中国铁道科学研究院
CHINA ACADEMY OF RAILWAY SCIENCES

无砟轨道路基设计与施工
Design and construction of high-speed railway subgrade

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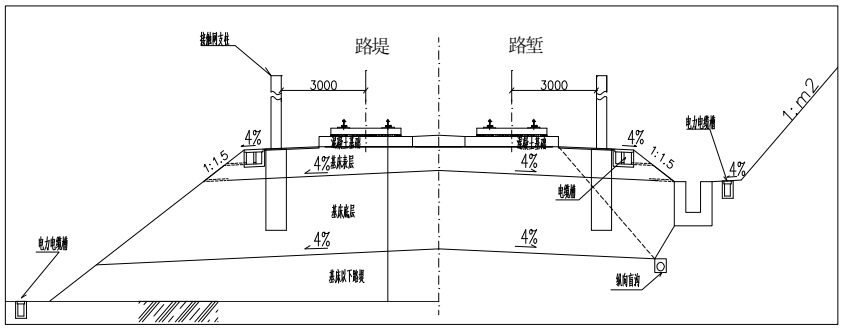
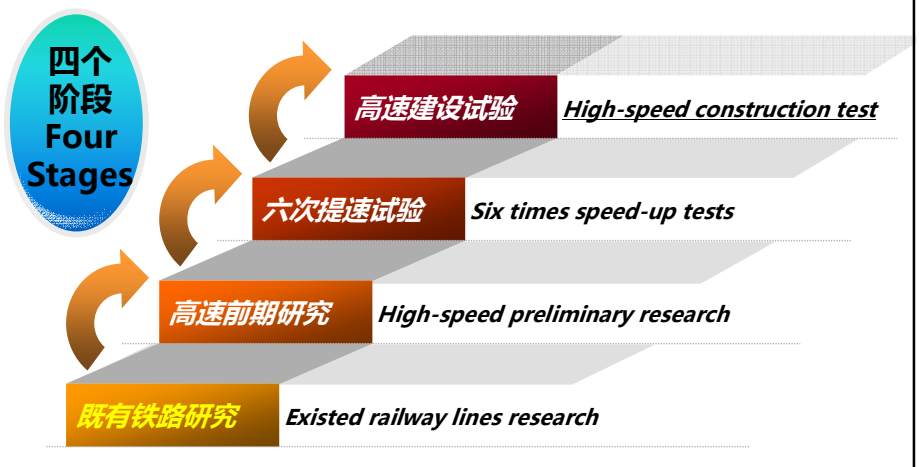
路基结构 Subgrade Structure

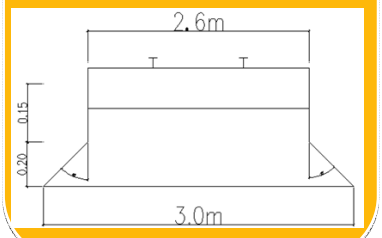


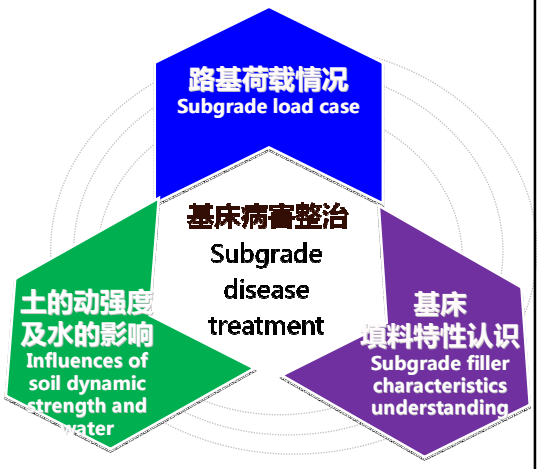
轨道类型 Track type	设计最高速度 (km/h)	双线线间距 (m)	路基面宽度	
			单线(m)	双线(m)
无砟轨道 Ballastless track	250	4.6	8.6	13.2
	300	4.8		13.4
	350	5.0		13.6
有砟轨道 Ballasted track	250	4.6	8.8	13.4
	300	4.8		13.6
	350	5.0		13.8



既有铁路研究
Existed railway lines research

路基面荷载
Subgrade load
（扩散简化计算）
(Spread simplified calculation)





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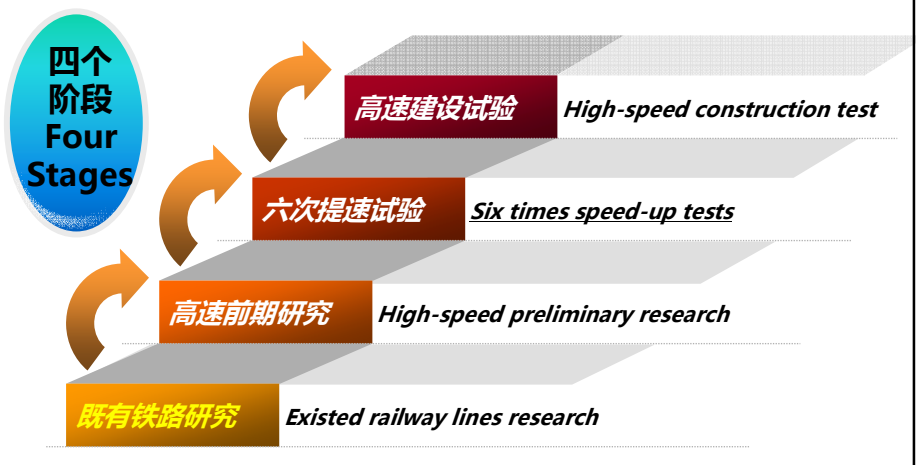

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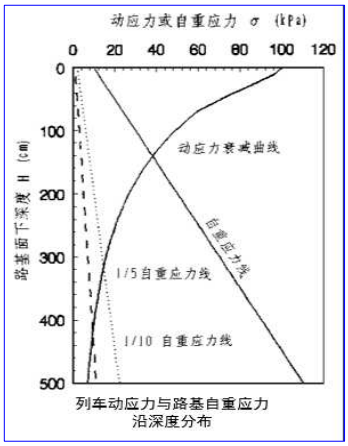
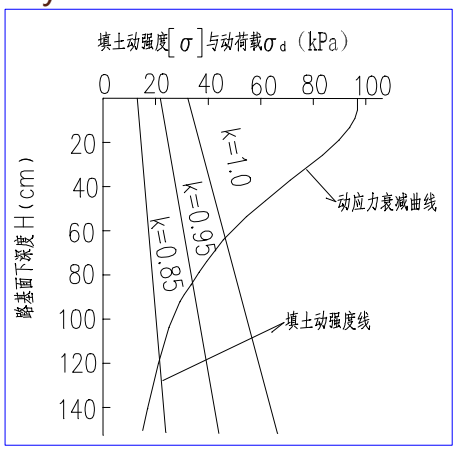
高速前期研究——基床深度、表层厚度

High-speed preliminary research——Subgrade depth、surface layer thickness





基床深度 3m；表层厚度 0.7m

Subgrade depth 3m; surface layer thickness 0.7m

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高速前期研究——中国基床深度、表层厚度

High-speed preliminary research——Subgrade depth、surface layer thickness in China

强调垫层的作用，采用层状强化结构：基床深度为3m；基床表层厚度 0.7m。

Emphasize the function of subcrust, using the laminated reinforced structure: subgrade depth was 3m; surface layer thickness was 0.7m

路基动变形不大于3.5mm

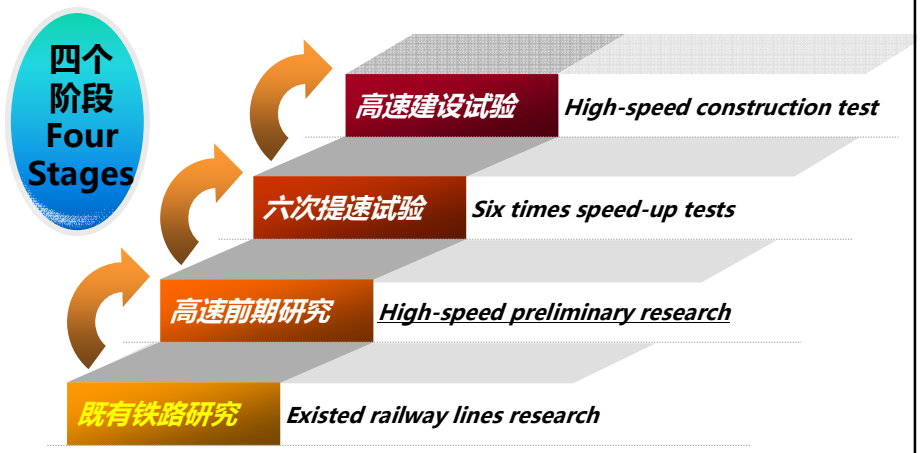
Subgrade dynamic deformation ≤3.5mm

变形条件
Deformation condition

强度条件
Strength condition

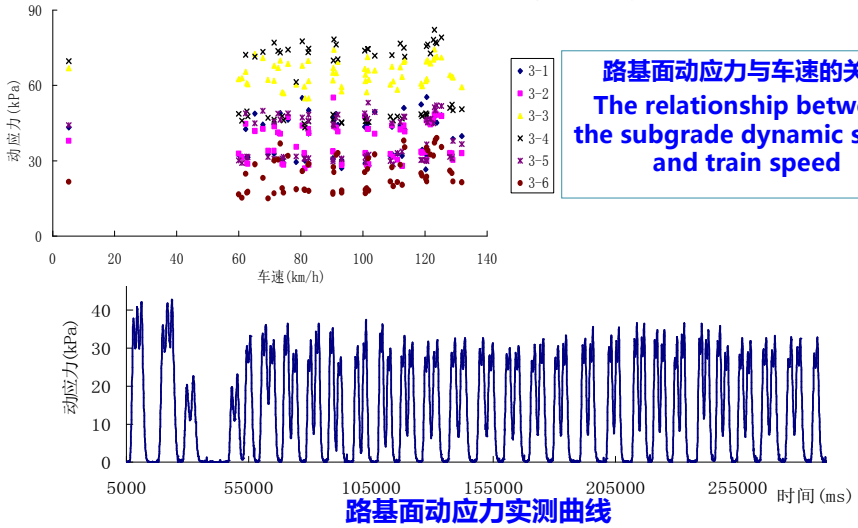
基床表层下填土上的动应力不大于填土允许应力

The dynamic stress on the soil underneath the surface layer of subgrade should not be greater than the allowable stress



六次提速试验---路基动应力

Six times speed-up tests——subgrade dynamic stress

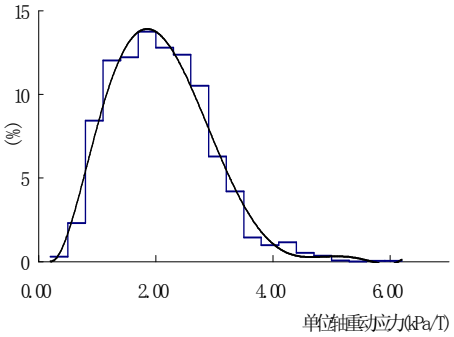


路基面动应力与车速的关系

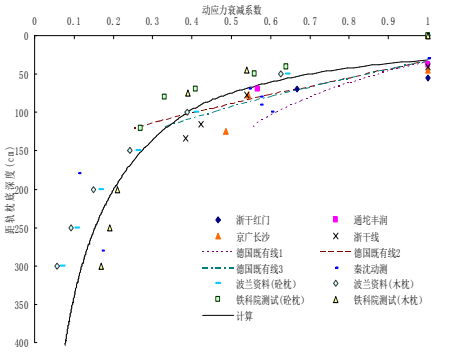
The relationship between the subgrade dynamic stress and train speed

路基面动应力实测曲线

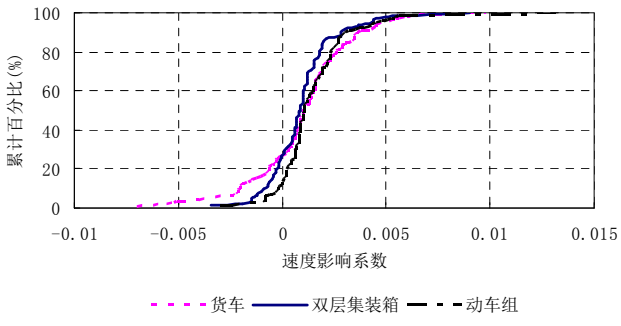
The measured curve of subgrade dynamic stress



荷载轴重系数
axle load coefficient



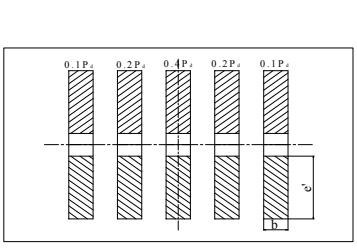
应力随深度的衰减
stress damping with depth

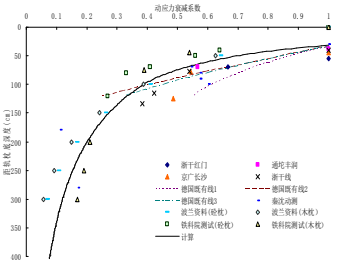


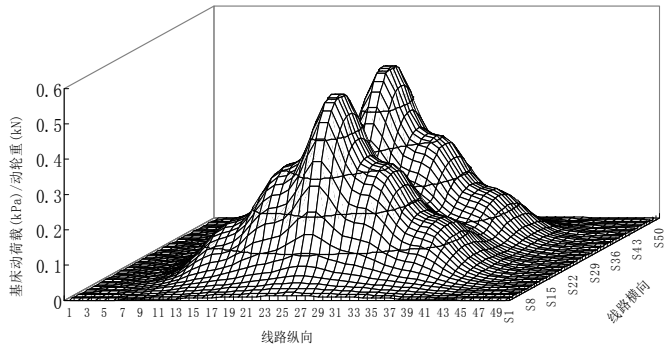
速度影响系数累计分布曲线
The cumulative distribution curve of speed influence coefficient

基床表面动应力计算公式：
The calculation formula of subgrade surface dynamic stress:

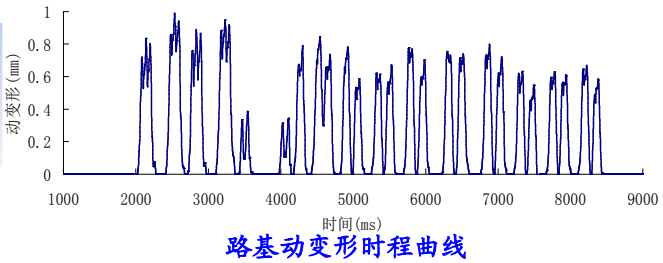
$$\sigma_{max} = 0.26 \times P \times (1 + av)$$





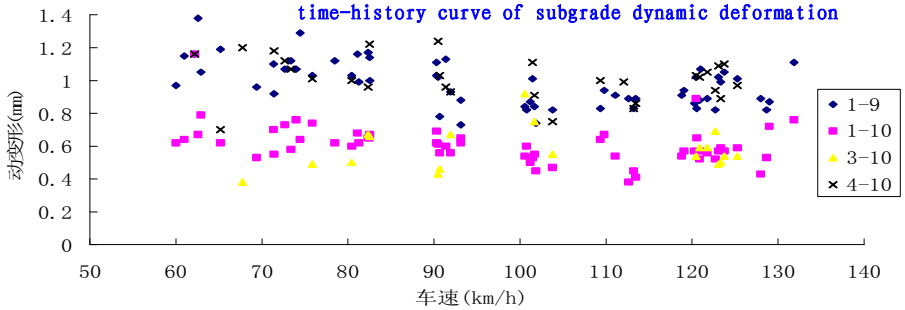


路基动变形
Dynamic deformation of subgrade



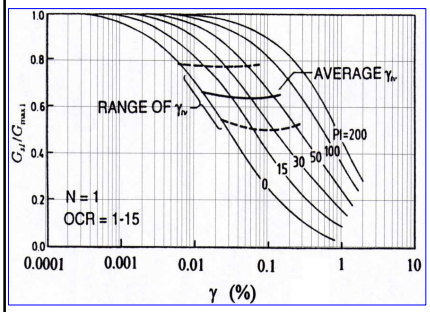
路基动变形时程曲线

time-history curve of subgrade dynamic deformation



动变形与车速的关系（试验列车）

Relationship between dynamic deformation and train speed (test train)



现场试验 In-situ test	计算值 Calculated value	位置 Location
0.29	0.28	有砟轨道 Ballasted track
0.30	0.28	
0.32	0.28	
0.37	0.44	
0.40	0.44	
0.44	0.45	
0.10	0.09	无砟轨道外侧 Ballastless track outside
0.08	0.08	
0.15	0.18	无砟轨道外侧

实测的路基动变形远小于限值3.5mm。
The measured subgrade dynamic deformation is much less than the limited value of 3.5mm.
采用与基床应变水平相当的模量参数时，计算与实测相吻合。
Using modulus parameters which on the same level with subgrade strain, the calculation results agree with the actual measurement.
路基动变形小于1mm的工点，路基状态良好。

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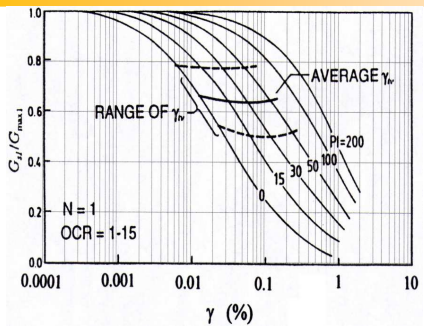
结构设计控制
Structure design control

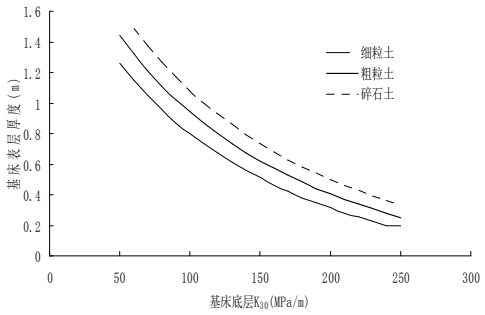
路基面动变形不大于1mm；

Subgrade surface dynamic deformation should less than 1mm;

基床动应变小于临界体积效应应变值

Subgrade dynamic strain should less than the value of critical volume effect strain



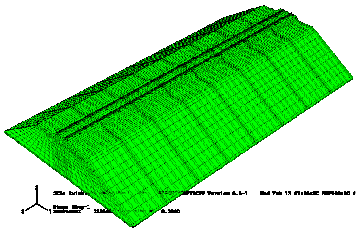


总结 Summary

1. 明确了路基面荷载的范围，以及轴重、速度等的影响规律Clear the range of subgrade surface load and influence rules of axle load, speed etc.
2. 明确了基床动荷载沿深度的传递特点Clear the characteristic of subgrade dynamic load transmit with depth
3. 获得了基床动应力和动变形的分析方法及参数取值Obtained the analytical method of subgrade dynamic strain and dynamic deformation and parameter selection
4. 提出了有砟轨道路基基床控制应变设计方法 Put forward a design method to control strain of ballasted track subgrade

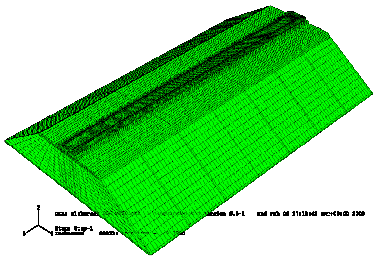
四个阶段 Four Stages

- 高速建设试验 *High-speed construction test*
- 六次提速试验 *Six times speed-up tests*
- 高速前期研究 *High-speed preliminary research*
- 既有铁路研究 *Existed railway lines research*



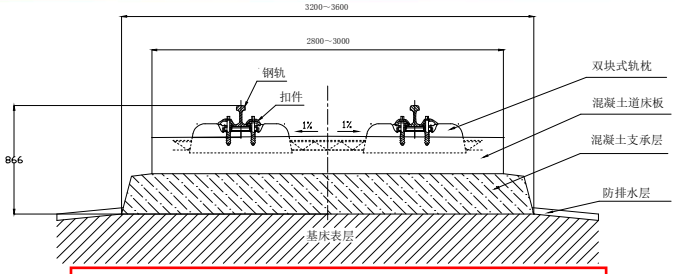
双块式无砟轨道/路基动力系统模型网格

Double-block ballastless track/subgrade dynamic system model grids



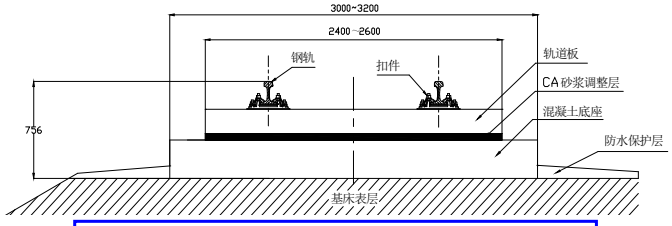
普通板式无砟轨道/路基动力系统模型网格

Common plate-type ballastless track/subgrade dynamic system model grids



路基上双块式无砟轨道横断面

Cross-section of double-block ballastless track subgrade

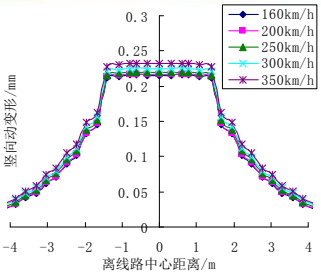


路基上Ⅰ型板式无砟轨道横断面

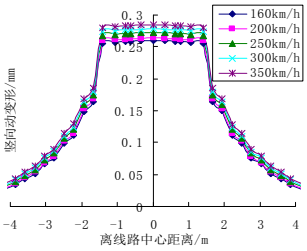
Cross-section of I plate-type ballastless track subgrade

双块式横向表层动变形

Transversely dynamic deformation of double-block ballastless track surface



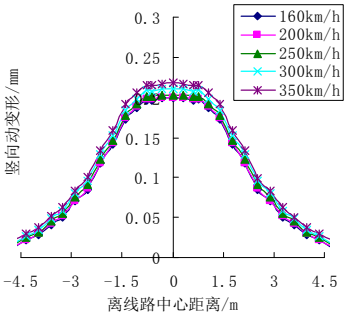
板中 Plate Middle

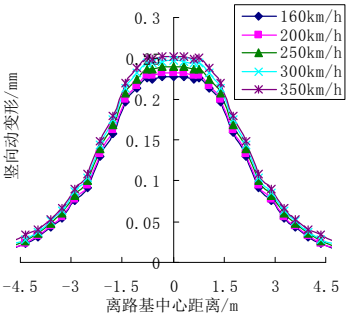


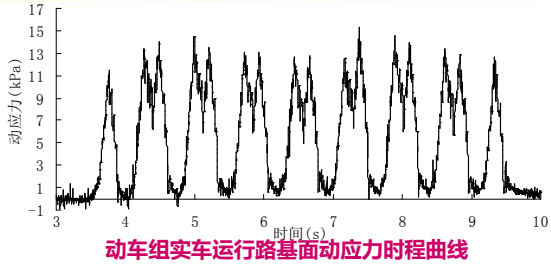
板端 Plate End

双块式横向底层动变形

Transversely dynamic deformation of double-block ballastless track bottom

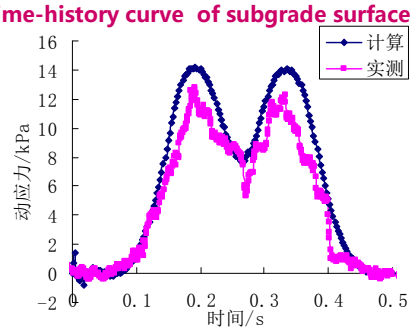






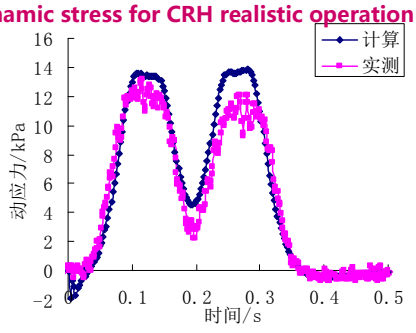
动车组实车运行路基面动应力时程曲线

Time-history curve of subgrade surface dynamic stress for CRH realistic operation



双块式板端轨下路基面动应力

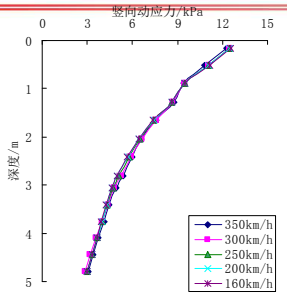
Double-block track subgrade surface dynamic stress

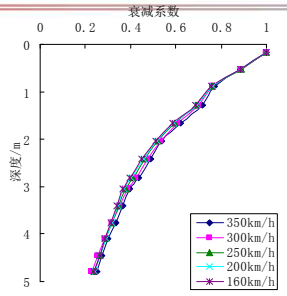


普通板式板端轨下路基面动应力

Plate-type track subgrade surface dynamic stress

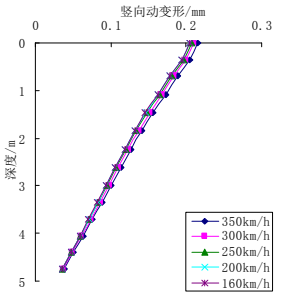
板中轨下
Plate middle under track

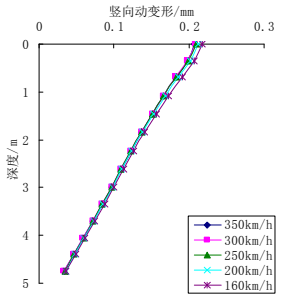




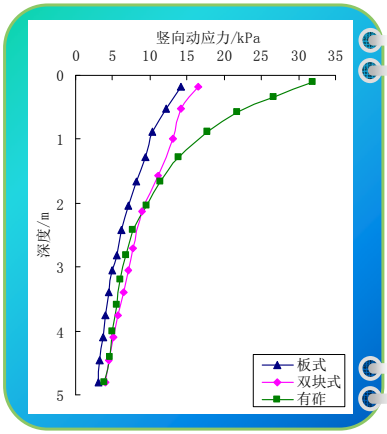
衰减系数
Damping coefficient

板中轨下
Plate middle under track





板中线路中心
Plate middle central line

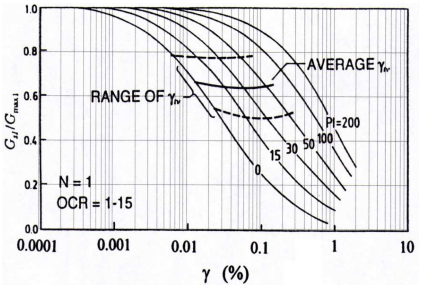


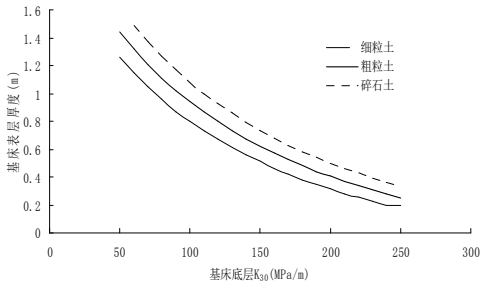
与有砟轨道相比，无砟轨道均化了路基荷载，表层荷载明显较小，随深度与有砟轨道趋于一致。

Compared with ballasted track, the ballastless track can average the subgrade load, the surface load decreased obviously, then closed to the subgrade load of ballasted track with depth increase.

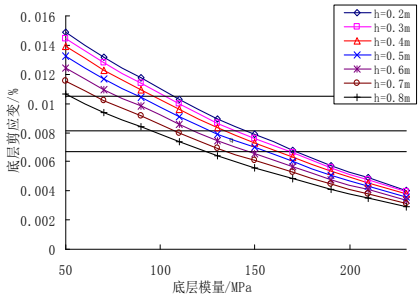
结构设计控制
Structure design control

- 路基面动变形不大于1mm；
  Subgrade surface dynamic deformation should less than 1mm;
- 基床动应变小于临界体积效应应变值
  Subgrade dynamic strain should less than the value of critical volume effect strain

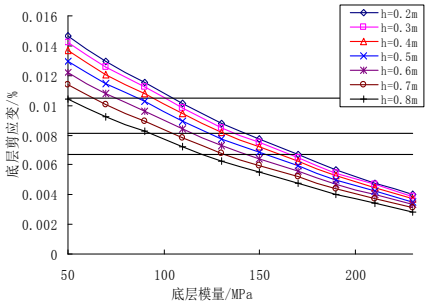




（4）计算基床表层厚度与底层模量的关系
Relationship between thickness of surface layer and modulus of subgrade bottom layer

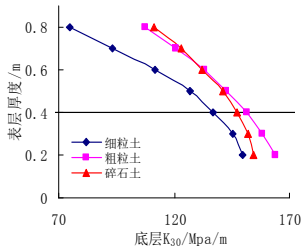


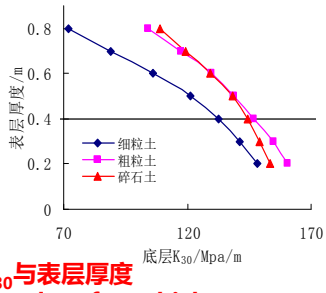
底层模量与底层最大剪应变关系（双块式）
Relationship between bottom layer modulus and the maximum shear strain (double-block type)



底层模量与底层最大剪应变关系（板式）
Relationship between bottom layer modulus and the maximum shear strain (plate-type)

(a)双块式 double-block

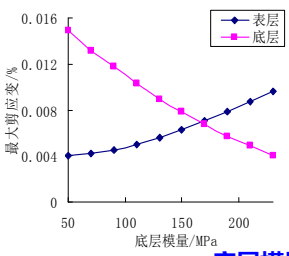


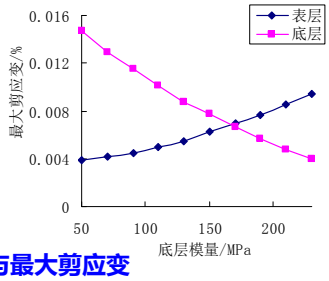


(b)板式 plate-type

底层K_{30}与表层厚度
Bottom layer K30 and surface thickness

(a)双块式 double-block





(b)板式 plate-type

底层模量与最大剪应变
Bottom layer modulus and the maximum shear strain

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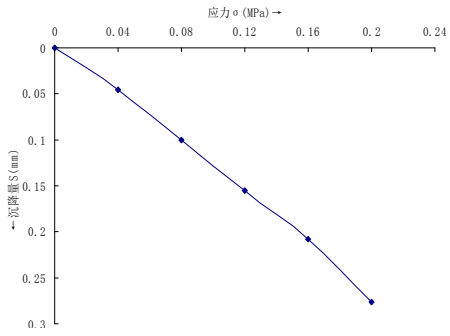
K_{30}和E_{v2}室内预估方法及试验
K_{30}&E_{v2} in-door estimate method and test

➢击实样预埋荷载板模拟试验
Compaction sample with pre-buried load plate simulation test

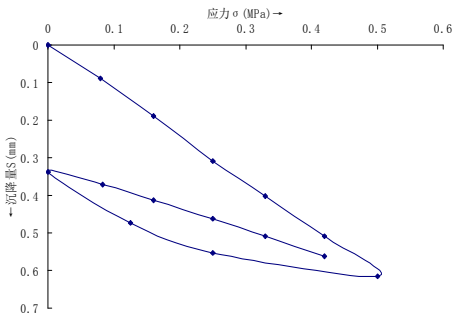

击实仪及击实制样
Compaction test apparatus and compaction sample preparation


传力架底面与击入土体的承载板
Bottom of force transmit frame and load plate buried into the soil

室内模拟试验
In-door simulation test



预估K30时应力—沉降量曲线
Curve of stress-subsidence with estimated K30



预估Ev2时应力—沉降量曲线
Curve of stress-subsidence with estimated Ev2

波速试验及其对K_{30}和E_{v2}的预估
Wave velocity test and the relationship to the estimation of K30 and Ev2

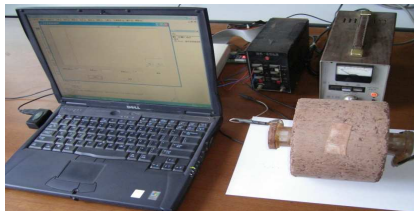
- 波速与K_{30}理论关系
  Theoretical relationship between wave velocity and K30

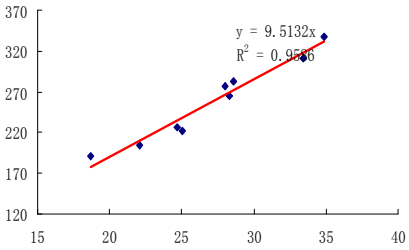
$$G=\rho v_s^2 \qquad K_{30}=\frac{4\rho}{\pi(1-\mu)r}v_s^2$$

$$G=\frac{E}{2(1+\mu)} \qquad \mu=0.21$$

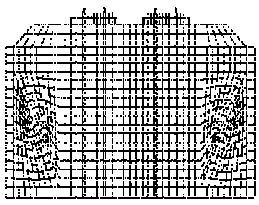
$$E=\frac{\pi}{2}(1-\mu^2)rK_{30}$$

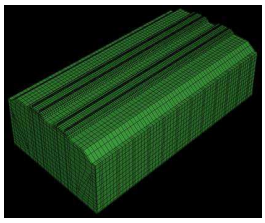
$$K_{30}=10.7\rho v^2$$

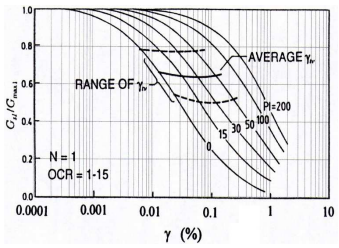


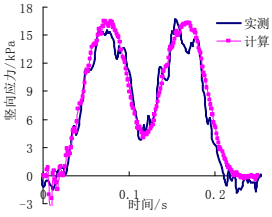


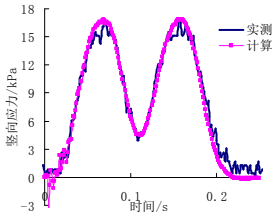
• 路基基床动态评价
Subgrade dynamic evaluation











剪应变限值
Shear strain limiting value

动应力限值
Dynamic stress limiting value

动变形限值
Dynamic deformation limiting value

小结 Brief summary

明确了无砟轨道的路基面荷载

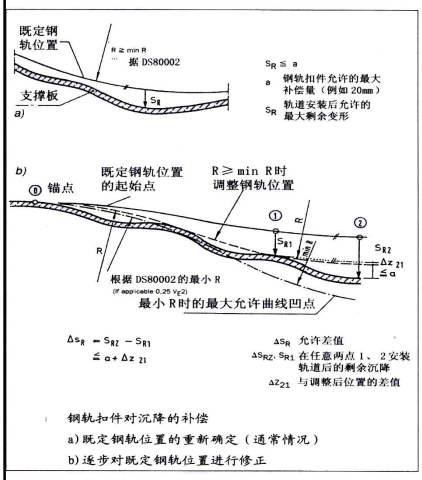
明确了基床动荷载沿深度的传递特点

形成了系统的控制应变基床结构设计分析方法

提出了路基的动态检定方法和标准

目录 Contents

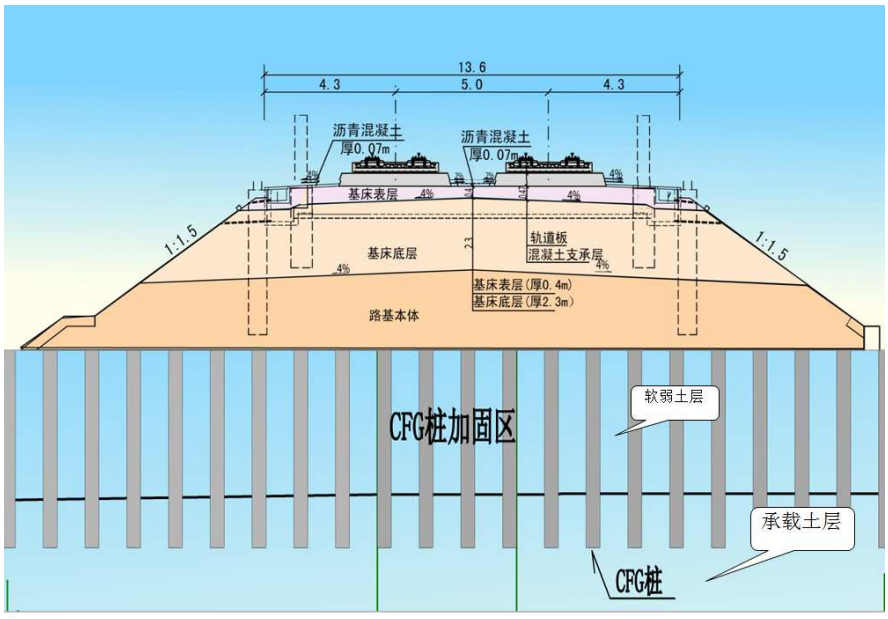
路基沉降限值
Subgrade subsidence limiting value



路基在无碴轨道铺设完成后的工后沉降应满足扣件调整和线路竖曲线圆顺的要求

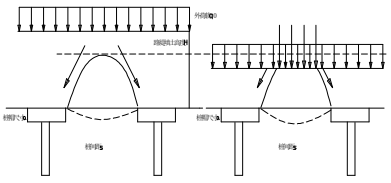
表2-2 不同速度目标值对应的路基工后沉降变形量限值

路基类别	高速铁路设计规范（试行）		
	有砟	有砟	无砟
工后沉降	100mm	50mm	≯15mm（无砟）
差异沉降	50mm	30mm	≯5mm，且折角小于1‰
不均匀沉降			轨道线路满足竖曲线半径 $R_s > 0.4 \cdot Vsj^2$
速度目标	250km/h	300~350km/h	250~350km/h

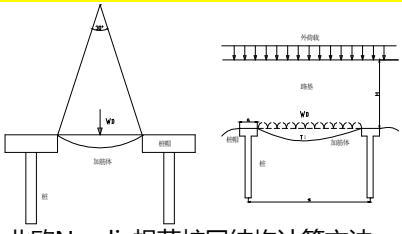


地基处理：桩网结构计算方法

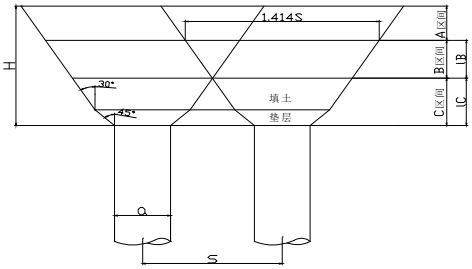
Foundation treatment: pile-net structure calculation method



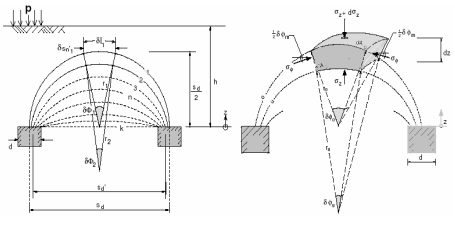
英国BS8006桩网结构计算方法



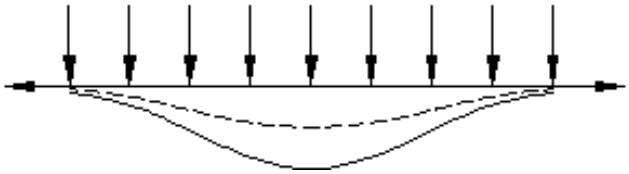
北欧Nordic规范桩网结构计算方法



日本规范桩网结构计算方法



德国规范有限元平衡分析法



网垫加筋体变形形态对其受力影响极大；
The deformation pattern of geo-mat has enormous influence on its stress;
提出综合考虑蠕变的桩网加筋结构体受力计算方法；
Put forward a stress calculation method of pile-net structure reinforcement which considering creep;
合理利用加筋网垫的初始松弛状态可改善筋材的受力状况，起到四两拨千斤的作用。
Reasonably using the initial relaxation state of reinforced geo-mat can improve the stress situation of the reinforced material, which have dramatically positive effect.

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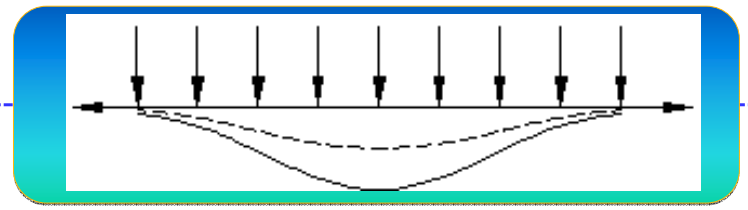

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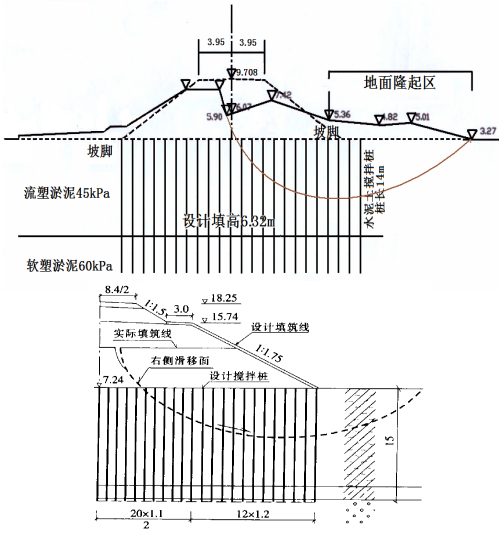
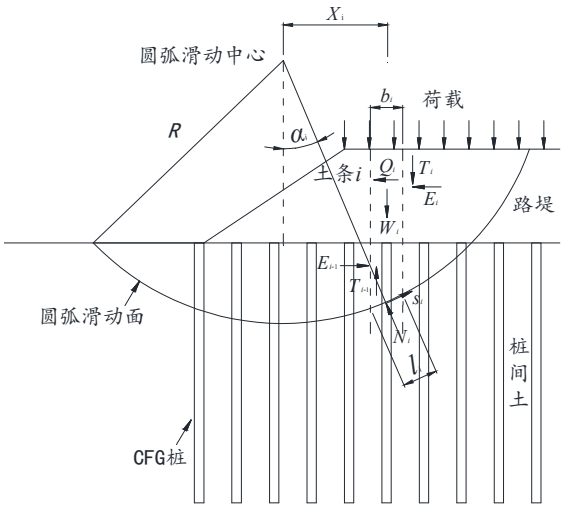
路基填筑过程中出现路基失稳
Instability occur during the subgrade filling process

施工期间路基失稳破坏
Instability failure during construction process



路基失稳
Subgrade instability

桩土作用与视抗剪强度
Pile-soil interaction and observed shear strength



桩的破坏形态：
Failure mode of pile:

- 剪切Shearing
- 弯曲Bending
- 转动Rotation

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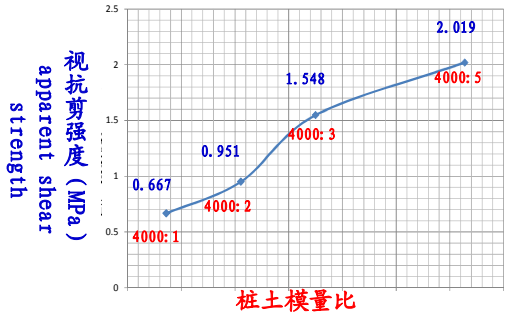
不同桩土模量桩体的视抗剪强度
Observed shear strength for different pile-soil modulus ratio

桩土模量比（GPa/MPa）	工况	土样	抗剪强度τ（MPa）	推应力（MPa）	剪力（N）	推力（N）	推-剪（N）	视抗剪强度（MPa）
4000:1	3	B	0.014	0.092	52.413	57.126	4.713	0.667
4000:2	2	A	0.020	0.133	75.229	81.955	6.726	0.951
4000:3	4	C	0.034	0.230	131.141	142.082	10.941	1.548
4000:5	5	D	0.043	0.286	162.523	176.792	14.269	2.019



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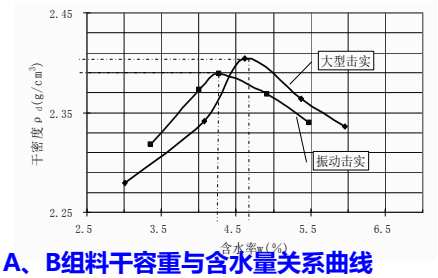
目录 Contents

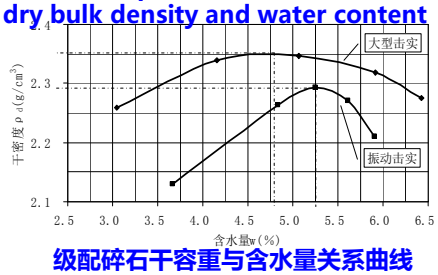
路基设计控制参数 Subgrade design control parameters

控制参数的种类和使用情况 Control parameter types and service condition

压实方法	中国			日本	德国	法国	英国	铁盟	意大利
	铁路系统	公路系统	水利系统						
压实系数K	√	√	√	√	√	√	√	√	√
地基系数K_{30}	√			√					
相对密度D_r	√								
孔隙率n	√								
承载比CBR		√							
含气率n_a				√	√				
变形模量E_{v2}					√	√		√	
变形模量E_v									
小型贯入N_{10}							√		
双指标配合使用情况	K_{30}、K	CBR、K	土料K	K_{30}、K	K、E_{v2}	K、E_{v2}	K、N_{10}	K、E_{v2}	K、E_v
	K_{30}、n			K_{30}、n_a	K、n_a				



A、B组料干容重与含水量关系曲线
Relationship between class A、B filler dry bulk density and water content



级配碎石干容重与含水量关系曲线
Relationship between graded gravel dry bulk density and water content

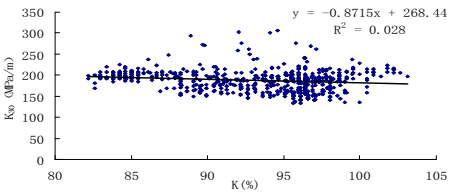
表面振动击实仪
Surface vibration compaction test apparatus

- 地基系数K_{30}
Foundation coefficient K30

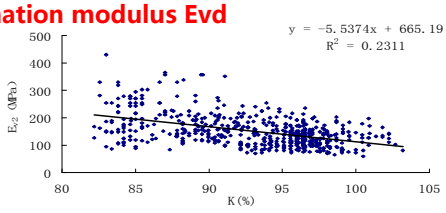
动态变形模量E_{vd}
Dynamic deformation modulus Evd

力学指标：地基系数K30、变形模量E_{v2}、动态变形模量Evd

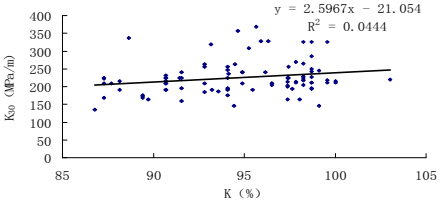
Mechanics index: foundation coefficient K30、deformation modulus Ev2 and dynamic deformation modulus Evd



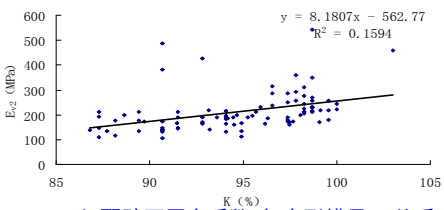
A、B填料压实系数K与地基系数K_{30}关系
Relationship between the compaction coefficient K of class A、B filler and the foundation coefficient K30



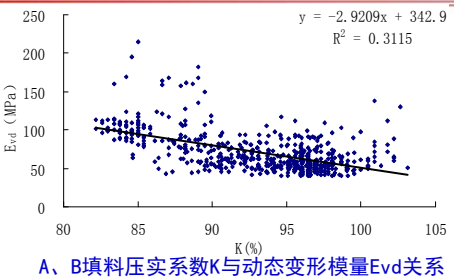
A、B填料压实系数K与变形模量E_{v2}关系
Relationship between the compaction coefficient K of class A、B filler and the deformation modulus Ev2



级配碎石压实系数K与地基系数K_{30}关系
Relationship between the compaction coefficient K of graded gravel and the foundation coefficient K30

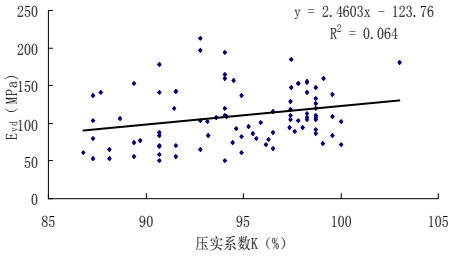


级配碎石压实系数K与变形模量E_{v2}关系
Relationship between the compaction coefficient K of graded gravel and the deformation modulus Ev2



A、B填料压实系数K与动态变形模量Evd关系

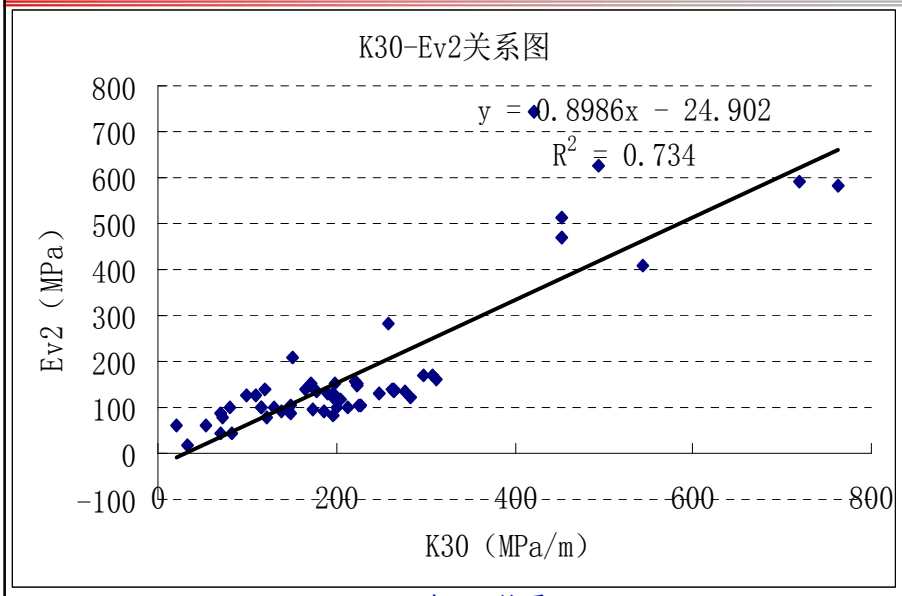
Relationship between the compaction coefficient K of class A、B filler and the dynamic deformation modulus Evd



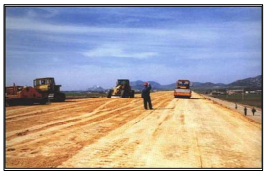
级配碎石压实系数K与动态变形模量Evd关系

Relationship between the compaction coefficient K of graded gravel and the dynamic deformation modulus Evd

压实系数与各个力学指标回归曲线的相关系数都很低，说明压实系数K与各个力学指标不相关，也即压实系数K与力学指标互相独立，不能互相取代。



K30与Ev2关系



沿线路纵向每100m每压实层抽样检验压实系数6点，每100m每填高约90cm抽样检验地基系数（无砟轨道可采用K30或Ev2）、动态变形模量各4点

测试方法 Test methods

压路机连续压实控制（CCC）

Road roller continuously compaction control

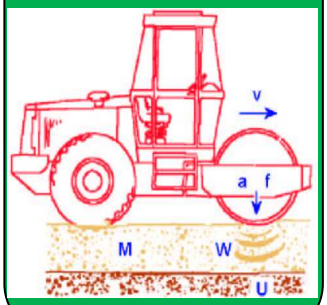
2

通过对振动轮的动力学性能的测试与分析，反映路面压实度变化。

1、减少检测测点的数量和提高效率，实时监测压实过程。

2、能够按照土质的变化情况不断调整压实参数，使压实作业始终在最优的条件下进行，提高功效和保证施工质量。

1



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动态验收 + 动态测试

动态验收

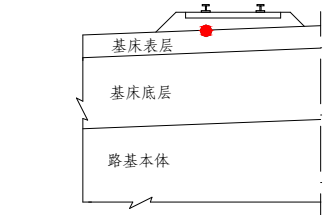
综合调试和动态检测是相互联系的一对概念，动态检测属于综合调试的技术工作，有其具体要求；动态检测执行铁道部动态检测相关标准。

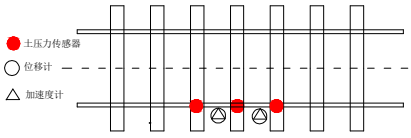
动态测试

通过测试列车通过典型路基及过渡段时基床的动荷载、动变形和振动状况，评价路基的动力性能是否满足相关标准要求。动态检测技术目前已成为高速铁路验收的必备检测项目。

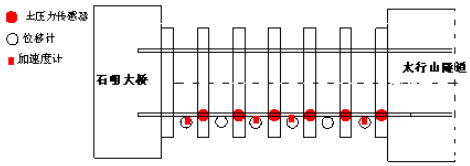
路基及过渡段动态检测
Subgrade and transition section dynamic detection

测点布置
monitoring points arrangement

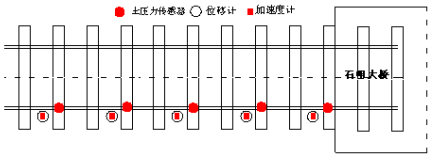




路堤、路堑及过渡段工点传感器埋设位置示意图
monitoring points arrangement on embankment、cutting and transition section



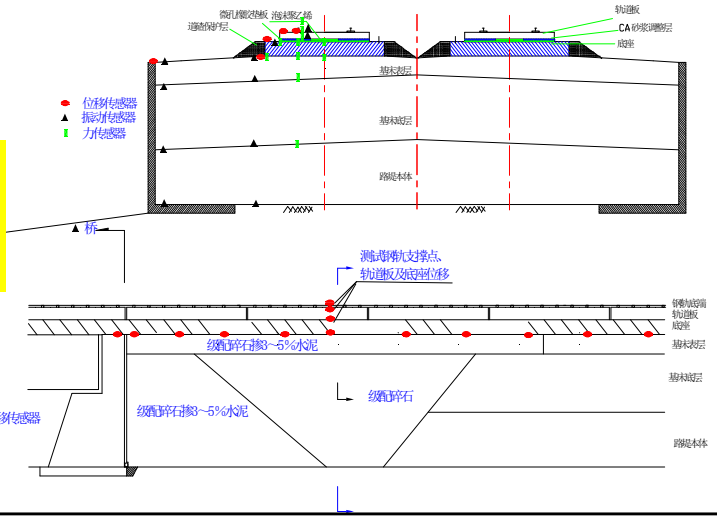
桥(隧)过渡段传感器埋设位置示意图
monitoring points arrangement on bridge (tunnel) transition section



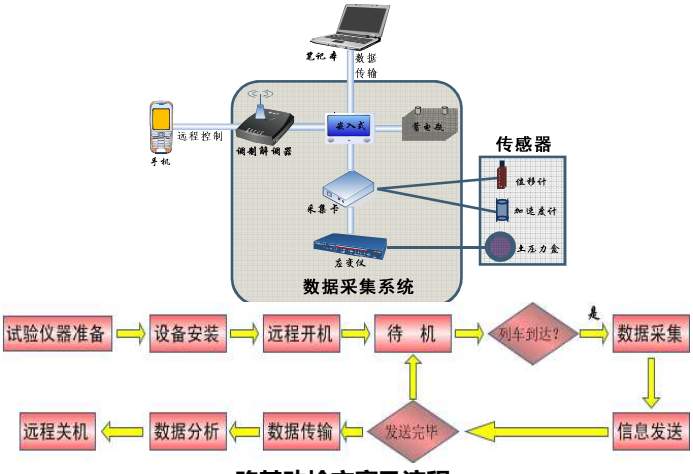
路桥过渡段传感器埋设位置示意图
monitoring points arrangement on road and bridge transition section

路基及过渡段动态检测
Subgrade and transition section dynamic detection

测点布置
Monitoring points arrangement



- 检测方法
- Detection method



路基动检方案及流程
Subgrade dynamic detection scheme and procedure

现场测点布置及数据采集系统图
In-situ monitoring points arrangement and data collection system

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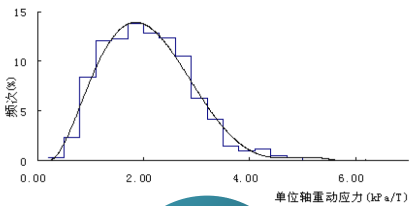


评判标准

路基动应力：动荷载的最大值不得大于通常情况（即相同情况的其他线路上的测试值）或测试均值的2倍

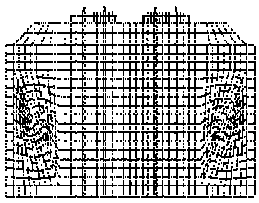
评判标准

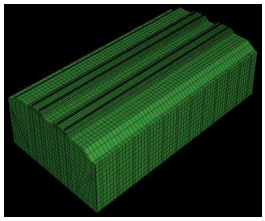
路基动变形及加速度：动变形及加速度最大值不得大于通常情况或测试均值的2倍

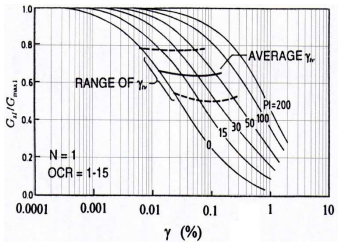
评判标准

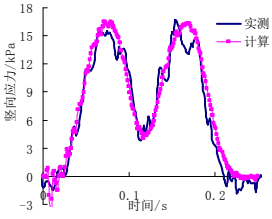
根据GB10070《城市区域环境振动标准》要求距离外侧线路中心线30m外环境振动其最大振级VLZmax≤80dB

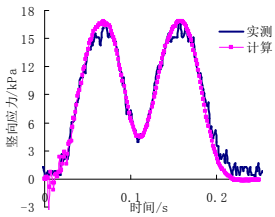
• 路基基床动态评价
Subgrade dynamic evaluation









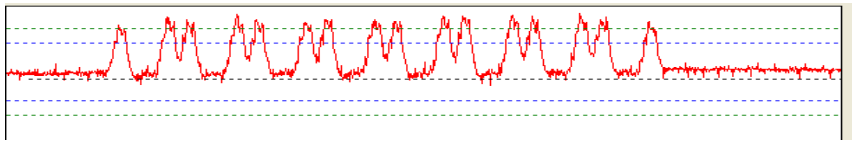


剪应变限值
Shear strain limiting value

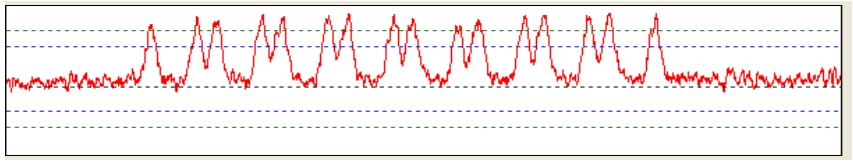
动应力限值
Dynamic stress limiting value

动变形限值
Dynamic deformation limiting value

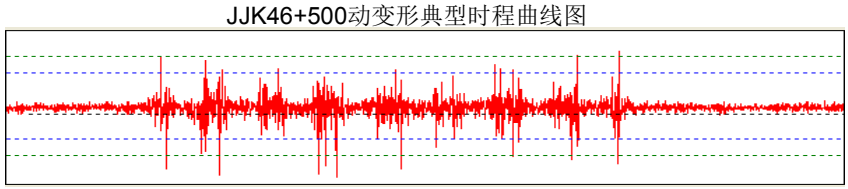
路基及过渡段动态检测
Subgrade and transition section dynamic detection



JJK23+027～107动应力时程曲线图



JJK46+500动变形典型时程曲线图



JJK46+500振动加速度时程曲线图

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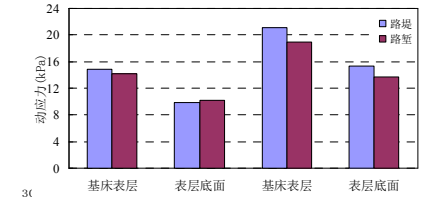
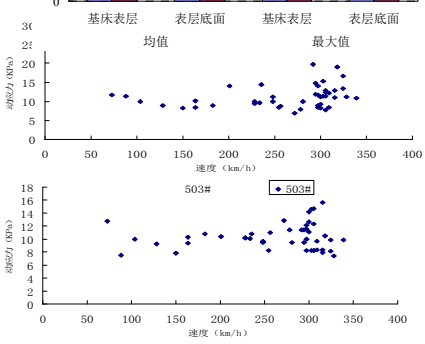
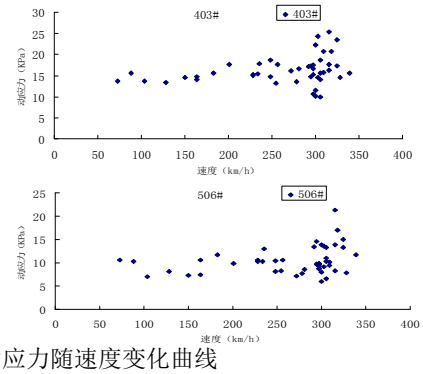
路基及过渡段动态检测
Subgrade and transition section dynamic detection



CRTS Ⅰ型双块式路堤与路堑结构动应力对比图
Comparison between CRTS-I double-block embankment and cutting structural dynamic stress





CRH2重车运行时动应力随速度变化曲线

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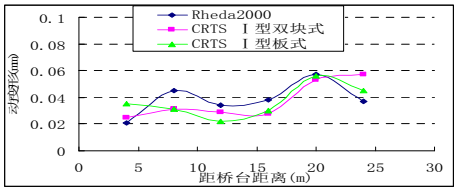
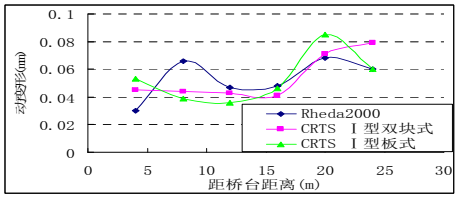
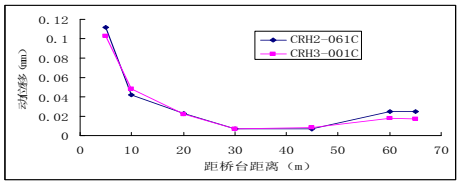
路基及过渡段动态检测
Subgrade and transition section dynamic detection



过渡段动变形分布图
Transition section dynamic deformation distribution





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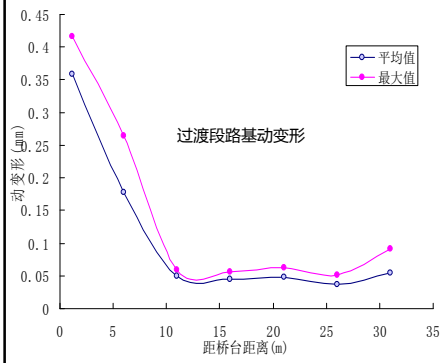
路基检测与评价技术 Subgrade detection and evaluation technology



➢动态检测
Dynamic detection

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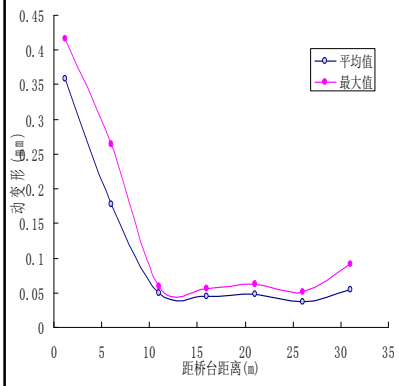
路基检测与评价技术 Subgrade detection and evaluation technology

➢动态检测
Dynamic detection



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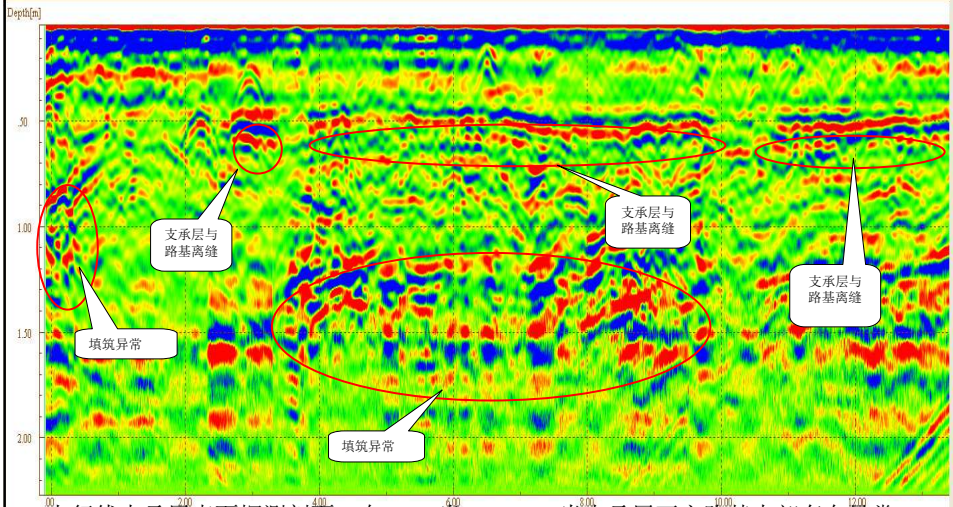

上行线支承层表面探测剖面：在0~0.3米，3.8~9.8米支承层下方路基内部存在异常；
在2.5~3.5米、4~10米及11~13米处支承层与路基存在离缝。
Up link support layer surface detection section:
unusual filing located at 0~0.3m, 3.9~9.8m under subgrade support layer;
separation gap occurred at 2.5~3.5m, 4~10m, 11~13m under subgrade support layer.

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二 高速铁路路基冻胀规律与特征 The low and characteristic of high-speed railway subgrade frost-heave

三 微冻胀填料冻胀特性及发育机制 Micro frost-heave filler and its development mechanism

四 高速铁路路基防冻胀结构与措施 Anti-frost heave structure and measures of high-speed railway subgrade

五 高速铁路路基冻胀维护 Maintenance of high-speed railway subgrade frost-heave

一、高速铁路冻胀问题
Frost-heave problems of high-speed railway

非冻胀填料 non-frost heave filler

微冻胀填料 micro frost-heave filler

轨道静态高低偏差容许值（单位：mm）

速度级 Velocity level	作业验收 Acceptance check	经常保养 Regular maintenance	临时补修 Temporary repair	限速 Speed limit
200～250km/h	2	5	8	11（限速至160km/h）
250～350km/h	2	4	7	8（限速至200km/h）

高速铁路变形控制要求 High-speed railway deformation control requirements

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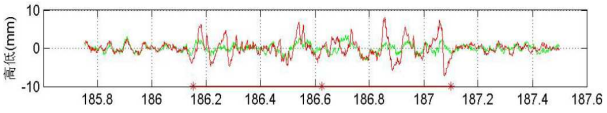
一、高速铁路冻胀问题
Frost-heave problems of high-speed railway

轨道不平顺
Track irregularity



结构损伤
Structure damage

维护工作量大
Great maintenance workload

高速铁路路基冻胀影响
Influence of high-speed railway subgrade frost-heave

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一、高速铁路冻胀问题
Frost-heave problems of high-speed railway

中国季节性冻土分布
Seasonal frozen earth area distribution

冻土面积约75%,
其中季节性冻土为53.5%

一、高速铁路冻胀问题
Frost-heave problems of high-speed railway

我国季节性冻土地区高速铁路统计(单位:km)

地区	序号	线路	长度	备注
东北	1	哈大	921	已运营
	2	长吉线	108	已运营
	3	盘营	90	已运营
	4	哈齐	286	
	5	沈丹	207	
	6	哈牡	300	
	7	京沈	700	
	8	吉图珲	360	
	9	哈佳	345	
西北	10	兰新	1766	已运营
	11	郑西	352	已运营
	12	大西	859	已运营
	13	西宝	138	
	14	宝兰	487	
共计			6919	

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一、高速铁路冻胀问题
Frost-heave problems of high-speed railway

- 气候严寒
- Extreme cold climate
- 降水较多
- More precipitation
- 穿越沼泽地
- Through wetland
- 路基比例高达85%
- 85% subgrade
- 最高时速400km/h
- Maximum speed 400km/h

一、高速铁路冻胀问题
Frost-heave problems of high-speed railway

高速铁路冻土路基涉及主要问题
The main problems of high-speed railway subgrade in frozen soil

- 高速铁路路基冻胀的时空特征？
- What's the temporal and spatial characteristics of High-speed railway subgrade?
- 高速铁路路基微冻胀填料冻胀发育机制？
- How to explain Micro frost-heave filler and its development mechanism?
- 高速铁路路基的防冻胀结构？
- What Anti-frost heave structure and measures of high-speed railway subgrade should be taken?
- 高速铁路冻胀的维护措施？
- How to maintain high-speed railway subgrade after frost-heave?

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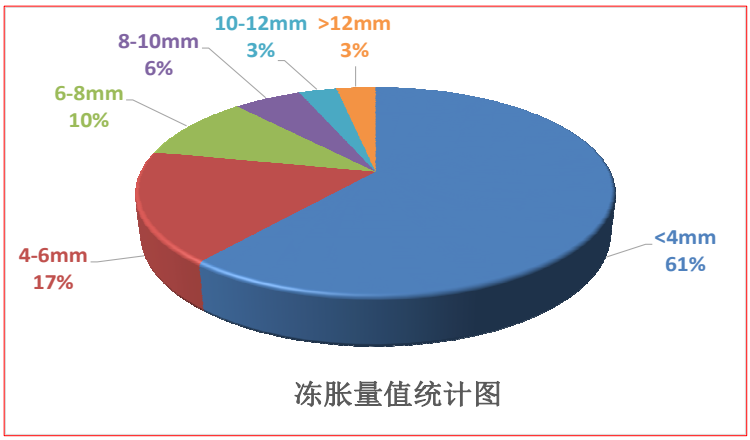
高速铁路路基 High-speed railway subgrade

二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



冻胀量值统计图

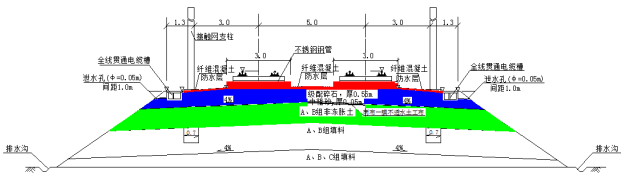
高速铁路路基冻胀情况统计（2012-2013年）

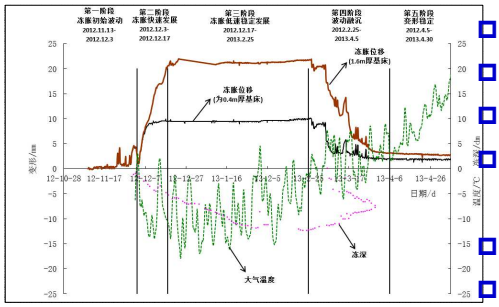
A high-speed railway subgrade frost heaving statistics (2012-2013)

二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave

高速铁路路基冻胀过程分析
Analysis of frost-heave process of high-speed railway subgrade

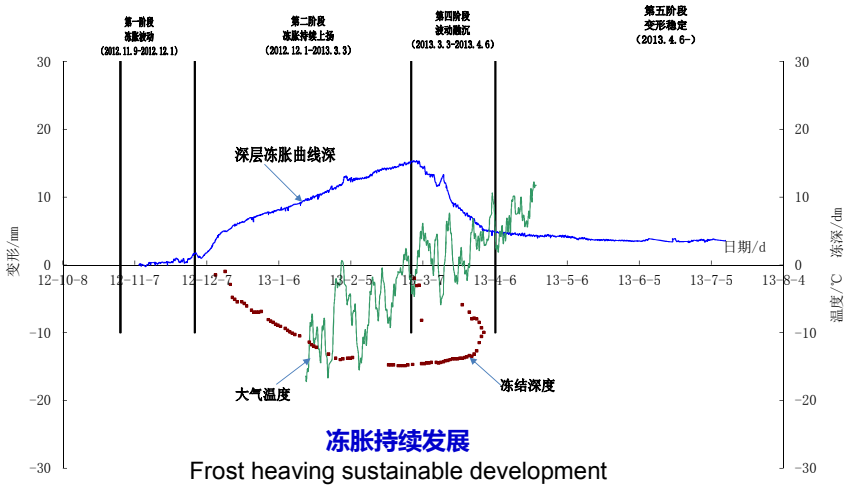




- **随气温有波动现象**
- **Fluctuated with temperature**
- **以表层冻胀为主**
- **Frost-heave mainly occurred at the surface layer**
- **冻胀随冻深瞬时发生**
- **Frost-heave instantly occurred with frost depth**

二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



冻胀持续发展

Frost heaving sustainable development

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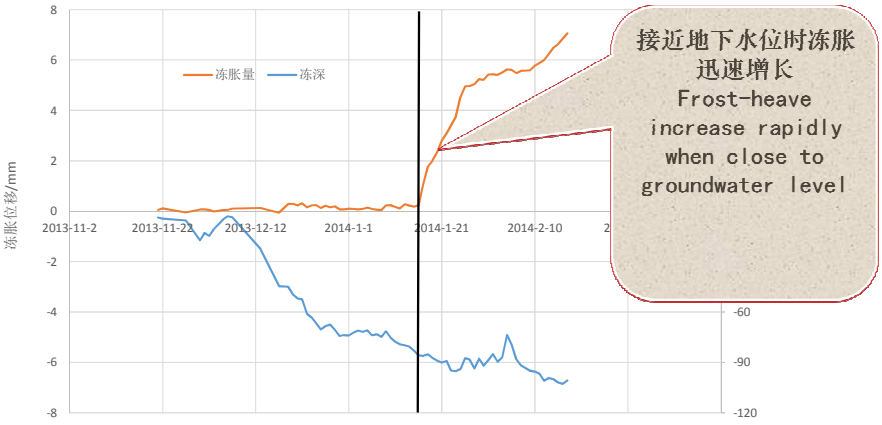
二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



地下水较高地段（地下水距路基面1.0m）

High groundwater level area (groundwater is apart from the subgrade surface 1.0m)

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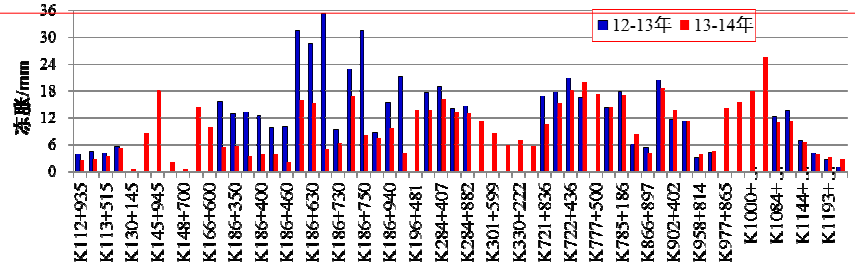
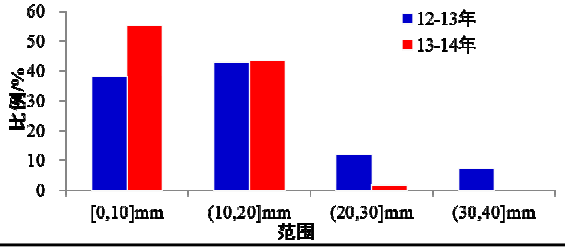
二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave

高速铁路路基冻胀量分布 distribution of high-speed railway subgrade frost-heave



最大冻胀统计
Statistic of the maximum frost heave



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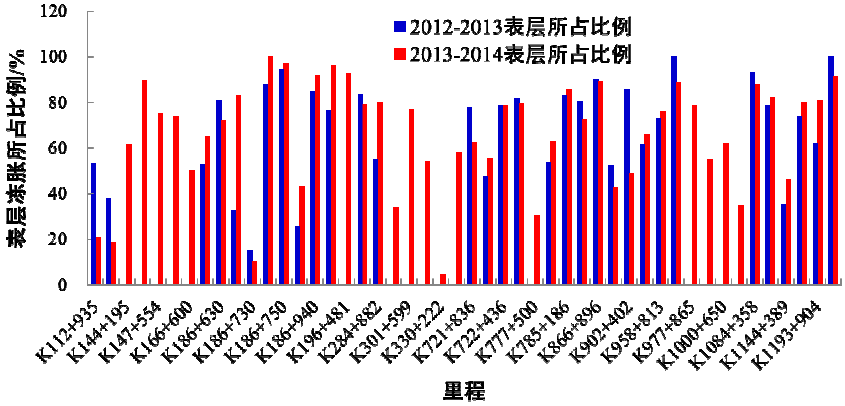
二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



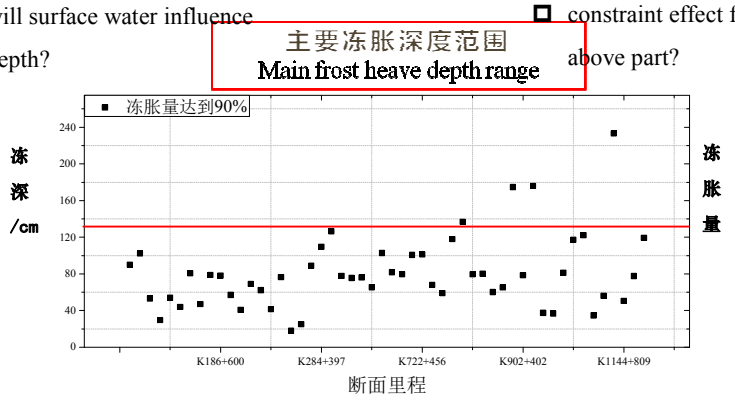
基床表层冻胀比例统计

The bed surface of frost heaving ratio statistics

二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave

- **地表水影响深度？**
- will surface water influence depth?
- **上部约束作用？**
- constraint effect from above part?



冻深达到130cm，90%监测断面冻胀量达到最大值的90%

Frozen depth of 130 cm, 90% monitoring cross section reach 90% of the maximum amount of frost heaving

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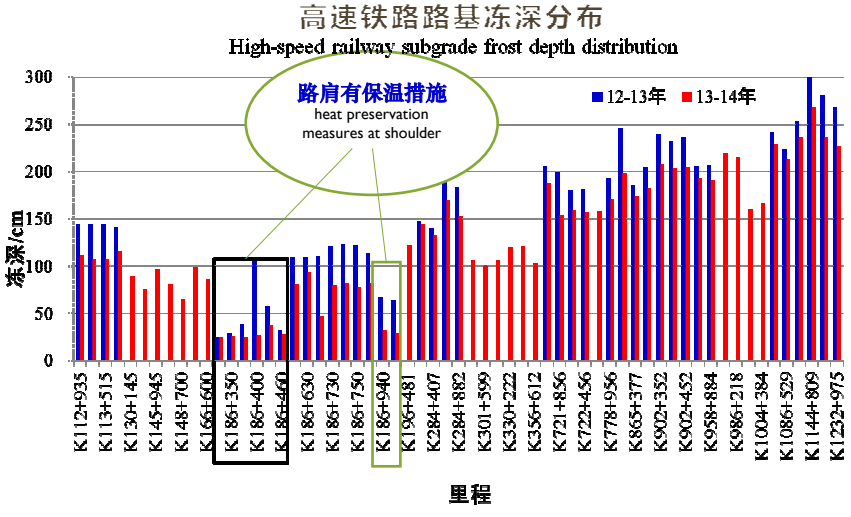
二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



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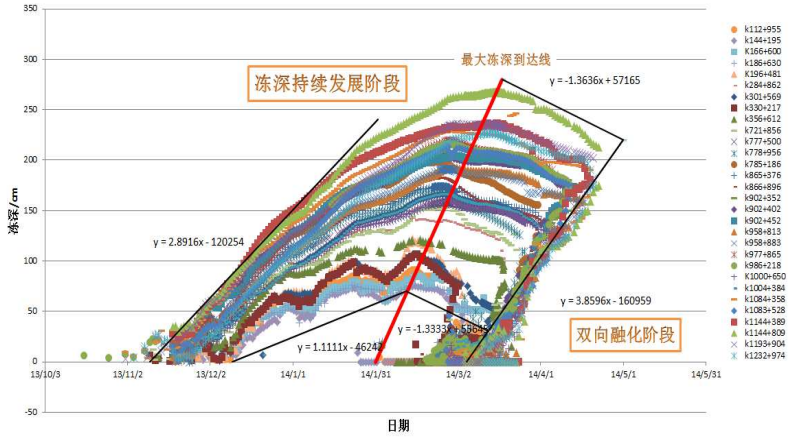
二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



冻深发展特征
Characteristics of frost depth development

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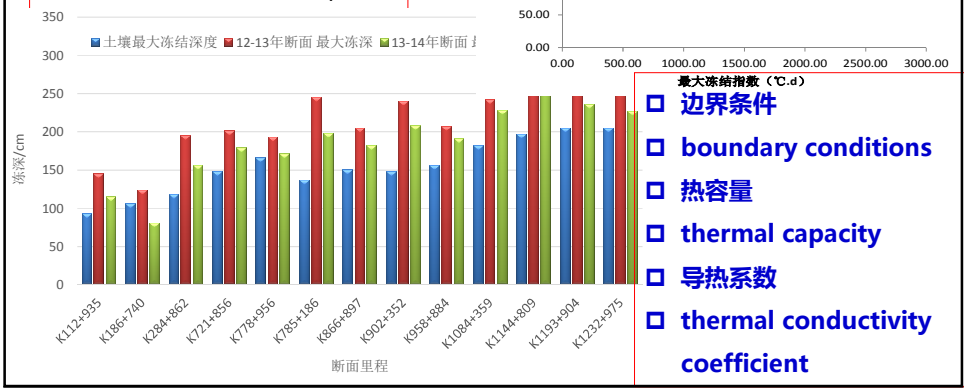
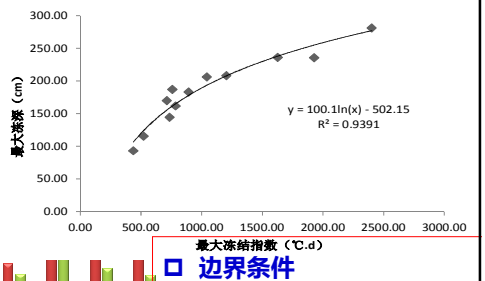
二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave

路基冻深与土壤最大冻结深度

The subgrade frost and maximum frozen soil depth

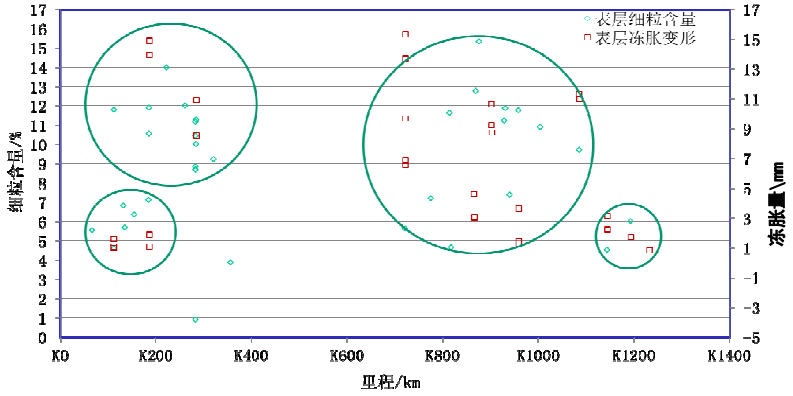




- 边界条件
- boundary conditions
- 热容量
- thermal capacity
- 导热系数
- thermal conductivity coefficient

二、高速铁路路基冻胀规律与特征

The low and characteristic of high-speed railway subgrade frost-heave



现场填料细粒含量与冻胀量

The site padding fine particle content and amount of frost heaving

高速铁路路基 High-speed railway subgrade

三、微冻胀填料冻胀特性及发育机制

Micro frost-heave filler and its development mechanism

核心问题：填料微冻胀性

Core problem: filler micro frost-heave characteristic

微冻胀填料特征：

micro frost-heave filler characteristic:

结构特性 structural characteristics

- **主要为粗颗粒，含少量细颗粒；**

Mainly for the coarse particle, containing a small amount of fine particles

- **水分转移路径不连续，不同部位相对独立封闭。**

Moisture transfer path of discontinuity, different parts of the relatively independent closed

冻胀特性 frost-heave characteristics

- **表现为“原位冻胀”，冻胀随冻结温度呈“瞬时性”；**

Characterized by "in situ frost heave, frost heave show " instantaneity "with freezing temperature

- **无明显宏观水分转移。**

No obvious macro water transfer

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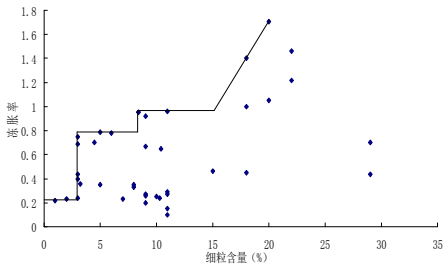
三、微冻胀填料冻胀特性及发育机制

Micro frost-heave filler and its development mechanism

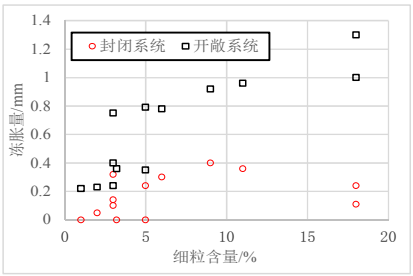
细颗粒影响

Fine particle impact



细粒含量与冻胀

Fine particle content and frost heave



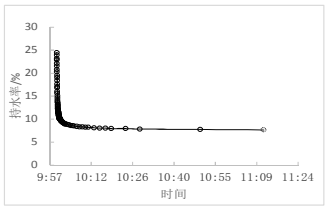
开敞与封闭系统

The open and closed systems

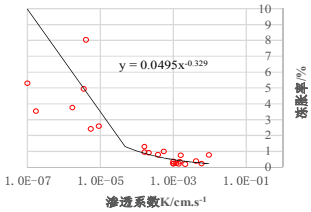
三、微冻胀填料冻胀特性及发育机制

Micro frost-heave filler and its development mechanism

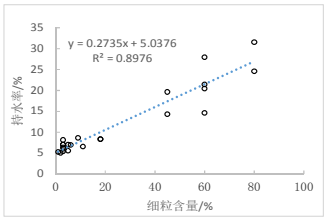
水的影响 influence of water



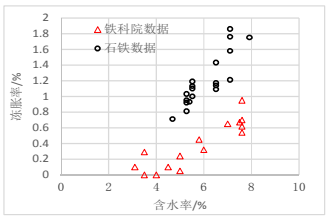
持水试验
Water retention test



渗透性与冻胀率
Permeability and frost-heave ratio



细粒含量与持水率
Fine particle content and the water retention ratio



含水率与冻胀率
moisture content and frost-heave ratio

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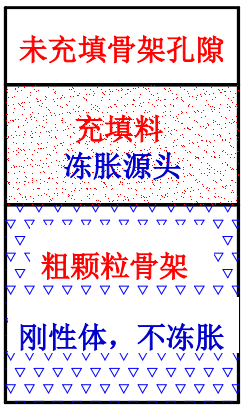
三、微冻胀填料冻胀特性及发育机制

Micro frost-heave filler and its development mechanism

微冻胀填料冻胀发育机制
Development mechanism of micro frost-heave filler



充填孔隙

能量最低原理

抬升骨架

$$\eta_{混}=\eta(N,\ \varphi,\ C,\alpha,\beta_0,d_s,\rho_w,w,\rho_{混},\ \theta,G_{骨架})$$

$$\eta_{混}=\left[\frac{\rho_{混}(M+\alpha)}{d_s\rho_w(1+0.01w)}-\frac{\rho_{混}(1-\theta)\alpha}{G_{骨架}\rho_w}\right]-M$$

$$M=\frac{\alpha-\frac{\alpha}{\beta}-\frac{1}{\beta}+\frac{1}{\beta_0}}{\frac{1}{\beta}-1}$$

$$\beta=\frac{-(2\alpha b-2\chi-2\alpha\chi+2b)+\sqrt{(2\alpha b-2\chi-2\alpha\chi+2b)^2-4\left(\alpha\chi-b-\alpha b+\frac{\chi}{\beta_0}\right)(\alpha\chi-b-\alpha b+\chi)}}{2\left(\alpha\chi-b-\alpha b+\frac{\chi}{\beta_0}\right)}$$

三、微冻胀填料冻胀特性及发育机制
Micro frost-heave filler and its development mechanism

微冻胀填料冻胀等级划分方案
The frost heave packing frost heave hierarchy scheme

冻胀等级 frost-heave rank	Ⅰ级	Ⅱ级	Ⅲ级	Ⅳ级	Ⅴ级	Ⅵ级
定性描述 qualitative description	极强微冻胀	强微冻胀	中上微冻胀	中下微冻胀	弱微冻胀	弱微冻胀
基床冻深（m） subgrade frost depth	0.4	0.7	1.5	2	2.5	3
定量描述（%） quantitative description	0.57～1.00	0.27～0..57	0.20～0.27	0.16～0.20	0.13～0.16	<0.13

高速铁路路基 High-speed railway subgrade

一 高速铁路冻胀问题 Frost-heave problems of high-speed railway

二 高速铁路路基冻胀规律与特征 The low and characteristic of high-speed railway subgrade frost-heave

三 微冻胀填料冻胀特性及发育机制 Micro frost-heave filler and its development mechanism

四 高速铁路路基防冻胀结构 Anti-frost heave structure and measures of high-speed railway subgrade

五 高速铁路路基冻胀维护 Maintenance of high-speed railway subgrade frost-heave

四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

高速铁路路基冻胀控制原则
Principle of high-speed railway subgrade control

影响因素 influence factors	控制措施
土性：Soil properties	➢采用非冻胀填料，细颗粒含量不超过5%； ➢Using the non frost-heave filler, fine particle content less than 5%
含水率：Water content	➢防、排、疏、渗；增大渗透性，减小自然持水率； ➢Waterproof, drainage, dewatering, seepage; increase permeability, reduce natural moisture content
温度：Temperature	➢保温。 ➢Heat preservation

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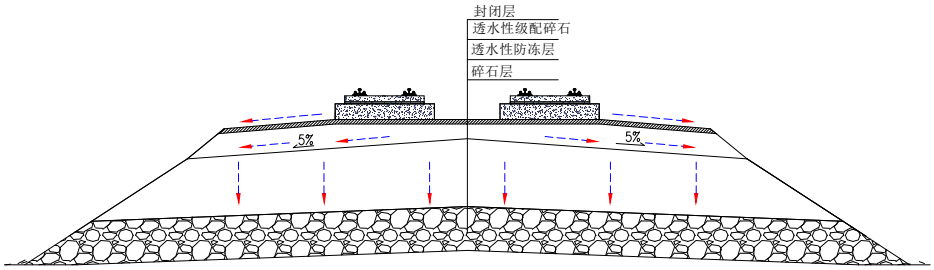
四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

高速铁路路基防冻胀控制原则
Principle of high-speed railway subgrade anti-frost heave control



典型防排疏渗路基结构

Typical subgrade structure of waterproof, drainage, dewatering, seepage

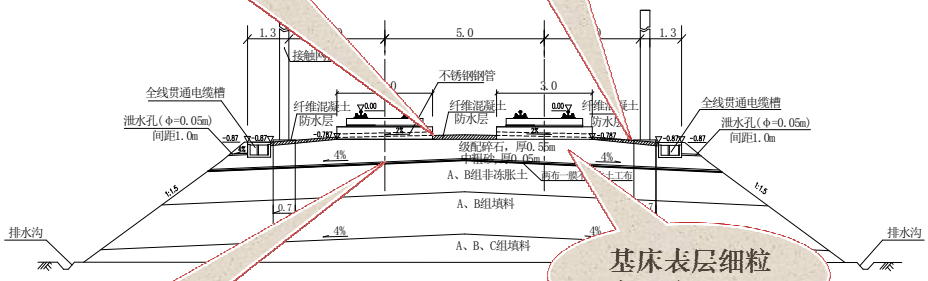
四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

高速铁路路基防冻胀结构—哈大高铁High speed railway subgrade anti-frost heave structure – Ha-Da

结构缝采用沥青膏
Structure seam using asphalt cement

纤维混凝土
Fiber reinforced concrete



两布一膜隔水层
wo cloth a membrane water-resisting layer

基床表层细粒含量控制在5%
Control the subgrade surface fine particle content less than 5%

路堤=混凝土封闭层+级配碎石+两布一膜+非冻胀AB组

Embankment = concrete seal coat + graded gravel + 2cloth&1membrane + non-frost heave class A、B filler

四、高速铁路路基防冻胀结构与措施

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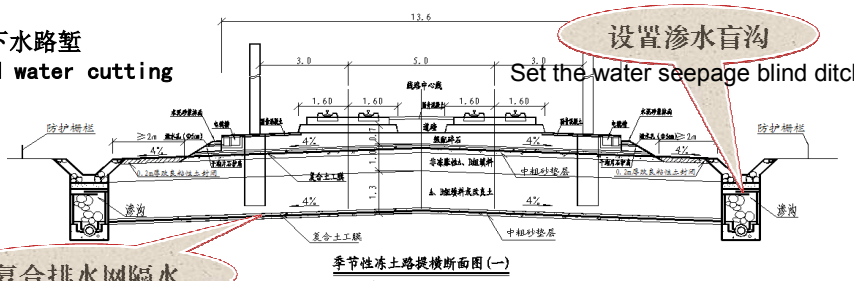
高速铁路路基防冻胀结构—哈大高铁High speed railway subgrade anti-frost heave structure – Ha-Da

地下水路堑
erground water cutting

设置渗水盲沟
Set the water seepage blind ditch



季节性冻土路提横断面图(一)

地下水水位较浅时

复合排水网隔水
Proof water using the composite drainage network

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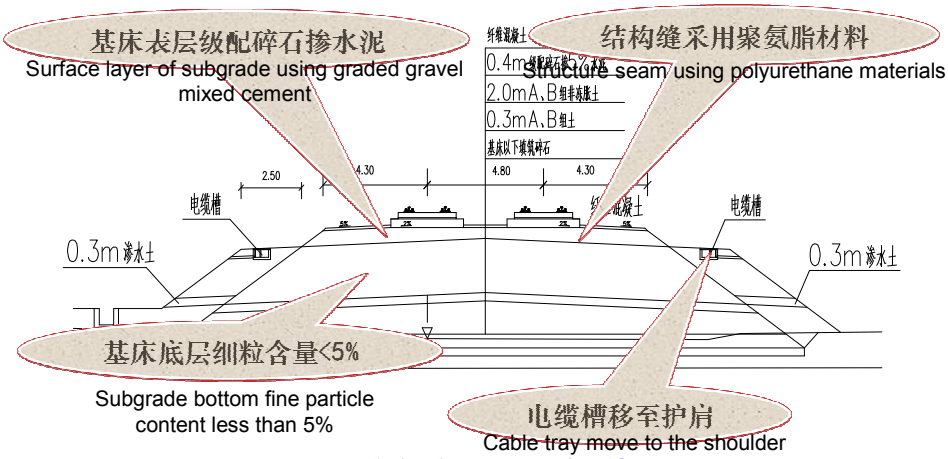
四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

高速铁路路基防冻胀结构—哈齐高铁High speed railway subgrade anti-frost heave structure – Ha-Qi



哈齐高速铁路路基防冻胀结构

Ha-Qi high speed railway subgrade frost-heave structure

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四、高速铁路路基防冻胀结构与措施

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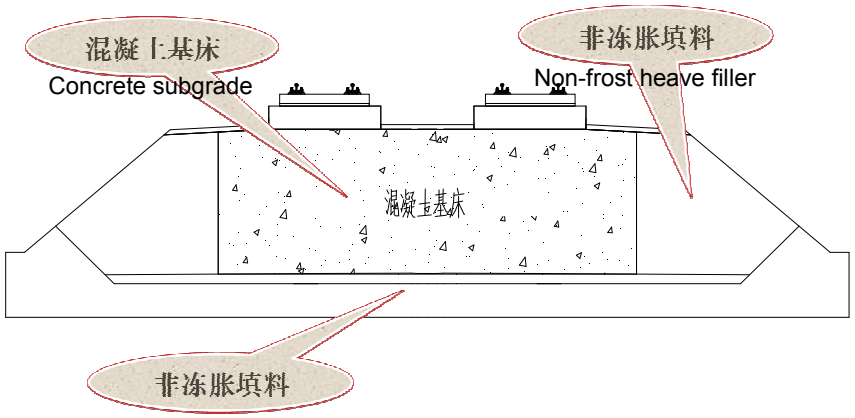
路基防冻胀结构—哈齐高铁 Subgrade anti-frost heave structure – Ha-Qi



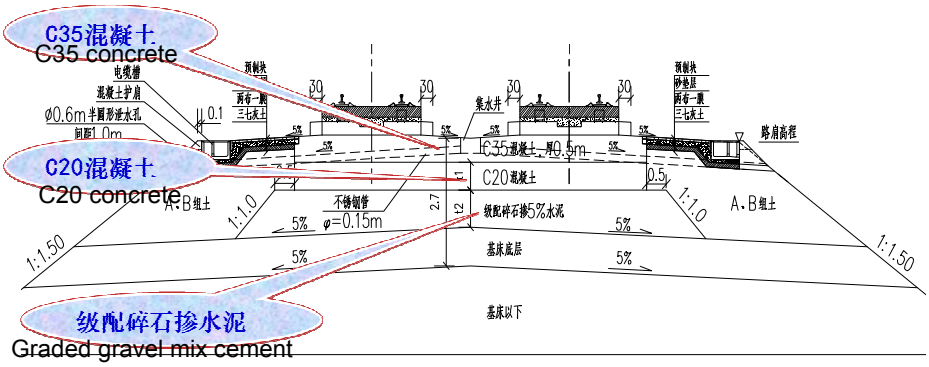
哈齐高速铁路混凝土基床

Ha-qi high speed railway concrete foundation bed

四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

路基防冻胀结构—京沈高铁混凝土基床Subgrade anti-frost heave structure – Jing-Shen



京沈高速铁路混凝土基床

Jing-Shen high-speed railway concrete foundation

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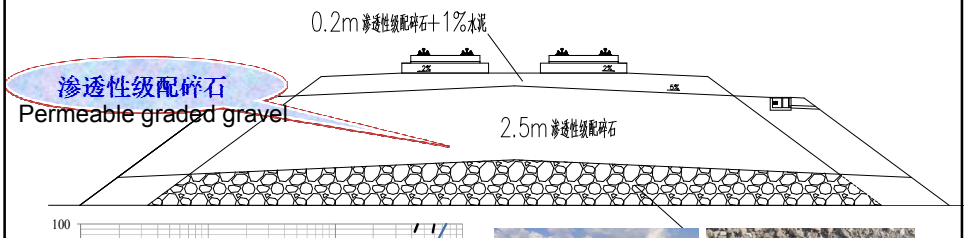
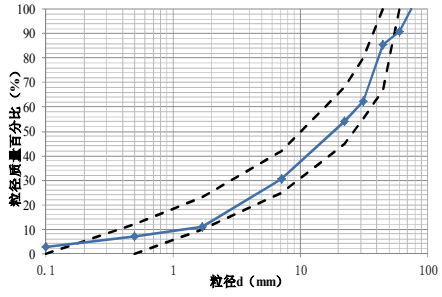
四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade





渗透系数7*10^{-4}m/s，自然持水率4%，冻胀率0.25%，细粒含量2.7%。

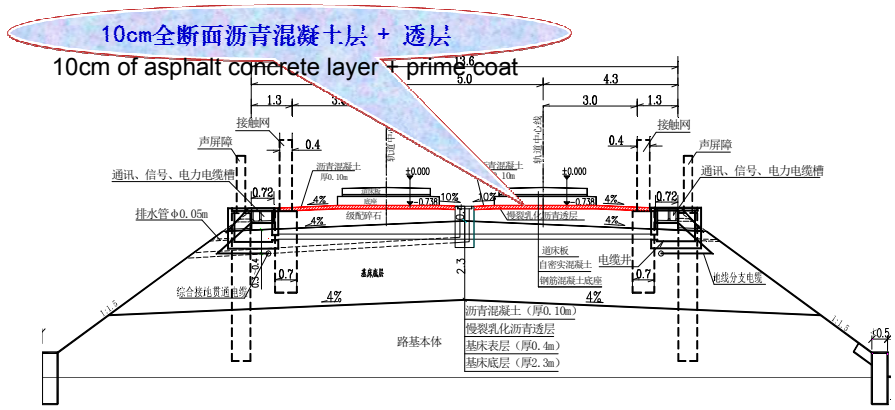
Permeability coefficient 7*10-4 m/s, natural moisture content 4%, frost-heave ratio 0.25%, fine particle content 2.7%.

四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

路基防冻胀结构—强化表面防水—郑徐高铁

Subgrade anti-frost heave structure, strengthening surface waterproof, Zheng-Xu high-speed railway



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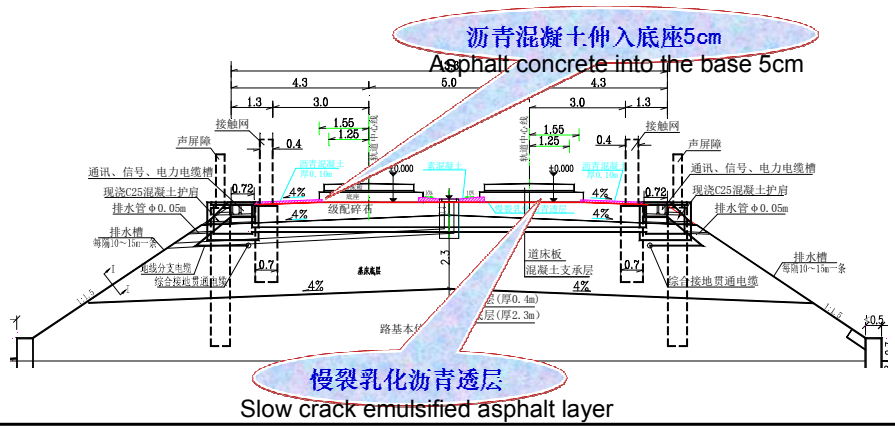
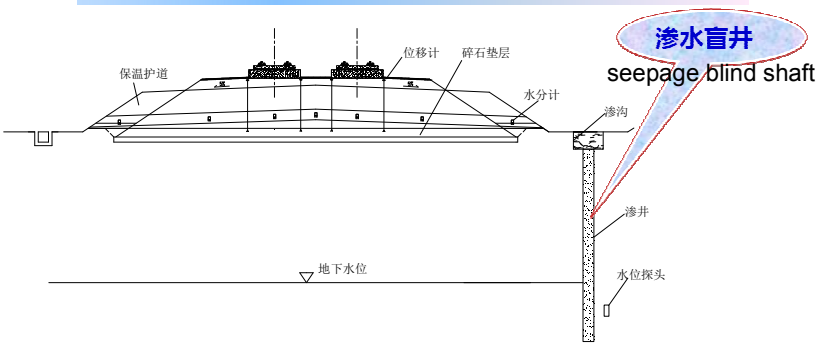


四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

路基防冻胀结构—地表积水排入地下—哈齐

Subgrade anti-frost heave structure – drain surface water into underground – Ha-qi



低矮路基渗水盲井

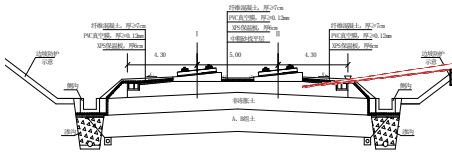
Low subgrade seepage blind shaft

四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

路基防冻胀结构—局部保温—哈大正线综合试验段

Subgrade anti-frost heave structure– partial heat insulation – Ha-da main line comprehensive test section

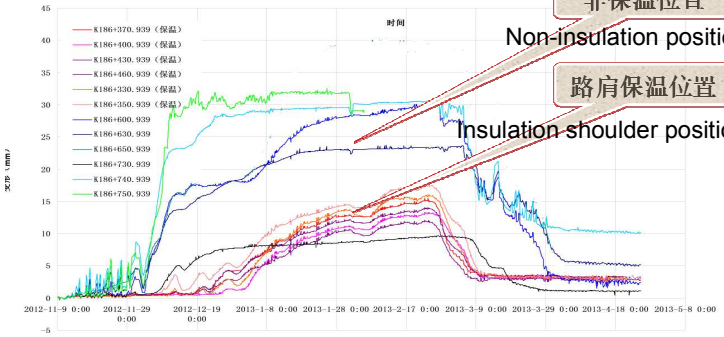


铺设0.10m保温板

Laid 0.10m insulation board

保温与非保温地段冻胀曲线对比

Contrast of heat preservation and thermal insulation section of frost-heave curve



非保温位置

Non-insulation position

路肩保温位置

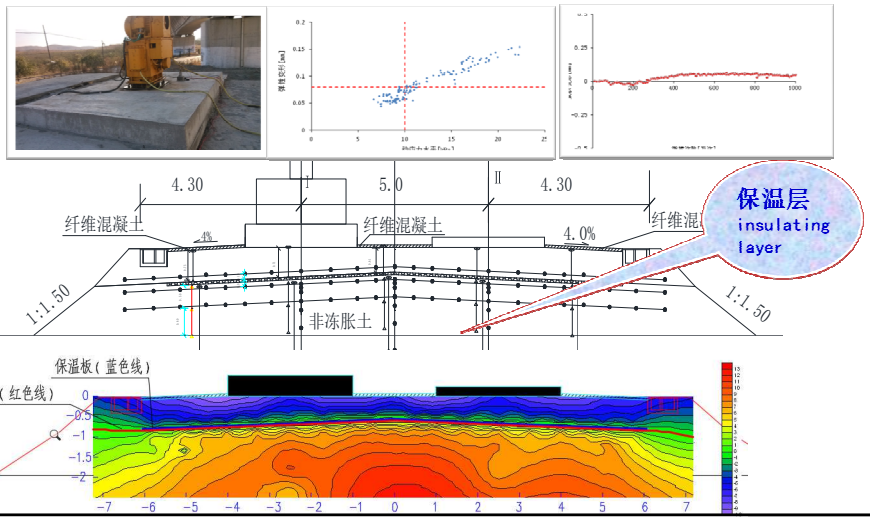
Insulation shoulder position

四、高速铁路路基防冻胀结构与措施

Anti-frost heave structure and measures of high-speed railway subgrade

路基防冻胀结构—全保温—哈大线外试验段

Subgrade anti-frost heave structure–full heat preservation, Ha-da line outside test section



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五、高速铁路路基冻胀维护

Maintenance of high-speed railway subgrade frost-heave

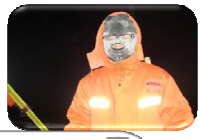
综合检测列车全线检测，人工添乘和晃车仪检查

Comprehensive detection the whole line of the train, artificial multiplication and check by sway train machine

1. 冻胀检查方法

I级及以上超限处所静态复核

Class I and above transfinite place static check



frost- heave check method

重点晃车处所采用轨检小车进行测量

Key sway area measured by track inspection trolley

分析病害原因，制定方案，上线进行维护

Analyzes the reasons of diseases, make plan, maintenance on-line。

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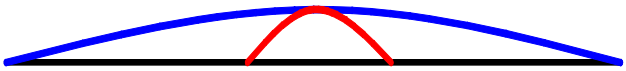
五、高速铁路路基冻胀维护

Maintenance of high-speed railway subgrade frost-heave

2. 线路调整 Line adjustment

垫高平顺
Raise up
increase regularity



预垫调低
Tune down
prefabricated mat

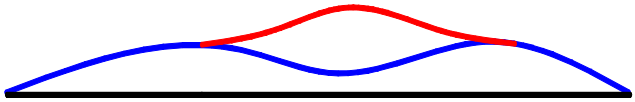
五、高速铁路路基冻胀维护
Maintenance of high-speed railway subgrade frost-heave

2. 线路调整 Line adjustment

兼顾冬夏的动态平顺调整
Dynamic regularity adjustment considered both winner and summer

调低
Turn down

垫高
Raise up



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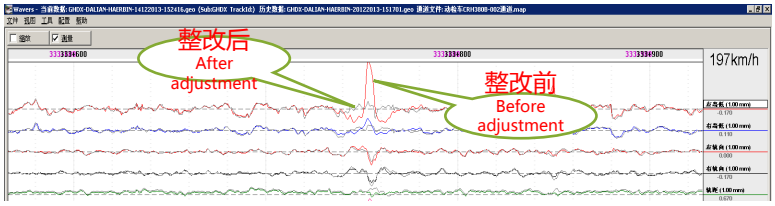
五、高速铁路路基冻胀维护
Maintenance of high-speed railway subgrade frost-heave

3. 调低铁垫板 Lower iron plate

可调整量增加6mm

Adjustable amount increase 6 mm



采用调低铁垫板前后波形对比
Waveform comparison before and after using lower iron plate

五、高速铁路路基冻胀维护

Maintenance of high-speed railway subgrade frost-heave

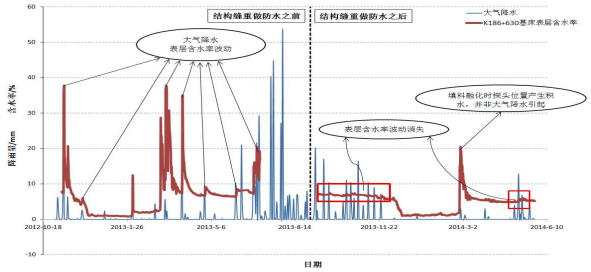
4. 表面封闭及伸缩缝封堵 Surface sealing and block off expansion joint

去掉水泥浮浆
Remove bleeding cement

刷底涂
Brush first coat

安装泡沫条
Install backer rod

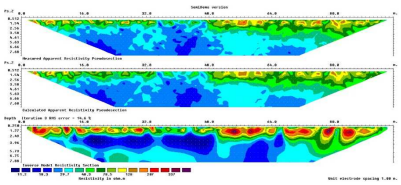
灌注硅胶
Perfusion silicone



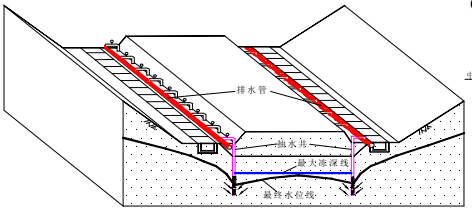
五、高速铁路路基冻胀维护

Maintenance of high-speed railway subgrade frost-heave

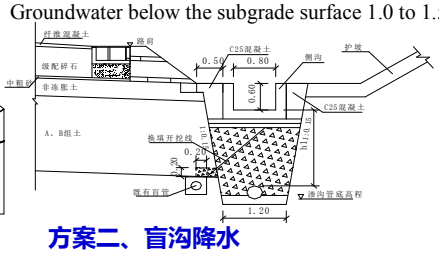
5. 路基降水整治技术 Remediation of roadbed precipitation



地下水位于路基面以下1.0-1.5m
Groundwater below the subgrade surface 1.0 to 1.5m



方案一、井点降水
Scheme 1: Well-point dewatering



方案二、盲沟降水
Scheme 2: Blind ditch drainage


谢 谢！
Thank you!