International Symposium on Geosynthetics and Sustainability
Environmental, Civil and Hydraulic Engineering

NGO
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Sustainability Benefits of Geosynthetics in Roadway Applications

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INTERNATIONAL GEOSYNTHETICS SOCIETY

• International Symposium on Geosynthetics and Sustainability •
• Technical University (TU) Delft • The Netherlands • 14 May 2024 •

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Worldwide Roadway Network

World roads:
64,285,009 km

Circumference of the earth:
40,075 km

 # rounds: 1,604

	Country	Total Length	Density	Paved		Year
		(km)	(km/100 km2)	(km)		
1	United States	6,832,000	69	5,124,000	75%	2023
2	India	6,700,000	204	4,500,000	67%	2023
3	China	5,200,000	54	4,578,000	88%	2022
4	Brazil	2,000,000	23	214,000	11%	2023
5	Russia	1,538,875	9	677,105	44%	2019
6	Japan	1,218,772	322	992,835	81%	2021
7	France	1,053,215	191	1,053,215	100%	2011
8	Canada	1,042,300	10	415,600	40%	2014
9	Australia	873,573	11	145,928	17%	2015
10	Mexico	817,596	42	175,526	21%	2020
11	South Africa	750,000	61	158,124	21%	2016
12	Thailand	702,989	137	—		2020
13	Spain	683,175	135	683,175	100%	2011
14	Germany	644,480	180	644,480	100%	2020
15	Sweden	573,134	127	140,100	24%	2016
16	Vietnam	570,448	172	148,338	26%	2019
17	Indonesia	544,474	28	283,102	52%	2019
18	Italy	487,700	162	487,700	100%	2007
19	Finland	454,000	135	78,000	17%	2019
20	Turkey	438,633	56	29,178	7%	2023
21	United Kingdom	424,129	175	424,129	100%	2020
22	Poland	423,997	136	291,000	69%	2022
23	Bangladesh	369,105	250	110,311	30%	2018
24	Argentina	281,290	10	117,616	42%	2017
25	Pakistan	263,775	30	185,063	70%	2022
26	Malaysia	238,823	72	116,169	49%	2016
27	Iran	223,485	14	195,485	87%	2018
28	Saudi Arabia	221,372	10	47,529	21%	2006
29	Philippines	216,387	72	61,093	28%	2020
30	Hungary	210,791	227	77,087	37%	2018
31	Uzbekistan	209,496	47	120,289	57%	2021
32	Colombia	204,389	18	32,280	16%	2021

Source: CIA World Factbook

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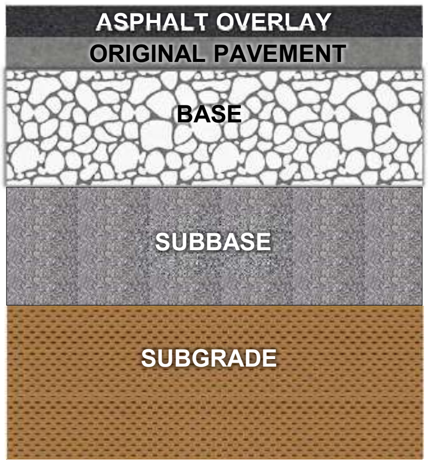
Geosynthetics in Roadway Applications



Zornberg (2017)

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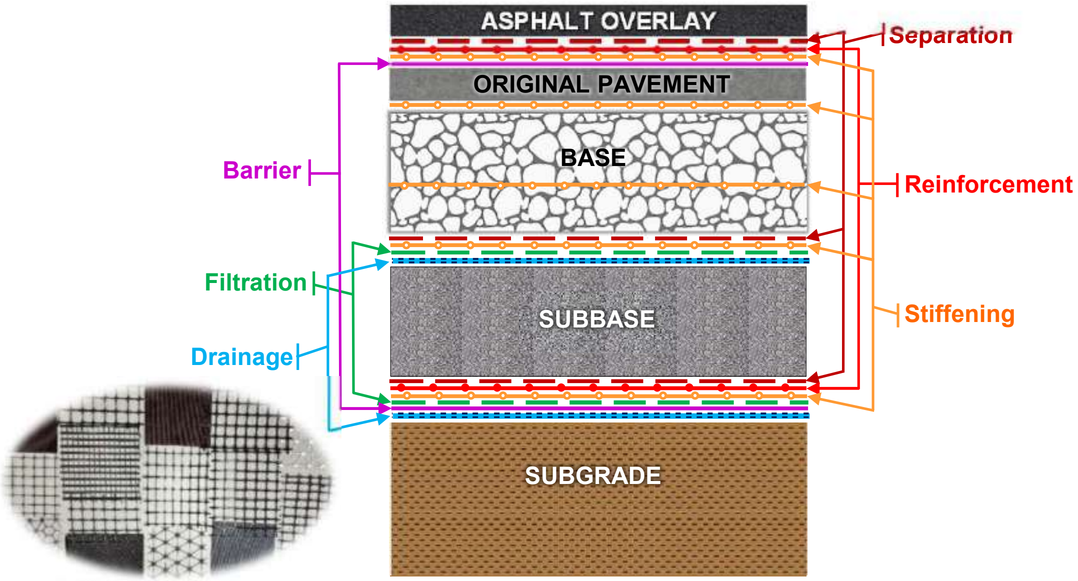
Geosynthetics in Roadway Applications



Zornberg (2017)

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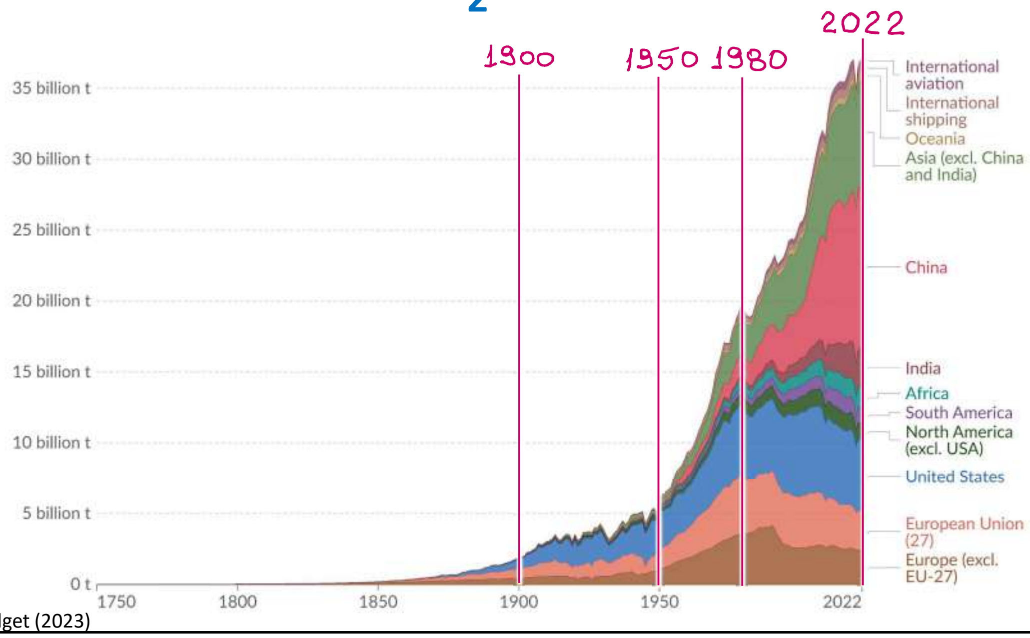
Annual CO_2 Emissions



Source:
Global Carbon Budget (2023)

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Sustainability Evaluation in this Study

- Six different applications involving geosynthetics in roadways were evaluated:
  1. Mitigation of reflective cracking in structural asphalt overlays
  2. Stabilization of unbound aggregate layers
  3. Reduction of layer intermixing
  4. Reduction of moisture in structural layers
  5. Stabilization of soft subgrades
  6. Mitigation of distress due to shrink/swell subgrades
- For each application, a case history was identified for which two design alternatives (with and without geosynthetics), deemed technically equivalent, had been considered
- Sustainability benefits were evaluated by conducting carbon audits and quantifying the differences in tCO_2e per lane-km

Zornberg, J.G., Subramaniam, S., Roodi, G.H., Yalcin, Y., and Kumar, V.V. (2024). "Sustainability Benefits of Adopting Geosynthetics in Roadway Design." *International Journal of Geosynthetics and Ground Engineering*, Springer (in press).

International Journal of Geosynthetics and Ground Engineering (2024) 10:47
https://doi.org/10.1007/s40891-024-00551-5

ORIGINAL PAPER

Sustainability Benefits of Adopting Geosynthetics in Roadway Design

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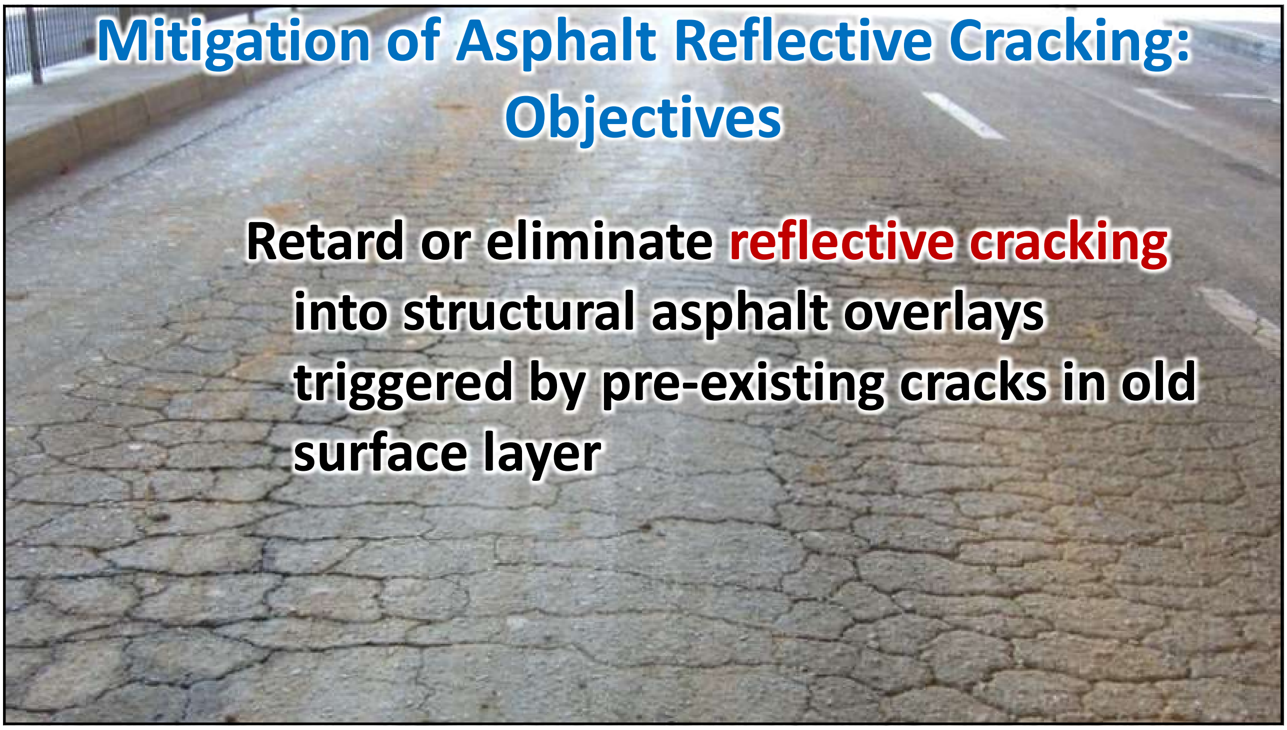
Received: 17 January 2024 / Accepted: 13 April 2024

Abstract
The world's roadway system is so extensive that its total length would encircle the Earth over 1,600 times if combined. Geosynthetics have provided sustainable alternatives in roadway projects, representing a significant portion of the total usage of geosynthetics in civil infrastructure. Yet, considering the significant extension of roadway projects worldwide, geosynthetic products are only utilized in a small fraction of them. Consequently, the opportunities to achieve sustainability goals by making more extensive use of geosynthetics in roadways are massive. The objective of this paper is to illustrate the sustainability benefits of adopting geosynthetics in roadway design. This is accomplished by quantifying the carbon footprint for six roadway projects, each involving at least two alternative designs: One with and the other without using geosynthetics. Each roadway project involved one of six different applications involving the use of geosynthetics. Specifically, they involved the use of geosynthetics to (1) mitigate reflective cracking in structural asphalt overlays, (2) stabilize unbound aggregate layers, (3) reduce layer intermixing, (4) reduce moisture in structural layers, (5) stabilize soft subgrades, and (6) mitigate distresses caused by expansive clay subgrades. The sustainability benefits were quantified by conducting carbon audits for the alternative designs for each roadway project. The results of the analyses indicate that the design alternatives involving geosynthetics always proved more sustainable than the conventional (without geosynthetics) alternatives, resulting in savings in the total carbon footprint that ranged from 16.3 to 44.44 tCO_2e per lane-km (or 11.6 to 50.11% decreased footprint in relation to conventional design alternatives). Overall, while the rationale for adopting geosynthetics in different roadway applications has generally focused on the benefits that they offer to improve the project's performance or reduce its costs, the evaluations in this study reveal that an additional reason to adopt geosynthetic solutions in roadway applications is their potential to provide significant sustainability benefits.



Mitigation of Asphalt Reflective Cracking: Objectives

Retard or eliminate **reflective cracking** into structural asphalt overlays triggered by pre-existing cracks in old surface layer

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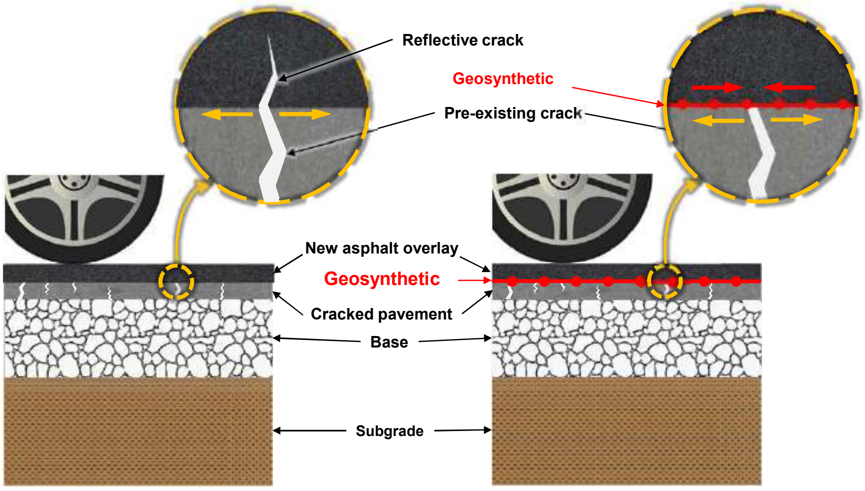
Mitigation of Asphalt Reflective Cracking: Tension Development Mechanism



Source: Zornberg (2017)

Overlay without Geosynthetic | Overlay with Geosynthetic

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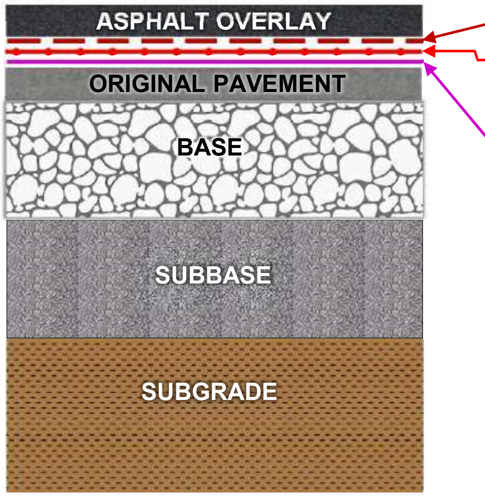
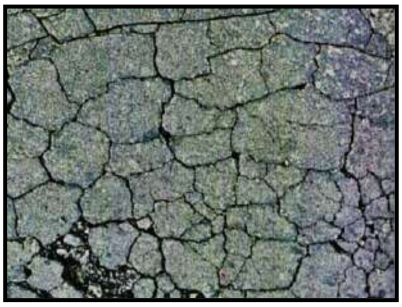
Mitigation of Reflective Cracking in Structural Asphalt Overlays: GS Functions





Source: Zornberg (2017a)

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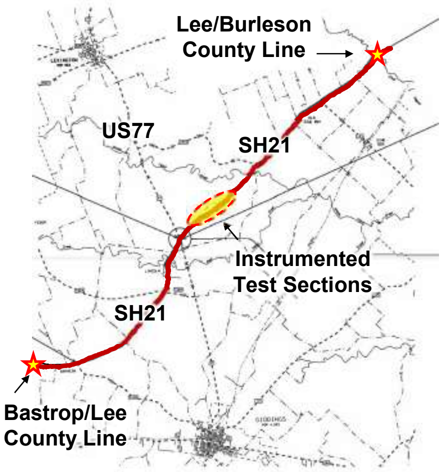
CH1: SH21, Lee County, Texas

- Mitigation of Asphalt Reflective Cracking -

- **Retrofitting a highway serving the energy sector**
  - Project length is about 18 miles, with 2 lanes in each direction
  - Pre-existing roadway sections included an original, 152-mm-thick, distressed and oxidized asphalt layer underlain by base and subbase layers with a total thickness of 381 mm
- **The challenge: Minimize reflective cracking**
  - Reflective cracking expected to be triggered by pre-existing cracks
  - Quantify additional structural capacity



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CH1: Design Alternatives

Design Requirements:

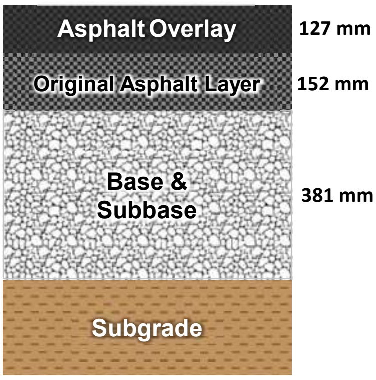
- Mitigate reflective cracking triggered by the presence of cracks in the original asphalt layer
- Evaluate possible increase in structural capacity by asphalt reinforcement

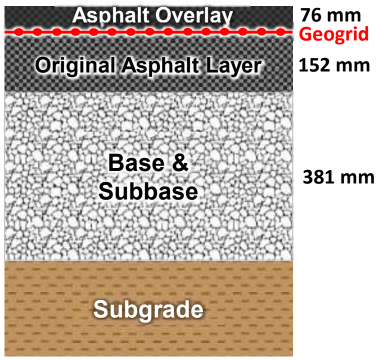
Design using GS:

- Geogrid-reinforced overlay
- The adopted product was a polymeric geogrid

Conventional Design:

- No geosynthetic
- Protection against reflective cracking by an asphalt overlay of increased thickness





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CH1: Construction

Construction involved:

- Application of binder tack coat
- Installation of polymeric geosynthetic reinforcement
- Construction of a thinner HMA overlay

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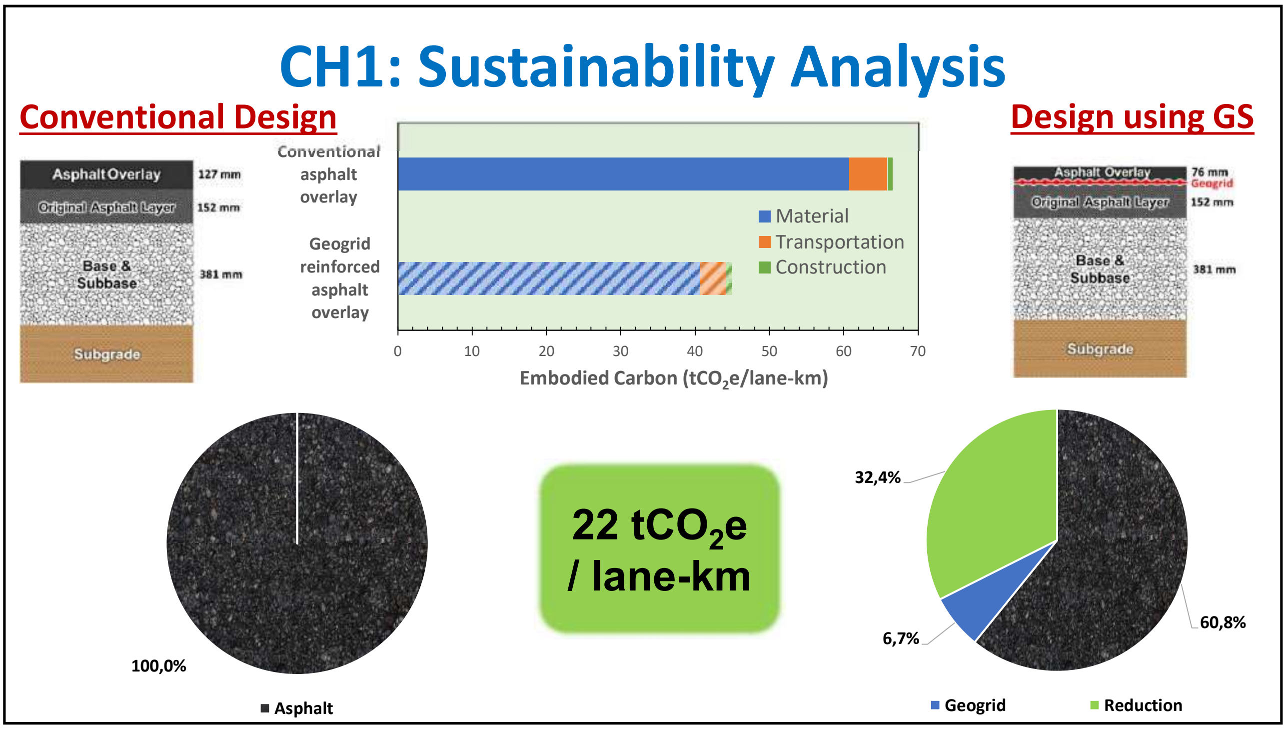
CH1: Sustainability Analysis
Conventional Design
Design using GS
Asphalt Overlay
Original Asphalt Layer
Base & Subbase
Subgrade
127 mm
152 mm
381 mm
76 mm
Geogrid
Conventional asphalt overlay
Geogrid reinforced asphalt overlay
Material
Transportation
Construction
0
10
20
30
40
50
60
70
Embodied Carbon (tCO2e/lane-km)
22 tCO2e / lane-km
100,0%
Asphalt
32,4%
6,7%
60,8%
Geogrid
Reduction

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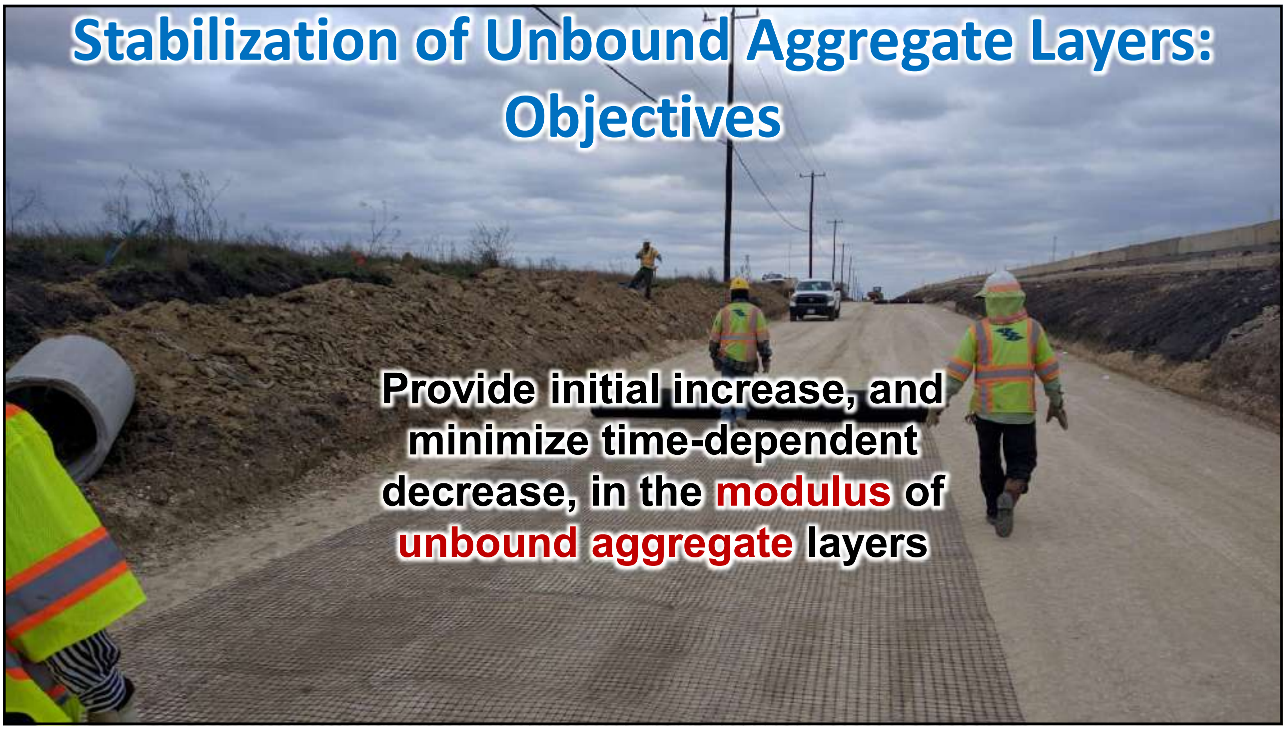
Stabilization of Unbound Aggregate Layers: Objectives
Provide initial increase, and minimize time-dependent decrease, in the modulus of unbound aggregate layers

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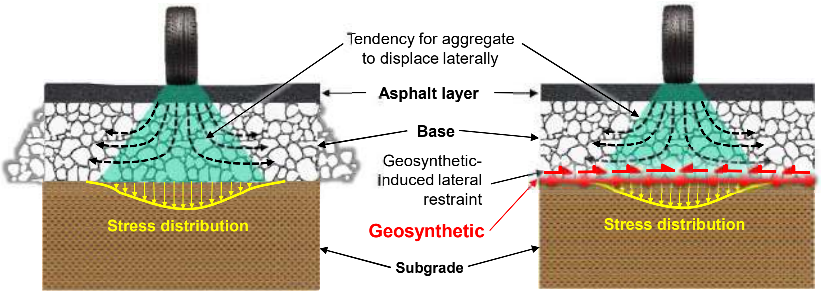
Stabilization of Unbound Aggregate Layers: Mechanisms



Non-stabilized Road Base

Stabilized Road Base

Source: Zornberg (2017b)

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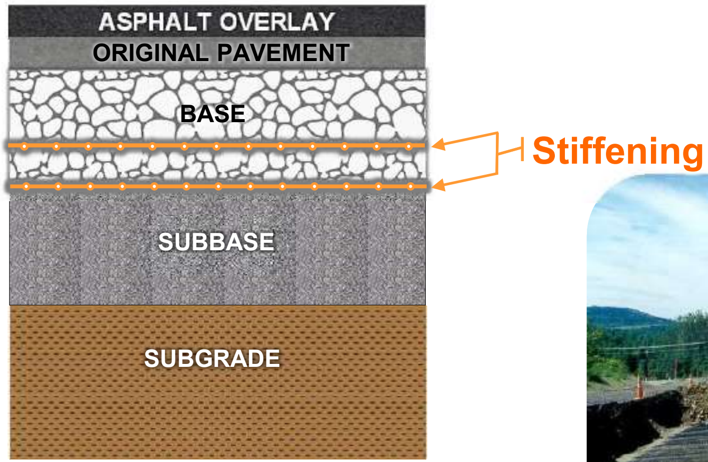
Stabilization of Unbound Aggregate Layers: GS Functions



Source: Zornberg (2017b)

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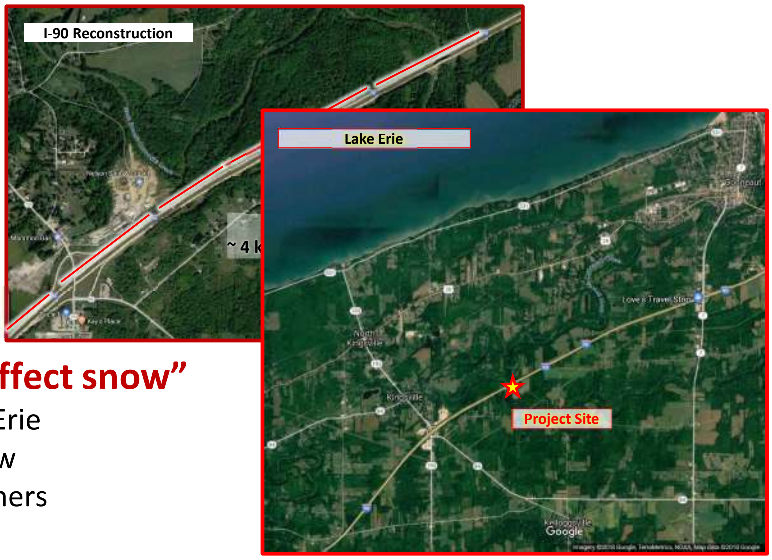
CH2: I90, Ashtabula, OH, USA

- Stabilization of Unbound Aggregates -

- **Reconstruction of Interstate Highway 90**
  - Length ~ 4 km (2.5 miles)
  - 2 lanes in each direction
  - Total width of 39’
  - Replacement of ramps and a bridge



- **The challenge: “Lake-effect snow”**
  - Due to proximity to Lake Erie
  - Short construction window
  - Construction over 3 summers

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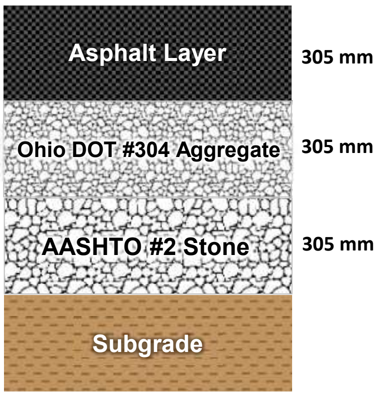
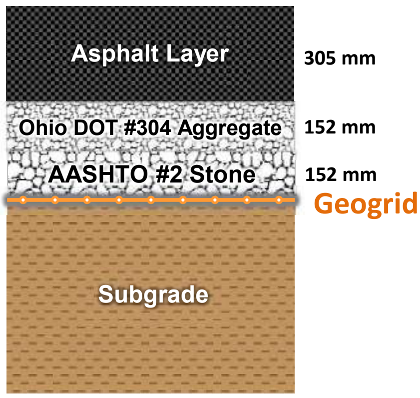
CH2: Design Alternatives

Design Requirements:
- Remove the old pavement and a thick subgrade layer
- Replace with high quality material

Design using GS:
- Geosynthetic-stabilized base
- Excavation reduced to 600 mm
- Base thickness reduced in half

Conventional Design:
- No geosynthetic
- 900 mm excavation





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CH2: Construction

- Adopted final design involved a **geosynthetic-stabilized** base
- Quantity of **base material** was reduced in half
- **Construction time** was reduced from 3 initially predicted summers to 2

Pictures Courtesy: Mike Clements

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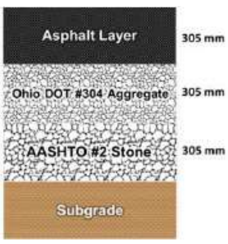
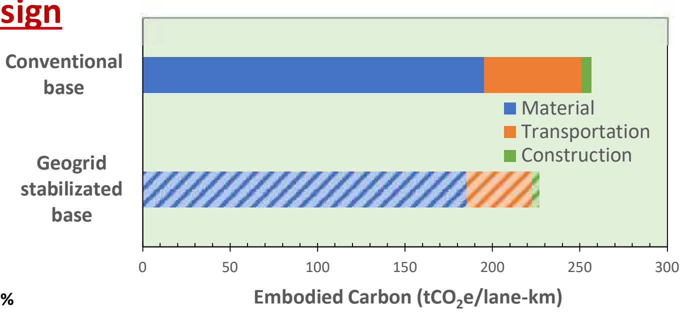
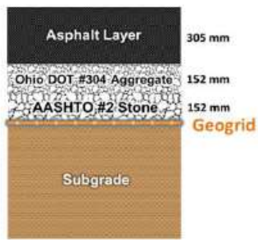
CH2: Sustainability Analysis

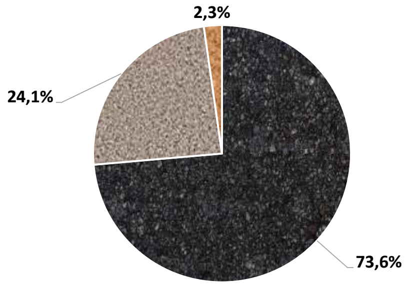
Conventional Design



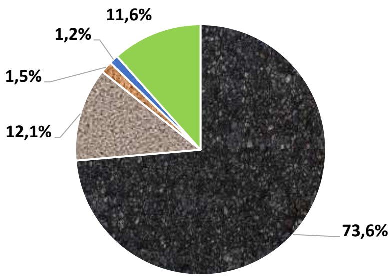


Design using GS





30 tCO_2e / lane-km



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Reduction of Layer Intermixing: Objective

Avoid **contamination** of unbound aggregate layers with fine-grained subgrade soil particles

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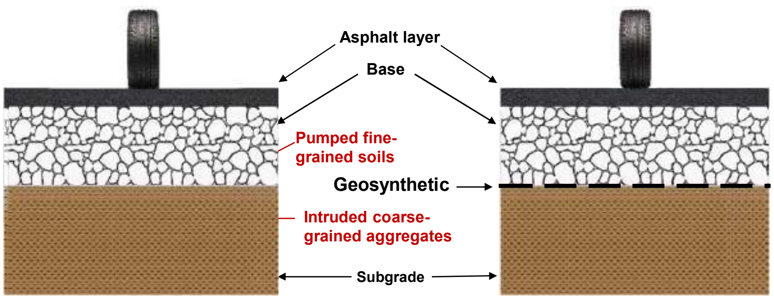
Reduction of Layer Intermixing: Mechanisms



Road without Geosynthetic Separator

Road with Geosynthetic Separator

Source: Zornberg (2017)

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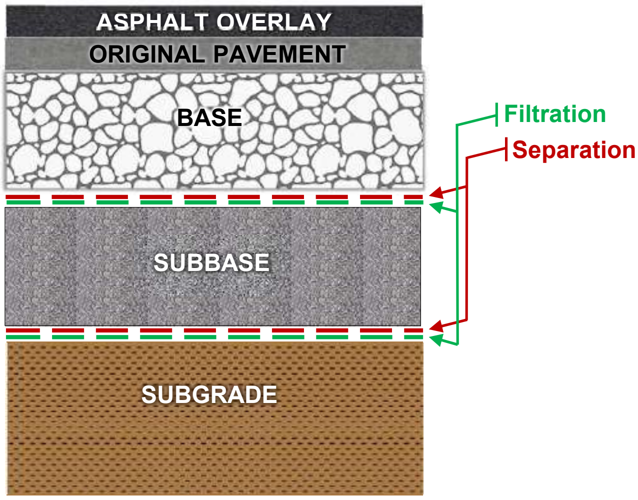
Reduction of Layer Intermixing: GS Functions



Source: Zornberg (2017)

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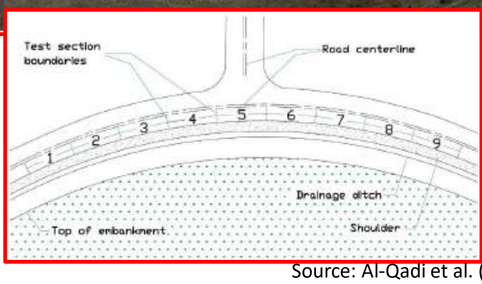
CH3: Bedford County, Virginia

- Reduction of Layer Intermixing -

- **Full-scale test sections**
  - Road sections involved:
    - Different **base course thickness**
    - Different **geosynthetic type**
  - Test sections were 15 m long
  - Subgrade: ML & CH, A-7-6
  - A "Class 3" geotextile was used
- **The challenge: Quantify benefits of geotextile separators**
  - Low volume road
  - Differences in maintenance costs



Source: Al-Qadi et al. (1997)

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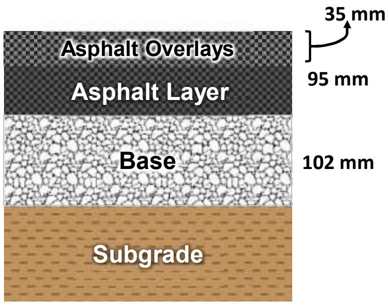
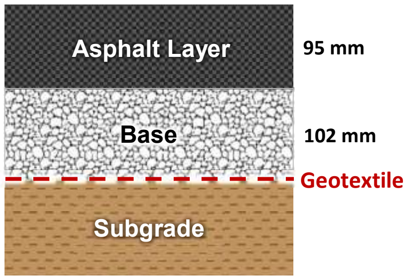
CH3: Design Alternatives

Design Requirements:
- Estimate service life based on the equivalent single axle load (ESAL) corresponding to a rutting depth of 20 mm

Design using GS:
- Geotextile Class 3
- CBR ranging from 6 to 10%
- Did not require asphalt overlays over design life

Conventional Design:
- No geosynthetic
- CBR ranging from 6 to 10%
- Required two overlays over design life





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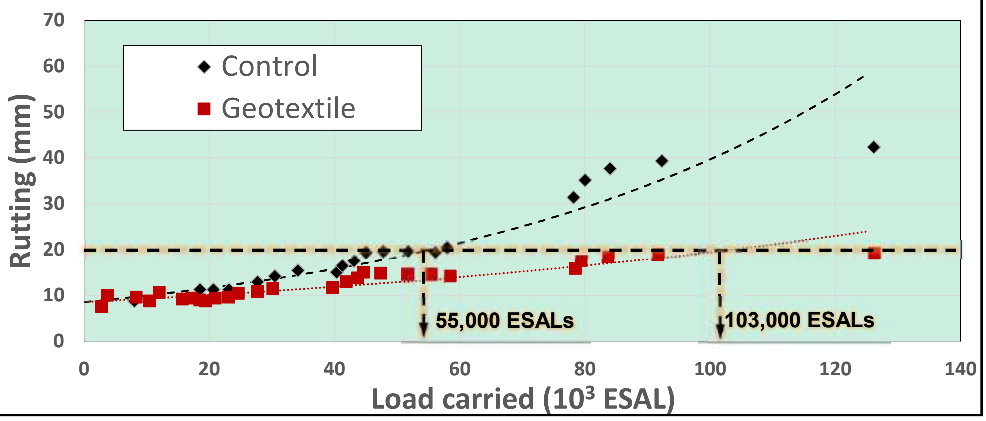
CH3: Quantification of Performance

- Serviceability requirements: 20 mm rutting depth
- Service life: 100,000 ESALs
- Rehabilitation period: 50% of virgin period

Section	Service life (yr.)	ESALs	No. of Rehabilitations in Design Life
1	4.0	55,161	2
2	7.5	102,923	0



Source:
Al-Qadi and Appea (2003)

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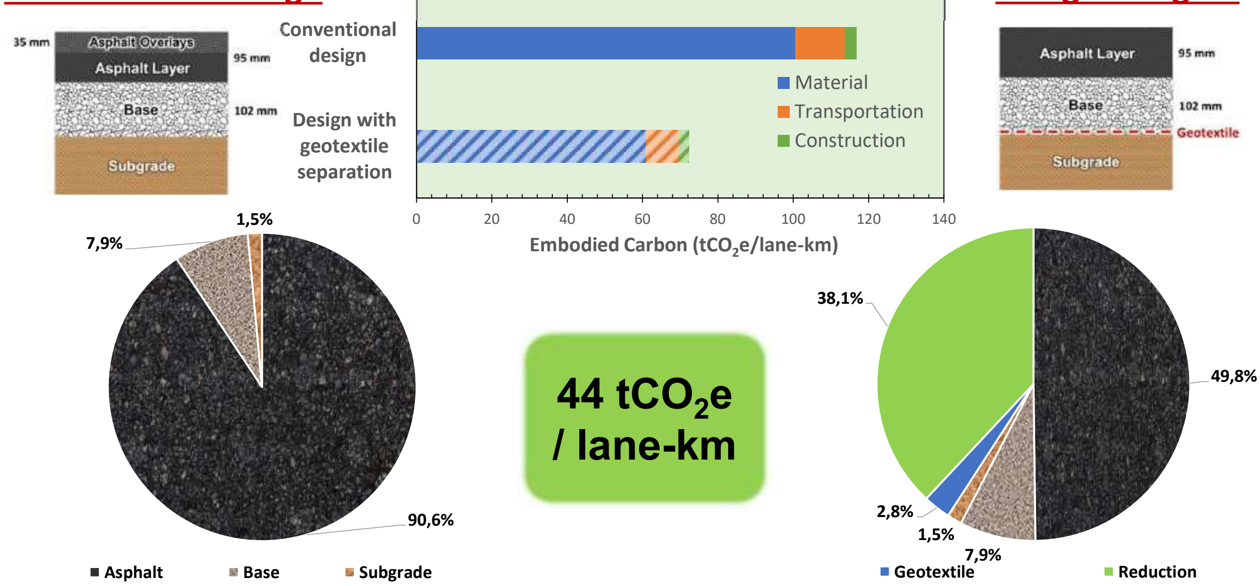
CH3: Sustainability Analysis (Cont.)

Conventional Design | **Design using GS**



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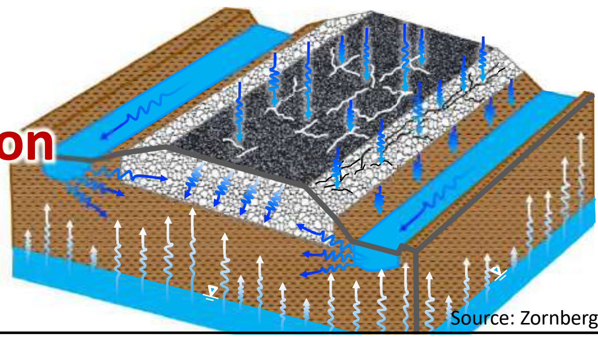
Reduction of Moisture in Structural Layers: Objectives

Provide in-plane drainage to minimize access and accumulation of moisture within structural layers



Source: Zornberg et al. (2016)

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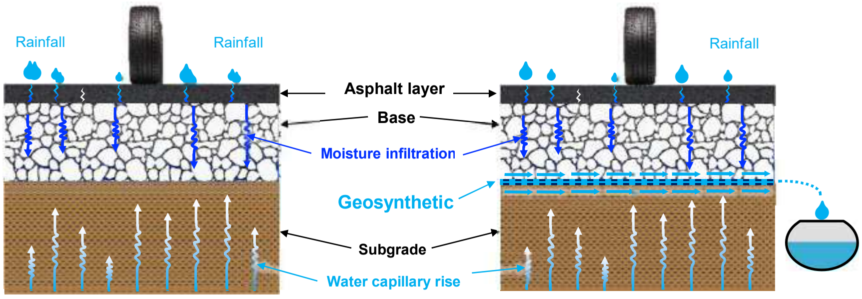
Moisture Reduction: Mechanisms



Road without Lateral Drainage

Road with Lateral Drainage

Source: Zornberg *et al.* (2017b)

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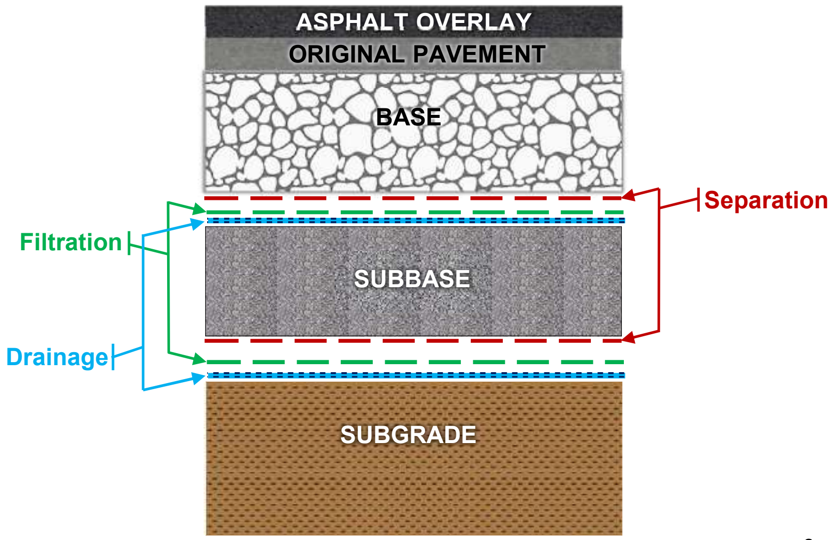
Moisture Reduction: GS Functions



Source: Zornberg *et al.* (2017a)

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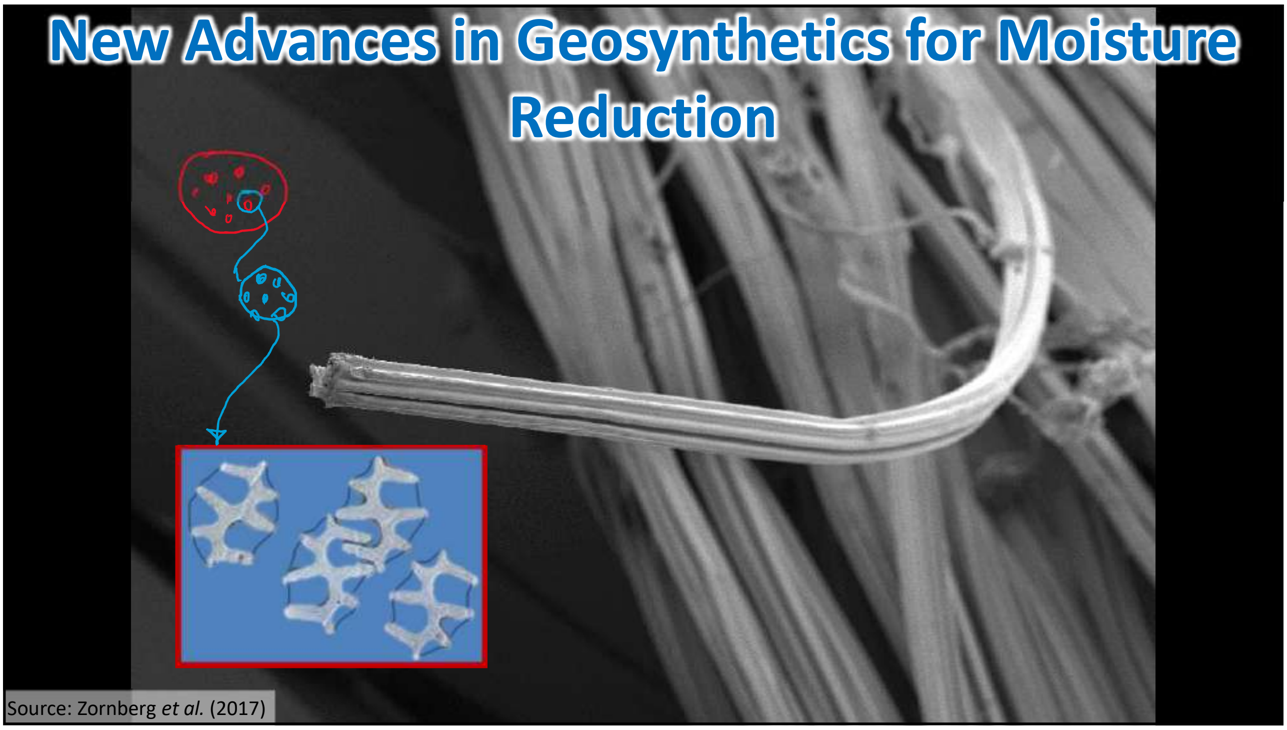
New Advances in Geosynthetics for Moisture Reduction



Source: Zornberg *et al.* (2017)

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CH4: Daniel Boone Bridge, St. Louis, USA

- Moisture Reduction -

- **Reconstruction of Daniel Boone Bridge**
  - In Interstate 64
  - Two original bridges:
    - 1935 bridge deteriorated beyond repair
    - 1980's bridge could not meet demand
- **The challenge: Stringent drainage requirements**
  - Site was characterized by a **high water table**
  - Good drainage needed for **approaching roadways** to minimize pavement distress

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CH4: Design Alternatives

Design Requirements:

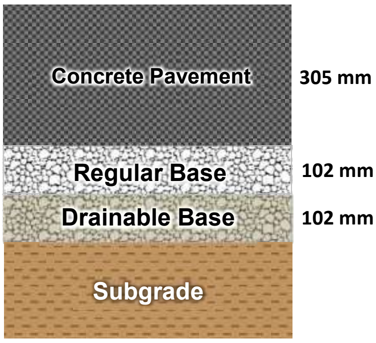
- Provide good drainage due to high water table scenario
- Minimize thickness of "Drainable Base," which was costly

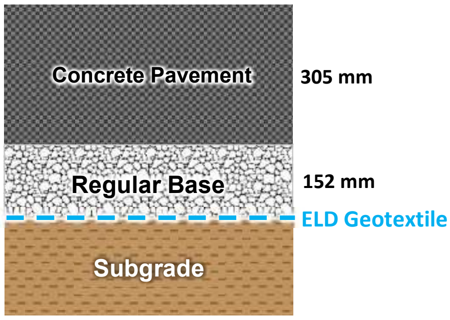
Design using GS:

- Enhanced Lateral Drainage (ELD) geotextile
- 51 mm reduction in base course thickness
- Geotextile also provides separation and stabilization

Conventional Design:

- No geosynthetic
- Includes "Drainable Base" ($40/ton) in addition to regular aggregate ($12/ton)





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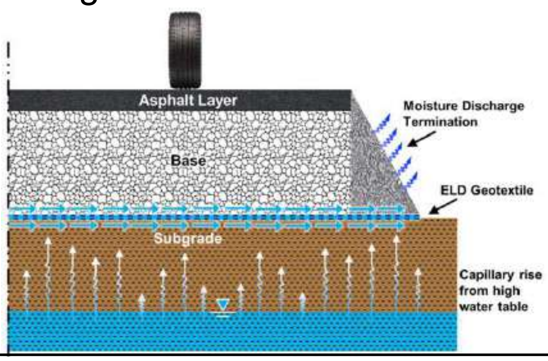
CH4: Drainage Layer Placement

- Adopted final design involved a **"wicking geotextile"** for internal drainage
- Moisture migrating upward from high water table is drained laterally



Source: Zornberg et al. (2017)

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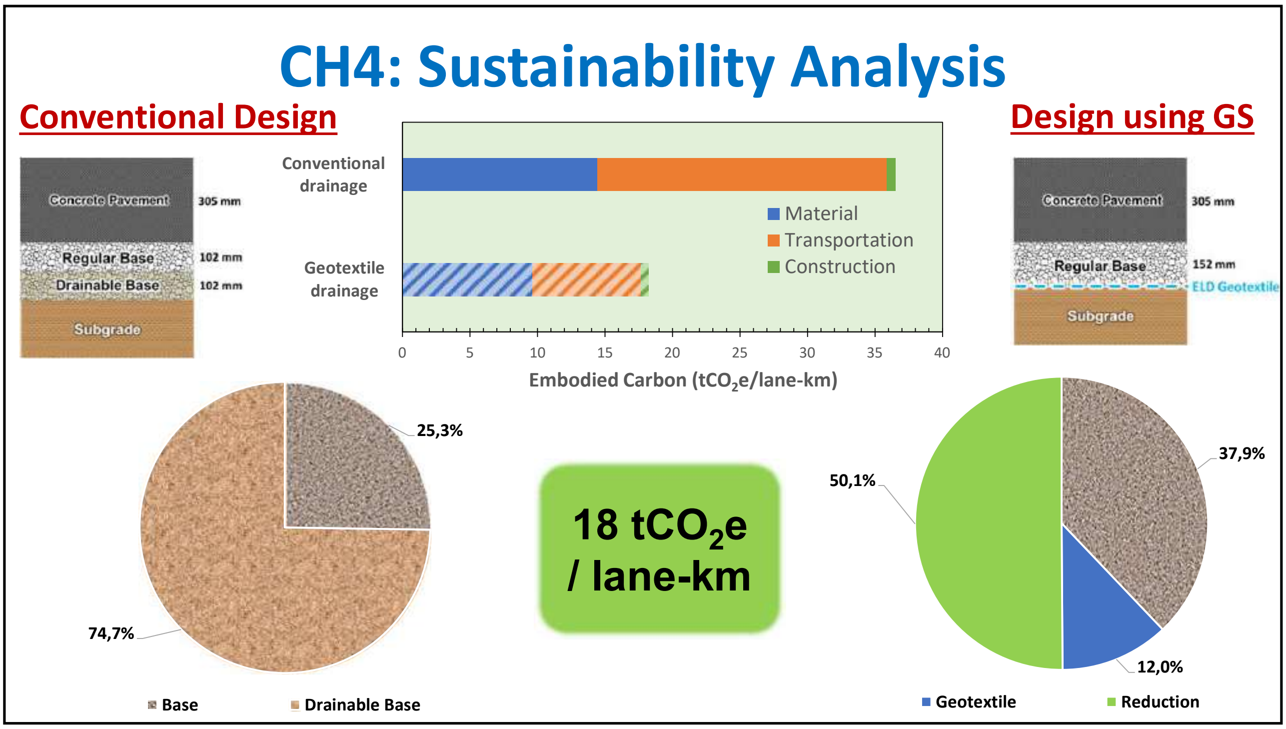
CH4: Sustainability Analysis
Conventional Design
Design using GS
Concrete Pavement
305 mm
Regular Base
102 mm
Drainable Base
102 mm
Subgrade
Conventional drainage
Geotextile drainage
Material
Transportation
Construction
0
5
10
15
20
25
30
35
40
Embodied Carbon (tCO_2e/lane-km)
Concrete Pavement
305 mm
Regular Base
152 mm
ELD Geotextile
Subgrade
25,3%
74,7%
Base
Drainable Base
18 tCO_2e / lane-km
50,1%
37,9%
12,0%
Geotextile
Reduction

37


Subgrade Stabilization: Objective
Increase the bearing capacity of soft subgrade soils
Source: Geosynthetic Institute (GSI)

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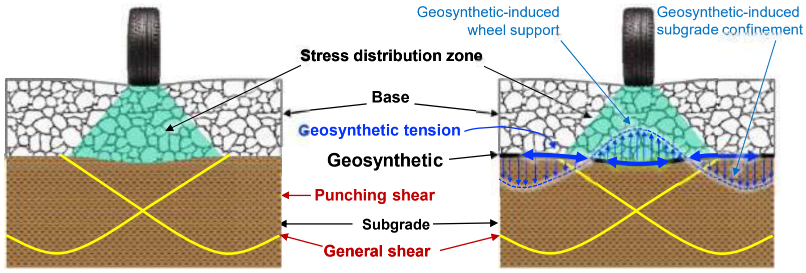
Subgrade Stabilization: Mechanisms



Non-stabilized Road Subgrade

Stabilized Road Subgrade

Source: Zornberg (2017)

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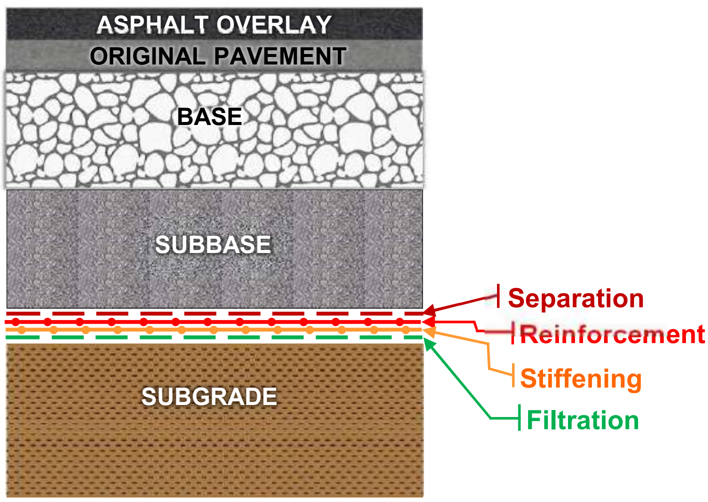
Subgrade Stabilization: GS Functions



Source: Zornberg (2017)

40

CH5: International Airport, Mexico City

- Subgrade Stabilization -

- **Construction of the International Airport, Mexico City**
  - Construction activities took place over the former **Lake Texcoco**
  - Highly compressible, soft clay
  - **MC ranging from 300 to 400%**
- **The challenge: Extremely soft foundation soils**
  - **Over 1 m-settlements** have been predicted
  - Water is saltier than seawater

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CH5: Design Alternatives

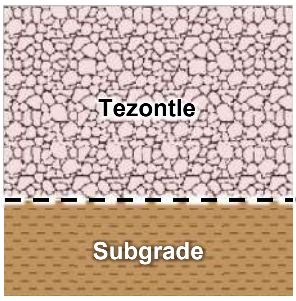
Design Requirements:

- The project should accommodate the use of Tezontle (a volcanic rock) in construction
- Project requires 48.3 km of internal roads

Tezontle

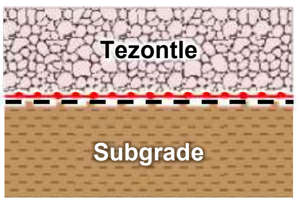
Conventional Design:

- No geosynthetic for stabilization
- Geotextile separator



Design using GS:

- Geosynthetic-stabilized subgrade
- Granular material was reduced by 500 mm
- Geotextile separator



Source: Zornberg et al. (2018)

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CH5: Construction

- **1,147 hectares** required improvement for construction
- In spite of problematic soils, construction progressed smoothly
- **Large quantities** of geosynthetics:

Geosynthetic type	Quantity used (m²)
Geogrids	7,717,800
Geotextiles	10,649,434
Geomembranes	213,952
Total	**18,581,186**

Pictures Courtesy: Lizeth Vergara

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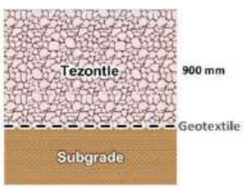
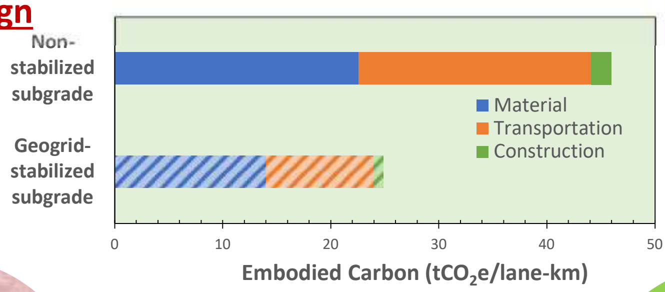
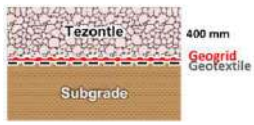
CH5: Sustainability Analysis

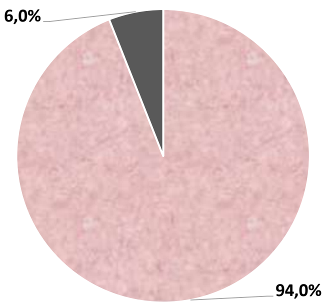
Conventional Design



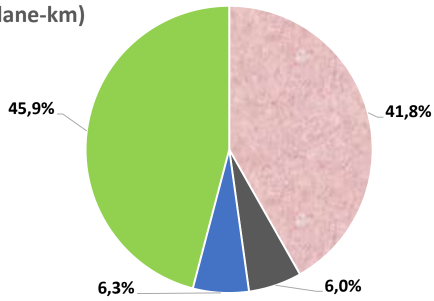


Design using GS





21 tCO_2e / lane-km



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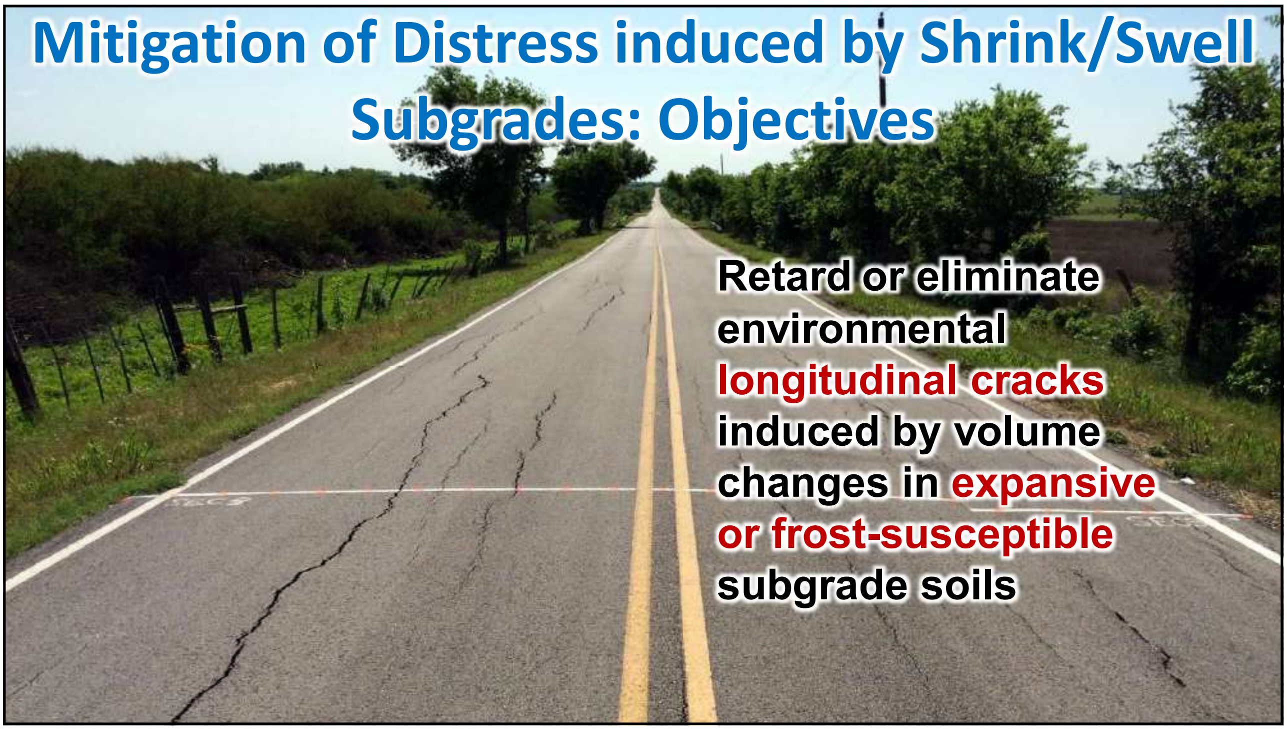
Mitigation of Distress induced by Shrink/Swell Subgrades: Objectives



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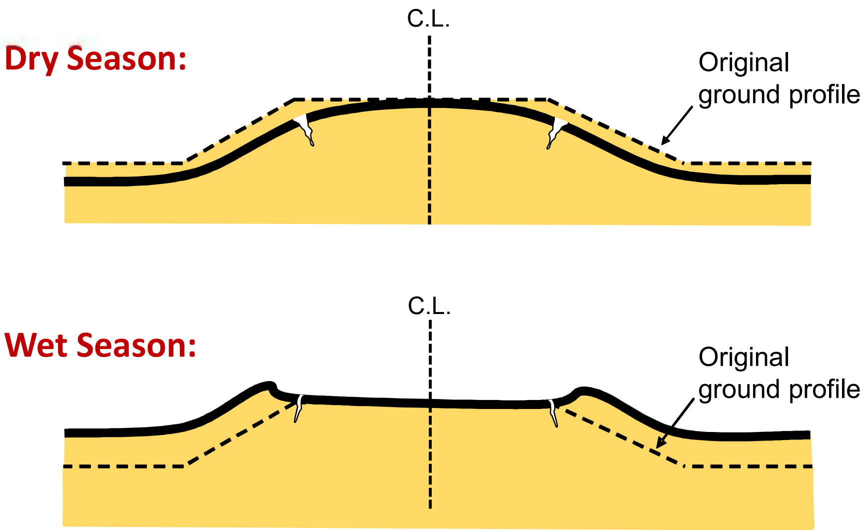
Understanding an Old Problem: Roadways over Expansive Clay Subgrades



Zornberg and Roodi (2021)

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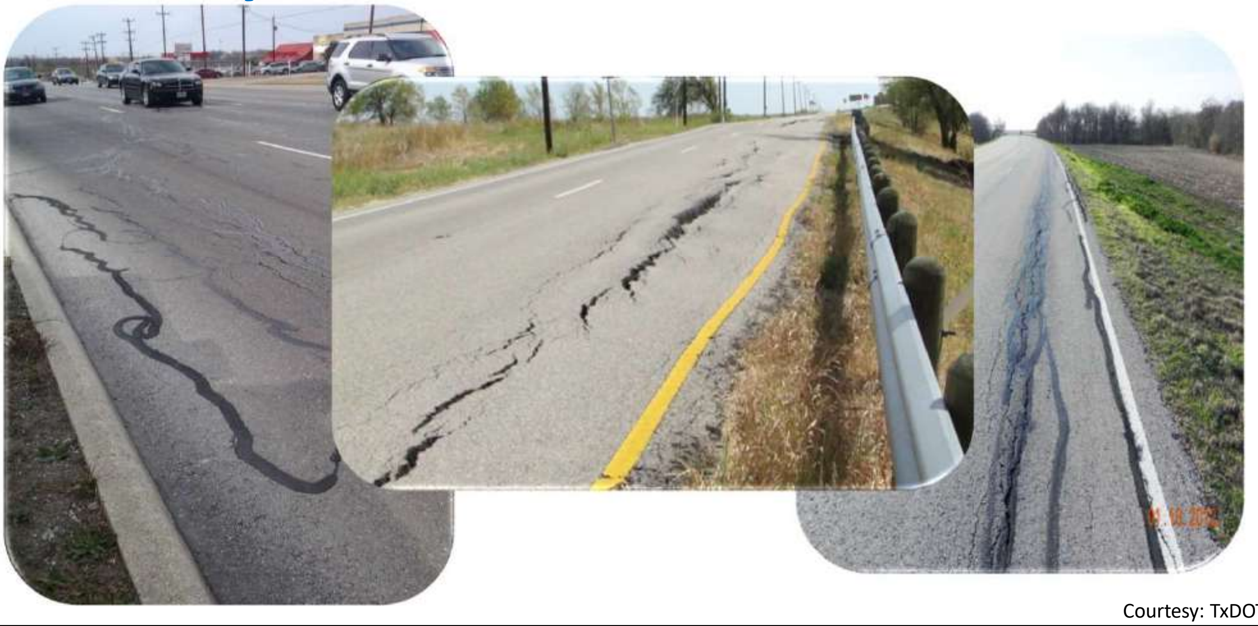
Roadway Distress due to Environmental Loads



Courtesy: TxDOT

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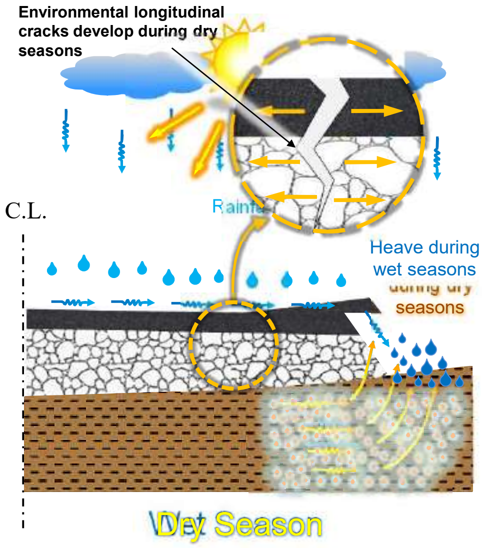
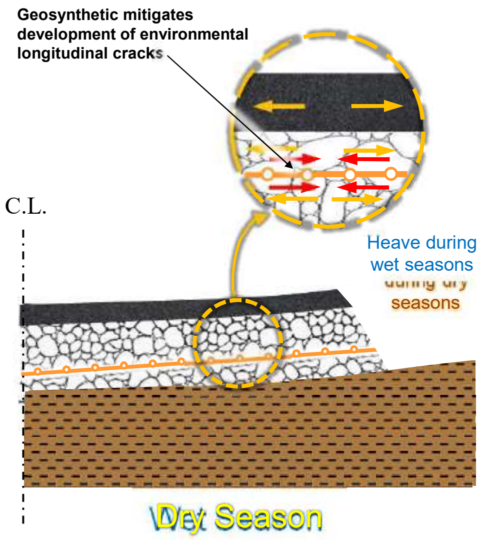
Geosynthetics for Roads on Shrink/Swell Subgrades

Non-Stabilized Roadway



GS-Stabilized Roadway



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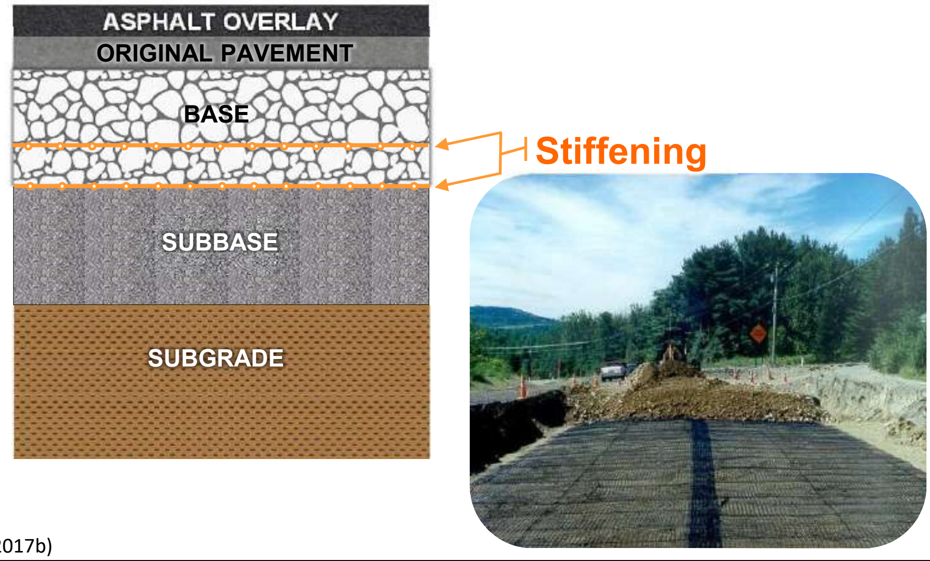
Mitigation of Distress Due to Shrink/Swell Subgrades (by Maintaining Integrity of Unbound Aggregates): GS Functions



Source: Zornberg (2017b)

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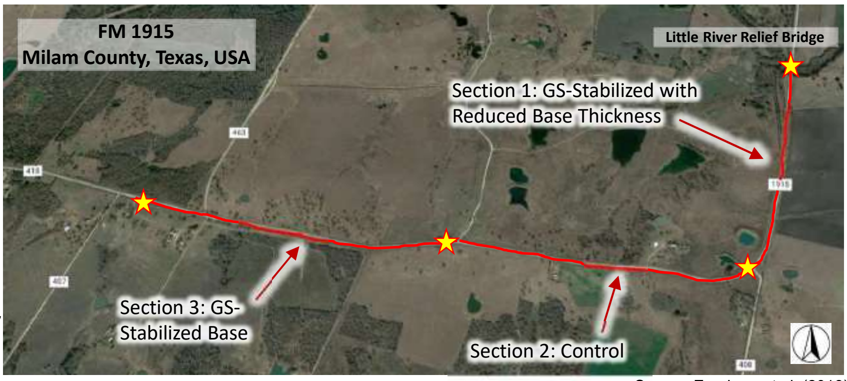
CH6: FM 1915, Milam County, Texas
- Mitigation of Distress due to Shrink/Swell Soils -

- **Reconstruction of low volume road on expansive clays:**
  - Founded on expansive clay subgrade with **PI ranging from 30 to 56**
  - Severe longitudinal cracks reported on an extension of **4 km south of Little River Relief Bridge**
- **The challenge: Minimize environmental longitudinal cracks**
  - Requires condition surveying during operation to quantify performance



Source: Zornberg et al. (2018)

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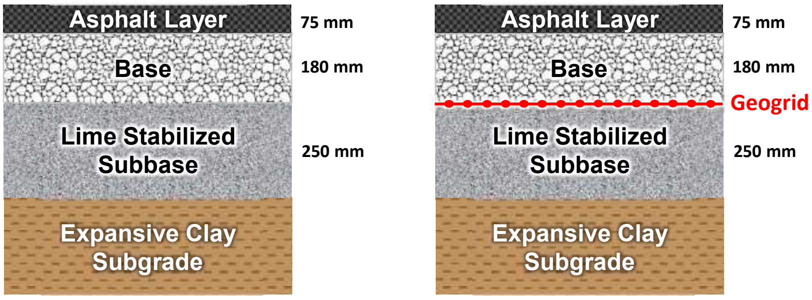
CH6: Design Alternatives

Design Requirements:
- Failure Criterion: Longitudinal cracks < 15%
- Design Life: 15 years

Design using GS:
- Geosynthetic-stabilized base
- Maintained thickness of other layers to assess difference in performance

Conventional Design:
- No geosynthetic
- Design typical for low volume road in Texas



Source: Zornberg et al. (2018)

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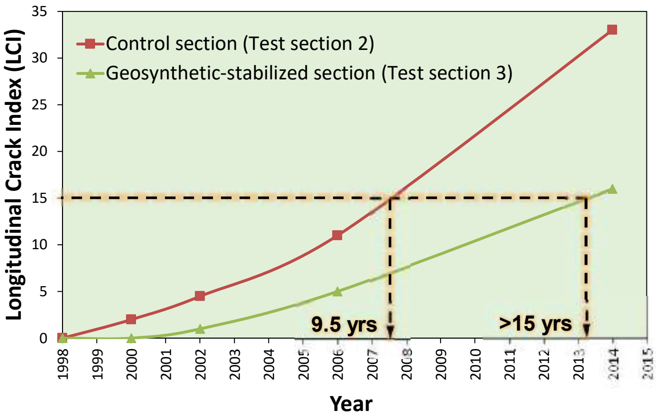
CH6: Quantification of Performance



- Control section (Section 2) required rehabilitation
- Geosynthetic-stabilized section did not require rehabilitation

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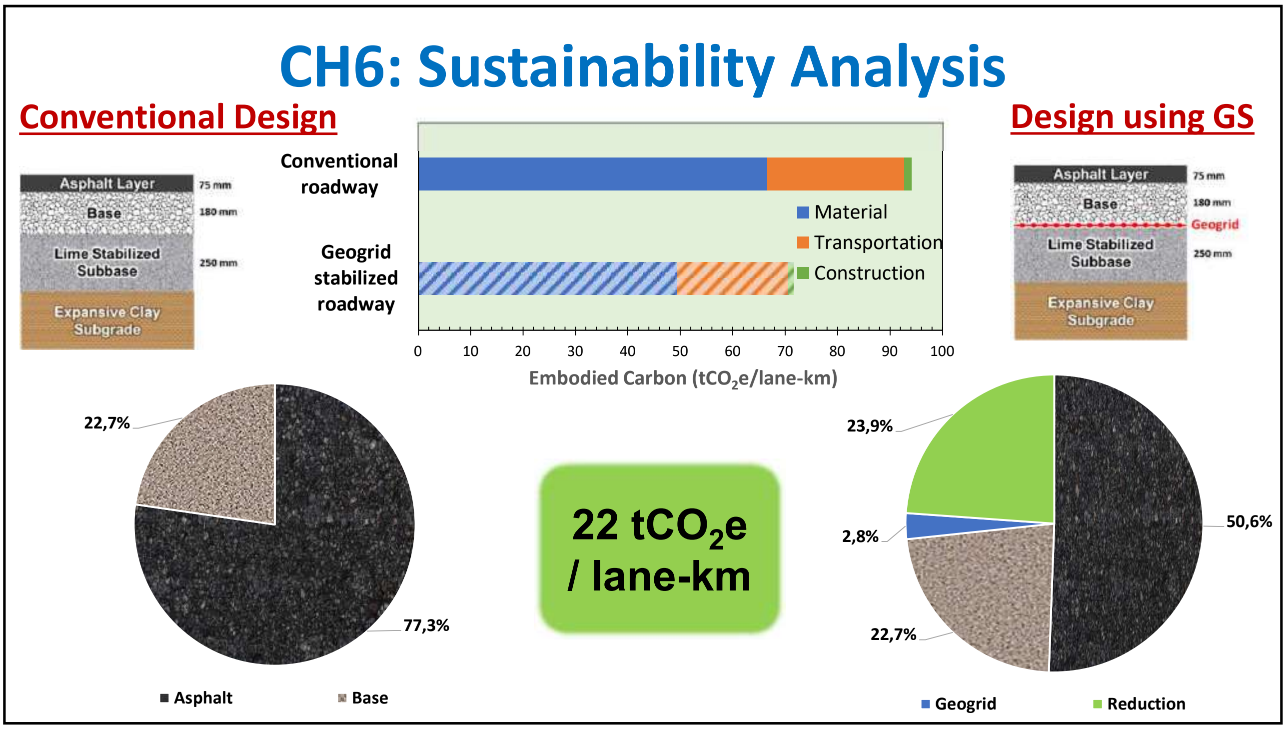
CH6: Sustainability Analysis
Conventional Design
Design using GS
Asphalt Layer
Base
Lime Stabilized Subbase
Expansive Clay Subgrade
75 mm
180 mm
250 mm
Geogrid
Conventional roadway
Geogrid stabilized roadway
Material
Transportation
Construction
0 10 20 30 40 50 60 70 80 90 100
Embodied Carbon (tCO_2e/lane-km)
22,7%
77,3%
Asphalt
Base
22 tCO_2e / lane-km
23,9%
2,8%
22,7%
50,6%
Geogrid
Reduction

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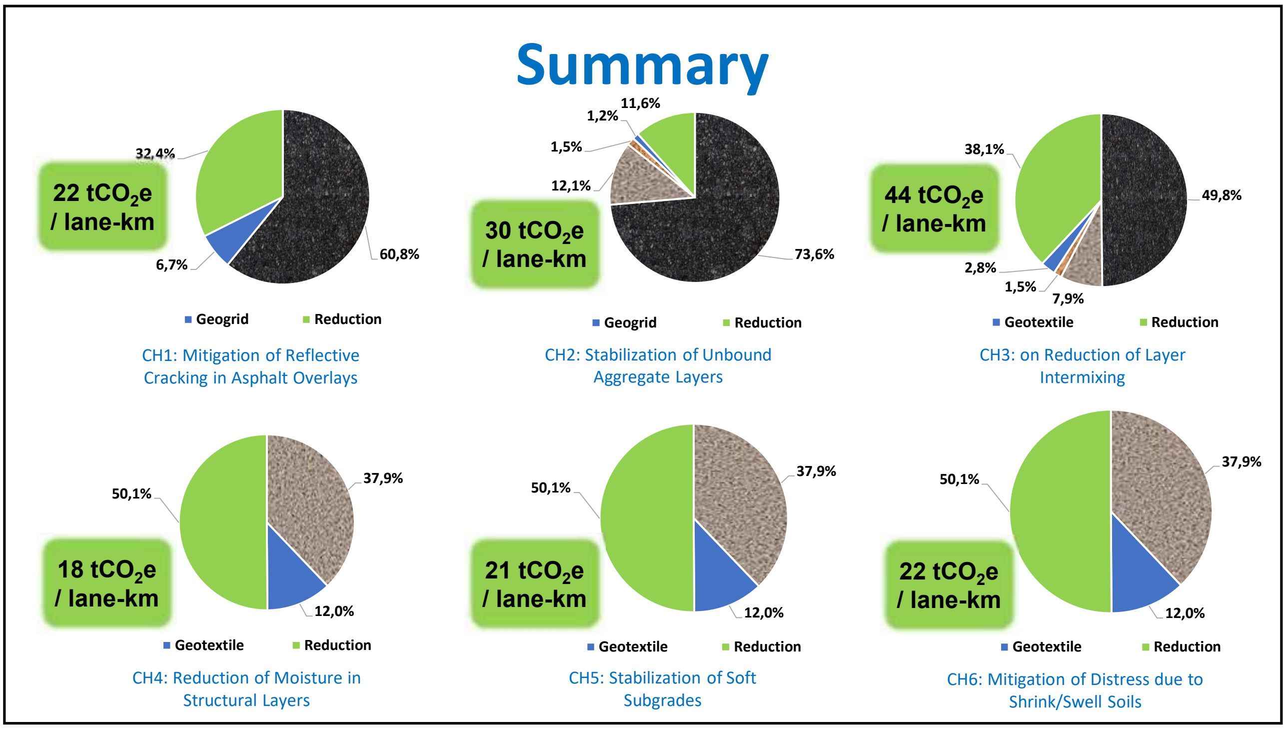
Summary
22 tCO_2e / lane-km
32,4%
6,7%
60,8%
Geogrid
Reduction
CH1: Mitigation of Reflective Cracking in Asphalt Overlays
30 tCO_2e / lane-km
11,6%
1,2%
1,5%
12,1%
73,6%
Geogrid
Reduction
CH2: Stabilization of Unbound Aggregate Layers
44 tCO_2e / lane-km
38,1%
49,8%
2,8%
1,5%
7,9%
Geotextile
Reduction
CH3: on Reduction of Layer Intermixing
18 tCO_2e / lane-km
50,1%
37,9%
12,0%
Geotextile
Reduction
CH4: Reduction of Moisture in Structural Layers
21 tCO_2e / lane-km
50,1%
37,9%
12,0%
Geotextile
Reduction
CH5: Stabilization of Soft Subgrades
22 tCO_2e / lane-km
50,1%
37,9%
12,0%
Geotextile
Reduction
CH6: Mitigation of Distress due to Shrink/Swell Soils

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Let's Do A Few Calcs …

Consider:

- That the case histories evaluated in this study are representative
  - Adopting a geosynthetic alternative in roadway design leads to an average reduction of *26.29 tCO_2e per lane-km* in carbon footprint
- That the costs (and carbon footprint) of roadway projects are amortized over a typical roadway design life of 15 years
  - Adopting a geosynthetic alternative leads to an annual average reduction of *1.75 tCO_2e per lane-km-year* in carbon footprint
- That the world's roadway network of 64,285,009 km (assuming two lanes per road) is designed using geosynthetics from now on
  - Annual average reduction of *225 million tCO_2e per year*
  - Or: annual CO_2 sequestered by approximately *100 million hectares of forest*
  - Or: annual CO_2 sequestered by a forest 24 times the area of the Netherlands

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Conclusions

In roadway applications:

- Geosynthetics have been shown to improve, often significantly, the system performance
- Geosynthetics have generally led to cost-effective solutions
- Geosynthetics have consistently resulted in more sustainable alternatives
  - Considering the significant extension of roadways worldwide, the opportunities to achieve sustainability goals by extensively using geosynthetics in roadways are massive

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Thank You
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Professor and Joe E. King Chair in Engineering
The University of Texas at Austin, USA
INTERNATIONAL GEOSYNTHETICS SOCIETY
• International Symposium on Geosynthetics and Sustainability •
• Technical University (TU) Delft • The Netherlands • 14 May 2024 •

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