Intelligent Construction Systems

Innovations in Compaction Control and Testing

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www.fhwa.dot.gov/pavements/

Intelligent Compaction, IC

What is "Intelligence?"

- Oxford Dictionary: *"…able to vary behavior in response to varying situations and requirements"*
- Ability to:
  - Collect information
  - Analyze information
  - Make an appropriate decision
  - Execute the decision

Key Question?

- *"Can we make the compaction process work smarter not harder?"*
  -- Jim Musselman (FL DOT)

FHWA IC Team

- 12 State Pooled Fund Partners…
- Roller & Test Equipment Manufacturers
- V. Lee Gallivan, HQ/RC
- Michael Arasteh, RC
- Fred Faridazar, RD
- Tom Harman, RC
- John D'Angelo, HQ
- Bob Horan, SaLUT *(Support Staff)*

We've come a long way!

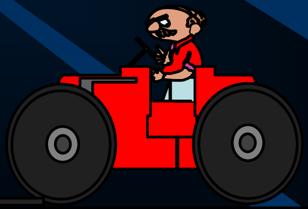
Because we always ask…

How can we do it better?

What's the next innovation?

Our Visit

- Goal of Roadway Compaction
- Conventional Limitations *“Challenges”*
- Goal of Intelligent Compaction, IC
- Roadway Compaction 101 *“Basics”*
- NCHRP IC Project
- Pooled Fund IC Project
- Shared Vision



Roadway Compaction

- Proper in-place density is vital for good performance
- Conventional compaction procedures have some limitations…

- Intelligent compaction technology appears to offer *“a better way”*

Conventional Limitations

- The Compaction Process…

Limited "On Fly" Feedback

Over or Under-Compaction Can Occur

Conventional Limitations

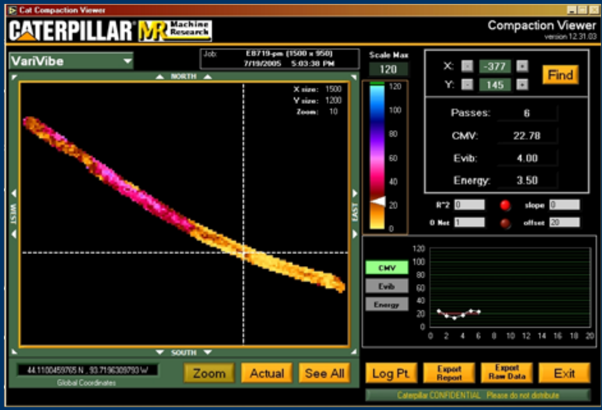
- Density Acceptance…

Limited Number of Locations

After Compaction is Complete

Intelligent Compaction

Can we make the process…smarter?



Improved Roller Technology

Sophisticated / Clear Documentation Systems

ACE
Ammann Compaction Expert

Advanced Hardware & Software

IC – Goals / Benefits

- **Short Term**
  - Improve density… better performance
  - Improve efficiency… cost saving$
  - Increase information… better QC/QA

- **Long Term**
  - Comprehensive Compaction Control (CCC)
  - Estimate pavement moduli?
  - Tie to M-E Design Guide (verify design)?
  - Performance specifications?

Roadway Materials Compaction 101

What are the basics of compaction?

Importance of Compaction

We've known it for a long time…

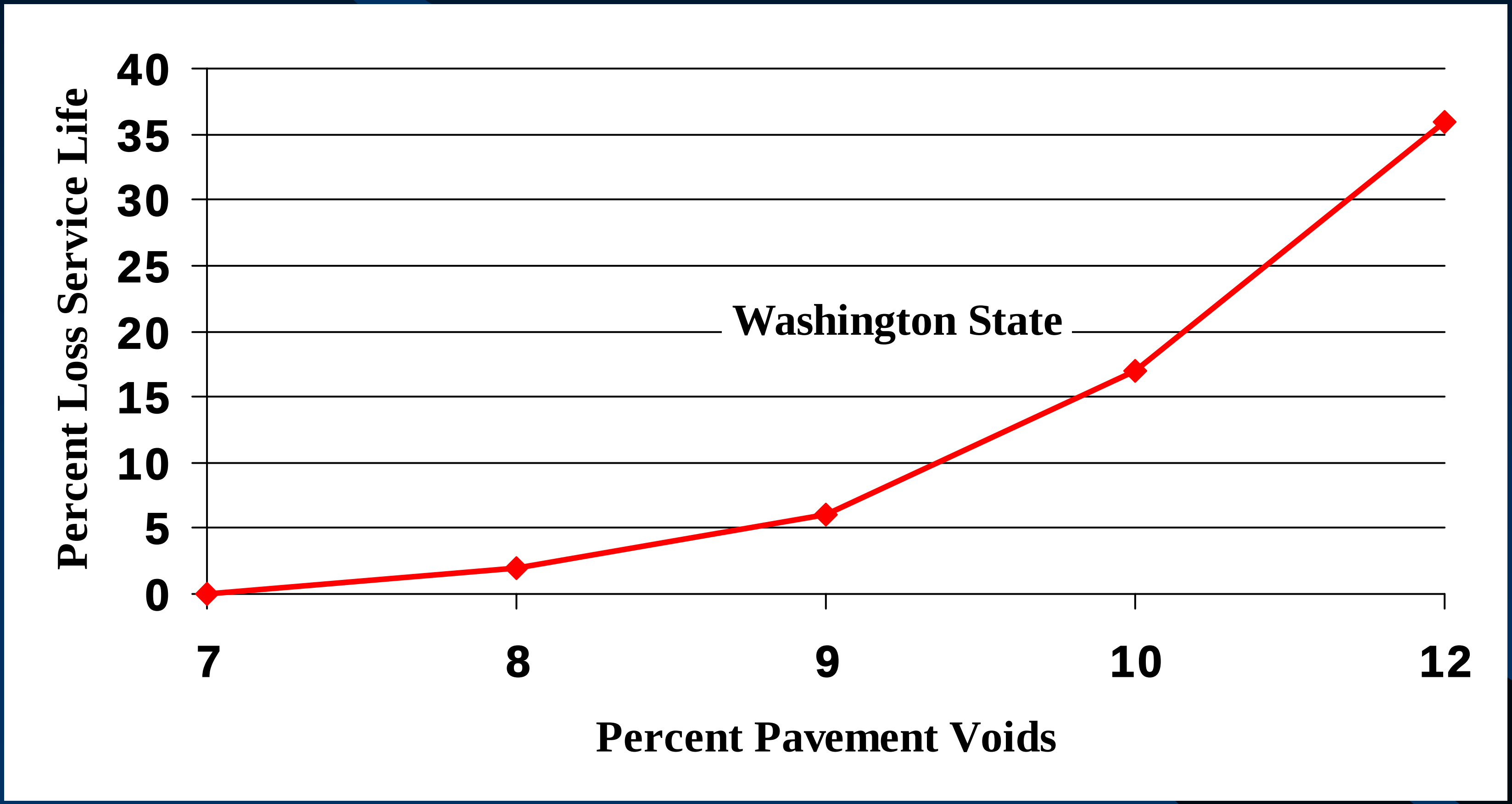
THE IMPORTANCE OF COMPACTION in highway construction has long been recognized. Recent laboratory and field investigation have repeatedly emphasized the value of thorough consolidation in both the base and surfacing courses. Thorough compaction in known to produce the following desirable results:

1. It increases interlocking of the aggregate particles, which is the primary factor in developing a high degree of stability.
2. It retards the entrance of moisture, thus preventing excessive loss of stability under adverse service conditions.
3. It reduces the flow of air and water through bituminous mixtures and is therefore an effective means of lessening damage from weathering and film stripping."

Reference -- "Public Roads, **May 1939**, authors J.T. Pauls and J.F. Goode"

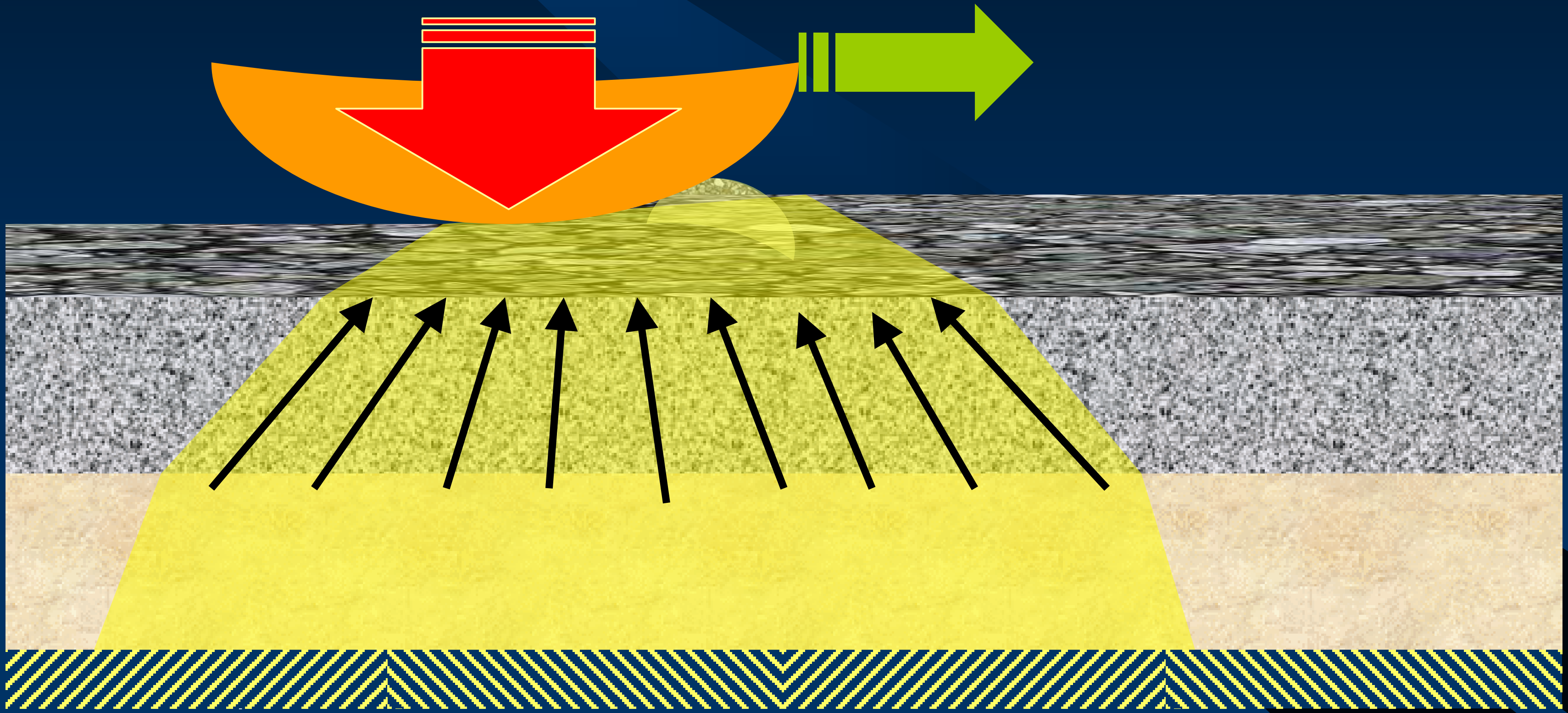
Basics of HMA Compaction

Effect of In-situ Air Voids on Life



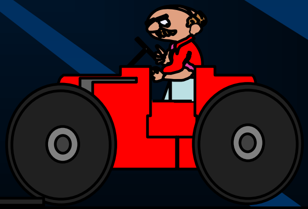
Basics of Compaction

- Effort (Roller) versus Resistance…

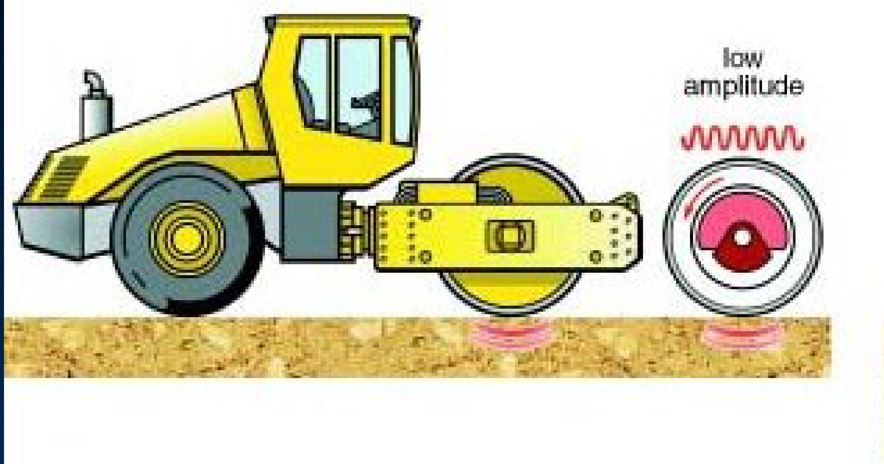


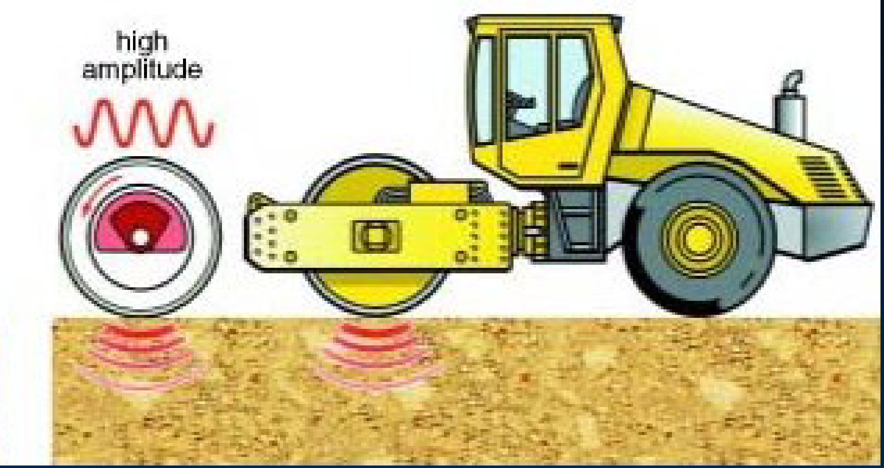
Basics of Compaction using Vibratory Rollers

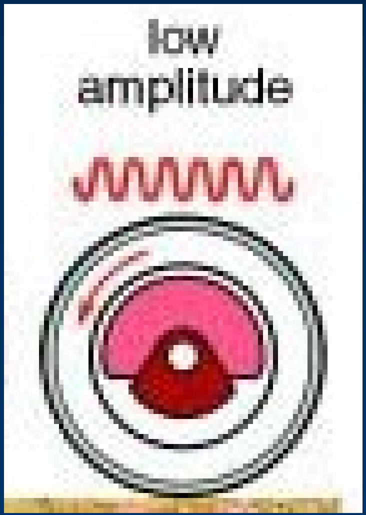
- Constant Mass
- Variables of Vibration
  - –Frequency, *f* (Hz)
  - –Amplitude, A
  - –Roller speed, *v* (fps)

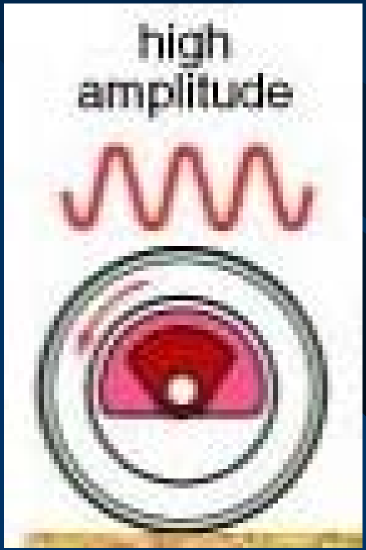


Basics of Compaction using Vibratory Rollers





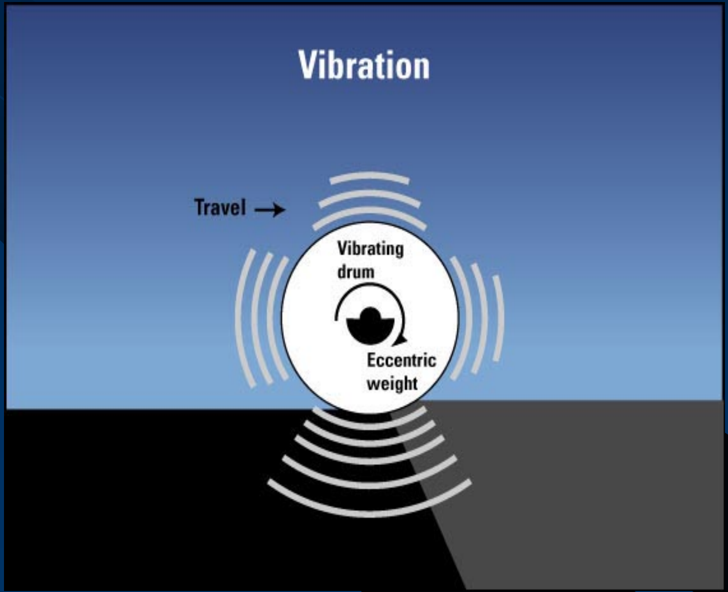




Courtesy Bomag America

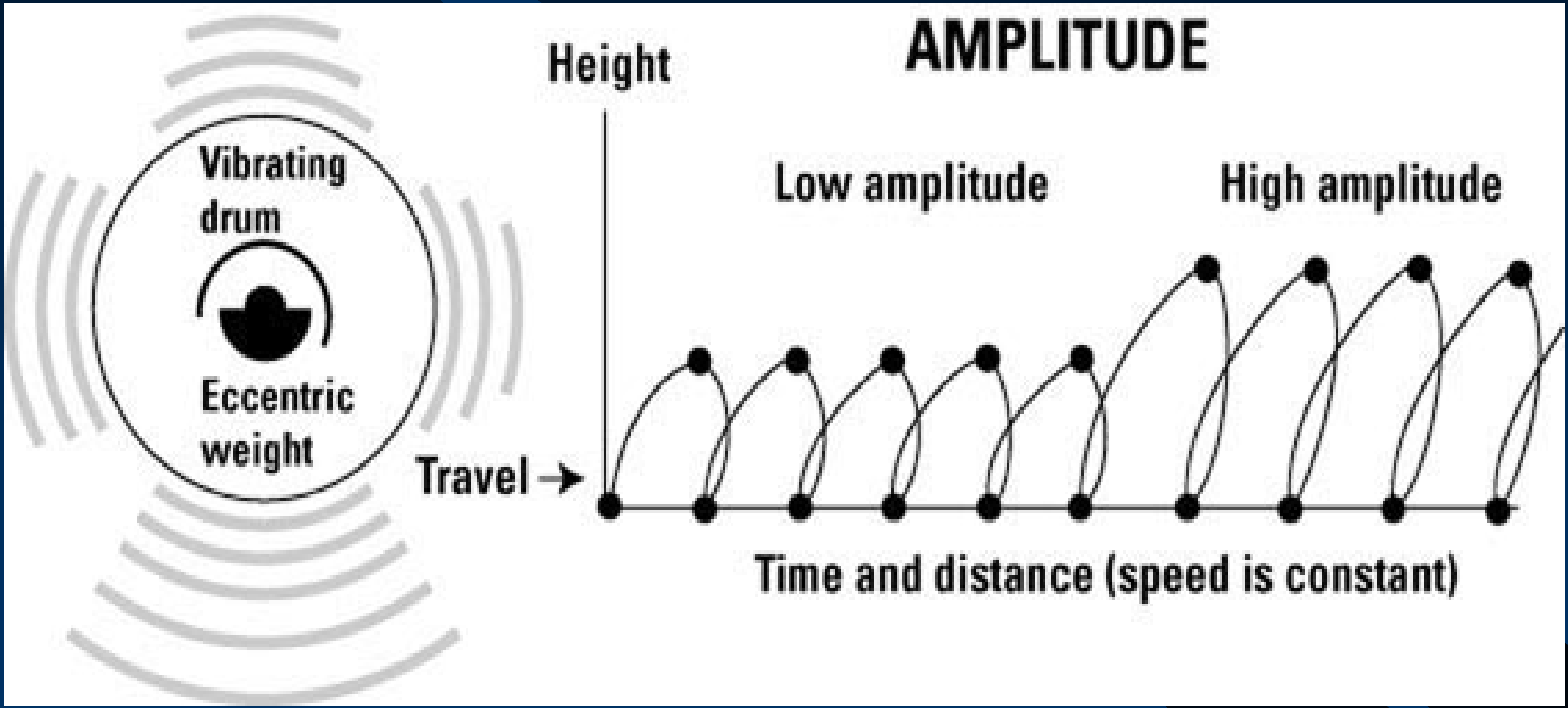
Vibratory Effort

- Vibration sets aggregates in motion
- Helps aggregates re-orient for better contact

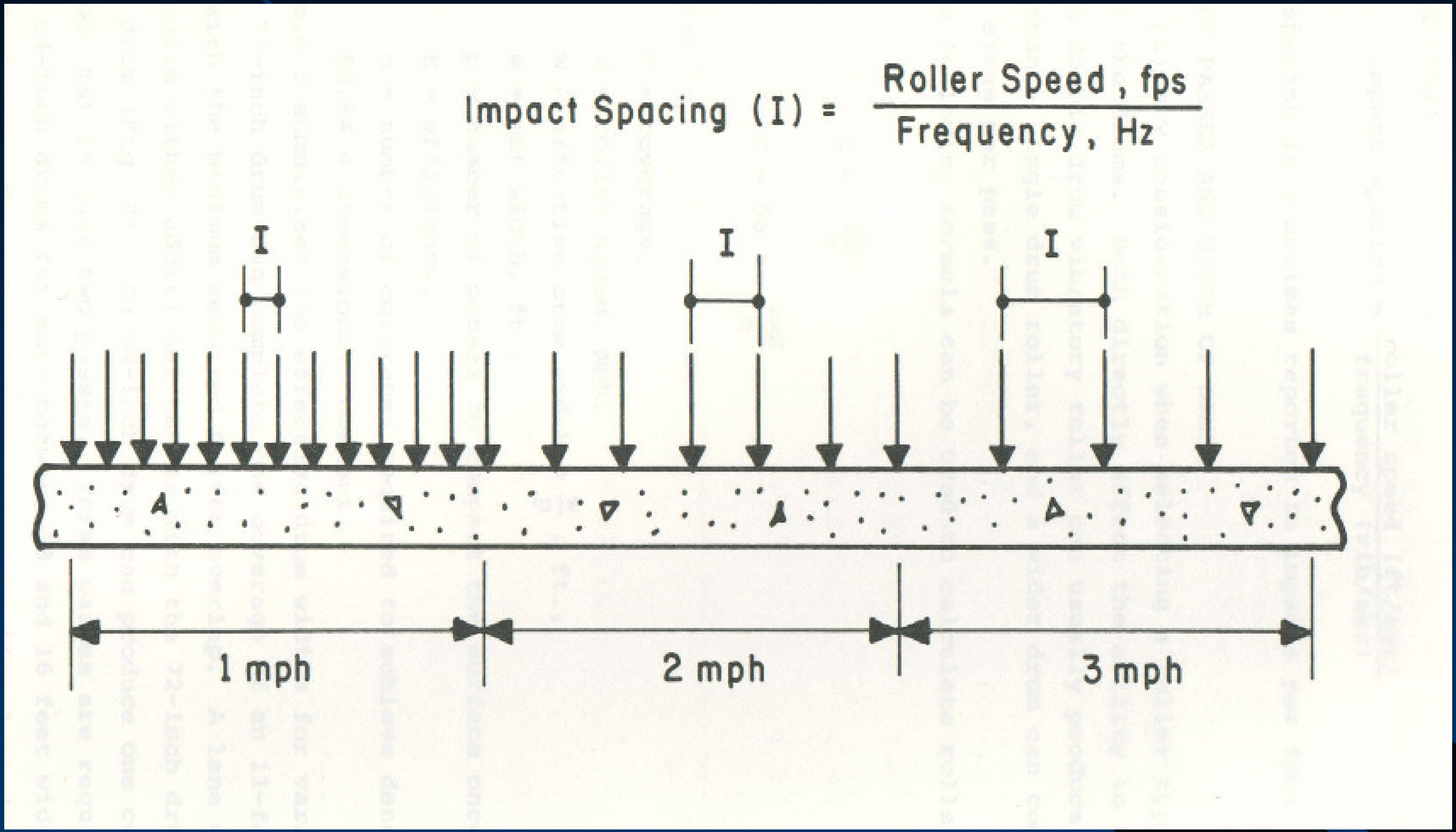


Amplitude

- Amplitude determines impact force

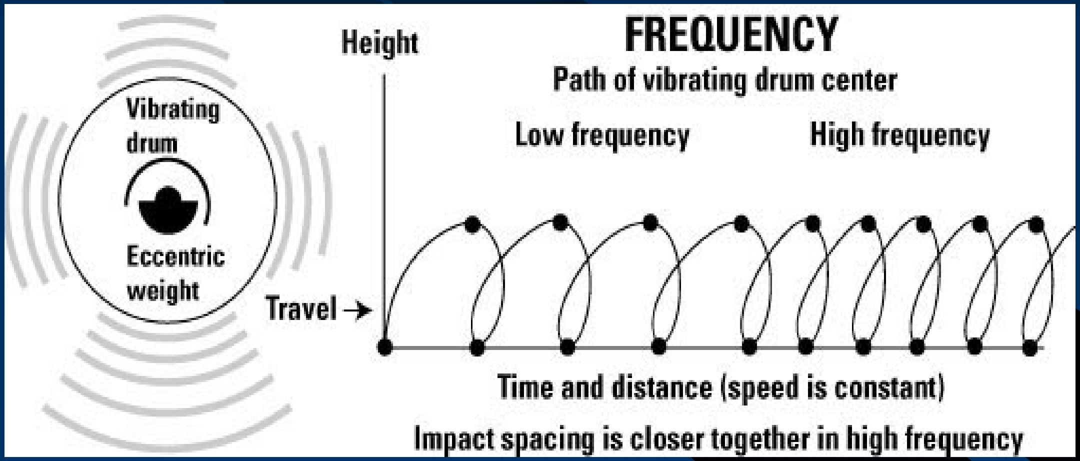


Impact Spacing, I = *f* (*v* , Hz)

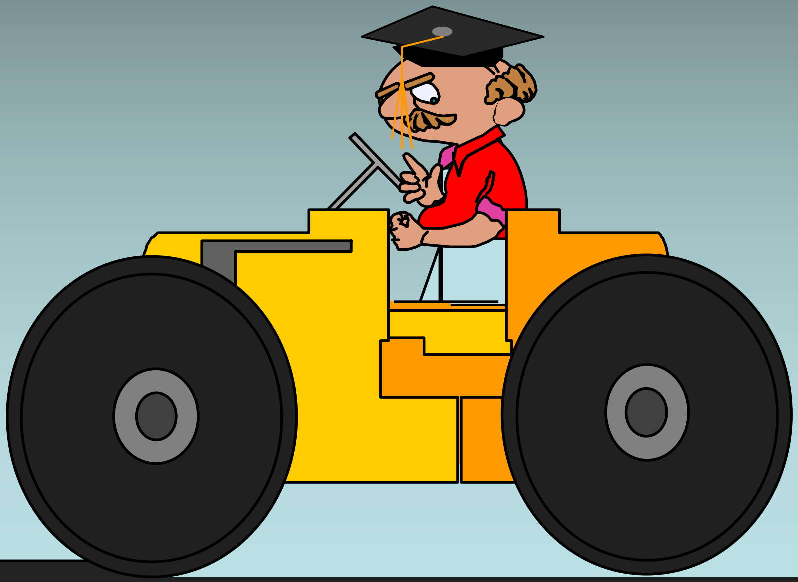


Optimization…

- Amplitude controls force & depth
- Frequency and Speed control Impacts
- Ex. "Best" results when impact spacing is 10 -14 impacts / foot for HMA

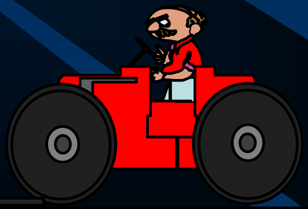


Intelligent Compaction, IC



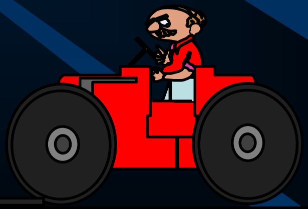
IC TPF / FHWA Definition

1. Vibratory rollers with measurement / control system
   - Measurement system, ex. material stiffness
   - Control system automatically changes parameters (amplitude and possibly frequency) based on measurement…

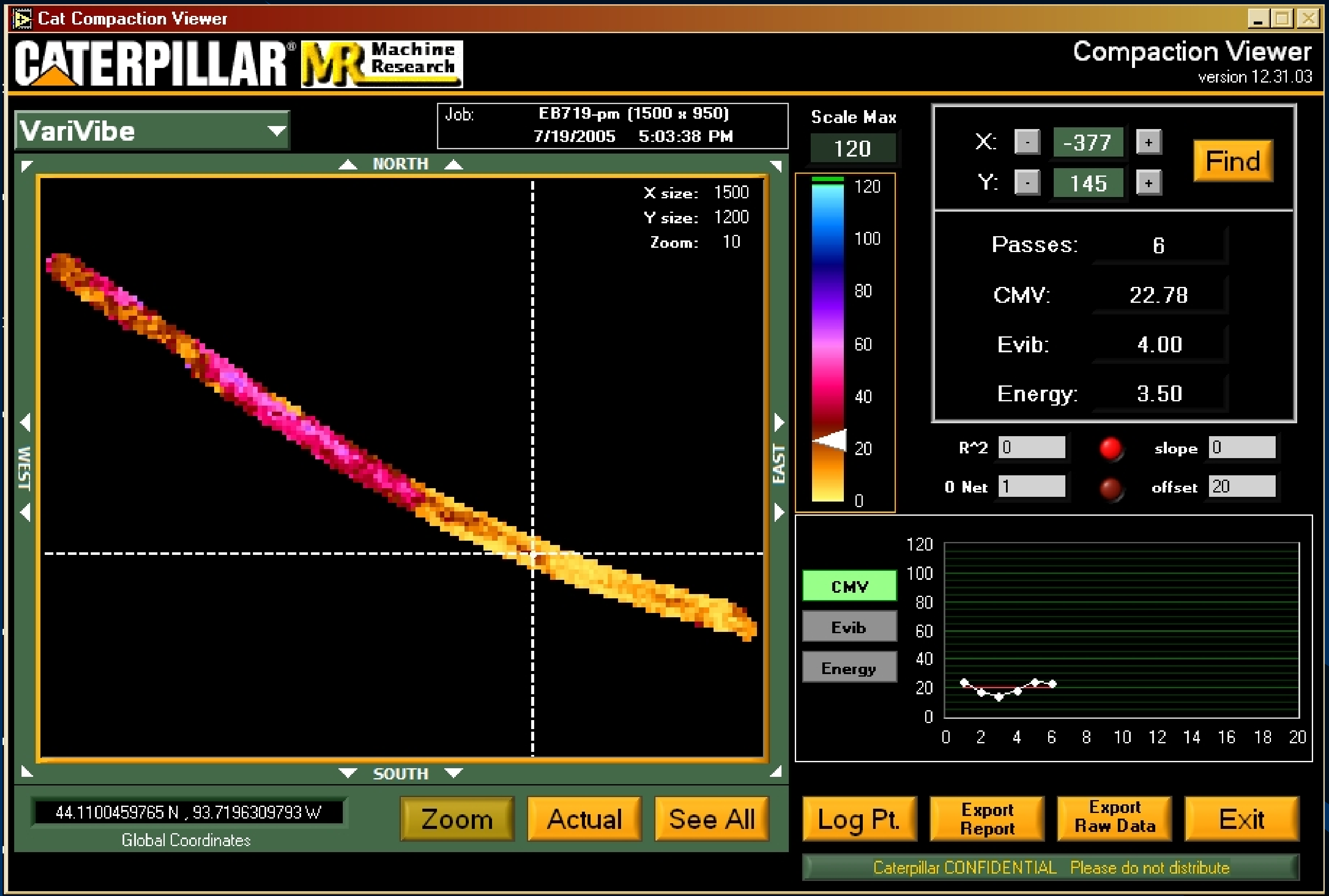


IC TPF / FHWA Definition

2. GPS-based documentation systems
   – Continuous recordation of materials stiffness
   – Continuous recordation of corresponding roller location
   – Color-coded mapping of stiffness



Ex. Caterpillar



Courtesy of Caterpillar

Ex. Sakai…

Controller Units

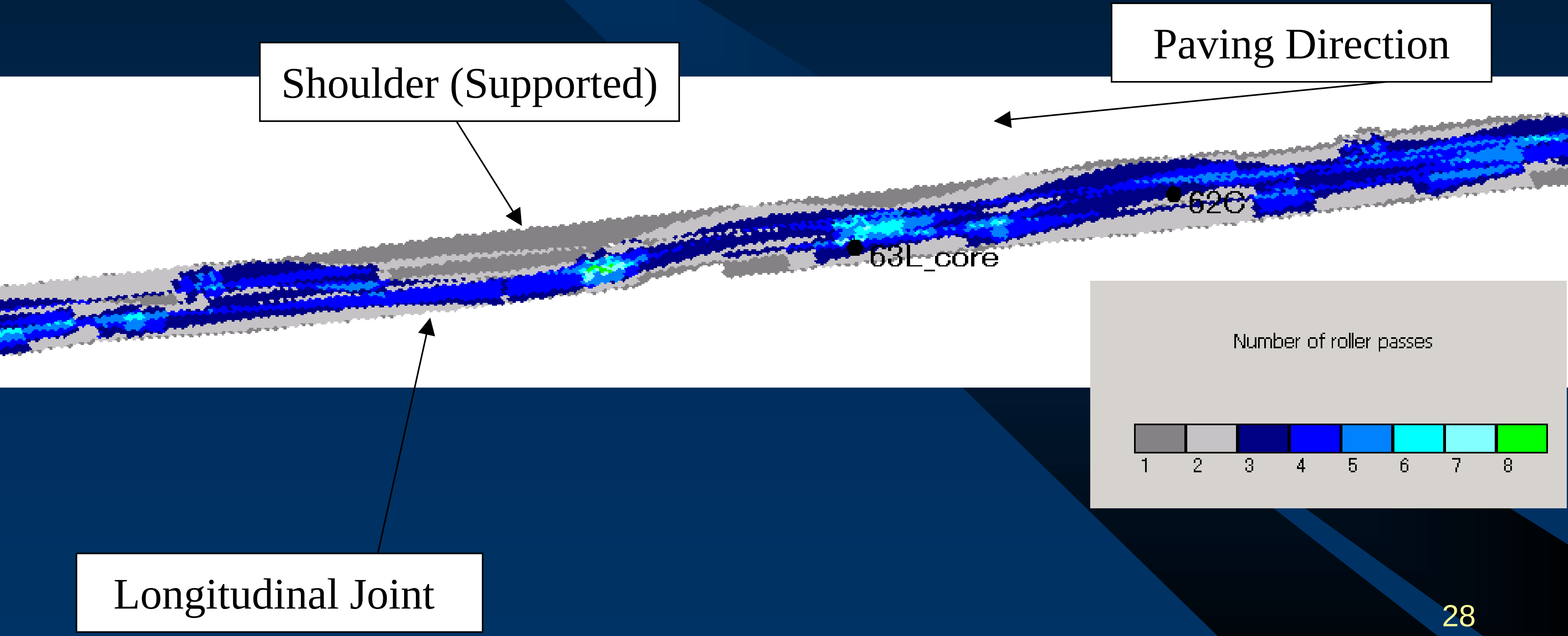
Thermo Gauge

Accelerometer

PC Display

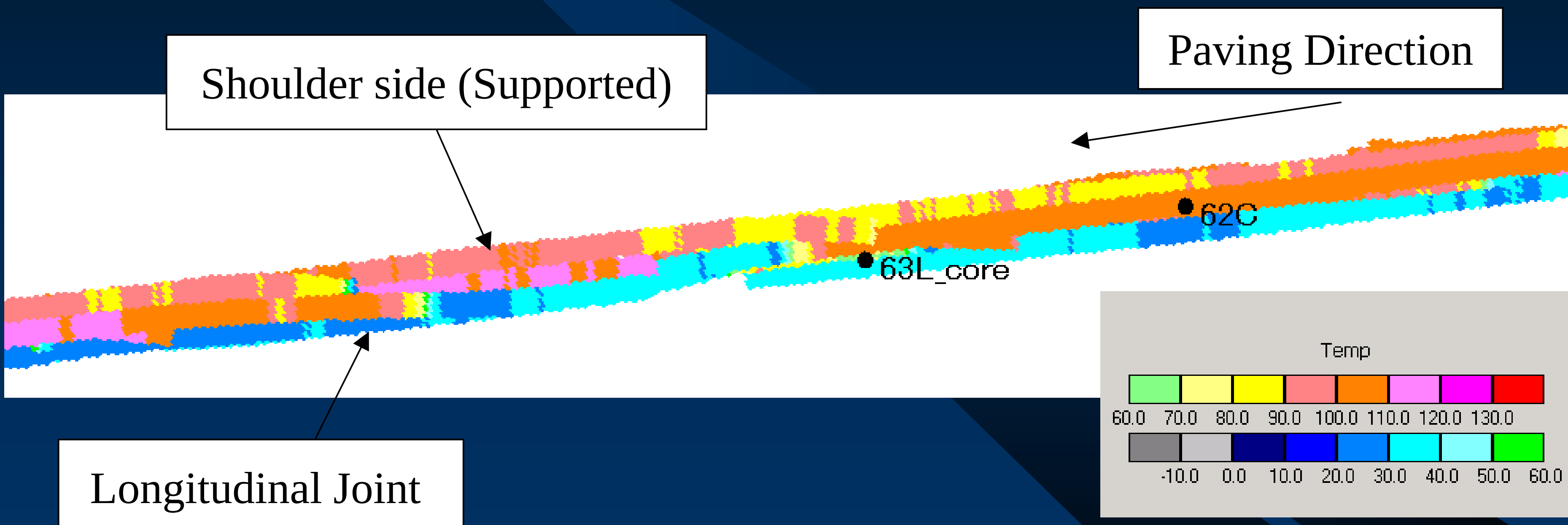
Sakai IC Roller Project

- Roller Passes



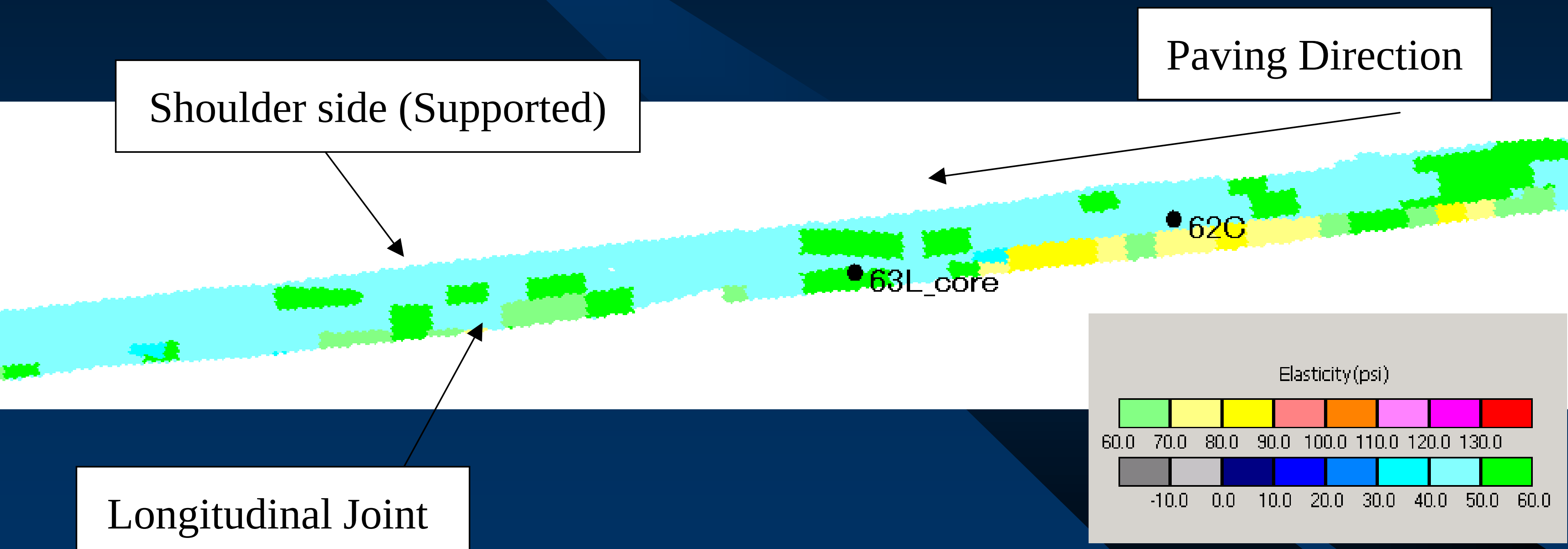
Sakai IC Roller Project

- Temperature

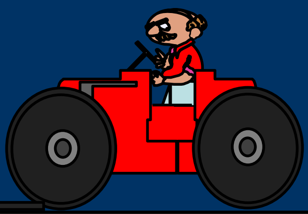


Sakai IC Roller Project

- Stiffness

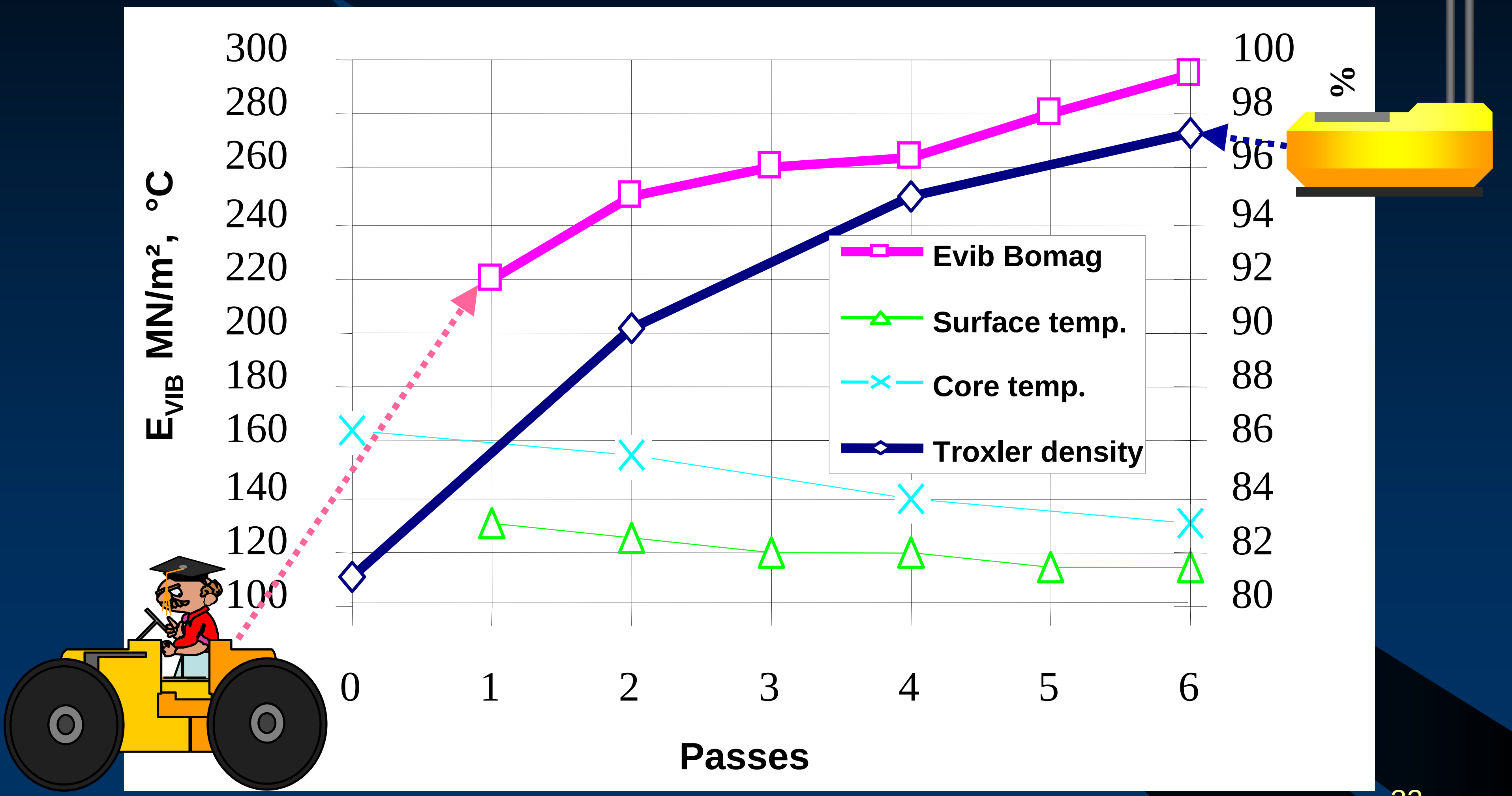


Benefits of IC



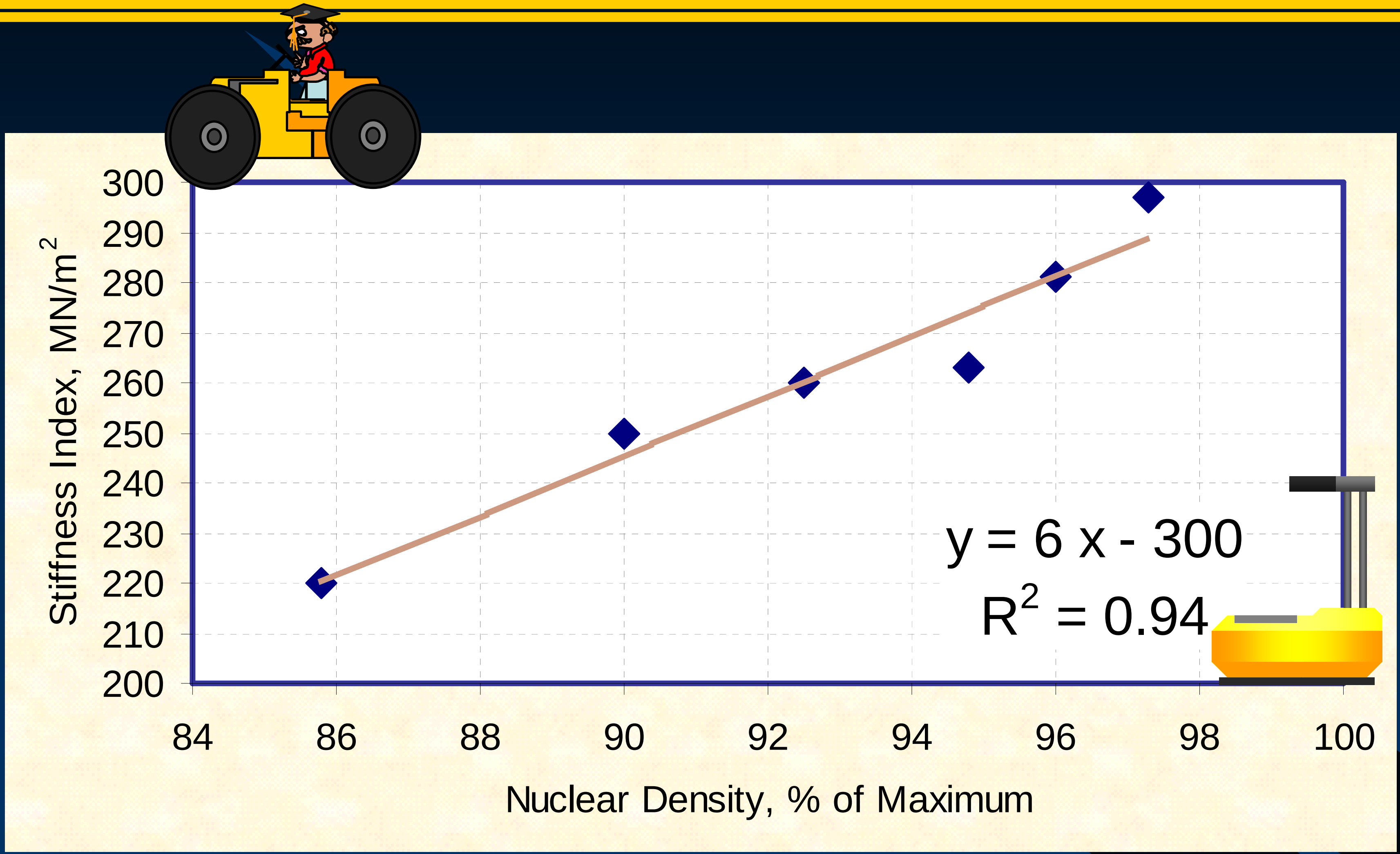
- **Maximum productivity** of the compaction process
- **Improved density** of pavement materials
- Measurement and recordation of **materials stiffness values**
- **Identification** of non-compactable areas
- **Improved depth** of compaction
- Reduction in highway repair **costs**

Bomag America
Generated Stiffness vs. Density



Courtesy Bomag America

Bomag America
Generated Stiffness vs. Density



Some Critical Research Topics…

- Construction specs on 4 different material types
  - Granular subgrade soil
  - Cohesive subgrade soil
  - Aggregate base and subbase
  - Asphalt pavement material

- Comparison of IC and conventional– Is IC really better?

Some Critical Research Topics…

- Correlation of roller-generated stiffness and in-place density?

- Correlation of roller-generated stiffness and in-situ test methods? (FWD, LWD, DCP, GeoGauge, etc.)

Some Critical Research Topics

- Needed accuracy of GPS
- Best methods of using roller-generated data in agency's QA and acceptance testing
- Assessment of roller operators ability to understand and utilize more complex equipment

National Research Efforts

- NCHRP 21-09 "Examining the Benefits and Adoptability of Intelligent Soil Compaction"

- Transportation Pooled Fund #954 – "Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base and Asphalt Pavement Material"

NCHRP 21-09 (Soils)

- Study of IC of subgrade soils (limited aggregate base/subbase)

- Objectives: Based on data / information obtained from field studies:
  - Develop generic IC construction specifications for subgrade soils
  - Evaluate the reliability of IC system components

NCHRP 21-09

Two year project in two phases

- Phase 1: One project
- Phase 2: Four projects
  - June, 2006 - June, 2008
  - Allocated Funding: $600,000
  - Awarded 12/05
    - Dr. Michael Mooney, Colorado School of Mines, Principal Investigator
    - Dr. David White, Iowa State University, Co-Principal Investigator

NCHRP 21-09
Phase One Project

July 2006; MnROAD Research Center

NCHRP 21-09
Phase One Project

NCHRP 21-09 Phase One Project

Iowa State University Geotechnical Mobile Lab

"Advancing Intelligent Construction"

NCHRP 21-09 Phase One Project

Mn/DOT Project
In-Situ Testing

Mn/DOT Project
Soils In-Situ Testing Equipment

Lightweight Deflectometer (LWD)

Geo Gauge

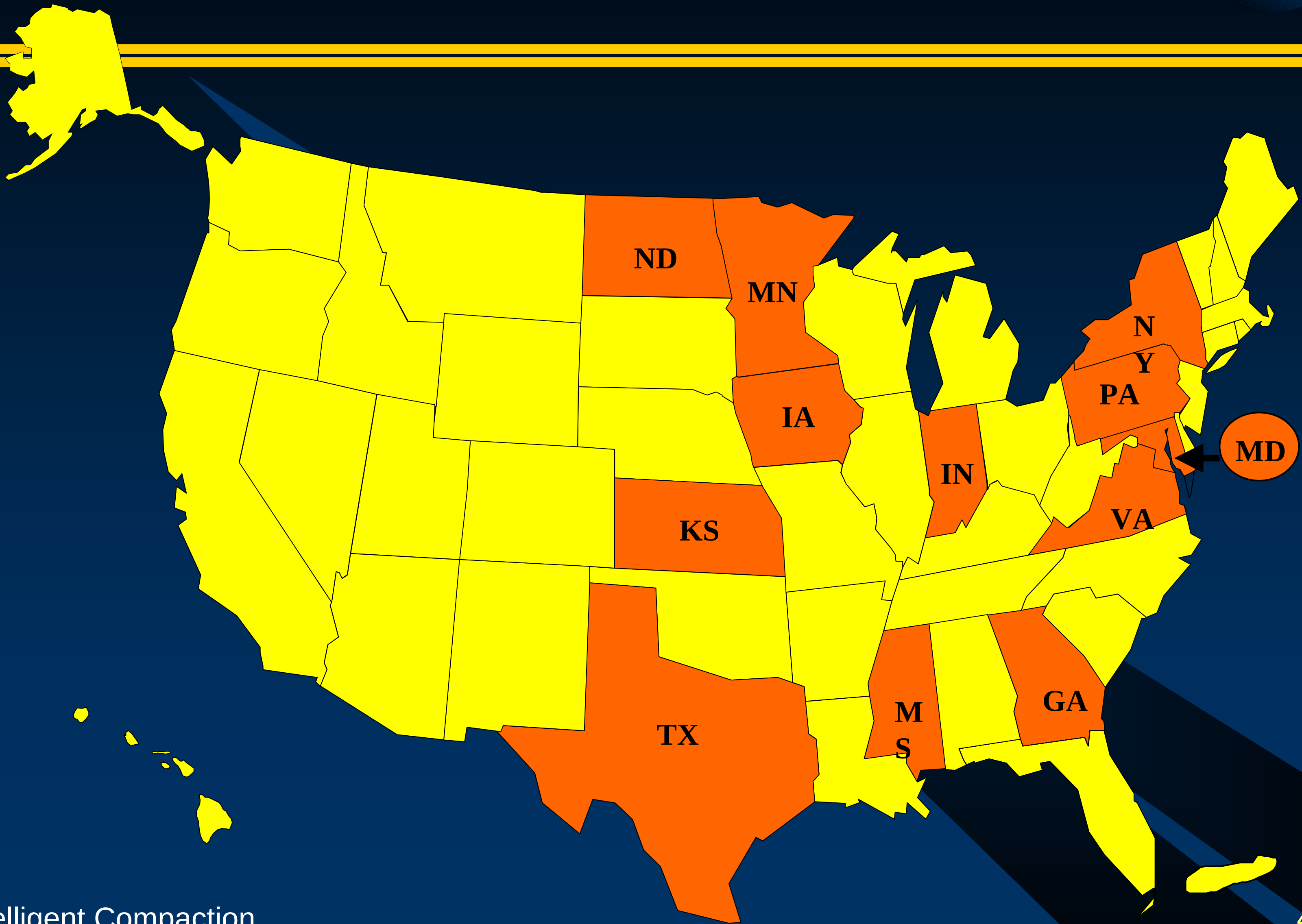
Dynamic Cone Penetrometer (DCP)

Question: Can the in-situ test results be correlated to roller-generated output?

Pooled Fund (Soils / HMA)

- 3 year study of IC for all materials
- Solicitation period ended on Dec 2005
- 12 participating states
- Estimate 1 project / State / year ~ 30?
- Close coordination with NCHRP project
- Stated goal to work closely with roller suppliers to increase the number of IC rollers and manufacturers

Accelerated Implementation of IC



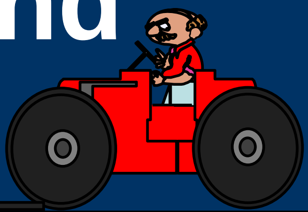
Pooled Fund, Objectives

- Objectives: Based on data obtained from field studies:
  - Accelerated development of QC/QA specifications for granular and cohesive subgrade soils, aggregate base and asphalt pavement materials…

Pooled Fund, Objectives

- Develop an experienced and knowledgeable IC expertise base within Pool Fund participating state DOT personnel
- Identify and prioritize needed improvements to and/or research of IC equipment and field QC/QA testing equipment (DCP, FWD, GeoGauge, etc)

Comparison on Pooled Fund and NCHRP Projects



- Pooled Fund #954
  - Specification develop.
  - Identify and prioritize needed improvements
  - More projects
  - All pavement materials and entire pavement structure
  - Active participation of state DOT personnel
  - Emphasis on inform./ technology transfer

- NCHRP 21-09
  - Specification develop.
  - Evaluate existing IC components
  - Detailed research on fewer projects
  - Primarily subgrade soils; some agg. base
  - Research team / NCHRP panel

State DOT IC Research

- Limited number of projects by several State DOTs (MN, NC, MD)
- Mn/DOT has conducted an ongoing research effort over last several years
  - 5 projects complete
  - Subgrade soils only
  - 3 different roller manufacturers
  - Compare roller-generated output to in-situ test methods (DCP, LWD and GeoGauge)
  - Required GPS-based, color coded mapping of roller output and locations

IC Rollers
Current Status

- 5 Roller Manufacturers have announced their intentions to supply IC rollers in US
  - 4 have announced plans to have both single drum soils rollers and tandem drum asphalt rollers
  - 1 has only single drum soils rollers, at this time
- 4 Manufacturers that currently have IC rollers for public display, at this time:
  - Bomag America (both single and tandem drum)
  - Ammann America (single drum)
  - Caterpillar (single drum)
  - Sakai America (tandem drum)

Special Issues for Asphalt IC

- Thin lift construction
- Allowable temperature ranges
- Surface vs. internal temperature measurement
- Non-destructive, in-situ stiffness / modulus companion tests

What have we learned so far?

- IC technology appears to have great potential to improve the compaction process
- Improved and more uniform density should increase pavement service life
- There is a great deal of interest among federal and state DOTs to learn more about it

What have we learned so far?

- Roller manufacturers are responding to this interest by performing R&D, providing rollers and by coordinate efforts with state and national research efforts
- Preliminary findings from studies in US are encouraging

Intelligent Compaction

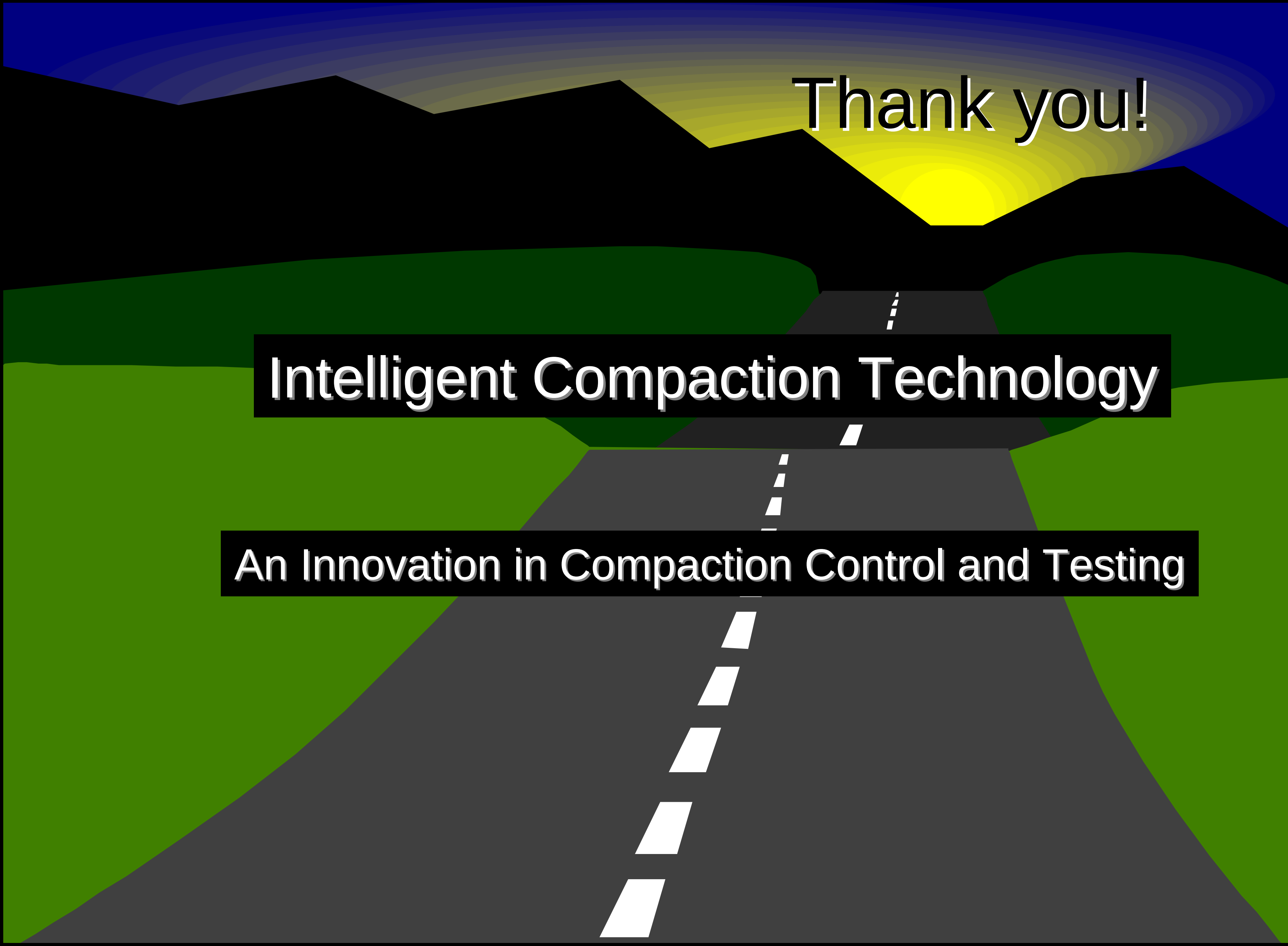
The Objectives

FHWA Strategic Plan

- Accelerate the development of IC
- Increase awareness and encourage acceptance
- Conduct needed research to clarify the advantages and appropriate uses of the technology
- Provide organizational support for the process of developing intelligent compaction technologies

IC – Goals / Benefits

- **Short Term**
  - Improve density… better performance
  - Improve efficiency… cost saving$
  - Increase information… better QC/QA


Thank you!
Intelligent Compaction Technology
An Innovation in Compaction Control and Testing

Additional Slides

Basics of HMA Compaction

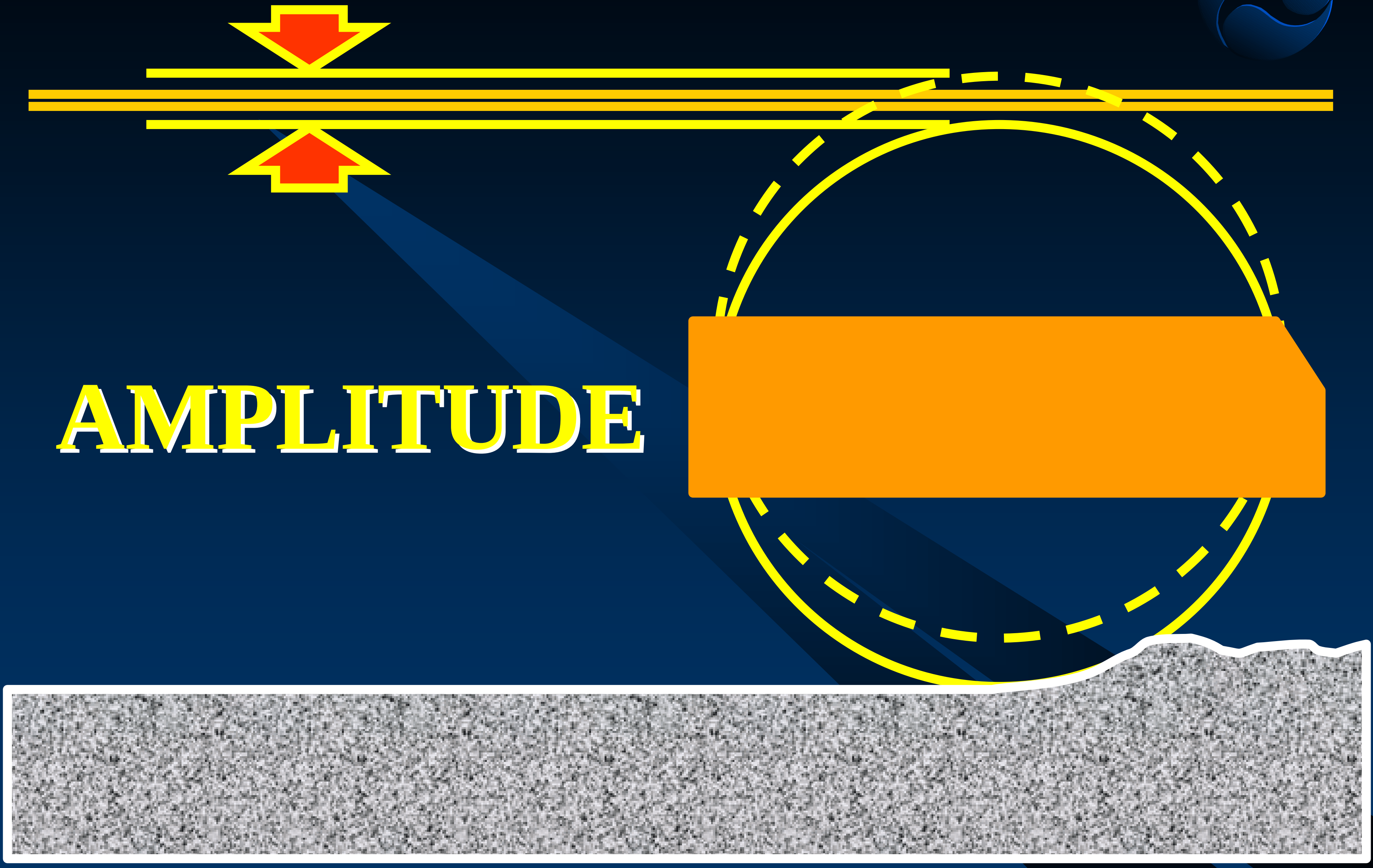
Compaction is the process of compressing HMA into a smaller, denser volume.

Asphalt coated aggregate particles are reoriented and consolidated, which increases the pavement density

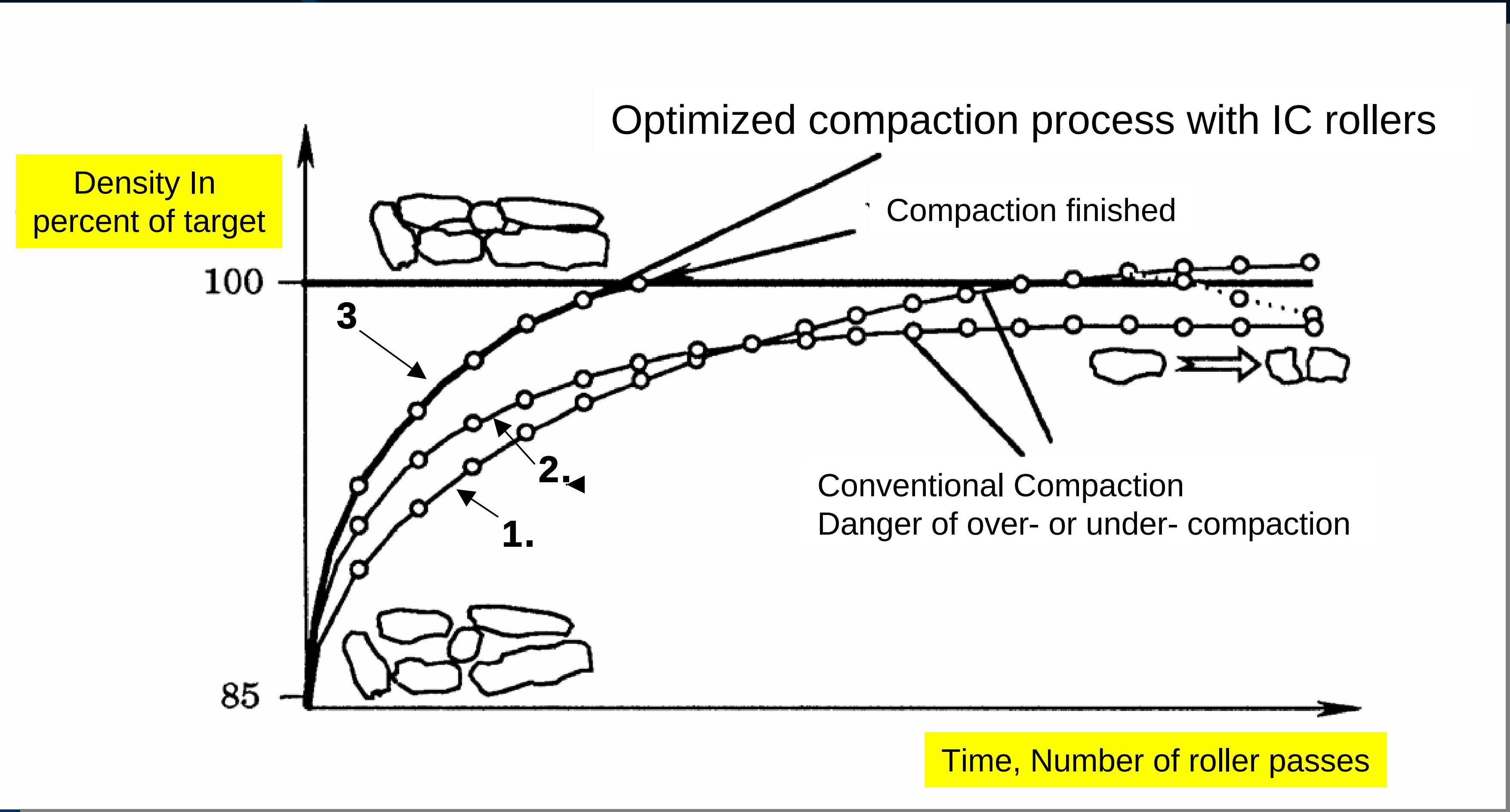
Basics of Soils Compaction

Compaction is the process of compressing material particles into a smaller, denser volume.

Material particles are reoriented and consolidated,, which increases the density

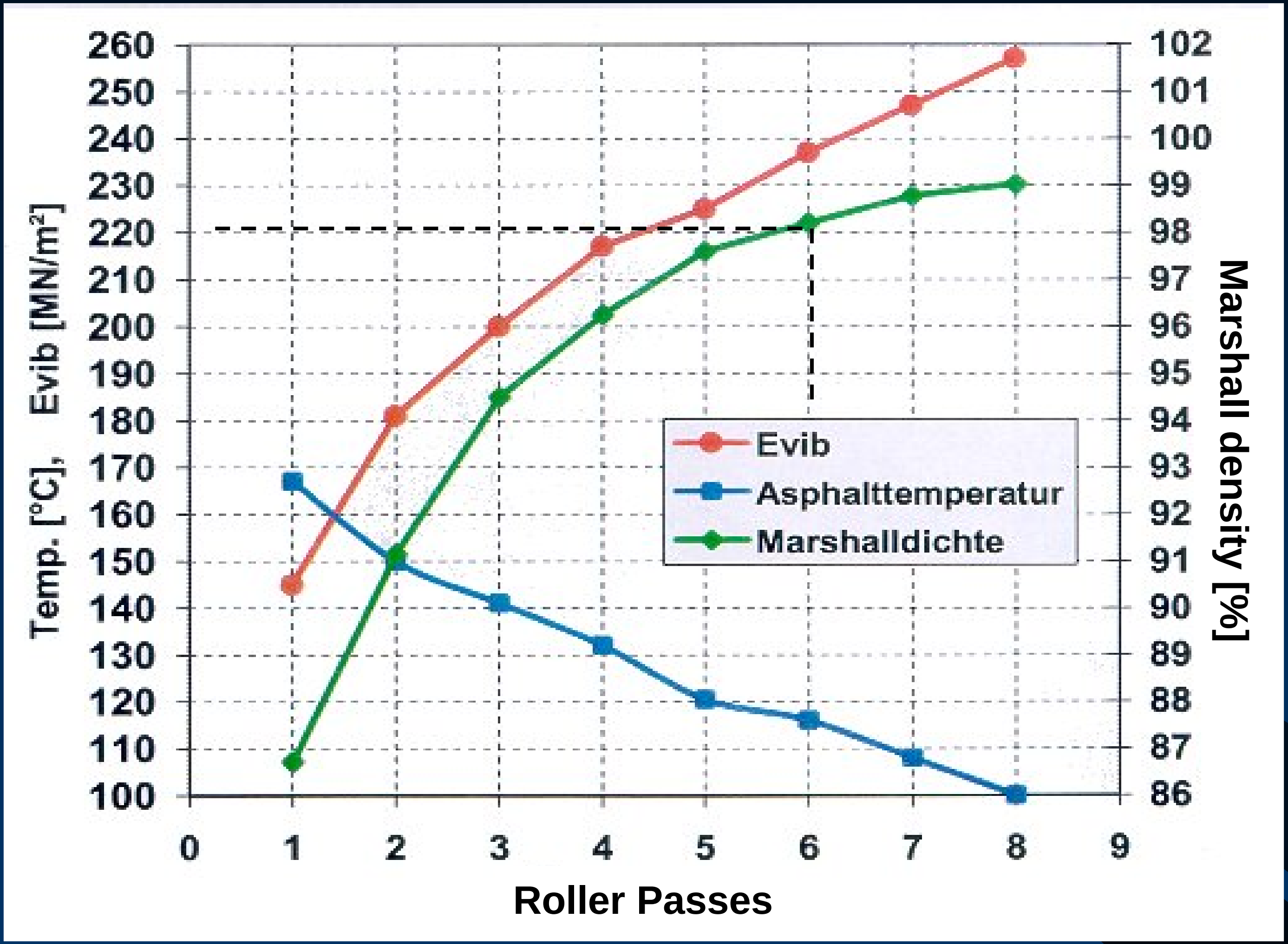

AMPLITUDE

Intelligent Compaction

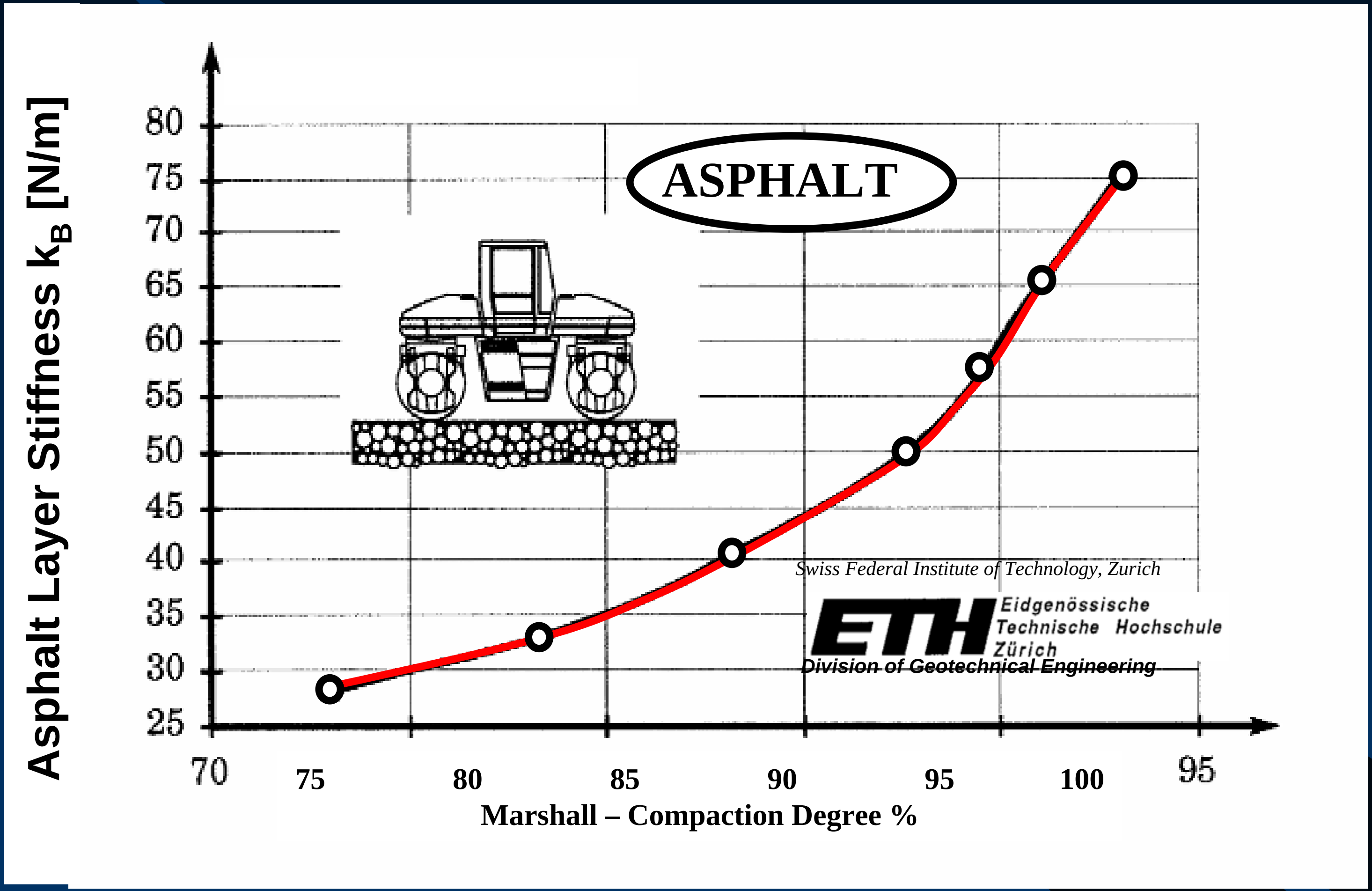


Courtesy of Ammann America

Roller Correlation
Generated Modulus vs. Density



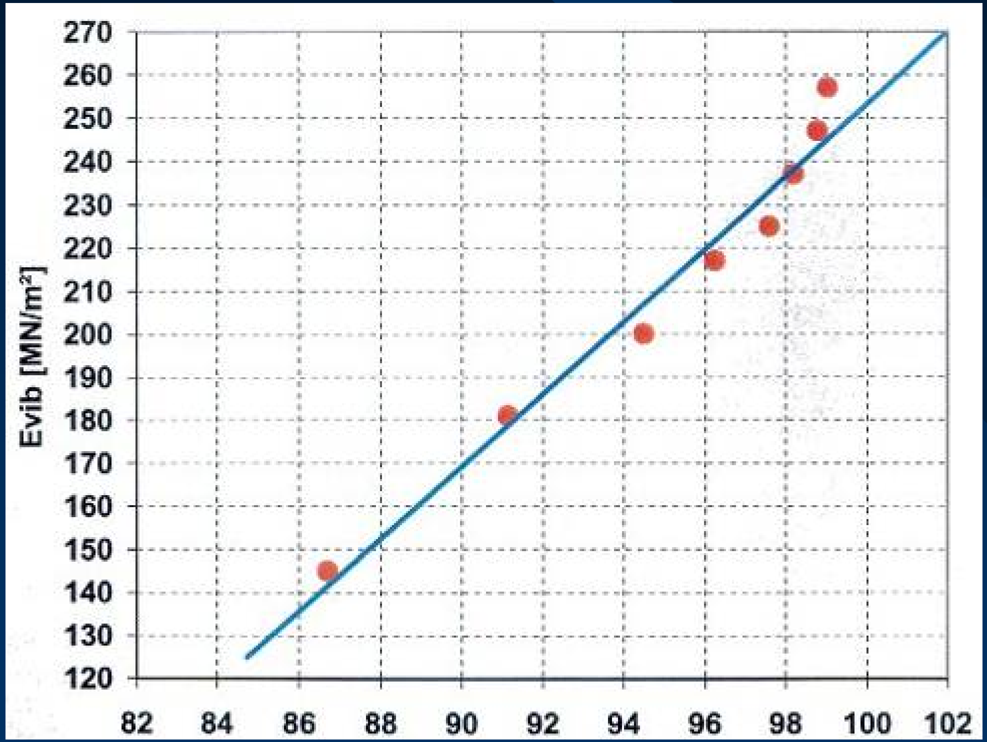
Roller Correlation Generated Stiffness vs. Density



Courtesy Ammann America

Roller Correlation
Generated Modulus vs. Density

E_{VIB} [MN/m²] vs. Marshall density [%]
Compaction test on asphalt wearing course (SMA)



Marshall density [%]

Perfect correlation:

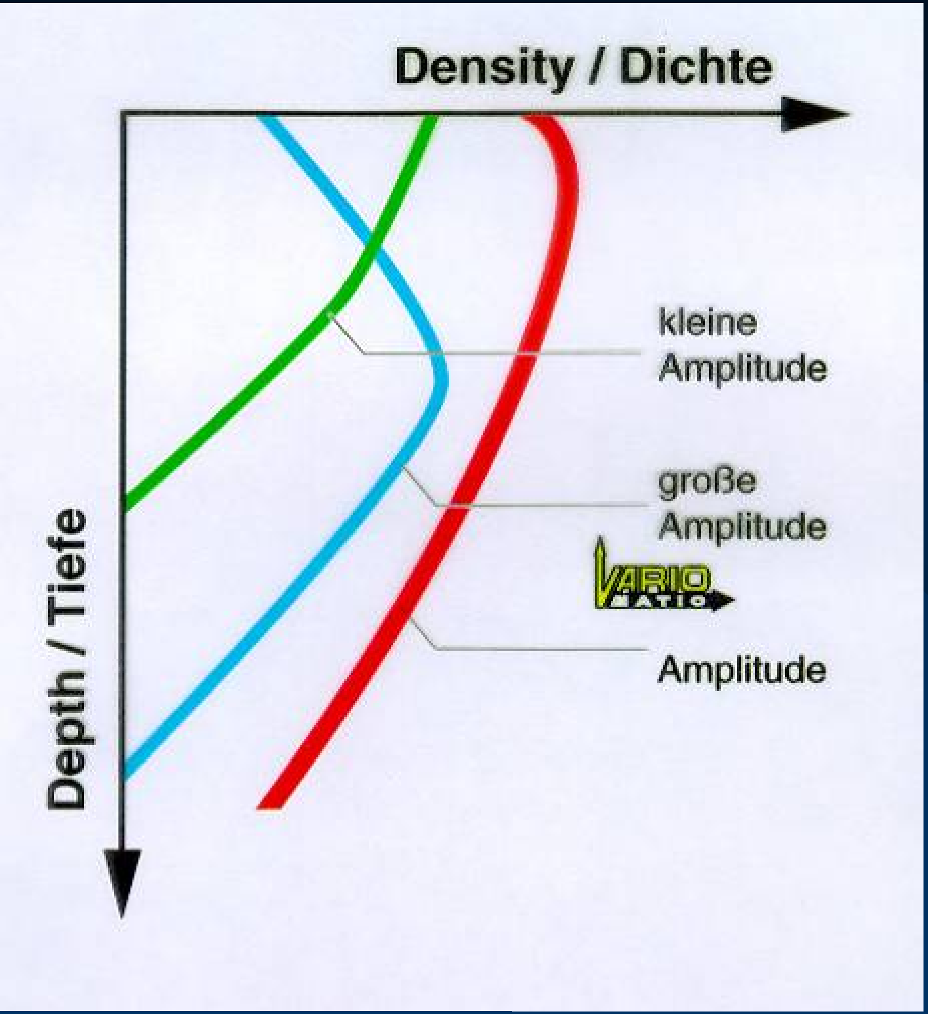
Evib + Marshall density

Adequate conditions:

- **Temperature between (170-120 °C)**
- **Asphalt layer on solid ground**

Courtesy Bomag America

Intelligent Compaction



Depth effect

Comparison:

Rotary exciter
(no infinite variation)

Variomatic
(automatic compaction)

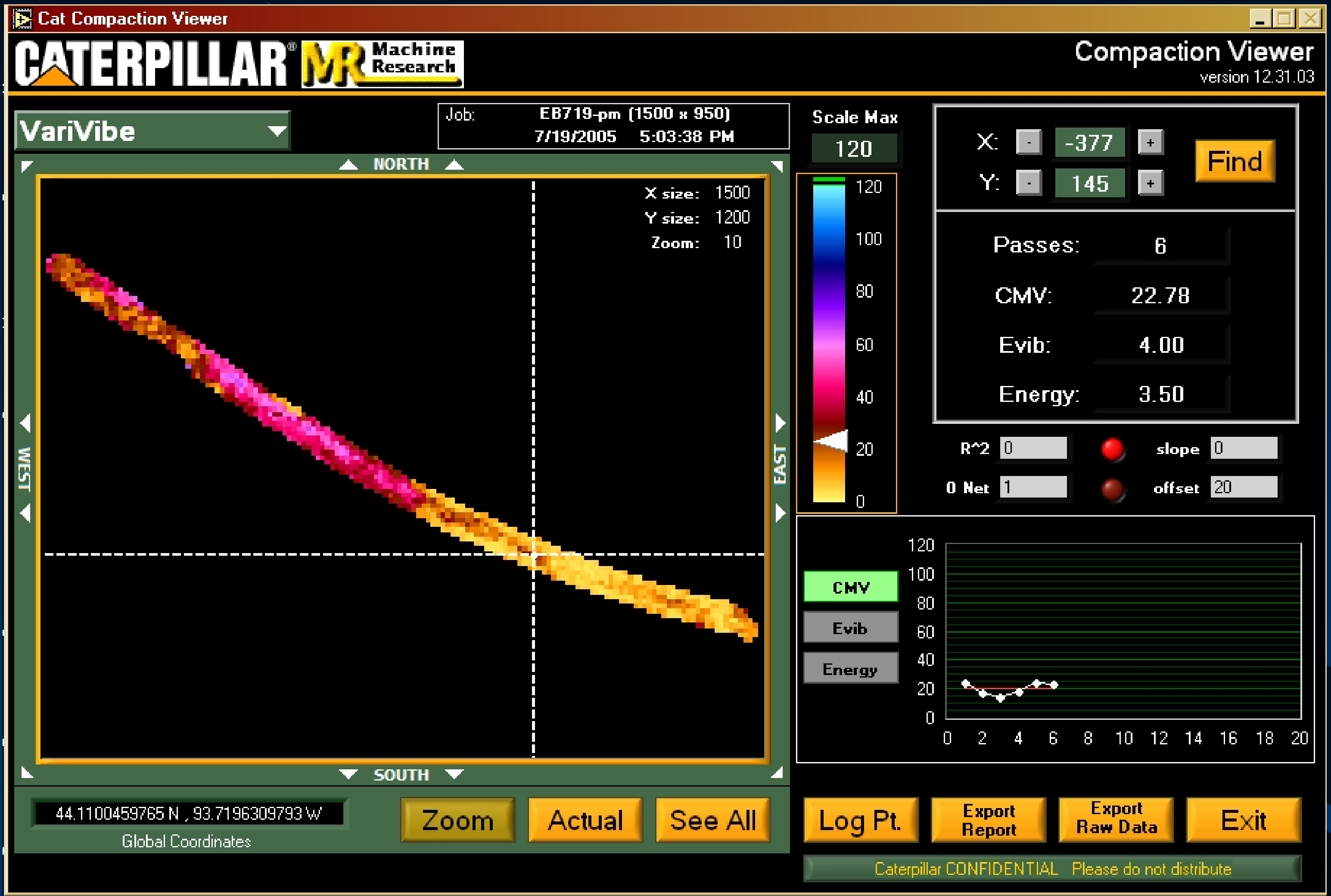
Courtesy Bomag America

Caterpillar
Single Drum Soils Roller

Caterpillar 2-D Mapping

Courtesy of Caterpillar

Caterpillar 2-D Mapping



Courtesy of Caterpillar

MnDOT TH 64 Project

MnDOT Project
Caterpillar Display

CCV Continuously Displayed on Screen

Color-coded mapping shows highest CCV obtained at all locations

Target CCV = 42

MnDOT Project
Caterpillar Display

Roller Icon shows operator roller position

Color-coded map shows total number of roller passes at all locations

Required Number Of Passes = 5

Bomag America

Single Drum IC Soils Roller

Tandem Drum IC Asphalt Roller and Display Panel

Bomag America

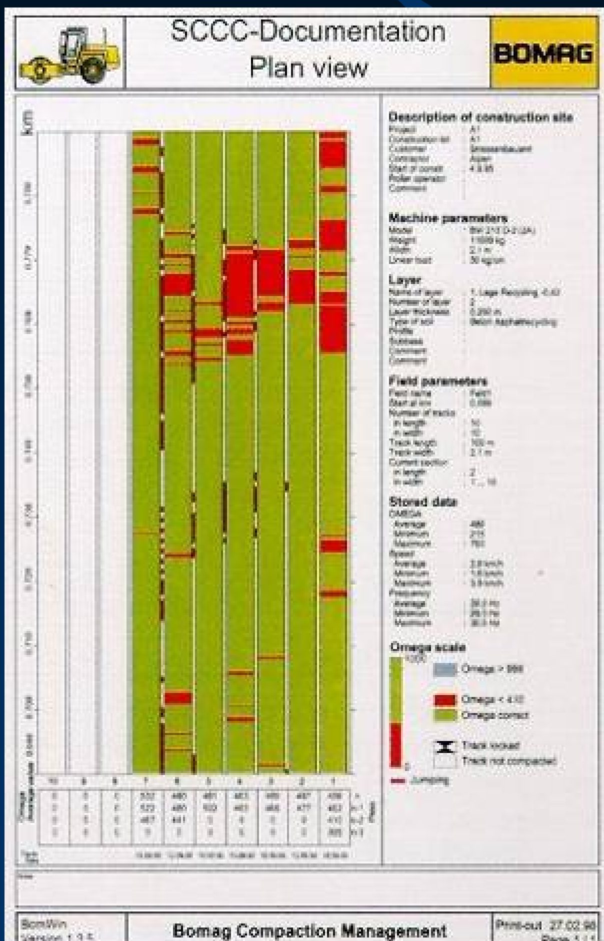
Bomag Operational Panel

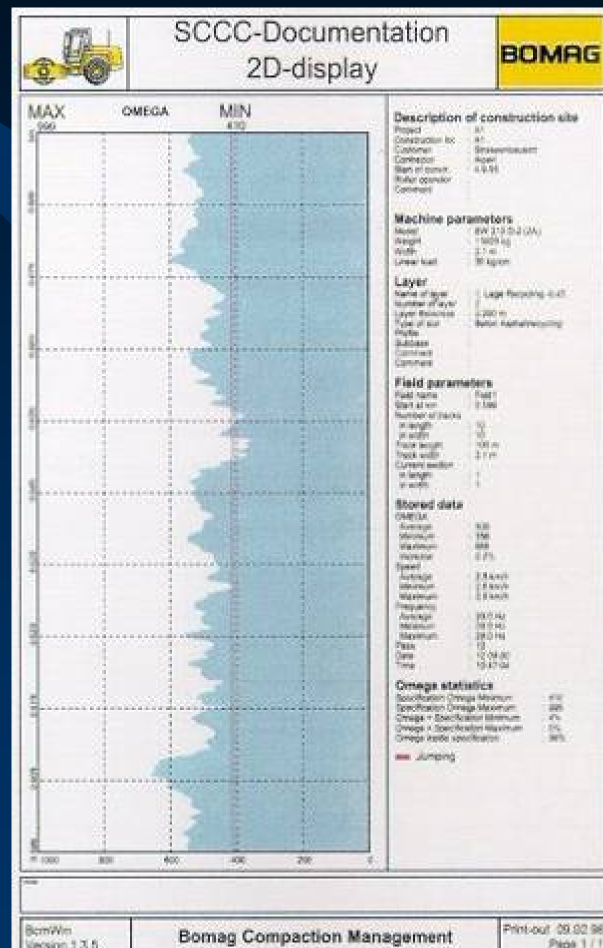
SETTINGS
- Escape
- Enter

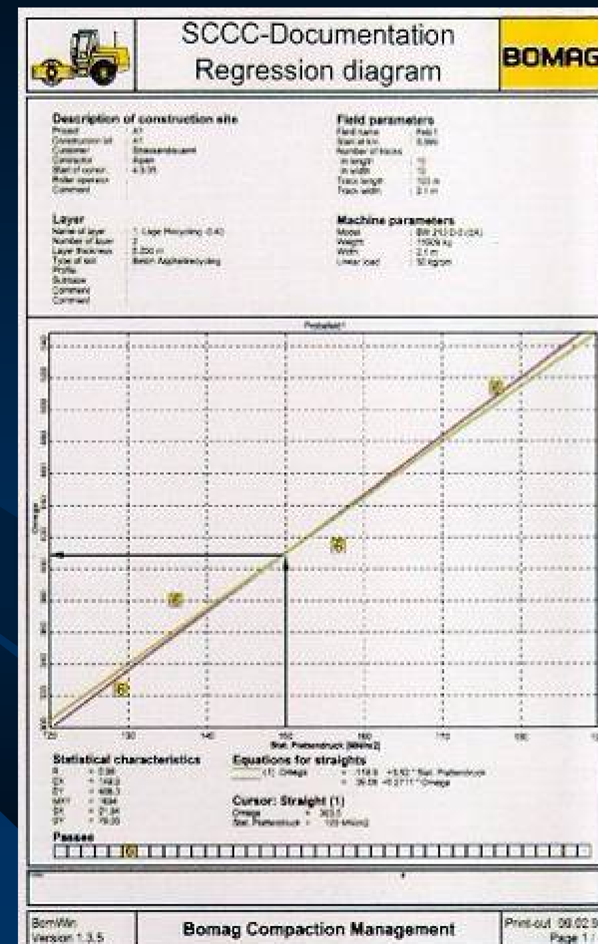
Courtesy of Bomag America

Intelligent Compaction

Bomag Subbase Case Study





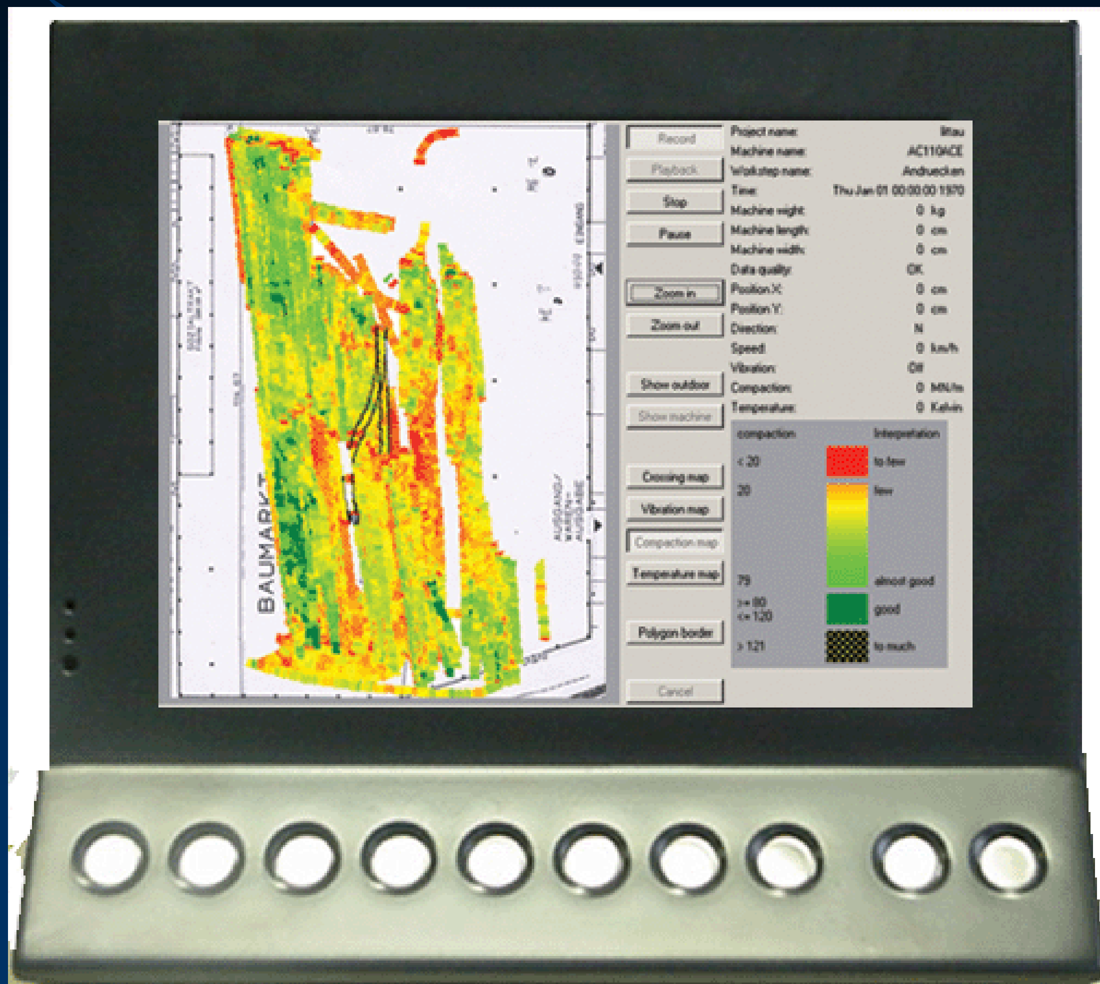


Courtesy of Bomag America

Ammann America
Single Drum IC Soils Roller

Ammann America IC Roller

Documentation System Display



Courtesy of Ammann America

Bomag BW 190AD Asphalt Manager

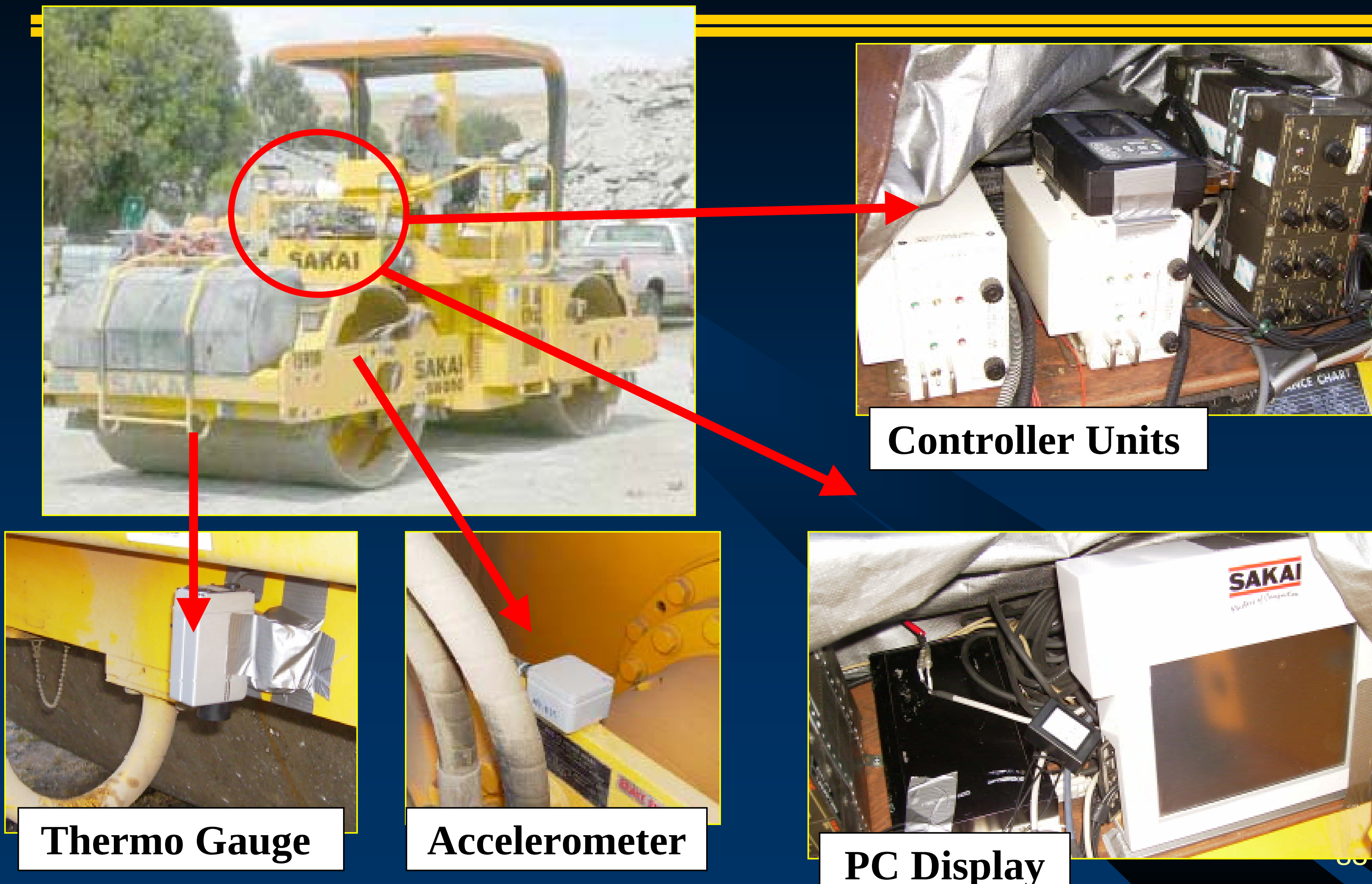
- 14 ton vibratory tandem drum roller
- 79” drum width
- Directional amp. (35% higher centrifugal force)
- 3 automatic and 7 manual setting modes

Sakai SW850 IC Roller

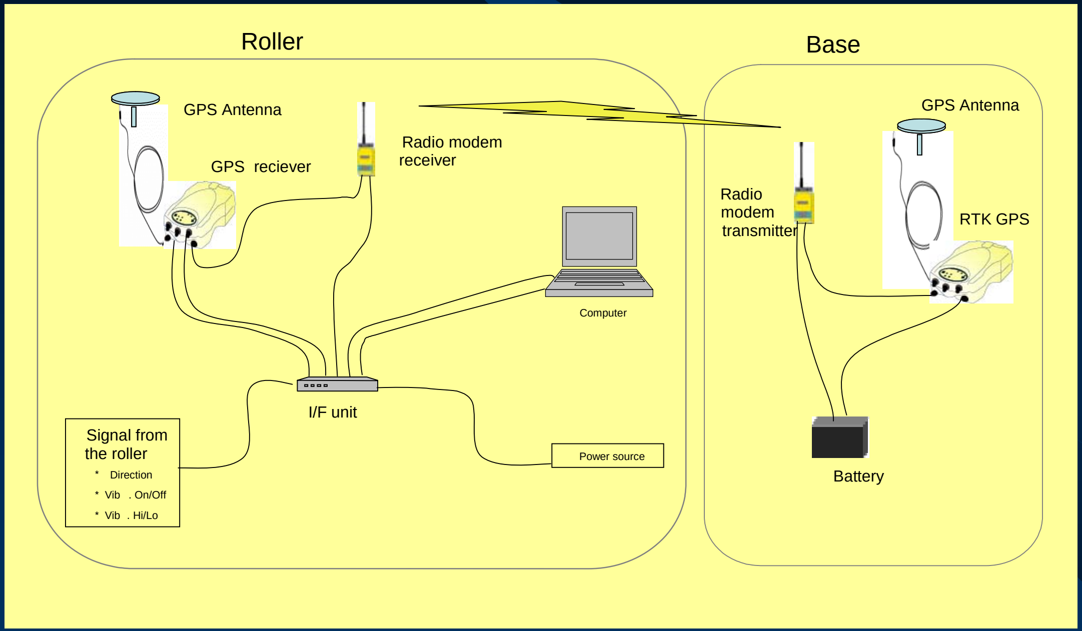
- 14 ton vibratory tandem drum roller
- 79” drum width
- Breakdown rolling: Low amplitude (0.013 in) and 4,000 vpm.

Graniterock Company, Watsonville, CA

Sakai IC Roller Measurement Device

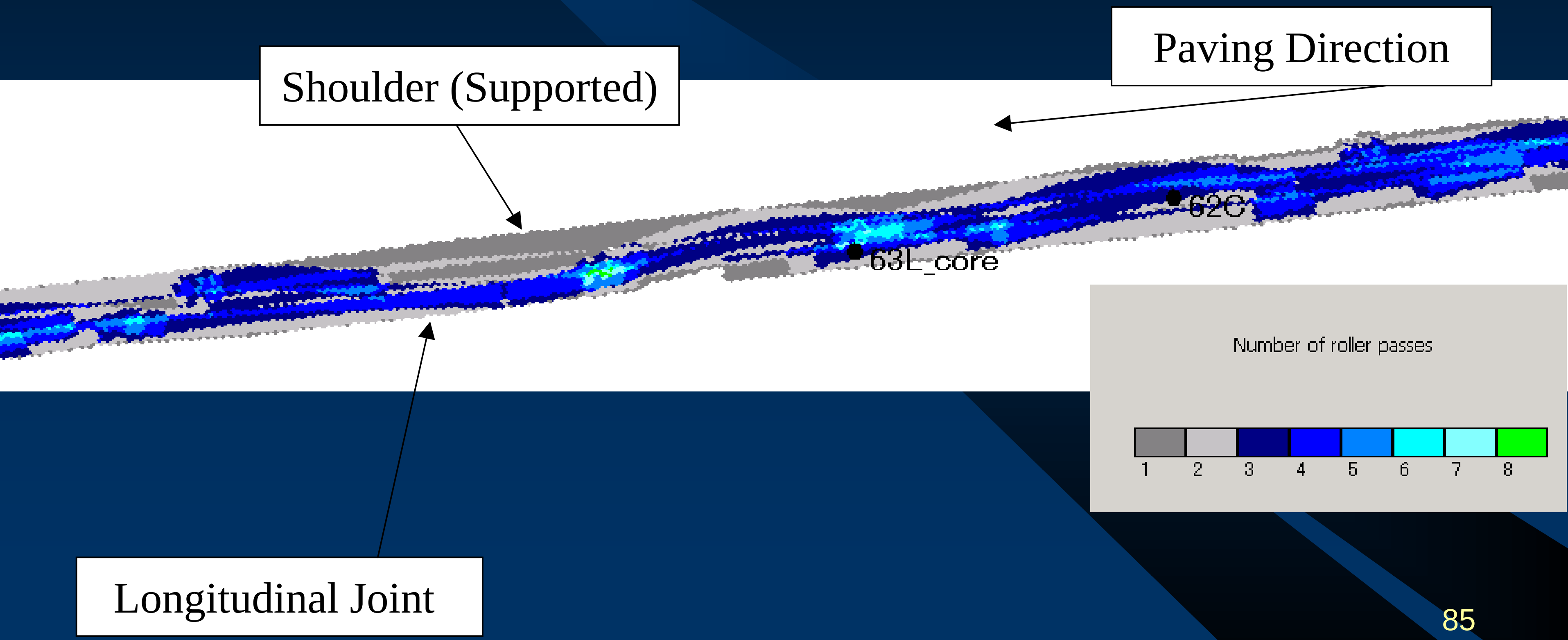


Sakai IC Roller: GPS Measuring, Recording & Mapping System



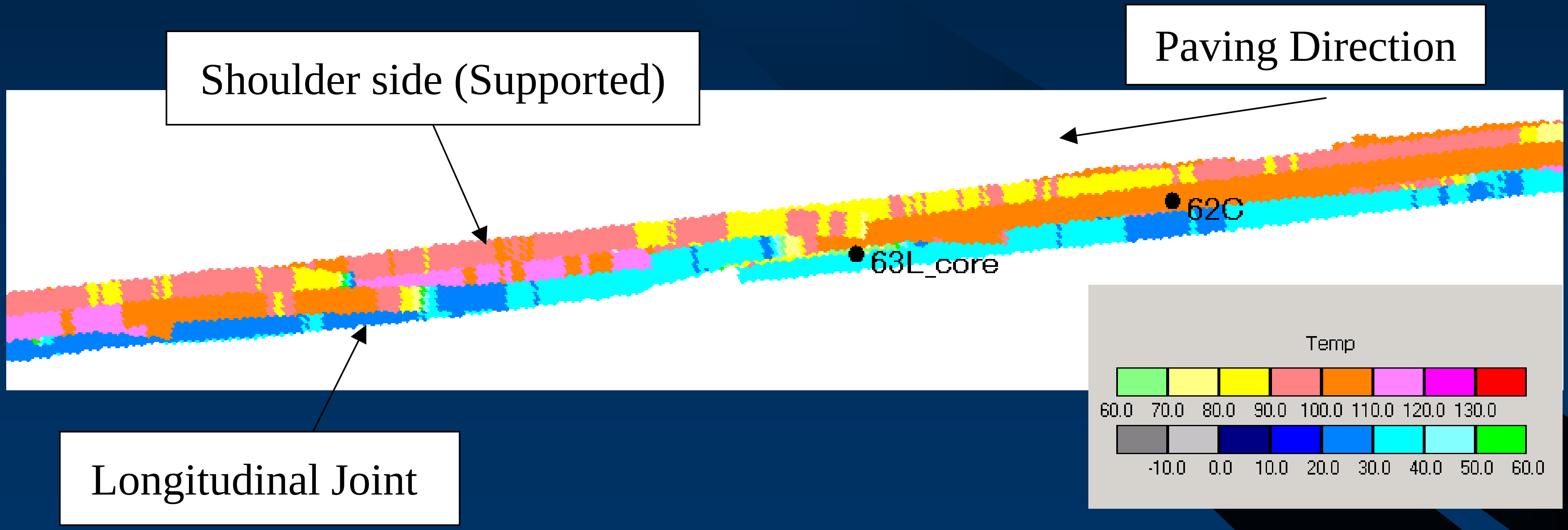
Sakai SW850 IC Roller Project

- Number of Roller Passes over each point of the pavement was highly variable



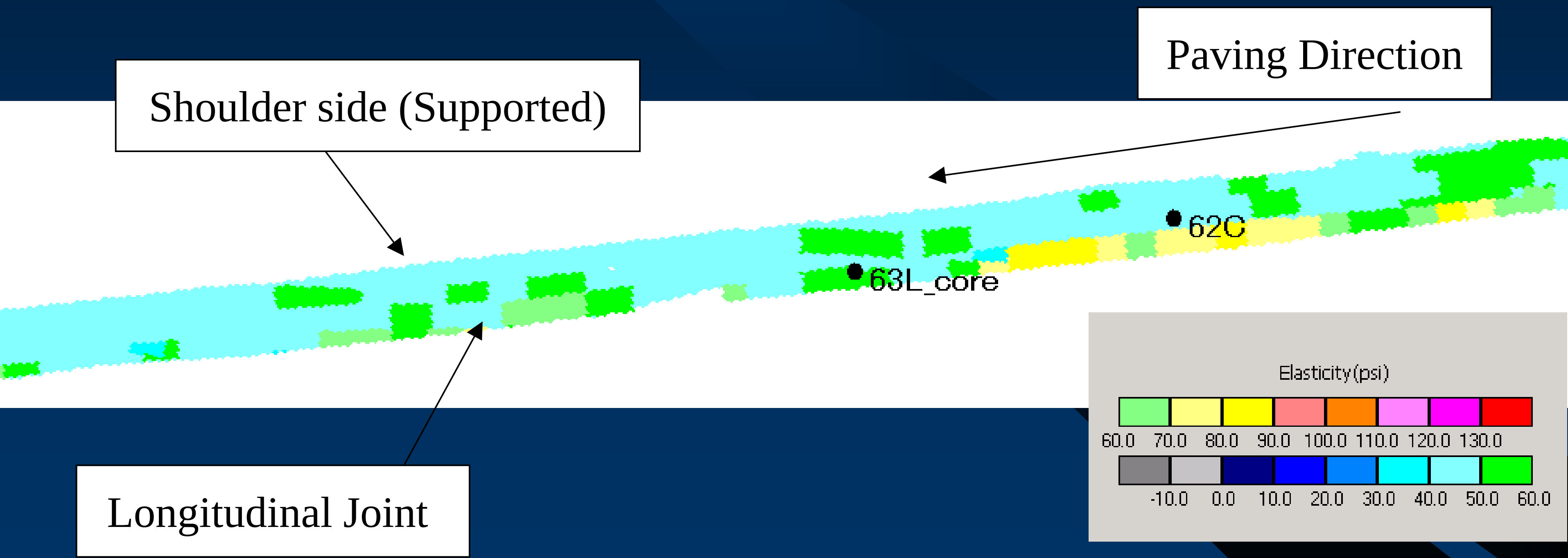
Sakai IC Roller Project

1. Temperature of pavement surface during breakdown rolling.
2. Variation: 270 ºF to 140 ºF.

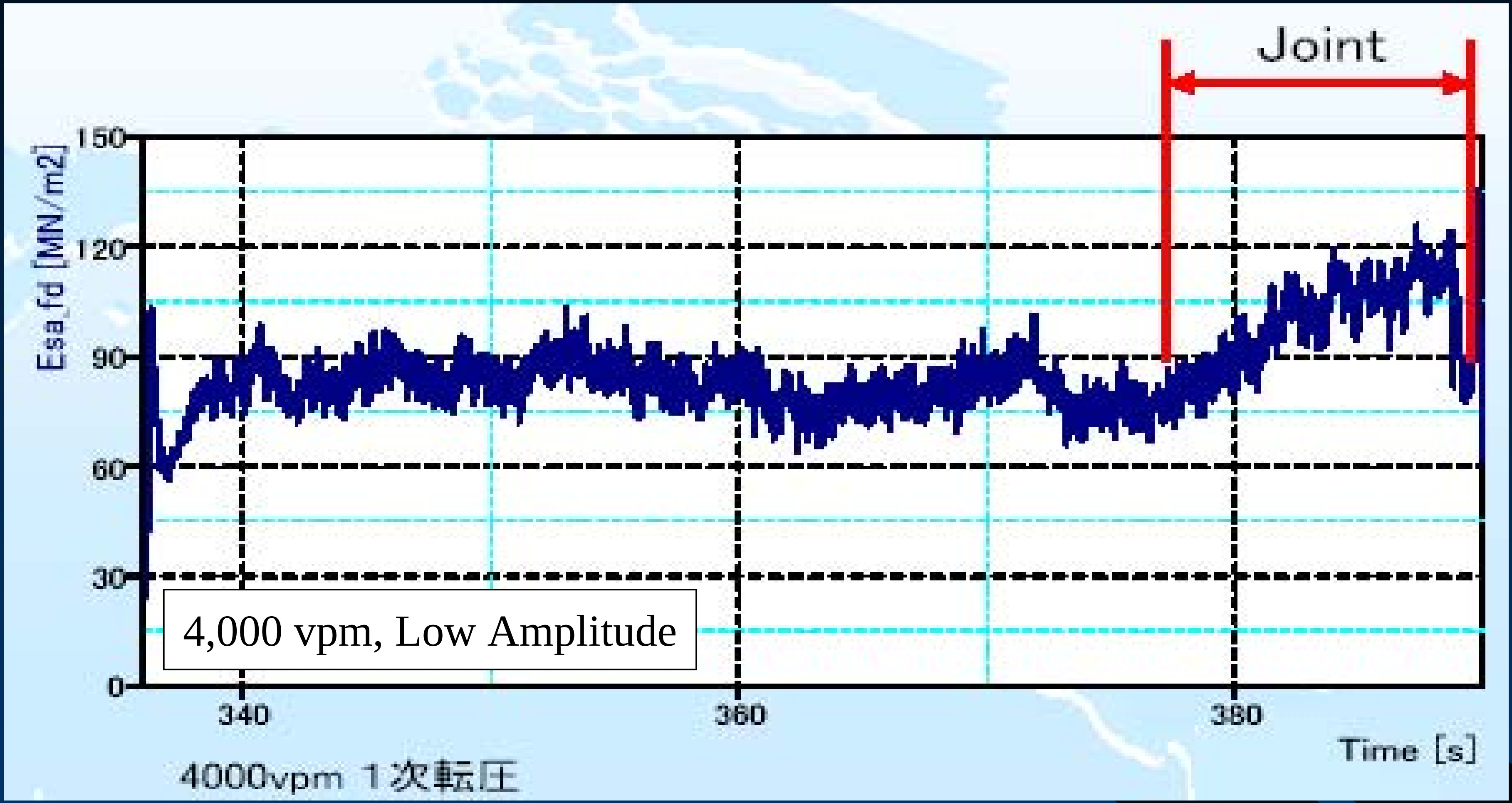


Sakai IC Roller Project

1. The stiffness at the final roller pass during breakdown rolling in each location.
2. Variation: 30 to 90 MN/m^2 (4,350 to 13,055 PSI) .



Sakai IC Roller Project

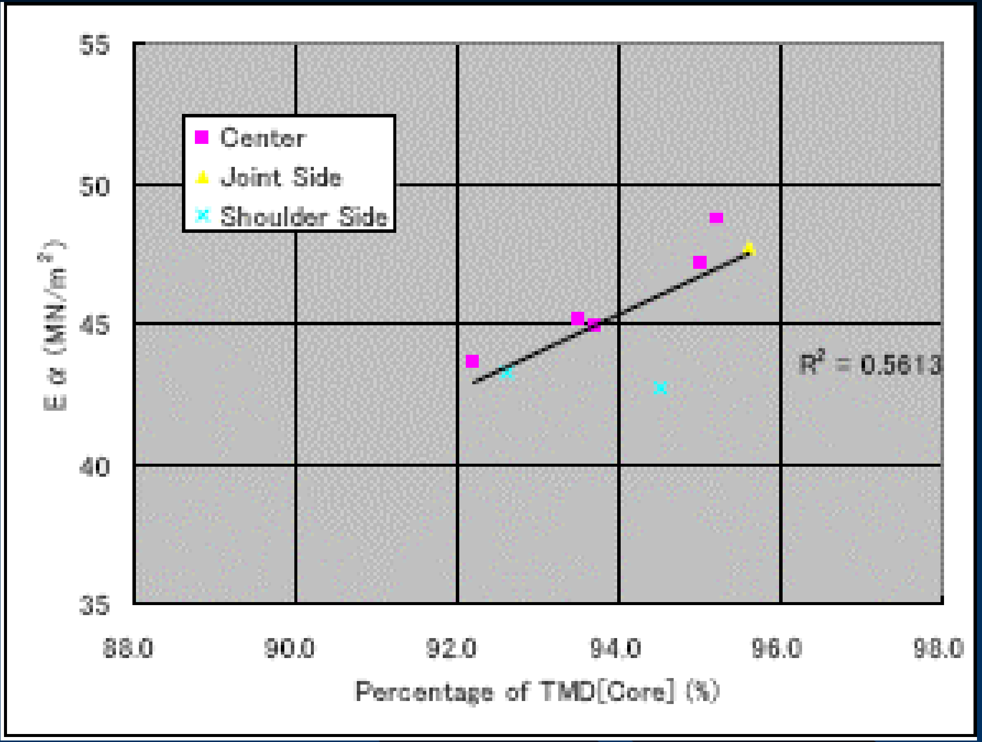


Distribution of roller-generated stiffness on final pass of breakdown rolling

Sakai IC Roller Project

Stiffness vs. Density During Breakdown Rolling

1. Fair correlation between stiffness of last breakdown roller pass and core density ($R^2 = 0.5613$)
2. All cores were cut after finishing rolling was done.
3. Coordinates of core locations were measured by GPS with accuracy of 5 ft.



Sakai IC Roller Project

Stiffness vs. Density During Finish Rolling

1. No correlation between stiffness and core density measured during finish rolling.
2. All cores were cut after finishing rolling was done.
3. Coordinates of core locations were measured by GPS with accuracy of 5 ft.