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Develop a Study for Geosynthetic Materials for Use in Reducing Pavement Section Thickness

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16. Abstract

Geosynthetics have been used to reinforce aggregate base courses to increase the structural support from the base to the pavement structure. This project aims to develop a study framework to evaluate and quantify the structural benefits under Nevada conditions. To achieve this objective, a five-stage research plan was developed to support a controlled field demonstration, with input regarding design, specification, and standards. This report provides a methodology to determine the expected design life of a specific site with known climate characteristics, subgrade modulus, and traffic. Included are recommendations for the pavement design, testing layout, testing plan, construction guidelines, preliminary implementation plan, and cost estimate.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

AADTT	Annual Average Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ASTM	American Society of Testing and Materials
BCR	Base Course Reduction
CBR	California Bearing Ratio
CS	Control Sections
DCP	Dynamic Cone Penetrometer
DOT	Department of Transportation
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
GMA	Geosynthetic Materials Association
GPS	General Pavement Study
GPR	Ground Penetrating Radar
GRI	Geosynthetic Research Institute
GSC	Geosynthetic Structural Coefficient
HMA	Hot Mix Asphalt
IRI	International Roughness Index
JMF	Job Mix Formula
LTPP	Long-Term Pavement Performance
ME	Mechanistic-Empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
MD	Machine Direction
M_r	Resilient Modulus
NCHRP	National Cooperative Highway Research Program
NDOT	Nevada Department of Transportation
QA	Quality Assurance
SP	Standard Pavement
SPS	Specific Pavement Studies
TBR	Traffic Benefit Ratio
TD	Transverse Direction
TRINA	Traffic Record’s Information Access
TS	Test Sections
USACE	U.S. Army Corps of Engineers

1.0 BACKGROUND

The Nevada Department of Transportation (NDOT) currently maintains 5,354 centerline miles of roadways that carry about 50% of the total vehicle miles traveled and 70% of all truck traffic in Nevada [1]. About 58% of the NDOT maintained centerline miles are in fair to very poor condition, of which 30% are in mediocre to very poor condition that will require rehabilitation or reconstruction. Consequently, NDOT's pavement rehabilitation and maintenance budget is under increased demand. This makes it critical that the value of pavement rehabilitation is extended to maintain the state highway system at an acceptable condition and meet the NDOT goal to "efficiently operate and maintain the state transportation system." NDOT continually looks for new technologies and design standards to stretch paving dollars by reducing rehabilitation costs and increasing pavement life. Several studies have been conducted to demonstrate the value added by geosynthetics in pavements. DOTs commonly use geosynthetics as filters, separation layers, and stabilization to facilitate construction on weak subgrades. Geosynthetics have also been used to reinforce aggregate base courses to increase the structural support from the base to the pavement structure. This is referred to as base reinforcement, which industry guidelines state increases service life or equivalent life with a reduced structural section [2].

NDOT has traditionally used geosynthetics to provide stable platforms for constructing pavements in localized areas where weak soils are present. The current NDOT standards do not recognize the use of geosynthetics to reduce pavement structural layer thicknesses. However, multiple DOTs have developed design guidelines that allow for a reduction in pavement structural thickness based on the expected stiffening of the aggregate base layer through geosynthetics. These guidelines are primarily based on laboratory studies, and while informative, they should be validated in the field to quantify their performance for Nevada's conditions.

2.0 OBJECTIVES

This research aimed to develop a study framework to evaluate and quantify structural benefits from geosynthetics placed within or at the bottom of aggregate base layers under Nevada conditions. This research plan:

- addressed the technical elements of designing and constructing the test sections,
- provided guidance on what data should be collected and at what frequency,
- provided recommended updates to the current NDOT specifications,
- and provided a tool for NDOT to maximize the benefits of current geosynthetics.

3.0 SCOPE AND OUTCOMES

To achieve this objective, a five-stage research plan was developed to support a controlled field demonstration project, with input regarding design, specification, and standards. These will allow for adjustments between different phases of the overall study. Figure 1 demonstrates the key considerations included during this first phase of the study.

Task 1: Literature Review
- Base Reinforcement
- Geosynthetics
- Specifications and Practices

Task 2: Experimental Design
- Site Selection
- Pavement Design
- Test Site Layout

Task 3: Evaluation and Testing Plan
- Pre-construction
- Construction
- Post Construction

Task 4: Specifications and Construction Guidelines
- Contract Documents
- Specifications

Task 5: Implementation Plan and Cost Estimate

Figure 1: Overall Key Considerations of Field Study Plan.

4.0 LITERATURE REVIEW

The chapter reviews the literature and peer agency practices as input to the development of the experimental design, testing plan, specifications, and construction guidelines.

4.1 Geosynthetic Types and Applications

The term geosynthetic encompasses a wide range of products, including geotextiles, geogrids, geomembranes, and geocomposites. The American Society of Testing and Materials (ASTM) defines geosynthetic as "a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system" [3].

Geosynthetic applications are usually defined by their primary function, which includes filtration, drainage, separation, reinforcement, fluid barrier, and protection. A standard classification for geosynthetics function depends on the subgrade soil condition in terms of California Bearing Ratio (CBR) or Resilient Modulus (M_r). For soft subgrade soils with CBR less than 3 ($M_r \sim 5000$ psi), the primary function is for reinforcement. Reinforcement is the addition of structural capacity to a pavement system by the transfer of load to the geosynthetic material. For intermediate strength subgrade with a CBR range of 3 to 8 ($5000 < M_r < 10,000$ psi), the primary function is stabilization, which is the use of geosynthetics in saturated conditions to provide the functions of separation and drainage [2]. For firm subgrades with CBR greater than 8 ($M_r \sim 10,000$ psi), separation is the primary function, which prevents the mixing of subgrade soil and an overlying aggregate material [4].

The reinforcing properties of geosynthetics are based on several mechanisms. The friction produced by geotextiles and interlock produced by geogrids creates lateral restraint of base and subgrade materials. An increase in bearing capacity can be expected due to the higher shear strength surfaces ultimately changing the potential bearing capacity failure surface. In addition, membrane support of wheel loads is commonly realized as a reinforcing property of geosynthetics, but it is only experienced under high deformation conditions. Components of lateral restraint have been described as including: (i) restraint of lateral movement of base aggregate through confinement; (ii) increase in modulus of base aggregate due to confinement; (iii) improved vertical stress distribution on subgrade due to increased base modulus; and (iv) reduced shear strain along the top of the subgrade [5]. A Traffic Benefit Ratio (TBR) commonly defines improved pavement life provided by geosynthetics. TBR is the ratio of the number of load cycles of a reinforced pavement structure to reach a defined failure state, to the number of load cycles for the same unreinforced section to reach the same failure state (TBR > 1.0 indicates an increase in pavement life). Failure state is typically defined as a maximum rut depth. The Base Course Reduction (BCR) is a percent reduction in the unreinforced base thickness for the same number of cycles to failure. TBR and BCR have been reported in the literature with substantial variations in their values (e.g., geotextiles BCR 22–33%; geogrids BCR 30–50%). It is common to find large TBR values that have been measured on significantly over-designed sections, causing extensive load cycles until failure. However, typical values of TBR for geotextile reinforcement reported in the literature are in the range of 1.5 to 10, and for geogrids, in the range of 1.5 to 70 [5].

Geosynthetics are grouped by material type, manufacturing method, and intended application. A preliminary review revealed over ten manufacturers of over 40 geosynthetic types for subgrade restraint and base reinforcement that could be used in this study. Table 1 summarizes the available woven fabric geotextiles and geogrid products at the time the literature review was conducted [6].

Table 1: Woven Geotextile and Geogrid Available Product List [6].

Manufacture	Product Name	Type	Description	Main Application
Tensar	InterAx NX650, NX750, NX850	Multilayer Integrally formed geogrid	Coextruded, composite polymer sheet, which is then punched and oriented.	Base Reinforcement, Subgrade Improvement
Tensar	TX130S, TX140, TX150L, TX16, TX190L, TX5, TX7, & TX8	Extruded geogrids	Punched polypropylene sheet, oriented in multiple, equilateral directions to form a triangular aperture.	Base Reinforcement, Subgrade Improvement
Tensar	BX1100, BX1200, BX1300, BX1500, BX4100, & BX4200	Integrally formed	Integrally formed polypropylene grids	Base Reinforcement, Subgrade Improvement
Tencate	Mirafi RS280i, RS380i, & RS580i	Woven geotextile	high tenacity polypropylene filaments formed into an innovative weave.	Base Reinforcement, Subgrade Improvement
Tencate	Mirafi BXG series (Biaxial)	Extruded geogrid	It is composed of polypropylene resin, that is extruded, punched and drawn into a grid structure	Base reinforcement and soil stabilization
BOSTD America	RX series, SX series, E'Grid (Biaxial)	Integrally formed	Integrally formed polypropylene grids	Base reinforcement and soil stabilization
Colbond	Enkagrid MAX	Welded geogrid	Biaxial extruded polypropylene or polyester laser welded bars.	Subgrade restraint
Colbond	Enkagrid TRC	Bonded composite	Biaxial geogrid composite of woven aramid fibers embedded in nonwoven filter layers.	Base/subbase reinforcement and subgrade restraint
Carthage Mills	Carthage Mills FX®-55	Woven geotextile	100% high-tenacity slit-film polypropylene yarns.	Subgrade restraint
Tenax Corporation	Tenax MS 220B, and 220	Extruded geogrid	Two layers of high strength biaxial oriented polypropylene geogrids	Base/subbase reinforcement and subgrade restraint
Tenax Corporation	Tenax MS 330, and 500	Extruded geogrid	Three layers of high strength biaxial oriented polypropylene geogrids	Base/subbase reinforcement and subgrade restraint
Tenax Corporation	Tenax MS 500	Extruded geogrid	Five layers of high strength biaxial oriented polypropylene geogrids	Base/subbase reinforcement and subgrade restraint
Terrafix	Terrafix® BX1500, 2000, 2500, and 3000	Extruded geogrid	Single layer of biaxial geogrid	Base reinforcement and subgrade restraint
Thrace-LINQ	Thrace-LINQ GTF 300	Woven geotextile	high-tenacity polypropylene slit-film	Subgrade restraint
US Fabrics	BaseGrid 22	Welded geogrid	Two layers biaxial polypropylene geogrid.	Base/subbase reinforcement
US Fabrics	BaseGrid 33	Sewn geogrid	Three layers of biaxial polypropylene geogrid.	Base/subbase reinforcement
US Fabrics	BaseGrid 50	Extruded geogrid	Five layers of biaxial polypropylene geogrid.	Base/subbase reinforcement
US Fabrics	US 200, 250 and 315	Woven geotextile	100% polypropylene slit film yarns	Subgrade restraint
Maccaferri	MacGrid EG 12.19, 19.29	Extruded geogrid	Polypropylene geogrids	Base reinforcement and stabilization

4.2 Geotextiles

Geotextiles and geogrids have been the most commonly used and researched geosynthetic products for enhancing pavement performance and are the basis for this study. Geotextiles are defined as a permeable geosynthetic comprised entirely of textiles and can be further categorized as woven or non-woven [3]. The most common use of geotextiles is underneath paved and unpaved roads to separate, stabilize, reinforce, and filter. Non-woven geotextiles are primarily used for separation, and woven geotextiles are most often used for stabilization. The effectiveness of the woven geotextile stabilization results from two factors. Primarily, the compacted aggregate above the geotextile serves to "seat" individual stones within the subgrade and geotextile. This fixed position, referred to as "seating," stabilizes the aggregate base layer. Second, stabilizing the subgrade soil due to a geotextile can change the soil failure mode from local shear to general shear. Due to this change in shear, the additional load is supported before the soil strength is exceeded, allowing for a reduced aggregate base layer thickness. This is economically viable as it saves initial costs and reduces maintenance required on the road [7].

Regarding using a geotextile for reinforcement purposes, woven geotextile is considered more appropriate than non-woven due to its higher tensile strength. The benefits of reinforcement rely heavily on the extent of system deformation permitted. Unpaved roads benefit from geotextiles since roads allow large amounts of deformation. Paved roads typically have low allowable deformations and do not receive as much benefit from reinforcement [7].

4.3 Geogrids

Geogrids are defined as a geosynthetic formed by a regular network of integrally connected elements with apertures that allow interlocking with surrounding soil, rock, earth, and other materials to function primarily as reinforcement [3]. Geogrids can be classified as extruded, woven, flexible, or welded, depending on their production process [8]. They are primarily designed to satisfy the reinforcement function.

Geogrids are characterized by their ribs, junction, and apertures, with performance properties dependent on these characteristics. The ribs of a geogrid have traditionally been defined as either longitudinal or transverse, as illustrated in Figure 2. The direction parallel to the direction of fabrication is known as roll length direction, Machine Direction (MD), or longitudinal direction. The direction perpendicular to fabrication and MD in the geogrid plane is known as Transverse Direction (TD) or the cross-machine direction. The longitudinal ribs are therefore defined as parallel to the direction of fabrication; the transverse ribs are perpendicular to the direction of fabrication. Some mechanical properties of geogrid, such as tensile modulus and tensile strength, depend on the testing direction. Generally, specifications will state which direction is required, or an average can be used in certain situations. Geogrid installation in pavements is usually with travel direction parallel to the direction of fabrication, or MD [9].

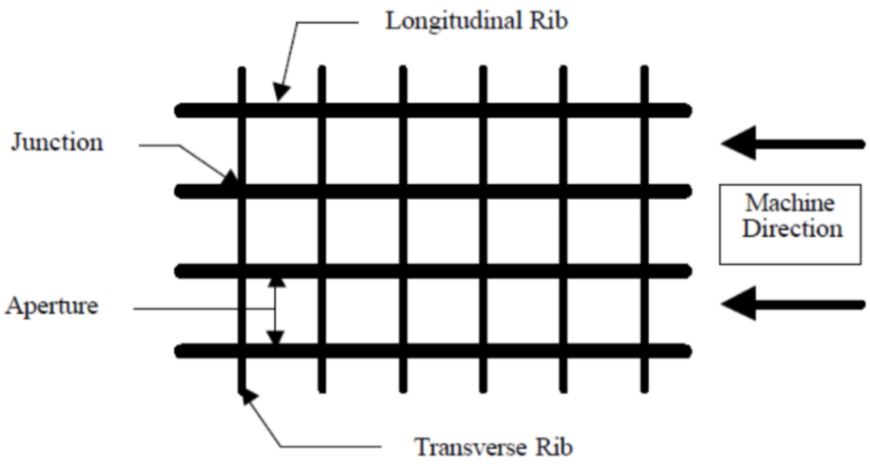


Figure 2: Geogrid Nomenclature [10].

Geogrids can be categorized into three main groups based on their aperture: uniaxial, biaxial, and triaxial. Recently, a new category has been developed called InterAx [11]. The product is still under development and not readily available, so it will not be included as part of this introduction. However, in the future, this product may be included as part of the field demonstration project. Uniaxial geogrids can carry high tensile loads applied in one direction along the roll length. Their open aperture structure interlocks with fill material to provide greater load transfer from the soil to the geogrid. Their main application is for reinforcing slopes, retaining walls, and embankments. Biaxial geogrids have tensile strength in two dimensions, and they are often used to reinforce pavements, including unpaved roads, railroads, and flexible pavements. Dong et al. revealed that biaxial geogrids could not provide constant tensile strengths when subjected to tension unaligned with the longitudinal and transverse ribs, which is one of the limitations of biaxial geogrids [12]. This led to the introduction of a triaxial geogrid with triangular apertures and ribs in three directions. This feature results in two benefits. First, the apertures allow soil particles to interact better with ribs. Secondly, triaxial geogrids can provide uniform tensile strengths in additional directions compared to uniaxial and biaxial geogrids. Triangular aperture geogrids have more stable grid structure than rectangular aperture geogrids due to their ability to transfer loads from one rib to the other in different directions, known as Junction Efficiency [13]. Currently, Tensar is the only manufacturer of triaxial geogrids; however, the patent for a triangular aperture geogrid is set to expire in 2023, allowing for additional manufacturers to produce and likely market a triaxial geogrid by the time the construction phase of this project is developed [14].

4.4 Base Reinforcement History

Historically, the main reinforcement mechanism attributed to geosynthetics in pavement practices is commonly called base course lateral restraint or base reinforcement. By laterally restraining the aggregate base, four components of reinforcement are potentially achieved: (i) preventing lateral spreading of the base aggregate; (ii) increasing confinement and thus the strength of the base (iii) improving vertical stress distribution on the subgrade; (iv) reducing shear stress in the subgrade. The reinforcement mechanism of a lateral restraint develops through shear interaction of the base course layer with the geosynthetic layer contained in or at the bottom of the base aggregate. Traffic loads applied to the roadway surface create a lateral spreading motion of the base coarse aggregate through tensile strains produced in the base. The lateral movement allows vertical displacement to develop, resulting in wheel path rutting. Placement of a geosynthetic layer in or at the bottom of the base course allows shear interaction between the aggregate and the geosynthetic as the base attempts to spread laterally. Shear load is transferred from the base aggregate to the geosynthetic and places the geosynthetic in tension. The geosynthetic restrains the lateral deformation and retards the development of increased strains within the base layer. This ultimately leads to a reduction of permanent deformation on the surface [5].

Granular material exhibits an increase in elastic modulus as a function of increasing confinement. Therefore, the second reinforcement mechanism is due to the increase in stiffness of the base course layer. However, this is only true when adequate interaction develops between the base and the geosynthetic. The increase in stiffness results in lower tensile strains in the base and at the bottom of the asphalt layer, essentially reducing fatigue of the asphalt layer.

The presence of a geosynthetic can also change the state of stress and strain in the subgrade. For a pavement system where the less stiff subgrade material is overlayed by a base layer, an increase in base stiffness results in better distribution of vertical stresses on the subgrade. Therefore, a third reinforcement component results from improved vertical stress distribution on the subgrade. Haas et al. and Perkins demonstrated reduced peak vertical stress on the subgrade when reinforcement was present [15] [16].

The reduction of shear strain in the subgrade layer describes the fourth reinforcement component. The decrease of shear strain transferred from the base to the subgrade is due to the energy absorbed by the geosynthetic. Houlsby and Jewell reveal that less shear strain, coupled with less vertical stress results in a less severe state of loading, leading to lower vertical strain in the subgrade [17].

However, there are limitations to the applications of reinforcement in pavements. Few studies provide a complete comparison utilizing various geosynthetics, pavement types, and thicknesses. A summary of case histories is included in Table 2. The selection of the geosynthetic for reinforcement heavily depends on the application. Austin and Coleman found that thin bases required consideration into separation and filtration to ensure the effects of the geosynthetic could be correlated to reinforcement rather than dominated by other functions that could mask the reinforcement benefit [18].

Geotextiles are often used when separation issues are noted, even when a geogrid is used for reinforcement. Kim et al. stated that geotextiles should always be placed at the base-subgrade interface due to their effectiveness in preventing the mitigation of fines [19]. However, the possible benefit of enhanced geotextile reinforcement can be overshadowed by the functional separation of pavement layers. Several studies indicate an optimum benefit when a woven geosynthetic is placed at the bottom of an 8-to-12-inch base layer. However, for thicker layers the optimal location has been found to be within the middle of the base later [5]. Luo et al. found that geogrids are more effective when placed at the center of thick aggregate base layers exceeding 10 in. in depth, and at the bottom for thinner base course layers, 6 to 10 in. depth [20]. Results from the study suggest that the placement of geogrid at the interface of the subgrade and base course will influence pressure reduction below the geosynthetic

Table 2: Case History of Geosynthetic Projects.

Author	Dimensions	Composite	Geosynthetic Type	Geosynthetic Location	Variable Investigated
Perkins et al. (2002) [21]	Four test sections (9.91x3.18 m)	AC - 75 mm Base - 300 mm Subgrade - Clay with CBR =1	Five sets of geogrids and two sets of geotextiles	Base/Subgrade interface 100mm and 40 mm above base/subgrade interface	Geosynthetic type/stiffness/location, temperature, pore water pressure
Ghafoori et al. (2016) [22]	4 test sections	AC - 3 inch Base - 12 and 16 inch Subgrade – R value = 40	Two biaxial and two triaxial geogrids	Interface between subgrade/base Middle of base layer	Geosynthetic type/stiffness/location/ BCR Value
Zornberg et al. (2008) [23]	32 test sections	AC - 25.4 mm Base - 178 mm Subgrade - Clay soil	Biaxial geogrid, woven geotextile	Interface between subgrade/base	Geosynthetic type/stiffness, and site factors
Webster (1993) [24]	4 traffic lanes with each having 4 test sections	AC - 50.8 mm Base - 305, 355, 457 mm Subgrade - CBR=7.1 and 2.5	Two geogrids	Subgrade surface Two sections with geogrid located mid base	Base course thickness, subgrade CBR values, geogrid types
Hossain & Schmidt (2009) [25]	4.8 km test section	AC - 165 mm Graded Base - 305 mm Subgrade - CBR=4.5 and 5.0	Geotextile	Interface of subgrade/base	Geosynthetic type/stiffness/location
Rajagopal et al. (2014) [26]	200 m long road section	Base - 200 mm Subgrade - CBR=4 and 8	Geogrids	200 mm below surface within the subbase layer	Geosynthetic type, subgrade stiffness
Hanandeh et al. (2016) [27]	Six test sections. Each lane 24x4 m	AC - 19 mm Base - 254 and 457 mm Subgrade - Native w/ heavy clay	Triaxial geogrid, high strength geotextile	Placed at the interface One section had two layers of geogrid applied at 1/3 of base layer	Geosynthetic type/stiffness/location, base thickness
Mousavi et al. (2016) [28]	Three test sections	AC - 50 mm Base - 230 mm Subgrade - Native soil A-4 and A-7-5	Triaxial Geogrid	Interface of base/subgrade	Subgrade CBR values, load repetitions on surface deformation
Cuelho et al. (2017) [29]	17 test sections 15.3 m long	Base - 277, 414, 632 mm (CBR=20) Subgrade - Native CL soil, CBR=1.79	Geogrids and geotextiles	Interface of base/subgrade	Base course thickness, geosynthetic type/stiffness

Note: AC = asphalt concrete; CBR = California Bearing Ratio.

Alternatively, Al-Qadi et al. constructed nine low-volume pavement design sections to investigate the optimal location for the installation of geogrid in pavements [30]. Testing was conducted using an accelerated loading facility utilizing heavily instrumented test specimens built on a subgrade with a CBR of 4. The study found that a single geogrid installed in the upper third of the layer for thick granular base materials improved the performance. Additionally, for thinner pavement sections geogrid placed in the upper third of the base material performed similarly to specimens with the geogrid placed at the base–subgrade interface. Reinforcement benefits are typically attributed to subgrade strengths up to a CBR of 8. It should be noted that there is a decrease in reinforcement benefit as the base thickness increases.

A summary of studies show that geotextiles tend to show more benefit for thin bases with CBR below 3 [5]. However, limitations exist when the separation issue masked the reinforcement benefit at low subgrade strength of CBR less than 1. Perkins et al. investigated an extruded biaxial geogrid and a woven geotextile on pavement performance, as defined by surface rutting [16]. It was found that with a base thickness of 12 in. (300 mm) the test sections with geogrid performed better than the sections using the geotextile product, while an improvement from the geotextile was still appreciable. The study determined that welded geogrids, woven geogrids, and integrally formed (extruded) geogrids provided the best overall performance compared to the two woven geotextile products.

4.5 Specifications and Practices

The first generation of geosynthetics specifications were simple and generally only specified a specific manufacturer. However, as geosynthetics market has grown, specifications should be based on the specific geosynthetic properties required for design, installation, and durability, while also being generic enough that multiple geosynthetic products would be allowed to compete. There are three primary options for specification of geosynthetics used to reinforce the aggregate base, or subbase, course of pavement structures: (i) specify specific products via an approved products list; (ii) specify by generic material properties; (iii) specify by performance requirements.

Various agencies have used an "approved product list" type of specification for geosynthetics. While the advantages to this method include convenience and minimizing the use of unwarranted geosynthetics, it also requires a considerable amount of testing by the agencies to ensure the products in their list are adequate, applicable, and inclusive. The number of geosynthetics available in the market has also grown and continues to do so, requiring the agency to continuously update the approved product list. Specifying by general material properties allows the requirements to be adjusted based on design and construction considerations for a specific project or region. Specifying by performance takes the generic method a step further by requiring testing the geosynthetic and soils from the project. While this ensures specific performance is met, it takes considerable time and effort for a contractor to evaluate the geosynthetic in this way, making it impractical in a traditional low-bid system.

Regardless of the method used, research recommends all geosynthetic specifications include [8]:

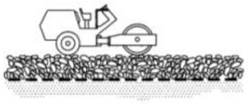
- General Requirements: Typically include products that are acceptable (geogrid, geotextiles, geomembranes, etc.), including acceptable polymeric material. Storage and handling can also be included in this section or reference to manufacturer recommendations are also acceptable.
- Seam and Overlaps: Requirements should be clearly specified. If sewing or mechanical fasteners are to be allowed, its needs to be clearly specified or referred to manufacturer's recommendations.
- Placement Procedures: Detailed installation instructions should be included in the specifications or construction drawings. They should include grading, ground-clearing requirements, aggregate specifications, minimum aggregate lift thickness, and equipment requirements. Holtz et al. recommend the installation procedure in Figure 3.

a. Prepare the ground by removing stumps, boulders, etc.; fill in low spots.
PREPARE THE GROUND

b. Unroll the geosynthetic directly over the ground to be stabilized. If more than one roll is required, overlap rolls. Inspect geosynthetic.
UNROLL THE GEOSYNTHETIC

c. Back dump aggregate onto previously place aggregate. Do not drive on the geosynthetic. Maintain 6 to 12 inches (150 – 300 mm) cover between truck tires and geosynthetic.
BACK DUMP AGGREGATE

d. Spread the aggregate over the geosynthetic to the design thickness.
SPREAD THE AGGREGATE



e. Compact the aggregate using dozer tracks or smooth drum vibratory roller.
COMPACT THE AGGREGATE

Figure 3: Recommended Installation Procedure for Geosynthetics [8]

- Repairs: Instructions for repairing damaged sections of the geosynthetic should be detailed including overlaps, sewn seams, or complete replacement.
- Acceptance and Rejection Criteria: Contract documents should state that final approval is determined by the engineer who can also accept or reject the geosynthetic material. In most cases, its recommended that a certification by the manufacturer be required to ensure proper acceptance/rejection.
- Specific Geosynthetic Properties: Specifications should include the desired properties of the geosynthetic, which typically are based on the geosynthetic's function.

Specific geosynthetic properties are usually not as simple, as physical properties of the geotextiles generally serve as index properties and are not generally adopted directly in design. Mechanical properties can quantify the geotextiles' resistance to tensile stresses mobilized from applied loads or installation conditions. Some tests are performed with the geotextile in isolation while others are performed under soil confinement (often called performance tests). Although most manufacturer specification sheets include some test results at varying strain levels, a single test method is not used. This makes it difficult for agencies to create a generic specification encompassing multiple manufacturers. Common test standards for evaluating geotextiles include [20]:

- ASTM D5199-12 Standard Test Method for Measuring the Nominal Thickness of Geosynthetics, to measure sheet thickness [31].
- ASTM D4751-21a Standard Test Method for Determining the Apparent Opening Size of a Geotextile, to measure the apparent opening size [32].
- ASTM D4491/D4491M-22 Standard Method of Test for Water Permeability of Geotextiles by Permittivity, to measure permeability [33].

- ASTM D5493-06 Standard Test Method for Permittivity of Geotextiles Under Load, to measure permittivity [34].
- ASTM D4595-17 Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method, to measure the tensile stiffness [35].
- ASTM D6241-22 Standard Test Method for Static Puncture Index Strength of Geotextiles and Geotextile-Related Products Using a 50 mm Probe, to determine the CBR puncture strength [36].
- ASTM D6706-01 Standard Test Method for Measuring Geosynthetic Pullout Resistance in Soil, to determine the geotextile-aggregate/soil interface properties [37].

Common test standards for evaluating geogrids include:

- ASTM D1777-96 Standard Test Method for Thickness of Textile Materials, to measure the dimension of the geogrid ribs [38].
- ASTM D5818-22 Standard Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics, to determine resistance to installation damage [39].
- ASTM D6637/D6637M-15 Standard Test Method for Determining Tensile Properties of Geogrids by the Single or Multi-Rib Tensile Method, to measure rib tensile stiffness [40].
- ASTM D7737/D7737M-15 Standard Test Method for Individual Geogrid Junction Strength, to measure the junction strength and junction efficiency [41].
- ASTM D7748/D7748M-14 Standard Test Method for Flexural Rigidity of Geogrids, Geotextiles, and Related Products, to measure flexural rigidity [42].
- ASTM D6706-01 Standard Test Method for Measuring Geosynthetic Pullout Resistance in Soil, to determine the geogrid-aggregate/soil interfacial properties [37].

Design strength of the selected geosynthetic must also be considered within specifications. The strength of the geosynthetic should be designed for the stress expected during construction, which may be greater than its service life. The geosynthetic must have enough strength to survive construction operations to provide its intended function. American Association of State Highway and Transportation Officials (AASHTO) M 288-21 Geosynthetic Specification for Highway Applications has established minimum geotextile properties to survive each level of construction [43]. The classifications are based on a list of strength properties meant to withstand varying degrees of installation survivability stresses, as provided below:

- Class 1 – for severe or harsh survivability conditions where there is a greater potential for geotextile damage
- Class 2 – for typical survivability conditions; this is the default classification to be used in the absence of site-specific information
- Class 3 – for mild survivability conditions

As mentioned previously, manufacturer specifications differ in testing requirements. The same can be seen with agency specifications. Table 3 through 5 summarize specifications for geotextiles and geogrids by state agencies and the Geosynthetic Materials Association (GMA). It’s important to note the variability in testing required as well as performance requirements. Very few agencies include specifications for geosynthetics and those that do have limited specifications. To ensure quality and performance of geogrids, the GMA created standard specifications [44]. However, these specifications are still in the developmental phase and unpublished.

Table 3: Agency Examples of Geotextile Specifications.

Property	Unit	Test Standard	USACE Spec.	CoDOT		Caltrans			WSDOT		NDOT	
				Woven	Non-woven	Class A1	Class A2	Class B1	Woven	Non-woven	Non-woven	
											Class 1	Class 2
Elongation at break	%	ASTM D4632	200	<50	≥50	<50	≥50	<50	<50	≥50	-	-
Grab Strength	lb	ASTM D4632	200	250	160	250	160	-	315	200	-	-
Puncture Strength	lb	ASTM D3786	80	500	310	620	620	620	620	430	-	-
Burst Strength	psi	ASTM D4834	250	-	-	-	-	-	-	-	-	-
Trapezoid Tear	lb	ASTM D4533	80	90	60	90	60	-	112	79	-	-
Apparent Opening Size (AOS)	in	ASTM D4751	<0.0165	<0.0165	<0.0083	<0.012	<0.012	<0.024	<0.0165	<0.0165	0.0059<AOS <0.0098	
Permittivity	sec^{-1}	ASTM D4491	0.05	0.5	0.5	0.05	0.05	0.2	0.1	0.1	0.5	0.5
Ultraviolet Degradation	%	ASTM D4355	50	70	70	70	70	70	50	50	50	50
Wide-Width Strip Tensile Modulus	lb./ft.	ASTM D4595	-	-	-	-	-	4800	-	-	-	-
Polymer Type	-	-	Polyester or Polypropylene						-	-	Needle-punched Polypropylene	

Note: CoDOT=Colorado Department of Transportation; WisDOT=Wisconsin; NDOT=Nevada.

Table 4: Agency Examples of Geogrid Specifications.

Property	Unit	Test Standard	CoDOT	Caltrans	WisDOT	NDOT
Rib Thickness	in.	ASTM D1777	0.05	0.04		
Junction Thickness	in.	ASTM D374	0.12	0.15		
Flexural Rigidity	mg-cm	ASTM D7748	750000	750000	250000	
Aperture Stability	kg-cm/deg	ASTM D7864	6.5			
Junction Strength	lb./ft.	ASTM D7737		1220 x 1830		
Junction Efficiency	%	ASTM D7737	93			
Tensile Strength	lb./ft.	ASTM D6637	410 x 620	410 x 620	500 x 500	780 x 1300
Ultraviolet Degradation	% Retained Strength @ 500 hr	ASTM D4355	70	100		
Torsional Rigidity	mm-kg/deg	GRI GG9		0.65		

Note: GRI GG9=Geosynthetic Research Institute Geogrid; CoDOT=Colorado Department of Transportation; WisDOT=Wisconsin; NDOT=Nevada.

Table 5: Consensus Geogrid Requirements by Geosynthetic Materials Association (GMA) [44].

Property	Test Method	Units	GMA Consensus Requirements		
			Class A	Class B	Class C
Tensile Strength (@ 2% Strain)	ASTM D6637	lb/ft	550	400	250
Ultimate Tensile Strength	ASTM D6637	lb/ft	3500	2500	1500
Junction Strength	ASTM D7737	lb	45	35	25
Percent Open Area	Direct Measure	%	70		
Ultraviolet Stability (Retained Strength)	ASTM D4355	%	70% after 500 hours of exposure		

Note: GMA=Geosynthetic Materials Association.

4.6 Modeling Techniques

Several research studies have been conducted on laboratory and field performance of geosynthetics. Still, to extend and solidify the use of geosynthetics, geosynthetic material must be incorporated into pavement design. The ability to predict the performance of geosynthetic-reinforced pavement and compare it to an unreinforced pavement is key for evaluating the cost-effectiveness of geosynthetics, and a necessary step for routine implementation at a state DOT level. Currently, most agencies use the 1993 AASHTO Guide for Design of Pavement Structures or AASHTOWare Pavement ME design software to design their pavements. However, neither method includes geosynthetic material for pavement design. Proposed design methods for geosynthetic reinforcement in pavement sections are either based on empirical and analytical considerations or analytical models modified by experimental data. To date, a general analytical design solution has not been found to address the many variables that impact performance. The conditions associated with the study's experiments limit all empirical design methods. Therefore, there has been a demand to address this limitation and multiple agencies have shifted towards developing their own solutions.

Table 6 summarizes some agencies that acknowledge using geosynthetics for base reinforcement and key considerations for pavement structural design. It’s important to note the differences in the geosynthetic types and the level of consideration each agency places on structural design using the geosynthetic. The considerations are specific to each agency’s geosynthetic application and vary with thickness, subgrade modulus, moisture, field tests, and soil type. However, the significant notion is that no specific method or unique set of considerations are consistent throughout the agencies.

Table 6: Agency Examples of Structural Design Considerations for Base Reinforcement.

Agency	**Reference**	**Geosynthetic Type**	**Structural Design Considerations**
Montana DOT	Geotechnical Manual (2008)	Geotextiles and geogrids	– Acknowledges structural contributions. – Laboratory and/or field tests with specific product with similar conditions to quantify the contribution of geosynthetic materials.
Colorado DOT	Pavement ME Design Manual (2021)	Geotextiles and geogrids (biaxial only).	– Follows NCHRP 01-50 recommendations to calculate the effective modulus of the composite aggregate base or subgrade. – Applicable for subgrade modulus between 0.5 and 5 ksi. – Thickness of the aggregate base can be adjusted, but not the asphalt layer thickness. – Minimum 6 in. of aggregate base or stabilized material above the geosynthetic layer.
Caltrans	Highway Design Manual (2020)	Geogrids and geotextiles (polypropylene punched and drawn geogrid only).	– Topic 665 provides guidelines for subgrade improvement with geosynthetic – Geosynthetics not recommended for subgrade with R-value > 40 or CBR > 6.5 or Mr > 9,500 psi – Aggregate base enhancement with biaxial geogrid only. – Subgrade Effective R-value <20 → Max BCR=25% – Subgrade Effective 20< R-value <40 → Max BCR=20%
Arizona DOT	Pavement Design Manual (2017)	Geogrid.	– Use only for soils with R-value between 10 and 19. – Increase R-Value by 10 when a geosynthetic is used for base reinforcement
USACE	Technical letter No. 1110-1-189	Geogrids Geotextiles.	– Design and construction guidelines include: – Geogrid placed at the bottom of a base with <14 inches thick; and in the middle of a base with ≥14 inches thick.
Wisconsin DOT	2021 Standard Specification	Geotextiles and geogrids.	– Vary property requirements based on use of the geotextile or geogrid – No specifications on when the geosynthetic is applicable or placement.
Washington State DOT	WSDOT 2021 Standard Specifications M 41-10	Geotextiles and geogrids.	– Applicable if the subgrade resilient modulus is < 5800 psi or if saturated fine sandy, silty, or clayey subgrade is present. – Must consider flow path of groundwater before selecting geotextile

Note: USACE=Geosynthetic Materials Association; CBR=California bearing ratio; BCR=base course reduction.

Design methods incorporating base reinforcement generally allow the user to evaluate a reduction in base course thickness or an increase in design life of a section containing a layer of geosynthetic reinforcement. Some methods have been based on specific proprietary geosynthetics, others have been established for generic types of reinforcement, and some have been generically established for any type of geosynthetic reinforcement. Design is usually based on the number of equivalent single axle load's (ESALs) anticipated to reach a specific rut depth in the pavement, the number of ESALs anticipated to reach an equivalent rut depth condition in an unreinforced section, or a modified structural number [20]. Some procedures use a modified base layer coefficient to account for the geosynthetic reinforcement and modify the structural number. Design procedures are usually available in chart format, and some computer programs have been developed.

AASHTO adopted the Mechanistic-Empirical Pavement Design Guide (MEPDG) as an interim pavement design standard in 2008 [45]. The AASHTOWare Pavement ME design software is currently being used to implement the MEPDG, incorporating the combined effects of traffic, climate, and material properties to conduct advanced mechanistic analysis of the pavement structure. Since 2007, NDOT, in collaboration with the University of Nevada, has been working on implementing the MEPDG procedure to design flexible pavements by developing the necessary materials databases for Nevada [46]. Currently, NDOT has a MEPDG manual that covers the various parts of the design process including an extensive database on the properties and performance of asphalt concrete (AC) mixtures and properties of unbound materials (base, subbase, and subgrade) [47]. However, the inclusion of geosynthetics within the software has yet to be implemented. This limitation requires use of alternative tools that can supplement the Pavement ME design software to address geosynthetic reinforcement.

4.6.1 NCHRP Project 01-50: Composite Geosynthetic Tool

One such tool was developed as part of a 2017 National Cooperative Highway Research Program (NCHRP) study, Project 01-50 “Quantifying the Influence of Geosynthetics on Pavement Performance” that is used to obtain an enhanced modulus for use in the AASHTOWare Pavement ME design software [20]. The enhanced modulus of the composite aggregate base or subgrade is estimated using the Composite Geosynthetic-Base Course Model, which is a computer subroutine developed to predict performance of pavements with geosynthetics. The computer program allows input of either geogrids or geosynthetics in the middle of the base layer or at the base-subgrade interface. Other inputs include hot mix asphalt (HMA) thickness, base thickness, HMA modulus, base modulus, base anisotropic ratio, geosynthetic sheet stiffness, and subgrade modulus. The tool targets equal critical strain values in the base or bottom of the asphalt layer of an unreinforced section to that of a reinforced section, depending on the location of the geosynthetic. The reinforced section is modified through the subgrade and base modulus resulting in the same structural design and strain values as the unreinforced section. Therefore, the incorporation of the geosynthetic serves as reinforcement through an increase in stiffness of the base and subgrade layer. The limitations to this tool are the conditions studied including the range of base modulus between 20-60 ksi and only modeling biaxial geogrids.

4.6.2 Tensar: Tensar$^+$

In contrast, Tensar$^+$ (formerly Spectra Pave) follows the empirically-based 1993 AASHTO Guide for Design of Pavement Structures. The design approach uses enhanced layer coefficients to account for the benefits of the geogrid. Tensar states these coefficients are based on extensive testing, including laboratory, field, and accelerated test tracks, and over 35 years of field performance [48]. These coefficients are specific to the selected Tensar triaxial geogrids. They are functions of the technical specifications of the geogrid, thickness of the asphalt layer, thickness of the aggregate base course, and subgrade strength. Originally, the software assigned TBR values to each type of geogrid, however past work demonstrated that the TBR is not a constant for each geogrid type or grade and benefit gained from the geogrid is significantly influenced by other factors. Therefore, an effective improvement in the response of the overlying layer was represented by an increase in the overlying layer coefficient.

The Tensar$^+$ software inputs are aggregate base and HMA layers thicknesses, layer coefficients, subgrade resilient modulus, and geogrid type that are then factored into the modified layer coefficient [13]. The tool is empirically based following the AASHTO 1993 design method, so the base modulus is not correlated. The tool is also limited in modeling only proprietary geogrids, specifically the Tensar triaxial line (TriAx) and is only applicable for base thicknesses greater than 6 inches for the unreinforced and reinforced design. It is noted that field verifications for Tensar products have heavily relied on observed permanent deformation and may pose limitations when accounting for other distress types.

4.6.3 TenCate: MiraSpec Road Design

Similarly, TenCate's MiraSpec Road Design software is similar to Tensar's Tensar$^+$, an analysis tool allowing the user to perform flexible pavement structural number and ESAL calculations based on 1993 AASHTO Guide for Design of Pavement Structures. The software allows for design with or without geosynthetics. However, the software only allows for reinforcement using several Mirafi RSi-Series and H_2Ri geotextiles. Like Tensar+, there is a recommended minimum base course thickness of 6 inches for any geotextile options. TenCate estimates a BCR of approximately 20-40% with subgrade strengths with a CBR of 10 or greater and 40-57% for CBR between 5 and 1 [49]. The software accounts for such benefit through incorporating a geosynthetic structural coefficient (GSC) to the AASHTO 1993 calculation for structural number. Adding an additional parameter to the structural number assumed the geosynthetic benefits the layer directly above the reinforcement and the remaining layers in the system above that.

5.0 EXPERIMENTAL DESIGN

This project's experimental design aims to evaluate and quantify the structural benefits of using geosynthetics under Nevada conditions to ease selection of a proper location to support a controlled field demonstration project. Different geosynthetic types and structural design thicknesses were utilized to predict design lives of an experimental section given expected subgrade, traffic, and climate characteristics. The objective is to determine if a specific site with known characteristics is predicted to fail within a reasonable time period, while having characteristics common throughout Nevada that can allow for further implementation of geosynthetics as reinforcement in the state.

This chapter documents the experimental design process for selecting a single test site location with multiple test sections. The approach and developed guidelines could be replicated at other sites if NDOT desired. Three key elements for successful implementation of the experimental design are: (i) selecting an acceptable site; (ii) proper layout of test sections within the site to draw meaningful results; and (iii) pavement design and analysis of test sections.

All assumptions and decisions related to the experimental design will be addressed in this section. If further analysis is necessary during any other phases of this project, this section along with the appendix can be referenced.

5.1 Site Selection

Selecting the ideal site will depend on subgrade modulus, climate, and traffic characterization based on the pavement design and analysis of the test sections. However, general considerations need to also be addressed prior to the characterization to address safety, uniformity, and research appropriateness. Possible test site selection should begin with a review of the original construction records, distress surveys, pavement design calculations, and geotechnical reports.

The existing pavement condition should be evaluated to provide insight into the expected performance if the existing pavement structure is similar to the proposed experimental pavement structures. The selected test site must have relatively uniform subgrade throughout the test sections to ensure differences in pavement performance can be attributed to the efficacy of the geosynthetic and not variations in subgrade support. The uniformity is also crucial to assume a representative subgrade modulus for pavement design and analysis. Available geotechnical investigation reports can be used to characterize the in-situ subgrade but should not be the only source of subgrade information. The objective is to find a consistent continuous stretch of subgrade. Further guidelines on characterizing the in-situ subgrade and pre-construction evaluations can be found in Section 6.0 within this report.

5.1.1 Geometric Constraints

As part of the Long-Term Pavement Performance (LTPP) Specific Pavement Study 10 (SPS-10), some geometric data (terrain type, horizontal curve, grade) were gathered as part of the nomination phase and available on the LTPP InfoPave ® website [50]. The results show that about 67% of the sections are in area of flat roadway with only 8% of the sections in areas with a grade of 2.5% or greater. In addition to these measures, all SPS-10 sections are in areas with full passing sight distance to reduce safety concerns. As the research test site for this project will undergo frequent evaluations requiring lane closures and personal working on-site, good sight distance in advance of and through the site is critical for safety. It is also recommended to limit vertical curves to 2.5%. Nearly all of the SPS-10 sections are located in a relatively straight roadway section with only slight horizontal curves. Therefore, horizontal curves in excess of 3 degrees should be avoided for this project.

Each SPS and general pavement study (GPS) has an experimental plan document outlining the variables to be studied, the monitoring tests, and schedule. These experimental plans also contain recommendations on where to place test sections. They include the following [51]:

- Test sections should not be located at the beginning of the production cycle to avoid anomalies due to production start-up.
- Test sections should be located on portions of the construction project that are relatively straight and have a uniform vertical grade. Horizontal curves greater than 3 degrees and vertical grades greater than 4 percent should be avoided.
- Traffic flow over the entire project shall be uniform and carry the same traffic stream. Intersections, rest stops, on and off ramps, and weaving areas should be avoided within the project boundaries. Traffic flow interruptions (ramps, intersections) should not occur within any of the test sections.
- All portions of the project that include test sections should be opened to traffic simultaneously.
- Underground structures such as culverts and pipes should be avoided when selecting the location of the test section. Subsurface structures should be located in transition zones between test sections.
- Each test section's entire length should be located on a cut or a fill. Cut fill and side hill transitions should be avoided, where possible.

5.1.2 Traffic

The ideal site will be an existing low traffic volume roadway that experiences relatively high truck traffic to test the efficacy of the geosynthetics. Low traffic volume is desired, as the experimental sections are designed to experience early distress so that the influence of the geosynthetics can be demonstrated in a short time period.

To properly characterize the amount of traffic, the annual average daily truck traffic (AADTT) compiled by NDOT was investigated [52]. Both state and US routes show variability with 80% of the traffic distribution under an AADTT of 1000 as shown in Figure 4. Approximately 50% of AADTT is below 400 for state routes and below 600 for US routes. The highest frequency for both routes occur at an AADTT below 200.

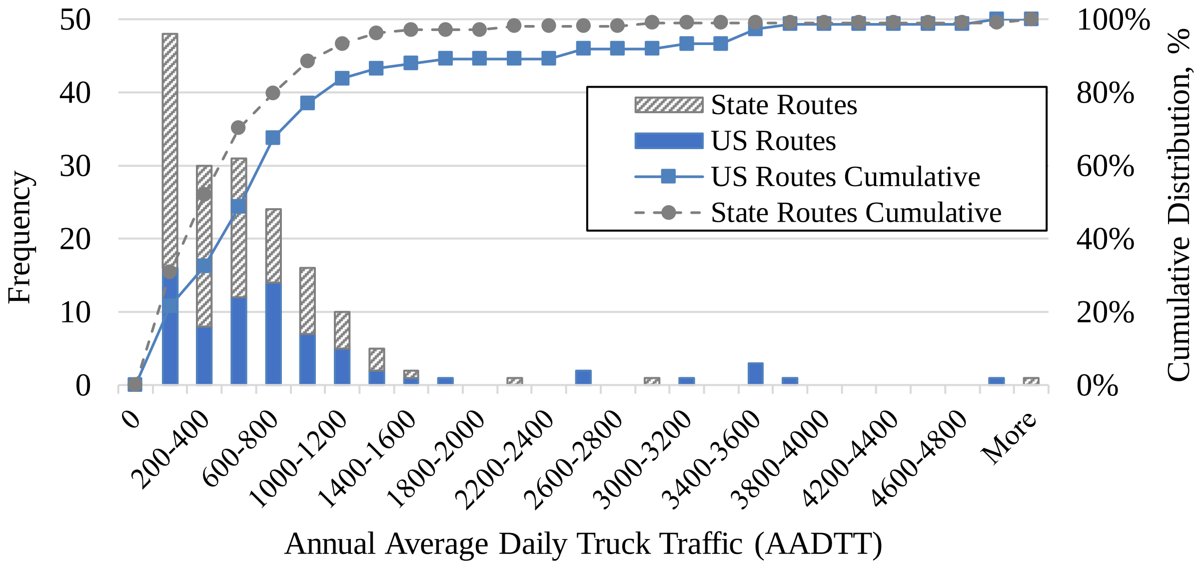


Figure 4: Traffic Distribution of Nevada State and US Routes.

Initial evaluations started with AADTT ranging from 100-1000 to account for variations across Nevada. However, after further analysis, a lower AADTT was warranted to meet the experimental pavement design and expected design life. Therefore, the following evaluations and final recommendations used an AADTT range from 50-250.

5.1.3 Climate

As the project will be constructed in Nevada, an initial evaluation targeted site locations in each of the three districts, beginning with one major city within each district. Las Vegas represented District 1, Reno represented District 2, and Elko for District 3. Further analysis confirmed that neighboring cities within the same district had similar climatic data gathered through LTTP Info Pave's MERRA climatic data [53]. Therefore, the selected three major cities served as the representative locations for climatic data within each district. All recommendations and data analysis hereafter correspond to those three representative cities (Reno, Las Vegas, and Elko).

5.1.4 Selection of Subgrade Properties

As mentioned in the literature review, the benefit of geosynthetics is highly dependent on the subgrade modulus. Generally, geosynthetic reinforcement provides a greater benefit if weaker subgrade is present, up to a CBR of 8 (M_r ~ 9700 psi) [5]. The selected M_r has a highly significant impact on the response of the pavement structure to the combined actions of traffic and climate, requiring an accurate and representative M_r value. However, M_r testing at the project level is rarely conducted but rather correlated to less expensive routine tests such as R-value. Therefore, data was obtained from previous projects in Nevada to determine typical R-values across the state. Figure 5 illustrates the variability in R-value ranging from 0-85.

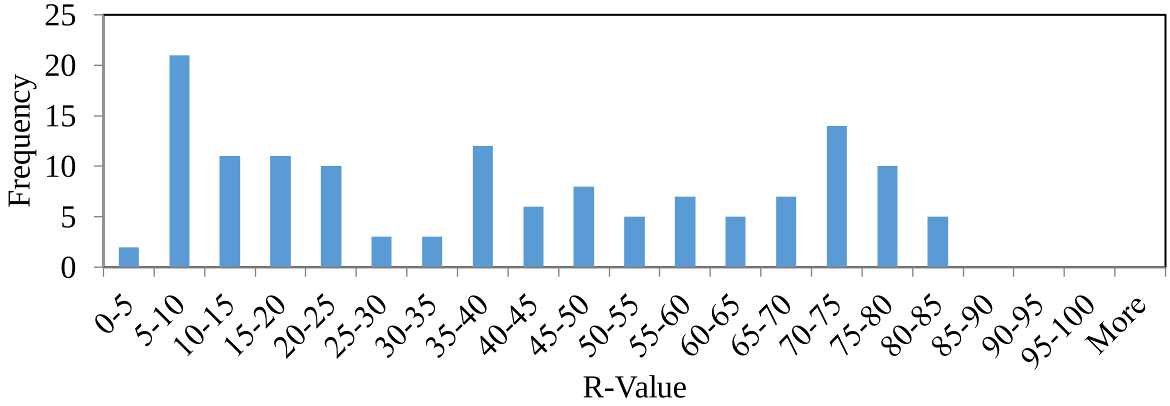


Figure 5: R-Value Frequency for Various Sites in Nevada.

Correlations relating R-value to M_r are typically based on a simple regression model. Yet, extensive research has shown that M_r values are affected by soil characteristics such as moisture content, gradation, Atterberg limits, and seasonal variations. A more accurate correlation is described by Equation 1 that includes R-value as well as soil characteristics [46]. This prediction model was explicitly calibrated for Nevada using materials acquired within the state.

Equation 1: Subgrade Resilient Modulus

$$ln(Mr) = 3.178 + 0.0188 * R - value + 0.0136 * P40 + 0.0315 * \Upsilon d + 0.043 * PI$$

Where:
M_r = subgrade resilient modulus, psi
R-value = resistance r-value
P40 = percent passing No. 40 sieve
γ_d = maximum dry density, pcf
PI = plasticity index

Previous projects from Nevada were analyzed again but with the new prediction model including the soil properties. There wasn't a strong linear correlation between R-value and M_r (Figure 6), with higher R-values showing variation in attributed M_r values. This demonstrated the impact of soil characteristics on the M_r values, thus further analysis continued referring to the M_r values with specific soil attributes rather than stating an R-value.

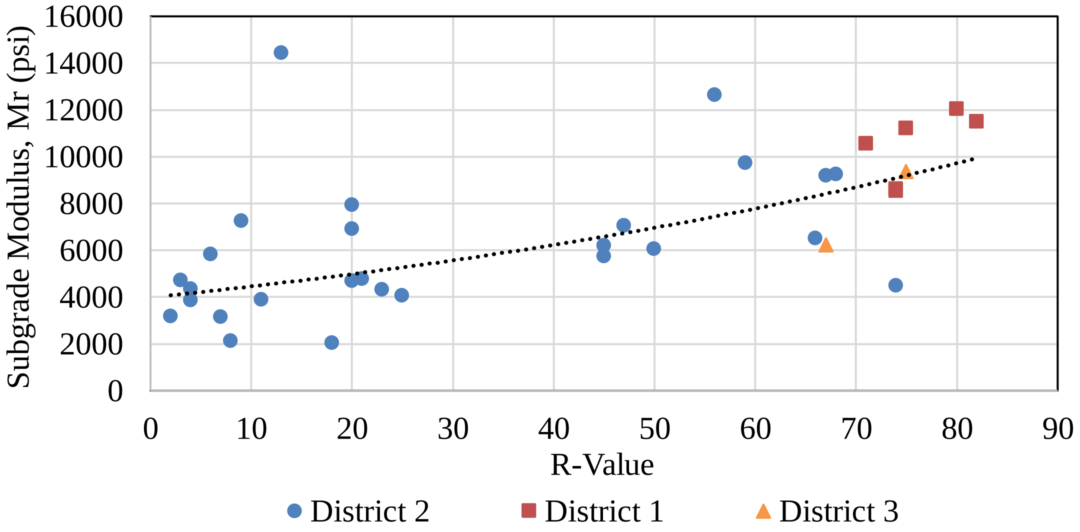


Figure 6: R-Value vs Subgrade Resilient Modulus for Previous Projects in Nevada.

To conduct the pavement design, representative M_r values were required. The majority of the projects demonstrated M_r values within 2000-12,000 psi. However, low M_r values (<2,000) would trigger a subgrade stabilization and thicker pavement structures that would likely mask the effect of base reinforcement. On the other hand, higher M_r values may not trigger the subgrade stabilization and will not experience any benefit from the addition of the geosynthetic. Therefore, four representative M_r values were selected for subsequent analysis, encompassing a range expected within Nevada and acknowledging the limitations to achieve the greatest benefit from the geosynthetics. The representative M_r values are 2120,4050, 5730, and 8540 psi. Information on their respective soil characteristics can be found in the Appendix. The ideal site location would have a M_r value within the representative range.

5.2 Pavement Design & Analysis

The experimental design for this project includes: i) designing a short life pavement section; and ii) designing geosynthetic reinforced pavement sections with reduced base thickness. Based on the literature review and analysis, the following information will provide NDOT with guidelines for designing the various pavement test sections for site-specific conditions. Design examples are included in a tabular format to guide the department is selecting a proper site based on the design and analysis resulting in a specific design life. Further information related to the analysis is included in the Appendix.

5.2.1 Base Reinforcement Software Evaluation

The first part of the study focused on evaluating the usefulness of various pavement design software that incorporate geosynthetics by analyzing their sensitivity to key design inputs and accessing reasonableness of their outputs. There must be confidence that sections with reduced thickness engage the geosynthetic reinforcement to demonstrate its value. In other words, the performance of reinforced pavement sections should show a significant difference in the life of the pavement when compared to unreinforced sections designed and constructed similarly. Therefore, the sections will also be evaluated using the AASHTOWare Pavement ME Design software per the NDOT 2019 Manual for Designing Flexible Pavements in Nevada for comparison [46].

Geosynthetics cannot be directly simulated in the software at this time. Therefore, they will be indirectly simulated by modifying the subgrade resilient modulus using the Composite Geosynthetic-Base Course Model from NCHRP Project 01-50. The process used to meet this objective is as follows:

- Select example projects (traffic, geographic location, soil classification).
- Conduct AASHTOWare Pavement ME design for new unreinforced flexible pavement.
- Design base-reinforced flexible pavements using tools/software.
- Evaluate base-reinforced pavements using Pavement ME and output from NCHRP 01-50 tool.
- Compare and access appropriateness.

Two projects located near Reno, Nevada were selected to evaluate the design tools as summarized in Table 7. The AADTT data was determined based on NDOT's traffic record's information access (TRINA) application. The unreinforced design was conducted using Pavement ME. Various base reinforcement software packages were investigated: Tensar$^+$, MiraSpec, MACREAD, and SecuCalc. MACREAD and SecuCalc were not fully developed by the time of analysis, therefore they were not considered further. The NCHRP Project 01-50 tool was utilized independently and supplemental to Pavement ME. When used alone, equal strain values from the unreinforced design were aligned to a reinforced design with a reduced base course thickness. As a supplement to Pavement ME, the modified subgrade modulus was input into the Pavement ME Design software to predict the performance of the geosynthetic-reinforced pavement. It is important to note that the NCHRP Project 01-50 tool provides a modified base and subgrade modulus. However, a consensus within the industry and state agencies suggests only implementing the modified subgrade modulus into Pavement ME, as including both modifications result in unrealistically high BCR factors.

Table 7: Example Project Data for Design Method Comparison.

Project	Annual Average Daily Truck Traffic (AADTT)	Base Modulus (ksi)	AC (inch)	Base (inch)	AC Permanent Deformation (inch)[1]	Permanent Deformation: Total Pavement (inch)[1]	AC Bottom-up Fatigue Cracking (% Lane Area)[1]
SR028	2,800	11	8	16	0.08	0.2	14.7
SR443	981	11	4	12	0.08	0.2	2.5

Note: SR=state route; AC=asphalt concrete; predicted distresses.

The results, illustrated as BCR, are shown in Figure 7. They indicate that adjusting only the subgrade modulus, as recommended, resulted in a reasonable BCR ratio comparable to literature values (geotextiles BCR 22–33%; geogrids BCR 30–50%) [5]. It is noted that Tensar+ analysis was based on a triaxial geogrid (Tensar TriAx 5), TenCate Miraspec on geotextile, and NCHRP Project 01-50 on biaxial geogrid. Therefore, adequate comparison relative to each other is not possible. However, the overall analysis correlated well with observations in other research studies, primarily that greater reduction in base course thickness is seen in lower subgrade modulus sections, with lower traffic and thinner unreinforced bases.

By comparing the use of NCHRP Project 1-50 as a stand-alone and supplemental to Pavement ME, it is evident that strains from the NCHRP modeling do not correlate with the same BCR as the modified subgrade modulus. This is primarily due to the pavement performance measures significantly influenced by traffic and climate factors, which have been considered in the current Pavement ME design software.

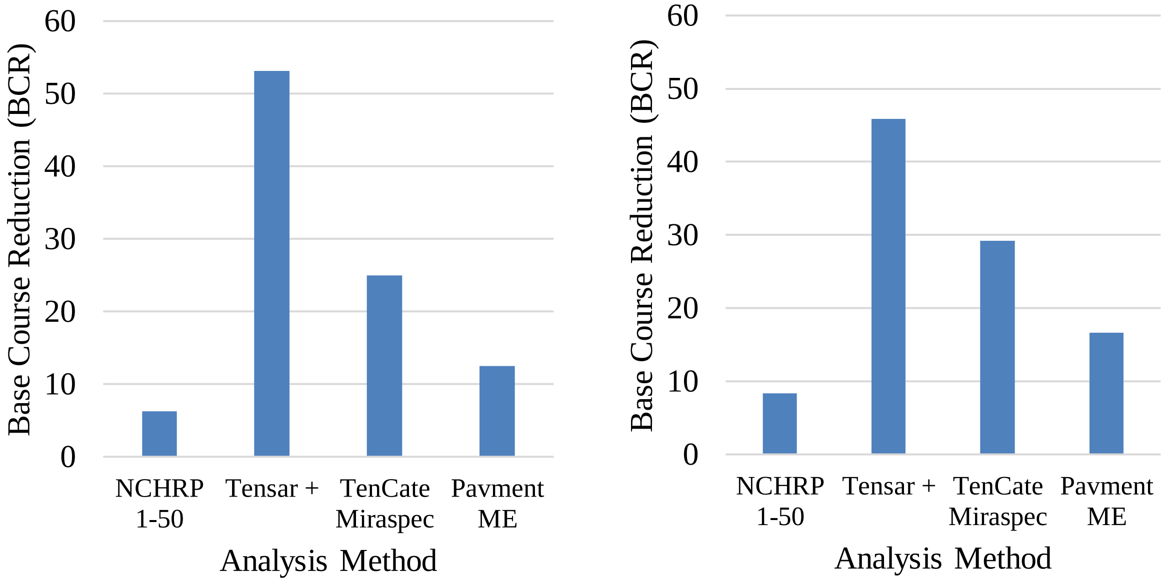


Figure 7: Design Method Tool Comparison for (left) SR028 and (right) SR443.

From this analysis and the final analysis described later in this section, the failure distress is fatigue cracking for both the unreinforced and reinforced designs. The performance of geosynthetic-reinforced flexible pavements includes fatigue cracking, permanent deformation, and international roughness index (IRI). However, it should be noted that locally calibrated performance models and transfer functions for rutting and fatigue are being used in the AASHTOWare Pavement ME. The key difference between running the ME analysis versus the AASHTO 1993 analysis, is the type of failure. The AASHTO 1993 designs failed by permanent deformation. While through the Pavement ME analysis AC fatigue cracking was the controlling distress. This difference in type of failure, is particularly noticeable when comparing BCR and expected design life, with AASHTO 1993 overpredicting the performance of the geosynthetic reinforcement.

5.2.2 Layer Thickness

This effort focuses on illustrating the benefits of a reinforced base layer within a short time in the field to accelerate implementation. NDOT aims for a target design life of 4 ± 2 years for the unreinforced design and approximately 15 years for the reinforced design. This would allow for a shorter monitoring period with no rehabilitation required in the process. Typically, test sections are constructed based on BCR estimates to produce a reinforced design with a reduced base course thickness. This design is compared to an unreinforced design with the original base course thickness.

Conversely, base reinforcement can also be evaluated based on extended design life. Therefore, targeting an extended design life will allow for the structural pavement section to be the same for both the unreinforced and geosynthetic-reinforced sections. This not only allows for a shorter evaluation and monitoring period, but also allows for improved uniformity and ease of construction.

Pavement ME was utilized to generate a structural design that would target the design life suggested by NDOT. Further analysis settled on using a 50% design reliability to ensure failure within the design life range without overdesigning. The only constraint was the NDOT minimum base layer thickness of 6 inches was to be used. It was determined that a 3-inch AC layer over a 6-inch base would satisfy the unreinforced design life of 4 ± 2 years for a majority of the subgrade and traffic combinations selected. However, it was also decided to implement a design with a thicker base layer of 12 inches to assess the impact of the geosynthetic on thicker designs and to validate previous field studies showing greater impact on thinner layers [5]. Thus, it is expected for the design life of the 12-inch base to go beyond the 4 years originally assumed.

5.2.3 Selection of Location and Type of Geosynthetic

NDOT aims to use reinforced base layers for midrange to poor subgrade conditions. As mentioned in the literature, geotextiles have been primarily used for separation and stabilization functions, specifically with subgrade with low CBR values (CBR < 3) [5]. They normally don't provide as much benefit from reinforcement in paved roads due to the lower allowable deformation [7]. Studies have also found that geogrids performed better than sections using geotextile products for reinforcement[16]. Based on previous research and knowledge of NDOTs implementation in midrange to poor subgrade conditions, improved base reinforcement with geosynthetics would be better showcased by using geogrids.

Previous studies utilizing geogrids as base reinforcement have predominately focused on using biaxial geogrids, with a few including triaxial geogrids due to their later introduction into the market. As more geosynthetics have developed, it is of interest to consider the use of other geogrids beyond the biaxial. Although high tensile strength of geogrids had generally correlated to good performance, the U.S. Army Corps of Engineers (USACE) revealed that high-performing geogrids that performed well in the laboratory according to maximum modulus and secant modulus at 2% did not correlate to actual field performance according to their TBR value [13]. They described the laboratory performance as the "tensioned membrane" effect where the strength that a geogrid offers when stretched does not offer appropriate support for the layers above it; rather the benefit is in how well the geogrid performs in the overall system with its interactions with the layers around it. Dong et al. explains the triaxial geogrid increased performance compared to biaxial as the geogrid's ability to evenly distribute a load through 360 degrees, without deforming elastically [12]. Therefore, triaxial geogrids can provide increased benefit as base reinforcement.

Implementing triaxial geogrids in this project is recommended to verify the need to modify existing NDOT specifications to include triaxial geogrids.

According to the literature, the benefits of geosynthetics in asphalt pavements depend on the aggregate base layer's thickness and the geosynthetic's location within that layer. Generally, geosynthetics were reported to be more effective in flexible pavements when placed at the base-subgrade interface of thin base sections (6-10 inches) and near the midpoint of thicker base layers (10 or more inches). However, utilizing the NCHRP Project 01-50 tool, it can be seen (Figure 8) that applying the geogrid at the base-subgrade interface decreases the compressive strain at the top of the subgrade significantly for base thickness between 9-12 inches compared to the unreinforced design. Incorporating the geogrid within the middle of the base layer (Figure 9) reduces the compressive strain at a base thickness of 10 inches yet fails to reduce the strain levels equal to that of the geogrid placed at the interface. For the specific conditions of this project, placing the geogrid at the middle of the base layer may be adequate for base thicknesses greater than 12 inches. As described previously, this project will focus on two design structures, with a base thickness up to 12 inches, therefore its recommended to place the geogrid at the base-subgrade interface.

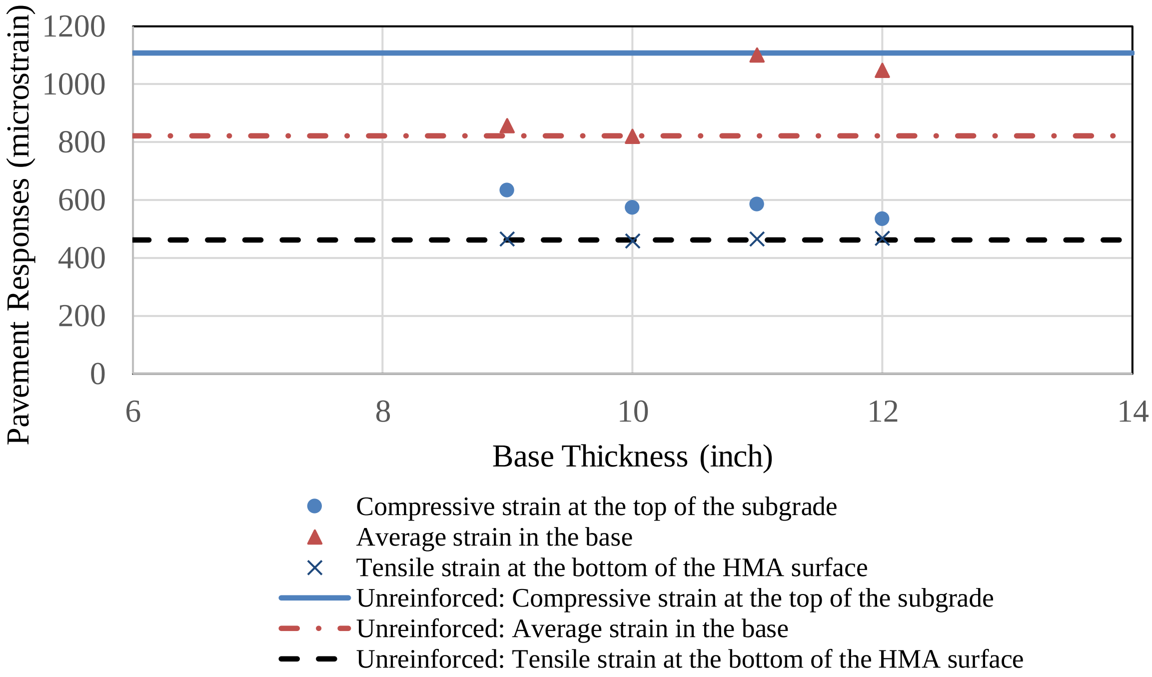


Figure 8: Pavement Responses for SR443 with Geogrid at Base and Subgrade Interface.

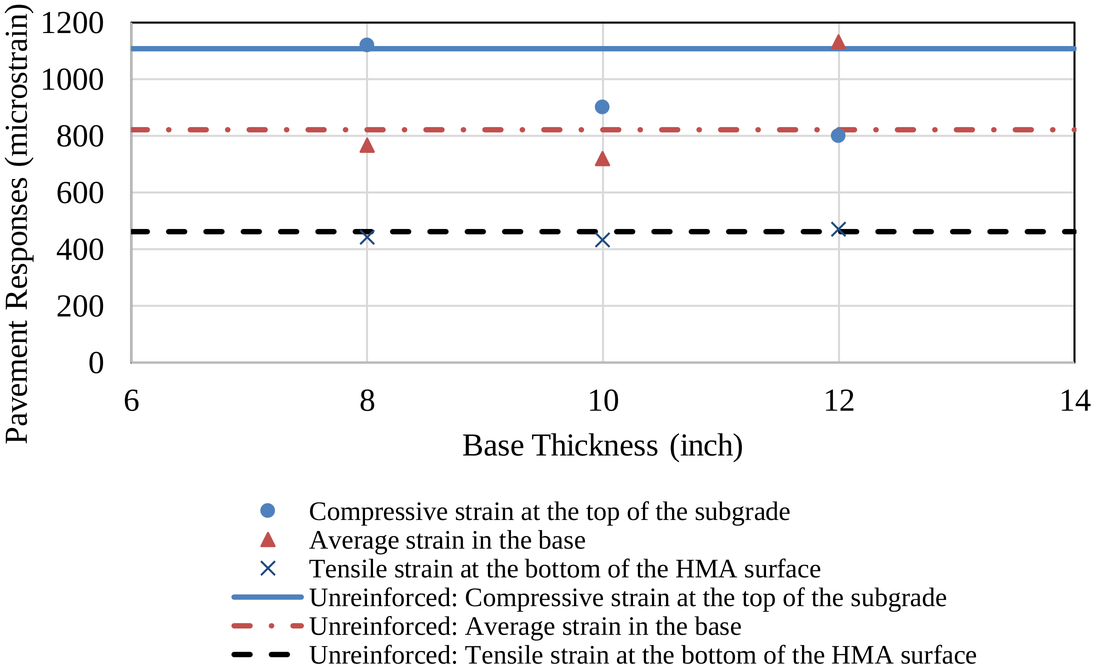


Figure 9: Pavement Responses for SR443 with Geogrid within Base Layer.

5.2.4 Recommended Design

Based on the analysis and evaluations described above, the final approach for this project can be summarized as:

- Utilizing climatic data from all three Nevada districts; Las Vegas, Reno, and Elko.
- Design for subgrade resilient modulus range from 2000-8000 psi based on soil characteristics from previous NDOT projects.
- AADTT range from 50-250 accounted for typical design traffic.
- Target a design life of 4 ± 2 years for the unreinforced design and approximately 15 years for the reinforced design using 50% reliability to shorten the evaluation period and accelerate implementation.
- Include two structural designs using geogrid at the base-subgrade interface to properly evaluate base reinforcement by the use of the geosynthetic.
    - 3-inch AC with a 6-inch base
    - 3-inch AC with a 12-inch base

The following sections will outline the parameters used to conduct the final design evaluation incorporating the summarized approach, resulting in the geosynthetic design tables found at the end of this section.

5.2.4.1 Selected Design Methods

Based on the previous analysis, the decision to go with geogrids as the geosynthetic narrowed the base reinforcement software option to utilizing the NCHRP Project 01-50 tool and Tensar+. Due to the significant influence that subgrade, climate, and traffic have on geosynthetic performance, Pavement ME would be the primary design tool. However, discussions with NDOT led to the inclusion of the 1993 AASHTO Guide for Design of Pavement Structures utilizing the NCHRP 1-50 tool to modify the subgrade modulus and incorporate the Tensar$^+$ base layer coefficient adjustments in the analysis. It has been discussed and noted that there is a significant difference between the design lives predicted by Pavement ME and AASHTO 1993, primarily due to the failure mechanism. Therefore, the final iterations will showcase different design lives across all three methods.

AASHTO 1993

The use of AASHTO 1993 method is incorporated in two different ways for the analysis of this project. The first includes the traditional design method with modifications to the base layer coefficient to account for the geogrid. The original parameters used are described in Table 8. The modification referred to as "reinforced design (adjusted coefficient)", utilized the base layer coefficients from the Tensar^{+} software using TriAx 8, shown in Note: R=reliability (%); Pi=initial serviceability index; Pt=terminal serviceability index; SD=standard deviation; HMA=hot mix asphalt.

Table 9. The adjusted base layer coefficients are a function of subgrade modulus and base layer thickness. However, it is noted that the coefficients only vary slightly (Figure 10), with greater change noticed at higher subgrade modulus. The second analysis utilized AASHTO 1993 design method with modifications to the subgrade modulus based on NCHRP Project 01-50. This modification is referred to as "reinforced design (effective modulus)" and is described below. As this design method does not account for climate, the calculated design lives are constant throughout location.

Table 8: Flexible Parameters Used for AASHTO 1993 Designs.

Flexible Parameters			
R	50	HMA Layer Coefficient	0.35
P_i	4.2	Base Layer Coefficient	0.1
P_t	2	Roadbed Modified Layer Coefficient	0.18
SD	0.45	Drainage Coefficient	1.0

Note: R=reliability (%); Pi=initial serviceability index; Pt=terminal serviceability index; SD=standard deviation; HMA=hot mix asphalt.

Table 9: Adjusted Base Layer Coefficients from Tensar^{+}.

Design Subgrade M_r (psi)	Adjusted Layer Coefficient	
	3"/12" Design	3"/6" Design
2120	0.154	0.195
4050	0.154	0.195
5730	0.154	0.194
8540	0.151	0.191

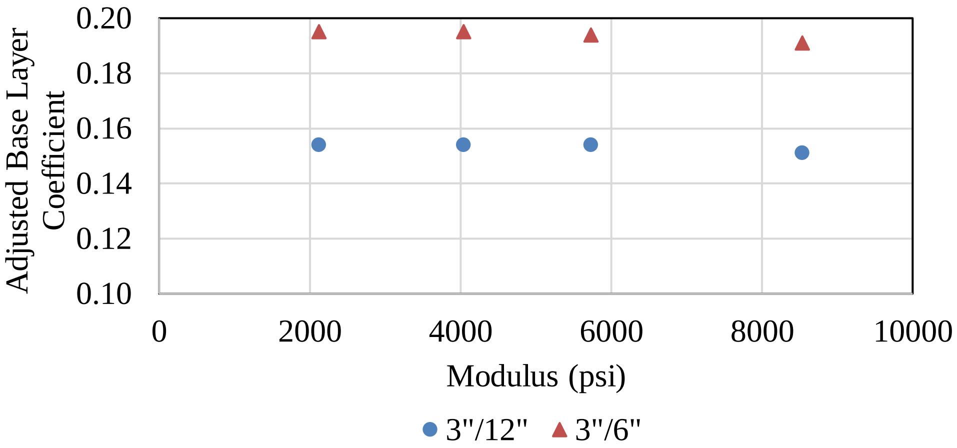


Figure 10: Adjusted Base Layer Coefficient Values from Tensar^{+}.

NCHRP Project 01-50

The composite geosynthetic base course model included as part of NCHRP Project 01-50 study was utilized to determine the modified subgrade modulus later implemented in Pavement ME and AASHTO 1993 design method to determine the geogrid-reinforced design life. The input parameters used in either case are listed in Table 10.

Table 10: Input Parameters for NCHRP 01-50 Tool.

HMA Modulus (ksi)	300
Base Anisotropic Ratio	0.35
Geosynthetic Sheet Stiffness (lb/in)	2400

Note: HMA=hot mix asphalt.

The modified subgrade and base modulus values determined based on design thickness and original subgrade modulus are summarized in Table 11. However, the modified base values are shown for informational purposes and were not included in the analysis. For the AASHTO 1993 design method, the modified subgrade values were used to replace the original subgrade values in the structural number calculation. Design life for the geogrid-reinforced design was then able to be computed. The procedure for implementation into Pavement ME is described below.

Table 11: NCHRP 01-50 Subgrade Inputs.

Composite Geosynthetic Tool (3-in/6-in Design)		
Original Subgrade Mr, psi	Modified Subgrade Mr, psi	Modified Base Mr, psi
2120	7600	15800
4050	9200	14920
5730	11700	14920
8540	16000	14920
Composite Geosynthetic Tool (3-in/12-in Design)		
Original Subgrade Mr, psi	Modified Subgrade Mr, psi	Modified Base Mr, psi
2120	7400	18200
4050	10600	18200
5730	13900	18200
8540	18600	18200

AASHTOWare Pavement ME

The method for using Pavement ME mirrors the NDOT manual for flexible pavement analysis [46]. All information for layer properties, soil characterization, seasonal coefficients, and traffic inputs are included as part of the Appendix.

NCHRP Project 01-50 modified subgrade modulus were used as input for the subgrade layer properties in Pavement ME. However, the soil characteristics of the subgrade layer are significant in determining the estimated distresses. Therefore, soil characteristics were determined from previous Nevada projects that correlated with each subgrade modulus within the selected range (2000-8000 psi) to properly see the impact of the change in subgrade properties. Each subgrade modulus variation was iterated with new climatic data from each region (Las Vegas, Reno, and Elko) and each traffic level (50-250 AADTT).

The distress types and their targets are included in Table 12 where failure is dependent on estimated distresses over the life of the pavement.

Table 12: Distress Type and Target for Pavement ME Designs.

Distress Type	Distress Target @ Specified Reliability	Reliability (%)
Terminal IRI (in/mile)	172	50
Permanent Deformation - Total Pavement (in)	0.5	50
AC Bottom-Up Fatigue Cracking (% lane area)	15	50
Permanent Deformation - AC Only (in)	0.15	50

Note: IRI=international roughness index; AC=asphalt concrete.

5.2.4.2 Unreinforced and Geogrid-Reinforced Design Life

Table 13 through 18 include the expected design life for each subgrade, traffic and climate combination evaluated as part of this study. Each design life is also grouped by design method, whether AASHTO 1993 or Pavement ME. The tables show the expected design life for the AASHTO 1993 design method for an unreinforced section, reinforced (effective modulus), and reinforced (adjusted coefficient). For the Pavement ME design method, expected design life for the unreinforced and reinforced (effective modulus) sections are shown. The tables' purpose is to determine if a specific site with known characteristics of climate, subgrade modulus, and traffic is expected to fail within the target design life of 4 ± 2 years for the unreinforced design and 15 years for the reinforced.

Table 13: Expected Design Life for District 1 with 6” Base.

Expected Design Life (Years) 3" AC / 6" Base Las Vegas, NV				Annual Average Daily Truck Traffic (AADTT)											
				50			100			200			250		
				Design Type											
				Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)
Subgrade Resilient Modulus (psi)	**0-2000**	**Design Method**	**AASHTO 1993**	0.3	5.0	1.6	0.1	2.6	0.8	0.1	1.3	0.4	0.1	1.1	0.3
			Pavement ME	14.0	29.5	NA	7.5	16.5	NA	3.7	8.5	NA	3.0	6.5	NA
	2000-4000		**AASHTO 1993**	1.2	7.6	6.76	0.6	4.0	3.52	0.3	2.0	1.80	0.2	1.6	1.45
			Pavement ME	20.5	32.5	NA	11.0	18.0	NA	5.5	10.0	NA	4.0	7.5	NA
	4000-6000		**AASHTO 1993**	2.7	12.4	13.6	1.4	6.7	7.4	0.7	3.5	3.9	0.6	2.8	3.1
			Pavement ME	21.5	33.0	NA	12.0	18.5	NA	6.5	10.5	NA	5.0	8.0	NA
	6000-8000		**AASHTO 1993**	6.5	22.5	27.3	3.4	12.8	15.9	1.7	6.9	8.7	1.4	5.6	7.1
			Pavement ME	32.0	45.0	NA	18.0	25.5	NA	9.7	17.5	NA	7.5	11.5	NA

Table 14: Expected Design Life for District 1 with 12" Base.

Expected Design Life (Years) 3" AC / 12" Base Las Vegas, NV				Annual Average Daily Truck Traffic (AADTT)											
				50			100			200			250		
				Design Type											
				Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)
Subgrade Resilient Modulus (psi)	**0-2000**	**Design Method**	**AASHTO 1993**	1.7	23.8	8.2	0.9	13.6	4.3	0.4	7.4	2.2	0.4	6.0	1.8
			Pavement ME	19.5	28.5	NA	10.2	15.5	NA	5.5	8.0	NA	4.5	7.0	NA
	2000-4000		**AASHTO 1993**	7.3	42.3	28.06	3.8	26.5	16.42	2.0	15.4	9.03	1.6	12.7	7.38
			Pavement ME	23.0	31.0	NA	12.5	17.0	NA	7.0	9.0	NA	5.2	7.5	NA
	4000-6000		**AASHTO 1993**	14.8	60.6	47.6	8.1	40.7	30.4	4.3	25.2	18.0	3.4	21.3	15.0
			Pavement ME	35.0	41.5	NA	20.5	25.5	NA	12.0	14.5	NA	8.5	11.0	NA
	6000-8000		**AASHTO 1993**	30.4	83.2	74.0	18.0	60.0	51.9	10.0	40.2	33.8	8.2	34.8	28.9
			Pavement ME	32.5	39.5	NA	19.0	24.0	NA	11.5	14.5	NA	9.0	10.5	NA

Table 15: Expected Design Life for District 2 with 6" Base.

Expected Design Life (Years) 3" AC / 6" Base Reno, NV				Annual Average Daily Truck Traffic (AADTT)											
				50			100			200			250		
				Design Type											
				Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)
Subgrade Resilient Modulus (psi)	**0-2000**	**Design Method**	**AASHTO 1993**	0.3	5.0	1.6	0.1	2.6	0.8	0.1	1.3	0.4	0.1	1.1	0.3
			Pavement ME	11.5	26.0	NA	6.0	13.5	NA	3.5	7.5	NA	2.5	6.0	NA
	2000-4000		**AASHTO 1993**	1.2	7.6	6.76	0.6	4.0	3.52	0.3	2.0	1.80	0.2	1.6	1.45
			Pavement ME	17.0	27.5	NA	9.0	15.0	NA	4.5	8.0	NA	3.5	7.0	NA
	4000-6000		**AASHTO 1993**	2.7	12.4	13.6	1.4	6.7	7.4	0.7	3.5	3.9	0.6	2.8	3.1
			Pavement ME	20.0	31.0	NA	11.0	17.5	NA	6.0	9.5	NA	5.0	8.0	NA
	6000-8000		**AASHTO 1993**	6.5	22.5	27.3	3.4	12.8	15.9	1.7	6.9	8.7	1.4	5.6	7.1
			Pavement ME	27.0	37.5	NA	15.0	21.0	NA	8.0	12.0	NA	7.0	9.5	NA

Table 16: Expected Design Life for District 2 with 12" Base.

Expected Design Life (Years) 3" AC / 12" Base Reno, NV				Annual Average Daily Truck Traffic (AADTT)											
				50			100			200			250		
				Design Type											
				Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)
Subgrade Resilient Modulus (psi)	**0-2000**	**Design Method**	**AASHTO 1993**	1.7	23.8	8.2	0.9	13.6	4.3	0.4	7.4	2.2	0.4	6.0	1.8
			Pavement ME	19.0	28.0	NA	10.0	15.0	NA	5.0	8.0	NA	4.0	6.5	NA
	2000-4000		**AASHTO 1993**	7.3	42.3	28.06	3.8	26.5	16.42	2.0	15.4	9.03	1.6	12.7	7.38
			Pavement ME	23.0	31.0	NA	12.0	16.5	NA	6.0	8.5	NA	5.0	7.5	NA
	4000-6000		**AASHTO 1993**	14.8	60.6	47.6	8.1	40.7	30.4	4.3	25.2	18.0	3.4	21.3	15.0
			Pavement ME	26.0	33.5	NA	14.5	19.5	NA	8.0	10.0	NA	7.0	9.0	NA
	6000-8000		**AASHTO 1993**	30.4	83.2	74.0	18.0	60.0	51.9	10.0	40.2	33.8	8.2	34.8	28.9
			Pavement ME	31.0	37.5	NA	17.0	21.0	NA	10.0	12.5	NA	8.0	10.0	NA

Table 17: Expected Design Life for District 3 with 6" Base.

Expected Design Life (Years) 3" AC / 6" Base Elko, NV				Annual Average Daily Truck Traffic (AADTT)											
				50			100			200			250		
				Design Type											
				Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)
Subgrade Resilient Modulus (psi)	**0-2000**	**Design Method**	**AASHTO 1993**	0.3	5.0	1.6	0.1	2.6	0.8	0.1	1.3	0.4	0.1	1.1	0.3
			Pavement ME	16.0	33.0	NA	8.5	18.0	NA	4.3	10.0	NA	3.5	8.5	NA
	2000-4000		**AASHTO 1993**	1.2	7.6	6.76	0.6	4.0	3.52	0.3	2.0	1.80	0.2	1.6	1.45
			Pavement ME	22.5	36.5	NA	12.5	21.0	NA	7.0	11.5	NA	5.2	9.0	NA
	4000-6000		**AASHTO 1993**	2.7	12.4	13.6	1.4	6.7	7.4	0.7	3.5	3.9	0.6	2.8	3.1
			Pavement ME	28.5	42.0	NA	16.0	24.5	NA	8.5	12.0	NA	8.5	11.0	NA
	6000-8000		**AASHTO 1993**	6.5	22.5	27.3	3.4	12.8	15.9	1.7	6.9	8.7	1.4	5.6	7.1
			Pavement ME	34.5	45.0	NA	19.5	28.0	NA	11.0	15.0	NA	9.0	13.0	NA

Table 18: Expected Design Life for District 3 with 12" Base.

Expected Design Life (Years) 3" AC / 12" Base Elko, NV				Annual Average Daily Truck Traffic (AADTT)											
				50			100			200			250		
				Design Type											
				Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)	Unreinforced	Reinforced (Effective Modulus)	Reinforced (Adjusted Coefficient)
Subgrade Resilient Modulus (psi)	**0-2000**	**Design Method**	**AASHTO 1993**	1.7	23.8	8.2	0.9	13.6	4.3	0.4	7.4	2.2	0.4	6.0	1.8
			Pavement ME	27.5	37.0	NA	16.0	22.5	NA	8.0	12.5	NA	7.0	10.0	NA
	2000-4000		**AASHTO 1993**	7.3	42.3	28.06	3.8	26.5	16.42	2.0	15.4	9.03	1.6	12.7	7.38
			Pavement ME	33.0	41.5	NA	18.0	24.5	NA	10.5	14.0	NA	8.0	11.5	NA
	4000-6000		**AASHTO 1993**	14.8	60.6	47.6	8.1	40.7	30.4	4.3	25.2	18.0	3.4	21.3	15.0
			Pavement ME	37.0	45.0	NA	22.5	27.0	NA	12.5	15.0	NA	10.2	13.0	NA
	6000-8000		**AASHTO 1993**	30.4	83.2	74.0	18.0	60.0	51.9	10.0	40.2	33.8	8.2	34.8	28.9
			Pavement ME	41.0	48.0	NA	23.0	28.0	NA	13.0	16.0	NA	11.0	13.5	NA

5.3 Test Site Layout

This test site layout was established based on the pavement design and analysis previously discussed and review of typical spacing for test sections. The recommended layout will comprise of eight sections including:

- Two standard pavement (SP) sections
- Two unreinforced control sections (CS) (One for each pavement structure)
- Four geogrid-reinforced test sections (TS) (Two for each pavement structure)

The standard pavement structure will be designed for a 20-year performance life, typical for the area and traffic of the selected site. SP sections will be present at the beginning and end of the test site, being incorporated in the experiment and undergoing the same level of evaluation during and after construction. The control sections are required for comparison to the test sections for each selected pavement structure and are expected to fail before the SP and TS sections. Biaxial and Triaxial geogrids are to make up the TS sections with two different pavement structures having different aggregate base thicknesses as summarized in Table 19. All TS will have the geogrid placed at the interface of the base and subgrade layers. The CS and TS sections will have the same plant mix thickness (3 inches) and all sections will have the same design of plant mix with the intent that the contractor constructs it uniformly throughout the project. All designs will use NDOT Type 1B aggregate base course material for the base layers [54].

A minimum test section length of 220 feet is recommended to provide sufficient length to permit consistent construction throughout the project. This will also allow for proper performance monitoring of each section during the span of the project. Each CS and TS should be separated by a transition zone of 80 feet, as recommended on Westrack to account for vehicle dynamics based on 40 mi/hr. speed [55]. This accounts for variability during the sections' construction and for damping any truck dynamic motion generated by damaged pavement in the previous test section [56]. The transition zone between the varying pavement structures should be at least 100 feet to account for higher construction variability and allow for a smoother transition into the test site. Therefore, the total length of the test site is expected to be 2,380 feet, as illustrated in Figure 11.

Table 19: Description of Test Site Layout by Test Section.

Section Name	Pavement Structure	Geosynthetic
Specific Pavement Structure (SPS)	Typical Pavement Structure	No
Control 1 (CS1)	3” AC on 6” AB	No
Test Section 1 (TS1)	3” AC on 6” AB	Yes (Geogrid 1)
Test Section 2 (TS2)	3” AC on 6” AB	Yes (Geogrid 2)
Control 2 (CS2)	3” AC on 12” AB	No
Test Section 3 (TS3)	3” AC on 12” AB	Yes (Geogrid 1)
Test Section 4 (TS4)	3” AC on 12” AB	Yes (Geogrid 2)
Specific Pavement Structure (SPS)	Typical Pavement Structure	No

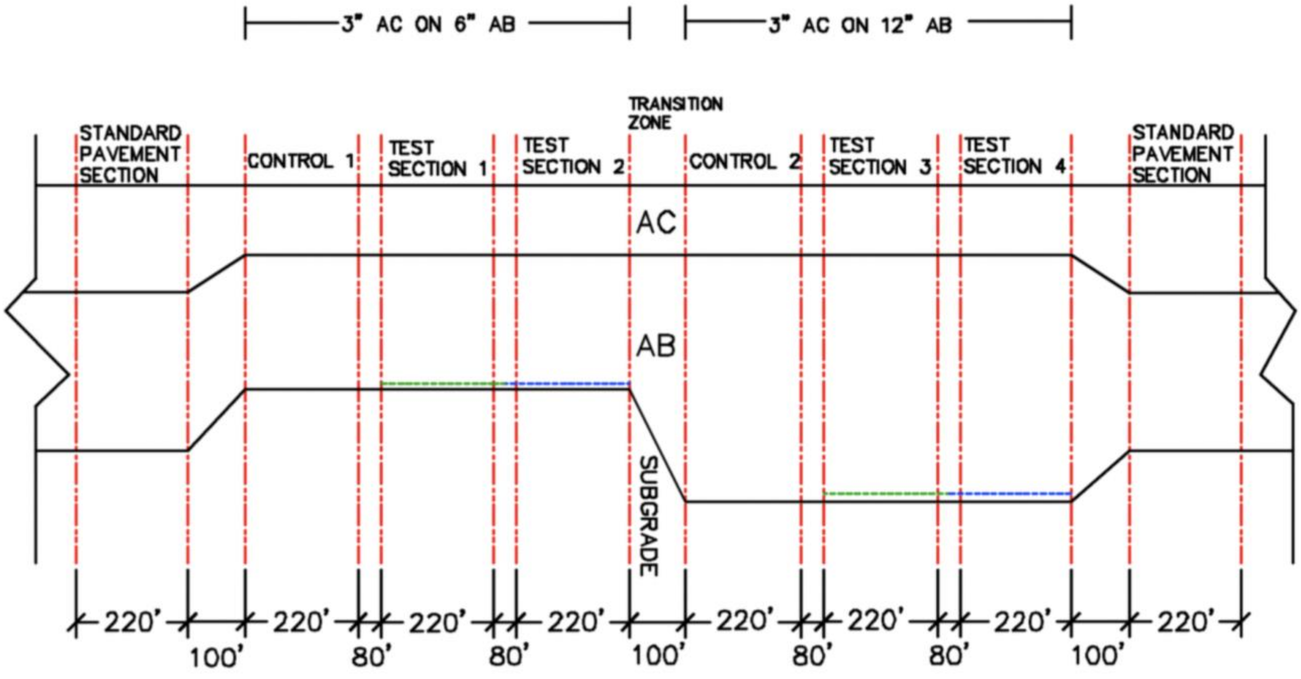


Figure 11: Cross Section Illustration of Test Site Layout.

Note: AC=asphalt concrete; AB=aggregate base.

6.0 EVALUATION AND TESTING PLAN

This chapter includes a testing plan developed with three distinct phases: pre-construction, construction, and post-construction. All data collected during the various phases of the testing plan need to be well-documented to help in future analysis of test sections performance. A database management system may need to be established in future phases of the project to ensure proper documentation.

This project aims to reach failure for the reinforced section within 15 years, not requiring rehabilitation in the process. Therefore, rehabilitation was not considered in the evaluation as failure state is anticipated, to make an adequate comparison between the unreinforced and reinforced sections. This will allow for better understanding of when to apply rehabilitation if geosynthetic is to be incorporated in other NDOT construction. Nonetheless, pavement condition will be monitored through the life. The aim is to observe the effectiveness of a reinforced base layer before reaching 15 years to accelerate implementation.

6.1 Pre-Construction

The pre-construction testing plan will continue after the initial site selection of a viable test site, including a review of roadway geometry, original construction records, pavement condition information, and geotechnical reports. Typical geotechnical reports do not have enough test results to characterize the subgrade within each proposed test section. Therefore, candidate test site locations will be further evaluated based on the falling weight deflectometer (FWD) test results, ideally with staggered tests at close intervals. Back calculated subgrade stiffness will be used to locate the most suitable test site location, ensuring a uniform location. For a new alignment, additional geotechnical soil investigation will be needed for candidate test site locations. Recommended subgrade tests like R-value, sieve analysis, Atterberg limits, and maximum dry density, can be used to estimate the resilient modulus of the subgrade soil. Beside sampling and laboratory analysis of subgrade soils, the dynamic cone penetrometer (DCP) can be utilized along the alignment to ensure a relative degree of uniformity exists. Recommendations on test spacing for existing and new alignment are summarized in Table 20.

Table 20: Recommended Testing for Alignment.

Existing Alignment			
Testing	**Test Spacing (ft)**	**Tests Per Section**	**Total Tests Performed Over Test Site**
FWD	20	11	120
New Alignment			
R-Value	200	1	12
Sieve Analysis	200	1	12
Atterberg	200	1	12
Dry Density	200	1	12
DCP	50	4	48
FWD	20	11	120

Note: DCP=dynamic cone penetrometer; FWD=falling weight deflectometer.

6.2 Construction

Considerable monitoring will be required during construction of the test site to minimize variability. At each stage of construction, standard quality assurance (QA) testing frequency is recommended to be increased. As the test sections consist of small quantities, the test results will be insufficient to determine quality and consistency if standard acceptance testing frequency is used for materials and construction. So, sampling and testing frequencies will need to be increased. Details are presented in Table 21 and Table 22. Particular attention must be paid to subgrade preparation to ensure the transition sections with large changes in base layer thickness are properly constructed to proper compaction and trimming. Aggregate base preparation including thickness and density play a crucial part in the project's outcome and therefore need consistent in-situ testing to verify uniformity. Bulk sampling of raw materials in adequate quantities for future testing will be necessary to test for fundamental engineering properties and performance tests. A report documenting pavement design, materials, and construction (as-built and QA) will need to be prepared so information will be readily available for future analysis of pavement performances.

Table 21: Recommended In-Situ Testing.

In-Situ Testing (Subgrade)			
Testing	**Test Spacing (ft)**	**Tests Per Section**	**Total Tests Performed**
In-place Density	20	11	88
DCP	40	5	40
LWD	25	9	72
FWD	10	22	176
In-Situ Testing (Aggregate Base)			
Testing	**Test Spacing (ft)**	**Tests Per Section**	**Total Tests Performed**
In-place Density	20	11	88
DCP	40	5	40
FWD	10	22	176
LWD	25	9	72
Straightedge	50	4	32

Note: DCP=dynamic cone penetrometer; LWD=lightweight deflectometer; FWD=falling weight deflectometer.

Table 22: Recommended Laboratory Testing.

Preparation and Geosynthetic Placement			
Material	**Test**	**Tests Per Section**	**Total Tests**
Aggregate Base	R-Value	1	8
	Sieve Analysis	1	8
	Atterberg Limits		3
	Fractured Faces		3
	Proctor		3
	Specific Gravity		3
	Resilient Modulus		3
Subgrade	R-Value	3	24
	Sieve Analysis	1	8
	Atterberg	1	8
	Max Dry Density	1	8
	Resilient Modulus		3
Plantmix	Dynamic Modulus	3 during paving	
	Sieve Analysis		
	Moisture		
	Bitumen Ratio		
	Moisture Content		
	G_{mm} Rice Density		
	Percent Air Voids		
	In-place Density	3	24
Geosynthetic	Aperture Size Range	15	60
	Rib Shape	15	60
	Tensile Strength (cross direction)	2	8
	Tensile Strength (machine direction)	2	8

6.3 Post Construction

Upon completion of test site construction, the roadway surface profile will need to be measured with an inertial profilometer. Each test site is relatively short; therefore, actual profile data will be analyzed to create baseline profiles for each section. Profile data will also be analyzed to provide a metric suitable for describing the ride quality over the test section. FWD testing will be required at test points and a straight edge used to verify rutting is not present at the end of construction, bisecting the FWD test points. The sections will need to be manually inspected to ensure no surface distresses/defects are present.

Following construction, the plantmix, base, and subgrade will also need to be sampled using a split barrel spoon sampler to verify layer thicknesses and the geosynthetic position. Samples of the geosynthetic should also be collected. Ground penetrating radar (GPR) can identify plantmix and aggregate base thicknesses throughout the test site. Similarly, cores can be used to verify thickness ad uniformity. A report documenting pavement design, materials, and construction (as-built and QA) will need to be prepared so information will be readily available for future pavement performance analysis.

The first routine monitoring is required within six months of opening the sections to traffic and should be scheduled twice a year. If located in an area subjected to freeze-thaw, monitoring will be done in the spring after the frost is out of the soil. The second monitoring will be done in late summer or early fall. If the site is in a non-freeze-thaw area, monitoring will be done in roughly 6-month intervals. The monitoring should include a detailed manual distress survey, FWD testing, and surface profile measured with an inertial profilometer to monitor the geosynthetic's influence over the sections' life. The recommended monitoring activities are summarized in Table 23.

Table 23: Recommended Post-Construction Monitoring Activities.

Post-Construction Initial Survey			
Test	**Spacing (ft)**	**Tests per Section**	**Total Tests**
Manual Distress Survey	Complete Coverage	1	8
FWD	10	22	176
Rutting and Profile	Complete Coverage		
Coring	One Each Side	2	16
Sampling (Split Spoon)	One Each Side	2	16
Routine Monitoring Surveys			
Manual Distress Survey	Complete Coverage		
FWD	10	22	176
Rutting and Profile	Complete Coverage		

Note: FWD=falling weight deflectometer.

7.0 SPECIFICATIONS AND CONSTRUCTION GUIDELINES

Specifications integrating all materials requirements and installation procedures differing from the 2014 NDOT Standard Specifications have been incorporated in a special provision to include the test sections on a typical NDOT contract. They are written as modifications to the NDOT Standard Specifications and potentially be the basis for future NDOT Standard Specifications. The special provisions have been attached as an appendix to this report. A brief explanation on its content is explained below.

NDOT Standard Specifications [54] currently referencing geosynthetics relevant to this project include:

- 203 Excavation and Embankment, which references geotextiles.
- 731 Engineering Fabrics, which references Pavement Reinforcing Fabric, geotextile (Class 1), geotextile (Class 2), geogrid (biaxial only), and geomembrane.

As the current specifications mention method of payment and typical Type 1B aggregate base is being utilized for this project, no further modifications on these bases are being made. However, modifications to specifications need to include recently developed geosynthetics. This project was designed on the basis of incorporating two different types of geogrids: biaxial and triaxial. Both may have multiple manufacturers that can meet the specified criteria by the time this project moves into the later phases. Therefore, no modifications are included on the existing biaxial specification but new criteria for inclusion of triaxial geogrids are listed in the special provision. Other modifications included in the special provision are handling, storage, and geogrid construction.

Geosynthetic manufacturers have installation guides developed to optimize the performance of their products. Common important elements include substructure preparation (clearing, grubbing, trimming, and compaction); storage and handling, direction of placement depending on geosynthetic type and strength of underlying material; overlap requirements; trimming and pinning or stapling; tensioning, placement of aggregates and spreading of aggregates while maintaining integrity of geosynthetic (displacement and waving); and grading and compaction. It is recommended that the manufacturer installation guides be utilized to determine handing and construction with the selected geosynthetic products unless otherwise specified in the special provisions.

Items that will be particularly important and not directly addressed in manufacturer guidelines include proper selection of geosynthetics and base materials based on site conditions, consistency of subgrade, and other mainline paving activities on the same project are performed before the geosynthetic sections. Proper documentation of the geosynthetic materials received and utilized are required to ensure materials delivered to the project are as expected. It should be noted that any torn, damaged, or defective geogrid will be rejected. This report also serves to identify proper selection of the geosynthetic and base materials. Specifically, the inclusion of a biaxial and triaxial geogrid meeting the required specifications as mentioned in the special provisions. Base and subgrade material properties should closely follow the recommendations made in Chapter 5.0 of this report. It is recommended that a test strip should be completed for the mainline paving, so any plantmix job mix formula (JMF) adjustments would be made and nuclear gauge calibrations would be completed. This is critical because the test sections will be too small to have separate test strips.

Similar to Section 401.03.15 for Pavement Reinforcing Fabric of the NDOT Standard Specifications [54], geosynthetic manufacturers will be required to have a company representative to deliver informational training to educate personnel on proper installation procedures and specifications and ensure cooperation and understanding among the Department's inspectors and Contractor personnel. Attendance of inspectors, consultants and contractor personnel involved with the project is mandatory with advanced notification of the training date, time and location. It will be equally important to require geosynthetic manufacturer representatives to monitor the construction operations to ensure proper installation during the first two days of installation. The manufacturer representatives are familiar with products, potential installation issues, and techniques for preventing and/or correcting them.

A complete construction report will need to be prepared prior to construction of the test sections. Cross sections of each test section will have to detail materials, thicknesses, slope and importantly location(s) of the geosynthetic(s) in the pavement sections, closely mirroring the recommendations provided in Chapter 5.3. In the future construction phase of this effort, the effectiveness of the specifications and guidelines can be evaluated, and refinements can be made based on the test section construction experience.

8.0 IMPLEMENTATION PLAN

This research is the first phase of a multi-phased project that fits into Stage 3 of the Five Stages of Research Deployment. The primary deliverable is a plan to support a controlled field demonstration, with input regarding design, specifications and standards, all of which will allow for adjustments as needed in the time between the different phases of the overall field study (planning, construction, data collection, and data analysis). Since this phase will not provide a selected test site location, an exact implementation plan cannot be provided. However, an overview of the additional steps required to successfully implement this reports plan are described here.

In the following years, it is expected that NDOT will continue searching for candidate test site locations based on the site selection criteria described in this report as well as comparison to the design life tables. Ideally targeting a climate, subgrade modulus, and traffic level that will allow for the reinforced section to fail within the next 15 years. Further evaluations into possible candidate sites will undergo the pre-construction evaluation to ensure it's a proper test site location. The special provisions can be further developed during this candidacy period if additional changes are required.

Once a test site location has been finalized, a bid package can be developed, following a more detailed cost estimate based on the current geosynthetics and their corresponding market price. This will lead to the test site construction which will require a detailed construction report including the layer thicknesses, grade, and location of the geosynthetic, which should reflect that of this report. Sampling and testing required during the construction stages should follow the recommended procedure in Chapter 6.0. Routine monitoring should continue twice per year over the course of the life of the pavement. However, the aim is to be able to make observations on the effectiveness of a reinforced base layer before reaching 15 years to accelerate implementation.

As monitoring of the test site continues, key observations and findings can be drawn from using reinforcement, type, and design structure. These observations can be used to further implement the use of geosynthetics in other projects within Nevada. During the monitoring stage, it’s important to expand on the insight and knowledge gained addressing the specifications and construction based on the documented information. This will allow for further specification modifications and construction or design changes that can improve the effectiveness of geosynthetics. Changes in sampling periods or tests may shift as the project progresses, identifying new items that may need to be observed as new research comes to light. By the end of the pavement life, lessons learned throughout planning, construction, data collection, and data analysis can be further evaluated to ensure the proper changes are made for future NDOT projects.

9.0 GEOSYNTHETIC COST ESTIMATE

There are many benefits to reinforcement of pavements with geosynthetics, with cost savings being a major benefit. It is typically recommended that an economic evaluation of a proposed reinforced pavement project be performed with a life-cycle cost analysis. This is the case, as typical projects will target similar design life between the unreinforced and reinforced sections by reducing the thickness of the aggregate base in the reinforced design. Therefore, in these cases, there is a significant difference in initial costs between the two structural designs. However, this project anticipates an extended design life using the same structural design with and without reinforcement. Therefore, costs for the unreinforced sections and geogrid-reinforced sections will be the same regarding aggregate base, HMA layer, and excavation-associated costs. Additional costs such as fuel, water, and dump truck visits will remain the same. However, there will be additional costs for the geosynthetic, including the product cost and associated costs for manpower and equipment required for installation. As there are no recent historical values for the associated costs of installing geosynthetics for NDOT, a common rule is that the associated costs will be about the same as the material costs.

Based on the test site layout described in Chapter 5.3, approximately 4,000 ft^2 of each geosynthetic type will be required, assuming a 12-ft lane width. Table 24 includes current cost estimates for readily available geosynthetics that meet the specification criteria as listed in the special provisions [57] [58]. Each model varies by roll size, therefore the total price accounts for the total number of rolls required to ensure 4,000 ft^2 of each geosynthetic. The triaxial geogrid is expected to have a higher cost at approximately $2,730 compared to the biaxial geogrid at an average cost of $1,980, in 2022 dollars. There is a high possibility that other manufacturers will begin producing triaxial geogrids in the coming years, which can lead to price drops closer to that of the biaxial.

Table 24: Cost Estimates for Geosynthetic Required (in 2022).

Brand	**Type**	**Model**	**Size (ftxft)**	**ft^2/roll**	**Effective ft^2/roll**	**Price/Roll**	**Price/ft^2**	**Rolls required**	**Total price**
Tensar	Biaxial	BX1200	13.1 x 164	2,148	2,122	$ 957.24	$ 0.44	2	$ 1,914.48
Tensar	Triaxial	TX8	13.1 x 328	4,296	4,296	$ 2,730.11	$ 0.64	1	$ 2,730.11
TenCate	Biaxial	Mirafi BXG120	12.9 x 164	2,115	2,090	$ 977.03	$ 0.46	2	$ 1,954.06
Hanes Geo	Biaxial	Terragrid RX1200	13.1 x 164	2,148	2,122	$ 1,001.73	$ 0.47	2	$ 2,003.46
BOSTD America	Biaxial	E’Grid RX1200	12.8 x 246	3,148	3,123	$ 1,019.73	$ 0.32	2	$ 2,039.46

Note: Effective ft^2/roll accounts for a 2-foot overlap at the ends of the roll if more than one roll is required.

10.0 FINDINGS AND RECOMMENDATIONS

The research objective for this study was to evaluate and quantify structural benefits from use of geosynthetics placed as reinforcement within or at the bottom of an aggregate base layer to support a controlled field demonstration project, with input regarding design, specification and standards. This phase of the study provides documentation and recommendations that allow for adjustments between different phases of the overall study.

From this study, the following conclusions can be made:

- Based on the literature, the test site should be in an area with good sight distance, limited vertical curves to not exceed 2.5% and limited horizontal curves to a maximum of 3 degrees.
- An AADTT range from 50-250 will account for the variation in traffic distribution across Nevada and meet the experimental pavement design and expected design life implemented for this phase.
- The ideal test site location should have an M_r value within 2000-8000 psi to trigger subgrade stabilization and demonstrate the benefits of adding the geosynthetic.
- It is recommended that the contribution of geosynthetics be modeled using the NCHRP Project 01-50 composite geosynthetic tool to determine an adjusted subgrade modulus to use as input in AASHTOWare Pavement ME and 1993 AASHTO Pavement Design. However, the use of the AASHTO 1993 design method is primarily accounting for permanent deformation, not fatigue. This may lead to AASHTO 1993 overpredicting or underpredicting the performance of the geosynthetic reinforcement based on the thickness of the base layer.

- Tensar$^+$ software's adjusted base layer coefficient values to be utilized within 1993 AASHTO Pavement Design to estimate the contribution of Triaxial geogrids to the pavement structure.
- Based on industry conversations and literature review, only the adjusted subgrade modulus should be used from NCHRP Project 01-50 tool and not the combination of base and subgrade as the combination overpredicts the benefit of using geosynthetics.
- Geogrid is recommended over geotextiles, based on improved base reinforcement showcased by geogrids when implemented in the midrange of subgrade conditions.
- To target a design life of 4 ± 2 years for the unreinforced design and approximately 15 years for the reinforced design, a pavement of 3-in. AC and 6-in. base is recommended. However, to analyze the impact of base thickness, its recommended to include a 3-in. AC over 6-in. base section. Both sections should include the geosynthetic at the interface between the base and subgrade layers to achieve the greatest benefit.
- The use of triaxial geogrids shows an increased benefit as base reinforcement as established in literature. It should be implemented to verify the need to modify existing specifications to include their use in future projects.
- The triaxial geogrids are expected to have a higher material cost, averaging \$2,730 compared to the biaxial geogrid averaging \$1,980 for a 4000 ft^2 reinforced test section area. However, there is potential for more competitive pricing as other manufacturers expand the triaxial geogrid market in the coming years.
- This phase implemented climate from Reno, Las Vegas, and Elko. Therefore, any significant deviation in climate from these three cities should be re-evaluated for an estimated design life.

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APPENDIX A: Pavement ME Inputs

The following tables summarize the inputs for AASHTOWare Pavement ME used for the recommended design life tables. If further analysis on different conditions other than the ones in this report are needed, these tables can be referenced for consistent results. All the information can also be found in the Pavement ME Design Manual for Nevada [46] , except for the subgrade soil characteristics which are specific to this project.

Table 25: Soil Characteristics Input for Each Subgrade Modulus Variation.

Modulus Variations	1	2	3	4
Mr	2120	4046	5729	8540
P#40	62	79	51.2	44.5
Maximum dry unit weight (pcf)	100	98	100	122.4
Plasticity index	8	12	0	1.9
Liquid limit	18	27	0	19.6
Water Content (%)	14.2	14.2	14.2	14.2
R-Value	8	25	45	74
af	72.6206662973122	91.9206414393732	8.64959773876554	6.47761027553226
bf	0.962316744900019	0.79801995567085	0.3	0.953390911228143
cf	0.450898772028596	0.32428952440868	3.71885007062255	0.872541789965476
hr	500	500	100	168.78

Table 26: Subgrade Gradation Inputs for Each Modulus Variation.

Sieve	Mr = 2120 psi	Mr = 4046 psi	Mr = 5729 psi	Mr = 8540 psi
Sieve Size	% Passing	% Passing	% Passing	% Passing
#200	42.5	51.0	21.0	18.1
#100		66.0		25.5
#50				37.1
#40	62.0	79.0	51.2	44.5
#30				
#16				
#10				81.4
#8				
#4	94.0	97.0	85.0	95.6
3/8-in				99.3
1/2-in				
3/4-in				
1-in				100

Table 27: Recommended Seasonal Coefficients for Subgrade Resilient Modulus.

Season	District 1	District 2 & 3
Spring	1.00	1.00
Summer	1.27	1.43
Fall	1.08	1.46
Winter	0.97	1.16

Table 28: Representative Base Layer Input Values for 6-inch Base Layer

Parameter	District 1	District 2	District 3
Heq	8.1681	8.1681	8.1681
D	4.5	4.5	4.5
Base Thickness (in)	6	6	6
AC Thickness (in)	3	3	3
R-Value	70	70	70
P#40	16.5	14.8	17.3
P#3/8	69.5	64.5	71.3
OMC	7.1	7.2	6.1
ln(Mr)	9.72	9.70	9.80
Mr (psi)	16758	16338	18206

Table 29: Representative Base Layer Input Values for 12-inch Base Layer

Parameter	District 1	District 2	District 3
Heq	18.2625	18.2625	18.2625
D	9	9	9
Base Thickness (in)	12	12	12
AC Thickness (in)	3	3	3
R-Value	70	70	70
P#40	16.5	14.8	17.3
P#3/8	69.5	64.5	71.3
OMC	7.1	7.2	6.1
ln(Mr)	9.64	9.61	9.72
Mr (psi)	15303	14919	16625

Table 30: Subgrade Modulus Adjusted for Seasonal Coefficient Used for Analysis of District 2 and 3 for the 6 in. Base Design Structure.

District 2&3 (3 in AC/ 6 in Base)								
Month	Original Mr = 2120		Original Mr = 3891		Original Mr = 5729		Original Mr = 8540	
	Original	Effective	Original	Effective	Original	Effective	Original	Effective
January	2459	8816	4514	10672	6646	13572	9906	18560
February	2459	8816	4514	10672	6646	13572	9906	18560
March	2120	7600	3891	9200	5729	11700	8540	16000
April	2120	7600	3891	9200	5729	11700	8540	16000
May	2120	7600	3891	9200	5729	11700	8540	16000
June	3032	10868	5564	13156	8192	16731	12212	22880
July	3032	10868	5564	13156	8192	16731	12212	22880
August	3032	10868	5564	13156	8192	16731	12212	22880
September	3095	11096	5681	13432	8364	17082	12468	23360
October	3095	11096	5681	13432	8364	17082	12468	23360
November	3095	11096	5681	13432	8364	17082	12468	23360
December	2459	8816	4514	10672	6646	13572	9906	18560

Table 31: Subgrade Modulus Adjusted for Seasonal Coefficient Used for Analysis of District 2 and 3 for the 12 in. Base Design Structure.

District 2&3 (3 in AC/ 12 in Base)								
Month	Original Mr = 2120		Original Mr = 3891		Original Mr = 5729		Original Mr = 8540	
	Original	Effective	Original	Effective	Original	Effective	Original	Effective
January	2459	8584	4514	12296	6646	16124	9906	21576
February	2459	8584	4514	12296	6646	16124	9906	21576
March	2120	7400	3891	10600	5729	13900	8540	18600
April	2120	7400	3891	10600	5729	13900	8540	18600
May	2120	7400	3891	10600	5729	13900	8540	18600
June	3032	10582	5564	15158	8192	19877	12212	26598
July	3032	10582	5564	15158	8192	19877	12212	26598
August	3032	10582	5564	15158	8192	19877	12212	26598
September	3095	10804	5681	15476	8364	20294	12468	27156
October	3095	10804	5681	15476	8364	20294	12468	27156
November	3095	10804	5681	15476	8364	20294	12468	27156
December	2459	8584	4514	12296	6646	16124	9906	21576

Table 32: Subgrade Modulus Adjusted for Seasonal Coefficient Used for Analysis of District 1 for the 6 in. Base Design Structure.

District 1 (3 in AC/ 6 in Base)								
Month	Original Mr = 2120		Original Mr = 3891		Original Mr = 5729		Original Mr = 8540	
	Original	Effective	Original	Effective	Original	Effective	Original	Effective
January	2056	7372	3774	8924	5557	11349	8284	15520
February	2056	7372	3774	8924	5557	11349	8284	15520
March	2120	7600	3891	9200	5729	11700	8540	16000
April	2120	7600	3891	9200	5729	11700	8540	16000
May	2120	7600	3891	9200	5729	11700	8540	16000
June	2692	9652	4942	11684	7276	14859	10846	20320
July	2692	9652	4942	11684	7276	14859	10846	20320
August	2692	9652	4942	11684	7276	14859	10846	20320
September	2290	8208	4202	9936	6187	12636	9223	17280
October	2290	8208	4202	9936	6187	12636	9223	17280
November	2290	8208	4202	9936	6187	12636	9223	17280
December	2056	7372	3774	8924	5557	11349	8284	15520

Table 33: Subgrade Modulus Adjusted for Seasonal Coefficient Used for Analysis of District 1 for the 12 in. Base Design Structure.

District 1 (3 in AC/ 12 in Base)								
Month	Original Mr = 2120		Original Mr = 3891		Original Mr = 5729		Original Mr = 8540	
	Original	Effective	Original	Effective	Original	Effective	Original	Effective
January	2459	8584	3774	10282	5557	13483	8284	18042
February	2459	8584	3774	10282	5557	13483	8284	18042
March	2120	7400	3891	10600	5729	13900	8540	18600
April	2120	7400	3891	10600	5729	13900	8540	18600
May	2120	7400	3891	10600	5729	13900	8540	18600
June	3032	10582	4942	13462	7276	17653	10846	23622
July	3032	10582	4942	13462	7276	17653	10846	23622
August	3032	10582	4942	13462	7276	17653	10846	23622
September	3095	10804	4202	11448	6187	15012	9223	20088
October	3095	10804	4202	11448	6187	15012	9223	20088
November	3095	10804	4202	11448	6187	15012	9223	20088
December	2459	8584	3774	10282	5557	13483	8284	18042

Table 34: General Information Design Inputs.

Design Inputs	
Design Life	20 Years
Design Type	Flexible
Base Construction	June, 2022
Pavement Construction	July, 2022
Traffic Opening	September, 2023

Table 35: Material Type Selection Inputs.

Layer Type	Material Type	Interface Friction
Flexible	Default Asphalt Concrete	1.00
Non-Stabilized	A-1-b	1.00
Subgrade	A-6	-

Table 36: Design Inputs for Asphalt Layers.

Design Inputs for Asphalt Layer	
Effective Binder Content (%)	8.5
Air Voids (%)	7.0
Poissons' Ratio	A = -1.63 B = 3.84E-06
Unit Weight (pcf)	District 1: 150 District 2 & 3: 145
Reference Temperature (°F)	70
Thermal conductivity (BTU/hr-ft-°F)	0.67
Heat capacity (BTU/lb-°F)	0.23
Asphalt content by weight (%)	4.5
Aggregate parameter	0.4021
Aggregate coefficient of thermal contraction (in/in/°F)	5E-06

Table 37: Design Inputs for Non-Stabilized Base Layer.

Design Inputs for Non-Stabilized Base Layer	
Poisson's ratio	0.35
Coefficient of lateral earth pressure (K_0)	0.5
Analysis type	Modify input values by temperature/moisture
Method	Resilient Modulus (psi)

Table 38: Gradation Inputs for Base Material According to Each District.

Sieve Size	Base Material		
	District 1	District 2	District 3
31.5 mm (1.5 inch)	100	100	100
25.0 mm (1 inch)	98.1	98.6	99.6
19.0 mm (3/4 inch)	93.8	95.3	94.1
12.5 mm (1/2 inch)	80.7	76.1	80.7
9.5 mm (3/8 inch)	69.5	64.5	71.3
4.75 mm (No. 4)	52.1	43.0	53.0
2.36 mm (No. 8)	35.5	29.6	39.8
2.00 mm (No. 10)	33.6	28.0	36.4
1.18 mm (No. 16)	25.7	22.5	29.6
0.6 mm (No. 30)	22.3	18.5	24.9
0.425 mm (No. 40)	16.5	14.8	17.3
0.3 mm (No. 50)	14.6	13.0	17.0
0.15 mm (No. 100)	11.6	9.5	11.0
0.075 mm (No. 200)	8.7	6.6	8.1

Table 39: Design Input Parameters for Base Material in Each District.

Pavement ME design input parameters	Base Material		
	District 1	District 2	District 3
LL	19.1	23.4	22
PI	3.4	3.7	4.7
Max. unit weight (pcf)	139.5	134.5	140.3
Saturated hydraulic conductivity (ft/hr)	5.32E-06	3.25E-04	5.95E-04
Specific gravity of solids	2.670	2.703	2.461
OMC (%)	7.1	7.2	6.1
SWCC Parameters			
a_f	1.6500	0.3740	39.4681
b_f	0.9959	1.3374	0.6486
c_f	2.9684	0.4776	12.7272
h_r	6.6648	2.5991	1499.9999

Table 40: General Design Inputs for Subgrade Layer.

Design Inputs for Subgrade	
Thickness (in)	Semi-infinite
Poisson's ratio	0.4
Coefficient of lateral earth pressure (K_0)	0.5
Analysis type	Monthly representative values
Method	Resilient Modulus (psi)

Table 41: General Traffic Inputs.

Number of lanes in design direction	1
Percent of trucks in design direction (%)	50
Percent of trucks in design lane (%)	100
Operational speed (mph)	45
Growth rate (%)	2.5

Table 42: Traffic Characterization and Distribution.

Vehicle Class	AADTT Distribution (%) (Level 3)	Growth Factor	
		Rate (%)	Function
Class 4	3.3%	2.5%	Linear
Class 5	34%	2.5%	Linear
Class 6	11.7%	2.5%	Linear
Class 7	1.6%	2.5%	Linear
Class 8	9.9%	2.5%	Linear
Class 9	36.2%	2.5%	Linear
Class 10	1%	2.5%	Linear
Class 11	1.8%	2.5%	Linear
Class 12	0.2%	2.5%	Linear
Class 13	0.3%	2.5%	Linear

Table 43: Axle Configuration Inputs Based on Vehicle Class.

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0	0
Class 5	2	0	0	0
Class 6	1.02	0.99	0	0
Class 7	1	0.26	0.83	0
Class 8	2.38	0.67	0	0
Class 9	1.13	1.93	0	0
Class 10	1.19	1.09	0.89	0
Class 11	4.29	0.26	0.06	0
Class 12	3.52	1.14	0.06	0
Class 13	2.15	2.13	0.35	0

Table 44: Design Inputs for Lateral Wander & Axle Configuration.

Design Inputs for Lateral Wander & Axle Configuration	
Mean wheel location (in)	18.0
Traffic wander standard deviation (in)	10.0
Design lane width (ft)	12.0
Average axle width (ft)	8.5
Dual tire spacing (in)	12.0
Tire pressure (psi)	120.0
Tandem axle spacing (in)	51.6
Tridem axle spacing (in)	49.2
Quad axle spacing (in)	49.2

Table 45: Climatic Station Selection.

Climatic Information			
City	Reno	Elko	Las Vegas
Climate Station	143521	145256	139497
Elevation	4506.09	5065.88	2005.11
Latitude	39.52	40.83	36.17
Longitude	-119.81	-115.763	-115.139

Table 46: Calibration Factors for Each District.

Parameter	District 1	District 2	District 3
AC Cracking - Bottom Up			
Bottom Up AC Cracking - Standard Deviation	1.13+13/(1+exp(7.57-15.5*LOG10(BOTTOM+0.0001)))	1.13+13/(1+exp(7.57-15.5*LOG10(BOTTOM+0.0001)))	1.13+13/(1+exp(7.57-15.5*LOG10(BOTTOM+0.0001)))
Bottom Up AC Cracking C1	0.8	0.8	0.8
Bottom Up AC Cracking C2:<5 in.	0.8	0.8	0.8
Bottom Up AC Cracking C2: 5 in. ≤ hac ≤ 12 in.	0.8	0.8	0.8
Bottom Up AC Cracking C2: >12in.	0.8	0.8	0.8
Bottom Up AC Cracking C3	6000	6000	6000
AC Cracking - Top Down			
Top Down AC Cracking C1	7	7	7
Top Down AC Cracking C2	3.5	3.5	3.5
Top Down AC Cracking C3	0	0	0
Top Down AC Cracking C4	1000	1000	1000
Top Down AC Cracking - Standard Deviation	200+2300/(1+exp(1.072-2.1654*LOG10 (Top+0.0001)))	200+2300/(1+exp(1.0722.1654*LOG10(Top+0.0001)))	200+2300/(1+exp(1.0722.1654*LOG10(Top+0.0001)))
AC Fatigue			
AC Fatigue BF1: < 5 in.	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004
AC Fatigue BF1: < 5 in. ≤ hac ≤ 12 in.	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004
AC Fatigue BF1: > 12 in.	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004	.005*(0.000398+0.003602/(1+EXP(11.02-3.49*hac)))/0.004
AC Fatigue BF2	1	1	1
AC Fatigue BF3	1	1	1
AC Fatigue K1	214.18	30.08	30.08
AC Fatigue K2	5.0284	5.0537	5.0537
AC Fatigue K3	2.3072	2.8904	2.8904
AC Rutting			
AC Rutting BR1	0.10451	0.16981	0.13654
AC Rutting BR2	1	1	0.9
AC Rutting BR3	1	0.9	0.8
AC Rutting K1	-2.9708	-3.2605	-3.4717
AC Rutting K2	1.7435	2.0055	2.0258
AC Rutting K3	0.3547	0.3161	0.3946
AC Rutting Standard Deviation	2.0*Pow(RUT,1.4546)+0.001	1.6874*Pow(RUT,1.5749)+0.001	0.4282*Pow(RUT,1.1019)+0.001
Subgrade Rutting			
Subgrade Rutting BS1	0.10734	0.24109	0.17763
Subgrade Coarse Grained Rutting K1	1.35	1.35	1.35
Subgrade Fine Grained Rutting K1	1.35	1.35	1.35
Subgrade A-3 Rutting K1	1.35	1.35	1.35
Subgrade Rutting Standard Deviation	0.12356*Pow(SUBRUT,0.5012)+0.001	0.1477*Pow(SUBRUT,0.6711)+0.001	0.1477*Pow(SUBRUT,0.6711)+0.001
Granular Base Rutting BS1	0.09008	0.08383	0.14634
Granular Base Rutting K1	2.03	2.03	2.03
Granular Base Rutting Standard Deviation	0.1477*Pow(BASERUT,0.6711)+0.001	0.1477*Pow(BASERUT,0.6711)+0.001	0.1477*Pow(BASERUT,0.6711)+0.001

[1]hac is the thickness of the plant mix bituminous layer in inches.

APPENDIX B: Special Provisions

SPECIAL PROVISIONS

These Special Provisions supplement and modify the "Standard Specifications for Road and Bridge Construction," 2014 Edition. All of the requirements and provisions of said Standard Specifications shall apply, except where modified by the plans and these Special Provisions.

SECTION 203 – EXCAVATION AND EMBANKMENT

Add the following section after section 203.03.18 on page 95 of the standard specification:

203.03.19 Geogrid.

(a) Geogrid Packaging, Handling, and Storage. Each roll shall be labeled or tagged to provide product identification sufficient to determine the product type, manufacturer, quantity, lot number, roll number, date of manufacturer, and the shipping date.

Follow the manufacturer's recommendations regarding storage, handling, and protection from sunlight. The manufacturer's representative shall be on site for the first two days of the fabric installation, or longer at the discretion of the Engineer, and shall monitor the operation to ensure proper installation

(b) Weather Limitations. The geogrid shall not be placed when weather or surface conditions, in the opinion of the Engineer, are not suitable for placement. This will normally be at times of wet and snowy conditions, heavy rainfall, extreme cold or frost conditions, or extreme heat.

(c) Equipment. Mechanical or manual laydown equipment shall be capable of laying the geogrid properly and smoothly, according to the manufacturer's recommendations.

(d) Subgrade Preparation. Correct and compact localized ruts, holes, defects, or soft yielding places which occur in the subgrade or subbase to required density and stability before geogrid placement as directed by the Engineer and at Contractor’s expense.

(e) Geogrid Placement. Place the geogrid in accordance with the manufacturer’s recommendations. The geogrid shall be rolled out along the alignment in the direction of advancing construction. All wrinkles and folds shall be removed. The geogrid may be cut to conform to curves.

At transverse joints, the top layer of the geogrid shall overlap the lower layer of geogrid in the direction that the aggregate base will be placed. Overlap the adjacent edges of the rolls at least 2 feet. Overlap the ends of rolls at least 2 feet in the direction of spread of material covering the geogrid. Transverse overlaps shall be offset by at least 5 feet. Hold the overlap in place with staples, pins, or small piles of material placed on the geogrid. If the geogrid shifts or becomes misaligned, realign it, and anchor it according to the manufacturer's recommendations.

Use plastic ties at overlap joints as directed by the Engineer. Space longitudinal ties 10 feet to 20 feet and transverse ties 4 feet to 5 feet or as directed by the Engineer.

Where excessive subgrade rutting is apparent, repair the area of deformation at Contractor’s expense and correct grid placement operations as recommended by the manufacturer or directed by the Engineer.

During installation cover the geogrid with aggregate as soon as possible. Do not leave uncovered for more than 10 Calendar Days. No vehicles may drive on the uncovered geogrid at any time.

SECTION 302 – AGGREGATE BASE COURSES

302.03.03 Spreading Class B Aggregates. This Subsection of the Standard Specifications is hereby deleted and replaced with the following:

No tracked vehicles shall be allowed on the geogrid until there is a minimum of 6 inches of material between the tracks and the geogrid.

The aggregate shall be spread in a uniform lift, maintaining the desired lift thickness at all times, unless otherwise allowed by the Engineer. The aggregate material shall be bladed onto the geogrid in such a manner that the aggregate rolls onto the grid ahead, by gradually raising the blade while moving ahead.

Rubber tire trucks (end and belly dumps) may drive over the grid at very low speeds, less than 5 mph, and dump aggregates on the geogrid as long as the underlying material is capable of supporting the trucks without rutting. Sudden stops and turning by trucks shall be avoided while on the geogrid.

Keep the geogrid taut and free from wrinkles during placement of the first lift. Remove slack in the geogrid in accordance with the manufacturer’s recommendations or as required by the Engineer.

302.03.06 Compaction. The first paragraph of this Subsection is hereby deleted and the following substituted therefore:

Aggregate base material shall not be mixed or processed on the geogrid. The aggregate base material shall be premixed at the stockpile area or another location in a manner approved by the Engineer. Aggregate base materials will be sampled for acceptance after premixing and prior to placement on the geogrid.

Geogrid damaged after or during construction will be repaired in accordance with the manufacturer's recommendations at Contractor’s expense. Ensure all repaired sections contain a minimum 3 feet overlap in all directions.

Compact the aggregate base with either a smooth wheeled roller with no vibrations or a rubber tire roller.

Any ruts that might develop during spreading or compacting the aggregate shall be filled with additional aggregate to maintain the design aggregate thickness.

SECTION 731 - ENGINEERING FABRICS

731.01.01 Materials Covered. The third paragraph of this Subsection is hereby deleted and the following substituted therefore:

During installation, the fabrics shall not be exposed to ultraviolet rays for more than 10 days.

731.03.04 Geogrid. This Subsection of the Standard Specifications is hereby deleted and replaced with the following:

The geogrid shall be single layered and shall be made of high-density polyethylene or polypropylene. The geogrid shall be manufactured by being extruded, coextruded, punched, or integrally formed.

The geogrid between stations “Alignment” XX+XX to “Alignment” XX+XX and “Alignment” XX+XX to “Alignment” XX+XX shall conform to the following:

PROPERTY	TEST METHOD	REQUIREMENT
Aperture Size Range	I.D. Callipered	25-50 mm (1-2 in.)
Aperture Shape	Visual Observation	Rectangular or Square
Ribs per Node	Visual Observation	4
Tensile Strength @ 5% Strain, Cross Direction	ASTM D6637	19.0 kN/m (1300 lb/ft) Minimum
Tensile Strength @ 5% Strain, Machine Direction	ASTM D6637	11.4 kN/m (780 lb/ft) Minimum

The geogrid between stations “Alignment” XX+XX to “Alignment” XX+XX and “Alignment” XX+XX to “Alignment” XX+XX shall conform to the following:

PROPERTY	TEST METHOD	REQUIREMENT
Rib Pitch Range	I.D. Callipered	22-44 mm (0.86-1.73 in.)
Aperture Shape	Visual Observation	Triangular
Ribs per Node	Visual Observation	6
Radial Stiffness @ 0.5% Strain	ASTM D6637	225 kN/m (15,400 lb/ft) Minimum

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