Study on Damage Evolution of Defective Materials in Five-Dimensional Space

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Abstract: A large number of engineering practices show that many engineering-related materials, such as rock, concrete, structural soil, ceramics and so on, have initial damage, that is, defective materials, and their damage evolution seriously affects the safety of the project, and even causes engineering failure. Therefore, it is of great significance to protect the safety of related projects to study the damage evolution mechanism and law of defective materials. However, the damage evolution mechanism and law of defective materials are extremely complex, which is not only related to the geometric characteristics of damage distribution, but also depends on the stress environment. Therefore, on the basis of describing the initial damage characteristics of defects such as rock, concrete, structural soil and ceramics, this paper studies and discusses the damage evolution and damage complexity of defective materials, and explores the mechanism of damage evolution of defective materials in five-dimensional space, so as to provide theoretical basis for civil engineering, water conservancy, mining and other engineering design and disaster prevention.

Key words: Defective materials, damage evolution, five-dimensional space, mechanical behavior.

1. Scientific Connotation

In engineering or industrial design, the material is often regarded as a continuous medium, regardless of its structure or structural defects. In fact, the materials involved in civil engineering, water conservancy, mining and other industries, such as rock, concrete, structural soil, ceramics and so on, have obvious structural characteristics, and there are a large number of macro, fine and micro damage (cracks or holes) inside, which is regarded as initial damage. In this paper, this kind of material with structural characteristics and defect damage is called "defective material" [1].

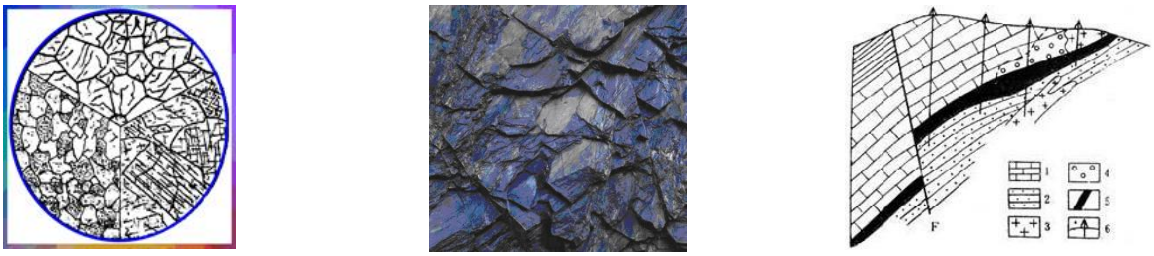
In fact, the initial damage distribution of defective materials is extremely complex, not only in three-dimensional distribution (integer dimension) in X, Y and Z directions, but also in fractal dimension (fractal dimension) in path, scaling law, space volume and so on. What is more complicated is that the deformation and even failure of defective materials is a process of continuous evolution and expansion of initial damage, and it has obvious time effect (T), that is, it evolves in X, Y, Z, T four-dimensional space. Through further in-depth study, it is found that the stress environment of defective materials involved in

civil engineering, water conservancy, mining and other projects has stages, such as tunnel excavation construction is carried out step by step. Each step of tunneling construction leads to the superposition of the surrounding rock involved by one step of force. Because this process can not be included in a certain dimension in the four-dimensional space of X, Y, Z and T, it is defined as five dimensions in this paper. That is, the F dimension of the acting force. In this paper, the complex process, mechanism and law of damage evolution, deformation and failure of defective materials will be studied in X, Y, Z, T, F five-dimensional space.

2. Structural Characteristics of Defective Materials

Rock, concrete, structural soil, ceramics and other materials have obvious multi-components (minerals, colloids, organic matter, pores, water, gas, etc.), multi-level (micro, meso, macro), polyphasic (solid, gas, liquid) and other structural characteristics, which determines that they are a complex composite medium, and they have complex structural forms due to various exogenous forces or preparation factors [2], [3].

For example, the rock has obvious crystal shape, habit, crystal size and crystal plane pattern (Fig. 1a). The rock mass is in a certain geological environment and is divided by rock layers, weak interlayers, faults, joints, fractures and other structural planes. (Fig. 1a-1b).



(a) Rock microstructure (b) Local rock mass (c) Geological structure map

Fig. 1. Microstructure and macrostructure of rock.

Concrete material is a kind of non-uniform multiphase medium. Due to forming technology, curing conditions and other reasons, there are a large number of randomly distributed cracks of various scales caused by dry shrinkage and condensation hardening, as well as all kinds of inclusions, bubbles and holes before the bearing of concrete members. At the same time, there are also artificial expansion joints, construction joints or cracks caused by loading [2]-[4] (Fig. 2).

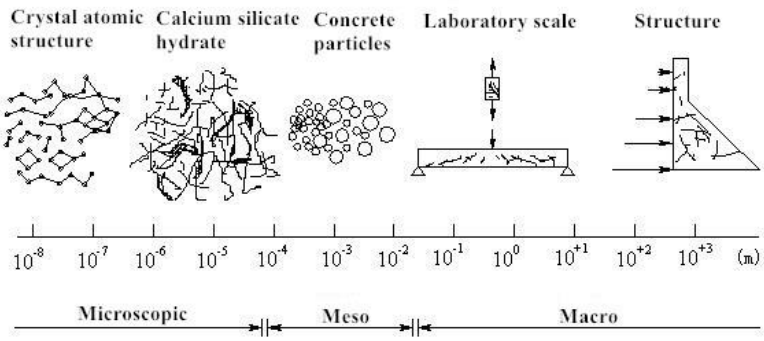


Fig. 2. Micro and macro structure of concrete.

In the process of soil formation, the spatial arrangement and connection form of soil particles are misplaced or interrupted, forming the so-called "structural soil" in this paper, in which the stratification and fissures, that is, bedding structure and fracture structure, result in the inhomogeneity of structural soil [4]-[6] (Fig. 3).

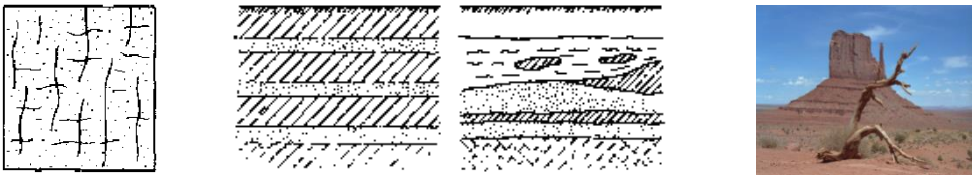


Fig. 3. Micro and macro structures of structural soil.

Ceramics are generally fired from powder raw materials, which are composed of many microcrystalline polycrystals, which inevitably exist grain boundaries, which make the actual strength of ceramics much lower than the theoretical value (1: 1000: 1: 100). There is a local separation or gap between grains on the grain boundary, and the atomic bond will break, resulting in cracks (Fig. 4).

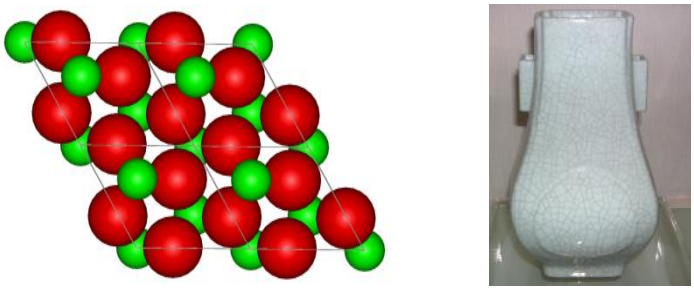


Fig. 4. Microstructure and macrostructure of ceramics.

To sum up, the defects of these materials are initial damage in physical sense, strength reduction in mechanical sense, material failure in engineering sense, and material failure goes through the whole process of deformation-fracture-contact-failure.

3. Five-Dimensional Space Problem of Damage Evolution of Defective Materials

The above analysis shows that the damage evolution process of defective materials depends not only on the initial damage distribution, but also on the stress environment in the later stage, and shows the cooperative characteristics of complexity evolving with time, and this process is obviously multi-dimensional [7]-[10].

Taking the initial damage in a rock test block as an example (Fig. 5), if only one point A in the damage area is discussed, it is geometrically a point with no size or dimension, and it is only a sign indicating the position. It exists in the uniaxial loading system of concrete test blocks.

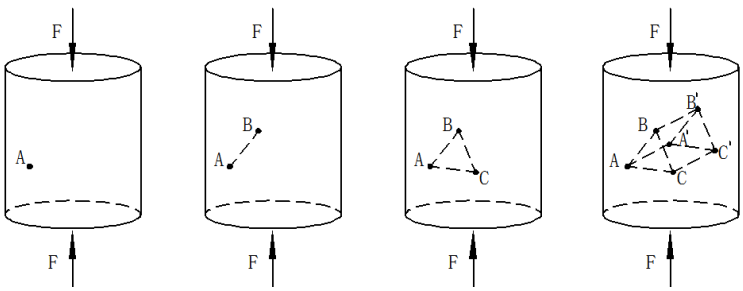


Fig. 5. Initial damage in a rock test block.

If the second point B in the damage area is selected, its single point feature is the same as above, which can be used to represent another location. However, if the two points A and B are connected, a finite size will be formed, that is, the length of the line between the two points, which is similar to a single crack without opening in the head-up view (or projection on the plane). This is the damage of the rock test piece

in one-dimensional space, and the two-point connection has a length LAB, but no width and depth.

If the third point C in the damage area is selected, its single point feature is still the same as above, and can also be used to represent the third location. However, if the two points A, B and C are connected into triangles in turn, a finite surface is formed, which has both length and width, which is similar to a single crack in a rock specimen with an opening in the head-up view (or projection on a plane). This is the damage of the rock specimen in two-dimensional space, and the crack has both length LAB, and width LBC (in this case, the maximum width), but there is no depth. In fact, the rock specimen, like everything in the world, is a three-dimensional object with length, width and height (or depth), and the damage in it also occupies the three-dimensional space, which is simplified to the ABCA'B'C'; in Fig. 5.

However, rock block damage is a process of continuous development and evolution over time. If the damage body is ABCA'B'C', at this moment and then it changes the next moment, That is $A_1B_1C_1A_1'B_1'C_1'$, If the damage at these two times is different along the timeline, it will damage $A_2B_2C_2A_2'B_2'C_2'$(Fig. 6), by analogy, this is the rock test block damage four-dimensional space;

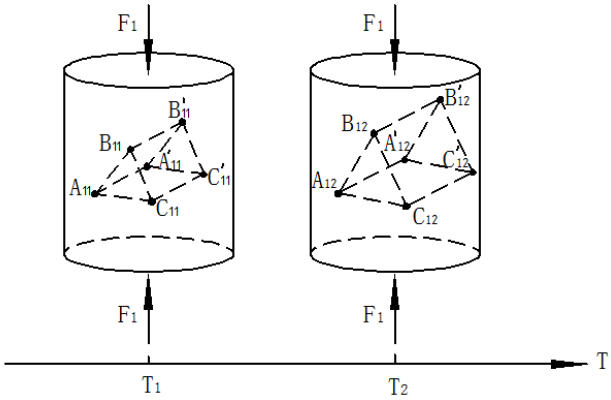


Fig. 6. Rock block damage.

What is more complicated is that in many projects, the stress environment of the defective materials involved is phased, for example, the tunnel excavation construction is carried out step by step, and each step of the tunneling construction leads to the superposition of the surrounding rock involved by one-step force. In order to simplify the explanation, taking the uniaxial loading of the rock test block as an example, the uniaxial pressure F is carried out step by step, and the damage inside the rock test piece not only evolves with the passage of time. And the evolution of each loading step is different, and continues to develop and evolve with the magnitude of loading force and loading speed, thus showing five-dimensional damage evolution, deformation and failure mechanism (Fig. 7).

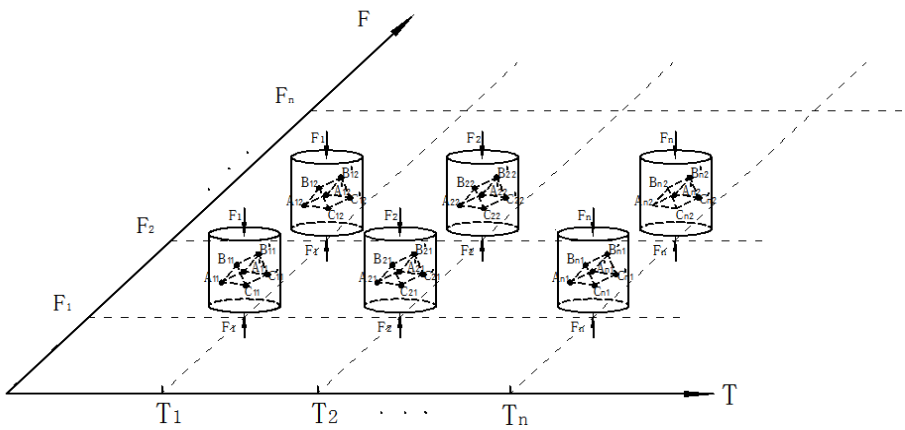


Fig. 7. Five-dimensional damage evolution.

4. Concluding

The damage evolution and deformation failure of defective materials is a kind of non-equilibrium and nonlinear evolution process, and it is a kind of collective effect of micro-damage structure, and it is very sensitive to the meso-structure configuration of materials. This makes the failure of defective materials a very complex phenomenon. In this paper, the dimensions of damage evolution and deformation and failure process of defective materials are excavated, and the five-dimensional space problem of damage evolution of defective materials is explored, which points out a new direction for the study of damage evolution and deformation and failure process of defective materials. Furthermore, it provides a theoretical basis for civil engineering, water conservancy, mining and other engineering design and disaster protection.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Guangming Yu, Huiyu Li, Qiong Qiu, Guanwen Liang, Yongyi Zhang, Jun Lei presided over the theoretical study, Guanwen Liang presided over the painting, and Yongyi Zhang presided over the later arrangement.

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