Bulletin of Chinese Academy of Sciences 院刊

Volume 35 | Issue 4 Article 6

April 2020

Cryosphere Engineering Science Supporting Interactivity Infrastructures Construction

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Abstract

The cryosphere is closely related to climate change, human engineering activities and social and economic development. Each element of cryosphere has significantly different influence characteristics on engineering. Disasters by glaciers, snow cover, and sea (river and lake) ice will mainly affect the construction, safe operation, and serviceability of engineering. Frozen soil is a special foundation soil for engineering structures, thus freezing-thawing disasters and thermal and mechanical stability change of frozen soil will directly affect the stability of engineering. As global change, the elements of cryosphere change and its hydrological and ecological environment, surface process changes have significant influence on engineering, thus it is needed to strengthen the relationship research between the engineering construction and safety operation and the environmental factors change. In addition, engineering security technology is also needed to be more comprehensive to consider the influence of climate and environment changes. Therefore, climate and environmental change will become an important factor to be considered in the construction, safe operation, and serviceability of engineering in the regions of cryosphere in the future. At the same time, the Belt and Road infrastructure construction not only brings opportunities to cryosphere engineering, but also faces greater challenges.

Keywords

cryosphere; engineering; climate change; the Belt and Road

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Citation: WU Qingbai, LI Zhijun, SHEN Yongping. Cryosphere Engineering Science Supporting Interactivity Infrastructures Construction[J], Bulletin of Chinese Academy of Sciences, 2020 (4): 443-449.

Cryosphere Engineering Science Supporting Interactivity Infrastructures Construction

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Abstract: The cryosphere is closely related to climate change, human engineering activities, and social and economic development. Each element of cryosphere has significantly different influence characteristics on engineering. Disasters by glaciers, snow cover, and sea (river and lake) ice will mainly affect the construction, safe operation, and serviceability of engineering. Frozen soil is a special foundation soil for engineering structures, and thus freezing-thawing disasters and thermal and mechanical stability change of frozen soil will directly affect the stability of engineering. With global change, the change in elements of the cryosphere, their hydrological and ecological environment, and surface process changes have significant influence on engineering. Thus, it is needed to strengthen the research on the relationship of engineering construction and safety operation with the environmental factors change. In addition, engineering security technology is also needed to be more comprehensive to consider the influence of climate and environment changes. Therefore, climate and environmental change will become an important factor to be considered in the construction, safe operation, and serviceability of engineering in the regions of cryosphere in the future. At the same time, the Belt and Road infrastructure construction not only brings opportunities to cryosphere engineering, but also faces greater challenges.**DOI:** 10.16418/j.issn.1000-3045.20200301001-en

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The cryosphere region is rich in oil, natural gas, mineral resources, etc. Social and economic development and resource development and utilization inevitably involve infrastructure construction such as highways, railways, waterways, airports, transmission lines, oil and gas pipelines, and ports and docks. Infrastructure construction in the cryosphere region will be restricted by various elements of the cryosphere. Meanwhile, infrastructure construction will also have an impact on all elements of the cryosphere. By studying the distribution law and change process of each element of the cryosphere and the reciprocal feedback between cryosphere disasters and projects, the safety guarantee technologies and disaster prevention and control technologies were put forward for major projects, so as to minimize and adapt to the great impact of the cryosphere change on engineering structures, which is of great significance to the development of the western region in China, the revitalization of northeast China, and the Belt and Road Initiative [1].

The safety of major engineering and the major running infrastructures in the cryosphere region will be greatly threatened by the cryosphere disasters induced by the changes of various elements of the cryosphere, such as glaciers, frozen soil, snow cover, and sea (river, lake) ice. Climate warming makes the engineering safety and service function in the cryosphere region face new balance and adaptation problems brought by environment changes, which is easy to induce great risks, especially in the period of rapid climate change at present. The construction and safe operation of planned the Belt and Road transportation infrastructure construction, Beijing-Moscow high-speed railway, China-Russia-Canada-America line, Arctic route, and other major engineering will face great challenges from the cryospheric change under climate change.

1 Main research task of cryosphere engineering science

Cryosphere engineering science is a science that studies the interaction between elements of the cryosphere (such as glaciers, snow cover, frozen soil, river ice, lake ice, and sea ice) and engineering structures. As an important branch of cryosphere science that serves human society and promotes social sustainable development, cryosphere engineering

Received: [（英）收稿日期]
Supported by: National Natural Science Foundation of China (41690144, 51979024)
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science is at the level of interaction, influence, and adaptation with other spheres [2]. The formation law and change process of elements of the cryosphere are the disciplinary basis for understanding cryosphere engineering science. The core contents of cryosphere engineering science are the interaction mechanism between elements of the cryosphere and engineering activities, routes of their adaptation to engineering, and the research and development of corresponding engineering security technology to adapt to the changes and influences of elements of the cryosphere.

In addition to the traditional engineering geological conditions, meteorological conditions, ocean conditions, and hydrological conditions, it is necessary for the cryosphere engineering science to study the temporal and spatial distribution and variation characteristics of elements of the cryosphere, local engineering conditions, cryosphere environment and disasters, etc. These basic engineering environmental conditions, especially the adaptability conditions of elements of the cryosphere which are related to engineering, are the core and application basis of engineering construction in the areas affected by the cryosphere. Only by understanding the potential limit force of these areas on engineering and the ability of the structures to bear external forces can we accurately grasp the design principles, design methods, and engineering measures of various projects and ensure the safe construction and operation of engineering structures.

Therefore, the main research tasks of cryosphere engineering science are as follows: ① through site investigation, in-situ monitoring, and numerical simulation, it should study the relationships of distribution characteristics and change process of elements of the cryosphere with the engineering stability and serviceability and predict the change processes of the elements of cryosphere and their influence on engineering stability; ② it should study the influence of anthropogenic activities on the environment of elements of the cryosphere and cryosphere disasters induced by it and put forward the engineering design principles, design parameters, engineering technical measures, and disaster prevention and control technologies to ensure the safe engineering operation, as well as the protection countermeasures for cryosphere environment; ③ it should study the serviceability of engineering under the influence of climate and environment change and its impact on social economy and put forward the scale and intensity of engineering construction and the adaptive technologies and measures of engineering in the areas affected by the cryosphere under climate change, so as to enhance the engineering service function of the cryosphere.

2 Research status

The understanding and research of various elements of the cryosphere began with the engineering construction of cryosphere regions. The demands of social and economic development make cryosphere engineering science develop and expand rapidly. Therefore, the research of cryosphere engineering science may be earlier than that of branch disciplines regarding elements of the cryosphere.

(1) Frozen soil engineering. From 1930s to 1950s, the research on major infrastructures, such as mines, highways, railways, airports, houses, development of oil and gas resources in circum-Arctic regions, was conducted. The Soviet Union has promoted the engineering research of frozen soil and cold regions through the Trans-Siberian Railway, Siberia-Pacific pipeline system, and the construction of northern cities [3]; Canada has promoted the research on engineering in frozen soil and cold regions through the oil and gas development in the Mackenzie Valley and the construction of Norman oil pipeline [4]; through the design and construction of frozen soil engineering in Alaska oil pipeline, the United States has promoted the engineering research of cold regions and formed the discipline system of frozen soil engineering; some other countries have made some progress in frozen soil engineering research. Since 1950s, China has carried out a large number of studies of engineering in the frozen soil areas of Qinghai-Tibet Plateau, Greater Khingan Range, and Lesser Khingan Range in northeast China around the construction of water conservancy infrastructures, highways, railways, oil pipelines, and other projects in cold regions [5]. The construction of Qinghai-Tibet Railway has promoted the rapid development of research on frozen soil engineering in China and formed the frozen soil engineering discipline.

(2) Glacier and snow cover engineering. In the early 1950s, dozens of research and engineering departments in China successively carried out investigations and prevention and control studies on snow cover and snow damage. At the end of 1970s, China carried out a study on the influence of the occurrence and development trend of glacier disasters on highway engineering in cold regions of glaciation areas and predicted the advancing and changing trend of Batura Glacier, which provided important scientific support for formulating highway restoration scheme. In particular, snow cover, wind-blown snow, avalanche, and their hazard mechanisms and prevention and control technologies are systematically studied, and a set of prevention principles as well as measures and design methods of comprehensive treatment for wind-blown snow in China are put forward [6], forming a relatively complete theoretical system of wind-blown snow on highways.

(3) River and lake (reservoir) ice engineering. There are various river and lake (reservoir) ice engineering structures in many countries, and the research focuses on the numerical simulation and model development of the whole process including the river and lake ice formation, development, and disappearance. Especially, with the historical and current hydrological and meteorological data, as well as the laws of ice freezing and thawing in rivers, reservoirs, and lakes, the future ice conditions are predicted, so as to formulate measures to deal with and prevent ice disasters in advance. In

order to reduce and prevent the influence of ice on the structures and safe operation of production, it is necessary to adopt ice engineering prevention and control technologies to ensure engineering safety.

(4) Sea ice engineering. In the late 19th century, Russian and Nordic scientists carried out the icebreaker design and the design of lighthouse resistant to ice. The construction of military bases in ice covered areas promoted the research of ice engineering in the United States and the Soviet Union. In particular, the research on sea ice engineering has developed rapidly in order to realize navigation all year round in ice areas to explore the Arctic region and ore energy. In recent years, oil and gas projects in Sakhalin in Russia, Barents Sea and Kara Sea in the Arctic have also promoted the research of sea ice engineering. The research on sea ice in Bohai Sea in China started in the early 1960s. It mainly focused on nuclear power plant projects, offshore wharf projects, and wind power generation projects in Bohai Sea and northern Yellow Sea, especially the structural vibration and its damage caused by sea ice. The factors considered in ice engineering design, such as the area and density of drift ice, the mechanical properties of ice, and the action mode of ice on structures [7] promoted the work of sea ice observation and numeralization of ice conditions. Targeting the exploitation of Arctic resources, the research on ice-ship interaction and engineering mechanical properties of polar ice will be developed.

Under the strong influence of climate change, environment change, and anthropogenic activities, and the impact of global change on engineering construction, it is urgent to describe the relationship between various elements of the cryosphere and major engineering structures and environmental and disaster effects of the elements and put forward environmental protection measures, cryosphere disaster prevention, control, and support technologies, and new technologies and methods for cryosphere engineering construction.

3 Relationship between elements of the cryosphere and engineering

Under the background of climate warming, the disasters caused by the changes in various elements of the cryosphere will have an important impact on engineering safety, and the frozen soil as the engineering foundation will also be affected by the engineering thermal disturbance. Thus, the prevention and control technologies of the cryosphere disasters and the safety guarantee technologies of the frozen soil thermal stability are the core of the engineering construction and safe operation in the cryosphere areas (Figure 1).

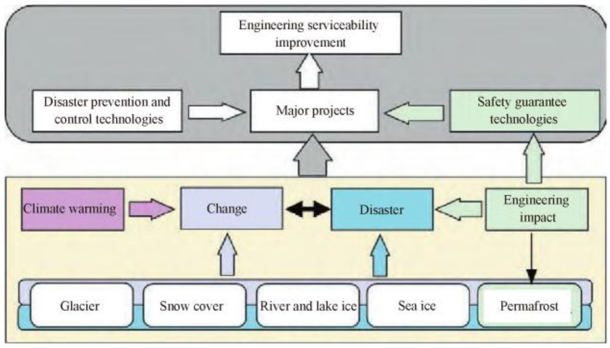

Figure 1 Relationship between elements of the cryosphere and engineering

As a geological body bearing engineering structures, frozen soil has complex interaction with engineering structures. On the one hand, engineering thermal disturbance will directly lead to rapid warming and melting of frozen soil in lower parts of the structures, which will cause frost heaving as well as melting and sinking deformation of engineering structures; on the other hand, frozen soil changes can also induce freezing and thawing phenomena such as thaw slumping, solifluction landslide, and frozen soil landslide, which affect the stability and safe operation of the upper or surrounding engineering structures. Therefore, in frozen soil engineering, it is necessary not only to put forward technical measures for preventing frost heaving and thawing collapse of soil itself according to different heat source forms and thermal effects of engineering, so as to slow down the influence on engineering stability and serviceability, but also to study the prevention and control technologies of secondary disasters induced by engineering effects. Since there is a close relationship between frozen soil and environment, protecting frozen soil environment can slow down the influence of environment changes on frozen soil degradation, which is conducive to reducing engineering diseases [8].

Glaciers and snow cover can not only be used as water resources in engineering construction areas in the form of solid water sources but also induce floods, avalanches, snowdrifts, and other disasters by sudden changes, which exceeds the preventive ability of human beings. Therefore, the change of glaciers and snow cover has great potential harm to the safe operation of projects, and engineering and technical measures should be taken to prevent the influence of glaciers and snow cover on the projects. The design principles and parameters of important structures, such as bridges and tunnels, are obtained through the research on the influence and evaluation of glacier distribution and snow and ice disasters on engineering stability in the affected areas, the analysis of occurrence scale of historical glaciers and snow-melting floods according to the importance of the projects, and the prediction of the future snow-melting floods. Therefore, the snow and ice disaster fortification standards, engineering design parameters, and disaster prevention and control methods of important structures are the core of engineering safety [9].

Sea (river, lake) ice can be used as temporary structures or transportation channels in winter. Meanwhile, fixed and floating components built on sea (river, lake) ice should resist the force of sea (river, lake) ice to reduce the risk of damage to structures by the force of sea (river, lake) ice. The interaction of river and lake (reservoir) ice with engineering is mainly reflected in the resistance ability and technologies of engineering structures to ice. For river ice and channel ice, it is necessary to understand the occurrence law of ice jam and ice dam, evaluate the influence of river ice on hydraulic structures, evaluate the static ice pressure of channel aqueduct and slope and the impact force of ice drift on piers in the river, so as to provide a basis for the scheme selection and optimization, planning, and construction of structure design. For reservoir ice, it is necessary to establish the design of anti-ice pushing on reservoir slope with observation parameters. For sea ice, it is necessary to carry out the design to meet the safe operation of structures resistant to ice. The flowing sea ice acts on rigid structures, and the service life of structures depends on the impact force of ice. For flexible structures, the vibration and fatigue damage of structures caused by ice breakage determine the life of structures.

4 Climate change and serviceability of cryosphere engineering

Under the influence of global warming, all elements of the cryosphere have changed significantly, thus affecting the engineering construction and safe operation in the cryosphere areas and changing engineering serviceability. Climate change increases the vulnerability of infrastructures, causing extra pressure on engineering structures beyond normal conditions and expected use.

The probability of glacier disasters such as glacier floods and glacial lake outburst caused by rapid melting of glaciers increases and major disasters occur frequently. Environmental disasters (floods, snow and ice disasters, etc.) affect the stability of hydropower stations, highway or railway subgrade works, bridges, and other engineering structures in the cryosphere areas[10,11] and make the engineering serviceability change. For the sake of ensuring the safe operation of engineering structures, glacier and snow disasters along hydropower stations, highways, and railways should be evaluated regularly and systematically and the fortification standards of engineer under climate change should be determined to improve the engineering serviceability.

Climate warming is accelerating the degradation of permafrost, resulting in a rapid increase in freezing-thawing disasters such as thaw slumping and frozen soil landslide, changes in the freeze-thaw cycle frequency, and the influence on the stability and fragility of infrastructures. The melting of permafrost near the surface changes the engineering serviceability of buildings, highways, railways, pipelines, and oil and gas infrastructures. Under the background of climate change, the elevation of the engineering serviceability of frozen soil needs to study and quantify the potential impact of climate change on infrastructures in permafrost regions, including a more comprehensive study of the relationship between public infrastructures and environmental pressure, the service life of infrastructures, and the operation and maintenance costs of engineering.

Climate warming will lead to earlier river break-up, later river freeze-up, and shorter ice flood period, and then results in significant changes in the occurrence and development of ice flood disasters (such as ice jam disaster, ice dam disaster, ice pressure, and ice drift impact) [12]. Ice flood disasters will have an important impact on piers, wharves, water diversion buildings, and river and canal revetments, and also directly affect the construction and operation of shipping, bridges, power generation, water supply and drainage projects, thus influencing the engineering serviceability.

Climate warming and the melting of sea ice have prolonged the ice-free period in the Arctic and expanded the ice-free range, leading to changes in ice age, ice density, ice drift velocity, ice thickness, ice temperature, and physical and mechanical properties of ice. As a result, the impact of sea ice on engineering is reduced and the serviceability of engineering structures and the capacity of Arctic passage are enhanced. However, the melting of sea ice reduces the serviceability of engineering structures that originally depends on sea ice. Meanwhile, the influence range of ice drift movement after sea ice melting expands, and the uncertainty of engineering structures in the Arctic ice areas increases. The relative movement of thick ice layer will still cause damage to structures.

5 Main engineering problems in the Belt and Road interactivity

The Silk Road Economic Belt runs through Eurasia, and there will be many special engineering problems in infrastructure construction along the route, including engineering characteristics of loess, frozen soil, and expansive soil, geological disasters that may occur in engineering construction, stability problems of foundation and roadbed, and ecological environment problems [13]. At the same time, there are glaciers, snow cover, permafrost, sea (river, lake) ice, etc. along the route. Sudden disasters in the cryosphere and the stability of frozen soil foundation will seriously affect the Land Silk Road infrastructure construction [14]. For example, the China-Pakistan Economic Corridor needs to pass through the high-altitude mountainous areas affected by the cryosphere, and climate warming increases the frequency of sudden events such as glacial lake outburst, floods, debris flow, and avalanches, which will directly threaten the safe operation of water conservancy facilities and highway facilities in the areas. In addition, freezing-thawing action also leads to a large number of geological disasters of slope collapse and instability in these areas [15].

The transportation and energy infrastructure construction of Silk Road Economic Belt, which passes through a wide range of cold regions, will face the challenge of the cryosphere disasters and various hidden dangers of engineering safety caused by them. Disasters associated with the melting of frozen soil and rock collapse under the influence of freezing and thawing will have an important impact on infrastructures in areas severely affected by engineering activities. For example, Karakoram Highway, Sino-Nepalese Highway, China-Mongolia-Russia Economic Corridor Project Infrastructure, China-Russia-Canada-America line will all face the impact of frozen soil melting on major projects (Figure 2). The construction of Beijing-Moscow high-speed railway and China-Russia-Canada-America line put forward higher requirements for engineering stability, and the high-speed railway construction technologies and control technologies for thermal stability of frozen soil will face greater challenges [16]. Therefore, it is necessary to study the interactions and corresponding mechanisms of the changes in elements of the cryosphere, regional geological structure, and geological disasters with major projects, as well as their influence on the stability and long-term serviceability of major projects.

Figure 2 Schematic diagram of major projects related to the Belt and Road Initiative in the cryosphere areas

It is modified according to Figure 1 in Reference [12].

The construction of Ice Silk Road under the background of the Belt and Road Initiative mainly includes ship engineering and port engineering related to Arctic navigation (Figure 2), which is inevitably affected by sea ice and frozen soil elements. For the emergency temporary ice and snow roads, airports, and wharves, the construction technologies should be studied in advance, and the control technologies for thermal erosion of coastal frozen soil, bank collapse, and subsea permafrost melting will also become the key to the safety of infrastructures. Meanwhile, the exploitation of mineral resources and comprehensive utilization of energy in the Arctic need corresponding countermeasures on the relatively weak engineering hard core. For example, Arctic environmental protection, mine engineering safety, and efficient resource exploitation technology, especially the mechanics research on frozen soil destruction, may become the key to the development and utilization of mineral resources.

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(Translated by [译者])

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