CCC & INTELLIGENT COMPACTION
填筑工程智能压实

BY
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第一节　发展历程

传统工艺的问题

缺乏反馈

过压

欠压

点式抽样控制的问题

有限取样

抽样点的代表性差，无法控制整体质量。

为时太晚

事后检验，发现问题不能在碾压过程中进行处理。

耗时较长

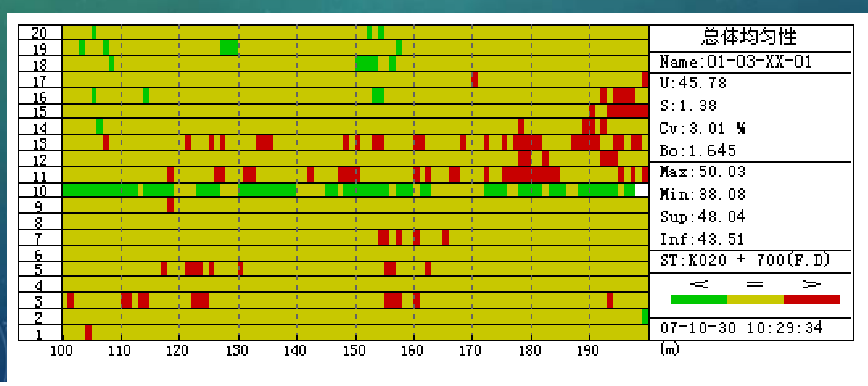
试验比较费时费力，给机械化施工程带来明显干扰。

压实工艺控制方法

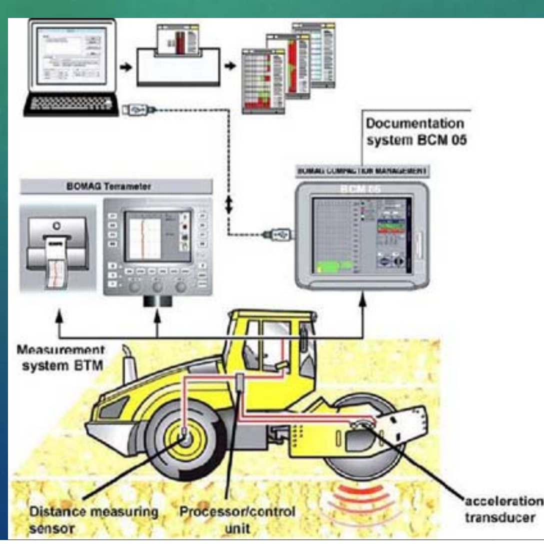
- 碾压遍数控制（岩土填料，沥青混合料）
- 碾压轮迹控制（填石和混填）
- 高程控制（填石和混填）
- 温度控制（沥青混合料）

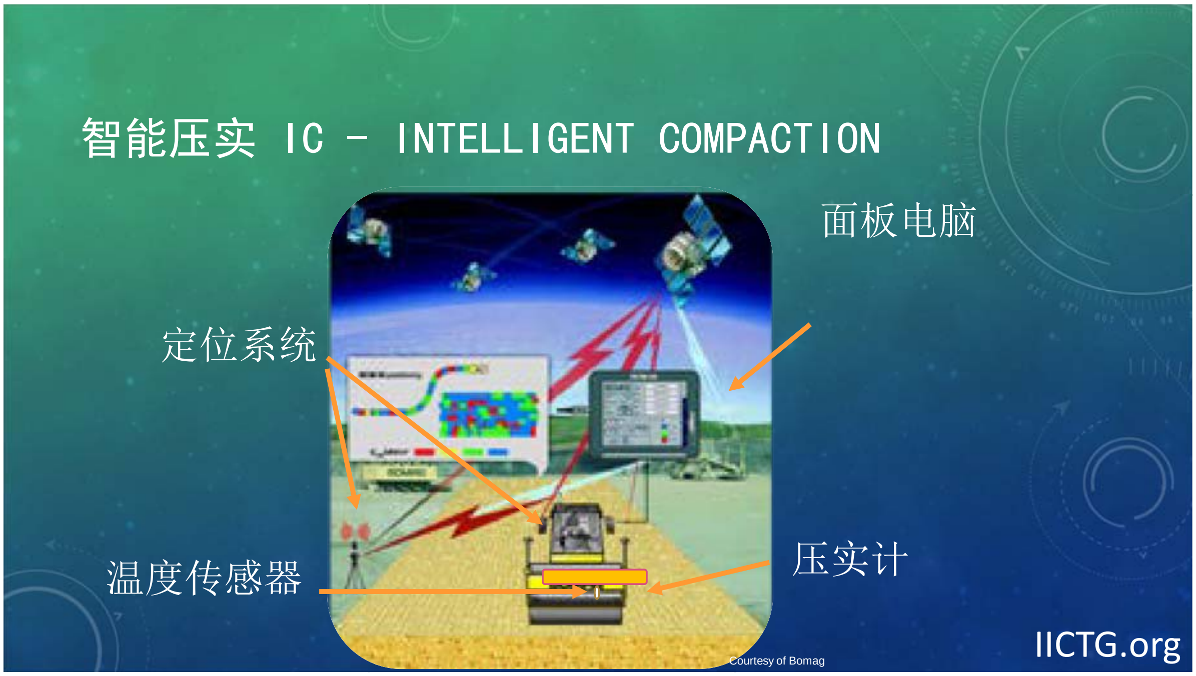
碾压遍数依据试验段得到，后续施工段的条件必须与试验段的完全一致，属于经验控制法。

- 实践证明，碾压遍数不变会导致碾压面某些区域没被压实、而另一些区域过度压实等，因此单纯控制碾压遍数还不能控制好填筑体的整体质量，优化碾压遍数才能得到更好的压实质量。

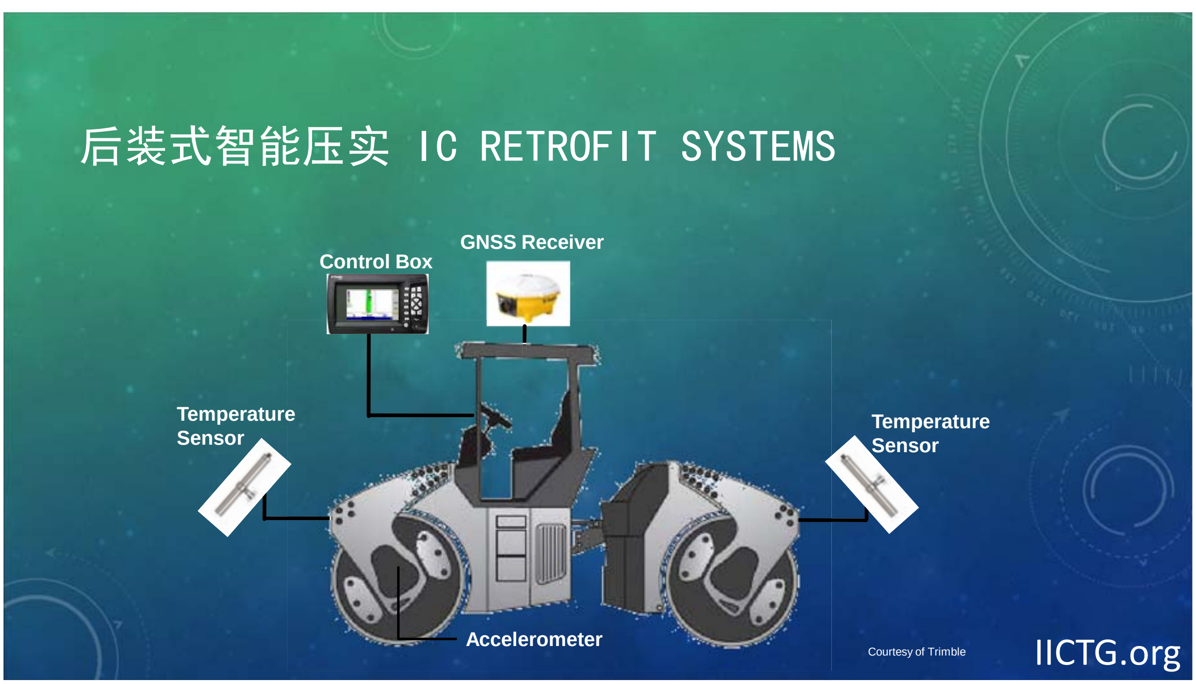


连续压实控制 CCC – CONTINUOUS COMPACTION CONTROL




智能压实 IC – INTELLIGENT COMPACTION
面板电脑
定位系统
压实计
温度传感器
Courtesy of Bomag
IICTG.org


Traditional Compaction Testing Method
1 / 1,000,000
取样
Compaction Testing and Coverage Mapping with AccuGrade
100 %
Coverage
全敷盖
智能压实测量
Courtesy of Caterpillar
IICTG.org


后装式智能压实 IC RETROFIT SYSTEMS
GNSS Receiver
Control Box
Temperature Sensor
Temperature Sensor
Accelerometer
Courtesy of Trimble
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传感器两种安装方式

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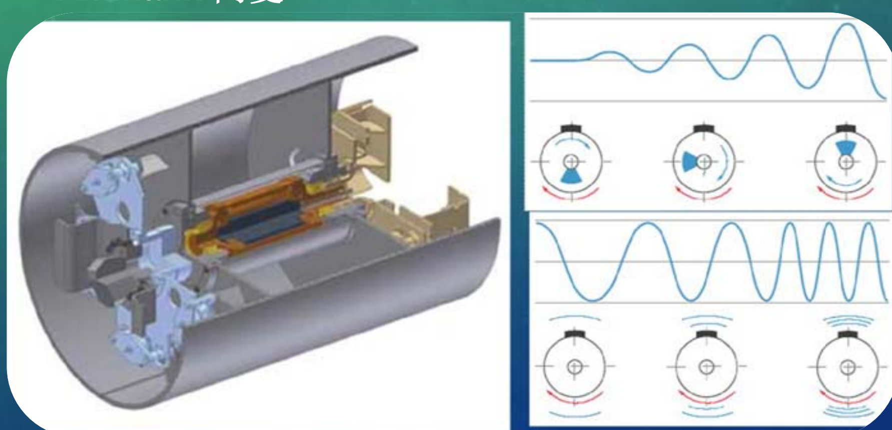
自动反馈控制 AUTO-FEEDBACK CONTROL - AFC

Ammann 阿曼



Courtesy of Ammann

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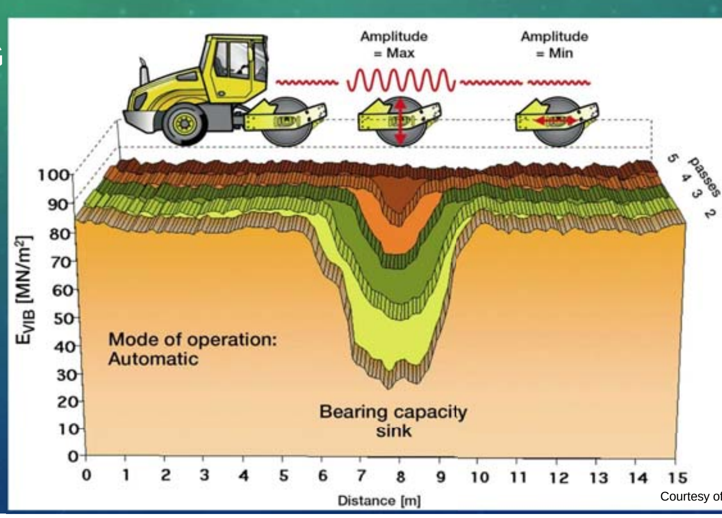
自动调幅压实控制系统 AUTO-FEEDBACK CONTROL - AFC

BOMAG 宝马格



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1960 到 1970

（1）1960's:

美国有人提出利用振动压路机碾压过程中的动力响应来连续评定碾压面压实质量的想法，但由于电子量测技术的限制而没能实现。

（2）1970's:

1975年，瑞典的GEODYNAMIK与DYNAPAC公司联合开发了一种称作压实计的产品（表针式），初步实现了愿望。其指标是无量纲的谐波比，即压实计值CMV

1980'S

其发展主要在欧洲。德国和瑞士开始加入这个研究中。

BOMAG、AMMANN和Geodynamik开始制造连续控制压实产品。其原理都是压实计原理，采用谐波比类指标，如德国的10CMV。

- 1982年，BOMAG首次将测量系统概念引入压路机。
- 1988年，中国水利水电部门开始采用压实计原理进行大坝碾压控制。
- 1989年，德国出现首个压路机信息管理系统。

1990'S (1/4)

国际上系统提出连续压实控制概念（Continuous Compaction Control，简称CCC）——是指在填筑体填筑碾压过程中，根据土体与振动压路机相互动态作用原理，通过连续量测振动压路机振动轮竖向振动响应信号，建立检测评定与反馈控制体系，实现对整个碾压面压实质量的实时动态监测与控制。

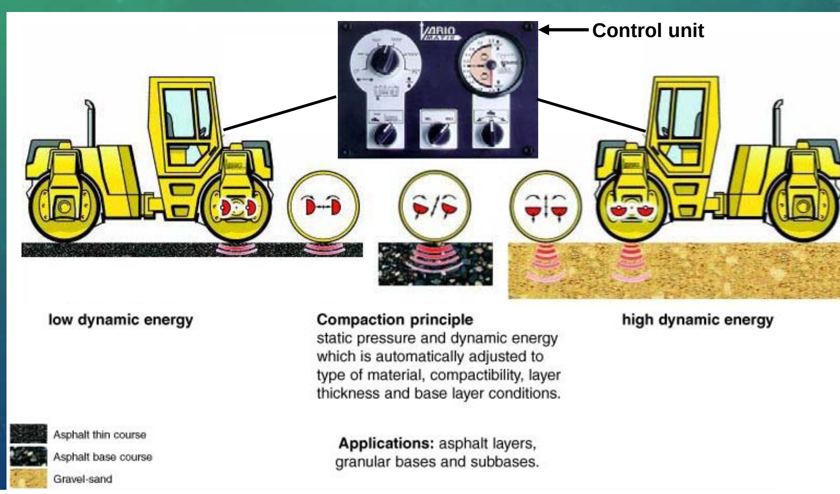
- 1992年的BAUMA会议展出了“智能压路机（ICM）”的首个原型。
- 1993年德国公路建设部（German Ministry of Highways Construction）首次推荐SCCC（土壤连续压实控制，智能压实的前身）。

1990'S (2/4)

- 1994年德国公路建设部引入了SCCC合同规范。
- 1996年德国带自动调幅智能压实系统（Variomatic）的压路机被首次用于沥青压实；
- 1998年德国研制具有自动调幅压实控制系统的压路机；

北欧国家开始制定标准，CCC已被纳入瑞典（BYA92、ATB Väg 2004），德国（ZTVE-StB-93、94、95、2007、2009，TP BF-StB E2 94）、奥地利（RVS 8S.02.6）和芬兰（Tielaitos91）的国家标准中。法国、爱尔兰和荷兰等国家也在计划引入CCC国家标准。预计欧洲共同体将会通过整合制定更统一的标准。

自动调幅智能压实系统（VARIOMATIC）



1990'S (3/4)

- 德国：由压实计原理的CMV向基于能量原理的方法发展，提出OMEGA（能量）和OMV（示波器显示值）等指标，均为无量纲量。
- 中国水利、公路部门采用压实计原理进行研究和应用。
- 1993年中国政府部门立项研究连续压实技术，哈尔滨建筑大学等科研团队根据振动压路机与填筑体相互作用，采用动力学理论，开始在室内和现场进行研究。1998年提出基于路基抗力指标的动力学方法，1999年成功研制“压实过程监控系统（CPMS）”并开始试验性应用。

2000'S (1/2)

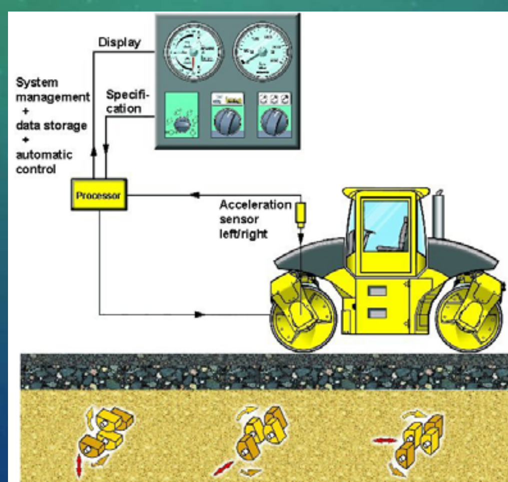
- 2000年德国开始采用力学方法研究连续压实问题，引入连续压实新指标——模量Evib；
- 2001年德国出现沥青压实专家系统（Asphalt manager）；
- 2001年美国Ammann公司将第一台带有ACE系统的AV 95串联式振动沥青压路机引入美国 – 刚度Kb。

智能压路机与智能压实概念的提出。

- 2004年，美国联邦公路局公布了一个“FHWA智能压实战略计划”。

宝马格 - 沥青压实专家系统

ASPHALT-MANAGER EVIB



1982 First compaction measurement system for soil compaction Terrameter BTM01

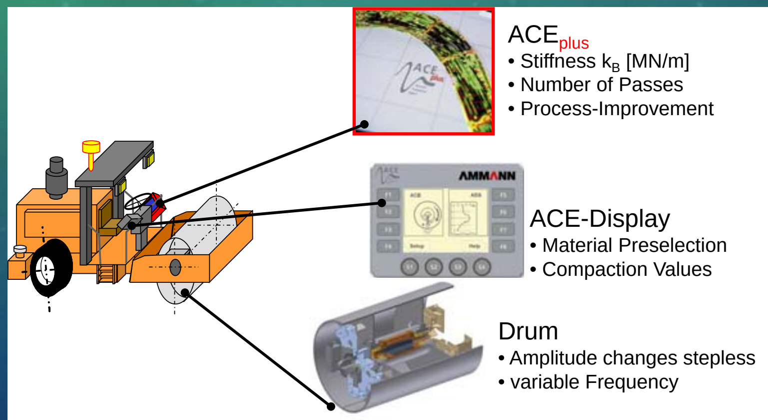
1995 First compaction management system BCM03 for large projects

1999 First intelligent soil compactor with automated controled variable amplitude and stiffness measurement system (Evib) / Variocontrol

2001 First intelligent asphalt compactor with automated controled variable amplitude and stiffness measurement system (Evib) / Asphalt Manager

2002 First 26 t polygonal roller for deep soil compaction

AMMANN ACE系统



2000’S (2/2)

- 2003年，美国卡特比勒发展MDP
- 2008年，美国经由共通研究基金(TPF)大力推展智能压实。
- 2008年，中国铁道部开始立项研究高速铁路路基连续压实控制成套技术（理论方法、测试技术、工程应用、技术标准）。控制系统为CPMS。

其它国家..............

2010’S (1/3)

- 2011年，中国颁布首部连续压实控制国家行业标准，并开始在高速铁路建设中加以应用。
- 2015年，中国铁路总公司颁布新的连续压实控制标准。
- 2016年，中国交通运输部公路路基连续压实控制系统标准报批。

2010'S (2/3)

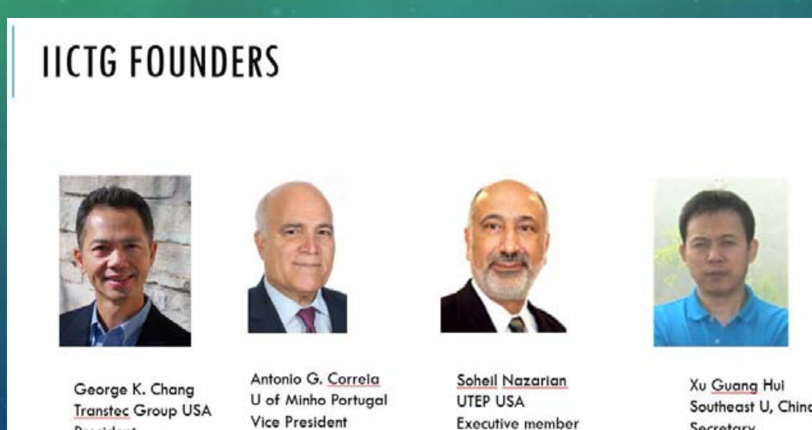
- 2012年后，美国联邦公路（FHWA）局颁布岩土填料及沥青混合料智能压实标准。2014年后，美国(AASHTO)颁布国家智能压实标准。 到2016年已有24州（美国有50州，所以近50%）交通局颁布州立智能压实标准。 ……
- 2015年， CAT提出适用于静力压路机的MDP指标，基于特定的填料的摩擦系数一定的思想。

其它国家……

2010'S (3/3)

- 2016年，国际智能建设技术学会（IICTG）成立
- 2016年，智能建设科技公司（美国/中国）推出UIC系列，采用抗力Fr与估算模量Eest两个指标，综合评定压实质量。

国际智能建设技术学会（IICTG）



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SECTION 2 PRINCIPLE
第二节 技术原理

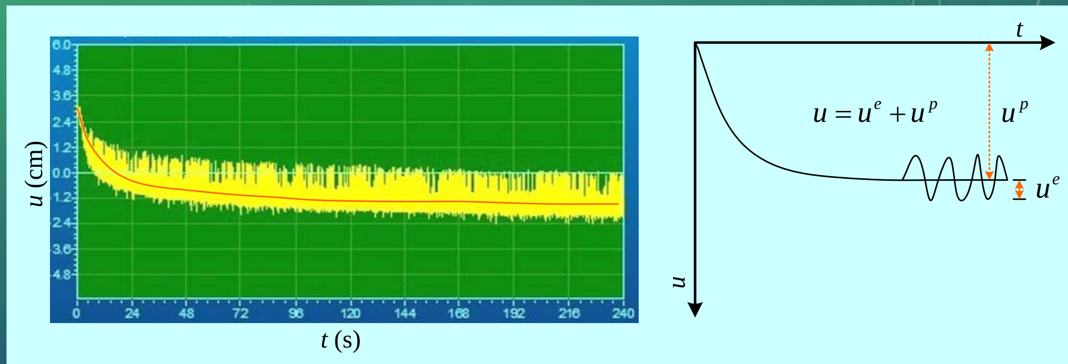
Interaction between a rigid vibrating cylinder and various types of filling body
刚性圆柱体（振动轮）与各种类型填筑体相互作用

Elastic and plastic filling body
弹塑性填筑体

High temperature, viscosity and elastic plastic filling body
高温粘弹塑性填筑体

Dynamics control problem

Deformation characteristics of filling body during rolling process
碾压过程中填筑体变形特征



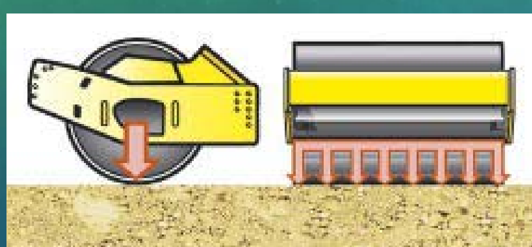
Rolling process： $\mu^p + \mu^e$ **At the end of rolling:** μ^e ， $\mu^p = 0$

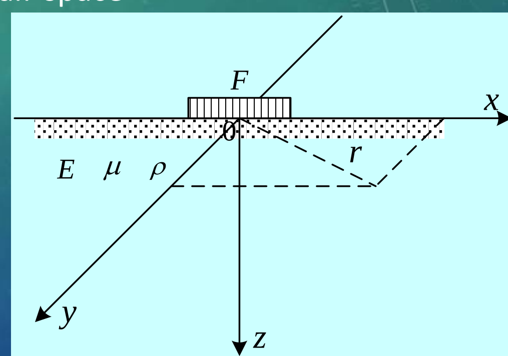
The elastic state can be modeled and analyzed according to the existing theory

对弹性状态可以按照已有的理论进行建模求解和分析

Mechanics analysis method
力学分析类方法

- Model 1 “Rigid wheel ～ elastic half-space "
  模型1 “刚轮～弹性半空间体”





The rigid wheel and elastic half space must be in close contact and can not bounce!

刚轮与弹性半空间体必须紧密接触，不能弹跳！

Geometric equations 几何方程

$$\varepsilon_x = \frac{\partial u}{\partial x}, \quad \varepsilon_y = \frac{\partial v}{\partial y}, \quad \varepsilon_z = \frac{\partial w}{\partial z}$$

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}, \quad \gamma_{yz} = \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}, \quad \gamma_{zx} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}$$

动力学方程 Kinetic equations

$$\begin{cases} \frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} = \rho \frac{\partial^2 u}{\partial t^2} \\ \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{zy}}{\partial z} = \rho \frac{\partial^2 v}{\partial t^2} \\ \frac{\partial \sigma_z}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} = \rho \frac{\partial^2 w}{\partial t^2} \end{cases}$$

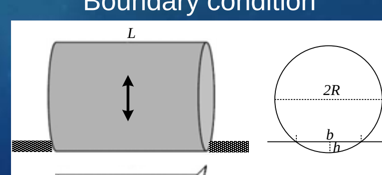
Constitutive equations 本构方程

$$\varepsilon_x = \frac{1}{E}[\sigma_x - \mu(\sigma_y + \sigma_z)], \quad \gamma_{xy} = \frac{1}{G}\tau_{xy}$$

$$\varepsilon_y = \frac{1}{E}[\sigma_y - \mu(\sigma_z + \sigma_x)], \quad \gamma_{yz} = \frac{1}{G}\tau_{yz}$$

$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_x + \sigma_y)], \quad \gamma_{zx} = \frac{1}{G}\tau_{zx}$$

Boundary condition 边界条件



Dynamic solution （$a \neq 0$）

Step:

- **Solution to the problem: displacement response, velocity response and acceleration response.**
- **Solving the inverse problem: also known as parameter identification. according to the system identification theory, according to the measured vibration wheel response, compared with the calculated value, solution modulus and density.**
- **Experimental verification: the identification of the parameters (modulus and density) compared with the results of conventional tests, meet the engineering accuracy requirements.**

步骤：

- 解正问题：包括位移响应，速度响应和加速度响应。
- 解反问题：也称作参数识别。按照系统识别理论，根据实测振动轮响应，与计算值比较，求取模量和密度。
- 试验验证：将识别得到的参数（模量与密度）与常规试验结果对比，满足工程精度要求。

Application of the key: quick to solve, to solve the inversion parameters are not unique.

应用的关键：快速求解，解决反演参数不唯一性。

Static solution （$a = 0$）

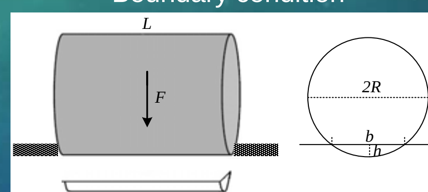
Statics equation

静力学方程

$$\begin{cases} \frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} = 0 \\ \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} = 0 \\ \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} = 0 \end{cases}$$

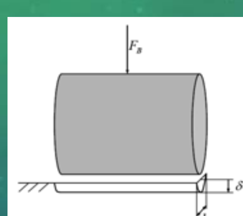
Boundary condition

边界条件



Static solution is simpler than the kinetic solution, and it can get the modulus - such as EVIB

静力学解答比动力学解答简单，可以得到模量——如EVIB



H. Hertz, 1895 :

$$b = \sqrt{\frac{16}{\pi} \cdot \frac{R(1-\nu^2)}{E} \frac{F_B}{l}}$$

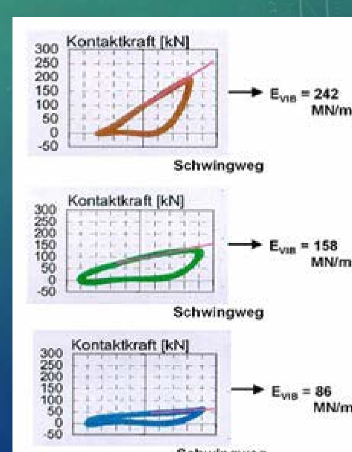
G. Lundberg, 1939 :

$$\delta = \frac{1-\nu^2}{E} \cdot \frac{F_B}{l} \cdot \frac{2}{\pi} \cdot (1{,}8864 + \ln \frac{l}{b})$$

$$\delta = f(F_B, E)$$

$$b \sim b(F, L, R, \mu, E)$$

$$\delta \sim \delta(F, L, b, \mu, E)$$

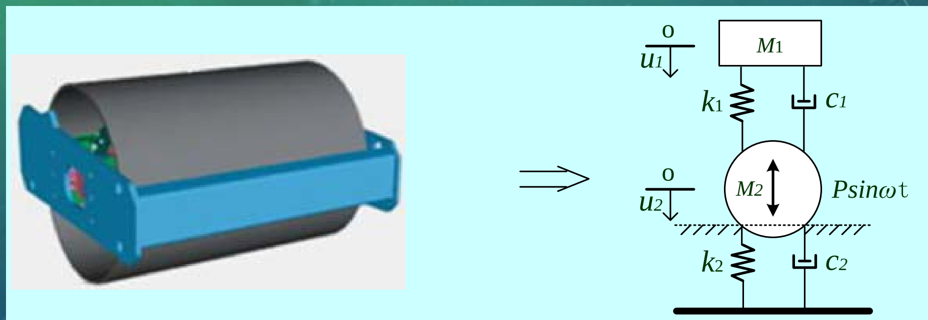


Courtesy of Bomag

Mechanics analysis method
力学分析类方法

- Model 2 “Mass ～ spring ～ damping"

  模型2 “质量～弹簧～阻尼”

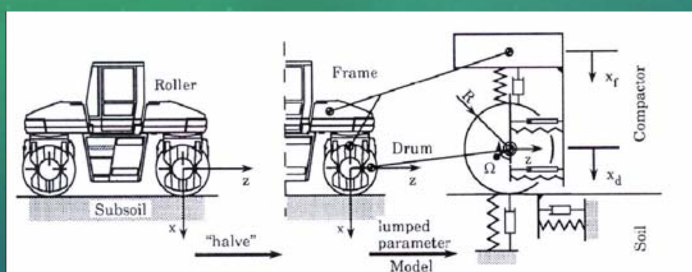


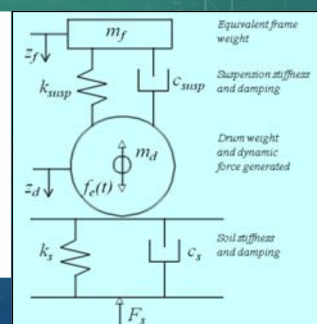
The rigid wheel and the filling body must be in close contact, can not bounce. Part of the filling body to participate in vibration, modeling should consider the quality of vibration.

刚轮与填筑体之间必须紧密接触，不能弹跳。部分填筑体参与振动，建模应考虑参振质量。

Simplifying: without taking into consideration the quality of the filling body

简化：不考虑填筑体参振质量





$$[M][\ddot{u}]+[K][u]+[C][\dot{u}]=[P]$$

$$[M]=\begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix} \quad [K]=\begin{bmatrix} K_1 & -K_2 \\ -K_1 & K_1+K_2 \end{bmatrix} \quad [C]=\begin{bmatrix} C_1 & -C_1 \\ -C_1 & C_1+C_2 \end{bmatrix}$$

$$[\ddot{u}]=\begin{bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{bmatrix} \quad [\dot{u}]=\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{bmatrix} \quad [u]=\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \quad [P]=\begin{bmatrix} 0 \\ P\sin\omega t \end{bmatrix}$$

K_s（K_2） =?

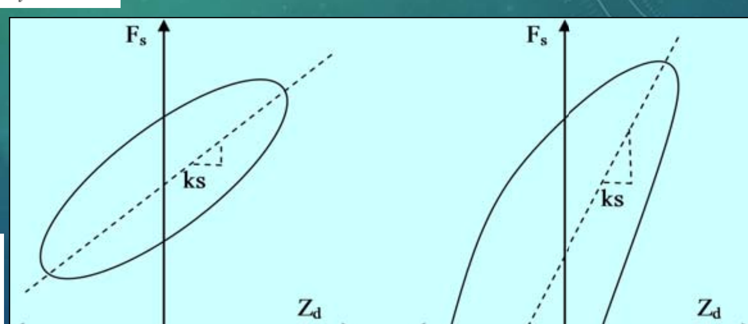
Approximate relation
近似关系

$$F_B \cong -m_d\ddot{x}_d + m_u r_u \Omega^2 \bullet \cos(\Omega t) + (m_f + m_d) \bullet g$$

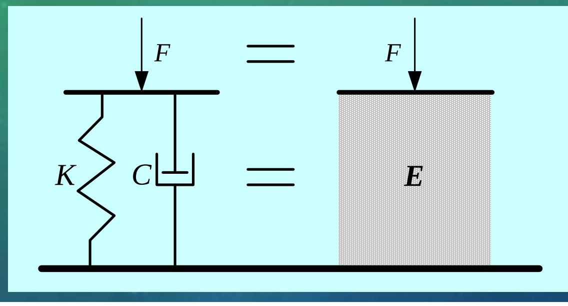
$$F_B \cong k_B x_d + d_B \bullet \dot{x}_d$$

$$K_B \sim K_B(M, f, P, C, x, \dot{x}, \ddot{x})$$

$$k_s = \Omega^2 \left[m_d + \frac{m_0 e_0 \cos\phi}{z_d} \right]$$



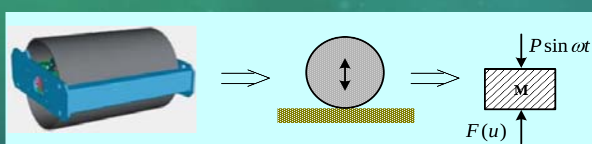
Stiffness and modulus conversion
刚度与模量转换

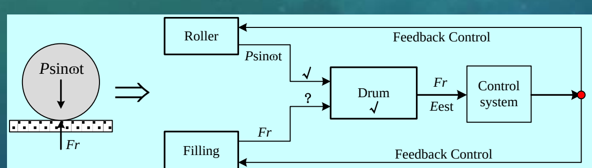


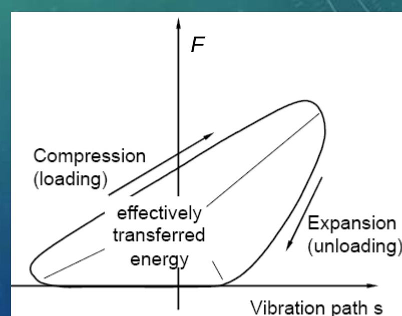
$$k_B = \frac{E \cdot L \cdot \pi}{2 \cdot (1-\nu^2) \cdot \left(2.14 + \frac{1}{2} \cdot \ln\left[\frac{\pi \cdot L^3 \cdot E}{(1-\nu^2) \cdot 16 \cdot (m_f + m_d) \cdot R \cdot g}\right]\right)}$$

Mechanics analysis method
力学分析类方法

- Model 3 "Rigid wheel ～ fill body" and " rigid wheel ～ elastic half space "
  模型3 “振动轮～填筑体”与“刚轮～弹性半空间体”组合





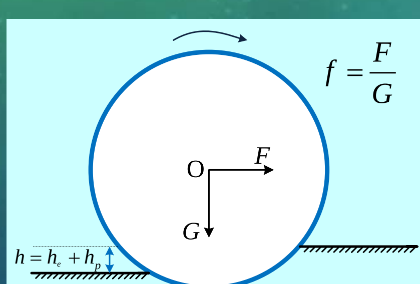


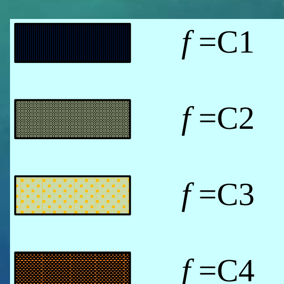
$$F_r = P \sin \omega t + Mg - \eta M f(\ddot{u}, \omega) \Rightarrow VCV$$

$$\delta = f(F_B, E) \qquad \Rightarrow E_{est}$$

Mechanics analysis method
力学分析类方法

- Model 4 Rolling resistance coefficient
  模型4 滚动阻力系数





f can be used as an objective index of the degree of compaction of the materials.

(Zhang Shiying, "road machinery engineering", Chinese Mechanical Industry Press, 1998)

f 可以作为材料压实程度的客观指标 （张世英，《筑路机械工程》，中国机械工业出版社，1998）

$$h = h_e + h_p = h_p，\quad h_e = 0$$

$$f_p = \frac{F}{G} = \frac{1}{(1+\mu)(1-\mu/3)}\sqrt{\frac{h}{D}}$$

$$h = h_e + h_p，\quad h_e \neq 0$$

$$f = \frac{F}{G}$$

$$G = Cb\sqrt{D}\left(1-\frac{\mu}{3}\right)(h^{\mu+0.5} + h_e^{\mu+0.5})$$

$$F = Cb\frac{h^{\mu+1} - h_e^{\mu+1}}{\mu+1}$$

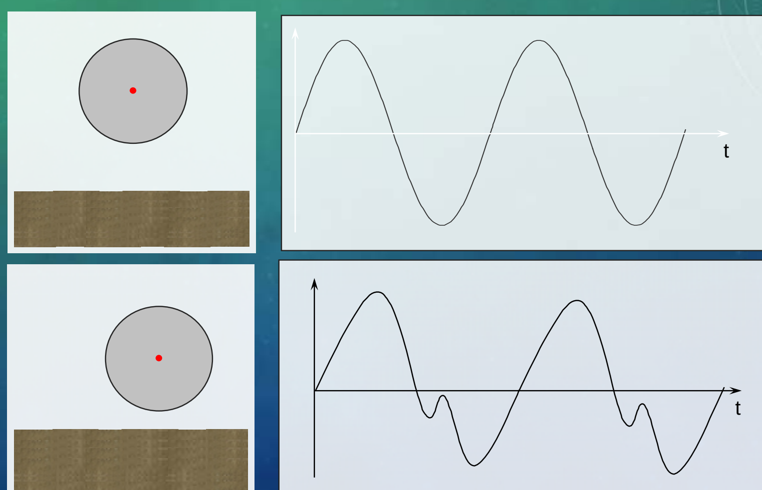
MDP

$$MDP = P_g - WV\left[\sin\theta + \frac{a}{g}\right] - (mV + b)$$

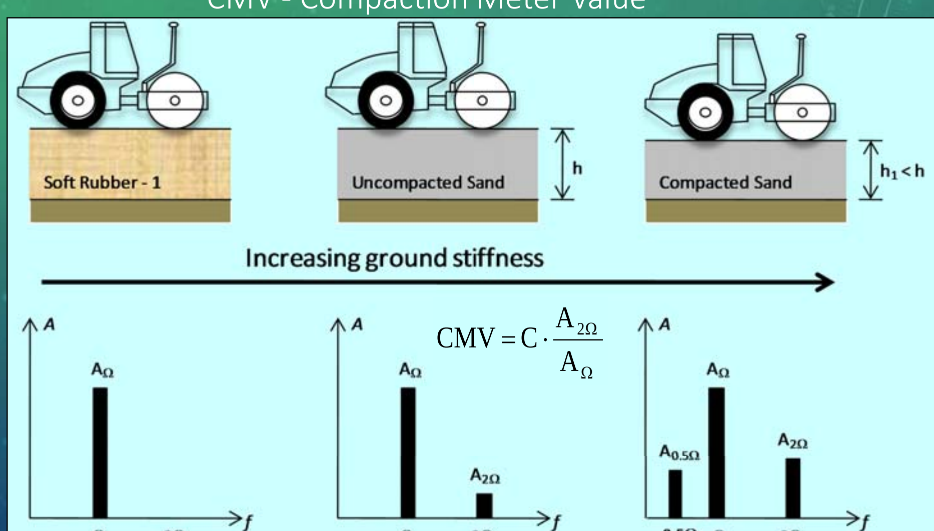
Response analysis method
响应分析类方法

Harmonic ratio 1

谐波比1

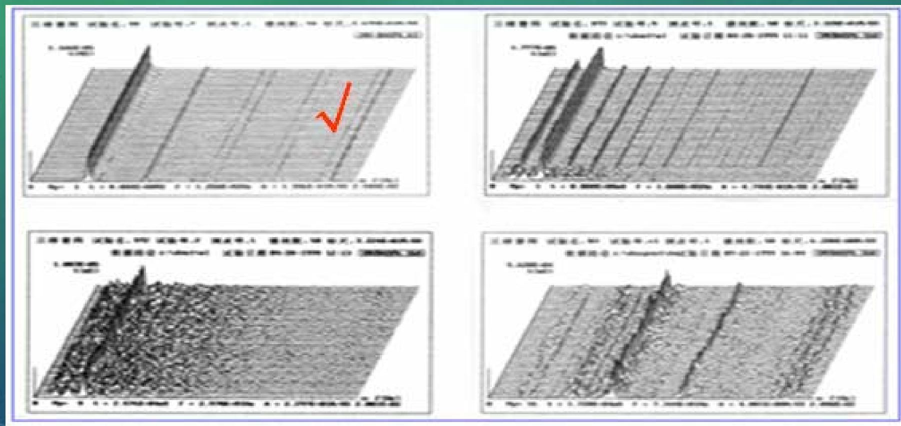


CMV - Compaction Meter Value



Application conditions for CMV

CMV 适用条件



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Response analysis method
响应分析类方法

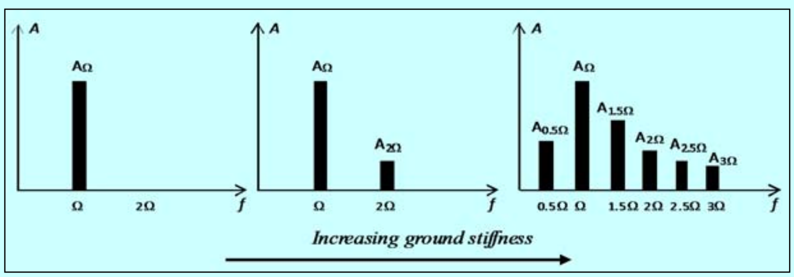
Harmonic ratio 2

谐波比2

CCV - Compaction Control Value

$$CCV = \left[\frac{A_{0.5\Omega} + A_{1.5\Omega} + A_{2\Omega} + A_{2.5\Omega} + A_{3\Omega}}{A_{0.5\Omega} + A_{\Omega}} \right] \times 100$$

$$CCV = \left[\frac{A_1 + A_3 + A_4 + A_5 + A_6}{A_1 + A_2} \right] \times 100$$



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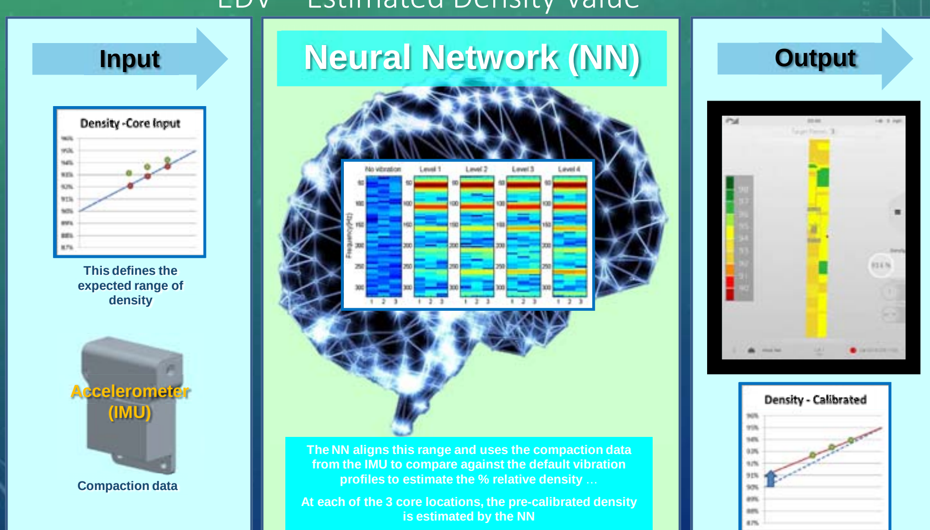
Other methods
其它方法

EDV – Estimated Density Value



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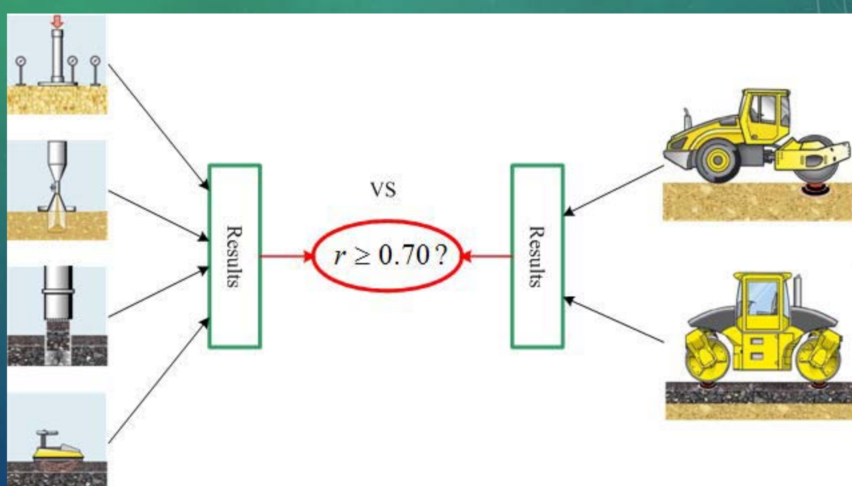
INTELLIGENT COMPACTION INDEX LIST
智能压实指标一览表

- Mechanics analysis method
  - Model 1 "Rigid wheel ~ elastic half space body" $E / \rho \Rightarrow E_{vib}$
  - Model 2 "mass ~ spring ~ damping" $K \Rightarrow K_B$
  - Model 3 "rigid wheel ~ fill body" and " rigid wheel ~ elastic half space body" $F_r / E_{est} \Rightarrow VCV$
  - Model 4 Rolling resistance coefficient f / MDP
- Response analysis method
  - Harmonic ratio 1 CMV
  - Harmonic ratio 2 CCV
- Other methods EDV

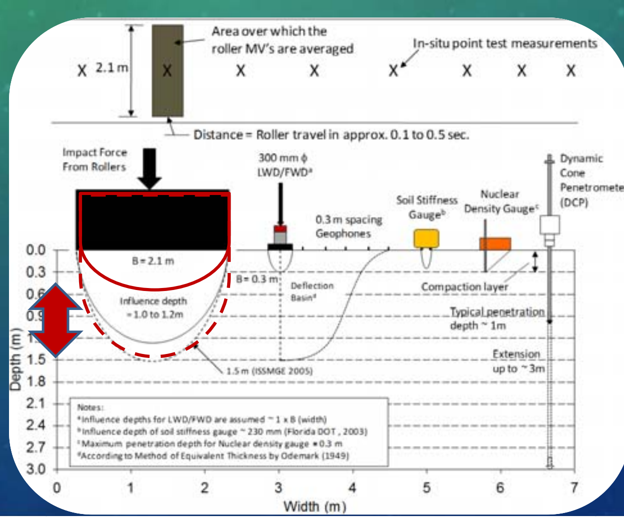
CONDITIONS FOR APPLICATION IN ENGINEERING
工程应用的条件

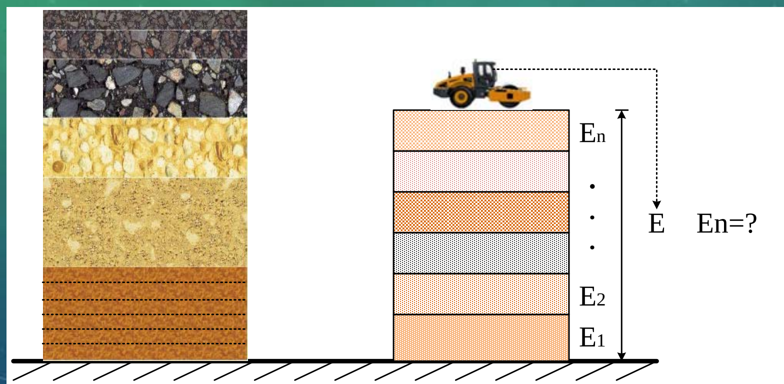


INFLUENCE OF DIFFERENT CONTACT AREA AND DEPTH
不同的接触面积及深度影响

0.5 m 20 in.

1.2 m 5 ft





CCC & INTELLIGENT COMPACTION
填筑工程智能压实

BY
DR. GEORGE K. CHANG, PROF. GUANGHUI XU
张国能博士, 徐光辉教授
IICTG FOUNDERS
国际智能建设学会发起人

SECTION 3 SPECIFICATIONS
第三节　规程

GOALS OF IC SPEC

- More Comprehensive Inspection
- Increase Construction Efficiency
- Develop a Link to Design
- Improve Pavement Performance
- Improve Safety

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SPECIFICATIONS FOR CCC AND IC

- Swedish Road Administration
- Federal Ministry of Transport of the Federal Republic of Germany
- The Austrian Federal Road Administration
- Finland
- International Society for Soil Mechanics and Geotechnical Engineering（ISSMGE）
- China Railway and Road Administration
- USA

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SPECIFICATIONS FOR CCC AND IC

Specifications to use roller-integrated measurement systems for CCC have been introduced in 1990's.

- Austria (in 1990,with revisions in 1993 and 1999)
- Germany (1994, with revision in 1997–2009)
- Sweden (1994, with revision in 2004)
- China（2011,2015,2016）
- USA
- The ISSMGE recently developed recommended construction specifications based primarily on the Austrian specifications.

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GERMAN

- ZTVE-StB 94, „Zusätzliche Technische Vertragsbedingungen und Richtlinien für Erdarbeiten im Stra§enbau".
- TB BF-StB Teil E 2 „Flächendeckende dynamische Prüfung der Verdichtung", Ausgabe 1994, FGSV591/E2.
- TB BF-StB Teil E 3 „Prüfung der Verdichtung durch Probeverdichtung und Arbeitsanweisung“, Ausgabe 1994, FGSV591/E3.

Finland

- Tienrakennustiden yleiset laatuvaatimukset ja tyselitykset, Tielaitos, Helsinki 1994

Sweden

- ATB Väg 2004, Kapitel E - Obundna material VV Publikation 2004:111.
- Yttäckande packningskontroll Metodbeskrivning 603:1994.

Austria

- Richtlinien für Verkehr und Stra§enwesen RVS 8S.02.6: „Kontinuierlicher walzenintegrierter Verdichtungsnachweis“, Juli 1993, FVS.
- …NORM S 2074 Teil 2, Nov. 1990, „Geotechnik im Deponiebau, Erdarbeiten“.;

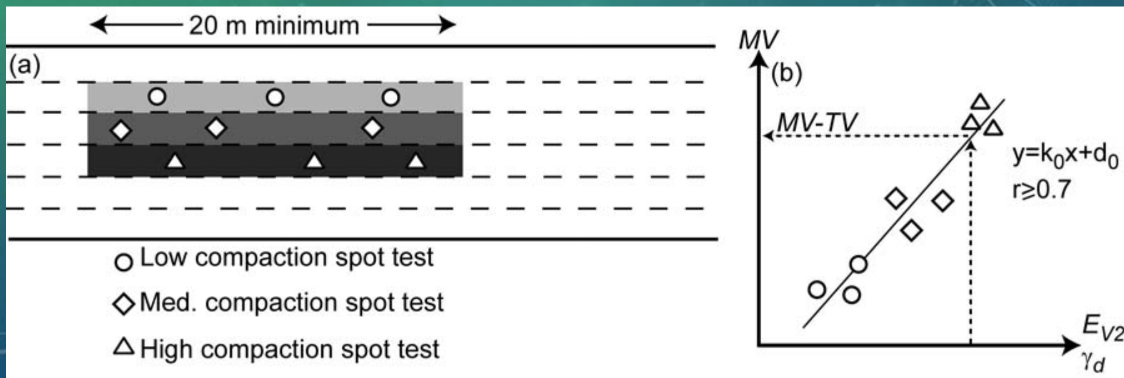
CHINA

- 《Technical Specification for Continuous Compaction Control of Fill Engineering of Railway Subgrade》（TB10108-2011）
- 《Technical Specification for Continuous Compaction Control of Fill Engineering of Railway Subgrade》（Q/CR 9210-2015）
- 《Technical condition for continuous compaction control system of fill engineering of subgrade for highway 》（2016 Approving）

USA

GERMAN SPECIFICATIONS

Calibration Approach (Method M2 in German Specifications)



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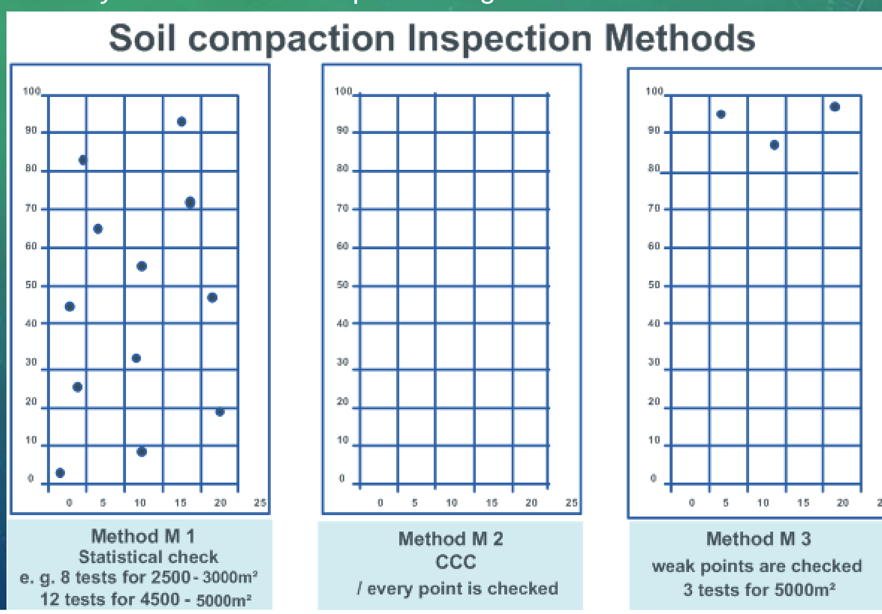
CCC to Identify Weak Areas for Spot Testing



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SWEDEN – SOILS IC (1994~)

- Vibratory or oscillating single-drum roller. Min. linear load 15–30 kN. Roller-mounted compaction meter optional
- Thickness of largest layer 0.2–0.6 m.
- Layer shall be homogenous and non-frozen. Protective layers < 0.5 m may be compacted with sub-base.
- Bearing capacity or degree of compaction requirements may be met. Mean of compaction values for two inspection points ≥ 89% for sub-base under roadbase and for protective layers over 0.5 m thick; mean should be ≥ 90% for roadbases. Required mean for two bearing capacity ratios varies depending on layer type.

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GERMANY – SOILS IC (1994~)

- Self-propelled rollers with rubber tire drive are preferred; towed vibratory rollers with towing vehicle are suitable.
- Each calibration area must cover at least 3 partial fields ~20 m. long
- Level and free of puddles. Similar soil type, water content, layer thickness, and bearing capacity of support layers. Track overlap ≤ 10% machine width
- The correlation coefficient resulting from a regression analysis must be ≥ 0.7. Individual area units (the width of the roller drum) must have a dynamic measuring value within 10% of adjacent area to be suitable for calibration.

AUSTRIA – SOILS IC (1999~) (1/2)

- Vibrating roller compactors with rubber wheels and smooth drums suggested
- 100 m long by the width of the site
- No inhomogeneities close to surface (materials or water content). Track overlap ≤ 10% drum width.
- Correlation coefficient ≥ 0.7. Minimum value ≥ 95% of Ev1, and median should be ≥ 105% (or ≥ 100% during jump mode).

AUSTRIA – SOILS IC (1999~) (2/2)

- Dynamic measuring values should be lower than the specified minimum for ≤ 10% of the track.
- Measured minimum should be ≥ 80% of the set minimum. Measured maximum in a run cannot exceed the set maximum (150% of the determined minimum). Standard deviation (of the median) must be ≤ 20% in one pass.

ISSGE – SOILS IC (2005~) (1/2)

- Roller chosen by experience
- 100 m by the width of the site
- Homogenous, even surface. Track overlap ≤ 10% drum width.
- Correlation coefficient ≥ 0.7. Minimum value ≥ 95% of Ev1, and mean should be ≥ 105% (or ≥ 100% during jump mode).

ISSGE – SOILS IC (2005~) (2/2)

- Dynamic measuring values should be lower than the specified minimum for ≤ 10% of the track.
- Measured minimum should be ≥ 80% of the specified minimum.
- Standard deviation (of the mean) must be ≤ 20% in one pass.

CHINA - SOILS IC (2011, 2015～2016)


UDC
TB
中华人民共和国行业标准
P
TB 10108—2011
J 1335—2011

铁路路基填筑工程
连续压实控制技术规程
Technical Code for Continuous Compaction Control of Fill Engineering of Railway Earth Structure

2011-11-15 发布
2011-12-01 实施

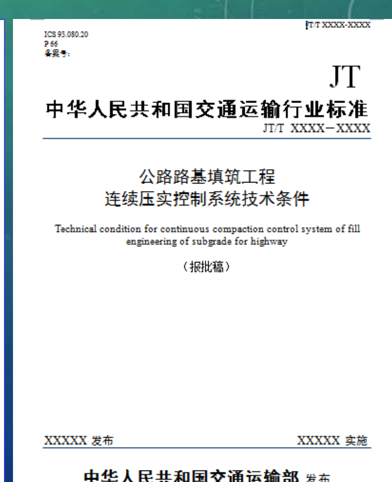
中华人民共和国铁道部 发布


Q/CR
Standard of China Railway Corporation
P
Q/CR 9210-2015

Technical Specification for Continuous Compaction Control of Fill Engineering of Railway Subgrade

Issued on February 16, 2015
Implemented since June 1, 2015

Issued by China Railway Corporation


JT/T XXXX-XXXX
ICS 93.080.20
P 66
备案号：
JT
中华人民共和国交通运输行业标准
JT/T XXXX—XXXX

公路路基填筑工程
连续压实控制系统技术条件
Technical condition for continuous compaction control system of fill engineering of subgrade for highway
（报批稿）

XXXXX 发布
XXXXX 实施

中华人民共和国交通运输部 发布

CHINESE RAILWAY SOILS IC SPEC

Step	Description	No.
Equipment check	Control the vibration performance of the vibratory roller	1
Correlation verification	Determine the correlation between VCV and conventional spot tests	2
Process control	Compaction degree, uniformity and stability control during rolling process	3
Quality test	Determining the spatial distribution of VCV and weak areas	4

Chinese CCC Standards

Equipment check

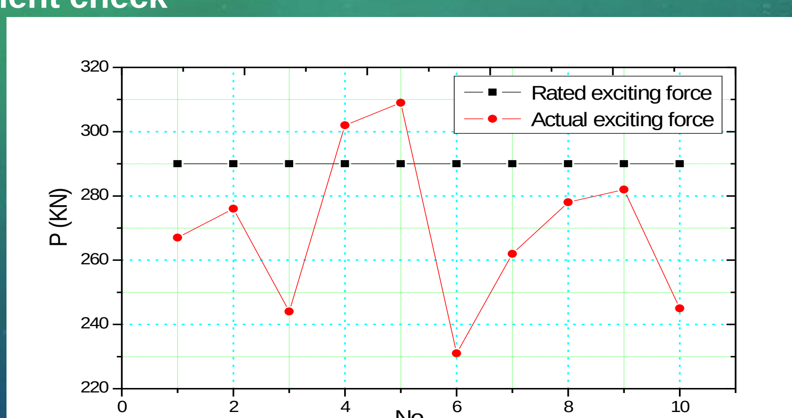
- The fluctuation of the vibration frequency of the vibratory roller shall not exceed ±0.5 Hz of the specified value during rolling and measurement.
- During rolling and measurement, the vibratory roller shall be running at a constant speed of 3.0 km/h and not greater than 4.0 km/h.
- The vibratory roller should be equipped with the corresponding signal interfaces for vibration frequency and traveling speed.
- The mounting interface for inspection equipment should be reserved at the corresponding location of the vibratory roller.

$$|f - f_0| \le 0.5\text{Hz}$$
$$v \le 4.0 km/h$$

Very important!

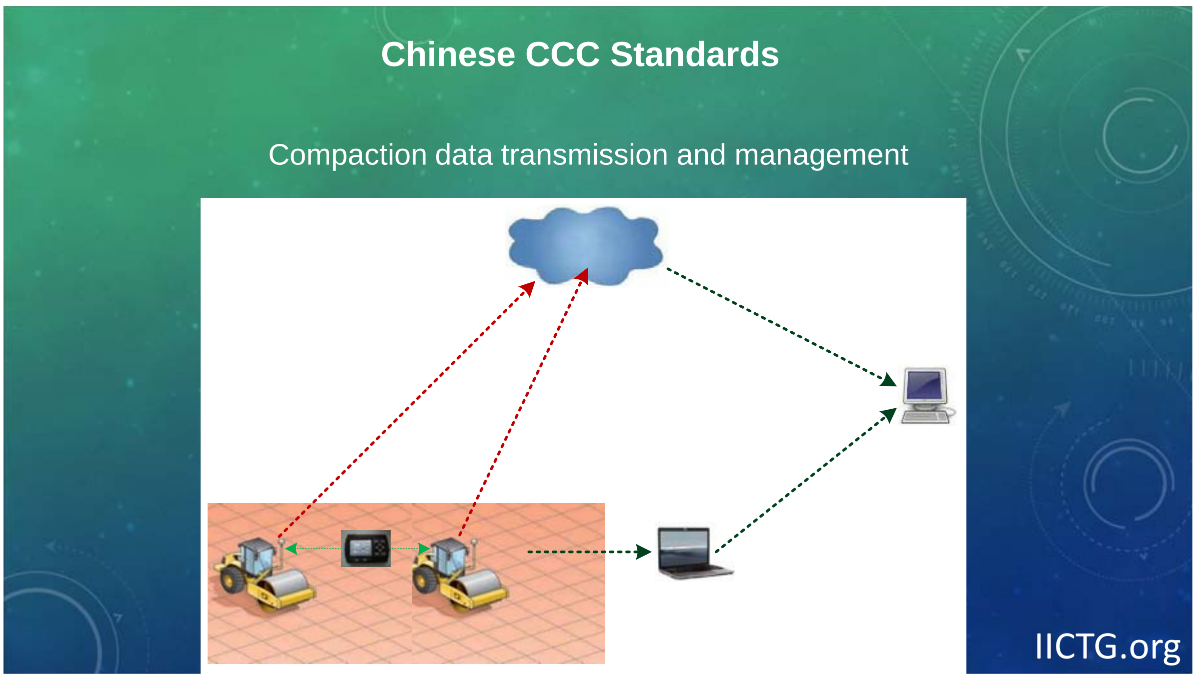
Chinese CCC Standards

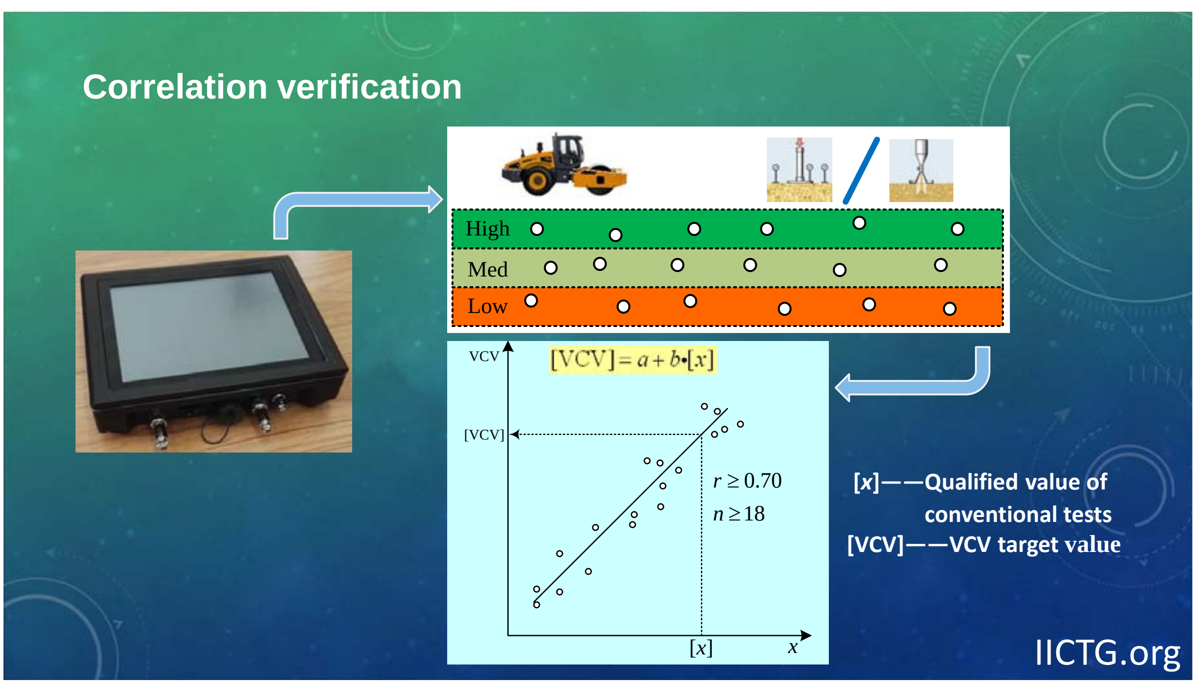
Equipment check



Unstable vibration frequency results in fluctuation of the exciting force, which affects the compaction effort and may causes undesired results.


Chinese CCC Standards
Selection of vibratory roller
Vertical vibratory roller
General vibratory roller
Vertical vibratory roller is better than general vibratory roller
IICTG.org


Chinese CCC Standards
Compaction data transmission and management
IICTG.org


Correlation verification
High
Med
Low
VCV
[VCV] = a + b•[x]
[VCV]
r ≥ 0.70
n ≥ 18
[x]
x
[x]——Qualified value of conventional tests
[VCV]——VCV target value
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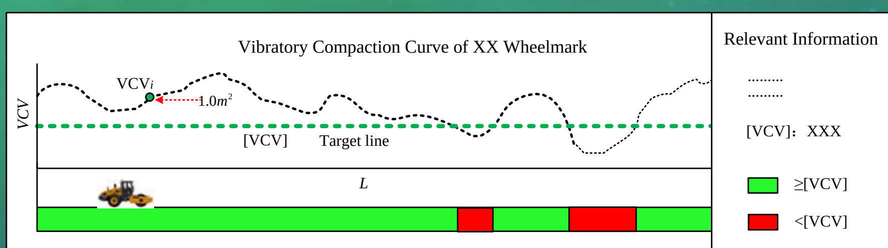
Process control

Compaction degree control —Control of the physical and mechanical properties of the compacted materials to achieve the level of the specified value to achieve sufficient strength and rigidity to support the upper structure.

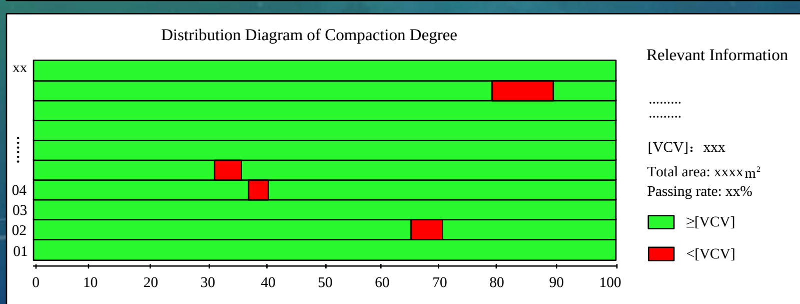
Compaction uniformity control—Control of the physical and mechanical properties of the compacted materials to achieve the uniform support for the upper structure.

Compaction stability control—Control the stability of the physical and mechanical properties of the compacted materials to support the upper structure under the designed loading (avoid fatigue cracking).

Compaction degree control



$$VCV_i \geq [VCV]$$



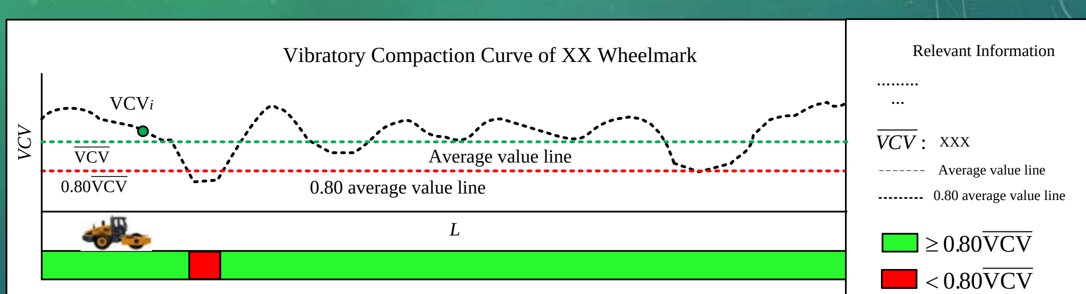
green / (green + red) ≥95%

Maximum Allowed Failed areas ——

High speed railway: < 5 m²

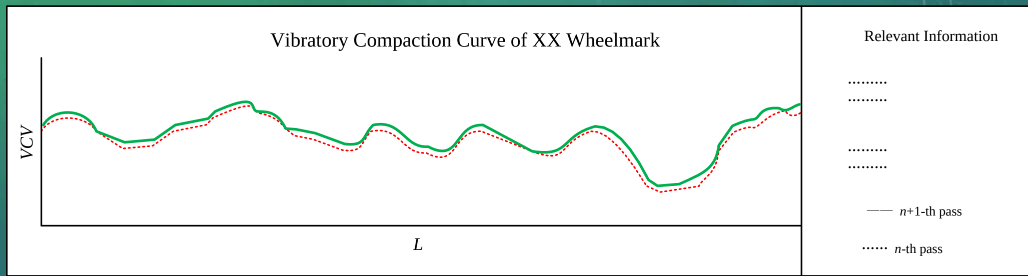
Ordinary railway: < 10 m²

Compaction uniformity control



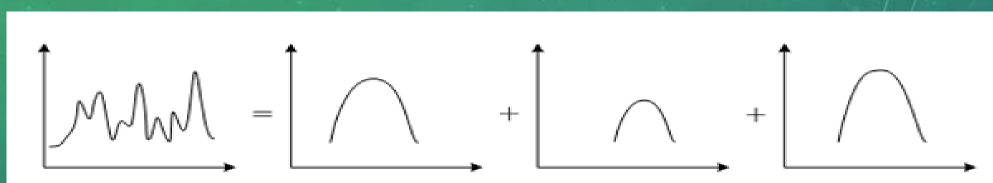
$$VCV_i \geq 0.80\overline{VCV}$$

Compaction stability control

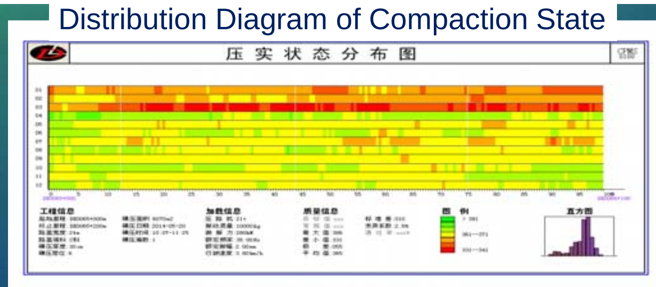


$$\frac{\left|VCV_{i+1}-VCV_i\right|}{VCV_i} \le \delta \qquad \delta \le 3\%$$

Quality test



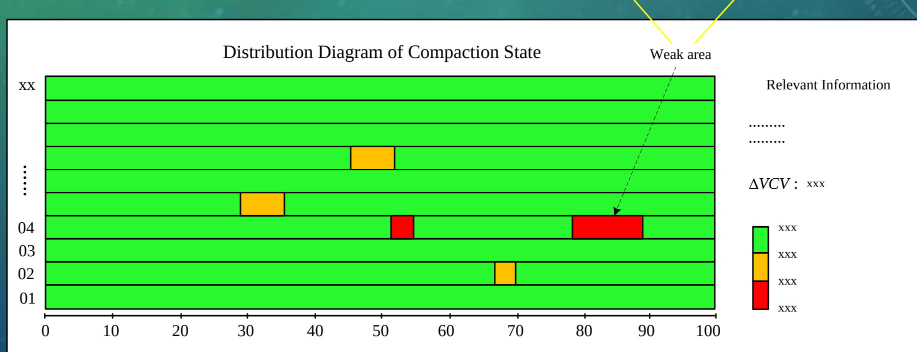
Distribution Diagram of Compaction State



The actual distribution of VCV can be decomposed into combination of various normal distributions. Thus, the weak areas can be identified.

Quality test

Weak points are checked

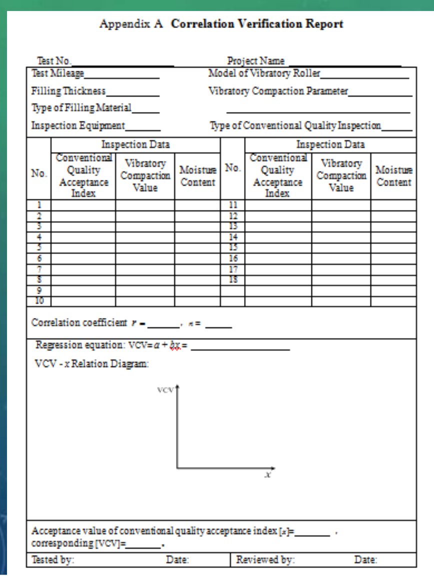


Chinese CCC Standards

Selective spot testing within weak areas

- For the majority of embankment materials (esp. coarse aggregate), density, foundation coefficient, modulus do not follow normal distributions. Therefore, limited spot tests are often not representative of the compacted areas.
- The key issue is how to select the locations for spot tests.
- As long as there is satisfactory correlation between VCV and spot tests, VCV can be used for acceptance. In case of spot tests within weak areas pass the acceptance criteria, the remaining compacted areas will be considered pass, too. Thus, the risk an be minimized.

Compaction Quality Report



Appendix A Correlation Verification Report

Test No.________ Project Name ________

Test Mileage________ Model of Vibratory Roller________

Filling Thickness________ Vibratory Compaction Parameter________

Type of Filling Material________

Inspection Equipment________ Type of Conventional Quality Inspection________

No.	Inspection Data: Conventional Quality Acceptance Index	Vibratory Compaction Value	Moisture Content	No.	Inspection Data: Conventional Quality Acceptance Index	Vibratory Compaction Value	Moisture Content
1				11			
2				12			
3				13			
4				14			
5				15			
6				16			
7				17			
8				18			
9							
10							

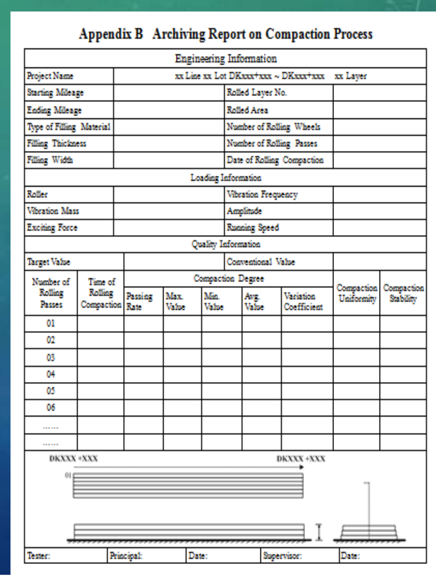
Correlation coefficient r = ______, n = ______

Regression equation: VCV= $a + bx$ = ________

VCV - x Relation Diagram:

Acceptance value of conventional quality acceptance index [x]=______, corresponding [VCV]=______.

Tested by: Date: Reviewed by: Date:



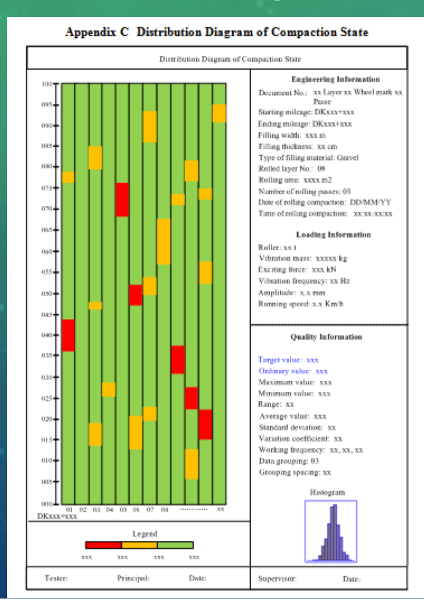
Appendix B Archiving Report on Compaction Process

Engineering Information			
Project Name	xx Line xx Lot DKxxx+xxx ~ DKxxx+xxx xx Layer		
Starting Mileage		Rolled Layer No.	
Ending Mileage		Rolled Area	
Type of Filling Material		Number of Rolling Wheels	
Filling Thickness		Number of Rolling Passes	
Filling Width		Date of Rolling Compaction	
Loading Information			
Roller		Vibration Frequency	
Vibration Mass		Amplitude	
Exciting Force		Running Speed	
Quality Information			
Target Value		Conventional Value	

Number of Rolling Passes	Time of Rolling Compaction	Compaction Degree: Passing Rate	Max. Value	Min. Value	Avg. Value	Variation Coefficient	Compaction Uniformity	Compaction Stability
01								
02								
03								
04								
05								
06								
……								
……								

Tester: Principal: Date: Supervisor: Date:

Compaction Quality Report



Appendix C Distribution Diagram of Compaction State

Distribution Diagram of Compaction State

Engineering Information

Document No.: xx Layer xx Wheel mark xx Passe
Starting mileage: DKxxx+xxx
Ending mileage: DKxxx+xxx
Filling width: xxx m
Filling thickness: xx cm
Type of filling material: Gravel
Rolled layer No.: 08
Rolling area: xxxx m2
Number of rolling passes: 03
Date of rolling compaction: DD/MM/YY
Time of rolling compaction: xx:xx-xx:xx

Loading Information

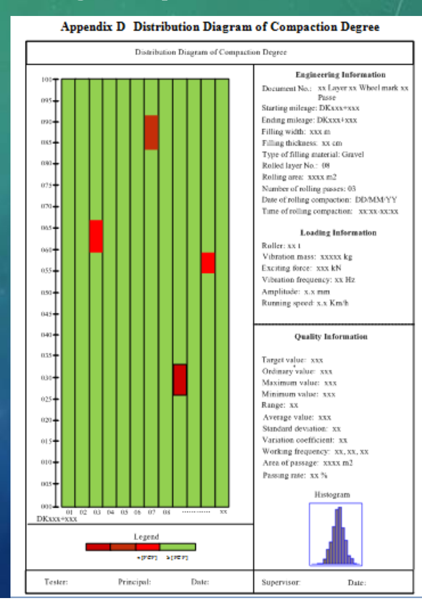
Roller: xx t
Vibration mass: xxxxx kg
Exciting force: xxx kN
Vibration frequency: xx Hz
Amplitude: x.x mm
Running speed: x.x Km/h

Quality Information

Target value: xxx
Ordinary value: xxx
Maximum value: xxx
Minimum value: xxx
Range: xx
Average value: xxx
Standard deviation: xx
Variation coefficient: xx
Working frequency: xx, xx, xx
Data grouping: 03
Grouping spacing: xx

Histogram

Tester: Principal: Date: Supervisor: Date:



Appendix D Distribution Diagram of Compaction Degree

Distribution Diagram of Compaction Degree

Engineering Information

Document No.: xx Layer xx Wheel mark xx Passe
Starting mileage: DKxxx+xxx
Ending mileage: DKxxx+xxx
Filling width: xxx m
Filling thickness: xx cm
Type of filling material: Gravel
Rolled layer No.: 08
Rolling area: xxxx m2
Number of rolling passes: 03
Date of rolling compaction: DD/MM/YY
Time of rolling compaction: xx:xx-xx:xx

Loading Information

Roller: xx t
Vibration mass: xxxxx kg
Exciting force: xxx kN
Vibration frequency: xx Hz
Amplitude: x.x mm
Running speed: x.x Km/h

Quality Information

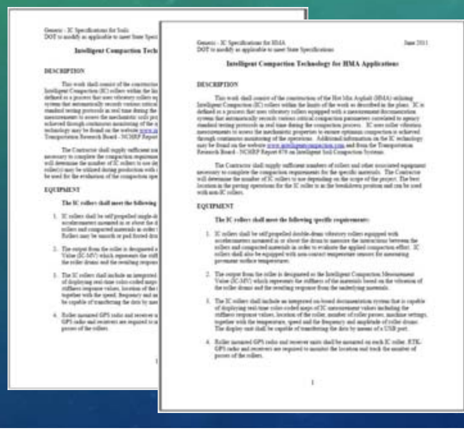
Target value: xxx
Ordinary value: xxx
Maximum value: xxx
Minimum value: xxx
Range: xx
Average value: xxx
Standard deviation: xx
Variation coefficient: xx
Working frequency: xx, xx, xx
Area of passage: xxxx m2
Passing rate: xx %

Histogram

Tester: Principal: Date: Supervisor: Date:

USA ASPHALT AND SOILS IC (2012 ~)

FHWA Soils/Asphalt IC



Generic - IC Specifications for HMA June 2011
DOT to modify as applicable to meet State Specifications

Intelligent Compaction Technology for HMA Applications

DESCRIPTION

EQUIPMENT

AASHTO

Standard Practice for

Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications

AASHTO Designation: PP 81-14[1]

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

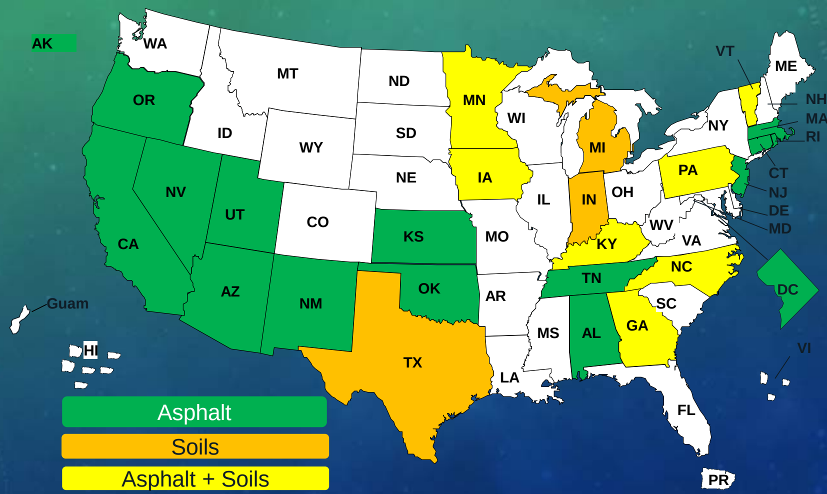
US NCHRP SOILS IC SPEC OPTIONS

1. Roller based QC with pre-selected ICMV target values
2. ICMV maps to target locations for QA test measurements
3. ICMV target values from compaction curves to target locations for QA point measurements
4. Calibration of ICMV measurements to QA point measurements
5. Performance based QA specification with incentive based payment

COMPONENTS OF IC SPEC

1. IC System Requirements
2. IC Data Requirements
3. Quality Control Plan
4. Training Requirements
5. GNNS/Datum Requirements
6. Test Sections and Target Values
7. QC for Production Areas
8. Payment and Measurements

US STATE DOT IC SPECS



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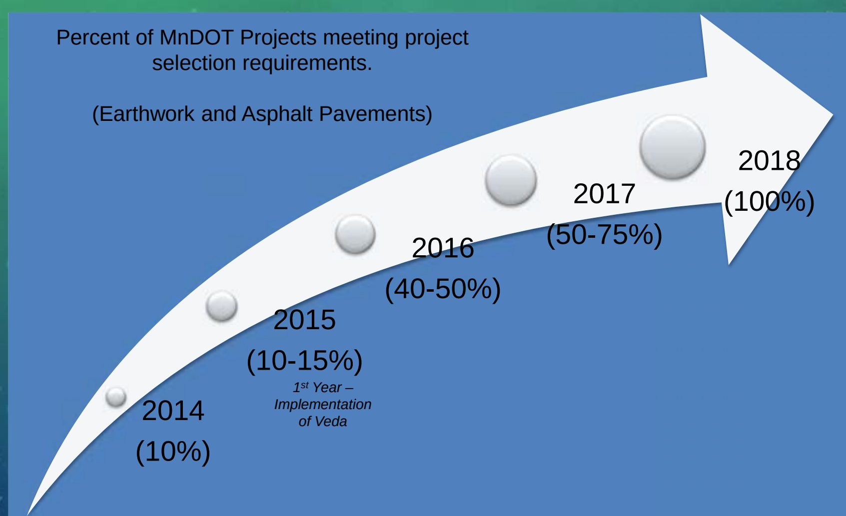
US MNDOT IC IMPLEMENTATION PLAN



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CCC & INTELLIGENT COMPACTION
填筑工程智能压实

BY
DR. GEORGE K. CHANG, PROF. GUANGHUI XU
张国能博士, 徐光辉教授
IICTG FOUNDERS
国际智能建设技术学会发起人

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SECTION 4 CCC/IC FOR ROCK AND SOIL
第四节　岩土填料碾压控制

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Application of CCC and IC in the construction of high speed railway is more in China .

在中国高速铁路建设中应用较多





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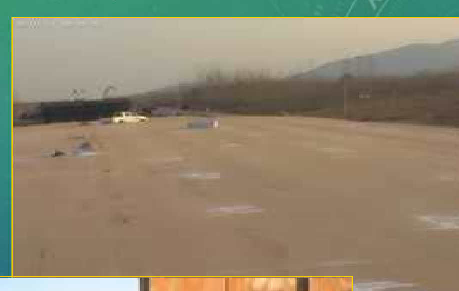
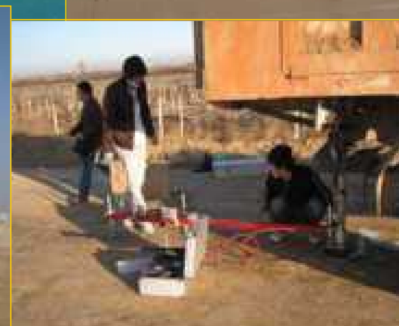
An example of high speed railway subgrade in China
以中国高速铁路路基为实例



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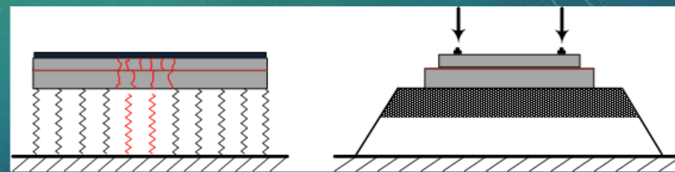
Uniformity control of high speed railway subgrade structure is especially important.
高速铁路路基结构的均匀性控制尤其重要



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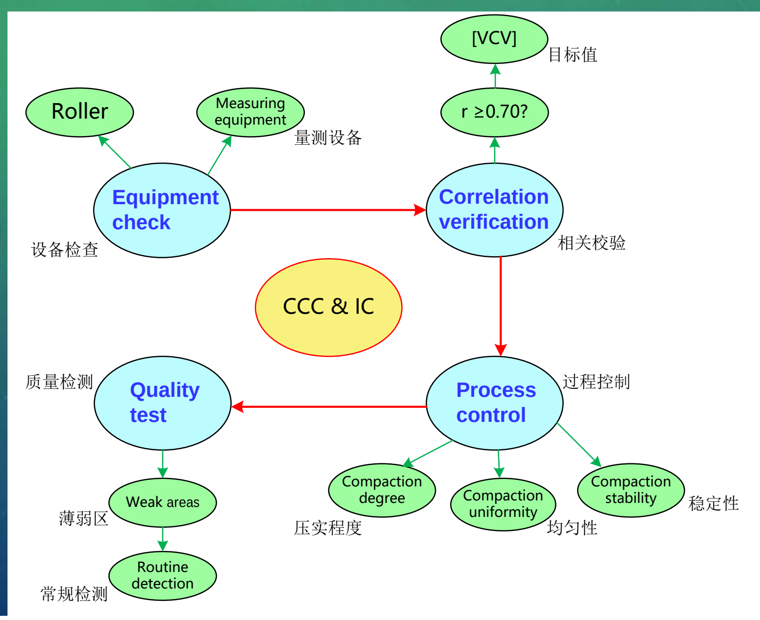
Step



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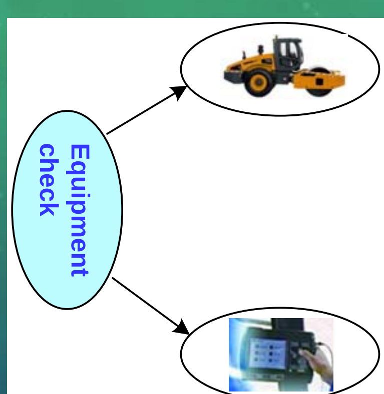
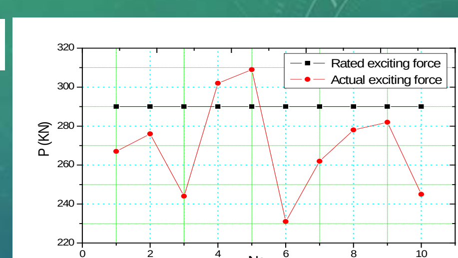


$$|f - f_0| \leq 0.5\text{Hz}$$



- Clear principle
- Clear index
- r ≥0.70
- Good application effect

查 原 理——原理清晰、模型可靠

看 指 标——连续指标物理意义明确、易于理解

勤 校 验——连续指标与常规指标一致性好，r≥0.70

重 实 践——工程应用效果好，满足规程要求

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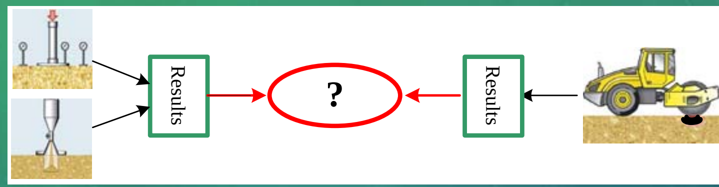
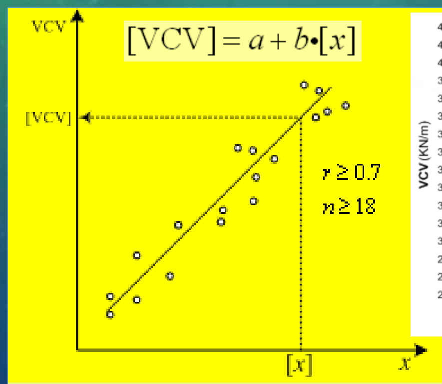
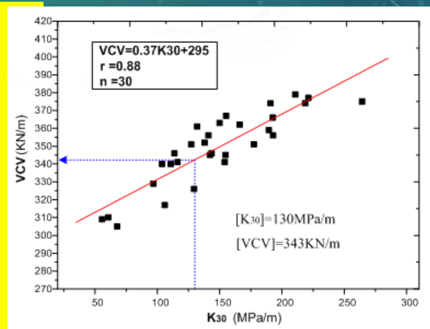
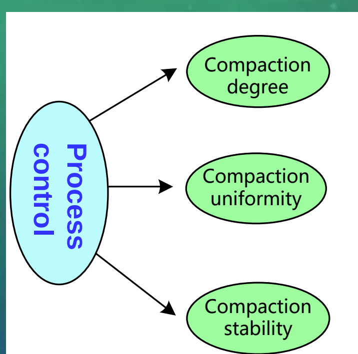
Correlation verification









Control of the physical and mechanical properties of the compacted materials to achieve the level of the specified value to achieve sufficient strength and rigidity to support the upper structure.

控制填筑体物理力学性能达到规定值的程度，解决填筑体是否有足够强度和刚度支承上部结构。

Control of the physical and mechanical properties of the compacted materials to achieve the uniform support for the upper structure.

控制填筑体物理力学性能的均匀分布程度，解决能否均匀支承上部结构。

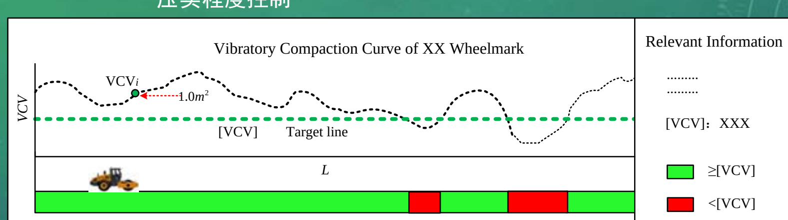
Control the stability of the physical and mechanical properties of the compacted materials to support the upper structure under the designed loading (avoid fatigue cracking).

控制填筑体物理力学性能的稳定程度，解决在重复荷载作用下填筑体能否长期、有效地支承上部结构（疲劳问题）。

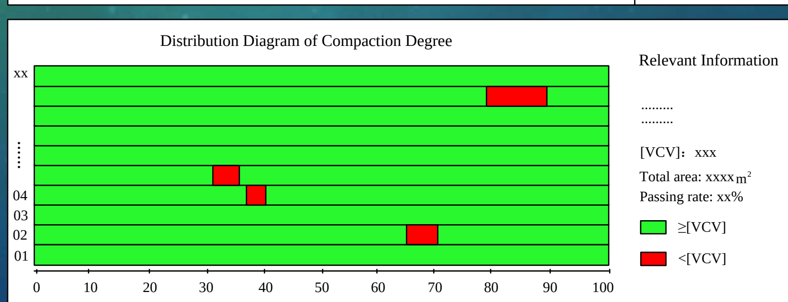
Compaction degree control

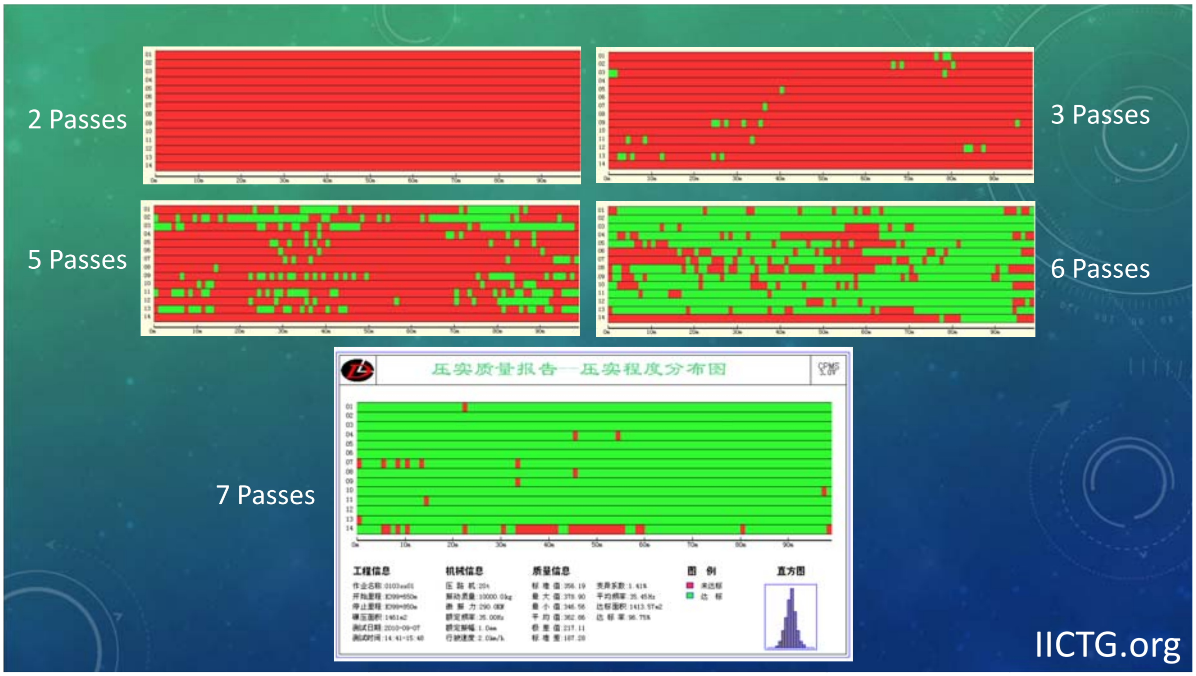
压实程度控制

$$VCV_i\geq[VCV]$$



The passing rate ≥95%





2 Passes
3 Passes
5 Passes
6 Passes
7 Passes
压实质量报告—压实程度分布图
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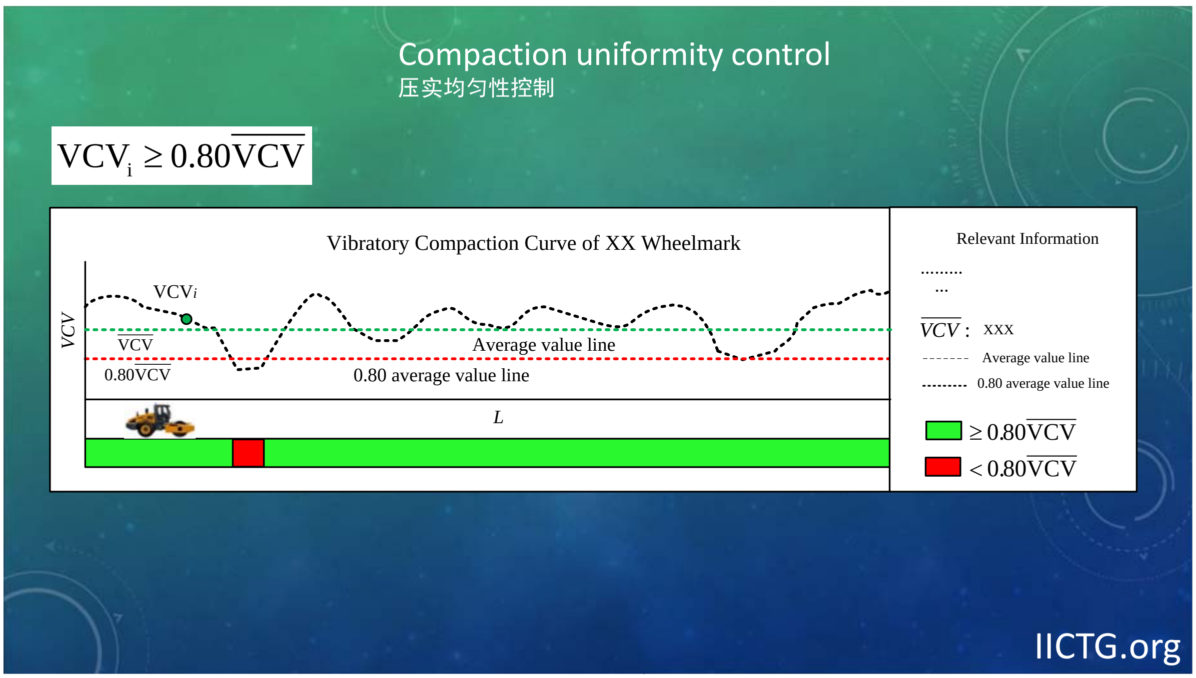

Compaction uniformity control
压实均匀性控制
$VCV_i \geq 0.80\overline{VCV}$
Vibratory Compaction Curve of XX Wheelmark
VCV
VCVi
$\overline{VCV}$
$0.80\overline{VCV}$
Average value line
0.80 average value line
L
Relevant Information
....
...
$\overline{VCV}$: xxx
Average value line
0.80 average value line
$\geq 0.80\overline{VCV}$
$< 0.80\overline{VCV}$
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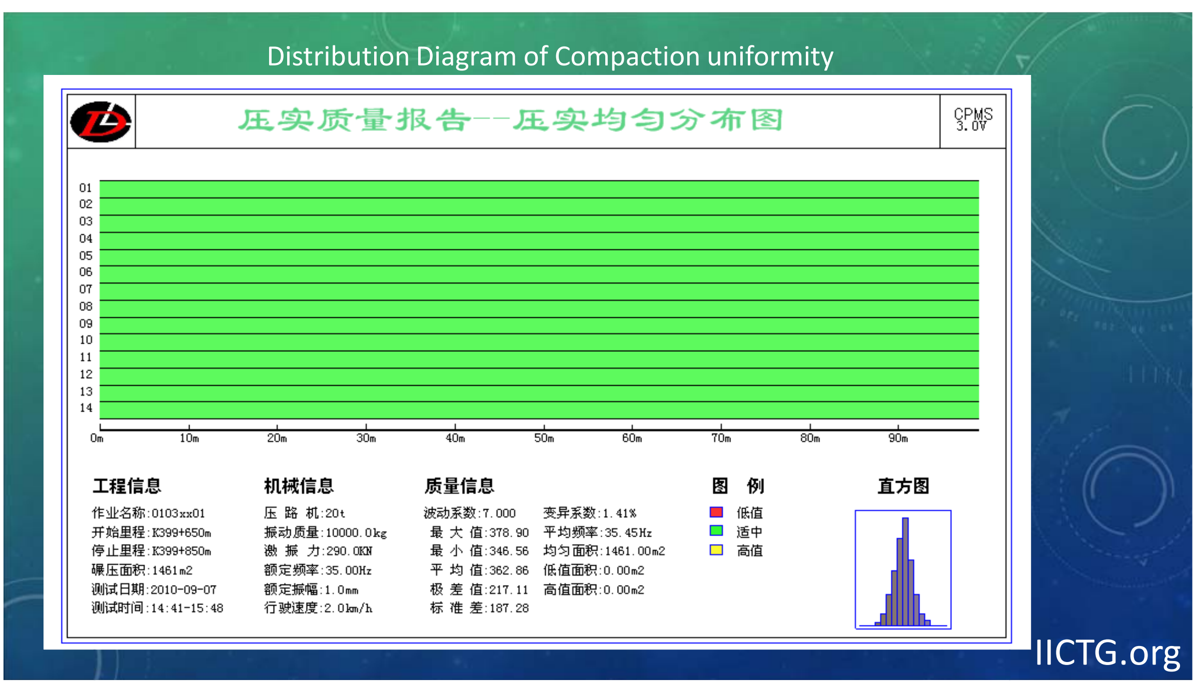
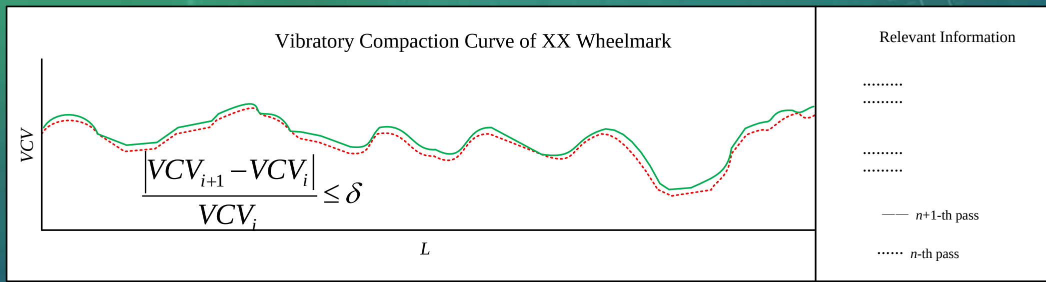


Distribution Diagram of Compaction uniformity
压实质量报告——压实均匀分布图
CPMS 3.0V
01
02
03
04
05
06
07
08
09
10
11
12
13
14
0m
10m
20m
30m
40m
50m
60m
70m
80m
90m
工程信息
作业名称:0103xx01
开始里程:K399+650m
停止里程:K399+850m
碾压面积:1461m2
测试日期:2010-09-07
测试时间:14:41-15:48
机械信息
压 路 机:20t
振动质量:10000.0kg
激 振 力:290.0KN
额定频率:35.00Hz
额定振幅:1.0mm
行驶速度:2.0km/h
质量信息
波动系数:7.000
最 大 值:378.90
最 小 值:346.56
平 均 值:362.86
极 差 值:217.11
标 准 差:187.28
变异系数:1.41%
平均频率:35.45Hz
均匀面积:1461.00m2
低值面积:0.00m2
高值面积:0.00m2
图 例
低值
适中
高值
直方图
IICTG.org

Compaction stability control
压实稳定性控制



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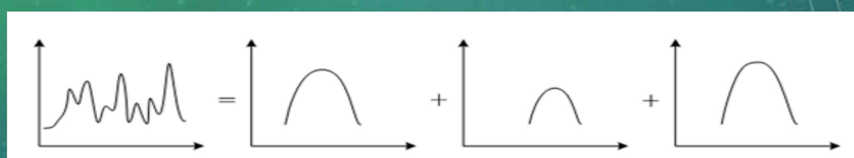
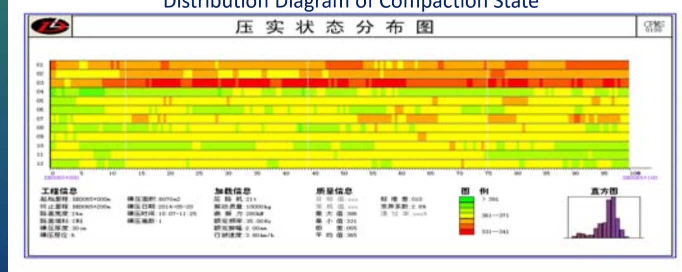
The actual distribution of VCV can be decomposed into combination of various normal distributions. Thus, the weak areas can be identified.
将碾压面的非正态分布分解为多个不同参数的正态分布，得到压实薄弱区。



Quality test

Distribution Diagram of Compaction State



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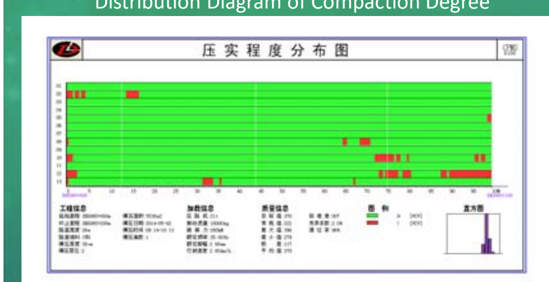
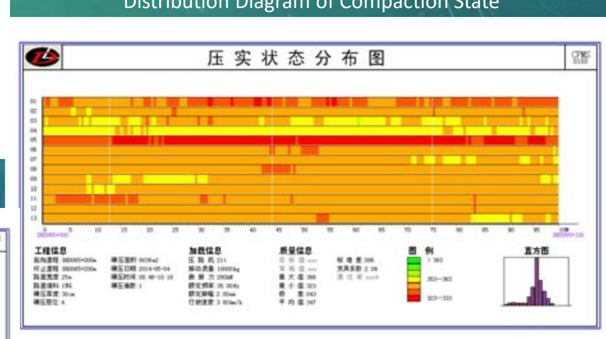
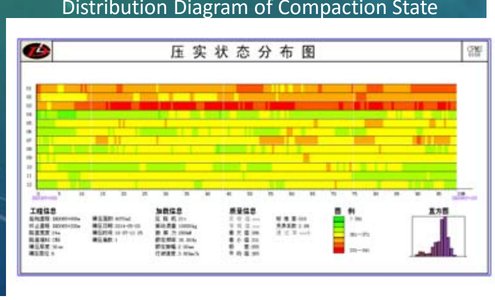
Distribution Diagram of Compaction Degree



Distribution Diagram of Compaction State



Distribution Diagram of Compaction State



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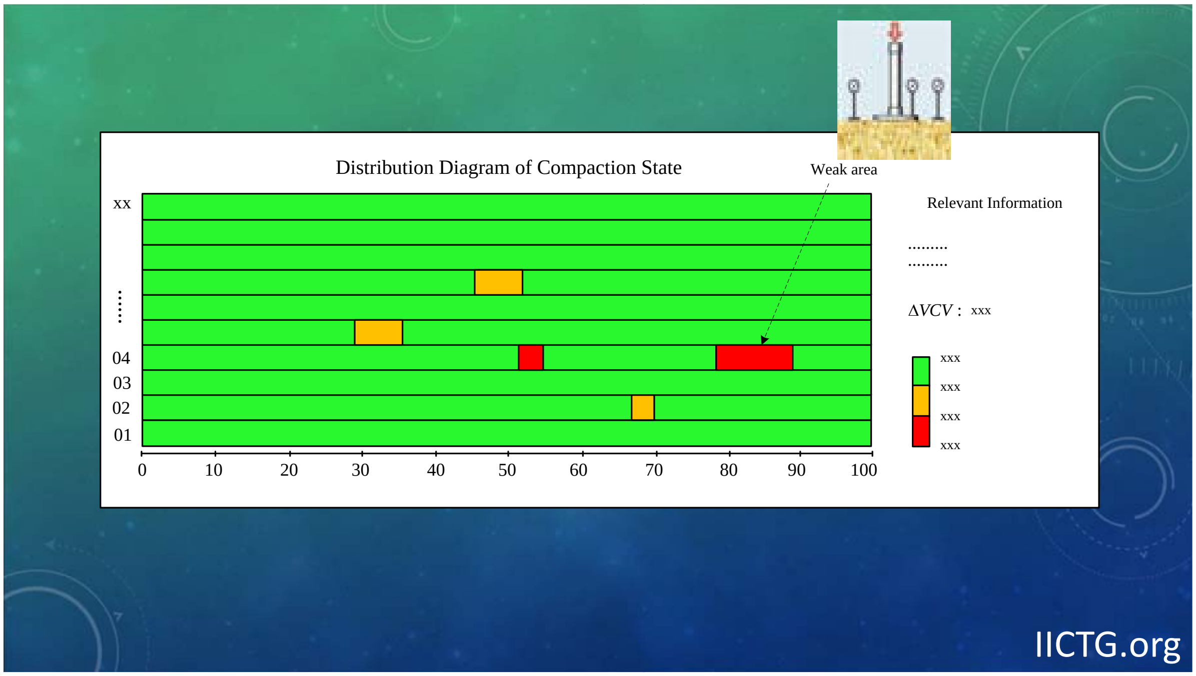
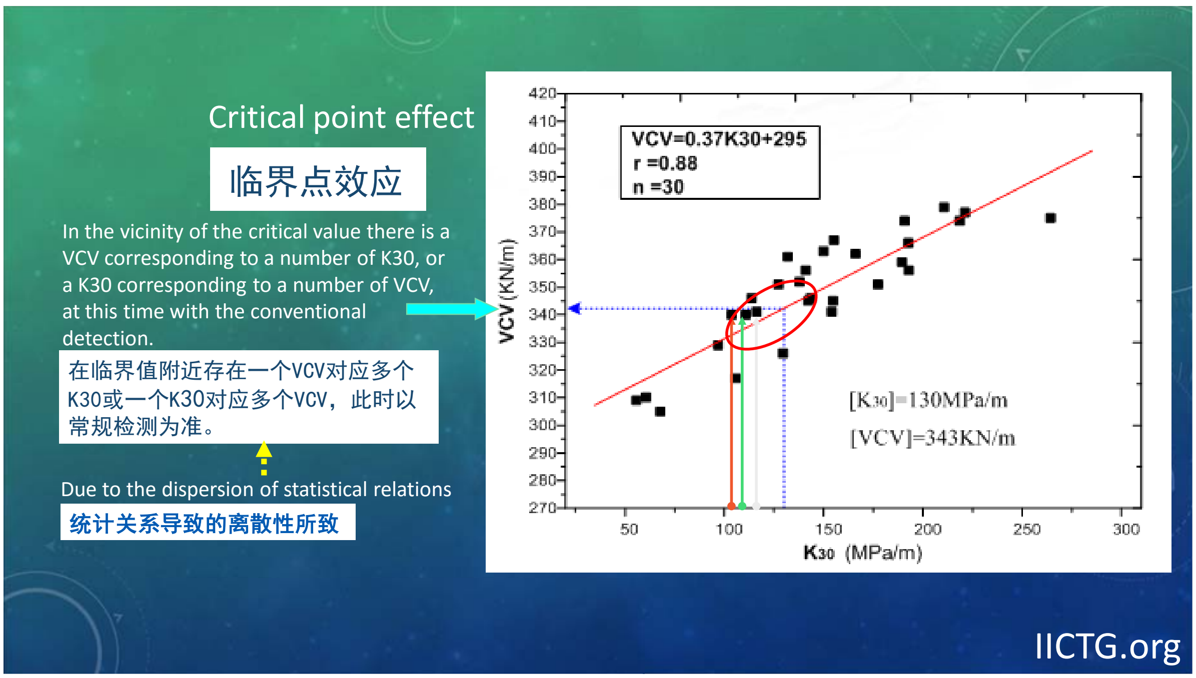
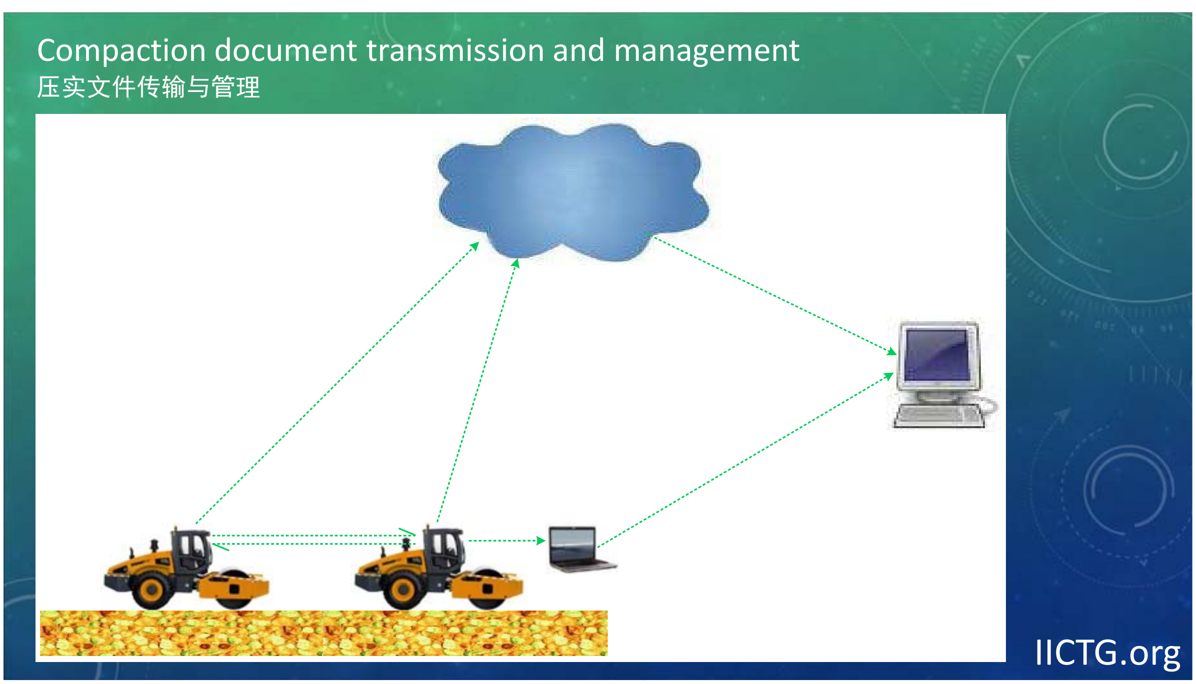
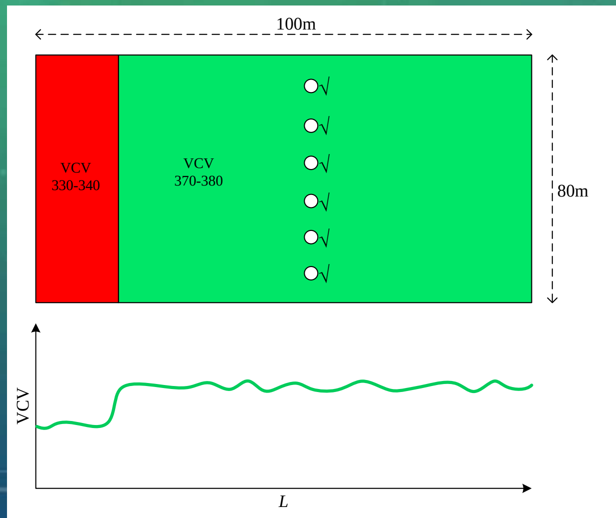

Distribution Diagram of Compaction State
Weak area
Relevant Information
....
....
ΔVCV : xxx
xxx
xxx
xxx
xxx
xx
04
03
02
01
0 10 20 30 40 50 60 70 80 90 100
IICTG.org


Critical point effect
临界点效应
In the vicinity of the critical value there is a VCV corresponding to a number of K30, or a K30 corresponding to a number of VCV, at this time with the conventional detection.
在临界值附近存在一个VCV对应多个K30或一个K30对应多个VCV，此时以常规检测为准。
Due to the dispersion of statistical relations
统计关系导致的离散性所致
VCV=0.37K30+295
r =0.88
n =30
[K30]=130MPa/m
[VCV]=343KN/m
VCV (KN/m)
K30 (MPa/m)
IICTG.org


Compaction document transmission and management
压实文件传输与管理
IICTG.org

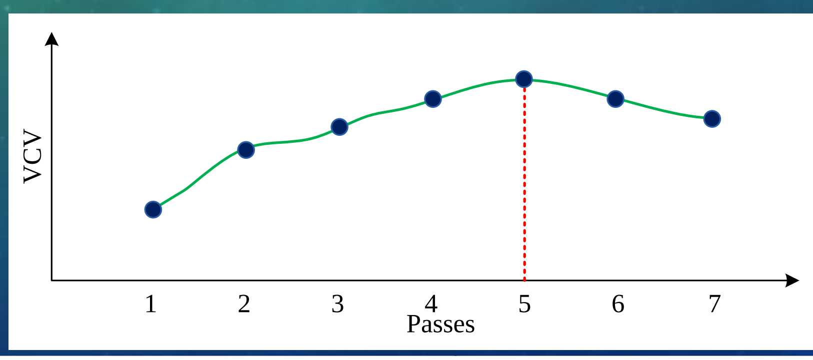
Advantage



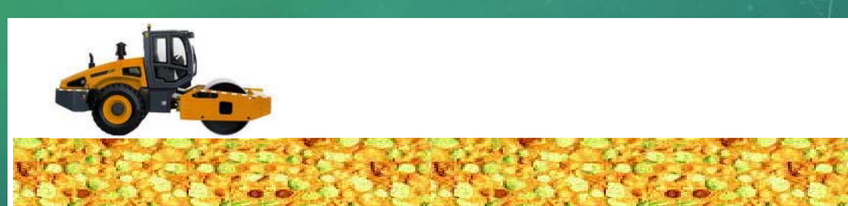
Testing of the entire rolling surface,
To prevent inadequate compaction and conventional detection.

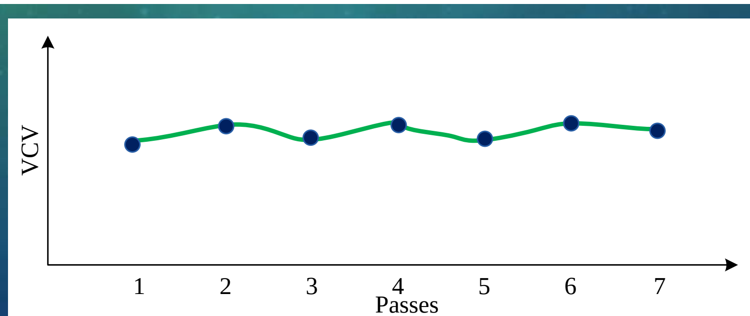
对整个碾压面进行全面检测，
防止欠压和常规检测的漏检

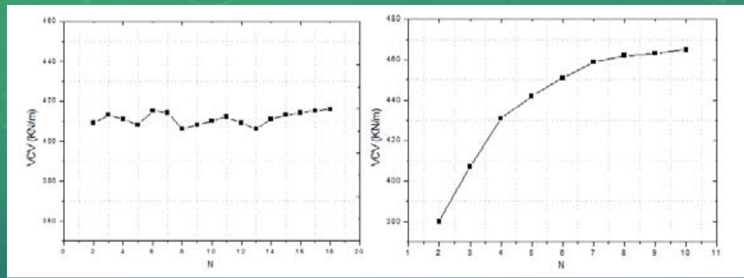
Optimize the number of roller compacted to avoid excessive compaction
优化碾压遍数，避免过压



Recognition compaction property of filling
识别填料可压实性

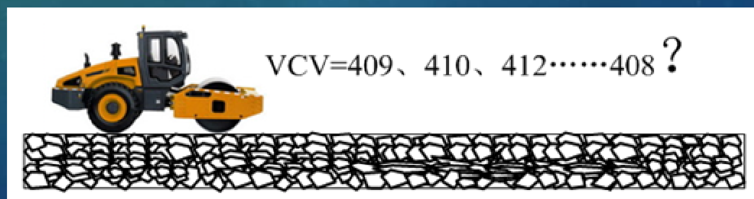






Unreasonable gradation
级配不合理

Reasonable gradation
级配合理



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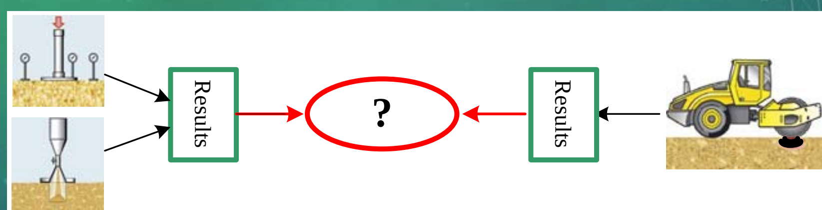
About correlation
关于相关性



Only the test results of roller are consistent with the results of conventional test, and can be used in the rolling quality control. （$r \geq 0.70$）

压路机检测结果与常规检测结果一致才能在碾压质量控制中进行应用。（$r \geq 0.70$）

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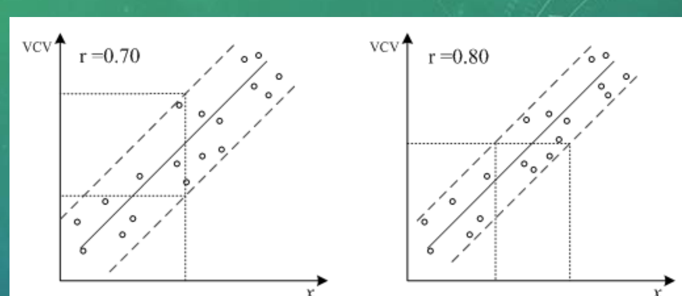
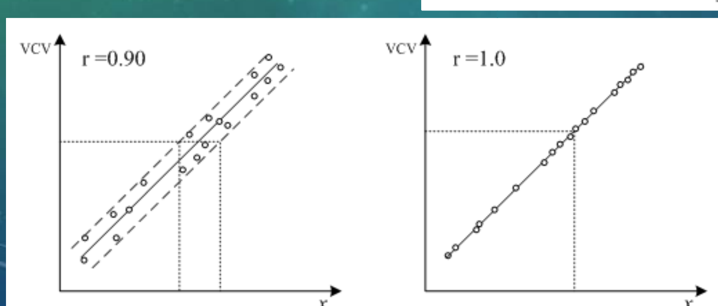
Relation between correlation coefficient and data dispersion degree
相关系数与数据离散程度的关系





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Applicability of control index influence correlation

控制指标的适用性影响相关性

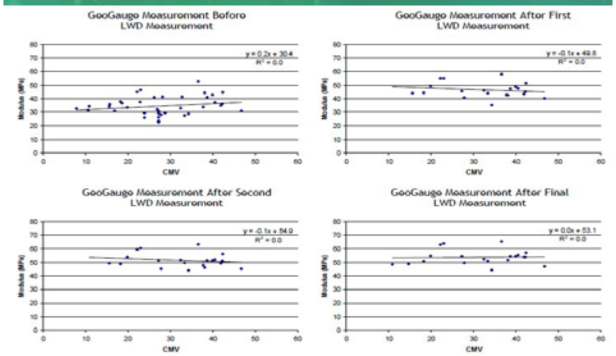

Figure 11

Comparison of CMV to GeoGauge

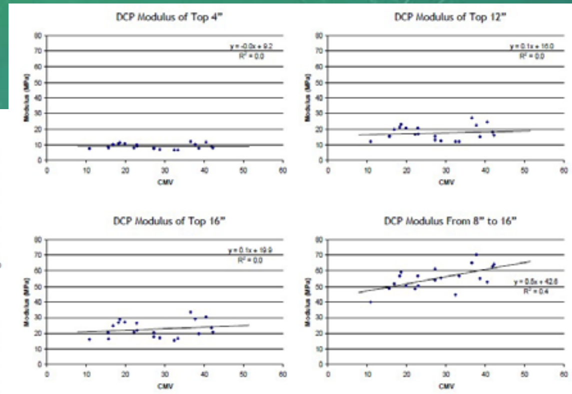

Figure 13

Comparison of CMV to DCP

Intelligent Compaction and In-Situ Testing at Mn/DOT TH53 MN/RC-2006-13

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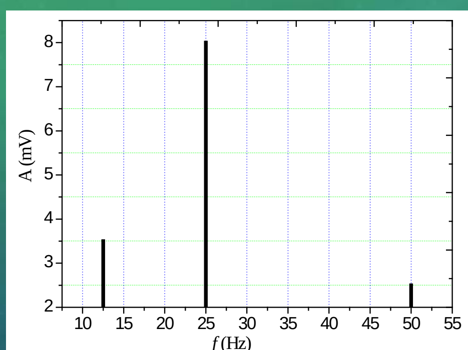
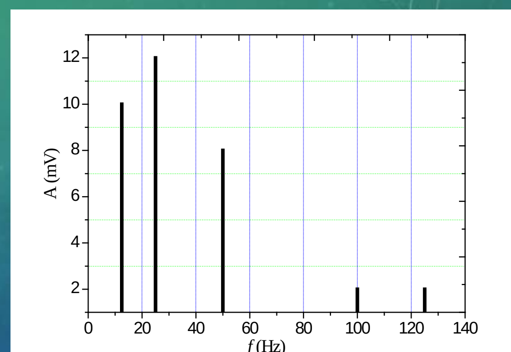
CMV=？



2 Passes



16 Passes

Japan Construction Institute of Civil Engineering （1992）

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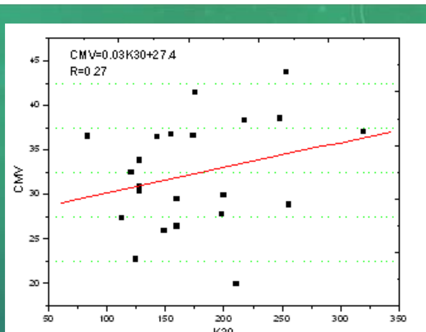
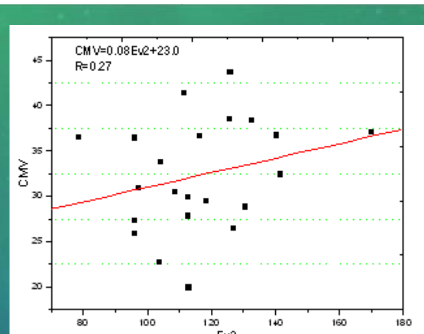
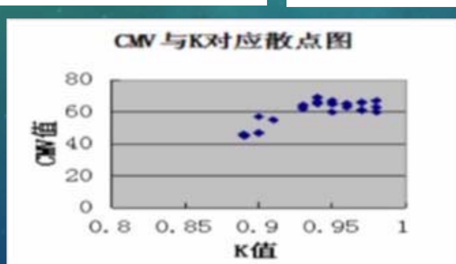


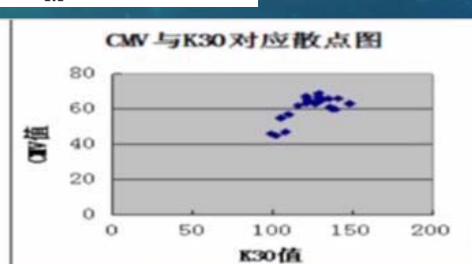


China's high speed railway

中国高速铁路

（2008—2011）





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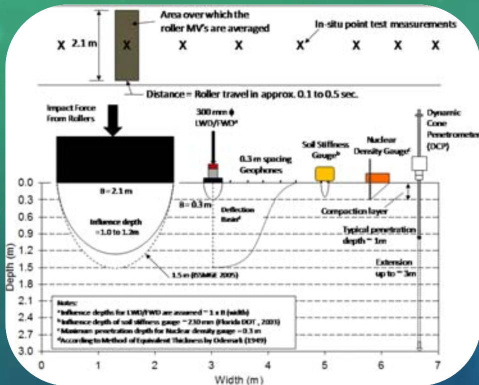
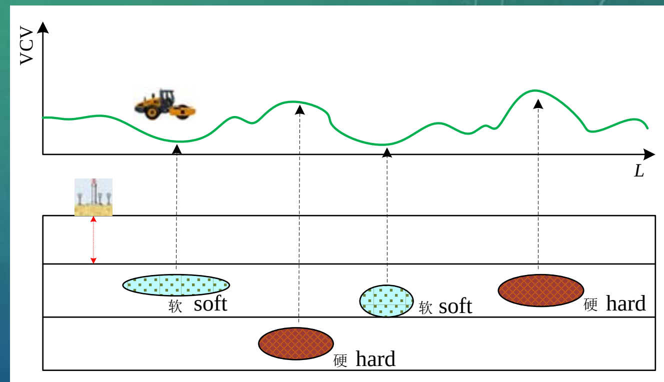
Detection range influence correlation
检测范围影响相关性





The characteristics of each filling layer not only affect the correlation, but also affect the accuracy of the compaction data.

各个填筑压层的特性不但影响相关性，也影响压实数据的正确性

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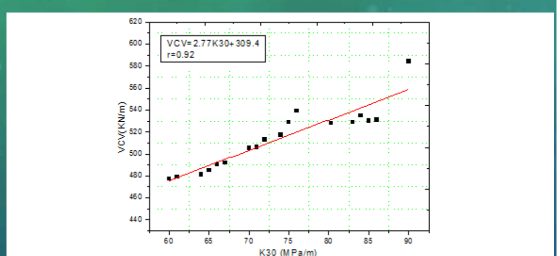
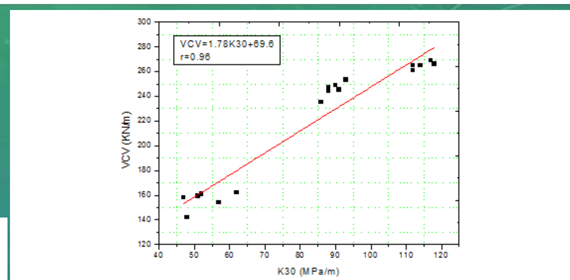
Filling material characteristics influences correlation
填料特性影响相关性

***r* ≥ 0.80**





Proper compaction efforts	压实效果明显
Adequate aggregate gradation	粗粒料级配良好
Adequate moisture content	细粒料含水量合适

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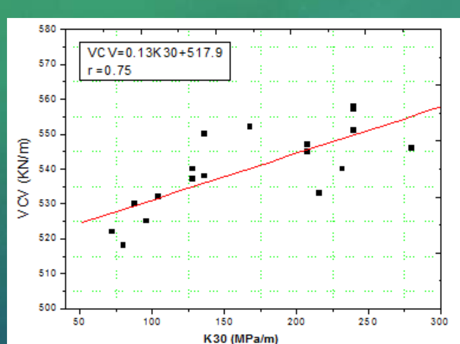
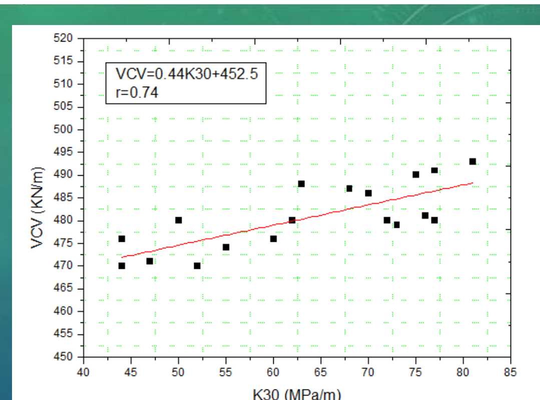
***r* = 0.70～0.80**





- **Compaction effort is satisfactory** 压实效果可以
- **Satisfactory course aggregate gradation** 粗粒料级配一般
- **Variable moisture contents in fine aggregates** 细粒料含水量有一定波动性

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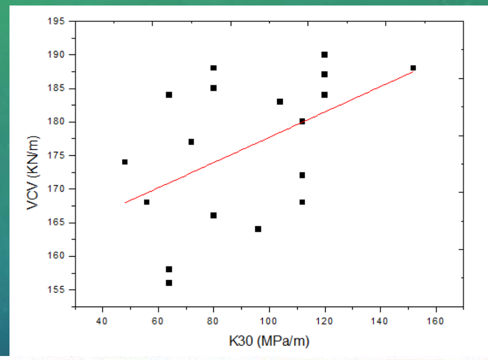
r < 0.70

- **Unsatisfactory compaction effort**
- **Inadequate coarse aggregate gradation**
- **Inadequate moisture contents in fine aggregate**

压实效果基本没有

粗粒料级配不好

细粒料含水量过大或者过小



CCC & INTELLIGENT COMPACTION
填筑工程智能压实

BY

DR. GEORGE K. CHANG, PROF. GUANGHUI XU

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国际智能建设技术学会发起人

SECTION 5 IC/CCC FOR ASPHALT

ASPHALT IC

Courtesy of HAMM

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DOUBLE DRUM IC ROLLERS

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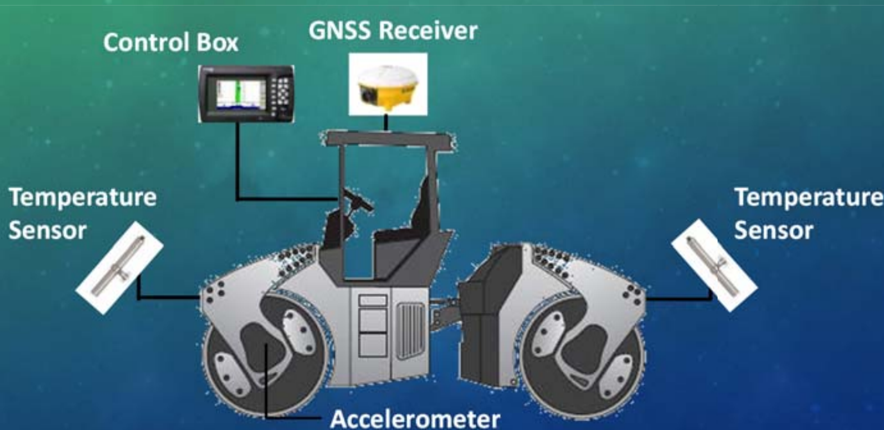
IC RETROFIT SYSTEM



Courtesy of Trimble

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VARIOUS ICMV

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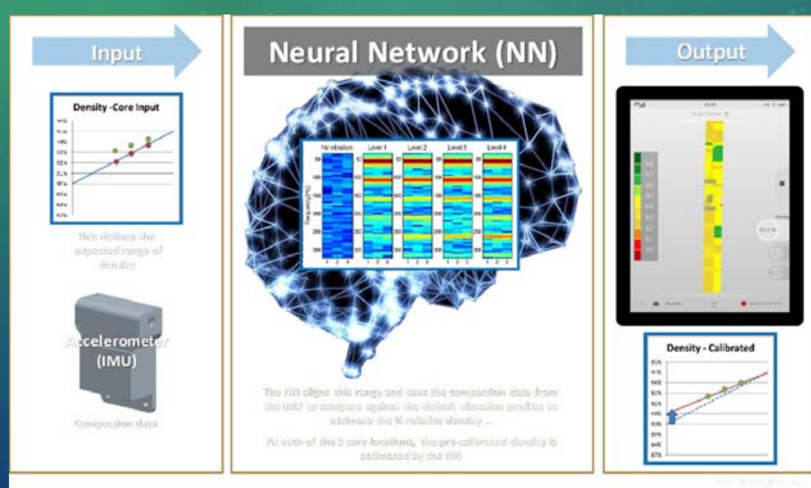
EDV – ESTIMATED DENSITY VALUE



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ASPHALT IC STILL EVOLVING

DENSITY VS ICMV (STIFFNESS)

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FACTORS AFFECTING ASPHALT COMPACTION

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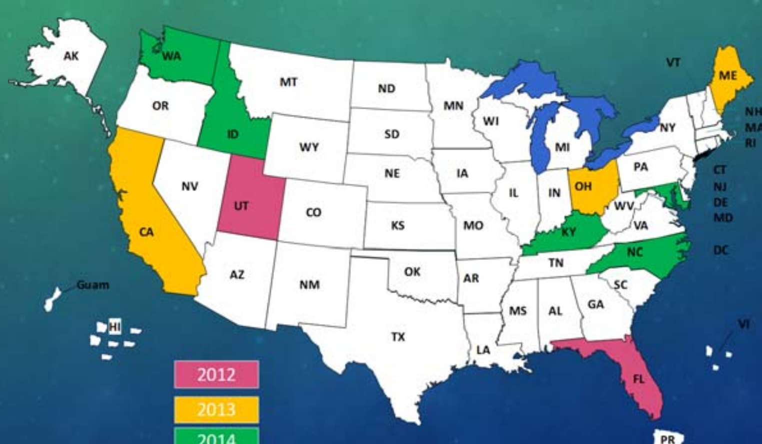
US FHWA IC & IN-PLACE ASPHALT STUDY (2012-2014)



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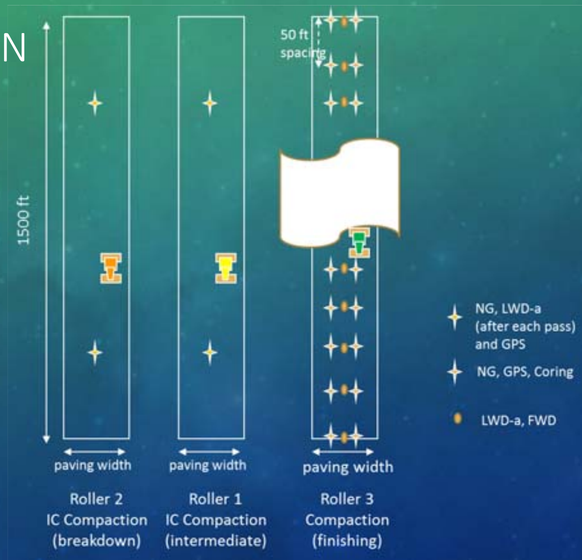
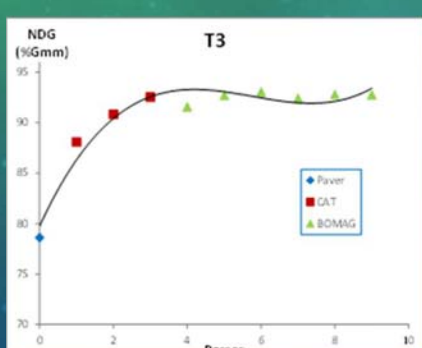
FIELD TEST PLAN

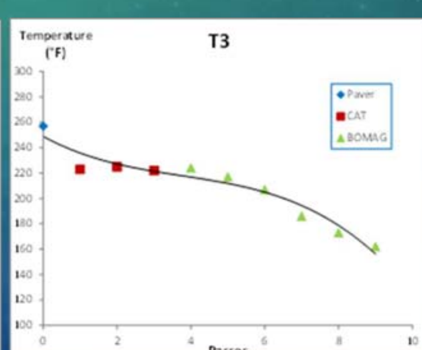


CORING OPERATION

9 sites
515 cores!

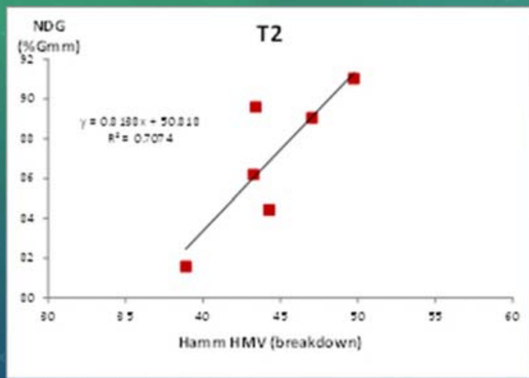
OPTIMUM COMPACTION WINDOW

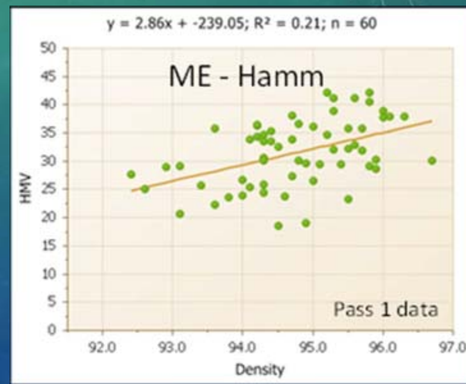




CA

NDG DENSITY VS ICMV

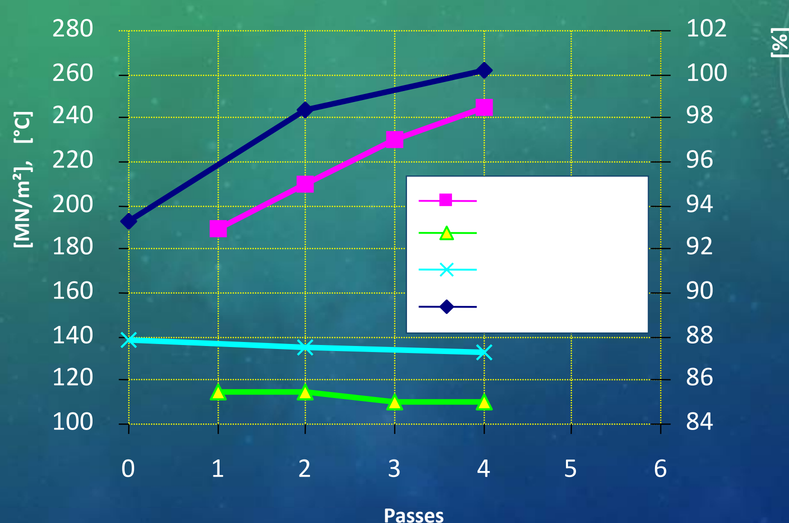




Breakdown

Final Coverage

ME IICTG.org



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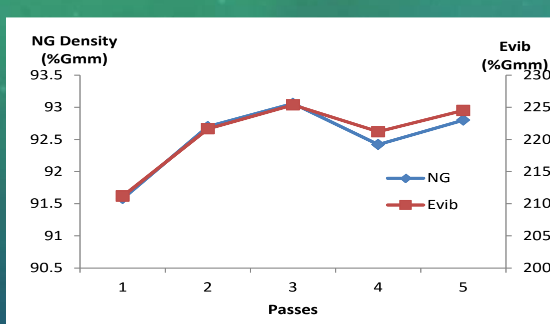
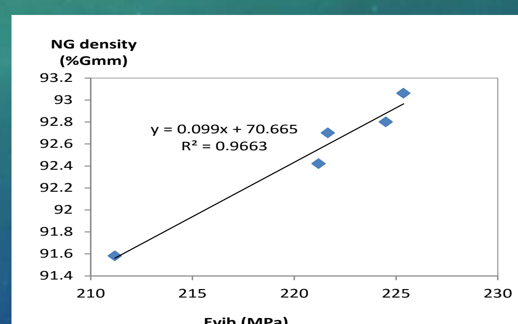
ASPHALT ICMV VS. DENSITY
智能压实检测值与沥青密度的关联性





Only during breakdown or intermediate compaction

FHWA IC demo in CA

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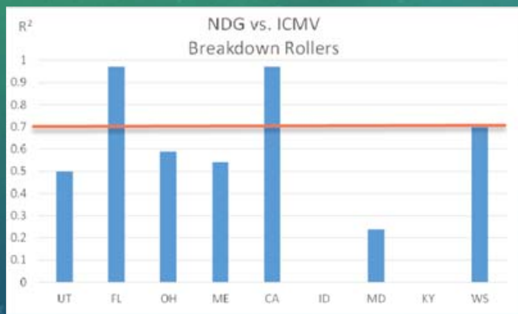
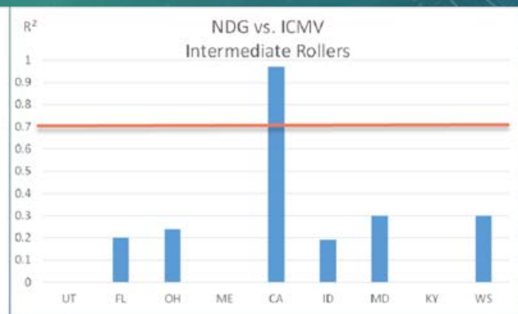
NDG DENSITY VS ICMV





breakdown

Intermediate

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IC-BASED DENSITY MODEL

$$\rho(i,j) = \rho_0 + (\rho_{max} - \rho_0) \times e^{-\left[\frac{a_1 ICMV(i,j) + a_2 f(i,j) + a_3 V_R(i,j) + a_4 (T(i,j) - T_r)}{j}\right]^{\beta}} + \varepsilon(i)$$

Heterogeneous Panel-Data Multivariate Nonlinear Model

Considering

- **Initial density (pass 0)**
- **Gmm**
- **ICMV**
- **Vibration Frequency**
- **Roller Speeds**
- **Mat Temperatures**
- **Reference temperature**

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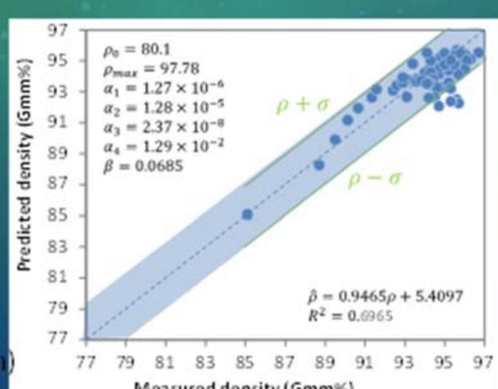
IC-BASED HMA DENSITY MODEL



ME

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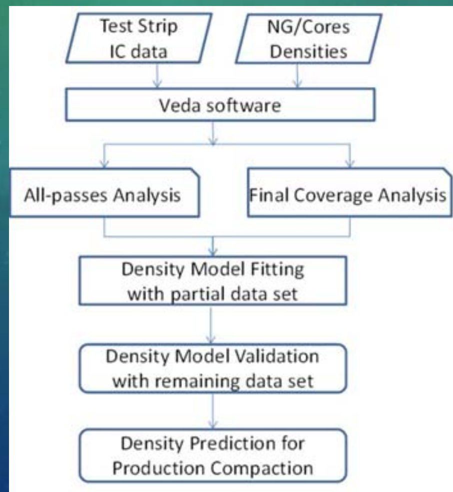
FIELD PROCEDURE FOR CALIBRATION OF HMA DENSITY MODEL



FHWA/TXDOT IC RETROFIT EVALUATION (2012-2013)

Asphalt Rodeo

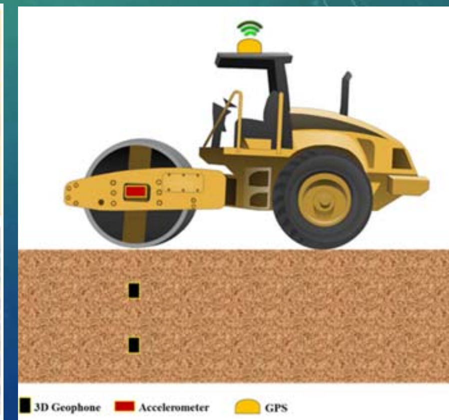
El Dorado Hills, CA

INSTALLATION OF ACCELEROMETERS

IC Retrofit

OEM

VERIFICATION KIT AND FIELD INSTRUMENTATION



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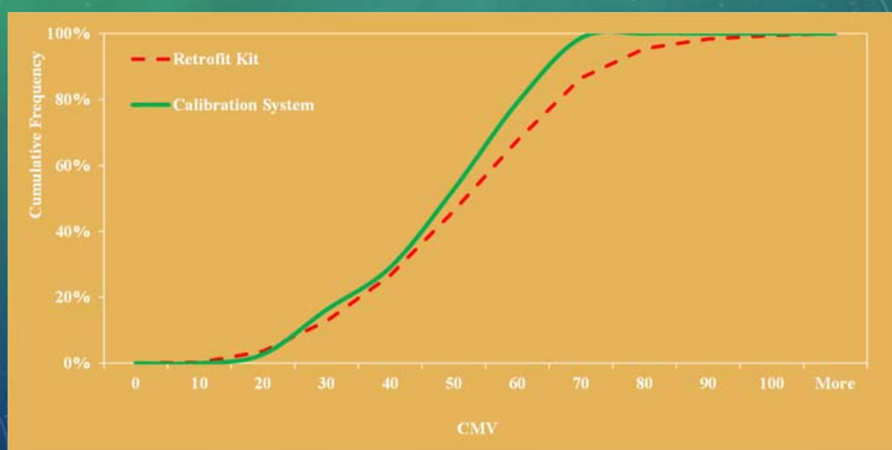
ICMV VERIFICATION



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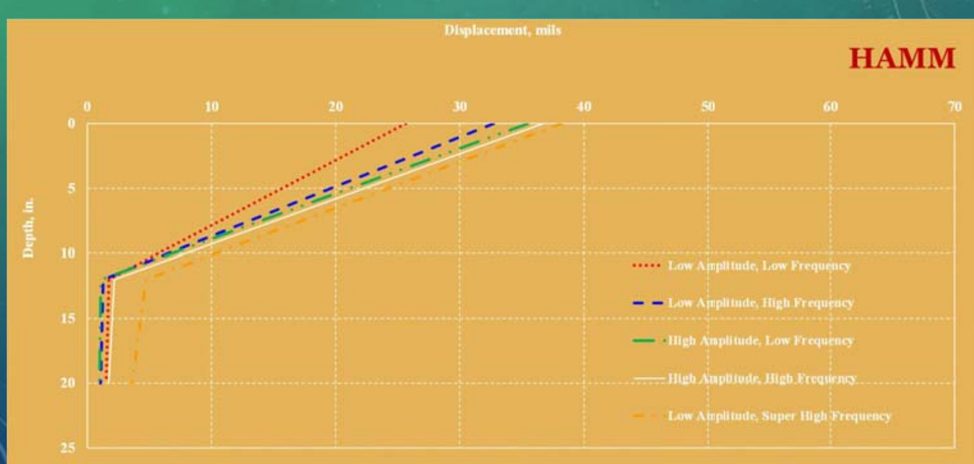
IC INFLUENCE DEPTH



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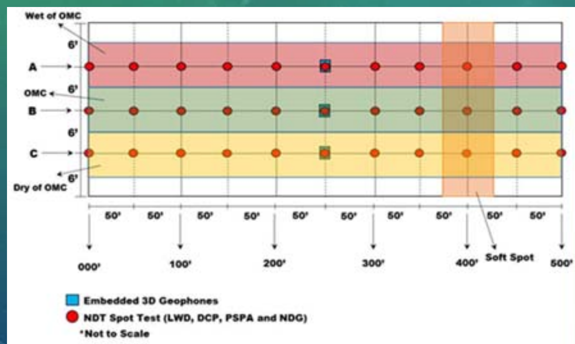
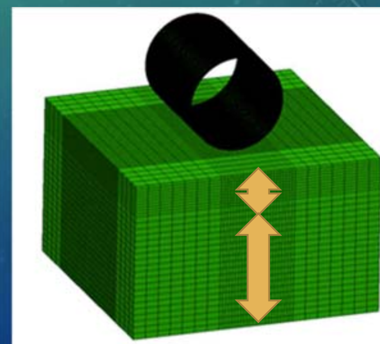
US NCHRP 24-45 IC STUDY (2015 ~ 2018)





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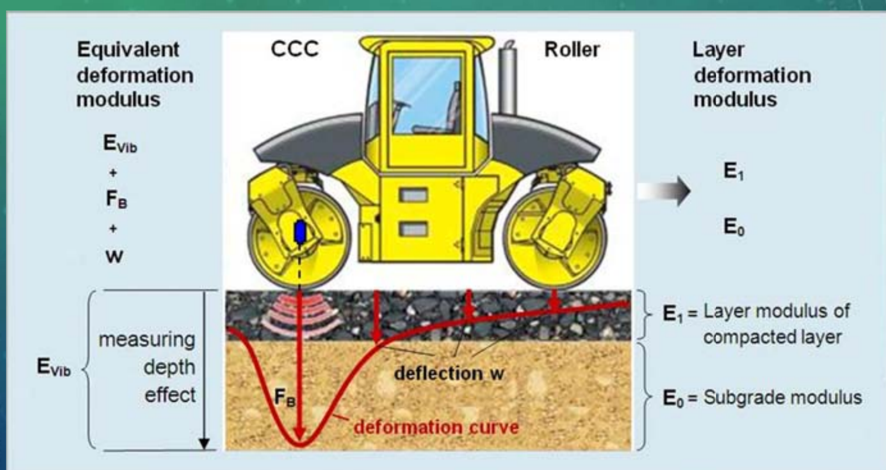
DE-COUPLED LAYER MODULI



Courtesy of Bomag

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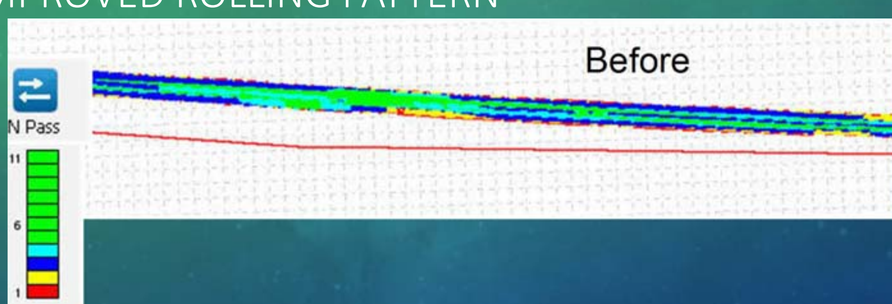
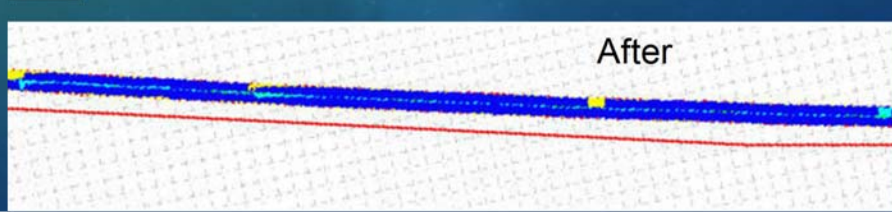
QC Benefits of Asphalt IC

IMPROVED ROLLING PATTERN



IN



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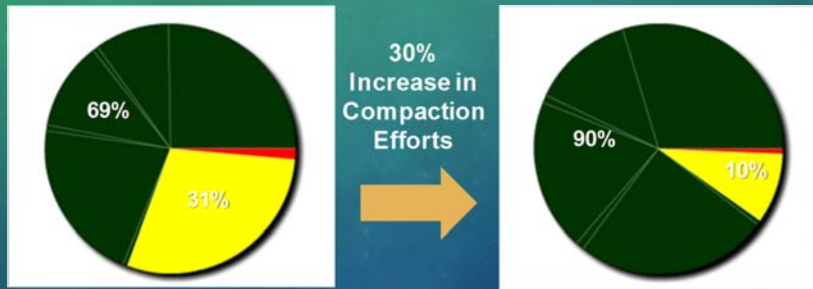
QC Benefits of Asphalt IC

IMPROVED CONSISTENCY AND EFFICIENCY



Lift 1 without IC

< 3 Passes: 31 %
≥ 3 Passes: 69 %
COV : 71%

Lift 2 with IC

< 3 Passes: 10 %
≥ 3 Passes: 90 %
COV: 55%

Courtesy of MNDOT

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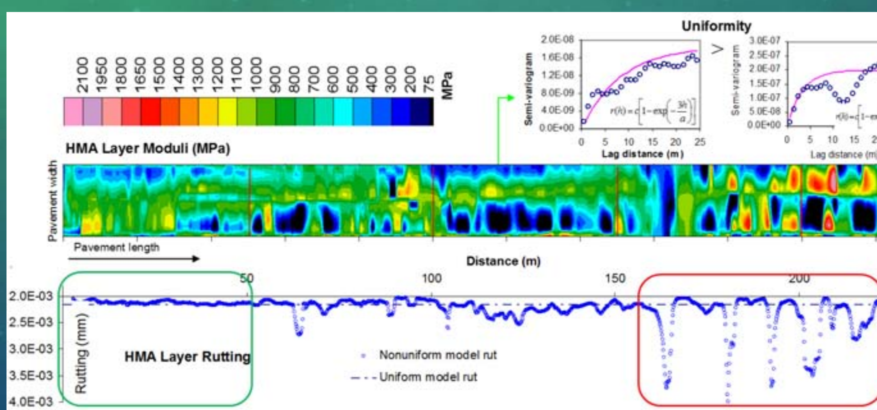
QC Benefits of Asphalt IC

IMPROVED UNIFORMITY AND PERFORMANCE



Xu et. al., RILEM (2012)

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CCC & INTELLIGENT COMPACTION
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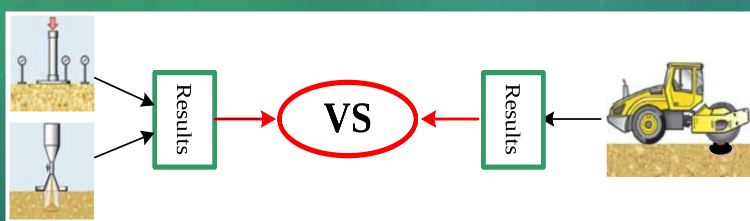
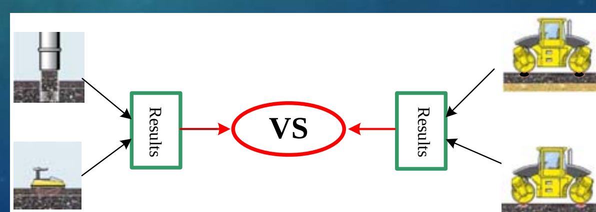
SESSION 6 FUTURE DEVELOPMENT OF IC
第六节 智能压实发展方向

Results from IC control and from conventional tests need to be well correlated.
保证智能压实控制结果与常规控制结果的一致性

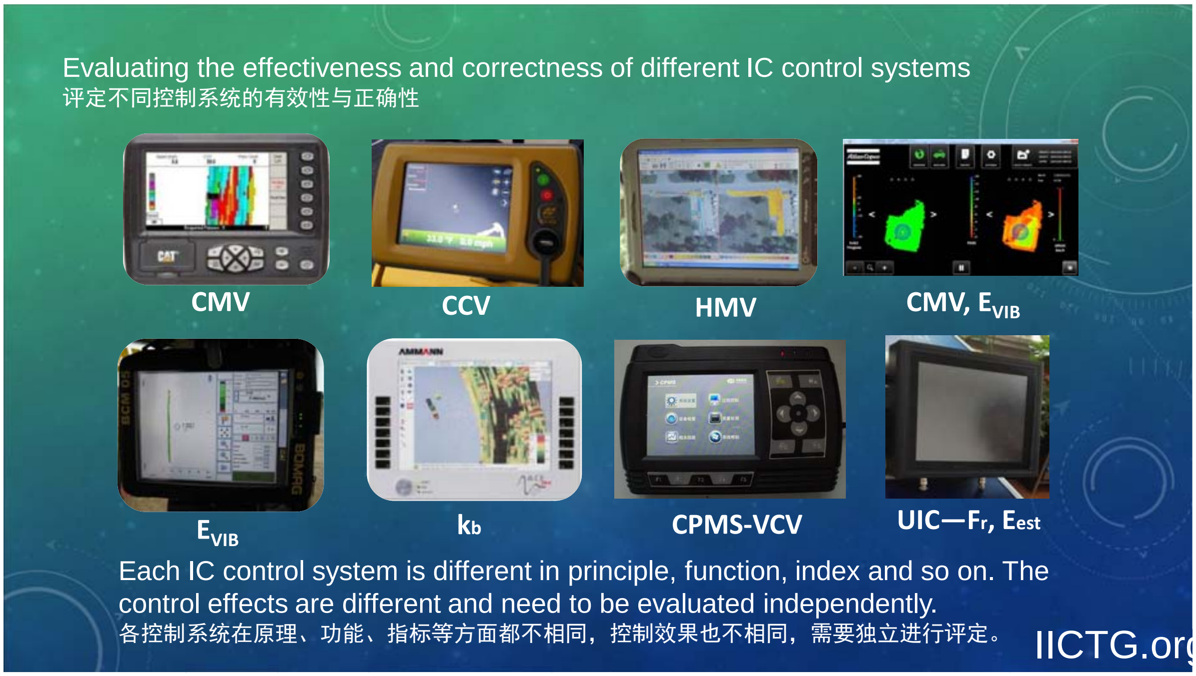


IC must be able to control the parameters of the filling body, and has good consistency with the results of the conventional control, especially for asphalt pavements.
智能压实必须能够控制填筑体参数本身，并且要与常规控制结果具有很好的一致性，特别是应用在沥青路面中。

Passes of roller compaction is one of the contents of the digital construction
控制碾压遍数只是数字化施工内容之一



Control Different Aspects of Asphalt Compaction
碾压沥青路面需要控制的内容


Evaluating the effectiveness and correctness of different IC control systems
评定不同控制系统的有效性与正确性
CMV
CCV
HMV
CMV, E_VIB
E_VIB
kb
CPMS-VCV
UIC—Fr, Eest
Each IC control system is different in principle, function, index and so on. The control effects are different and need to be evaluated independently.
各控制系统在原理、功能、指标等方面都不相同，控制效果也不相同，需要独立进行评定。
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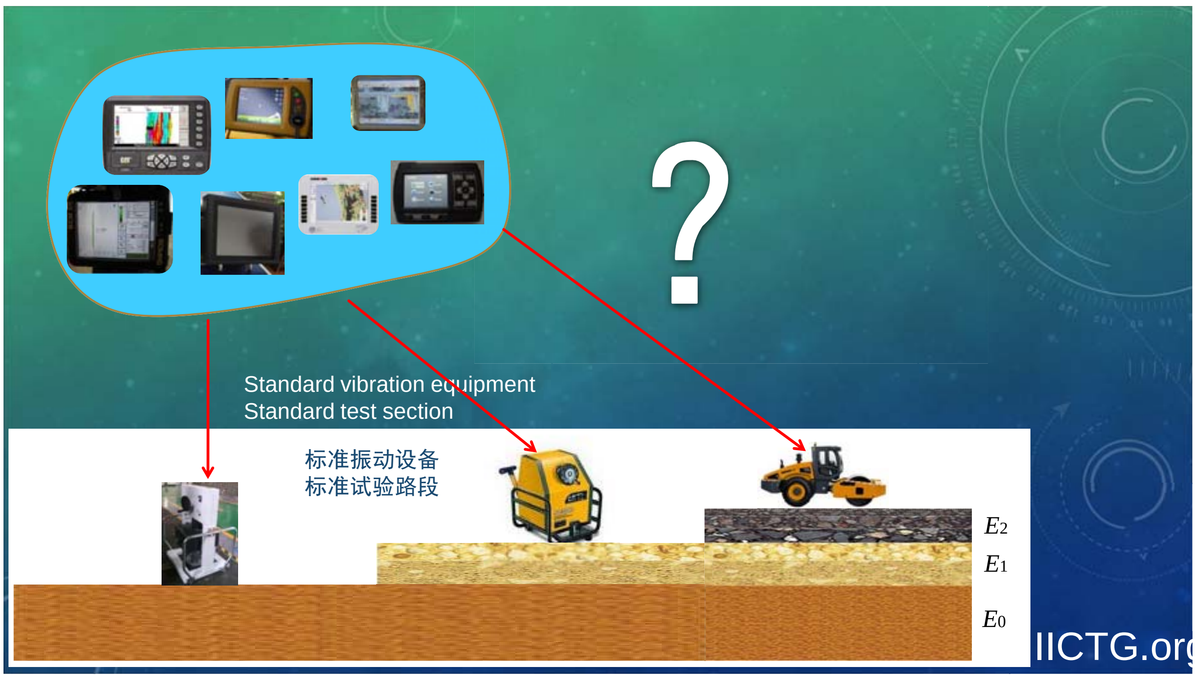
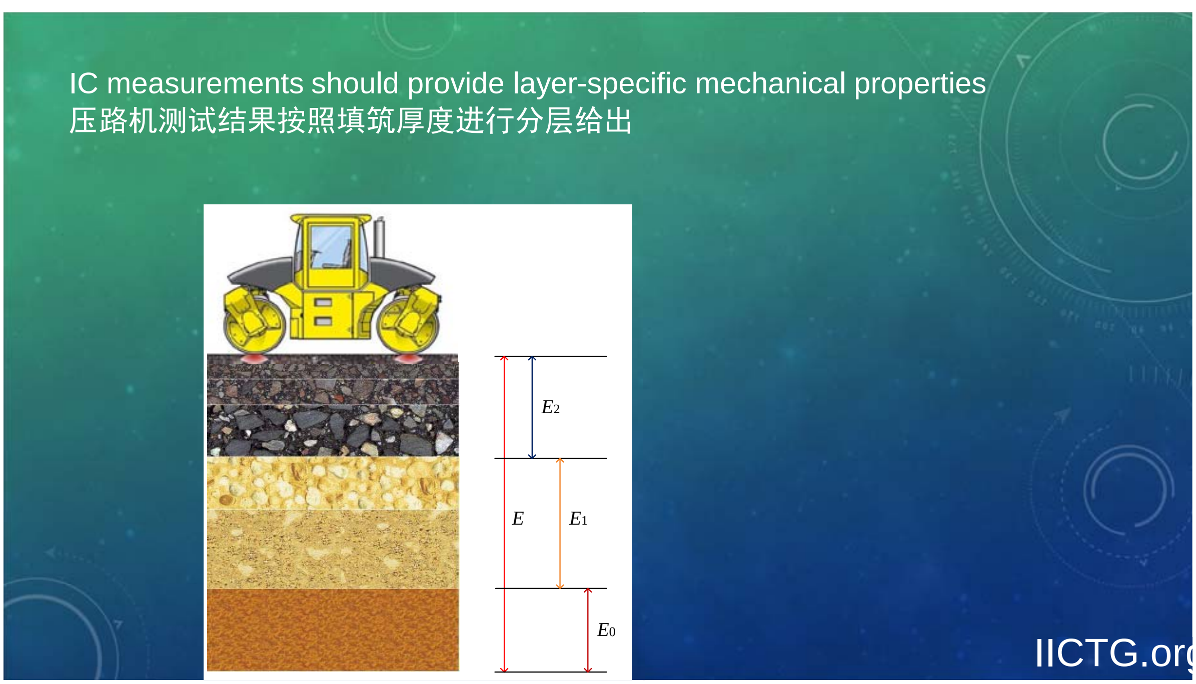

?
Standard vibration equipment
Standard test section
标准振动设备
标准试验路段
E2
E1
E0
IICTG.org


IC measurements should provide layer-specific mechanical properties
压路机测试结果按照填筑厚度进行分层给出
E2
E
E1
E0
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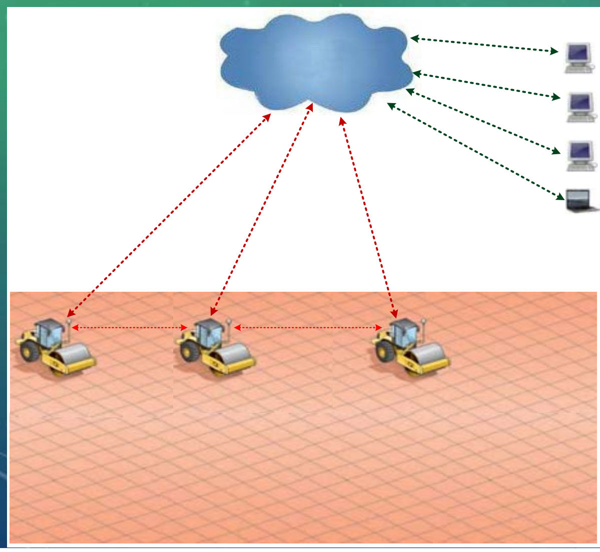
Integration of Internet, Cloud Technology and IC
物联网、云技术与智能压实的进一步结合



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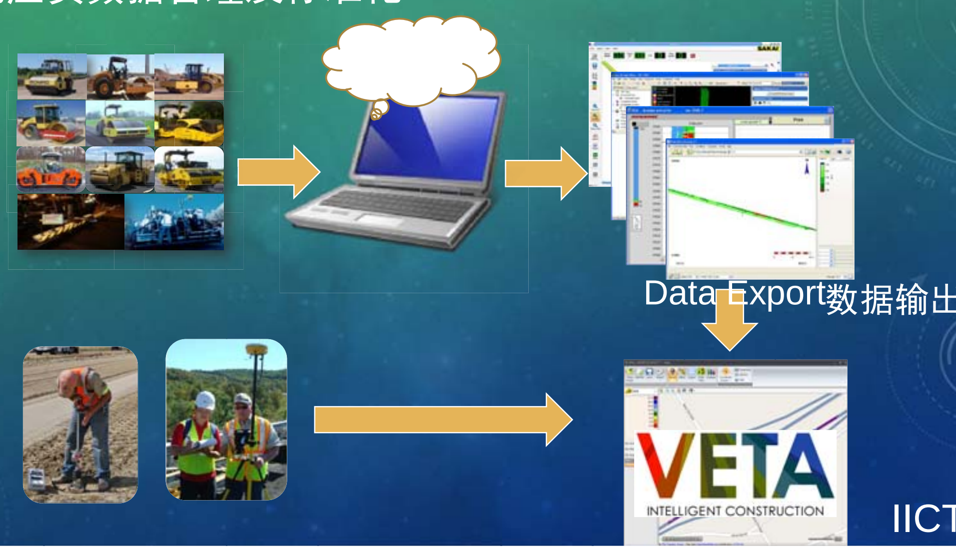
IC DATA MANAGEMENT AND STANDARDIZATION
智能压实数据管理及标准化



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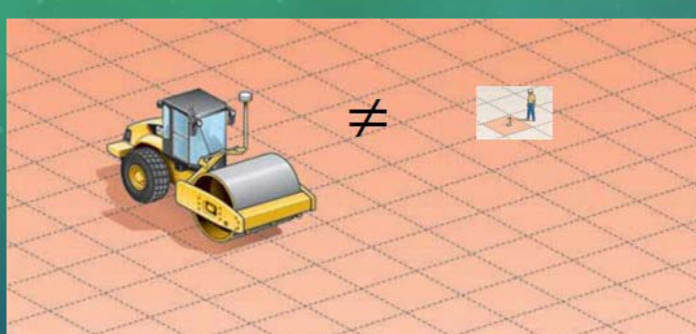
Can IC replace the conventional tests?
智能压实能否取代常规检测?



- 目前的智能压实不等同于常规检测。
- 未来有可能采用智能压实控制技术替代常规压实质量控制。
- 常规检测除了检测压实质量外，还具有获取用于分析计算参数的作用。

- Current IC measurements are not the same as conventional detection.
- It is possible to replace conventional compaction quality control with IC control technology in the future.
- In addition to measure compaction quality, conventional tests also include parameters for analysis and calculation.

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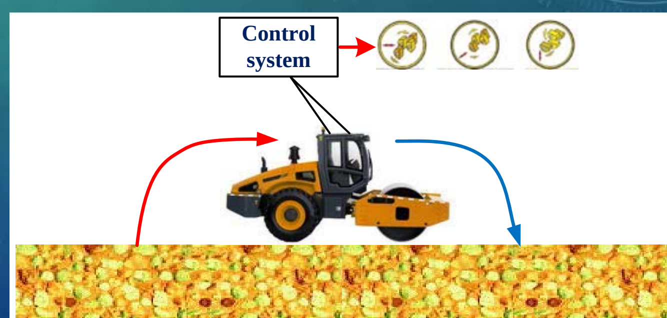
Number of conventional tests for compacted weak area

NATION	Area of weak area	Number of conventional tests
SWEDEN	10m^2	2 Spots/5000m^2
GERMANY	10m^2	3 Spots/5000m^2
CHINA	5-10m^2	1 Spots /100m
AUSTRIA	It only provides routine testing in weak areas.	

Understanding IC
理解智能压实

- IC is developed from the concept of early intelligent rollers, abbreviation of intelligent compaction control (ICC), and subsequent development of CCC.
- IC automatically adjust roller operating parameters based on the continuous roller responses to optimize compaction.

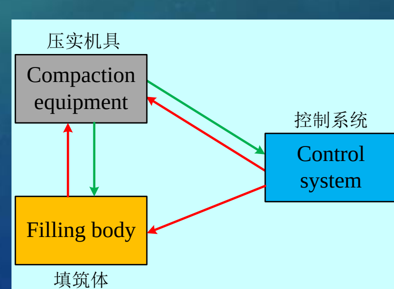
- 智能压实是从早期智能压路机的概念演变而来的，际是智能压实控制（ICC）的简称，也是连续压实控制技术的进一步发展。
- 智能压实质就是根据压路机响应来连续识别填筑体力学参数，再根据该参数大小和分布自动调节压路机工艺参数进行优化压实作业，以便得到更好的压实效果。



Understanding IC
理解智能压实

- The modern IC is the organic combination and the comprehensive performance of the interaction of the "filling body ~ the compaction equipment ~ control system", which is the core of the control system's function.
- The control system not only provide feedback to the operators, but also automatically adjust the compaction equipment parameters based on the levels of "intelligence".
- IC is still in the primary stage and expected to incorporate artificial intelligence and other technologies.

- 现代智能压实是"填筑体～压实机具～控制系统"三者相互作用的有机结合和综合表现，其核心是控制系统的功能。
- 控制系统既可以向操作者发出反馈控制指令，也可以自动调控压实机具，关键在于这个控制系统的智能化程度。
- 尚处于初级阶段，需要与人工智能等技术的进一步结合。



Understanding IC
理解智能压实

IC control system should——
- include intelligence to learn, reason, deduce and make decisions.
- manually or automatically adjust compaction operation based on the filling characteristics.
- carry out adaptive rolling operations with compaction equipment.

控制系统应具有的功能——
- 具有一定的智慧，能够在碾压过程进行学习、抽象、推理和决策等。
- 具有根据填料特性调控（人工或自动）压实机具的能力。
- 具有与压实机具结合进行自适应碾压作业的能力。

——DEVELOPMENT OF IC EQUIPMENT
发展智能压实设备

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Understanding IC
理解智能压实

IC key technologies
- Identify the compaction state of the filling body based on roller responses
- Identify the compactability of filling body
- Control operating parameters of compaction equipment

关键技术——
- 碾压过程中如何根据压实机具的某种反应来识别填筑体的压实状态
- 填料的压实性如何识别
- 压实机具工艺参数如何调控

——DEVELOPMENT OF IC EQUIPMENT
发展智能压实设备

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Understanding IC
理解智能压实

Future IC :
Driverless compaction equipment operated based on a work plan, real-time measurements of filling body related information, and automatically adjust and optimize compaction for utmost efficiency to achieve desired compaction quality.

未来的智能压实应该是这样的：无人或有人驾驶的压实机具按照设定的碾压作业方案进入施工现场，在碾压过程中，根据实时检测到的填料和填筑体相关信息，自动改变和优化压实工艺参数，以最小的代价完成碾压作业，达到规定的压实质量。

——DEVELOPMENT OF IC EQUIPMENT
发展智能压实设备

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关于国际智能建设技术学会

- International Intelligent Construction Technology Group
- www.IICTG.org
- A forum for intelligent construction technology experts around the world
- Initially intelligent compaction and thermal profiling
- Will extend to 3D design/modeling, AMG, BIM, and etc.
- Biannual conferences

- 网站www.IICTG.org
- 国际智能建设技术专家的论坛
- 初期为智能压实及沥青路面压实
- 以后延伸到三维设计/建模，自动机械控制, BIM等
- 两年一次大会

ABOUT IICTG MEBERSHIP
关于国际智能建设技术学会会员

- Welcome to join IICTG as members
- Apply via IICTG website (www.IICTG.org)

- 欢迎加入成为会员
- 请网上申请（www.IICTG.org)


Thanks
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