

# Subgrade and Pavement Design Strategies for Different Road Settlement Sections

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**Abstract:** The quality of road engineering construction largely determines the road operation safety and driving comfort. However, in road engineering construction, the settlement of subgrade and pavement has always been an insurmountable problem. Therefore, in road construction practice, targeted treatment should be carried out for the sections prone to settlement, and subgrade and pavement design strategies for these settlement sections should be carried out, so as to reduce the risk of settlement and ensure the improvement of road engineering quality and safety.

**Keywords:** Road engineering; Settlement section; Subgrade and pavement design

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## 1. Introduction

The issue of road settlement has always been one of the major factors affecting driving safety and comfort. Hence, it is highly valued by construction enterprises. Once settlement occurs, the road structure will be damaged, resulting in road cracks, and the service life of the road will also be negatively affected. From the perspective of subgrade construction and pavement settlement, it is necessary to effectively control the occurrence rate of road settlement.

## 2. Common settlement sections in road engineering

### 2.1. Road-bridge connection

Subgrade and bridge are the most important components of road engineering. They have specific requirements in terms of stiffness, strength, expansion, and contraction. Especially at the road-bridge connection, the overall stress effect needs to be dispersed to meet the overall road engineering quality and the safe operation standard. From the perspective of mechanics, there are clear differences in the mechanical properties of road and bridge structures. Under the influence of self-weight, environment, driving load, and other factors, the road-bridge connection is prone to uneven settlement, resulting in uneven stress. This will not only cause “vehicle jumping” at the bridge head, but also leave a negative impact on the stability of the road structure, which may lead to serious safety accidents <sup>[1]</sup>.

### 2.2. High fill subgrade section

In road engineering construction, high fill subgrade working conditions are inevitable. The disadvantages of high fill subgrade include greater self-weight, long stability cycle, and difficult quality control. Serious settlement deformations easily occur, which may even cause cracks in varying degrees. Therefore, high fill

subgrade sections have become one of the most common sections with settlement issues in engineering [2].

### **2.3. Filling and excavation combination section**

In the construction of high slope filling and excavation combination section, the construction method of high slope bench excavation, backfilling, and compaction is usually adopted. However, in construction practice, this method will directly lead to difficult compaction at the contact position of filling and excavation, resulting in great differences in subgrade compactness, stiffness, and strength between this specific section and other sections. In addition, the filling side slope is generally located at the position of the slope and steep slope, and it is difficult for its stability to meet the quality requirements of road construction, which poses a threat to the safety of the project operation [3].

### **2.4. Soft soil subgrade section**

Soft soil subgrade is a common adverse geological condition in road engineering construction. Soft soil subgrade is characterized by high water content, large pores, high compressibility, and poor stability. These characteristics not only pose a challenge for engineering construction, but also increase the settlement risk of subgrades [4].

### **2.5. Ponding section**

From the cause analysis of road settlements, the ponding on pavement is largely the cause. Due to the immersion of subgrade and pavement over a long period of time, the materials soften, and their overall strength and bearing capacity significantly reduce, resulting in subgrade settlement [5].

## **3. Cause analysis of subgrade and pavement settlements in road engineering**

With the accelerating pace of China's social and economic development in recent years, the scale of road engineering construction is expanding, and the number of projects is increasing year by year. However, there are still many issues in the design of road subgrade and pavement, resulting in the occurrence of road settlements from time to time, which leaves bad impact on the quality and safety of road operations. Through continuous investigations, it is found that the causes of subgrade and pavement settlements are mainly reflected in several aspects.

### **3.1. Poor quality control of raw materials**

In the engineering construction process of concrete pavement, the selection of raw materials will have an impact on the construction level of the project. For example, when selecting cement materials, if the selected materials have low strength, poor frost resistance, and insufficient stability, there will be an increased risk of pavement settlement. Another example is in the selection of aggregate; if the selected coarse aggregate is unreasonable, and the grading has great fluctuations, the flatness and stability of the pavement will be seriously affected, resulting in uneven settlements from time to time [6]. If the maximum particle size of the coarse aggregate is not reasonably controlled, the flexural tensile strength and strength of the concrete will be reduced when used in concrete configuration, which will greatly reduce the life cycle of road engineering.

### **3.2. Inaccurate concrete proportioning and measurement**

Inaccurate concrete proportioning and measurement are the main causes of subgrade and pavement settlement in road engineering. If the water-cement ratio is not controlled in the concrete configuration process, it will change the concrete pavement structure [7]. If the water-cement ratio of the concrete is large, the internal density and strength of the concrete will be reduced; if the ratio is too large, the amount of

drying shrinkage will increase, which will result in pavement drying shrinkage settlement.

### **3.3. Unreasonable structural design of subgrade and pavement**

When the structural design of subgrade and pavement in road engineering construction is unreasonable, uneven settlement will occur in the road structure. At present, reinforced concrete structures are used for the construction of subgrade and pavement in domestic road projects. In order to effectively improve the overall strength of these projects, designers usually adopt the construction methods of increasing the number of reinforcement and selecting high-specification fillers to ensure that the strength of the road structure meets the demand of the driving load. Currently, many domestic road engineering construction projects are adopting large plate structure forms, in order to improve the road strength, but the uneven settlement of subgrade and pavement still cannot be prevented in many engineering projects due to unreasonable design <sup>[8]</sup>.

### **3.4. Insufficient subgrade compaction at the back of the abutment**

In the construction of roads and bridges, the filling of the back of the abutment is the main measure of ensuring that there will be no serious settlement issues in this section. However, in reality, due to the difficulty of earth-rock filling at the back of the abutment and the influence of various factors, the quality control level of the construction is substandard. After being put into operation, the subgrade and pavement structures will have different degrees of settlement issues due to the influence of long-term driving load, thus introducing huge potential safety hazards to travelers <sup>[9]</sup>.

### **3.5. Unreasonable bridge head design**

In the operation of road and bridge engineering, the bridge head structure bears the largest traffic load. If the structural design of the bridge head is unreasonable, the overall quality of the project will be affected. In the design process, if the design department does not conduct strict on-site investigations before carrying out the engineering design, there will be significant differences between the design scheme and the actual situation on site, which will eventually affect the overall quality level of the engineering construction, and thus resulting in serious uneven settlements of subgrade and pavement <sup>[10]</sup>.

### **3.6. The lack of construction quality control**

During road engineering construction, high-quality and efficient quality control can effectively reduce the incidence of subgrade and pavement settlement issues. However, the reality is that many construction enterprises are not making enough effort in this aspect <sup>[11]</sup>. On the one hand, the base construction quality control is not strict, resulting in inconsistencies between the base elevation and the design scheme, and the top elevation is higher than the design elevation, resulting in various problems, such as insufficient pavement layer thickness and poor pavement flatness, which would eventually lead to settlement and plate breaking; on the other hand, construction enterprises do not fully control the water content of the base course during concrete pavement construction, resulting in the full absorption of water in the concrete, which causes large shrinkage force, and thus aggravating the pavement settlement issue.

## **4. Subgrade and pavement design strategies for road settlement sections**

### **4.1. Improve the treatment scheme of soft soil subgrade**

In road route selection, it is necessary to avoid bad sections, such as soft soil subgrade. If soft soil subgrade is inevitable, the stability of the entire soft soil base can be stably improved through the scientific application of modern construction technologies, such as drainage consolidation technology, reinforcement technology, chemical reinforcement technology, and powder jet pile technology, so as to ensure that the

subgrade stability meets the quality requirements of road construction. However, during the application of various construction technologies, scientific selection should be made in consideration of the different characteristics of soft soil subgrade section to ensure that the role of each technology can be maximized to its full potential <sup>[12]</sup>.

#### **4.2. Select appropriate subgrade filling materials**

As aforementioned, in the construction of high fill subgrade, the filling material has strong compressibility. Hence, subgrade settlement tends to occur. Therefore, the filling material should be reasonably selected in the construction of high fill subgrade. For example, selecting coarse-grained soil with better gradation, and ensuring the layered filling of similar soil would be beneficial. In general, stone-filled subgrade does not cause settlement issues, but hard and non-weathered stones should also be selected. The top width, height, and inclination of stone masonry subgrades should be reasonably designed. When geological conditions change, sectional design should be adopted, and settlement joints should be reserved. During the construction of filling subgrade at hillsides, reinforcement treatment must be done well. For example, setting toe protection will prevent the filling subgrade from sliding along the slope. Second, the selected filling materials should have good water stability, in order to ensure that they will not undergo significant changes due to the change in water volume. This will be a guarantee to the stability of the overall structure <sup>[13]</sup>.

#### **4.3. Carry out the subgrade design work well for the filling and excavation combination section**

The filling and excavation combination section, which refers to the excavation of the upper part and the filling of the lower part, often occurs at steep slopes. When the embankment is built on the slope with the natural cross slope of the ground greater than 1:5, the land base should be designed with steps of no less than 1 meter in width, and the bottom step should be designed with an inward inclined slope of 2° to 4°. If the filling and excavation section is located at the steep slope section with hard rock, it will be difficult to build when the amount of filling is small and the slope extends far, but shoulder protection can be set as the support and blocking structure. The shoulder protection should be built with non-weathered rubble, and the height should not be higher than 2 meters. The base should be set with an inward inclination of 1:5, so as to ensure that the role of shoulder protection will be fully maximized <sup>[14]</sup>.

#### **4.4. Attach importance to the treatment of road-bridge junction**

The high stress at the road-bridge junction may result in uneven settlements, which have a direct impact on the safety of subsequent road operations. Therefore, this issue should be addressed urgently. On the one hand, road and bridge structures should be further optimized to ensure that the foundation treatment is in place and its bearing capacity can meet the load requirements of the superstructure; on the other hand, the abutment approach slab can be set at the road-bridge junction to prevent settlement issues from occurring at that section. In addition, the approach slab also has the function of rotating with the settlement of the fill; thus, it also plays a buffer role. Even if settlement occurs in the filling at the back of the abutment, it will not cause unevenness in the connection.

#### **4.5. Select appropriate pavement construction materials**

From the analysis of road pavement structure, there are three basic components: surface course, base course, and cushion. The cushion is generally located on the subgrade, so its strength and water stability requirements are high. Once the cushion's strength and water stability deteriorate, settlement deformation will occur under the action of groundwater and surface water. The base course is mainly a pavement bearing structure; therefore, in addition to meeting the quality requirements of road design in terms of its strength,

frost resistance, and water stability, a strong load diffusion capacity is also required, so as to ensure that the load transmission and diffusion can be realized in time when the road pavement is subjected to external load <sup>[15]</sup>. According to relevant standards, it can be divided into four grades: high-grade pavement, sub high-grade pavement, intermediate-grade pavement, and low-grade pavement. The selection of base course materials and the pavement surface should be strictly implemented in line with the quality design requirements of different grades of road pavement. For example, when selecting the concrete base materials for intermediate-grade pavement, the cement stabilized fine-grained soil, lime stabilized soil, and fly ash stabilized fine-grained soil should not be more than those of high-grade pavement; in the selection of advanced pavement structure materials, asphalt concrete and cement concrete materials should be selected; these materials not only satisfy the requirements for strength and frost resistance, but also realize the savings in construction cost; in the selection of the base course materials for medium and low-grade pavements, dirt, gravel, soil, and other simple materials are generally used.

#### **4.6. Improve the road waterproof and drainage design**

In order to effectively reduce the incidence of road settlement issues, having a good road waterproof and drainage design will minimize the probability of subgrade water damage and ensure the normal operation of road engineering. In order to achieve this goal, enterprises must first select the process technology in a scientific manner. By ensuring the rationality and scientificity of the construction scheme, the road quality will be able to meet the design requirements as well as obtain good drainage and subgrade stability effects with the implementation of the process technology. In the design scheme, the basic requirements for waterproof and drainage construction, base inspection, subgrade paving, and compaction construction should be included, and the construction unit should implement them in strict accordance with the scheme requirements during construction.

##### **(1) Base inspection**

The construction quality of the subgrade waterproof layer is largely affected by the surface condition of the base. Therefore, in engineering construction practice, it is necessary to inspect the base, in order to ensure that the surface condition of the base meets the requirements of the engineering construction. In grass-roots procuratorial work, it is crucial to ensure that it is flat, clean, tidy, and dry. If the cleanliness of the subgrade base is substandard, clean water should be used for flushing; on the other hand, if there are plenty of stains on the surface, caustic soda can be used to remove them first; if the surface of the base course is uneven and depressed, it should be filled with asphalt concrete to create a flat surface.

##### **(2) Subgrade paving**

Before paving the waterproof subgrade, it is necessary to check whether the road edge stones have been set according to the drawings, whether the subgrade filler is compacted, and whether the pavement joint width and line are in compliance. Paving can be carried out only after the confirmation of these steps <sup>[16]</sup>. In order to prevent the problem of longitudinal joints during paving, the full width paving method is usually adopted in accordance with the construction specifications and design standards. Since the construction of asphalt pavement has certain requirements for temperature, when the external temperature is too low or too high, the paving should be stopped.

##### **(3) Subgrade compaction**

Subgrade compaction is the final and most important process in road construction and waterproof subgrade construction. If the degree of compaction is not adequate, materials will be loose, and they will fall off, thus pit problems will occur with later use. Therefore, in order to ensure the compactness of the pavement, it is necessary to roll in three stages; namely, initial compaction, re-compaction, and final compaction. During the initial rolling, a smooth steel wheel roller should be used 4 to 6 times to level the pavement, stabilize the asphalt concrete of the pavement layer, and improve the material density.

After the initial compaction, the pavement is basically formed, but the compactness of the pavement still does not meet the design requirements; hence, it needs to be rolled again for another 4 to 6 times with the help of a vibratory roller. The purpose of the final compaction is to ensure a flat pavement. The smooth steel wheel roller should be rolled in sequence, so as to eliminate the wheel marks left during initial compaction and re-compaction, as well as further enhance its compactness. In order to achieve the purpose of saving materials, the three rolling processes ought to be carried out under the guidance of technicians and completed in a single event. The on-site commander shall judge the rolling effect. If the rolling is unsatisfactory, the number of times for rolling will be increased to ensure that the compactness of the pavement layer meets the engineering design standards.

## 5. Conclusion

In a word, road settlement sections are sections that are most likely to cause road safety accidents. In order to effectively reduce the risk of driving safety, the sections most prone to settlement issues should be identified; these include road-bridge connection, high fill subgrade section, filling and excavation combination section, soft soil subgrade section, and ponding section; additionally, the causes of settlement should be explored, and subgrade and pavement design strategies for different settlement sections should be carried out, so as to ensure that the overall strength and stiffness of subgrade and pavement will meet the road engineering quality design standards.

## Disclosure statement

The author declares no conflict of interest.

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