Ground Collapse

Distribution Characteristics of Ground Collapse

The study area is widely distributed with loess, sand, soft soil, and poor geological bodies such as subterranean rivers and beaches. Artificial fill is also extensively present, making the geological conditions complex.

Based on the analysis of 14 ground collapse cases, the collapse depth is generally within the range of the fill soil or at the junction of the fill layer and the underlying stratum within a 2m range. The thickness of the fill soil is typically 1-5m, and the depth of the collapse is generally 1-2m. The lithological combination below the surface for 5-10m where collapses occurred includes "fill soil—loess" in 10 cases (71.4%), "fill soil—loamy clay" in 3 cases (21.4%), and only in the case of the West Xi Road Qingfeng New Village sidewalk collapse, it was "road foundation fill—silt." The main geological factors causing ground collapse in Hangzhou are "artificial fill + loess (sand)," with a significant correlation between the spatial distribution of ground collapses and the distribution of sand layer, artificial fill, and subterranean rivers and beaches.

Size of Ground Collapse

In the 14 collapses studied in the area, the depths were 0.8m, 5m, 2m, 1m, 1.5m, 1.5m, 0.5m, 2m, 0.8m, 1m, 1m, 2m, 2.9m, 1.7m respectively, and the thickness of fill soil were 4.1m, 2.5m, 2.3m, 3.5m, 0.9m, 1.5m, 0.6m, 4.6m, 0.7m, 1.3m, 3.5m, 4.7m, 1.6m, 1.7m respectively.

Typical Cases of Ground Collapse

Case1

On June 30, 2020, at around 9:45 AM, a ground collapse occurred at a public parking space, covering an area of about 5m² and a depth of approximately 0.8m. There was water accumulation in the pit, and a parked white motor vehicle fell into the collapse pit, suffering minor damage. No personal injuries were reported.

The collapse site and the onsite situation show that the soil layers within the depth can be divided into 6 layers from top to bottom. Below the road surface structure layer of this road section, there is a sand cushion layer of about 1m, followed by a 25m thick layer of loess and sand soil, both of which are prone to erosion. The collapse occurred in the shallow loess layer.

Reason for Collapse: Leakage occurred in the drainage pipeline beneath the collapsed road surface, forming a channel for soil erosion. Over time, a cavity formed and gradually expanded beneath the road surface, and the movement of the road surface load aggravated the destruction of the road surface structure layer.

Case 2:

On April 21, 2016, a ground collapse occurred southeast of the intersection of Wener Road and Xueyuan Road in Hangzhou, covering an area of about 10m² and a depth of about 2m, located above the under-construction "Hangzhou Metro Line 2 Xueyuan Road Station."

Geological Background: The collapse site belongs to the lacustrine and swamp plain geomorphological unit. According to geological drilling data near the collapse site, the soil layers within 20m of the site can be divided into 5 layers from top to bottom. The overall geological characteristics of the site are that the shallow part (5-7m) consists of poor-quality soil layers, and the surface part consists of a 2-4m thick layer of miscellaneous fill, which is uneven in nature and has significant differences in water richness and permeability.

Reason for Collapse: There was an abandoned rainwater pipe underground on the south side of the intersection of Xueyuan Road and Wener Road, which was poorly maintained and leaking, causing the powder or sand particles in the miscellaneous fill below it to be washed away, forming a void; construction vibrations also had an impact.

Case 3:

Around 7 PM on December 29, 2020, a sudden ground collapse occurred on the sidewalk of West Xi Road, Qingfeng New Village, Xihu District, Hangzhou, covering an area of about 25m². The collapse resulted in two fatalities.

Geological Background: The ground elevation of the collapse site is about 3.70-4.80m. The overall geological characteristics of the site are that the shallow part (5-7m) consists of poor-quality soil layers, while the middle and lower parts consist of better-quality weathered bedrock. Specifically, the surface part consists of a 2-5m thick layer of miscellaneous fill, which is uneven in nature and has significant differences in water richness and permeability, mainly consisting of filled dark beaches and dark ponds. Below the miscellaneous fill layer, there is a 1-4m thick layer of silt with extremely poor physical and mechanical properties. The middle part of the site consists of a 12-15m thick layer of hard soil and a layer containing viscous soil and gravel, which are poor in water richness and weak in permeability. Below 17-20m, there is weathered bedrock, consisting of tuff and muddy fine sandstone.

Reason for Collapse: This section of the road had undergone multiple renovations, with many pipelines buried underground, causing significant disturbances to the surrounding soil layers. In addition, abandoned pipeline trenches were poorly maintained, making it difficult to drain accumulated water, exacerbating deformation. Near the collapse site, there was shield construction for Metro Line 3. The dark beach soil body itself had a high water content, with extremely poor soil properties, prone to deformation. Under the influence of repeated vibrational loads, it was susceptible to disturbances or deformations.

Analysis of the Causes of Ground Collapse

Based on the analysis of ground collapse cases, the main causes of ground collapse in Hangzhou are as follows:

1.Widespread distribution of poor geological conditions such as fill soil, loess (sand), and dark beaches.

Ground collapses (cavity hazards) generally develop in the fill soil layer, loess and fine sand distribution areas, and sections of subterranean rivers and beaches. The main characteristic of the soil body is low structural strength, which is prone to soil erosion under the long-term action of leaking pipes or strong underground water seepage, leading to the formation of underground cavities and ground collapse.

2.Defects in the structure of underground drainage pipelines.

Defects in the drainage pipeline structure mainly include misalignment, disconnection, rupture, leakage, etc. The main causes of these defects include uneven foundation settlement, poor quality of pipe materials, poor quality of structural fillers and construction, unqualified inspection wells, and substandard closed water tests. When structural defects occur in pipelines, they provide a channel for soil erosion. The elevation of the drainage pipelines is basically consistent with the widely distributed loess and fine sand layer in the region. This layer has a loose structure and strong permeability, making it prone to loss. Defects in drainage pipelines gradually form zones of soil erosion, loose development, cavitation, and deformation settlement.

3.Inadequate compaction of foundation backfill in dark beaches.

Historically, the plain area had a crisscrossing network of rivers and streams. After long-term use and transformation, many dark beaches were formed in various forms. Due to loose backfilling of the foundation, the soil layers have uneven particles and large porosity, resulting in poor geological conditions of loose backfill soil in both visible and invisible beach development areas. Improper treatment of dark beaches and other foundations and loosely backfilled soil consolidating and settling over time gradually form voids and cavities beneath rigid ground panels. Along with the loss of sandy soil with water, cavities gradually expand, and rigid pavements lose support, gradually subsiding, cracking, and eventually collapsing.

4.Influence of hydrogeological conditions.

Long-term, high-intensity precipitation during the rainy season causes road surfaces to be soaked in water for extended periods, dramatically increasing the amount of rainwater infiltration through the road surface, increasing pressure on urban drainage pipelines and scouring and expanding hidden underground cavities, thus increasing the probability of ground collapse in a short period. Fluctuations in the level of underground water in the phreatic zone can also promote the loss of sandy soil, facilitating the formation of cavities. The use of underground space causes changes in underground water flow and discharge conditions. Local underground water flow is impeded, and water levels rise, soaking and changing the stress in soil layers, causing soil loosening and leading to subsidence of the road base.

5.Disturbances caused by human engineering activities.

Surface and underground construction around the ground disturbs the strata, damages underground structures, breaks the original equilibrium of the soil body, causes soil loosening and uneven deformation, triggers surface water infiltration and pipeline leakage, leading to soil erosion, road base loosening, etc. Some deep and large foundation pits have been pumping large amounts of underground water for a long time, leading to rapid declines in the groundwater level in surrounding areas. The pressure on the overlying water-bearing layers of underground soil is reduced, causing the overlying soil body to sink. Large-scale pumping of underground water causes fine particles in the foundation soil to be pumped out, forming underground cavities that gradually develop and lead to collapse. V. Ground Collapse Risk Assessment

Key Points for Risk Identification

Based on the analysis of the geological background characteristics and factors causing ground collapse, risk identification can be conducted from the following aspects:

Areas with loess and sandy soil distribution, development of subterranean rivers and beaches, and regions with thick layers of fill soil are high-risk areas for ground collapse.

Sections near deep pits and subway constructions pose higher risks, especially where the depth of construction is greater.

Areas with dense underground pipelines, especially those with active and abandoned rainwater, sewage, and water supply pipelines, are at higher risk of ground collapse.

Results of Ground Collapse Risk Assessment in the Study Area

The total area of the study region is 31.97 square kilometers. The area with low risk of ground collapse is 14.16 square kilometers, accounting for 44.31% of the study area. The area with medium risk is 7.33 square kilometers, representing 22.94% of the study area. The high-risk area is 4.59 square kilometers, constituting 14.35% of the study area, and the area with very high risk is 5.89 square kilometers, making up 18.4% of the study area.

Economic Losses and Casualties Caused by Ground Collapse in the Study Area

On November 15, 2008, a severe ground collapse incident occurred at the construction site of Hangzhou Metro's Xianghu Station. This accident resulted in 21 deaths and 24 injuries, with direct economic losses amounting to 49.61 million yuan. The causes of the accident were multifaceted, involving serious defects and problems, including violations in construction and monitoring failures. This incident was one of the major accidents caused by ground collapse in Hangzhou in recent years.

Ground Subsidence

Current Status of Ground Subsidence

Regional Ground Subsidence: According to level measurements and InSAR monitoring data from 2010 to 2021, areas with a cumulative subsidence greater than 100mm cover approximately 8.4 km², mainly distributed in Xiaoshan District's Yaqian Street, Binjiang District's Changhe Street, and Linping District's Renhe Street. The maximum cumulative subsidence recorded was 127.5mm in Yaqian Street, Xiaoshan District. Areas with a cumulative subsidence greater than 50mm cover about 400.5 km².

From 2017 to 2019, areas with a subsidence rate greater than 6mm per year covered 85.4 km², mainly distributed in Xiaoshan District's Yaqian Street, Binjiang District, Ningwei Street, Changhe Street, and Linping District's Tangqi Town, with the highest subsidence rate being 10.7mm per year. From 2019 to 2021, the subsidence trend significantly slowed down, with subsidence areas in Linping District's Tangqi Town and Qiantang New District nearly disappearing. The area with a cumulative subsidence greater than 10mm was about 4.993 km².

Subsidence Along Subway Lines

The overall ground subsidence along subway lines is not significant, but partial subsidence exists along some subway lines, such as from the Passenger Transport Center Station to Xiasha West Station on Line 1, from Xixing Station to Binhe Road Station, from Chuangyuan Road Station to Liangmu Road Station on Line 3, from Wulinmen Station to Xiangji Temple Station, etc., with a subsidence rate of about 4-6mm per year. On Line 4 from Pengbu Station to Mingashi Road Station, which is under construction, the subsidence rate is about 4-6mm per year. Near the Sports Center on Line 7, Xin'gang Station, Xiaoshan International Airport, Jiangdong Second Road Station, and Liubao Station on Line 9, the subsidence rate is about 9mm per year. Near Liangzhu Station on Line 2, the subsidence rate exceeds 12mm per year.

II. Analysis of the Causes of Ground Subsidence

Early Ground Subsidence Related to Groundwater Extraction

Ground subsidence monitoring data from 2010 to 2019 show that the amount of subsidence and the area affected are closely related to the control of groundwater extraction. After effective control of the groundwater level, the amount and range of ground subsidence gradually decreased. Before 2010, continuous ground subsidence occurred in the area due to groundwater extraction. From 2010 to 2014, there was significant ground subsidence in the groundwater extraction areas of Gongshu Sanjiacun, Xiangfu Bridge, and Yuanpu District. From 2015 to 2017, there was still some subsidence in the groundwater extraction areas of Gongshu Sanjiacun and Xiangfu Bridge, but almost no subsidence in Yuanpu District.

Related to Marine and Lake Facies Soft Soil

In the Hangzhou area, Quaternary strata less than 60m deep alternating between marine and terrestrial facies appear, especially in soft soil layers less than 40m deep, which are widely developed and thick, easily causing ground subsidence. The trend of ground subsidence development shows that in areas where the soft soil layer is more developed and the hard soil layer is missing, the phenomenon of ground subsidence is more severe, such as in the northern part of Linping District and Yaqian Street in Xiaoshan District.

Related to the Richness of Underground Water

Ground subsidence is closely related to the richness of underground water. The richness of underground water is consistent with the spatial distribution of ancient river channels. Near the main streamlines of ancient rivers, single well outflow amounts to 1000-3000m^3 per day. Among the 13 ground subsidence centers (subsidence greater than 30mm) that have appeared, 10 are located in areas where the single well outflow of confined water is greater than 3000m^3 per day. The spatial distribution characteristics are basically consistent with the morphology of the water-rich sections of confined water, such as in Renhe Street, Tangqi Town, and Yaqian Street in Xiaoshan District.

Related to Human Engineering Activities

Binjiang, Xiaoshan, and other areas are still in the stage of large-scale urban construction, which to some extent increases the possibility of ground subsidence. Excavation and drainage of pits can easily cause a significant drop in water levels, leading to a reduction in the pore water pressure of the overlying water-bearing soft soil layer, causing the soft soil layer to consolidate and lose water, and compress the soil layer. This is seen in places like Hangzhou Qianjiang Economic Development Zone, Lin'kong Economic Development Zone, Zhineng Valley High-Tech Industrial Park, and Dajiangdong Economic Development Zone.

Artificial extraction of sand from rivers for land reclamation in areas such as Dajiangdong Economic Development Zone's reclaimed land area results in ground subsidence due to the short sedimentation time, high compressibility, and high water content under natural compaction.

III. Susceptibility Evaluation Results of Ground Subsidence in the Study Area

In the study area, the region with a cumulative subsidence of 96mm-128mm covers an area of 7.95 square kilometers, the region with 64mm-96mm covers 6.51 square kilometers, and the region with 0mm-64mm covers 17.51 square kilometers.

Population Density of the Study Area: The area with a population density of 1.08 people per square meter covers 9.96 square kilometers; the area with a population density of 0.87 people per square meter covers 12.7 square kilometers; the area with a population density of 1.17 people per square kilometer covers 6.23 square kilometers.

GDP of the Study Area: The area with a GDP of 21.51 covers 9.96 square kilometers; the area with a GDP of 20.38 covers 12.7 square kilometers; the area with a GDP of 30.21 covers 6.23 square kilometers.

Detailed Geological Data and Human Modification Data of the Study Area: The silt soil of Hangzhou City is mainly distributed in the plain area. Due to the terrain and geomorphological characteristics, the plain area with alluvial and marine deposits is the most typical region. Considering the overall disaster situation and potential ground subsidence points, this study selects the Binjiang and Xiaoshan districts south of the Qiantang River as the typical filled soil-silt soil areas for research, covering an area of 36.88 square kilometers. This area includes important urban metro lines such as lines 4, 5, and 6, as well as main urban roads like Fengqing Expressway and Shidai Overpass, making it a region in Hangzhou City where human activities have significantly altered the landscape. The study area is located along the western edge of the Xiaoshao Plain, north of the Hangzhou complex inclined hills, and south of the Puyang River plain. The terrain mainly consists of plains with some low hills, monotonous geomorphological types, clear boundaries, flat terrain, dense river networks, and is primarily composed of sandy silt, silt, and sand-gravel layers buried at a depth of about 35-50m. Human activities have a profound impact, with high-rise buildings using sand-gravel layers or bedrock as the foundation. The sediments are mainly gray to dark gray silty clay and mud silty clay with distinct horizontal stratification and high water content. The Quaternary strata in the study area are mainly the lower part of the Holocene Qh41, formed during the early stage of the Fuyang marine transgression, mainly characterized by alluvial deposits, often appearing as river valley plains, river terraces, etc. The strata are composed of sand and gravel, with good sorting and roundness, relatively loose structure, and a thickness of 2-12m. Boreholes selected in the study area were used to draw east-west and north-south cross-sections based on actual sampling results. The aquifers in the study area are close to the surface, generally with water levels buried within 3m, with a thickness of 1.5-28.8m, and the bottom generally buried at 10.8-38.5m, mainly consisting of Holocene transgressive and lacustrine aquifers. The bottom of the aquifer group is a soft soil layer of the lower Holocene transgression, mainly composed of Holocene silty clay, sandy silt, silty clay, and silty sand aquifers, with relatively poor permeability; the deeper confined water in the pores, under natural conditions, due to its extremely gentle hydraulic gradient, has very slow underground flow, in a relatively "static" state, with almost no water cycle interaction. Groundwater recharge, runoff, and discharge conditions are poor. Only when the impermeable cap and base are absent, does it have certain hydraulic connections with the upper unconfined water and the lower confined water. The aquifer in the study area has good water richness, with unconfined water well flow generally above 1000m3/d, and confined water well flow generally above 3000m3/d. The depth of ground subsidence in the study area is generally within the range of filled soil or within 2m of the interface between the fill layer and the underlying strata, with a fill thickness of generally 1-5m, and a subsidence depth of generally 1-2m. The subsidence soil is characterized by upper fill and lower silt or upper fill and lower silty clay. Field surveys show that most subsidence disease points are related to and significantly distributed in the areas of artificial fill layers of silt and silt soil.

Rainfall Data of the Study Area: In the study area, areas with rainfall of 0-23mm account for 35%, areas with 23-41mm account for 35%, and areas with 41-60mm account for 30%.

Monitoring Status of Ground Subsidence and Settlement: Second, Construction of a Comprehensive Monitoring Network for Groundwater-Force-Heat. For different types of geological risk issues, by monitoring changes in stratum compression deformation, water level, moisture, stress, chemical composition, etc., and fully utilizing new technologies and methods such as distributed fiber optics, a comprehensive monitoring network for groundwater-force-heat is constructed. The first part involves monitoring the underground space structure of the city. Using distributed fiber optic acoustic sensors (DAS) and a green air gun source area, the dynamic changes in the geological structure of Hangzhou's main urban area up to 200m underground are monitored every two years. Using distributed geophysics based on smart lampposts, the dynamic changes in the geological structure of the central urban area, Qianjiang New City, Xiaoshan Science City, etc., up to 50m underground are monitored 1-2 times a year, with a monitoring accuracy of 5m. The second part is to improve the urban groundwater monitoring network. On the basis of the existing groundwater monitoring network mainly for groundwater resource assessment, additional groundwater monitoring points are set up in key planning and construction areas such as the central urban area, Jianggan District, Binjiang District, and Qiantang New District to monitor the dynamic changes in water level (water head), water temperature, and water chemistry of unconfined and confined water up to 60m underground. Based on hydrogeological units, the monitoring density of shallow groundwater in plain areas is not less than 4 points per 100 square kilometers, the monitoring density of confined aquifers is not less than 3 points per 100 square kilometers, and the monitoring density in karst distribution areas is not less than 2 points per 100 square kilometers. The monitoring elements include water level, water quality, and water temperature. Water level and temperature are monitored once a day with an accuracy of 1cm; water chemistry is monitored once a year. Systematically grasp the regional groundwater environment status and trends in Hangzhou, analyze the connection between regional groundwater environmental changes and ground subsidence and collapse risk issues, construct an urban groundwater safety protection barrier, and provide data support for urban groundwater resource security and groundwater environmental safety. On the basis of the existing groundwater monitoring network, the third part is the monitoring of ground subsidence and collapse under engineering influence. Targeting geological risk issues such as ground subsidence and collapse caused by engineering construction, in areas with poor soil such as soft soil and saturated sand soil, combined with regional ground subsidence monitoring networks, urban planning, and engineering construction, ground surface deformation in the central urban area is monitored using methods such as InSAR and laser scanning. High-precision GPS, fiber optics, displacement sensors, etc., are used to monitor soil deformation up to 60m underground along subway lines and in soft soil distribution areas along the Tiaoxi River and Qiantang River. Monitoring of stratum compression deformation, water levels (water heads), moisture, and other elements in different aquifers is conducted. High-precision GPS, fiber optics, and displacement sensors are monitored once a day with an accuracy of 5mm; leveling, bedrock benchmarks, and stratified benchmarks are monitored twice a year with an accuracy of 1cm. Predict and warn of ground subsidence and collapse along key engineering routes, analyze their occurrence and development mechanisms, and ensure the safety of urban engineering construction and underground space development and utilization. The fourth part is the monitoring of karst ground collapse. In the West Lake, Xianlin-Liuxia, Zhuan Tang, and other areas with medium to high risk of karst collapse, ground deformation is monitored using distributed fiber optics, karst cover soil deformation is monitored using displacement sensors, and karst groundwater levels are monitored using pressure sensors. Predict and warn of karst collapse to ensure the safety of engineering construction and environmental safety in karst distribution areas. In medium to high-risk areas, the monitoring density of karst groundwater is not less than 2 points per square kilometer, using distributed monitoring to monitor the stress changes and ground deformation of hidden karst cover rock layers, monitoring once a day with a deformation monitoring accuracy of 5mm and a water level monitoring accuracy of 1cm.

Requirement:

Now please play the role of a geological expert. Ground subsidence and ground collapse are both ground deformation geological hazards. If you need to make a weight judgment on the ground deformation geological hazards in the study area, the total weight is 1. Please judge the impact of the two hazards on the basis of the information I provided. The influence of the study area and its importance to the study area are then weighted to determine the weight of ground subsidence and ground subsidence, and a basis for judgment is provided.