Back-calculation for layer modulus of asphalt pavement based on equivalent stress dispersion method

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Introduction

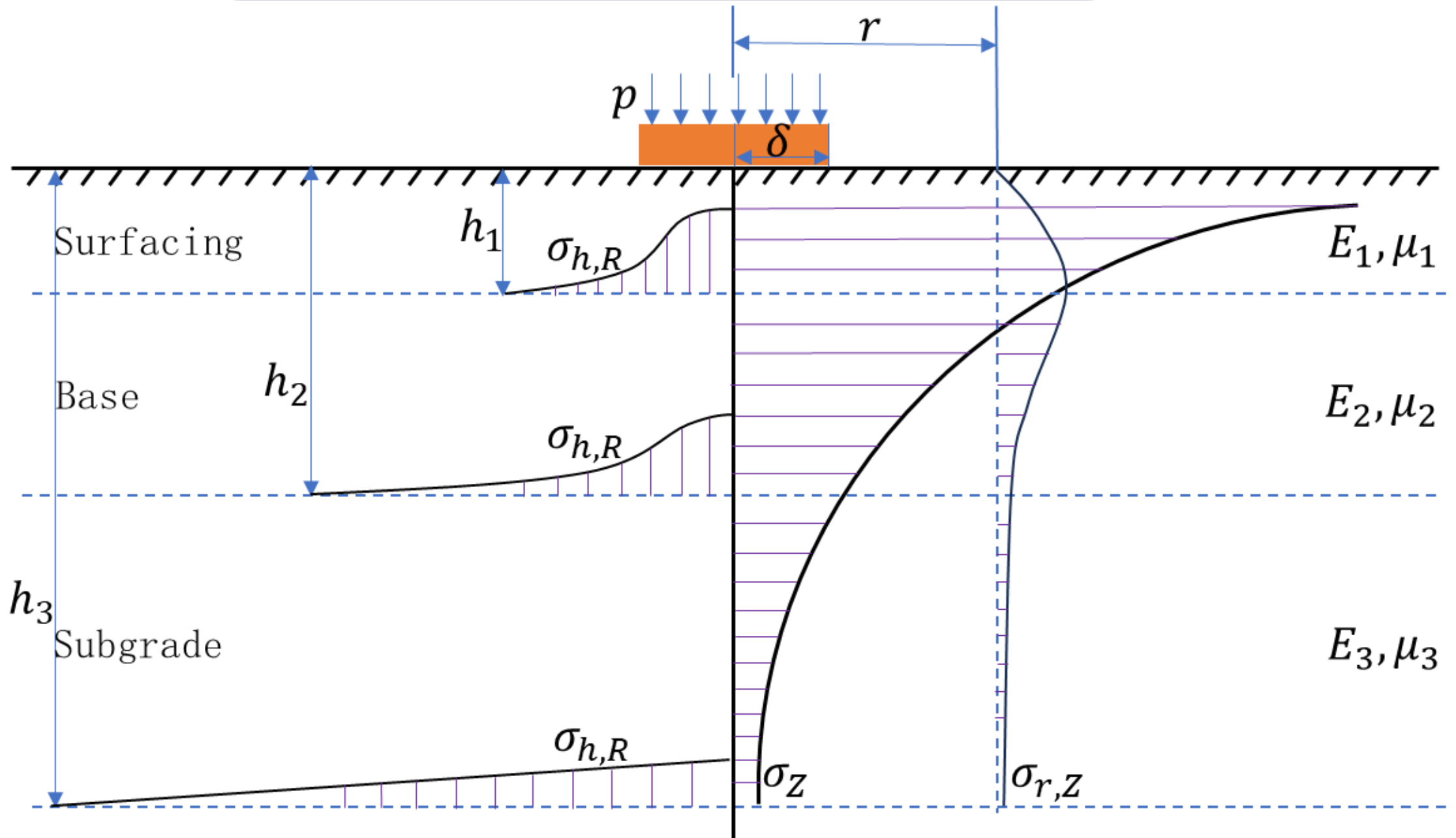
The modulus of road structural layer is a crucial parameter for evaluating the performance and durability of asphalt pavements. Despite this, global methodologies for inversely determining the modulus predominantly include database search techniques, the deflection basin characteristic method, and neural network approaches. These methods confront substantial technical hurdles such as inadequate inversion accuracy, solution non-uniqueness, and calculation result instability.

To improve the precision and dependability of the modulus inversion results for asphalt pavement structural layers, this paper introduces a stress equivalent diffusion model for pavements, grounded in the deformation theory of elastic semi-infinite bodies. It delves into the stress and deformation mechanisms within asphalt pavements, deriving expressions and solution equations for the computation of vertical stress and displacement in asphalt pavements based on equivalent stress diffusion principles. The method enhances both the efficiency and precision of computational processes for inversion models within the domain of asphalt pavement engineering.

Objectives

The goal of this paper is to develop an inversion model for determining the modulus of asphalt pavement structural layers using the equivalent stress dispersion method. Furthermore, study aims to examine the influences on the inversion accuracy of this model through finite element numerical simulation experiments.

Method



$$(1)\begin{cases}\sigma_r=\frac{p}{2}[\int_0^\infty(1-\frac{z}{\delta}x)\sin xe^{\frac{z}{\delta}x}J_0(\frac{r}{\delta}x)dx-\frac{\delta}{r}U]\\ \sigma_\theta=\frac{p}{2}[2\mu\int_0^\infty\sin xe^{\frac{z}{\delta}x}J_0(\frac{r}{\delta}x)dx+\frac{\delta}{r}U]\\ \sigma_z=\frac{p}{2}[\int_0^\infty(1+\frac{z}{\delta}x)\sin xe^{\frac{z}{\delta}x}J_0(\frac{r}{\delta}x)dx]\\ \tau_{zr}=\frac{p}{2}\frac{z}{\delta}\int_0^\infty x\sin xe^{\frac{z}{\delta}x}J_1(\frac{r}{\delta}x)dx\\ u=\frac{(1+\mu)p\delta}{2E}U\\ U=\int_0^\infty(1-2\mu-\frac{z}{\delta}x)\frac{\sin x}{x}e^{-\frac{z}{\delta}x}J_1(\frac{r}{\delta}x)dx\\ w=\frac{(1+\mu)p\delta}{2E}\int_0^\infty(2-2\mu+\frac{z}{\delta}x)\frac{\sin x}{x}e^{-\frac{z}{\delta}x}J_0(\frac{r}{\delta}x)dx\end{cases}$$

$$(2)\begin{cases}\frac{\sigma_{z,r_0,1}}{E_1}+\frac{\sigma_{z,r_0,2}}{E_2}+\frac{\sigma_{z,r_0,3}}{E_3}=l_{r0}\\ \frac{\sigma_{z,r_1,1}}{E_1}+\frac{\sigma_{z,r_1,2}}{E_2}+\frac{\sigma_{z,r_1,3}}{E_3}=l_{r1}\\ \frac{\sigma_{z,r_2,1}}{E_1}+\frac{\sigma_{z,r_2,2}}{E_2}+\frac{\sigma_{z,r_2,3}}{E_3}=l_{r2}\end{cases}$$

Based on Guo Dazhi's [19-21] solution, the stress and displacement components for an elastic half-space subjected to arbitrary axisymmetric loads can be derived, as illustrated in Eq. (1). The equation for determining the elastic modulus of the individual layers is provided in Eq. (2), The equation for determining the elastic modulus of the individual layers is provided in Eq. (2) , which can be solved by writing a MATLAB script.

Results

1. Influence of asphalt pavement layer thickness on modulus inversion of the equivalent stress diffusion model.

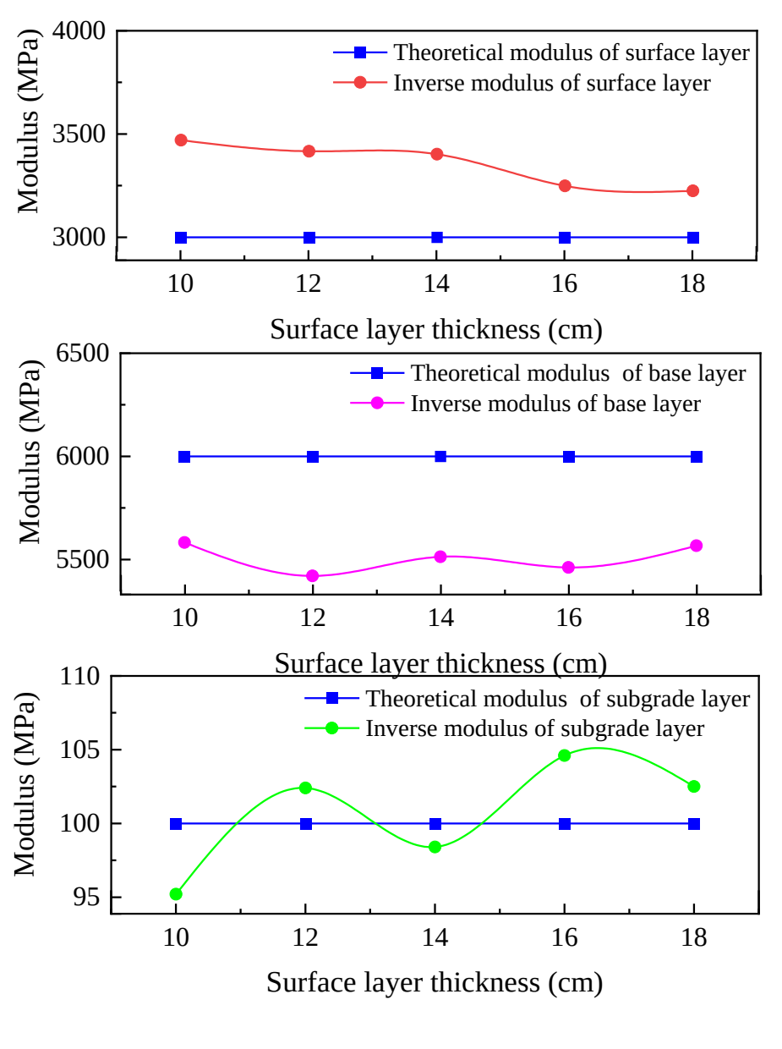


Fig.3. Influence of surface thickness variation on modulus back-calculation

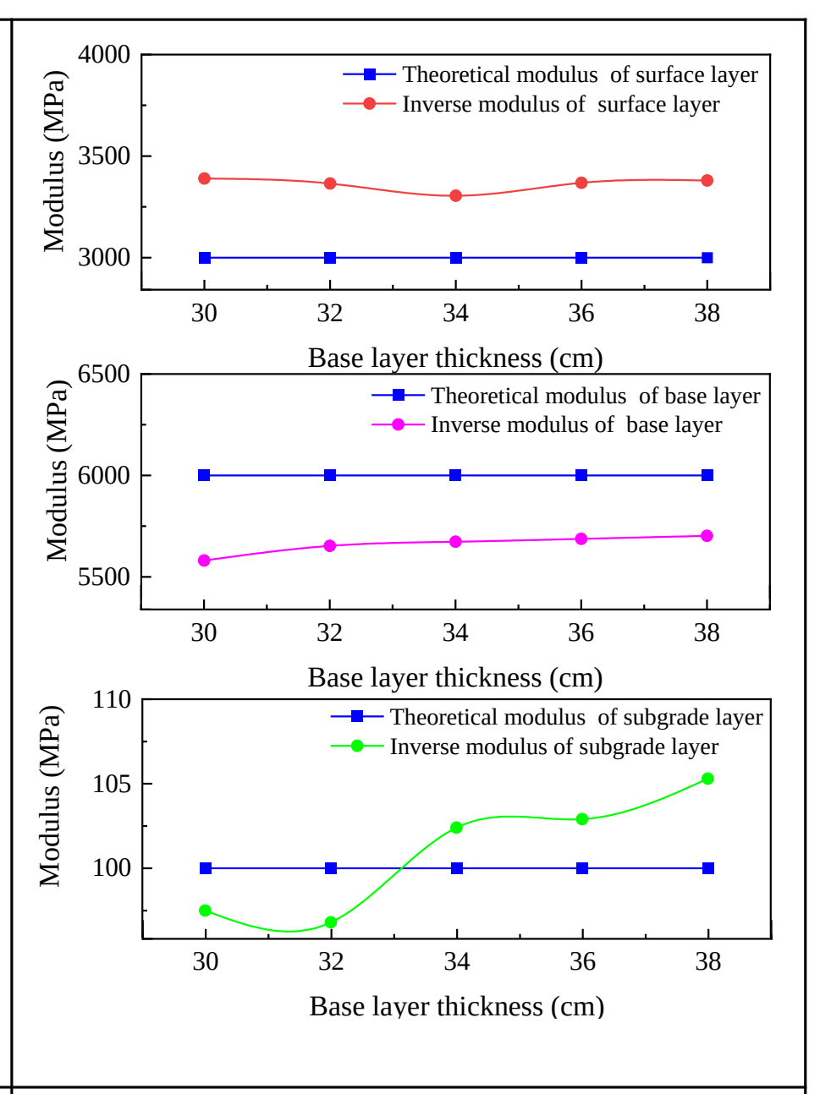


Fig.4. Influence of base thickness variation on modulus back-calculation

2.Influence of asphalt pavement layer densities on modulus inversion of the equivalent stress diffusion model.

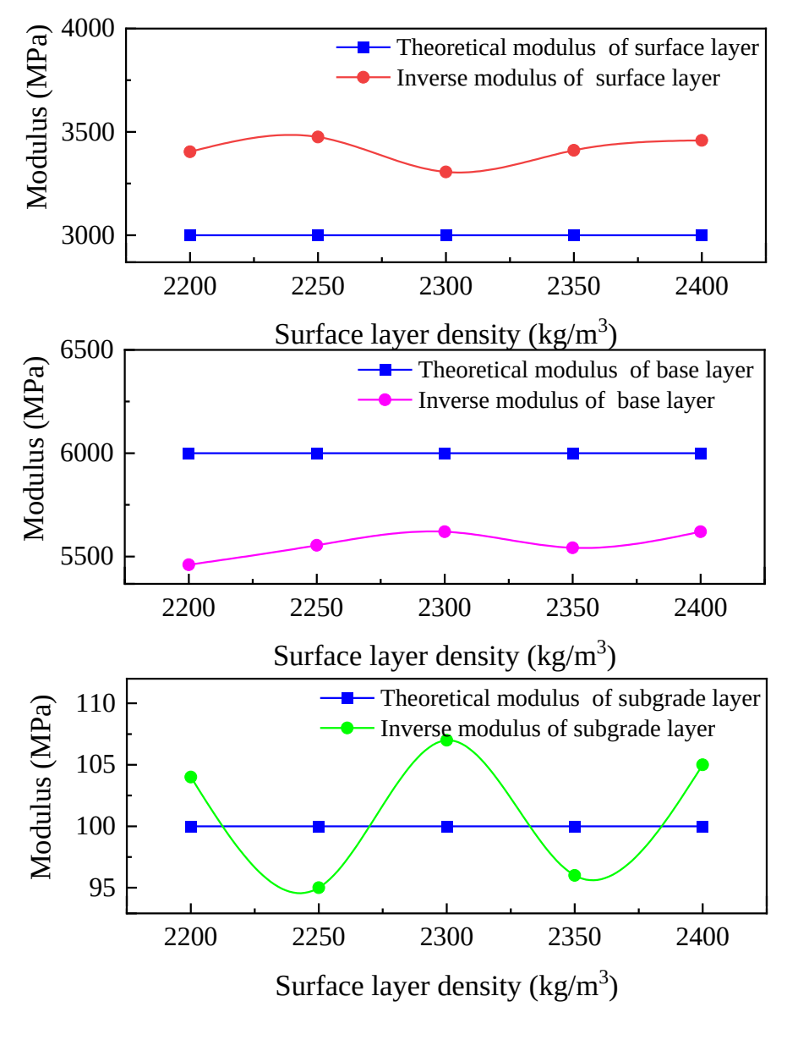


Fig.5. Influence of surface density variation on modulus back-calculation

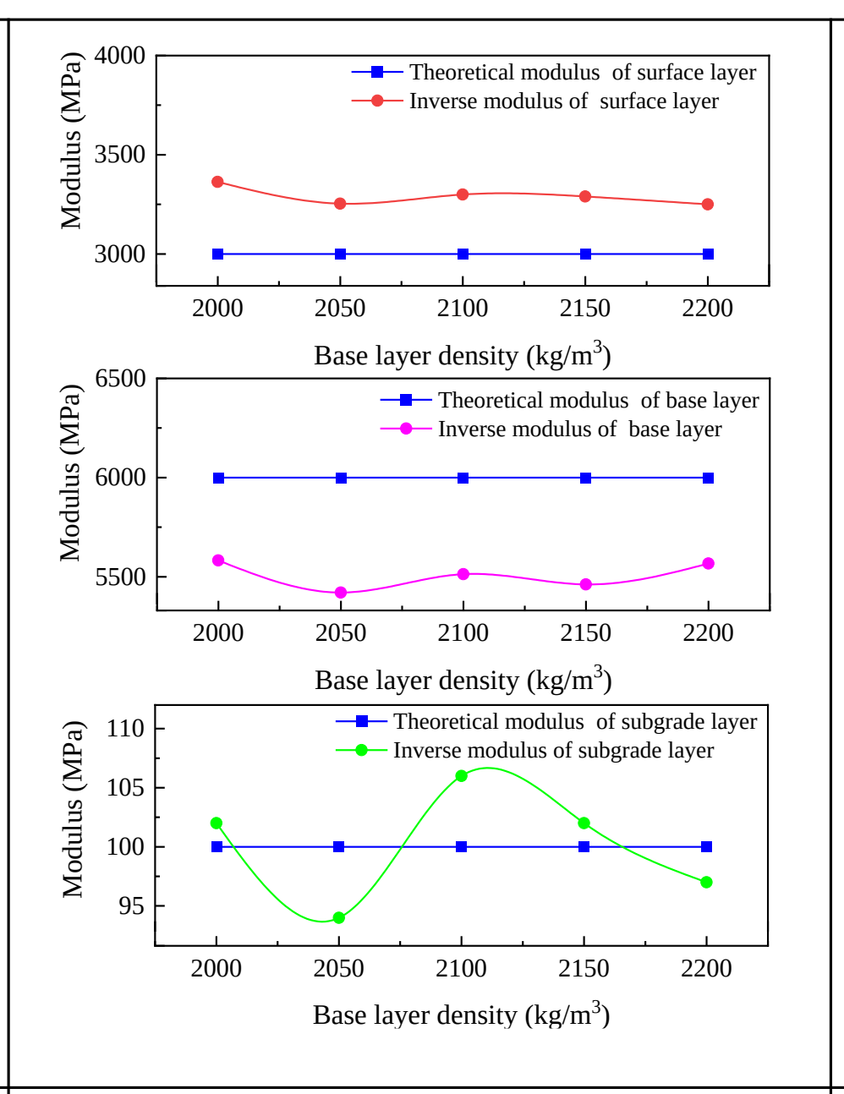


Fig.6. Influence of base density variation on modulus back-calculation

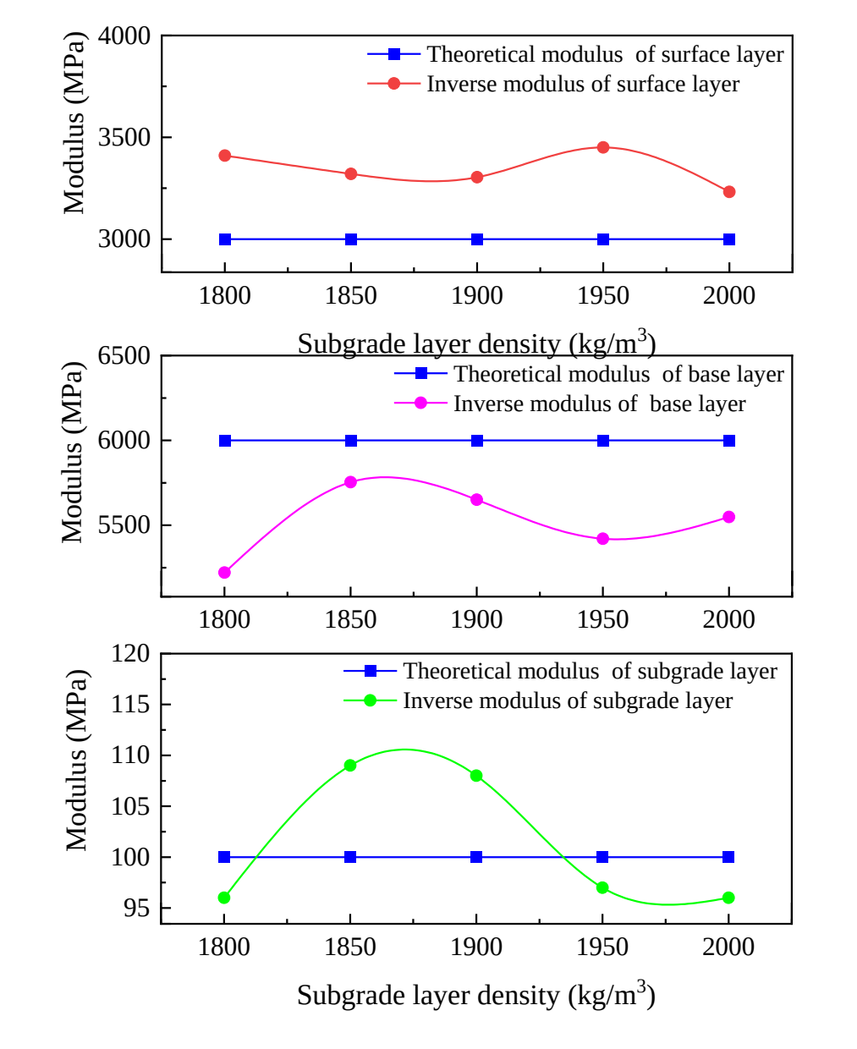


Fig.7. Influence of subgrade density variation on modulus back-calculation

3.Influence of asphalt pavement layer count on modulus inversion of the equivalent stress diffusion model.

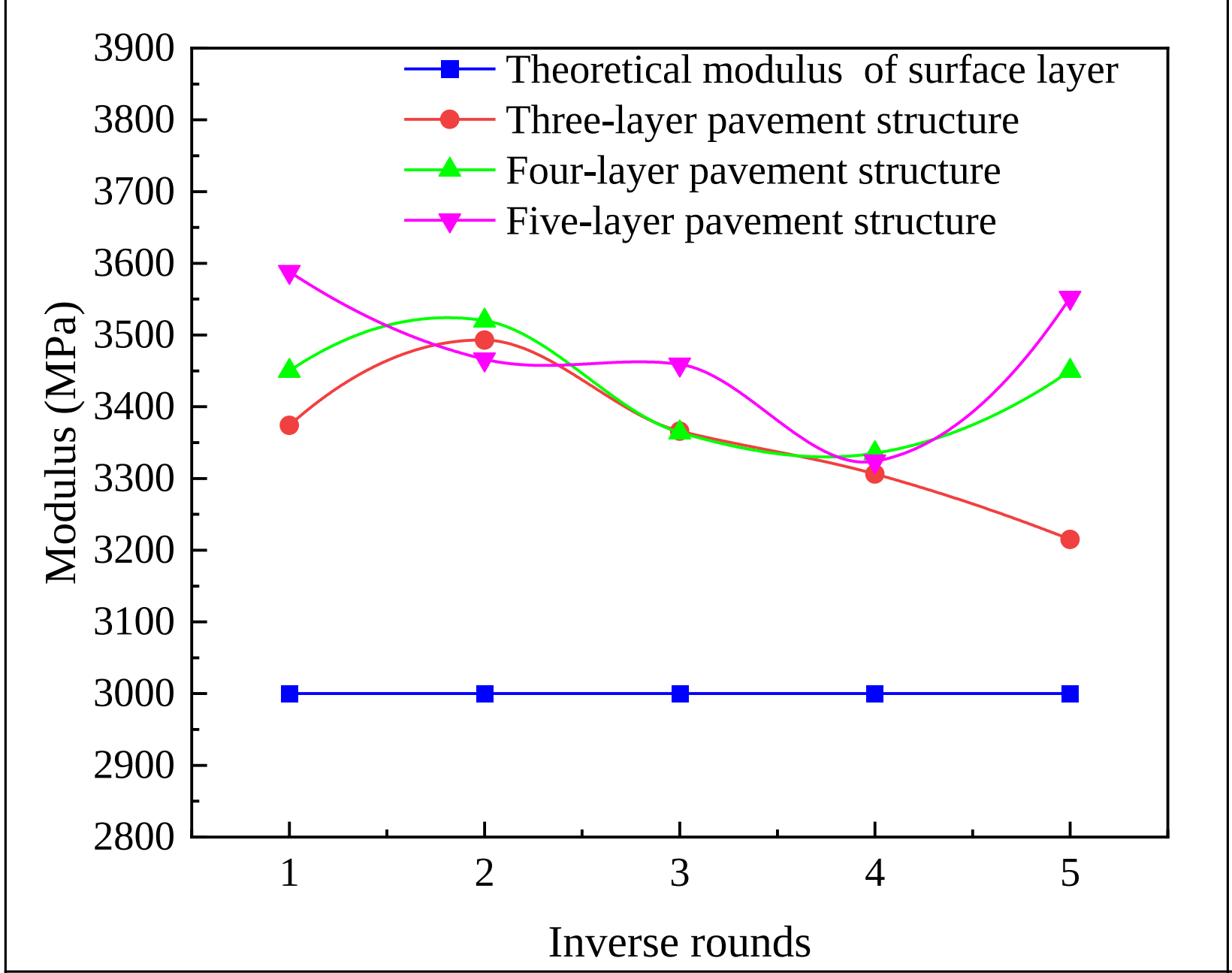


Fig.8. Influence of road structure layers on base modulus back-calculation

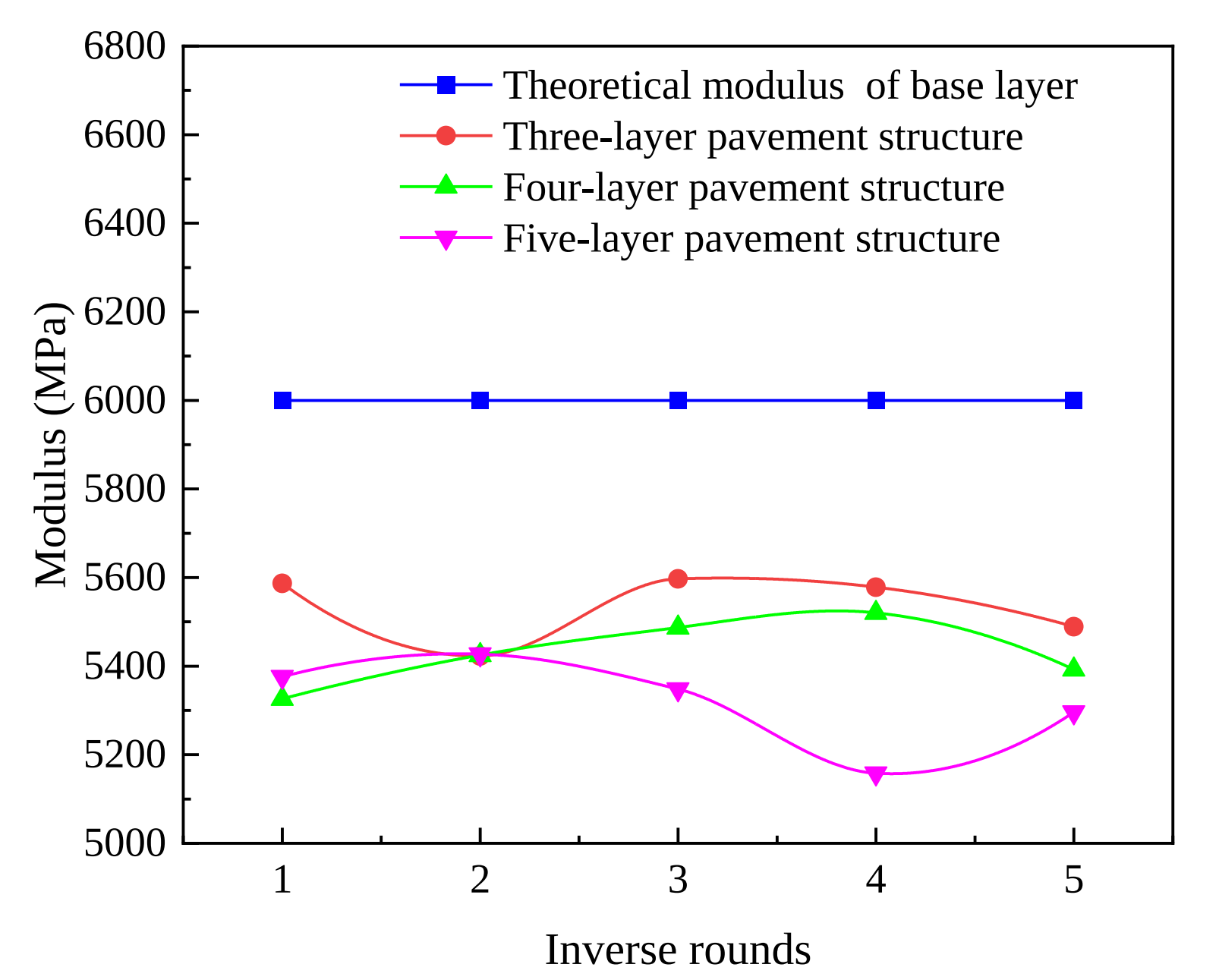


Fig.9. Influence of road structure layers on base modulus back-calculation

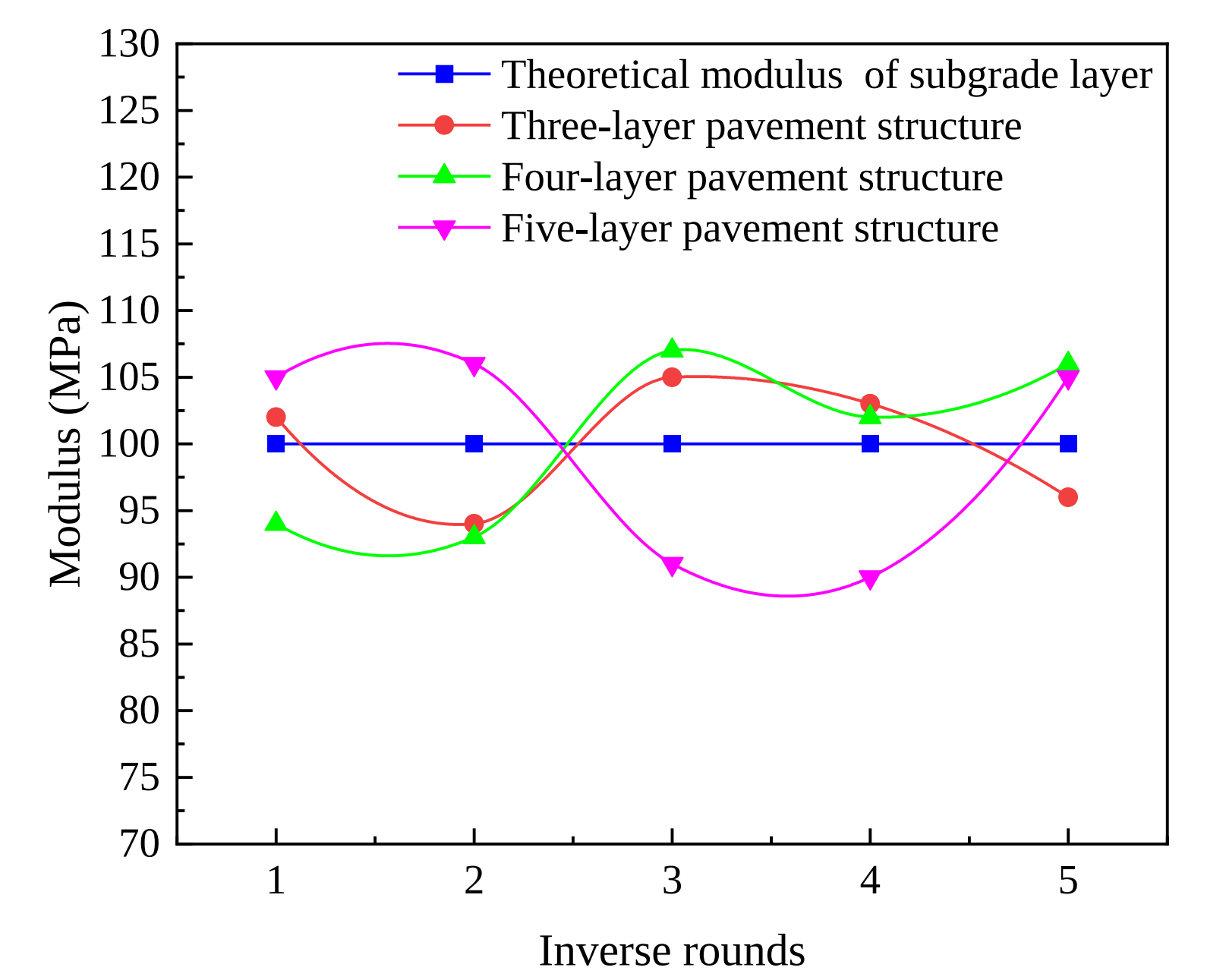


Fig.10. Influence of road structure layers on subgrade modulus back-calculation

Discussion

- The variability in the thickness of both asphalt pavement surface layer and base layer significantly impacts the precision of modulus inversion for surface layer. On average, the inversion errors are approximately 11.75% for surface layer and 12.05% for base layer.
- The variability in density across the asphalt surface layer, base layer, and subgrade layer primarily affects the precision of modulus inversion for each layer. On average, the inversion errors are as follows: the surface layer experiences an error of approximately 13.70%, the base layer has an error of about 9.71%, and the subgrade layer incurs an error of around 11.44%.
- The number of layers in a pavement structure plays a crucial role in the accuracy of modulus inversion for both surface and base layers. As the layer count in pavement structure rises, the inversion error for modulus of these structural layers tends to increase progressively. Conversely, the modulus of subgrade layer is relatively insensitive to the increase in the number of pavement layers, exhibiting an average inversion error of less than 7.01%.

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