

Hazards of Urban Land Subsidence and Disaster Prevention and Mitigation Measures

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Abstract: Ground subsidence is a kind of geological disaster, which is due to natural and human factors under the action of the formation of the ground vertical drop phenomenon. The natural factors mainly include the large range and small rate of land subsidence caused by an earthquake, volcanic activity, and tectonic movement, which is beyond human control at present. The human factors mainly refer to the non-standard pumping construction design, the transition mining of underground resources, etc. Although the scope of its formation is small, the rate and range are large. Its occurrence and development have an inseparable relationship with human activities, which can be controlled and prevented through certain ways and measures. Correct understanding of these characteristics for disaster assessment, to prevent and reduce disaster, and thus avoid unnecessary losses.

1. The Part of the City and General Situation of Land Subsidence in Our Country

Land subsidence is a common geological hazard in cities. Due to the synergistic action of human construction activities and the adverse natural environment, the soil on the surface of the stratum has settled. This makes the surface of the region in different degrees of decline compared to the original, the destruction of the original natural stability of the foundation. The occurrence of sedimentation impacts urban construction planning, transportation safety, social and economic development, and the stable development of the human living environment.

Through investigation, about 70 cities in our country have suffered unnatural land surface damage affected by land subsidence. There are 16 cities with land subsidence greater than 0.5 m within the region. In five cities, Tianjin, Taipei, Chiayi, Shanghai, and Yilan, part of the settlement amount is more than 2 m. The maximum settlement area of Shanghai's urban area is 850 km², and the settlement amount is 2630 mm. The main reason is the irrational pumping of artificial water, and the secondary reason is the tectonic subsidence. It first appeared in 1921, and the disaster became increasingly serious from 1949 to 1965, and was slightly relieved in 1966 when the disaster was paid attention to by the government. The maximum subsidence in the urban and suburban areas of Tianjin is 2630mm, and the subsidence area is 7,000 km². The main reason is the excessive use of groundwater, and the natural consolidation and tectonic subsidence are the secondary reasons. According to the investigation, the disaster roughly occurred in 1923, developed from 1959 to 1985, and was effectively controlled in the next few years. The maximum settlement of Taipei City is

2000 mm smaller than that of Shanghai and Tianjin, and the settlement area is 300 km². The main reason for this is still excessive pumping. The disaster started in 1950 and developed rapidly after the 1970s. The maximum settlement amount of Cangzhou City is 1001 mm, but the settlement area is three times as much as that of Shanghai. The cause of subsidence is also excessive water extraction. The situation worsened after 1971 and was not well governed; Six cities, including Jiaxing, Fuyang, Baoding, Hengshui, Changzhou, and the East suburb of Beijing, have a settlement of 0.5-1.0 m[1].

All kinds of problems caused by land subsidence cannot be underestimated. It not only causes great economic losses but also threatens people's life safety. The main cause of land subsidence in these cities is still man-made. If human beings go on like this, it is like lifting a stone to drop on their own feet, self-destruction. To develop, human beings need not only to obtain nature but also to live in harmony with nature with the attitude of scientific development. Land subsidence is dangerous, but what is more dangerous is not knowing how to protect and cherish the earth. Urban land subsidence is shown in the figure 1:



Figure 1: Land subsidence caused serious house collapse.

2. Overview of Land Subsidence Disasters

2.1 Definition of Land Subsidence

(1) Generalized land subsidence refers to the reference point of a coastline in the four-dimensional space, which will change with the change of environmental conditions. Its main logic is that when the sea level rises, the basement will decline. The main reason is that the soil layer is compressed and compacted by human economic activities and the coastline reference point changes accordingly.

(2) In a narrow sense, ground subsidence refers to the consolidation and compaction of loose strata in the original natural state under the action of one or more factors, resulting in the reduction of ground elevation. This phenomenon is summed up as a kind of local engineering geological phenomenon.

2.2. Mechanism of Land Subsidence

Under normal conditions, land subsidence mainly develops slowly and lasts for a long time, and has a wide impact on the region. The causes are involved in many aspects. According to a large number of surveys and experiments, about 77.6% of land subsidence events are due to the compaction of the cohesive soil layer, and the remaining 22.4% are due to the compaction of the

sand layer. In principle, the compaction of the cohesive soil layer is an important cause of land subsidence[2]. As underground water resources are extracted, the confined aquifer depressurizes, while pore water pressure in the upper and lower clay layers gradually rises, creating a water head gradient toward the aquifer. Pore water in the marviscose layer flows toward the aquifer, and the clay layer becomes compacted. In the process of water release in the clay layer, the flow of water and its permeability act on the soil structure at the same time, so the structure is very easy to deform and damage, and at this time, the soil gravity field will change, because the clay layer water release. The plastic viscose squeezed in the center of subsidence will move sideways due to the force. Strong water flow occurs in the pumping and aquifer, and under this action, the aquifer particles are constantly closely packed together. The intensity and time of pumping are related to the tightness of the particles. The influence of the above activities is manifested as land subsidence on the ground.

2.3. Causes of Land Subsidence and Treatment Measures

2.3.1. Geological Reasons

Mainly due to changes in the natural environment caused by the settlement are these several: first, due to the action of gravity, the surface of the original loose or relatively loose strata in the loose layer will be compacted downward, become dense and hard than the original change, then the thickness of the stratum will change, that is, the ground settlement. Second, under the action of the geological structure, the ground sag and subsidence[3]. Third, the earthquake caused the ground settlement. An earthquake is a stress anomaly below the ground. To bring the stress back to a state of equilibrium, the stress will be released, and the ground may collapse. As a result of these processes, human civilization will be damaged to varying degrees, such as through cracks and depressions in buildings. When the land sinks below sea level, the seawater may flow back into the depression, causing flooding is shown in the figure 2.



Figure 2: Land subsidence threatens residential safety.

The relationship between geological disasters and the geological environment is very close. The occurrence of geological disasters changes the geological environment, and the change of the geological environment also affects the occurrence of geological disasters. Whenever a geological disaster occurs, no matter whether it is minor or severe, the geological environment is bound to be affected. By using the settlement generated by different characteristics and laws of each geological environment, the soil mass in the disaster area can be replaced. That is to remove the surface soil with severe liquefaction, and then use the new soil to meet the requirements in practice. External

forces can also be applied to the soil. Under the action of external forces, the water and gas in the pores of the soil are squeezed out, resulting in the rearrangement of soil particles, reducing the compressibility of the soil, and thus improving the bearing capacity of the foundation. The method of the sand pile is also effective. As the sand piles push in, the softening the soil around produces lateral compression, and the strength of the soil is improved. Sand piles in clay foundations can conduct good dredging of water penetrating in. Under the action of overhead load, the original lengthy horizontal penetration time of pore water is also greatly compressed, and the settlement and drainage performance of soft soil foundation is enhanced so that the consolidation speed of soil becomes faster.

2.3.2. Human Causes

The main man-made cause of land subsidence is the excessive exploitation of groundwater[4]. Land subsidence is not the only harm caused by overexploitation of groundwater. Although water is the source of life, this practice is no doubt harmful. If you want water, you have to find another way. The overexploitation of underground water has occurred in the China from time to time, resulting in a total land subsidence of more than 60,000 km². A large area of ground settlement appears in the city, and cracks and deformation occur in the components of roads and bridges. Some underground pipeline equipment appeared short circuit, broken lines, and other faults; water drains in the city were also damaged. The collapse of the ground makes the fertility of the originally fertile farmland begin to decline and even causes farmers to waste farmland; in this situation, the residents' buildings appear to crack or even collapse in a straight line, and the flood control capacity is greatly reduced, so that the standard reference points of various monitoring begin to deviate, which is a huge impact on the construction of various sectors of the national economy, causing the loss of human, material and financial resources, and even endangering people's life safety. The damage of land subsidence to the city is shown in Figure 3.



Figure 3: Cracks caused by settlement. (a) cracks in bridge members; (b) Cracks appearing in the drainage tank.

We can start from the production wells in the city, refer to the minimum standard of land subsidence control, understand the specific situation of available resources in the city, estimate the actual resource exploitation amount according to the specific situation, and finally arrange the existing production pattern reasonably according to the calculation results. After the utilization of groundwater resources, recharge measures should be taken to better avoid secondary pollution[5]. The simplest method of artificial recharge is shown in Figure 4. The treated water can permeate naturally in the filtration tank. This is because the aquifer can be kept in its initial equilibrium by artificial recharge, and a certain percentage of pore hydraulic pressure can be restored, raising the groundwater level in the region. During the rainy season, some surface water resources without

excessive pollution should be stored and properly processed. As early as in some foreign countries, such as Mexico and Germany, the method of artificial irrigation controlling land subsidence has made a good effect. Recently, the method of reclamation has been used in Shanghai and Beijing in our country.

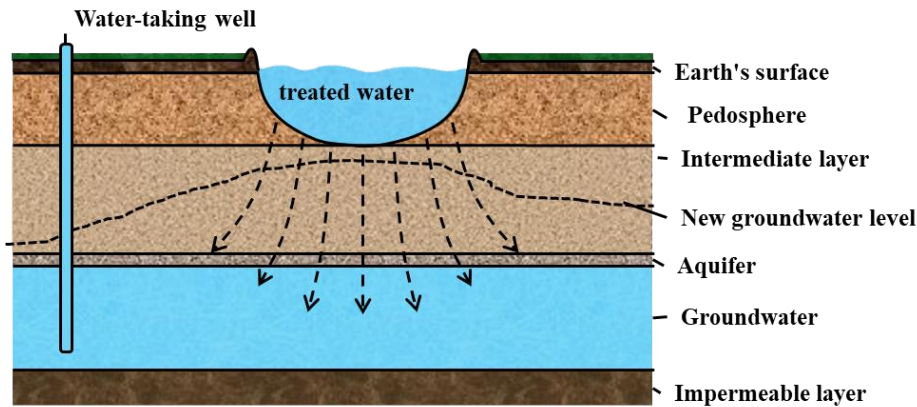


Figure 4: Manual recharge.

The exploitation of geothermal resources is also an important cause of settlement. Geothermal resources refer to the earth's internal geothermal energy, geothermal fluids, and some of the components that can be processed and then used. It is a new compound of heat, water, and more. Compared with traditional resources, geothermal resources have strong performance, high efficiency, and stability, and to a certain extent, solve people's production and life problems. In some coastal areas of our country, the reserves of geothermal resources are very large. The human pursuit of resources is increasing year by year, which makes the exploitation of geothermal resources continuously improve. There are many kinds of geothermal resources, such as underground hot water resources, which are not only easier to exploit, but also very low cost. Due to the complexity of geological structure characteristics in our country, when extracting underground hot water in some areas, it will cause a certain level to drop. While the pore water pressure falls, the effective stresses increase for relative stability to keep, which will inevitably cause constant compaction of strata.

The exploitation of natural resources should be based on the premise of not destroying the ecological balance. It is a good choice to find new alternative energy sources and develop new renewable resources. As for how to exploit geothermal resources, the equilibrium critical point of formation destruction is different because of the different geological structures and lithology of water-bearing groups in different geological environments. Therefore, to improve the utilization rate of geothermal resources, reasonable selection of mining strata and scientific arrangement of delamination mining, and strictly prohibiting mining of non-geothermal abnormal areas are effective methods to control land subsidence.

2.3.3. Surface Load is Also One of the Causes of Land Subsidence

Due to the continuous progress of human science and civilization, to meet the needs of people's survival, the scale of the city keeps expanding. The damage of a single building on the ground is limited, but the variety of strange buildings keeps increasing. The construction of new energy sources such as high-speed railways and subways, the popularity of transportation facilities such as bridges and tunnels, and the influence of transportation load, the aggravation of surface load also accelerates the ground settlement to some extent.

It is the combination of wisdom and sweat of architects and urban planners that makes the layout

of a city reasonable and reflects the local life atmosphere. For high-rise buildings with small density and large spacing, a pile foundation can be used to transfer the load to a deeper soil layer if the buried depth of the foundation is large under a certain plot ratio, to alleviate the occurrence of ground settlement to a certain extent. Avoiding too much concentration of buildings in one area can also effectively reduce the surface load of the stratum.

2.3.4. Land Subsidence Caused by the Greenhouse Effect

First of all, the greenhouse effect is a great harm to the earth, and human beings have an inescapable responsibility for causing the greenhouse effect. Global surface warming makes glaciers melt, the sea level will continue to rise, then the ground will sink relatively, and many unknown "hazards" are staring at the earth on which human survival depends.

Carbon dioxide is one of the most important contributors to the greenhouse effect, and it is produced in large quantities through the use of traditional energy sources such as coal and gasoline. According to the current form of development law, the world's various countries using coal as the main energy era has passed. On the one hand, the vegetation coverage of desert areas should be improved. On the other hand, the use of traditional harmful energy should be abandoned while meeting the production demand. The development and utilization of new energy becomes increasingly important.

3. Our Country's Development of Land Subsidence Prevention

3.1. Laws Related to the Prevention and Control of Land Subsidence

The key to accelerating the connection between the region and the city and planning the settlement prevention and control work standard is to establish a sound legal environment. When the problem of ground subsidence involves several regions, it is difficult to achieve an ideal result if only a single administrative region is regulated and the adjacent region is not treated. Therefore, effective coordination and cooperation between regions are the key points of the whole governance work. While considering the problems between regions, they should also take into account the problems of adjacent regions. According to the specific actual situation, the interregional collaborative work should be managed, and the regions or adjacent regions where problems occur should be regarded as an indivisible whole. It is particularly important to build a comprehensive network monitoring system, which can monitor the ground situation at all times and detect the change in the groundwater level. As early as the beginning of the 12th Five-Year Plan, the Ministry of Natural Resources began to deploy the land subsidence monitoring network throughout the country, and the InSAR remote sensing monitoring area reached 750,000 km², which is enough to show the importance of the government to the prevention and control of land subsidence. To ensure a legal guarantee for the prevention and control work, the Ministry of Land and Resources, the National Development and Reform Commission, and ten other ministries and commissions jointly issued the National Land Subsidence Prevention and Control Plan (2011-2020) in 2012. In 2013, the state began to implement the management of exploitation by the published water resources management system and seriously dealt with the excessive exploitation of water resources. To scientifically manage water resources in overextraction areas, the Ministry of Water Resources and the Ministry of Land and Resources jointly issued the National Plan for Groundwater Utilization and Protection (2016-2030) in 2017. In recent years, the state has carried out a standardized and comprehensive treatment for groundwater overextraction, and the work of preventing and controlling land subsidence has entered the comprehensive control stage, and the control has achieved good results. In 2019, compared with 2015, the area of serious land subsidence decreased

by about 1000 km², which is a considerable effect.

3.2. Detection and Methods of Related Indexes of Land Subsidence

Groundwater is a key index of land subsidence, and it is essential to optimize the three-dimensional monitoring network of groundwater and land subsidence. We will continue to promote the standardized construction of bedrock markers and stratified indicators and strengthen the rational allocation of water resources in major urban built-up areas. For some major national projects, such as the Qinghai-Tibet Railway project, settlement monitoring should be carried out in the construction area. The implementation of the national south-north water diversion project is very difficult, so it is necessary to strengthen the implementation methods and allocate resources according to the real situation of water resources in different regions. For areas with priority in groundwater overextraction control, land subsidence prediction and risk assessment should be carried out proactively to dynamically identify key areas at all times. The treatment based on groundwater overextraction should be combined with the treatment of land subsidence to achieve all-around integration: scientific allocation of water and soil resources, while emphasizing that the relevant indicators of groundwater level control in the middle and deep layers must be constrained by land subsidence.

Nowadays, land subsidence monitoring technology has developed rapidly, and the global positioning System (GPS) has been widely used in it, while regional leveling means have been gradually phased out[6]. Fujiwara Hao of Japan used GPS technology to describe the changes in the settlement process, which is the use of the results of the reverse deduction. Today, the subsidence of the Yangtze River Delta can be fully monitored because Shanghai has laid an information system (LSIS) and GPS monitoring network in the region, and conducted a comprehensive analysis of land subsidence map results so that the changing trend of land subsidence can be tracked at every moment.

InSAR technology is a method that is at the forefront of science and technology and is being studied constantly.[7] InSAR technology can detect the region throughout the day and obtain a large range of ground dynamic change information with high precision. The time-series-based InSAR technology is not affected by weather, and it is not a problem to obtain historical deformation data. All these are beyond the reach of traditional monitoring means, and its basic workflow is shown in Figure 5. Compared with GPS, the average settlement rate obtained by the two is not only different, but the information coverage obtained by InSAR is larger, more comprehensive, and accurate, and its practicability cannot be ignored. Due to the complex operation technology of InSAR, the economic cost of consumption is relatively high, so GPS technology is widely used now.

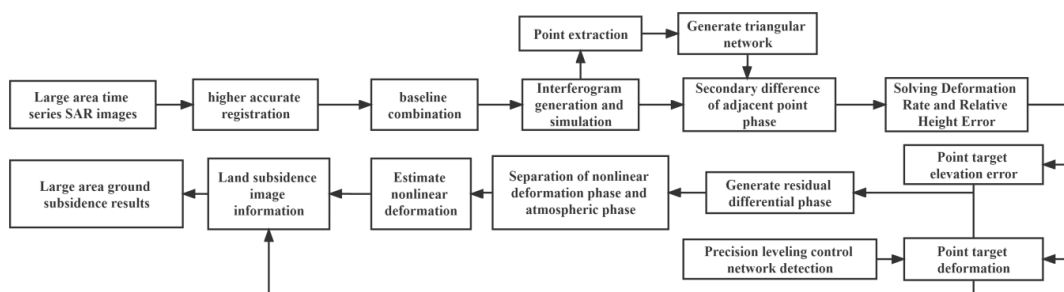


Figure 5: InSAR technical process.

3.3. Establish Relevant Norms and Systems

To promote the legislative process of national land subsidence prevention and control, we can start from the following aspects: to set up a metering and control mechanism for groundwater exploitation, to strictly control the amount of exploitation, effectively avoid blind and arbitrary mining phenomena, eliminate the waste of water resources, and prohibit mining in some areas; Strengthen the monitoring and supervision of geothermal development, adhere to the principle of heat extraction rather than water extraction, to ensure that the use of thermal reservoir heat and subsequent recharge can maintain a certain balance; Good use of natural precipitation, and development, utilization and management to prevent excessive liquefaction of soil and ground settlement caused by the compaction of shallow surface soil under the action of high-rise buildings; In the planning of urban construction in soft soil areas, various aspects should be considered, and the nature of adjacent areas should be taken into consideration together, to scientifically and reasonably prevent the natural consolidation of soft soil areas due to special geological conditions, and prevent the land subsidence disasters according to law. To establish an incentive mechanism for saving and protecting water and civilized exploitation of groundwater; to create the existing ecological water and industrial water prices can meet the actual dynamic adjustment mechanism; As for the traditional planting structure, it is constantly adjusted according to the existing conditions, such as adjusting the time of fallow and changing crop distribution. Major projects to improve and optimize the restoration of aquifers, such as areas where water sources need to be replaced and the replacement water sources need to be strictly controlled.[8-10]

3.4. Strengthen the Control over Urban Construction

Cities need to develop, but also need to prevent the development process that may bring environmental geological disasters, which requires the government departments and related construction units between joint attention and efforts. First of all, it is necessary to control the construction of dense high-rise buildings and factories, reasonably control the approval of high-rise buildings in the space density and foundation design, and reduce the superposition of ground load, which plays a positive role in the prevention and control of the ground settlement. Secondly, the design of urban traffic lines should not be too dense. Reasonable traffic restriction management measures should be adopted for the number of traffic vehicles, and measures such as strengthening the control of vehicle load overload should be adopted to alleviate the trend of land subsidence.

3.5. Strengthen the Publicity of Land Subsidence Prevention and Control Work

The publicity of the harm of land subsidence and the prevention and control work of the society should be in place, instead of just doing some superficial efforts, the whole people should attach great importance to it and make due contributions to the prevention and control work of land subsidence. Environmental protection requires human beings to consciously and unreservedly protect natural resources and make their rational use, which is closely related to people's normal work and life. Now the subsidence of the road surface, which makes traffic jam, destroys the normal order of society, and even there are casualties from time to time. Strengthen the publicity of land subsidence, prevention and control, arouse the awareness of the whole people, and everyone can participate in it to reduce the influence of human factors and reduce the loss caused by disasters.

4. Conclusion

Although the prevention and control of land subsidence are complicated, it is not only related to

difficult technical problems but also related to social and economic development. However, human beings must realize that there is only one earth, and everyone can't stand idly by. The grave situation of the deteriorating geological environment can't afford any wanton destruction. The prevention and control of land subsidence not only need the attention of the government but also need the joint efforts of all social personnel.

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