Engineering Technology
Open Access Journal

Juniper Publishers
key to the Researchers

Research Article
Volume 5 Issue 4 - October 2023
DOI: 10.19080/ETOAJ.2023.05.555667

Eng Technol Open Acc


# Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement

**Fouzieh Rouzmehr[1]* and Mehdi Mousav[i2]**

[1]*Assistant Professor, PhD., Civil and Architectural engineering Department, Texas A&M University-Kingsville, Kingsville, Texas, USA*

[2]*Geotechnical Engineer, Kingsville, Texas, USA*

**Submission**: October 16,2023; **Published:** October 27, 2023

***Corresponding author:** Fouzieh Rouzmehr, Assistant Professor, PhD., Civil and Architectural engineering Department, Texas A&M University-Kingsville, Kingsville, Texas, USA

**Abstract**

Pavement is a structural system constructed on the existing ground to facilitate safe, reliable, and comfortable traffic movement. In the case of rigid pavement, the uppermost layer consists of concrete, while the underlying layers can include base, subbase, and subgrade materials. Over the past few decades, researchers and engineers have recognized the critical role of the materials used in these layers. In Texas, two common configurations are utilized for pavement construction: 4-inch Hot Mix Asphalt Concrete (HMAC) directly on subgrade or a combination of 1-inch HMAC and 6-inch Cement Stabilized Base (CSB) on subgrade. This paper aims to compare these two setups, considering various properties, in order to identify the optimal combination of underlying layers that minimizes stress and deflection under traffic loads while simultaneously reducing project costs. To achieve this, a series of field tests were conducted, followed by extensive computer analysis. Ultimately, a cost analysis was performed to assess the cost-effectiveness of the proposed pavement configuration.

**Keywords:** Base; Base and Subbase; CSB; Concrete Pavement; Deflection; FEM Modelling; FWD

**Abbreviations:** PCC: Portland Cement Concrete; HMAC: Hot Mix Asphalt Concrete; CSB: Cement Stabilized Base; AC: Asphalt Cement; FWD: Falling Weight Deflectometer

## Introduction

Pavement serves as a vital infrastructure, providing a safe and efficient surface for the movement of traffic. In the context of rigid pavement, a top layer of concrete is supported by underlying layers that may include base, subbase, and subgrade materials, as illustrated in (Figure 1). Early in the history of rigid pavement construction, Portland Cement Concrete was directly placed on natural soil without the incorporation of base or sublayers. However, as traffic volumes and speeds increased, issues arose, notably with natural soil displacement through joints and cracks in the concrete slab [1].

Over the past few decades, the significance of the materials used in these underlying layers has become increasingly apparent to researchers and engineers. A variety of base and subbase materials have been explored for rigid pavement, each with unique characteristics and advantages. The primary role of the base layer is to offer support to the concrete slab and ensure uniform load distribution. Alternatives for base materials include dense and open-graded unbound materials, cement-stabilized bases, lean concrete bases, and Cement-Stabilized Bases (CSB) in conjunction with a layer of Asphalt Cement (AC) acting as a bond breaker.

Among these options, cement treatment bases have frequently exhibited strong performance. An ideal base material should possess qualities such as resistance to moderate friction, the potential for bonding with the concrete slab, water resistance, and consistent compatibility. It must also offer flexibility to minimize curling or warping stress while avoiding tendencies that lead to cracking and reflective issues in the concrete slab. Additionally, a moderate level of friction is necessary to prevent shear stress between the concrete and the base layer. In Texas, pavement construction often involves 4-inch Hot Mix Asphalt Concrete (HMAC) or 1-inch AC with 6-inch CSB on a treated subgrade [2].

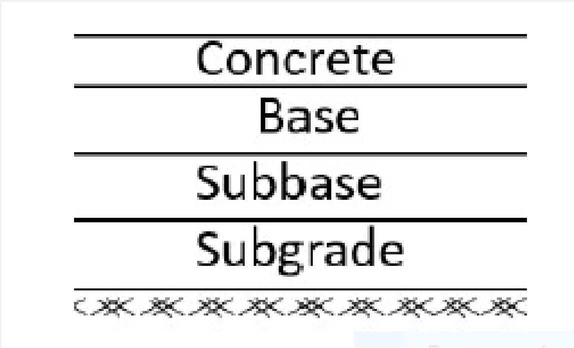


**Figure 1:** Overall pavement configuration.

The key characteristic of a quality rigid pavement foundation is not just its strength but, more critically, its ability to provide uniform, continuous support devoid of abrupt spatial and material transitions. The design of rigid pavement relies on the structural carrying capacity of Portland Cement Concrete (PCC) and the consistency of support offered by the underlying layers.

Traditionally, in the simplification of designing rigid pavements, it was assumed that the thickness of PCC design was independent of the base strength or stiffness, with a constant k-value of 300 psi/in applied uniformly across the layers under concrete [2]. In practice, it is evident that the properties and thickness of these layers significantly impact concrete stress and deflection, thereby offering potential for design optimization.

The assessment of pavement support, encompassing base, subbase, and subgrade layers, is typically based on the modulus of subgrade reaction (referred to as the k-value). One central assumption in concrete pavement design is that the support's deflection at any point beneath a concrete section is directly proportional to the vertical stress applied at that point. Incorporating a base or subbase layer may enhance subgrade protection, provide increased support for PCC slabs, and augment the k-value. Achieving a stable, smooth surface is facilitated through the use of stabilized bases under concrete pavements. However, a base layer that is excessively rigid may introduce unintended problems [3,4]. Overly stiff bases cannot adapt to changes in slab shape induced by environmental factors (e.g., curling and warping) [5]. This can lead to increased stresses and deflections within the slab, particularly during the concrete's early life stages, which may eventually result in cracking. In general, base thickness depends on the support required for construction equipment and the nature and condition of the subgrade [1]. A minimum subbase thickness of 4 inches is recommended for unstabilized subbases, 4 inches for cement-stabilized subbases, and 2 inches for asphalt-treated subgrades. Quality control measures for unstabilized and cement-treated subbases should adhere to compression or density standards, with cement-treated subbases aiming for a strength range of 300 to 800 psi [6,7]. The choice of base type should be based on local material availability, cost-effectiveness through life cycle cost analysis, and the intended purpose of the base [8]. Assessing the expected performance of a specific design feature, such as base type, is complex, as it is influenced by various other design elements [9-11].

Irrespective of the base type chosen, two critical principles have been consistently proven effective:

i. Treating the cementitious base surface to prevent bonding and minimize friction at the interface between the PCC layer and the base.

ii. Selecting a base type that resists excessive deflection under traffic loads [1].

To assess deflection under traffic loads, the Falling Weight Deflectometer (FWD) test is employed. The primary purpose of this test is to gauge the structural adequacy of existing pavement and its capacity to handle anticipated traffic loads. As observed in Hveem's pioneering work, a strong correlation exists between pavement deflection (indicative of structural adequacy) and the pavement's ability to carry traffic loads at the specified service level [12]. This early insight has been integrated into overlay design, allowing the determination of the necessary overlay thickness to reduce maximum overlay deflection to acceptable levels [13]. The maximum tensile stress in a pavement occurs at the bottom of the concrete slab under wheel loading. Reducing this stress is crucial


**How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

to preventing future cracking. According to the fatigue criterion, concrete experiences fatigue when its stress exceeds its strength. Thus, reducing stress can extend the concrete's design life.

The properties of subbase layers, whether placed on subgrade or under subbases, directly influence concrete slab stresses and strains, thereby impacting the long-term pavement performance. Modulus of elasticity, often indirectly determined by compressive strength in unyielding substrates, is a commonly used parameter to measure this interaction between the foundation and the concrete slab. Contrary to intuition, excessively rigid foundations pose challenges for the functionality of the concrete surface. If concrete slabs have full contact with an extremely rigid base (infinite modulus of elasticity) and remain perfectly flat, they will experience zero deflection and zero flexural stress, leading to premature fatigue. Stiffer support systems, while reducing deflection, increase stress under environmental loads such as curling and warping.

Additionally, thicker underlying layers enhance support stiffness, emphasizing the critical role of subbase thickness and stiffness, as determined by compressive strength, in the concrete base system [7]. Considering the aforementioned discussions and the various parameters involved, the objective of this study is to evaluate different base configurations commonly used in Texas, including 4-inch HMAC or 1-inch HMAC with 6-inch CSB, while also assessing the impact of varying elastic moduli for all layers. The aim is to identify the most effective combination of underlying layers for rigid pavement, minimizing stress and deflection under FWD loading conditions while optimizing project costs. This study also examines the effects of increasing the thickness of the bond breaker. To achieve this objective, a series of field tests were conducted, followed by extensive computer analysis. The study culminates in a simple cost analysis to determine the cost-effectiveness of the proposed pavement configuration.

## Field Results

Four projects were selected, and FWD testing was conducted every 20 feet on top of a base layer prior to concrete placement. Two base types were used; one was 4-in. ASB and the other 1-in. or 1.5-in. ASB on 6-in. CSB. The top 6-in. of subgrade soil in these projects were treated with lime. At each project, several alignments were selected along the centerline of the roadway, and FWD testing was conducted along those alignments. (Table 1) shows the average deflections on base layers along alignments chosen at the four projects. (Table 1) illustrates, in general, deflections were more considerable on 4-in. ASB than the other base type. Large variabilities were observed along alignments within a project, especially at US 75 and SH 114 projects, and a difference was also observed in average deflections among SH 114, IH 35, and IH 45 projects, even though similar base structures were used, indicating a need for better quality control during construction [14].

**Table 1:** Test sections and FWD results.

| District | Base Type | Test Section | Length [ft.] | Average Deflectionon Base @9,000 lb.[mils] |
|---|---|---|---|---|
| Dallas | 4-in. AC over 6-in LTS | US 75 (1) | 2000 | 17.5 |
| | | US 75 (2) | 2000 | 21.5 |
| | | US 75 (3) | 2000 | 23.3 |
| | | US 75 (4) | 1300 | 37.8 |
| | | US 75 FR (5) | 500 | 42.5 |
| | | US 75 FR (6) | 500 | 37 |
| Dallas | 1.5-in. AC over 6-in CSB | SH 114 (1) | 1120 | 14.4 |
| | | SH 114 (2) | 1120 | 21.2 |
| | | SH 114 (3) | 860 | 16.3 |
| | | SH 114 (4) | 860 | 10.3 |
| | | SH 114 (5) | 1000 | 28.7 |
| | | SH 114 (6) | 1000 | 28.1 |
| Waco | 1.0-in. AC over 6-in. CSB | IH 35 (1) | 500 | 8.8 |
| | | IH 35 (2) | 500 | 9.8 |
| Houston | 1.0-in. AC over 6-in. CSB | IH 45 FR [A] | 680 | 9.7 |
| | | IH 45 FR [B] | 1100 | 11 |
| | | IH 45 FR [C] | 1100 | 9.1 |
| | | IH 45 FR [D] | 1080 | 9.1 |
| | | IH 45 FR [E] | 1080 | 9.8 |
| | | IH 45 FR [F] | 1080 | 8.5 |



**How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

## FEM Modeling

To assess the structural responses of pavements under the application of Falling Weight Deflectometer (FWD) loads, a 3-dimensional finite element analysis was conducted using the ABAQUS software. The primary objective of this FEM analysis was to complement the field test results, highlight any disparities, and, most significantly, identify the most suitable layered base configuration to achieve optimal performance. The initial phase of the FEM modeling involved replicating a pavement section comprising a 4-inch HMAC layer over a subgrade, as illustrated in (Figure 2). These model results were cross-validated using Burmister's hand-calculated layered pavement equations, with corresponding numerical values employed for verification. In this modeling scenario, both the HMAC layer and the subgrade were considered to exhibit linear elastic behavior, characterized by a Poisson's ratio of 0.3. The elastic modulus values assigned to the HMAC and subgrade were 400 ksi and 10 ksi, respectively.

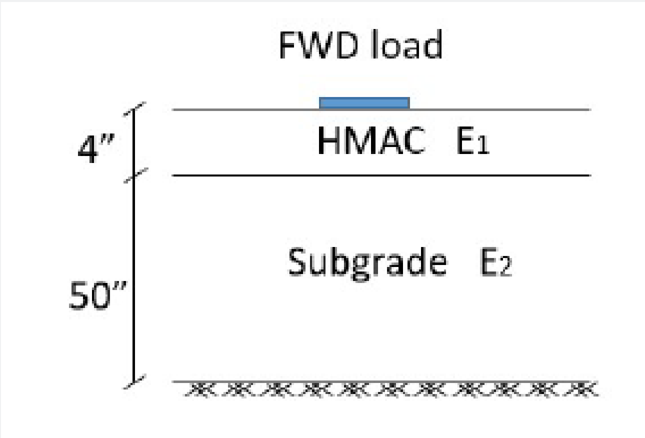


**Figure 2:** Configuration of 4-in HMAC and subgrade.

The foundational work in pavement analysis was pioneered by Donald M. Burmister in 1943 when he introduced the concept of a two-layer theory. In this theory, the pavement structure is considered as an elastic upper layer resting upon a semi-infinite elastic subgrade. This approach laid the groundwork for understanding pavement behavior under load. Burmister (1958) further advanced the theory by developing a chart for computing vertical surface deflection in a two-layer system. This chart served as a valuable tool for assessing the response of pavement structures to various loads. The deflection in such a system is calculated using the following equations under a flexible plate: $\Delta = (1.5 \times p \times a \times F2) / E2$

In this equation, E2 represents the modulus of the lower layer, often referred to as the subgrade. Additionally, the term F2 is denoted as the deflection factor, a dimensionless parameter that is instrumental in the analysis. The value of F2 is determined based on the interplay between the dimension a/h1, where h1 signifies the thickness of the first layer, and the ratio E1/E2. (Figure 3) presents the graphical representation from which the deflection factor, F2, is derived. By utilizing the chart and these equations, pavement engineers can effectively estimate vertical surface deflections within a two-layer pavement system. This understanding is pivotal for assessing the performance and structural integrity of pavements subjected to various loading conditions [15]. Burmister's contributions have played a significant role in the development of pavement analysis methods and continue to be foundational in the field of pavement engineering.

The results from both the Finite Element Modeling (FEM) analysis and the application of Burmister's equation have been collated in (Table 2). Notably, the data in this table showcases an intriguing convergence: both the FEM modeling and Burmister's equation yield identical deflection values of 30 mils. With only two data points presented in the table, one from Burmister's equation and the other from FEM modeling, the perfect alignment of these results underscores the remarkable accuracy of the FEM modeling approach. This remarkable consistency affirms the FEM modeling's capability to precisely predict and reproduce pavement deflection, emphasizing its robustness and effectiveness as a tool for pavement engineering assessments. After validating the FEM modeling approach, two distinct layered systems, one consisting of 4-inch HMAC and the other of 1-inch HMAC with a 6-inch CSB as depicted in (Figure 4), were simulated. These models incorporated varying material properties and were subjected to a 9000 lbs. FWD load to assess the impact of differing layer stiffness on deflection.


How to cite this article: Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

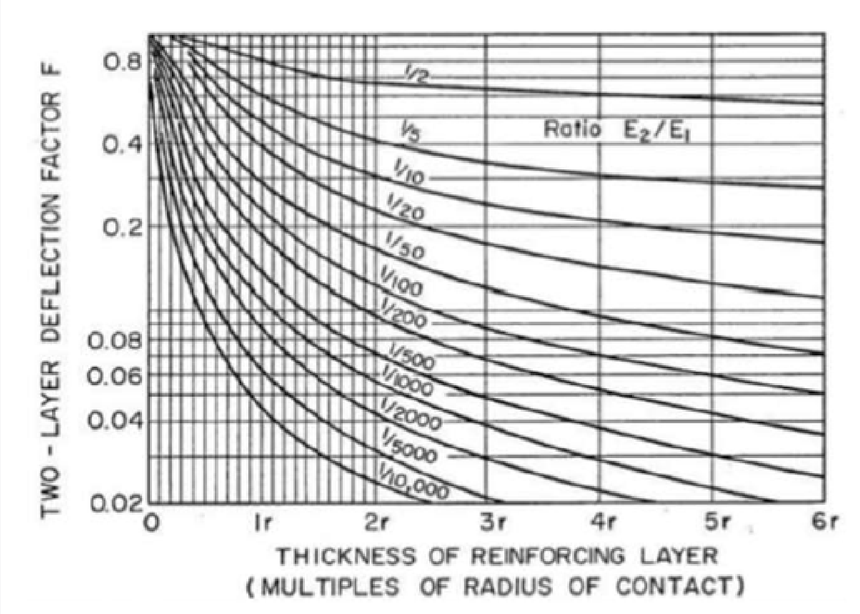


**Figure 3:** Burmister's graph.

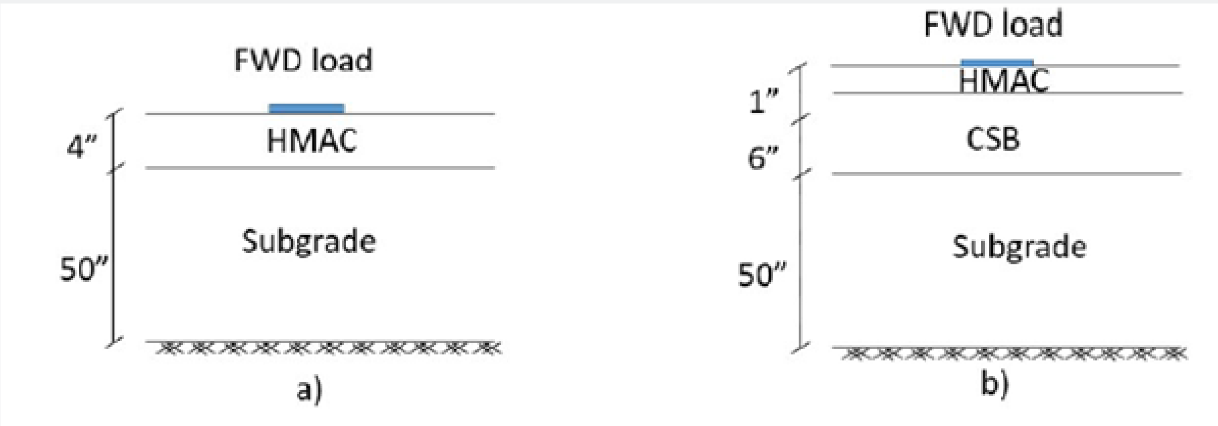


**Figure 4:** Slab configuration; a) 4-in HMAC and subgrade, b) 1-in AC, 6-in CSB and subgrade.

(Figure 5) illustrates the overall geometry of the analysis model, with the applied load positioned at the center of the surface. It is assumed that the soil layer at a certain depth remains fixed and is unaffected by traffic loads. The mesh quality of the model, comprising 21,421 linear hexahedral elements of type C3D8R, is depicted in Figure 5. In anticipation of the increased importance of results in the vicinity of the load application, a denser mesh was employed in that specific area. An example of deflection results obtained from the FEM modeling under the FWD load can be observed in (Figure 6).

The deflection results from FEM modeling under FWD loading, considering various elastic values for the layers, have been compiled in (Table 3). (Figures 7(a),7(b)& 7(c)) visually depict the graphical representations illustrating the influence of various layer configurations and layer stiffness on deflection. These results provide valuable insights into the performance of different layered pavement options. Notably, the data indicates that utilizing a 1-inch HMAC layer in conjunction with a 6-inch CSB leads to significantly reduced deflections when compared to a 4-inch HMAC layer over a subgrade. These findings are



**How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

consistent with the results obtained from field testing, reaffirming the practical applicability of these observations. Furthermore, the analysis highlights that the stiffness of the HMAC layer has a limited effect on the overall results. However, the stiffness of the CSB layer plays a more significant role, as an elevated CSB stiffness results in smaller deflections, showcasing the impact of this particular layer's properties on pavement performance.

**Table 2:** Comparison of the results of two layer system (4-in HMAC and subgrade) with FEM and Burmister's equation.

| | FEM | Equation |
|---|---|---|
| Deflection (mils) | 30 | 30 |

**Table 3:** FEM deflection results under FWD load for different base systems.

| **4-in HMAC and subgrade** | | | |
|---|---|---|---|
| S.G./AC | 300 ksi | 400 ksi | 500 ksi |
| 6000 psi | 46 | 42 | 38 |
| 10000 psi | 32 | **30** | 27 |
| 15000 psi | 24 | 22 | 21 |
| **1-in HMAC, 6-in CSB and subgrade** | | | |
| **S.G=6000 psi** | | | |
| AC/CSB | 0.5 million psi | 1.5 million psi | 2.5 million psi |
| 300 ksi | 22 | 14 | 11 |
| 400 ksi | 21 | 14 | 11 |
| 500 ksi | 20 | 14 | 11 |
| **S.G=10000 psi** | | | |
| AC/CSB | 0.5 million psi | 1.5 million psi | 2.5 million psi |
| 300 ksi | 16 | 11 | 9 |
| 400 ksi | 16 | 11 | 9 |
| 500 ksi | 15 | 10 | 9 |
| **S.G=15000 psi** | | | |
| AC/CSB | 0.5 million psi | 1.5 million psi | 2.5 million psi |
| 300 ksi | 13 | 9 | 7 |
| 400 ksi | 12 | 9 | 7 |
| 500 ksi | 12 | 8 | 7 |

**Figure 5:** Mesh model adopted in the analysis.



**How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

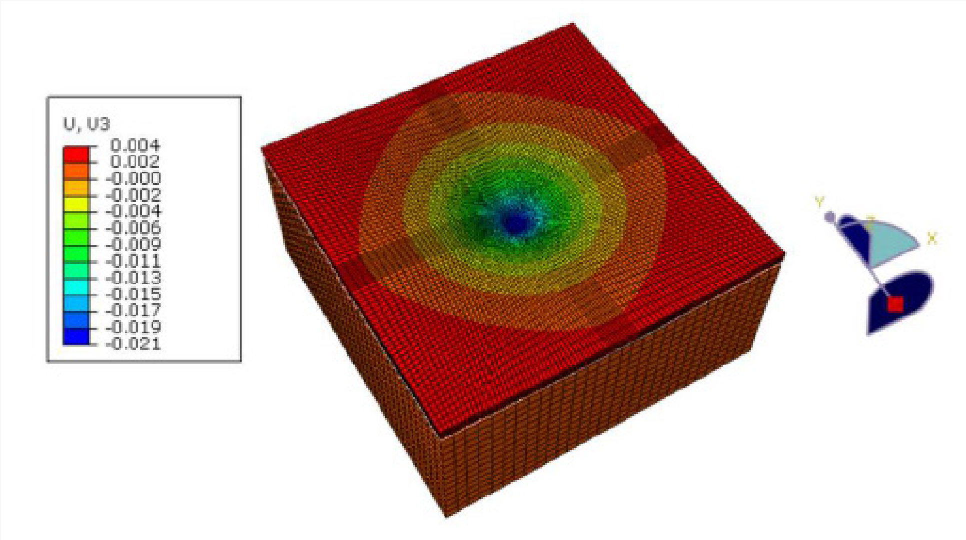


**Figure 6:** Deflection (mils) Under FWD load (9000 lbs.) for 4-in HMAC with E=500ksi and subgrade with E=15000 psi.

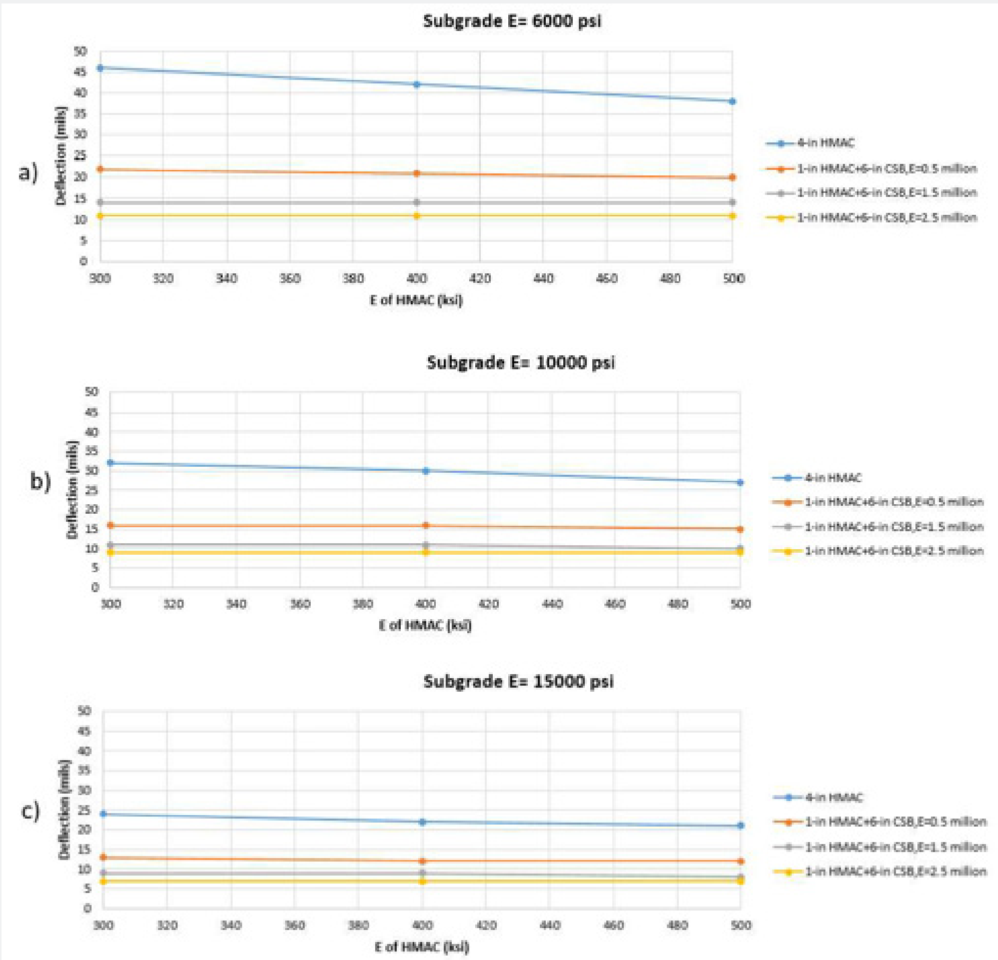


**Figure 7:** Effect of different layers options and the stiffness of layers on deflection; a) Subgrade E=6000 psi, b) Subgrade E=10000 psi, c) Subgrade E=15000 psi.



**How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

To explore the influence of HMAC layer thickness, models were constructed using different HMAC layer thicknesses while maintaining a 6-inch CSB layer. (Figure 8) presents the deflection results for models with elastic moduli of 400 ksi, 1.5 million psi, and 15000 psi for HMAC, CSB, and subgrade, respectively. The graph visually demonstrates a notable trend: as the thickness of the HMAC layer increases, the deflection decreases. This reduction in deflection with increasing HMAC layer thickness is a positive outcome, suggesting that a thicker HMAC layer contributes to enhanced pavement performance and reduced surface deflections.

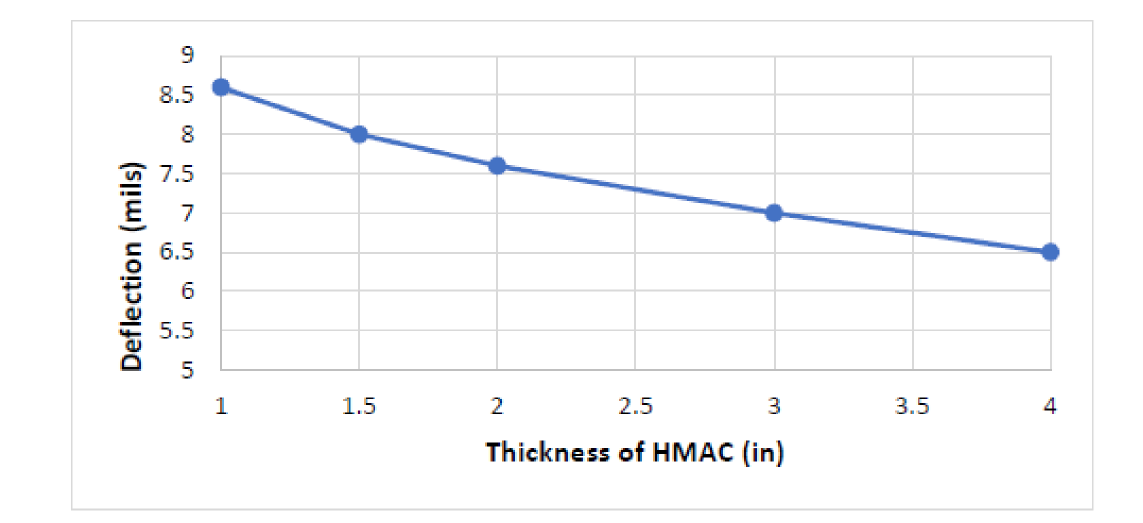


**Figure 8:** Effect of thickness of HMAC bond breaker on deflection.

In order to comprehensively assess the impact of the base layer on concrete pavement performance, two distinct concrete pavement models were developed, each built on a different base configuration. (Figure 9(a)) illustrates the concrete layer superimposed on the 4-inch HMAC base, while (Figure 9(b)) showcases the concrete layer atop the 1-inch HMAC layer, a 6-inch CSB, and the underlying subgrade. In these models, a consistent set of elastic modulus values was employed. The concrete layer, HMAC layer, CSB layer, and the subgrade were all assigned respective elastic modulus values of 5 million psi, 400 ksi, 1.5 million psi, and 15,000 psi. The aim of these simulations was to scrutinize how different base configurations influence the behavior of the overlying concrete layer. The analysis considers not only the thickness and stiffness of the base but also the interaction between the concrete layer and the supporting layers, offering a comprehensive examination of the structural responses in these configurations.

The stress and deflection results from FEM modeling of (Figure 9(a)) and (Figure 9(b)) are collected in (Table 4) and (Table 5) respectively. To facilitate a comprehensive comparison of the Maximum Principal Stress and deflection exhibited by concrete slabs with varying thicknesses and distinct base layer configurations, a series of graphical representations are presented in (Figure 10). These graphs offer a visual depiction of the stress and deflection characteristics across different scenarios, enabling a more insightful analysis of the performance and behavior of the concrete slabs under various conditions.

The results show that the base system with 1-inch HMAC and 6-inch CSB consistently yields lower stress and reduced deflection in the concrete slab. Notably, as we progressively increase the thickness of the concrete slab, the influence of the base system becomes less pronounced. For instance, when employing a 7-inch concrete slab with a 4-inch HMAC base, the stress results are 242% higher, and the deflection results are 134% greater compared to using the 1-inch HMAC and 6-inch CSB base system. Similarly, with a 13-inch concrete slab, these figures exhibit increases of 170% and 111% for stress and deflection, respectively. This trend underscores the significant role played by the choice of base layers, particularly for thinner concrete slabs, in minimizing stress and deflection, contributing to the structural integrity of the pavement system.

## Results and Discussion

The objective of this study was to evaluate different types of bases primarily used in Texas, including 4-inch HMAC or 1-inch HMAC with a 6-inch CSB. These two configurations were compared, examining various elastic moduli for all the different layers, in order to determine the most optimal combination for serving as underlying layers for rigid pavement. The primary goals were to reduce stress for preventing bottom-up fatigue cracking and to


How to cite this article: Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

minimize deflection under FWD loads. The study encompassed a series of field tests followed by extensive computer analysis. The results consistently demonstrate that when a base system comprising 1-inch HMAC and 6-inch CSB is utilized, significantly reduced deflections are observed in comparison to when a base system comprising 4-inch HMAC. These findings are consistent with the outcomes of our field testing. Additionally, it is revealed by the study that while the stiffness of the HMAC layer has a limited effect on results, decreased deflections are brought about by employing a base system with higher stiffness for the CSB layer.

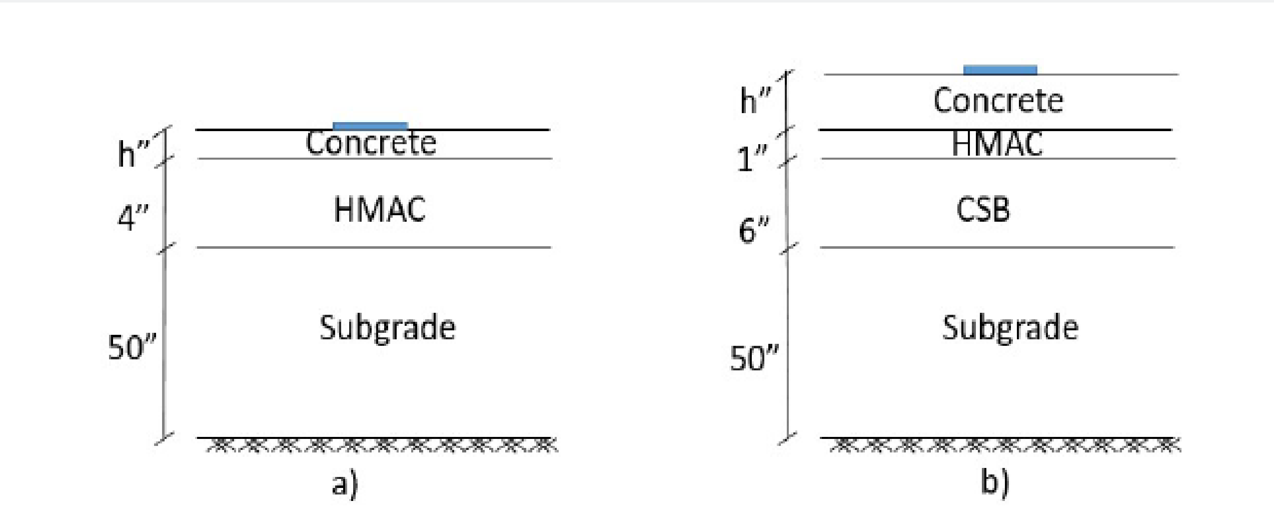


**Figure 9:** Pavement configuration; a) concrete and 4-in HMAC and subgrade, b) Concrete, 1-in HMAC, 6-in CSB and subgrade.

**Table 4:** Stress and deflection results for the pavement with concrete, 4-in HMAC and subgrade.

| Concrete layer Thickness (in) | Max Principal Stress (psi) | Deflection (mil) |
|---|---|---|
| 7 | 126 | 4.7 |
| 8 | 109 | 4.3 |
| 9 | 96 | 3.9 |
| 10 | 84 | 3.6 |
| 11 | 76 | 3.3 |
| 12 | 65 | 3.1 |
| 13 | 58 | 2.9 |

**Table 5:** Stress and deflection results for the pavement with concrete, 1-in HMAC, 6-in CSB and subgrade.

| Concrete layer Thickness (in) | Max Principal Stress (psi) | Deflection (mils) |
|---|---|---|
| 7 | 52 | 3.5 |
| 8 | 50 | 3.3 |
| 9 | 47 | 3.1 |
| 10 | 43 | 2.9 |
| 11 | 40 | 2.8 |
| 12 | 37 | 2.7 |
| 13 | 34 | 2.6 |

Moreover, an increase in the thickness of the HMAC layer results in reduced deflections, a favorable outcome for pavement performance. It is further emphasized by the data that consistently, lower stress levels and deflections are exhibited by the 1-inch HMAC and 6-inch CSB base system, especially in thinner concrete slabs. For instance, when a concrete thickness of 7 inches is used, a choice of a 4-inch HMAC base results in stress levels that are 242% higher and deflections that are 134% greater compared to the use



**How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

of the 1-inch HMAC and 6-inch CSB base system. Similarly, for a 13-inch concrete slab, results indicate increases of 170% for stress and 111% for deflection, compared to the 1-inch HMAC and 6-inch CSB base system. As demonstrated in (Figure 11) and (Figure 12), the stress and deflection results for a 10-inch concrete slab with the 1-inch HMAC and 6-inch CSB base system closely resemble those for a 13-inch concrete slab with a 4-inch HMAC base system.

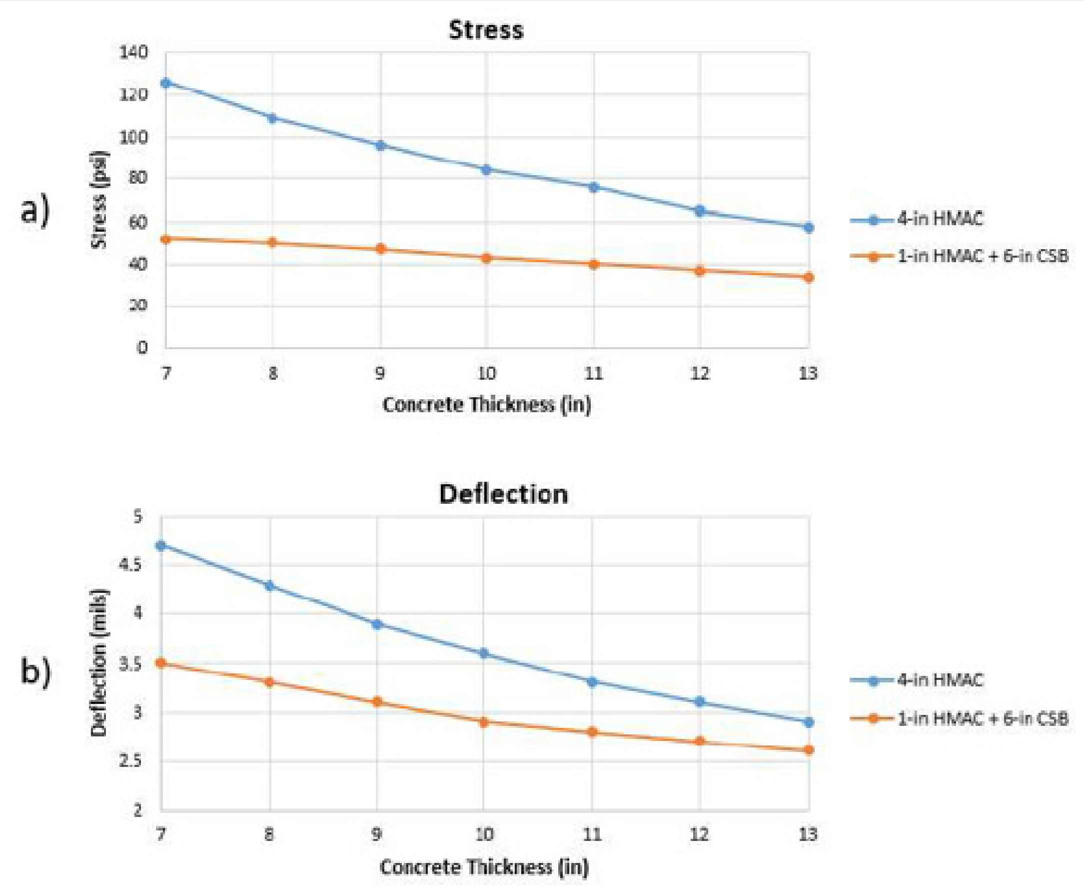


**Figure 10:** FEM results of concrete pavement with different base systems; a) Max principal stress of concrete, b) Max deflection; at the bottom of the concrete slab.

This implies that the distresses resulting from traffic loading over the design life will be consistent for both pavement designs. Various components, including the initial cost, maintenance cost, rehabilitation cost, and user-related expenses, are encompassed by the total cost of a project throughout its design life. When equivalent levels of distress are exhibited by both pavements, it can be deduced that rehabilitations, maintenance efforts, and user costs will remain uniform across both design options. In essence, the sole distinguishing factor in the overall project costs between these two designs would be the initial cost. Therefore, if the initial cost of either design is proven to be lower, it would emerge as the more cost-effective alternative.

To illustrate this with a concrete example, consider (Figure 11), featuring a 10-inch concrete slab, 1-inch HMAC, and a 6-inch CSB, and (Figure 12), comprising a 13-inch concrete slab and 4-inch HMAC. Both of these options constitute a 17-inch pavement system, encompassing the concrete slab and the base layers. Consequently, the cost comparison primarily depends on the expense associated with each component, including labor costs. To perform a straightforward cost estimate calculation, the Texas Department of Transportation's average unit price list workbook was consulted [16]. For instance, the unit price for cement-stabilized subgrade with a thickness of 6 inches is $2.01 per square yard. The installation of a 1-inch flexible base and pavement typically amounts to approximately $125 per square yard. According to the most recent industry data, the cost of concrete per cubic yard hovers around $113 for ready mix delivery [17]. (Table 6) provides a comprehensive breakdown of the overall cost calculation for these two projects. In summary, the utilization of 4-inch HMAC is, on average, approximately 36% more costly than the employment of 1-inch HMAC in conjunction with a 6-inch CSB as the base, making the latter a more financially prudent choice.


How to cite this article: Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

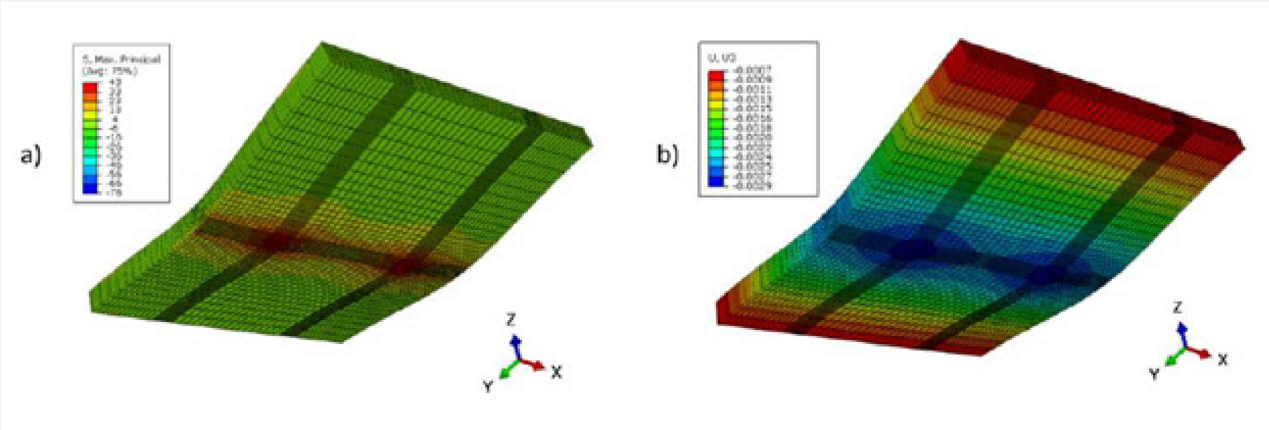


**Figure 11:** a) Max stress at the bottom of concrete b) Max Deflection at the bottom of concrete for 10-in concrete slab over 1-in HMAC and 6-in CSB as base.

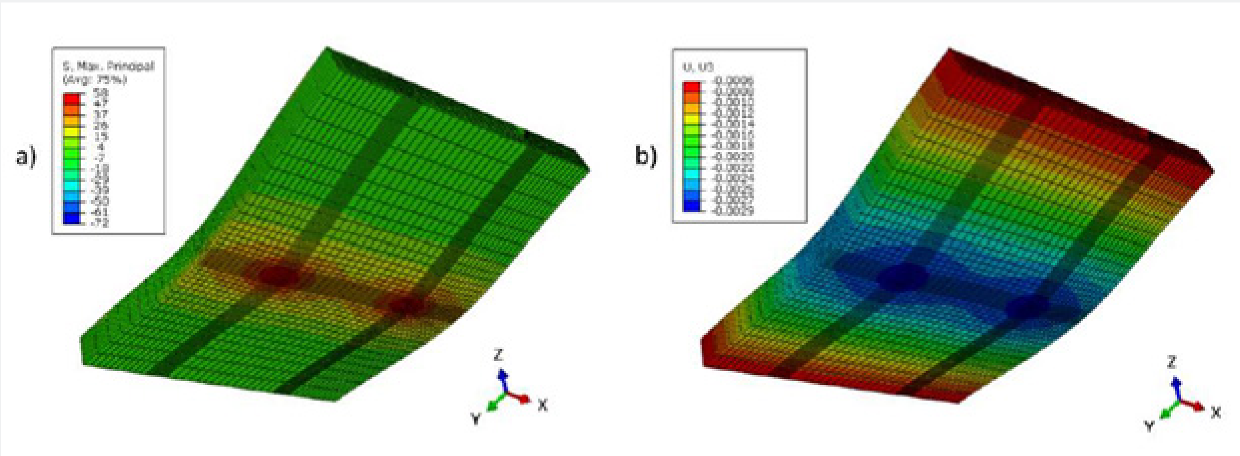


**Figure 12:** a) Max stress at the bottom of concrete b) Max Deflection at the bottom of concrete for 13-in concrete slab over 4-in HMAC as base.

**Table 6:** Cost estimation of two options with same deflection and stress under FWD load.

| | 13-in concrete over 4-in HMAC [$] | 10-in concrete over 1-in HMAC and6-in CSB [$] |
|---|---|---|
| Concrete | $1469 | $1130 |
| HMAC | $500 | $125 |
| CSB | - | $2.01 |
| Total price | $1969 | $1257.01 |

## Conclusion

Based on our comprehensive study, it becomes evident that the construction of a 1-inch HMAC layer in combination with a 6-inch CSB for rigid pavement, particularly when subjected to varying traffic loads, emerges as the optimal choice. This configuration significantly mitigates the stress and deflection experienced by the concrete slab, enhancing pavement performance and longevity. Our research yields several key findings for the better performance of rigid pavement:


How to cite this article: Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667

i. **Stiffer CSB Layer:** The inclusion of a Cement Stabilized Base (CSB) layer results in a more rigid base system, leading to a noticeable reduction in stress and deflection within the concrete slab under applied loads.

ii. **1-Inch HMAC as a Bond Breaker:** The 1-inch HMAC layer serves as an effective bond breaker, preventing the pavement from experiencing excessive stress and deflection due to environmental factors such as curling and warping.

iii. **Falling Weight Deflectometer (FWD) Testing:** FWD testing emerges as a highly recommended quality control method for assessing the performance of the base layer, providing valuable insights into pavement behavior under load.

However, it's essential to note that our study did not account for the impact of environmental loading, including temperature and moisture variations. Further research will be necessary to model concrete pavement responses under these environmental conditions, particularly in the context of different base systems. This future investigation will enable a comprehensive evaluation of how base layers influence stress and deflection responses in concrete slabs, contributing to a more holistic understanding of pavement performance.

## Acknowledgement

This study was partially funded by TxDOT.

## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References


1. US Department of Transportation (2017) Bases and Subbases for Concrete Pavements. Federal Highway Administration.
2. Texas Department of Transportation (2019) Rigid Pavement Design. TxDOT Manual System.
3. American Concrete Pavement Association (1995) Subgrades and Subbases for Concrete Pavements. Engineering Bulletin, pp. 1-102.
4. American Concrete Pavement Association (2007) EB204 Subgrades and Subbases for Concrete Pavements. Engineering Bulletin.
5. Youn Su Jung, Dan G Zollinger, Byoung Hooi Cho, Moon Won, Andrew J Wimsatt (2012) "Subbase and Subgrade Performance Investigation and Design Guidlines for Concrete Pavements, pp. 1-170.
6. Portland Cement Association (2006) The Road Recycled: Full-Depth Reclamation with Cement. PCA.
7. American Concrete Pavement Association (2007) Subgrades and Subbases for Concrete Pavements. Illinois: Engineering Bulletin.
8. Cole LW, Hall MJ (1996) Relative Costs of Various Concrete Pavement Features. Transportation Research Record: Journal of the Transportation Research Board 1574(1): 99-102.
9. Hoerner TE, Smith KD, Bruinsma JE (2004) Incremental Cost and Performance Benefits of Various Features of Concrete Pavements. Federal Highway Administration, pp. 1-215.
10. FHWA (1992) Report on the 1992 U.S. Tour of European Concrete Highways. Federal Highway Administration, Washington, DC, USA.
11. Hall K, Danwood D, Vanikar S, Tally R, Cakler T, et al. (2007) Long-Life Concrete Pavements in Europe and Canada. Federal Highway Administration, Washington, DC, USA, pp. 1-82.
12. Hveem FN (1955) Pavement Deflections and Fatigue Failures. Highway Research Board Bulletin 114. Highway Research Board, pp. 1-45.
13. Cheryl Allen Richter (2017) Using Falling Weight Deflectometer Data with Mechanistic-Empirical Design and Analysis, Volume III: Guidelines for Deflection Testing, Analysis, and Interpretation, U.S. Department of Transportation, Federal Highway Administraition, pp. 1-126.
14. Fouzieh Rouzmehr, Pangil Choi, Jeong Hee Nam, Moon Won (2021) Improvements of quality assurance testing program for subgrade and base layer construction. Construction and Building Materials, 310: 125-157.
15. Burmister, Highway Research Board, 1943.
16. Texas Department of Transportation (2020) "https://www.txdot.gov/business/letting-bids/average-low- bid-unit-prices.html".
17. "https://www.concretenetwork.com/concrete-prices.html" [Online].



DOI: 10.19080/ETOAJ.2023.05.555667



 **How to cite this article:** Fouzieh R, Mehdi M. Comparison of the Effect of Different Base Layers on the Performance of Concrete Pavement. 2023; 5(4): 555667. DOI: 10.19080/ETOAJ.2023.05.555667