Stabilisation in Pavements – Design, Performance & Economy

Webinar on Stabilisation in Road Construction – Performance & Economy - Oldest Method of Pavement Quality Enhancement Still Not Used Routinely; How Can this be Changed for all Future Works

Nov 6th, 2024

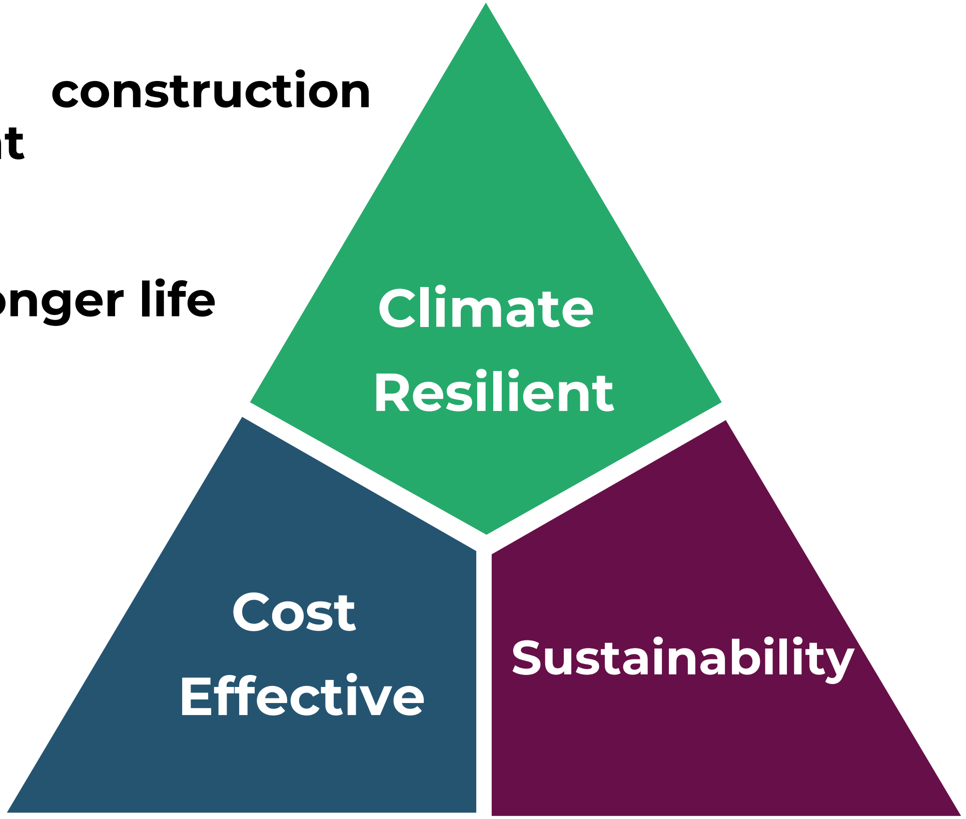
Shubham Kalore, PhD,
Manager – Roads,
Zydex Industries Private Limited
Vadodara, Gujarat, India

Presentation Structure

- ❑ Understanding Stabilization Methods
- ❑ Mix-Design Considerations
- ❑ Stabilized Pavement Design
- ❑ Issues and Potential Solutions
- ❑ Performance of Stabilized Pavements
- ❑ Economy

Why Stabilization?

- **Aggregates mining & hauling for road construction unsustainable as it disturbs ecology & environment**
- **Need to construct with less of material and with longer life**
- **Use of discerning technologies is an imperative**



Stabilization in Pavements

Stabilization

- Technique to improve the properties of soil and pavement layers.

Types of Stabilization

- Mechanical Stabilization: Addition of Granular Material and/or Compaction
- Chemical Stabilization (e.g., cement, lime, polymers, silanes, etc.)

Benefits/Purposes of Stabilizations

- Solutions for Problematic/soft Soils
- Reduce Surface Deflections
- Reduce Plasticity Index
- Increase Durability
- Cost Economy, reduced thickness due to increased strength compared to unbound materials

Selection of Stabilizer

IRC SP 89 2010: Guidelines for Soil and Granular Material Stabilization Using Cement, Lime and Flyash

Increases the strength and durability by reducing plasticity.

Type of Stabilization	Soil Properties					
	More than 25% passing 0.075 mm sieve			Less than 25% passing 0.075 mm sieve		
	PI < 10	10 < PI < 20	PI > 20	PI < 6, PP < 60	PI < 10	PI > 10
Cement	Yes	Yes	-	Yes	Yes	Yes
Lime	-	Yes	Yes	No	-	Yes
Lime-Pozzolana	Yes	-	No	Yes	Yes	-

Zydex Innovating for Sustainability

Selection of Stabilizer

IRC SP 89 Part-II 2018: Guidelines for the Design of Stabilized Pavements

a) Natural Inorganic Powder Binders

b) Silane Based Chemicals

c) Waste Oils

d) Petroleum Based Products

e) Liquid Stabilized Products

f) Synthetic Polymers

g) Sulphonate Lignin

Selection of Gradation

Sr. No.	Material	Gradation Reference: Base	Gradation Reference: Subbase	Specifications
i	All types of aggregates including marginal aggregates	Table 400-4, Clause 403.2.2	Grading IV, Table 400-1, Clause 401.2	According to MORTH (2013)
ii	Reclaimed Asphalt Pavement Material			
iii	Reclaimed Concrete Pavement Material			
iv	Industrial, Construction and Demolition Wastes			
v	Mines Waste	Table 400-3, Clause 402.3.2		
vi	All types of soil having PI ≤ 20 for sub-base and PI < 10 for base	Table 400-3, Clause 402.3.2		

MORTH Table 400-4: Grading Limits of Material for Stabilization with Cement	
IS Sieve Size	Percent Passing
53.00 mm	100
37.5 mm	95 – 100
19.0 mm	45 – 100
9.5 mm	35 – 100
4.75 mm	25 – 100
600 micron	8 – 65
300 micron	5 – 40
75 micron	0 – 10

Mix-Design for Stabilization

Mix Design Objectives

- Provide adequate strength and Durability
- Construction Ease
- Economy

Test Requirements

1. Unconfined Compressive Strength Tests
   - Cube / Cylindrical Sample
2. Durability
   - Wetting and Drying test (ASTM D559) 12 Cycles

Pavement Design for Stabilization

Resilient Modulus (Mr) for Stabilized Base and Subbase Materials

Mr = 1000*UCS for rapid Hardening CS
Mr = 750*UCS for slow Hardening CS/CCS
UCS = Unconfined Compressive Strength in MPa (7 and 28 days for Rapid Hardening & Slow Hardening Stabilizers respectively)

- For design, 20% of Mr value derived from the given relations shall be taken.
- If the elastic modulus is obtained from four-point beam testing, the Mr value for design should be used directly, applying a minimum safety factor of 1.5.
- However, E value should be restricted to 1700 MPa.
- Flexural strength can be taken as 20% of UCS for Fatigue analysis for design of thickness following IRC 37 recommended procedure

Specifications for Stabilization

Requirements for Base Layer

- UCS in the range of 4.5 MPa to 7 MPa
- Laboratory strength shall be >1.1 times the design strength
- Upper limit for Mr is 1400 MPa based on UCS and 1700 MPa based on beam testing
- Flexure and Cumulative damage analysis as suggested in IRC:37 (2018) shall be carried out.

Requirements for Subbase Layer

- UCS in the range of 0.75 MPa to 1.5 MPa
- Mr value for design shall be 400 MPa

Cautions / Issues in Design

- AUSTROADS (Jameson,2013) caution using empirical relationships preliminarily due to data variability.
- They recommend measuring the flexural modulus with a four-point bending test under dynamic loading instead of relying on empirical equations.
- The elastic modulus-UCS multiplier of 1000 is valid only for 28-day UCS measurements, not for 7-day results.
- This multiplier is suitable for high-quality crushed rock or natural gravel but not for conditions outlined in IRC SP 89 Part I and II, which apply to soil-aggregate mixtures with PI < 20 for sub-base and < 10 for base layers.
- For granular mixes with PI between 5-10%, the modulus typically ranges from 1000 to 4000 MPa.
- Guidelines suggest flexural strength as 20% of UCS; however, direct measurement of flexural strength/modulus of rupture is preferred, with empirical evaluation used only when testing equipment is unavailable.

Modulus using Four-point Beam Bending Test

- IRC SP 89 Part-II recommend a four-point beam test with dynamic loading, Annexure provides procedure for static or monotonic loading.
- The formula of modulus needs correction as it does not consider the deflection or strain value

- Elastic / Flexural modulus is suggested to be evaluated using 4-point beam testing, following the procedure outlined in the AUSTROADS Test Method AGPT/T600.
- The guide specifies the application of repeated haversine loading, with load amplitudes up to 40% of the ultimate breaking load.
- The flexural modulus is calculated for load cycles 50 to 100 using the equation:

$$E = \frac{P}{\Delta}\frac{{L_s}^2 a}{WH^3}\left(\frac{3}{4} - \frac{a^2}{{L_s}^2}\right)$$

E = flexural modulus (MPa), P = peak force (N)
L_s = distance between the supporting rollers (mm)
W = mean beam width (mm)

H = mean beam height (mm)
Δ = resilient deflection at the center of the beam (mm)
a = distance between loading roller and supporting roller (mm)

Fatigue Models

- The fatigue equations recommended in IRC 37 (2018) are developed by AUSTROADS and AASHTO for base layer materials for non-plastic soils.
- Gradations limits are much stringent (follows Fuller Curve) compared to gradation limits specified in MORTH.
- The fatigue equations are not applicable to soil-aggregate materials with PI in the range of 5 to 10 % both CS or CCS base layers.
- Fatigue models are required for CS / CCS stabilized materials specific to materials specifications used in India.

Impact of Moisture on Modulus

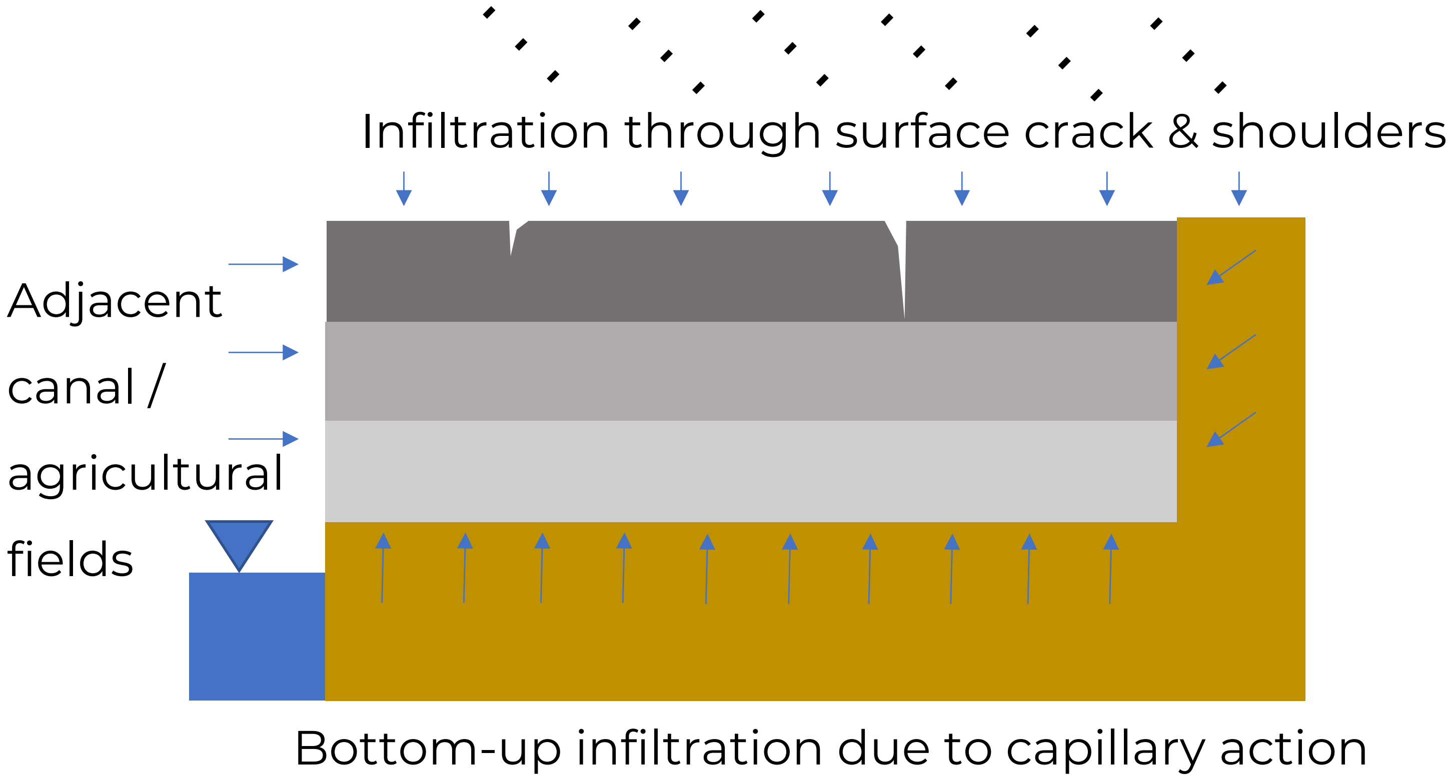
Pavements are designed by considering worst case scenario for each of pavement material

- Subgrade: Four Days Soaked CBR (California Bearing Ratio)
- Stabilized Layers: Impact of moisture on Modulus?

UCS - 7/28 days curing (Unconfined Compressive Strength) → Elastic Modulus and Modulus of Rupture → Fatigue Life

- Durability testing assesses moisture susceptibility and resistance to repeated adverse weather conditions.
- Reflects abrasion resistance through mass loss during wet-dry cycles.
- Does not indicate the material stiffness under wet/dry under loading when wet.

Sources of Water Ingress in Pavements



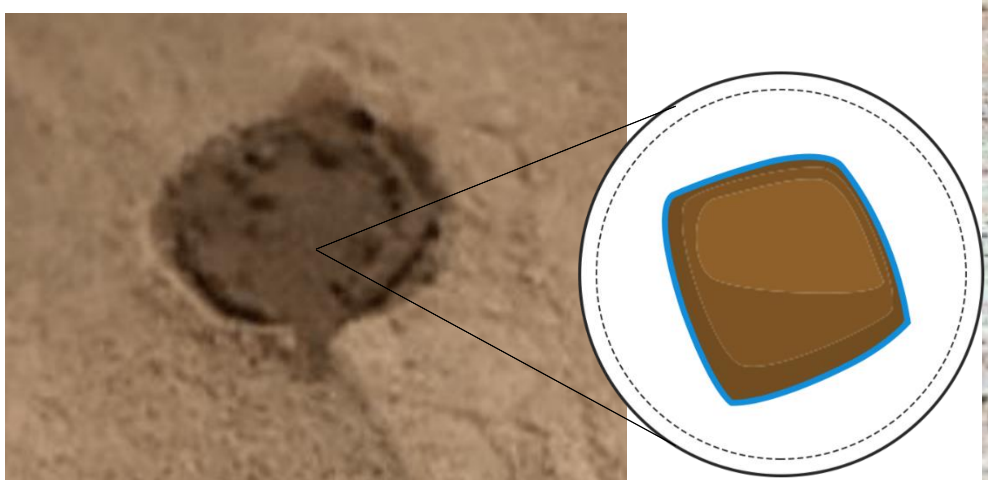
- ✓ Degradation of modulus
- ✓ Weaking of structural layer
- ✓ Formation of Potholes

Potential Solution

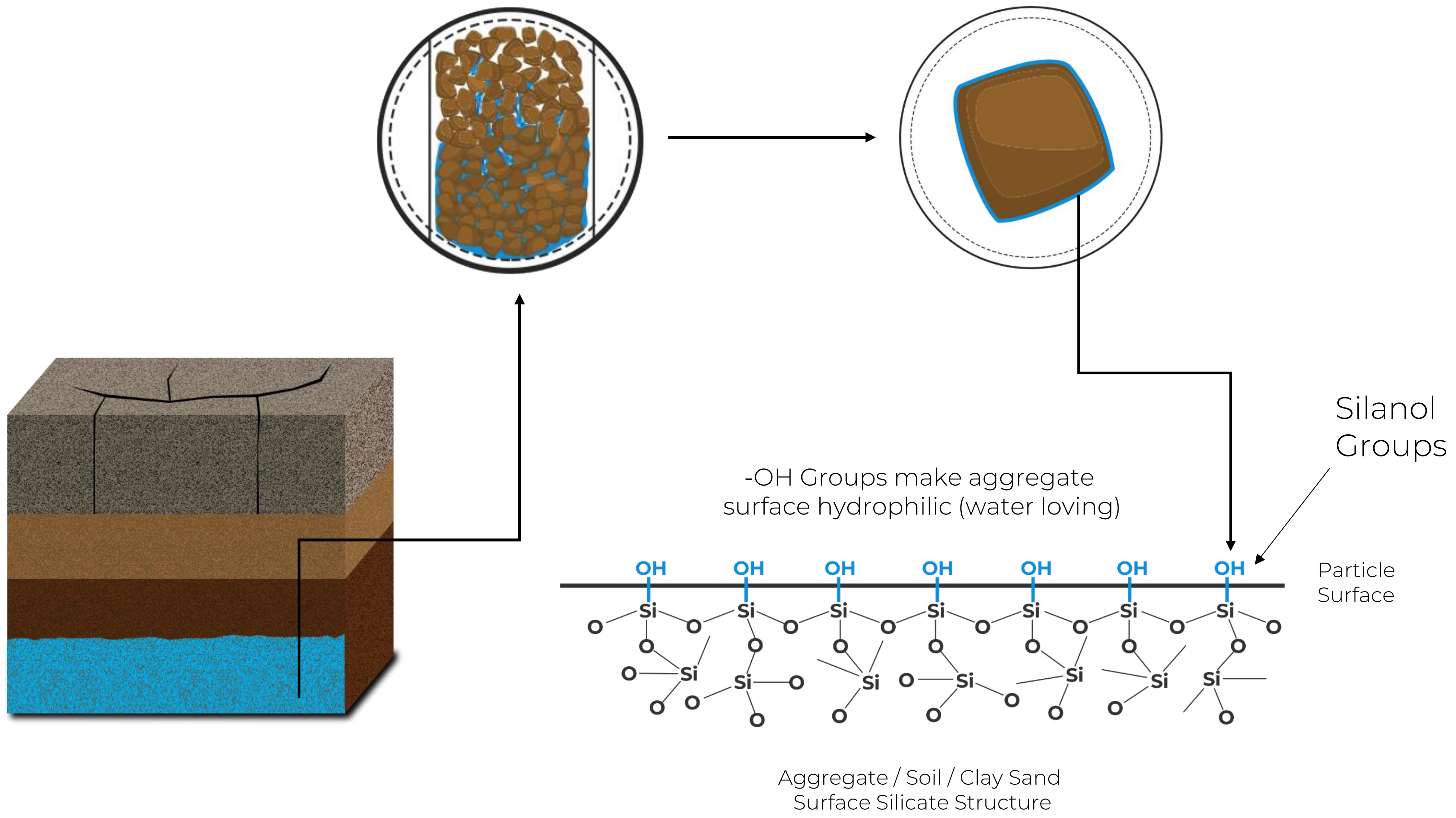
Organosilane Chemistry to Reduce Moisture Damage in Pavements:

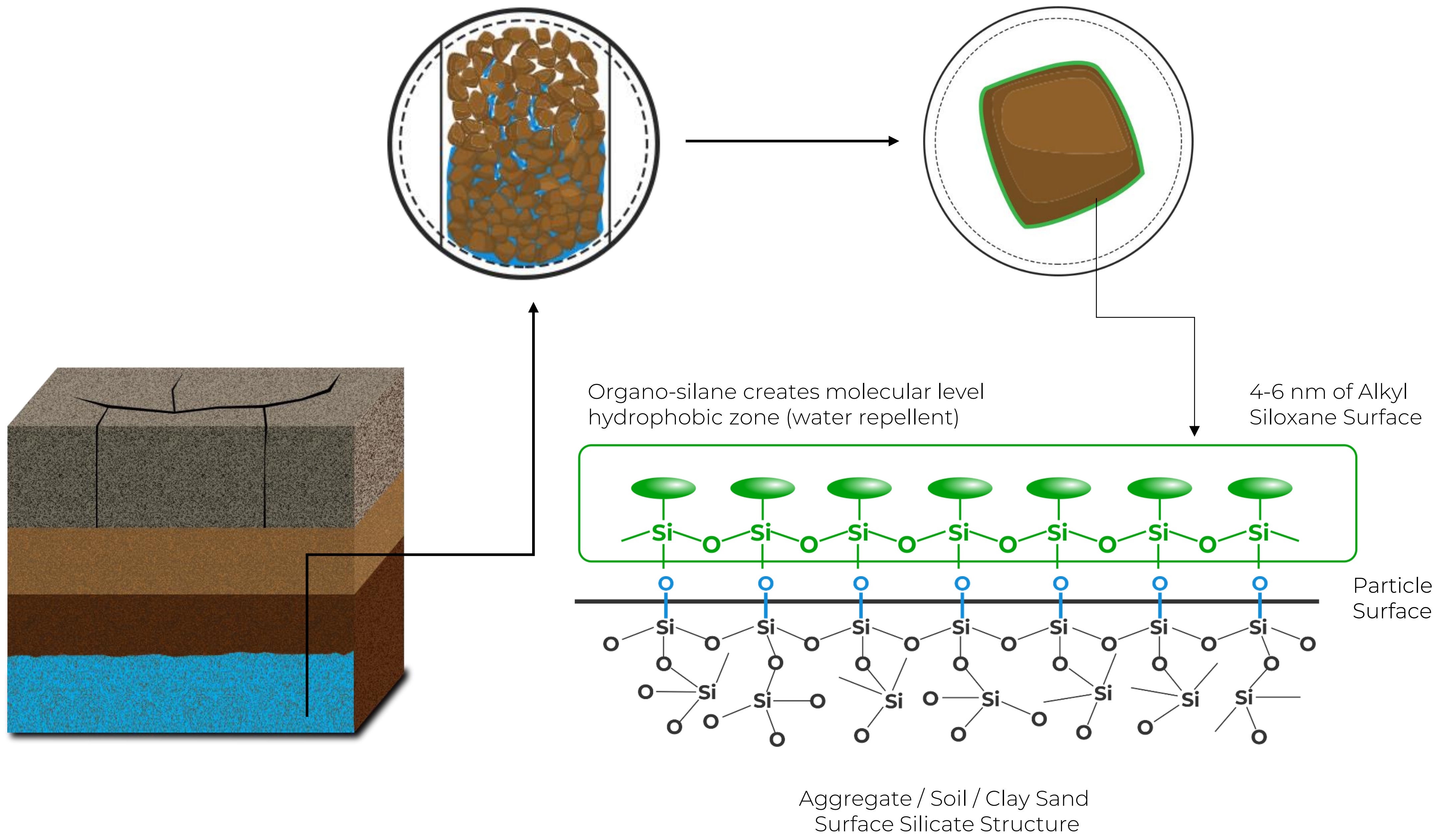
- **Base / Soil Stabilization**
- Trackless and Moisture Resistant Tack Coats
- Antistrips & Warm Mix Asphalt

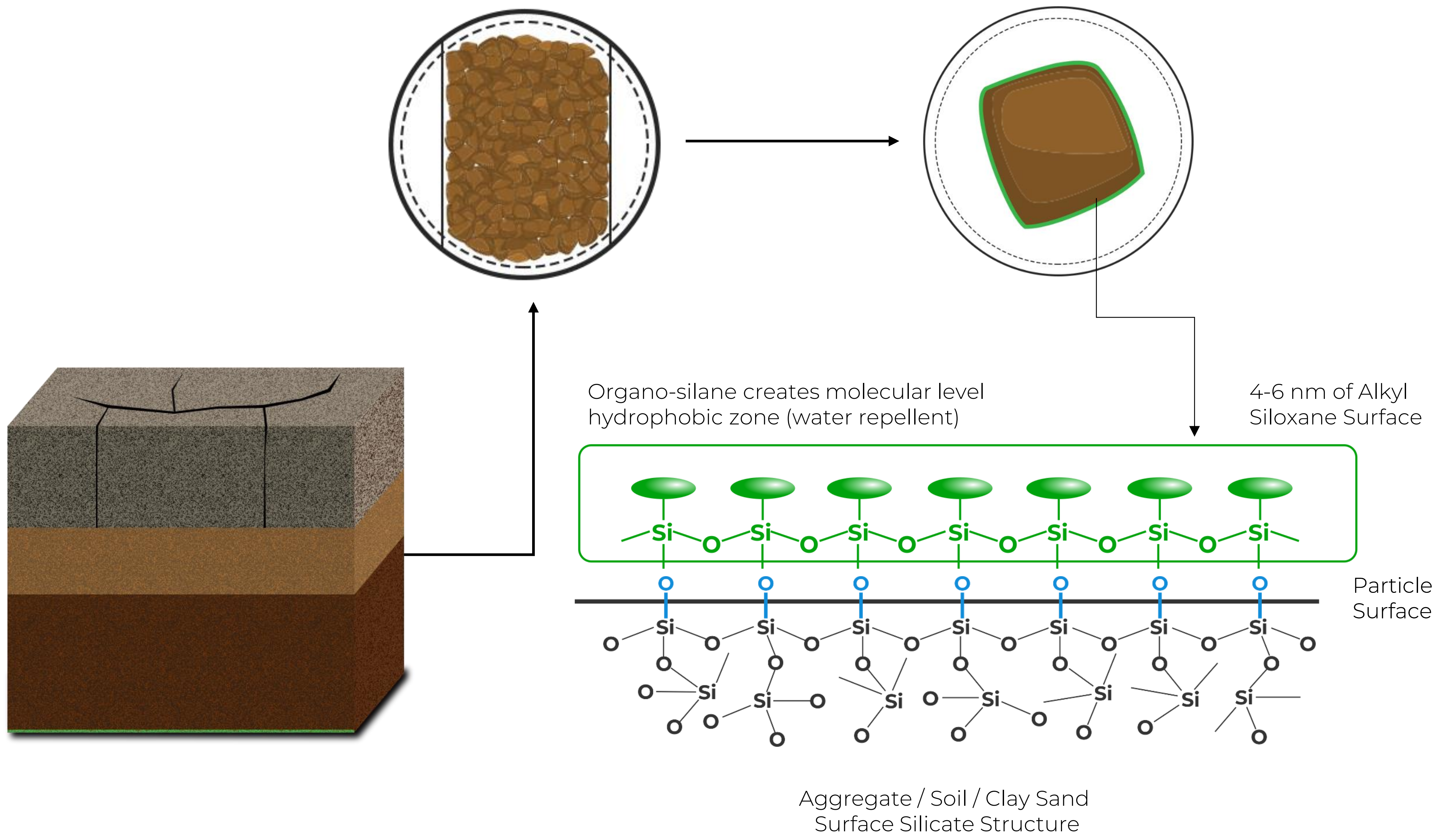
What are Organosilanes



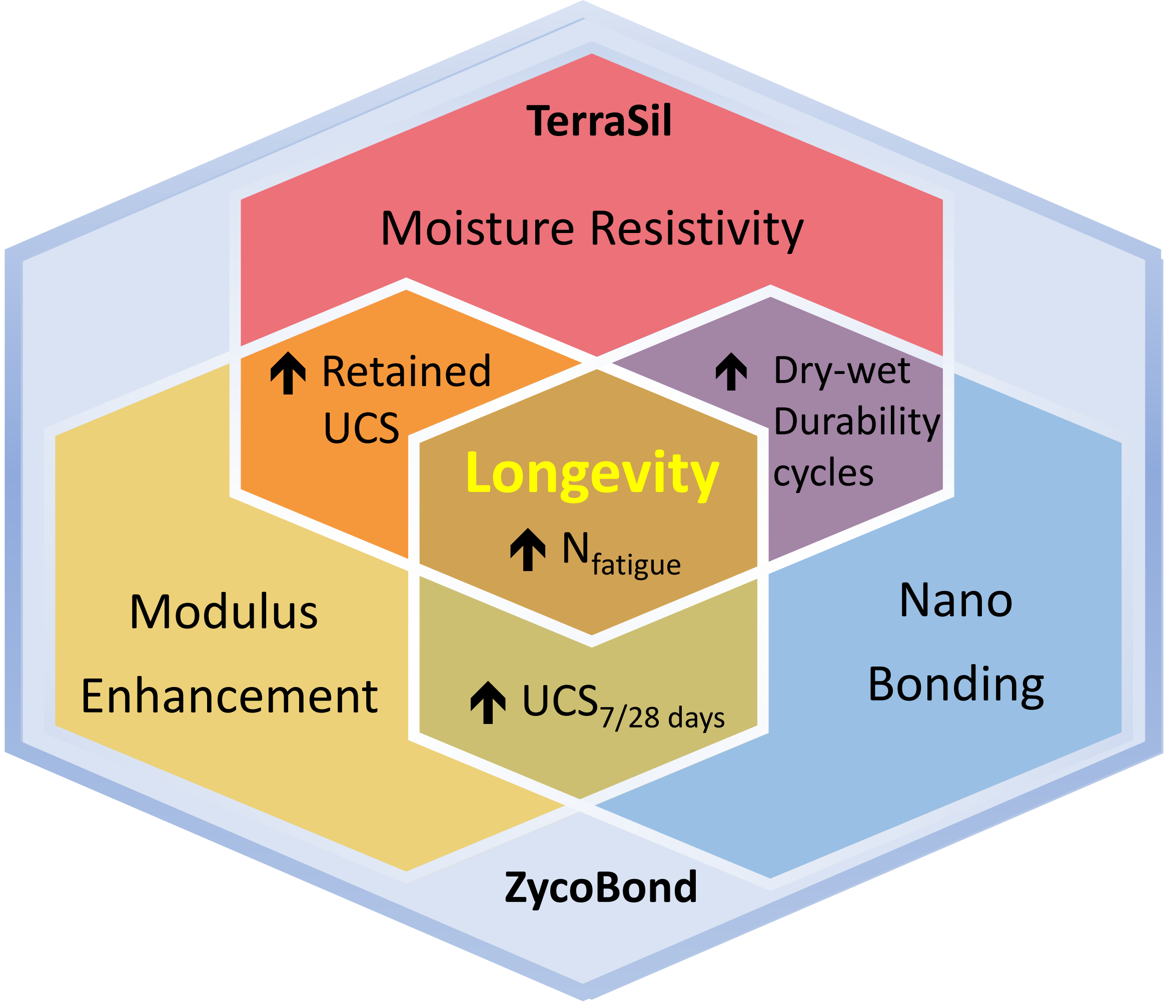
Untreated Soil


Silanol
Groups
-OH Groups make aggregate
surface hydrophilic (water loving)
OH
Si
Particle
Surface
Aggregate / Soil / Clay Sand
Surface Silicate Structure


Organo-silane creates molecular level
hydrophobic zone (water repellent)
4-6 nm of Alkyl
Siloxane Surface
Particle
Surface
Aggregate / Soil / Clay Sand
Surface Silicate Structure

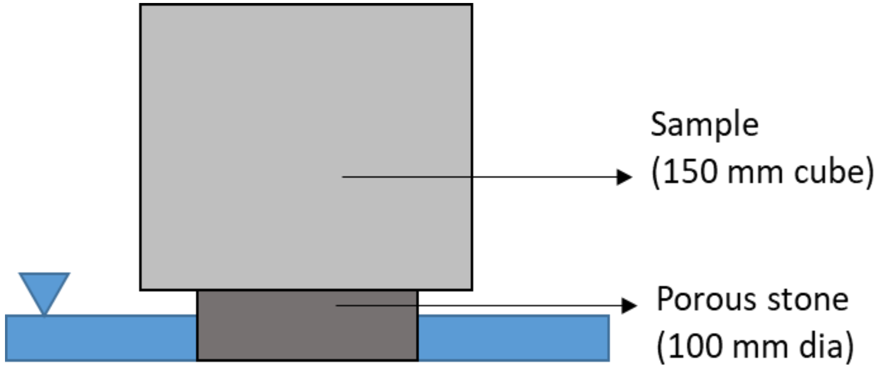

Organo-silane creates molecular level hydrophobic zone (water repellent)
4-6 nm of Alkyl Siloxane Surface
Particle Surface
Aggregate / Soil / Clay Sand Surface Silicate Structure

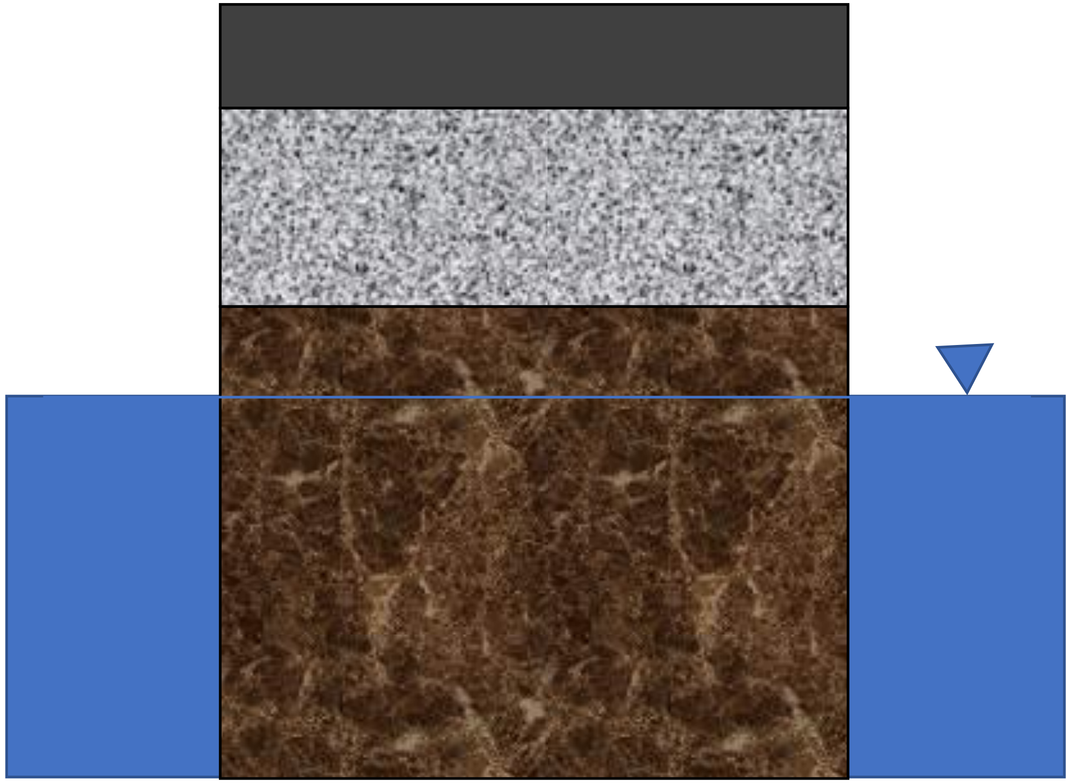
Value Addition of TerraSil and ZycoBond



- Resistance to Deformation
- Water Resistivity
- Fatigue Performance Improvement

Impact of Moisture on Stabilized Materials

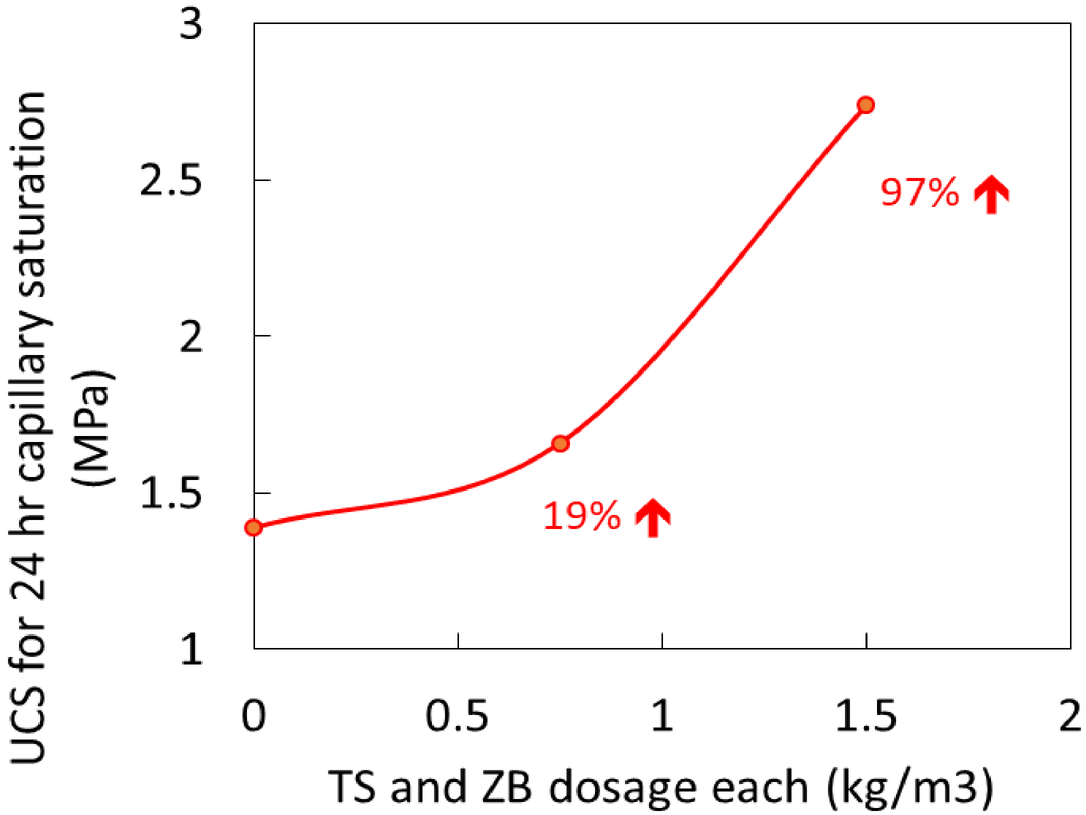




Pavement Section

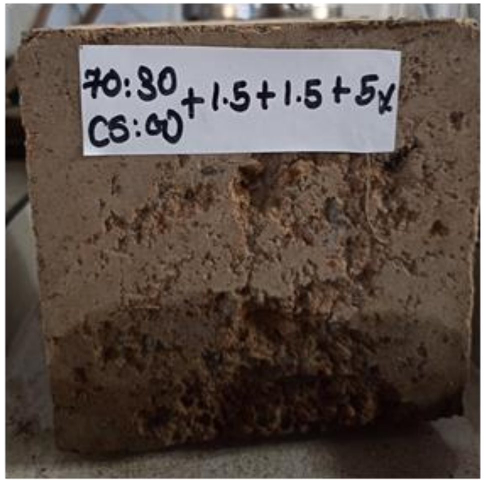
Impact of Moisture on Stabilized Materials

UCS after 7 days of curing with only Cement 4% is 3.9 MPa



Cement 5%

C 5%; TS and ZB 0.75 Kg/m^3



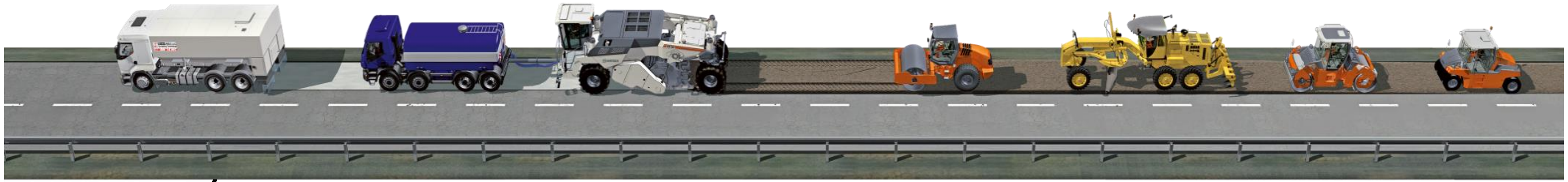
C 5%; TS and ZB 1.5 Kg/m^3

Construction Methodology

WMM Plan

Preparation of Mix	Transportation & Laying	Compactio n	Curing	Finished Surface

Recycler



Cement/ Additive Spreading	Water & Chemical Additive	In-situ Recycling	Rolling & Grading	Final Compaction

1. Shoulder Excavation & Material Removal

2. Scarification with Recycler

3. Grading and Mixing with Grader

4. Compaction

5. Cement Spreading with Spreader

6. Recycling and Additive Mixing

7. Compaction with Pad Foot Roller

8. Grading and Mixing with Grader

9. Compaction with Vibro Roller

10. Compaction with PTR

11. Water Curing

Performance of Stabilized Pavements

Post Construction ……

FDR UP


GPS Map Camera
Pipri Mohan, Uttar Pradesh, India
Unnamed Road, Pipri Mohan, Uttar Pradesh 271851, India
Lat 27.679318°
Long 81.358635°
16/08/23 10:25 AM GMT +05:30
Google

FDR UP

Zydex
Innovating for Sustainability

Construction & Maintenance of Archoo - Batambis 18 km Road
Package: JK06-68, Year: 2018

- **Water & Frost Resistant Soil Aggregate Layer constructed with 77% lesser aggregates**
- **High strength Stabilized Base with CBR 100%**
- **BM Layer Eliminated**
- **Locally available soils Used**
- **Faster Construction**

Zydex
Innovating for Sustainability

Archoo To Batambis JK0668

Karnataka PMGSY – PIU Dharwad

Mar-2021

Mar-2024

Mangundi to Nigadi via Benkankatti 2 km Road, Package no. KN-13-05 Year: 2021

Karnataka PMGSY – PIU Haveri

Mar-2021

Mar-2024

Shribadgi to Chillur badni via Allipur 2.0 km Road, Package no. KN-27-20 Year: 2021

Karnataka PMGSY – PIU Uttar Kannada

Mar-2021

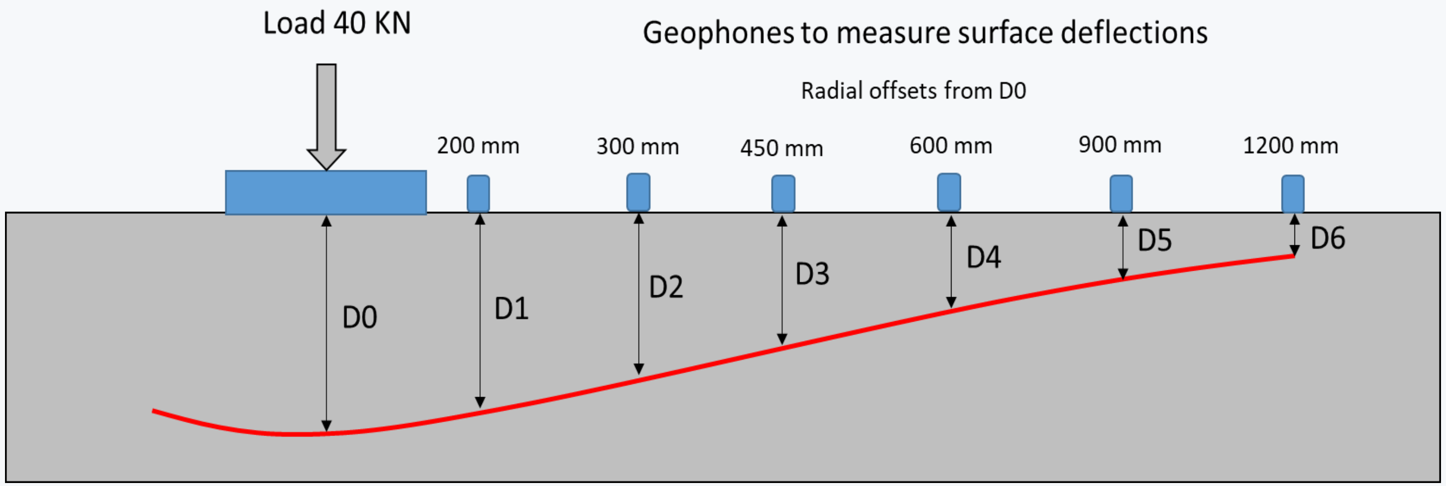
Mar-2024

MRL 18 Tenkal Cross (MDR) to Taluk Boundary (Mavinkatta) Via Ummachgi 1.54 km Road, Package no. KN-27-91 Year: 2021

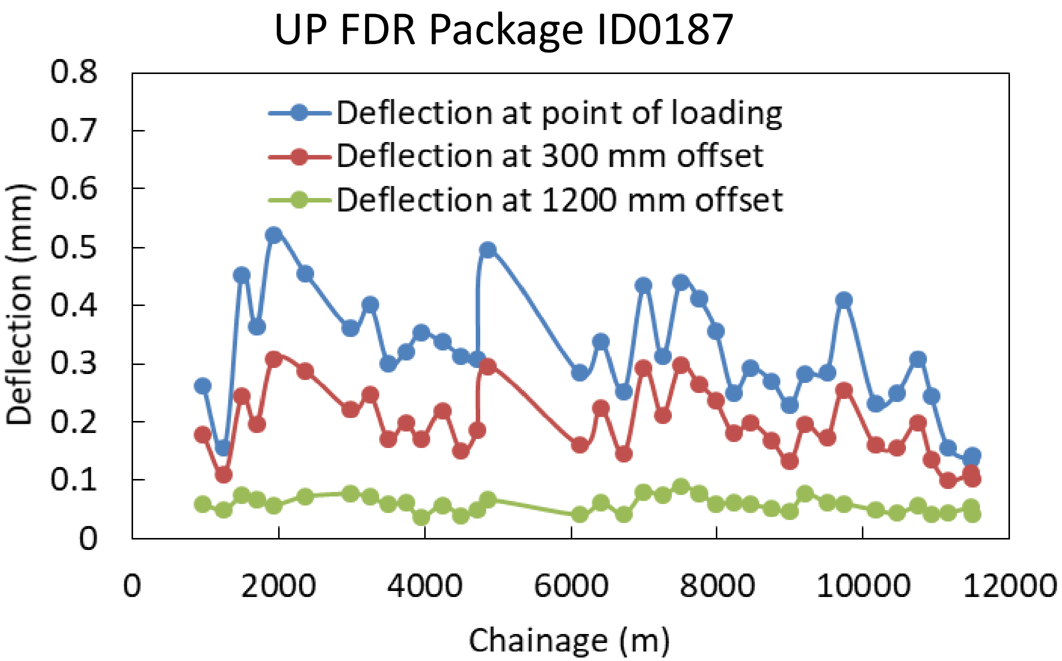
Zydex Innovating for Sustainability

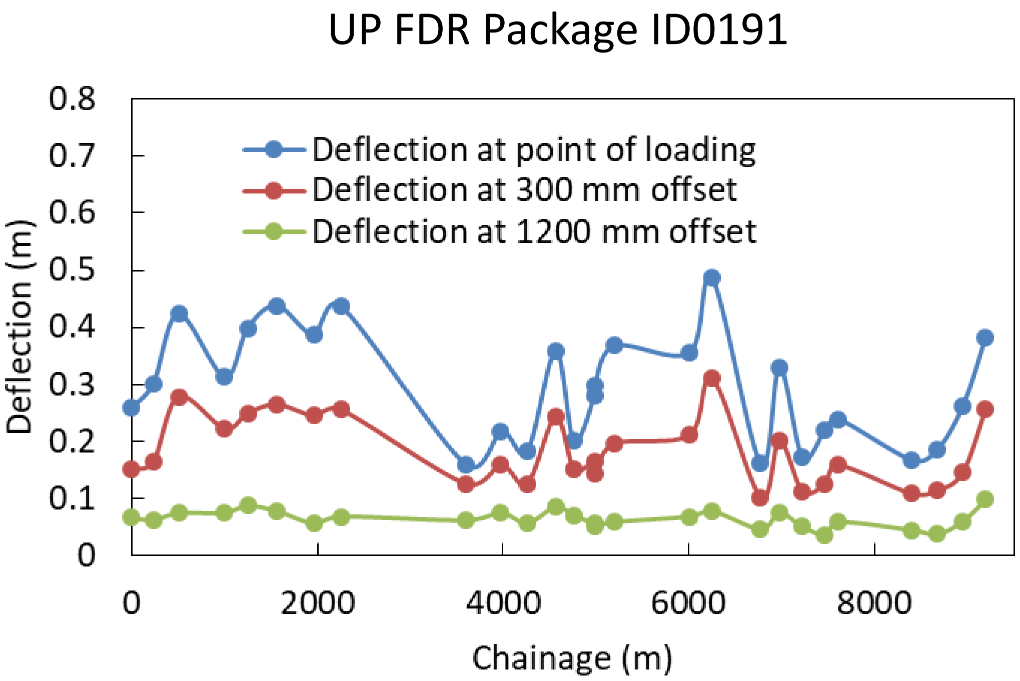
Structural Evaluation

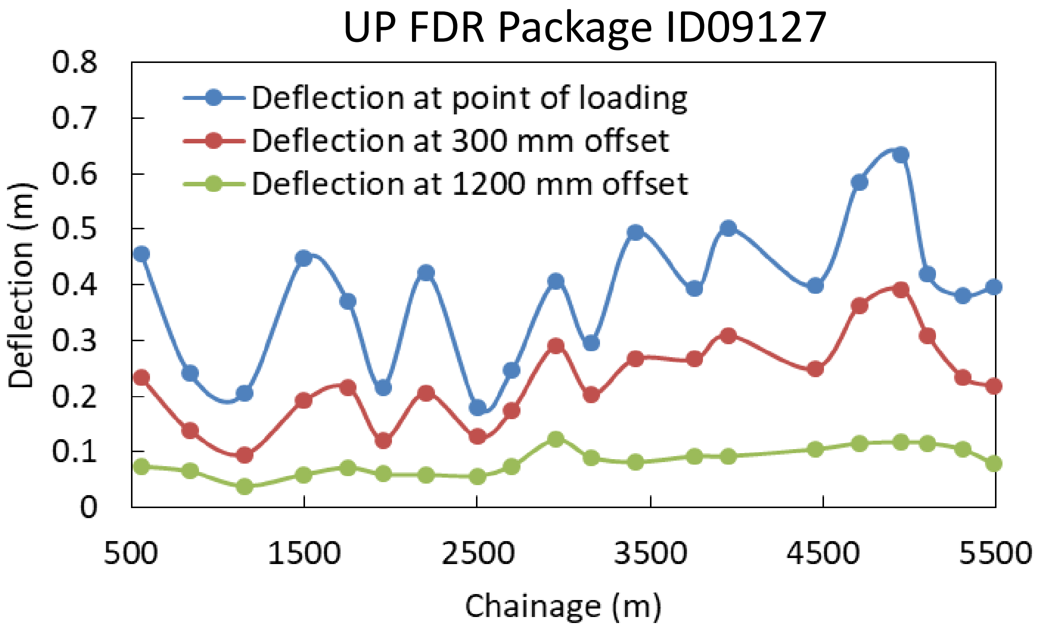
- FWD testing was conducted on the 20 FDR packages using a standard FWD equipment from KUAB.
- The device applies a dynamic load of 40 kN to the pavement surface using bearing plate of 300 mm diameter, simulating the impact of a vehicular load.
- Surface deflections were measured using geophones placed at predetermined distances from the load plate:

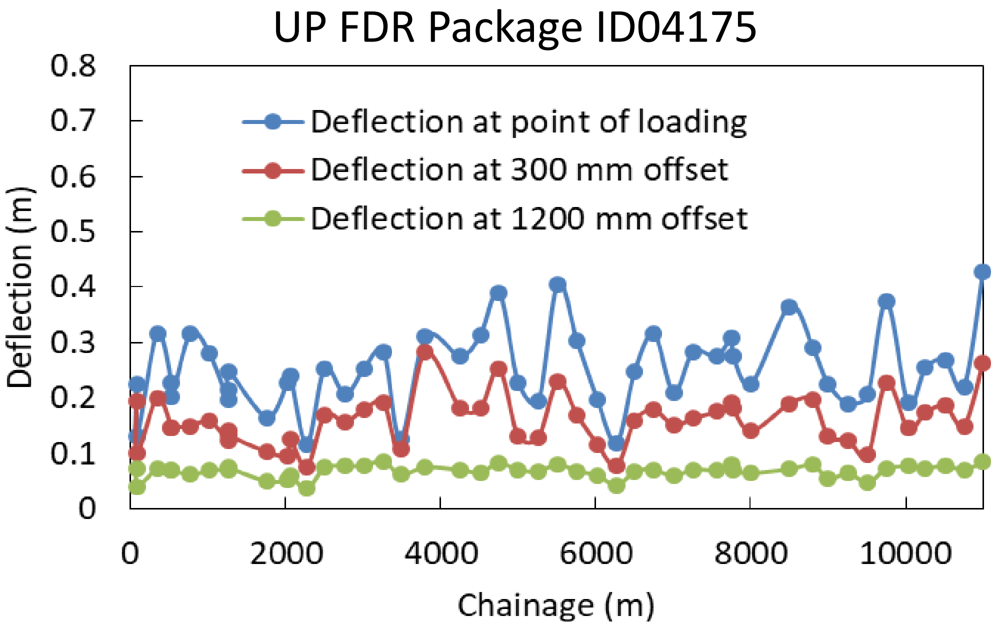


Zydex Innovating for Sustainability


UP FDR Package ID0187
Deflection at point of loading
Deflection at 300 mm offset
Deflection at 1200 mm offset
Deflection (mm)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
2000
4000
6000
8000
10000
12000
Chainage (m)


UP FDR Package ID0191
Deflection at point of loading
Deflection at 300 mm offset
Deflection at 1200 mm offset
Deflection (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
2000
4000
6000
8000
Chainage (m)


UP FDR Package ID09127
Deflection at point of loading
Deflection at 300 mm offset
Deflection at 1200 mm offset
Deflection (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
500
1500
2500
3500
4500
5500
Chainage (m)


UP FDR Package ID04175
Deflection at point of loading
Deflection at 300 mm offset
Deflection at 1200 mm offset
Deflection (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
2000
4000
6000
8000
10000
Chainage (m)

FWD – Back Calculation Procedure

- IRC 115 (2014) endorses KGP-Back software for back-calculating moduli using linear elastic theory.
- It is limited to three layers: Surface, Base, and Subgrade.
- Specifications are developed for conventional unbound layers; semi-rigid applicability depends on input seed moduli.
- KGP-Back does not directly output the goodness of fit or quantify relative error during convergence of deflection bowl.
- To improve accuracy, seed moduli should be iteratively adjusted to ensure proper convergence.
- For better evaluation, compare KGP-Back's deflection bowl with IITPave results for surface deflection to analyze relative error in terms of R^2 and Root Mean Square Error (RMSE).

FWD – Back Calculation Procedure

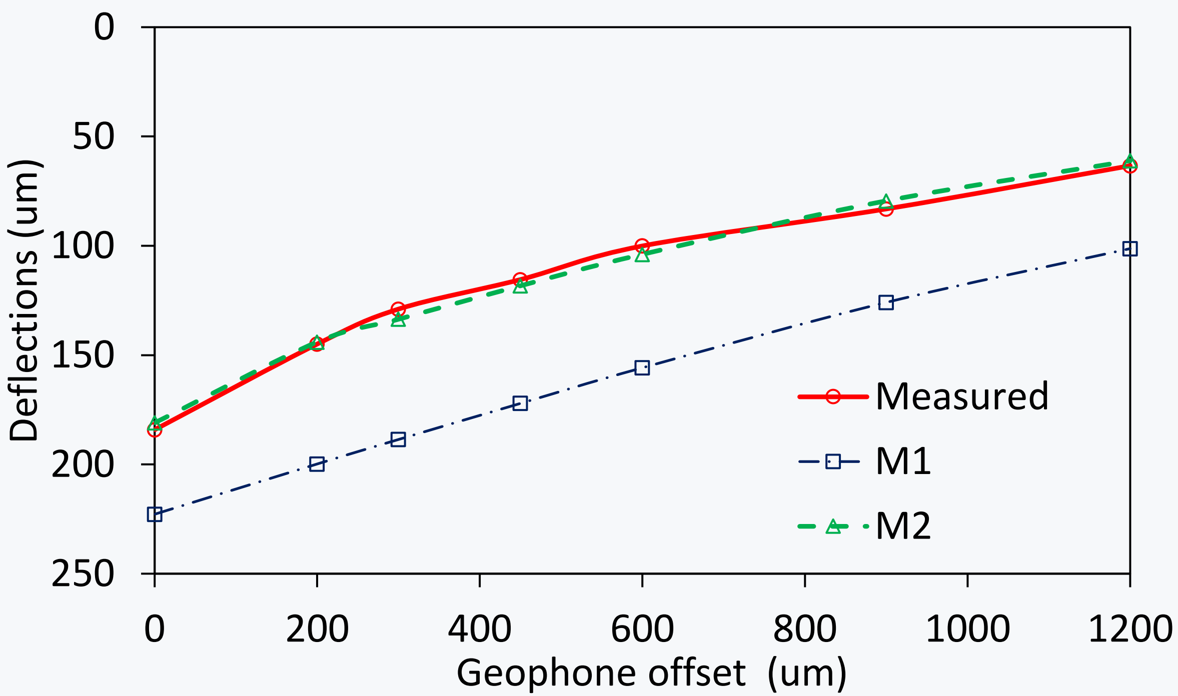


Table 1 Seed and Back Calculated moduli for the measured deflection data shown in Figs. 6 and 7

Group	Seed Modulus (MPa)			Back Calculated Modulus (MPa)			RMSE (um)	R^2
	BC	Base	Sub.	BC	Base	Sub.		
M1	750-3000	4500-7000	20-100	759	4502	99	70.1	0.984
M2	750-3000	500-10000	20-200	3268	1445	110	17.7	0.996

Zydex Innovating for Sustainability

Average Back-Calculated moduli for FWD evaluated FDR pavements								
Package ID	Cement Content (%)	TS and ZB Content each (kg/m^3)	Avg. Def. D_0 (mm)	BC Thickness (mm)	Base Thickness (mm)	Back-Calculated Avg. Moduli (MPa)		
						BC	FDR	Subgrade
UP01123	4.0	1 + 1	0.45	40	250	1870	1047	121
UP0187	4.5	1 + 1	0.34	40	250	2067	2004	158
UP0188	4.5	1 + 1	0.43	40	250	1614	1250	126
UP0190	4.5	1 + 1	0.39	40	250	1889	1284	137
UP0191	4.0	1 + 1	0.31	40	250	1753	3490	153
UP09122	4.5	1 + 1	0.29	40	250	1560	3288	156
UP09123	5.0	1 + 1	0.29	40	250	1587	1977	143
UP09124	5.0	1 + 1	0.36	40	250	2024	2761	134
UP09127	5.0	1 + 1	0.41	30	210	1829	3300	130
UP3156	4.5	1 + 1	0.40	40	250	1317	3207	135
UP4792	5.0	1 + 1	0.42	40	250	2009	1432	124
UP4793	4.0	1 + 1	0.35	40	250	1578	3250	125
UP4794	5.0	1 + 1	0.43	40	250	1809	3029	120
UP4795	6.0	1 + 1	0.27	40	250	1561	4799	149
UP58130	5.0	1 + 1	0.41	40	250	2366	1575	135
UP58153	5.0	1 + 1	0.32	40	250	1235	1880	129
UP58172	5.0	1 + 1	0.39	40	250	1859	1502	124
UP58183	5.0	1 + 1	0.29	40	250	1973	3239	164

- The results indicate that the average moduli for the base layer exceeds the typical design moduli (600-1000 MPa).
- Results suggests that the pavements are effectively meeting structural requirements.

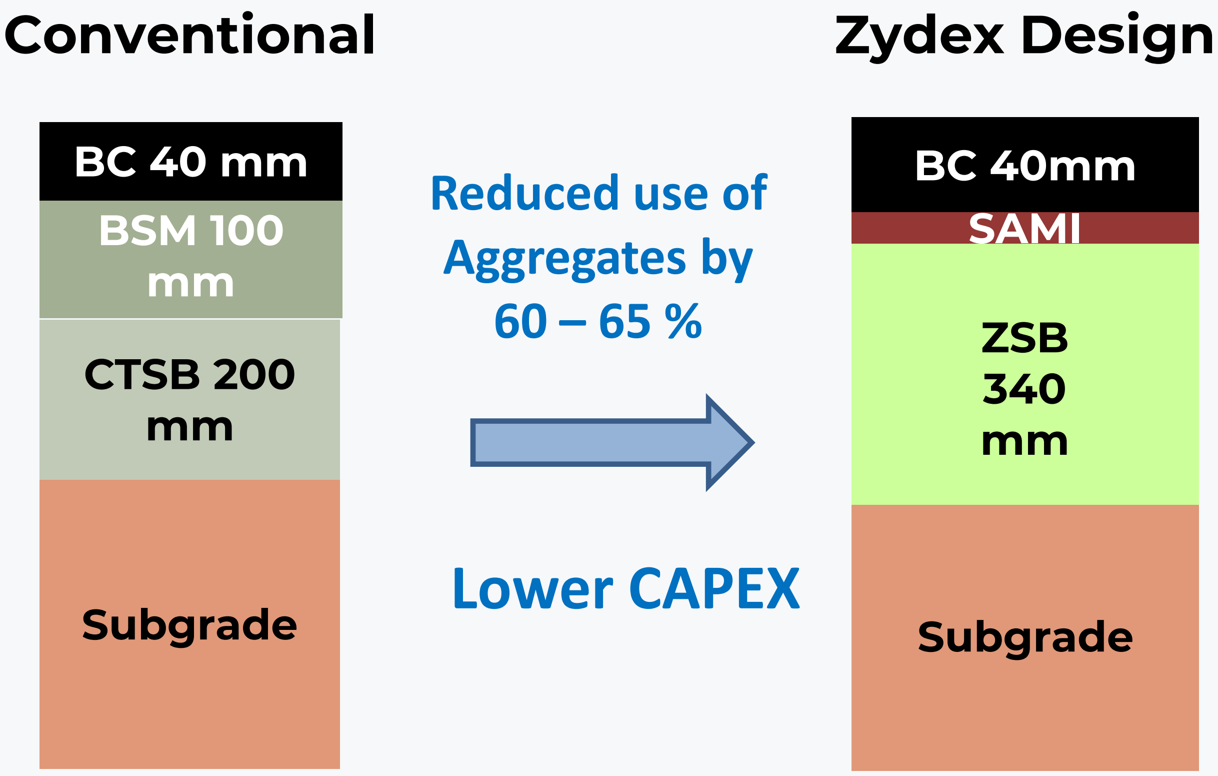
Base Stabilization using TerraSil under HVS Testing

Heavy Vehicle Simulation Testing

- HVS testing on Provincial Road D1884 in South Africa used G8 materials, typically unsuitable for base layers.
- Final rut depth of 8 mm after 7 million ESALs, with no structural failure under 80 kN loads.
- The stabilized base showed high water resistance and minimal deformation in wet conditions.
- Slight deflection increase under higher loads demonstrated traffic resilience, while stability under 40 kN loads prevented fatigue damage.
- Initial base stiffening was followed by fatigue under prolonged heavy loads.
- Nano-silane improved load capacity, ensuring durability with strong UCS and ITS results.
- Modification cut costs by 43% compared to conventional design.

Economy- NH 208

- Jurichhara- Bamanchara section
- Effective Sub Grade CBR: 8% Design Traffic: 20 MSA
- Length: 14.5 Km



Rethink Roads for a Sustainable Future

THANK YOU!

Shubham Kalore, PhD
Technical Manager - Roads
Zydex Industries Private Limited
Vadodara, Gujarat, India
Email: shubhamkalore@zydexgroup.com
Mobile: 9604868930

Zydex Innovating for Sustainability