Land Subsidence Monitoring in China

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Outline
◆ Land subsidence in China
◆ Land subsidence monitoring in China
◆ Case study
--- Shanghai
--- Tianjin
Three major subsidence regions in China:
- North China Plain
- Yangtze River Delta
- Fen-Wei Faulted Basin

Tianjin, Shanghai, and Xi'an

There are more than 50 subsidence cities mainly in these three regions.
As large as 79,000 square kilometers of land has dropped more than 200 millimeters and about 50 cities have wide-spread land subsidence.

**Land subsidence in China**

In the Yangtze River Delta

- About 10,000 square kilometers of land has dropped more than 200 mm.
- The accumulative subsidence of Shanghai and Wuxi are 2980mm and 2800mm, respectively.

Accumulative subsidence contour in the Yangtze Delta (until 2010)
Land subsidence in the Yangtze River Delta--Shanghai Region

- Between 2002 and 2006, the land subsidence in the whole city was controlled to a certain extent, and the average sinking rate was 12.7mm/a.
- Between 2006 and 2010, the cumulative subsidence amount of most areas was relatively small, between 0-25mm. The area of accumulative subsidence greater than 50mm amounted to 162km².

Land subsidence in Su-Xi-Chang region of Jiangsu province:
- In recent ten years, subsiding rate has decreased greatly due to prohibition and limitation of groundwater withdrawal. Now the area of subsiding rate greater than 10mm/a is about 500km².
Land subsidence in China

In Hang-Jia-Hu plain of Zhejiang province:
- Land subsidence originated in about 1964, in late 1970s-early 1980s, land subsidence developed rapidly;
- Since 2006, land subsidence was efficiently controlled by prohibiting and limiting groundwater withdrawal. Until 2010, the areas of subsiding rate greater than 10mm/a were about 195km², decreasing 92% as compared to 2005.

Land subsidence in the Yangtze River Delta -- Hang-Jia-Hu Region

The maximum accumulative subsidence was 3300mm in Tanggu area of Tianjin. In 2009, the area of subsiding rate in Tianjin region greater than 10mm/a and 50mm/a was 6800 km² and 1300 km², respectively.
Land subsidence in China

Factors for land subsidence

- **Geological conditions:**
  thick soft sediments with high compressibility

- **Dynamic conditions:**
  (1) groundwater overdraft;
  (2) engineering construction

Rapid expansion and development of industrialization and urbanization are also most important factors for land subsidence.

A water tower in Tianjin was cracked due to land subsidence
Land subsidence in China

The walls of houses were cracked due to land subsidence.

Land subsidence in China

The mouth of wells disjointed from ground.
Land subsidence in China

The navigation capacity of bridges were greatly decreased.

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Land subsidence in China

Floods and storm tides occurred frequently in the coastal cities (Tianjin, October 11, 2003)

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Land subsidence in China

The tidal dike has been reinforced for several times in many coastal cities.

Economic loss due to land subsidence

Estimate of total economic loss due to land:
- Shanghai is ¥13 billion yuan (2001-2010), or ¥300 billion yuan (1921-2010).
- Su-Xi-Chang region is ¥17 billion yuan until 2000.
- Tianjin city is about ¥120 billion yuan until 2003.

The average total loss is ¥9-10 billion/a.
The annual direct loss is ¥0.8-1.0 billion yuan.

The total economic loss consists of direct and indirect loss, and indirect loss accounts for 80-90% of the total economic loss.
Land subsidence monitoring in China

Since 1999, China Geological Survey (CGS) started the National Program on Investigation and Monitoring of Land Subsidence.

- Borehole extensometers and automatic monitoring system;
- Global positioning systems (GPS);
- InSAR (Interferometric Synthetic Aperture Radar);
- Leveling measurements;
- Automatic monitoring system for groundwater levels.

Groundwater monitoring:
- Groundwater level: 625 wells;
- Groundwater quality: 285 wells;
- Automatic monitoring points: 72 points.

Land subsidence monitoring:
- Benchmark on bedrock: 72 points;
- Borehole extensometer: 83 points;
- Ground crack monitoring: 8 points;
- GPS roving stations: 554 points;
- GPS permanent tracking stations: 12 points;
- Automatic monitoring points: 72 points.

Investigation and monitoring works in the Yangtze river delta
Land subsidence monitoring in China

InSAR (Interferometric Synthetic Aperture Radar): covering 67000 km².

Investigation and monitoring works in the Yangtze river delta

Shanghai deployed facilities like leveling nodes, borehole extensometers and bedrock bench marks in different geological formation areas along project lines, and had formed a land subsidence backbone network that is independent but still tightly associated with the leveling network of the central city.

Engineering Land Subsidence Monitoring Network in Urban Areas of Shanghai city
Land subsidence monitoring in China

**Groundwater monitoring:**

Groundwater level: 436 wells;

**Land subsidence monitoring:**

Benchmark on bedrock: 2 points;
Borehole extensometer: 17 points;
GPS roving stations: 45 points;
Leveling nodes: 1742 points.

Investigation and monitoring works in Tianjin Region

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Land subsidence induced by the exploitation of ground water

This picture shows the bund before 100 years. The embankment did not exist at that time.

This picture presents the current bund, the embankment have been rise several times since it was built.
The water table of the 4th confined aquifer in Shanghai in 2007

The change feature of water table of the 4th confined aquifer since 1961
Based on the long-term monitor of ground water, the chemical component of ground water in Shanghai area was stable.
The monitor station for land subsidence

The benchmark net used for monitoring land subsidence in the central city
Precise leveling

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SITUATION OF SHANGHAI LAND SUBSIDENCE

- Structure and variety of groundwater mining and artificial recharge

- There are total five confined aquifers.
- The 4th aquifer is the main exploitation layer.
- Before 1964, groundwater was excessively mined, which resulted in serious land subsidence.
- Groundwater mining have been restricted since 1964, artificial recharge have been utilized.
- Now, through adjusting mining plan, the quantity of mining is gradually decreasing.
General situation of land subsidence

- Through leveling survey, the landmark which lies to Shanghai Ningbo road has reflected the land subsidence at that time between 1910 and 1919.
- From 1921 to 1948, land subsidence is more visible than before.
- From 1966 to now, land subsidence has been controlled through decreasing exploitation.

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With the rate increasing, the diversity of Shanghai land subsidence is visible in space. The data of subsidence separated from each other seriously, what indicated the difference for sedimentation. That has impact on municipal infrastructure.

ANALYSIS OF INFLUENCED FACTORS OF SHANGHAI LAND SUBSIDENCE

- Before 1966, groundwater mining is primary factor of land subsidence, which resulted in serious land subsidence.
- From 1966 to 1990, government have adopted prevention and cure measures to control land subsidence, the setting velocity has been kept within the minimum range.
- Since 1990, large-scale construction is another main factor, which accelerated land subsidence.

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Groundwater mining is the primary factor of Shanghai land subsidence.

- Historically, excess groundwater mining has resulted in groundwater level decreasing, and groundwater level descent funnel is formed, which will induce serious land subsidence.
- Clay layers are non-elastic, the compression of which has the character of hysteresis. So, when groundwater level ascends, land subsidence still continues.

**LAND SUBSIDENCE MONITORING**

- Shanghai has established a monitoring network of land subsidence, including land subsidence monitoring stations, groundwater level monitoring wells, extensometers, GPS, and others.
- Generally, leveling is the primary method to master the state of Shanghai land subsidence, also GPS and INSAR techniques are used every year to monitor the land subsidence.
Monitoring station of land subsidence

Distribution of GPS monitoring point
Control of land subsidence in Shanghai

By control of exploitation, recharging of groundwater, adjusting the level of groundwater exploitation, etc., land subsidence was controlled well.

Recharging well (deep aquifer)  Recharging well (shallow aquifer)
Tianjin is a coastal city and a major economic centre in the north of China. It covers an area of 11000Km² with about 10 million people.

Tianjin accumulative land subsidence from 1967 to 2009

Accumulative land subsidence in Tanggu district of Tianjin reached 3.3m.
The land subsidence has exceeded 8000 Km² and the several cones of depression occurred.

In recent years, with development of economy, several new centers of land subsidence appeared.

The maximum accumulative subsidence is over 3.3m at present.

And the rates of these area were more than 40mm/a.

Tianjin began to utilize groundwater resources in1923. According to historical leveling points, land subsidence happened, along with the development of groundwater.

**Land subsidence history**

- **Initial period**
  - 12Mm³/a
  - 10-20mm/a

- **Growth period**
  - 12-100Mm³/a
  - 10-100mm/a

- **Serious period**
  - 100Mm³/a
  - 80-100mm/a

- **Controlled period**
  - 20Mm³/a
  - 10-20mm/a

**Distribution of Land Subsidence**

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losses due to storm tide increased

Characteristics of land subsidence in Tianjin

- The Quaternary and Neogene deposits have a thickness exceeding 1000m.
- It’s difficult to provide enough water to meet the growing demands.
- The causes of land subsidence are complex and varied.
The causes of land subsidence can be divided into two kinds:

**Natural factors**
- Neotectonic movement
- Sea level rising

**Artificial factors**
- Petroleum production
- Geothermal development
- Gas production
- Groundwater over-exploitation
Artificial factors

Load of high buildings

Artificial factors

Dewatering
Thank you for your attention!!