THE PRELIMINARY EXPLORATION OF UNDERGROUND ANT NESTS MATERIALS AND STRUCTURE

Zhou Wei[1] Qu Wenjun[1] Zhang Zhi[2]
(1 Department of Building Engineering, Tongji University, Shanghai 200092, China;
2. The High School Affiliated to Shanghai University, Shanghai 200444, China）

Abstract: An ant nest is a construction body with a complex structure. Natural underground ant nests generally have good air circulation, appropriate temperature and relative humidity, with trees and natural barriers around. Also, it has a good physical structure, pressure resistance, waterproofing, thermal insulation and moisture effect. The paper first introduced the history and status quo of researches on the material and structure of ant nests and summarized the trend and dynamic of the researches. And then the characteristics of the site selection of underground ant nests are investigated and the interactions among underground ant nests, soil and environment are elaborated from two aspects of behavior characteristics of selecting nest sites and environmental characteristics of ant nests. Finally, the natural underground ant nests are obtained in different geological conditions. The 3D simulation diagram of the internal structure of the nests is made by frozen CNC milling and computer synthesis for the observation of structure characteristics of natural underground ant nests. The structure characteristics of underground ant nests are used to preliminary study the bionic design of underground constructions, predict the application prospect of the structure of underground ant nests in civil engineering and propose the practical application value.

1 THE RESEARCH HISTORY AND STATUS QUO

The form and internal structure of natural underground ant nests may vary because of ants species and scales, different species of ants can build their own version of “mansions and villas” in different types and style. Complex underground ant nests systems feature large scale, and stable internal environment. They generally have good air circulation, appropriate temperature and relative humidity, with trees and natural barriers around. They also have a good physical structure, pressure resistance, waterproofing, thermal insulation and moisture effect. Natural underground ant nests generally are structured with a main nest chambers and many channels linked chambers, extending outward forming a nest- center network system(Li Dong 1992).

Records about ants document a long history, but even now the research of underground ant nests material and structure domestic and foreign is still lacking. So far, a few biologists have simulated ant nest structural models of different species by pouring dental plaster into the nests(Walter R.Tschinkel 2003), but no systematic study has done against ant nests material and structure. Currently, major ant research is directed to ants’ medicinal properties, surface fungi, nutrition ingredient analysis, social division of labor, ants’ performance management and ant colony optimization(Tang Jue et al.1995). The research directions that are related to our civil engineering would be: ant colony optimization for the optimized design(A.Colorni et al.1992) of civil engineering structure; research on structure of ant-nest system in dam-body and their strength and stability(Gao JiaCheng and Gan Xinmin 2003); architectural bionics research on termite nests(Gao Fuju and Liu Xiliang 2001) and the effect on the properties of cement and concrete by calcimining the termites’ clay(A.U. Elinwa 2006). Being one of the most common insects, little research has been toward ant nests, especially toward structural engineering. We all admit that ants are great architects of the animal kingdom, with unique structure, appropriate temperature and humidity control function, ants do build themselves a warm and comfortable “home”. The secrets of nature are waiting for us to explore, so about the ants’ “home”, what is the structure of the home, and what kind of building materials are they made of, and what about the mechanical characteristic, what kind

of inspiration do they give us on our projects in real life and what can be applied to the civil engineering field? All these series of questions are waiting to be solved by us structural engineers.

2 UNDERGROUND ANT NESTS INTERACT WITH THE SOIL ENVIRONMENT

Through building nest process, ants dig the deeper soil up to the top and loose soil, and they function better than the earth worms in tropical areas. Ants carry the plant seeds, leaves and animal residues into the nest, and fully blend the organic matter with the soil, which increase the soil content of carbon, nitrogen, phosphorus and other elements; the PH value between the nest soil and the surrounding soil are noticeably different(Wu Jian and Wang Changlu 1995). So, the soil is the important carrier for ants living activities, and all kinds of ants' behavior activities have also greatly influenced the soil environment, or even change the physicochemical property of soil environment. We take the iridomyrmex anceps which are commonly seen in Shanghai area as an example, and investigate the underground nests location choice and the characteristics of the external structure of the nests entrances, and analyze the characteristic of the ant nests external relations with soil and environment. Iridomyrmex anceps belong to the iridomyrmex category: they spread out in China Shanghai, Zhejiang, Fujian, Guangdong and other places. Worker ants are 3.5~4.5mm long, the head, chest and abdomen are dark brown. They normally build their nests upon the tree trunks, outside tree roots and foraging inside houses. Their scent gland can give out stinky smell, and they will bite if startled. They prefer sweet food, meat, cereal, insects, etc.

2.1 Features of underground ant nests site selection

From observing the ant nests entrances around Shanghai Tongji University campus green belts and along the small streams, we found that iridomyrmex anceps nests entrances mostly distributed around moist areas in the grass that are relatively sparse; and 10-30cm away from tree roots, and about 1cm fall head with the surrounding topsoil. Obvious anthills can be spied around the entrances and exits. The gateway is normally 2-3mm in diameter with covered by material such as plant leaves and stems. In the environment of outdoor temperature 26 ℃ and the relative humidity of atmosphere 55%, we measured the quantity per square meter, the diameter and the 1cm surrounding environmental temperature and relative humidity of the nests entrances and exits. (Table 1)

Table 1 Iridomyrmex anceps ant nests entrances and exits observation record chart

Location	Entrance quantities per square meter		Diameters of the entrances and exits (mm)		Entrances and exits temperature (℃)		Entrances and exits relative humidity (	
	Value of number	Average value	Value of number	Average value	Value of number	Average value	Value of number	Average value
River bank	6	8	2.7	2.7	25.2	25.4	61	63.2
	5		3.2		25.1		63	
	7		2.6		25.6		64	
	10		2.5		25.4		58	
	8		2.8		25.8		68	
	11		2.5		25.5		65	
Green belt	7	6	2.5	16.6	24.3	24.5	57	55.1
	5		2.7		24.8		55	
	5		3.3		24.6		54	
	8		2.6		24.2		55	
	7		2.6		24.6		55	
	6		2.9		24.7		55	

Through investigation we found that the location features are: first, high relative humidity surrounding, more sparse grass, the less human activities the more ant nests; second, the entrances and exits are generally slightly higher than the topsoil about 1-2cm, to prevent the rain water intrusion; third, the entrances and exits are small and hidden for protection of being discovered by natural enemies and attacked; four, reply on the natural formation of structure such as cracks and small holes for their entrances and exits. Therefore, hidden degrees, soil moisture, nesting materials in soil (such as little rocks, tree branches, litter and soil hole, etc) to be used, soil temperature and useable food resources are all factors(B.Braschler and B. Baur. 2003)to determine the selection for underground ant nests locations.

2.2 Underground ant nests environmental catachrestic

Ants can mix their saliva or feces with soil and sawdust and build their nests underground, up at the surface or upon vegetation. The main aspects of ant nests environment are temperature, humidity and CO_2 concentration. Internal temperature of the underground nests is relatively stable, inner climate is similar to the environment for a simpler structured nest, complex structured nests can adjust the internal temperature. Internal temperature can be adjusted by building nests in a lower shade, thicker outside walls for the nests, keeping hay around or reserving space, and ventilating through the entrances, exits and the cracks on the nests. Ants nest activities decrease the anthill soil bulk density, reduce the water content(Yu Xiaojun et al 2010)of anthills (the inside of the nest must be maintained to a certain humidity level). To maintain the required humidity, the ants can dig channels to the water recourses, use building materials that absorb moisture, use metabolic water. In the soil, the ants' breathing and nesting activities can produce CO_2 , (the internal CO_2 concentration is between 1%-4%) and the nest internal CO_2 concentration can also be adjusted through air flow and by their own activities.

2.3 The influence of underground nests on the soil environment

Ant species and activity characteristics are diverse, and the interaction between the soil environment and its mechanism is complicated. Underground nests influence on soil environment mainly focuses on the soil water content, PH value and soil chemical properties. Fomica cunicularia's nesting sand hill behavior has influence on different slope topography soil. The results show that formica cunicularia nesting sand hill changes the soil properties, raises soil moisture content, lows PH value, raises conductivity, and increases the content of organic matter and total nitrogen(Liu Rentao et al. 2009). Wagner found that compared with the soil outside the nest, the harvester ant nests soil nutrients of nitrate, ammonia, phosphorus and potassium content is significantly higher than the outside soil; but no much change was observed to calcium and magnesium ion concentration and soil water content; PH value decreases, the nest soil is meta-acid compared with the outside nest soil sample(Wagner D et al. 1997). Jan Frouz found that the rapid available phosphorus, rapid available calcium and all carbon content in lasius niger linnaeus nest soil is significantly higher than the soil outside the nest; the PH value in the nest is higher compared with the outside nest soil, but lower than the alkali soil outside the nest(Jan Frouz et al. 2003). Underground ant nests can improve the soil chemical properties in certain ways, by abandoning their leftovers and uric acid and feces in the soil, it increases the soil organic matter and total nitrogen content, compared with the soil with no ant nests, the soil content of organic matter, P,N and K are all increasing, these differences in poor soil is particularly prominent, and the degree of changes is related to the size of the ant colony, biomass and soil flipping amount(Chen Yingwu et al. 2007).

3 UNDERGROUND ANT NESTS MATERIALS

3.1 underground ant nests material collecting

Iridomyrmex anceps are commonly seen ants in Shanghai area, their activities have seasonal effect, generally during October to April, ants rarely go out of the nest foraging, and it is hard to find any trace of ants, but during June to September, it is the peak season for ant activities. During the peak activity season, we tract their moving path, look for the location of the nest gateways, and observe the outside structural characteristic of the gateways. During the site acquisition, we first determine the nest strike, dig

down vertical 30-50cm from the furthest gateway, then cut down the sand layer by layer in 1cm horizontal layer thickness; based on the nest strike, observe, measure, record the inside nest structure, including the strike, diameter, shape and depth of the major channels and minor channels, also size and depth of the minor chambers at each level. First look for ant nest entrances with stable life order, then determine the size of the nest structure. Digging out 40cm×40cm×40cm size of clod from different soil conditions(green belts, river bank, etc.)(photo 1, 2)

Photo 1: the entrances and exits of a stable life ordered ant nest

Photo 2: Size of the underground ant nest soil block sample

3.2 Characteristics of underground ant nests materials

Through field investigation, iridomyrmex anceps prefer warm and moist soil environment for their nests, the nests material has a large water content. Lay two same sized clods with and without the ant nest inside for a month at room temperature, water content changed slightly lower for the clod contains the nest, but there showed noticeable dropping of the water content for the clod that does not contain the nest.

Oven drying method is used to determine the soil water content, drill 0-20cm soil sample from 3.5mm diameter soil, dry the sample under the condition of 105 °C, repeat 6 times; Cutting ring-method is used to measure the soil capacity between the nest soil and 0-20cm depth soil 1m away from the nest, repeat 6 times; sieve the nest soil with the soil sieve and then weigh the separated withered plant bodies, and measure the volume with the measuring cylinder drainage method. Through the experiment we found that the nest soil water content is lower than the soil nearby the nest, which means the ant nest activities reduce the nest soil water content. Compared with the adjacent soil, the ant nest soil bulk density decreased by about 50%, the withered plant bodies and the soil weight are 0.068 and 0.169g/cm^3,the volume ratio is 5:1.

4 UNDERGROUND ANT NESTS STRUCTURE

4.1 Underground ant nests frozen CNC milling experiments

Pack the dug out ant nest clay with carton and then quickly put it into the freezer, fast freeze it with the temperature of -18 °C. Take it out f
with the CNC machine immediately, and make the ant nest entrance as the center reference point, and photo record all the locations of channels and chambers on the cross section. (photo 3,4)

Photo 3: Transverse cutting diagram of Numerically controlled machine tools

Photo 4: Cameras locating frozen soil cross-section diagram

4.2 The experimental results and analysis

Through the site acquisition and the frozen CNC milling experiment we found that, on the surface of the size 40cm×40cm clay, there are about 3 to 5 ant entrances with a diameter range from 4mm to 2mm. Branches appear 2 to 4cm below the surface, and the branch channels are ablate shape and slant down. Horizontal extended chambers can be seen as going down the channels at different depths, chambers are connected by winding and turning channels; the chambers vary from different sizes and irregular shapes, and the inner walls are firm and smooth; the chambers at the very bottom of the channels are relatively bigger, ant bodies and trails of food can be observed in the chambers. Through cross cutting the six ant nests, we found that there are generally 3 levels through the vertical direction: level one is 2-10cm below the surface; layer two is 10~20cm below the surface; level three is 20cm below the surface. There are multiple channels and chambers at each level, the chambers are 2-4cm long , 3-2cm wide , and 1 2cm tall. (photo 5,6)

Photo 5: Ant nest internal structure the frozen of the ant nest interior cutaway view

Photo 6: Computer simulation of a cross- soil section

This shows that the underground ant nests are very complicated and unique structured, they are waterproof and thermal insulation, also functional to meet all demands like storage, conservation and cleaning, etc. The nest of iridomyrmex anceps is structured much simpler compared to other larger nests, although the depth of the nests, the chambers and the complexity of the underground channels may vary because changes of the temperature, humidity or the size of the group, the longitudinal depth is generally no more than 50cm, and the horizontal expending range is relatively small. There are normally several to dozens of chambers, random scattered in the soil of different depth, the chambers and the inner walls of

the channels are smooth and firm. And we generally believe that ants mixed their saliva and other secretions into the building materials when they build their chambers and inner walls of the channels, so that the nests structures would be more solid and also they will reduce the damage from the rain.

5 UNDERGROUND ANT NESTS BIONICS DESIGN

The role of bionics in Architecture design has attracted widespread attention; the performance and application of architectural bionics methods include five aspects: form bionic, structure bionic, function bionic, material bionic and construction bionic. Underground ant nests structure has significant characteristics in these five aspects of bionic design.

From the angle of form bionic, ant nests structure has made a reversal tree shaped underground space through their own channels and chambers. The channels stretch horizontally and lengthways through certain patterns, any chambers can be reached through the channels, and all chambers function different ways but also supplement each other, this associates that the ant nests structure can be applied to human underground shopping malls or museums and other public buildings. From the angle of structure bionic, ant nests structure has excellent mechanical properties, the gateway has antiknock, water resistance, impact resistance, etc, and the chambers of all levels can resist the soil pressure evenly, so it can be applied to projects like human air-defense, garbage and nuclear waste disposal. From the angle of function bionic, underground nests have the characteristics of constant temperature, constant humidity and good air circulation; these can be applied to the exploration of underground living facilities. From the angle of material bionic, after calcinations the underground nest soil material shows similar function as coal ash, and this can be used for experimental study on modified concrete. From the angle of construction bionic, the ants can establish a complete system of complex nests, and undertake such a huge engineering construction, also the well orderly construction procedures offer us a very good reference for our construction procedure.

6 CONCLUSION AND PROSPECT

Take iridomyrmex anceps as am example, this paper preliminary discusses the interaction between the underground ant nests and the soil and environment, and summarizes the basic characteristics of the underground ant nests materials and structure, explores the potential value of science and engineering for underground ant nests materials and structure, and lays the foundation for promoting the application of ant nests materials and structure. Through the research we found:

(1) Iridomyrmex anceps prefer to nest the ambient that is high relative humidity, and sparse grass and less human activities, the entrances and exits are rather small and hidden, generally slightly higher than the topsoil around 1~2cm, and they reply on some of the natural formation of the structure such as cracks and small holes as the entrances and exits.

(2)Temperature inside the underground ant nests is relatively stable, the interior microclimate of a simpler structured ant nest is similar to the surrounding environment, complex ant nests can adjust the interior temperature by itself, and inside the ant nests certain humidity must be maintained.

(3)The nest soil water content is lower than the soil nearby the nest, which means the ant nest activities reduce the nest soil water content.

(4)Through frozen CNC milling and computer synthesis method we are able to make a 3D simulated image of the interior structure of the ant nests, and we found out that the underground ant nests are very complicated and unique structured, they are waterproof and thermal insulation, also functional to meet all demands like storage, conservation and cleaning, etc.

(5)Form bionic, structure bionic, function bionic, material bionic and construction bionic, underground ant nests structure has significant characteristics in these five aspects of bionic design.

We can expect that the underground ant nests material and structure have extraordinary performances, this whole new material structure can be applied to civil engineering related fields. The nest step for this topic would be:

(1)Determine the natural porosity, plasticity and liquidity index and the osmotic coefficient of the ant nests soil, complete the ant nest soil property analysis, and determine the properties of the soil.

(2)Through the triaxial shear test of the ant nest soil, the normal soil without the ant nest and the saturated soil we get the internal friction angle(φ) and the cohesion(c); under the condition of non lateral confinement, give axial compressive force on the ant nest soil till the sample broke down, to determine the non lateral confinement compressive strength(q_u) of the soil; combined with compression modulus E_s, $a_{1\text{-}2}$ compression coefficient index, we sum up the geotechnical engineering properties of the ant nest soil.

(3)Using SEM scanning electronic microscope to observe and analyze the ant nests material surface morphology, determine the ant nests soil mineral composition through XRD atlas analysis and ultrasonic testing, through thermo gravimetric analysis to study the thermal stability and components of the ant nests material, separate sampling the fragment material of the ant nest ektexine of passageway and ektexine of cell and proceed microanalysis, summarize the material properties of the ant nests soil.

(4)Calcinate the ant nests material and blend in the after calcination product in concrete block following certain proportion, and study the strength and durability of the concrete block, to determine the after calcination ant nests soil production property.

We hope to put forward a variety of questions related to civil engineering with underground ant nest material and structure, and develop a civil engineering branch field of underground ant nests material and structure, guide the scientific technicians to do deeper research about the related questions but not referred here in this topic.

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