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# Foamed Lightweight Soil Material for Solving Bridge Bumping on Soft Soil Foundations

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***Abstract:*** *Bridge bumping is a key generic technological problem in bridge constructions. Weak foundation and additional stress are caused by filling materials and rigid-flexible mutation. Traditionally, complex reinforcements for soft soil foundations are adopted with little efficiency. As a new type of lightweight man-made soil, foamed lightweight soil with a light bulk density and adjustable unconfined compressive strength can effectively solve this problem. A typical design method of bridge head with foamed lightweight soil is presented and discussed in this study. The main mechanisms of foamed lightweight soil in mitigating the influence of different stiffness of abutment and soft soil are analyzed accordingly.*

***Keywords:*** *foamed lightweight soil, bridge bumping, roadbed, additional stress*

## 1. Introduction

Foamed lightweight soil is a new type of lightweight man-made soil filling material, developed in the field of civil engineering in recent years [1]. It is composed of a curing agent, water, and a pre-made bubble with a certain proportion of raw soil (sand, clay, and engineering waste soil) [2]. After adequate mixing and stirring, foamed lightweight soil is prepared and then cured to develop strength [3,4]. Its main characteristics are smaller bulk density, freely adjusted strength, small thermal conductivity, excellent shock resistance, heat/sound insulation, anti-freezing and thawing performance, and easier construction [5,6], shown in Table 1.

*Table 1: Main characteristics of foamed lightweight soil*

| No. | Characteristics | Specifications |
|---|---|---|
| 1 | Easily obtained raw materials | Raw materials contained cements, water and fine sand, coarse aggregates like stones are not required. Fine sand can adopt the abundant aeolian sand existed in desertification area. |
| 2 | Well freezing and thawing resistance | The volume ratio of bubbles reaches 40-70 vol. %, so that the coefficient of thermal conductivity is low. |
| 3 | Adjustable strength | The strength can be adjusted in 0.3-8MPa freely. |
| 4 | Durability | Belongs to the cement product, having good durability as well as concrete. |
| 5 | Easy construction | More than 500m can be pumped. The flowability is excellent, and no need for vibration and compaction. |
| 6 | Self-standing | Able to backfill vertically, and no force is generated on the retaining wall. |
| 7 | Lightweight | The range of bulk density: 5~13 $kN/m^3$. |

Thanks to the above features, foamed lightweight soil cast-in-situ has obvious advantages in constructions such as widening a road, landslide area, retaining wall back, steep section, tunnel holes, and buried pipes [7]. In contrast with traditional soft soil, foamed lightweight concrete is lighter in bulk density and stronger in resisting external forces. Thus, this new type of material is proposed for solving the bridge bumping problem in soft soil foundation constructions [8,9]. In the northwest of China, frost heaving, turning over of mud, and thawing settlement of foundations are commonly existed due to the cold climate in winter. In southwest China, gullies are crisscrossed, and structures like culverts and retaining walls are set to cope with the uneven topography. The phenomenon of bridge bumping and retaining walls heaving or even collapsing are occurred commonly. Although various technical measures have been carried out for the prevention and treatment of such problems, they have not been solved fundamentally with certain applicability and limitations. The developing and utilizing

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cast-in-place foamed lightweight soil provide a new type of technical measure [10], solving the above-mentioned problems and promoting the highway construction in western China positively.

## 2. Main Cause For Bridge Bumping

Bridge bumping belongs to a key generic technological problem in bridge construction [11,12]. Bridges are typically built with reinforced concrete slabs which link the bridge deck to the roadway. The reinforced concrete slabs are usually supported by the bridge abutment and embankment, providing a smooth and safe transition of vehicles from roadway to bridge or from the bridge to the roadway. However, cases have been collected about the bridge bump at the bridge head or bridge end since drivers feel “jumping” when vehicles approach or leave the bridges [8]. This problem is serious since the bridge needs maintenance after a short period of service. The main reasons for this phenomenon are listed below.

### *2.1. Weak foundation*

Differential settlement is the leading cause of bridge bumping. Culverts are usually located in gully sections, with high groundwater levels and soft foundations typically. Such soil contains organic substances and a large volume of pores, and the moisture content inside is generally higher than limited liquid. Hence, saturated normal soft soil is often characterized by high compressibility, small permeability coefficient, high sensitivity, and low shear strength. Once disturbed, the original structure of soft soil is damaged, and the unconfined compressive strength significantly reduces. Since the filling position of the subgrade at the bridge head is relatively high, and the additional stress caused by the foundation is large, it is easier to cause settlement under structural weight and vehicle load in such a weak foundation, which usually spends years or even ten years to make this settlement stable.

### *2.2. Compression of filling materials*

Compression settlement depends on the characteristics of filling materials, construction conditions, and the setting of protective drainage in front and back of the abutment. To mitigate the post-construction settlement of filler at the abutment back, porous permeable filling materials are generally used. However, the compaction machine could not closely work on the back of the abutment during construction due to the narrow space of the construction site. As a result, the pores in filling material particles cannot be eliminated completely. In addition, low-quality filling materials with performance lower than the requirements of design and specifications lead to compression and settling inevitably under the vertical and vibration load of highways and vehicles, resulting in a car bumping.

### *2.3. Rigid-flexible mutation*

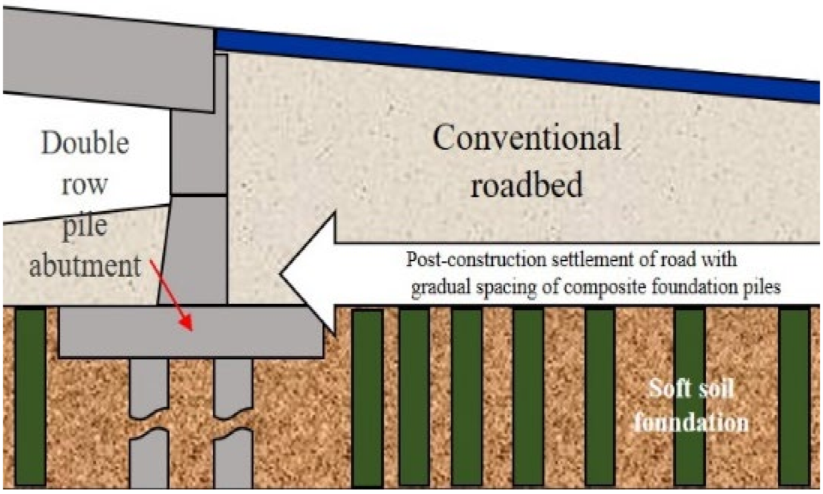


*Figure 1: Conventional backfill in bridge and culvert transition.*

Different rigid pavements produce different vibration effects on the bumping area [13]. The energy

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absorption of flexible materials is larger than that of rigid materials. Herein, the bridge is a rigid structure supported on the rock strata by a double row pile abutment (Fig. 1). However, the roadbed connected with the structural abutment belongs to a flexible body, with smaller rigidity and greater flexibility compared to the abutment. Obviously, there is a large stiffness difference between roadbed and abutment, which inevitably leads to large plastic deformation differences and stiffness mutation. Although the post-construction settlement of road with the gradual larger spacing of composite foundation piles is adopted in the conventional roadbed, the stiffness and settlement difference of each pile still aggravates the vibration effect of the bridge bumping.

Although the abutment pile foundation is usually treated by the soft foundation and back excavation construction is carried out on basis of stable foundation settlement. The abutment and abutment pile foundation are moved sideways or even broken due to the filling soil load and pressure of the deep foundation. These seriously affect the construction quality of the project. Thus, the conventional method includes usually three overlays of pavement to meet the designed pavement line, since the settlement of soft soil foundation is not stable and continues to grow after the overlay is constructed (Fig.2).

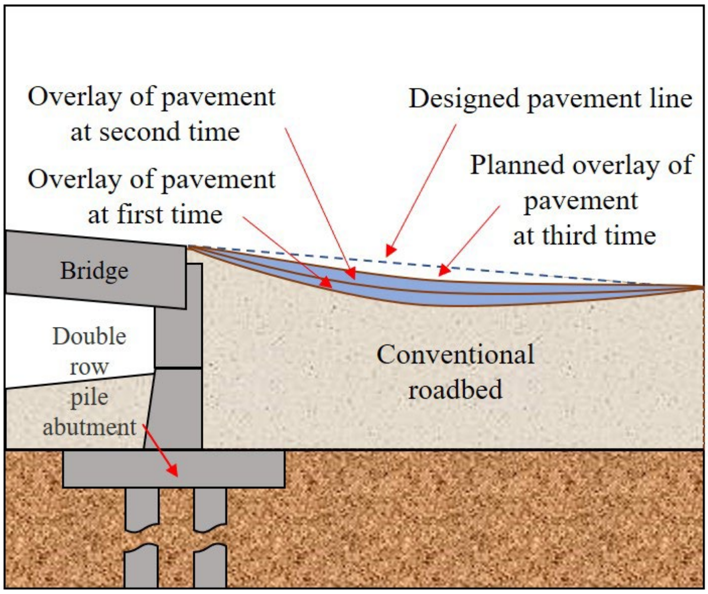


*Figure 2: Overlays of pavement.*

### 3. Solving Bridge Bumping With Foamed Lightweight Soil

For a long time, the research on increasing the bearing capacity of soft foundations has been conducted, but less investment has been carried out in reducing the weight of backfilling soil. As a result, the problem of abutment bumping is hard to be solved. When foamed lightweight road material is introduced, a solution to the above problem becomes simple. The mechanism is schematically shown in Fig.3 without piles. Due to the lightweight nature of foamed lightweight soil, the structural dead weight is dramatically reduced. Besides, the modulus of elasticity and strength of foamed lightweight soil is higher than that of soft soil, providing more support and less deformation under dead load and live load. By reducing the additional stress of the foundation and realizing rigid abutment to flexible subgrade, the technology of foamed lightweight soil optimizes the abutment structure for the bridge. The filling transition section with foamed lightweight soil is then developed. Foamed lightweight soil with high resistance under compression can support itself after solidification [14]. Besides, the stepped filling method smoothens the stiffness difference and achieves a smooth transition after construction settlement for the abutment, filling material, and embankment, solving the bridge bumping problem eventually.

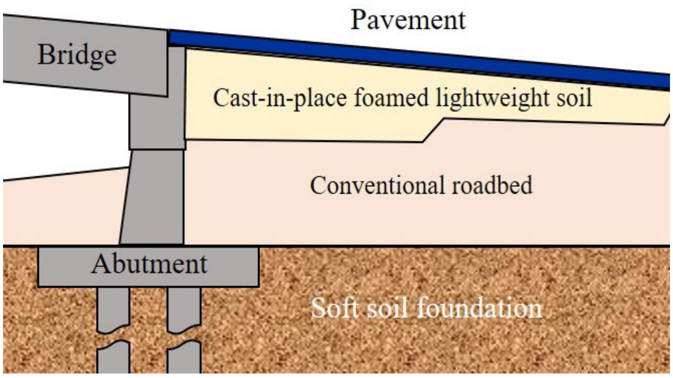


*Figure 3: Foamed lightweight soil in bridge head.*

As shown in Fig. 3, foamed lightweight soil was adopted to construct an appropriately shaped transition section at the joint of abutment and subgrade junction. It slows down and homogenizes the gradient change of the settlement curve near the junction, meeting the requirements of the continuous and uniform settlement. The main mechanisms are as follows.

▪ Foamed lightweight soil can greatly reduce the load of fill or the additional stress of soft foundation, mitigate the settlement and lateral movement of foundation, and improve the stability of embankment;

▪ Foamed lightweight soil can eliminate the post-construction settlement of the filling material itself.

▪ Foamed lightweight soil can alleviate the rigid and flexible mutation of abutment and subgrade materials.

▪ After curing, foamed lightweight soil can be self-standing, generating low pushing and squeezing force on the abutment structure. It can optimize the structure of abutment moderately, and even reduce span to cut the cost.

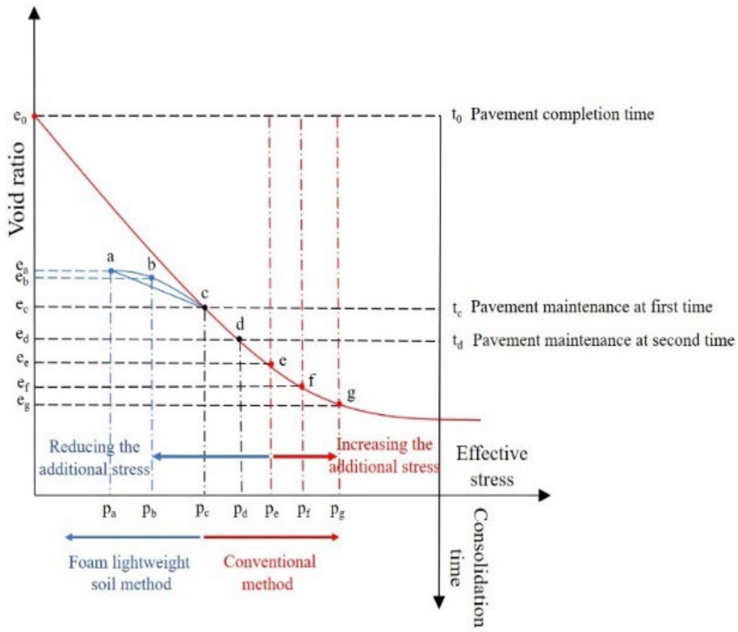


*Figure 4: Method comparison and optimization path diagram.*

Figure 4 illustrates the additional stress of foamed lightweight soil and conventional soil. A conventional method typically increases the additional stress along with the service duration of the embankment. This requires engineers to conduct maintenance after the completion of pavement. However, the application of foamed lightweight soil in the bridge project induces smaller effective stress on the system. As the consolidation time goes on, the void ratio of the cast-in-situ slab becomes smaller, and a more stable structure after servicing for a period.

Based on the above principle, another design method of the embankment at the end of the bridge is proposed, schematically shown in Fig. 5. According to different stiffness and deformation at various distances from the bridge head, the height of the cast-in-situ FSL slab is changing correspondingly. Besides, metal nets are adopted to reinforce the FSL slab with higher stiffness and contribute to the deformation compatibility when external forces are applied to the system. With such improvement, single row pile abutment is constructed. Bridge bumping is then effectively solved by the load gradient transition road settlement after construction. Less maintenance is required for this new type of soft soil foundation treatment.

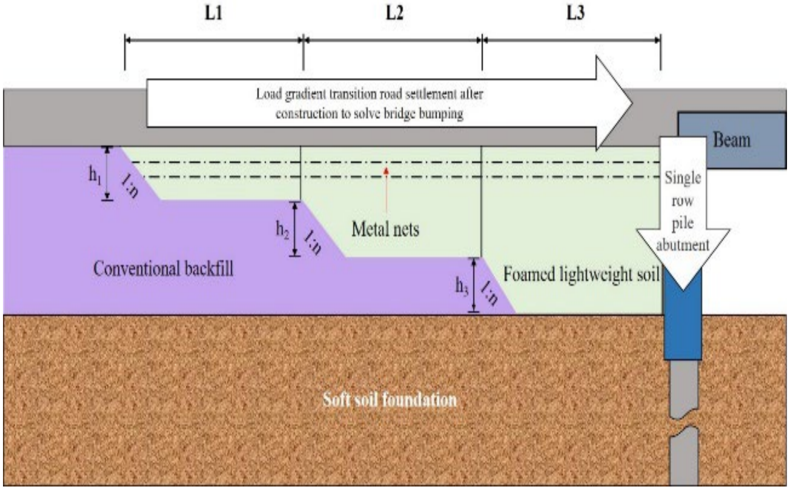


*Figure 5: Foamed lightweight soil backfill in bridge and culvert transition section.*

## 4. Environmental and Economic Benefits of Foamed Lightweight Soil

Using foam lightweight soil material consumes a large amount of waste materials [15] such as fly ash, silica fume, red mud, ammonia residue, palm oil fuel ash [16], and steel slag. It makes waste profitable, reduces the amount of cement significantly, and produces low carbon and environmental protection. The new technology greatly promotes the development of infrastructure in China to low carbon and energy saving. According to the actual application results, using foam lightweight soil backfill saves cement by 44kg/m3 and reduces carbon dioxide emission. Conventional backfill in bridge and culvert transition is combined for composite foundation pile construction, and foam lightweight soil method backfill greatly shortens the construction time and does not affect the environment. It is applied in engineering practice to improve efficiency.

## 5. Conclusion

Bridge bumping often develops at bridge ends and has become one major bridge construction and maintenance problem in bridge engineering. Foamed lightweight soil characterized by a light bulk density and adjustable unconfined compressive strength effectively solves this problem. The main mechanisms of foamed lightweight soil in mitigating the influence of different stiffness of abutment and soft soil are summarized as follows.

- Reduction in self structural weight and additional stress from filling materials
- Mitigation in the settlement and lateral movement of the foundation
- Improvement in the stability of the embankment
- Alleviation in rigid and flexible mutation
- Self-standing feature resulting in low pushing and squeezing forces.

The application of foamed lightweight soil not only improves the integration of a new type of bridge head but also contributes to the environment since solid waste is consumed as raw material in

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the composite.

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