KIZILGUL,MUHAMMED MUTLU YAPICI,ELVAN DUMAN**	71

ENHANCING ON TIME PERFORMANCE THROUGH FLIGHT TIME PREDICTION A MACHINE LEARNING APPROACH **SEDA SOYKAN,SEFER BADAY**	74
PERFORMANCE EVALUATION OF CLASSIFICATION ALGORITHMS FOR DEFECT DETECTION IN PATTERNED FABRIC IMAGES **YUNUS EMRE MERAL,OSMAN GOKALP**	79
ON TRENDS OF INVESTMENT PORTFOLIO MANAGEMENT A BIBLIOMETRIC ANALYSIS **DARIUS SABALIAUSKAS,JOLANTA MILIAUSKAITĖ**	83
USING BIG DATA FOR OPTIMIZING ADVERTISING CAMPAIGNS IN SOCIAL NETWORKS **ARJAN KRASNIQI,BERAT MAKSUTAJ,ERBLIN JANUZAJ**	89
RANGE ANGLE BEAMPATTERN SYNTHESIS WITH LOGARITHMICALLY INCREASING CONCENTRIC CIRCULAR FREQUENCY DIVERSE ARRAY **UGUR YESILYURT**	99
RULE BASED DIAGNOSTIC ALGORITHM UTILIZING PATHOLOGICAL FINDINGS IN BREAST CANCER **HILAL HAZEL YORDAN,MUHAMMED KURSAD UCAR**	103
POLARIZATION AND OBLIQUE INCIDENCE INSENSITIVE DUAL BAND METAMATERIAL ABSORBER FOR WI FI APPLICATIONS **BAHAR ILA,ERCAN YALDIZ**	107
DESIGN AND IMPLEMENTATION OF BLDC MOTOR THRUST MEASUREMENT AND TEST SYSTEM **ALPASLAN DURMUS,EROL DUYMAZ,AHMET MURAT KADIOGLU,FATIHA BAYKAL,CEBRAIL OLMEZ,HUDAVER ATASOY**	111
IMPACT OF FEATURE AND SENSOR SELECTION ON EMG SIGNAL PROCESSING **EMIN MOLLAHASANOGLU,YUSUF SEVIM**	114
MACHINE LEARNING BASED CLASSIFICATION OF NEONATAL HYPERSPECTRAL SIGNATURES **MUHAMMET MUSTAFA ERGIN,MUCAHIT CIHAN,MURAT CEYLAN**	119
COMPARISON OF DIFFERENT SEGMENTATIONS IN AUTOMATED DETECTION OF HYPERTENSION USING ELECTROCARDIOGRAPHY WITH EMPIRICAL MODE DECOMPOSITION **YUNUS EMRE ERDOGAN,ALI NARIN,WALID HARIRI**	123
PERMANENT MAGNET SYNCHRONOUS MOTOR DESIGN FOR ROPE DRIVEN GEARLESS ELEVATOR MACHINE **AHMET FENERCIOGLU,DAGHAN ATAKAY,EMRE PINARBASI**	127
BRAIN TUMOR SEGMENTATION AND CLASSIFICATION FROM MRI IMAGES **BEKIR HAKAN AKSEBZECI,MAHMUT BUYUKBAS,ALPEREN OZCELIK,HASAN HUSEYIN ERKEN**	131
AGRIVOLTAIC SYSTEMS COMBINING FOOD AND ENERGY PRODUCTION **MUSTAFA SACID ENDIZ**	136
CHARACTERISTICS OF FOAM CONCRETE WITH CAPRIC ACID DIATOMITE COMPOSITE **SULTAN ASLANTAS,ALI YARAS**	139
FOAM CONCRETES CONTAINING CAPRIC ACID EXPANDED PERLITE COMPOSITE PHYSICO MECHANICAL PROPERTIES **ZELIHA YUKSEL,ALI YARAS**	142
STATISTICAL ANALYSIS OF HARDNESS OF HIGH DENSITY POLYETHYLENE COMPOSITES **ECEM AYDIN,ALI YARAS,BILAL DEMIREL,BILAL KURSUNCU**	145

USE OF DRINKING WATER TREATMENT SLUDGE AND EGG SHELL FOR CLAY FREE BRICK PRODUCTION **GIZEM BAKIROGLU,ALI YARAS**	148
NON DISABLED MODULAR USB CHARGE SUPPORTED EMBEDDED STOP BUTTON DESIGN AND APPLICATION FOR BUSES **CEM EKER,ALEV YUKSEL PECELI,FERHAT COMERT,YUNUS EMRE TARHAN,DAMLA CEREN TEKTAS,EDA NUR UYUK MADEN,YAVUZ CATMAZ,ABDULLAH VIDINLIOGLU,DUYGU CELIK,ENES GENC**	152
ERGONOMIC DISABLED RAMP DESIGN AND APPLICATION FOR PUBLIC TRANSPORTATION VEHICLES **CEM EKER,OMER DOGAN DOGANCIK,SEMIH ICYUZ,METEHAN ONAT,YAVUZ CATMAZ,ELIF CAK,DUYGU CELIK,ALEV YUKSEL PECELI**	156
ARTIFICIAL INTELLIGENCE SUPPORTED UNMANNED AERIAL VEHICLE WITH SEMI AUTONOMOUS FLIGHT CONTROL FOR FOREST FIRE DETECTION **ABDULLAH GENC,EMRE KOYUN**	160
TUBULAR PERMANENT MAGNET LINEAR MOTOR DESIGN FOR AIRCRAFT ACTUATOR INSTEAD OF HYDRAULIC ACTUATORS **HALIT UZUNER,KADIR ERKAN**	165
OPTIMAL SPHERICAL MECHANISM DESIGN FOR SUN TRACKING ON TWO AXIS **ZIYA OZCELIK,OSMAN ACAR,AZIM HANSU**	171
NUMERICAL INVESTIGATION OF FLOW AND HEAT TRANSFER IN ASYMMETRICAL TRIANGULAR CORRUGATED CHANNELS WITH TRIANGULAR OBSTACLES **SELMA AKCAY**	180
THE EFFECT OF BACKWARD TRIANGULAR TYPE VORTEX GENERATORS AT DIFFERENT CHORDWISE DIRECTIONS **MEHMET SEYHAN,MUHAMMET AKIF OZDEN**	186
RECENT DEVELOPMENTS ON REFRIGERATION SYSTEMS THAT USE EJECTORS AS EXPANDERS FOR PERFORMANCE ENHANCEMENT **OGUZ CALISKAN,H KURSAD ERSOY**	191
THERMAL ANALYSIS AND DESIGN OF COMPOSITE STRUCTURES UNDER REALISTIC FLOW CONDITIONS **DAMLA PEHLIVAN,HASAN AYDOGAN**	196
CONTROLLED DISCRETE CHIP FORMATION IN TURNING WITH CNC PROGRAMMING **MUHAMMED EMIN DURSUN,SINAN KESRIKLIOGLU**	205
VEHICLE CRASH SYSTEM DESIGN **ARIF DOGAN,BULENT AYDEMIR**	211
THE FEASIBILITY STUDY OF A VEHICLE CRASH SYSTEM **ARIF DOGAN,BULENT AYDEMIR**	215
INVESTIGATION OF THE IMPACT BEHAVIOR OF STRUCTURAL STEEL COATED WITH THERMAL FLAME SPRAYING METHOD **SERAFETTIN EKINCI,BUKET CAKAR ACIKGOZ**	219
DEVELOPMENT OF AN INNOVATIVE COMMERCIAL STEAM PEELING SYSTEM FOR VARIOUS VEGETABLE PEELS **ZAFER KAHRAMAN,MURAT HACI,ORKUN UGUR**	224
DEVELOPMENT OF WASHER DISINFECTOR PROTOTYPE FOR VARIOUS GLASS MEDICAL PRODUCTS **ZAFER KAHRAMAN,MURAT HACI,SONER GURCU,HAKAN SERHAD SOYHAN**	229
DETERMINATION OF TOOL WEAR SURFACE ROUGHNESS AND CUTTING TEMPERATURE PARAMETERS IN MILLING ST37 STEEL **UNAL DEGIRMENCI,USAME ALI USCA,SERHAT SAP**	233

SYSTEM HEAT TRANSFER OF USING ALUMINUM HONEYCOMB AS THERMAL RESISTANCE EXPERIMENTAL INVESTIGATION OF ITS EFFECTS ON **CUMA ALI YILMAZ,ADNAN BERBER**	238
INVESTIGATION OF TORSIONAL AND SOFT STOREY BEHAVIOR OF A REINFORCED CONCRETE BUILDING IN ADANA PROVINCE ACCORDING TO TURKEY BUILDING EARTHQUAKE CODE 2018 **DUYGU ERTURKMEN**	245
ESTIMATION OF THE UNCONFINED COMPRESSIVE STRENGTH OF CEMENT STABILIZED CLAY USING ARTIFICIAL NEURAL NETWORKS ANN **ZAINAB RAZZAQ ALMAHMODI,SULEIMAN KHATRUSH,METIN MEHMETOGLU**	250
STEADY STATE SEEPAGE ANALYSIS OF DAM FOUNDATION MADE OF DIFFERENT LAYERS **TIMUCIN ALP ASLAN,BEYTULLAH TEMEL**	256
INVESTIGATION ON FRESH PROPERTIES OF GEOPOLYMER MORTAR **ASENA KARSLIOGLU KAYA,MEHMET INANC ONUR**	263
CHALLENGES ENCOUNTERED IN COLUMN TESTS UNDER ECCENTRIC AXIAL LOAD AND PROPOSED SOLUTIONS **AHMET OZBAYRAK**	267
VEHICLE DETECTION AND COUNTING IN TRAFFIC VIDEOS USING DEEP LEARNING **AHSEN BATTAL,YUNUS EMRE AVCI,ADEM TUNCER**	272
ANALYSIS OF SURFACE ROUGHNESS IN MACHINING OF AL SI BASED ALLOYS AN EXPERIMENTAL STUDY **CEM ALPARSLAN,SENOL BAYRAKTAR**	276

Steady State Seepage Analysis of Dam Foundation Made of Different Layers

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***Abstract* - In this study, the steady-state seepage problem of dam foundations made of different layers has been investigated. Equations obtained by using Darcy's law and continuity equations are solved by finite element method (FEM) based on Galerkin's method. A program written in the Fortran programming language has been utilized for the solution process. The paper presents the determination of hydraulic head, pore water pressure values, uplift pressure beneath the dam, and seepage quantities for dam foundations with different layers. To verify and ensure the accuracy of the written programs, the suggested method results are compared with those obtained from SEEP/W, a finite element CAD software.**

Keywords - Steady-state seepage, Galerkin method, Fortran program, Uplift pressure, Seep/w program.

I. INTRODUCTION

Dams are crucial engineering structures. Seepage can lead to stability issues in dams, which may ultimately result in their collapse. Therefore, seepage in dams is of great significance and is extensively studied by numerous researchers.

Mesci [1] examined the methods applied to find the seepage quantity in the dam body in his thesis. In addition, flow lines and equipotential lines were calculated and assessed graphically. El-Jumaily and Al-Bakry [2] investigated the seepage problem in dams with heterogeneous foundations using the finite volumes method. Moharrami et al. [3] centered on a numerical approach to assessing the effectiveness of cutoff wall systems in addressing uplift pressure and piping issues. Çalamak et al. [4] reviewed the effects of blanket, chimney, and toe drains on seepage in dams, assessing their performance in separate cases for different material types and geometric characteristics. Ullah et al. [5] utilized SEEP/W software to model the seepage quantity at the Baz Ali small dam. For the 2D steady-state seepage flow problem of water through the soil beneath an impermeable dam the singular function boundary integral method (SFBIM) was implemented by Elliotis [6]. Arshad et al. [7] used SEEP/W to develop a finite element model for a non-homogeneous earth dam in their study. Chouireb and Djehiche [8] modeled seepage flows in earth dams equipped with a vertical drainage system and compared the results with observed data (case study: Harreza Dam, Algeria). Zhang et al. [9] aimed to solve the seepage analysis of a concrete dam foundation consisting of different soil layers using the flow network method. Norouzi et al. [10] conducted a study considering various parameters to examine the seepage phenomenon at the foundation of Sabalan Dam. Wang et al. [11] suggested the FE-Meshfree method for performing steady-state seepage analysis. The seepage analyses for the dam body and foundation were conducted by Çoşkun [12] using the Steady State Groundwater module within the Slide program. Polater [13] aimed to perform seepage analysis for embankment dams using different impermeable materials. Farhadian et al. [14] examined the seepage analysis of the Peygham-Chay Dam using the SEEP program and investigated the effect of Cutoff Walls on seepage. Chen et al. [15] established a three-dimensional finite element model of a typical earth dam with a polymer cutoff wall using numerical simulation technology to analyze the impact of the number, location, and random defects in the wall on the seepage characteristics. Abokwiek et al. [16] investigated the seepage event occurring at the dam foundation, taking into account various parameters such as dam dimensions like width and depth, reservoir water level, soil permeability, and ambient temperature. Charrak et al. [17] studied the seepage beneath the Sidi Abdelli earth dam, considering various parameters such as discharge seepage, exit gradient, and uplift pressure.

As a result of the investigations carried out by the researchers, many studies have been encountered that examined the steady-state seepage phenomenon occurring in dams with different methods and programs. However, no study has been found that examines the seepage problem occurring in dams with foundations consisting of layers using the FEM based on the Galerkin method.

II. MATHEMATICAL FORMULATIONS

The 2D steady-state seepage within a permeable, anisotropic soil is mathematically represented through the subsequent partial differential equation, employing Darcy's principle and continuity equations, as referenced in [18].

$$K_x(\partial^2 h)/(\partial x^2) + K_z(\partial^2 h)/(\partial z^2) = 0 \quad (1)$$

In this context, K_x and K_z represent the hydraulic conductivity coefficients in the x and z directions, while h signifies the total hydraulic head.

The total hydraulic head value is expressed as the sum of the elevation head and the pressure head, as the velocity head is neglected due to the very slow movement of water in the ground.

$$h = z + p/\gamma_w \quad (2)$$

The partial differential form of eq. (1) is transformed into integral form by employing the weighted residuals method as depicted below:

$$\int\int_{A_e} \psi\left(K_x(\partial^2 h)/(\partial x^2) + K_z(\partial^2 h)/(\partial z^2)\right)dA = 0 \tag{3}$$

Eq. (4) is derived by applying partial integration to eq. (3).

$$\int\int_{A_e} \left(K_x(\partial\psi/\partial x)(\partial h)/(\partial x) + K_z(\partial\psi/\partial z)(\partial h)/(\partial z)\right)dxdz - \int_{\Gamma} \psi\left((\partial h/\partial x)n_x + (\partial h/\partial z)n_z\right)d\sigma = 0 \tag{4}$$

Here, the second part of the equation specifies the boundary conditions. In the Galerkin formulation, the variation of the hydraulic load is taken as weight functions.

$$\psi = \delta h \tag{5}$$

After substituting the weight functions, the element integral form is transformed into matrix form.

$$\int\int_{A_e} \left(K_x(\partial(\delta h)/\partial x)(\partial h)/(\partial x) + K_z(\partial(\delta h)/\partial z)(\partial h)/(\partial z)\right) dxdz - \int_{\Gamma} (\delta h) q d\sigma = 0 \tag{6}$$

The FEM stands as a highly efficient numerical technique. It entails dividing the problem domain into multiple elements of restricted dimensions and offering approximations for the system's nodes. In this particular investigation, an isoparametric 8-noded serendipity element is utilized in the formulation. Eq. (7) furnishes the hydraulic head values at any location within the element.

$$\{h\} = \begin{bmatrix} N_1 N_2 N_3 N_4 N_5 N_6 N_7 N_8 \end{bmatrix} \begin{Bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \\ h_5 \\ h_6 \\ h_7 \\ h_8 \end{Bmatrix} = [N]\{h\} \tag{7}$$

here, *[N]* denotes the matrix of shape functions, and *{h}* represents the vector of element hydraulic heads. The coordinates of any point inside the quadratic element are determined according to the shape functions

$$x = \sum_{i=1}^{8} N_i x_i \qquad z = \sum_{i=1}^{8} N_i z_i \tag{8}$$

here x_i and z_i are the coordinates of a node. For the chosen isoparametric element, the geometric shape functions are the same as the interpolation shape functions. Therefore, the hydraulic load at any point within the element is calculated from the element node loads based on the shape functions.

$$h(\xi,\eta) = \sum_{i=1}^{8} N_i(\xi,\eta) h_i \tag{9}$$

Substituting Eq. (7) into Eq. (6) the element integral form takes the following equation form.

$$\int\int_{A_e} (\partial(\delta h)/\partial x) \begin{pmatrix} K_x(\partial[N]\{h\})/(\partial x) \\ +(\partial(\delta h)/\partial z) K_y(\partial[N]\{h\})/(\partial z) \end{pmatrix} dxdz - \int_{\Gamma} (\delta h) q d\sigma = 0 \tag{10}$$

Eq.(10) is based on the hydraulic head gradient vector. This vector can be calculated through the *[B]* matrix, which includes the derivatives of the interpolation functions.

$$\{gv\} = \begin{Bmatrix} \partial h/\partial x \\ \partial h/\partial z \end{Bmatrix} = \begin{bmatrix} \partial[N]/\partial x \\ \partial[N]/\partial z \end{bmatrix} \{h\} = [B]\{h\} \tag{11}$$

Accordingly, the variations of the hydraulic load are as in eq. 12.

$$\delta h = N\{\delta h\} \qquad \delta h^T = N\{\delta h\}^T \tag{12}$$

Substituting of eqs. (11-12) into eq. (10). It results in

$$\int\int_{A_e} (\partial(\delta h)/\partial x) \begin{pmatrix} K_x(\partial[N]\{h\})/(\partial x) \\ +(\partial(\delta h)/\partial z) K_z(\partial[N]\{h\})/(\partial z) \end{pmatrix} dxdy - \int_{\Gamma} (\delta h) q d\sigma = 0 \tag{13}$$

The eq. (13) is presented in its simplified form as follows:

$$\{\delta\Delta\}^T \left(\int\int_{A_e} \left([B]^T [K][B]\right) dA \{h\} \right) - \int_{\Gamma} [N]^T q d\sigma = 0 \tag{14}$$

where $[K]$ is defined as the conductivity matrix. The element seepage matrix, $[g_e]$, and the element applied flux vector, $\{f_s\}$ are:

$$[g_e]_{(8*8)} = \int\int_{A_e} \left([B]^T [K][B]\right) dA \; ; \; \{f_s\}_{(8*1)} \int_{\Gamma} [N]^T q d\sigma \tag{15}$$

The typical expression of the finite element equation used in the analysis of steady-state seepage is

$$[g_e]\{h\} = \{f_s\} \quad (16)$$

For the analyzed flow region, with the help of the coding technique, the contributions of the elements are taken to create the system conductance matrix and system load vector.

$$[G]\{H\} = \{F\} \quad (17)$$

where *[G]* is the global seepage matrix, $\{H\}$ is the system hydraulic head vector and {F} is the system load vector for all nodes. By performing a numerical solution under specified boundary conditions, the total hydraulic head at nodal points is determined. Subsequently, the Seepage rate per unit width and pressures value can be readily.

III. Numerical Examples and Discussion

In this section, the steady-state seepage problem in dams consisting of layered foundations has been investigated with FEM based on Galerkin method and SEEP/W [19] program. Additionally, seepage rate per unit width, hydraulic head, pore water pressure values, and uplift pressure beneath the dam have been determined using the suggested method and provided in tabular form.

In this study, the seepage phenomenon occurring at the foundation of the dam geometry provided in Fig. 1 ([20]) has been investigated. Various layer conditions have been considered in the seepage analysis, which encompasses four different cases (Fig. 2).

The material and geometric properties of various soil layers in the dam foundation are presented in Table 1.

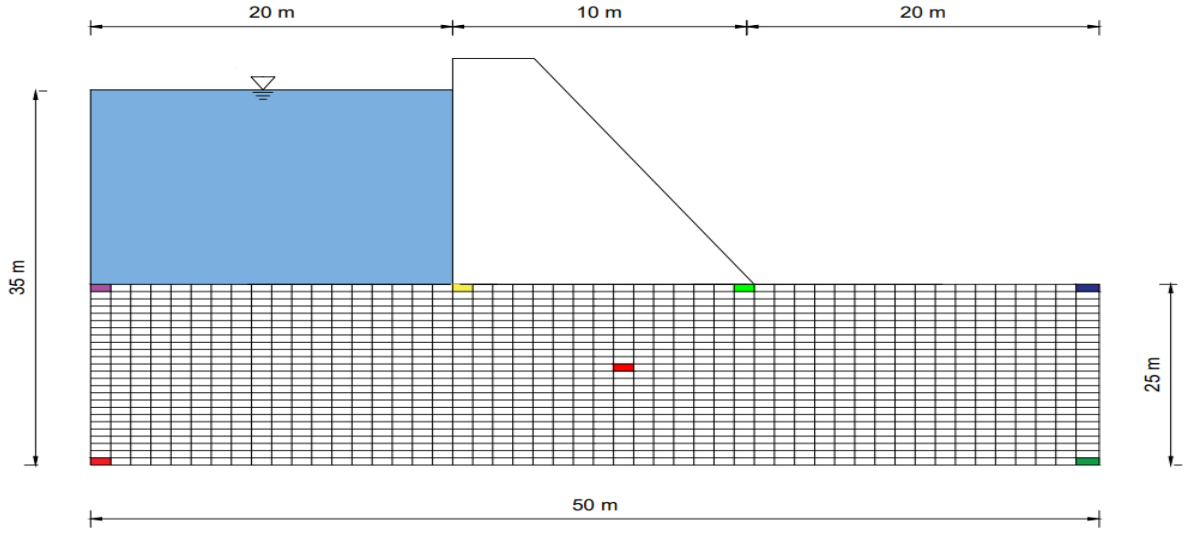
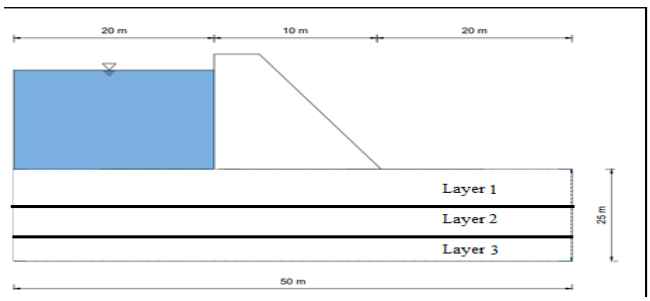
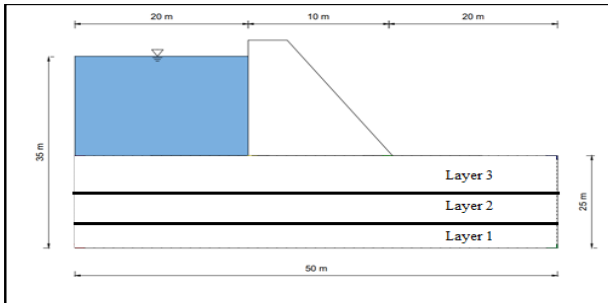


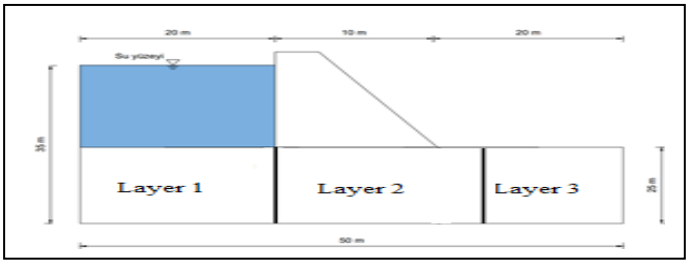
Fig.1 Geometric properties of the dam foundation.



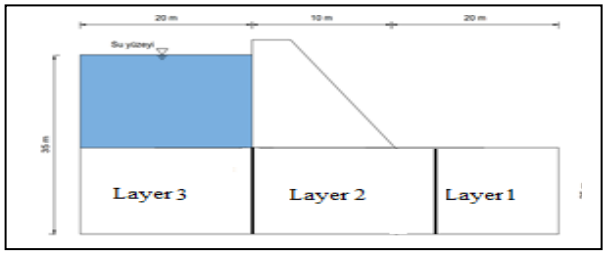
Case A



Case B



Case C



Case D

Fig. 2 Geometry and material properties of the dam for different case

The Seepage rate per unit width of the dam foundation, calculated by FEM based on the Galerkin method, is given in Table 2 with the results obtained from the SEEP/W program.

It can be seen clearly in Table 2 that the proposed method results are in excellent agreement with SEEP/w. Additionally, from Table 2 it can be observed that the highest seepage rate occurs in Case D.

Table 1. Materials and geometry properties of dam foundation different soil layers.

		Case A		Case B		Case C		Case D	
Layer	**Permeability Coefficient K_x, K_z (m/s)**	**Height (m)**	**Length (m)**	**Height (m)**	**Length (m)**	**Height (m)**	**Length (m)**	**Height (m)**	**Length (m)**
1	10^{-7}	10	50	5	50	25	20	25	10
2	10^{-6}	10	50	10	50	25	20	25	20
3	10^{-5}	5	50	10	50	25	10	25	20

Table 2. Calculation results of Seepage rate per unit width of different soil layers. ($m^3/s/m$)

	Seep/W[13]	**Present Study**
Case A	1.220 E-06	1.212 E-06
Case B	5.630 E-06	5.627 E-06
Case C	3.885 E-06	3.898 E-06
Case D	9.481 E-06	9.478E-06

The hydraulic head and pressure values of the dam have been computed and are presented in Table 3 for the locations at the ends and the midpoint of the foundation (1, 50, 1200, 1250), as well as for the two elements (1221, 1231) situated beneath the downstream and upstream areas of the structure.

One of the most critical factors related to the safety and stability of hydraulic structures is uplift force. Uplift pressure beneath hydraulic structures applies an upward force against dam foundations due to seepage beneath the hydraulic structure. This uplift pressure, which exerts forces upward against the structure's foundations, is known as the uplift force. If the uplift force cannot be balanced with the weight of the soil, it can lead to stability issues. Therefore, by calculating the uplift pressure, the uplift force acting on the structure is determined and presented in Fig.3 and Table 4.

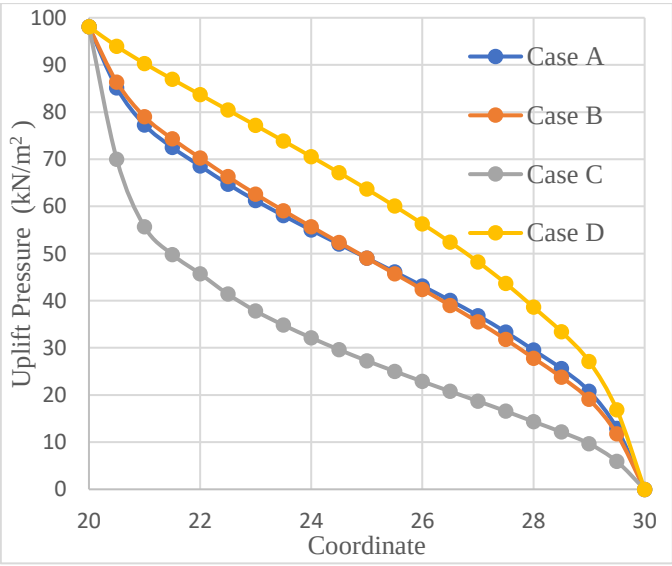


Fig. 3 The uplift force acting on the dam

As mentioned earlier, when designing a hydraulic structure, it is essential to consider the seepage issue and ensure that the uplift force is balanced with the structure's weight.

CONCLUSIONS

In this study, 2D steady-state seepage analysis in the dam foundation consisting of different soil layers has been carried out using the FEM based on the Galerkin approach. Moreover, For dam foundations with different layers, hydraulic head, pore water pressure values, uplift pressure beneath the dam, and seepage quantities have been determined and presented in tabular form. The prepared Fortran program has demonstrated that it can be easily and effectively applied to layered environments.

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Table 3. Hydraulic head and pressure load values of the dam with different soil layers

			Case A		Case B		Case C		Case D	
NODE	**X (m)**	**Y (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**
1	0.0	0.0	30.178	30.178	33.808	33.808	29.757	29.757	34.618	34.618
2	0.5	0.0	30.178	30.178	33.807	33.807	29.755	29.755	34.618	34.618
3	1.0	0.0	30.178	30.178	33.802	33.802	29.748	29.748	34.617	34.617
99	49.0	0.0	29.822	29.822	26.198	26.198	25.232	25.232	30.432	30.432
100	49.5	0.0	29.822	29.822	26.193	26.193	25.232	25.232	30.425	30.425
101	50.0	0.0	29.822	29.822	26.192	26.192	25.232	25.232	30.422	30.422
102	0.0	0.5	30.178	29.678	33.81	33.31	29.759	29.259	34.618	34.118
103	1.0	0.5	30.178	29.678	33.804	33.304	29.751	29.251	34.617	34.117
151	49	0.5	29.822	29.322	26.196	25.696	25.232	24.732	30.429	29.929
152	50	0.5	29.822	29.322	26.19	25.69	25.232	24.732	30.42	29.92
153	0.0	1.0	30.179	29.179	33.815	32.815	29.766	28.766	34.618	33.618
154	0.5	1.0	30.179	29.179	33.813	32.813	29.764	28.764	34.618	33.618
155	1.0	1.0	30.178	29.178	33.808	32.808	29.757	28.757	34.618	33.618
251	49.0	1.0	29.822	28.822	26.192	25.192	25.232	24.232	30.422	29.422
252	49.5	1.0	29.822	28.822	26.187	25.187	25.231	24.231	30.416	29.416
253	50.0	1.0	29.821	28.821	26.185	25.185	25.231	24.231	30.413	29.413
1873	24.0	12.0	30.035	18.035	30.343	18.343	26.755	14.755	33.119	21.119
1874	24.5	12.0	30.017	18.017	30.172	18.172	26.713	14.713	32.961	20.961
1875	25.0	12.0	30	18	30	18	26.668	14.668	32.805	20.805
1950	24.0	12.5	30.037	17.537	30.353	17.853	26.79	14.29	33.087	20.587
1951	25.0	12.5	30	17.5	30	17.5	26.699	14.199	32.763	20.263
2025	24.0	13.0	30.039	17.039	30.363	17.363	26.827	13.827	33.054	20.054
2026	24.5	13.0	30.019	17.019	30.182	17.182	26.78	13.78	32.886	19.886
2027	25.0	13.0	30	17	30	17	26.731	13.731	32.72	19.72

Table 3. Hydraulic head and pressure load values of the dam with different soil layers

			Case A		Case B		Case C		Case D	
NODE	**X (m)**	**Y (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**	**Hydraulic Head (m)**	**Pressure Head (m)**
3649	0.0	24.0	34.553	10.553	34.942	10.942	34.641	10.641	34.974	10.974
3650	0.5	24.0	34.553	10.553	34.942	10.942	34.64	10.64	34.974	10.974
3651	1.0	24.0	34.553	10.553	34.942	10.942	34.64	10.64	34.974	10.974
3689	20	24.0	33.497	9.497	33.7	9.7	30.89	6.89	34.847	10.847
3690	20.5	24	33.151	9.151	33.357	9.357	30.826	6.826	34.52	10.52
3691	21.0	24	32.659	8.659	32.876	8.876	30.217	6.217	34.182	10.182
3710	30.5	24	26.162	2.162	25.968	1.968	25.468	1.468	26.485	2.485
3711	31.0	24	25.984	1.984	25.787	1.787	25.375	1.375	26.245	2.245
3747	49.0	24	25.447	1.447	25.058	1.058	25.016	1.016	25.37	1.37
3748	49.5	24	25.447	1.447	25.058	1.058	25.016	1.016	25.369	1.369
3749	50.0	24	25.447	1.447	25.058	1.058	25.016	1.016	25.368	1.368
3750	0.0	24.5	34.777	10.277	34.971	10.471	34.82	10.32	34.987	10.487
3751	1.0	24.5	34.777	10.277	34.971	10.471	34.82	10.32	34.987	10.487
3770	20.0	24.5	34.065	9.565	34.181	9.681	32.274	7.774	34.91	10.41
3771	21.0	24.5	32.877	8.377	33.057	8.557	30.731	6.231	34.204	9.704
3780	30.0	24.5	25.935	1.435	25.819	1.319	25.405	0.905	26.208	1.708
3781	31.0	24.5	25.499	0.999	25.4	0.9	25.191	0.691	25.631	1.131
3799	49.0	24.5	25.223	0.723	25.029	0.529	25.008	0.508	25.185	0.685
3800	50.0	24.5	25.223	0.723	25.029	0.529	25.008	0.508	25.184	0.684
3801	0.0.	25	35	10	35	10	35	10	35	10
3802	0.5	25	35	10	35	10	35	10	35	10
3803	1.0	25	35	10	35	10	35	10	35	10
3841	20.0	25	35	10	35	10	35	10	35	10
3842	20.5	25	33.68	8.68	33.803	8.803	32.137	7.137	34.576	9.576
3843	21.0	25	32.878	7.878	33.054	8.054	30.676	5.676	34.206	9.206
3861	30.0	25	25	0	25	0	25	0	25	0
3862	30.5	25	25	0	25	0	25	0	25	0
3863	31.0	25	25	0	25	0	25	0	25	0
3899	49.0	25	25	0	25	0	25	0	25	0
3900	49.5	25	25	0	25	0	25	0	25	0
3901	50.0	25	25	0	25	0	25	0	25	0

Table 4. The Uplift Force Acting on the Dam

		Case A			**Case B**			**Case C**			**Case D**		
X (m)	Y (m)	Hydraulic Head (m)	Pressure Head (m)	Uplift Pressure (kN/m^2)	Hydraulic Head (m)	Pressure Head (m)	Uplift Pressure (kN/m^2)	Hydraulic Head (m)	Pressure Head (m)	Uplift Pressure (kN/m^2)	Hydraulic Head (m)	Pressure Head (m)	Uplift Pressure (kN/m^2)
20	25	35	10	98.100	35	10	98.100	35	10	98.100	35	10	98.100
20.5	25	33.68	8.68	85.151	33.803	8.803	86.357	32.137	7.137	70.014	34.576	9.576	93.941
21	25	32.878	7.878	77.283	33.054	8.054	79.010	30.676	5.676	55.682	34.206	9.206	90.311
21.5	25	32.391	7.391	72.506	32.575	7.575	74.311	30.076	5.076	49.796	33.865	8.865	86.966
22	25	31.99	6.99	68.572	32.165	7.165	70.289	29.659	4.659	45.705	33.532	8.532	83.699
22.5	25	31.599	6.599	64.736	31.759	6.759	66.306	29.22	4.22	41.398	33.199	8.199	80.432
23	25	31.244	6.244	61.254	31.381	6.381	62.598	28.854	3.854	37.808	32.866	7.866	77.165
23.5	25	30.917	5.917	58.046	31.024	6.024	59.095	28.55	3.55	34.826	32.531	7.531	73.879
24	25	30.605	5.605	54.985	30.678	5.678	55.701	28.276	3.276	32.138	32.191	7.191	70.544
24.5	25	30.3	5.3	51.993	30.338	5.338	52.366	28.019	3.019	29.616	31.845	6.845	67.149
25	25	30	5	49.050	30	5	49.050	27.779	2.779	27.262	31.49	6.49	63.667
25.5	25	29.7	4.7	46.107	29.662	4.662	45.734	27.552	2.552	25.035	31.123	6.123	60.067
26	25	29.395	4.395	43.115	29.322	4.322	42.399	27.332	2.332	22.877	30.74	5.74	56.309
26.5	25	29.083	4.083	40.054	28.976	3.976	39.005	27.118	2.118	20.778	30.341	5.341	52.395
27	25	28.756	3.756	36.846	28.619	3.619	35.502	26.906	1.906	18.698	29.917	4.917	48.236
27.5	25	28.401	3.401	33.364	28.241	3.241	31.794	26.689	1.689	16.569	29.452	4.452	43.674
28	25	28.01	3.01	29.528	27.835	2.835	27.811	26.463	1.463	14.352	28.937	3.937	38.622
28.5	25	27.609	2.609	25.594	27.425	2.425	23.789	26.24	1.24	12.164	28.408	3.408	33.432
29	25	27.122	2.122	20.817	26.946	1.946	19.090	25.987	0.987	9.682	27.766	2.766	27.134
29.5	25	26.32	1.32	12.949	26.197	1.197	11.743	25.603	0.603	5.915	26.718	1.718	16.854
30	25	25	0	0.000	25	0	0.000	25	0	0	25	0	0.000