

Research Article

Study on the Mechanical Mechanism and Prevention Method of Casing Moving up: Taking the Jidong Oilfield as an Example

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Received 29 April 2022; Accepted 18 August 2022; Published 11 October 2022

Academic Editor: Liang Xin

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In the production process of oilfields, the proportion of oil and water wells scrapped or overhauled by casing moving up continues to increase, especially in some onshore oilfields near the coast, which is more prominent. In order to clarify the causes of casing moving up and propose the treatment method of casing moving up, this paper first establishes the buckling deformation model of groundwater extraction-induced surface settlement and the buckling deformation model of casing on the surface settlement stress field and then combines the relationship between the axial jackal force generated by the buckling deformation of the casing of different well structures and the jacking strength of the casing head to give the criterion for the casting of the casing moving up. Taking Jidong Oilfield as an example, the displacement of running-up wells on 50 casings was analyzed, and the identification compliance rate reached 85.68%, and the variation law of running-up on casing with time and casing structure was given, which provided scientific guidance for subsequent casing running-up protection. Based on the model, it is concluded that enhancing the casing structure, the length of the casing cementing and sealing section, and enhancing the casing prestress are helpful for preventing the casing from moving up.

1. Introduction

In recent years, in the process of oilfield development, different degrees of oil and water wellhead casing have occurred in major oilfields at home and abroad, resulting in elevated or skewed wellhead devices, affecting normal production, making operation and construction difficult, and even causing oil and water wells to be overhauled. The moving up rate of wellhead casing in North China Oilfield in China has reached more than 80% (40% of the moving up is serious), and the moving up rate of the Dagang southern oilfield in China has reached more than 10%, and the serious one accounts for more than 8%, and with the extension of the exploitation time, the casing moving up situation has intensified, which has seriously affected the normal production of major oilfields. After the casing occurs, the harm caused by the casing can be mainly summarized as follows: (1) The wellhead is elevated

or deflected due to the upward movement of the casing in the oil layer, which leads to the leakage at the clamp or flange connection of the ground pipeline, resulting in ground pollution. As a result, the suspension of the pumping unit will knock against the root box of the wellhead tree, increasing the probability of damage and injury to facilities and equipment, affecting the normal production, and causing potential safety hazards. (2) The moving up stress makes the wellhead process weak, and it is easy to cause pollution after the wellhead process is broken. (3) It is easy to make some part of the casing elastic deformation, resulting in permanent deformation of the overall plastic casing, so that there are certain defects in the well structure. (4) In a few oil wells, the wellhead trees also move reciprocally with the stroke of the pumping unit, which affects the pump efficiency. Different failure modes of casing moving up in Jidong oilfield are shown in Figure 1.



FIGURE 1: Damage mode of Jidong oilfield casing moving up.

Statistics of casing moving up and treatment results in different production areas of Jidong Oilfield are shown in Figure 2.

Jeanne et al. [1], Schmid et al. [2], and Li et al. [3] have studied the effects of agricultural production and surface water use on surface subsidence. Rateb and Abotalib [4] analyzed the influencing factors of surface subsidence in the Nile Delta region through satellite systems and GPS systems, and most scholars believe that the downward axial pressure exerted on the casing caused by groundwater exploitation to force the casing to buckle and deform is the main cause of the casing moving up (Yang et al. [5]; Cai [6]; Zhao et al. [7]; Xue et al. [8]). They determined the overall surface settlement law by studying vertical pressure displacements formed by the flow of water in underground rock and soil or coal seams (Jia et al. [9]; Pineda and Sheng [10]; Yu et al. [11]; Zhang et al. [12]; Zhao et al. [13]). Jia et al. [14] invented a set of ground settlement test devices caused by underground pumping of pressurized water, which is specially used for indoor experiments to study the problem of surface settlement. Li et al. [15] and Liu et al. [16] and Du and Olson [17] and Xue et al. [8] were numerically simulated and experimentally studied for the effects of permeability parameters on the entire surface settlement, respectively. Galloway et al. [18] and Zhang [19] have investigated surface settlement processes and nonlinear engineering settlement control problems based on time-varying parameters, respectively. Therefore, this paper establishes a mechanical model of surface water exploitation inducing surface settle-

ment and a buckling model of casing column being squeezed by axial extrusion, combines the hydrogeological characteristics and cementing process characteristics of Jidong Oilfield to carry out casing moving up prediction, the prediction is accurate at 85.68%, and puts forward the preventive measures for casing moving up in Jidong Oilfield, which provides a scientific guidance scheme for casing moving up treatment in the later stage of oilfield.

2. Study on the Model of Nest Loss Caused by Surface Settlement

The schematic diagram is shown in Figure 3; with the surface mining, the entire geological body settles with the formation fluid, and with the difference of time, the settlement intensity of the formation changes accordingly; considering the relationship between the geological body and the formation fluid coupling change, the surface settlement model is as follows:

Assuming that the mechanical behavior of the rock layer can be described as a linear pore elasticity, the strain and stress of the target rock formation can be expressed by Hooke's law.

The rock layer is assumed to have settlement only in vertical direction and no lateral strain, resulting in only uniaxial deformation. Suppose that any aquifer is mined, and the water level drop displacement is defined as

$$u_{\text{water}} = C_m D_{\text{water}} \alpha \Delta p_p. \quad (1)$$

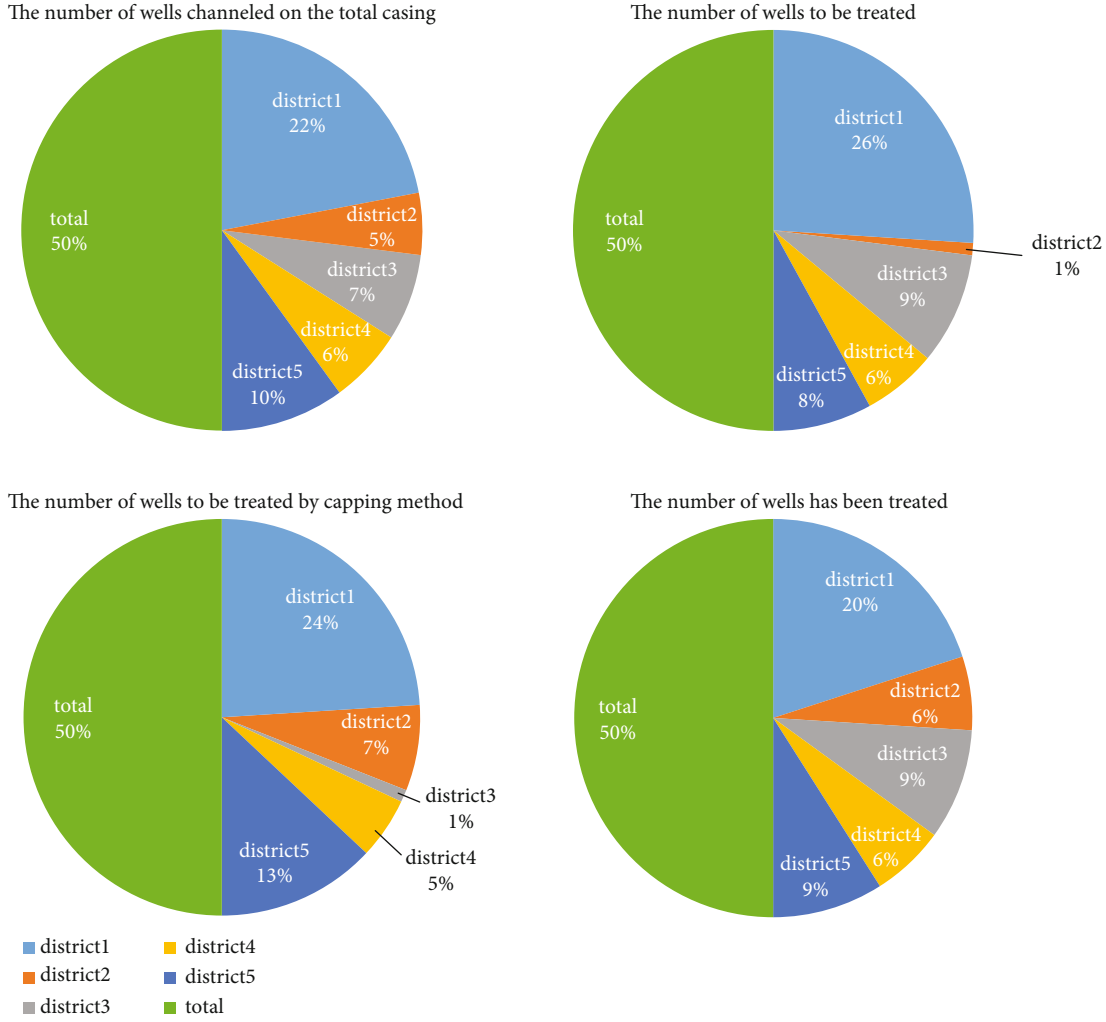


FIGURE 2: Statistical chart of casing moving up and treatment results in Jidong Oilfield.

In the equation, C_m is the elastic compression coefficient; D_{water} is the depth of the aquifer; α is the Ramé coefficient; Δp_p is the change of pore pressure.

The compressibility coefficient C_m is related to the Young's modulus E and Poisson's ratio, which is defined as

$$C_m = \frac{(1 + \mu)(1 - 2\mu)}{E(1 - \mu)}. \quad (2)$$

The overall descending displacement of the overall aquifer can be expressed as

$$u = u_{water} + u_{indirect} = \sum_1^N C_{m(i)} D_{water(i)} \alpha_{(i)} \Delta p_{p(i)}, \quad (3)$$

where $u_{indirect}$ is the indirect compaction resulting from overlying and underlying geological units hydraulically connected to the target formation and N is the total number of formations including overlying and underlying layers.

3. Mechanical Model of Casing Column Deformation under Surface Settlement

3.1. *Surface Sedimentation Induces Deformation of the Casing.* The mechanical nature of casing moving up refers to the formation compaction and subsidence caused by a large amount of underground fluid being taken out (or lost), which increases the load on the upper end of the casing which was originally fixed at both ends of the oil and gas well and leads to casing bending and deformation [20]. When the casing load increases to a certain extent, the upper end of the casing breaks through the restraints of the wellhead device and suddenly rises relative to the ground. In the process of slow ground subsidence, the surface casing sinks along with the ground subsidence, while the oil casing below the cement return height basically does not move. At first, the upper oil casing sinks along with the surface casing, slowly releasing the tensile deformation, so that the stress neutral point gradually moves up, then gradually changes from the tensile state to the free state, and finally to the compressed state, which not only bears the weight of the upper casing.

Figure 4 shows the deformation state of the casing under different mechanical actions: (a) the free equilibrium state of

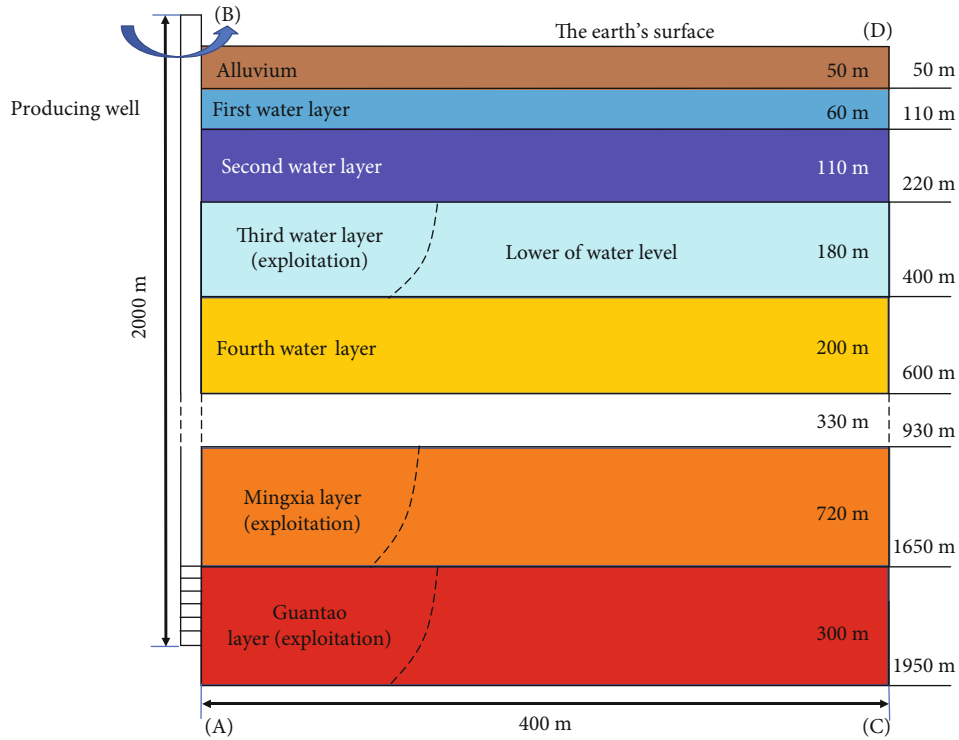


FIGURE 3: Schematic diagram of aquifer settlement.

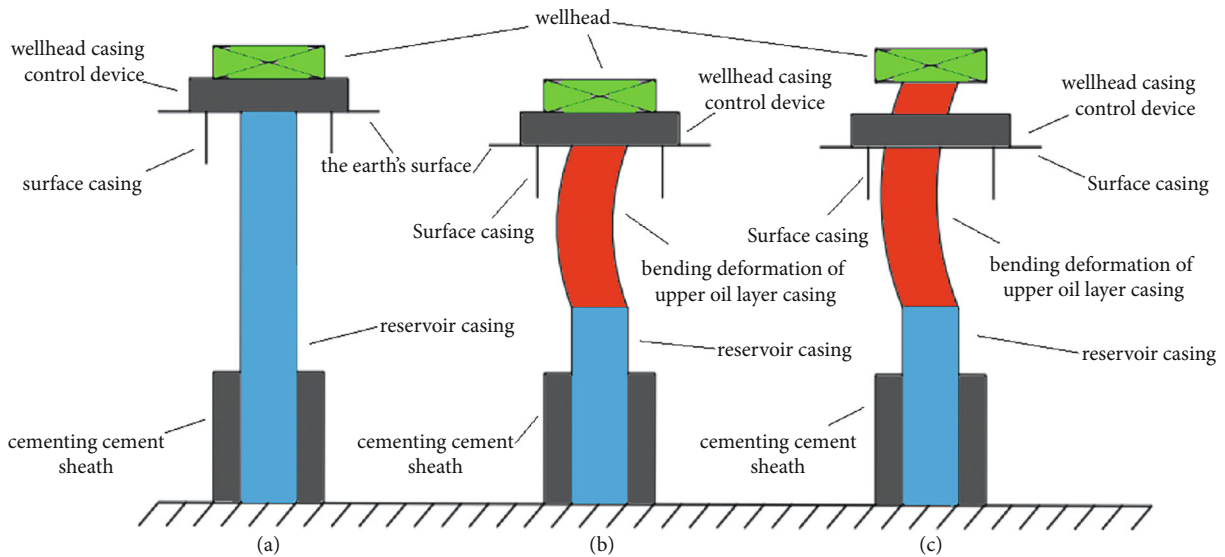


FIGURE 4: Deformation state of casing under different mechanical action.

the surface without sedimentation after cementing; (b) the sedimentation squeeze of the casing does not occur in the moving up state; and (c) the casing is squeezed by the surface sedimentation.

Assuming that the influence of horizontal ground stress is not considered, the bending deformation of the casing caused by formation settlement can be reduced to the instability of the rod which can be reduced to the problem of pressure rod stability in material mechanics. That is shown in Figure 5, where P is the axial load; P_1 is the axial upward

bushing bending thrust on the casing head; F_2 is the weight of the casing of the noncementing section in the direction downward, KN; and P_3 is the prestressed load applied to the cementing, MPa.

3.2. Mechanical Model of Surface Settlement Induced Casing Deformation and Moving up on the Casing. As shown in Figure 6, it can be considered that the casing deformation, caused by the surface subsidence, is caused by the top pressure acting on the ideal straight rod in the axial direction.

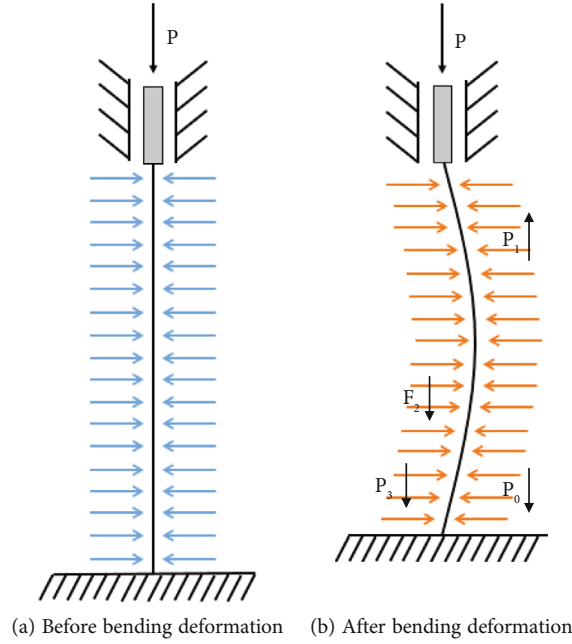


FIGURE 5: Schematic diagram of bending deformation of casing.

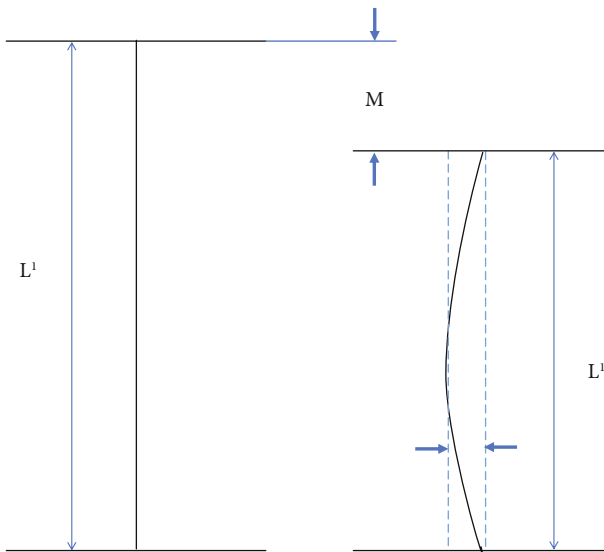


FIGURE 6: Diagram of the relationship between ground settlement and casing bending deformation.

Ideally, the straight rod does not rotate in the axial direction. When the surface subsidence is unobvious, the buckling and the jacking force of the straight rod are neglectable. At this time, the restraining force at the top casing head is enough to overcome the jacking force, so as to ensure that the casing does not move up. During the pressure relief stage of work-over, the casing string remains intact. Relatively, if the surface subsidence is extensive, the straight rod will undergo a great buckling deformation. Consequently, the jacking force of the casing is enormous, and the casing will be permanently deformed and damaged.

According to Figure 6, assuming that the original length of the casing is L , after the ground settlement occurs, the length change of the pressure rod ΔL can be known by setting the ground settlement amount to M :

$$\Delta L = M, \tag{4}$$

$$L - M = L_1. \tag{5}$$

Since the amount of ground settlement M relative to the length of the casing L is small, the deflection calculation formula d can be approximately written as

$$d^2 = \left(\frac{L}{2}\right)^2 - \left(\frac{L-M}{2}\right)^2. \tag{6}$$

Since the amount of ground drop is much smaller than the length of the entire casing column, that is, $M \ll L$. Therefore, if the deflection of the pressure rod at both ends remains small, the deflection of the midpoint and δ the axial load can be expressed as near as the formula:

$$\frac{\delta}{L} = \frac{\sqrt{8}}{\pi} \sqrt{\frac{P}{P_{cr}} - 1} \left[1 - \frac{1}{2} \left(\frac{P}{P_{cr}} - 1 \right) \right]. \tag{7}$$

In the equation, P is the axial load; P_{cr} is the critical load fixed at both ends of the sleeve string.

According to the relationship of formulas (4)~(7), the axial load of the bending deformation of the pipe column during the surface settlement process can be obtained. In the actual casing cementing process, the axial load is affected by the following forces, which are the axial upward bushing bending thrust on the casing head P_1 ,

TABLE 1: Table of surface settlement in Jidong Oilfield.

Well number	Well of settlement center	Water cut group	Depth of groundwater(m)	Water level elevation (m)
235	A	II + III	84.19	-82.17
249	B	III + IV	79.87	-80.67
112	C	III	75.83	-74.07
109	D	III	73.06	-70.87
114	E	III	71.20	-68.94
36	F	II + III	70.96	-68.70
170	G	II + III	67.83	-65.82

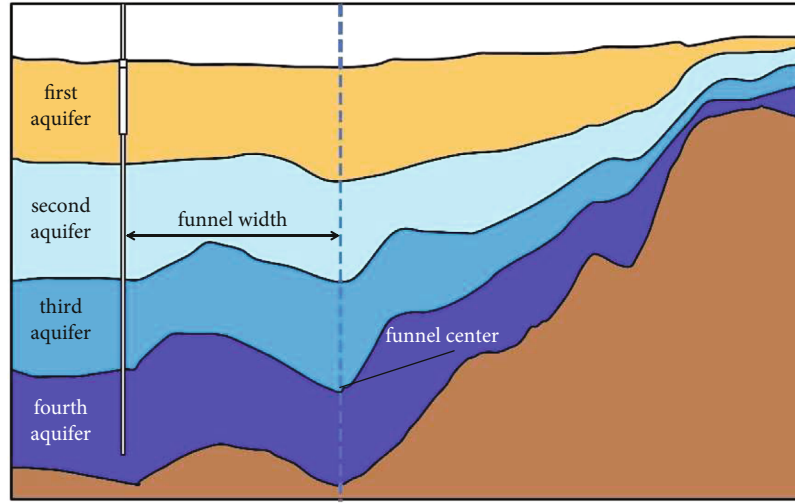


FIGURE 7: Schematic diagram of hydrogeological model in study area.

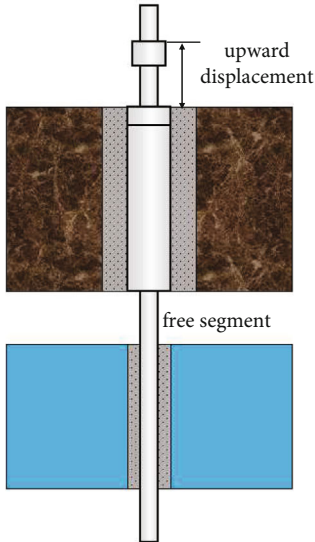


FIGURE 8: Diagram of well structure of casing run-up.

according to the mechanical relationship $P_0 = -P$; the weight of the casing of the noncementing section in the direction downward F_2 , KN; and the prestressed load applied to the cementing P_3 , MPa.

According to the mechanical interaction relationship in Figure 5, the combined force acting on the top of the casing head F_0 can be expressed as

$$P_0 = P_1 - \frac{F_2}{A} - P_3. \quad (8)$$

A is the casing that acts on the annular area of the casing head.

Assuming that the line weight of any casing is q_i , equation (8) can be rewritten as

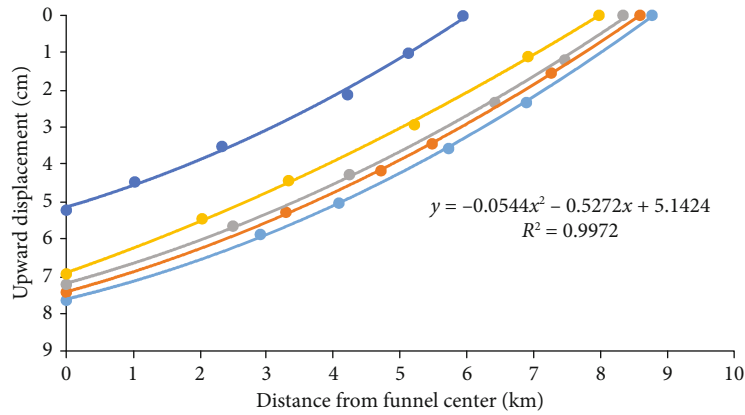
$$P_0 = P_1 - \frac{\sum_{i=1}^3 q_i l_i}{A} - P_3. \quad (9)$$

Combined with the schematic diagram of the mechanical state of Figure 5, the conditions for the occurrence of the casing string are

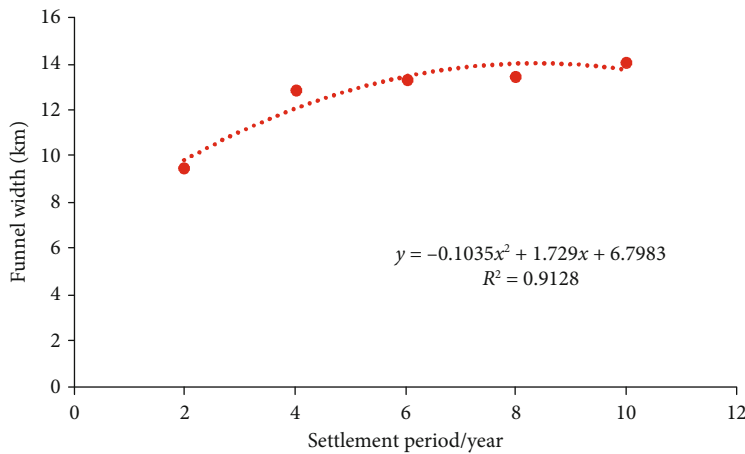
$$P_0 > P_r. \quad (10)$$

Similarly, the conditions satisfied by the available casing string without moving up are

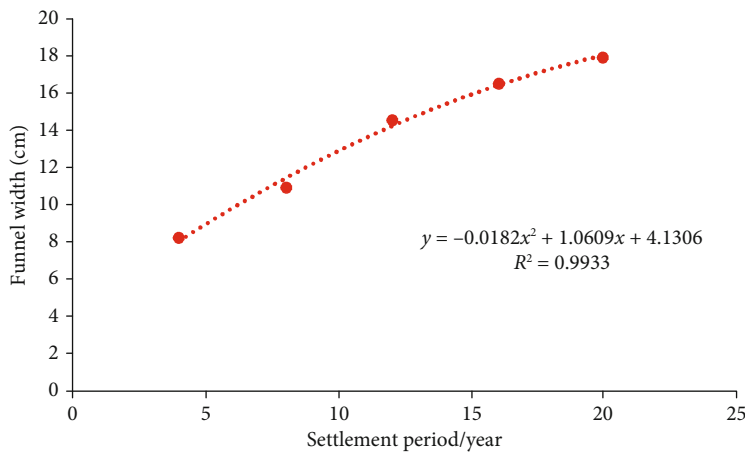
$$P_0 \leq P_r. \quad (11)$$



(a) The relationship between the amount of distance from the center of the funnel



(b) The relationship between the width of the funnel as a function of the settlement period



(c) The relationship between the sedimentation volume at the center of the funnel as a function of the sedimentation cycle

FIGURE 9: Curve relation of surface subsidence with time.

In the formula, the welding strength of the annular steel plate is P_r , MPa.

4. Case Study Analysis

4.1. Study Blocks and Basic Parameters. Liuzan Oilfield (Liu 102 and Liu 103 blocks), the focus of this project, is located in the north of the secondary structural belt of Nanpu Sag. The

strata drilled from top to bottom in the study area are Quaternary Pingyuan Formation, Neogene Minghuazhen Formation, and Guantao Formation, among which the lower member of Minghuazhen Formation and Guantao Formation are the main oil-bearing strata of this fault block with burial depth of 1450 m~2300 m. The lower Ming Formation can be divided into 2 oil groups and 29 small formations, and the Guantao Formation can be divided into 3 oil groups and 24 small

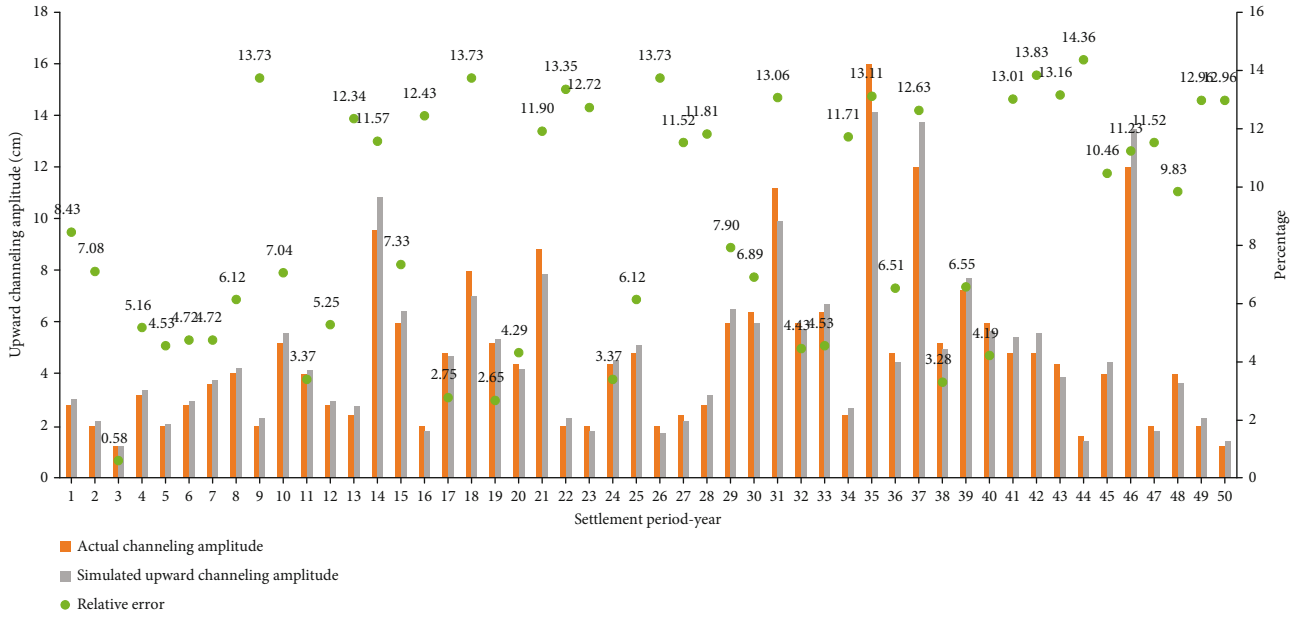


FIGURE 10: Curve relationship of surface settlement in LN5-6 well over time.

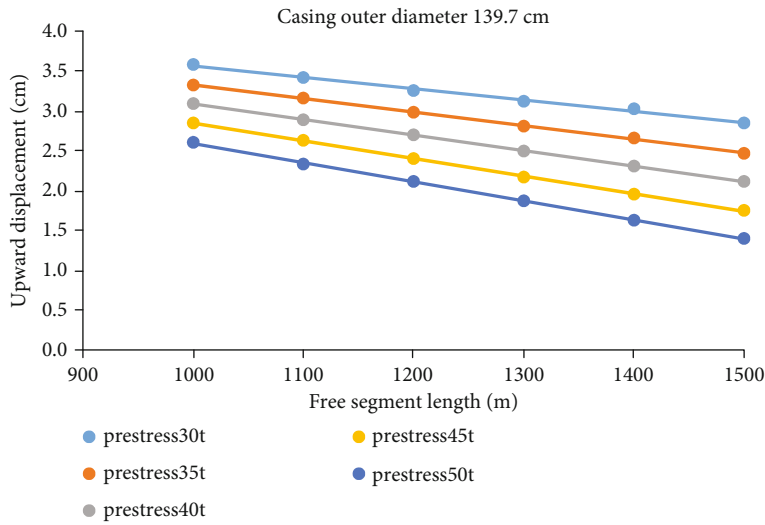


FIGURE 11: The relationship between the moving up amount and the length of the free segment under different prestresses of the two open wells (casing outer diameter 139.7 mm).

formations. The porosity is mainly 24%~36%, with an average of 32.8%, and the permeability is mainly $100 \times 10^{-3} \mu\text{m}^2 \sim 10000 \times 10^{-3} \mu\text{m}^2$, with an average of $2258.72 \times 10^{-3} \mu\text{m}^2$. The pore water of quaternary unconsolidated rocks can be divided into shallow groundwater and deep groundwater according to the buried conditions and into phreatic and confined groundwater according to the hydraulic properties of groundwater. According to the lithology and hydrogeological characteristics of quaternary sediments, the quaternary aquifer system in the study area is divided into four aquifer groups from top to bottom. The buried depth of the bottom interface of the first aquifer group is 40 m~60 m; The buried depth of the bottom interface of the second aquifer group is 120 m~170 m; the third aquifer group has a buried depth of

250 m~350 m at the bottom interface; the bottom interface of the fourth aquifer group is buried 350 m~550 m deep. Fifty wells were selected from the block for the study. Statistical table of formation water level in Jidong Oilfield is shown in Table 1. The center of the well is replaced by the letters A-G. The hydrogeology and subsidence funnel of the whole area are shown in Figure 7, and the casing run-up well structure is shown in Figure 8.

4.2. Analysis of Calculation Results. As shown in Figure 9, one cycle is calculated as 2 years, and as the settling cycle goes, the moving up of casing increases. The amount of moving up in the first settling cycle is large, and with the cycle going by, the amount of moving up decreases; from

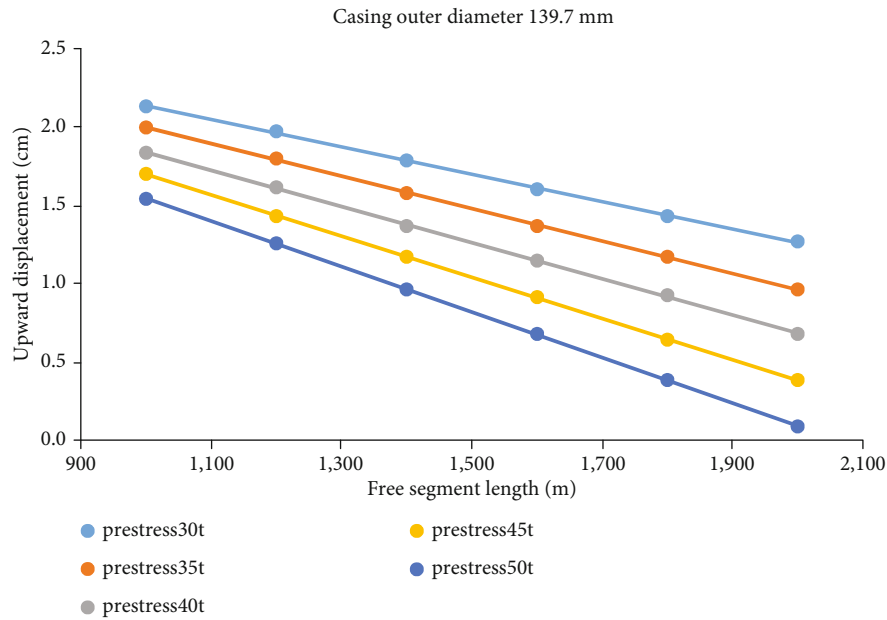


FIGURE 12: The relationship between moving up amount on casing with free segment length under different prestresses of three-open wells (casing outer diameter 139.7 mm).

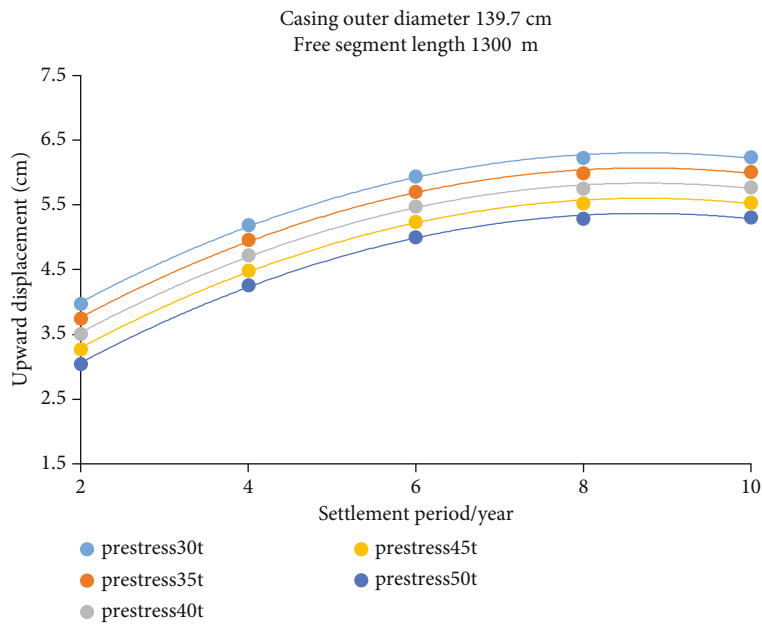


FIGURE 13: Relationship between the amount of moving up in different prestresses of the two-open wells with time (casing outer diameter 139.7 mm).

the third cycle onwards, the moving up amplitude increases by about 0.21 cm.

As shown in Figure 10, the maximum error of the moving up height calculated by the model is 14.32%, and the maximum error occurs in the forty-third well. The results show that it is feasible to use the model to calculate the casing moving up caused by the surface subsidence. Therefore, it is an effective to prevent casing moving up by avoiding overexploitation of subsurface water.

- (1) The relationship between the amount of moving up under different prestresses with the length of the free segment

The calculation results show that as the length of the free section of the casing continues to increase, the amount of moving up on the casing gradually decreases. The amount of moving up on the casing is basically linear with the length of the free segment, the greater the

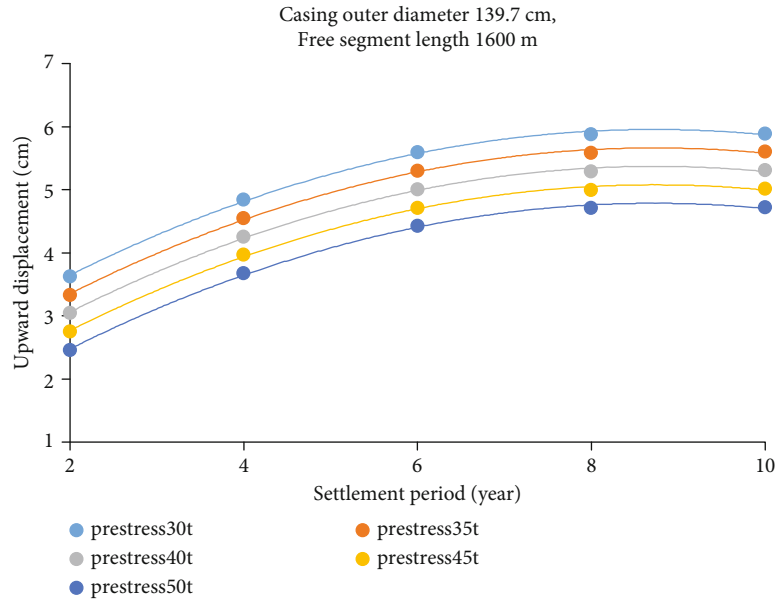


FIGURE 14: Relationship between the amount of moving up under different prestresses of three-open wells with time (casing outer diameter 139.7 mm).

prestress, the smaller the amount of moving up on the casing, and the amount of moving up on the casing of the three-open well is significantly smaller than the amount of moving up on the casing of the two-open well. It can be shown that the effectively increased casing cementing prestress, free section length, and three-open well structure cementing can effectively prevent casing moving up.

As shown in Figures 11–14, the calculation results show that with the increase of the settlement cycle, the moving up amount on the casing gradually increases, but with the increase of the settlement time, the increase in the moving up amount gradually decreases, and the relationship between the upper moving up and the settlement time changes approximately exponentially, and the larger the prestress, the smaller the moving up amount on the casing. The amount of moving up on the casing of the three-open well is still less than the amount of moving up on the casing of the two-open well. It can be seen that casing moving up mainly occurs in the early stage of sedimentation induction moving up and should be effectively treated in the early stage.

5. Conclusions

- (1) The 50 actual casing wells in the block were simulated and calculated by the evaluation model of surface settlement and prestressed cementing casing moving up, and the maximum error between the theoretical numerical simulation calculation results and the actual casing moving up results was 14.32%, and the accuracy rate was 85.68%
- (2) The calculation results show that the law of the larger the amplitude of the moving up on the casing is basically satisfied, the closer the distance from the

center of the settlement funnel. The funnel changes relatively largely in the early stage of settlement, and the relative change in settlement in the late sedimentation period is relatively slow

- (3) Through the mechanical model of buckling deformation, it can be seen that increasing the casing prestress in the cementing process and increasing the casing prestress in the cementing process can effectively prevent the casing moving up, and the jacking force on the casing of the three-open well body structure is significantly less than the jacking force on the casing of the two-open well body structure, so increasing the level of the casing can effectively prevent the casing moving up
- (4) According to the judging conditions, when the top force on the casing is greater than the weld of the casing head, the shear stress is allowed, so the shear stress of the weld can also be inhibited by high-quality weld process or by increasing the weld area to increase the shear stress of the weld

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declared that there is no conflict of interest.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (Grant No. 52074088, Grant No. 52174022, Grant No. 51574088, and Grant No. 51404073),

the Talented Reserves of Heilongjiang Province Science Foundation for Distinguished Young Scholars of Northeast Petroleum University (Grant No. SJQHB201802), the Development of Western Oil Fields Special Project (Grant No. XBYTKT202001), Talented Reserves of Heilongjiang Province Science Foundation for Distinguished Young Scholars of Northeast Petroleum University (Grant No. SJQH202002), Heilongjiang Postdoctoral Foundation (LBH-Q20074), Heilongjiang Province Postdoctoral Research Initiation Project (LBH-Q21086).

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