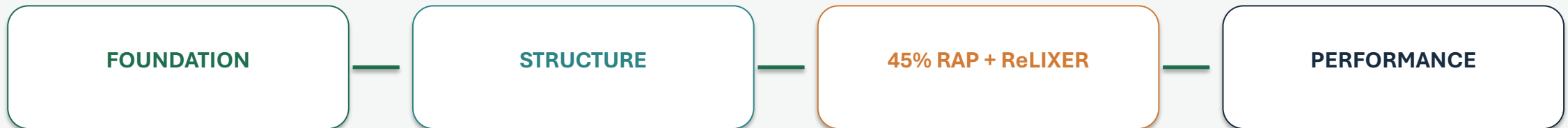


AN INTEGRATED SUSTAINABLE PAVEMENT APPROACH

COMBINING SUBGRADE STABILIZATION, STRUCTURAL OPTIMIZATION AND PERFORMANCE-VERIFIED HIGH-RAP ASPHALT RECYCLING

Stabilized foundation → optimized structure → performance-verified recycled surface



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ICA / IC Infrastructure Group · Karadeniz Technical University · Türkiye

Türkiye: The Framework Already Exists

Regulatory and technical foundations for asphalt recycling

Türkiye is not starting from zero.

POLICY & CIRCULARITY

- Twelfth Development Plan (2024–2028)
- Green transformation
- Recyclable construction materials
- Environmentally responsible construction technologies

REGULATORY FRAMEWORK

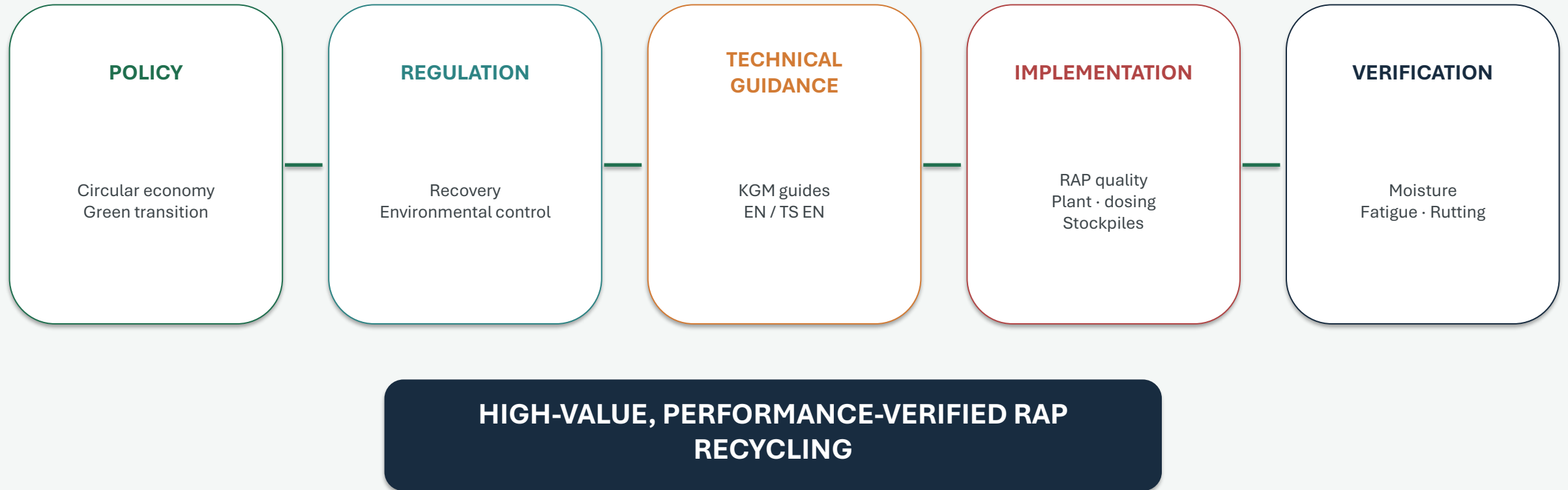
- Waste management and recovery
- Environmental permitting / licensing
- Controlled processing and reintroduction of reclaimed materials

TECHNICAL FRAMEWORK

- KGM Asphalt Recycling Guide (2023)
- KGM technical guidance
- EN / TS EN performance methods
- Moisture · Fatigue · Rutting

The next challenge is to translate this framework into higher-value, performance-verified recycling practice.

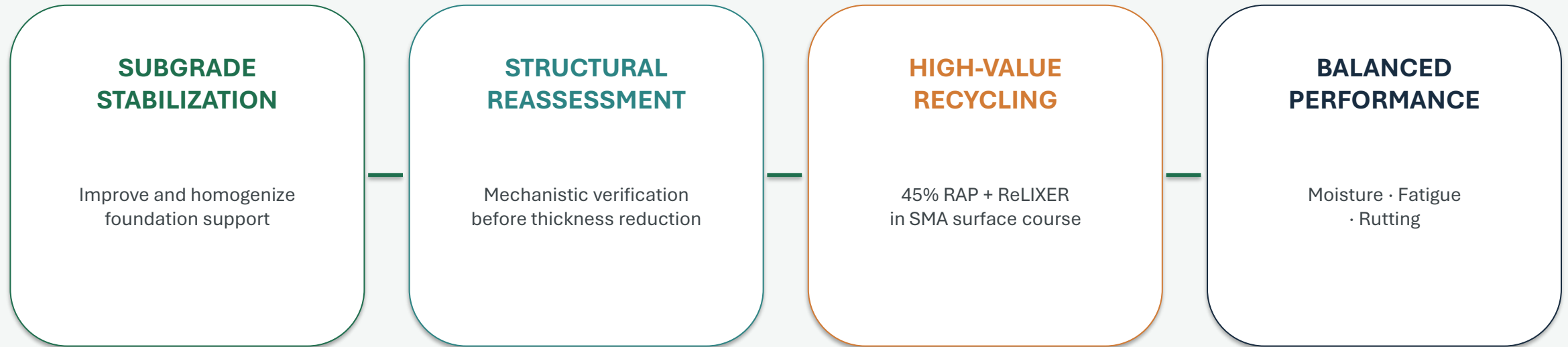
From Regulatory Readiness to Performance-Based Recycling



The next step is not simply more recycling. It is verified, higher-value recycling.

Integrated Pavement-System Philosophy

Resource efficiency is addressed at more than one level of the pavement system.



Neither higher RAP content nor reduced pavement thickness is an objective in itself.

Both remain conditional on verified material and structural performance.

Preliminary Structural Optimization Scenario

Conceptual — not a final structurally validated design

REFERENCE STRUCTURE

Total thickness

70 cm

4 + 13 + 13 + 20 + 20 cm

PRELIMINARY SCENARIO

Total thickness

60 cm

4 + 12 + 12 + 17 + 15 cm

-10 cm

**≈14.3% nominal
thickness reduction**

8 cm of the 10 cm reduction occurs in granular base/subbase layers.

Verification required: measured post-stabilization properties → mechanistic analysis → field validation.

Research Question

Can high RAP return to a demanding, high-value surface course?

45% RAP introduces a substantial aged-binder contribution.

THE CHALLENGE

Aged binder
Stiffness / cracking concern
Moisture susceptibility
Permanent deformation balance

THE APPROACH

Rejuvenation technology
45% RAP + 4% ReLIXER
SMA Type 1A surface mixture
Benchmark against two references

THE QUESTION

Can the high-RAP system maintain a balanced performance profile?

Moisture
Fatigue
Rutting

High recycled content is meaningful only if the resulting mixture performance is demonstrated.

Three SMA Mixture Systems

SMA 50/70

Conventional baseline

50/70 penetration-grade binder
Optimum binder $\approx 6.7\%$
Air voids $\approx 3.0\%$

SMA REF

Polymer-modified reference

PMB
Optimum binder $\approx 6.6\%$
Air voids $\approx 3.0\%$

SMA 45% RAP + 4% ReLIXER

High-RAP rejuvenated system

45% reclaimed asphalt
4% ReLIXER
Optimum binder $\approx 6.6\%$
SMA surface-course concept

RAP characterization: binder content 3.86% by total mixture mass; recovered aggregate gradation characterized before use.

Balanced Performance Framework

MOISTURE

AASHTO T 283

ITSR
Conditioned ITS

FATIGUE

EN 12697-24

4PBB · constant strain
20°C · 10 Hz · 250 $\mu\epsilon$

RUTTING

EN 12697-22

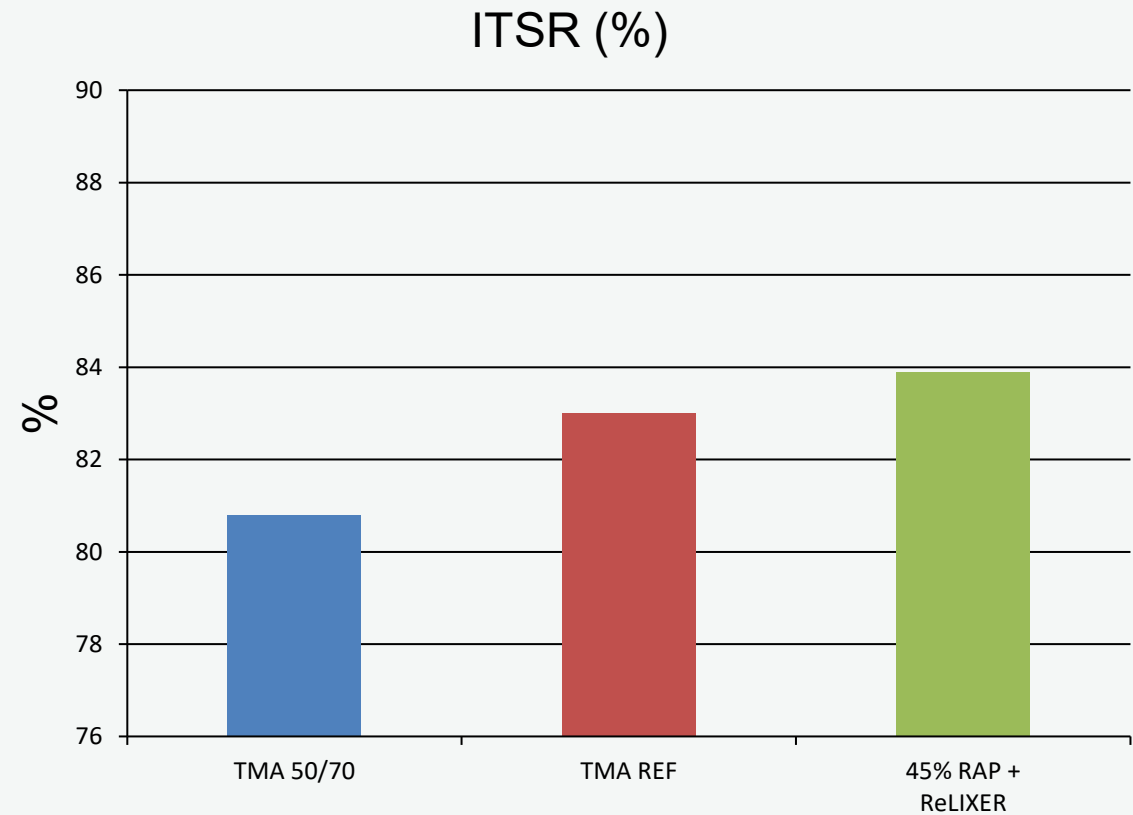
Procedure B
Rut depth · PRD · WTS

No single indicator is used to define an “optimum” mixture.

The objective is to examine the performance balance across major distress mechanisms.

Moisture Susceptibility

AASHTO T 283



KEY FINDINGS

ITSR

80.8% → 83.0% → 83.9%

Conditioned ITS (kPa)

934 → 975 → 1,314

Strength loss after conditioning

19.2% → 17.0% → 16.1%

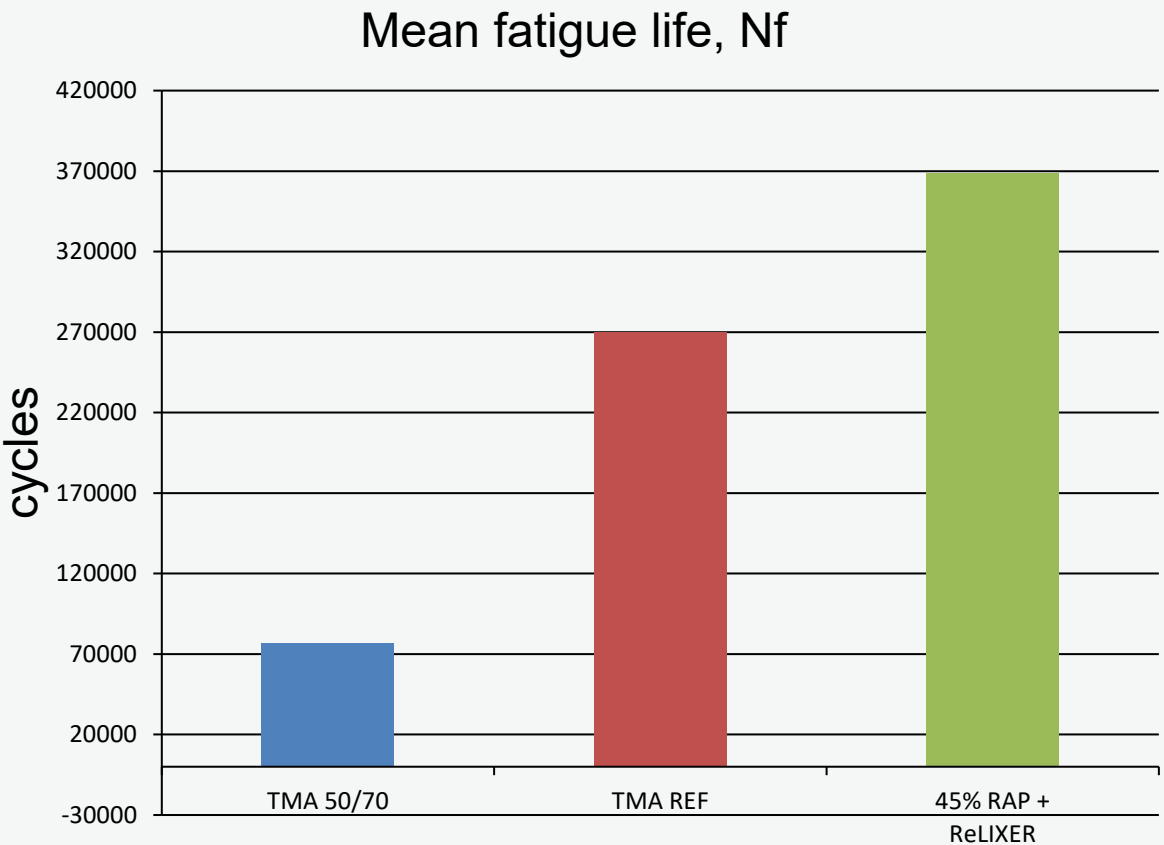
45% RAP + ReLIXER maintained moisture resistance and exhibited the highest retained-strength ratio.

Interpretation applies to the complete mixture system; the individual ReLIXER effect was not isolated.

ITS reported in SI units (kPa) for the European audience.

Fatigue Performance

EN 12697-24 · 4PBB · 20°C · 10 Hz · 250 µε



DESCRIPTIVE RESULTS

Mean Nf

76,650 → 270,167 → 368,500 cycles

Median Nf

75,850 → 268,000 → 373,500 cycles

CV

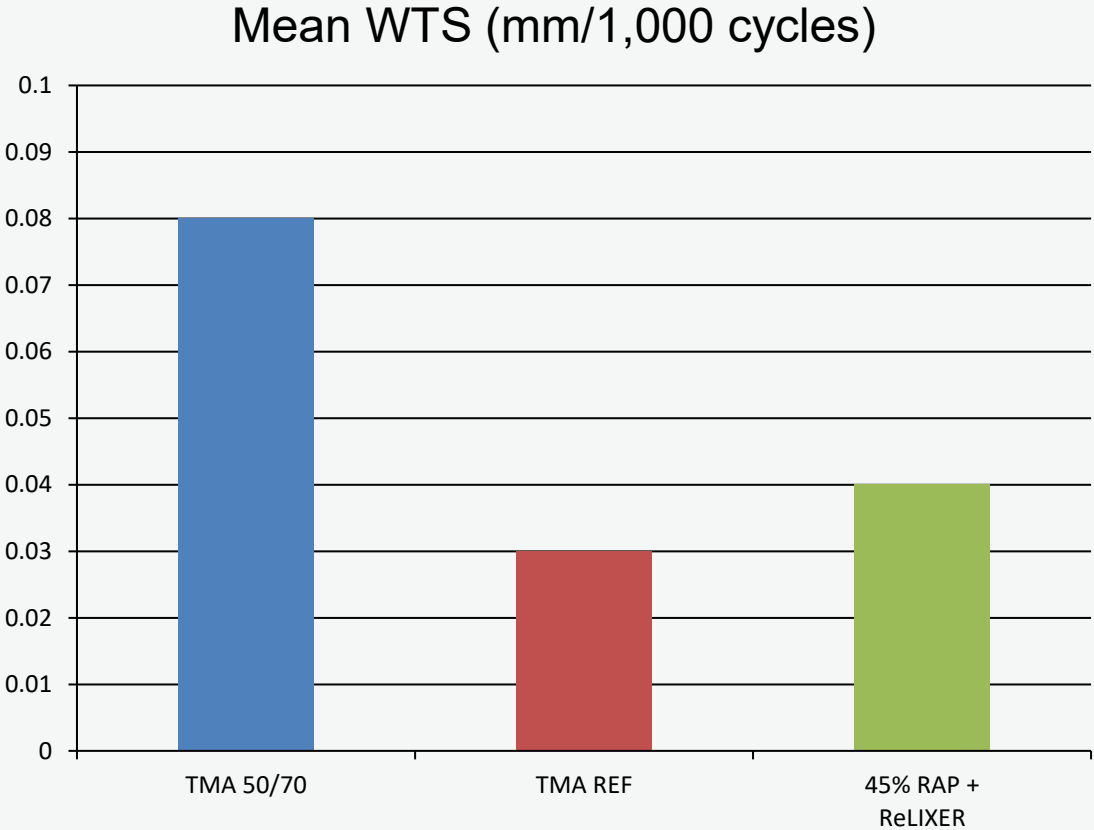
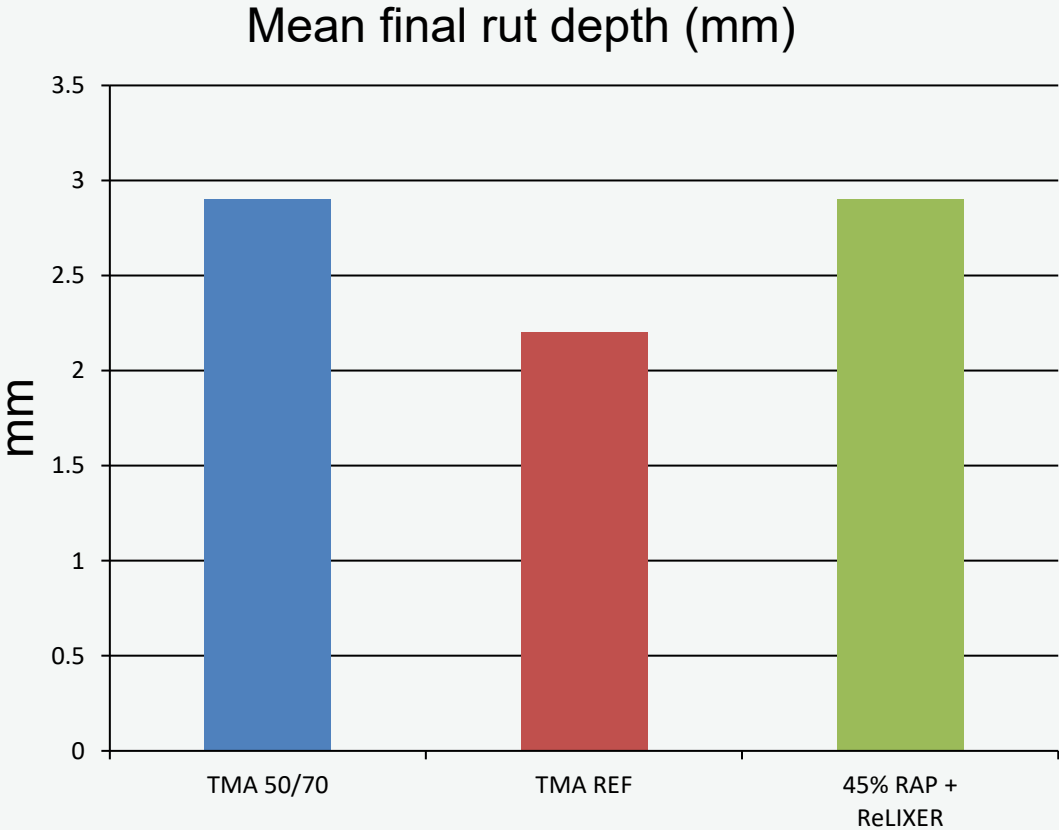
12.5% → 34.9% → 16.5%

High-RAP/ReLIXER mean fatigue life $\approx 4.81 \times$ SMA 50/70 and 36.4% above SMA REF.

High-RAP statistics are based on the four specimens included in the manuscript comparison.

Permanent Deformation Performance

EN 12697-22 · Procedure B · 10,000 cycles / 20,000 wheel passes



SMA REF achieved the lowest final rut depth; the high-RAP mixture matched SMA 50/70 in final rut depth but showed a lower deformation rate.

Balanced Performance: No Single Test Tells the Whole Story

Indicator	SMA 50/70	SMA REF	45% RAP + 4% ReLIXER
Mean fatigue life	76,650	270,167	368,500*
ITSR	80.8%	83.0%	83.9%
Mean rut depth	2.9 mm	2.2 mm	2.9 mm
WTS	0.08	0.03	0.04

SMA REF: strongest final rutting resistance

45% RAP + ReLIXER: highest mean fatigue life and ITSR

The results demonstrate a balanced performance profile across the investigated distress mechanisms. The 45% RAP + 4% ReLIXER system combined the highest mean fatigue life and ITSR with maintained permanent-deformation resistance.

What Does the High-RAP / ReLIXER Result Mean?

The 45% RAP + 4% ReLIXER system demonstrated a balanced laboratory performance profile across fatigue, moisture susceptibility and permanent deformation.

FATIGUE

Highest mean and median fatigue life among the three investigated systems.

MOISTURE

Highest ITSR and highest conditioned ITS.

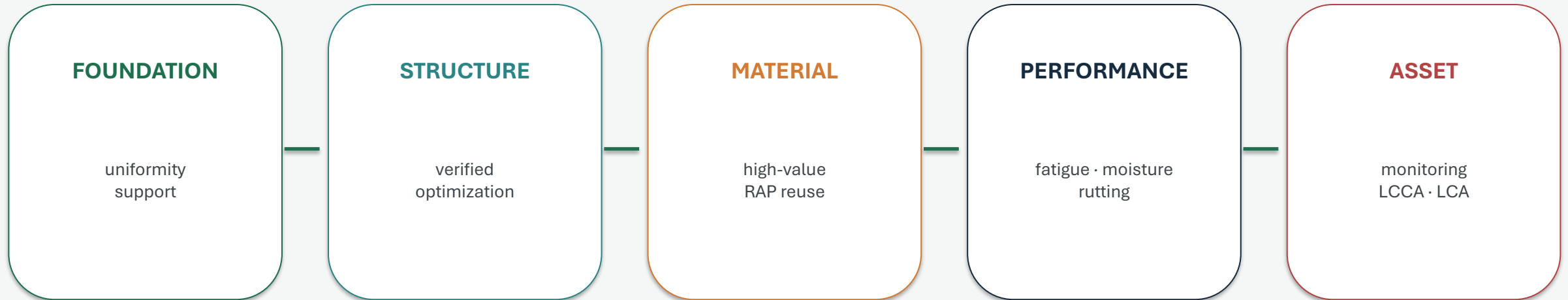
RUTTING

Same final rut depth as SMA 50/70; WTS close to SMA REF.

The investigated results support rejuvenation as an enabling technical pathway for managing the aged-binder contribution in high-value, high-RAP SMA design.

The results demonstrate the performance of the complete 45% RAP + 4% ReLIXER mixture system, supporting the potential of rejuvenation as an enabling technology for high-value, high-RAP SMA applications.

From Mixture Performance to Long-Term Motorway Asset Management

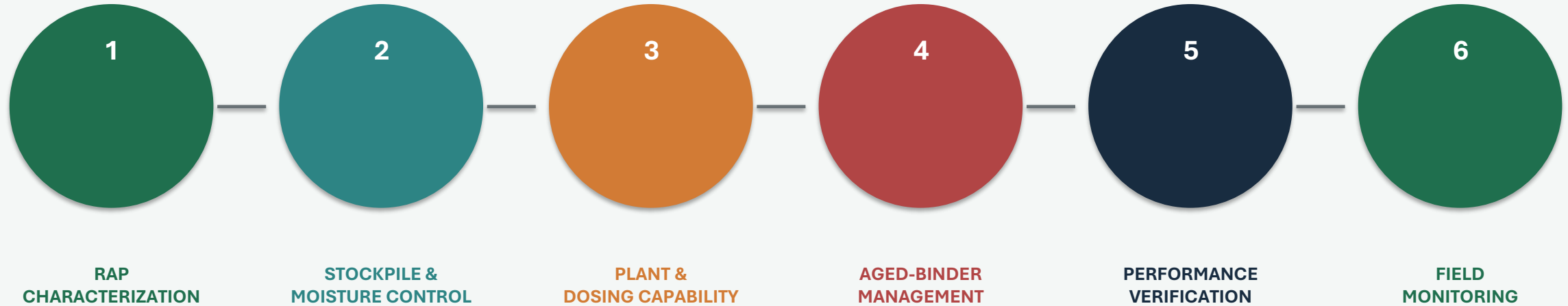


Long-term value cannot be inferred from laboratory results alone.

Field monitoring + mechanistic verification + life-cycle cost analysis + life-cycle environmental assessment

The laboratory programme is an initial component of a broader performance-based circular pavement asset-management framework.

Türkiye Roadmap: From Recycling Quantity to Verified Performance



RECLAIMED ASPHALT AS AN ENGINEERED RESOURCE — NOT ONLY A SUBSTITUTE MATERIAL

Performance-based circularity requires a system, not only a higher RAP percentage.

Conclusions



45% RAP + 4% ReLIXER maintained satisfactory moisture resistance

ITSR = 83.9%; highest conditioned ITS.



Fatigue response was particularly favourable

Mean Nf = 368,500 cycles under the investigated 4PBB conditions.



Rutting performance remained balanced

Final rut depth = 2.9 mm; WTS = 0.04 mm/1,000 cycles.



Structural optimization remains conditional

70 → 60 cm is preliminary and requires measured post-stabilization properties and mechanistic verification.

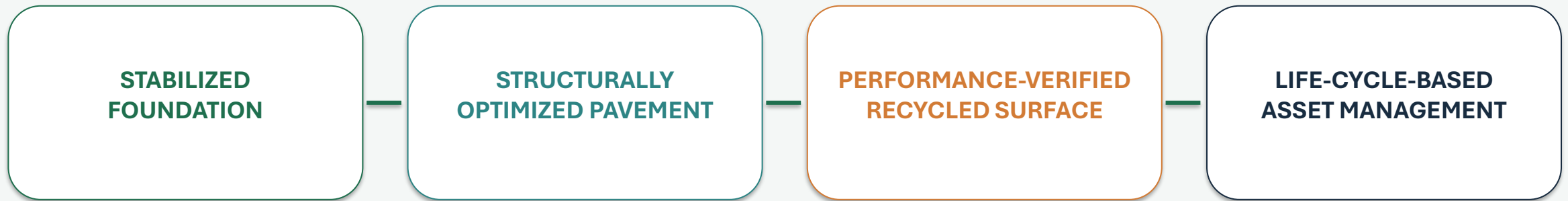


The key direction is performance-verified circularity

Higher RAP and reduced thickness are not independent objectives.

From Recycling Quantity to Verified Performance

The broader contribution is an integrated engineering direction — not a universally optimum mixture or a universally applicable reduced thickness.



Circularity should not be achieved at the expense of pavement performance.

The objective is to achieve both.

Next step: project-specific structural verification + field trial + long-term monitoring.

THANK YOU

Questions & Discussion

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