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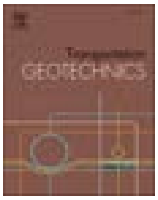

Installation of geosynthetic interlayers during overlay construction: Case study of Texas State Highway 21

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ABSTRACT

Geosynthetic interlayers in the form of geotextiles, geogrids, and geocomposites have been used to minimize reflective cracks and enhance overlay performance through functions such as stress relief, reinforcement and moisture barrier. However, proper geosynthetic installation and asphalt overlay construction practices are essential to the adequate performance of geosynthetic-reinforced asphalt overlays. In this study, various factors determining the successful construction of a geosynthetic-reinforced asphalt overlay are discussed in light of experiences during the construction of experimental test sections constructed in Texas State Highway 21. The project included nine different types of geosynthetic interlayers including four polymeric geogrid composites, three fiberglass geogrid composites, one fiberglass grid, and a fiberglass paving mat. The experimental test section included both sensor- and non-instrumented sections. The constructability evaluation of such experimental sections revealed that the primary factors influencing tack coat type and application rates include the pre-existing surface condition, geosynthetic type and their asphalt retention capacities. The geosynthetic installation procedures adopted in the experimental sections were proficient and comprised a specialized installation equipment that is capable of pre-tensioning the geosynthetics during the installation to minimize wrinkles and irregularities. Additionally, particularly high temperature of the pre-existing asphalt surface resulted in blistering of geotextile backing and subsequently leading into an excessive bleeding of tack coat through the geosynthetic apertures that resulted in tracking of construction equipment wheels. Recommendations on efficient geosynthetic installation and overlay construction techniques include adopting the tack coat type and application rates based on project-specific conditions, and using such tack coat to determine the asphalt retention capacity of the geosynthetic interlayer to be used in the project. Additional recommendations include minimizing the movement of construction vehicles on top of the geosynthetic interlayer, and adopting asphalt sanding technique to restore the friction between the paver and surface to minimize possible damage to the geosynthetic interlayer.

Introduction

Geosynthetics in the form of geogrids, geotextiles, geocells, geomembranes, and geonets can be incorporated into the different layers of pavement systems to enhance their performance through functions such as separation, filtration, reinforcement, stiffening, barrier, drainage and protection (e.g., [28]). Specifically, the enhanced pavement performance can be achieved through applications such as reflective crack minimization in asphalt overlays (e.g., [13,23–24]), base layer stabilization (e.g., [12,20,22,29]) and soft subgrade stabilization (e.g., [1,14]).

Among the applications entailing the use of geosynthetics in hot mix asphalt layers, the mitigation of reflective cracks using paving geotextiles correspond to one of the earliest uses of geosynthetics in roadways [26]. Reflective cracking can be defined as the reflection of cracks and ruts from the pre-existing asphalt layer on to the new asphalt overlay due to repeated traffic and temperature loads [8,23]. Specifically, repeated traffic loads induce bending and shear stresses, while temperature variations induce tensile stresses in the vicinity of pre-existing cracks, accelerating crack growth into the overlay [18]. Paving interlayers such as geotextiles, geogrids, and geocomposites have been employed to minimize the development and progression of reflective cracks into overlays, thereby extending the pavement service

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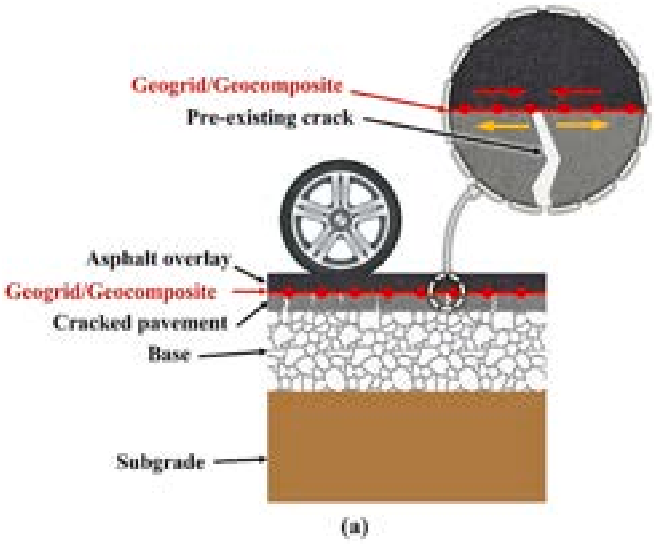

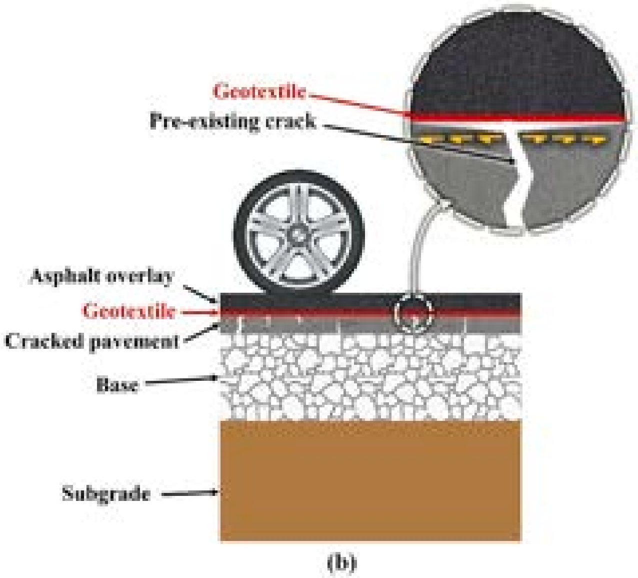

Fig. 1. Reflective crack mitigation mechanisms using geosynthetics: (a) Tension development mechanism; and (b) Stress-relief mechanism.

life.

The main mechanisms involved in applications aimed at retarding reflective cracking include tension development and stress relief [28]. The tension development mechanism results in stress redistribution within the asphalt overlay while maintaining confinement of the pre-existing asphalt layer. As shown in Fig. 1a, the effectiveness of this mechanism mainly depends on developing adequate interface bond strength between the geosynthetic and adjacent asphalt layers, including the preexisting asphalt and the new overlay. On the other hand, the stress relief mechanism involves development of horizontal deformations leading to controlled interface debonding in the vicinity of pre-existing cracks. As shown in Fig. 1b,. through controlled debonding, potential reflective cracks are intersected and diverted sideways. The tension development mechanism involves the reinforcement function of geosynthetics, which can be achieved by geogrids and geocomposites that have been manufactured by products such as polyester and fiberglass. On the other hand, the stress relief mechanism typically involves use of bitumen-impregnated nonwoven paving geotextiles, placed at the interface between pre-existing and new asphalt layers.

Recent studies [11,9–10,15–16,17] have shown that the geosynthetic reinforcement of asphalt overlays can provide additional design benefits by increasing the asphalt layer structural capacity and therefore reducing the required asphalt thickness or extending the pavement service life. These additional benefits could be achieved when the paving interlayers selected to retard reflective cracking involve the tension development mechanism, which depends on achieving a strong interface bond between the pre-existing and new asphalt layers. The bond between the pre-existing and new asphalt layers is influenced by multiple factors including the pre-existing surface condition (e.g., oxidized, milled, level-up), the type and rate of the tack coat, the type of geosynthetic interlayer (e.g., geotextile, geogrid, geocomposite), and the physical and tensile characteristics of the geosynthetic interlayer (e.g., aperture size, material composition, asphalt retention capacity).

Regardless of the mechanisms involved, proper installation is crucial to the realization of the benefits from geosynthetic interlayers. This paper summarizes the experiences and lessons learned during the geosynthetic installation and asphalt overlay construction along Texas State Highway 21 (SH21), which benefited from having used nine different geosynthetic interlayers in different test sections. A brief overview of the main steps involved in geosynthetic-reinforced overlay construction is presented first, followed by a detailed description of the SH21 rehabilitation project, and geosynthetic and tack coat materials used. Specific experiences and lessons learned from the SH21 rehabilitation project are then discussed, and recommendations for the efficient construction of geosynthetic-reinforced asphalt overlays are summarized in conclusion.

Steps for Geosynthetic-Reinforced Asphalt Construction

The following four basic steps should be properly executed to achieve proper construction of geosynthetic-reinforced overlays: 1) surface preparation, 2) tack coat application, 3) geosynthetic placement, and 4) asphalt overlay construction [7,19]. This section briefly explains each step.

Step 1: Surface Preparation

The pavement surface should be initially prepared so that it is leveled, clean, dry, and free of loose materials, oil, and sharp objects or edges [25]. Typical surface preparation protocols require that cracks wider than 3 mm be cleaned and sealed. Potholes, vertical joints, and faulted cracks should be leveled to be even with the existing pavement surface [7]. In cases of extremely rough and uneven surfaces, a leveling course of asphalt concrete mix with a thickness of 20 mm to 25 mm has been typically applied [7]. Additionally, depending on the type of the geosynthetic interlayer installed, the requirement of leveling course has been decided. Specifically, geosynthetic interlayers made up of fiberglass products have been typically installed on a leveled surface, while those made up of polymeric products have been installed on different surface conditions such as oxidized, milled, and leveled surfaces.

Step 2: Tack Coat Application

The second step involves the adequate design and proper application of the tack coat. The appropriate tack coat material and application rate is product-specific, so it should be carefully selected for each geosynthetic reinforcement after consultation with the manufacturer. Hot asphalt binder is typically recommended as the best choice for tack coat. Cutbacks and emulsions have been used successfully as well, but their application rate and cure time should be carefully selected to achieve the desired performance [25]. However, specific geosynthetic manufacturers do not recommend using cutbacks and emulsions, instead recommend using a performance grade (PG) asphalt binder same as that used in the asphalt overlay, as a tack coat. On the other hand, the tack coat application rates typically depend on the type of the tack coat (e.g., asphalt binder, asphalt emulsion), type of geosynthetic interlayer (e.g., geotextile, or geogrid, or geocomposite), condition of the pre-existing surface (e.g., fresh, oxidized, milled), and temperature of the pre-

Fig. 2. Overall extents of SH21 rehabilitation project.

existing surface.

The tack coat should be uniformly applied to an area that typically extends atleast 100 mm beyond the geosynthetic width on each side [7,25]. The proper tack coat temperature is also critical, as it should be high enough (for e.g., between 140 °C to 160 °C for an asphalt binder) to spread uniformly at the time of application [7,21]. However, the tack coat temperature should be comparatively lower at the time of geosynthetic placement to prevent damage or shrinkage of the geosynthetic reinforcement.

Step 3: Geosynthetic Placement

After the binder tack coat has decreased its temperature to suitable values (e.g., 85 °C for the case of polypropylene products), or an emulsion tack coat has completed the breaking time (e.g., about 0.5 to 1 hr. for slow-setting emulsions), the geosynthetic interlayer should be placed over the tack coat by a trained crew using specialized equipment capable of applying controlled tension to the geosynthetic during installation [7,21]. The applied tension should be carefully selected to be high enough to minimize wrinkles and folds but below a value that would overstretch the geosynthetic, as this would result in its thinning and compromise its ability to absorb tack coat. If the geosynthetic becomes oversaturated with tack coat (e.g., on hot installation days), special measures should be taken to prevent tracking of the geosynthetic by construction traffic wheels. Recommended solutions have included allowing the tack coat to cool over comparatively long periods or spreading hot mix asphalt on saturated areas [7,25]. While a few recommended installation techniques [25] suggest a reduction in tack application rate and application of sand to prevent the tracking. However, practices involving reduction of the tack coat rate or sand spreading should be avoided, since they compromise the development of adequate interface bond strength between the geosynthetic and asphalt layers. Depending on the dimensions of the road and geosynthetic rolls, overlaps between geosynthetic rolls may be needed along the longitudinal and transverse directions. The magnitude of overlap generally ranges from 50 mm to 150 mm and the manufacturer of each geosynthetic type should be consulted on the appropriate overlap dimensions.

Step 4: Asphalt Overlay Construction

The final step involves asphalt overlay placement, which should be completed immediately after the installation of the geosynthetic interlayer. It is recommended that an asphalt temperature ranging from 120 °C to 160 °C be maintained [7]. The asphalt overlay should be hot enough to melt the binder tack coat placed under the geosynthetic interlayer to create a strong bond among the pre-existing asphalt layer, the geosynthetic interlayer and the new asphalt overlay. However, an

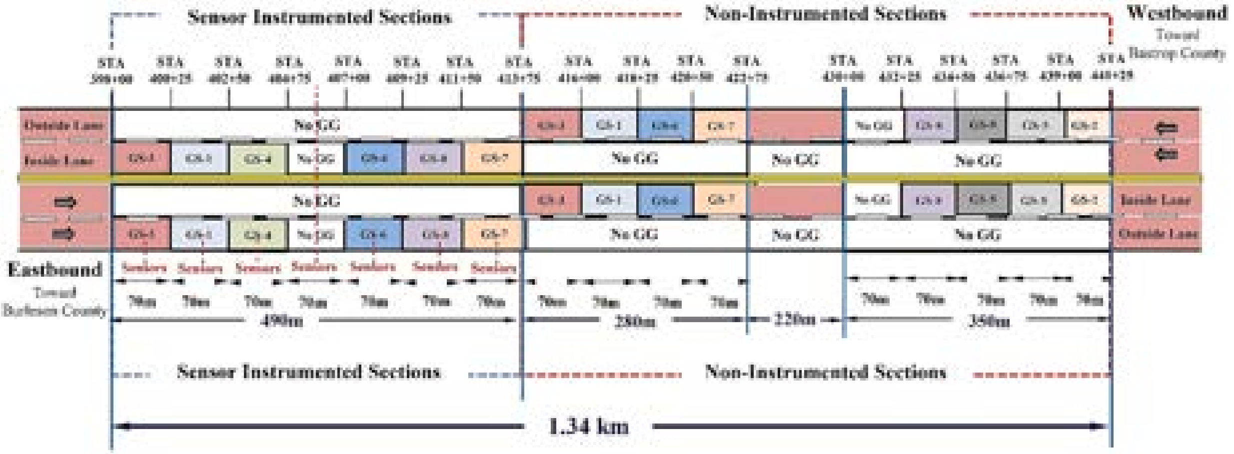

Fig. 3. Schematic layout of SH21 experimental test sections.

excessively high temperature should be avoided to minimize potential impact on the geosynthetic properties [19,21]. A minimum asphalt overlay thickness, typically ranging from 25 mm to 38 mm has been typically recommended by manufacturers to ensure the asphalt overlay maintains enough heat to facilitate migration of the melted asphalt binder through the geosynthetic.

Project Background: Texas State Highway 21

Texas State Highway (SH) 21 extends between San Marcos, TX on the west and the Texas-Louisiana border on the east, measuring approximately 500 km and covering roughly 12 different counties. The Texas Department of Transportation (TxDOT) proposed rehabilitating a portion of SH21 measuring approximately 33 km between the Bastrop/Lee (west) and Lee/Burleson County (east) lines during summer 2019. The rehabilitation program included half- or full-depth repairs followed by the installation of a 20-mm-thick level-up asphalt course, application of tack coat, installation of a geosynthetic interlayer (polymeric geogrid composite) and construction of an asphalt overlay. The asphalt overlay consisted of a 50-mm-thick dense-graded asphalt mix, referred to as TY-D, overlain by a 25-mm-thick overlay mixture, referred to as TOM. As part of the SH21 rehabilitation project, the University of Texas at Austin (UT-Austin), in coordination with TxDOT, developed a research study to evaluate the performance of asphalt overlays reinforced with different types of geosynthetic interlayers.

Fig. 2 shows the overall extent of the 33-km-long SH21 rehabilitation project within Lee County and the location of the experimental test sections. As the figure indicates, the experimental test sections were located to the east of the intersection of United States Highway (US) 77 and SH21. As part of the UT Austin-TxDOT research study, 32 experimental test sections (each approximately 70-m-long) involving different types of geosynthetic reinforcements (about 1.34 km in total length) were constructed. The roadway within the rehabilitation project limits consisted of four undivided lanes, each of which had a width of 3.35 m, and a paved shoulder with a width ranging from 0.6 m to 1.2 m. A schematic layout of the experimental test sections including sensor-instrumented and non-instrumented sections is presented in Fig. 3. Specifically, seven sections (six geosynthetic-reinforced and one unreinforced) of the eastbound outside lane (between STA 398 + 00 and STA 413 + 75) were instrumented with various sensors including moisture sensors in the subgrade; geophones in the subbase, base and pre-existing asphalt layers; asphalt strain gauges in the pre-existing asphalt layer; and thermocouples in the pre-existing asphalt and overlay. Additional moisture sensors were installed in the subgrade soil across all four lanes of the unreinforced section between STA 404 + 75 and STA 407 + 00. Experimental test sections that did not include any sensors are referred to as non-instrumented sections (see Fig. 3). The test section layout was designed so that the influence of traffic and temperature loadings on both inside and outside lanes could be considered. Consequently, the sensor-instrumented sections had geosynthetic interlayers on the westbound inside lane and eastbound outside lane, while the non-instrumented sections had geosynthetic interlayers on the westbound outside lane and eastbound inside lane (see Fig. 3). Furthermore, each geosynthetic-reinforced section had a companion unreinforced section to facilitate comparison of their responses under varying traffic and temperature conditions.

The main objective of this research study was to evaluate the efficacy of adopting different types of geosynthetic reinforcements (i.e., interlayers that provide reinforcement function via tension development mechanism) below the asphalt overlay to increase overlay structural capacity and thereby minimize overlay thickness. Increased roadway capacity provided by geosynthetic reinforcements would be quantified in terms of reductions in settlement and strains under traffic loads. Eventually, characterization of such increased structural capacity may be incorporated into future pavement design to reduce asphalt thickness or extend the pavement service life. However, and considering the multiple geosynthetic types involved in the construction of the asphalt overlays, this paper focuses on the experiences and lessons learned from the geosynthetic installation and overlay construction in the experimental test sections.

Materials

Geosynthetic Interlayers

The geosynthetic interlayers evaluated in this study were all expected to provide reinforcement function within the asphalt layers via tension development mechanism (see Fig. 1a). However, a wide variety of geosynthetic materials in different forms are available in the market to fulfill this function. Two important characteristics of geosynthetic materials to fulfill reinforcement functions include tensile reinforcement characteristics and geosynthetic-asphalt bond strength. Fiberglass interlayer materials are comparatively stiffer than polymeric materials such as Polyester (PET) and Polyvinyl alcohol (PVA). On the other hand, geosynthetic-asphalt bond strength depends on a variety of factors including geosynthetic forms (e.g., geogrid, geotextiles, geocomposites), aperture sizes (e.g., in case of geogrids), and coatings. Accordingly, to represent various materials that are most commonly used in the asphalt reinforcement market, a wide range of geosynthetic interlayers were selected as asphalt reinforcements for this study. These materials can be categorized into four main groups, based on their material composition, physical and tensile characteristics: polymeric geogrid composites,

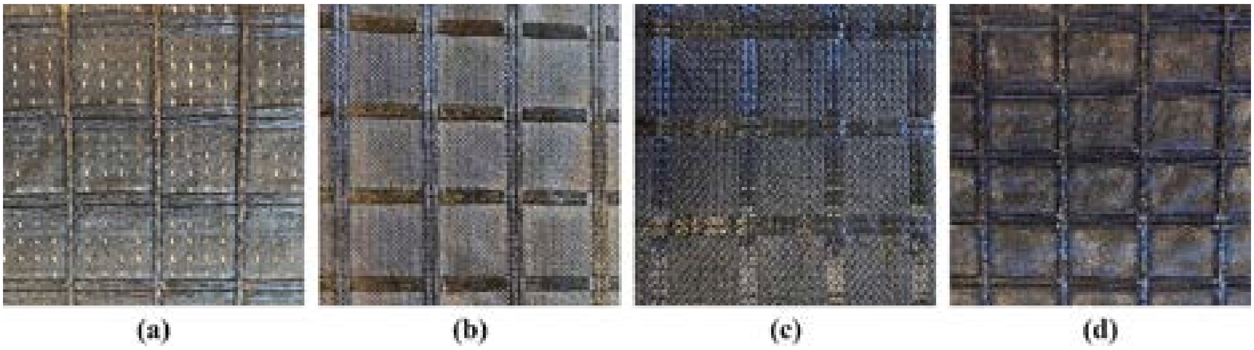

Fig. 4. Polymeric geogrid composites adopted in the study: (a) GS-1; (b) GS-2; (c) GS-3; and (d) GS-4.

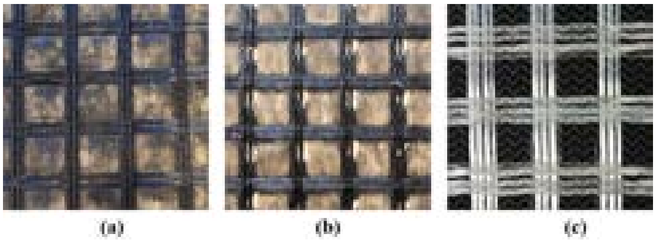

Fig. 5. Fiberglass geogrid composites adopted in the study: (a) GS-5; (b) GS-6; and (c) GS-7.

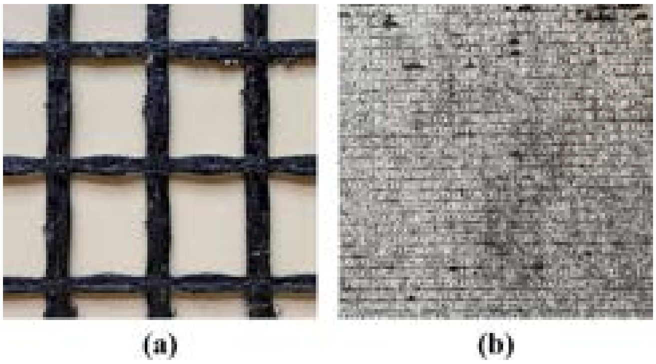

Fig. 6. Fiberglass products adopted in the study: (a) fiberglass grid (GS-8); and (b) fiberglass mat (GS-9).

fiberglass geogrid composites, a fiberglass grid and a fiberglass mat. Specifically, nine different types of geosynthetic reinforcements, including four different polymeric geogrid composites (Fig. 4), three different fiberglass geogrid composites (Fig. 5), one fiberglass grid (Fig. 6a) and one fiberglass mat (Fig. 6b), were adopted in the experimental test sections in addition to multiple unreinforced (control) sections. Several of the materials had a non-woven geotextile backing to facilitate their installation on tack coats. Detailed characteristics of each group of geosynthetic materials are discussed next.

Polymeric geogrid composites

The polymeric geogrid composites consist of either polyester (GS-1, GS-2 and GS-3) or polyvinyl alcohol (GS-4) geogrids backed by a thin geotextile layer, and having a nominal tensile strength of 50 kN/m in both Machine Direction (MD) and Cross-Machine Direction (CMD). The strains at ultimate tensile strength were about 10% (in both MD and CMD) for all polyester geogrid composites and about 5% (in both MD and CMD) for the polyvinyl alcohol geogrid composite. The polyester geogrid composites GS-1 and GS-2 involved a high-modulus polyester geogrid and a lightweight non-woven geotextile, while GS-3 involved a high-modulus polyester geogrid and a non-woven geotextile. The polyvinyl alcohol geogrid composite GS-4 involved a high modulus polyvinyl alcohol geogrid and a lightweight non-woven geotextile. The polymeric geogrid composites selected were coated with a binder to enhance their bonding properties. Fig. 4 shows pictures of these products and Table 1 summarizes their characteristics as provided by the manufacturers.

Table 1
Properties of Polymeric Geogrid Composites adopted in this study.

Properties	Test Method	GS-1	GS-2	GS-3	GS-4
Mass/unit area (g/m^2)	ASTM D5261 [4]	270	230	275	210
Aperture size (mm)	Measured	40 (MD) × 40 (CMD)	31 (MD) × 31 (CMD)	34 (MD) × 34 (CMD)	40 (MD) × 40 (CMD)
Ultimate tensile strength (kN/m)	ASTM D6637 [6]	50 (MD), 52 (CMD)	58 (MD), 65 (CMD)	67 (MD), 61 (CMD)	50 (MD), 50 (CMD)
Strain at ultimate tensile strength (%)	ASTM D6637 [6]	10 (MD), 11 (CMD)	11 (MD), 10.5 (CMD)	14 (MD), 13 (CMD)	5 (MD), 5 (CMD)
Asphalt retention capacity (l/m^2)	ASTM D6140 [5]	0.47	0.47	0.47	0.47
Melting point (°C)	ASTM D276 [2]	250	250	250	235
Roll dimensions: length × width (m)	Measured	150 × 4	150 × 4	75 × 3.75	150 × 4

*MD: Machine direction; CMD: Cross-machine direction.

Table 2
Properties of fiberglass geogrid composites adopted this study.

Properties	Test Method	GS-5	GS-6	GS-7
Mass/unit area (g/m^2)	ASTM D5261 [4]	320	596	678
Aperture size (mm)	Measured	30 (MD) × 30 (CMD)	30 (MD) × 30 (CMD)	38 (MD) × 38 (CMD)
Ultimate tensile strength (kN/m)	ASTM D6637 [6]	50 (MD), 50 (CMD)	100 (MD), 100 (CMD)	115 (MD), 115 (CMD)
Strain at ultimate tensile strength (%)	ASTM D6637 [6]	< 3	< 3	< 3
Asphalt retention capacity (l/m^2)	ASTM D6140 [5]	0.47	0.47	1.2
Melting point (°C)	ASTM D276 [2]	255	300	800
Roll dimensions: length × width (m)	Measured	150 × 3.9	100 × 3.9	45 × 3.8

*MD: Machine direction; CMD: Cross-machine direction.

Table 3
Properties of fiberglass grid (GS-8) and fiberglass mat (GS-9) adopted in this study.

Properties	Test Method	GS-8	GS-9
Mass/unit area (g/m^2)	ASTM D5261 [4]	432	237
Aperture size (mm)	Measured	25 (MD) × 25 (CMD)	–
Ultimate tensile strength (kN/m)	ASTM D6637/ D5035 [3]	100 (MD), 100 (CMD)	50 (MD), 50 (CMD)
Strain at ultimate tensile strength (%)	ASTM D6637/ D5035 [3]	< 3	< 5
Asphalt retention capacity (l/m^2)	ASTM D6140 [5]	–	0.47
Melting point (°C)	ASTM D276 [2]	232	232
Roll dimensions: length × width (m)	Measured	100 × 1.5	275 × 3.95

*MD: Machine direction; CMD: Cross-machine direction.

Table 4
Particle size distribution of TY-D and TOM asphalt mixtures adopted in this study.

Particle Size (mm)	Percentage Passing (%)	
	TY-D	TOM
19	100	–
12.7	98	100
9.5	94.3	96.9
4.75	66.9	48
2.38	37.7	24.5
0.6	19.7	16.9
0.3	10.6	8.5
0.075	5.3	5.1

Fiberglass geogrid composites

Three different fiberglass geogrid composites were adopted in this study. They have ultimate tensile strengths of 50 kN/m (GS-5), 100 kN/m (GS-6) and 115 kN/m (GS-7) at a strain of about 3% in MD and CMD. The fiberglass geogrid composites GS-5 and GS-6 are composed of continuous high-strength fiberglass filaments with a lightweight nonwoven geotextile backing, and are completely coated by a binder, as presented in Fig. 5a (GS-5) and 5b (GS-6). The product GS-7 consists of fiberglass filament yarns incorporated into a thick nonwoven polypropylene paving geotextile, as shown in Fig. 5c. The physical and tensile properties of the selected fiberglass geogrid composites, as provided by the manufacturers, are summarized in Table 2.

Fiberglass grid

The fiberglass grid GS-8 consists of high-strength fiberglass filaments coated with elastomers and arranged uniformly in MD and CMD resulting in a square aperture of 25 mm. In addition, GS-8 has a pressure-sensitive adhesive backing bonded to a polymer tack film, making it a self-adhesive geosynthetic reinforcement that does not require additional tack coat to bond to the adjacent asphalt layers. The product GS-8, shown in Fig. 6a, has an ultimate tensile strength of 100 kN/m at a strain of 3% in MD and CMD. Table 3 summarizes the characteristics of the fiberglass grid provided by the manufacturer.

Fiberglass mat

The fiberglass mat GS-9 presented in Fig. 6b is composed of fiberglass mesh combined into a high-performance polyester mat. This product has an ultimate tensile strength of 50 kN/m at a strain of 5% in MD and CMD. A summary of the physical and tensile properties of GS-9 provided by the manufacturer is shown in Table 3.

Tack Coat and Asphalt Concrete

Two different types of tack coats and asphalt mixtures were used during asphalt overlay construction along SH21. The tack coats included a polymer-modified asphalt cement (AC-15P) that was applied as tack coat on the level-up asphalt course prior to the installation of geosynthetic reinforcements; and a cationic, slow-setting, low-viscosity, harder residue emulsion (CSS-1H) that was applied as tack coat over the first overlay lift before placing the second (final) overlay lift. The two lifts of asphalt overlay involved two different types of asphalt mixtures. The first lift consisted of a dense-graded asphalt mixture, referred to as Type-D mix (TY-D), while the final lift consisted of a thin-wearing course asphalt mixture, referred to as Thin-Overlay Mixture (TOM). Table 4 presents the particle size gradations of the two asphalt mixtures adopted in the rehabilitation project. The TY-D and TOM asphalt mixtures used Performance Grade (PG) 64–22 binder at an optimum binder content of 5.2% and PG 76–22 binder at an optimum binder content of 6%, respectively (by weight of aggregates). In addition, a warm mix additive (Evotherm) at a rate of 0.4% (by weight of aggregates) was added as compaction aid to both the TY-D and TOM asphalt mixtures.

Overlay Construction & Lessons Learned

The experimental test sections were constructed in two stages: the first stage involved construction of the non-instrumented sections (between STA 413 + 75 and STA 441 + 25), followed by construction of the instrumented sections (between STA 398 + 00 and STA 413 + 75) in the second stage. As discussed in the subsequent sections, the overlay construction process involved set up of road closures, followed by tack coat application, geosynthetic installation and lastly the placement and compaction of the asphalt overlay. Additional discussions include

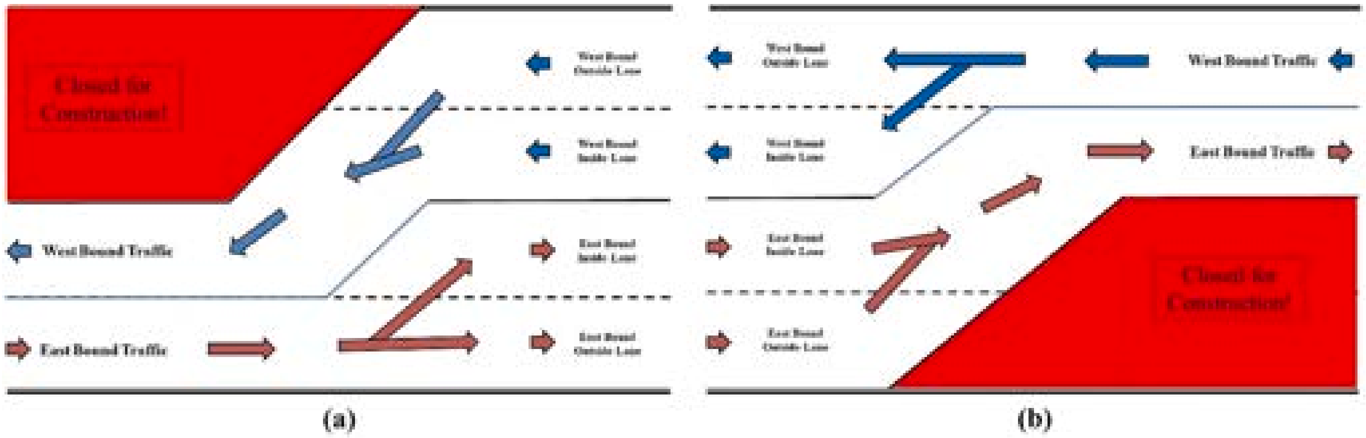

Fig. 7. Schematic of roadway closure for rehabilitation of: (a) westbound lanes; and (b) eastbound lanes.

Fig. 8. Polymer asphalt cement (AC-15P) tack application in experimental test section.

experiences and lessons learned during the different stages of overlay construction process.

Road Closure Activities

The rehabilitation project along SH21 involved repairing the pre-existing asphalt layer, installing a 20-mm-thick level-up asphalt course, applying tack coat, installing geosynthetics and constructing the asphalt overlay. Because SH21 was open to public traffic, closure of the roadway and diversion of traffic was required prior to the commencement of roadwork. As described in Project Background: Texas State Highway 21, the project comprised of four undivided lanes, including two lanes each to accommodate east- and westbound traffic. For this study, two lanes remained open to public traffic and two lanes were closed for roadway rehabilitation throughout all stages of construction. Fig. 7 presents schematics of the roadway closures for the rehabilitation of the westbound and eastbound lanes, respectively. As depicted in the figure, the traffic from the westbound lanes was gradually diverted to the eastbound inside lane, while the eastbound traffic was limited to the eastbound outside lane only, facilitating the closure of the two westbound lanes for retrofitting. After completion of the westbound lane rehabilitation, the traffic from the two eastbound lanes was gradually diverted to the westbound inside lane, while the westbound traffic was limited to the westbound outside lane only (see Fig. 7b). The traffic diversion and lane closures shown in Fig. 7 was adopted at different stages of rehabilitation, including tack coat application, geosynthetic installation, and overlay construction, all of which were completed in different segments and sequences. Specifically, the entire stretch of experimental test sections was divided into two parts and rehabilitated, including the rehabilitation of non-instrumented sections (STA 413 + 75 to STA 441 + 25) followed by the rehabilitation of sensor-instrumented sections (STA 398 + 00 to STA 413 + 75). The rehabilitation sequence involved consecutive rehabilitation of the four lanes, starting with the non-instrumented sections of the westbound lanes followed by the eastbound lanes and vice versa for the sensor-instrumented sections. The sections were also rehabilitated in the direction of traffic, i.e., westbound lanes were rehabilitated from east to west and eastbound lanes from west to east. Overall, the road closure activities employed during the rehabilitation of SH21 was particularly successful in accomplishing the objectives of overlay construction along with no significant disruptions in traffic patterns within the project limits. Additionally, future rehabilitation projects involving similar roadway profiles with undivided four-lane are recommended to adopt the road closure procedure described in this study.

Table 5
Tack coat application rates adopted in this study.

Geosynthetic Interlayers	Tack Application Rate (l/m^2)	
	Recommended	Revised
GS-1	0.54	0.50
GS-2	0.54	0.50
GS-3	0.54	0.50
GS-4	0.54	0.50
GS-5	0.54	0.50
GS-6	0.54	0.50
GS-7	1.45	1.35
GS-8	–	–
GS-9	0.58	0.54

Tack Coat Application

Two different types of tack coat were used during the overlay construction. The first type, AC-15P, was applied as a tack coat on the 20-mm-thick level-up asphalt course that was placed after the pre-existing asphalt layer was repaired and prior to the installation of geosynthetic interlayers. A second type, CSS-1H, was applied as a tack coat at a rate of 0.27 l/m^2 on the 20-mm-thick level-up asphalt course in the unreinforced experimental section as well as over the 50-mm-thick TY-D layer prior to construction of the 25-mm-thick TOM layer in unreinforced and geosynthetic-reinforced sections.

In preparation for tack coat application, the level-up and TY-D asphalt surfaces were cleared of any raised pavement markers, dirt, sand, leaves and other loose impediments. Furthermore, any traces of vegetation and organic matter were removed and the surface was confirmed to be completely dry before tack coat application, in accordance with TxDOT Special Specification 3062: Polymeric Composite Paving Geogrid for Asphalt Pavement Overlay Reinforcement [27]. Such a surface preparation technique is essential to maintain adequate bond between the asphalt layers (in unreinforced section), and between geosynthetic and adjacent asphalt layers (in reinforced sections). Fig. 8 shows a photograph of the tack distributor truck spraying AC-15P tack on the surface of the level-up asphalt course in the experimental test section. As the figure shows, the tack coat was sprayed through multiple nozzles at a constant rate and temperature to achieve a uniform tack application across the entire lane width. The tack coat was applied approximately 15 to 30 min prior to the installation of geosynthetic

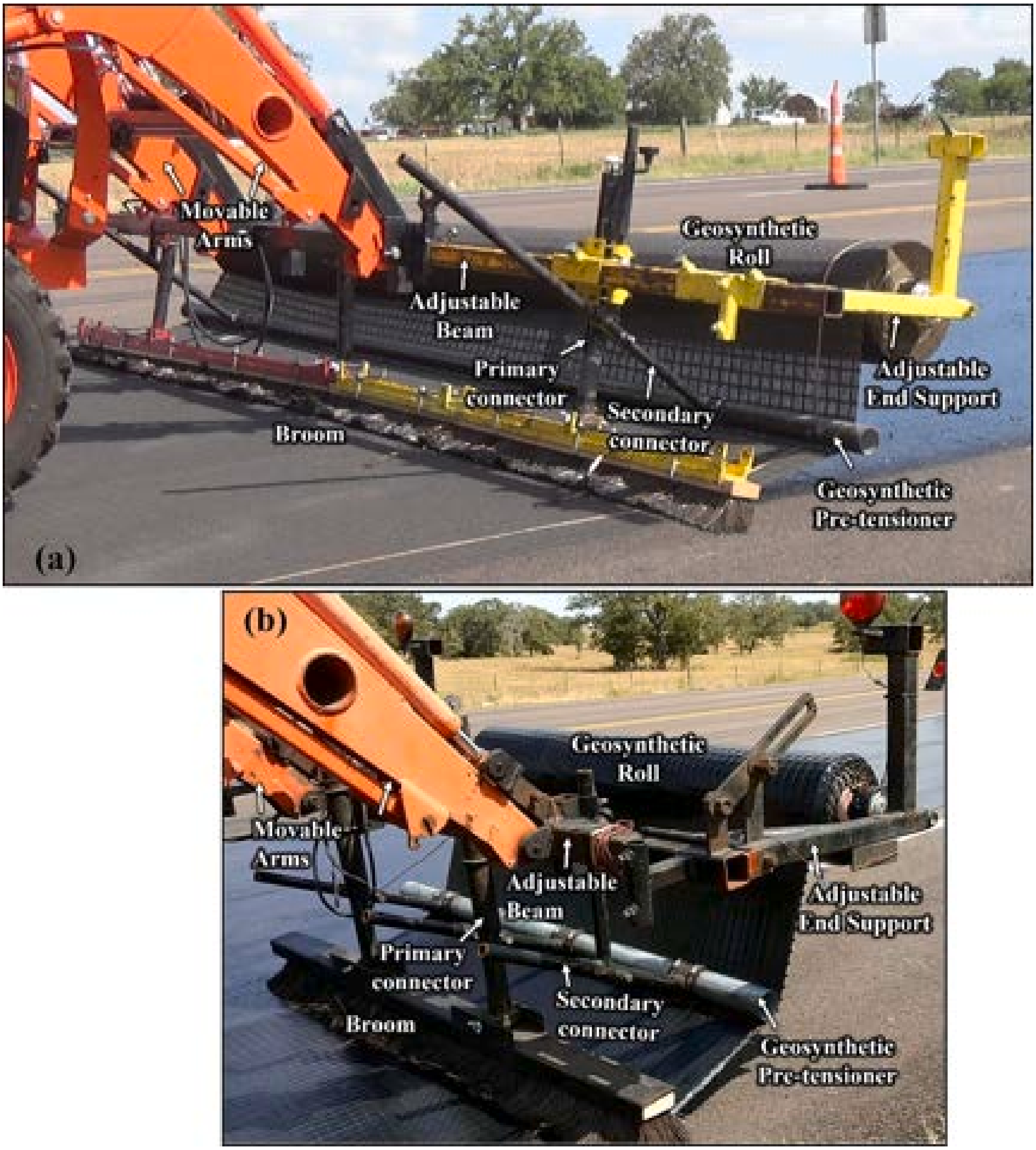

Fig. 9. Photos showing various parts of geosynthetic installation tractor used to install: (a) all geosynthetic interlayers except GS-8; and (b) GS-8.

interlayers to ensure that the geosynthetic interlayers bond well with the tack coat and the pre-existing asphalt layer.

The application rates adopted for tack coat AC-15P for the non-instrumented experimental test sections reinforced with different geosynthetic types were based on the manufacturers' recommendations, as summarized in Table 5. The manufacturer recommended tack coat application rates are based on the asphalt retention capacity of the geosynthetic interlayer that are typically determined using a standard tack coat type (e.g., asphalt binder) at a standard room temperature. As indicated in the table, most manufacturers recommended a tack application rate of 0.54 l/m^2, except for the sections reinforced with GS-7 and GS-8, which had the highest (1.45 l/m^2) and lowest (no tack) application rates, respectively. The high tack application rate recommended for the experimental test section reinforced with GS-7 was due to the comparatively high asphalt retention capacity of this geosynthetic (see Table 2). On the other hand, GS-8 had a self-adhesive polymer tack film to bond with adjacent asphalt layers and therefore required no tack coat prior to the installation. However, it should be noted that using the manufacturers' recommended tack application rates resulted in an additional construction effort that resulted in delays during the asphalt overlay construction in non-instrumented sections. Specifically, due to the comparatively high temperature, tack coat flushing and over-impregnated bitumen spots were observed at several locations (see Section: Lessons learned from tack application and geosynthetic installation). Consequently, the tack application rates were decreased slightly for the remaining experimental test sections involving geosynthetic interlayers (i.e., sensor-instrumented sections). The revised values, which were adopted after consultation with manufacturer site representatives, are listed in the last column of Table 5. Overall, the tack coat application of the sections involving different geosynthetic interlayers were adjusted to suite the site-specific conditions. Additionally, it is recommended to consider the tack coat type and application rates based on the site-specific conditions rather than typical pre-existing recommendations.

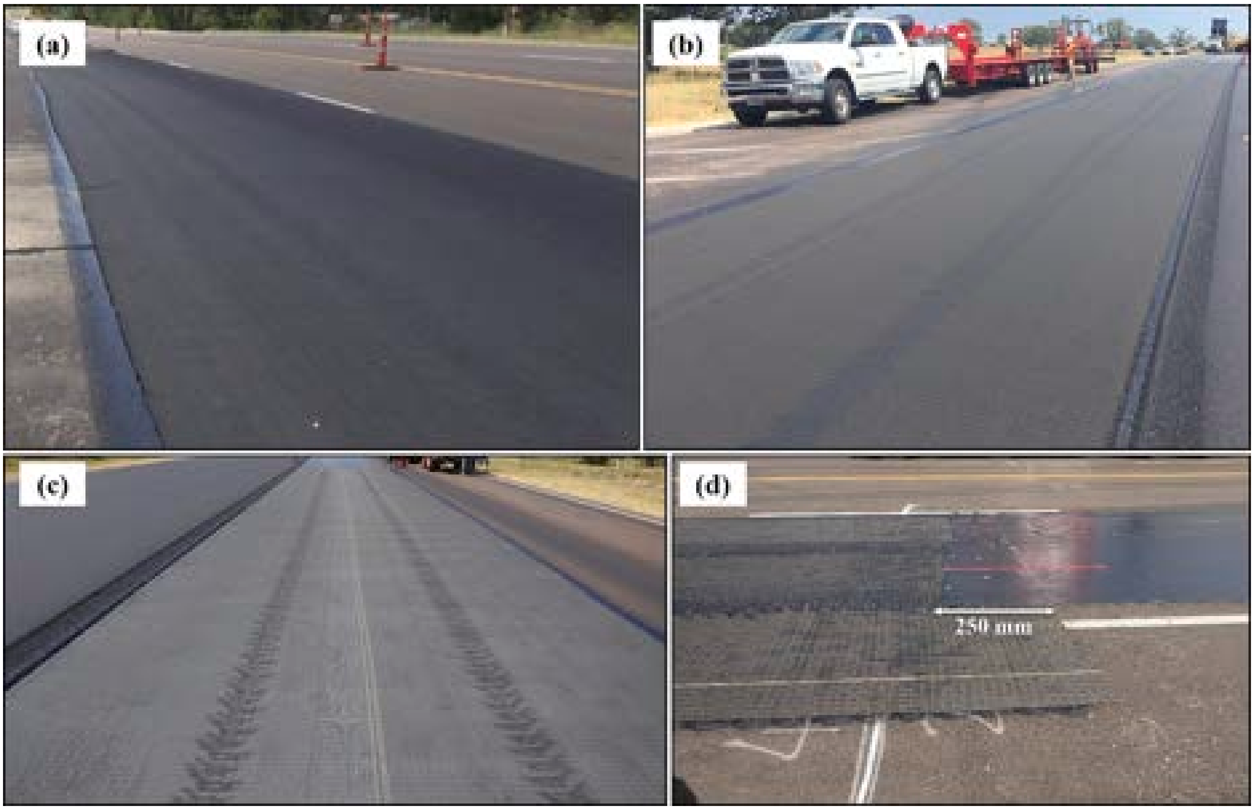

Fig. 10. Photos showing proficient geosynthetic installation in experimental test sections: (a) GS-1; (b) GS-2; (c) GS-3; and (d) overlap between geosynthetics GS-6 and GS-8 in longitudinal direction.

Fig. 11. Photos showing poor geosynthetic installation: (a) numerous wrinkles along roadway; (b) inadequate geosynthetic overlap in longitudinal and transverse directions; (c) no geosynthetic overlap in longitudinal direction; and (d) excess geosynthetic overlap in longitudinal direction.

Fig. 12. Influence of temperature on tack coat and geosynthetics: (a) blistering of geotextile backing; and (b) tracking of geosynthetic installation tractor wheels.

Geosynthetic Installation

Following the application of AC-15P tack coat in the experimental test sections, nine different types of geosynthetic interlayers were installed using customized geosynthetic installation tractors (see Fig. 9a and 9b). As shown in these figures, the geosynthetic installation tractor includes two movable arms connected to an adjustable beam that holds the geosynthetic roll; a broom held by a primary connector; and a geosynthetic pre-tensioner, with adjustable end support, held by a secondary connector. The ends of the geosynthetic roll are secured by the tractor's end supports, which were adjusted to accommodate the width of the geosynthetic interlayers selected for this study. Aside from GS-8, which has a width of 1.5 m, the products considered herein measure between 3.75 m and 4 m in width (see Tables 1, 2 and 3). Consequently, a different geosynthetic installation tractor that could accommodate geosynthetic rolls up to only 2 m wide (see Fig. 9b) was used for installation of GS-8. Fig. 9b also highlights the installation of GS-8 in the experimental test section without a tack coat application on the pre-existing asphalt surface. The geosynthetic pre-tensioner functions to pre-tension the geosynthetic interlayer during installation, thereby minimizing wrinkles. The broom slides swiftly on top of the geosynthetic interlayer being installed and promotes the bonding of geosynthetic and

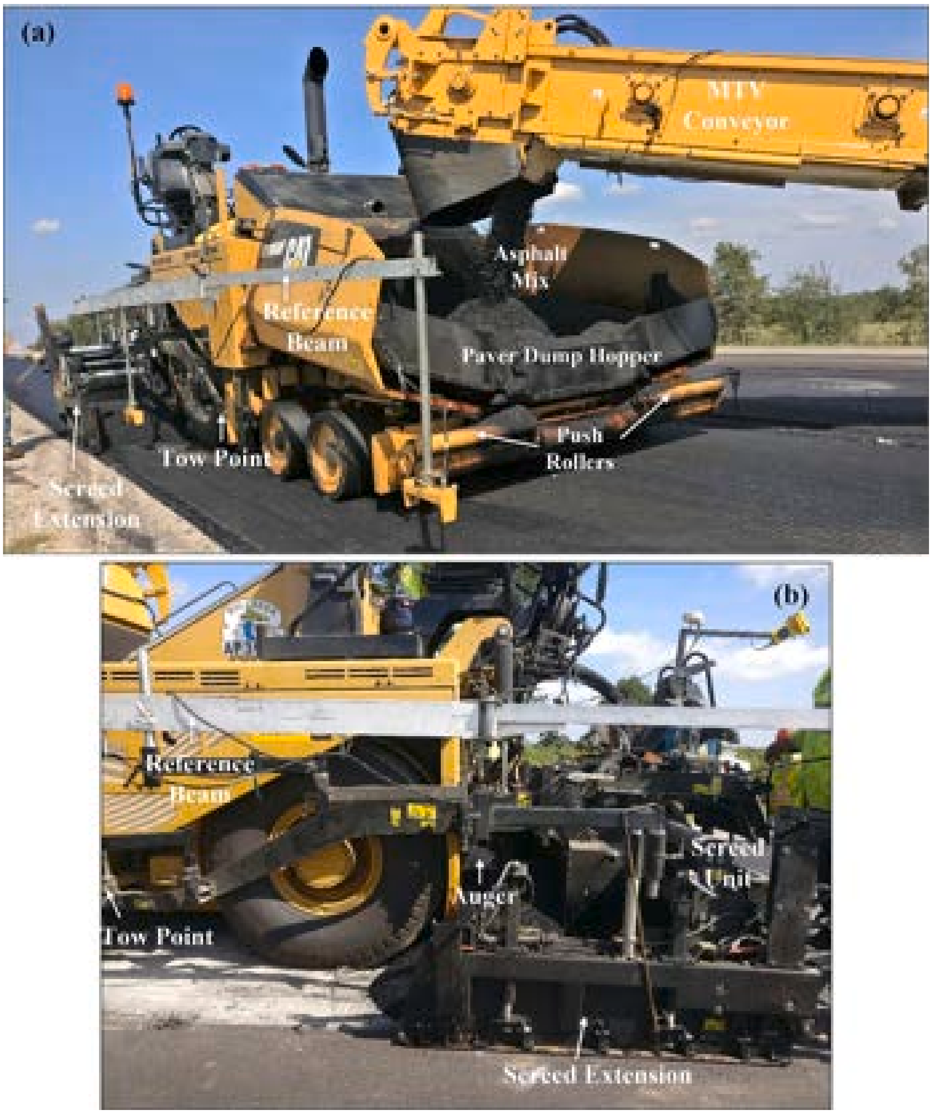

Fig. 13. Asphalt paver used in overlay construction: (a) overall view; and (b) side view.

tack coat. Geosynthetic interlayers must be installed with minimum folds or wrinkles, and any wrinkles or folds exceeding 25 mm must be slit and laid flat or pulled in the direction of traffic [27]. Additionally, the geosynthetic overlaps in the longitudinal and transverse directions should be at least 150 mm and 100 mm respectively, per TxDOT specifications [27]. Such overlaps between multiple rolls of geosynthetic interlayers along both longitudinal and transverse directions is essential to obtain adequate bond between the interlayers and subsequently between the geosynthetic interlayer and adjacent asphalt layers. In addition, the bond between interlayers and asphalt layers at such overlaps is essential to avoid any possible weak spots due to the geosynthetic installation or the overlay construction activities.

Geosynthetic installation in different test sections is displayed in Fig. 10 to illustrate the different techniques adopted in this project to ensure proficient geosynthetic installation. Fig. 10a, 10b and 10c shows the installation of geosynthetic products GS-1, GS-2 and GS-3, respectively (see Fig. 3), which are shown to result in installation without folds or wrinkles. Fig. 10d shows the overlap in the longitudinal direction between GS-6 and GS-8 with an end-to-end overlap length of about 250 mm. While the photos in Fig. 10 depict proper geosynthetic installation in several experimental test sections, lack of adequate supervision led to poor geosynthetic installation in several roadway sections beyond the experimental test section limits. Fig. 11 presents examples of poor geosynthetic installation at a number of locations beyond the experimental test sections but within the 33-km-long rehabilitation project. Fig. 11a and 11b shows multiple wrinkles exceeding 25 mm along the roadway and inadequate geosynthetic overlap in the longitudinal and transverse directions, respectively. Fig. 11c and 11d show no geosynthetic overlap and excess geosynthetic at the overlap in the longitudinal direction, respectively. Figs. 10 and 11 also reveal that the geosynthetic interlayers (specifically the composite products) were installed with the grid side facing down (i.e., geotextile facing up). When installed with the geotextile side facing up, construction traffic can avoid direct contact with the tack coat and geogrid. This light-weight geotextile is melted by the overlaying hot mix layer to facilitate interlock and bonding between the interlayer and asphalt as well as bonding between the asphalt layers (e.g., GS-1, GS-4, GS-5, GS-6). Overall, the geosynthetic installation procedures adopted in the experimental sections were proficient compared to the rest of the project. It is recommended to adopt an efficient geosynthetic installation technique to achieve the objectives expected from the geosynthetic interlayer installed during the asphalt construction.

Lessons Learned from Tack Application and Geosynthetic Installation

The ambient air and pre-existing asphalt surface temperatures

Fig. 14. Asphalt overlay construction equipment used in SH21 rehabilitation project.

greatly influence the bonding characteristics between the tack coat and geosynthetic interlayers. Typically, the tack application rates for geosynthetic-reinforced overlays are recommended based on the asphalt retention capacity of the geosynthetic interlayer, condition of the pre-existing asphalt surface (e.g., old and oxidized layer or a relatively new level-up layer or milled surface), temperature of the pre-existing asphalt surface (e.g., hot or cold) and type of tack coat adopted (e.g., asphalt binder or asphalt emulsion, slow-, medium- or rapid-setting). Accordingly, the manufacturer-suggested tack application rates were adopted in the non-instrumented experimental test sections prior to geosynthetic installation (see Table 5). However, the nonwoven geotextile backing of some of the geosynthetic interlayers (e.g., GS-1, GS-4, GS-5, GS-6) blistered shortly after installation due to high temperature of the pre-existing asphalt surface, as exhibited in Fig. 12a. Additionally, such high pre-existing asphalt surface temperatures increased the tack coat temperature and decreased its viscosity, causing the tack coat to bleed through to the geosynthetic surface via the blistered geotextile backing. This blistered geotextile backing exposed the tack coat to the surface (bleeding) through the reinforcement apertures, resulting in tracking of the geosynthetic installation tractor wheels shown in Fig. 12b.

The tack application rates suggested by the geosynthetic manufacturer were based on the asphalt retention capacity of the geosynthetic interlayer determined according to ASTM D6140 [5], which are typically determined using a standard tack coat type (e.g., asphalt binder) at a standard room temperature (e.g., 25 °C). However, the binder used to determine the asphalt retention capacity per ASTM D6140 differed from that used in the experimental test sections. The pre-existing asphalt surface temperature also affected the actual tack coat temperature at the site. Consequently, tack application rates were adjusted (i.e., reduced) to accommodate project conditions for each geosynthetic interlayer based on recommendations from manufacturer representatives (see Table 5). An additional side effect of tack coat is the tracking of construction equipment wheels, which may compromise the tensile properties of geosynthetic interlayers and is addressed in the following section.

Asphalt Overlay Construction

The asphalt overlay construction for this project involved placing two lifts of asphalt concrete, including a 50-mm-thick TY-D layer overlain by a 25-mm-thick TOM layer, on geosynthetic interlayers. The TY-D layer was placed directly on the geosynthetic interlayer and compacted, while the TOM layer was installed after the application of CSS-1H tack coat at a rate of 0.27 l/m^2 on the TY-D layer. The construction process for the TY-D and TOM layers were identical and required an asphalt paver, Material Transfer Vehicle (MTV) and asphalt trucks.

Fig. 13 displays overall and side views of the asphalt paver used in the overlay construction. It consists of a dump hopper in the front that collects the asphalt mix being fed by the MTV and asphalt trucks. The paver has push rollers in the front (see Fig. 13a) to accommodate direct feeding from asphalt trucks, although these were not utilized for this project. An auger at the back mixes the asphalt before it is leveled by the towed screed unit (see Fig. 13b), which was extended on either side of the paver to accommodate paving the entire lane width before roller compaction, as shown in Fig. 13. Additionally, a reference beam extending from the front of the paver to beyond the screed unit was mounted to facilitate maintaining a uniform asphalt thickness. In Fig. 14, the asphalt truck, MTV and paver used to construct the asphalt overlay for the SH21 rehabilitation project are depicted. As shown in the figure, these three vehicles were arranged so that the asphalt mix was unloaded from the truck into the MTV dump hopper, mixed, and then transferred to the paver dump hopper via the MTV conveyor. Paver conveyors then transferred the asphalt mix to the rear of the paver, where it was thoroughly mixed by augers, and subsequently placed on the geosynthetic surface, leveled with the screed and eventually compacted. The MTV works in tandem with the paver, feeding the asphalt mix to it continuously so that the paving operation is uninterrupted. A typical sequence of asphalt feeding, from the asphalt trucks to the MTV to the paver, is summarized in Fig. 15. As shown in the figure, the MTV and paver moved forward, paving the eastbound outside lane, while the

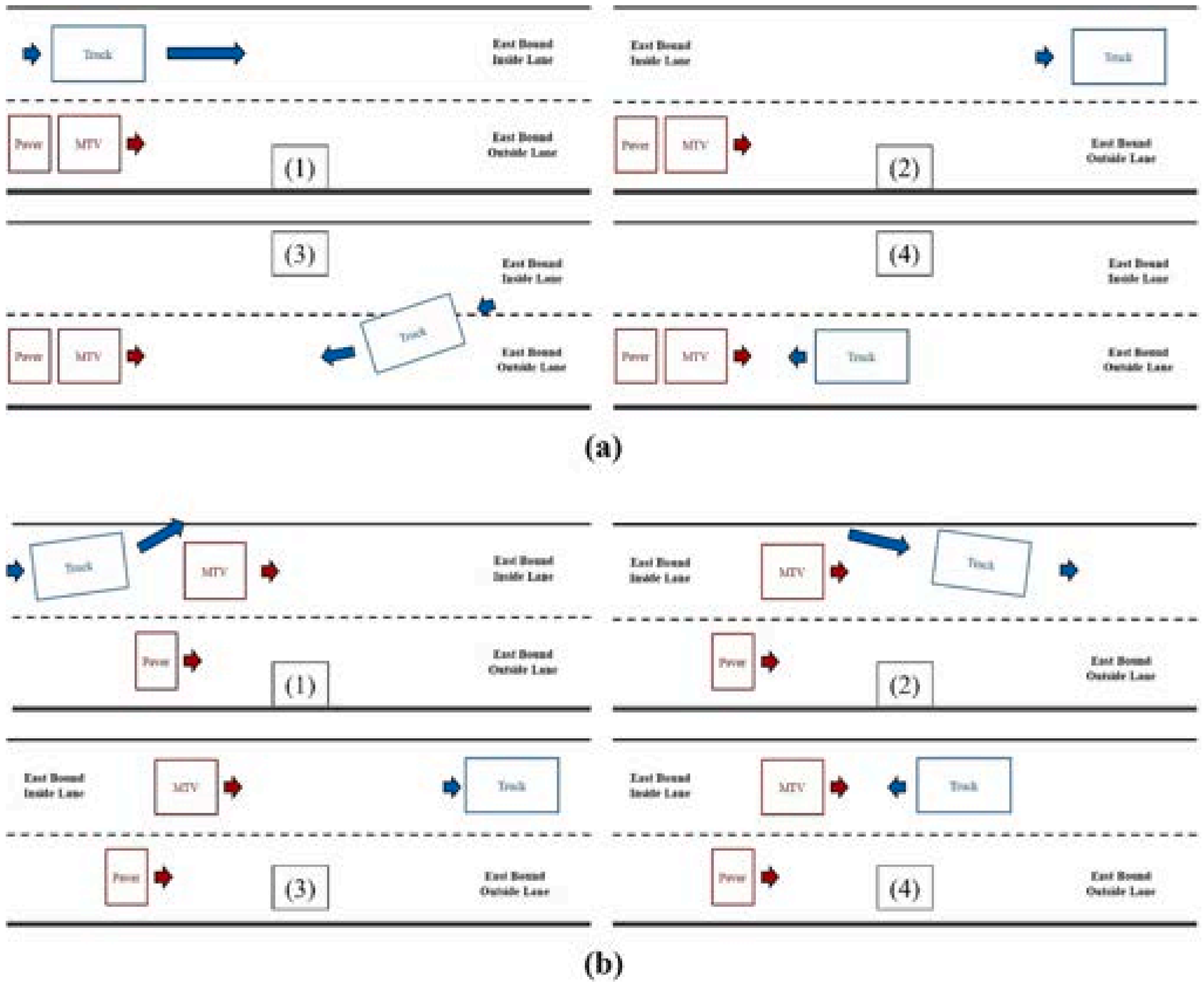

Fig. 15. Schematic of asphalt feeding sequence to Material Transport Vehicle (MTV) and paver in SH21 rehabilitation project: a) typical arrangement initially used in non-instrumented sections; and b) revised arrangement adopted to minimize damage to geosynthetic.

asphalt truck approached the MTV and paver from the adjacent lane (i.e., eastbound inside lane), passed them and finally backed up to the MTV to feed the asphalt. The asphalt truck, MTV and paver assembly moved on top of the geosynthetic interlayer during the paving of a few non-instrumented test sections. However, that resulted in complications (see next Section) and as a measure, the overlay construction process was revised during the paving of the rest of non-instrumented and sensor-instrumented test sections. The complications and the technical reasons behind the adoption of a revised overlay construction process is detailed next.

Lessons Learned from Overlay Construction

Paving operations involved the MTV and paver concurrently placing the asphalt and slowly advancing, while trucks stopped frequently during asphalt feeding to the MTV (see previous Section). The discontinuous movement of the asphalt trucks on the tack coat exposed portions of the geosynthetic interlayer led to the tracking of wheels, compromising the installed geosynthetic interlayer properties. Fig. 16a shows the truck wheel picking up the tack coat and geosynthetic interlayer along the wheel path, while Fig. 16b shows the geosynthetic reinforcement after truck movement. As the figure demonstrates, the geosynthetic reinforcement flanking the wheel path appears bonded with the pre-existing asphalt surface, while the geosynthetic within the wheel path was stretched and partially damaged. Such damage to the geosynthetic reinforcement, which had been adequately installed without wrinkles, would compromise the intended benefit to the asphalt layer and pavement system. Specifically, the location of the damage along the construction equipment wheel path is critical to the performance of the geosynthetic because it lies along the wheel paths of future road traffic.

To overcome this critical construction issue, the overlay construction process was revised by moving the MTV and asphalt trucks to the adjacent lane while feeding asphalt to the paver. The revised arrangement of construction vehicles, presented in Fig. 17, restricted the movement of construction equipment on top of the geosynthetic interlayer to the paver only, thereby minimizing damage to the geosynthetic caused previously by the movement of MTV and asphalt trucks on the installed interlayer surface. The sketches provided in Fig. 15b demonstrate the revised asphalt overlay construction sequence. However, revising the construction process as previously described may not necessarily be possible (or prove very challenging) in projects with single-lane construction closures. Therefore, adopting an appropriate tack coat type and application rate are crucial to minimize such damages

Fig. 16. Photos showing damage to geosynthetics caused by truck movement: (a) during truck movement; and (b) after truck movement.

and achieve the intended performance from geosynthetic interlayers. It is also important to evaluate the tensile and physical properties of geosynthetic interlayers if they are damaged during geosynthetic installation and overlay construction, such that adequate properties may be incorporated in the actual pavement design. Furthermore, it is recommended that geosynthetic manufacturers consider possible installation and construction damages in their products' reported properties.

On the other hand, construction vehicles need an increased acceleration when paving along an upslope road (e.g., in a summit curve). Fig. 18 shows the longitudinal profile of the experimental test sections, including both sensor- and non-instrumented sections, which consist of both summit and valley curves with several up- and down-slopes. Specifically, the sensor-instrumented sections between STA 398 + 00 and STA 407 + 00 have an upward slope with a gradient of 1.9% followed by

Fig. 17. Revised overlay construction process.

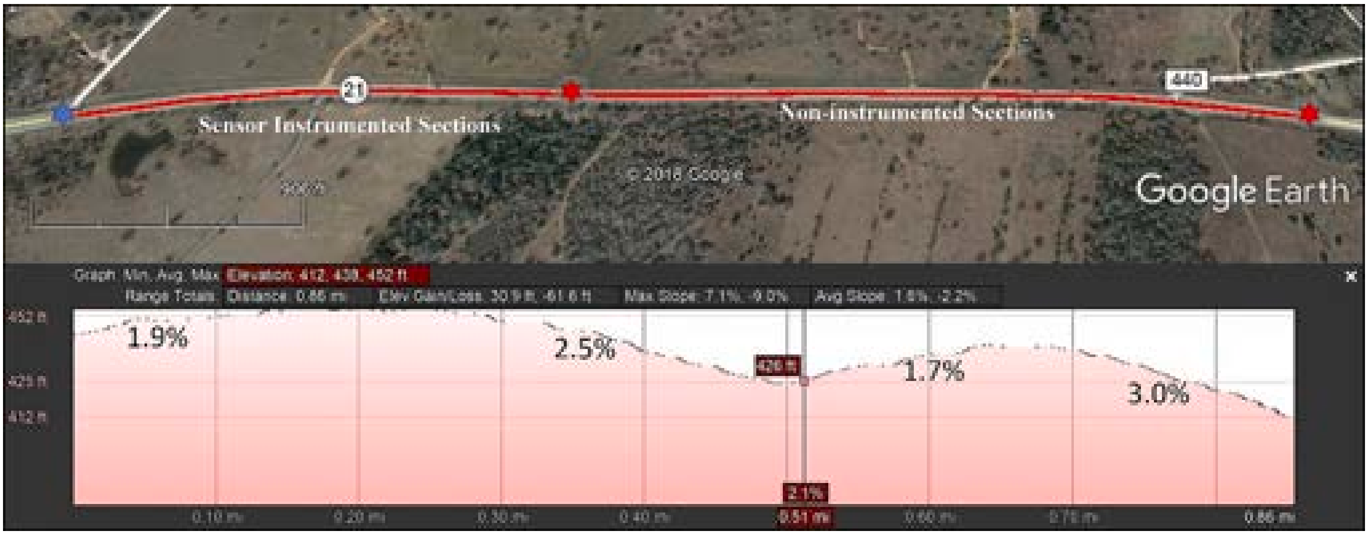

Fig. 18. Longitudinal profile of experimental test sections.

a downward slope with a gradient of 2.5% that continues through the end of the sensor-instrumented sections and four of the non-instrumented sections (i.e., until STA 422 + 75). The remaining non-instrumented test sections, starting at STA 422 + 75 and ending at STA 430 + 00, have an upward slope with a gradient of 1.7% followed by a downward slope with a gradient of 3% until the end of the non-instrumented test sections (i.e., STA 441 + 25). This profile resulted in an upward roadway slope of 3% during construction of the non-instrumented test sections in the westbound lanes that required an increased acceleration of construction vehicles.

The blistered geosynthetic interlayers and bled tack coat (discussed in Section: Lessons learned from tack application and geosynthetic installation) resulted in reduced friction between the tires and geosynthetic interlayer, requiring increased acceleration and thus additional wheel rotations. Specifically, the friction loss was more significant for the MTV and paver wheels since they moved forward along the upward slope, while the asphalt trucks moved backward on a downward slope to feed asphalt to the MTV. However, per the revised overlay construction arrangement detailed earlier (see Fig. 15b), the MTV and asphalt trucks were moved to the adjacent lane and the paver remained in the same lane. Consequently, a solution to the loss of friction for the paver was still needed to maintain continuous construction operations and avoid further damaging the geosynthetic interlayer. The increase in paver wheel rotation also resulted in the wheels pulling the geosynthetic interlayer at the overlaps in the longitudinal direction. As shown in the pictures in Fig. 19, the geosynthetic product GS-7 initially had an end-to-end overlap of at least 250 mm in the longitudinal direction (see Fig. 19a), which decreased significantly as the paver wheels approached the overlap and also caused significant wrinkles (see Fig. 19b). Similarly, the significant wrinkles caused by the paver wheels while approaching

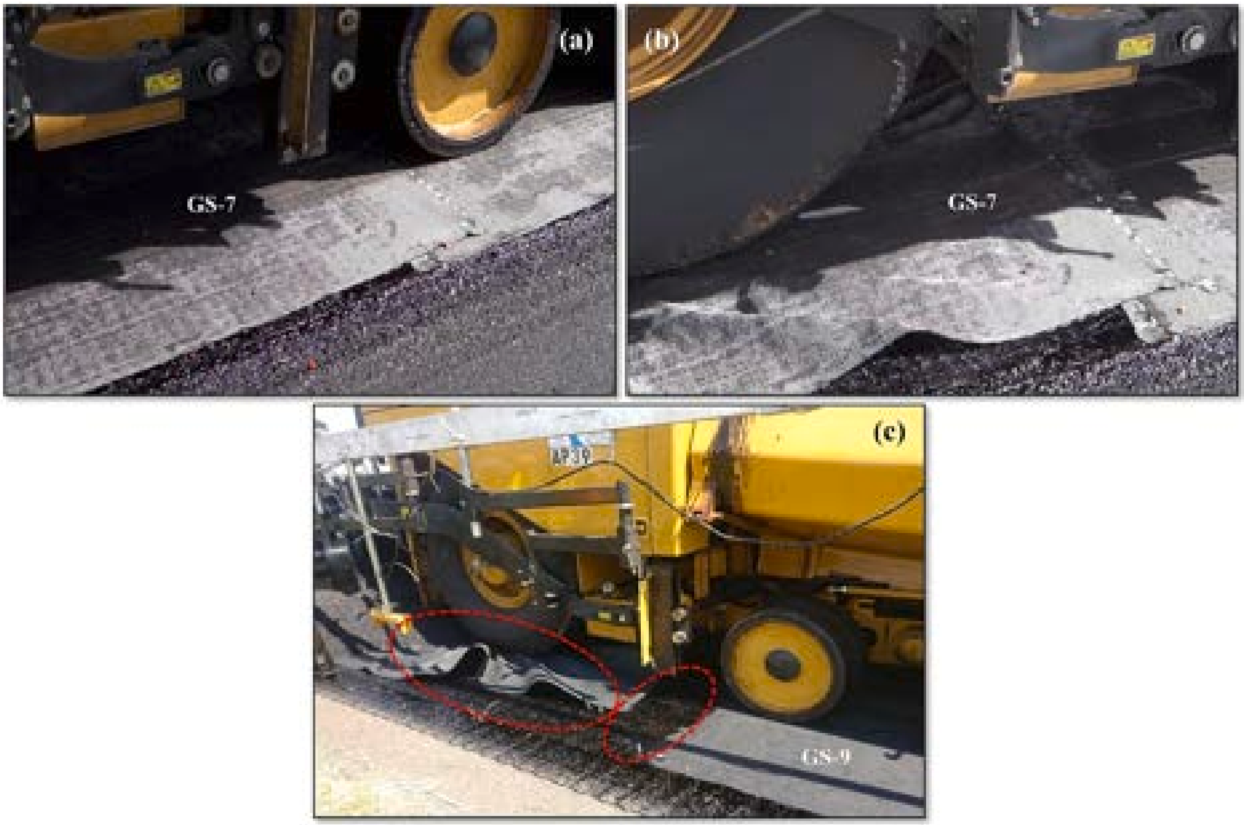

Fig. 19. Influence of grade and paver on geosynthetic overlap: (a) GS-7: before paver approaches the overlap (b) GS-7: after paver approaches the overlap; (c) GS-9: after paver approaches the overlap.

the overlap between the two rolls of the same geosynthetic product GS-9 is depicted in Fig. 19c. Learning from these observations, the solution adopted to increase friction and avoid possible damage to the geosynthetic interlayer was to lightly spread hot mix asphalt from the paver hopper along the paver wheel paths (Fig. 20a) and on the geosynthetic overlap (Fig. 20b). This mitigative measure is referred to herein as asphalt sanding and differs from the traditional use of sand, which is deemed undesirable for this purpose because it would absorb tack coat and compromise the expected performance of the geosynthetic. The adoption of asphalt sanding technique to restore the friction between paver wheels and the surface, was a spontaneous decision made by the research team, manufacturers' representatives, and the contractor during the construction process. Such decisions may seem essential to navigate through situations that were encountered during the construction of geosynthetic-reinforced overlay sections summarized in this study. Overall, asphalt sanding was very effective in restoring the friction between the paver and surface, thereby enhancing the efficiency of overlay construction without any damage to the geosynthetic interlayer.

Conclusions and Recommendations

This study discusses the installation of geosynthetic interlayers and construction of asphalt overlays in several experimental test sections along State Highway 21 in Texas, US. Specifically, the experimental test sections comprised of nine different types of geosynthetic interlayers that are widely incorporated during the asphalt overlay construction with an objective to mitigate reflective cracking. Hence, a comprehensive field evaluation involving the constructability as well as the performance evaluation of such experimental sections is particularly relevant. Specifically, to understand the various factors affecting successful geosynthetic installation and overlay construction. The experiences and lessons learned from this study is summarized below:

- The road closure activities employed during the rehabilitation of SH21 was particularly successful in accomplishing the objectives of overlay construction along with no significant disruptions in traffic patterns within the project limits. Additionally, future rehabilitation projects involving similar roadway profiles with undivided four-lane are recommended to adopt the road closure procedure described in this study.
- The tack coat types were adopted per TxDOT recommendations, while application rates were initially selected based on general geosynthetic manufacturers' recommendations. The particularly high temperature of the pre-existing asphalt surface resulted in blistering of geotextile backing and subsequently leading into an excessive bleeding of tack coat through the geosynthetic apertures. To overcome this issue, the tack coat application rates were adjusted (i.e., reduced) according to the manufacturers' recommendations for the site-specific conditions.
- The primary influencing factors on the tack coat type and application rate include the pre-existing surface conditions (e.g., hot, cold, milled, oxidized, level-up), geosynthetic type (e.g., paving geotextile, geogrid, geocomposite) and asphalt retention capacity of the geosynthetic interlayer. Hence, it is recommended that the tack coat type and application rates should be selected based on project-specific conditions including the pre-existing surface temperature and should not be prescribed based on typical recommendations.
- The geosynthetic installation procedures adopted in the experimental sections were proficient compared to the rest of the project. Additionally, examples of proper and poor geosynthetic installation techniques were demonstrated in this study to highlight that proper installation is critical in achieving the intended benefits (reinforcement function) from geosynthetic interlayers.
- An efficient and proper geosynthetic installation technique comprised a specialized installation equipment that is capable of pre-

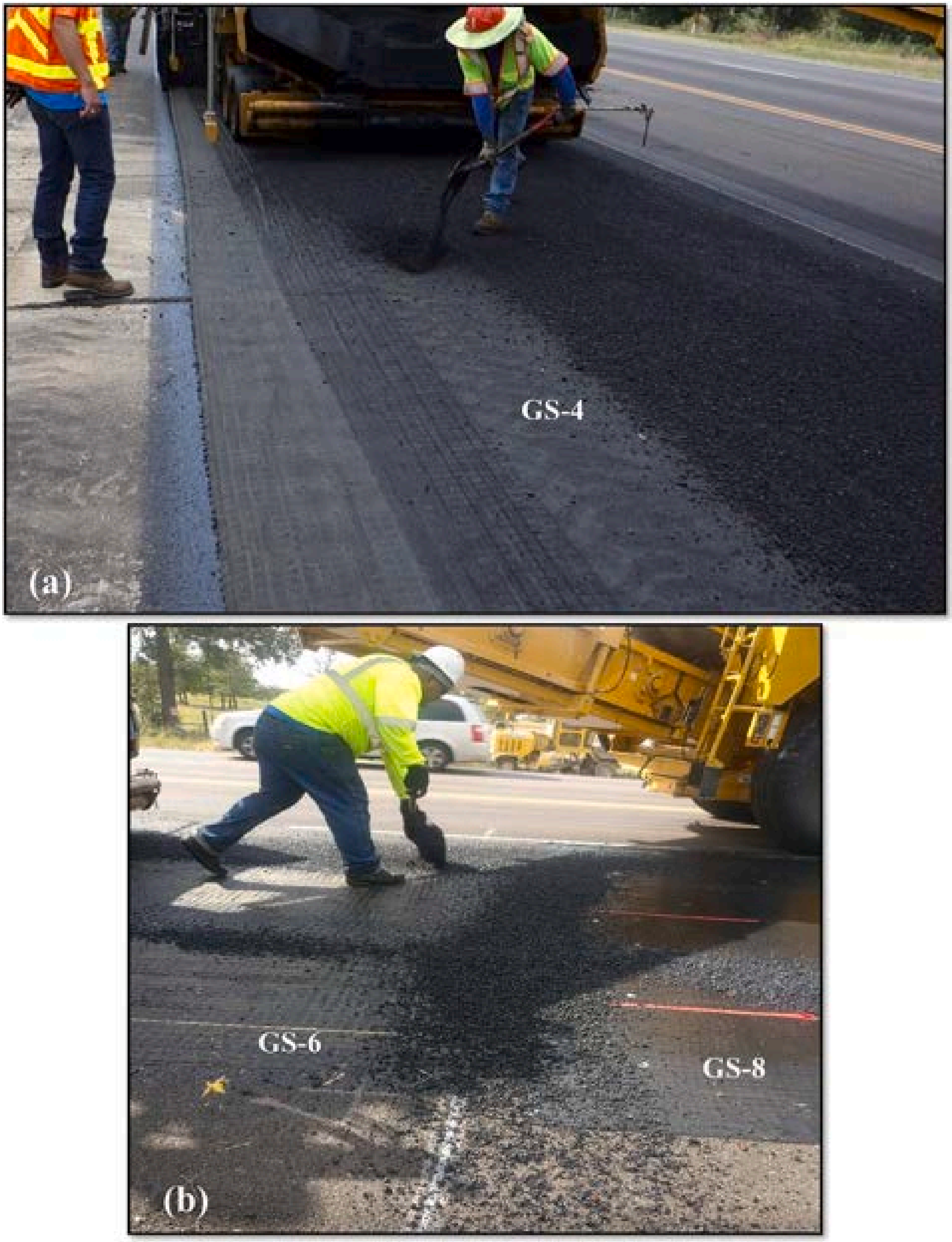

Fig. 20. Asphalt sanding: (a) uphill paver wheel path; and (b) geosynthetic overlap.

tensioning the geosynthetics during the installation to minimize wrinkles and irregularities that may compromise the intended performance of the geosynthetic reinforcement. Hence, it is recommended to adopt an efficient geosynthetic installation equipment to achieve the objectives expected from the geosynthetic interlayer installed during the asphalt construction.

- The asphalt retention capacity of a geosynthetic interlayer was confirmed to depend on the binder or emulsion type used, which may not necessarily be identical across different grades of binder or emulsions adopted as tack coats in asphalt construction. Hence, it is important to use a project-specific tack coat to determine the asphalt retention capacity of the geosynthetic interlayer to be used in a given project.
- An additional side effect of excessive tack coat bleeding through the geosynthetic apertures is the tracking of construction equipment wheels, which may compromise the tensile properties of geosynthetic interlayers. Arrangement and movement of construction equipment (i.e., asphalt trucks, MTV, paver) on top of the geosynthetic reinforcement should be carefully designed based on a project's roadway plan and profile. As a general rule, movement of construction and paving equipment on the geosynthetic should be limited to minimize possible damage to geosynthetics during construction. It is also recommended that installation and construction damage factors be included in the technical data sheets of geosynthetic products.
- Asphalt sanding technique adopted herein to overcome the effects of grade and paver on geosynthetic interlayers, was found to be particularly effective in restoring the friction between the paver and surface, and enhanced the efficiency of overlay construction without damaging the geosynthetic reinforcement. This corrective measure can be adopted in future geosynthetic-reinforced overlay construction operations.
- Among the different geosynthetic interlayers adopted in this study, it was determined that the interlayers that had a full coverage (i.e., geocomposite, paving mat) did not encounter significant complications during the construction of geosynthetic-reinforced asphalt overlay sections. While, it is also important to highlight some minor complications were encountered in the case of geogrids and geocomposite products with thin backing.

Overall, the lessons learned from this project underscore that achieving the desired performance from the geosynthetic reinforcement of asphalt overlays requires not only a suitable geosynthetic product but also proper installation procedures. A proper geosynthetic installation and overlay construction technique is often governed by multiple factors, including the pre-existing surface temperature, tack coat type and application rate, material composition, physical properties and asphalt retention capacity of the geosynthetic reinforcement, and the overlay construction equipment and process.

The authors currently analyze and interpret the data recorded by the installed sensors in various test sections and will present sensor installation protocols and related findings in their upcoming publications. Preliminary results have been presented and discussed by Kumar et al. [17].

CRediT authorship contribution statement

V. Vinay Kumar: Conceptualization, Methodology, Investigation, Resources, Visualization, Writing – original draft, Project administration. **Gholam H. Roodi:** Conceptualization, Methodology, Visualization, Writing – review & editing. **S. Subramanian:** Conceptualization, Formal analysis. **Jorge G. Zornberg:** Visualization, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

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

Data availability

No data was used for the research described in the article.

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