NESMEA 2005
OCTOBER 18 & 19
INNOVATIONS IN COMPACTION OF HOT MIX ASPHALT
CHUCK DEAHL
BOMAG AMERICAS, INC.
Asphalt Manager
Intelligent Compaction
INTELLIGENT COMPACTION

- A system for measuring the stiffness of HMA on the roller
- A recording of that stiffness measurement
- Proof of the stiffness of the HMA as related to density
- Providing information for the roller to make decisions
INTELLIGENT COMPACTION IS:

A SYSTEM FOR MEASURING THE STIFFNESS OF A GIVEN MATERIAL IN MEGA NEWTONS /METERED SQUARED OR P.S.I. AND RECORDING THAT INFORMATION, TO BE UTILIZED AS A DOCUMENT OR PROOF OF ACHIEVING A GIVEN AMOUNT OF COMPACTION. THIS SYSTEM IS MOUNTED ON A MOBILE ROLLER TO RECORD THESE MEASUREMENTS AND THEN RELATE THESE MEASUREMENTS TO MEASURING DEVICES.
1. DENSITY
2. SMOOTHNESS
3. NOISE REDUCTION
4. BALANCED PRODUCTION
needed for compaction

- mix confinement
- correct mix temperature
8.4 Importance of Compaction

- Improve Mechanical Stability
- Improve Resistance to Permanent Deformation
- Reduce Moisture Penetration
- Improve Fatigue Resistance
Compaction achieved by...

Pressure

Impact

Vibration

Manipulation
Surface Covering Compaction Measurement

1983  Terrameter BTM 01 ( OMEGA )

1993  Guidelines for Surface Covering Measurements
      National Research Association

1994  ZTVE / TP BF-StB 94, proof methods FDKV/ SCCC

1996  Compaction Management System BCM 03

1998  VARIOCONTROL

2001  Measuring device for evaluation of stiffness (Evib)

2004  Modular Measuring System  with GPS support
BOMAG Compaction Technology

1996  Variomatic for asphalt rollers
1998  Variocontrol for soil rollers
2000  Evib (MN/m²)
2001  Asphalt Manager
2004  Research project of German DOT (BAST), Oct / Nov. 2004;
VARIOMATIC roller with directed vibration

Control unit

low dynamic energy

Compaction principle
static pressure and dynamic energy which is automatically adjusted to type of material, compactibility, layer thickness and base layer conditions.

Applications: asphalt layers, granular bases and subbases.
Worldwide proven design:

Several hundreds Tandem rollers

BW 151 AD-2

BW 174 AD
Vibration Systems

Rotary exciter  Oscillation  directed
Rotary exciter

Oscillation

directed
Non Directed Forces:
## Vibration systems / Overview

<table>
<thead>
<tr>
<th></th>
<th>Vibration</th>
<th>Oscillation</th>
<th>Variomatic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principle</strong></td>
<td>Rotary exciter with unbalanced weight</td>
<td>2 rotary exciters with 2 unbalanced weight</td>
<td>2 rotary exciters with 2 unbalanced weight counter rotating</td>
</tr>
<tr>
<td><strong>Oscillation</strong></td>
<td>non directed</td>
<td>directed horizontally</td>
<td>directed horizontally to vertically</td>
</tr>
<tr>
<td><strong>Amplitudes</strong></td>
<td>up to 8</td>
<td>2 fixed amplitudes</td>
<td>automatic variation</td>
</tr>
<tr>
<td></td>
<td>up to 1,3 mm</td>
<td>ca. 1,3 mm</td>
<td>0 - 0,9 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>horizontal/vertical</td>
</tr>
<tr>
<td><strong>Frequencies</strong></td>
<td>35 - 70 Hz</td>
<td>33 - 42 Hz</td>
<td>35 - 50 Hz</td>
</tr>
<tr>
<td><strong>Control system</strong></td>
<td>manual</td>
<td>manual</td>
<td>automatic variation</td>
</tr>
</tbody>
</table>
Directed exciter system

Advantages vs. Rotary exciter:

- Better depth effect
- Excellent Asphalt surfaces
  - Eveness
  - Grip / roughness
Benefits for contractors:

- Universal use on
  - Road base
  - Wearing course layers
  - Thin layers
- Higher compaction performance
- Uniform compaction, even on sub-bases with inhomogeneous stiffness
- Better evenness and more uniform surface structure
- Low tendency to scuffing
Compaction of 6 cm asphalt binder course 0/10, RN13 France
Operating weight and compaction technique affect smoothness and eveness

15 t tandem vibratory roller
8 passes

8 t BOMAG VARIOMATIC BW 151 AD
8 passes
Density and roughness measurement on asphalt binder layer

Punctual compaction measurement with portable isotope probe

Continuous compaction measurement with mobile isotope probe
[1 measurement / 10 m]
### Comparison between conventional compaction concept and VARIOMATIC

<table>
<thead>
<tr>
<th></th>
<th>Compaction</th>
<th>Roughness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Portable isotope probe</td>
<td>Mobile isotope probe</td>
</tr>
<tr>
<td></td>
<td>[1 measurem./10 m]</td>
<td>[1 measurem./10 m]</td>
</tr>
<tr>
<td></td>
<td>n   X1     σ</td>
<td>n   X1     σ</td>
</tr>
<tr>
<td>4 passes with 25 t rubber tire roller and 4 passes with 15 t tandem vibratory roller</td>
<td>14 92,5% 1,22</td>
<td>59 94,6% 1,29</td>
</tr>
<tr>
<td>8 passes with BW 151 AD-2 VARIOMATIC</td>
<td>14 92,5% 0,54</td>
<td>59 93,8% 1,06</td>
</tr>
</tbody>
</table>

n = number of measurements, X1 = mean value of achieved Gyrator test compaction value (93% Gyrator value ~ 98% Marshall value), X2 = mean value of characteristic roughness value.
1996
Variomatic

1998
Variomatic 2

advanced, more powerful
also for split drums!
Latest developments of compaction technology

1996  Variomatic for asphalt rollers
1998  Variocontrol for soil rollers
2000  Evib (MN/m²)
2001  Asphalt Manager
Directed Exciter System

Vibration motor

Exciter housing (slewable)

Unbalanced weights (counter rotating)
inner: No. 2 + 3
outer: No. 1 + 4

Compaction force

Travel motor

Slewing motor S
Force Direction Control:
Infinite adjustment of exciter housing from horizontal to vertical.
Asphalt Manager with new measuring value $E_{\text{VIB}}$ [MN/m²] and temperature gauge
Acceleration meters

Force direction control
Benefits for Operators:

No critical decisions required

All operators achieve better results:
- good and uniform compaction

Continuous information on
- asphalt temperature
- compaction increase
The Operator

Asphalt Manager: Easy to understand
## Technical Data

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>BW 141 / 151 AD AM</th>
<th>BW 190 / 203 AD AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oper. weight kg</td>
<td>8.000</td>
<td>8.400</td>
</tr>
<tr>
<td>Drum width in</td>
<td>59</td>
<td>66</td>
</tr>
<tr>
<td>Amplitudes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>front mm</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>rear mm</td>
<td>0.64 / 0.27</td>
<td>0.6 / 0.25</td>
</tr>
<tr>
<td>Frequencies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>front / rear Hz</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Centr. force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>front kN</td>
<td>160</td>
<td>168</td>
</tr>
<tr>
<td>rear kN</td>
<td>80 / 34</td>
<td>80 / 34</td>
</tr>
</tbody>
</table>

Front: AM  
Rear: Std. Exciter
### Bomag Operational Panel

#### Compaction Modes

<table>
<thead>
<tr>
<th>Manual</th>
<th>Auto</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 x</td>
<td>3 x</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,2 mm</td>
<td>0 - 0,2 mm</td>
</tr>
<tr>
<td>0,4</td>
<td>0 - 0,6</td>
</tr>
<tr>
<td>0,6</td>
<td>0 - 0,93</td>
</tr>
<tr>
<td>0,7</td>
<td>0 - 0,93</td>
</tr>
<tr>
<td>0,93</td>
<td>0 - 0,93</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,08 in</td>
<td>0,08 in</td>
</tr>
<tr>
<td>0,24 in</td>
<td>0,24 in</td>
</tr>
<tr>
<td>0,37 in</td>
<td>0,37 in</td>
</tr>
</tbody>
</table>
Test procedure:

- Mark the track to be compacted
- „Manual operation mode“ with
- Fixed amplitude
- Fixed working speed
Bomag Operational Panel

SETTINGS
- Escape
- Enter
$E_{\text{VIB}}$ Max. / $E_{\text{VIB}}$ Min.

$E_{\text{VIB}}$ Average

Frequency

Average Speed

Track length

Temperature
$E_{VIB}$ and Density as function of passes; BW 174 AD Asphalt Manager, Automatic mode; Asphalt Base 0/32 CS B65, Nürnberg A3

- $E_{VIB}$ [MN/m²], [°C]
- Evib
- Surface temp.
- Core temp.
- Troxler density

- 4 cm SMA 0/11 S
- 8 cm Binder 0/22
- > 10 cm ATS 0/32
$E_{\text{VIB}}$ and Density as function of passes; BW 174 AD Asphalt Manager, Manual mode 4; Wearing course SMA 0/11S PmB45, Nürnberg A3

- 4 cm SMA 0/11 S
- 8 cm Binder 0/22
- > 10 cm ATS 0/32

**Graph Details:**
- **Y-axis:** $E_{\text{VIB}}$ [MN/m$^2$], [°C]
- **X-axis:** Passes

**Legend:**
- **Evib**
- **Surface temp.**
- **Core temp.**
- **Troxler density**
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?
BOMAG ASPHALTMANAGER

PASS NO. 3 Rev.
BOMAG Em Rev 2-8 ENG
BU19 60-4 AM

Settings: Auto 2.
Envi Max. = 25520 psi
Envi Min. = 12896 psi
Envi Average = 16972 psi
Frequency = 2950 rpm
Average speed value = 3.5 mph
Track length = 152.1 ft

Scale (ft) → Envi (psi×100) → Temperature (F)

0 100 200 300 400 500
Advantages:

- Immediate determination of dynamic stiffness in MN/m² ($E_{\text{VIB}}$)
- $E_{\text{VIB}}$ can be correlated with the increase of compaction
- $E_{\text{VIB}}$ is widely independent from roller parameters
- $E_{\text{VIB}}$ printouts for area covering compaction control

In Development:

- Target $E_{\text{VIB}}$ values to be pre-selectable
- „Ready“ indication if target value is achieved (red light)
- „Ready“ indication if no further compaction is possible (red light)
Further advantages:
better gradability- less shoving effect

Automatic force adaption with travel direction
Evib (MN/m²) Vibration modulus

Equivalent for dynamic Stiffness;

Directly picked up by the roller;

Physical value for compaction increase on asphalt.
Benefits for Contractors: Investment for Profit

Compaction
- Uniform and predictable results whilst rolling
- Avoids under / overcompaction
- Better evenness and roughness
- Eliminates drum bouncing

Economical and quality aspects
- More efficient roller utilisation with fewer passes
- Reduced shock loads in sensitive environment
e.g. buildings, bridges
- Area coverage method
Compaction test on asphalt wearing course (stone mastix asphalt)

Perfect correlation:
Evib + Marshall density

Adequate conditions:
• Temperature between (170-120 °C)
• Asphalt layer on solid ground
Compaction test on asphalt wearing course (stone mastix asphalt)

Increase of Evib = Increase of compaction
Comfort + Quality:

Compaction of joints hot against cold

- avoids shock loads
- no bouncing
- better eveness
Leipzig:

“Augustusplatz”

Compaction on a parking roof top;

Alternatives:

15 t static roller - 15 cm layers
With BVM - 40 cm layers
Application

Avoids shock loads on bridges and near buildings

Depth control via force adjustment

• 3 automatic control ranges
• 6 manual force directions (fixed)
<table>
<thead>
<tr>
<th>FEATURES</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular Design Principle:</td>
<td>Less Expenses for Warehousing, Training, and Logistics;</td>
</tr>
<tr>
<td>- Operator Platform</td>
<td></td>
</tr>
<tr>
<td>- Central Electric System</td>
<td></td>
</tr>
<tr>
<td>- Travel- / Vibration Pumps and Motors</td>
<td></td>
</tr>
<tr>
<td>- Support Legs</td>
<td></td>
</tr>
</tbody>
</table>
Surface Quality

Racing Course „Sachsenring“

Perfect Results:
- Roughness
- Evenness
**Application soil compaction**

Support for compaction works and measuring paths on sub-grade, frost blanket layers and non-bonded bearing layers: the $E_{Vib}$ value increases with increasing compaction. Weak spots are localized.

**Application asphalt compaction**

Support for compaction works on asphalt layers. If compaction is performed within a narrow temperature range (e.g. 120° – 150°C) and the sub base is of sufficient stability, $E_{Vib}$ will show the increase in compaction. A direct statement on the density is only possible after performing comparison measurements with an isotope probe (Troxler). Compaction force and depth effect can be adapted to the layer to be compacted and to the substrate (see matrix of recommended applications).

<table>
<thead>
<tr>
<th>Condition of the substrate</th>
<th>Setting</th>
<th>Asphalt bearing course</th>
<th>Asphalt binder</th>
<th>Asphalt pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Easy to compact</td>
<td>Difficult to compact</td>
<td>Asphalt concrete</td>
</tr>
<tr>
<td><strong>evenly firm (stable)</strong></td>
<td>Automatic: Force level</td>
<td>3</td>
<td>2-3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>alternative: Manual*: Position</td>
<td>6-3</td>
<td>4-3</td>
<td>5-3</td>
</tr>
<tr>
<td></td>
<td>Compaction temperature</td>
<td>&gt; 80°C</td>
<td>&gt; 80°C</td>
<td>&gt; 100°C</td>
</tr>
<tr>
<td><strong>yielding (soft)</strong></td>
<td>Automatic: Force level</td>
<td>2</td>
<td>1-2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>alternative: Manual*: Position</td>
<td>4-2</td>
<td>3-2</td>
<td>3-2</td>
</tr>
<tr>
<td></td>
<td>Compaction temperature</td>
<td>&gt; 80°C</td>
<td>&gt; 80°C</td>
<td>&gt; 100°C</td>
</tr>
<tr>
<td><strong>Layers on bridges</strong></td>
<td>Automatic: Force level</td>
<td>1-2</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>alternative: Manual*: Position</td>
<td>3-2</td>
<td>2-1</td>
<td>2-1</td>
</tr>
<tr>
<td></td>
<td>Compaction temperature</td>
<td>&gt; 80°C</td>
<td>&gt; 80°C</td>
<td>&gt; 100°C</td>
</tr>
</tbody>
</table>

Temperature specifications related to the asphalt surface, * in manual mode start with higher level first, and reduce after.
Display, direction of vibrations

Display of vibration direction and amplitude
- Shows the direction of drum vibration and the size of the vertical amplitude.

EVIB display
- EVIB shows the dynamic stiffness of the material to be compacted in MN/m².
  - EVIB responds to changes in density. With increasing density, the asphalt becomes firmer (stiffer). The EVIB value increases.
  - EVIB responds to temperature changes. With dropping temperature, the asphalt becomes firmer (stiffer), even if the end of compaction is not yet reached. EVIB increases with decreasing temperature.
  - EVIB responds to deviations in the stiffness of the substrate (base layer). On a soft substrate and with a pre-selected high force level, the EVIB may remain low.

Temperature gauge
- The temperature is permanently detected as asphalt surface temperature. Depending on layer thickness, ambient temperature, and wind force, the mix temperature inside the core of the layer may be up to 40°C higher. At a surface temperature of 80°C, compaction should be completed.

Emergency switch
- In case of an electronics failure, the emergency switch enables the selection of two vibration directions: horizontal (left) or vertical (right).

Selector switch
- Operating mode
  - Manual/Automatic

Manual mode
- 6 selectable amplitudes each with constant direction of vibration

Automatic mode
- 3 selectable force ranges with amplitude control, limited to compaction force and depth effect
Asphalt Manager + BOMAG GPS System

- Surface covering compaction control on asphalt layers
- GPS receiver
- GPS reference station
- Roller PC for data managing and graphical representation of roller position and stiffness values
- Position accuracy: better than 10 cm
- CAD based evaluation program
Roller positioning with total station (Geodimeter) for continuous compaction control on asphalt layers
Surface Covering Compaction Measurement

**Maschine**
- Modell: DW 174 Variomatic 2
- Gewicht: 9000 kg
- Bandagenbreite: 1,53 m
- Innentlkn. 77 kg/cm
- Frequenz: 46 Hz

**Baustelle**
- Ort: DONAG/TF/Testgelände
- Feld: Bodenart: Grubenkies
- Flächeninh. 0,30 m

**Einstellparameter**
- Amplitude: Automatik
- Kraftstufe: 3

**Bearbeitungszeit**
- Datum: 01.03.01
- Bearbeiter: Wallrath

![Graphical representation of compaction measurement](image)
Reference station on the job site
    High accuracy: up to 5 cm

GPS Reference service with reference satellite
    Accuracy: up to 100 cm
> OmniSTAR (world wide) ~ 1500,- Euro annual charge
> EGNOS (Europe, not yet in operation) free of charge
> WAAS (North America)

Local Reference network (reference service)
    High accuracy: up to 5 cm (depending on service)
> Ascos (since 2001, Ruhrgas / Germany,
    (only available in Rhine Area)
GPS / positioning with Reference Station

- Two GPS Antenna
- Reference station (Trimble)
- High accuracy (5cm)
- RTK (real time)
- BCM 05 positioning software
TRAVEL SPD LMT = MPH
ADJ. WITH CONTROL HANDLE
HI MAT TEMP LIMIT 310 F
ADJ. WITH CONTROL HANDLE
LOW MAT TEMP LIMIT 110 F
ADJ. WITH CONTROL HANDLE
Compaction of Superpave Mixes

Compactive Force  Pressure Vibration  Pressure Manipulation  Pressure

Temperature Zones  300° - 285°  240° - 200°  170 - 150°

TENDER ZONE
QUESTIONS????

QUESTIONS????

QUESTIONS????

QUESTIONS????