



# Global Road Infratech Summit & Expo

05-06 FEBRUARY 2026

Hotel The Ashok | New Delhi | India



*Paper ID: 35*

## *An Effective Role of NNDG in SMA layer*

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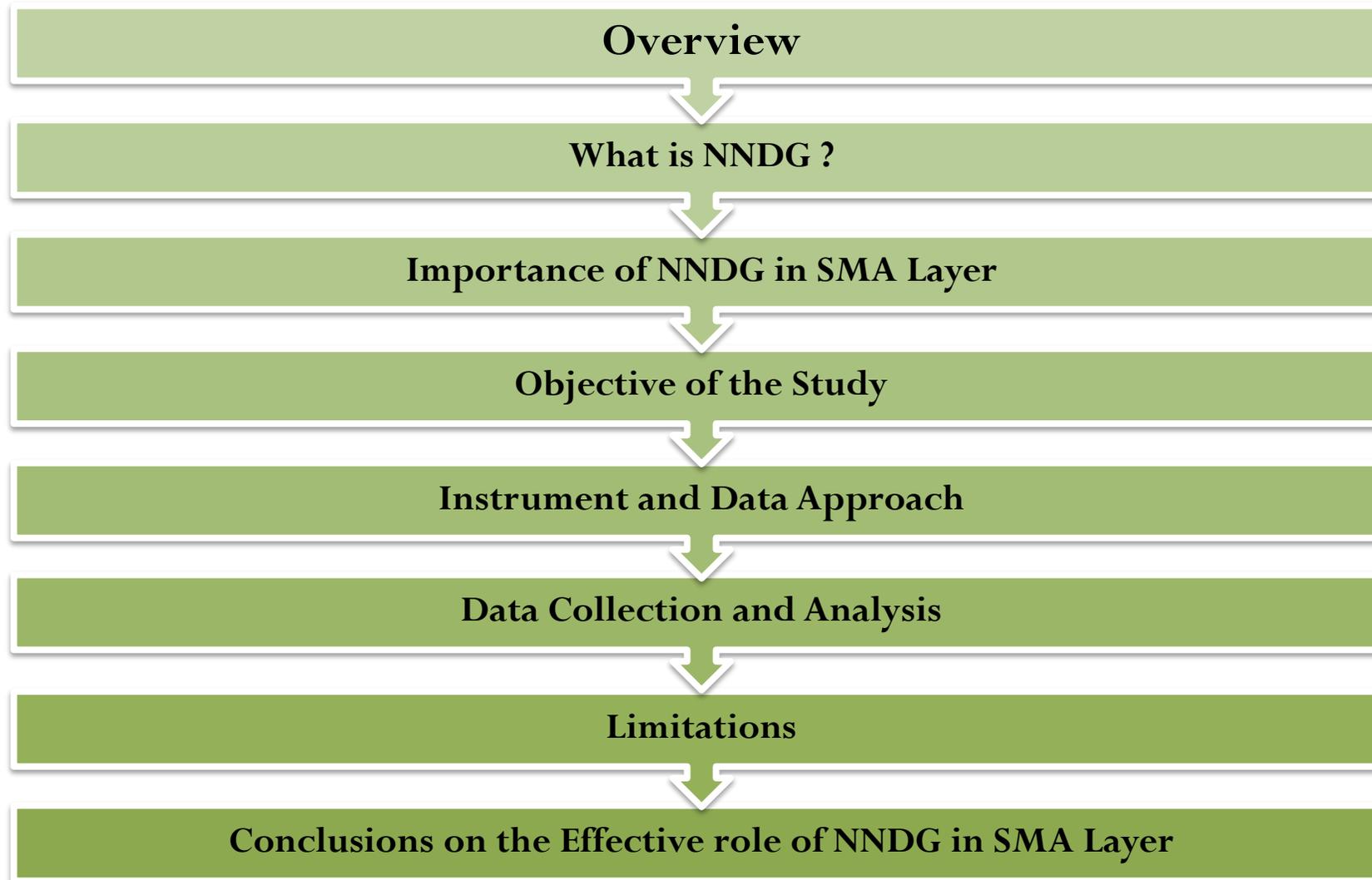


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## Stone Matrix Asphalt Benefits

SMA offers high durability and excellent resistance to rutting, making it ideal for highways.

## Limitations of Nuclear Gauges

Nuclear density gauges have radiation hazards and regulatory issues, posing safety concerns.

## Advantages of NNDG

Non-Nuclear Density Gauges provide safe, accurate, and real-time compaction monitoring without radiation.

## Study Findings and Benefits

Strong correlation of NNDG readings with core density, validates its use for quality control and efficiency.

# What is NNDG ?



A Non-Nuclear Density Gauge is an advanced, radiation-free field instrument that measures the in-place density of asphalt and other pavement layers using electromagnetic impedance technology.



**Precision without radiation** –  
Safe for operators and environment

**Instant feedback** – Enables  
intelligent compaction control during  
rolling

**Cost-efficient & sustainable** –  
Reduces reliance on destructive core  
sampling

# How to use NNDG ?

## Marking the area for Base Plate



## Taking Measurement



## Checking Reading



## Measurements on Display



# Importance of NNDG in SMA Layer

- Stone Matrix Asphalt is a bitumen rich, gap-graded, highly rut resistance mix designed to serve heavy-load traffic, where mix compaction is the cornerstone of durability. Achieving the specified in-place density ensures stone-on-stone contact, minimizes voids, and prevents premature rutting.
- The Non-Nuclear Density Gauge (NNDG) transforms this process by delivering real-time, radiation-free density measurements during compaction. Its importance lies in:

**Safety and Compliance:** Eliminates radioactive sources, removing regulatory hurdles and health risks.

**Precision and Speed:** Provides instant, accurate feedback for intelligent rolling decisions before the mat cools below critical temperature.

**Cost and Sustainability:** Reduces destructive core sampling, accelerates quality control, and supports green construction practices.

**Performance Assurance:** Enables uniform compaction across SMA layers, ensuring long-term structural integrity and superior service life.

# Objective of the Study

Evaluate the effectiveness of Non-Nuclear Density Gauge (NNDG) as a safe, practical alternative to nuclear gauges for SMA pavement compaction monitoring.

Validate accuracy and reliability of NNDG by correlating its readings with core density results.

Analyze compaction trends across roller passes to identify the optimum rolling effort for achieving target density without over-compaction.

Demonstrate real-time decision-making benefits for intelligent compaction and quality control.

Highlight sustainability and cost-efficiency by reducing reliance on destructive testing and radiation-based instruments.

## Non Nuclear Density Gauge (NNDG)

- Model: Pavement Quality Indicator (PQI 380 or equivalent)

### Measurement Principle

- Uses impedance spectroscopy, where a low-voltage electric field is transmitted through the asphalt layer.
- The device measures the electrical impedance, which is influenced by:
  - Aggregate gradation
  - Asphalt binder type
  - Air void content
  - Moisture
- Since electrical impedance varies predictably with mixture density, the gauge converts this electrical response into density ( $\text{kg/m}^3$  or  $\text{lb/ft}^3$ ) using calibration curves.

### General Principle Across NNDGs

- Every NNDG works on variations of these electromagnetic properties:
  - Dielectric constant
  - Electrical resistivity
  - Impedance
- Material properties change systematically with asphalt density, allowing device to compute % compaction.

# Instrument and Data Approach

## Why This Works Technically

- As asphalt is compacted:
- Air voids reduce
- Contact between aggregates increases
- Conductive paths and dielectric behavior change
- Electrical impedance becomes more stable and predictable
- Thus, NNDGs interpret density by analyzing these electrical characteristics, rather than radiation absorption

## Calibration Requirement

- Because electrical properties differ for every mix:
- The NNDG must be calibrated using core densities.
- The difference between PQI/NNDG density and core density is computed.
- An offset (average difference in the density) is applied to make readings match the specific mix.
- This ensures accuracy and repeatability for each project.

## Advantages Over Nuclear Gauge

- No radioactive source → No shielding, storage, license, or decay issues.
- High repeatability due to stable electronics.
- Instant stabilization (nuclear gauges need warm-up and drift correction).
- No radiation scattering errors.
- Better spatial resolution (larger measurement footprint).

## Data Collection Approach

- Five points were selected on the freshly compacted mat for calibration.
- NNDG readings were recorded using a five-point cloverleaf pattern at each location.
- Corresponding cores were extracted and tested in a certified lab using the AASHTO T 166 standard.
- The average offset was computed and programmed into the NNDG for further readings.

# Instrument and Data Approach



**Average Reading** PQI 380

Push #1 Button to start reading 1 of 5

**Density Summary**

1.	5	2
2.	1	3
3.	4	
4.		
5.		

Mix: Fine  
Project: Rt 67 & 30

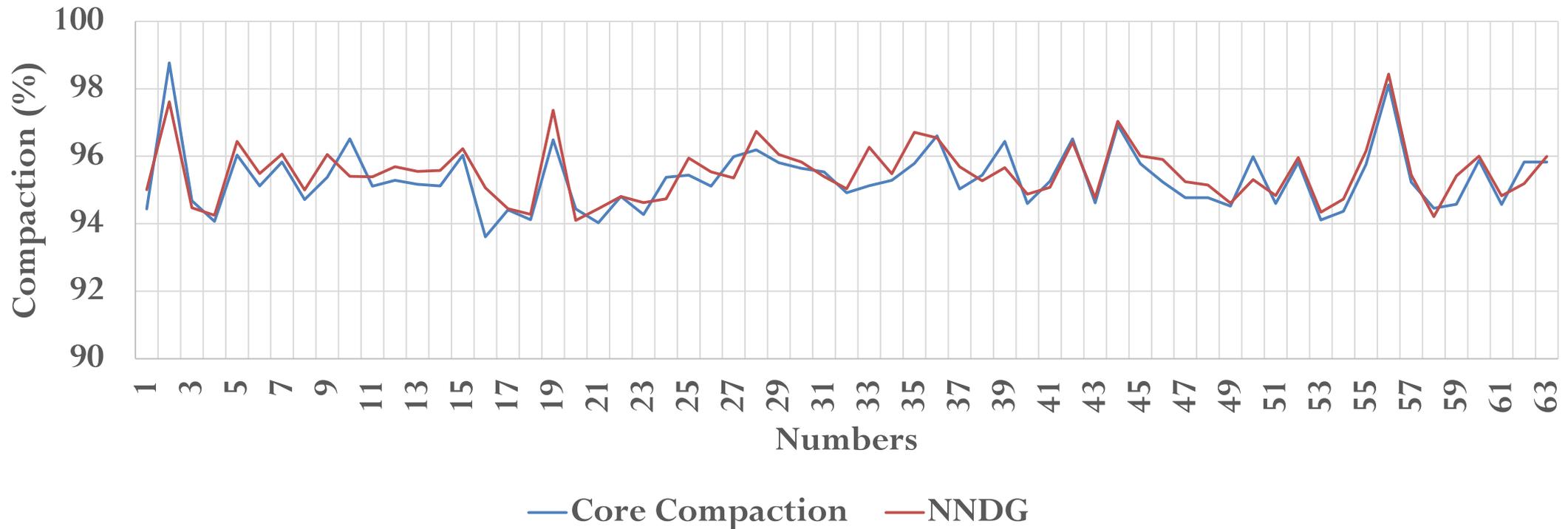
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# Instrument and Data Approach

- A strong correlation was found between core results and NNDG measurements, with similar trends observed in compaction values.

Parameter	Value
Correlation (r)	0.86
R <sup>2</sup>	0.74
RMSE (%)	0.51

### Core vs NNDG Compaction (%)



## Statistical Relationship: Core vs NNDG

### 1. Correlation Coefficient (r)

$$r = 0.863$$

- Indicates a **strong positive correlation**
- As core density increases, NNDG readings also increase consistently

### 2. Coefficient of Determination ( $R^2$ )

$$R^2 = 0.744$$

- About **74.4% of the readings** in NNDG readings is near to core density.

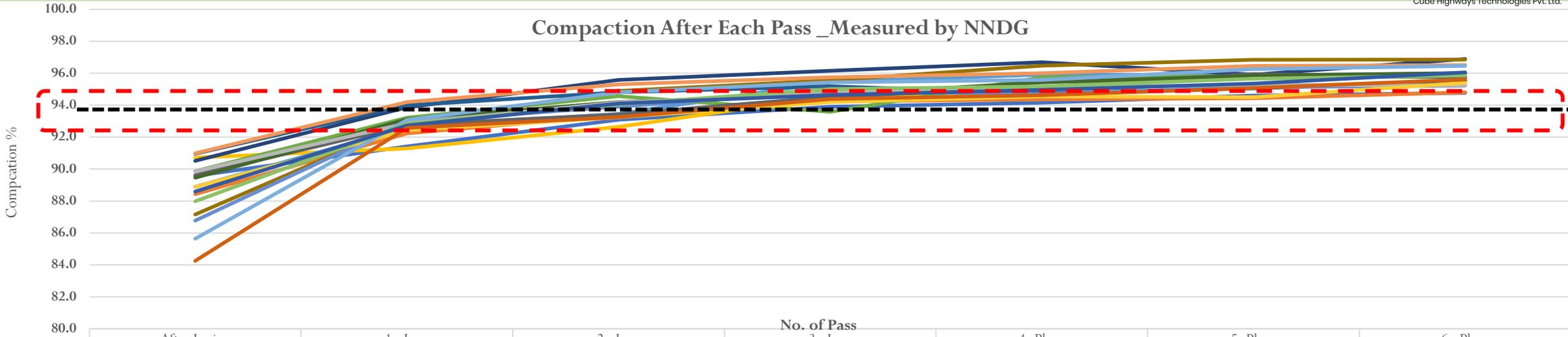
### 3. Root Mean Square Error (RMSE)

$$RMSE = 0.51 \% \text{ density}$$

- Average deviation between NNDG and core density is **~0.5%**.

Parameter	Value
Correlation (r)	0.86
$R^2$	0.74
RMSE (%)	0.51

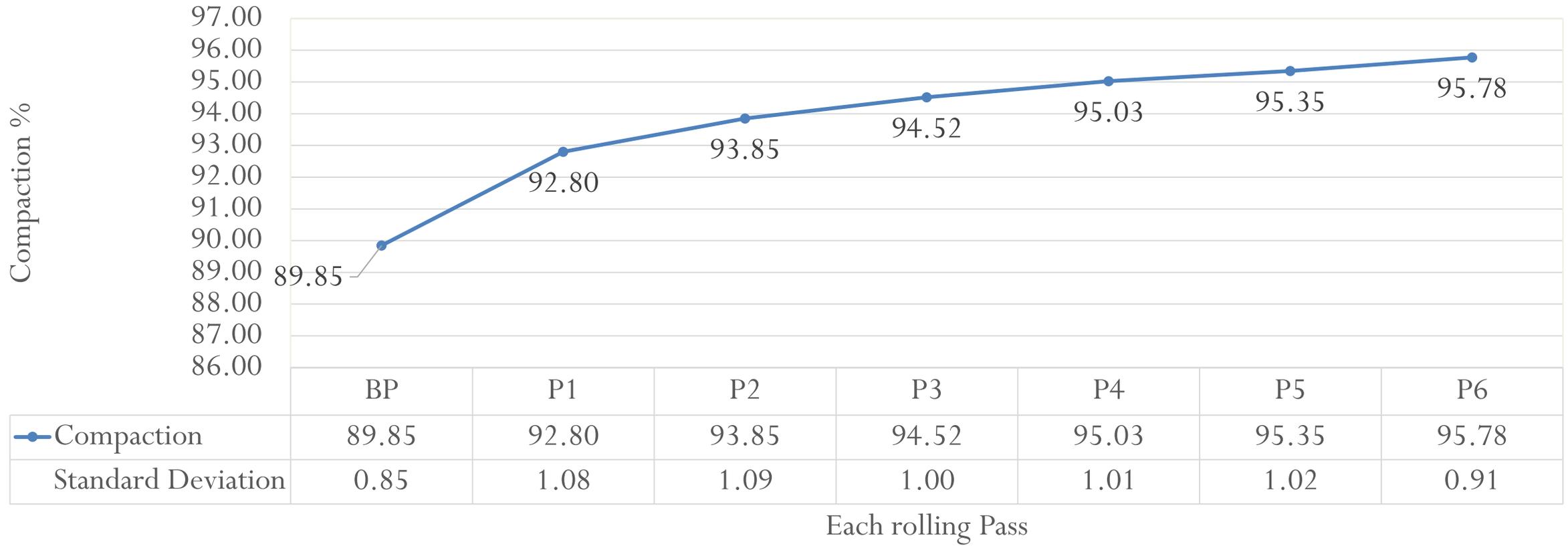
# Instrument and Data Approach



	After Laying	1 - Low	2 - Low	3 - Low	4 - Plane	5 - Plane	6 - Plane
305+650	89.6	91.4	93.1	93.9	94.2	94.6	94.8
305+688	88.4	92.2	93.4	94.2	94.4	94.4	94.8
306+550	90.7	91.3	92.6	94.6	94.6	95.1	95.5
306+590	88.9	92.6	93.5	95.5	95.9	95.9	96.0
316+500	89.9	93.2	94.6	93.6	95.7	95.8	95.7
316+545	90.5	93.9	95.6	96.2	96.7	95.9	96.9
319+070	89.6	92.8	93.4	94.5	95.1	96.0	95.7
325+270	87.2	92.9	94.9	95.6	96.5	96.8	96.9
325+320	91.0	94.0	94.8	95.2	94.7	95.0	95.5
325+090	89.5	93.1	94.2	94.6	95.4	95.8	96.0
325+240	86.8	93.0	93.9	94.9	94.7	95.1	95.2
323+250	91.0	94.2	95.3	95.8	96.0	96.5	96.5
319+400	89.9	92.9	94.2	94.8	95.1	95.3	95.2
319+350	88.9	92.4	93.2	94.2	94.5	94.5	95.4
318+060	85.6	93.1	94.8	95.4	95.6	96.3	96.5
318+040	88.0	92.8	94.1	95.0	95.2	95.7	95.9
316+950	88.6	92.7	94.1	94.6	95.0	95.3	96.1
316+830	84.3	92.6	93.3	94.4	94.6	95.1	95.6

# Instrument and Data Approach

- Density readings were recorded using NNDG after base point (BP or just after laying) and subsequent rolling passes (Pass 1 to Pass 6).
- A total of 350 compaction recordings were collected, with 50 measurements taken at each pass. The data clearly shows a consistent trend in compaction behavior from the base pass through six subsequent rolling passes.



—●— Compaction      Standard Deviation

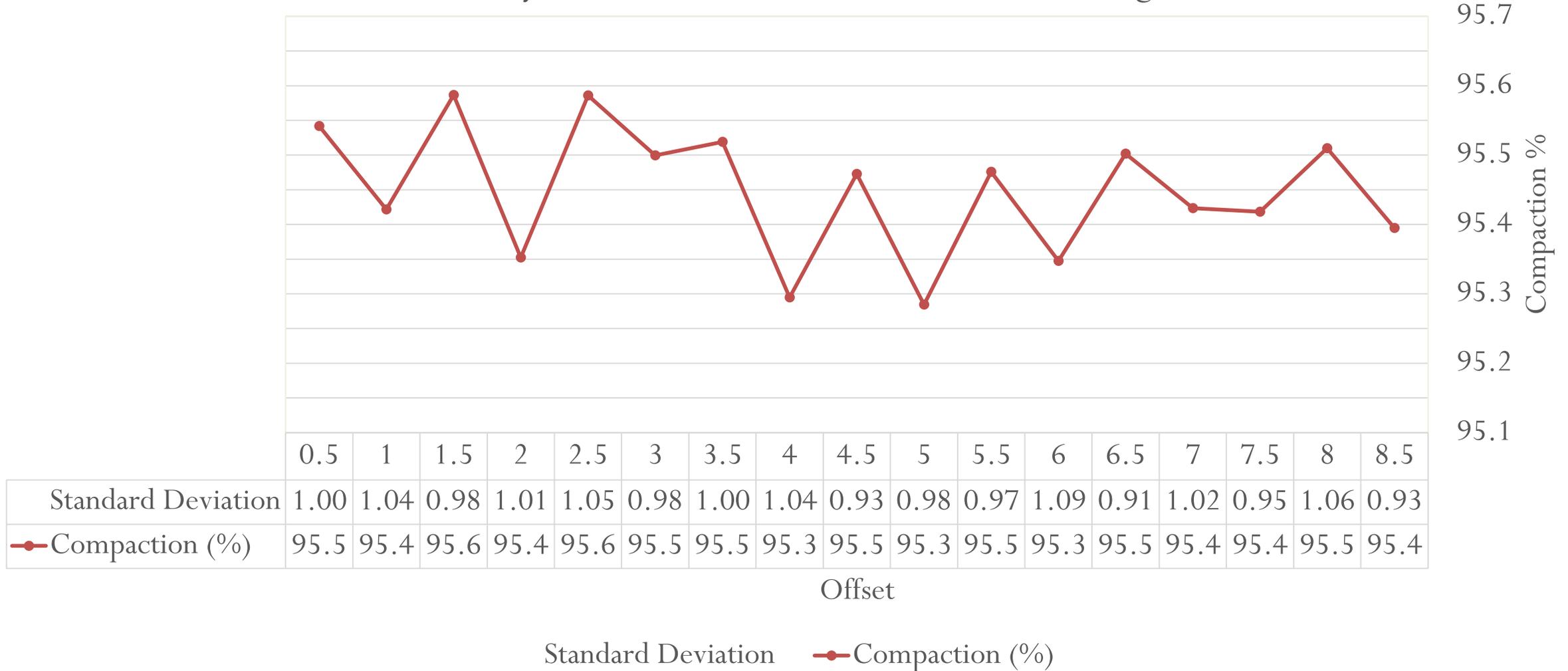
# Instrument and Data Approach

- We have recorded almost 2500 readings and observed average compaction between from 95.2 to 95.6 at each offset.

Offset	Number of Readings	Average Compaction
0.5	190	95.542
1	105	95.422
1.5	193	95.587
2	117	95.432
2.5	179	95.586
3	117	95.499
3.5	191	95.519
4	117	95.295
4.5	139	95.473
5	124	95.284
5.5	136	95.476
6	116	95.347
6.5	175	95.502
7	176	95.424
7.5	199	95.418
8	204	95.510
8.5	18	95.395

# Instrument and Data Approach

Statistical Analysis of NNDG data at each 0.5m offset range



## Effect of Surface Irregularity and Moisture.

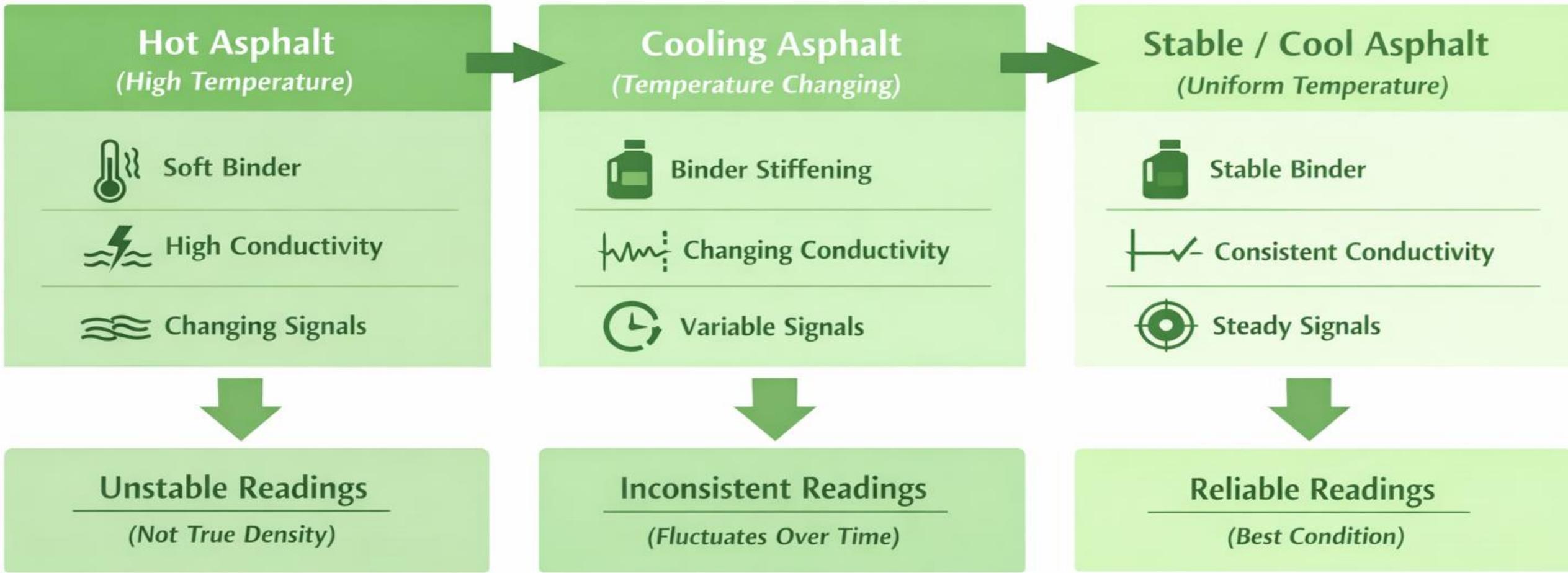
- PQI-380 accuracy depends on uniform contact between the sensor plate and pavement surface
- Irregular, rough, or segregated surfaces hinder proper seating, leading to unstable impedance measurements
- Presence of loose aggregates or surface texture variations introduces measurement variability
- Although equipped with relative moisture detection, excessive or non-uniform surface moisture alters electrical conductivity
- Moisture correction is limited and cannot fully compensate for wet or partially saturated surfaces
- Manufacturer recommends measurements on clean, flat, and dry surfaces for reliable results

## Calibration Sensitivity and Operational Constraints

- PQI-380(NNDG) is highly material-dependent, requiring calibration for each asphalt mix design
- Accuracy relies on the quality and representativeness of calibration cores
- Errors in core density, coring location, or laboratory testing directly propagate into PQI results
- Incorrect input of aggregate size, lift thickness, or maximum theoretical density (MTD) causes systematic bias
- Offset corrections apply only after calibration and do not correct prior measurements
- Periodic factory recalibration is required, indicating potential electronic drift over time

# Limitations

## Effect of Pavement Temperature on PQI-380 (NNDG) readings



NNDG ensures accurate density without radiation hazards.

Enhances compaction efficiency and quality of the SMA layer.

Supports sustainable pavement construction and reduces core cutting.

Real-time data enables correction, helps identify soft spots and inconsistencies.

Recommended for SMA applications.

*Global Road Infratech Summit & Expo (GRIS-2026)*  
*05-06 February 2026, New Delhi, India*

**THANK YOU**



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