Deep Resources Engineering 3 (2026) 100200

Contents lists available at ScienceDirect

Deep Resources Engineering

journal homepage: www.keaipublishing.com/en/journals/deepre/

Review

Casing damage in oil and water wells: Causes and prevention

Jiang-Feng Liu [a], Xin-Yue Zhang [a,*], Li-Yuan Yu [a,*], Xiao-Liang Wang [b], Yun-Hu Lu [c], Zi-Hao Zhang [a], Zhi-Jie Jian [a]

[a] State Key Laboratory of Intelligent Construction and Healthy Operation and Maintenance of Deep Underground Engineering, China University of Mining and Technology, Xuzhou 221116, China
[b] Tarim Oilfield Company, PetroChina, Korla, Xinjiang 841000, China
[c] College of Petroleum Engineering, China University of Petroleum, Beijing, Beijing 102249, China

ARTICLE INFO

Keywords:
Casing damage in oil and water wells
Causes of casing damage
Preventive measures
Treatment measures

ABSTRACT

Casing damage represents a persistent and multifaceted challenge in oil and gas development, often manifesting as structural deformation, rupture, or seal failure. These issues not only compromise well integrity and production continuity but also pose environmental risks through potential hydrocarbon leakage. Despite extensive operational experience, the mechanisms underlying casing damage at various development stages remain poorly understood. This study presents a systematic investigation into the types and causes of casing damage arising during drilling, cementing, perforation, and water injection operations. It identifies the complex interplay among stress variations, thermal fluctuations, corrosive fluids, and mechanical disturbances as key contributors to casing failure. What distinguishes this work is its integrative analysis of stage-specific damage mechanisms, including cement slurry discontinuity, rock slippage due to injection-induced stress changes, and corrosion from high-salinity fluids. The study proposes targeted preventive and remedial strategies tailored to distinct damage types and operational contexts—such as enhanced casing materials, optimized perforation techniques, and dynamic injection control. For wells already affected, adaptive repair methods like plastic deformation shaping and precision sealing are examined for their effectiveness. By bridging engineering practice with a mechanistic understanding of casing failure, this research provides actionable insights for mitigating casing damage. Furthermore, it presents a forward-looking vision in which artificial intelligence and data-driven diagnostics facilitate predictive maintenance and intelligent field management, thereby improving oilfield safety, longevity, and productivity.

1. Introduction

During oil and gas field development, casing damage is a common and serious engineering issue. It not only significantly increases operational costs but also disrupts the injection-production balance, reduces production capacity, and can trigger safety and environmental incidents such as oil and gas leaks, posing a severe threat to the long-term stability of field operations. Statistics show that approximately 7 % of oil wells in countries such as Canada, China, the Netherlands, Norway, the United Kingdom, and the United States exhibit at least one type of casing damage [1]. In China, for instance, casing deformation was predominant in the early stages of the Daqing Oilfield development. With increasing production intensity, localized deformation gradually evolved into more severe failures such as casing rupture and sealing failure. Since 2000, the problem has worsened, with large-scale casing damage occurring in some areas, reaching a maximum failure rate of 28.5 % [2]. To date, approximately 30,000 wells in major oilfields such as Daqing, Jilin, and Shengli have been affected by casing damage, and the casing failure rate in the Tarim Oilfield has also shown a continuous upward trend, reaching 15.8 % [3]. In one Iranian oilfield, over 18 % of wells have experienced casing collapse due to reservoir compaction, salt rock creep, and poor cement bonding since 1974 [4].

Casing failures manifest in various forms, including casing deformation (e.g., bending, diameter reduction, unilateral flattening) [5,6]; casing rupture (e.g., offset joints, longitudinal cracks, circumferential cracks) [7–9]; corrosion damage (such as CO_2 corrosion, sulfide corrosion, and bacterial corrosion)[10–12]; and sealing failures (e.g., thread leakage, cement sheath debonding, and formation of micro-annular channels)[13–15]. These damages typically result from a combination of formation stress, thermal stress, corrosion, and improper operational

---

* Corresponding authors.
E-mail addresses: zhangxinyue@cumt.edu.cn (X.-Y. Zhang), yuliyuan@cumt.edu.cn (L.-Y. Yu).

https://doi.org/10.1016/j.deepre.2025.100200
Received 27 February 2025; Received in revised form 9 June 2025; Accepted 10 June 2025

practices, characterized by sudden onset and complex evolution mechanisms.

As illustrated in Fig. 1, the causes of casing damage are multifaceted, often resulting from the interaction of various geological and operational factors. From a mechanical perspective, geological changes such as stress concentration in surrounding rocks, mudstone softening due to water absorption (Fig. 1b), salt rock creep, fault slip (Fig. 1c), and overburden subsidence can induce casing bending and shear failure. Additionally, cyclic loading caused by alternating injection and production operations often leads to fatigue damage in the casing string [16–18]. During drilling, axial loads and lateral disturbances may lead to mechanical failures. During cementing, poor slurry properties, inadequate sealing, and annular channeling can compromise sealing integrity, resulting in crossflow, leakage, and other wellbore problems (Fig. 1d) [19]. In the perforation stage, high-density perforation generates high pressures that can damage the wellbore structure and cause compression and shear deformation in the cement sheath around perforation tunnels, weakening casing protection and potentially displacing the casing string (Fig. 1e). Corrosion (Fig. 1a) caused by chemicals and microorganisms such as sulfate-reducing bacteria (SRB), thiogenic bacteria (TGB), and iron bacteria (FB) is also significant, especially in CO_2 and H_2S-rich reservoirs where rapid corrosion can lead to casing perforation and rupture [20–23]. During production, casing damage may also occur due to reservoir compaction, sand production (Fig. 1f), and thermal stresses induced by high- or low-temperature fluids [23]. In offshore heavy oil thermal recovery wells, the injection of high-temperature fluids and recovery of low-temperature fluids reduce casing material yield and tensile strength, causing localized casing deformation and eventual failure by deformation, rupture, corrosion, or wear [24,25]. In CO_2-enhanced oil recovery (EOR) processes, the injection of low-temperature liquid CO_2 can cause annular fluid freezing, resulting in volume expansion and casing-tubing failures [26]. If not detected and mitigated in time, such damages pose not only operational risks but also environmental hazards such as groundwater contamination, soil infiltration, and toxic fluid leakage, leading to long-term ecological impacts [27].

Considering the complexity and dynamic nature of casing damage, a comprehensive, full-cycle prevention and control strategy should be implemented. Prevention efforts should focus on optimizing casing material and structural design, improving cementing quality, and enhancing operational control [28–30]. For remediation, corresponding techniques should be applied based on the type of damage: deformation can be addressed by explosive or mechanical reshaping; severe rupture or corrosion may require inner casing placement or plugging operations; and sealing failures can be repaired using high-strength plugging materials [31–33]. Furthermore, real-time monitoring technologies such as fiber optic sensing and acoustic emission detection can improve the early-stage detection and diagnosis of casing damage [34,35].

Although several previous reviews have discussed specific types of casing damage or individual preventive methods, a systematic and comprehensive review covering casing damage types, mechanisms, evolution processes, and mitigation strategies remains lacking, especially concerning the integration of geological, engineering, and environmental factors. Therefore, this paper systematically summarizes recent advances and practical experiences in casing damage diagnosis, prevention, and remediation, in terms of damage types, underlying mechanisms, and technical approaches, and outlines potential directions for future research. This study aims to provide theoretical support and technical reference for improving the safety, cost-effectiveness, and sustainability of oilfield development.

2. Types of casing damage

2.1. Deformation

Casing deformation, also known as radial plastic deformation, is typically caused by axial stress variations due to in-situ stress changes or by external extrusion pressure exceeding internal pressure [1]. This may

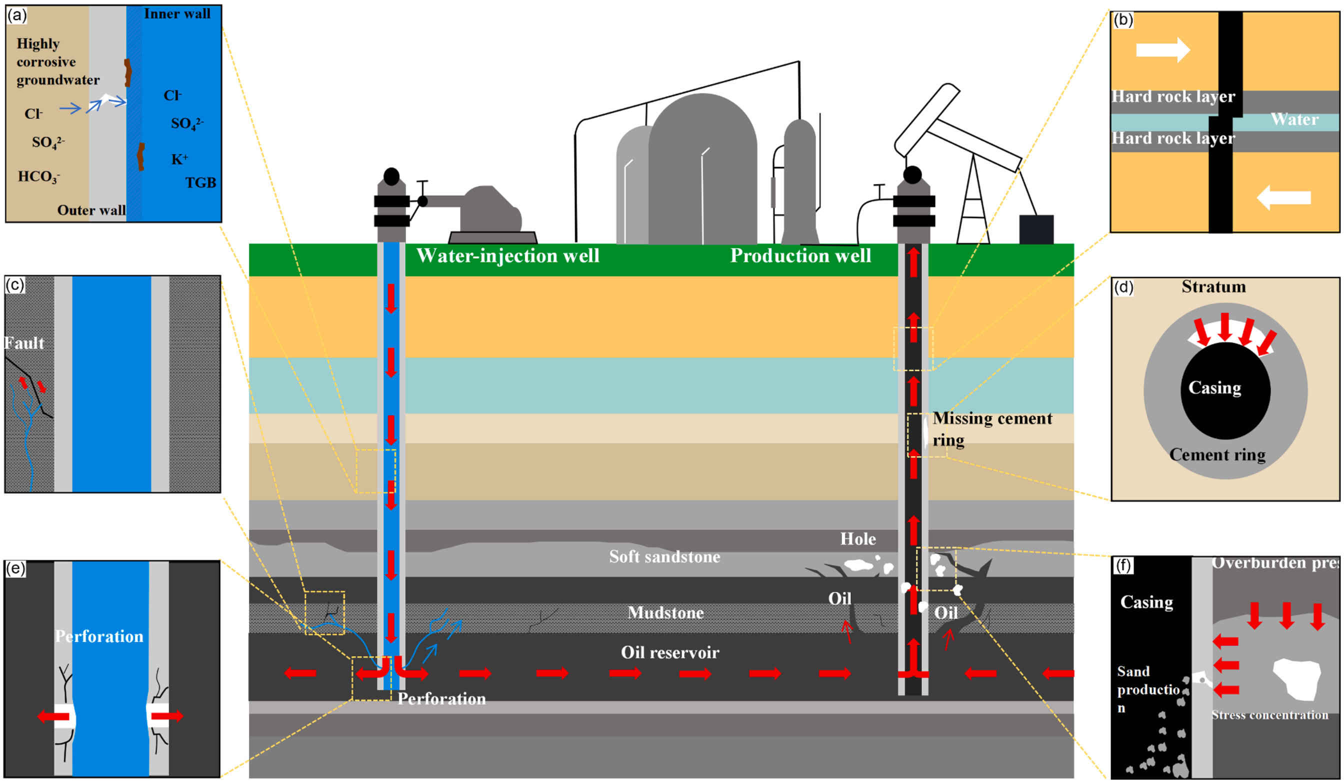

Fig. 1. Mechanism of sheath loss in oil and water wells.

result in bending, diameter reduction, or unilateral extrusion of the casing, as illustrated in Fig. 2. Specifically, ovalization arises from uneven stress distribution in the underground rock formations, which creates non-uniform radial stress around the casing, causing the cross-section to deform into an elliptical shape. This phenomenon is commonly observed in mudstone formations. Bending deformation refers to the axial deviation of the casing under unidirectional force, often accompanied by ovalization, which reduces its load-bearing capacity. It is primarily attributed to factors such as sand production, formation deformation, and metal fatigue. Diameter reduction occurs when the casing is exposed to significant tensile or localized compressive loads, resulting in a reduced internal diameter compared to its original size. This typically occurs in water-saturated mudstone formations, where the swelling of mudstone exerts external compressive or axial tensile forces on the casing. Unilateral extrusion is induced by lateral forces or concentrated loads exerted from a specific direction within the formation, leading to localized compression on one side of the casing's cross-section[36].

2.2. Rupture

Casing rupture, as illustrated in Fig. 3, refers to the development of perforations or fractures in the casing wall, resulting from poor material quality, internal stress effects, severe sand production, or long-term corrosion. Misalignment and fracture occur when casing rupture causes displacement and overlapping deformation between the upper and lower wellbores. This can be categorized as non-collapse misalignment, typically caused by rock layer sliding due to mudstone swelling, and collapse misalignment, which is primarily induced by geological phenomena such as fault slippage and crustal movement [38]. The latter generates significant in-situ stress, leading to cement sheath failure and borehole collapse. Once the cement sheath fractures, debris such as cement fragments, mud, and fine sand may be pushed into the wellbore under formation pressure, complicating repairs. Under uneven loading conditions, casing misalignment may involve angular displacement in the circumferential direction or radial displacement in the transverse direction, resulting in a form of multi-directional deformation known as casing torsional misalignment [39].

Another common form of casing rupture is corrosion-induced perforation, which occurs when the casing is exposed to corrosive agents found in formation water, oil-phase liquids, and acidic solutions during drilling and production. The severity of corrosion is influenced by temperature and pressure, with corrosion most frequently occurring during the water injection and production stages. Additionally, casing splitting can manifest as either longitudinal or circumferential fractures [40]. Longitudinal splitting is typically caused by perforation operations or internal pressure acting on substandard casing materials, resulting in fractures parallel to the casing axis. In cases where the casing undergoes end expansion failure, it deforms outward at its ends. If expansion failure does not occur, circumferential cracks may develop along the casing wall.

Early research on casing shear failure primarily focused on the buckling behavior of casings under geometrical imperfections. Huang et al. (2000) predicted the ultimate compressive strength of geometrically imperfect casings using the finite element method (FEM) and validated the accuracy and reliability of the model through full-scale experimental tests [42]. Subsequent studies by domestic and international scholars systematically investigated the deformation and buckling behavior of casing structures with various geometrical cross-sections—such as square, rectangular, elliptical, and conical hollow sections [43–45]. Their findings demonstrated that structural geometry significantly influences the load-bearing capacity of the casing. These studies laid a theoretical foundation and provided technical support for understanding casing damage mechanisms and shear failure behavior under complex stress conditions. In recent years, researchers have continued to advance the theoretical and experimental investigation of casing failure. Based on the modified elastic modulus approaches and the unified twin-shear strength theory, new mechanical models have been developed to analyze coiled tubing failures, further enhancing the evaluation framework for casing integrity [46,47].

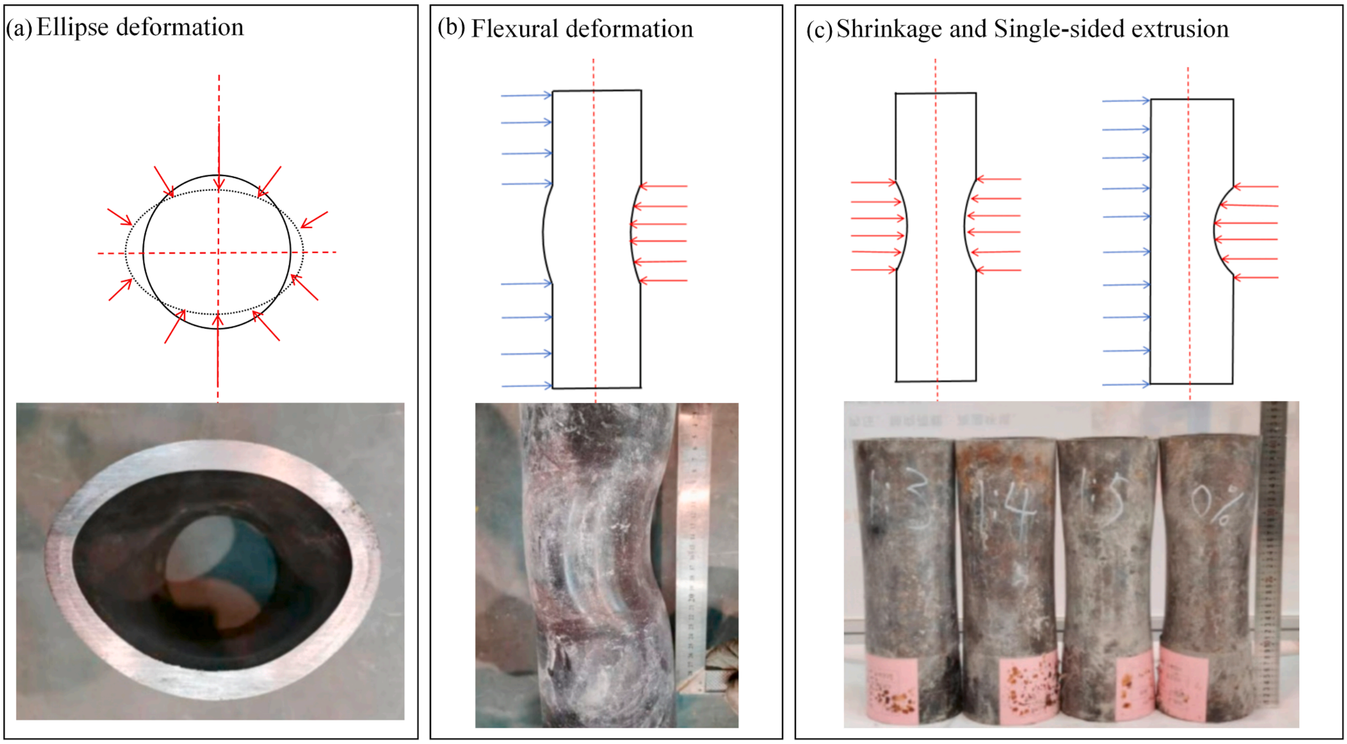

Fig. 2. Types of casing deformation and related case examples[37].

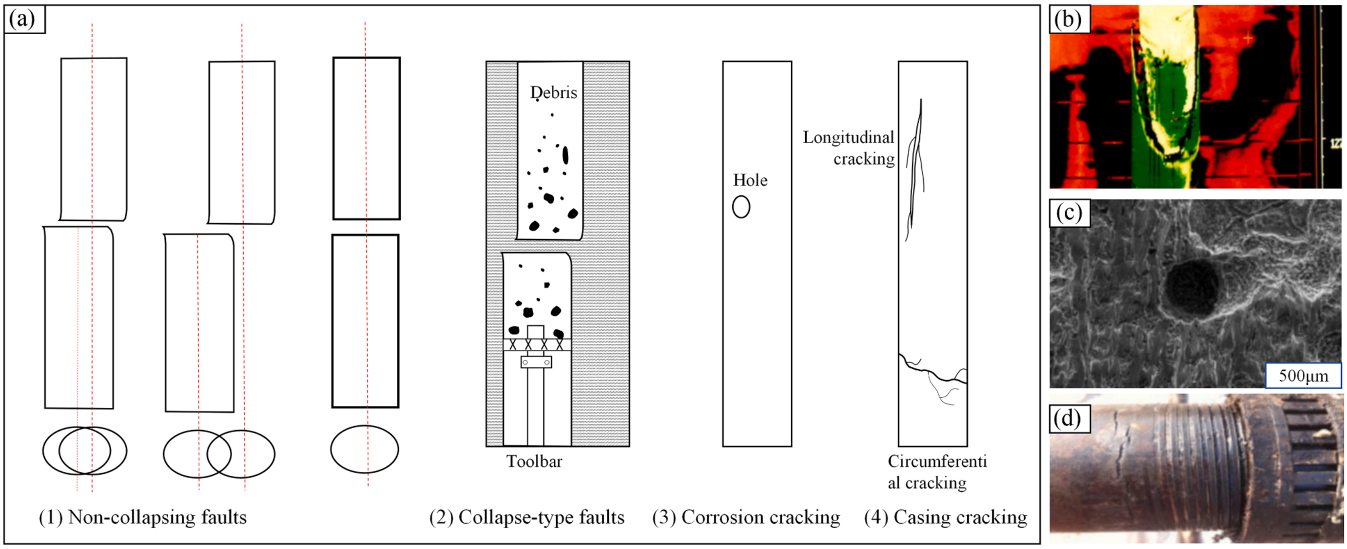

Fig. 3. Types of casing failure: (a) schematic diagram; (b) three-dimensional view of casing shear failure; (c) SEM image of corrosion-induced fracture; (d) field case image of casing failure[20,26,41].

2.3. Sealing damages

Seal failures in casing systems, frequently encountered during oil and gas extraction, are primarily attributed to mismatched threads, thread disengagement, inadequate sealing, cement sheath debonding, and the formation of micro-annular channels. As exploration extends into deeper and more complex reservoirs, premium threaded connections (PTCs) in tubing and casing must withstand extremely high combined loads. Under such demanding conditions, sealing failures frequently occur [13,14]. Field evidence from numerous oilfields indicates that seal failure often originates from damage to the primary sealing surface, which evolves into a leakage path [48]. Currently, stress evaluation methods for casing threads include analytical approaches, experimental techniques, and finite element analysis (FEA). Researchers have derived formulas for circumferential stress, radial stress, and contact pressure in threaded connections [49–51]. Within the elastic range, the performance of casing threads can be assessed under both static and dynamic loads. In recent years, Lian et al. have conducted fatigue fracture analyses of casing threads using FEA to investigate variations in thread stress [52]. Mou et al. developed an axisymmetric FEA model for BEAR threads based on elastoplastic mechanics, enabling quantitative and comprehensive evaluation of thread stresses in high-pressure gas wells [53].

3. Causes of casing damage

Casing damage is a common and complex engineering issue in oil and gas extraction, occurring at various stages of oilfield development and influenced by multiple factors. During the drilling and cementing stages, rock pressure, formation temperature, formation fluid activity, and cementing quality can all contribute to casing damage. During the perforation stage, the application of high pressure and the resulting stress concentration, especially around perforation holes, significantly compromises the structural integrity of the casing. This degradation in mechanical performance reduces its protective capacity and accelerates the progression of casing damage. During the water injection phase, excessive injection pressure, casing corrosion, shale swelling due to water absorption, and fluid-solid coupling effects can exacerbate casing deformation and failure. Additionally, fault reactivation and rock layer slippage often lead to casing misalignment and rupture. In the oil and gas extraction phase, sand production and reservoir compaction also present significant threats to casing integrity. In weakly cemented sandstone formations, sand production exposes the casing to a combination of formation stress and hydrodynamic forces, causing stress concentration and leading to casing bending and deformation. Overall, the causes of casing damage involve complex geological, engineering, and chemical factors that interact with one another, necessitating comprehensive preventive and remedial measures (Table 1).

3.1. Drilling stage and cementing stage

During the drilling and cementing stages, casing damage can be caused by rock pressure, formation temperature, formation fluid activity, cement sheath loss, improper plugging treatments, and poor cementing quality. Drilling disrupts the stable geo-stress field, releasing rock stress that exceeds the pre-drilling state, which can lead to casing deformation under rock mass stress [63]. In addition to rock pressure, formation temperature, and fluid activity also contribute to casing damage. A significant temperature difference between the inner and outer casing walls can induce thermal expansion and contraction effects, increasing interfacial stress, particularly at casing joints, and leading to fatigue failure. Statistics indicate that in cyclic steam wells, 85 % of failures occur at the connections, while the remaining cases are attributed to casing damage caused by poor joint alignment[64]. As the internal casing temperature rises with fluid inflow, thermal expansion occurs, while fluid outflow results in rapid cooling and contraction, inducing additional deformation. Simulation results indicate that the cement adjacent to the casing is also prone to tensile cracking during heating and cooling processes, which is detrimental to the integrity of oil and water wells[65]. In formations characterized by plastic flow and creep, such as shale and salt rock layers, or in deep, high-temperature, and high-pressure environments [54], the casing may undergo ovalization and shrinkage [55]. Furthermore, central casing wear affects casing integrity and mechanical strength, potentially leading to severe deformation, failure, or well abandonment [56,57].

Cementing quality directly influences both oil and gas production and longevity. Borehole diameter variations, casing eccentricity, and discontinuous cementing operations can lead to localized cement sheath loss. Under thermal stress, the casing is more likely to deform in areas lacking cement support. Studies using finite element models have examined the impact of cement sheath loss on casing deformation [69]. As shown in Fig. 4a, research indicates that when the cement sheath loss angle is between 30° and 40°, the casing experiences peak equivalent stress. As the loss angle increases, casing stress decreases, and when the

Table 1
Summary of casing failure types and causes in different stages of oilfield development.

Stage	Possible types of casing damage	Causes	Countermeasures	References
Drilling and cementing	Bending deformation, elliptical deformation, diameter reduction, casing failure, loss of wellbore integrity	Release of rock stress; formation temperature, pressure, and fluid effects; poor cementing quality, interface debonding between the cement sheath and casing.	Optimization of casing performance; improvement of cement slurry properties.	[54–57]
Perforation	Bending deformation	High pressure generated by high-density perforation sometimes damages the wellbore and cement sheath.	Select appropriate perforation techniques based on specific geological factors and construction conditions.	[6,58]
Water injection development	Casing deformation, casing buckling, corrosion-induced rupture	Casing corrosion; water absorption and expansion of mudstone and salt layers; fluid-solid coupling in permeable rocks; fault reactivation	Apply anti-corrosion coatings to the casing; use corrosion inhibitors; add corrosion-resistant additives to cement slurry; control injection pressure	[59,60]
Oil and gas production	Casing deformation, casing buckling, corrosion-induced rupture	Sand production from the reservoir; reservoir compaction	Chemical, mechanical, and composite materials for sand control	[61,62]

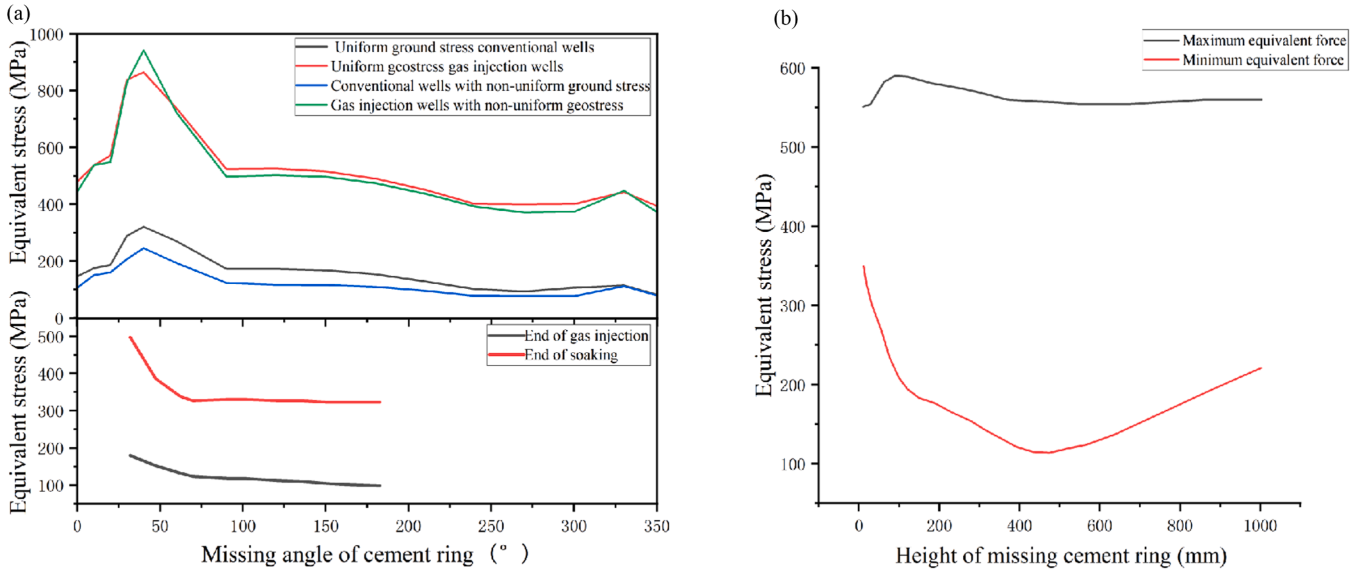

Fig. 4. Effect of missing angle of cement ring and missing cement ring height on casing stress: (a) missing angle of cement ring [66,67]; (b) missing cement ring height on casing stress [68].

cement sheath is fully lost, the casing is no longer affected by thermal stress [70,71]. As shown in Fig. 4b, the maximum casing stress occurs when the missing height of the cement sheath is approximately 80 mm. Additionally, the stresses on the missing sections are nearly equal, regardless of the variation in missing heights [68]. At the same time, factors such as a missing cement ring, increased casing eccentricity and reduced residual drilling fluid pressure can cause debonding at the interface between the cement sheath and the casing [19,72]. This debonding forms an interfacial annulus, compromising wellbore integrity, promoting corrosion, and reducing casing strength.

3.2. *Perforation stage*

Perforation is a critical step in oil and water well production. After cementing, perforation techniques such as overbalanced and underbalanced perforation are used to create channels between the formation and wellbore. High-density perforation can generate excessive pressure, damaging the wellbore structure and inducing compression and shear deformation in the cement sheath. Stress concentration effects cause localized failure of the cement sheath at perforation holes, weakening casing protection and potentially altering the casing string position [6,58]. Scholars have used finite element models to study the effects of hole diameter, hole density, and hole distribution on casing strength. These studies indicate that an increase in hole diameter intensifies stress concentration at the perforation site. However, increasing hole density can alleviate stress concentration at the perforation itself, but it may also exacerbate stress between adjacent perforations. Therefore, selecting an appropriate hole density is crucial. The influence of phasing on the casing shows limited regularity [73,74], but closer circumferential spacing between perforation holes results in more severe local damage to the casing [75]. For the same parameters, smaller casing diameters and greater casing thicknesses lead to higher residual casing strength after perforation [76]. For thermal recovery wells, Geng et al. conducted transient thermal simulations to analyze the impact of thermally induced stresses on casing integrity. Their results confirmed that during the perforation stage, casings are subjected to alternating high-temperature and high-pressure loads, with thermal stress being a key factor contributing to casing damage [77].

3.3. *Casing damage during water injection development*

During water injection, injected water may enter formations through leakage pathways, causing casing corrosion, shale, and salt rock swelling, fluid-solid coupling effects, and fault reactivation, leading to casing damage. High-pressure water injection increases stress on the casing and cement sheath, potentially inducing casing deformation and dislocation [78].

3.3.1. *Corrosion of casing*

In different corrosive environments, the causes and mechanisms of casing corrosion are different, in addition to the quality of the casing itself; the high concentration of ions in the extraction fluid in Table 2 and the interaction of microorganisms, CO_2, H_2S, etc. all cause the casing to be corroded, which is common in oil and gas extraction. As shown in Fig. 5, casing corrosion is widespread in oil and gas extraction and can be classified into internal and external corrosion. Internal corrosion occurs predominantly in high-water-cut oilfields, under the catalytic promotion of sulfate-reducing bacteria (SRB), saprophytic bacteria (TGB), and ferro-bacteria (FB), a series of chemical reactions occur in the ions such as Cl^-, SO_4^{2-}, K^+, and HCO_3^- in the highly corrosive extraction fluid [59,60], which makes the inner wall of the casing be corroded. External corrosion, on the other hand, is prevalent in oilfields and is mainly formed by the combined effects of CO_2 [81], highly corrosive formation water [82], H_2S [83], and elemental sulfur [20], with the corrosion products dominated by $FeCO_3$, Fe_3O_4, and FeS. Among the corrosion mechanisms, sulfide-induced corrosion can generate hydrogen atoms that diffuse into the steel matrix and subsequently recombine into hydrogen molecules, thereby inducing hydrogen embrittlement. This phenomenon reduces the mechanical strength of the casing, potentially leading to structural failure and compromising oil and gas production operations. Notably, steels with higher strength levels exhibit greater hydrogen diffusion coefficients and elevated concentrations of diffusible hydrogen, resulting in increased susceptibility to hydrogen embrittlement [84].

Casing corrosion mechanisms vary depending on environmental conditions. Besides casing material defects, interactions between high-concentration ions in produced fluids and microorganisms, CO_2, and H_2S contribute to corrosion. As shown in Fig. 5, casing corrosion is widespread in oil and gas extraction and can be classified into internal and external corrosion. Internal corrosion occurs predominantly in high-water-cut oilfields, where sulfate-reducing bacteria (SRB), saprophytic bacteria (TGB), and ferric bacteria (FB) catalyze chemical reactions involving Cl^-, SO_4^{2-}, K^+, and HCO_3^- [59,60]. External corrosion is common in oilfields and results from CO_2 [81], highly corrosive formation water [82], H_2S [83], and sulfur compounds [20], producing corrosion products such as $FeCO_3$, Fe_3O_4, and FeS. Sulfide corrosion introduces hydrogen atoms into steel, leading to hydrogen embrittlement, reducing casing strength, and increasing failure risks. The higher the steel strength, the greater the hydrogen diffusion coefficient, making high-strength materials more susceptible to hydrogen embrittlement [84].

3.3.2. *Softening of mudstone by water absorption*

In normally consolidated sandstone formations, the injection of water does not significantly alter the integrity of the rock matrix, and the in-situ stress conditions remain largely stable[85]. However, when water is injected into mudstone formations, the mudstone undergoes hydration-induced softening and swelling, resulting in significant changes in its mechanical properties. With increasing moisture content, the elastic modulus and strength of mudstone decrease sharply, while the Poisson's ratio and internal friction angle increase [86]. The stress-strain curve becomes more flattened, the failure mode transitions from tensile splitting to shear failure, and the extent of plastic deformation increases [87]. Simultaneously, the creep strain rate, steady-state creep rate, and heterogeneity in creep loading also rise, imposing substantial loads on both the casing and surrounding strata, which may lead to casing collapse[88,89].

Scholars have extensively studied the mechanisms of mudstone swelling and softening upon water absorption, as well as the corresponding mechanical behavior. Wang et al. employed the Finite-Discrete

Table 2
Ion concentration content and microbial content of the extracted fluid in different blocks[79,80].

Block	Casing damage	Total ion concentration (mg/L)								Microbial content (cells/mL)		
		K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	S^{2-}	SRB	TGB	FB
A	Yes	12700	140	1645	346	21843.23	7424.73	1562.11	60	2.0	2.5 × 103	2.5 × 103
A	No	15250	90	759	368	25742.02	7676.34	1751.27	—	0.6	0.6	0.6
B	Yes	3825	125	1039	178	9746.98	6930.52	1409.56	—	2.5	2.5	2.5
B	No	18325	92.5	52.75	168.5	23592.68	—	—	—	0	0	0
C	Yes	91	9038.1	79.2	24.6	7722.9	4350	217.6	414.2	104	102	103

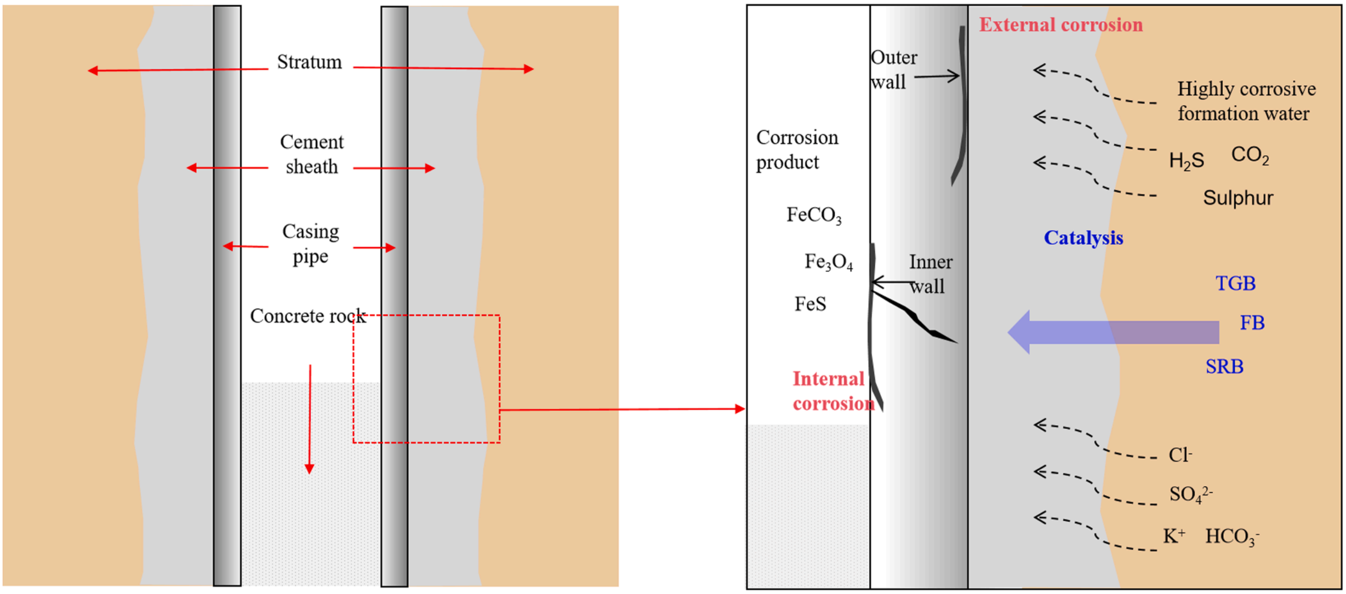

Fig. 5. Schematic diagram of casing corrosion.

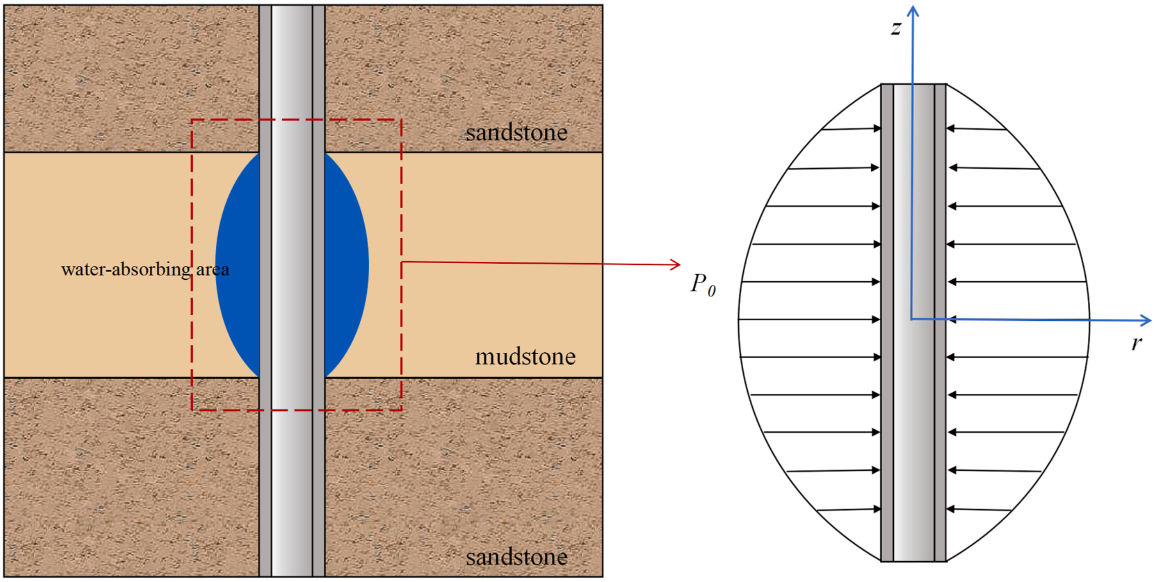

Fig. 6. Schematic diagram of casing load under mudstone hydration and softening[89].

Element Method (FDEM), combined with uniaxial, triaxial compression, and swelling tests, to investigate the expansion behavior, mechanical response, and failure modes of water-affected mudstone [90]. Lu et al. found through a series of hydration and uniaxial compression experiments that the mineral composition, cementation type, and water temperature significantly affect the mechanical behavior of mudstone [91]. When evaluating the impact of formation stress on casing loads, a simplified assumption is often made that the local load on the casing is linearly distributed to facilitate analysis [92]. However, after mudstone swells upon water uptake, local expansion generates high pressures, and the axial load on the casing first increases and then decreases. Chen et al. proposed a new method to predict casing stress in locally expanding mudstone formations. By integrating theoretical derivation with finite element analysis (Fig. 6) under parabolic loading, they derived an analytical solution for casing stress in such formations [89]. Additional finite element studies on casing and cement sheath behavior in viscoelastic mudstone indicate that the compressibility of both mudstone and cement materials must be accounted for when calculating casing loads [93].

3.3.3. *Fluid-solid coupling effect and reactivation of fault*

According to studies on fluid-solid coupling effects, plastic deformation or creep induced by injection-induced pore pressure buildup is one of the primary causes of casing damage in oil-bearing formations. The severity of casing damage increases with lower casing yield strength, higher rock strength, and greater formation permeability, all of which contribute to elevated compressive stress. As injection pressure increases, the casing exhibits a more rapid rate of elastic deformation, and plastic deformation occurs earlier, thereby significantly increasing the likelihood of damage occurrence [2,94,95]. Based on fluid-solid coupling theory, Liu et al. simulated the variation in Mises stress of N80 casing during the injection phase and proposed injection pressure control strategies to mitigate casing damage [96].

Comprehensive effects of crustal movement, natural disasters, and the water injection phase may lead to fault reactivation and stratum slippage [97,98]. These phenomena can cause casing fractures (Fig. 7). Water injection acts as a lubricant on fault surfaces, reducing the rock's shear strength and concentrating stress near the fault plane, which may induce casing yield [99]. During high-pressure water injection development, when the injection pressure is far higher than the formation fracture pressure or even the overlying rock pressure, the phenomenon of stratum slippage becomes more severe. There is a clear linear positive correlation between stratum slippage and casing deformation. When the slip interface forms a 90° angle with the wellbore, the deformation of the casing reaches its maximum[85,100].

Regarding the mechanisms of fault slip, Hao et al. investigated fault reactivation and slip behavior using the cohesive contact method based on the traction-separation law (TSL). Lele et al. combined the Mohr-Coulomb theory with finite element methods to analyze the impact of injection and production activities on fault activity. Zhao et al. examined formation slippage induced by cold water injection into thermally active faults, concluding that fault stability is highly dependent on the bonding conditions of the fault plane. Even under initially stable conditions, thermal contraction effects may trigger fault slip [101–103]. To further explore the influence of temperature on injection-induced fault slip, Shen et al. conducted a series of shear slip experiments, showing that elevated temperatures reduce fault stability and promote slip. Shao et al. developed a simplified 3DEC numerical model to simulate the hydraulic responses during fault reactivation [104]. Frederic et al. experimentally measured the relationship between fault displacement and fluid

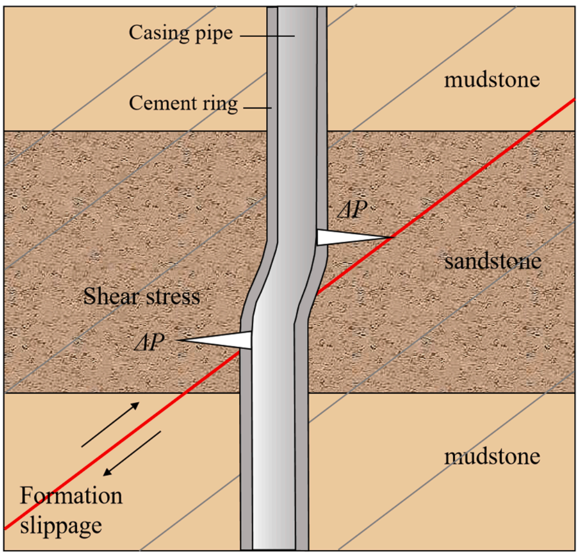

Fig. 7. Schematic diagram of casing damage caused by fault reactivation and formation slippage.

pressure, revealing how fluid-solid coupling mechanisms can induce stable fault creep during injection processes [105]. Wang et al. conducted injection experiments on high-permeability sandstone samples under critical stress conditions and found that total torque release is primarily determined by the total injected fluid volume, rather than the slip behavior itself [106]. Additionally, Zhu et al., using the deep geothermal reservoir in Rongcheng as a case study, analyzed the influence of porosity and permeability on fault instability risk induced by fluid injection. Their findings suggest that long-term water injection may elevate the ambient thermoelastic stress levels, thereby pushing critically or subcritically stressed faults toward instability [107]. In summary, injection-induced fault slip is one of the key mechanisms behind casing damage. Effective control and accurate prediction of this phenomenon are essential for maintaining casing integrity and ensuring the safe and efficient development of oilfields.

3.4. *Oil and gas exploitation stage*

In the oil and gas extraction stage, common causes of casing damage include sand production from the reservoir and reservoir compaction. Sand production typically occurs in weakly cemented, unconsolidated sandstone reservoirs. This typically occurs when the perforation structure is compromised, and the combined effects of fluid drag and formation stress [61] transport fragmented rock particles along with the oil and formation fluids through the perforated interval. When there is a small amount of sand production, the skeleton structure of the sandstone is damaged, and small cavities form near the perforation holes. These cavities induce local stress concentrations. If the applied stress remains below the casing's critical deformation threshold, no significant deformation will occur [62]. As shown in Fig. 8, as the cavities expand, the stress propagates to the casing, causing bending and deformation. When significant sand production occurs, the overlying formation loses support from the underlying rock layers. Under vertical stress, deformation is triggered, which can lead to further collapse. Ultimately, this results in the formation of an arch-shaped surface in the overlying rock [108]. This may cause elliptical deformation or unidirectional flattening of the casing. In severe cases, the casing may rupture or collapse completely [109]. In later stages, when sand production is minimal or absent, corrosion can reduce the casing wall thickness. As the critical force for casing deformation decreases, the casing will deform once the applied stress exceeds this threshold.

Oil formation compaction refers to the phenomenon of consolidation and compression of subsurface loose structures as well as sediments under overlying loads, with water expelled and volume reduced. Oil formation compaction changes the original nature and stress state of the rock, the external load of the casing increases, and the casing bends or even breaks under the induced tensile and shear forces [100,110]. In addition to the above two common causes of sleeve damage, the casing stress changes and wellbore temperature changes during oil and gas production affect the integrity of the cement ring and increase the risk of casing damage. Lower casing stress during the production phase decreases the tension hoop stress, and hoop stress during the injection phase increases with casing stress, increasing the risk of radial casing fracture [111]. Increased wellbore temperature reduces the sealing ability of the cement sheath, affecting the integrity of the entire well and causing corrosion breakage of the casing, and decreased wellbore temperature may lead to failure of the casing-cement sheath interface, which will directly lead to annular gas flux [112].

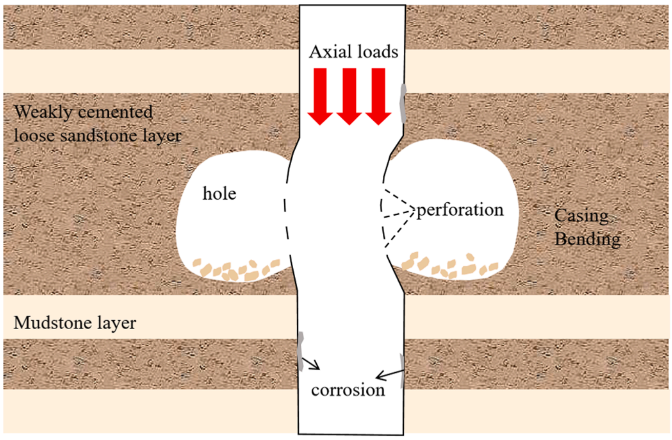

Fig. 8. Schematic diagram of oil formation out of sand.

4. Response measures

4.1. *Protective measure*

4.1.1. *Optimisation of casing performance*

By optimizing the design of HST premium threaded casing connections, the adaptability of casing strings to complex wellbore environments can be significantly enhanced, reducing the risk of plastic deformation and connection failure caused by stress concentration [113–115]. In areas where mudstone formations are adjacent to productive reservoirs, traditional methods that estimate maximum external loads based on overburden pressure are often insufficient under complex geological conditions. Instead, the concept of non-uniform "equivalent external extrusion stress" induced by mudstone and shale creep should be adopted to evaluate casing resistance [116,117]. Increasing casing wall thickness remains a practical and effective measure for enhancing collapse resistance and improving safety margins. To optimize structural performance under complex mechanical loads, Wan et al. developed a 3D finite element model and derived a set of equations to calculate the ultimate load under slippage conditions. They also optimized the slippage structure to improve external wall stress distribution and reduce peak stress values [118]. Shokry et al. proposed eliminating intermediate casing strings and implementing a two-stage wellbore design, which has been successfully applied in 25 wells [119]. Rassoul et al. introduced a new mathematical model that incorporates geological uncertainty into a set of predefined scenarios, enabling optimal placement of casing strings. This method has demonstrated good performance in offshore projects in Iran [120]. For deep and ultra-deepwater well applications, Nguyen et al. explored the coupling between casing design and CAML (Casing While Drilling) technology, as well as drilling fluid performance. This approach has been successfully deployed in a Black Sea offshore drilling operation[121]. To address annular pressure problems caused by thermal expansion, Zhang et al. developed a pressure-relief casing structure based on a closed annulus pressure mechanism. This design increases annular volume to mitigate the conflict between limited annular space and thermal expansion of the annular fluid[122]. In summary, casing design optimization has evolved from strengthening materials and connectors to addressing structural layout, thermo-mechanical coupling, and geological uncertainty. These advancements offer a more systematic and refined technical framework to ensure well integrity in deep and complex oil and gas wells.

4.1.2. *Performance improvement of cementing slurry*

To improve cementing quality, high-strength, low-density cement slurries should be used, and the return of cement slurry should be controlled. The low-density, high-strength cement slurry system offers excellent settling stability (Table 3). Ultrafine particles, acting as reinforcing agents, are added to the cement slurry to fill the spaces between larger, heavier particles (e.g., cement, hematite, and silica fume particles). These particles undergo a hydration reaction, forming a stable suspension system with a reticulated structure [123,124]. The properties of the cement sheath are further optimized by reducing the cement's modulus of elasticity and Poisson's ratio, which helps mitigate the risk of casing damage [38,71,125]. For casings in areas with submerged

Table 3
Properties of different low-density, high-strength cement pastes [123].

Density (g/cm^3)	Mass						Thickening time (min) (30 ℃, 5 MPa)	Compressive strength (MPa) (90 ℃ , 24 h, normal pressure)
	G-grade cement	Expanded glass beads	PZW-A	G60S	GH221L	G603		
1.30	100	58	50.0	3.2	1.8	0.1	371	11.9
1.40	100	32	35.0	2.6	1.2	0.1	278	16.0
1.50	100	18	32.0	2.6	1.2	0.1	290	17.6
1.60	100	11	25.0	2.2	1.0	0.1	285	18.2

mudstone, ductile and elastic materials can be added to the cement slurry, while increasing the height of the cement returns [116] to prevent formation creep and corrosion that could lead to casing failure. In high-risk areas prone to extrusion or slippage, the addition of hollow particles [37,126] or hollow glass microspheres (HGM) [127] to the slurry can effectively absorb formation displacement. Rubber [128] can also be used as a buffer layer, replacing the cement sheath to protect the production casing. The development of the new sealing-type graded cement injector [129] provides a novel cementing technology for ultra-deep wells. It prevents cement slurry leakage during secondary cementing, enables a single upward return of the slurry to the wellhead, and ensures cement filling of the annular space above the graded injector, as well as the quality of cementing in the casing segments.

With the advancement of drilling technology and the development of ultra-deep hydrocarbon resources, the number of high-temperature and high-pressure (HTHP) wells (formation temperatures >180 °C) is increasing, placing higher demands on the thermal resistance of cement slurries. Studies have shown that incorporating 35 %–40 % fine sand or powder into the slurry can effectively maintain its mechanical strength under elevated temperatures [130,131]. Zou et al. developed an ultra-high-temperature conventional-density (UHTE) cement slurry using high-temperature additives DRF-1S and DRH-2L, significantly enhancing its thermal resistance and mechanical stability [132]. Khan et al. synthesized a terpolymer nanocomposite (TPN) that meets the rheological performance requirements of cement slurry under HPHT conditions and exhibits excellent compressive strength and fluid loss control in laboratory evaluations [133]. Qian et al. developed a high-temperature retarder (UHTR) characterized by outstanding thermal stability, strong retardation at elevated temperatures, and good low-temperature adaptability, making it suitable for cementing in high-temperature wells [134]. For low-temperature operations where lightweight cement slurry (LWC) often suffers from inadequate early compressive strength, Mozaffari et al. optimized the formulation to improve hydration rate and mechanical performance, addressing the needs of cementing in cold formations. In response to diverse geological conditions and wellbore complexities, cement materials are evolving toward multifunctional and high-performance systems, focusing not only on initial cementing quality but also on ensuring long-term wellbore integrity and sustained casing protection.

4.1.3. *Optimization of perforation technology and parameters*

Reasonable perforation hole density and phase angle can effectively reduce initial casing damage during perforation and increase the remaining strength of the casing, ensuring the safety of the wellbore during oil and gas production. Common perforation technologies include deep penetration poly-energy perforation, composite perforation, directional perforation [135], negative pressure and dynamic negative pressure perforation [136–138], full-diameter perforation, and new tubing-conveyed perforation technologies [139]. Building on this foundation, international researchers have proposed the use of laser perforation technology. Experimental results demonstrate that employing a 500 W Nd: YAG laser can induce fracture formation around the target zone, thereby enhancing permeability and offering a novel approach for unconventional reservoir stimulation[140]. The selection of appropriate perforation methods depends on specific geological factors and construction conditions [141,142]. Optimizing perforation parameters requires combining previous experience with the geological and engineering conditions of the field, including sensitivity analysis of multiple parameters such as wellbore dimensions, perforation diameter, density, phasing, compaction degree, and depth. When crustal stress increases, it is essential to reduce perforation density and increase the phase angle to maintain the integrity of the casing structure [74]. In loose reservoirs, increasing perforation density within a reasonable daily fluid production limit can significantly reduce the likelihood of casing damage [143]. As oil field depth increases, conventional perforators and perforating technologies may no longer meet the requirements for deep and ultra-deep well development. Studies on the effects of tubing column vibration in ultra-deep wells show that axial vibration increases with tubing length, while transverse and torsional vibrations decrease. Additionally, axial, transverse, and torsional vibrations of the tubing column increase with higher shot charge levels [144]. Future research should focus on developing temperature-resistant shot charges for deep wells, high-pressure perforators, sulfur-resistant and anti-explosive perforating tools, and techniques for deep-well perforation operations [145,146]. With the advancement of deep learning, machine learning-based perforation parameter prediction methods are emerging. These approaches enable fast and accurate estimation of perforation penetration depth, effectively overcoming the limitations of traditional empirical models under complex conditions[147].

4.1.4. *Casing corrosion protection*

During waterflooding operations, annular protection technologies, as illustrated in Fig. 9, can be applied to enhance long-term corrosion resistance. These include the application of anti-corrosion coatings on the casing surface and the staged injection of corrosion inhibitors during production. Currently, commonly used annular protection fluids in China consist of compound systems combining corrosion inhibitors, biocides, and scale inhibitors. Formulations based on imidazoline derivatives, phosphonates, nitrogen-containing heterocycles, and dispersants have proven effective in suppressing the growth of sulfate-reducing bacteria (SRB), gas-producing bacteria (TGB), and iron bacteria (FB), thereby reducing the corrosivity of annular fluids[148]. Owing to their low cost and ease of use, corrosion inhibitors are widely adopted in casing protection. To further enhance the anti-corrosion and

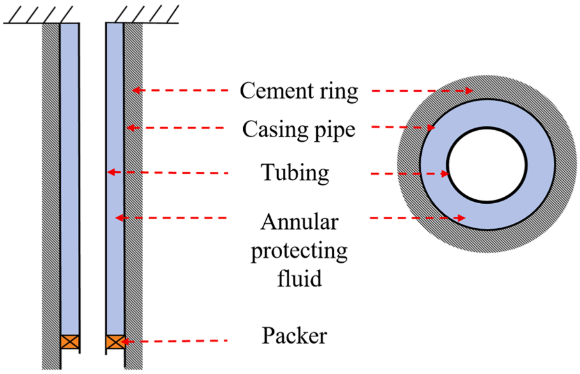

Fig. 9. Ring air protection technology.

mechanical performance of the cement sheath, additives such as corrosion-resistant inorganic powders, alkali-activated mineral materials, hydrophilic polymers, and water-based resins can be incorporated into the cement slurry[149]. Internationally, other widely used inhibitors include film-forming agents, volatile corrosion inhibitors (VCIs), alkaline additives, and antimicrobial agents, which are selected based on specific wellbore conditions. Traditional coating materials such as phenolic resins, epoxy resins, phenolic varnishes, nylon, and other polymer-based coatings are commonly used in tubing and casing protection systems [150]. In recent years, the development of glass-reinforced epoxy (GRE) and internal plastic coatings (IPC) has further improved corrosion resistance and mechanical strength [151,152]. Additionally, to address localized corrosion caused by non-metallic inclusions, recent studies have shown that yttrium oxide (Y_2O_3) inclusions can effectively suppress corrosion, providing a theoretical basis for the compositional design of high-resistance casing steels [153].

4.1.5. *Control of water injection pressure*

During the water injection stage, the injection volume and pressure should be carefully controlled based on formation conditions. Simultaneously, monitoring of injection wells must be strengthened to avoid abnormal formation pressure [154]. Proper adjustment of injection pressure is critical for enhancing oilfield production and preventing adverse effects caused by pressure abnormalities. The injection pressure should be slightly higher than the formation pressure to ensure effective oil displacement [155]. However, excessively high injection pressure can cause water to flow along natural fractures, triggering formation slippage and resulting in casing damage. Conversely, low injection pressure may lead to inadequate oil displacement.

To maintain appropriate injection pressure and production balance [156], various methods can be employed. These include adjusting the operational status of pumps in injection wells, modifying the water outlet of injection wells, utilizing injection pipe networks, and combining these approaches with layered injection processes. The addition of compound surfactants can further improve oil recovery rates [155,157]. Moreover, incorporating a single-flow valve structure in the injection cylinder of an eccentric water injection column has been shown to enhance sand prevention effectiveness [158].

4.1.6. *Sand control techniques*

During oil and gas extraction, sand control techniques are essential to prevent the formation of sand from entering the wellbore and to ensure stable oil production. Based on their principles and implementation methods, sand control technologies are generally categorized into three types: mechanical sand control, chemical sand control, and integrated mechanical-chemical sand control. Mechanical sand control is the most widely applied approach. It relies on physical screening and fills barriers to block sand particles, with commonly used methods including slotted liners, wire-wrapped screens, pre-packed screens, fracture packing, gravel packing, and high-pressure water packing [159,162,163]. Among these, gravel packing is suitable for sandstone reservoirs and effectively supports wellbore walls, preventing collapse and sand intrusion [164]. Wire-wrapped screens and pre-packed screens are ideal for wells with moderate sand production, offering good filtration along with high fluid permeability. Fracture packing integrates stimulation and sand control to enhance the development of low-permeability reservoirs. Chemical sand control involves injecting specific chemical agents (e.g., organic resins, inorganic grouts) into the formation to bond or reinforce unconsolidated sands and thus control sand production [165]. Common techniques include artificial borehole walls and resin-consolidation, suitable for reservoirs with high porosity and poor natural cementation [159–161]. This method offers strong adaptability, simple operation, and minimal formation damage, making it ideal for complex well profiles and sections unsuitable for mechanical methods. Table 4 compares various sand control techniques in terms of application conditions and advantages/disadvantages, providing a reference for selecting appropriate solutions based on geological and operational needs.

In field practice, wellbores often face complex conditions such as casing deformation or severe sanding, where a single sand control method may be inadequate. In such cases, sand control can be integrated with other processes—such as sand washing, water plugging, and stimulation—into multifunctional systems. For example, in wells with severe casing deformation, a “sand-washing and control integration” technique is commonly used: hydraulic or mechanical methods are first employed to remove fine sand and blockages from the wellbore, followed by the implementation of an appropriate sand control strategy to restore productivity[166]. In wells with fine or muddy sand that impairs conventional sand control effectiveness, cyclical sand removal can help maintain production stability [167]. For high water-cut wells, a “water-plugging and sand control” integrated process can extend well life and enhance recovery by simultaneously managing water influx and sand production. Overall, rational selection and optimization of sand control technologies are key to maintaining long-term, efficient operation of oil and gas wells. As reservoir development becomes increasingly complex, sand control technologies are evolving toward intelligent, environmentally friendly, and system-integrated solutions. Emerging technologies—such as smart screens, nano-material sand control, and dissolvable metal proppants—are being gradually deployed in the field, offering broader technical pathways for effective sand management under complex well conditions.

Table 4
Common chemical anti-sanding processes[159–161].

Chemical sand control technology	Sand control material	Advantages	Disadvantages
Artificial wellbore	Cement slurry, pre-coated gravel, emulsified cement, water-carrying dry powder sand, resin slurry, resin walnut shells, etc.	Widely available materials, simple process, and construction	Large material usage, low strength, short effective duration
Resin-bonded formation	Porous resins, phenolic resins, furan resins, urea-formaldehyde resins, brominated epoxy resins, etc.	High bonding strength, simple process	Expensive, long construction time, not environmentally friendly
Polymer gel	In-situ crosslinked polymer gel, preformed polymer gel (PPG), and foamed polymer gel.	High injection rate, high heat resistance, high mechanical resistance, high-pressure resistance, high salt resistance, high penetration porosity, low formation damage	Expensive, complex construction, can reduce formation permeability after use.
Nanoparticles	SiO_2, TiO_2, ZrO_2, CeO_2	Good sand consolidation effect	High cost
Electrolysis	-	Minimizes formation damage	Uncertainty about applying electrolysis in reservoir conditions
Welded glass	-	Constant porosity and permeability, good temperature resistance, strong resistance to high-speed fluid	Expensive, long construction time

4.2. Governance measures

4.2.1. Casing deformation wells

For casing deformation, techniques such as blast shaping and mechanical shaping can be employed to ensure the continued production of wells. Common mechanical shaping tools include solid expandable tubes (SET), Smith expansion cones, and rolling shapers. Solid expandable tubes can be expanded in both inner diameter (ID) and outer diameter (OD), with a maximum radial expansion rate of up to 25 %. They do not interfere with subsequent patching or production operations [168]. Additionally, expandable tubes can be used to prevent and control formation creep [54]. The effectiveness of prevention and control increases with the wall thickness of the SET, leading to longer casing lifespans. Smith expansion cones address the issue of stuck drilling caused by extrusion self-locking in the contact area between the cone and casing. However, accurate determination of the casing's deformation value is necessary when using this tool. It is also essential to control the number of expansion cone replacements to avoid exacerbating damage to the casing and cement sheath [169]. Rolling shaping is a more convenient, efficient, and cost-effective technique compared to other methods. It causes minimal damage to the casing and surrounding cement sheath and requires less torque and repair force than alternative shaping methods [170,171]. For wells with slight deformation, small-diameter tools for grinding, milling, and snap sealing can be used for production. Severe deformations, however, require blast shaping, solid expandable tubing, or rolling shaping techniques for repair.

4.2.2. Wells with casing leakage

For oil and water wells experiencing leakage, effective plugging measures must be implemented to ensure continued production. Common plugging methods include mechanical processes such as casing patching, sleeve removal, and replacement, and plugging with leakage containment materials (LCM). Traditional plugging materials, including graphite, marble, nut shells, and fibers, were widely used in earlier applications. In recent years, advanced plugging materials have been developed, including bridging types, high water-loss types, absorbent swelling types, flexible gel types, and curable materials [172]. Building on these innovations, intelligent plugging materials have been introduced, such as temperature-responsive adhesive-loss plugging materials (TALCM) [173,174], shape memory polymer plugging materials [175,176], and self-repairing gels [177] (Table 5). In addition to these measures, advanced casing damage detection techniques, such as distributed acoustic sensing (DAS) [178], TV imaging [179], and magnetic detection [180–182], should be employed to assess the extent of casing damage in oil and gas wells. Utilizing these technologies enables more accurate diagnostics, leading to effective treatment outcomes.

4.3. Diagnostic and monitoring techniques

Effective diagnostic and monitoring technologies are essential for early detection of casing damage and for maintaining the integrity of oil and water wells. Current monitoring approaches encompass both traditional logging methods and advanced intelligent techniques, enabling multidimensional evaluation of casing stress conditions. Owing to their maturity and high reliability, traditional methods remain widely used in field operations. Caliper logging tools, equipped with multiple high-resolution arms, are employed to detect changes in borehole diameter and identify casing ovalization, bending, and shear deformation [184]. Electromagnetic inspection tools (e.g., Magnelog™, PAL, Vertilog™, ACX™) assess variations in casing wall thickness and diameter based on phase shifts in electromagnetic signals. While effective for identifying corrosion and wear, these tools are generally limited to qualitative analysis and struggle to provide real-time monitoring or differentiate complex failure modes [185,186]. Pressure tests are commonly used to evaluate the sealing integrity of the casing and cementing system; abnormal pressure drops often indicate leaks, fractures, or loose connections. Cement bond logging tools (e.g., CBL/VDL) are typically employed to assess the quality of cement sheaths and are frequently used in combination with ultrasonic imaging (USIT), acoustic scanning (CAST), radioactive tracer techniques (RATS), and standard annular pressure testing (SAPT) to improve diagnostic accuracy [187].

Given the limitations of conventional detection techniques in terms of real-time monitoring, intelligent sensing technologies have gained traction in recent years, offering enhanced accuracy and timeliness in identifying casing damage. Since its introduction to the oil and gas industry in the 1990s, fiber-optic sensing has emerged as a key technology for long-term, high-precision, and remote monitoring [188,189]. Distributed Temperature Sensing (DTS) enables continuous tracking of downhole temperature variations, which aids in detecting thermal anomalies and fluid leakage [190]. Distributed Acoustic Sensing (DAS) captures and analyzes acoustic signals within the wellbore to enable real-time detection and localization of leaks and mechanical impacts [191]. Distributed Strain Sensing (DSS), based on Brillouin scattering, allows for continuous static strain measurement along the fiber, making

Table 5
Types of blocking materials [183].

Plugging materials			Advantage	Disadvantage	Conditions of application
Bridging type	Granular	Walnut shells, rubber, diatomaceous earth, shells, etc	Low impact on drilling fluid rheology, low cost, easy to operate	Poor matching of stratum leakage channel dimensions, the low pressure-bearing capacity of the plugging layer, prone to repeated leakage	Formations that are not highly permeable or leaky have a very important place in drilling fluid plugging
	Flaky	Mica flakes, vermiculite, rice husk, resin flakes, etc			
	Fibrous	Sawdust, flax fiber, carbon fiber, etc			
High water loss category		Clay, fly ash, asbestos fiber, calcium carbonate, etc	Easy to use, quick results, high success rate	Plugging effect on malignant leakage needs to be further improved	Crack plugging with low leakage rate and small size
Absorbent swelling type		Water-absorbent resin, pre-crosslinked gel particles, etc	Expansion plug, good deformability, independent of the shape and size of the leakage channel	Poor suction delay effect and temperature resistance	Porous, fractured strata
Flexible gel type		Polyacrylamide gels, polyacrylonitrile gels, polyvinyl alcohol gels, biogels, etc	Excellent deformability under pressure	Generally low resistance to temperature and salt, poor long-term blocking stability	Plugging of different types of strata
Curable type		Cement, slag, polyurethane, phenolic resin, etc	High pressure blocking ability, easy-to-control curing time, low price, simple preparation and operation process.	Poor resistance to dilution by drilling fluids and formation water, difficult to control curing time, high construction safety risk	Malignant loss of stratigraphy
Intelligent material type		Temperature-responsive adhesive loss plugging materials, shape memory polymer plugging materials, self-healing gels, etc	Excellent mechanical properties and high efficiency	It is still in the basic research stage, and its mechanism of action still needs to be further studied.	Autonomous adaptation to various complex formations

it suitable for detecting casing deformation caused by geostress variations, thermal expansion, or borehole instability—though its precision is generally lower than that of DAS [192]. Zhou developed a real-time stress monitoring system for casings by integrating Brillouin Optical Time Domain Reflectometry (BOTDR) with Fiber Bragg Grating (FBG) technology[193]. In recent years, machine learning has emerged as a powerful data-driven modeling tool capable of capturing the relationship between system states and critical variables. Applications in the oil and gas sector include directional drilling optimization, lithology classification, shale reservoir delineation, production forecasting, and casing failure analysis. Noshi et al. applied artificial neural networks and Python programming to model and predict casing failure based on historical data [194–196]. In the Granite Wash area of the Anadarko Basin in the U.S., machine learning was used to identify key factors influencing casing damage and quantify their relative importance, thereby supporting casing integrity management [197,198].

In conclusion, the continuous advancement of diagnostic and monitoring technologies—particularly the integration of intelligent sensing and data-driven approaches—is progressively enhancing the timeliness and accuracy of casing damage detection. These developments provide a solid technical foundation for early warning and intelligent management of casing integrity in oilfields.

5. Conclusion

Casing damage in oil and gas production occurs across all stages of the well lifecycle, including drilling, cementing, perforation, water injection, and production. It is driven by complex and multifactorial interactions involving mechanical, chemical, and geomechanical processes. This study systematically reviews existing literature and field data to elucidate the underlying failure mechanisms associated with common forms of casing damage, such as deformation, rupture, and sealing failure. During the cementing stage, discontinuities or poor bonding in the cement slurry can lead to stress concentration, which may result in casing deformation. During water injection, formation slip and high-pressure fluid interaction significantly increase the risk of casing shear failure. Additionally, prolonged exposure to corrosive media accelerates casing wall thinning and perforation. To address casing damage at different development stages, this study proposes phase-specific prevention and mitigation strategies. These include using high-performance casing and advanced cement slurries to enhance wellbore integrity during drilling and cementing; optimizing perforation parameters and techniques to reduce dynamic impact damage during perforation; applying annular corrosion protection technologies and precise control of injection pressure to suppress corrosion and formation instability during water injection; and implementing mechanical-chemical composite sand control technologies during production to mitigate formation sand-induced mechanical damage to the casing.

By integrating geomechanical analysis, material performance optimization, and intelligent monitoring technologies, this work establishes a comprehensive “prevention–diagnosis–repair” technical framework. In particular, real-time monitoring systems based on fiber-optic sensing and machine learning-driven risk prediction models significantly enhance early-stage damage detection capabilities. As ultra-deep and unconventional resource development progresses, future efforts should focus on improving multi-physics coupling simulation accuracy, developing AI-driven dynamic control platforms, and innovating eco-friendly materials such as degradable sand control agents and self-healing cement to meet extreme operational challenges. This study provides both theoretical support and a technical paradigm for full lifecycle casing management, promoting safer, more efficient, and sustainable oil and gas development.

CRediT authorship contribution statement

Jiang-Feng Liu: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft. **Xin-Yue Zhang**: Investigation, Visualization, Writing – original draft, Writing – review & editing. **Li-Yuan Yu**: Supervision, Writing – original draft. **Xiao-Liang Wang**: Supervision, Resources. **Yun-Hu Lu**: Writing – review & editing. **Zi-Hao Zhang**: Writing – original draft. **Zhi-Jie Jian**: Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are grateful for the support of the National Key Research and Development Plan of China (2021YFC2902101), and the Natural Science Foundation of Jiangsu Province of China (Grant No. BK20240107).

References

[1] A.I. Mohammed, B. Oyeneyin, B. Atchison, et al., Casing structural integrity and failure modes in a range of well types - a review, J. Nat. Gas. Sci. Eng. 68 (2019) 102898.

[2] J.F. Li, J.T. Liu, L. Yang, et al., Mechanism and key controlling factors of casing damage in water injection development of daqing oilfield, Oil Extr. Eng. (2023) 57–65 (Chinese).

[3] T. Wang, S.L. Yang, W.H. Zhu, et al., Law and countermeasures for the casing damage of oil production wells and water injection wells in Tarim oilfield, Pet. Explor. Dev. 38 (2011) 352–361 (Chinese).

[4] S. Salehi, G. Hareland, K.K. Dehkordi, et al., Casing collapse risk assessment and depth prediction with a neural network system approach, J. Pet. Sci. Eng. 69 (2009) 156–162.

[5] J. Xie, Y. Liu, Analysis of casing deformations in thermal wells, in: Abaqus Users' Conference, RI, 2008.

[6] Z. Wan, H. Yu, Z. Zhao, et al., Analysis of casing safety after perforation operation in the curve section of ultra deep hydrogen production horizontal wells, Int. J. Hydrog. Energy 82 (2024) 567–582.

[7] A.A. Daneshy, Impact of off-balance fracturing on borehole stability and casing failure, in: SPE Western Regional Meeting, Irvine, California, 2005, pp. SPE-93620-MS.

[8] M.B. Dusseault, M.S. Bruno, J. Barrera, Casing shear: Causes, cases, cures, SPE Drill. Complet. 16 (2001) 98–107.

[9] N.J. Adams, R.F. Mitchell, A.W. Eustes, et al., A causation investigation for observed casing failures occurring during fracturing operations, in: SPE Hydraulic Fracturing Technology Conference and Exhibition, 2017, pp. D021S005R004.

[10] T.L. Skovhus, R.B. Eckert, E. Rodrigues, Management and control of microbiologically influenced corrosion (MIC) in the oil and gas industry—Overview and a north sea case study, J. Biotechnol. 256 (2017) 31–45.

[11] Y. Choi, D. Young, S. Nešić, et al., Wellbore integrity and corrosion of carbon steel in CO_2 geologic storage environments: A literature review, Int. J. Greenh. Gas. Control 16 (2013) S70–S77.

[12] L. Popoola, A. Grema, G. Latinwo, et al., Corrosion problems during oil and gas production and its mitigation, Int. J. Ind. Chem. 4 (2013) 35.

[13] X. Bai, K. Tong, Z. Huang, et al., Analysis and investigation of casing joint slippage failure in a high-displacement deep-sea well located in the South China Sea, Eng. Fail. Anal. 170 (2025) 109245.

[14] W. Chen, Q. Di, H. Zhang, et al., The sealing mechanism of tubing and casing premium threaded connections under complex loads, J. Pet. Sci. Eng. 171 (2018) 724–730.

[15] Y. Xi, Y. Yao, X. Guo, et al., Failure evaluation mechanism of cement sheath sealing integrity under casing eccentricity during multistage fracturing, Pet. Sci. 21 (2024) 3428–3445.

[16] R. Gholami, B. Aadnoy, N. Fakhari, A thermo-poroelastic analytical approach to evaluate cement sheath integrity in deep vertical wells, J. Pet. Sci. Eng. 147 (2016) 536–546.

[17] R. Gholami, V. Rasouli, B. Aadnoy, et al., Geomechanical and numerical studies of casing damages in a reservoir with solid production, Rock Mech. Rock Eng. 49 (2016) 1441–1460.

[18] P.M.T.M. Schutjens, P. Fokker, U.B.B. Rai, et al., Compaction- and shear-induced well deformation in tyra: Geomechanics for impact on production, Rock Mech. Rock Eng. 52 (2019) 5205–5224.

[19] C. Gu, X. Li, Y. Feng, et al., Numerical investigation of cement interface debonding in deviated shale gas wells considering casing eccentricity and residual drilling fluid, Int. J. Rock Mech. Min. Sci. 158 (2022) 105197.

[20] X. Du, X. Dai, Z. Li, et al., Corrosion analysis and anti-corrosion measures of oil casing of sulfur content gas wells: A case study of daniudi gas field in the ordos basin, Energy Rep. 7 (2021) 1280–1292.

[21] H. Peng, Z. Xu, Z. Xia, et al., Closed wellbore integrity failure induced by casing corrosion based on solid-chemical coupling model in CO_2 sequestration, Geoenergy Sci. Eng. 241 (2024) 213140.
[22] L. Zhou, X. Huang, W. Song, et al., Multi-factor corrosion model of TP110TS steel in H_2S/CO_2 coexistence and life prediction of petroleum casings, Int. J. Press. Vessels Pip. 209 (2024) 105204.
[23] J.T. Fredrich, J.G. Arguello, G.L. Deitrick, et al., Geomechanical modeling of reservoir compaction, surface subsidence, and casing damage at the belridge diatomite field, SPE Reserv. Eval. Eng. 3 (2000) 348–359.
[24] D. Hou, Z. Zhang, Y. Geng, et al., Study on channeling-leakage pressure of casing-cement sheath-stratum assembly in thermal recovery wells, Fuel 356 (2024) 129592.
[25] X.W. Dong, H.L. Liu, B. Xie, et al., Exploration and practice of casing design method for heavy oil thermal recovery wells, Drill. Prod. Technol. 43 (6) (2020) 76–79 (Chinese).
[26] S. Chen, H. Wang, Y. Liu, et al., Root cause analysis of tubing and casing failures in low-temperature carbon dioxide injection well, Eng. Fail. Anal. 104 (2019) 873–886.
[27] L. Poberezhna, L. Poberezhnyi, L. Shkitsa, et al., Predicting environmental risks in case of oil and gas equipment failures, Procedia Struct. Integr. 59 (2024) 739–744.
[28] C. Hu, C. Ai, F. Wang, Optimization of casing design parameters to mitigate casing failure caused by formation slippage, Struct. Durab. Health Monit. 12 (2018) 85.
[29] F.Z. Qi, C.J. Yang, Z.S. Liu, Improve cementing quality of complicated oil and gas wells-ensure long-term sealing performance of cement sheath, Oil Forum 32 (1) (2013) 19–22 (Chinese).
[30] S. Papavinasam, Corrosion control in the oil and gas industry, Elsevier, 2013.
[31] J.A. Uribe-Patino, A. Casero, D. Dall'Acqua, et al., A comprehensive review of casing deformation during multi-stage hydraulic fracturing in unconventional plays: Characterization, diagnosis, controlling factors, mitigation and recovery strategies, in: SPE hydraulic Fracturing Technology Conference and Exhibition, 2024, pp. D021S005R005.
[32] Y. Lin, K. Deng, D. Zeng, et al., An experimental study on reshaping C110 deformed casing with spinning casing swage, Nat. Gas. Ind. B 2 (2015) 257–262.
[33] J. Sun, Y. Bai, R. Cheng, et al., Research progress and prospect of plugging technologies for fractured formation with severe lost circulation, Pet. Explor. Dev. 48 (2021) 732–743.
[34] N. Johnson, Research and modernization of inspection and monitoring practices for pipeline, casing, and tubing, Author Prepr. (2024).
[35] X. Li, T. Parker, M. Farhadiroushan, et al., Evaluating a concept of using distributed optical fiber temperature and strain sensor for continuous monitoring of casing and completion mechanical deformation in intelligent wells, in: Offshore technology conference, 2004, pp. OTC-16285-MS.
[36] W. Liu, B. Yu, J. Deng, Analytical method for evaluating stress field in casing-cement-formation system of oil/gas wells, Appl. Math. Mech. 38 (2017) 1273–1294.
[37] S.Y. Yang, B. Zeng, Y. Yan, et al., Research on casing deformation mechanism and prevention technology in salt rock creep formation, J. Pet. Sci. Eng. 220 (2023) 111176.
[38] X. Zhang, J. Li, H. Zhang, et al., Analysis of casing deformation failure mechanism based on fault slip, Eng. Fail. Anal. 127 (2021) 105430.
[39] G.B. Zhang, G.B. Yang, H.H. Chen, et al., Preliminary study on casing damage issues in the Middle East HF oilfield, in: Proc. 33rd National Gas Academic Annual Conf., Nanning, China, 2023 (Chinese).
[40] W.A. Gong, Several issues concerning the compressive strength of casing, Pet. Drill. Prod. Mach. Commun. (1977) 31–47.
[41] S. Peng, J. Fu, J. Zhang, Borehole casing failure analysis in unconsolidated formations: A case study, J. Pet. Sci. Eng. 59 (2007) 226–238.
[42] X. Huang, M. Mihsein, K. Kibble, et al., Collapse strength analysis of casing design using finite element method, Int. J. Press. Vessels Pip. 77 (2000) 359–367.
[43] N.K. Gupta, A. Khullar, Collapse of square and rectangular tubes in transverse loading, Arch. Appl. Mech. 63 (1993) 479–490.
[44] L.A. Merzhievskii, A.D. Resnyanskii, Deformation and collapse of hollow conical casing, Combust. Explos. Shock Waves 23 (1987) 212–219.
[45] L. Wu, J.F. Carney III, Initial collapse of braced elliptical tubes under lateral compression, Int. J. Mech. Sci. 39 (1997) 1023–1036.
[46] W. Huang, D. Gao, A theoretical study of the critical external pressure for casing collapse, J. Nat. Gas. Sci. Eng. 27 (2015) 290–297.
[47] S. Tong, D. Gao, Elastic-plastic collapse limit analysis of coiled tubing under complex stress state, J. Pet. Sci. Eng. 174 (2019) 106–114.
[48] K. Hamilton, B. Wagg, T. Roth, Using ultrasonic techniques to accurately examine seal-surface-contact stress in premium connections, SPE Drill. Complet. 24 (2009) 696–704.
[49] Y. Mou, Z. Lian, Q. Zhang, et al., Stress analysis of tubing thread of the gas seal test in deep gas well, in: Advances in Materials Processing: Proceedings of Chinese Materials Conference 2017 18th, 2018, pp. 1015-1028.
[50] E. Tsuru, M. Ueno, M. Ogasawara, et al., Performance of tubular connections under the loading conditions of horizontal wells, SPE Drill. Complet. 11 (1996) 242–248.
[51] N. Yoshihiro, N. Seiichi, K. Tetsuro, Leak-proof tests of special joints for oil country tubular goods, Sumitomo Met 26 (1974) 97–105.
[52] Z. Lian, H. Liang, T. Shi, et al., Development and application of screw structure of miniature drilling tool for super-deep wells, J. Oil Drill. Prod. Technol. 38 (2016) 160–165.
[53] Y. Mou, Z. Lian, Q. Zhang, et al., Stress analysis of tubing thread of the gas seal test in deep gas well, Singapore, 2018, pp. 1015-1028.
[54] F. Wang , H. Zhang, W. Zhu, Study of requirement design about damage and protection simulation system to warfield target, in: 2010 International Conference on Computing, Control and Industrial Engineering, 2010, pp. 337-340.
[55] H. Wang, R. Samuel, 3D geomechanical modeling of salt-creep behavior on wellbore casing for presalt reservoirs, SPE Drill. Complet. 31 (2016) 261–272.
[56] Q. Zhang, Z. Lian, T. Lin, Prediction of residual burst strength of worn casing by theoretical and numerical modelling, Int. J. Press. Vessels Pip. 188 (2020) 104195.
[57] Y. Fouad, N. Merah, M.A. Azeem, et al., Wear characteristics of zirconia-toughened epoxy/Kevlar-honeycomb composite lining for drilling casing, Heliyon 10 (2024) e37333.
[58] X. Liu, J. Li, G. Liu, et al., Numerical study on damage law and influencing factors of cement sheath under perforation conditions, Pet. Sci. Technol. 42 (2024) 613–633.
[59] X. Guo, T. Shi, Z. Zhang, et al., Stress corrosion cracking behavior of high strength casing steel in working fluids, J. Nat. Gas. Sci. Eng. 29 (2016) 134–140.
[60] X. Li, W. Zhao, S. Shi, et al., Corrosion product film formation mechanism of 110H-13Cr casing steel in simulated ultra-high-temperature gas environment for shale oil production, Corros. Sci. 226 (2024) 111662.
[61] H. Wu, X. Zhai, H. Ji, et al., Casing strength analysis in sand production zones of sandstone reservoirs, Sci. Technol. Eng. 13 (2013) 2662–2665 (Chinese).
[62] F. Li, Q. Tang, W. Yan, et al., Research on the failure analysis and prediction method of casing deformation under the synergistic effect of sand production and corrosion, Eng. Fail. Anal. 154 (2023) 107706.
[63] D. Tiab, E.C. Donaldson, Chapter 9 - effect of stress on reservoir rock properties, in: D. Tiab, E.C. Donaldson (Eds.), Petrophysics (Fourth Edition), Gulf Professional Publishing, Boston, 2016, pp. 483–582.
[64] G. Maharaj, Thermal well casing failure analysis. in: SPE Latin America/ CaribbeanPetroleum Engineering Conference, 1996, pp. SPE-36143-MS.
[65] A. Lavrov, J. Todorovic, M. Torsæter, Numerical study of tensile thermal stresses in a casing-cement-rock system with heterogeneities, in: 49th U.S. Rock Mechanics/Geomechanics Symposium, 2015, pp. ARMA-2015-110.
[66] Y. Chen, Z. Lian, M. Chen, et al., Thermal stress coupling analysis of wellbores in thermal recovery wells with circumferential cement sheath loss, Petrol. Drill. Tech. (2008) 108–110 (Chinese).
[67] P. Zhao, Z. Zhao, L. Liu, Analysis of the influence of cement sheath loss on casing damage, Oil Gasfield Surf. Eng. 28 (2009) 40–41 (Chinese).
[68] Z. Lian, Z. Luo, H. Bu, et al., Mechanism and prevention of casing damage caused by annular cement sheath loss, Petrol. Drill. Tech. 39 (2017) 435–441 (Chinese).
[69] Z. Zhang, S. Xiang, H. Yang, et al., Study on the integrity assessment of geothermal wellbore under thermal and non-uniform in-situ stresses coupling effects, Appl. Therm. Eng. 255 (2024) 123744.
[70] D. Liu, X. Chen, K. Zuo, et al., Numerical analysis of the effect of cement sheath defects on casing damage in heavy oil thermal recovery wells, Santa Fe, NM, United states, 2022.
[71] R. Zhang, B. Zhang, L. Cao, et al., Evaluation of the casing strength reliability in deep gas well by taking into account the cement quality and strength uncertainty: Method, analysis and application, Geoenergy Sci. Eng. 234 (2024) 212623.
[72] K. Shaygan, S. Haghshenas Lari, H. Mahani, et al., Geomechanical investigation of casing collapse using finite element modeling: The role of cement sheath integrity, Geoenergy Sci. Eng. 233 (2024) 212579.
[73] X. Liu, J. Li, H. Yang, et al., A new investigation on optimization of perforation key parameters based on physical experiment and numerical simulation, Energy Rep. 8 (2022) 13997–14008.
[74] Y. Xi, Y. Yao, P. Chen, et al., Investigation of casing stress distribution and parameter optimization during the transient impact process of multi-hole perforation operations, Eng. Fail. Anal. 155 (2024) 107761.
[75] H.J. Kareem, H. Hasini, M.A. Abdulwahid, Effect of perforation density distribution on production of perforated horizontal wellbore, Pet. Explor. Dev. 51 (2024) 464–475.
[76] Y. Zou, L. Tao, N. Liu, et al., Study on the internal pressure strength of perforated casing in high pressure formation, Atlanta, GA, United states, 2023.
[77] L. Geng, D. Liu, L. Han, et al., Numerical analysis of casing damage in heavy oilthermal recovery wells, in: IOP Conference Series Earth Environmental Science, 2021, pp. 012011.
[78] C.Y. Hu, F.J. Wang, C. Ai, Calculation model for stick-slip deformation in weak horizontal structural surface formation after water inflow, ACS Omega 6 (35) (2021) 22888–22899.
[79] K. Zhao, Z. Chen, J. Xu, et al., Analysis of casing corrosion causes and evaluation of anti-corrosion measures in oil wells, Corros. Prot. 44 (2023) 86–92 (Chinese).
[80] X. Fang, J. Chi, B. Nan, et al., Experimental study on the corrosion behavior of casing materials in formation water environments, Appl. Chem. Eng. 52 (2023) 2976–2980.
[81] Z. Zhang, C. Ding, W. Liu, et al., Study on corrosion of Cr-containing steel under different CO_2 partial pressures at high temperatures, Geoenergy Sci. Eng. 243 (2024) 213365.
[82] A. Singh, K.R. Ansari, Y. Lin, et al., Corrosion inhibition performance of imidazolidine derivatives for J55 pipeline steel in acidic oilfield formation water: Electrochemical, surface and theoretical studies, J. Taiwan Inst. Chem. Eng. 95 (2019) 341–356.
[83] H. Liu, J. Sun, Z. Zheng, Study on causes and prevention measures of casing damage in CO_2 test area of X oilfield, in: J. Lin (Ed.), Springer Series in

Geomechanics and Geoengineering, Springer Nature Singapore, Singapore, 2024, pp. 393–400.

[84] Q. Du, Z. Liu, J. Yang, et al., Hydrogen permeation and hydrogen damage behavior of high strength casing steel in acidic environment, Int. J. Electrochem. Sci. 18 (2023) 100136.

[85] G. Cai, X. Wang, Analysis of casing damage and prevention caused by high-pressure water injection in oilfields, Petrol. Mach. 62 (2001) 32–34.

[86] X. Huang, C. Yang, J. Liu, et al., Experimental study on mudstone's creep behavior under different water contents and its effect on casing damage, Chin. J. Rock Mech. Eng. 27 (S2) (2008) 3477–3482 (Chinese).

[87] J. Tang, T. Lan, Y. Lai, et al., Softening mechanism and characteristics of mudstone after absorbing moisture, Appl. Clay Sci. 254 (2024) 107398.

[88] J. Fang, Y. Wang, D. Gao, On the collapse resistance of multilayer cemented casing in directional well under anisotropic formation, J. Nat. Gas. Sci. Eng. 26 (2015) 409–418.

[89] Z. Chen, X. Li, W. Wang, et al., Theoretical analysis of casing collapse in locally expansive mudstone, J. Pet. Sci. Eng. 203 (2021) 108643.

[90] T. Wang, C. Yan, Investigating the influence of water on swelling deformation and mechanical behavior of mudstone considering water softening effect, Eng. Geol. 318 (2023) 107102.

[91] Y. Lu, L. Wang, X. Sun, et al., Experimental study of the influence of water and temperature on the mechanical behavior of mudstone and sandstone, Bull. Eng. Geol. Environ. 76 (2017) 645–660.

[92] Z. Chen, W. Zhu, Q. Di, Elasticity solution for the casing under linear crustal stress, Eng. Fail. Anal. 84 (2018) 185–195.

[93] X. Wang, Z. Qu, Y. Dou, et al., Loads of casing and cement sheath in the compressive viscoelastic salt rock, J. Pet. Sci. Eng. 135 (2015) 146–151.

[94] X. Huang, H. Mao, J. Liu, et al., Application of ANSYS in forecasting of water injection well casing damage, Chin. J. Rock Mech. Eng. 24 (S1) (2005) 5146–5150 (Chinese).

[95] L. Han, F. Yin, S. Yang, et al., Coupled seepage-mechanical modeling to evaluate formation deformation and casing failure in waterflooding oilfields, J. Pet. Sci. Eng. 180 (2019) 124–129.

[96] J.J. Liu, X.B. Yu, Stress analysis on the combination of casing-cement ring-surrounding rock considering fluid-solid coupling, Electron. J. Geotech. Eng. 17 (2012) 1863–1873.

[97] Z.Y. Zhang, C. Ai, H. Zheng, Study on the mechanism of casing damage due to water injection, Adv. Mater. Res. 524-527 (2012) 1602–1605.

[98] L.P. Guo, Y.M. Zhang, L. Wang, Research on effect of water injection pressure on casing damage in Pu-Bei oil field, in: Proceedings of 2012 International Conference on Measurement, Information and Control, Harbin, 2012, pp. 610-613.

[99] F. Zhang, Z. Jiang, Z. Chen, et al., Hydraulic fracturing induced fault slip and casing shear in sichuan basin: A multi-scale numerical investigation, J. Pet. Sci. Eng. 195 (2020) 107797.

[100] X. Zhang, J. Li, P. Liu, et al., Analysis of factors influencing casing deformation in shale gas wells under fault slip conditions, Sci. Technol. Eng. 21 (2021) 6651–6656.

[101] H. Yu, Y. Tuo, T. Lin, et al., On how water injection may induce fault reactivation and slippage: A numerical method, Petroleum 10 (4) (2024) 646–659.

[102] S.P. Lele, T.E. Tyrrell, B.J. DeMartin, Effect of faulting regime, Poisson's ratio, and non-uniform reservoir deformation on fault reactivation due to injection and production, in: ARMA US Rock Mechanics/Geomechanics Symposium, 2020, pp. ARMA-2020-1595.

[103] Q. Zhao, S.D. Glaser, A. Lisjak, et al., Numerical simulation of fault slip during geothermal energy extraction, in: ARMA US Rock Mechanics/Geomechanics Symposium, 2020, pp. ARMA-2020-1388.

[104] W. Shiu, Y. Guglielmi, B. Graupner, et al., Modelling the water injection induced fault slip and its application to in-situ stress estimation, Int. J. Rock Mech. Min. Sci. 137 (2021) 104537.

[105] F. Cappa, M.M. Scuderi, C. Collettini, et al., Stabilization of fault slip by fluid injection in the laboratory and in situ, Sci. Adv. 5 (2019) eaau4065.

[106] L. Wang, G. Kwiatek, E. Rybacki, et al., Injection-induced seismic moment release and laboratory fault slip: Implications for fluid-induced seismicity, Geophys. Res. Lett. 47 (2020) e2020GL089576.

[107] S. Zhu, C. Feng, L. Xing, et al., Changes in fault slip potential due to water injection in the rongcheng deep geothermal reservoir, Xiong'an new area, north China, Water 14 (2022) 410.

[108] H. Zhao, Z. Guan, Mechanical analysis of production casing damage caused by sand production in oil reservoirs, J. China Univ. Petrol. Nat. Sci. Ed. 30 (66) (2006) 53–56 (Chinese).

[109] H. Zhao, Z. Guan, Mechanical analysis of production casing damage in severely sand-producing wells, Petrol. Drill. Tech. 100 (2005) 88–91 (Chinese).

[110] K. Furui, G.F.F. Fuh, N. Morita, Casing- and screen-failure analysis in highly compacting sandstone fields, SPE Drill. Complet. 27 (2012) 241–252.

[111] X. Li, C. Gu, Z. Ding, et al., THM coupled analysis of cement sheath integrity considering well loading history, Pet. Sci. 20 (2023) 447–459.

[112] J. Guo, H. Yang, H. Yan, Sealing failure of a cement sheath under temperature variation, Geomech. Energy Environ. 33 (2023) 100429.

[113] C. Ruan, X. Wang, R. Zhang, et al., Key technology for the deployment of rotary tail pipe in high-angle wells, Petrol. Drill. Tech. 44 (2016) 52–57 (Chinese).

[114] Y. Xia, Design analysis of HSM-2 type special threaded casing connection, Weld. Pipe 39 (2016) 22–26 (Chinese).

[115] C. Chen, X. Guo, X. Sun, et al., Structural parameter optimization of the flat connection special threaded oil casing, Mech. Eng. Mag. (2023) 115–117 (Chinese).

[116] S. Gao, H. Huang, Y. Ye, et al., Research on mechanism and prevention technology of casing damage in A'nan Oilfield, in: Proceedings of the International Field Exploration and Development Conference 2022, Singapore, 2023, pp. 2722-2731.

[117] J. Xie, Failure analysis and performance improvement measures of casing strings, M.S. Thesis, China Univ. Petrol. (East China), 2015, pp. 56 (Chinese).

[118] Z. Wan, Z. Lian, D. Yang, et al., Failure analysis of wellhead casing and optimization of slip hanger in ultra deep wells, Proc. Inst. Mech. Eng. Part C. 238 (2024) 9221–9234.

[119] A. Shokry, A. Elgibaly, Well design optimization through the elimination of intermediate casing string, J. King Saud. Univ. Eng. Sci. 34 (2022) 571–581.

[120] R. Khosravanian, B.S. Aadnoy, Optimization of casing string placement in the presence of geological uncertainty in oil wells: Offshore oilfield case studies, J. Pet. Sci. Eng. 142 (2016) 141–151.

[121] T.C. Nguyen, R. de Oliveira, E. Al-Safran, et al., Casing-design optimization with CAML technique and drilling-fluid performance, SPE Drill. Complet. 32 (2017) 208–212.

[122] B. Zhang, Z. Guan, A.R. Hasan, et al., Development and design of new casing to mitigate trapped annular pressure caused by thermal expansion in oil and gas wells, Appl. Therm. Eng. 118 (2017) 292–298.

[123] B. Zhang, S. Xia, H. Pan, et al., Research and application of low-density high-strength cement slurry for cementing, Fault Block Oil Gas. Field 16 (2009) 120–122 (Chinese).

[124] S. Zheng, T. Liu, G. Jiang, et al., Direct evidence of pore structural effects on the compressive strength of lightweight cement slurry containing nano silica fume and hollow glass microspheres, Constr. Build. Mater. 411 (2024) 134703.

[125] D. Zheng, S.Z. Miska, E. Ozbayoglu, The influence of formation creeping on wellbore integrity, in: SPE 2021 Symposium Compilation, 2021, pp. D011S002R003.

[126] Y. Yan, M. Cai, W. Ma, et al., Research on casing deformation prevention technology based on cementing slurry system optimization, Pet. Sci. 21 (2) (2024) 1231–1240.

[127] P. Liu, J. Li, H. Yang, et al., Study on a new method of controlling casing shear deformation based on hollow glass microspheres cement sheath, Energy Rep. 8 (2022) 5192–5203.

[128] T.G. Kristiansen, L. Delabroy, G.A. Obando Palacio, et al., Implementing a strategy for shale as well barrier in new wells, in: SPE/IADC International Drilling Conference and Exhibition, Virtual, 2021.

[129] D. Zheng, Y. Chen, C. Zou, et al., New technology and application of graded cementing for deep and ultra-deep wells in Tarim basin, Drill. Prod. Technol. (2023) 29–34 (Chinese).

[130] H. Mao, Z. Qiu, Z. Shen, et al., Hydrophobic associated polymer based silica nanoparticles composite with core–shell structure as a filtrate reducer for drilling fluid at utra-high temperature, J. Pet. Sci. Eng. 129 (2015) 1–14.

[131] X. Chang, J. Sun, Z. Xu, et al., A novel nano-lignin-based amphoteric copolymer as fluid-loss reducer in water-based drilling fluids, Colloids Surf. A Physicochem. Eng. Asp. 583 (2019) 123979.

[132] Q. Zou, X. Chen, S. Zhong, et al., Performance experiment of ultra high temperature cementing slurry system, Front. Mater. 11 (2024) 1383286.

[133] F. Khan, A. Tandon, V. Dhar, et al., Cement slurry design for high-pressure, high-temperature wellbores using polymer nanocomposite: A laboratory scale study based on the compressive strength and fluid loss, Energy Fuels 36 (2022) 6820–6830.

[134] Q. Feng, Q. Wan, Z. PENG, et al., Synthesis, performance evaluation and retarding mechanism study of ultra-high temperature retarding agent for cementing slurry, Constr. Build. Mater. 451 (2024) 138783.

[135] A.M.A. Rahman, H. Bakar, K.G. Daly, et al., Oriented perforation using tubing conveyed perforating TCP gun with dynamic underbalance DUB as sand control method in low angle wells, offshore sarawak, Malaysia, Dubai U. Arab Emir. (2019).

[136] A.M. Othman, V. Sharma, P. Singh, et al., Enhancing well productivity with customised completion and underbalanced perforation - a case study of AbuDhabi, UAE, Jkt. Indones. (2023).

[137] M.I. El Shiekh, M.M. Koriesh, M.L. Vazquez, et al., Improving the productivity of highly damaged intervals in low draw-down oil wells using dynamic under-balance gun type: Case study in gulf of suez offshore field, Egypt, Dubai U. Arab Emir. (2023).

[138] A. Al Suleimani, A.S. Al Hinai, A. Nunez, et al., Dynamic underbalance perforating for production enhancement and frac optimization in tight gas wells: Case study from sultanate of Oman, Abu Dhabi U. Arab Emir. (2023).

[139] Q. Liu, W. Li, H. Liu, et al., Innovation of tubing conveyed perforating technology in the Agadem field, Niger, in: Proceedings of the International Field Exploration and Development Conference 2022, Singapore, 2023, pp. 13-23.

[140] M. Bakhtbidar, R. Hafizi, M. Bakhtbidar, et al., Effectiveness assessment of a new advanced laser perforation technique for improving well productivity, Opt. Laser Technol. 129 (2020) 106301.

[141] C. Zhao, J. Wang, Q. Lu, Development status and prospects of modern oil and gas well perforation technology, Petrochem. Technol. 29 (2022) 216–218 (Chinese).

[142] H. Liu, F. Wang, Y.C. Wang, et al., Oil well perforation technology: Status and prospects, Petrol. Explor. Dev. 41 (6) (2014) 798–804.

[143] C. Tan, W. Yan, Q. Tang, et al., Casing damage prediction model based on the data-driven method, Math. Probl. Eng. 2020 (2020) 1–9.

[144] J. Liu, Y. Jian, Y. Chen, et al., Shock vibration response characteristic of perforating tubing string in ultra-deep wells, Geoenergy Sci. Eng. 228 (2023) 212008.

[145] Z. Du, J. Liu, X. Guo, et al., Investigation of key problems of clustering perforation string running in horizontal well with unconventional oil-gas reservoirs, Pet. Sci. Technol. 42 (2024) 2106–2132.

[146] S.E. Chernyshov, S.G. Ashikhmin, Y.A. Kashnikov, et al., Well perforation optimization using an abrasive jet technique to create oriented slotted channels in terrigenous reservoirs, Heliyon 10 (2024) e27311.

[147] A. Elhadidy, A. Helmy, M. Heikal, et al., Optimizing well perforation with machine learning: A breakthrough in predictive modeling, in: GOTECH, Dubai, UAE, 2025, pp. 224556-MS.

[148] Y. Li, Z. Cai, L. Huang, et al., A comparative study of the corrosion behavior of P110 casing steel in simulated concrete liquid containing chloride and annulus fluid from an oil well, Coatings 14 (3) (2024) 294.

[149] Y. Zhang, J. Wen, X. Yin, et al., Application of anticorrosive materials in cement slurry: Progress and prospect, Front. Mater. 9 (2022).

[150] G. Mubarak, C. Verma, I. Barsoum, et al., Internal corrosion in oil and gas wells during casings and tubing: Challenges and opportunities of corrosion inhibitors, J. Taiwan Inst. Chem. Eng. 150 (2023) 105027.

[151] Q.J. Sharif, O.J. Esmail, G. Radhakrishnan, et al., Experience with fiberglass (GRE) lined carbon steel tubular for corrosion protection for oil production applications, San Antonio, TX, United States, 2012, pp. 4578-4591.

[152] D.C. Hsi, R.C. Woollam, Field evaluation of downhole corrosion mitigation methods at Prudhoe Bay Field, Alaska, Houston, TX, United states, 2001, pp. 305-310.

[153] R. Gao, S. Yang, C. Chen, et al., New strategies for suppressing localized corrosion induced by inclusions: A case study of rare earth Y-treated oil casing steel, Corros. Sci. 252 (2025) 112969.

[154] Z. Song, Y. Liu, J. Yang, et al., Application of remote monitoring and controlling intelligent separated layer water injection technology in BQ oilfield, Dagang, in: International Petroleum Technology Conference, Dhahran, Saudi Arabia, 2024.

[155] Z. Yi, Analysis of water injection development technology for low-permeability oil fields, China Petrol. Chem. Stand. Qual. 43 (2023) 166–168 (Chinese).

[156] H. Yao, Cause analysis and prevention of casing damage in X Oilfield, in: Proceedings of the International Field Exploration and Development Conference 2020, Singapore, 2021, pp. 1125-1131.

[157] Z. Wang, C. Dai, J. Liu, et al., Anionic-nonionic and nonionic mixed surfactant systems for oil displacement: Impact of ethoxylate chain lengths on the synergistic effect, Colloids Surf. A Physicochem. Eng. Asp. 678 (2023) 132436.

[158] G. Zhai, Current status and development of layer-by-layer water injection technology in oil and gas field development, Chem. Eng. Des. Commun. 49 (2023) 41–43 (Chinese).

[159] A. Safaei, M. Asefi, M. Ahmadi, et al., Chemical treatment for sand production control: A review of materials, methods, and field operations, Pet. Sci. 20 (2023) 1640–1658.

[160] S.Z. Marandi, M.B. Salehi, A.M. Moghadam, Sand control: Experimental performance of polyacrylamide hydrogels, J. Pet. Sci. Eng. 170 (2018) 430–439.

[161] J. Du, Q. Huang, P. Liu, et al., Review of recent advances in chemical sand production control: Materials, methods, mechanisms, and future perspectives, Energy Fuels 38 (2024) 21845–21872.

[162] S. Yuan, Y. Bai, H. Jiang, et al., Multi-objective optimization of sand control for slotted liner based on genetic algorithm, Math. Pract. Theory 51 (2021) 113–119 (Chinese).

[163] M. Muhammad, A.A. Ali Rasol, Advances and challenges of sand production and control in oilfields: A review, Results Eng. 25 (2025) 104596.

[164] E. Khamehchi, E. Reisi, Sand production prediction using ratio of shear modulus to bulk compressibility (case study), Egypt. J. Pet. 24 (2015) 113–118.

[165] A. Salahi, A.N. Dehghan, S.J. Sheikhzakariaee, et al., Sand production control mechanisms during oil well production and construction, Pet. Res. 6 (2021) 361–367.

[166] S. Jiang, J. Feng, B. Wu, et al., Research on sand control technology for sand-producing wells with casing deformation, Petrol. Knowl. (2020) 52–53 (Chinese).

[167] S. Chen, J. Wei, G. Zhong, et al., Experiment and application of combined lifting and sand production removal technology for sand-producing oil wells, Petrochem. Technol. 30 (2023) 166–168 (Chinese).

[168] B. Xu, Y. Zhang, H. Wang, et al., Application of numerical simulation in the SET (Solid Expandable Tubular) repair for casing damage wells, Petrol. Explor. Dev. 36 (5) (2009) 651–657.

[169] X. Zhai, Y. Lou, M. Wang, et al., Study on critical parameters of smith expandable cone reshaping, Petrol. Mach. 40 (98) (2012) 1–3 (Chinese).

[170] K. Deng, W. Liu, B. Liu, et al., Repairing force for deformed casing shaping with spinning casing swage and damage behaviour of cement sheath, Appl. Math. Model. 70 (2019) 425–438.

[171] K. Deng, W. Liu, Y. Lin, et al., Experimental and numerical investigation on repairing process of cement-casing repaired by rolling reshaper, J. Pet. Sci. Eng. 166 (2018) 305–312.

[172] X. Bai, L. Deng, Y. Yan, et al., Synthesis and performance evaluation of water-absorbing resin coated withpolymethyl methacrylateas a lost circulation material, J. Appl. Polym. Sci. 140 (24) (2023) e53955.

[173] S. Lei, J. Sun, Y. Bai, et al., Plugging performance and mechanism of temperature-responsive adhesive lost circulation material, J. Pet. Sci. Eng. 217 (2022) 110771.

[174] K. Cui, G. Jiang, C. Xie, et al., A novel temperature-sensitive expandable lost circulation material based on shape memory epoxy foams to prevent losses in geothermal drilling, Geothermics 95 (2021) 102145.

[175] R. Lashkari, S.A. Tabatabaei-Nezhad, M.M. Husein, Evaluation of shape memory polyurethane as a drilling fluid lost circulation and fracture plugging material, Geoenergy Sci. Eng. 222 (2023) 211445.

[176] Q. Ma, M. Ren, C. Wang, et al., High performance shape memory epoxy syntactic foam composites as lost circulation material in deep drilling, Macromol. Mater. Eng. 309 (3) (2023) 2300303.

[177] R. Wang, C. Wang, Y. Long, et al., Preparation and investigation of self-healing gel for mitigating circulation loss, Adv. GeoEnergy Res. 8 (2023) 112–125.

[178] X. Wang, J. Han, J. Liu, et al., Application of ultrasonic casing damage detection technology in coalbed methane well casing inspection, China Sci. Pap. 16 (2021) 1030–1034 (Chinese).

[179] Y. Cuan, Z. Wang, J. Han, Research on TV imaging casing damage detection and classification method based on C4.5 decision tree, J. Phys. Conf. Ser. 1437 (2020) 012132.

[180] B. Sun, S. Chu, J. Fan, et al., A design of magnetic memory sensor of oil well casing damage detection, in: Proceedings of the International Field Exploration and Development Conference 2018, Singapore, 2019, pp. 1778-1787.

[181] B. Hu, Y.L. Meng, R.Q. Yu, Magnetic detection technique for double-layer steel tubing and casing damage, Insight Non Destr. Test. Cond. Monit. 59 (2017) 81–84.

[182] Z. Yan, Y. Li, J. Liu, et al., MIT/MTT and visualization logging technology and its application, in: 2022 4th International Conference on Intelligent Control, Measurement and Signal Processing (ICMSP), Hangzhou, China, 2022, pp.180–183.

[183] J. Sun, Y. Bai, R. Cheng, et al., Research progress and prospects of leak plugging technology for fractured wells in leak-prone formations, Petrol. Explor. Dev. 48 (2021) 630–638 (Chinese).

[184] D. Lavery, A. Imrie, The silver lining to squeezing salts: Practical cased holelogging and interpretation method determines if mobile formations act as annularbarriers for plug and abandonment applications, in: SPE/IADC Drilling Conferenceand Exhibition, 2017, pp. D022S022R004.

[185] L.E. Martin, A.E. Fouda, R.K. Amineh, et al., New high-definition frequency tool for tubing and multiple casing corrosiondetection, in: Abu Dhabi International Petroleum Exhibition and Conference, 2017, pp. D041S116R003.

[186] B. Das, R. Samuel, load-resistance monitoring and predictive analysis, in: HPHT wellintegrity, Offshore Technology Conference, 2017, pp. D011S004R002.

[187] K.K. Kyi, A.G.J. Wang, Issues with cement bond and cement evaluation logs-casestudies from offshore Malaysia, in: International Petroleum Technology Conference, 2015, pp. D041S038R004.

[188] Z. Zhou, Optical fiber smart bragg grating sensors and intelligent monitoring systems of civil infrastructures, Harbin Institute of Technology, Harbin, 2003.

[189] J.P. He, H.L. Wu, Z. Zhou, Long-term, monitoring of a civil defensive structure based on distributed brillouin optical fiber sensor, Pac. Sci. Rev. 9 (2007) 97–102.

[190] L. Paterson, C. Boreham, M. Bunch, et al., The CO2CRC Otway stage 2B residual saturation and dissolution test: Test concept, implementation and data collected, Milestone Report to ANLEC, 2011.

[191] A. Dahi Taleghani, L. Santos, Diagnostic methods: Integrity tests, in: A. Dahi Taleghani, L. Santos (Eds.), Wellbore Integrity: From Theory to Practice, Springer International Publishing, Cham, 2023, pp. 103–121.

[192] J. Saw, X. Zhu, L. Luo, et al., Distributed fiber optic sensing for in-well hydraulic fracture monitoring, Geoenergy Sci. Eng. 250 (2025) 213792.

[193] Z. Zhou, J. He, M. Huang, et al., Casing pipe damage detection with optical fiber sensors: A case study in oil well constructions, Adv. Civ. Eng. 2010 (2010) 638967.

[194] Q. Cao, R. Banerjee, S. Gupta, et al., Data drivenproduction forecasting using machine learning, in: SPE Argentina Exploration and Production of Unconventional Resources Symposium, 2016, pp. D021S006R001.

[195] J. Pollock, Z. Stoecker-Sylvia, V. Veedu, et al., Machinelearning for improved directional drilling, in: Offshore Technology Conference, 2018, pp. D031S031R001.

[196] T. Hoeink, C. Zambrano. Shale discrimination with machine learning methods, in: ARMA US Rock Mechanics/Geomechanics Symposium, 2017, pp. ARMA-2017-0769.

[197] C.I. Noshi, S.F. Noynaert, J.J. Schubert, A novel data mining approach inpredicting casing failures for improved drilling performance and productionoptimization, in: Casing failure Data Analytics, SPE Annual Technical Conferenceand Exhibition, 2018, pp. D011S001R003.

[198] C. Noshi, S. Noynaert, J. Schubert, Data mining approaches for casing failure prediction and prevention, in: International Petroleum Technology Conference, 2019, pp. D021S018R001.

Jiang-Feng Liu, born in 1984, is currently a professor at State Key Laboratory of Intelligent Construction and Healthy Operation and Maintenance of Deep Underground Engineering, China University of Mining and Technology. He received his PhD in Civil Engineering from Ecole Central de Lille (Central School of Lille) and French National Centre for Scientific Research (CNRS)-Laboratory of Mechanic of Lille (LML), France, in 2013. His current research focuses on coupled fluid and gas transport in geomaterials, and its application in deep underground energy material storage (carbon–hydrogen–waste–energ) and deep energy mining. He has published more than 80 papers in refereed scientific journals, and he currently presides over 20 national and provincial scientific research projects.