US 20250258976A1

(19) United States
(12) Patent Application Publication
Bokhamsin et al.
(10) Pub. No.: US 2025/0258976 A1
(43) Pub. Date: Aug. 14, 2025

(54) DESIGNING VARIABLE STRENGTH WELL CASINGS

(71) Applicant: **Saudi Arabian Oil Company**, Dhahran (SA)

(72) Inventors: **Nada M. Bokhamsin**, Dammam (SA); **Sara Almulhim**, Dhahran (SA); **Moath I. Gazlan**, Khobar (SA); **Omar A. Dajani**, Al Khobar (SA); **Denis Sabitov**, Moscow (RU); **Hussain AlBahrani**, Qatif (SA)

(21) Appl. No.: **18/436,847**

(22) Filed: **Feb. 8, 2024**

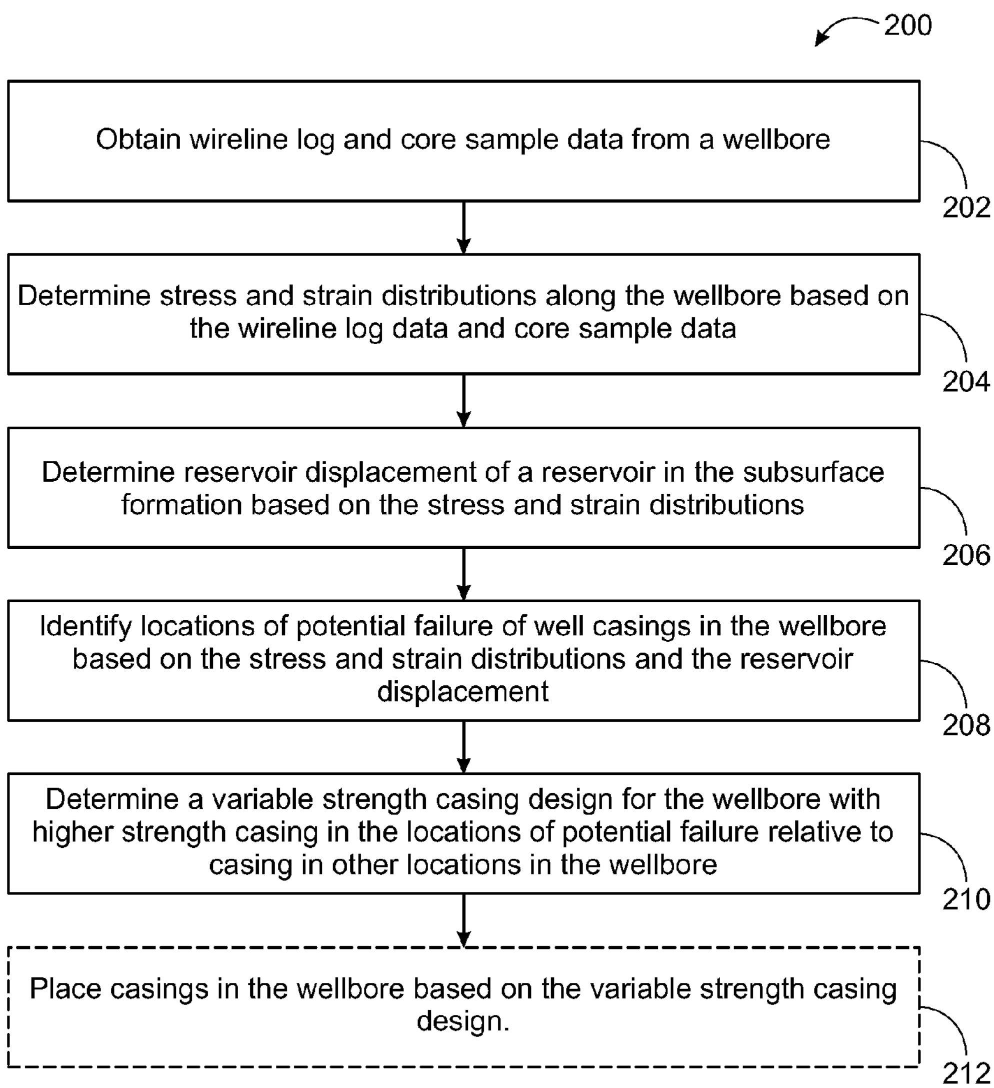
Publication Classification

(51) **Int. Cl.**
G06F 30/23 (2020.01)
G06F 30/17 (2020.01)
G06F 119/02 (2020.01)
G06F 119/14 (2020.01)

(52) **U.S. Cl.**
CPC ***G06F 30/23*** (2020.01); ***G06F 30/17*** (2020.01); *G06F 2119/02* (2020.01); *G06F 2119/14* (2020.01)

(57) **ABSTRACT**

Systems and methods for designing variable strength casings for a wellbore in a subsurface formation include obtaining wireline log data and core sample data from the wellbore; determining stress and strain distributions along the wellbore based on the wireline log data and core sample data; determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions. Locations of potential failure of well casings in the wellbore are identified based on the stress and strain distributions and the reservoir displacement; and a variable strength casing design for the wellbore is determined with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.



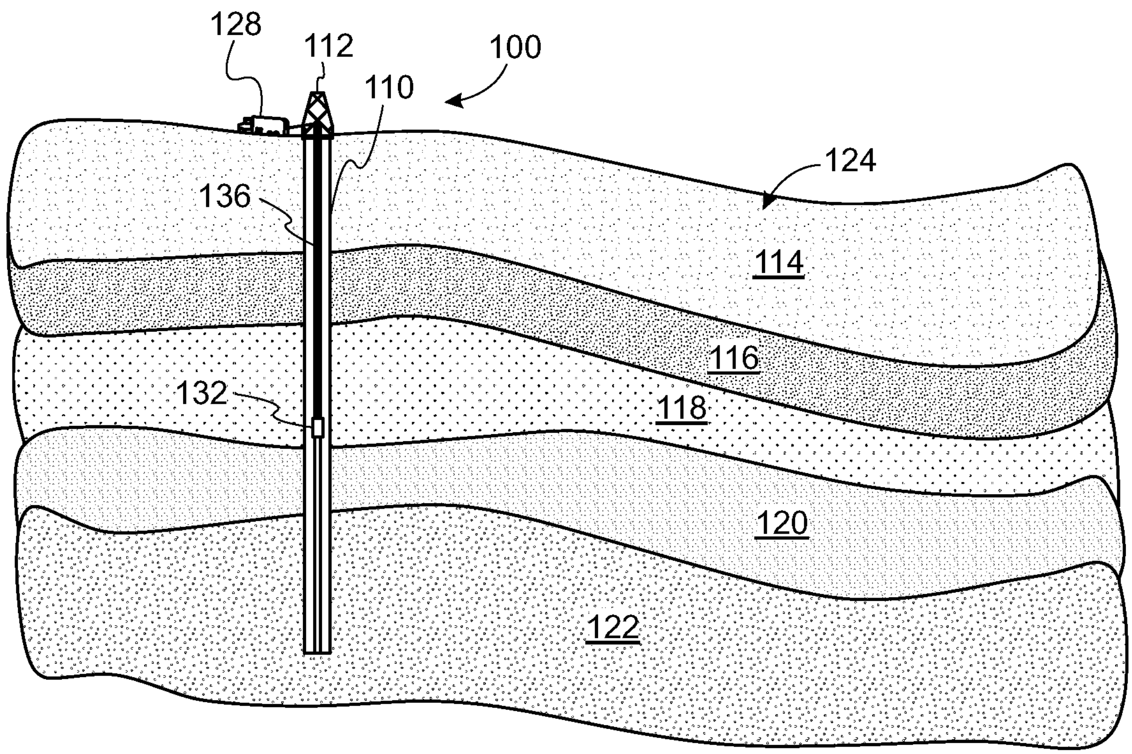


FIG. 1

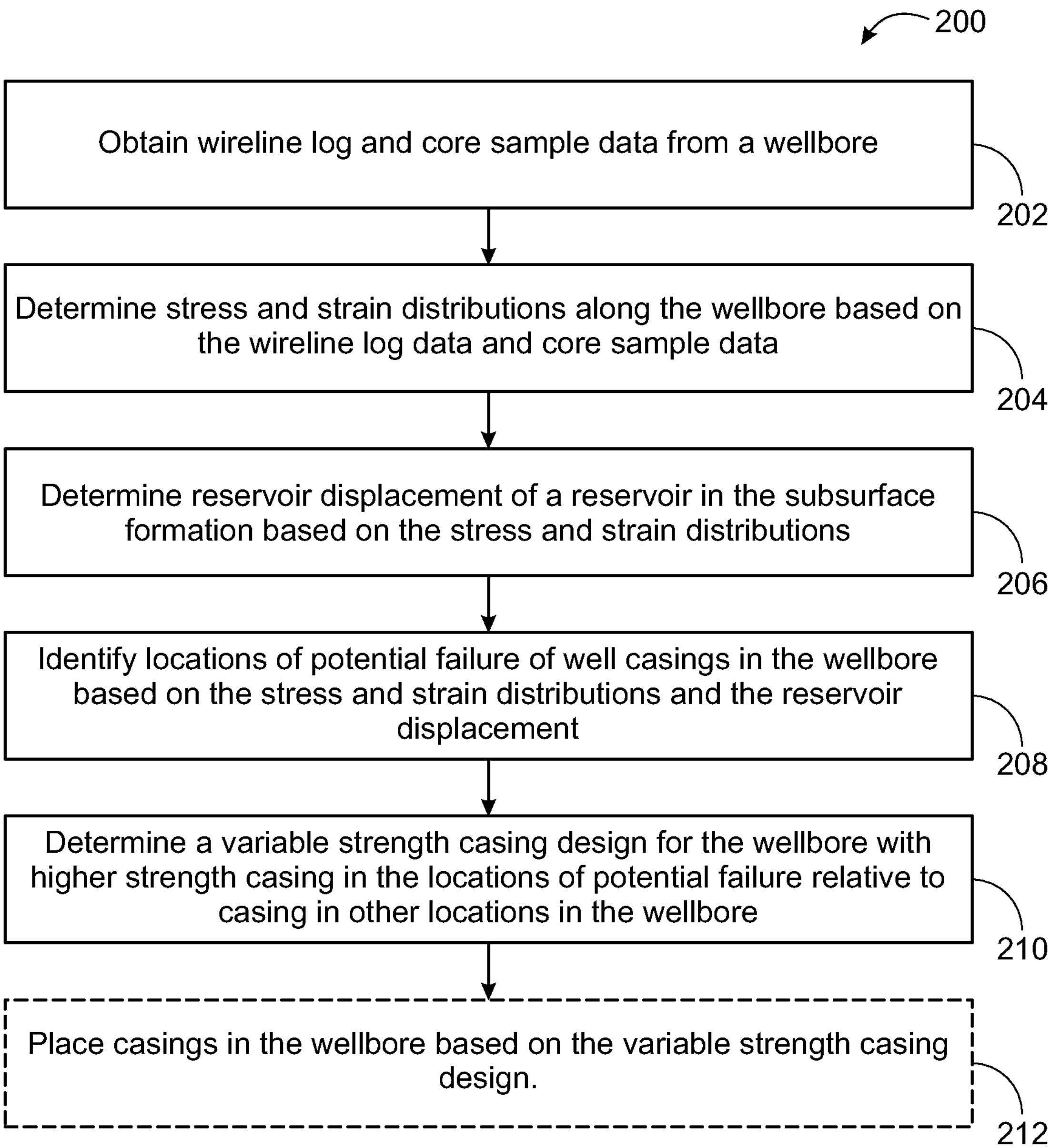

200
Obtain wireline log and core sample data from a wellbore
202
Determine stress and strain distributions along the wellbore based on the wireline log data and core sample data
204
Determine reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions
206
Identify locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement
208
Determine a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore
210
Place casings in the wellbore based on the variable strength casing design.
212

FIG. 2

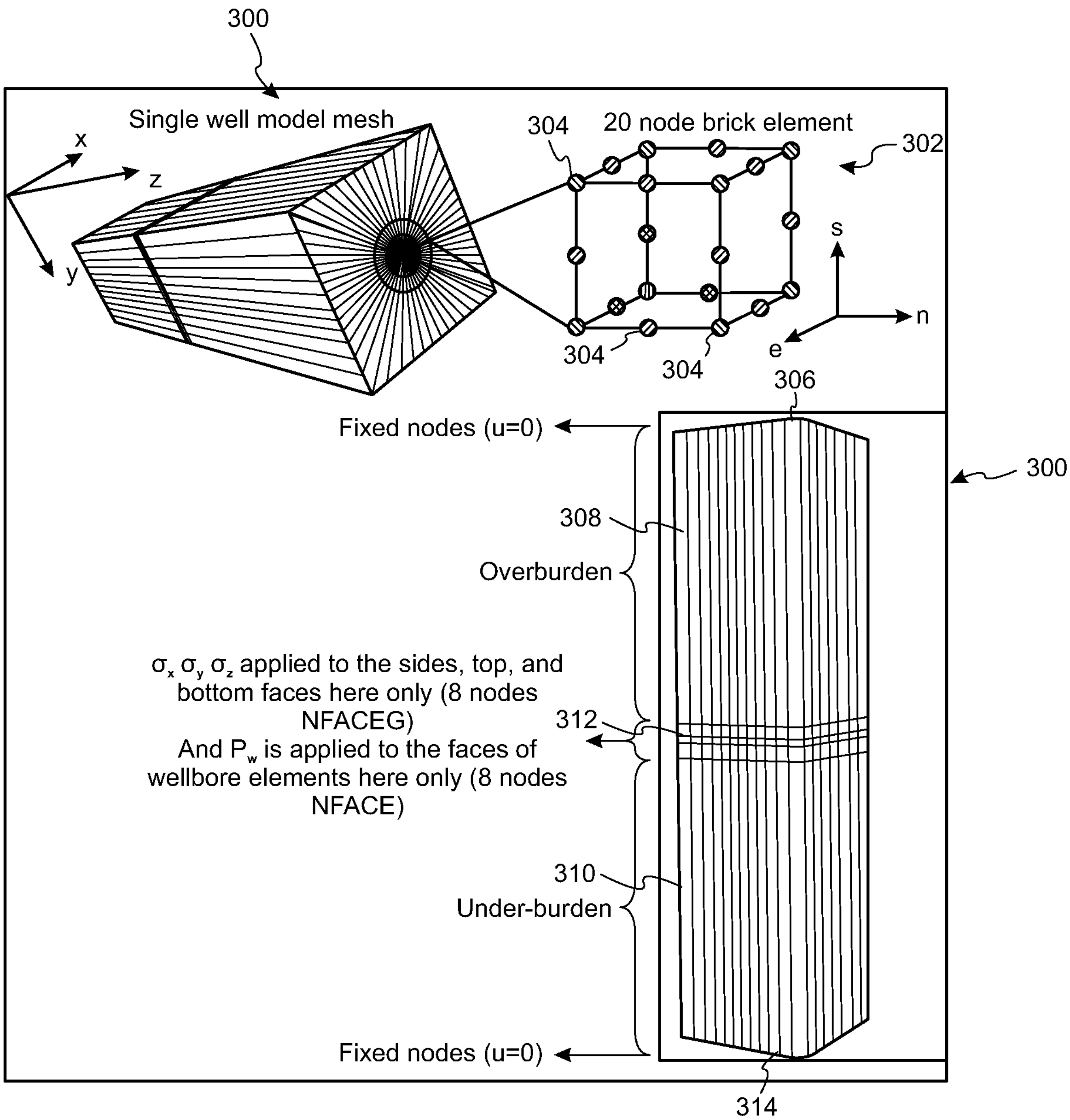

300
Single well model mesh
x
z
y
304
20 node brick element
302
s
n
e
304
304
306
Fixed nodes (u=0)
300
308
Overburden
σx σy σz applied to the sides, top, and bottom faces here only (8 nodes NFACEG)
312
And Pw is applied to the faces of wellbore elements here only (8 nodes NFACE)
310
Under-burden
Fixed nodes (u=0)
314

FIG. 3

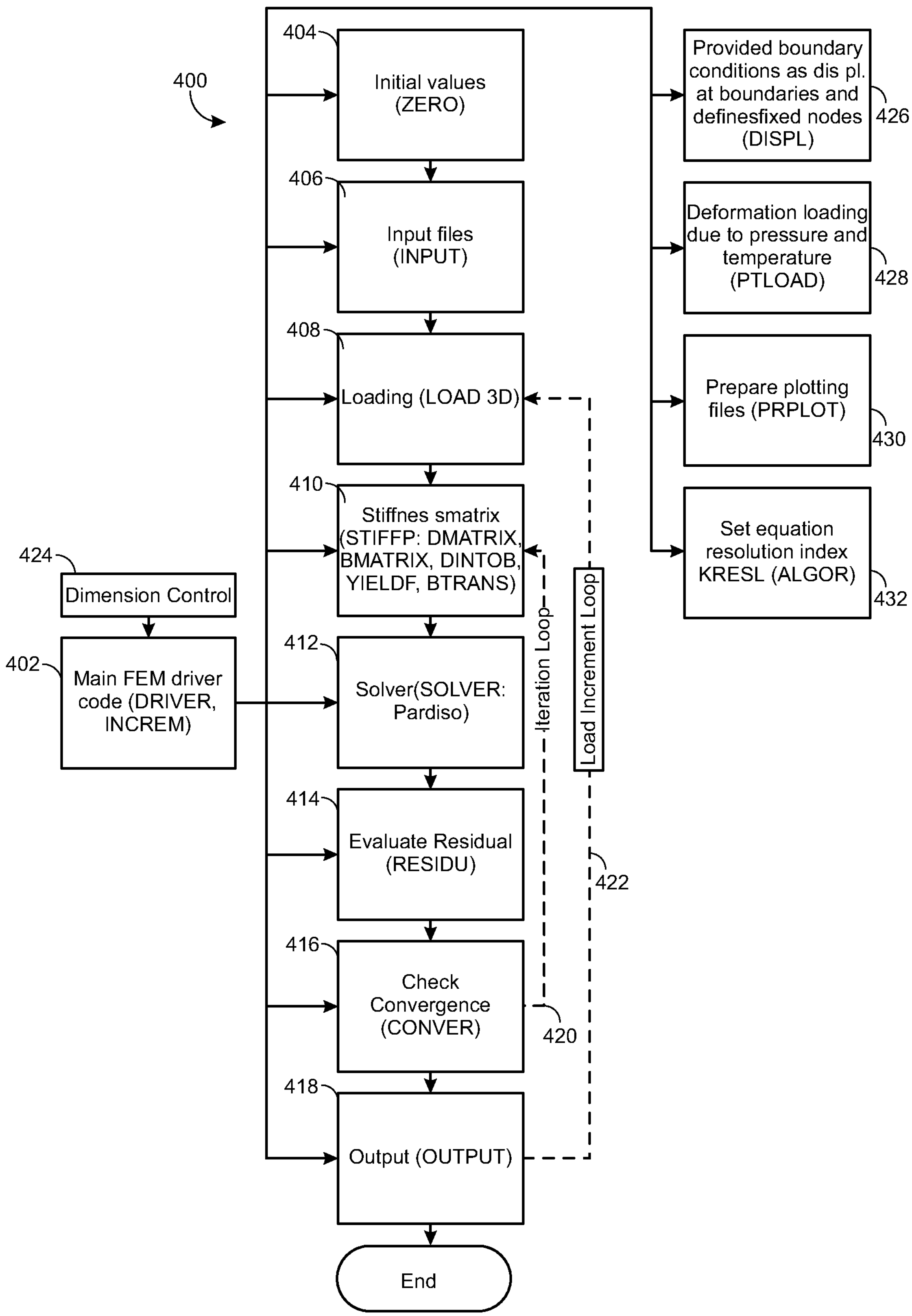

400
404
Initial values (ZERO)
406
Input files (INPUT)
408
Loading (LOAD 3D)
410
Stiffnes smatrix (STIFFP: DMATRIX, BMATRIX, DINTOB, YIELDF, BTRANS)
412
Solver(SOLVER: Pardiso)
414
Evaluate Residual (RESIDU)
416
Check Convergence (CONVER)
418
Output (OUTPUT)
End
424
Dimension Control
402
Main FEM driver code (DRIVER, INCREM)
Iteration Loop
420
Load Increment Loop
422
Provided boundary conditions as dis pl. at boundaries and definesfixed nodes (DISPL)
426
Deformation loading due to pressure and temperature (PTLOAD)
428
Prepare plotting files (PRPLOT)
430
Set equation resolution index KRESL (ALGOR)
432

FIG. 4

500

502 506 508 504

Base Case	Case 1	Case 2	Data Source
Depth of top of reservoi (D), ft	6789	10000	3D Reservoir model
Reservoir thickness (H), ft	856	100	
Middle of reservoir, ft	7217	10050	
Reservoir radius (R), ft	18864.83	1320	
Vertical stress gradient, psi/ft	1.1	1	Wireline logs
Pore pressure gradient, psi/ft	0.6	0.6	MDT wireline logs
Depletion (ΔP), kpsi	-0.8	-5	
Reservoir Young's modulus (E_r), kpsi	6410	1000	Experimental rock mechanical lab testing conducted on core plugs that are obtained from the reservoir, the overburden formation, and the underburden formation.
Reservoir Poisson's ratio (V_r)	0.2835	0.2	
Overburden and underburden Young's modulus (E_c), kpsi	6410	1000	
Overburden and underburden Poisson's ratio (C_c)	0.2835	0.2	
Rock matrix Young's modulus (E_m), kpsi	9825	9825	
Rock matrix Poisson's ratio (V_m)	0.2	0.2	
Ratio between rock matrix and rock bulk compressibility ($\beta = c_r/c_b$)	0.09595755	0.89821883	
Reservoir shear modulus (G)	2497.08	416.6667	
Reservoir uniaxial compressibility (C_M)	1.16E-05	0.000808397	
Cap rock shear modulus (G)	2497.08	416.6667	
Cap rock uniaxial compressibility(C_M)	1.16E-05	0.000808	

FIG. 5

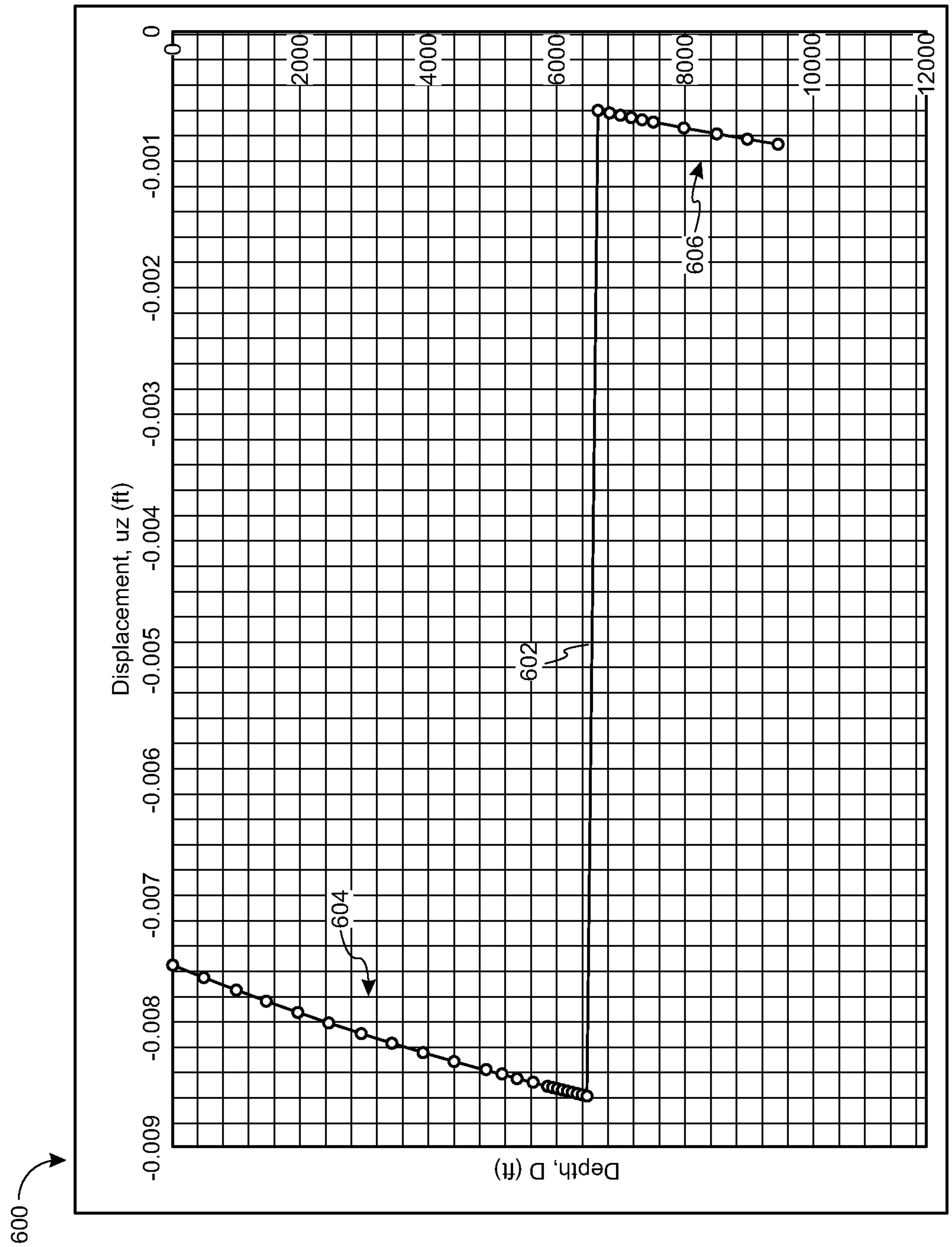
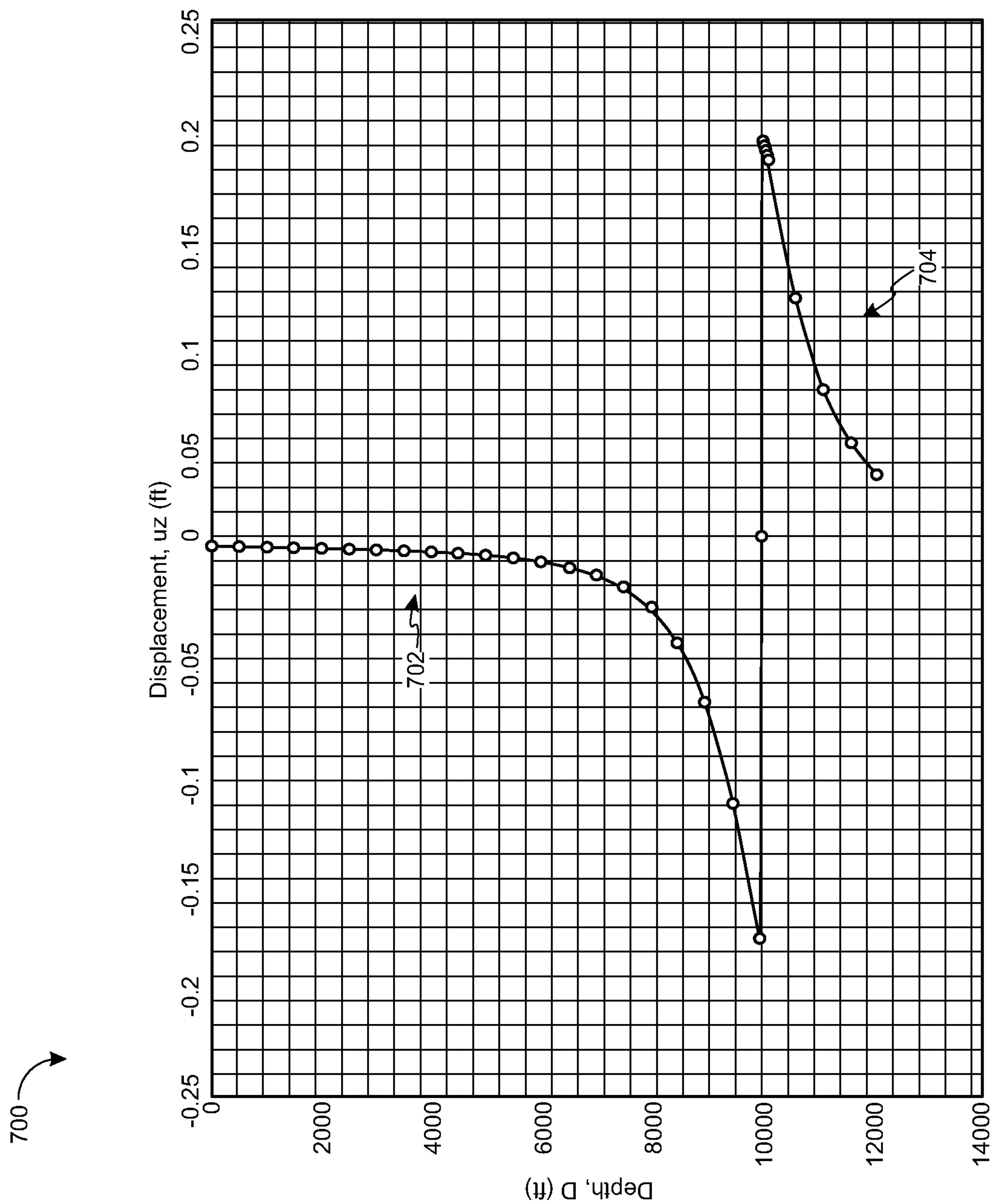

600
Displacement, uz (ft)
Depth, D (ft)
0
-0.001
-0.002
-0.003
-0.004
-0.005
-0.006
-0.007
-0.008
-0.009
0
2000
4000
6000
8000
10000
12000
602
604
606

FIG. 6



700
Displacement, uz (ft)
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
Depth, D (ft)
0
2000
4000
6000
8000
10000
12000
14000
702
704

FIG. 7

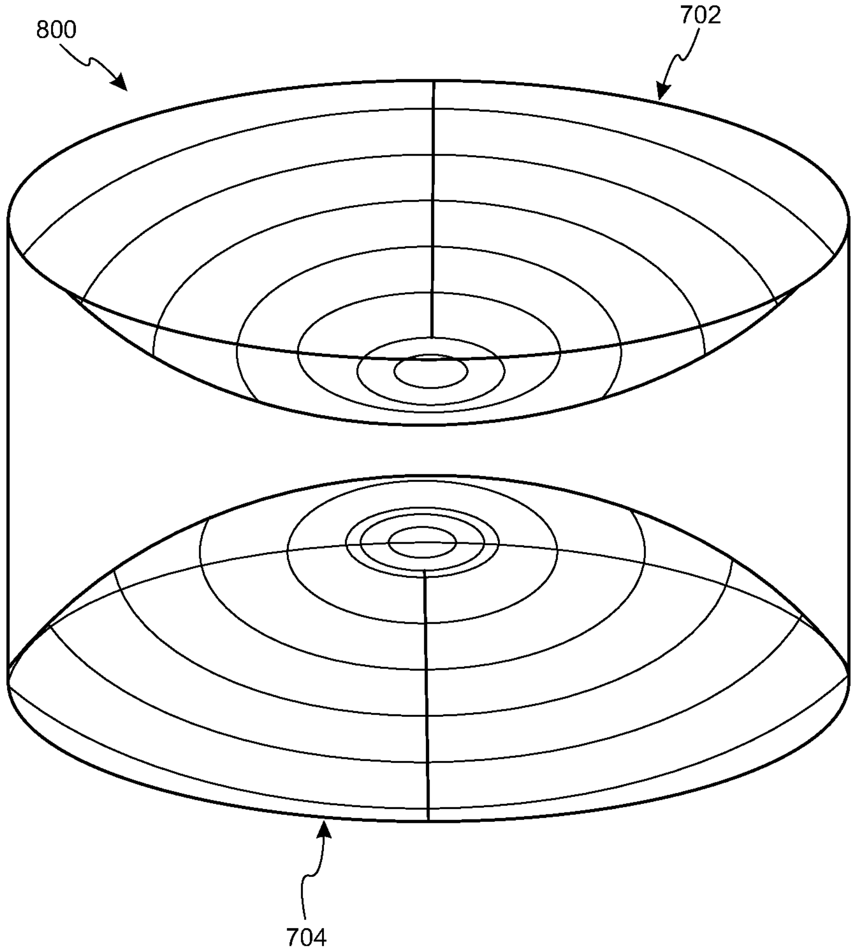
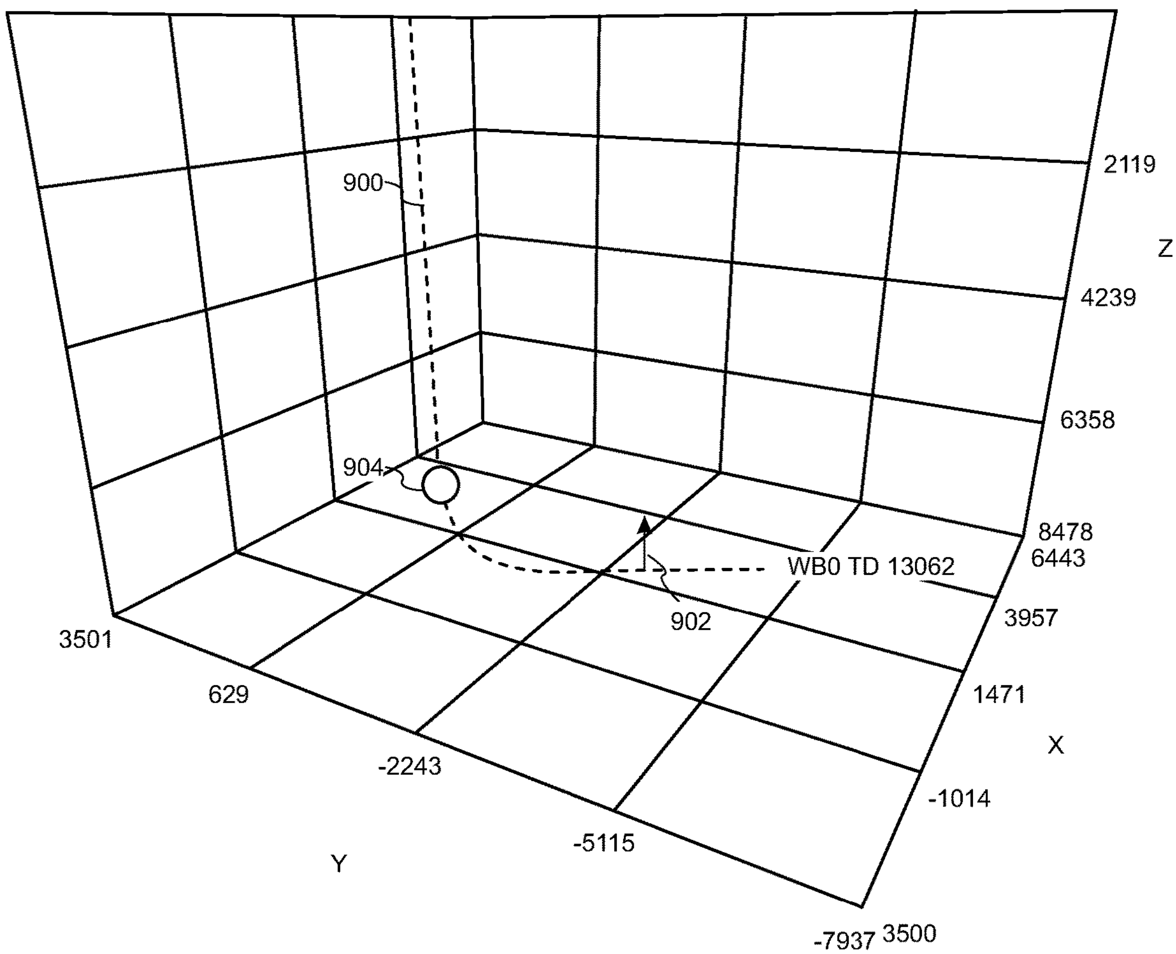


FIG. 8



900
904
902
WB0 TD 13062
2119
Z
4239
6358
8478
6443
3957
1471
X
-1014
3500
3501
629
-2243
-5115
-7937
Y

FIG. 9

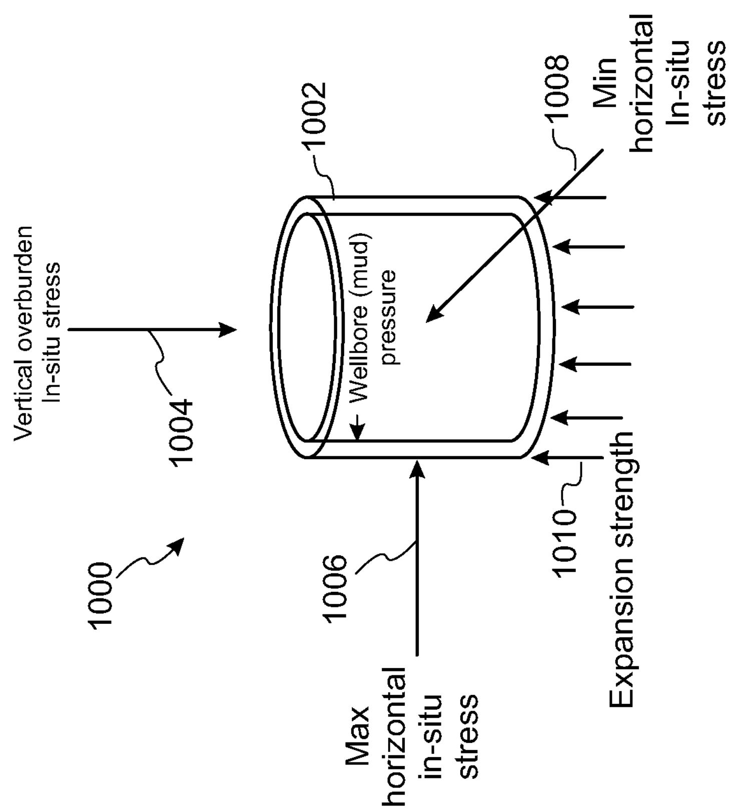

1000
Vertical overburden
In-situ stress
1004
1002
1008
Min
horizontal
In-situ
stress
Wellbore (mud)
pressure
1006
Max
horizontal
in-situ
stress
1010
Expansion strength

FIG. 10

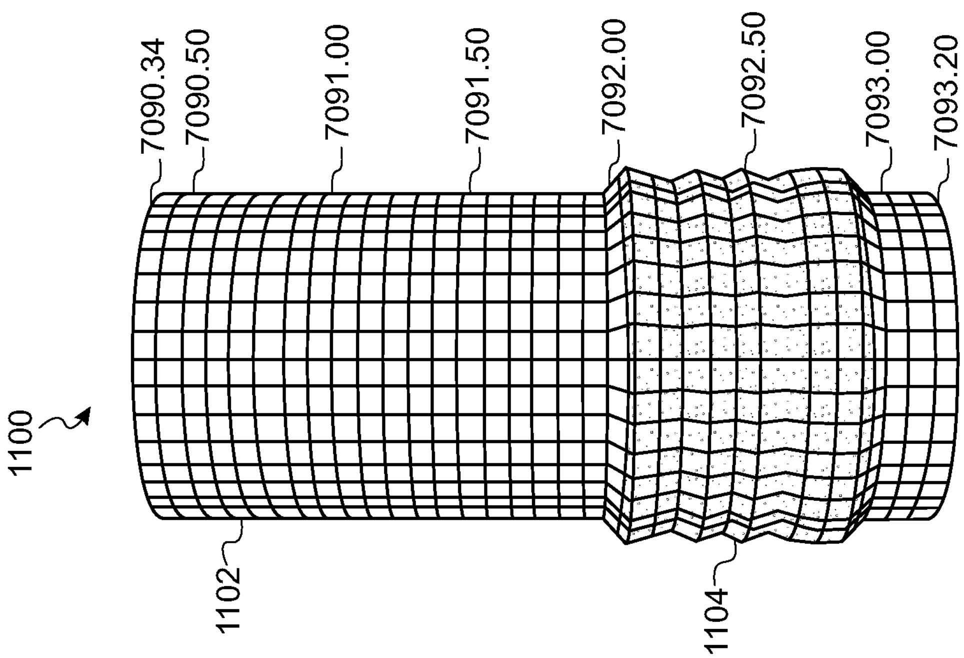

1100
7090.34
7090.50
7091.00
7091.50
7092.00
7092.50
7093.00
7093.20
1102
1104

FIG. 11

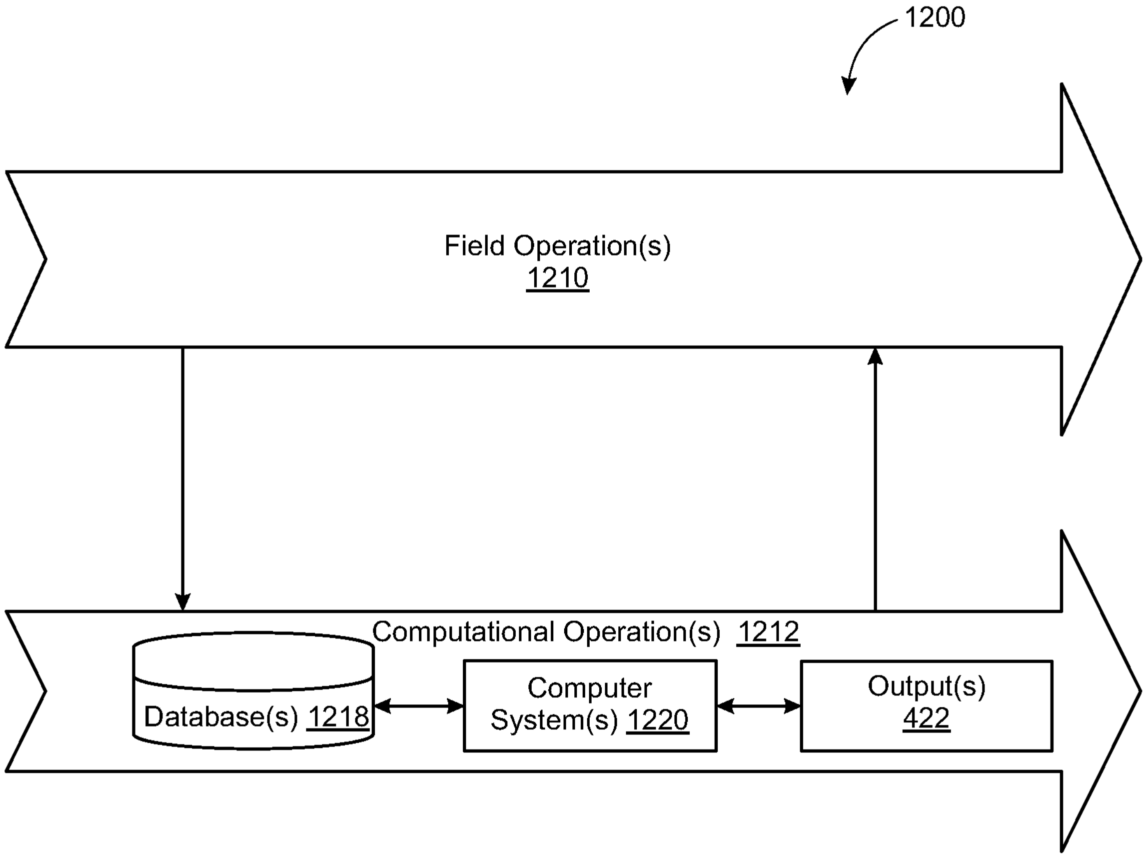

1200
Field Operation(s)
1210
Computational Operation(s) 1212
Database(s) 1218
Computer
System(s) 1220
Output(s)
422

FIG. 12

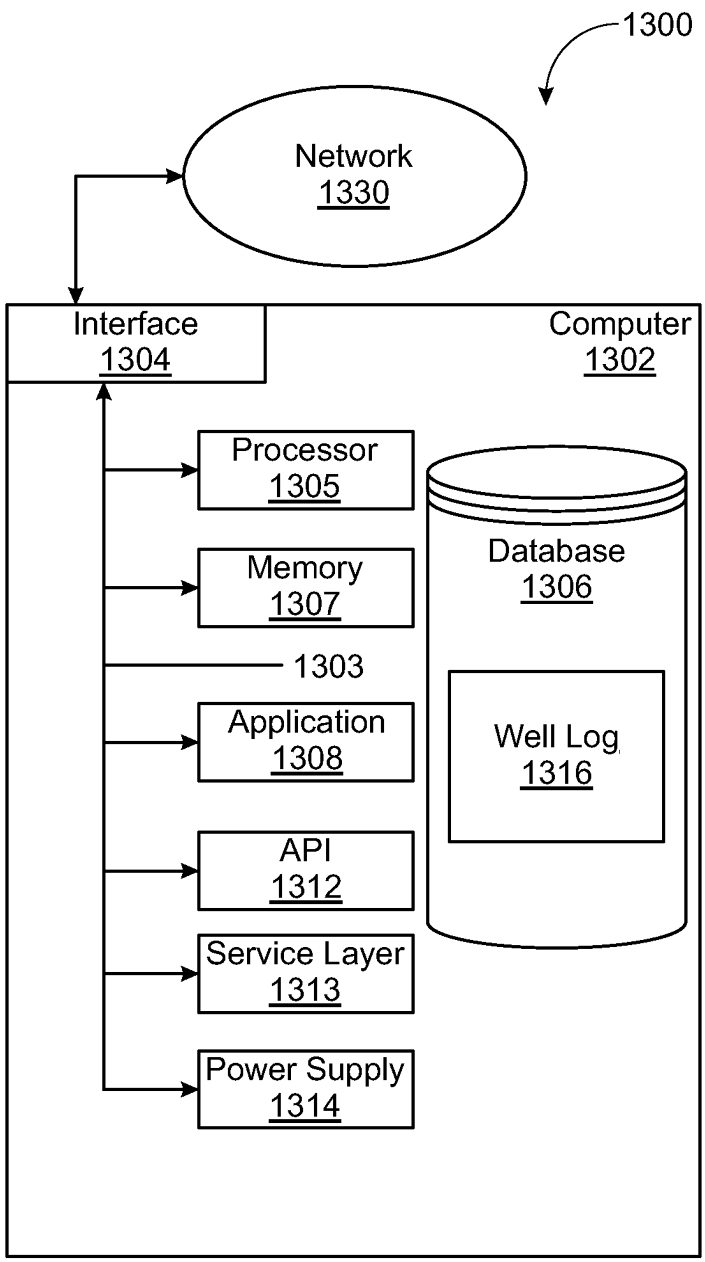

1300
Network
1330
Interface
1304
Computer
1302
Processor
1305
Memory
1307
1303
Application
1308
API
1312
Service Layer
1313
Power Supply
1314
Database
1306
Well Log
1316

FIG. 13

DESIGNING VARIABLE STRENGTH WELL CASINGS

TECHNICAL FIELD

[0001] The present disclosure relates to well casings for a well drilled in a subsurface formation.

BACKGROUND

[0002] Well casings include linings installed in a well after the well is drilled. Well casings include pipes (e.g., steel pipes) that extend through the depth of the well providing stabilization to the well. Well casings also provide a flow path for fluids produced from the well to be extracted at the surface. Well casings are typically cemented in place after being placed in the well.

SUMMARY

[0003] This disclosure describes systems and methods for designing variable strength casings for a wellbore in a subsurface formation. Field sampling operations can be performed to generate wireline logs and core samples from the wellbore. Stress and strain distributions along the wellbore are determined based on the wireline log data and core sample data from the wellbore. A reservoir displacement of a reservoir in the subsurface formation is determined based on the stress and strain distributions. The locations of potential failures of well casings in the wellbore are identified based on the stress and strain distributions and the reservoir displacement. A variable strength casing can be designed for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

[0004] During the casing design process, the burst pressure, tensile strength, and collapse resistance of the casing are typically considered. Changes in stresses acting on the casing due to changes in the reservoir during the life of the well can propagate deformations in the well casing, which are not captured by initial reservoir or casing conditions. Casing deformations can compromise a well's integrity and production rates from the well. Methods such as wireline logs, e.g., multi-finger caliper logs, can be used to detect casing deformations, which can lead to delays in hydrocarbon production processes and can result in costly workover and remediation operations if deformations are found.

[0005] Implementations of the systems and methods of this disclosure can provide various technical benefits. Specific weak points in the well casing are located and identified at the design stage preventing future failures of the well casing that would require costly workover operations to replace deformed or otherwise compromised casing. The inputs to the method include wireline logs and core sample data providing realistic modelling of the well location in the subsurface. In addition to pore pressure estimations and flow rates, the strength of the well casing is determined based on reservoir stress and displacement variations taking into account more than burst pressure, tensile strength and collapse resistance of the casing. Changes in stresses acting on the casing can change over the lifetime of the well resulting due to, for example, reservoir subsidence (e.g., gradual caving in or sinking). In the systems and methods of this disclosure, subsidence of the reservoir is accounted for at the design stage mitigating potential failures due to reservoir displacement. The method considers plasticity of the subsurface formation to generate more realistic models of the subsurface as compared with models not including plasticity. Using variable strength casings can reduce costs for the well casing by including high strength casings only at the locations with the highest stresses and including lower strength casings at other locations as compared with including high strength casings for the entire well. Strategically placing the high strength well casings reduces risks of premature failure of the well casing as well as reducing cost. The variable strength well casing provides targeted reinforcement of the most vulnerable sections of the wellbore more efficiently using materials and resources by not over-engineering less vulnerable sections of the wellbore.

[0006] The details of one or more implementations of these systems and methods are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of these systems and methods will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0007] FIG. **1** is a schematic illustrating a wireline operation.

[0008] FIG. **2** is a flow chart of a method for designing variable strength well casings.

[0009] FIG. **3** is a schematic illustration of a mesh for a single well model.

[0010] FIG. **4** is a flow chart for a workflow for determining stiffness for a subsurface formation.

[0011] FIG. **5** is a table of parameters for determining reservoir displacement in a subsurface formation.

[0012] FIG. **6** is a plot of displacement of a center of a reservoir with overburden regions above the reservoir and underburden regions below the reservoir.

[0013] FIG. **7** is another plot of displacement of a center of a reservoir with overburden regions above the reservoir and underburden regions below the reservoir.

[0014] FIG. **8** is an illustration of a reservoir shape after experiencing compaction.

[0015] FIG. **9** is a schematic of a well trajectory in a subsurface formation.

[0016] FIG. **10** is a free-body diagram of a section of well casing.

[0017] FIG. **11** is a visualization showing deformations of a section of well casing subjected to reservoir stresses.

[0018] FIG. **12** illustrates hydrocarbon production operations that include field operations and computational operations.

[0019] FIG. **13** is a block diagram illustrating an example computer system used to provide computational functionalities associated with described algorithms, methods, functions, processes, flows, and procedures according to some implementations of the present disclosure.

[0020] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0021] This specification describes systems and methods for designing variable strength casings for a wellbore in a subsurface formation. A data processing system (e.g., a computer or control system) obtains wireline log data and core sample data from the wellbore. The data processing system determines stress and strain distributions along the wellbore based on the wireline log data and core sample data from the wellbore. The data processing system determines a reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions. The data processing system identifies locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement. The data processing system determines a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

[0022] FIG. **1** illustrates a wireline operation **100** (e.g., a well logging operation) in which a wellbore **110** extends downhole from a wellhead **112**. The wellbore **110** is a vertical wellbore but wireline operations can also be performed in other wellbores, for example, slanted or horizontal wellbores. In the wireline operation **100**, the wellbore **110** penetrates through five layers **114**, **116**, **118**, **120**, **122** of a subsurface formation **124**. A control truck **128** lowers a logging tool **132** (e.g., a sidewall coring tool) down the wellbore **110** on a wireline **136**.

[0023] The logging tool **132** is a string of one or more instruments with sensors operable to measure petrophysical properties of the subsurface formation **124**. For example, logging tools can include resistivity logs, borehole image logs, porosity logs, density logs, or sonic logs. Resistivity logs measure the subsurface electrical resistivity, which is the ability to impede the flow of electric current. These logs can help differentiate between formations filled with salty waters (good conductors of electricity) and those filled with hydrocarbons (poor conductors of electricity). Porosity logs measure the fraction or percentage of pore volume in a volume of rock using acoustic or nuclear technology. Acoustic logs measure characteristics of sound waves propagated through the well-bore environment. Nuclear logs utilize nuclear reactions that take place in the downhole logging instrument or in the formation. Density logs measure the bulk density of a formation by bombarding it with a radioactive source and measuring the resulting gamma ray count after the effects of Compton scattering and photoelectric absorption. Sonic logs provide a formation interval transit time, which is typically a function of lithology and rock texture but particularly porosity. The logging tool includes a piezoelectric transmitter and receiver and the time taken for the sound wave to travel the fixed distance between the two is recorded as an interval transit time.

[0024] As the logging tool **132** travels downhole, measurements of formation properties are recorded to generate a well log. In the illustrated operation, the data are recorded at the control truck **128** in real-time. Real-time data are recorded directly against measured cable depth. In some well-logging operations, the data is recorded at the logging tool **132** and downloaded later. In this approach, the downhole data and depth data are both recorded against time. The two data sets are then merged using the common time base to create an instrument response versus depth log.

[0025] In the wireline operation **100**, the well logging is performed on a wellbore **110** that has already been drilled. In some operations, well logging is performed in the form of logging while drilling techniques. In these techniques, the sensors are integrated into the drill string and the measurements are made in real-time, during drilling rather than using sensors lowered into a well after drilling.

[0026] Using a wireline coring tool, core samples can be obtained in addition to obtaining well logs. A core sample is a usually cylindrical piece of the subsurface formation that is removed by a special drill and brought to the surface. Core samples can be used to measure petrophysical properties of the subsurface formation such as grain size, porosity, and permeability. Core samples can also be used to measure geomechanical properties of the subsurface formation such as Young's modulus, Poisson's ratio, and shear modulus. Core samples can be taken from the sidewalls of a drilled well. When sidewall core samples are repeated along the length of the well, the properties measured from the core samples can be compared and correlated with well logging measurements.

[0027] FIG. **2** is a flow chart of an example method **200** for designing variable strength well casing for a well in a subsurface formation. The method **200** can be implemented on a data processing system such as a computer or control system.

[0028] Properties of the subsurface formation can be measured by logging wells and/or taking core samples from the well. During well logging the data processing system can record data from the logging tools. Similarly, while analyzing core samples, the data processing system can record measurements taken from the core samples.

[0029] The data processing system obtains wireline log data and core sample data from the wellbore (step **202**). For example, the data processing system records wireline log data and core sample data during a wireline operation (e.g., wireline operation **100**). The wireline logs include, for example, one or more of a density log a compressional acoustic slowness log, and a shear acoustic slowness log. The core sample data includes, for example, one or more of density, porosity, permeability, Young's modulus, Poisson's ratio, reservoir compressibility, reservoir shear modulus, and unconfined compressive strength. In some implementations, the data processing system accesses the wireline log data and/or the core sample data from a data store.

[0030] The data processing system determines stress and strain distributions along the wellbore based on the wireline log data and core sample data (step **204**). For example, the data processing system determines the stress and strain distributions using a three-dimensional poro-elasto-plastic geomechanics model. In some implementations, the geomechanics model is a finite element model and nodes of the three-dimensional finite element model include geomechanical properties derived from the wireline log data and the core sample data. The stress distribution can include body stresses and traction stresses on the wellbore resulting from loading of the wellbore structure. Sources of the loading include in-situ stresses from the geological formation, stresses from inside the wellbore due to hydrostatic pressure and frictional pressure losses of fluid within the wellbore, and expansion, compaction, or fault movements of the geological formation.

[0031] A poro-elasto-plastic geomechanics model offers several advantages over other models used in drilling engineering. Conventional models typically use linear elastic models relying on analytical solutions or simplified numerical solutions. Such simplified solutions inherit unrealistic assumptions resulting in inaccurate or unrealistic estimations of in situ stresses. The use of plasticity, in the geomechanics model, captures more realistic material behavior of the subsurface formation. Another advantage offered by this model over other numerical solutions is its calculation speed, which is fast enough to allow for a real-time/while-drilling implementation of the model. Factors that enable faster run times compared to other numerical models include a 3D mesh optimization which minimizes the number of grids, the 3D model size considers only a representative block of the geological formation and well as opposed to modeling the full reservoir/geological formation, and the solver used to solve the system of linear equations. The model used in this approach can be return a result within 30 seconds compared with other numerical models that can have a run time that extends into days.

[0032] In some implementations, the geomechanics model applies a discretization using the minimization of the total potential energy of the 3D representative block of the geological formation and the well structure within it as illustrated in FIG. **3**. The discretization decomposes the 3D representative block of the geological formation and the well structure into finite elements. The minimization of the total potential energy produces the following equilibrium:

$$u\int_{V^e}((B^T)D\ B)d\Omega=\int_{V^e}N^TF\ d\Omega-\int_{S^e}N^TT\ d\Gamma, \tag{1)}$$

where u is the displacement, B and B' are the strain-displacement matrix and its transpose, respectively. NT is the transpose of the quadratic Serendipity shape functions vector, which are derived, for example, for a 20-node isoperimetric brick element, D is the consistent tangent matrix, which is formulated based on mechanical properties of the rock, F is the body force, and T is the traction force. The body and traction forces reflect the in-situ stresses and mud weight loading on the wellbore. The integrations in this equation are performed at the element volume (V^e) with respect to the volume variable (Ω) or at the element surface (S^e) with respect to the area variable (Γ). The matrix resulting from the integral in the expression on the left hand side of equation 1 is known as the stiffness matrix (K^e).

[0033] The geomechanics model uses a plastic flow rule for strain hardening or strain softening to reflect the plastic behavior of the rock, which occurs beyond the yield point. For example, the total strain is the addition of two components, which are poro-elastic strain (ε^e) and a plastic strain (ε^p). The plastic flow rule assumes that the flow direction is perpendicular to the vied surface ψ:

$$\Delta\varepsilon_{ij}^p=\lambda\frac{\partial\psi(\sigma_{ij})}{\partial\sigma_{ij}}, \tag{2}$$

where $\varepsilon_{ij}{}^p$ is the plastic strain tensor, σ_{ij} is the stress tensor, and A is the plastic strain multiplier. The associative flow rule is applied by assuming that the plastic potential surface is the same as the yield surface ψ. It also assumes the yield surface expands without changing the flow direction. An example of a yield criterion in the geomechanics model is the Drucker-Prager criterion, where yielding will take place when the deviatoric stress tensor (S_{ij}) and the mean stress (σ_m) satisfy the following relationship:

$$\psi(\sigma_{ij})=\sqrt{\frac{1}{2}S_{ij}S_{ij}}-a_0+a_1\sigma_m=0, \tag{3}$$

where constants a_0 and a_1 are determined experimentally as material properties and are used to correlate the Drucker-Prager criterion to the Mohr-Coulomb criterion.

[0034] The following expression for strain hardening can then be used to calculate the scalar plastic strain ε^p from the plastic strain tensor determined by the flow rule:

$$\varepsilon^p=\int\sqrt{\frac{2}{3}d\varepsilon_{ij}^p d\varepsilon_{ij}^p}\,. \tag{4}$$

[0035] The data processing system determines a reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions (step **206**). In some implementations, the data processing system determines reservoir displacement by simulating hydrocarbon production from the reservoir using a reservoir simulator.

[0036] Both the compaction and expansion of a reservoir can be significant geological and engineering considerations in the context of natural resources and energy extraction. Reservoir depletion refers, for example, to the gradual reduction of the reservoir's fluid content, such as oil or gas, as it is produced over time. This process leads to decreased reservoir pressure and lower production rates. Compaction or expansion relates to the subsurface movements and changes that occur within the reservoir as fluid is extracted or injected. As fluids are withdrawn, the porous rock formation can compact, leading to subsidence of the surface above. Conversely, injection processes can cause expansion and potential uplift of the formation. Managing the compaction and expansion effects can be important for sustainable resource extraction, minimizing environmental impacts, and ensuring long term productivity of the reservoir. The displacement of subsurface formations or reservoirs as a result of compaction or expansion can impact the structural integrity of casing strings and cement sheaths that are bonded and attached to these formations. The estimation of formation displacement throughout the life cycle of a well can be important for determining both the magnitude and localization of potential pipe deformation.

[0037] There are several methods to determine formation displacement. For example, formation displacement can be determined using a reservoir simulator or geomechanics model. Simulating the subsurface formation displacement includes considering pore pressure changes over time (either due to injection or depletion) in the 3D model. Alternatively, or additionally, the formation displacement can be estimated using an analytical solution. An example of an analytical solution is shown in equation 5 where the uniaxial compressibility (c_m) is initially calculated using Young's Modulus (E) and Poisson's Ratio (v) determined through core sample tests,

$$c_m=\frac{(1+\nu)(1-2\nu)}{E(1-\nu)}. \tag{5}$$

[0038] In some implementations, the solution of Geertsma 1973a (Geertsma, J. "Land subsidence above compacting oil and gas reservoirs." *Journal of Petroleum Technology* 25, no. 06 (1973): 734-744) is used to determine the formation subsidence. The Geertsma 1973a solution considers the geometric properties (e.g. areal extent and reservoir thickness), planned pressure depletion, and relevant rock mechanics properties (e.g., reservoir compressibility and Poisson's ratio). According to this solution, the surface subsidence (u_z) at the land surface or seabed can be computed by considering the pressure depletion (ΔP) at depth (D) and the radial distance (r). Uniaxial compressibility (c_m) and Poisson's Ratio (v) are utilized in a nucleus-of-strain approach, with the nucleus representing an infinitesimal volume where the depletion is applied, as described in equation 6. The total subsidence can be calculated using:

$$u_z(r, 0) = -\frac{1}{\pi} c_m (1 - v) \frac{D}{(r^2 + D^2)^{1.5}} \Delta PV. \tag{6}$$

[0039] Geertsma 1973b (Geertsma, J. "A basic theory of subsidence due to reservoir compaction; the homogeneous case." (1973)) also provides a numerical approximation of the subsidence at any subsurface point within a finite volume (V) using equation 7. Here, R_1 and R_2 represent the distances between the point of interest and the nucleus of strain and the image point of the nucleus of strain (above ground surface by magnitude D), respectively, and $\hat{z}$ denotes the unit vector in the z-direction.

$$u_z(r, 0) = -\Delta p \ V \frac{c_m}{4\pi} \left\{ \frac{R_{z1}}{R_1^3} + (3 - 4v) \frac{R_{z2}}{R_2^3} - 6z(z + D) \frac{R_{z2}}{R_2^5} + \frac{2\hat{z}}{R_1^3} [(3 - 4v)(z + D) - z] \right\} \tag{7}$$

[0040] The data processing system identifies locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement (step **210**). For example, the data processing system identifies locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore. In some implementations, the data processing system identifies locations of potential failure based on locations having a larger reservoir displacement relative to reservoir displacement at other locations.

[0041] The data processing system determines a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore (step **212**). For example, the data processing system determines a wall thickness for the casing that can withstand the determined stresses, strains, and reservoir displacements at the identified locations of potential failure. In some implementations, the data processing system selects casing sizes from a set of standard casing sizes.

[0042] In some implementations, the method **200** includes placing casings in the wellbore based on the variable strength casing design (step **214**). For example, the data processing system can generate control commands to control equipment to install casings in the wellbore based on the variable strength casing design.

[0043] FIG. **3** is a schematic of an example single well model mesh **300** that can be used in a geomechanical model to design variable strength casings for a wellbore. The model mesh **300** includes brick elements **302** such as 20-node isoperimetric brick elements. The brick elements **302** can be cuboids (as shown) and other shapes are also possible (e.g., tetrahedrons, hexagonal prisms, etc.). The nodes **304** of the brick elements can be assigned properties of the formation (e.g., geomechanical properties derived from well log data and/or core sample data). The properties of the formation assigned to the nodes **304** can vary based on variation in the subsurface formation being modeled (e.g., the distribution of properties can be heterogeneous). At the top **306** of the model mesh **300**, a fixed boundary condition (e.g., no displacement) is applied to the nodes. The upper portion **308** of the model mesh **300** includes regions of overburden. The lower portion **310** of the model mesh **300** includes regions of underburden. The middle portion **312** of the model mesh **300** includes the reservoir portion of the subsurface formation. Normal stresses are applied to the side, top, and bottom faces of the brick elements **302** in the middle portion **312**. Pw values are also applied to the faces of the brick elements **302** in the middle portion **312**. Pw represents the inside wellbore stresses that results from hydrostatic pressure and frictional pressure losses of the wellbore fluids. The At the bottom **314** of the model mesh **300**, a fixed boundary condition is applied to the nodes. NFACEG represents the surfaces of the finite elements that are exposed to outer boundary within the geological formation. NFACE represents the surfaces of the finite elements that are exposed to the inside of the wellbore.

[0044] FIG. **4** is an example workflow **400** for modeling a subsurface formation. In an example implementation of a geomechanics model solved using a finite element method (FEM), the FEM is implemented through **33** subroutines and a driver code **402**. The driver code **402** calls twelve main subroutines that perform several functions including initializing (**404**) values, receiving (**406**) the input file, applying (**408**) loads to the mesh, constructing (**410**) the global stiffness matrix, and solving (**412**) the system of equations.

[0045] After solving (**412**) the system of equations, e.g., as described by Equation (1), and determining the displacements u, the data processing system calculates (**414**) residual forces to check (**416**) for convergence and equilibrium by subtracting the left-hand side of the system of equations from the right-hand side in the global form, where the left-hand side is the global stiffness matrix multiplied by displacement and the right-hand side is the body and traction forces. The value obtained from the subtraction of these two quantities should be equal to zero if the equilibrium condition is fully satisfied. However, that is not always achievable, therefore, a tolerance value is set to check for convergence. For example, the tolerance value is set to be close to but not equal to zero. Once the residual forces are calculated and found to be less than the set tolerance value the data processing system determines that convergence is achieved, and outputs (**418**) the results. Otherwise, the residual forces are carried to the next iteration of steps **410-416**. Steps **408-418** can be repeated for separate load increments, where the load increments are defined in the input file manually. These processes are carried out in two loops with the convergence loop **420** nested in the load increment loop **422**. The driver code **402** also includes routines for dimension control **424**, displaying (**426**) boundary conditions, deformation loading (**428**) due to effects of pressure and temperature, preparing (**430**) plotting files, and setting (**432**) an equation resolution index.

[0046] FIG. **5** is a table **500** showing example variables **502** used for determining displacement (e.g., compaction) of a subsurface formation. Sources **504** of the variables **502** and two sets of example values **506**, **508** for the variables **502** are also shown. The variables **502** and values **506**, **508** can be used in conjunction with equations 5, 6, and/or **7** to determine displacement of the reservoir.

[0047] FIG. **6** is a plot **600** of reservoir subsidence for an example reservoir. The plot **600** shows the displacement of the center of the formation as a function of depth. To illustrate the extent of displacement along the reservoir section, results were plotted after conducting the required calculations for compaction using values **506** shown in table **500**. The reservoir is assumed to be disc-shaped for the purpose of calculating the reservoir volume. After compaction, the reservoir's shape transformed into a compacted bowl shape. The center of reservoir section **602** encountered a subsidence of approximately 0.08 ft (~1 in). The overburden **604** and underburden **606** formation sections did not undergo any compaction. However, due to the subsidence of the reservoir zone, the center of both overburden **604** and underburden **606** formations shifted downward.

[0048] FIGS. **7** and **8** show reservoir subsidence based on the variable values **508** from table **500**. FIG. **7** shows a plot **700**, and FIG. **8** shows a three dimensional rendering **800**. The subsidence behavior in plot **700** is different than the situation in plot **600**. In this case, depending on the mechanical properties of each layer, the overburden formations **702** shift downward while the underburden formations **704** shift upwards simultaneously forming a downward concave shape in the overburden formations **702** and a concave upward shape in the underburden formations **704**.

[0049] Equations 5-7 used for FIGS. **6-8** can be utilized for calculating expansion as well as compaction. In the case of expansion, the formation will behave differently than when there is compaction. With water injection, for example, the increase in formation pore pressure would expand the reservoir section. Consequently, the center of overburden formations will be shifted upward, while the center of underburden formations can experience a downward displacement.

[0050] During drilling operations, various forces and stresses act upon the wellbore, which can originate, for example, from in-situ stresses of the formation or from forces imposed by the drilling fluid. If these stresses exceed the casing's yield strength, the forces can lead to deformations of the casing that can require expensive remedial jobs to repair the casing string. Identifying potential weak points in the wellbore before placing the casing can reduce risks and avoid potential failures.

[0051] FIG. **9** illustrates a trajectory **900** for an injector well. The arrow **902** indicates the direction of reservoir expansion along the z-axis. The wellbore experiences five distinct loads: three principal in-situ stresses, internal wellbore fluid pressure, and expansion stress. These stresses are depicted schematically in the free body diagram of FIG. **10**.

[0052] The data processing system considers the trajectory **900** of the wellbore and calculates the stresses encountered at each point enabling identification of the locations along the wellbore that are prone to casing deformation at the design phase. In the trajectory **900**, the data processing system identified the kick-off point **904** (e.g., the point at which a directional well deviates from vertical) as the weakest spot along the trajectory. Accordingly, the data processing system can determine a design to place higher strength casing at this location to avoid deformation of the casing. By proactively addressing weak points, the risk of costly casing failures can be significantly reduced, enhancing the overall efficiency and safety of wellbore operations.

[0053] FIG. **10** is an example free-body diagram **1000** illustrating the stresses experienced by casing **1002** in a wellbore. The casing **1002** experiences three principal in situ stresses: vertical overburden stress **1004**, maximum horizontal in situ stress **1006**, and minimum horizontal in situ stress **1008**. The casing **1002** also experiences expansion stresses **1010** caused by expansion of the reservoir, and wellbore pressure stresses **1012** from fluids in the wellbore (e.g., mud, oil, gas, etc.).

[0054] FIG. **11** is a visualization **1100** of casing deformation as a result of stresses exceeding a yield limit of the casing **1102**. For example, at the kick-off point **904**, the stresses can exceed a nominal yield limit of casing in the wellbore. The visualization **1100** shows buckling **1104** where the casing **1102** fails. When deformation such as buckling **1104** is localized in the casing **1102**. It can be more efficient to strengthen the casing at the identified weak location (e.g., high stress location) in the wellbore as compared with strengthening all of the casing in the well bore.

[0055] FIG. **12** illustrates hydrocarbon production operations **1200** that include both one or more field operations **1210** and one or more computational operations **1212**, which exchange information and control exploration for the production of hydrocarbons. In some implementations, outputs of techniques of the present disclosure (e.g., the method **300**) can be performed before, during, or in combination with the hydrocarbon production operations **1200**, specifically, for example, either as field operations **1210** or computational operations **1212**, or both. For example, the method **300** collects data during field operations, processes the data in computational operations, and can determine locations to perform additional field operations.

[0056] Examples of field operations **1210** include forming/drilling a wellbore, hydraulic fracturing, producing through the wellbore, injecting fluids (such as water) through the wellbore, to name a few. In some implementations, methods of the present disclosure can trigger or control the field operations **1210**. For example, the methods of the present disclosure can generate data from hardware/software including sensors and physical data gathering equipment (e.g., seismic sensors, well logging tools, flow meters, and temperature and pressure sensors). The methods of the present disclosure can include transmitting the data from the hardware/software to the field operations **1210** and responsively triggering the field operations **1210** including, for example, generating plans and signals that provide feedback to and control physical components of the field operations **1210**. Alternatively or in addition, the field operations **1210** can trigger the methods of the present disclosure. For example, implementing physical components (including, for example, hardware, such as sensors) deployed in the field operations **1210** can generate plans and signals that can be provided as input or feedback (or both) to the methods of the present disclosure.

[0057] Examples of computational operations **1212** include one or more computer systems **1220** that include one or more processors and computer-readable media (e.g., non-transitory computer-readable media) operatively coupled to the one or more processors to execute computer operations to perform the methods of the present disclosure. The computational operations **1212** can be implemented using one or more databases **1218**, which store data received from the field operations **1210** and/or generated internally within the computational operations **1212** (e.g., by implementing the methods of the present disclosure) or both. For example, the one or more computer systems **1220** process inputs from the field operations **1210** to assess conditions in the physical world, the outputs of which are stored in the databases **1218**. For example, seismic sensors of the field operations **1210** can be used to perform a seismic survey to map subterranean features, such as facies and faults. In performing a seismic survey, seismic sources (e.g., seismic vibrators or explosions) generate seismic waves that propagate in the earth and seismic receivers (e.g., geophones) measure reflections generated as the seismic waves interact with boundaries between layers of a subsurface formation. The source and received signals are provided to the computational operations **1212** where they are stored in the databases **1218** and analyzed by the one or more computer systems **1220**.

[0058] In some implementations, one or more outputs **1222** generated by the one or more computer systems **1220** can be provided as feedback/input to the field operations **1210** (either as direct input or stored in the databases **1218**). The field operations **1210** can use the feedback/input to control physical components used to perform the field operations **1210** in the real world.

[0059] For example, the computational operations **1212** can process the seismic data to generate three-dimensional (3D) maps of the subsurface formation. The computational operations **1212** can use these 3D maps to provide plans for locating and drilling exploratory wells. In some operations, the exploratory wells are drilled using logging-while-drilling (LWD) techniques which incorporate logging tools into the drill string. LWD techniques can enable the computational operations **1212** to process new information about the formation and control the drilling to adjust to the observed conditions in real-time.

[0060] The one or more computer systems **1220** can update the 3D maps of the subsurface formation as information from one exploration well is received and the computational operations **1212** can adjust the location of the next exploration well based on the updated 3D maps. Similarly, the data received from production operations can be used by the computational operations **1212** to control components of the production operations. For example, production well and pipeline data can be analyzed to predict slugging in pipelines leading to a refinery and the computational operations **1212** can control machine operated valves upstream of the refinery to reduce the likelihood of plant disruptions that run the risk of taking the plant offline.

[0061] In some implementations of the computational operations **1212**, customized user interfaces can present intermediate or final results of the above-described processes to a user. Information can be presented in one or more textual, tabular, or graphical formats, such as through a dashboard. The information can be presented at one or more on-site locations (such as at an oil well or other facility), on the Internet (such as on a webpage), on a mobile application (or app), or at a central processing facility.

[0062] The presented information can include feedback, such as changes in parameters or processing inputs, that the user can select to improve a production environment, such as in the exploration, production, and/or testing of petrochemical processes or facilities. For example, the feedback can include parameters that, when selected by the user, can cause a change to, or an improvement in, drilling parameters (including drill bit speed and direction) or overall production of a gas or oil well. The feedback, when implemented by the user, can improve the speed and accuracy of calculations, streamline processes, improve models, and solve problems related to efficiency, performance, safety, reliability, costs, downtime, and the need for human interaction.

[0063] In some implementations, the feedback can be implemented in real-time, such as to provide an immediate or near-immediate change in operations or in a model. The term real-time (or similar terms as understood by one of ordinary skill in the art) means that an action and a response are temporally proximate such that an individual perceives the action and the response occurring substantially simultaneously. For example, the time difference for a response to display (or for an initiation of a display) of data following the individual's action to access the data can be less than 1 millisecond (ms), less than 1 second(s), or less than 5 s. While the requested data need not be displayed (or initiated for display) instantaneously, it is displayed (or initiated for display) without any intentional delay, taking into account processing limitations of a described computing system and time required to, for example, gather, accurately measure, analyze, process, store, or transmit the data.

[0064] Events can include readings or measurements captured by downhole equipment such as sensors, pumps, bottom hole assemblies, or other equipment. The readings or measurements can be analyzed at the surface, such as by using applications that can include modeling applications and machine learning. The analysis can be used to generate changes to settings of downhole equipment, such as drilling equipment. In some implementations, values of parameters or other variables that are determined can be used automatically (such as through using rules) to implement changes in oil or gas well exploration, production/drilling, or testing. For example, outputs of the present disclosure can be used as inputs to other equipment and/or systems at a facility. This can be especially useful for systems or various pieces of equipment that are located several meters or several miles apart, or are located in different countries or other jurisdictions.

[0065] FIG. **13** is a block diagram of an example computer system **1300** used to provide computational functionalities associated with described algorithms, methods, functions, processes, flows, and procedures described in the present disclosure, according to some implementations of the present disclosure. The illustrated computer **1302** is intended to encompass any computing device such as a server, a desktop computer, a laptop/notebook computer, a wireless data port, a smart phone, a personal data assistant (PDA), a tablet computing device, or one or more processors within these devices, including physical instances, virtual instances, or both. The computer **1302** can include input devices such as keypads, keyboards, and touch screens that can accept user information. Also, the computer **1302** can include output devices that can convey information associated with the operation of the computer **1302**. The information can include digital data, visual data, audio information, or a combination of information. The information can be presented in a graphical user interface (UI) (or GUI).

[0066] The computer **1302** can serve in a role as a client, a network component, a server, a database, a persistency, or components of a computer system for performing the subject matter described in the present disclosure. The illustrated computer **1302** is communicably coupled with a network **1330**. In some implementations, one or more components of the computer **1302** can be configured to operate within different environments, including cloud-computing-based environments, local environments, global environments, and combinations of environments.

[0067] At a high level, the computer **1302** is an electronic computing device operable to receive, transmit, process, store, and manage data and information associated with the described subject matter. According to some implementations, the computer **1302** can also include, or be communicably coupled with, an application server, an email server, a web server, a caching server, a streaming data server, or a combination of servers.

[0068] The computer **1302** can receive requests over network **1330** from a client application (for example, executing on another computer **1302**). The computer **1302** can respond to the received requests by processing the received requests using software applications. Requests can also be sent to the computer **1302** from internal users (for example, from a command console), external (or third) parties, automated applications, entities, individuals, systems, and computers.

[0069] Each of the components of the computer **1302** can communicate using a system bus **1303**. In some implementations, any or all of the components of the computer **1302**, including hardware or software components, can interface with each other or the interface **1304** (or a combination of both), over the system bus **1303**. Interfaces can use an application programming interface (API) **1312**, a service layer **1313**, or a combination of the API **1312** and service layer **1313**. The API **1312** can include specifications for routines, data structures, and object classes. The API **1312** can be either computer-language independent or dependent. The API **1312** can refer to a complete interface, a single function, or a set of APIs.

[0070] The service layer **1313** can provide software services to the computer **1302** and other components (whether illustrated or not) that are communicably coupled to the computer **1302**. The functionality of the computer **1302** can be accessible for all service consumers using this service layer. Software services, such as those provided by the service layer **1313**, can provide reusable, defined functionalities through a defined interface. For example, the interface can be software written in JAVA, C++, or a language providing data in extensible markup language (XML) format. While illustrated as an integrated component of the computer **1302**, in alternative implementations, the API **1312** or the service layer **1313** can be stand-alone components in relation to other components of the computer **1302** and other components communicably coupled to the computer **1302**. Moreover, any or all parts of the API **1312** or the service layer **1313** can be implemented as child or submodules of another software module, enterprise application, or hardware module without departing from the scope of the present disclosure.

[0071] The computer **1302** includes an interface **1304**. Although illustrated as a single interface **1304** in FIG. **13**, two or more interfaces **1304** can be used according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. The interface **1304** can be used by the computer **1302** for communicating with other systems that are connected to the network **1330** (whether illustrated or not) in a distributed environment. Generally, the interface **1304** can include, or be implemented using, logic encoded in software or hardware (or a combination of software and hardware) operable to communicate with the network **1330**. More specifically, the interface **1304** can include software supporting one or more communication protocols associated with communications. As such, the network **1330** or the interface's hardware can be operable to communicate physical signals within and outside of the illustrated computer **1302**.

[0072] The computer **1302** includes a processor **1305**. Although illustrated as a single processor **1305** in FIG. **13**, two or more processors **1305** can be used according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. Generally, the processor **1305** can execute instructions and can manipulate data to perform the operations of the computer **1302**, including operations using algorithms, methods, functions, processes, flows, and procedures as described in the present disclosure.

[0073] The computer **1302** also includes a database **1306** that can hold data for the computer **1302** and other components connected to the network **1330** (whether illustrated or not). For example, database **1306** can be an in-memory, conventional, or a database storing data consistent with the present disclosure. In some implementations, database **1306** can be a combination of two or more different database types (for example, hybrid in-memory and conventional databases) according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. Although illustrated as a single database **1306** in FIG. **13**, two or more databases (of the same, different, or combination of types) can be used according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. While database **1306** is illustrated as an internal component of the computer **1302**, in alternative implementations, database **1306** can be external to the computer **1302**.

[0074] The computer **1302** also includes a memory **1307** that can hold data for the computer **1302** or a combination of components connected to the network **1330** (whether illustrated or not). Memory **1307** can store any data consistent with the present disclosure. In some implementations, memory **1307** can be a combination of two or more different types of memory (for example, a combination of semiconductor and magnetic storage) according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. Although illustrated as a single memory **1307** in FIG. **13**, two or more memories **1307** (of the same, different, or combination of types) can be used according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. While memory **1307** is illustrated as an internal component of the computer **1302**, in alternative implementations, memory **1307** can be external to the computer **1302**.

[0075] The application **1308** can be an algorithmic software engine providing functionality according to particular needs, desires, or particular implementations of the computer **1302** and the described functionality. For example, application **1308** can serve as one or more components, modules, or applications. Further, although illustrated as a single application **1308**, the application **1308** can be implemented as multiple applications **1308** on the computer **1302**. In addition, although illustrated as internal to the computer **1302**, in alternative implementations, the application **1308** can be external to the computer **1302**.

[0076] The computer **1302** can also include a power supply **1314**. The power supply **1314** can include a rechargeable or non-rechargeable battery that can be configured to be either user- or non-user-replaceable. In some implementations, the power supply **1314** can include power-conversion and management circuits, including recharging, standby, and power management functionalities. In some implementations, the power-supply **1314** can include a power plug to allow the computer **1302** to be plugged into a wall socket or a power source to, for example, power the computer **1302** or recharge a rechargeable battery.

[0077] There can be any number of computers **1302** associated with, or external to, a computer system containing computer **1302**, with each computer **1302** communicating over network **1330**. Further, the terms "client," "user," and other appropriate terminology can be used interchangeably, as appropriate, without departing from the scope of the present disclosure. Moreover, the present disclosure contemplates that many users can use one computer **1302** and one user can use multiple computers **1302**.

[0078] Implementations of the subject matter and the functional operations described in this specification can be implemented in digital electronic circuitry, in tangibly embodied computer software or firmware, in computer hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Software implementations of the described subject matter can be implemented as one or more computer programs. Each computer program can include one or more modules of computer program instructions encoded on a tangible, non transitory, computer-readable computer-storage medium for execution by, or to control the operation of, data processing apparatus. Alternatively, or additionally, the program instructions can be encoded in/on an artificially generated propagated signal. The example, the signal can be a machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. The computer-storage medium can be a machine-readable storage device, a machine-readable storage substrate, a random or serial access memory device, or a combination of computer-storage mediums.

[0079] The terms "data processing apparatus," "computer," and "electronic computer device" (or equivalent as understood by one of ordinary skill in the art) refer to data processing hardware. For example, a data processing apparatus can encompass all kinds of apparatus, devices, and machines for processing data, including by way of example, a programmable processor, a computer, or multiple processors or computers. The apparatus can also include special purpose logic circuitry including, for example, a central processing unit (CPU), a field programmable gate array (FPGA), or an application specific integrated circuit (ASIC). In some implementations, the data processing apparatus or special purpose logic circuitry (or a combination of the data processing apparatus or special purpose logic circuitry) can be hardware- or software-based (or a combination of both hardware- and software-based). The apparatus can optionally include code that creates an execution environment for computer programs, for example, code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of execution environments. The present disclosure contemplates the use of data processing apparatuses with or without conventional operating systems, for example LINUX, UNIX, WINDOWS, MAC OS, ANDROID, or IOS.

[0080] The methods, processes, or logic flows described in this specification can be performed by one or more programmable computers executing one or more computer programs to perform functions by operating on input data and generating output. The methods, processes, or logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, for example, a CPU, an FPGA, or an ASIC.

[0081] Computer readable media (transitory or non-transitory, as appropriate) suitable for storing computer program instructions and data can include all forms of permanent/non-permanent and volatile/non-volatile memory, media, and memory devices. Computer readable media can include, for example, semiconductor memory devices such as random access memory (RAM), read only memory (ROM), phase change memory (PRAM), static random access memory (SRAM), dynamic random access memory (DRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), and flash memory devices. Computer readable media can also include, for example, magnetic devices such as tape, cartridges, cassettes, and internal/removable disks.

[0082] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of what may be claimed, but rather as descriptions of features that may be specific to particular implementations. Certain features that are described in this specification in the context of separate implementations can also be implemented, in combination, in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations, separately, or in any suitable sub-combination. Moreover, although previously described features may be described as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can, in some cases, be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0083] Particular implementations of the subject matter have been described. Other implementations, alterations, and permutations of the described implementations are within the scope of the following claims as will be apparent to those skilled in the art. While operations are depicted in the drawings or claims in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed (some operations may be considered optional), to achieve desirable results. In certain circumstances, multitasking or parallel processing (or a combination of multitasking and parallel processing) may be advantageous and performed as deemed appropriate.

[0084] Moreover, the separation or integration of various system modules and components in the previously described implementations should not be understood as requiring such separation or integration in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0085] Accordingly, the previously described example implementations do not define or constrain the present disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of the present disclosure.

[0086] Furthermore, any claimed implementation is considered to be applicable to at least a computer-implemented method; a non-transitory, computer-readable medium storing computer-readable instructions to perform the computer-implemented method; and a computer system comprising a computer memory interoperably coupled with a hardware processor configured to perform the computer-implemented method or the instructions stored on the non-transitory, computer-readable medium.

[0087] A number of implementations of these systems and methods have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of this disclosure. Accordingly, other implementations are within the scope of the following claims.

Examples

[0088] In an example implementation, a method for designing variable strength casings for a wellbore in a subsurface formation includes obtaining wireline log data and core sample data from the wellbore; determining stress and strain distributions along the wellbore based on the wireline log data and core sample data; determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions; identifying locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement; and determining a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

[0089] An aspect combinable with the example implementation includes placing casings in the wellbore based on the variable strength casing design.

[0090] In another aspect combinable with any of the previous aspects the wireline log data includes one or more of a density log, a compressional acoustic slowness log, and a shear acoustic slowness log.

[0091] Another aspect combinable with any of the previous aspects includes determining stress and strain distributions based on a poro-elasto-plastic geomechanics model.

[0092] In another aspect combinable with any of the previous aspects, the poro-elasto-plastic geomechanics model includes a three-dimensional finite element model.

[0093] In another aspect combinable with any of the previous aspects, nodes of the three-dimensional finite element model include geomechanical properties derived from the wireline log data and the core sample data.

[0094] In another aspect combinable with any of the previous aspects, the poro-elasto-plastic geomechanics model is discretized based on a minimization of total potential energy.

[0095] In another aspect combinable with any of the previous aspects, identifying locations of potential failure includes identifying locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore.

[0096] In another aspect combinable with any of the previous aspects, determining reservoir displacement includes simulating hydrocarbon production from the reservoir using a reservoir simulator.

[0097] In another aspect combinable with any of the previous aspects, the stress distribution includes body stresses and traction stresses on the wellbore.

[0098] In another example implementation, a system for designing variable strength casings for a wellbore in a subsurface formation includes at least one processor and a memory storing instructions that when executed by the at least one processor cause the at least one processor to perform operations including obtaining wireline log data and core sample data from the wellbore; determining stress and strain distributions along the wellbore based on the wireline log data and core sample data; determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions; identifying locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement; and determining a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

[0099] In an aspect combinable with the example implementation, the operations include placing casings in the wellbore based on the variable strength casing design.

[0100] In another aspect combinable with any of the previous aspects, determining stress and strain distributions is based on a poro-elasto-plastic geomechanics model.

[0101] In another aspect combinable with any of the previous aspects, the poro-elasto-plastic geomechanics model includes a three-dimensional finite element model, wherein nodes of the three-dimensional finite element model include geomechanical properties derived from the wireline log data and the core sample data.

[0102] In another aspect combinable with any of the previous aspects, identifying locations of potential failure includes identifying locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore.

[0103] In another aspect combinable with any of the previous aspects, determining reservoir displacement includes simulating hydrocarbon production from the reservoir using a reservoir simulator.

[0104] In another example implementation, one or more non-transitory, machine-readable storage devices storing instructions for designing variable strength casings for a wellbore in a subsurface formation, the instructions being executable by one or more processors, to cause performance of operations including obtaining wireline log data and core sample data from the wellbore; determining stress and strain distributions along the wellbore based on the wireline log data and core sample data; determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions; identifying locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement; and determining a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

[0105] In an aspect combinable with the example implementation, determining stress and strain distributions is based on a poro-elasto-plastic geomechanics model.

[0106] In another aspect combinable with any of the previous aspects, the poro-elasto-plastic geomechanics model includes a three-dimensional finite element model, where nodes of the three-dimensional finite element model include geomechanical properties derived from the wireline log data and the core sample data.

[0107] In another aspect combinable with any of the previous aspects, identifying locations of potential failure includes identifying locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore.

What is claimed is:

1. A method for designing variable strength casings for a wellbore in a subsurface formation, the method comprising:
- obtaining wireline log data and core sample data from the wellbore;
- determining stress and strain distributions along the wellbore based on the wireline log data and core sample data;
- determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions;
- identifying locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement; and
- determining a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

2. The method of claim **1**, further comprising:
- placing casings in the wellbore based on the variable strength casing design.

3. The method of claim **1**, wherein the wireline log data comprises one or more of a density log, a compressional acoustic slowness log, and a shear acoustic slowness log.

4. The method of claim **1**, wherein determining stress and strain distributions is based on a poro-elasto-plastic geomechanics model.

5. The method of claim **4**, wherein the poro-elasto-plastic geomechanics model comprises a three-dimensional finite element model.

6. The method of claim **5**, wherein nodes of the three-dimensional finite element model comprise geomechanical properties derived from the wireline log data and the core sample data.

7. The method of claim **4**, wherein the poro-elasto-plastic geomechanics model is discretized based on a minimization of total potential energy.

8. The method of claim **1**, wherein identifying locations of potential failure comprises identifying locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore.

9. The method of claim **1**, wherein determining reservoir displacement comprises simulating hydrocarbon production from the reservoir using a reservoir simulator.

10. The method of claim **1**, wherein the stress distribution comprises body stresses and traction stresses on the wellbore.

11. A system for designing variable strength casings for a wellbore in a subsurface formation, the system comprising:
- at least one processor and a memory storing instructions that when executed by the at least one processor cause the at least one processor to perform operations comprising:
  - obtaining wireline log data and core sample data from the wellbore;
  - determining stress and strain distributions along the wellbore based on the wireline log data and core sample data;
  - determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions;
  - identifying locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement; and
  - determining a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

12. The system of claim **11**, further comprising:
- placing casings in the wellbore based on the variable strength casing design.

13. The system of claim **11**, wherein determining stress and strain distributions is based on a poro-elasto-plastic geomechanics model.

14. The system of claim **13**, wherein the poro-elasto-plastic geomechanics model comprises a three-dimensional finite element model, wherein nodes of the three-dimensional finite element model comprise geomechanical properties derived from the wireline log data and the core sample data.

15. The system of claim **11**, wherein identifying locations of potential failure comprises identifying locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore.

16. The system of claim **11**, wherein determining reservoir displacement comprises simulating hydrocarbon production from the reservoir using a reservoir simulator.

17. One or more non-transitory, machine-readable storage devices storing instructions for designing variable strength casings for a wellbore in a subsurface formation, the instructions being executable by one or more processors, to cause performance of operations comprising:
- obtaining wireline log data and core sample data from the wellbore;
- determining stress and strain distributions along the wellbore based on the wireline log data and core sample data;
- determining reservoir displacement of a reservoir in the subsurface formation based on the stress and strain distributions;
- identifying locations of potential failure of well casings in the wellbore based on the stress and strain distributions and the reservoir displacement; and
- determining a variable strength casing design for the wellbore with higher strength casing in the locations of potential failure relative to casing in other locations in the wellbore.

18. The one or more non-transitory, machine-readable storage devices of claim **17**, wherein determining stress and strain distributions is based on a poro-elasto-plastic geomechanics model.

19. The one or more non-transitory, machine-readable storage devices of claim **18**, wherein the poro-elasto-plastic geomechanics model comprises a three-dimensional finite element model, wherein nodes of the three-dimensional finite element model comprise geomechanical properties derived from the wireline log data and the core sample data.

20. The one or more non-transitory, machine-readable storage devices of claim **17**, wherein identifying locations of potential failure comprises identifying locations along a trajectory of the wellbore having higher stress states relative to other stress states along the trajectory of the wellbore.

* * * * *