Density of Asphalt Pavements: How to Specify and Measure to Ensure Pavement Performance

NCHRP 20-07/Task 382

by

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In-Place Density is the single most important property of the asphalt mixture in the pavement.

NCHRP Study Objectives

- Collect information on current practices
- Evaluate how density is measured and specified

Through

- Literature Search
- Technical Survey

Report Topics

- General Issues in Density of Asphalt Pavements
- Specification Types for Control of Density
- Density Measurements Techniques
- Construction Parameters Affecting Density
- Longitudinal Joint Construction
- Emerging Technologies in Determination of In-Place Density

Pavement Life

- 10 percent decrease in pavement life for each 1 percent increase in air voids
  - Multiple researchers have confirmed

Cost and Performance

- Cost of Aggregate and Binder are significantly higher than cost of compaction

BUT

- Effect of achieving density is equal in importance to aggregate and binder in terms of pavement performance.

Definitions

- Density – weight per unit volume
- Compaction – process of increasing density of mix through paving and rolling operations
- Reference Density – value to which in-place density is compared
- Percent Density – percentage of reference density achieved during compaction process

Project Survey

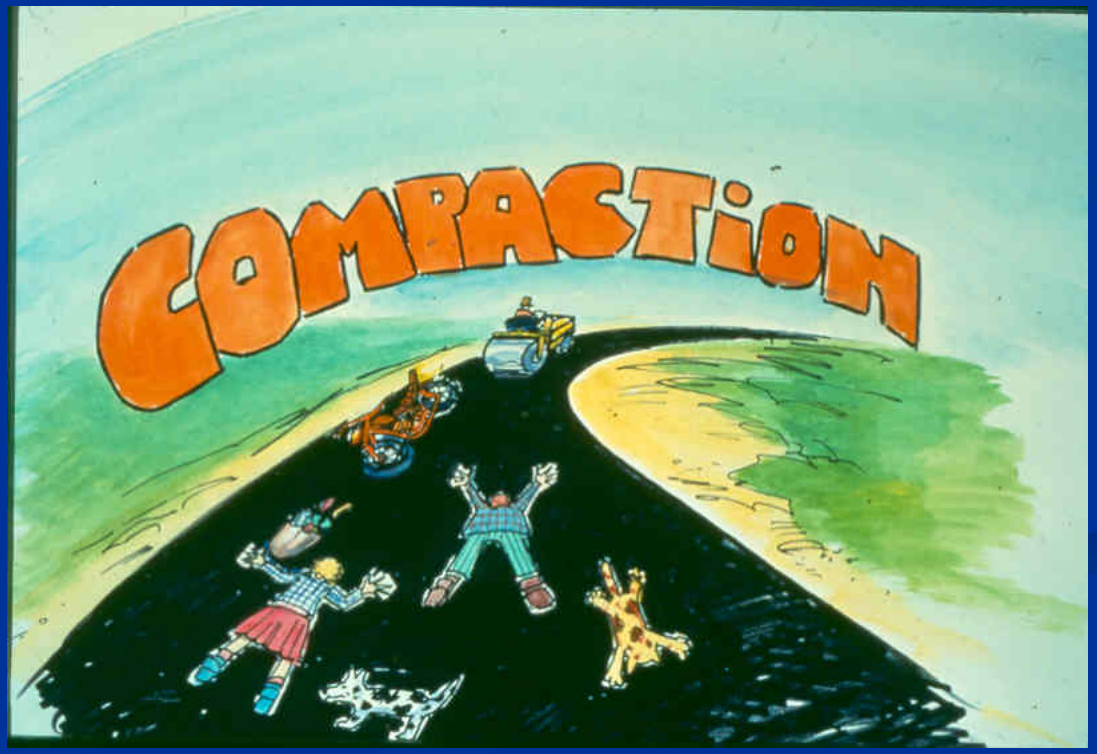
- State DOT
  - Materials
  - Construction
- NAPA Membership
- State Asphalt Pavement Associations
- Ministries of Transport Canada
- International Pavement Associations

100 Responses (50 DOT's plus DCDOT)

General Issues in Density of Asphalt Pavements

Factors Affecting Density

- Materials
- Initial Density
- Traffic



Factors Affecting Density

- Materials
  - Asphalt Binder
    - Temperature Susceptibility
    - Rheology
  - Aggregate
    - Surface Texture
    - Shape
    - Maximum Size
    - Gradation
    - Absorption

Factors Affecting Density

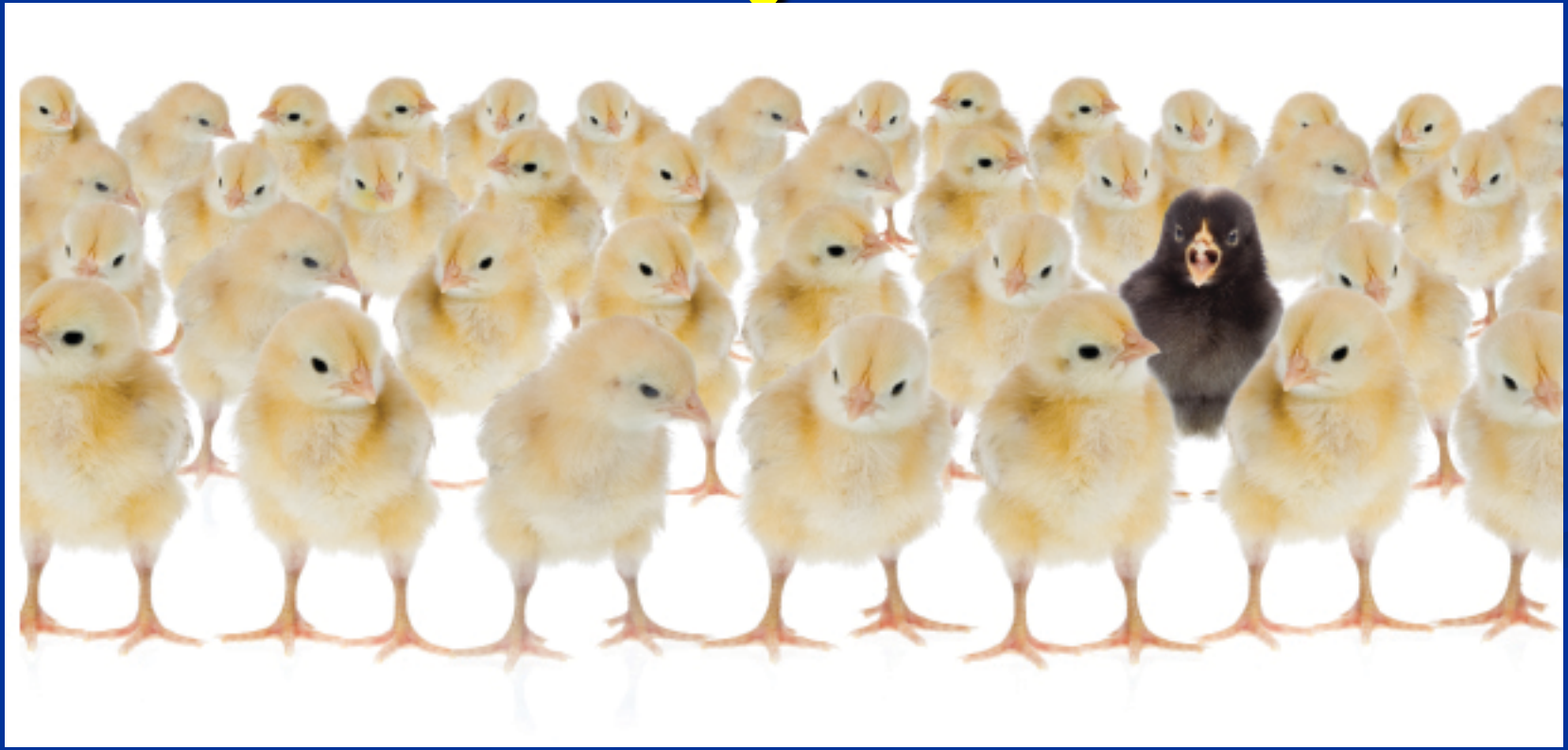
- Initial Density (Construction)

• Subgrade Support • Lift Thickness • Equipment • Rolling Sequence • Rolling Procedures • Base Temperature	• Moisture • Wind Velocity • Ambient Temperature • Pavement Temperature • Time of Year

Factors Affecting Density

- Traffic
  - Vehicle Weight and Type
  - Axle Configuration
  - Lane Distribution
  - Daily Distribution
  - Yearly Distribution

Survey Says…



Issues Related to Density

Roller Operations	5.45
Mix Design	5.17
Binder Content	5.06
Aggregate Properties	3.44
Paver Operations	3.22
Environmental Factors	2.87
Binder Stiffness	2.83

Weaknesses

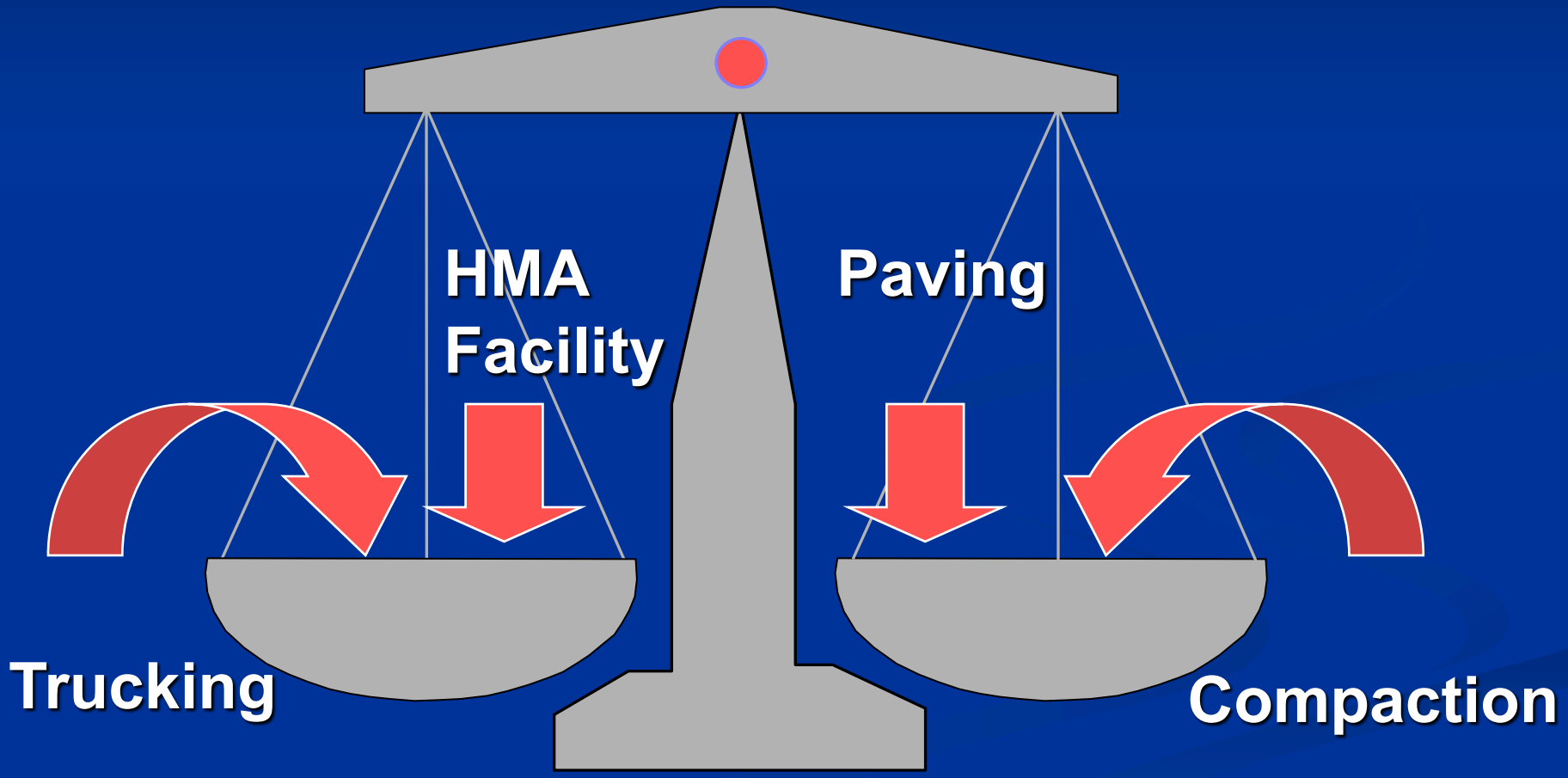
Trained Operators	78.8
Adequate Quality Personnel	46.5
Method of Density Measurement	45.5
Density Measurement Equipment	33.3
Other	28.3
Compaction Equipment	27.3
Laydown Equipment	15.2

Weaknesses

- "Other" included:
  - Effect of underlying layers
  - Unplanned schedule interruptions
    - Accidents, weather, breakdowns, etc.
  - Low bid contract environment encouraging low binder content
  - Specifications requiring overly stiff and dry mixes

Balancing Production Rates

Balancing Production Rates



Problem Getting Density?

- Most respondents said they generally don't have a problem achieving density
  - Comments were that density may be marginal
  - Some contractors using asphalt content to adjust density

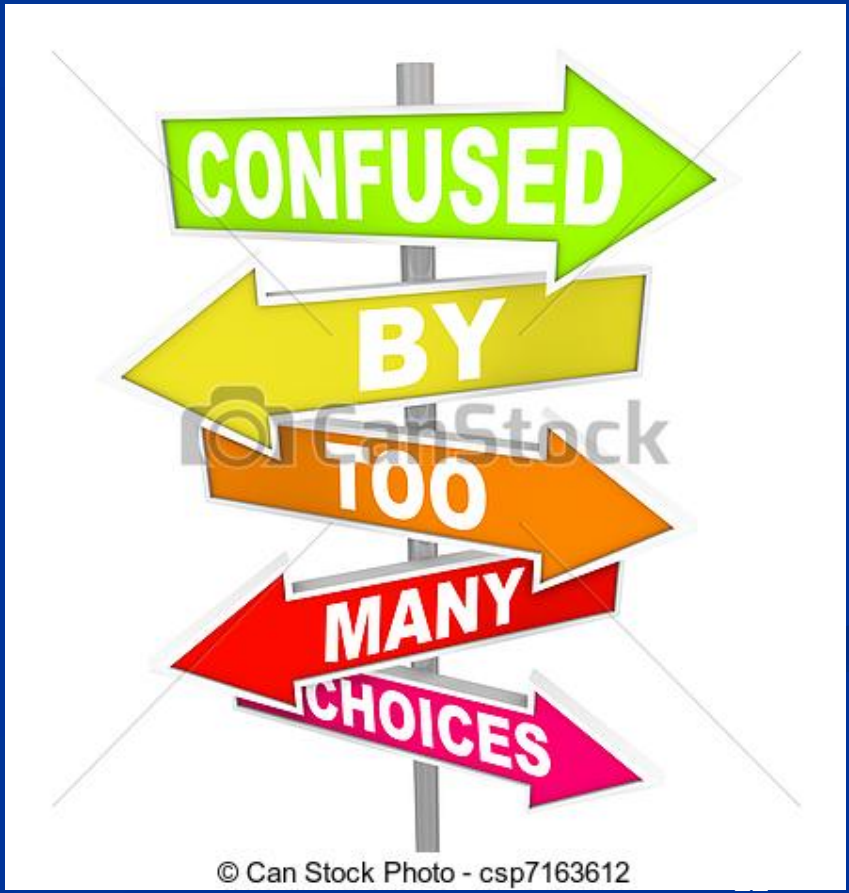
Most believe their density spec is adequate

Under/Over Compaction?

- 98% believe under compaction is a problem
- Only 64% believe over compaction is a problem

- Literature clearly recommends both an upper and lower specification limit for density

Specification Types for Control of Density



Density Specification

- All have a density specification
- 60% waive for thin lift application
- 80% have end-result specification
  - Pay factor range from 25-50%
    - 90% between 35 and 50%
    - 70% between 40 and 50%
  - 75% both incentive and disincentive
    - 12 agencies use disincentive only

Density Specifications

- Comments
  - Incentives only offset disincentives
  - “Bonuses are awarded too often”
  - We only use penalties
  - Agencies should want bonus as it indicates better quality work

Measurement Responsibility

- 94% say QC is responsibility of contractor
- 87% say assurance is responsibility of agency
  - 12 agencies use contractor results for acceptance

Reference Density

- Use of Gmm widely recommended in literature
- Recommended to be based on plant produced mix
- 92% use Gmm
- Only 74% from plant produced mix

Where is Gmm sample taken?

- Truck at plant 42.7
- Uncompacted behind paver 39.3
- At plant discharge 12.4
- Truck at paver 5.6

- Some are not following AASHTO/ASTM requirements for sampling location

Frequency of Gmm Test

- Brown/Cominsky: Routinely test/every sample

- 67% test on every sample
- 88% either every sample or daily

- Some rarely test (or never)

Control Limits

- TRB E-C173 describes
  - Engineering Limits
  - Specification Limits
  - Acceptance Limits

Response rate was low

Perhaps confusion on differences

Specification Limits

- 89% of respondents
  - Lower limit: 91-93% density
  - 57% lower limit: 92%
- 77% of respondents
  - Upper limit: 97-98% density
  - 21% no upper limit

Acceptance Limits

- 88% of respondents
  - Lower limit: 90-92% density
  - 46% lower limit: 92%
- 71% of respondents
  - Upper limit: 97-98% density
  - 46% upper limit of 97%
  - 35% no upper limit

Density Measurements Techniques


CAT
CB64
VERSA-VIBE
ZIEGLER
BR

3 PATTERN DECISIONS:

1. How many passes?
2. How many repeat passes?
3. How to be sure mix is rolled at correct temperature?
4. How fast to roll?

Quality

- Quality cannot be tested or inspected into the mix; it must be “built in”.
  - Cominsky 1998

Density Measurement

- Cores
- NDT
  - Nuclear
  - Electromagnetic

Cores are historical standard

How to patch core holes not well established


TRUELER
TS-640B
THIN LAYER DENSITY GAUGE

Coring

- Cores used to determine density of compacted mix for quality control and payment
- Core density usually different from nuclear density, but a correlation can be made between them

Density Measurement

Tool	Quality	Control	Acceptance	Acceptance	# Agencies
	Allowed	Commonly Used	Allowed	Commonly Used	
Cores	75	46	87	78	51
Nuclear	80	71	33	32	20
Thin Lift	58	42	22	20	13
Electromagnetic	4846	38	12	6	5

Core Drying

- Literature recommends vacuum drying to achieve most accurate measurement of Gmb
- 70% use oven drying
- 44% use vacuum drying

Core Absorption

- 18% have a limiting value of 1%
- 30% have a limiting value of 2%
- 15% use dry back procedure
- 21% have no absorption evaluation

Absorption testing not commonly done

May create problems in volumetric control of mix

Random Sampling

- 94% use random sampling
  - Most will relocate core if too close to pavement edge
  - Only 67% will relocate if too close to road hardware

NDT Gauges

- Nuclear: Calibration, Standardization, and Correlation
- Electromagnetic: Standardization and Correlation

Procedure	% Responses
Calibration	53.5
Standardization	40.0
Correlation	83.5

- 16% don't correlate gauge to cores!

Sample Size

- 52% use 4” Cores
- 58% use 6” Cores

It is known that the large volume sample is more representative

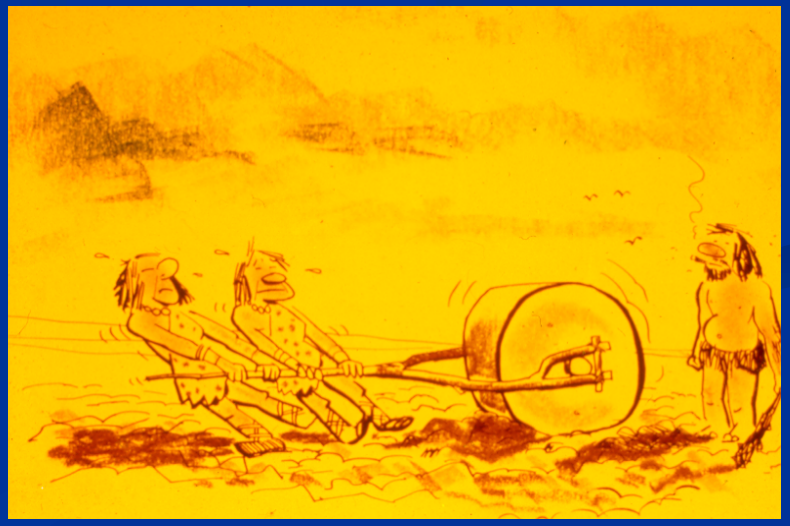
%Density Comparison

- 54% use PWL
- 46% use Average
- 11% use lowest single measurement

Construction Parameters Affecting Density

Factors Affecting Density

- Materials
- Initial Density
- Traffic



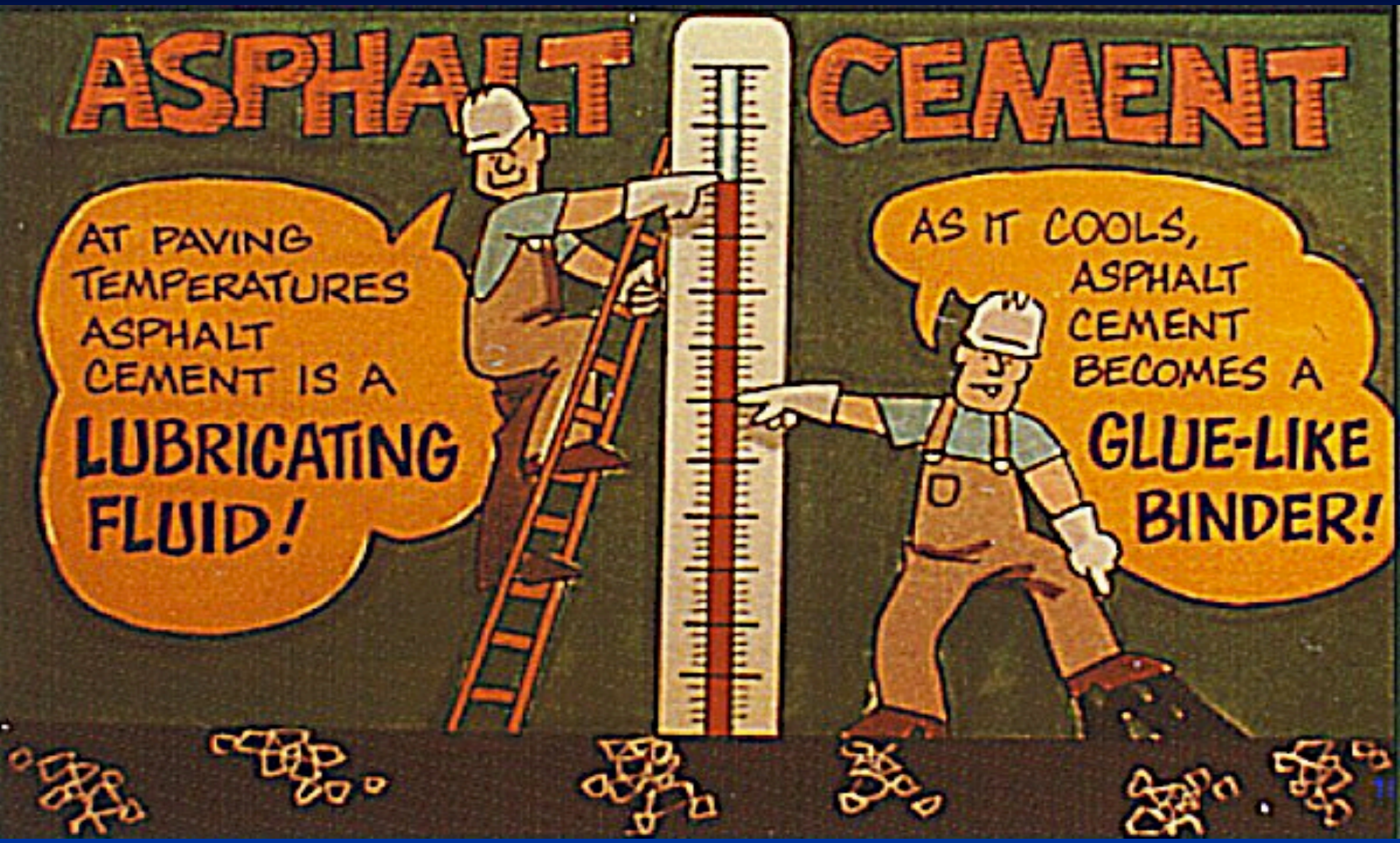
Importance of Compaction

- Improve Mechanical Stability
- Improve Resistance to Permanent Deformation
- Reduce Moisture Penetration
- Improve Fatigue Resistance
- Reduce Low-Temperature Cracking Potential

Mix Compaction

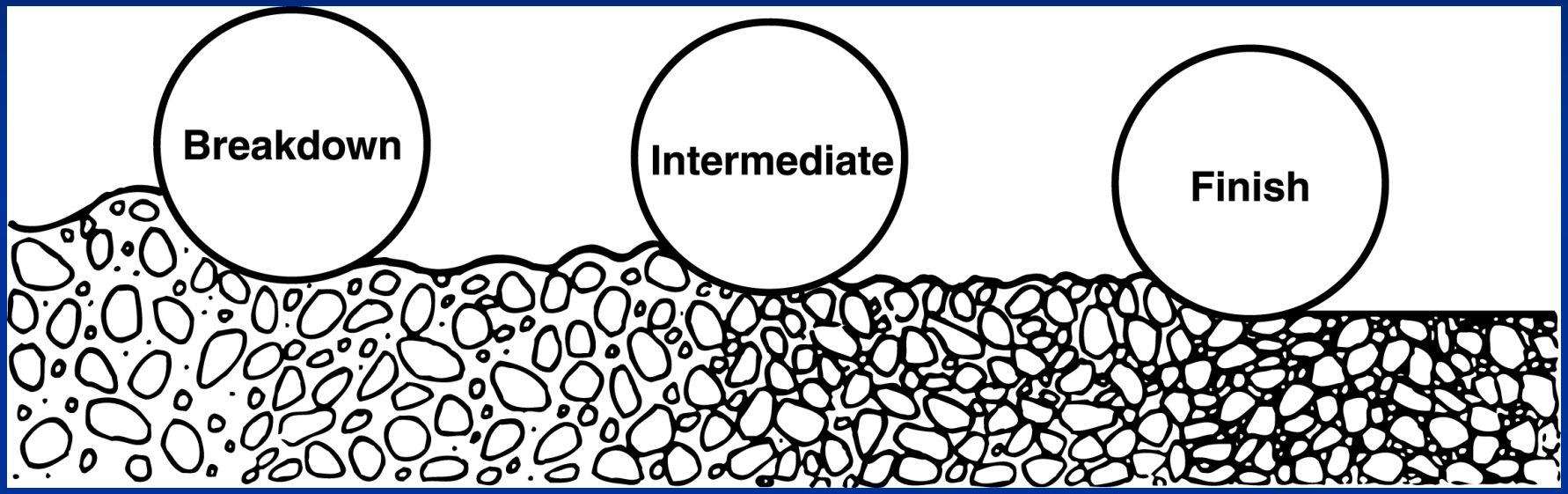
- Asphalt binder holds particles together
  - Provides lubrication at high temperatures
  - Provides cohesion at in-service temperatures
- Prevents air and water intrusion into mat


AGGREGATES
"DENSE GRADED" MIXES ARE MOST COMMON...
FINE
MEDIUM
COARSE


ASPHALT CEMENT
AT PAVING TEMPERATURES ASPHALT CEMENT IS A LUBRICATING FLUID!
AS IT COOLS, ASPHALT CEMENT BECOMES A GLUE-LIKE BINDER!


AGGREGATE
ASPHALT CEMENT
AIR VOIDS
FRACTURED OR CRUSHED FACES ARE BEST!
"RIVER RUN" GRAVEL

Density Growth



- Primary compaction
- Aggregate movement

- Some additional compaction
- Binder movement

- Minimal additional compaction
- Smooth surface

Lift Thickness

- ~70% of respondents indicated a lift thickness to NMAS ratio of 3:1
- A concern expressed:
  - If ¾” mix is designed at 4” thick and project requires two 2” lifts, ratio is violated

Vibrating Screed

Response	Percent Responses	
	Required	Used
Yes	39.4	51.0
No	50.5	30.6

Establish Roller Pattern

- 84% use NDT to establish roller pattern
- 64% have no formal procedure for establishing roller pattern
- 94% say contractor is responsible to establish roller pattern
- 79% say contractor is responsible to ensure roller pattern

- Inspector role varies

Roller Pattern Adjustments

Mix Type	89.2%
Air Temperature	67.5
Wind Speed	60.2
Base Temperature	60.2
Inspector On Site	42.2

83% have no roller training requirements

Roller Types

Position	Percentage Responses				
	DDV	PTR	DDS	TWR	OSC
Breakdown	93.5	12.0	14.1	6.5	23.9
Intermediate	65.2	57.3	25.8	4.5	21.4
Finish	23.3	6.7	84.4	6.7	16.7

Roller Issues

- 92% said contractor makes roller type decision
- Ability to achieve density is chief driver
- 76% do not verify weight of roller
- 79% do not verify the frequency of DDV

Compaction Additives

- WMA the primary additive
- 2016: 1/3 of total market
- 75% of WMA is foaming
- 82% use additives to enhance density achieved
- WMA often used at hot mix temperatures

Production

- 66% place less than 2,000tpd
- 73% place less than 3,000tpd

- Comments:
  - Significant variability exists
  - Mix, weather, lane closure time, MOT, project staging

Paver Operations

- 88% said paver speed was 20-40fpm
- Europe: 10-15fpm
- Interesting to note that comments indicated that slower speed was used for PWL job
- 72% think a slower speed would improve density
- Same percentage said there shouldn't be a max speed specification

Longitudinal Joint Construction

Longitudinal Joints

- AI Study
  - one of the highest reasons for premature failure
  - Overband or joint sealer if density is less than 92% of Gmm

- 41% have specification
- 44% don't
- Many are considering specification

Longitudinal Joints

- 78% take cores at joint
  - 13 used NDT
- 77% determined location by statistical lot
- Significant variation in frequency of testing

Longitudinal Joints

- 52% minimum density of 90%
  - Remaining are divided +/-
- Within 2% of mainline is common
- 41% use both incentive and disincentive
- 20% disincentive only
- Decision to use:
  - 33% Agency specification writer
  - 36% in standard specifications

Emerging Technologies in Determination of In-Place Density

Emerging Technologies

- IC is the main density related issue
- Two elements:
  - Density Control
  - Roller Management
- Research to date has shown that density control is not reliable in determination of density
- Tamping bar screed not widely used

Intelligent Compaction

- 65% indicated that IC is not being used
- 72% have no IC specification
- Some pilot/demonstration projects

- New technology needs time to evolve

Summary – General Issues

- 3 Most important issues: Roller Ops, Mix Design and Binder Content
- Major weaknesses: Trained Operators, Adequate QC/QA personnel and method of density measurement
- Density not a routine problem
- Density specification is adequate
- Incentives work

Summary – Specification Types

- In-place density common specification
- Thin lifts are problematic
- End-result spec with pay factor most common
- Composite pay factor varies widely
- Contractor responsible for QC, Agency for acceptance
- Many do not use Gmm from plant produced mix

Summary – Specification Types

- Primary sampling locations
  - truck at plant
  - uncompacted behind paver
- Gmm test procedures vary
- Some do not measure Gmm routinely

Summary – Specification Types

- Specification Limits
  - Lower: 91-93
  - Upper: 97-98
- Acceptance Limits
  - Lower: 90-92
  - Upper: 97-98
- 35% have no upper limit for specification or acceptance limits

Density Measurement

- Nuclear density gauge most commonly used tool for QC
- Core samples most commonly used for acceptance
- Oven drying most common
- Vacuum drying should be considered
- Random sampling used by most

Density Measurement

- Correlation using cores not uniformly performed for NDT
- Frequency of NDT not uniform
- Use of 4” vs. 6” cores evenly distributed
- PWL and average most common approaches to compare to acceptance

Construction Paramenters

- Minimum lift thk to NMAS: 3:1
- Vibrating screed used by about half
- Roller pattern established using NDT
- No formal procedure for establishing roller pattern
- Roller pattern established and controlled by contractor

Construction Parameters

- Breakdown position: DDV
- Intermediate position: DDV and PTR
- Finish roller: DDS
- Contractor decides roller type
- Weight and frequency not verified
- WMA commonly used
- Typical tonnage: <3,000 tpd
- Typical paver speed: 20-40 fpm

Longitudinal Joints

- Increasing in use
- Joint Specification being considered by many
- Typical Specification: % density
- Cores most commonly used for density
- Specification: 88-92%
  - Most common minimum 90%
- Both incentive and disincentive factors

Emerging Technologies

- Most agencies do not have an IC spec
- Most are not currently using IC
- Density control not currently reliable
- Roller management is useable
- Tamping bar screeds not widely used

Recommendations

- QC/QA activities should be uniformly performed
- Training for all personnel is key
- Frequency of testing is highly variable
- Density testing should be performed for all projects
- Both a minimum and maximum density should be specified

Recommendations

- Absorption evaluation of all cores should be performed
- Testing for Gmm should be performed during plant production of mix
- Standard procedures for NDT should be followed
- Ensure adequate testing is performed

Recommendations

- Consider requiring a vacuum drying procedure
- Roller management should be used to ensure consistency of roller patterns
- Consider requiring joint sealer for all longitudinal joints

Thanks to All who Participated!

- Results published in NCHRP Report 856

Thank You!

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