Underground grain storage engineering

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Abstract
This article discusses the project of underground grain storage in China. This project is characterized by low-temperature, damp-proof, antiseptic, moth-proof, mould-proof, quake-proof, which is against natural calamities. It is important in preserving environment, saving land, developing and using resources, and storing grain scientifically. It has good social, environmental and economic benefit. It is one of the outstanding storage facilities in China. It is worth using for reference by grain scientific workers home and abroad.

Introduction
'Food is the first necessity for the people.' Grain is the essential consumer goods for human beings, and basis of social existence and development. It is the key part of the base of economic development, which plays a special and important role. Therefore, grain researchers from different countries try to work out advanced scientific grain storing techniques and facilities.

For decades, a great number of successful ground storage such as granary with horn shape, granary with house shape, and grain storage silo have been put into use after continual hard work of practice, research and innovation by grain researchers in China. This paper studies underground grain storage engineering, a kind of new facility that was put into use, learned from Chinese ancient storage technique in special historical setting. It is really helpful to solve the problems of worsening environmental condition, limited farmland and natural resources. The fruitful achievements on this field will, practically and theoretically, improve grain reserve condition.

History of Underground Grain Storage

Ancient underground storage
China is well known for its long history and ancient civilization, and so with the underground storage. It is recorded in the historical documents that Chinese learned how to store grain under the ground with the help of natural low temperature in the Age of Yangsao Culture of primitive society 5000 – 6000 years ago. For the underdeveloped cultivating condition and productivity, the quantity of storage is quite limited. Underground cellar with small top and wider bottom was used at that time, the way of which was simple, economic and effective.

A larger group of underground grain reserves facilities were unearthed in the west suburb of Luoyang in Henan Province, which had been built since Han Dynasty. One square bin is 3.44 meters long, 3.1 meters wide and 1.4 meters high. The diameter of another round one is 3.6 meters that is 1.2 meters high. The largest one found so far is Hanjia Granary in Luoyang City, constructed in the throne of Suyang Emperor. It is 612 meters across from east to west, 750 meters across from south to north, and about 450,000 square meters. The total volume is capable to store about 125,000 tons, which is one of the largest official grain granaries in Sui and Tang Dynasties. One of the Hanjia granaries excavated in 1969 is filled with black carbonized grain. According to the data in historical relics, the diameters of those granaries count from 8 to 15 meters with the height from 6 to 10 meters. The total storage capacity is over 58 ls. As far as the construction and grain reserving measures are concerned, the raw clay of the wall, condensed and baked, is in brick-red with board, covered by board, grain chaff and reed mats. When the bin is filled, the top is covered by grain chaff and reed mats, then sealed with plaster, and finally again covered by thick soil. It is rare throughout the world to underground grain storage on that large scale, to which low-temperature is applied, and to work on grain reserve and put it into use in ancient times. The discovery of ancient technique is helpful for us to study underground storage facility.

Development of the study on underground storage
The study on this topic began in 1960s. The first seminar related to underground storage technique was held by former Grain Ministry in Sanmenxia City, Henan Province in 1965. Various kinds of underground storage bins such as horizontal silo, vertical silo, granary with horn shape, with double-curved arch shape, and so on, have ever since been built, funded on the special purpose of studying and trial construction, after years of hard work. Over years of
application and testing, the second seminar concerned to underground granary construction technique was held by Commercial Ministry in Henan Province in 1970s. Experts from many provinces and cities were present this seminar. Underground granary with horn shape cited in Henan province was considered as the best one, and should be popularized. Underground granary was then popularized in many provinces in China, its location was selected more reasonably to overcome the disadvantage of low utilization ratio of those granary built before. Mechanized and automatic facilities of intake and outtake grain were adopted in construction. The cone-shape bottom replaced flat one for automation grain discharge. Handcarts were replaced with trucks or trains for grain loading and unloading operation, saving the labor force and increasing availability of the granary in underground stone granary. A large number of underground bins were built with the encouragement of our admistration known as 'Deeper caves dug, and more grain stored.' Based on the improvement of the study and application on underground grain storage, National Underground Granary Management Experience-exchangung Conference was held by Commerce Ministry in Liaoning Province in 1984. The operation and management of experience was summarized, many scientific data on underground grain reserving were available, and underground grain storage techniques were future developed. The underground grain storage facility with Chinese characters therefore came into being, reserving a lot of grain in China and with high benefits.

Success in Underground Grain Storage

Outstanding low-temperature effect

As grain is something living, if it is stored under 15°C, some destructive insects and microorganisms can no longer exist, grow or reproduce, and grain itself declines and even is quite weak in breath than under regular temperature. So the nutrient substances in grain slows the loss of catabolism. Grain stored under low temperature is safe. Grain reserved with the temperature lower than 20°C, quasi-low temperature, can achieve similar effect as mentioned above.

How to lower the temperature? There are two ways: the first is natural low temperature, the other is artificially lowered temperature, which by using refrigerating machines or air-conditioners to realize ventilation and cooling. However, low-temperature of underground storage can be achieved naturally or almost naturally. According to the data of the study on underground grain storage, there are differences in temperature changing. The temperature of grain in ground storage is affected by that of the granary which is influenced by air temperature; while the temperature of the grain in underground storage is influenced by that of the granary which by that of ground that is affected by air temperature. Moreover, since ground is good at heat insulation, temperature variation is in reverse proportion to the depth of strata; the lower the stratum is, the more stable the temperature will be. The temperature about 16 meters underground called invariant ground-temperature strata, the annual range of temperature fluctuation is 0.1°C only. The actual temperature of strata with invariant temperature is different with the variation in latitude and soil property. It is low in high-latitude north China, and high in low-latitude south, seeing table 1.

From this table, low temperature in underground granary is suitable for high and middle latitude regions in China, since the constant temperature in underground granary in low latitude is comparatively high. However, with the development of science and technology, the expense of cooling the underground granary dynamically is much lower than that of refrigerating the ground granary, for the constant temperature in the underground granary is considered as the value when cooling with the highest temperature not more than 20°C.

Good damp-proof effect

Grain storage is affected by moisture. The waterproof and damp-proof structure plays an essential role in moisture of underground granary. If the granary is in good airtight and damp-proof condition, it is basically in constant humidity condition. Since the underground granary is located inside soil, it is in good airtight condition if the door of the granary is constructed scientifically. This problem can be solved in China. Those underground bins rebuilt from civil air-defense shelters with airtight doors of better quality provide a better airtight condition.

The treatment on drainage, waterproof and damp-proof plays an essential role in underground granary construction. Reliable measures should be taken, such as building filtering wall, side ditch, fence drain, main ditch and water draining appliance to drain off water which entered from rock cracks and soil. Flexible and rigid waterproof and damp-proof treatments are effective. With the development technology for water and damp-proof materials, the popularization of underground storage facility becomes more and more promising in recent years. New flexible water-proof materials is better than old ones at anti-permeation, adhesion of base course, remaining stable when the temperature changing, and anti-aging, which does not flow when temperature grows high or does not crack when it becomes low. With the technology improvement on new material, waterproof and damp-proof treatment became more convenient, effective and reasonable.

The grain quality stored in underground bins is directly related to relative humidity. If the humidity of the granary grows too high, the whole ecosystem will speed up its
metabolism, which can result in grain heating, worms and mould. If the humidity is too low, the grain will suffer water loss, quicker aging, which can influence the quality of the grain and cause the difficulty of its processing. Therefore, successful water and damp control with low temperature solves the key problem in safe underground grain storage.

Table 1. Latitude and underground granary constant temperature in seventeen cities and counties in China.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Temperature°C</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hainan (center part)</td>
<td>19°</td>
<td>29</td>
<td>Regular temperature</td>
</tr>
<tr>
<td>Nanling, Guangxi</td>
<td>22°</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Fuzhou, Fujian</td>
<td>26°</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Cangnan, Zhejiang</td>
<td>27°</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Dongtou, Zhejiang</td>
<td>27°</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Chongqing, Sichuan</td>
<td>29°</td>
<td>19</td>
<td>Quasi-low temperature</td>
</tr>
<tr>
<td>Xiangshan, Zhejiang</td>
<td>29°</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Zhenhai, Zhejiang</td>
<td>29°</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Daishan, Zhejiang</td>
<td>30°</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Hangzhou, Zhejiang</td>
<td>30°</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Shengsi, Zhejiang</td>
<td>30°</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Songjiang, Shanghai</td>
<td>31°</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Lianyangang, Jiangsu</td>
<td>34°</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Yantai, Shandong</td>
<td>37°</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Changdao, Shandong</td>
<td>37°</td>
<td>14</td>
<td>Low temperature</td>
</tr>
<tr>
<td>Luda, Liaoning</td>
<td>38°</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Yitong, Jilin</td>
<td>43°</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Sources: Grain and oil storage, by Nanjing Grain College (1985)

Slower grain aging and deterioration rate

The quality of grain under regular storage often gets worse as the storage life grows longer. According to the study, bad quality of grain is chiefly caused by grain heating and molding, which resulted from the activity of microorganism and respiration of grain itself. During this process, mould spores grow in large number, and this will influence the quality of the grain as both seed and food. The grain embryo suffers lower germinating ability because of mould, since faster respiration and microorganism decomposing nutrient substance. The grain weight, nutrient value and processing quality will be reduced. However, grain in underground bins can avoid heating and molding and can put off its aging because of low temperature and humidity control. This is able to slow its deterioration especially for maintaining its quality as food and in cooking.

The low temperature preservation research on durum wheat with 11.9% water was carried out in Britain. After sixteen-year storage, no distinct mould or abnormal odor and taste were found, and germination percentage is above 87%. In accordance with chemical analysis, the crude protein of wheat is 12.9% with no changing, fat is 2.9% with additional 0.5%, full-sugar amount slightly lower, titration acid is 0.38 - 0.4% which is normal. In addition, the fatty acid rose steadily from 8.6 to 25.2 KOH mg/100g, while it would risen to 43.8 KOH mg/100g under regular temperature; vitamin B is 3.6 - 3.7 mg almost remains stable; flour processing technical quality and baking quality are better than those under regular temperature. The data of domestic underground grain reserve have shown that underground grain storage period is 50 - 100% longer than that of ground storage, and can slower grain deterioration and maintain grain edible and seed quality.

Powerful earthquake-proof and anti-calamity

Granary storage is important for a country. It is necessary for the stability and development of a nation or society to keep enough grain storage. Granary engineering is stipulated as one of the key earthquake-proof engineering projects, so it should require high quake-proof rank and more capital invested for higher construction cost. Underground grain storage is better at earthquake-proof than ground one. Investigation and research after earthquake in
Japan, in which earthquake often attacks, showed that earthquake is less destructive for underground buildings than for ground ones, and underground buildings have many advantages. This viewpoint is proved by the investigation report after great earthquake in Tangshan of China, and a underground granary with horn shape in Inner Mongolia, whose cover is consolidated with steel reinforce concrete, experienced an earthquake of 6.3 degree, and had no clear destructive signs. Since earthquake is less strong for experienced an earthquake of 6.3 degree, and had no clear destructive signs. Since earthquake is less strong for underground construction than ground one, underground granary is more powerful in earthquake-proof and able to prevent grain storage from being attacked by natural disasters.

Underground grain storage is better at typhoon, whirlwind, tornado and hail prevention than ground storage facility.

Low pest rate

Grain stored is partially damaged by insects. Most insects start growing at about 15°C, and dying naturally in 100 – 200 days at the constant temperature of under 15°C. The growth and generating of insects depend on humidity in the granary if the temperature is under 15°C. Low humidity can prevent insects. Since underground grainary is damp-proof and under low effective accumulative temperature, the generations of insects is less than grain stored under regular temperature.

Molding is another factor in grain storage, such as the effect by flavacin, candidukin, and astergillus niger, and so on. Temperature change, humidity and water percentage is three main factors in preventing microorganisms. Most microbes can be controlled be limiting water percentage of the grain stored. Underground grain storage is effective in reserving grain due to its damp-proof, lower temperature and limited water percentage of grain. The data about the harm of insects and microbes in various years tells the advantage of underground granary storage.

In addition, underground grain storage limits the growth and generating of insects by the low temperature. It is airtight, cut off from the outside world with a few doors and few windows, so it is hard for insects to enter. In this way, a little or little chemical mixture is used to preserve the quality of grain and avoid food pollution and harm to the people.

**Typical Benefits**

**Good social effects**

With the development of the urban areas, the underground grain storage could bring remarkable social benefits. The population of the cities all over the world became double in the past thirty years, and goes on increasing. The cities in both developed and developing countries grow constantly, and this results in limited land, more condensed located buildings and less green areas. Ecological balance has been destroyed. People’s health condition is affected by poor environment. The space on earth is limited, while the population is increasing. The relation between urban construction area and agricultural area is intense. Since it mainly lies in the city, grain storage facility takes up the space underground, which has undeniable social benefits of relaxing the increasingly intense soil, energy and pollution crises.

Underground grain storage regained its vitality and benefits in the national situation of China. People developed and used millions-of-square-meter civil air-tight shelters built with billions of capital and hard work by military and civil forces called on with of encouragement of ‘Deeper caves dug and more grain stored’ in special historical period. They exploited which resources of civil underground shelters already existed by rebuilding them rather than invest more raw materials or capital to achieve great benefit. Thus the application of underground space saved more money and is more productive. One example of which was Underground Granary 803 in Hangzhou of China.

**Good environmental effect and long-run development strategy**

Underground grain storage reserves grain scientifically and saves space for green area. The environmental benefit is great. It manages to keep ecological balance and to alleviate ‘heat island effect’ in the city and deterioration of ecological environment.

According to ‘The Ninth Five-Years Program of National Economic and Social Development’ and the sketch of long-term goals in 2010, grain output will rise from 465 mil tons in 1995 to 490 – 500 mil tons in 2000. The increased 25 – 35 mil-ton grain needs 70 thousands mu land, equal to 4667 hectare for building granary if reserving every 100 ton grain needs 100-mu land. To save so much land will be quite beneficial for the environment at the turn of centuries. As environment and land are basic conditions for humans to survive and develop, it is more important for China to save land and keep environmental balance, in which is only of 7% farmland, 21% grain output, and 22% population compared respectively to each total sum of world. Human beings will never survive or develop without good ecological environment and constantly available natural resources. The application of underground grain storage facility is one of those long-term strategies in China, which protects the environment and ecology. This contribution is carried out by the people of today, but it will benefit following generations.

**Great economic effect**

*Lower cost of grain reserve*

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Grain stored in underground bins is almost in good condition, due to low temperature and humidity usually without overturning or fumigating. As fresh period is comparatively longer, labor and storage fee will be reduced. The average preservation amount of grain in underground granaries of each person is more than that of ground granaries. It is shown in relevant data that the cost of underground grain storage is lower than that of ground one. (For details please refer to technology of grain storage in China)

**Energy saving**

Most underground granary can work without artificial refrigerating and save energy since it is at low or quasi-low temperature and not influenced by the weather. Energy used in artificial refrigerating underground granary is much less than that in ground bins even in low-latitude area to quasi-low temperature. The constant temperature of underground granary is lower than that of ground one. Therefore, it saves money and is quite beneficial.

**Land saving**

Underground granary takes up less land than ground bins in China. Less or no farmland is taken for underground bins to meet the need of our national situation of large population with limited land. It is economic to rebuild former civil underground shelters to save land and achieve great economic benefit rather than take up more land or build ground granary with largest amount of money.

**Construction fee saving**

The cost of constructing underground granary is lower than that of ground one about 50 - 70%, for it saves constructing material. The cost of ground granary during ‘The Eighth Development Program of National economy and Society in Five Years’ is about 10 million yuan or even higher for capacity of every 50000 tons. As grain output will increase 25 - 35 million tons in 2000 than that in 1995, it saves construction cost to build underground granary, which will go further if the former civil underground shelters are reconstructed and used as granary. It only needs damp-proof and airtight techniques, so it is economical.

**Conclusion**

From ancient times till today, underground grain storage has grown more promising especially in recent decades of scientific study and research in China. It is well known to the world. United Nations Food and Agriculture Organization visited and investigated storage facility in China, and in Rome in 1982 prepared a report about underground granary of China. UNFAO also visited 803 Underground Granary in Hangzhou province.

Food, energy, environment and resources are key issues at the turn of centuries. Underground grain storage in China succeeds to facilitate grain reserve, save energy, protect environment and land, and use underground space. International exchange of science and technology is popular. In this way, people abroad can know more about China. The interchange of this technique will increase technical exchange and cooperation, and help international researchers to learn about it. It is sure that underground granary storage facility of China will benefit human beings in future.

**References**