Research on influence factors and control methods of backfill compactness

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Abstract. With the accelerating process of urbanization in China, civil engineering construction develops steadily, building modeling is very different, and the trend of functional diversification is gradually revealed. As the basic process of construction engineering, the quality of earthwork backfill plays an important role in engineering construction. If the quality of the backfill cannot meet the design requirements, the surface subsidence will affect the appearance of the building and cause quality defects, and the insufficient bearing capacity and uneven compaction of the backfill will cause quality accidents such as the inclination of the main structure or structural cracking. In this paper, taking a certain engineering earthwork backfill project as an example, through the dismantling of the construction process of backfill, from the source of backfill soil to the control of backfill quality process, using the measured data to analyze and study the factors affecting the compactness of backfill. The results show that the main factors affecting the compactness of backfill are soil particle size, moisture content, compaction thickness and compaction times. Through the experimental study, the targeted quality control measures are put forward to ensure that the overall quality of the construction project meets the design requirements.

1. Introduction
As an indispensable basic work in the process of building construction, the importance of backfill engineering directly affects the overall quality of the main structure. It is often used for the backfill of foundation trench outside the building, the room backfill inside the building, the backfill of roof soil and landscape road subgrade. The construction quality of the backfill of the foundation trench outside the building plays an important role in the quality of the landscape and structures outside the building. If the backfill compactness cannot meet the design value, it is easy to cause the surface subsidence around the main structure. When the compactness deviation is large and seriously insufficient, it may even lead to the imbalance of soil bearing capacity in the active earth pressure zone around the main structure, the inclination of the main structure and other major quality accidents. The construction quality of room backfill directly affects the construction quality of indoor building ground decoration surface. When the value of backfill compactness is unstable, the large dispersion and low value will lead to insufficient bearing capacity or uneven ground settlement of ground base, which will lead to quality accidents such as ground hollowing, cracking and dislocation. When the filling base subsides seriously, it will even cause serious damage to the decorative structure wall. If the compactness deviation of roof covering soil and landscape subgrade backfill soil is large and fails to meet the
design requirements, the problems of surface settlement, slab bottom void, mud pumping, slab surface cracking will occur in the follow-up landscape roads and landscape structures. To sum up, when the construction quality of backfill cannot be guaranteed, it is easy to reduce the use function of buildings, and even seriously affect the structural safety. Therefore, in the construction process, we must pay attention to the quality control of earthwork backfill construction.

In this paper, taking the construction of a certain engineering earthwork backfill project as an example, through the analysis of the compaction data of representative backfill detection points, the main factors affecting the backfill compactness are analyzed, including soil particle size, moisture content, compaction thickness, compaction times, etc., and each influencing factor is studied. The results show that the soil particle size affects the dispersion of compactness, the soil moisture content plays a decisive role in achieving the standard of compactness, and the selection of compaction thickness and compaction times has an impact on compactness. Finally, this paper puts forward the corresponding technical measures for the influencing factors of backfill compactness to ensure the numerical stability of backfill compactness at the construction site and meet the design compactness requirements.

2. Potential accidents caused by quality problems of backfill construction
The common construction quality problems of backfill are mainly reflected in the lack of compactness, bearing capacity, soil moisture, post construction settlement with large deviation of compactness value, high moisture content, damages of rubber soil and frozen soil caused by too thick compaction thickness. For example, insufficient compactness of backfill leads to the settlement of backfill soil in the later stage, which leads to the quality accident of floor subsidence and cracking, seriously affects the use function of owners, and even leads to structural safety accidents. The large deviation of backfill compactness leads to the existence of soil pores, and the soil moisture content is too high after being eroded by rainwater in the later stage. Due to the repeated action of long-term load, it is easy to change the soil properties, reduce the load bearing capacity of backfill, and finally lead to the imbalance of soil pressure, resulting in the tilt and cracking of the main structure. Due to the damage of freezing and thawing environment, the volume expansion of pore water in the soil decreases to the freezing point, which leads to the release of soil stress, causing the structural floor dislocation and the uplift of slab bottom, and then leading to the failure of slab structure in the main structure.

3. Analysis on influence factors of backfill compactness
In this paper, taking the quality problems existing in the construction process of a solid project earthwork backfill as an example, through the analysis of the construction process of the backfill, combined with the construction site backfill compactness test, the compactness is analyzed. The results show that the value of compactness fluctuates greatly when the soil particle size is large, and the compactness value of backfill is inversely proportional to the soil moisture content, and the stability of compactness value of backfill is also related to the compaction thickness and compaction times. The influence factors of backfill compactness can be divided into two categories: one is soil factor of soil source (soil particle size and soil moisture content), the other is backfill construction technology and environmental influencing factors (compaction thickness and compaction times).

3.1 Too large soil particle size lead to great fluctuation in the numerical change of backfill compactness and uneven stress of backfill
Through the analysis of the field measured data of soil particles (as shown in Figure 1), it is found that the particle size of backfill soil has a great impact on the quality of backfill soil. After the backfill soil whose particle size is less than 40mm is compacted, the compactness value is more stable and concentrated, the soil appearance is more delicate and smooth, and the soil surface cracks are less after compaction. When the soil particle size is 40mm ~ 50mm, the compactness value deviates from the design value and fluctuates greatly. At the same time, there are more diffusion cracks on the
compaction surface of backfill soil with large particle size as the center. Even if the backfill (when the soil contains large particle size) is preliminarily accepted, there are two situations in the later stage: first, because there is a large particle size (≥50mm) soil, the soil is relatively soft after crushing, and it is easy to cause weak stress in the later stage, which leads to the partial decline of backfill compactness, as shown in Figure 2. In the second case, when the larger particle size is not crushed, because the soil particle size is larger and the integrity of the individual is good, it cannot form an integrated joint stress with the surrounding soil, and the stress points are more concentrated in the stress process, which is easy to cause the backfill to spread outward with the particle size as the center point, resulting in cracking damage and surface cracking of the backfill, which seriously affects the integrity of the backfill, as shown in Figure 3.

3.2 The higher soil moisture content leads to the lower compactness of the backfill, which is easy to cause the destruction of the rubber soil

According to the on-site soil ring knife sampling, the backfill samples are numbered, dried and heated in batches to obtain the quality of soil after drying, and then the soil moisture content. Taking samples
of the same soil moisture density for research, it is found that the numerical stability of compactness value is poor when the soil moisture content is high, and the numerical value is generally low. When the soil moisture content exceeds the optimal moisture content, rubber soil disease is prone to occur, resulting in the decline of soil bearing capacity.

Through the comparative test, it is found that the optimal moisture content of different soil sources also has deviation. Taking the moisture content of sandy loam and loess as an example, when the moisture content of sandy loam backfill exceeds 18%, the overall backfill compactness declines, and the discrete fluctuation is large, as shown in Figure 4. When the moisture content of loess backfill exceeds 25%, the rubber soil disease occurs, the compaction data cannot meet the design requirements, and the soil bearing capacity is generally low, as shown in Figure 5. In addition, when there are organic impurities or humic soil in the soil, because the soil is loose and has large pores, the soil moisture content per unit volume is higher and the soil compactness is loose, and the compactness value is more discrete. When it is used as the source of backfill soil, the value of backfill compaction is discrete and unstable, and the bearing capacity of soil after backfill compaction is generally low, so it is difficult to ensure that the backfill compaction meets the design requirements.

![Figure 4. Relationship between moisture content and compactness of sandy loam](image1)

![Figure 5. Relationship between moisture content and compactness of loess](image2)
3.3 *If the single layer compaction thickness is too thick or too thin, the compactness of backfill is low, and the soil properties change*

When the soil from different soil sources is used as backfill, through the field compaction test and apparent acceptance, it is found that the backfill compactness with different soil quality, moisture content and particle size is closely related to the single layer compaction thickness. If the single layer compaction thickness of backfill is not selected for on-site backfill, and the single layer compaction thickness of backfill is too thick or too thin, it is easy to cause insufficient compaction of backfill or soil pulverization, resulting in settlement after backfill, as shown in Figure 6. When the moisture content exceeds the specified moisture content, the rubber soil disease and collapsible loess disease are easy to appear when the compaction thickness is thick (as shown in Figure 7), and the soil bearing capacity cannot meet the design requirements and other quality problems occur, which seriously affect the backfill construction quality and cause hidden trouble to the subsequent process and the structure itself.

![Figure 6. Too thin backfill compaction thickness and too many disturbance times lead to soil pulverization](image)

![Figure 7. The high moisture content of soil leads to the formation of rubber soil](image)

3.4 *Too few compaction times lead to low compactness of backfill, which cannot meet the design requirements*

If the compaction times are too few, the compactness of the backfill cannot meet the design requirements, which will easily lead to the settlement and subsidence of the backfill, resulting in the cracking of the main structure. At the same time, when the compaction times are less, the backfill soil is easy to have pores and poor compactness. When it is eroded by rain water in the later stage, it is easy to pulverize and cause soil structure damage. When it is damaged by freezing and thawing environment, it is easy to cause pore water solidification and volume expansion. The soil stress release eventually leads to the uplift of the surface or the deformation and damage of structures. In addition, it is necessary to standardize the compaction method in backfill soil compaction. Taking mechanical compaction as an example, if the vibration of mechanical compaction is too early and the initial compaction speed is fast, the phenomenon of mechanical soil driving is easy to occur, which will lead to local uplift damage of backfill soil, and at the same time, the failure of staggered platform between layers of backfill soil.

4. **Quality control method of backfill construction**

4.1 *The soil source of backfill should be selected according to the geotechnical test*

Before the selection of soil source, the geotechnical test should be carried out strictly to determine the important parameters of soil. According to the particle size and moisture content of backfill soil, the corresponding measures are taken. The experimental results show that it is appropriate to select the soil source whose particle size is less than 40mm as the backfill soil source, which can effectively reduce the cracking of backfill soil and insufficient compactness caused by too large particle size, and
ensure that the compactness is relatively concentrated, and improve the data accuracy. The soil moisture content should be controlled according to the characteristics of different soils, and the soil with the optimal moisture content should be selected. For example, the moisture content of sandy loam should be 15% ~ 18%, and that of loess should be 19% ~ 25%. The compactness of backfill can be effectively controlled, and the value is relatively stable, which can meet the design requirements. When selecting the soil source, it is strictly forbidden to select the soil source with uneven texture and poor soil structure performance such as organic soil, humus soil, muddy soil and frozen soil, so as to avoid the occurrence of backfill soil quality problems caused by its own structural problems.

4.2 Backfill compactness test must be done on site

Due to the open-air, changeability and randomness of working procedure, many uncontrollable factors and insufficient attention of construction management, the construction quality of backfill is seriously affected. Therefore, necessary test measures should be taken to monitor the compaction process and compactness results of backfill, so as to effectively ensure the compaction quality of backfill layer by layer, and avoid the structural slab cracking, surface subsidence and structural inclination caused by post construction settlement or compactness not meeting the design requirements. During the compaction test, the soil samples in the construction process and the backfill soil after the completion of compaction operation should be dried and fried to ensure the accuracy of soil moisture content and other important parameters. According to the changes of parameters, the data analysis method should be used to sort out and coordinate the data, so as to determine whether the compactness of soil after backfill meets the design requirements, and then take targeted measures to control the quality, the real-time monitoring of soil quality and construction process plays a substantial role in reducing the quality problems caused by the instability of backfill compactness or low compaction due to the change of backfill material.

![Figure 8. Compactness test](image-url)
4.3 According to the soil condition of backfill, select the appropriate compaction times and thickness
The compaction times and method of backfill should be determined according to the soil conditions. The compaction method of backfill should adopt the principles of static pressure before vibration, slow before fast, light before heavy. At the same time, attention should be paid to the overlapping of wheel tracks. The compaction sequence should be determined in advance according to the actual situation of the site. In principle, it should be compacted from one end to the other or from low to high. In the process of mechanical backfilling and compaction, it is better to use manual assistance, and the parts that cannot be touched by machinery should be treated by manual compaction in time to ensure that the backfill working face is fully compacted. After the initial static pressure compaction of the backfill surface, according to the conditions of the backfill working face and the main structure itself, the repeated rolling can be combined with the vibration compaction to ensure that the backfill is fully compacted. At the same time, the vibration compaction should adopt the measures of low amplitude and high frequency. The single-layer compaction thickness of backfill should be determined according to the nature of soil source. Taking this project as an example, the virtual paving thickness of sandy loam should be controlled at about 300mm, and the virtual paving thickness of loess backfill should be controlled at about 250mm.

![Figure 9. Detail mechanical backfill compaction](image1)

![Figure 10. Layered compaction of backfill](image2)

4.4 The suitable construction time should be selected according to the natural environment conditions
As the main material of backfill operation is soil, its moisture content is easily affected by the natural environment, so it is necessary to avoid rain erosion during construction and after compaction, and the construction of backfill operation should avoid rainy days. In case of rain erosion during construction, it is advisable to take closed isolation measures for water and soil isolation. If the constructed backfill soil is soaked by rain, it should be excavated and sunned after sunny days, or mixed with quicklime and cement to improve the soil properties, so as to avoid the structural settlement caused by the decrease of bearing capacity due to the change of soil properties caused by rain erosion. Due to the water content of backfill soil, construction in winter or negative temperature environment should be avoided. The finished construction surface should be covered with materials with good temperature and water insulation effect, so as to reduce the structural settlement, cracking and other quality accidents caused by freeze-thaw damage.

5. Conclusion
As the basic process of the construction industry, the importance of backfill engineering should be highly valued by people in the construction industry. In recent years, the slab cracking, structural deformation and building inclination caused by the quality problems of backfill construction occur repeatedly, which seriously affect the functional use of the owners, so the owners' claims increase year by year. As the backfill is a concealed project, it cannot be inspected in the later stage. Once there is a quality problem, it can only be reworked. It often needs to break the decorative surface of the structure, which is time-consuming and labor-consuming, and has a great negative impact on the society.
Therefore, in the process of backfill construction, it is necessary to strictly control the soil source and construction process methods, select the appropriate environment for construction, strengthen the real-time monitoring in the field, eliminate the hidden dangers of backfill construction quality, ensure the quality of backfill construction, and avoid the later maintenance cost.

The compactness control of backfill is a complex process, which directly affects the construction quality of backfill. Based on the analysis of the compactness test data of a real project, this paper puts forward two kinds of important factors that affect the compactness of backfill, namely, the factors of soil itself (soil particles, moisture content) and the construction technology and environmental factors (compaction thickness, compaction times). Then the quality control measures of backfill are put forward. It is suggested that the geotechnical test section should be done before construction to analyze the soil characteristics of soil source. According to the soil characteristics, the soil source with soil particle size less than 40mm and suitable moisture content should be selected, and the backfill method, backfill single layer compaction thickness and compaction times should be determined to prevent in advance. In the process of construction, real-time compaction test is carried out to control the process. At the same time, the influence of external environment on backfill operation should be avoided, and the deviation should be corrected in time, so as to ensure that the construction quality of backfill meets the design requirements.

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References
[1] Zhang H. Talking about the backfilling and compaction technology of the earthwork in construction engineering[J]. Jiangxi inspection. 2020(12):160+162.
[2] Yuan J. Analysis of the control and treatment method of backfill in the construction of the building[J]. Construction &design for project. 2019(21):40-41+44.
[3] Liang M. Relevant approaches and methods for quality control of earthwork backfill in civil engineering construction[J]. Building materials and decoration. 2016(43):7-8.
[4] Wang Ha, Qiao A, Wang Y. Quality management and control of earthwork backfill[J]. Water Conservancy Technical Supervision. 2016(43):7-8.