Review Article

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A review of genetic classification and characteristics of soil cracks

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Abstract: Soil cracks are one of the most important physical properties of soil. The formation of soil cracks is a result of interactions between the inner and external conditions of soil. Specifically, the inner conditions include physical and chemical properties of soil, and the external conditions refer to natural and anthropogenic factors. Previous studies of soil cracks mainly focus on the soil properties and the natural environment (NE), such as soil cracks produced by biotic and abiotic processes. Very few studies have focused on the soil environmental changes induced by other external conditions, such as geological processes and anthropogenic activity. To systematically illustrate the soil fissure, according to the characteristics of soil cracks, and considering the properties of soil preferential flow path, the geneses and the characteristics of soil cracks have been comprehensively analyzed and summarized in this study. Two major types of soil cracks have been proposed: one is the cracks caused by NE and the other is the cracks caused by anthropogenic activity. Additionally, based on the specific differences of these geneses, these two types of soil cracks have been further divided into six subtypes and fourteen sub-subtypes, respectively. In this article, a genetic classification method of soil cracks is systematically proposed, which provides a new approach for the related research of soil cracks.

Keywords: soil cracks, classification, geneses, natural environment, human engineering, characteristics

1 Introduction

The formation of soil cracks can be regarded as a result of interactions between inner and external conditions of soil. Soil cracks can directly affect the groundwater infiltration, solute transport, crop growth, soil strength, and so on. Specifically, soil cracks can directly influence the productivity of agricultural lands as well as forestry lands, and soil cracks can also directly affect a variety of civil and environmental engineering designs, such as constructions of water reservoirs, highways, tunnels, and canals. Therefore, it is of great significance to study soil cracks.

Cracks, in a broad sense, are the interfaces in any solid materials. Cracks have been termed differently in many fields of study, such as gaps, pores, voids, and fractures. In geology, cracks are also named as joints, which have been divided into primary joints, structural joints, and weathering joints based on their formation causes [1,2]. Soil can be somewhat regarded as a special type of rock; hence, soil cracks are often called joints in soil science, such as the vertical joints developed in loess region of China [3]. In some studies, soil cracks may also be named as fissures, fractures, pores, and so on [4–6]. Additionally, soil cracks have been classified as a category of soil pores by some researchers [7,8]. For example, Fitzpatrick clearly indicates that soil cracks are one kind of soil pores and that soil pore shapes vary in morphology [9]. Soil cracks are sometimes called macropores, which are highly conducive to soil moisture movement and chemical transport [10].

Macropores in soil are characterized by the diversity of geometric shapes, the complexity of spatial distribution, and the multiple factors of geneses, and definitions of macropores vary greatly due to different research purposes, methods, and perspectives. For instance, the soil cracks were secondary discontinuities caused by the expansion of soil pores under the influence of the external environment [5]. Additionally, Luxmoore defined macropores based on the capillary potential theory and indicated that the capillary potential of a macropore must be greater

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than -300 Pa and that the equivalent diameter of a macropore calculated by equations of the water surface tension and the capillary force is greater than 1 mm [11]. According to the hydraulic conductivity of pores in soil, Luxmoore proposed three soil porosity classes: micro-, meso-, and macroporosity of soil, their equivalent pore diameter ranges are <10 , 10 – $1,000$, and $>1,000$, respectively. Then, Skopp emphasized a consistent set of terms based on the function of pore classes [12]. Seven and Germann clearly indicated that soil cracks, characterized by larger diameter and longer length, are regular in shape as well as orientation [7]. From a hydrodynamic perspective, Beven and Germann regarded the macropores as cracks that can conduct nonequilibrium conduit flow [8].

Additionally, in some sense, regardless of the aperture size and shape, any pores in soil that can lead to the preferential migration of water and solutes can be called soil cracks [13]. According to the authors of this article, the soil cracks concept should be generalized to all spaces in soil except for primary pores in small size formed among the skeleton particles in the soil matrix. Moreover, the soil cracks are all kinds of interspaces with large sizes, which are formed after the formation of soil and induced by external conditions, such as chemical processes, biological processes, and physical processes.

From what has been discussed above, cracks have an important effect on soil mass. However, up to now, it is lack of a unified classification method for soil cracks. Therefore, two major types of soil cracks, including 6 sub-types and 14 sub-subtypes, have been proposed in this article. The proposed soil crack types provide a new approach for the systematical classification of soil cracks.

2 Genetic types of soil cracks

2.1 Overview of soil crack geneses

The geneses of soil cracks, affected by soil properties and external environment, are diverse. However, different classifications of soil cracks have been proposed in previous studies, due to the differences in research methods, cognitive perspectives, and applications. According to geneses, soil pores can be classified into two types, biogenic pores and abiogenic pores. The biogenic pores can be subdivided into root holes and animal channels, and the abiogenic pores include soil fractures and pores between the aggregates. Additionally, according to the formation time, soil cracks can be classified into primary and secondary cracks; according to the spatial scale, soil

cracks can be classified into small and large pores; according to the geneses, soil cracks can be classified into biological, physical, and chemical cracks [14,15]. Hence, biological processes have been considered in the existing researches on the classification of soil cracks. However, only the direct effects of the biological processes on crack formation were studied up to present, and the indirect effects of the biological processes on crack formation were not considered. Furthermore, the studies about the effects of anthropogenic activities on soil crack formation are rarely seen in the literature.

A necessary factor for soil crack formation is the external environment, both naturally occurred and anthropogenic. Different environmental factors may lead to differences in types, distribution characteristics, and spatial combination of soil cracks. The existing researches have paid more attention to swell–shrink cracks in soil caused by changes in soil moisture [6]. However, soil cracks caused by other natural factors (e.g., geological processes) have received much less attention. Additionally, there has been no systematic study and classification for soil cracks affected by engineering factors.

Soil properties may be changed by different kinds of anthropogenic activities, such as irrigation, fertilization, and planting [16,17]. Additionally, soil physical and mechanical properties may be directly affected by engineering practices, such as constructions of large-scale water reservoirs, exploitations of mineral resources, and groundwater pumping [18–21]. In the geotechnical engineering, mining engineering, and other related fields, only the cracks produced by the deformation of soil and their impacts on the engineering have been discussed.

With the ever-increasing anthropogenic activities over much greater spatial and temporal scales, the impact of human activity over the soil environment steadily increases. For instance, the scale of a single mine in a modern large coal mine can reach nearly 100 km², and a large oil field may be spread over thousands of square kilometers. Extensive surface deformation may be caused by the mining of underground mineral resources (e.g., solid mineral resources, underground water, oil, and gas), and soil cracks caused by such human activity may aggravate water and soil erosion and affect engineering safety [16,22,23].

Based on the study of the influence factors of soil cracks, the authors put forward a genetic classification method of soil cracks.

2.2 Genetic classification of soil cracks

According to the characteristic differences between soil cracks that are caused by natural environment (NE) and

that are caused by human activity, two major types of soil cracks are proposed in this study: one is the cracks caused by NE and the other is the cracks caused by human engineering (HE; see Figure 1). The NE type is further divided into three subtypes and ten sub-subtypes, and the three subtypes include the cracks caused by hypergenesis, biotic processes, and geological processes. The HE type is further divided into three subtypes and four sub-subtypes, and the three subtypes include the cracks caused by mineral resources mining, underground construction engineering, and surface construction engineering (see Table 1).

3 General characteristics of soil cracks with different genetic types

3.1 Soil cracks caused by NE

Some pictures of soil cracks caused by various NE processes are listed in Table 2. Characteristics of these soil cracks will be explained as follows.

3.1.1 Soil cracks caused by hypergenesis

Hypergenesis occurs on the earth surface and is the result of atmospheric, water, and biological interactions driven by solar energy, gravitational energy, and solar and lunar

gravitational energies. Solar energy can directly and indirectly affect the formation of cracks and the structural changes in soil. For instance, solar radiation can directly affect the temperature and moisture of soil, which may lead to soil swell–shrink or soil freeze–thaw. Additionally, solar energy has an influence on changes in the biological environment, which can directly and indirectly affect the crack formation and structural changes in soil.

The characteristics of soil cracks caused by hypergenesis are quite different. From the distribution characteristics of soil cracks on the surface, the soil cracks caused by the soil swell–shrink induced by the changes in soil water content under hypergenesis are quite common. These cracks are characterized by greatly variable sizes and the irregular plane distributions [43]. For instance, in the cultivated land and pond swamps of southern China, soil often has small cracks of several centimeters to dozens of centimeters due to drought. While in northern China, long dry seasons can lead to large cracks in soil that are several meters long in depth [44,45]. In permafrost and other cold climate zones, snowmelt may occur due to freeze–thaw cycling in soil, which can lead to the formation of ice wedge cracks [46,47]. The ice wedge cracks are mainly formed in the saturated fine-grained soil in the cold climate zone. The distribution of ice wedge cracks is characterized by sparse distribution, small scale, and dozens of centimeters depth [48]. Soil cracks in saline soil may be produced by the dissolution and crystallization of salt minerals. Compared with other types of soil cracks, such soil cracks are irregularly distributed in soil, and the size of a single crack is usually small. Furthermore, such cracks are usually densely distributed like a honeycomb [49]. General characteristics of soil cracks caused by different hypergenesis can be summarized as follows.

3.1.1.1 Cracks caused by swell–shrink

The length of cracks is from several centimeters to several meters. The surfaces of these cracks are reticulated and staggered. The formation periods of these soil cracks are short, which are consistent with the dry–wet cycling periods of soil. The greater the degree of drought is, the larger the crack size becomes. Additionally, the speed of soil rehydration determines the disappearance rate of soil crack. In fact, the crack evolutionary cycle is generally short [50–52].

3.1.1.2 Cracks caused by freeze–thaw cycling

The length of cracks is from several centimeters to several meters. The crack surfaces are mostly serrated and rough.

Figure 1: Genetic types of soil cracks.

Table 1: Genetic types of soil cracks

Major type	Genesis type		Instructions
	Subtype	Sub-subtype	
NE	Hypergenesis	Swell–shrink	Soil cracks caused by changes in soil moisture [24,25]
		Freeze–thaw cycling	Soil cracks caused by expansion and contraction of soil under freeze–thaw cycling [26,27]
	Biotic processes	Dissolution and crystallization of salt minerals	Soil cracks caused by dissolution and crystallization of salt minerals in salinized soil [28,29]
		Plant root development	Soil cracks formed by the interface between plant roots and soil during the development of plant roots. And secondary soil cracks formed by root decay (e.g., a tubular cavity) or induced by spalling during the development of plant roots [30,31]
		Activities of rodents and burrowers	Holes directly produced by activities of rodents or burrowers. Additionally, soil cracks may be formed by the deformation and collapse of these large holes [32]
	Geological process	Hydrogeological processes	Holes and piping channels formed by subsurface water corrosion and dissolution [33]
		Landslide effects	Soil cracks formed in landslide body (e.g., tensile cracks at the trailing edge and shear cracks at the lateral edge) induced by the landslide deformation or failure [34]
		Karst collapse	Deformation of overlying soil caused by shallow karst collapse [35]
		Earthquakes	Soil cracks caused by the deformation of soil induced by vibration [36]
		Ground fracture	Regional surface deformation caused by crust movement and other factors [37]
HE	Mining mineral resources	Underground mining	Underground water, solid mineral resources, petroleum and natural gas [38]
		Opencast mining	Opencast mining may induce slope deformation, surface deformation, and even changes of groundwater seepage [39]
	Underground engineering	Underground traffic and chamber constructions	Surface deformation caused by underground excavation of urban subway, tunnel, and spillway [40]
	Surface engineering	Ground building foundation pit, cutting, and artificial slopes	Soil deformation caused by artificial slopes and other surface engineering [41]

These cracks normally, featured by complex spatial patterns, mainly are wedge tensile cracks on different scales. The scale of these cracks varies greatly in the same area. Such cracks are caused by the freeze–thaw cycle of soil. The time of formation and evolution of these soil cracks depend on the period of the freeze–thaw cycle of soil [53].

3.1.1.3 Cracks caused by dissolution and crystallization of salt minerals

The length of cracks is from several millimeters to several centimeters. The cracks are mainly formed in the soil with crystallization of salt minerals during the dry season. The time of crack formation is concentrated in the stage of the

dissolution and recrystallization of salt minerals in soil. The size of a single crack is small, and the spatial distribution regularity of cracks is not strong.

3.1.2 Soil cracks caused by biotic processes

Soil cracks caused by biotic processes can be further divided into two sub-subtypes, including types of cracks caused by plant root development and activities of rodents and burrowers, respectively. Both living and decayed roots could serve as preferential flow paths, and soil cracks induced by roots can be divided into two kinds: one is cracks formed between soil and plant roots during plants' growth (live cracks) and the other is cracks formed by the

Table 2: Pictures of soil cracks caused by different NE processes

No.	Sub-subtype	Distribution range and area	Pictures	Description	No.	Sub-subtype	Distribution range and area	Pictures	Description
1	Swell–shrink	Surface soil		Soil cracks caused by swell–shrink	2	Freeze–thaw cycling	Mid-to-high latitude area, low-temperature zone		Soil cracks caused by ice wedge [42]
3	Dissolution and crystallization of salt minerals	Saline soil distribution area		Soil cracks caused by carbonate dissolution in Cenozoic soil at Port Campbell National Park on the Pacific coast of Australia	4	Plant root development	Plant root distribution zone		Soil cracks caused by development of tree root system
5	Activities of burrowers	Burrower activity area		Soil cracks caused by animal cave	6	Hydrogeological processes	Groundwater seepage area		Soil cracks caused by groundwater overexploitation in North China Plain

(Continued)

Table 2: Continued

No.	Sub-subtype	Distribution range and area	Pictures	Description	No.	Sub-subtype	Distribution range and area	Pictures	Description
7	Landslide effects	Landslide body and its surrounding area		Soil cracks developed at the back edge of soil landslide	8	Karst collapse	Karst subsidence area and its boundary zone		Soil cracks caused by ground surface collapse in karst process in Jiangxi, China
9	Natural and man-made earthquakes	Earthquake affected area		Soil cracks caused by Wenchuan earthquake (2008) in Sichuan, China	10	Ground fracture	Stress changing area		Soil cracks caused by ground fracture in Shanxi, China

death and decay of plant roots (dead cracks) [54–56]. Compared with the former, the latter tends to be larger in size. Hence, these two kinds of soil cracks are not only different in genesis but also different in spatial distribution. With respect to the spatial distribution, the dead cracks are closely related to cracks caused by the activities of burrowers. The characteristics of soil cracks caused by roots vary greatly because of the differences in species and sizes of the root system. For example, the root depth of herbaceous plants is generally about 30 cm, whereas the root depth of deep root trees is up to 200 cm [45,57]. In fact, holes produced by activities of rodents or burrowers may be different in size as well because of the difference of animal species and individual sizes. In addition, there exists another type of soil cracks that are related to the biotic processes. For instance, root growth can lead to spalling of soil around the root, and collapse of a burrower cave can loosen surrounding soil and then create cracks [58–60]. These cracks, normally located only above the root or the cave, are induced by the deformation of soil under external forces. Hence, the general characteristics of such cracks are similar to the soil cracks caused by karst collapse, slope failure, and engineering practices [61,62].

In terms of the geometric features of cracks, the interfaces between roots and soil, as well as holes caused by rodents or burrowers, are not cracks in a strict sense. However, from the perspective of soil crack preferential flow path, they have the same effects as other cracks. General characteristics of soil cracks caused by different biotic processes can be summarized as follows.

3.1.2.1 Cracks caused by plant root development

The length of cracks is from several centimeters to several meters. The distribution areas and combination features of soil cracks are consistent with that of the plant root system. A single crack normally extends from the root to the diagonal downward direction. Compared with the cracks formed by the interfaces between plant roots and soil, the cracks (channels) caused by the decay of the plant roots (on the same size level) are large, distinctly. Cracks of different sizes interweave within the same area. Soil cracks induced by spalling during the development of plant roots belong to tensile fracture, which are distributed in the soil body above the distribution zone of large roots. The soil cracks associated with plant root development differ greatly in size in the same area and have a long evolutionary cycle [63].

3.1.2.2 Cracks caused by activities of burrowers

The length of cracks is from several centimeters to tens of meters. The cracks formed by activities of different kinds of animals vary greatly. Holes (cracks) produced by large burrowers have larger scales. The spatial distribution of these cracks is mostly from vertical or inclined to horizontal. Additionally, the cracks induced by the collapse or deformation of burrower-activity-forming holes have some specific features. Specifically, these cracks are irregular in shape, large in scale, short in formation time, and rapid in evolution.

3.1.3 Soil cracks caused by geological processes

Soil cracks, characterized by different mechanical properties, can also be caused by geological processes of internal or external forces. The external geologic processes, for example, include hydrogeological processes, landslide, and karst collapse processes. The tension joints and shear joints of rock masses in geology, taken as an example of soil crack here, are featured by that the size of a single joint varies greatly [1]. The karst collapse may lead to surface subsidence and soil cracks. These soil cracks are distributed in rings around the collapse center and inclined toward the center of collapse. And the scale of these cracks is consistent with that of the karst collapse body [64]. Additionally, subsurface erosion and dissolution may occur in soil induced by groundwater flow, which can produce small and irregular holes and piping channels [65].

Soil cracks induced by the regional crustal movement are also widely distributed. For instance, large ground fractures are common in northwest China. Soil cracks caused by such geological processes are usually distributed in regular spaces. This type of soil cracks normally extends to hundreds or even thousands of meters in space, and both depth and width of these cracks can reach tens of meters [66–68]. Soil cracks induced by earthquakes also have a large scale impact. These cracks, featured by obvious shear, compression, or tensile forces, can cut different layers of rock and extend to the deep rock [69]. General characteristics of soil cracks caused by different geological processes can be summarized as follows.

3.1.3.1 Cracks caused by hydrogeological processes

The length of cracks is from several centimeters to several meters. The crack distribution direction is consistent with

the movement direction of groundwater. These cracks can be divided into two kinds: one is caused by corrosion and the other is caused by dissolution. Compared with the latter one, the former is larger in size, more irregular in shape, weaker in the spatial distribution pattern.

3.1.3.2 Cracks caused by landslide effects

The crack length scale varies greatly. The cracks distributed in landslide body and edge zone have different mechanical properties of extrusion, tension or shear. Direction of the crack extension may be parallel, vertical, or oblique to the landslide slip direction. For the cracks in one landslide, their size varies greatly, and their evolution period depends on landslide movement and stability law.

3.1.3.3 Cracks caused by karst collapse

The crack lengths are different in size. The cracks are circularly distributed around the central point of the collapse. The cracks normally are inclined to the collapse center. The spatial distribution of cracks is parallel to the karst subsidence area. From the perspective of the mechanical properties, the cracks mainly include extrusion cracks and tensile cracks. The evolution periods of these cracks depend on the activity routines of karst collapse.

3.1.3.4 Cracks caused by natural and man-made earthquakes

The crack length scale is overall large. The cracks distributed in the area affected by seismic activity mainly are extrusion cracks, tension cracks, or shear cracks. The crack scale varies greatly. The cracks in different sizes exist simultaneously in the same location. The crack evolution cycle is short. The crack surfaces are generally straight and regular.

3.1.3.5 Cracks caused by ground fracture

The length of cracks is from hundreds of meters to thousands of meters. The cracks are distributed in the active area of ground stress. The cracks are characterized by large scale, deep depth, and long extension. Additionally, the crack evolution cycle is long.

3.2 Soil cracks caused by HE

Soils can be affected by industry, agriculture, and other human activities such as the underground mining, the underground construction, and large-scale groundwater extraction [70,71]. Some pictures of soil cracks caused by various NE processes are listed in Table 3. Such activities may induce physical deformation of surface soil and generate cracks. The characteristics of these soil cracks are similar to that of soil cracks caused by natural processes (e.g., karst collapse, ground fracture, and earthquake) [72,73]. However, to some extent, the characteristics of the spatial distribution and the mechanical property evolution of these soil cracks are unique, which will be addressed in the following.

3.2.1 Soil cracks caused by underground mining

Engineering practice may cause mechanical deformation of soil and induce cracks in soil. These cracks can be divided into two categories: one is directly caused by surface subsidence in mining areas and the other is caused by the surface soil deformation in the periphery of the mining area after the groundwater recession [74,75].

Underground solid mineral exploitation is usually conducted in different phases following a certain engineering design, resulting in a certain space-time evolution characteristics of surface land deformation above the underground mining site. Specifically, while the mining range of underground mineral resources keeps changing, the corresponding surface soil goes through a complete cycle of “cracking–closing.” In particular, the generated cracks can close during the collapse process [76]. However, some of such closed cracks can still serve as preferential flow paths due to the relatively high permeability of those cracks as compared to the surrounding soil matrix. Some studies indicate that, during the underground mining, the evolution period of cracks in surface soil is relatively short. However, after the crack is formed, the cracks immediately impose an influence on the transport processes of sediment and soil nutrients with the aid of preferential water flow [15,63]. Soil reconstruction can occur because the water-loaded sands can fill the cracks; the sand-filled cracks in the reconstructed soil can still be considered as the preferred flow channels, which has a lasting impact on the soil hydrological process in the region.

General characteristics of soil cracks caused by underground mining can be summarized as follows. The length of cracks is mainly from tens of meters to hundreds of meters.

Table 3: Pictures of soil cracks caused by different HE

No.	Genesis type	Distribution range and area	Pictures	No.	Genesis type	Distribution range and area	Pictures
1	Underground solid mining	Zones above and around the goaf		2	Opencast mining and foundation pit engineering	Edge of open stops
3	Underground structure engineering	Surface and boundary of the engineering area		4	Surface engineering construction	Surface boundary of the engineering area

The cracks distribute along the subsidence and approximately parallel to the surface. Scale of the cracks is featured by large surface openings and large cutting depth. Additionally, the extension of a single crack is long, and the large tensile cracks perpendicular to the surface are dominant. The cracks generally develop within the whole unsaturated zone above the groundwater level. The crack formation periods are related to underground mining speed. Additionally, with the rapid development of mining, new cracks are formed and the previous cracks can be quickly closed.

3.2.2 Soil cracks caused by opencast mining and foundation pit

There exist two forms of damage to the surface soils induced by open-pit mining and foundation pit of large surface construction projects, and these two damage forms have similar features. Such two forms of soil deformation (or damage) include uneven settlement of soil and weakened confining of local soils. These cracks are mainly distributed in the peripheral zones of mining or construction sites, and the soil cracks show a steplike distribution around the center of mining or construction sites. The large cracks tilt slightly to the center of mining or construction sites. The combined forces of groundwater seepage and gravity can lead to soil deformation, resulting in an elevation-dependent crack distribution pattern. The preferential flow formed in surface soil cracks is nonplanar spatially [21]. Additionally, cracks produced by such engineering processes can be classified into two categories, one is compressional shear cracks, and the other is tensile cracks. Taking the deformation soil, for example, along the direction of soil motion, the front part of the soil body is dominated by the compressive shear cracks, whereas the rear part is dominated by the tensile cracks. To slowdown or avoid soil movement, soil reinforcement and antimovement techniques are normally implemented in the foundation pit construction processes [77], making the soil cracks caused by the foundation pit usually much weaker than those caused by open-pit mining.

General characteristics of soil cracks caused by opencast mining and foundation pit can be summarized as follows. The length of cracks are mainly from tens of meters to hundreds of meters. Geneses and distribution characteristics of the cracks are similar to that of cracks induced by landslides. The cracks are normally distributed parallel along the boundary of the mining pit. The crack formation period is affected by the mining scale,

the mining duration, and the physical and mechanical properties of soil. In the early stage of mining, the surface soil cracks are dominated by the tensile cracks formed by the instability of the slope, and the widths of these cracks are large. These cracks can close after a long time of stabilization. Hence, the cracks have a long evolutionary period.

3.2.3 Soil cracks caused by other underground and surface engineering

Compared with the engineering practice mentioned above, surface soil deformation and soil cracks can also be produced by some other engineering practices such as the construction of urban subway, tunnels and spillway, and so on [78–80]. However, the overall scale of such engineering practices is small, and the soil deformation is monitored closely and controlled strictly. Therefore, the scale of soil cracks induced by such engineering practices is relatively small compared with that of soil cracks caused by open-pit mining or foundation pit. The detailed characteristics of such soil cracks can be summarized as follows.

3.2.3.1 Cracks caused by underground engineering

The mechanical properties and spatial distribution of the cracks are similar to surface soil cracks induced by underground mining. The length of cracks is from several meters to tens of meters. The cracks distribute along the subsidence area and its edge zone, and the main cracks are approximately parallel to the engineering boundary line. Every large single crack normally has many small cracks on its both sides. The evolution of cracks evolves with the engineering period, and these cracks can be closed finally.

3.2.3.2 Cracks caused by surface engineering

The mechanical properties and spatial distribution of the cracks are similar to surface soil cracks induced by opencast mining. The soil cracks distributed along the boundary of slope or foundation pit. The scale of the soil crack is affected by the engineering scale and the physical and mechanical properties of soil. The soil cracks form fast, and the period of the cracks is affected by the engineering scale and the construction technology. The cracks generally

become closed and stable after a long time, and the cracks usually have a long evolutionary cycle.

The types of human activity are diverse, but soil cracks caused by human activity all have similar features that can be summarized as follows. First, the distribution range of cracks is clearly visible. Second, the cracks have certain identifiable mechanical properties. Third, the formation and evolution periods of cracks are predictable. Additionally, the distribution of cracks is closely related to the layout and scale of engineering practice. Specifically, the soil cracks are mainly developed in the zones above and around the underground engineering. And the soil cracks are mainly distributed in parallel bands or concentric circles with certain regularity.

4 Discussion

Most of the previous studies focused on one certain type of soil cracks, and the systematical study of genetic types of soil cracks is rarely carried out [24–42]. The generation mechanisms and driving factors of soil cracks caused by different genes affect soil cracks variously. Two major types of soil cracks are proposed in this study: one is the cracks caused by NE and the other is the cracks caused by human activity. The discussion about the soil cracks will be expanded on the following points:

- (1) Comparing the cracks induced by these two types, there exist some similar or identical characteristics between them. Two sub-subtypes of soil cracks are taken as an example here: one is the cracks induced by the karts collapse or landslide and the other is the cracks induced by the mining or foundation pit. Both types of cracks are characterized by different mechanical properties formed by direct damage of soil structure caused by external forces. Therefore, the soil cracks induced by different genes may have common features.
- (2) Engineering practices can directly cause the damage of soil and form various soil cracks and also affect the change of soil moisture, which indirectly affects the formation of cracks. The rate of soil water loss can be obviously accelerated by the surface soil cracks. Hence, in areas with intensive human activities, soil cracks completely formed by natural factors are rarely seen, but soil cracks caused by both natural and man-made factors should be integrated into one genetic type.
- (3) In terms of evolution of formed crack, apart from the fact that the soil structure is damaged and large soil cracks are formed in a short time due to the

earthquake and large landslide, the time required for generating soil cracks by other natural factors is relatively long. The depth and width of a single crack are generally small and vary with the change of soil environment such as water content. Additionally, the distribution area of soil cracks caused by natural environmental effects is relatively stable after formation, whereas soil cracks formed by engineering practices are likely to change with the spatial progress of different phases of engineering practices.

- (4) According to the formation time and genetic mechanism of cracks, there are primary and secondary cracks caused by biotic process and geological process. For example, the cracks caused by plant root development and rodent activities can be deemed as the primary cracks. While the cracks caused by the root decay and the collapse of the rodent holes can be deemed as the secondary cracks caused by the biotic process. In the same way, the new cracks may be formed by soil deformation induced by the dissolution around the original dissolving gap. The original dissolving gap and the new cracks are the primary and secondary cracks, respectively.

In a word, some soil cracks are formed by the joint influence of multiple genes. In the future, the differences of physicochemical and mechanical properties of soil cracks with different genetic types can be studied based on quantitative analysis, and that will be of great significance to the study of soil cracks.

5 Conclusion

Based on the genes of soil cracks, two major types of soil cracks are proposed in this study: one is the cracks caused by NE and the other is the cracks caused by human activity. These two major types of soil cracks have been further divided into six subtypes and fourteen sub-subtypes, respectively. Then general characteristics of every sub-subtype soil crack are analyzed. However, the differences in formation, evolution, and physical and mechanical properties of different types of soil cracks need to be further studied.

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