Scientific Research Publishing

Open Journal of Civil Engineering, 2026, 16(1), 60-82
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Linear Design Technology of a Subgrade Prefabricated Interlocking Structure

Yu Sun[1*], Linyi Pan[1], Luo Ji[2], Yue Yuan[3], Guomin Deng[3]

[1]University of Shanghai for Science and Technology, Shanghai, China
[2]Shanghai Jinxing Municipal Design Consulting Co., Ltd., Shanghai, China
[3]Shanghai Pudong Road and Bridge Group Co., Ltd., Shanghai, China
Email: *ysun@usst.edu.cn

How to cite this paper: Sun, Y., Pan, L.Y., Ji, L., Yuan, Y. and Deng, G.M. (2026) Linear Design Technology of a Subgrade Prefabricated Interlocking Structure. *Open Journal of Civil Engineering*, **16**, 60-82.
https://doi.org/10.4236/ojce.2026.161004

Received: January 14, 2026
Accepted: February 23, 2026
Published: February 26, 2026

Abstract

There is little research on prefabricated subgrade in the field of road engineering. A significant aspect within this domain is the design of road alignments. Considering these factors, this paper specifically addresses the study of design methods for prefabricated interlocking subgrade structures. After analyzing the disadvantages of traditional rectangular prefabricated blocks, inspired by the concept of the short shield method, the paper proposes to adjust the shape of prefabricated blocks to trapezoid. By utilizing AutoCAD, this study simulates the placement of prefabricated blocks under different road alignments and arrangement modes. The corresponding number of prefabricated blocks and pavement layout is calculated based on the linear elements and design principles of various planes and longitudinal sections. The technology for designing prefabricated interlocking subgrade structures presented in this paper can provide valuable insights for the construction of prefabricated subgrades, with potential for wide-ranging application and promotion.

Keywords

Road Engineering, Interlocking Structure, Alignment Design, Prefabricated Assembly

1. Introduction

The concept of prefabricated structure was first mentioned in the 1960s, and it was first applied in the field of construction by foreign countries [1] [2] because of its fast construction speed and low construction cost. With the development of the city, the technical level of the prefabricated structure has been improved as a whole, and the environmental protection requirements in the field of civil engineering have become higher and higher, which makes the prefabricated concrete structure develop again. The prefabricated structure has been widely used in the field of municipal engineering, and the research on the prefabricated structure in the field of road engineering has gradually increased [3] [4]. The prefabricated structure is a concrete component that is composed of prefabricated components as the main force subject, and the structure is assembled and connected. In the field of transportation, prefabricated structures are mainly used in pavements [5]-[10], bridges [11]-[15] and tunnels [16]-[19], but there are few studies on prefabricated roadbeds.

Due to the prefabricated subgrade will produce joints during assembly, it will affect the smoothness of the road and the comfort of driving. At present, the research of prefabricated structure design technology is mainly aimed at the joint design between prefabricated road panels. Cao *et al.* [20] studied a new type of prefabricated cantilever composite subgrade structure, and used ABAQUS finite element software to reveal the mechanical response performance of the prefabricated cantilever composite subgrade structure. Dong *et al.* [21] proposed to design a specific joint between prefabricated blocks, and the results show that the optimal design scheme of the prefabricated base is that the depth of the transverse groove is 10 mm, the degree of lateral tilt of the base block is 0.25, the modulus of the mortar is 6 GPa, and the width of the joint is 30 mm. Cheng *et al.* [22] configured three groups of cement mortar with different additives and analyzed the advantages of cement mortar as a joint filling material for prefabricated subgrade blocks through indoor tests.

However, in reality, the alignment of the road is not uniform, and corresponding transition curves should be set between different alignments to ensure smooth driving and passenger comfort. In view of the above deficiencies in the research of prefabricated subgrade, this paper carries out the research on the adaptive design of road alignment for prefabricated subgrade. The research results can provide data support and theoretical guidance for the engineering application of prefabricated subgrade.

2. Materials and Methods

2.1. Prefabricated Block Monomer Design

There are two common types of prefabricated blocks: cavity prefabricated subgrade blocks and hexagonal prism prefabricated subgrade blocks. Considering road drainage and construction production costs, this study selects cavity prefabricated subgrade blocks. Since the prefabricated pavement is assembled using these blocks, the size of the prefabricated blocks will affect the paving of the pavement. Prefabricated blocks with smaller plane sizes will require more blocks to be paved on the same road, reducing road surface smoothness. Larger prefabricated block plane sizes result in heavier block weights, increasing the difficulty of construction during the paving process. Generally, the geometric size of a thin-walled box culvert with a diaphragm is 4 × 3.2 × 0.7 m, as shown in Figure 1.

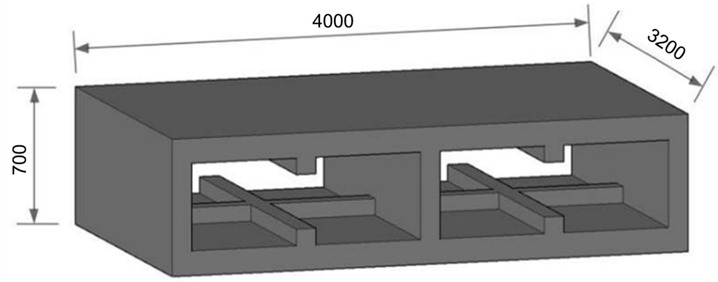


Figure 1. Cavity prefabricated subgrade (unit: mm).

To prevent thermal expansion and cold contraction of cement concrete materials, minimize stress changes resulting from temperature and humidity fluctuations in the pavement structure, and facilitate pavement construction, road engineering typically incorporates various types of joints, including longitudinal and transverse joints, to divide the pavement into regular-shaped concrete slabs. After comparing different connection methods, the dapped-end connection was found to have excellent mechanical performance, as well as the advantages of simple production, fast installation, and a reduced structural layer. This connection method is widely used in foreign projects and can serve as a reference for prefabricated subgrade connections. Therefore, in this paper, a dapped-end connection is selected as the form of prefabricated block connection, as illustrated in Figure 2.

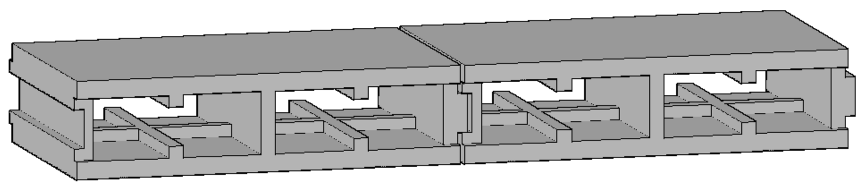


Figure 2. The connection form of the dapped-end connection.

2.2. Adaptability Analysis of Road Alignment

The circular curve is one of the important components of the plane alignment elements. It mainly plays the role of connecting the road turning and maintaining the continuity and comfort of the road alignment. The turning of the assembled road mainly depends on the position of the prefabricated block. In order to ensure that the radius of the circular curve meets the specification requirements of the assembled road, it is necessary to determine the deflection angle of the prefabricated subgrade, the width of the joint and the required base of the prefabricated road. Through the basic formulas such as circle and angle, the number of prefabricated blocks and the calculation method of the radius of the circular curve can be gradually derived to provide guidance for pavement construction.

When the prefabricated subgrade is paved in the same direction at a fixed angle, the enclosed curve is a circular curve. According to the rectangular shape of the cavity prefabricated block, this paper considers fixing the deflection angle α of the adjacent prefabricated blocks, and each two prefabricated blocks are connected by the tail. The number of prefabricated blocks mainly refers to the number of prefabricated blocks that need to be prepared at least to complete the assembly operation under the condition of determined circular curve rotation angle α_0 and joint width L_0. Under the condition of a certain joint width, the deflection angle between adjacent prefabricated blocks can be calculated by the arc formula $l = \alpha R$. Suppose that the width of the joint is L_0, the deflection angle between the prefabricated blocks is shown in Equation (1):

$$\alpha = \frac{L_0}{R} \tag{1}$$

After calculating the deflection angle between adjacent prefabricated blocks, the deflection angle α is continued until the sum of the deflection angles reaches the specified preset value, and the number of prefabricated blocks required is at least $\left[\frac{\alpha_0}{\alpha}+1\right]$, where [ ] is the integer symbol, and the last two adjacent prefabricated blocks The deflection angle is $\left(\alpha_0 - \left[\frac{\alpha_0}{\alpha}\right]\cdot\alpha\right)+\alpha$.

The length of the circular curve consists of two parts, one is the total transverse length of the prefabricated block, and the other is the total length of the joint at the joint. Since the length of the circular curve is much larger than the longitudinal length of a single prefabricated block, the connection between the prefabricated block and the joint can be approximately regarded as an arc connection, so the length of the circular curve can be expressed as the sum of the joint width at the midline of the prefabricated block and the transverse length of the prefabricated block.

The length of the circular curve is the length of the middle line of the road, so it needs to be converted with the joint width L_0 unit. The conversion formula is as shown in Equation (2):

$$L_0' = \frac{L_0}{2} = \frac{\alpha\pi}{\alpha_0} \tag{2}$$

Assuming that the number of prefabricated blocks is x, $x-1$ joints are generated between adjacent prefabricated blocks, and the lateral size of a single prefabricated block is W. The formula for calculating the length of the circular curve is shown in Equation (3):

$$L = Wx + \frac{\alpha\pi}{A}(x-1) \tag{3}$$

Finally, the radius of the circular curve is calculated as shown in Equation (4):

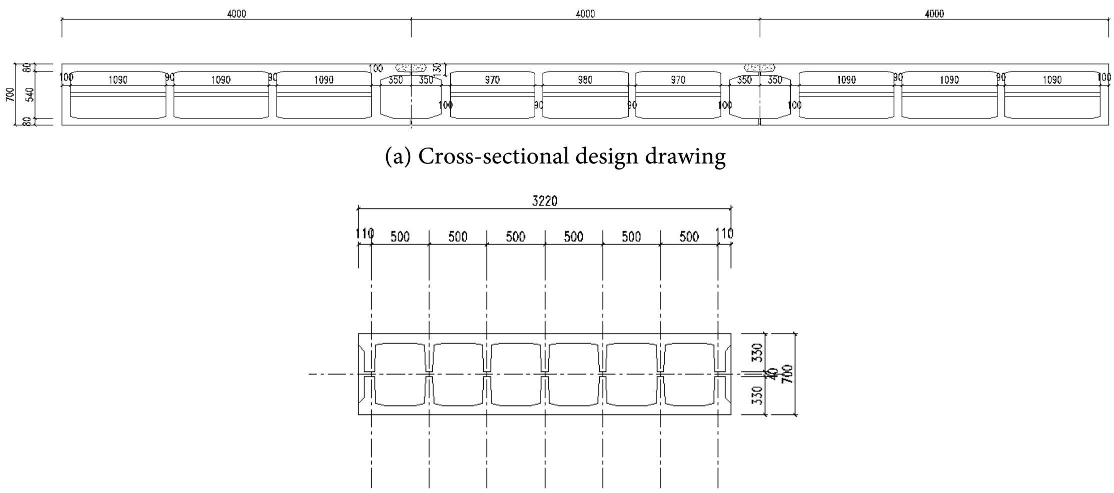
$$R = \frac{L}{\alpha} \tag{4}$$

Under certain design conditions, the number of prefabricated blocks and the radius of circular curve are calculated according to the formula. In order to further verify the rationality of the rectangular prefabricated block pavement, the pavement structure is simulated from the perspective of mechanical analysis, and the appropriate size adjustment is carried out.

3. Calculation of Rectangular Prefabricated Block

3.1. Design Condition

For the sake of continuity and driving comfort, this study takes the third-level highway with a subgrade width of 12 meters and a pavement width of 10 meters as the object of study. The design speed is 40 km/h, with two lanes, and the design vehicle is a minibus with a capacity of 2000 vehicles/h. The general minimum radius of the circular curve at this design speed is 100 meters. According to the design length of 4 meters of the cavity prefabricated subgrade, the 12-meter-wide subgrade consists of three thin-walled box culvert prefabricated blocks with diaphragms, as depicted in the horizontal and vertical design drawings in **Figure 3**.



(a) Cross-sectional design drawing

(b) Longitudinal section design drawing

Figure 3. Design of the prefabricated structure of a thin-walled box culvert with a diaphragm (unit: mm).

3.2. Rectangular Prefabricated Block Circular Curve Assembly Design

Existing prefabricated road cases typically involve straight lines and do not address the issue of curve fitting. The overall assembly method is relatively straightforward. However, the application of prefabricated chain structure technology to vehicle roads will inevitably encounter curve-related challenges in the future. In the design process, it is necessary to fit the road curve through the selection and arrangement of prefabricated blocks, which will determine the overall feasibility of the construction method.

When the road alignment is a straight line, the rectangular paving prefabricated block meets the mechanical performance test requirements. However, when the road alignment is a circular curve, the turning design needs to be accomplished by adjusting the deflection angle between adjacent prefabricated blocks, as shown in **Figure 4**:

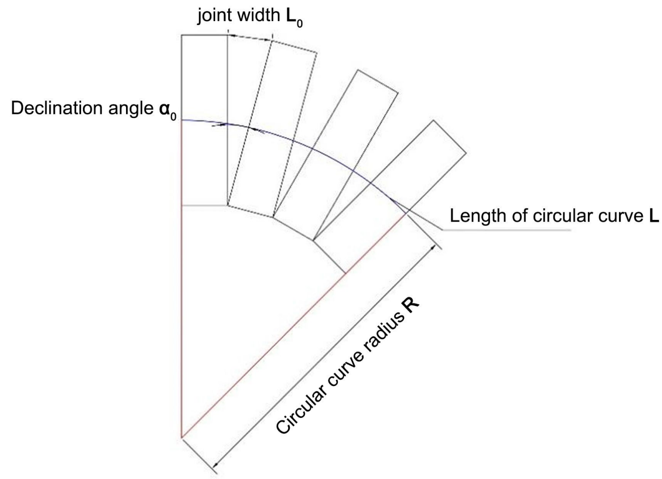


Figure 4. Joint width diagram.

The joint width L_0 refers to the interval distance between the tops of the two prefabricated blocks; the radius of the circular curve is the distance from the center line of the prefabricated block to the center of the circle connected according to this method. The length of the circular curve is the curve distance along the circumferential direction from the center line of the first prefabricated block to the last prefabricated block. In this section, the rotation angle of the circular curve is set to 60˚, and different joint widths are used to calculate the number of prefabricated blocks and the radius of the circular curve, so as to select the appropriate joint width to assemble the prefabricated roadbed.

The following is an example of calculating the number of prefabricated blocks with a joint width L_0 = 40 cm and the rotation angle $\alpha_0 = 60^\circ$:

$$\alpha = \frac{L_0}{R} = \frac{180}{\pi} \cdot \frac{L_0}{12} = \frac{15L_0}{\pi} = 1.91^\circ$$

$$x = \left[\frac{60}{\alpha} + 1 \right] = 32$$

$$\alpha' = \left(60 - \left[\frac{60}{\alpha} \right] \cdot \alpha \right) + \alpha = 2.7^\circ$$

where α is the deflection angle, x is the number of prefabricated blocks and α' is the last deflection angle. The deflection effect is shown in **Figure 5**:

The following is the calculation process of the length and the radius of circular curve:

$$L_0' = \frac{L_0}{2} = \frac{\alpha \pi}{60}$$

$$L = 3.2x + \frac{\alpha \pi}{60}(x-1) = 108.6(\text{m})$$

$$R = \frac{L}{\alpha} = \frac{3L}{\pi} = 103.71(\text{m})$$

where L_0' is the length of road centerline, L is the length of circular curve, and R is the radius of circular curve.

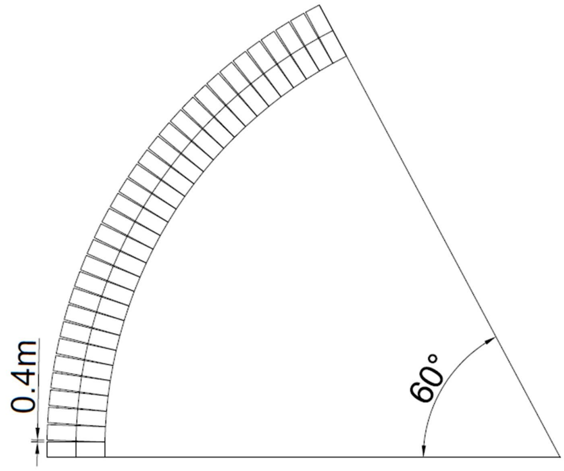


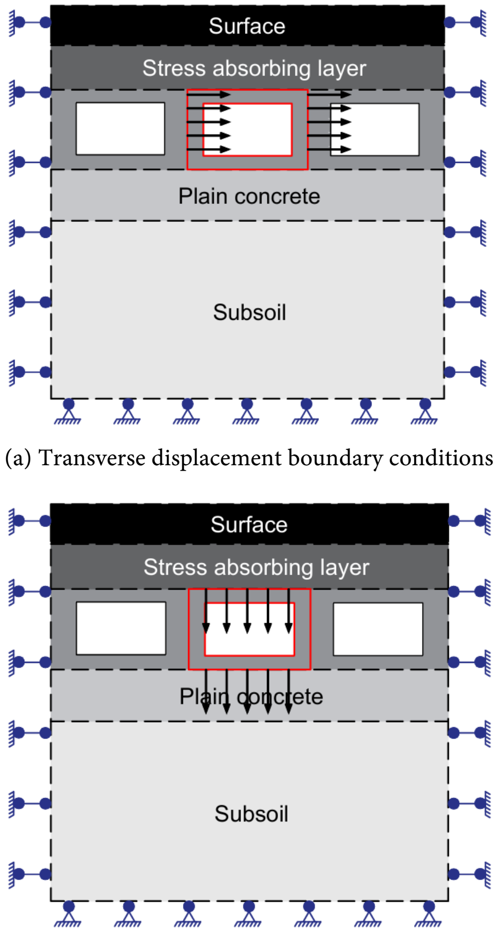
Figure 5. Circular curve design under 40cm joint width.

When the joint width is 40 cm, the calculated radius of the circular curve is 104 meters, which meets the requirements of the road route design. However, the continuity and smoothness of the car traveling on the road may be affected due to the too wide joints, and the existence of the joints has an important impact on the performance and service life of the road.

3.3. Analysis of Mechanical Properties of Rectangular Prefabricated Block

When prefabricated concrete components are assembled on a large scale, the nodes and component joints become the key links affecting the progress and overall quality of the project. The load transfer capacity of joints is to characterize the ability of joints in transferring the load from one side to the other side, which is the weakest part of pavement structure. When the road alignment is straight, the rectangular paving prefabricated block meets the mechanical performance test requirements. The turning design of the road needs to rely on the deflection angle between the adjacent prefabricated blocks. However, when the radius of the circular curve is taken as a general value, if the joint width between the corresponding prefabricated blocks is too wide, it will lead to the reduction of the bearing capacity at the joints and easy to cause road damage. According to the previous calculation results, in order to analyze the influence of transverse joints and vertical vehicle loads, this section will analyze the mechanical characteristics of rectangular prefabricated blocks under different loading conditions from the perspective of finite element simulation, and partially adjust the rectangular working conditions.

In order to study the force characteristics of different pavement structures after deformation, transverse and vertical displacement are applied to the box girder located in the middle of the finite element model. The transverse displacement is used to simulate the joints generated, and the vertical displacement is used to simulate the dislocation caused by the traffic load in the course of use. The boundary conditions are set as shown in **Figure 6**. The two displacement boundary conditions are applied to the finite element simulation of pavement, and the influence of displacement boundary conditions on the mechanical response of box girder is compared and analyzed.



(a) Transverse displacement boundary conditions

(b) Vertical displacement boundary conditions

Figure 6. Boundary condition setting of structural sensitivity analysis.

According to the literature research, the deflection degree of pavement under load can be divided into three levels: slight, moderate and severe. The deflection degree of the SMA-13 + AC-25 combination under normal road is slight, and the structure can meet the requirements of use within the service life. Therefore, this paper establishes the pavement structure model with the combination of SMA-13 + AC-25 as the surface layer, in which the stress absorbing layer is the asphalt-treated permeable base.

Interface Conditions: In the model, the interface between the prefabricated concrete blocks and the overlying asphalt layers (SMA-13 + AC-25) is assumed to be fully bonded, simulating an ideal composite action achieved through a bonding agent or interlocking surface texture in practice. This assumption implies no relative slip under service loads.

The transverse displacements (1 mm, 2 mm, 5 mm, 10 mm, 20 mm) are applied to the box girder joints in the middle of the finite element model. The deflection distribution of the pavement structure model under the transverse displacement boundary condition is shown in Figure 7:

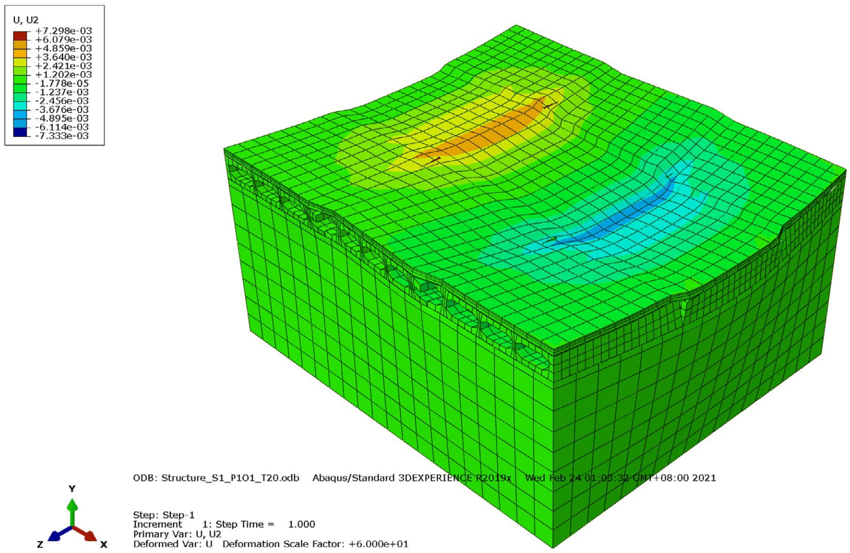


Figure 7. Deflection finite element effect diagram of pavement model under transverse displacement.

When the prefabricated structure is subjected to transverse displacement, one side shows the trend of uplifting first and then sinking, and the other side shows the trend of sinking first and then uplifting. Along the transverse direction of the road surface, at about the joint of the prefabricated structure, the deflection of the road surface appears an inflection point, where the maximum deflection of the road surface is about 5.4 mm, and then the deflection of the road surface shows a reverse change, and the maximum deflection can reach 8.4 mm, which indicates that the road surface is affected by the transverse displacement of the prefabricated structure.

The vertical displacement (10 mm, 20 mm, 50 mm, 100 mm, 200 mm) is applied to the box girder joints in the middle of the finite element model. The deflection distribution of the pavement structure model under the vertical displacement boundary condition is shown in Figure 8:

When the prefabricated structure is subjected to vertical displacement, the deflection distribution presents a "U" shape along the transverse direction of the pavement. The bottom width of the "U" shape is equal to the width of the prefabricated structure, and the bottom deflection value of the "U" shape is equal to the vertical displacement, while there is an obvious deflection mutation phenomenon at the edge of the prefabricated structure.

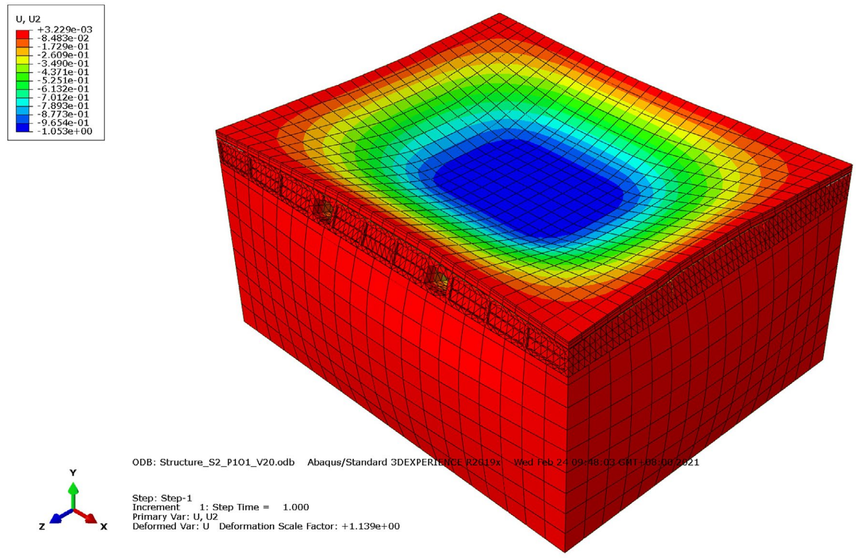


Figure 8. Deflection finite element effect diagram of pavement model under vertical displacement.

It can be seen from the mechanical simulation of the finite element that when the larger the radius of the circular curve, the larger the width joint between the prefabricated blocks, the corresponding transverse displacement and vertical displacement is also larger, which is easy to produce bending deformation at the joints, resulting in uneven roads and affecting the driving comfort of the road. Therefore, the conventional rectangular prefabricated block cannot meet the needs of the road, so this paper will propose a trapezoidal prefabricated block to improve this phenomenon.

4. Calculation of Trapezoidal Prefabricated Block

4.1. The Shape Design of Trapezoidal Prefabricated Block

The concept and design of trapezoidal prefabricated blocks are inspired by the general wedge segment used in tunnel shield construction. This approach allows for line fitting through the assembly of different postures. This paper utilizes a trapezoidal thin-walled box culvert with a diaphragm. Depending on the road alignment, the assembly and adjustment of prefabricated blocks can achieve the purpose of generating straight lines and curves. The design of trapezoidal prefabricated blocks has various advantages. For straight line sections, the use of alternating trapezoidal blocks (two postures) is primarily intended to standardize production and minimize mold types. While standard rectangular blocks could be used for straight segments, employing a single block shape (trapezoidal) for the entire project simplifies logistics, inventory management, and production scheduling. This standardization can lead to overall project cost savings by reducing model investment, minimizing changeover time, and streamlining operations, despite a potentially higher per-unit production cost for trapezoidal blocks compared to mass-produced standard rectangles. Additionally, the production process at the factory can be continuous, without any interruptions due to the requirements of road construction. The shape of a section of a trapezoidal prefabricated block is presented in **Figure 9**.

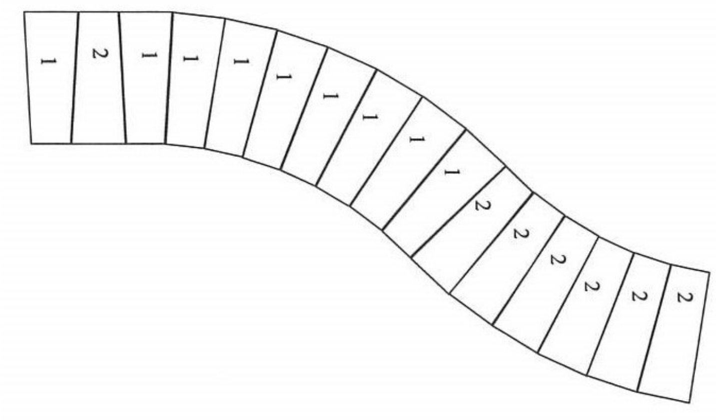
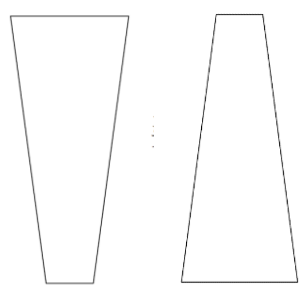


Figure 9. Shape of a section trapezoidal prefabricated block.

The key aspect in the paving design of trapezoidal prefabricated blocks is determining the ring width and amount of wedging based on the horizontal and vertical curve elements, as well as the deviation requirements of the road. The deviation calculation of each ring lining is achieved through the layout. The process of assembling prefabricated blocks involves different layout methods to achieve the desired road alignment. To accomplish this, it is necessary to clarify the posture of the prefabricated block and the corresponding advance amount of the block in each posture. Subsequently, the appropriate prefabricated block posture can be selected based on the required advance amount for different types of road alignments. For a specific trapezoidal prefabricated block, there are only two postures (rotating 180˚) for a certain section, making it relatively simple to find a posture that closely aligns with the design curve. The two postures for a section are illustrated in **Figure 10**.



(a) Posture 1 (b) Posture 2

Figure 10. Top view of two postures of trapezoidal prefabricated blocks.

4.2. The Size Design of Trapezoidal Prefabricated Block

When the road alignment is a straight line, the fitting of the straight line is realized by setting the prefabricated blocks of two postures to be alternately connected, which are connected in the same way as the rectangular prefabricated blocks, and the specific manifestation is shown in Figure 11.

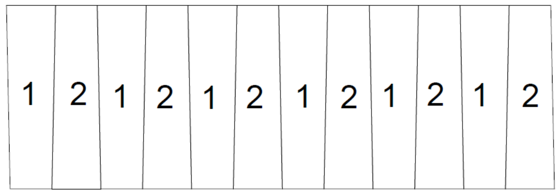


Figure 11. Linear laying of trapezoidal prefabricated block.

When all the prefabricated blocks are assembled according to the posture 1, the road alignment is shown as a circular curve, as shown in Figure 12.

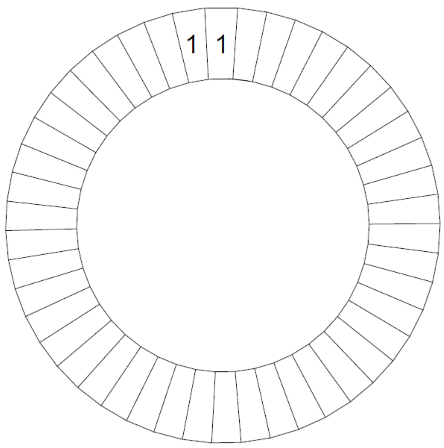


Figure 12. Circular curve laying of trapezoidal prefabricated block.

The following is an example analysis. In the case of posture 1, the radius of the circular curve is 500 m, which matches the size of the prefabricated block. The longest side of the trapezoidal prefabricated block matches the side length of the rectangular prefabricated block, and the length of the lower bottom edge is 3.2 m. Like in the rectangular prefabricated block, three trapezoidal prefabricated blocks are joined together to form a road with a width of 12 m. Therefore, the only parameter that needs to be calculated is the length of the upper bottom edge, which is determined by the design circle curve radius. The shape of the block is shown in Figure 13.

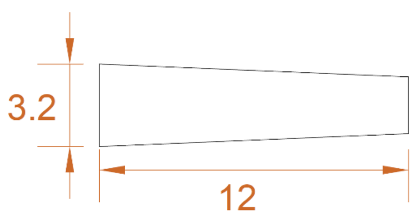


Figure 13. The lower bottom edge length and width of the prefabricated block (unit: m).

The circular curve length corresponding to the lower bottom edge of the trapezoidal prefabricated block can be calculated preferentially by the arc formula $l = \alpha R$, as shown below Equation (5):

$$l_1 = \alpha\left(R + \frac{d}{2}\right) \tag{5}$$

where l_1 is the circular curve length, α is the turning angle of the circular curve, R is the radius of the circular curve, and d is the width of the road.

The number of prefabricated blocks n can be calculated by the length of the circular curve l_1, as shown in Equation (6):

$$n = \left[\frac{l_1}{x_1}\right] + 1 \tag{6}$$

where x_1 is the lower bottom edge of the prefabricated block monomer and $[x]$ is an integer function, which means that the maximum integer is no more than x.

The upper bottom edge of the prefabricated block monomer can be calculated by Equation (5) and (6), as shown in Equation (7):

$$x_2 = \frac{\alpha\left(R - \frac{d}{2}\right)}{n} \tag{7}$$

where x_2 is the upper bottom edge of the prefabricated block monomer.

Assuming that the radius of the circular curve R = 500 m, the width of the road d = 12 m, the turning angle of the circular curve $\alpha = 60^\circ$, and the lower bottom edge x_1 = 3.2 m, the following can be calculated:

$$l_1 = 530(\text{m})$$

$$n = 166(\text{blocks})$$

$$x_2 = 3.12(\text{m})$$

The final size of the prefabricated block is shown in **Figure 14**:

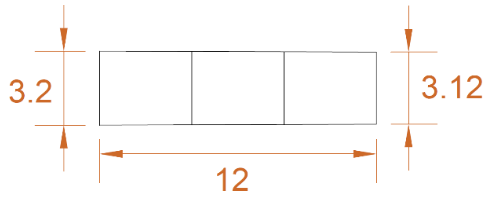


Figure 14. Prefabricated block size (top view, unit: m).

4.3. Plain Alignment Design

The process of laying a circular curve is relatively simple. The key is to determine the radius of the circular curve to determine the appropriate size of the prefabricated block. The flow chart is shown in **Figure 15**.

Due to the continuous change of the radius of curvature of the transition curve, the placement of the prefabricated blocks in the process of paving the prefabricated blocks needs to be dynamically changed according to the trajectory of the curve. By increasing the number of prefabricated blocks and adjusting the combination of postures, prefabricated blocks can be applied to most road alignments. For the two prefabricated block postures, the fitting deviation between the assembly sequence and the transition curve is linearly superimposed. Therefore, this section uses AutoCAD to fit the transition curve and simulate the laying method of the prefabricated block on the road. By comparing the deviation between each posture and the transition curve, the posture lying more in line with the road alignment can be selected. Finally, the deviation between each prefabricated block and the transition curve is minimized to achieve overall optimization. The flow chart is shown in Figure 16.

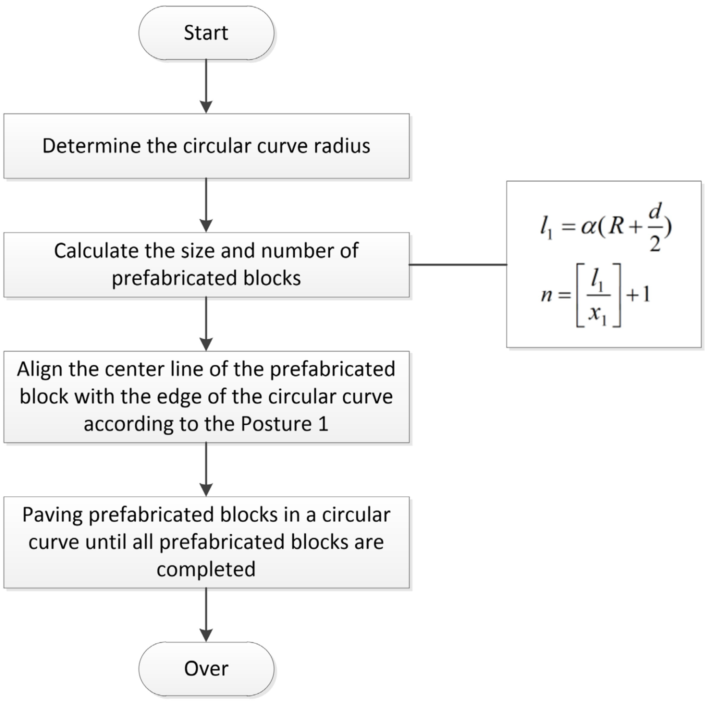


Figure 15. Flowchart of circular curve paving.

Using a minimum transition curve of 50 m as an example, we calculate the deviation between the prefabricated block and the transition curve for each posture. In the design, the transition curve is typed using the prefabricated block paving process, as shown in Figure 17. According to the layout results, there are 11 pieces in posture 1 and 5 pieces in posture 2.

To further determine the selection rules for the two postures, we counted the deviations of the 16 prefabricated blocks. The statistical results are presented in Table 1. A positive deviation refers to the transition curve being above the middle line of the trapezoidal prefabricated block, while a negative deviation refers to the transition curve being below the trapezoidal prefabricated block. The maximum deviation is 4.8 cm, the minimum deviation is 0 for the first prefabricated block, and the average deviation is 2.01 cm.

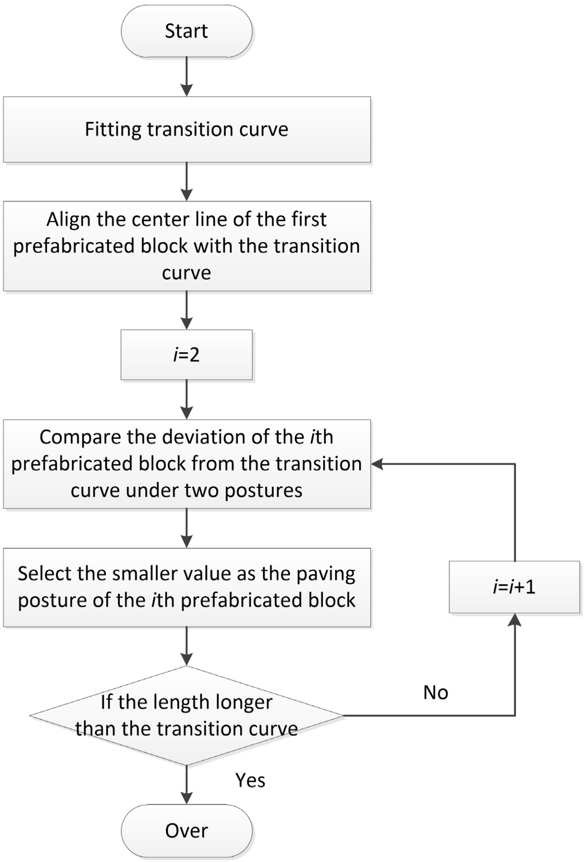


Figure 16. Flowchart of transition curve paving.

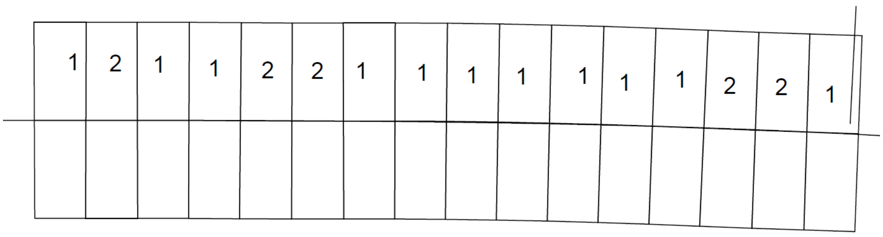


Figure 17. Layout according to the minimum transition curve.

Table 1. Deviation between each prefabricated block and the transition curve.

Prefabricated block i	Deviation (cm)	Prefabricated Block i	Deviation (cm)
1	0	9	4.8
2	0.6	10	4.2
3	0.2	11	2.8
4	0.8	12	0.8
5	−0.16	13	−2.1
6	0.3	14	−3.2
7	3	15	0.4
8	4.5	16	4.3

Through experimental simulation of the two postures, we found that when posture 1 is connected to posture 1, the positive deviation decreases or the negative deviation increases. This approach is suitable for cases with positive deviation. When posture 1 is connected to posture 2, the positive deviation or negative deviation further increases during the conversion process from posture 1 to posture 2. When posture 2 is connected to posture 2, the positive deviation increases or the negative deviation decreases, which is suitable for cases with negative deviation.

The sudden increase in deviation from prefabricated block 6 to prefabricated block 7 is due to the negative deviation of prefabricated block 5. To avoid further increasing the deviation, prefabricated blocks 5 and 6 are placed in posture 2. However, prefabricated block 7 must be placed in posture 1 and shared with 4 prefabricated blocks for correction. The last prefabricated block exceeds the planned 50 m transition curve, but it can be properly corrected in the straight line connected to it.

To ensure optimal plane alignment for plane alignment elements, it is crucial to maintain continuous and balanced alignment changes at junctions. This paper adopts a symmetrical basic shape curve, specifically combining plane curves in the following order: straight line, transition curve, circular curve, transition curve, and straight line. During the assembly process, special attention should be given to the connection between the transition curve and the circular curve. First, any deviation should be reduced to zero through posture revision, after which the circular curve can be assembled. Failure to do so may result in positive and negative deviations, causing irregularities in road alignment, which can negatively impact driving comfort and safety. A flow chart depicting the design of the plane curve combination is illustrated in Figure 18.

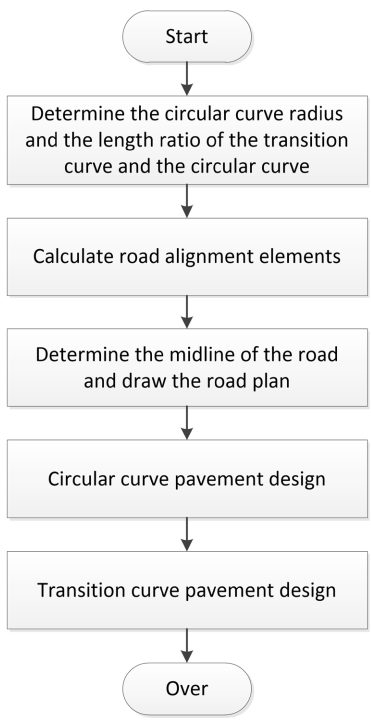


Figure 18. Plane curve combination design pavement flowchart.

4.4. Vertical Section Design

The design of the vertical dimensions of the prefabricated block is similar to that of the horizontal dimensions. While the horizontal size design primarily focuses on adjusting the length of the prefabricated block, the vertical design involves adjusting the length according to the width of the side. The prefabricated block is cut into wedges at an angle, resulting in vertical undulation of the longitudinal section. A three-dimensional representation of the prefabricated block is shown in Figure 19.

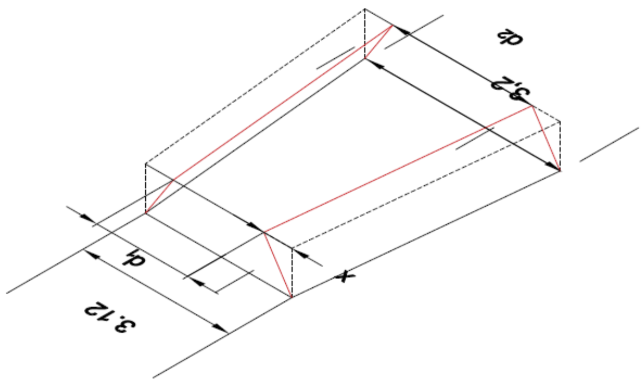


Figure 19. Three-dimensional effect diagram of the prefabricated block (unit: m).

The size diagram of the prefabricated block shows a circular curve with a radius of 500 meters as an example. The two triangular prisms along the dotted line indicate the longitudinal adjustment of the prefabricated block. Through two size adjustments, the plane and longitudinal section deflection of the road alignment can be simultaneously achieved. Taking the short side length as an example, the adjusted side view of the prefabricated block is shown in Figure 20.

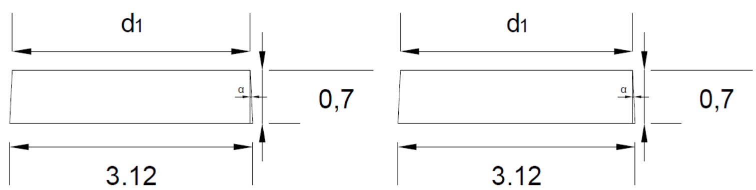


Figure 20. Prefabricated block side view (unit: m).

where d_1 is the length of the upper bottom edge of the short side of the prefabricated block, d_2 is the length of the upper bottom edge of the long side of the prefabricated block, and x is the unilateral length cut during adjustment. In the longitudinal adjustment, the unilateral length of the long side and the short side is x. α is the deflection angle generated by the prefabricated block.

To calculate the length of the upper bottom edge d_1, the radius and length of the vertical curve must be determined first. The radius of the vertical curve is set as the radius of curvature R at the inflection point of the quadratic parabola (the connection between two straight slope sections), while the length of the vertical curve is denoted as L.

The calculation method for the number of prefabricated blocks required for laying vertical curves is shown in Equation (8):

$$n_1 = \left[\frac{L}{x + d_1}\right] + 1 = \left[\frac{2L}{x_2 + d_1}\right] + 1 \tag{8}$$

where n_1 is the number of prefabricated blocks required for laying vertical curves, [ ] is the integer sign, and x_2 is the upper bottom edge of the prefabricated block.

The relationship between the deflection angle of the prefabricated block and the algebraic difference in the vertical curve slope can be obtained from the deflection law of the prefabricated block, as shown in Equation (9):

$$\omega = 2n_1\alpha \tag{9}$$

where ω is the algebraic difference in the total deflection angle of the vertical curve with two slope gradients and α is the deflection angle of the prefabricated block.

The length of the upper bottom edge of the short side of the prefabricated block can be calculated using the triangle formula, as shown in Equation (10):

$$d_1 = x_2 - 2h\tan\frac{\omega}{2n_1} \tag{10}$$

where d_1 is the length of the upper bottom edge of the short side of the prefabricated block and h is the height of the prefabricated block.

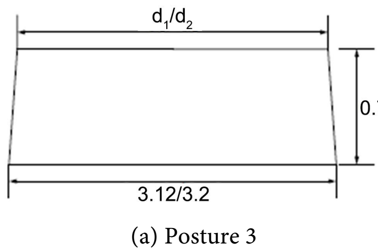
The unilateral length cut is shown in Equation (11), and the length of the upper bottom edge of the long side is shown in Equation (12):

$$x = \frac{x_2 - d_1}{2} \tag{11}$$

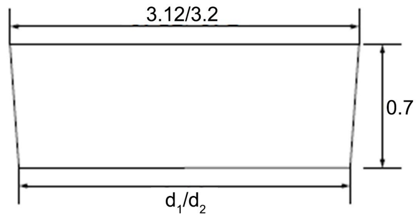
$$d_2 = x_1 - 2x \tag{12}$$

where x is the unilateral length cut and d_2 is the length of the upper bottom edge of the long side of the prefabricated block.

Since the vertical curve is in the form of a quadratic parabola and the longitudinal slope is small, a single posture cannot be used for paving. Therefore, a similar approach to plane curve paving is employed. The deviation of the two postures should be considered simultaneously to achieve optimal paving. **Figure 21** shows the side views of postures 3 and 4 of the trapezoidal prefabricated block (m).



(a) Posture 3



(b) Posture 4

Figure 21. Side view of two postures of trapezoidal prefabricated blocks (unit: m).

A flow chart of the pavement design of the vertical curve is shown in **Figure 22**. Like in the transition curve process, the vertical curve parameters should be determined first, and the size of the prefabricated block should be calculated based on these parameters. Then, the pavement should be laid according to the principle of minimizing the total deviation from the road planning midline under different attitudes. When the length reaches the vertical curve length, the vertical curve section pavement ends.

According to the calculation formula, the size of the prefabricated block mainly depends on the length L of the vertical curve and the algebraic difference of the slope. In order to compare the difference of the paving of prefabricated blocks under different vertical curve radius, this paper selects the concave vertical curve on the basis of the circular curve radius of 500 meters, and the radius is 3000 meters, 4300 meters and 6000 meters respectively. For the length of the concave vertical curve, the length value is 170 meters.

According to the calculation formula, it can be seen that the size of the prefabricated block mainly depends on the length of the vertical curve and the algebraic difference of the slope. In order to compare the difference of the paving of prefabricated blocks under different vertical curve radius, this paper selects the concave vertical curves with the radius of 3000 meters, 4300 meters and 6000 meters on the basis of a circular curve radius of 500 meters to verify the three cases respectively. For the length of the concave vertical curve, the length value is 170 meters.

When the radius of vertical curve $R = 3000$ m, then $\omega_1 = 5.7\%$, $d_1 = 3.117$ m, $d_2 = 3.197$ m, $n_1 = 55$. According to the flowchart of the vertical curve paving, the deviation of the posture of each prefabricated block is compared, and finally the laying method with the smallest total deviation is obtained. The specific layout posture is as follows, including 32 pieces of posture 3 and 23 pieces of posture 4, as shown in **Figure 23**.

When the radius of vertical curve $R = 4500$ m, then $\omega_2 = 3.7\%$, $d_1 = 3.118$ m, $d_2 = 3.198$m, $n_1 = 55$, and it has 31 pieces of posture 3 and 24 pieces of posture 4, as shown in **Figure 24**.

When the radius of vertical curve $R = 6000$ m, then $\omega_2 = 2.8\%$, $d_1 = 3.119$ m, $d_2 = 3.199$ m, $n_1 = 55$, and it has 27 pieces of posture 3 and 28 pieces of posture 4, as shown in **Figure 25**.

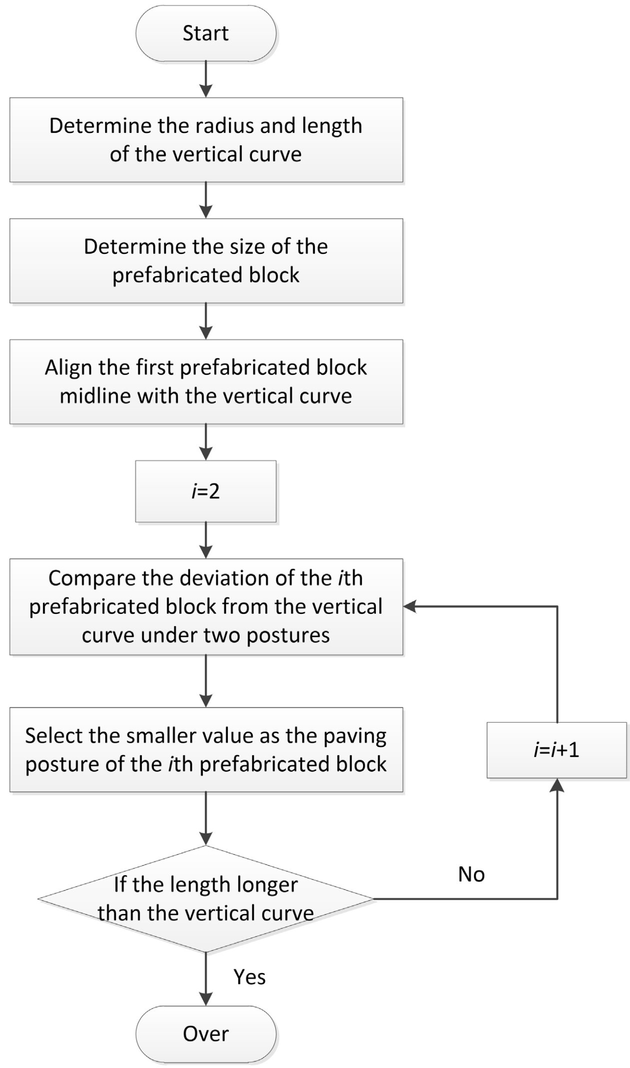


Figure 22. Flowchart of vertical curve paving.

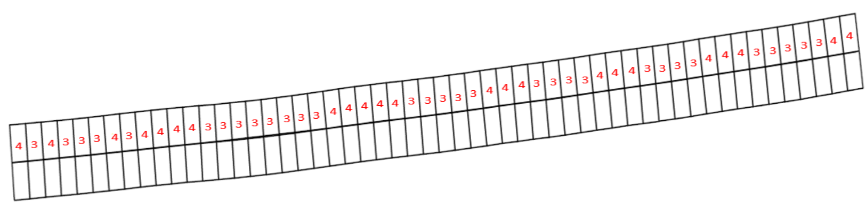


Figure 23. Pavement design with a vertical curve radius of 3000 meters.

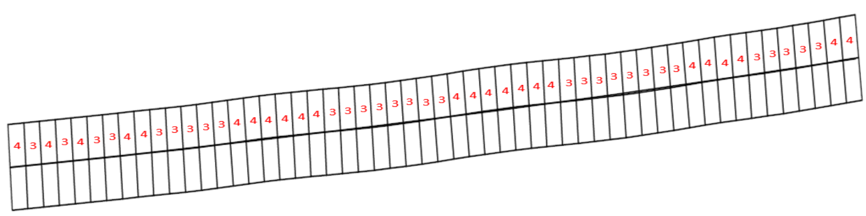


Figure 24. Pavement design with a vertical curve radius of 4500 meters.

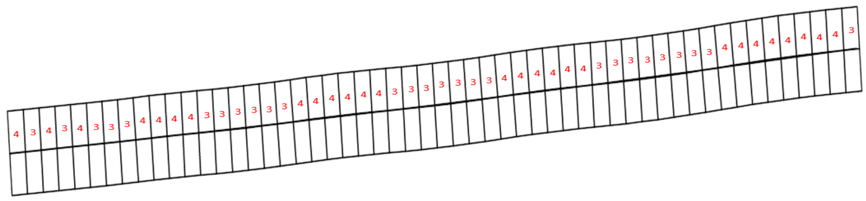


Figure 25. Pavement design with a vertical curve radius of 6000 meters.

Comparing the prefabricated blocks paving design under three vertical curve radius, it can be clearly seen that the larger the vertical curve radius is, the more the prefabricated block posture 4 is required, and the number of posture 4 and posture 3 tends to be balanced.

Generally, the road alignment design only needs to meet the plane and vertical requirements, and there are few cases that meet the plane, vertical and cross requirements. Therefore, this paper will not go into detail on the cross-section design.

5. Conclusions

Compared with the traditional on-site construction method, the use of assembled prefabricated subgrade can greatly improve the production efficiency and engineering quality, save labor costs, and for the prefabricated subgrade, road demolition still retains a certain value. After the demolition of the prefabricated subgrade, it can be reused in the construction of other roads, with the advantage of reusability.

In the design of circular curve pavement, the original rectangular prefabricated subgrade block cannot realize the road turning well due to the large width joint and the low load capacity. This paper proposes the trapezoidal prefabricated block and the circular curve turning design of the road is realized by using the deflection angle of the upper and lower bottom edges of the trapezoidal prefabricated block. After testing, the deviation generated by this method is small, which can better meet the needs of assembled road curves.

The paving design of the transition curve and the vertical curve needs to combine the two postures of the trapezoidal prefabricated block. The paving idea is to determine the posture selection of each prefabricated block according to the plain and vertical curve elements and deviation requirements of the line according to the road paving sequence. It is necessary to clarify the posture of the prefabricated block and the corresponding advance amount under the two postures, and then to select the appropriate prefabricated block posture according to the advance amount required by various types of lines.

In this paper, the pavement calculation is carried out under the given road grade, design speed, circular curve radius and other numerical conditions. The conclusions of this paper can be generalized to different grades of roads to provide design ideas for different road alignments.

Acknowledgements

The authors would like to thank Ministry of Science and Technology of the People's Republic of China for conducting Design theory and engineering technology of intensive block type high strength and low carbon mining in super large scale open-pit mine (2023YFC2907301) and Civil Aviation Airport Safety and Operation Engineering Technology Research Center for conducting the Key Technology of the Application of Municipal Solid Waste Incineration Bottom Ash in Airport Asphalt Pavement (KFKT2023-05) for supporting this study. Also, thanks to all the co-authors for their help in writing the paper. Furthermore, the authors are grateful to fellow authors whose studies serve as a good starting point for the current research and are used as references in this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zhao, G., Yang, Y., Zhang, H. and Zhang, G. (2019) A Case Study Integrating Field Measurements and Numerical Analysis of High-Fill Slope Stabilized with Cast-In-Place Piles in Yunnan, China. *Engineering Geology*, **253**, 160-170. https://doi.org/10.1016/j.enggeo.2019.03.005

[2] Sha, M., Liu, P., Gao, J. and Ma, H. (2021) Research Status and Application of Prefabricated Concrete Frame Joints. *E3S Web of Conferences*, **260**, Article ID: 03025. https://doi.org/10.1051/e3sconf/202126003025

[3] Yang, X.R. (2021) Development Status of and Outlook for Construction Technology for Prefabricated Metro Stations in China. *Tunnel Construction*, **41**, 1849-1870.

[4] Zhang, L., Huang, J.K., Liu, W., Shen, S.J. and Li, Y.G. (2018) Design and Building Method for Fabricated Light-Wood Frame Structures by Building Information Modeling. *Journal of Zhejiang University* (*Engineering Science*), **52**, 1676-1685.

[5] Li, F., Liu, H. and Wang, Z.J. (2021) Study on Stability of Roadbed in Highway by Prefabricated Composite Structure. *Journal of China & Foreign Highway*, **41**, 12-16.

[6] Yin, J.M., Jiang, Y. and Dong, X.J. (2020) Standardized Design and Performance Analysis of Prefabricated Construction Temporary Road. *IOP Conference Series*: *Earth and Environmental Science*, **525**, Article ID: 012046. https://doi.org/10.1088/1755-1315/525/1/012046

[7] Abdullah, M.A.H., Rashid, N.A., Abdul Rani, A.L. and Omar, M.F. (2020) New High Strength Water Retaining Interlocking Pavers Block for High Mechanical Performing Pavement and Reducing Runoff. *IOP Conference Series*: *Materials Science and Engineering*, **743**, Article ID: 012025. https://doi.org/10.1088/1757-899x/743/1/012025

[8] Vaitkus, A., Kleizienė, R., Vorobjovas, V. and Čygas, D. (2019) Mixture Strength Class and Slab Dimensions' Effect on the Precast Concrete Pavement Structural Performance. *The Baltic Journal of Road and Bridge Engineering*, **14**, 443-471. https://doi.org/10.7250/bjrbe.2019-14.452

[9] Sadeghi, V. and Hesami, S. (2018) Finite Element Investigation of the Joints in Precast Concrete Pavement. *Computers and Concrete*, **21**, 547-557.

[10] Bołtryk, M., Falkowski, K. and Pawluczuk, E. (2017) A Report on the Fabrication of Concrete Pavement with the Application of Anionic Bitumen Emulsion. *Construc-*

tion and Building Materials, **154**, 1004-1014.
https://doi.org/10.1016/j.conbuildmat.2017.08.028

[11] Knapton, J. (1976) The Design of Concrete Block Roads. Cement and Concrete Association.

[12] Clark, A.J. (1981) Further Investigations into the Load-Spreading of Concrete Block Paving. Cement & Concrete Association Technical Report.

[13] Luo, X.Y., Zhou, L.Y. and Yu, Z.W. (2002) Application of Prefabricated Prestressed Steel Truss and Concrete Composite Bridge. *Highway*, No. 7, 75-78.

[14] Han, Z.Q., Guo, M.Q. and Jin, M.J. (2021) Study on Mechanical Properties of Exterior Transverse Prestressed Reinforcement of Prefabricated Hollow Slabs. *Journal of China & Foreign Highway*, **41**, 171-174.

[15] Zhang, W.T., Zhao, Z.K. and Cheng, G. (2024) Research Progress of Prefabricated Concrete Bridge Structure. 2024 *World Transport Convention* (*WTC*2024) *Proceedings* (*Bridge Engineering*, *Tunnel Engineering and Rail Transit*), Qingdao, China, 26-29 June 2024, 9.

[16] Bai, H., Huang, Z., Qin, M., Ma, S. and Zhang, C. (2023) Nonlinear Static Behavior Analysis of Single/Double-Layer Frame Tunnels with Mortise and Tenon Joint. *Structures*, **55**, 876-890. https://doi.org/10.1016/j.istruc.2023.06.074

[17] Li, L., Lu, T., Jia, R., Li, Y., Zhou, W., Khater, A., *et al.* (2020) Research on Assembly Waterproofing Technology of Prefabricated Utility Tunnel. *IOP Conference Series*: *Earth and Environmental Science*, **455**, Article ID: 012170.
https://doi.org/10.1088/1755-1315/455/1/012170

[18] Duan, X., Dong, Q. and Ye, W. (2019) Experimental Study on Seismic Performance of Prefabricated Utility Tunnel. *Advances in Civil Engineering*, **2019**, Article ID: 8968260. https://doi.org/10.1155/2019/8968260

[19] Xin, J., Jiang, Q., Li, S., Chen, P. and Zhao, H. (2023) Fracturing and Energy Evolution of Rock around Prefabricated Rectangular and Circular Tunnels under Shearing Load: A Comparative Analysis. *Rock Mechanics and Rock Engineering*, **56**, 9057-9084. https://doi.org/10.1007/s00603-023-03532-8

[20] Cao, X., Yin, L., Peng, C., Ryhuang, and Wu, Z. (2023) Modeling of the Mechanical Characteristics of the Prefabricated Cantilever Structure. *Journal of Physics*: *Conference Series*, **2476**, Article ID: 012068.
https://doi.org/10.1088/1742-6596/2476/1/012068

[21] Dong, Z., Guo, Z., Zhang, H. and Li, J. (2022) Optimal Design of Prefabricated Base Joint for Asphalt Pavement Based on Finite Element Method and Field Deflection Test. *Construction and Building Materials*, **345**, Article ID: 128301.
https://doi.org/10.1016/j.conbuildmat.2022.128301

[22] Cheng, Y., Wang, H., Zhang, Y., Li, L., Bai, Y., Sun, X., *et al.* (2021) Evaluation of the Properties of Cement Mortar Used in Prefabricated Road Base as Caulking Material. *Journal of Testing and Evaluation*, **50**, 1859-1870.
https://doi.org/10.1520/jte20210297