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Application of Finite Element Technique: A Review Study

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Abstract

The finite element approach is used to solve a variety of difficulties, including well bore stability, fluid flow production and injection wells, mechanical issues and others. Geomechanics is a term that includes a number of important aspects in the petroleum industry, such as studying the changes that can be occur in oil reservoirs and geological structures, and providing a picture of oil well stability during drilling. The current review study concerned about the advancements in the application of the finite element method (FEM) in the geomechanical field over a course of century.

Firstly, the study presented the early advancements of this method by development the structural framework of stress, make numerical computer solution for 2D thermal stress then stress analysis of the airplane. The second part focused on the most recent developments of FEM, and this method generates new techniques for solving these problems, such as the 1D, 2D, and 3D finite element models; the dynamic program method (DPM); the finite discrete element method (FDEM); and the finite element extended method (FEXM). The third part of this study presented the reservoir finite element simulation used for injection well testing inside unconsolidated oil sand reservoirs. Also improvement of the FE software program for the analyses, finite element extended approach to convert a 3D fault model were introduced. In addition, the study explored the development of a 3D and 4D model utilizing Visage for FEM analysis for geomechanics investigations, and the software eclipse for pressure drop prediction in carbonate reservoir weak formation and presented the Finite-Element Smoothed Particle Method (FESPM).

Keywords: Finite element method, geomechanical model, finite discrete element method, dynamic program model.

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1- Introduction

Geomechanics is a branch of science that studies the relationship between geology and rock mechanical properties. In other words, it is concerned with the effects of stress on distort or failure of rocks caused by changes in stress direction, abnormal pressure, temperature, and fluid flow caused by production. Wellbore instability is one of the most complicated problems that can occur during the drilling process, increasing nonproductive time. As a result, the cost of drilling will rise, and geomechanical analysis will be required to reduce this high cost [1]. Areas with strong topographic pressure, such as shale layers, can lead to wellbore instability [2].

A numerical method, such as finite element methods (FEM), is required to solve this deformation. The term "finite element measurement" refers to a numerical model that can be used to identify problems and find solutions in several fields of study. Grid deformation, temperature change, phase flow, and magnetic current power are some of the most common locations of interest that are solved using the finite element method.

While the problems that could be solved using this method included a complex geomechanical model, the distribution of stress, and subsidence issues caused by pressure depletion in the reservoir rock, analysis type solutions were not allowed for these problems because the values at any point in the reservoir structure measurement using math terms were unknown [3]. To obtain a satisfactory solution for the issues mentioned, the FEM relied on a numerical calculation; this method will convert these issues into an arrangement stimulation algebraic formula, rather than using the differential formulation [3].

2- Early Development of FEM

In the 1940s, Alexander Paul Hrennikoff developed the field structural framework method for stress analysis and its application to two fields of elasticity, which is essentially an arithmetic procedure that can be applied to any problem involving a rectangular plate by the two-dimensional stress and strain situation in a bent plate. The most important aspect of the framework method is that it may be used to solve a wide range of insoluble elastic problems. This method is credited with laying the groundwork for the finite element method [4]. Douglas McHenry presented in 1943 a numerical computer solution for practically all problems involving 2D thermal stress, including material in the elastic area; this element is about sequential approximation, in which the rigor of the output was entirely determined by the amount of work done. The computer's resourcefulness in utilizing such expedient for solving those difficulties will play a key role in the method's successful practical use [5].

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In 1947, Levy enhanced the pliability or force approach using Castigliano's theory, as well as a stress analysis of the airplane construction based primarily on equilibrium conditions [6]. Following that, in 1953, he proposed a new computation termed the (stiffness method) as an alternative for determining stress and deformation in statistical analyses for aircraft structures. Poisson's ratio's function in creating anticlastic curvature has also been overlooked, despite the fact that the equations he creates are too difficult to answer by hand. When the Poisson ratio is ignored, a mistake could be made [7]. Turner et al. (1956) were the first to handle 2D elements. They were derived from the stiffness matrix for elements, as well as 2D triple and perpendicular finite elements for the stress effect into the plane, and these proceedings were summed up as the hardness method for determining the overall matrix for hardness structure. By incorporating improvements to the digit program into the turner's job, the speed of the software can be increased. Programs for performing such computations can be developed using the basic concepts provided in this study [8]. Gallagher began working on 3D problems in triangular and rectangular shapes in 1962, developing a complicated structure analysis approach for heating and elastically stress and strain deformation in structural components as show in Fig. 1 below. The accuracy of the data acquired thus far has been called into doubt. This can be improved by using rectangular pieces and just using tetrahedrons to denote irregular borders [9].

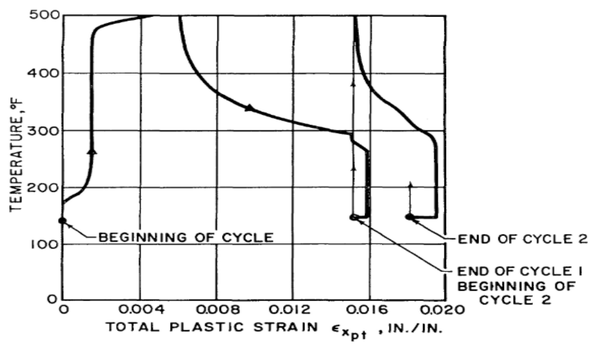

Fig. 1. Total Strain Vs Temperature [9]

By studying the matrix discrete-element stiffness to formulation of the linear system issues in mechanics of the engineering, Archer improved a strategy that may give proper or almost approximate solving for static stress-displacement, elastic constancy, and dynamic response problems in 1965. The techniques discussed for using the discrete-element impact method to handle the public static load, elastic stability, and deformation problems provide a considerable improvement in the capacity of this approach to provide accurate numerical solutions for the general analysis of structures [10]. In 1968, Zienkiewicz et al. presented the visco-elastic approach for stress and strain analysis, which involved employing models linked to a series and keeping a running total of strain for analysis with fixed or changing temperature properties, the fact that this formulation is a computer model that can be applied to deep well [11]. In 1970, Zienkiewicz and Parekh subediting in expression a finite element operation using curved and program for both 3D and 2D, isoparametric elements were a method that applied by using the time-step resolution, and their utility was explained through a number of transient field problems dealing with heat conduction problems. The two-dimensional software includes simple triangle as well as curved features. The three-dimensional software contains linear, parabolic, and cubic hexahedra based on elements. It will be seen that predefined boundary inflows are comparable to external loads and that the thermal transfer coefficient functions as an external stiffness associated with boundaries [12].

Ted Belytschko demonstrated a computational mechanism for overcoming difficulties related to large-displacement nonlinear dynamics for nuclear power reactors in 1976. Time integration methods are classified into two types: explicit and implicit. The time step must be small enough. This is the only limitation of these approaches. A wide range of reactor safety concerns can be addressed using the applications offered [13]. Lyness et al in 1977 applied the technique of the weighted residuals for measurement the magnetic field of the three-dimensional problem in heterogeneous source in expression of the unknown potential porosity and a known analytical solution. The scalar potential appears to be the most efficient approach for the analysis of nonhomogeneous three-dimensional issues, and it is expected that finite element and integral approaches will be merged in the future for practical work [14]. Table 1 listed a summary of early development.

3- Recent Advances

Improvements to the finite element method and its applications in geomechanical studies were first seen in 1995, when Jin-Zhang et al. demonstrated these native techniques for measuring shear strength in a curve while referring to the position of critical slip surface potential and the dynamic programming method (DPM) was improved. The results were obtained using a finite method-DPM for a curve that was in a state known as homogenous, and a typical finite element mechanism was used as a comparison approach to examine the bridge in flexible clay. The FEM– improved dynamic program method (DPM) does have the benefit of over-limit equilibrium methods in that it can represent the strain behavior of soil as well as the slope's stage development [15].

To estimate the change in the rock structure caused by pressure depletion in 2003, Wan et al. used a number of linked geomechanical models for reservoir fluid flow. These models will have employed a stabilized finite element technique to provide a solution for stress balancing and the equation of pressure. This approach can cause pressure oscillations in low-permeability zones or at very early stages [16]**.** In the same year, Onate and Rojek introduced the integration of two methods: element discrete method (EDM) blending with finite element method (FEM), which means that any geomechanical problems in a dynamic reservoir can be analyzed. Integration of those methods can be used for spherical 2D, also known as cylindrical 2D, the discretizing by immobile elements and the FEM can deal with the solid zoning. This enables us to apply the proposed formulation to situations involving substantial plastic deformation in the domain's continuum. Equipment in stone-cutting operations can be modeled using the discrete formulation [17].

Table 1. Summary of Early Development

No	Author	Name of study	Objective	year
1	Alexander Paul Hrennikoff.	Plane Stress and Bending of Plates by Method of Articulated Framework.	Development framework method of stress analysis .	1940
2	Douglas Mchen.	Lattice Analogy for the Solution of Stress Problem.	calculation numeral solution of nearly kind having troubles of 2D stress .	1943
3	SAMUEL levy.	Computation of Influence Coefficients for Aircraft Structures with Discontinuities and Sweepback.	show coefficients was outlined which uses Castigliano's theorem, together with a stress analysis of the airplane structure.	1947
4	Samuel levy.	Structural Analysis and Influence Coefficients for Delta Wings.	method is show for measurement the stresses and deformations in delta wings.	1953
5	Turner, clough, Martin, and Topp.	Stiffness and Deflection Analysis of Complex Structures.	method is developed for determined stiffness influence coefficients of complex shell-type structures.	1956
6	Richard H. Gallagher, Joseph padlog and P. P. Bijlaard.	Stress Analysis of Heated Complex Shapes.	New relationships are proposed for the analysis of solids.	1962
7	John S. Archer.	Consistent Matrix Formulations for Structural Analysis Using Finite-Element Techniques.	make a dynamic analysis by improved a technique that may be give correct or nearly approximate solving for static stress displacement, elastic constancy, and dynamic problem.	1965
8	Zienkiewicz, O. C., M. Watson, and I. P. King.	Numerical Method of Visco-Elastic Stress Analysis	introduced a vlsco-elastie method for stress and strain by using a models linked with a series and through keep a running total of strain.	1968
9	Zienkiewicz, O. C., and C.J. Parekh.	Transient Field Problems: Two-Dimensional and Three-Dimensional Analysis by Isoparametric Finite Elements.	Introduced finite element operation utilize program of curved for both 3D and 2D by using the time step resolution.	1970
10	Belytschko, Ted.	Survey of Numerical Methods and Computer Programs for Dynamic Structural Analysis.	Show a numerical mechanism for resolving problems that associated with large-displacement nonlinear dynamic.	1976
11	Zienkievicz , Lyness and D.R Owen	Three-Dimensional Magnetic Field Determination Using a Scalar Potential-A Finite Element Solution.	applied the technique of the weighted residuals for measurement in three-dimensional problem.	1977

In 2004, Hammah et. al. introduced a Stability Analysis for the Rock Using the Finite Element Method and examined the Finite Element Techniques (FET) analysis for the measurement of rock safety factors for which strength is modeled by the widely used Hoek-Brown failure criterion, the shear strength reduction (SSR) first outcomes will be used as a standard mechanism for FES slope of Mohr-Coulomb criteria. However, it might be able to include the SSR approach for general Hoek-Brown strength automatically into a FE computational engine, as there will be no necessity for explicitly determining factored general Hoek-Brown parameters in this case [18]. By combining an element agreement into another reservoir commercial stimulation, Liu and Han (2004) demonstrated finite element and finite different methods for stress distribution with a reservoir fluid model, resulting in a 3-D difference in elastic stress solving with fluid flow and pressure prediction. On larger situations, the results reveal that the accuracy of solving finite difference stress calculations is no better than finite element. It looks into using an iterative technique to produce a more fully connected solution for finite element stress estimation and reservoir simulation fluid flow [19]. When WONG used Galerkin's least square (GLS) mechanism to discretize the saturation equation in 2005, the finite element approach was continuous development in terms of the Geomechanics-Thermal Reservoir Simulator. The data show how the vertical displacements at the surface of the formation have altered through time as show in Fig. 2. Due to heat transmission and fluid flow, the surface heaves to a maximum value of strain [20].

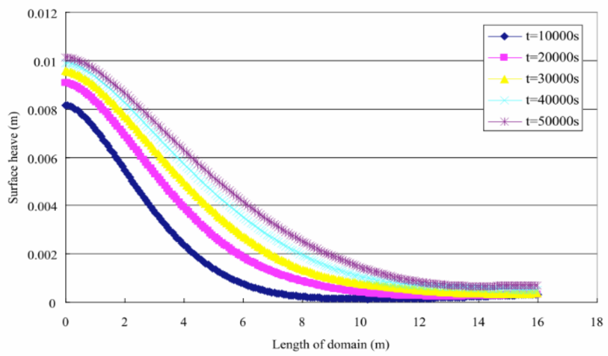

Fig. 2. Surface Displacement Results at Different Time [20]

Jha and Juanes (2006) also show a simulation framework calculation to the fluid flow with the geomechanics of reservoirs, where the theory of biot's for fluid flow in single phase regime with linear poroelasticity was the physical mean of this model, where the unknown variables are the pressure, fluid velocity, and rock displacement, and the unknown variables are space with time discretization of these equations. This study focused solely on single-phase linear poroelasticity. Clearly, this is insufficient for simulating and predicting many geomechanical processes in reservoirs and near-wells [21]. Another advancement for FIM occurred in 2008, when Maria Tchonkova et al. developed new porelasticity numerical solutions using mixed finite element formulated a new equation with four unknown classifications (change in space, stress, formation pressure, and speed) that were tested on 2D and 1D classic porelasticity problems. This research can also be viewed as a hybrid least-squares approach stabilization strategy. More test functions can be applied to stabilize the chosen regions of displacements and stresses (pressures and velocities) if they are still not consistent [22]. In 2009, Brice Lecampion introduced a new finite element extended technique (FEXM) for handling hydraulic fracture issues that took into consideration the presence of an internal pressure within the crack. The findings demonstrate how critical it is to compensate for the loss of division of unity inside the transition region between the enriched and the rest of a mesh. To get accurate results, a point-by-point matching approach appears to suffice. For good performance, a connection of the single addition to expressing by enrichment functions is often required [23]. In 2012, Mahabadi et. al. presented a new combined code element method called Y-Geo FDE or finite discrete element method (FDEM) for the application of geomechanical studies. Which was a design by innovative thinkers that used numerical technology to integrate the characteristics of continuous-model approaches with the method of DEM to overcome the disability of those methods to catch the cumulative damage with the failure that may occur in the rocks as show in Fig. 3 below [24]. Hamed et al. (2016) utilized the finite element method and the SICMA/W program to analyze the stress and displacement distribution around a tunnel that was open to the sea in Baghdad [25]. Table 2 show a summary of recent advances.

4- Reservoir Finite Element Techniques

The reservoir model typically does not account for changes in stress during production or injection, so a finite element method was designed to connect the two models. In 2013, Bin Xu and Wong demonstrated the importance of enhanced oil recovery when they used finite-element simulation for injection well testing inside unconsolidated oil sand reservoirs. Well tests such as transit bottom hole pressure data will allow us to determine reservoir flow properties, and the 3D element model is applied to history match the bottom hole pressure replay determined from oil sand zones by using injection wells. Plastic shearing and geometric deformations, rather than hydraulic fracture, are prevalent at the water injection rate used in this research [26]. Wang et.al. (2013) developed a large finite element method (LFEM) approach to expression meshing and interpolation mechanism (MIMSS) for soil rock in both dynamic and static states. Where this mechanism was introduced to the development calculation ability during the moving of the boundary conditions for both dynamic and static analyses. The results illustrate the utility of this technique in geomechanics for dealing with dynamic massive deformation situations. It creates a link that allows traditional geotechnical continuum finite element techniques to be applied to issues that were previously the domain of fluid mechanics [27]. Morillo et al. discussed the improvement of the FE software program for the analyses, building model, and stimulation calculation by connecting the fluid model and geomechanical model in 2014. The standard conditions were assumed to be homogeneity and isotropy in the rock, as well as the elastic action on the rock formation with little deformation, a nearly static balance, and the fracture. Vertical displacements reveal that the presented profiles from the software and those from the listed authors are quite similar as shown in Fig. 4 below, indicating that the program generally functions correctly with gravity activated. The spatial discretization generates a time-dependent differential equation that can be solved using the finite difference method [28].

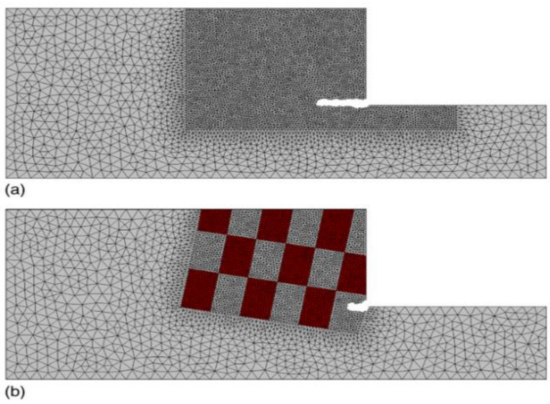

Fig. 3. Rock Failure for Two Model as Follows: (a) Homogeneous Model, (b) Blocky Model [24]

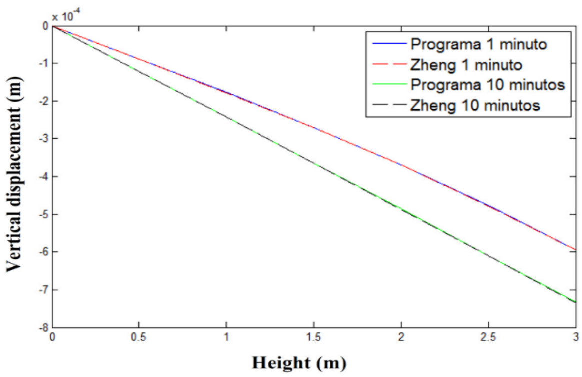

Fig. 4. Vertical Displacement of the Sample, Compared with the Zheng et al Solution, Time Intervals of 1 minute, and 10 minutes [28]

Table 2. Summary of Recent Advances

No	Author	Name of study	Objective	year
1	Zou, Jin-Zhang, David J. Williams, and Wen-Lin Xiong.	Search for Critical Slip Surfaces Based on Finite Element Method.	measurements the local shear strength using finite element method	1995
2	Wan, J., L. J. Durlofsky, T. J. R. Hughes, and K. Aziz.	Stabilized Finite Element Methods for Coupled Geomechanics - Reservoir Flow Simulations.	uses a number of coupled geomechanical models for reservoir fluid flow to determine the change happened in the rock structural.	2003
3	Onate, E., and J. Rojek.	Combination of Discrete Element and Finite Element Methods for Dynamic Analysis of Geomechanics Problems.	show combination of discrete element method (DEM) and finite element method (FEM) for dynamic analysis of geomechanics problems.	2003
4	Hammah, Reginald E., John H. Curran, T. E. Yacoub, and Brent Corkum.	Stability Analysis of Rock Slopes using the Finite Element Method.	Stability Analysis for the Rock using the Finite Element Method and checked the application of Finite Element techniques.	2004
5	Liu, Q., T. Stone, G. Han, R. Marsden, and G. Shaw.	Coupled Stress and Fluid Flow Using a Finite Element Method in a Commercial Reservoir Simulator.	showing a method for stress and reservoir fluid flow utilized an FEM in a communal reservoir software.	2004
6	Du, J., and R. C. K. Wong.	Development of a Coupled Geomechanics-Thermal Reservoir Simulator Using Finite Element Method.	Show a discussion on the development of a coupled geomechanics-thermal reservoir simulator using finite element method (FEM).	2005
7	Juanes, Ruben, and Birendra Jha.	A Locally Conservative Finite Element Framework for the Simulation of Coupled Flow and Reservoir Geomechanics.	show a simulation calculation formula to reservoir fluid flow and geomechanics..	2006
8	Tchonkova, Maria,John Peters, and Stein Sture.	A New Mixed Finite Element Method for Poro-elasticity.	New Development for the pore-elasticity numerical solutions by mixed the finite element formulated.	2008
9	Lecampion, Brice.	An extended Finite Element Method for Hydraulic Fracture Problems.	New finite element extended method was introduced by for the solving of hydraulic fracture problems.	2009
10	Mahabadi, Omid K., A. Lisjak, A. Munjiza, and GJIJoG Grasselli.	New Combined Finite-Discrete Element Numerical Code for Geomechanical Applications.	New combined code element method for application of the geomechanical studies .	2012
11	Abdullah, Hamed H., Ameer H. Al-Saffar, and Raed S. Jasim	Stresses and Displacements Analyses around Tunnel Opening Under Water Body Using Finite Element Method (FEM) in Baghdad City/Middle of Iraq.	Utilized the finite element method and the SICMA/W program to analyze the stress and displacement distribution.	2016

In several oil and gas fields, rock mechanical properties and analysis of in-situ stress and pore pressure are very important to study and understand the deformation that may be occurring inside the formation. In 2015, Kumar and Rima demonstrated that these rock properties can be determined using FEM and that the three major stresses can be predicted using a 2D stress model as shown above in Fig. 5. There is vertical stress (SV) gradients in the range of 21.00 to 22.85 MPa/km. Within typically pressured to over-pressured sediments, minimum horizontal principal stress (Sh) magnitudes range from 64 percent to 76 percent of SV, whereas maximum horizontal principal stress (SH) magnitudes range from 90 percent to 92 percent. The following methodology can be used to create geomechanical finite element models for a variety of reservoir types, including The finite element model's in situ stresses inside the inter-well space and undrilled areas of the reservoir are validated versus stress orientation [29].

At the same time, Jean and Sukumar use the finite element extended approach to convert a 3D fault model into a geomechanical reservoir model by considering hard solid displacement and pore pressure in a three-dimensional -mechanical model (FEXM). Using a Mohr-Coulomb type criterion in geomechanics, the fault is treated as an internal displacement discontinuity that allows slippage [30]. Nicola Castelletto et al, in 2016 suggestion that work with FEM for heterogeneous media can help for solved the problem of geomechanics in equilibrium state. A range of numerical experiments using synthetic or realistic geomechanical parameters are used to test the approach. The numerical findings show that the multiscale technique is capable of delivering precise results [31]. In 2017, Osman Hamid et al built a 3D and 4D model utilizing Visage for FEM analysis for geomechanics investigations and the software eclipse for pressure drop prediction in carbonate reservoir weak formation as shown in Fig. 6. The formation's compaction has an impact on not just the weaker rock, but rather the overburdened and the under burden. According to the models, permeability decreased by 18% as the formation was depleted. Such discoveries are critical for future improvement, particularly in difficult places where stress sensitivity is high [32]. In the same year, Yarlong Wang proposed a dual porosity model for two-phase fluid flow in fracture reservoirs. Using FEM to create a saturation formula with time and pressure, he discovered that the single porosity model may be used for two-phase flow. The impact of two-phase flow on the geomechanics aspect of difficulties will be the focus of future studies, which will focus on the saturation change on pore pressure and effective stresses. Alternatively, the skeletal deformation as a function of saturation change will be fascinating [33].

For the purpose of determining the stability of a wellbore, Bharatsai created a muster case study in 2017, for which a geomechanical model was built to discuss these issues and determine the modification and changes of the reservoir's geomechanical properties, as well as to measure the magnitude and direction of in-situ stresses. After that, he created a 3-D finite geomechanical model that included the formation's elastic anisotropy. Due to a larger Young's Modulus value for Middle Bakken sandstone, the stress change caused by the thermal effect on drilling fluid on the borehole wall is greater for the Middle Bakken Formation than for the Upper and Lower Bakken Formations [34]. Babak et al. (2018) used the 3D finite element method to create an optimized confirm the meshing system for the well hole stability study. Modeling the state of stresses surrounding the wellbore as shown in Fig. 7 with this meshing technique yielded satisfactory agreement with drilling data in both FEM approaches. Analytical estimates As early warning signs of wellbore instability & breakdown, radial strain, and displacement measurements are presented [35]. In 2018, Wei Zhang et al. presented the Finite-Element Smoothed Particle Method (FESPM), which is utilized to solve large-scale issues in geomechanics. They discovered that the FESPM has advantages over the original PFEM in that the entire field variables are determined via recurrent information transit between the particles and the points of Gaussian distribution, which eliminates any errors or added difficulty to the solution technique. The FESPM has been proven to be a promising numerical method for studying big problems in geomechanics [36].

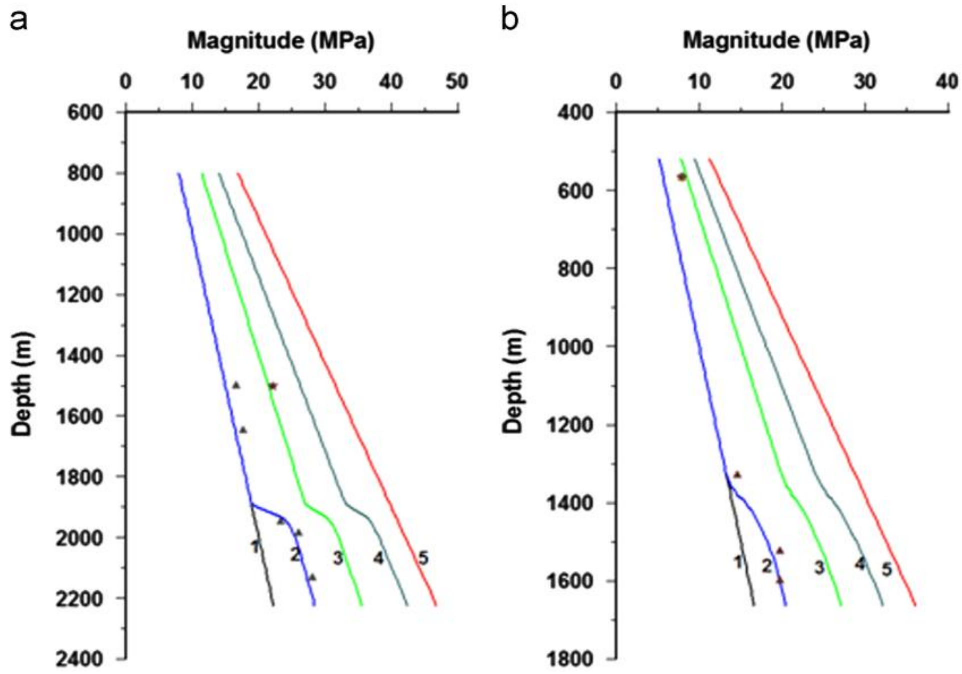

Fig. 5. Ground Stress Rates for (a) Well KG, (b) Well KS. Profiles of Earth Stress for (a) Well KG and (b) Well KS. Hydrostatic Pressure, High Pore Pressure, Minimum Horizontal Stress, Fracture Pressure, and Vertical Stress Are Indicated by Lines 1, 2, 3, 4, and 5. The Leak-off Test (LOT) and RFT Pressure Levels Are Represented by the Star and Triangle Symbols [29]

Jun et al. published a paper in 2019 that focuses on the construction of bridges. The finite element technique models fault deformation and fluid flow inside the reservoir during the flow cycle. In this study, the finite element method is used to assess flow back around hydraulic fractures in complex fracture networks, taking into consideration the combined impacts of flow and geomechanics. Because of the linked effects, the complex fracture networks in unusual reservoirs and physical characteristics impacts on diverse reservoir porosity and permeability are considerably minimized [37]. In 2020, Feizi Masouleh Used a finite element model, and coupled processes involving matrix deformation and fluid flow were studied. The reservoir's stress varies as a result of production from a propped open fracture. The stress change, on the other hand, is anisotropic. This shift in stress occurs near the horizontal well that is generating it. The novel numerical poroelastic solution allows for more realistic estimations of stress & pore pressure distribution near fractures, enabling the creation of better products [38]. Chen et al, in 2021 overcome the problem of continuous grid corner points and calculation failure, a finite volume approach one-way coupling model implemented in the C++ programming language has been developed to compute the distribution of the subsurface stress field. The findings show that a finite method is a viable tool for thermal, hydraulic, and mechanical simulation [39]. Danesh et al, 2022 used the finite element method to simulate a 2D natural gas couple model and found that the subsidence was greater at the start of production and subsequently declined and that as production increased, the subsidence rate also increased

[40]. In the same year, Yingli Xia et al. used a finite element model to combine (water/gas) with a geomechanical model and discovered that the shear stress grew during production, producing sand migration and an increase in vertical subsidence. When the ratios of permeable anisotropy were raised, the max subsidence increased by around 81 percent [41]. Yuyang Liu et al. proposed a method for calculating effective stress in low Permeability (K) reservoirs by combining the mechanical and flow models in 2022. The results show that by using 3D geological models paired with various numerical approaches, the proposed methods may be utilized to create the effective stress (σ_e) and pore pressure fields in a reservoir and then forecast the σ_e value in the reservoir [42]. When some researchers utilize this technology, it begins to be employed in the oil fields of Iraq. In the Rumelia oil field, Amani et al. developed in 2021 an experimental and numerical approach for determining hydrodynamic fracture and non-fracture for two core. When combined with the ANSYS finite element program for pressure and velocity distribution, the dual porosity and permeability approach utilized by Amani increased productivity for the Rumelia core by roughly 10% [43]. In order to determine the vertical and horizontal stress distribution in the depletion reservoir, Raed and Al-jawad presented a four-dimensional finite element model in 2022. The findings indicate that the mud window will be affected by the change in stress during production, and the maximum horizontal stress reduction was 322 psi [44]. Table 3 listed a summary of reservoir finite element.

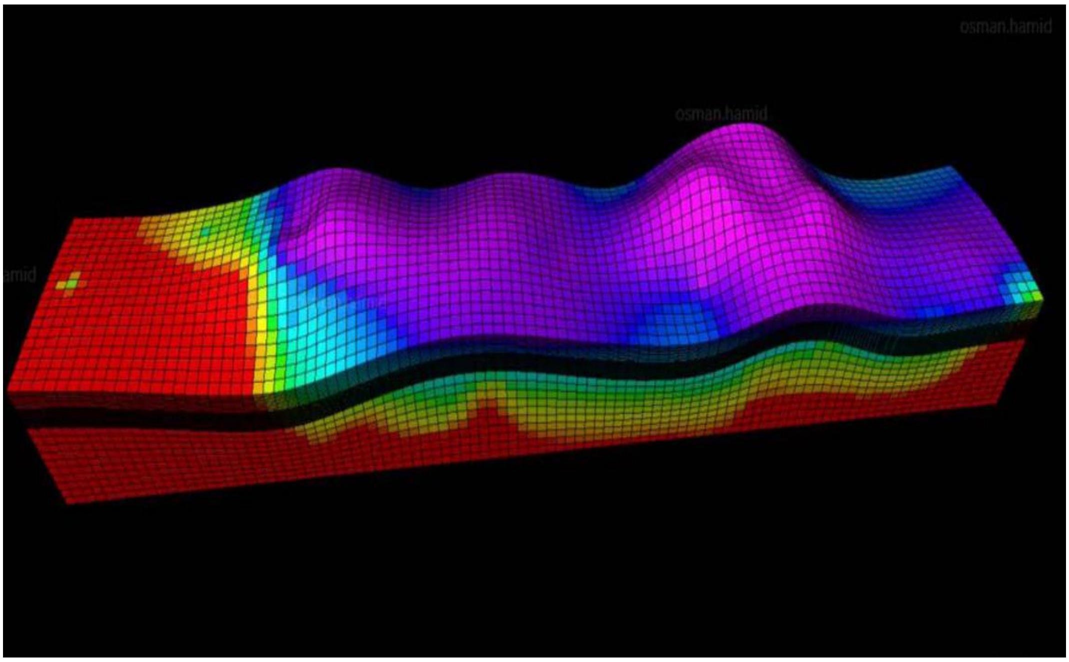

Fig. 6. Pore Pressure Depletion during the Time [32]

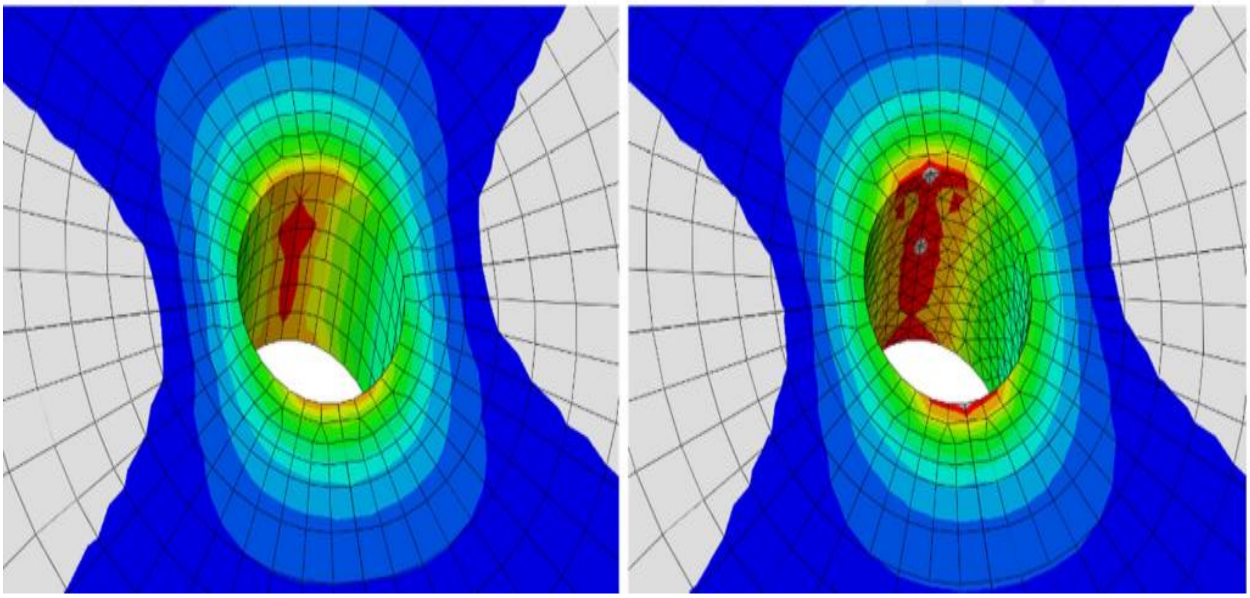

Fig. 7. Von Misses Stress around Wellbore [35]

Table 3. Summary of Reservoir Finite Element

No	Author	Name of study	Objective	year
1	Bin Xu and Ron C.K. Wong	Coupled finite-element simulation of injection well testing in unconsolidated oil sands reservoir	using FEM stimulation for well injected inside reservoir unconsolidated oil sand.	2013
2	D. Wang, M.F. Randolph, D.J. White	A dynamic large deformation finite element method based on mesh regeneration	improve the computational capacity of both static and dynamic analyses that include moving boundaries.	2013
3	A. Morillo, et al.	Development of a Finite Element Computer Simulation Platform for a Cou- pled Reservoir and Geomechanics System	the improvement for FEM software program for the modeling, analysis, and simulation.	2014
4	Dip Kumar Singha and Rima Chatterjee	Geomechanical modeling using finite element method for prediction of in-situ stress in Krishna–Godavari basin, India	determined these rock properties and prediction the three import stress by using 2D stress model.	2015
5	Jean H. Prévost and N. Sukumar	Faults simulations for three-dimensional reservoir-geomechanical models with the extended finite element method	make 3D faults model for reservoir-geomechanical by consider hard solid displacement and pore pressure in a three-dimensional mechanical mode.	2015
6	Nicola Castelletto , Hadi Hajibeygi and Hamdi A. Tchelepi	Multiscale finite-element method for linear elastic geomechanics	suggestion formula work for solve geomechanical troubles in equilibrium state.	2016
7	Hamid, Osman, Ahmed Omair, and Pablo Guizada.	Reservoir Geomechanics in Carbonates	building a 3D and 4D model using the finite element method for geomechanical studies and the fluid flow simulator Eclipse.	2017
8	Yarlong Wang	Two Phase Flow Coupled to Geomechanics with Dual Porosity Model: Simulating Fractured Reservoirs by Finite Element Method	introduced dual porosity model for two phase fluid flow in fracture reservoir using finite method	2017
9	Bharatsai Alla	Wellbore Stability Analysis of Sanish Field using 3-D Finite Element Model: Bakken Case Study	Geomechanical model was built to discuss problems and to determine the modification and changes of the Geomechanical properties	2017
10	Babak Ravaji, Sohrab Mashadizade and Abdolnabi Hashemi	Introducing optimized validated meshing system for wellbore stability analysis using 3D finite element method	build an optimized confirm meshing system for the wellbore constancy analysis using 3D finite element method	2018
11	Wei Zhang ; Weihai Yuan and Beibing Dai	Smoothed Particle Finite-Element Method for Large-Deformation Problems in Geomechanics.	show techniques called Finite-Element Smoothed Particle Method	2018
12	Jun et al.	Flow back Analysis of Complex Fracture Networks in the Unconventional Reservoir Using Finite Element Method with Coupled Flow and Geomechanics.	Finite element method is used to assess flow back around hydraulic fractures in complex fracture networks	2019
13	Feizi Masouleh	Geomechanical modeling of reservoir using finite element method.	Used a finite element model, and coupled processes involving matrix deformation and fluid flow	2020
14	Chen et al.	Application of the finite volume method for geomechanics calculation and analysis on temperature dependent poromechanical stress and displacement fields in enhanced geothermal system.	Finite volume approach one-way coupling model implemented in the C++ programming language has been developed to compute the distribution of the subsurface stress field	2021
15	Danesh et al.	Prediction of interactive effects of CBM production, faulting stress regime, and fault in coal reservoir: Numerical simulation.	Used the finite element method to simulate a 2D natural gas couple model and found that the subsidence.	2022
16	Yingli Xia et al.	Geomechanical Response Induced by Multiphase (Gas/Water) Flow in the Mallik Hydrate Reservoir of Canada.	used a finite element model to combine (water/gas) with a geomechanical model.	2022
17	Yuyang Liu et al.	An Approach for Predicting the Effective Stress Field in Low-Permeability Reservoirs Based on Reservoir-Geomechanics Coupling.	calculating effective stress in Low-K reservoirs by combining the mechanical and flow models.	2022
18	Majeed, Amani J., Ahmed Al-Mukhtar, Falah A. Abood, and Ahmed K. Alshara	Numerical study of the natural fracture using dual porosity-dual permeability model for Rumaila Field, southern Iraq.	experimental and numerical approach for determining hydrodynamic fracture and non-fracture for two core. When combined with the ANSYS finite element program for pressure and velocity distribution.	2021
19	Allawi, Raed H., and Mohammed S. Al-Jawad.	4D Finite element modeling of stress distribution in depleted reservoir of south Iraq oilfield.	presented a four-dimensional finite element model.	2022

5- Conclusion

The objective of this study was to provide some background information on the FEM's history and a summary of its current engineering problem-solving abilities. It is crucial to remember that the method's initial development was fully focused on how to generate equations for the approach, use them in practical applications, calculate the stresses of aircraft, and utilize them in computer programs. The method was developed to encompass solving any engineering problem; it was used to calculate stresses in geomechanical investigations and to generate 1D, 2D, and 3D models as well as to determine how fluid flow affected reservoir pressure and how those changes affected on stresses.

Presently, modern technology allows for the discretization and division of almost anything into finite elements, whether it be a solid, liquid, or gas by creating 3D and 4D models to connect the geomechanical and reservoir models. Therefore, it is imperative that all nations realize that the effective application of the Finite Element Method is their most important tool for development.

The history of the finite element method, the utility of employing this method, and the problems that can be solved using FEM are all covered in this study. These formulated equations are required by the oil and gas business in order to make changes to problems that may arise in the future. In a word, the finite element method is the way of the future; it has a lot of power, which we will hopefully realize in the following years.

Abbreviations

Acronym	Definition
1D	One-Dimensional
2D	Two- Dimensional
3D	Three- Dimensional
FEM	Finite Element Methods
DPM	Dynamic Program Method
FDEM	Finite Discrete Element Method
FEXM	Finite Element Extended Method
EDM	Element Discrete Method
SFEM	Stabilized Finite Element Methods
FIC	Finite Calculus
SSR	Shear Strength Reduction
FET	Finite Element Techniques
FES	Finite Element Slop
GLS	Galerkin's Least Square
BHP	Bottom Hole Pressure
LFEM	Large Finite Element Method
MIMSS	Meshing and Interpolation Mechanism Small Strain
FECS	Finite Element Computer Simulation
FESPM	Finite-Element Smoothed Particle Method
σ_e	Effective stress

References

[1] Shaban Dharb, and Hassan Abdul Hadi, "Geomechanical Analysis to Avoid Serious Drilling Hazards in Zubair Oilfield, Southern Iraq," In Iraqi Journal of Science ,2020, pp.1994-2003, https://doi.org/10.24996/ijs.2020.61.8.16.

[2] Saleh, Talib A, "Using Sonic Log to Predict Abnormal Pressure Zones in Selected Oil Wells (Western of Iraq)," Iraqi Journal of Chemical and Petroleum Engineering, vol. 15, no. 2 ,2014, pp. 9-14.

[3] Logan, Daryl L," A first course in the finite element method," 6nd ed., Cengage Learning. Canada, 2016.

[4] Hrennikoff, Alexander Paul, "Plane stress and bending of plates by method of articulated framework," PhD diss., Massachusetts Institute of Technology, 1940.

[5] McHenry, Douglas, "A LATTICE ANALOGY FOR THE SOLUTION OF STRESS PROBLEMS," In Journal of the Institution of Civil Engineers, Vol. 21, 1943, pp. 59-82, https://doi.org/10.1680/ijoti.1943.13967.

[6] Levy, Samuel, "Computation of influence coefficients for aircraft structures with discontinuities and sweepback," In Journal of the aeronautical Sciences, Vol.14, 1947, pp. 547-560, https://doi.org/10.2514/8.1454.

[7] Levy, Samuel, "Structural analysis and influence coefficients for delta wings," In Journal of the Aeronautical Sciences, Vol. 20, 1953, pp. 449-454, https://doi.org/10.2514/8.2690.

[8] Turner, M. Jon, Ray W. Clough, Harold C. Martin, and L. J. Topp, "Stiffness and deflection analysis of complex structures," In Journal of the Aeronautical Sciences, Vol.23, 1956, pp.805-823, https://doi.org/10.2514/8.3664.

[9] Gallagher, Richard H., Joseph padlog, and P. P. Bijlaard, "Stress analysis of heated complex shapes," In ARS Journal, Vol.32, 1962, pp.700-707, https://doi.org/10.2514/8.6128.

[10] Archer, John S, "Consistent matrix formulations for structural analysis using finite-element techniques," In AIAA journal, Vol. 3,1965, pp.1910-1918, https://doi.org/10.2514/3.3279.

[11] Zienkiewicz, O. C., M. Watson, and I. P. King, "A numerical method of visco-elastic stress analysis," International Journal of Mechanical Sciences, Vol.10, 1968, pp.807-827, https://doi.org/10.1016/0020-7403(68)90022-2.

[12] Zienkiewicz, O. C., and C.J. Parekh, "Transient field problems: two-dimensional and three-dimensional analysis by isoparametric finite elements," In International Journal for Numerical Methods in Engineering, Vol. 2,1970, pp. 61-71, https://doi.org/10.1002/nme.1620020107.

[13] Belytschko, Ted, "A survey of numerical methods and computer programs for dynamic structural analysis," In Nuclear Engineering and Design, Vol.37, 1976, pp.23-34, https://doi.org/10.1016/0029-5493(76)90050-9.

[14] Zienkiewicz, O., John Lyness, and D. J. R. D. J. R. Owen, "Three-dimensional magnetic field determination using a scalar potential--A finite element solution," In IEEE Transactions on Magnetics, Vol.13, 1977, pp.1649-1656, https://10.1109/TMAG.1977.1059650.

[15] Zou, Jin-Zhang, David J. Williams, and Wen-Lin Xiong, "Search for critical slip surfaces based on finite element method," In Canadian Geotechnical Journal, Vol.32, 1995, pp.233-246, https://doi.org/10.1139/t95-026.

[16] Wan, J., L. J. Durlofsky, T. J. R. Hughes, and K. Aziz, "Stabilized finite element methods for coupled geomechanics-reservoir flow simulations," In SPE Reservoir Simulation Symposium. One Petro, 2003, https://doi.org/10.2118/79694-MS.

[17] Onate, E., and J. Rojek, "Combination of discrete element and finite element methods for dynamic analysis of geomechanics problems," In Computer methods in applied mechanics and engineering, Vol. 193, 2004, pp.3087-3128, https://doi.org/10.1016/j.cma.2003.12.056.

[18] Hammah, Reginald E., John H. Curran, T. E. Yacoub, and Brent Corkum, "Stability analysis of rock slopes using the finite element method," In Proceedings of the ISRM regional symposium EUROCK. 2004.

[19] Liu, Q., T. Stone, G. Han, R. Marsden, and G. Shaw, "Coupled stress and fluid flow using a finite element method in a commercial reservoir simulator," In SPE Asia Pacific Oil and Gas Conference and Exhibition. One Petro, 2004, https://doi.org/10.2118/88616-MS.

[20] Du, J., and R. C. K. Wong, "Development of a coupled geomechanics-thermal reservoir simulator using finite element method," In Canadian International Petroleum Conference. One Petro, 2005, https://doi.org/10.2118/2005-027.

[21] Juanes, Ruben, and Birendra Jha, "A locally conservative finite element framework for the simulation of coupled flow and reservoir geomechanics," In SPE Annual Technical Conference and Exhibition. One Petro, 2006, https://doi.org/10.2118/102812-MS.

[22] Tchonkova, Maria, John Peters, and Stein Sture, "A new mixed finite element method for poro-elasticity," In International journal for numerical and analytical methods in geomechanics, Vol. 32, 2008, pp.579-606, https://doi.org/10.1002/nag.630.

[23] Lecampion, Brice, "An extended finite element method for hydraulic fracture problems," In Communications in Numerical Methods in Engineering, Vol. 25, 2009, pp.121-133, https://doi.org/10.1002/cnm.1111.

[24] Mahabadi, Omid K., A. Lisjak, A. Munjiza, and GJIJoG Grasselli, "Y-Geo: new combined finite-discrete element numerical code for geomechanical applications," In International Journal of Geomechanics, Vol. 12, 2012, pp.676-688, http://dx.doi.org/10.1061/(ASCE)GM.1943-5622.0000216.

[25] Abdullah, Hamed H., Ameer H. Al-Saffar, and Raed S. Jasim, "Stresses and Displacements Analyses around Tunnel Opening Under Water Body Using Finite Element Method (FEM) in Baghdad City/Middle of Iraq," Iraqi Journal of Science, vol. 57, 2016, pp.1267-1279.

[26] Xu, Bin, and Ron CK Wong, "Coupled finite-element simulation of injection well testing in unconsolidated oil sands reservoir," In International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 37, 2013, pp.3131-3149, https://doi.org/10.1002/nag.2182.

[27] Wang, Dong, M. F. Randolph, and D. J. White, "A dynamic large deformation finite element method based on mesh regeneration," In Computers and Geotechnics, Vol.54, 2013, pp.192-201, https://doi.org/10.1016/j.compgeo.2013.07.005.

[28] Morillo, Atilio, José Moreno, Robert Quintero, M. Gambús, Orlando Zambrano, V. Marcano, J. Araque et al, "Development of a finite element computer simulation platform for a coupled reservoir and geomechanics system," In SPE Latin America and Caribbean Petroleum Engineering Conference. One Petro, 2014, https://doi.org/10.2118/169431-MS.

[29] Singha, Dip Kumar, and Rima Chatterjee, "Geomechanical modeling using finite element method for prediction of in-situ stress in Krishna–Godavari basin, India," In International Journal of Rock Mechanics and Mining Sciences, Vol. 73, 2015, pp.15-27, https://doi.org/10.1016/j.ijrmms.2014.10.003.

[30] Prevost, Jean H., and N. Sukumar, "Faults simulations for three-dimensional reservoir-geomechanical models with the extended finite element method," In Journal of the Mechanics and Physics of Solids, Vol. 86, 2016, pp.1-18, https://doi.org/10.1016/j.jmps.2015.09.014.

[31] Castelletto, Nicola, Hadi Hajibeygi, and Hamdi A. Tchelepi, "Multiscale finite-element method for linear elastic geomechanics," In Journal of Computational Physics, Vol.331, 2017, pp.337-356, https://doi.org/10.1016/j.jcp.2016.11.044.

[32] Hamid, Osman, Ahmed Omair, and Pablo Guizada, "Reservoir geomechanics in carbonates," In SPE Middle East Oil & Gas Show and Conference. One Petro, 2017, https://doi.org/10.2118/183704-MS.

[33] Wang, Yarlong, "Two phase flow coupled to geomechanics with dual porosity model: simulating fractured reservoirs by finite element method," In SPE Reservoir Characterisation and Simulation Conference and Exhibition. One Petro, 2017, https://doi.org/10.2118/186067-MS.

[34] Alla, Bharatsai, “Wellbore Stability Analysis of Sanish Field using 3-D Finite Element Model: Bakken Case Study,” In University of Louisiana at Lafayette, 2017.

[35] Ravaji, Babak, Sohrab Mashadizade, and Abdolnabi Hashemi, "Introducing optimized validated meshing system for wellbore stability analysis using 3D finite element method," In Journal of Natural Gas Science and Engineering, Vol. 53, 2018, pp.74-82, https://doi.org/10.1016/j.jngse.2018.02.031.
[36] Wei, Zhang, Yuan Weihai, and Dai Beibing, "Smoothed Particle Finite-Element Method for Large-Deformation Problems in Geomechanics," In American Society of Civil Engineers, 2018, https://doi.org/10.1061/(ASCE)GM.1943-5622.0001079.
[37] Li, Jun, Yuetian Liu, Liang Xue, Ziyan Cheng, Xiangming Kong, and Songqi Li, "Flow back Analysis of Complex Fracture Networks in the Unconventional Reservoir Using Finite Element Method with Coupled Flow and Geomechanics," In Abu Dhabi International Petroleum Exhibition & Conference. One Petro, 2019, https://doi.org/10.2118/197372-MS.
[38] Feizi Masouleh, Shahla, "Geomechanical modeling of reservoir using finite element method," In 2020.
[39] Chen, Peipei, Jiang Sun, Chunyang Lin, and Wei Zhou, "Application of the finite volume method for geomechanics calculation and analysis on temperature dependent poromechanical stress and displacement fields in enhanced geothermal system," In Geothermics, Vol.95, 2021, pp.102138.2021, https://doi.org/10.1016/j.geothermics.2021.102138.
[40] Danesh, Nima Noraei, Yixin Zhao, Teng Teng, and Mohsen S. Masoudian, "Prediction of interactive effects of CBM production, faulting stress regime, and fault in coal reservoir: Numerical simulation," In Journal of Natural Gas Science and Engineering, Vol.104419,2022, https://doi.org/10.1016/j.jngse.2022.104419.
[41] Xia, Yingli, Tianfu Xu, Yilong Yuan, Xin Xin, and Huixing Zhu, "Geomechanical Response Induced by Multiphase (Gas/Water) Flow in the Mallik Hydrate Reservoir of Canada," In SPE Journal, Vol. 27, 2022, pp.434-451, https://doi.org/10.2118/206746-PA.
[42] Liu, Yuyang, Xiaowei Zhang, Wei Guo, Lixia Kang, Rongze Yu, and Yuping Sun, "An Approach for Predicting the Effective Stress Field in Low-Permeability Reservoirs Based on Reservoir-Geomechanics Coupling," In Processes, Vol.10, 2022, pp.633.2022, https://doi.org/10.3390/pr10040633.
[43] Majeed, Amani J., Ahmed Al-Mukhtar, Falah A. Abood, and Ahmed K. Alshara, "Numerical study of the natural fracture using dual porosity-dual permeability model for Rumaila Field, southern Iraq," Arabian Journal of Geosciences, vol. 14, 2021, pp.1-9, https://doi.org/10.1007/s12517-021-08229-2.
[44] Allawi, Raed H., and Mohammed S. Al-Jawad, "4D Finite element modeling of stress distribution in depleted reservoir of south Iraq oilfield," Journal of Petroleum Exploration and Production Technology, vol. 12, 2022, pp. 679-700, https://doi.org/10.1007/s13202-021-01329-5.

تطبيقات تقنية العناصر المحدودة: بحث مراجعة

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الخلاصة

يتم استخدام نهج العناصر المحدودة لحل مجموعة متنوعة من الصعوبات، بما في ذلك استقرار تجويف البئر، وإنتاج تدفق السوائل وآبار الحقن، والمشكلات الميكانيكية، والهندسة المدنية، والعلاج الطبي، من بين أمور أخرى. الميكانيكا الجيولوجية مصطلح يشمل عددًا من الجوانب المهمة في صناعة البترول، مثل دراسة التغيرات التي يمكن أن تحدث في مكامن النفط والهياكل الجيولوجية وتقديم صورة لاستقرار آبار النفط أثناء الحفر. سيكون هذا البحث دراسة مراجعة تعنى بالتطورات في تطبيق طريقة العناصر المحدودة FEM في المجال الجيوميكانيكي على مدار قرن من الزمان.

كان أول شيء في هذه الدراسة هو تقديم التطورات المبكرة لهذه الطريقة من خلال تطوير الإطار الهيكلي للضغط، وعمل حل كمبيوتر رقمي للإجهاد الحراري ثنائي الأبعاد ثم تحليل الإجهاد للطائرة. الجزء الثاني كان يقدم أحدث التطورات في FEM وهذه الطريقة تولد تقنيات جديدة لحل هذه المشاكل، مثل نماذج العناصر المحدودة احادي وثنائي وثلاثي الابعاد، طريقة البرنامج الديناميكي DPM؛ طريقة العناصر المحدودة المنفصلة FDEM؛ وطريقة العناصر المحدودة الممتدة FEXM. تم تقديم الجزء الثالث من هذه الدراسة لمحاكاة عنصر الخزان المحدود المستخدم في اختبار بئر الحقن داخل خزانات النفط غير المجمعة، وتحسين برنامج FE للتحليلات، ونهج ممتد للعناصر المحدودة لتحويل نموذج ثلاثي الأبعاد، وبناء نموذج ثلاثي الأبعاد ونموذج رباعي الأبعاد باستخدام Visage لتحليل FEM لتحقيقات الجيوميكانيكا وبرنامج eclipse للتنبؤ بانخفاض الضغط في التكوين الضعيف لخزان الكربونات وعرض طريقة الجسيمات المتناهية للعنصر المتناهي FESPM. طريقة العناصر المحدودة سوف تتألق في المستقبل، وتطبيقاتها في مجموعة متنوعة من العلوم الهندسية، لا سيما في مشاكل صناعة البترول والهندسة المدنية والجيولوجية، ستصل إلى قوتها تمامًا.

الكلمات الدالة: طريقة العناصر المحدودة، موديل جيوميكانيكي، طريقة العناصر المنفصلة المحدودة، نموذج برنامج ديناميكي.