Monitoring and Analysis of Ground Subsidence of East China

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Abstract: Ground subsidence is classified into artificial and natural ground subsidence. The natural ground subsidence is a normal phenomenon, which is caused by gravity. Generally the development of natural ground subsidence is rather slow, and its subsidence level is 1mm~2mm per year. Artificial ground subsidence is a geologic disaster, and its inducement is the excessive exploitation of underground liquids (groundwater, petroleum and natural gas etc.) and the subsidence of ground empty areas from mining. In addition, the subsidence of karst is an important factor causing ground subsidence (of course, the non-human factor). People's awareness and research on ground subsidence trace roughly to the 1920s, and people still have various opinions and understandings on the matter of ground subsidence. The rules and exact inducement of ground subsidence is a very complex scientific subject, and people conceive many misunderstandings and ambiguous recognition. With the help of Precision Level Monitoring technology and GPS technology, tens of year's Field Monitoring, the article brings forth the opinion that ground subsidence is recoverable to a certain extent, and concludes the scope of the subsidence threshold value of ground subsidence recoverability based on the systematic analysis on Field Monitoring data. It depicts the proper method and monitoring essentials of the Field Monitoring on ground subsidence.

Introduction

Surface subsidence is a quite serious geological calamity, which has been caused by various kinds of factors, including natural reasons and even artificial factors. In order to study the basic law of surface subsidence and effective controlling-methods, lots of people have made large various fruitful observation, analysis and studies in all kinds of typical areas and put forward kinds of views and conclusions[1]-[6]. There are both rational and deficient aspects among those kinds of view and conclusions from a broad view. The research group and the author have been devoted to the research work of surface subsidence for many years, so researchers have their own unique opinion and view on the understanding of surface subsidence.

After a long period of analysis on the monitoring materials of large amount of surface subsidence, researchers the researchers find that surface subsidence has a certain recovering ability. The subsided area can resume himself within the certain subsidence volume (whether the author calls this range recoverable subsidence threshold value). The basic law of surface subsidence is to subside, resume (or resumes partly), and subsides again, resumes again (or resumes partly again). When it subsides over the recoverable threshold value, the irrecoverable subsidence out-of-shape (out-of-shape permanently) will come into being. Gradually, more and more places came to out-of-shape permanently. The accumulation of these places came into subsidence basin, subsidence funnel or ground collapse (stalactites and stalagmites cave or artificial cavity will come into being when there are already some big holes underground).

There must be accurate and reliable monitoring data for support if researchers want to study the subsidence laws of earth's surface. In order to obtain the monitoring data as accurate as possible, the research group and the author have made a systematic research on the scientific monitoring methods of earth's surface subsidence, and summarized some efficient and high-accuracy monitoring methods. This text introduces the methods and requirements to set up earth's surface subside monitoring point (including datum point and deformation piece) in details, and also recommended in details about both of earth's surface GPS accurate monitoring method and accurate level gage monitoring method, including main point of monitoring, course of monitoring and data processing aspects. In additions, this article has probed into the impaction rules that kinds of monitoring methods have made on the reliability of earth's surface monitoring data, and also recommended the reliable and rational thick difference criterion on monitoring data.

According to the reliable and high-accuracy monitoring data of fixed point and normal position surface subsidence, researchers have made comparatively deep scientific and systematic analysis of the reason of East China subsidence in recent years[7]-[15]. On this basis, the initial conclusion on the recoverable subside threshold value of East China surface, and the mathematic relationship among recoverable subside threshold value, stratum structure and underground water-table change, have been made out. The research group and the author have used the returning analysis theory and computer modeling technology when researchers made analysis on the relationship among recoverable subsidence threshold value, stratum structure and underground water-table change.

The research group and the author have made out the recoverable surface subside theory model of East China according the mathematics relationship among recoverable subsidence threshold value, stratum structure and water table change. Researchers have set up the computer dynamic simulation system initially according to the software development. This system can demonstrate the emergency, development and gradual deformation of recoverable earth's surface subsidence.

Rock and Soil Engineering Index Closely Related to Ground Subsidence

There are extremely close correlations between the ground subsidence and the engineering properties of the superficial rock and soil of the earth. The author and the research group find out that the engineering properties of the superficial rock and soil greatly affecting the ground subsidence include the following index on rock and soil: dry density ρd, penetration coefficient k, compression [rock and soil compression coefficient a (-kPa-1) under side limitation; side limitation compression modulus (also side limitation deformation modulus) Es (-kPa); rock and soil bulk compression coefficient mv; rock and soil compression index Cc].

The dry density ρd of rock and soil means the density of the rock and soil after absolutely dried, and equals to the mass per unit soil grains with gas neglected.

$\rho_d=m_s/V$ (1)

In Formula (1), V is the original volume of rock and soil sample (volume of original shape); ms is the mass after drying the rock and soil sample (usually, volume of dried sample V′ is less than original volume V).

Dry density ρd of rock and soil is completely different from its mass density ρ, usually, ρd ＜ρ.

Rock and soil mass density is the ratio of the mass of rock or soil grain to the mass of water (4℃) in the same volume. Usually, researchers regard rock and soil average mass density as mass density.

Rock and soil penetration coefficient k means the proportion coefficient of the water penetration performance of rock and soil.

$k=v/i$ (2)

In Formula (2), v is the mean section penetration rate (mm/s or m/day); i represents the hydraulic slope fall (i=Δh/L). By Darcy Raw (French engineer H. Darcy, test in 1856).

The compression properties of rock and soil include the rock and soil compression coefficient a (kPa-1), rock and soil side compression modulus (side deformation modulus) Es (kPa), volume compression coefficient mv, compression index Cc under side limitation.

$E_s=(1+e_0)/a$ (3)

In (3), e0-hole ratio after compressed

$m_v=1/E_s$ (4)

The relations between its compression parameters are as follows: Es is larger, and the soil compression is relatively small. Besides, a, mv and Cc are large, the compression is large, the compression coefficient a is large, and the deformation is large.

Lab Research on the Relations among Engineering Performance Parameters of Several Rock and Soil

Through laboratory tests, the research group and the author find out that there are certain correlations among the soil engineering parameters, which can be represented by certain function formula. Based on laboratory results and regression analysis method, researchers conclude the approximate math relation between dry density ρ and penetration coefficient k, dry density ρ and compression modulus E.

The relation between dry density ρ and penetration coefficient k is shown as below.

$ln\rho=k^{0.0432}$ (5)

in Formula (5), ρ-t/m^3, k-cm/s.

Relation between dry density ρ and compression modulus E is expressed as below

$\rho=\ln E$ (6)

In Formula (6), ρ-t/m^3, E-MPa .

Determination of Subsidence Threshold Value on Ground Subsidence Recoverability

In recent 20 years, the research group and the author have always been collecting the national surveying data in level net and general geologic investigation and prospecting data from State Geology & Mine Ministry (State Resource Ministry), provincial geologic and mine bureau in East China regions (include Hebei, Beijing, Tianjin, Shandong, Jiangsu, Henan, Anhui, Shanghai, Zhejiang in China. see Fig. 1). Researchers found out that state level points in different periods ascended or descended irregularly, which was obvious even if the surveying errors were eliminated. The variation of the heights of state level points objectively reflects that the rise and fall of the ground surface, upon which the author find out the recoverability of ground subsidence. Therefore, the research group and the author started the research on the recoverability of the ground subsidence.

Fig. 1 Remote image of parts of East China

In the research, the author surveyed rock and soil (or rock mass) over the hard rock in the research area on their engineering performance series parameters, and selected some that were closely related to the ground subsidence.

National level net data shows that the level height of the point at the hard rock is basically unvaried, whereas the level point buried in rock and soil varied obviously, apparently, the height variation of the rock and soil level point reflects the rise and fall of the ground. Therefore, in the research of ground subsidence recoverability, the research group and the author make the level point of the hard rock in research area as the reference point for regional ground subsidence variation, and the variation of the height difference between the rock and soil level point and the hard rock level point in deferent terms is the ground subsidence. Supposed that the height of the hard rock level point is always H (of course, not a constant because of surveying errors, but it is no more 3mm than H), the repeat surveying height of certain rock and soil level point is H', H'', respectively.

Then the height difference between the rock and soil level point and the hard rock level point, in the first surveying, h':

$h' = H' - H$;

Then the height difference between the rock and soil level point and the hard rock level point, in the second surveying, h'':

$h'' = H'' - H$;

The ground subsidence of the rock and soil level point is $\delta h = h'' - h'$; the positive δh value means ground falls, and negative value δh means that the ground rises.

Through the surveying of the rock and soil (or rock mass) level point on their engineering performance parameters, researchers obtain its compression modulus E, penetration coefficient k, dry density ρ and parameters of rock and soil.

In the ground subsidence values of the rock and soil level point from all national level net surveying data in different terms, the difference between the maximum subsidence δh and the maximum risingδh″ (or minimum subsidence δh′) as to the same level point is the recoverability recovery volume h, then

$h=\delta h-\delta h''$

or

$h=\delta h-\delta h'$

based on the relations between recoverability recovery volume h, compression modulus E, penetration coefficient k, dry density ρof several groups, together with regression analysis theory, the research group and the author draw a primary conclusion on the experienced mathematic formula on subsidence threshold value of the ground subsidence recoverability in East China regions, that is,

$$h=[(kD)/(E\rho)]\times 10^3 \qquad (7)$$

In Formula (7), h is the recoverability recovery volume-m, k stands for the average penetration coefficient of the rock and soil above the hard rock-cm/s, D means the thickness of the rock and soil above the hard rock-m, E refers to the average compression modulus of the rock and soil above the hard rock-MPa, ρ is the dry density of the rock and soil above the hard rock-t/m^3.

If the depth of rock and soil layers above the hard rock is D_i, and compression modulus is E_i, penetration coefficient k_i, dry density ρ_i, then

$D=\sum D_i$

$E=\sum[E_i\times D_i] / \sum D_i$

$k=\sum[k_i\times D_i] / \sum D_i$

$\rho=\sum[\rho_i\times D_i] / \sum D_i$

Conclusion

The ground subsidence problem is a complex scientific matter, which needs the support of numerous, continuous, highly reliable and multiple-subject basic field surveying data, requires the hard, persistent and continuous works of global scientists as well as the assistance of basic theories and acknowledge on many subjects.

The ground subsidence is featured by special internal rules and certain recoverability. It follows the basic rules from fall, recovery (or partial recovery), fall again, recovery again (or partial recovery), and the unceasing, gradual, extremely slow subsidence is the basic development tendency of the earth, any block of the earth may be slowly thinner gradually.

The opinions and the results in this article are based on special region, its reliability and validity requires the verification in a larger scope, and its errors on limitation and representation are unavoidable. The author hopes your comments and corrections on the false and improper places; also, the author hopes this article is able to help enlighten the research on ground subsidence.

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