轨道工程

Railway Track Technology

主讲教师：任娟娟

Ren, Juanjuan Assistant Prof. & Dr.

School of Civil Engineering

Southwest Jiaotong University

绪论

Introduction

一、教学目标 Course purpose

1. 了解高速铁路的产生和发展；

A）know：The Development and Generation of the High-speed Rail;

2. 了解中国高速铁路的现状与未来；

B）know：Current and Future Situations of Chinese High Speed Railway ;

3. 理解高速铁路与我们的生活；

C）understand：The High Speed Railway and Our Life;

4. 了解学习轨道工程课程的内容。

D）know：About this course.

二、教学过程 Teaching procedure

第一讲 高速铁路的发展

Part1 The Development and Generation of the High-speed Rail

1. 世界范围内铁路轨道首次的出现 **The appearance of railway**

On September 27th , 1825, the steam locomotive,"Voyager" started trial operation and succeeded.In Britain,the first railway line in the world from Stockton to Darlington was built and taken into operation.

1825 年 9 月 27 日，蒸汽机车“旅行者号”试运行并获得成功。世界第一条铁路，英国斯托克顿至达林顿铁路线建成通车。

2. 铁路的在运行速度、里程等方面的发展 **The development of railway in speed、mileage and so on.**

3. 高速铁路的出现 **The generation of the high-speed railway**

According to the present definition from the international conferenceof the world’s high-speed railway in 2011,high-speed railway must satisfy three conditions: 1) a new built line, 2) EMU trains at speed of 250 km/h, 3) special train control system.

按照 2011 年世界高速铁路大会的定义，高速铁路必须同时具备三个条

件：新建的专用线路、时速 250 公里动车组列车、专用的列车控制系统。

4. 高速铁路在各国的发展 **The development of the high-speed railway in some countries**

- Japanese High-speed Railways 日本高速铁路
- French High-speed Railways 法国高速铁路
- German High-speed Railways 德国高速铁路

5. 高速铁路技术特点 **The technical features of the high-speed railway**

- Fast speed、high density、good comfort 速度快、密度高、舒适性好
- Less land occupied、low energy、low pollution 占地少、低能耗、低污染
- Good benefit of transportation 运输效益好
- Safety、reliability 、punctuality 安全、可靠、正点

第二讲 中国高速铁路的现状与未来

Part 2 Current and future situations of Chinese High-Speed Railway

1. 中国高速铁路的现状 **Present development situation in China**

By the end of November, 2012, there are nearly 12000 km high-speed railways having been built in China (including Beijing-Wuhan high-speed railway, Harbin-Dalian high-speed railway. Both will be taken into operation at the end of this year).
截止到 2012 年 11 月底，中国高速铁路建成里程已近 1.2 万 km(含年底将开通的京广高铁北京-武汉段和哈大高铁)

2. 国内部分高速铁路线路介绍 **Some high-speed railway lines in China**

Beijing-Tianjin inter-city railway 京津城际

- Put into operation in August 1st , 2008
- Total length:120 km; Travel time: 30 minutes
- The top speed : 350 km/h
- The minimum operation interval : 3 minutes
- The top test speed of CRH3 : 394.3 km/h
- The top test speed of CRH2-300 is 383 km/h

Hefei-Wuhan PDL 合武客专

- Total length : 364 km

- Put into operation : April 11th , 2009
- Design speed :250km/h
- Travel time : 2 hours

Chengdu-Dujiangyan high-speed railway 成都至都江堰高速铁路

- Operation speed : 220 km/h
- Put into operation : May 12th , 2010
- Total length : 65 km

Beijing-Shanghai high-speed railway 京沪高铁

- Total length:1318km;Design speed:350km/h;Travel time is about 4 hours;24 stations
- Construction started: April 18th,2008
- Track Engineering finished : Nov. 15th , 2010
- Put into operation :June 30th , 2011

3. 中国高速铁路未来发展规划 **Developmental planning of high speed railway in China**

In 2020, China's railway mileage will reach more than 120,000 kilometers, and the main-busy route will be separated as dedicated lines of passengers and freight. Among them, newly built high speed railway will reach over 16,000 kilometers, together with other newly built railway and existing speeded-up lines, China's Railway rapid transportation network will reach more than 50,000 km.

到 2020 年，我国铁路营业里程将达到 12 万公里以上，主要繁忙干线实现客货分线。其中，新建高速铁路将达到 1.6 万公里以上，加上其他新建铁路和既有线提速线路，我国铁路快速客运网将达到 5 万公里以上。

第 3 讲 课程内容介绍

Part 3 Introduction of this course

About this course 关于本课程

- Dedicated for: Master student
- Credit: 3
- Background: Civil Engineering, Road and Railway Engineering preferential

Requirements 学习要求

- Students should not only listen to the classes and master what the teacher presents, but also read some recent published papers, journals or books and give a final report to show the ability of their leaning in this semester.

Purpose 学习目标

- From this class, the students are expected to learn about the basic knowledge

about railway track structures, the main track types and their characteristics, the basic design method of continuous welded rail, the calculation method of track structure.

Contents of this course　本课程目录

第一章　有砟轨道结构

Chapter 1　Ballasted Track Structure

一、教学目标 Course purpose

1. 掌握有砟轨道结构的组成；

A）master：the composition of track structure;

2. 掌握有砟轨道各个组成结构的特点。

A）master：the characteristic of each composition of the track structure;

二、教学过程 Teaching procedure

第一讲 有砟轨道结构组成

Part 1　Composition of Ballasted Track Structure

1. 有砟轨道结构的基本组成部分 Basic components of the ballasted track structure

- 钢轨 **rail**
- 扣件 **faster**
- 轨枕 **sleeper**
- 道床 **track bed**
- 下部基础 **lower foundation**

2. 有砟轨道的优缺点 Advantages and disadvantages of ballasted track

◆ **优点：**建设费用低、建设周期短、易修复、调整简单、机械化维修效率高、噪音小。

◆ **缺点：**道砟容易流动、需不断进行维修；道床维修量大。

第二讲 钢轨

Part 2 Rail

1. 钢轨的功能及基本要求 Function and basic requirements

◆ 钢轨的功能 function

- 支承和引导机车车辆的车轮
- 承受车轮传来的力并传递到轨枕上
- 为车轮滚动提供连续、平顺和阻力最小的表面
- 兼供轨道电路之用

◆ 轨道对钢轨的基本要求 Rail requirements

- 耐磨性好 high resistance to wear,
- 抗压性好 high resistance to compression,
- 耐疲劳性强 high resistance to fatigue,
- 具有足够的抗弯性能、抗拉性能、硬度 high yield strength, tensile strength and hardness,
- 抗脆性破坏 high resistance to brittle fracture,
- 良好的弯曲性能 good weld ability,
- 材质具有高纯度 high degree of purity,
- 良好的表面性能 good surface quality,

2. 钢轨的类型及断面形式 Rail types and Profiles

◆ 钢轨的类型 Rail types

- 以每米大致质量 kg 数表示 Rail types are divided by its unit weight in China, such as 75,60,50,43kg/m
- 另外钢轨按厂制钢轨长度的不同可分为：标准轨和缩短轨
- 按材质的不同可分为：碳素轨、合金轨、热处理轨
- 按强度的不同可分为五级：850、900、1000、1200、1300MPa
- 按货源可分为：国产轨、进口轨、试验轨

◆ 钢轨的断面 Rail profiles

➢ 钢轨断面 工字型———最佳抗弯性能

➢ 钢轨断面需满足的要求 Rail profiles should meet the following requirements:

– The running surface should be broad enough and formed in such a way that the surface pressure due to the contact between wheel and rail is minimized.

– Taking into account a long service life, the head height should allow for a sufficient wear clearance.

– The rail web must be of sufficient thickness to ensure carrying capacity and flexural strength.

– The foot must be of enough width to ensure high stability and to minimize surface pressure exerted on sleepers.

– The section modulus of the rail has to be adapted vertically and horizontally to the expected loads.

– To achieve a favorable stress flow the transition areas should be of sufficient radii.

– Height and foot width have to be chosen in such a way as to ensure enough tilt resistance.

– Due to static reasons the centre of gravity should be at approximately half the rail height.

◆ 钢轨的材质及机械性能 **the material and mechanical performance of rail**

➢影响钢轨性能的因素

– 化学成分(chemical constituents)

– 金属组织(matel structure)

– 热处理工艺(heat treatment process)

➢钢轨钢化学成分：Fe、C、Mn、Si、P、S

➢钢轨的物理性能

– 强度极限
– 屈服极限
– 疲劳极限
– 伸长率
– 断面收缩率
– 冲击韧性
– 硬度

➢钢轨重型化、强韧化、纯净化

The strengthening technology of rail 钢轨强化技术

■ Rail alloying 钢轨合金化

- 加入合金元素 Si、Mn、Cr，钢轨整体强化，表面硬度均匀，可焊性好
- The rail heat treatment 钢轨热处理
- 钢轨接头冲击力大，轨端 30-70mm 范围进行轨顶淬火处理，提高抗磨能力
- 全长淬火：电感应加热加速奥氏体向珠光体转变，提高强度和韧性
- combine heat reatment with alloying 热处理与合金化结合

3. 钢轨伤损及合理使用 Rail failure and fair use of the tail

◆ 钢轨伤损 Rail failure

➢ 钢轨在使用过程中，发生折断、裂纹及其它影响和限制钢轨使用性能的伤损

➢ 钢轨伤损分类：根据伤损在钢轨断面上的位置、伤损外貌及伤损原因等分为九类 32 种伤损，用两位数编号分类，十位数表示伤损的部位和状态，个位数表示造成伤损的原因

◆ 钢轨伤损类型 Types of rail failure

➢ 钢轨折断 brittle fractures of rail

➢ 钢轨磨耗 Rail wear

➢ 钢轨接触疲劳伤损 contact fatigue of rail

➢ 剥离 Rail stripping

➢ 轨头核伤

◆ 钢轨的合理使用 Proper use of rail

➢ 钢轨发展方向：重型化、强韧化和纯净化 the heavy duty, strengthening, purification

➢ 合理使用钢轨 intelligent use

➢ 应根据钢轨综合经济效益分析，确定钢轨合理的使用周期，实行钢轨分级使用制度，并积极做好旧轨整修工作

➢ 钢轨的分级使用 Using the rail by classification

➢ 钢轨整修技术 Rail maintenance technology

◆ 钢轨打磨 Rail grinding

➢ 修理性打磨 Maintenance grinding

➢ 预防性打磨 Preventive grinding

➢ 钢轨断面(廓形)打磨 Rail grinding (outline shape)

◆ **高速铁路钢轨的主要伤损 The main damage of high speed rail**

➢ 轨头龟裂 The rail head creaking

➢ 隐伤（又称踏面裂纹或踏面压溃）Hidden defect

➢ 蜂窝状裂纹 Honeycomb crack

◆ **预留轨缝计算 rail gap**

➢ 原则

✓ 最高轨温时不形成瞎缝

✓ 最低轨温时不超过构造轨缝 18mm

➢ 计算公式

第三讲 轨枕

Part 3 Seeper\tie

1.轨枕的功能及类型 Function and type of sleeper

◆ **轨枕的功能 function of sleeper**

➢ 承受来自钢轨的各向压力，并弹性地传布于道床

➢ 有效地保持轨道的几何形位，特别是轨距和方向

➢ 坚固、弹性、耐久性，扣件接口，抵抗水平位移

◆ **轨枕的类型 sleeper types**

➢ Divided by material 按材质分：wooden sleeper 木枕、concrete sleeper 混凝土枕、steel sleeper 钢枕、resin sleeper 树脂枕

➢ Divided by use purpose 按使用目的：normal sleeper 普通轨枕、switch sleeper 岔枕、bridge sleeper 桥枕

➢ Divided by structure form 按结构型式：integral type 整体式；combined type 组合式； half sleeper 半枕；broad tie 宽轨枕

➢ Divided by the structural and laying method 按构造及铺设方法：transverse sleeper 横向轨枕、longitudinal sleeper 纵向轨枕及 short tie 短枕

2.木枕 Wooden Sleeper

◆ **木枕 wooden sleeper**

➢ 木枕优缺点 **Advantages and disadvantages of wooden sleeper**

– 弹性好，可缓和列车的动力冲击作用；易加工、重量轻，运输、铺设、养护维修方便；与钢轨联结比较简单；有较好的绝缘性能等；

– 消耗大量优质木材，资源有限，价格较贵；易腐朽、磨损，使用寿命短；强度、弹性不完全一致，在机车车辆作用下会形成轨道不平顺，增大了轮轨动力作用。

◆ **木枕失效 Wooden sleeper failure**

➢ 腐朽

➢ 机械磨损

➢ 开裂

◆ **木枕处理 Wooden sleeper treatment**

➢ 防腐：最有效，水溶性防腐剂、油类防腐剂，密封蒸灌

➢ 减磨：铁垫板

➢ 防裂：控制含水量，改善干燥工艺，防腐浆膏掺麻筋填塞裂缝，钉钉或铁丝捆扎使裂缝愈合

3.混凝土枕 concrete sleeper

◆ **混凝土枕类型及特点 Characteristics and types of concrete sleeper**

➢ 混凝土轨枕为发展方向：材源多，尺寸精度高，轨道弹性均匀，提高了轨道稳定性；使用寿命长，可以降低轨道的养修费用；自重大、纵、横向阻力较大，提高了线路的稳定性；刚度较大，要求较好的轨道弹性

◆ **I 型枕**

➢ 设计条件：轴重 21t、速度 85km/h，1840 根/km

➢ 不足：螺栓孔间纵裂、轨下正弯矩裂缝

◆ **II 型枕**

➢ 设计条件：轴重 23t、速度 120km/h，60kg/m 钢轨，年运量 60Mt，按疲劳可靠度设计

➢ 承载能力：较 I 型枕，轨下正弯矩提高 13%-25%，枕中负弯矩提高 14%-41%,基本能适应次重型、重型轨道

➢ 不足：安全储备不够，枕中顶面横向裂缝、沿螺栓孔纵裂、枕端龟裂、侧面纵向水平裂缝、挡肩斜裂等，难以适应重型和特重型轨道

◆ **III 型枕**

➢ 设计条件：轴重 23t，速度 200km/h，轨枕配置 1760 根/km

➢ 轨枕型式尺寸设计的优化：增加长度、加宽轨底，增大支承面积，提高线路稳定性

➢ 提高轨枕设计承载能力

➢ Ⅲ型轨枕与先进的扣件相配套：有挡肩扣件、无挡肩扣件

◆ **小曲线 III 型枕的缺点**

IIIb 型

➢ 绝缘轨距块强度不足

➢ 扣件无法调高

➢ 弹条Ⅲ型扣件扣压力衰减速率快

➢ 预埋铁座易锈蚀，且又无法更换

IIIa 型

➢ 轨距挡板座易松脱

➢ 混凝土枕挡肩破损严重

◆ **混凝土枕受力特点 Stress characteristics of concrete sleeper**

➢ 弹性基础上的短梁

➢ 轨枕受力状况与道床支承条件有关

– 中间不支承　　I 型枕

– 中间部分支承　II 型枕

– 全支承　　III 型枕

◆ **混凝土枕外形及尺寸 Shape and parameters of concrete sleeper**

轨枕形状：混凝土枕截面为梯形，上窄下宽：节省混凝土用量，减轻自重，便于脱模

➢ 轨枕顶面宽度：轨枕抗弯强度、钢轨支承面积、轨下衬垫宽度、扣件尺寸等因素综合考虑

- 承轨槽：轨枕顶面支承钢轨的部分，设置 1:40 轨底坡
- 轨枕底面宽：减少道床压力、便于捣固

– II 型枕：两端梯形，中间矩形，增大支承面积，使 R、q 重合，底面压花或凹槽，
– III 型枕：增大支承面积

◆ **轨枕长度 sleeper length**

- 轨枕长度与轨枕受力状态有关

– 长枕可减少枕中负弯矩，但增大轨下正弯矩
– 以轨下正弯矩与枕中负弯矩保持一定比例确定轨枕长度

- 混凝土枕长度一般在 2.3-2.7m 之间

– Ⅰ、II 型枕长度均为 2.5m
– III 型枕长度有 2.6m 和 2.5m 两种

- 国内外主要干线普遍采用 2.6m 长轨枕

– 减小枕中负弯矩
– 提高纵横向稳定性和整体刚度，改善道床、路基工作状态，利于铺设无缝线路，适当减少轨枕配置根数

◆ **轨枕高度 The width of sleeper**

- 轨下部位高、中间部分矮
- 轨下截面正弯矩、枕中截面负弯矩
- 直线配筋、各截面配筋相同

– 轨下截面配筋重心应在截面形心之下
– 枕中截面配筋重心应在界面形心之上

◆ **轨枕间距 sleeper spacing**

- 轨枕间距与每公里配置的轨枕根数有关
- 轨枕根数应根据运量、行车速度及线路设备条件确定，并和钢轨及道床等综合考虑，合理配套，以求在最经济的条件下，保证轨道具有足够的强度和稳定性。
- 轨枕加密，可减小道床、路基面、钢轨以及轨枕本身受力，利于保持轨距、方向，保证高速行车安全
- 轨枕过密，则不经济，净距过小，影响捣固质量

➢ 接头处车轮的冲击动荷载大，轨枕的间距适当减小，且应有一个过渡间距

➢ 每节钢轨下轨枕间距应当满足：a＞b＞c。接头轨枕间距 c 一般是给定的：对于 50kg/m 及以上钢轨，木枕 440mm，混凝土枕 540mm

◆ **混凝土宽枕 Concrete broad sleeper**

➢ 轨枕与道床接触面上的摩阻力增大，提高了轨道的横向稳定性

➢ 支承面积较混凝土枕大一倍，使道床的应力大为减少，可以减小道床的振动加速度，使道床的变形减小，残余变形积累过程延缓，轨道几何形位易于保持，整个轨道结构得到加强。

➢ 密排铺设，枕间空隙用沥青混凝土封塞，有效地保持道床的整洁，延长道床的清筛周期

➢ 宽轨枕轨道的维修养护工作量很少，仅为混凝土枕轨道的 1/2-1/4

➢ 宽轨枕轨道外观整洁美观

第四讲 联结零件

Part4 Connection components

◆ **联结零件定义**

➢ 连接钢轨或连接钢轨和轨枕的部件

➢ 保证钢轨间或钢轨与轨枕的可靠联接

– 钢轨接头联结零件 rail joint：把钢轨联结起来，使钢轨形成一个整体，抵抗弯曲和变形。
– 中间联结零件 fastening：实现钢轨与下部基础的联结。

◆ **钢轨接头联结零件 Connection components of rail joint**

➢ 组成：夹板、螺栓、弹簧垫圈等 Composition: splint, bolts, spring washers,etc.

➢ 作用：在接头处把钢轨连接起来，满足行车要求及钢轨伸缩的要求 Function: connecting the rails at the joints to meet the requirements of traffic and rail expansion

◆ **接头夹板 Joint splint**

➢ 承受弯矩、传递纵向力、阻止钢轨伸缩——一定刚度及足够强度

➢ 斜坡支承双头对称型夹板（双头式夹板）

– 斜坡——楔入贴紧轨腰，磨耗后可再次拧紧使之贴紧
– 螺栓孔——圆形与长圆形相间，实现轨缝

◆ **接头类型 rail joint types**

➢ 绝缘接头 Insulated joints

– 普通高强绝缘接头 Ordinary high-strength insulated joints
– 胶接绝缘接头 Glued insulated joints

➢ 伸缩接头

➢ 冻结接头 frozen joints
– 普通冻结接头 Ordinary frozen joints
– 哈克紧固件 Hacker Fasteners

➢ 焊接接头 Welded joints

➢ 加强接头 Strengthen joints

◆ **扣件**

➢ 扣件作用 function

– 能把钢轨牢固地固定在其支承体上
– 能对支承体缓冲来自钢轨的冲击力作用，减轻振动，改善环境
– 能抵抗来自钢轨的水平力、抵抗钢轨的小返和回转
– 具有必要的钢轨垂向和横向的调整量
– 在钢轨和支承体之间具有足够的绝缘性能
– 构造简单，批量生产时成本低廉

➢ 木枕扣件 Wooden sleeper fasteners

– 分开式（K 式扣件）
– 混合式

➢ 混凝土枕扣件 Concrete sleeper fasteners

– 扣板式扣件 Buckle plate fasteners
– 弹条 I 型扣件 Elastic fastener type I
– 弹条 II 型扣件 Elastic fastener type II
– 弹条III型扣件 Elastic fastener type III
– 弹条 IV 型扣件 Elastic fastener type IV
– 弹条 V 型扣件 Elastic fastener type V

➢ 无砟轨道扣件 fasteners for ballastless track

– WJ-7 型扣件
– WJ-8 型扣件

◆ **扣件技术参数 Technical parameters of concrete sleeper fasteners**

➢ 足够扣压力（约 10kN）——纵向阻力要求 Enough Buckle pressure (approximately 10kN) - Longitudinal resistance requirements

➢ 适当弹性 Appropriate flexibility

– 橡胶垫板+弹条

– 满足轨道稳定与减振要求

➢ 较大调整量 Larger adjustment amounts

– 混凝土枕螺栓孔间距和承轨槽宽度一定

– 曲线轨距加宽、钢轨磨耗、钢轨水平调整

➢ 绝缘性能 Insulation property

➢ 扣件节点刚度

– 扣压件前端刚度

– 轨下胶垫刚度

➢ 钢轨与轨下结构的联结方式

➢ 轨下结构对钢轨的绝缘性能

➢ 钢轨高度和平面位置的可调性能

◆ **钢轨扣件的技术动向 Technology trends of rail fastening**

➢ 适应高速化、环保化、省力化和可调化四大基本准则 **Adapt to four basic criteria as high-speed, environmental protection, labor-saving and adjustable.**

➢ 钢轨扣件中的低刚度、长寿命、低成本及其相互协调是现代钢轨扣件的重大技术动向 **The low stiffness, long life, low cost and their coordination of rail fastening is a major modern technology trends for rail fastenings.**

第五讲 道床
Part 5: Ballast bed

1、道床功能及对材质的要求

The functions and material requirements of ballast bed

（1） 道床功能：

The functions of ballast bed

- 承受轨枕的压力并均匀地传递到下部基础
  Bear the pressure of the sleeper and evenly to a lower base
- 提供纵横向阻力，保持轨道稳定
  Provide lateral resistance, and maintain stability of the rail
- 提供弹性，减缓轮轨冲击和振动
  Provide elasticity, ease the wheel/rail impact and vibration
- 排水性能，提高路基的承载能力、减少基床病害
  Drainage performance, increasing the bearing capacity of subgrade, the decrease of bed disease
- 便于轨道养护维修作业，校正线路的平纵断面。
  Convenience of track maintenance and repair work, correct cross and vertical sectioncircuit of the track.

（2）对道床材料的要求：

The material requirements of ballast bed

- 质地坚韧，有弹性，不易压碎和捣碎；排水性能好，吸水性差；不易风化，不易被风吹动或被水冲走。
  Strong but pliable in texture, elastic, not easily crushed and mash; Good drainage performance, water imbibition is poor; Not easily weathered, not easy to be driven with the wind or washed away by water.
- 道砟材料：碎石、天然级配卵石、筛选卵石、粗砂、中砂、熔炉矿砟
  Railway ballast materials: crushed stone, natural pebble, screening of pebble, coarse sand, medium sand and furnace mineral waste residue

（3）道砟技术条件：

Technical conditions of ballast

- 道砟分级 **Ballast grading**：
  特级、一级、二级 **Super, level 1, level 2**
- 技术参数 **Technical parameters**：
  材质参数：抗磨耗、抗冲击、抗压碎、渗水、抗风化、抗大气腐蚀
  Material parameters: crushing, abrasion resistance, impact resistance, resistance to water penetration, weathering resistance, resistance to

atmospheric corrosion

质量参数：道砟粒径、级配颗粒形状、表面状态、清洁度

Quality parameters: ballast diameter, gradation particle shape, surface state and cleanliness

- 特重型轨道、隧道内轨道及宽轨枕采用一级道砟
  Extra heavy duty track, track in tunnel and wide level ballast sleeper is adopted level 1
- 重型力求一级道砟
  Heavy duty track strive to level 1
- 客专特级——增强稳定，减少磨损、粉化和飞砟
  Passenger railway line is adopted super -- to enhance stability and decrease wear, pulverization and frantic crushed stone
- 道砟级配 **Ballast gradation:**
  道砟中颗粒的分布，影响道床物理力学性能和养护维修工作量
  Particle distribution in ballast, affect the physical and mechanical properties of ballast bed and maintenance workload
- 道砟颗粒形状及清洁度
  Ballast particle shape and cleanliness
  表面形状影响自身强度和轨道纵横向阻力
  Surface shape influence their own strength，rail longitudinal and lateral resistance
  清洁度：控制土团、粉末或其他杂质
  Cleanliness: control soil, powder or other impurities

2、道床断面

Ballast bed section

- 道床断面主要特征：道床厚度、顶面宽度及边坡坡度
  Main features of fracture surface of track: thickness of ballast bed , width of the top of the ballast bed and grade of side slope

3、道床的变形

Deformation of the track bed

- 道床变形：道床作为散粒体结构，本身具有弹、塑性，弹性变形可以恢复，而塑性变形部分则成为永久变形，或称残余变形，残余变形累积后将引起轨道下沉
  Ballast bed deformation: Track has the elasticity and plasticity as itself the grain structure. Elastic deformation can be restored, however, the plastic deformation part would become permanent deformation or the residual deformation. After accumulated residual deformation will cause the track sink
- 残余变形原因：道砟颗粒相互错位、重新排列，颗粒破碎、粉化
  Residual deformation reasons: ballast particle dislocation, rearrange, crushing, powder particles

- 道床的下沉阶段：初期急剧下沉和后期缓慢下沉两个阶段。
  Roadbed subsidence stage: the early sinking sharply and late slowly sinks

4、碎石道床在高速铁路中的问题
The problem of crashed stone ballast bed in the high-speed railway

- 碎石道床是轨道弹性的主要来源
  Ballast bed is the main source of elasticity of track
- 道砟粉化现象严重
  Ballast pulverization phenomenon is serious
- 道床飞砟现象：
  Ballast bed flying ballast phenomenon：
  飞道砟成为法国钢轨表面伤损的主要原因；飞砟还会撞击列车底部，损坏高速列车
  Flying ballast is the main causes of rail surface injuries；flying ballast will also hit the bottom of the train, damage to the high-speed train
- 道床飞砟原因：冰块下落引起道砟飞散；列车风达到 50m/s 以上；下雪或大机捣固以后，道砟颗粒间的摩擦系数及咬合力降低。
  Ballast bed flying ballast reason：Ice falling cause ballast flying; train wind reach above 50 m/s; snow or big machine after tamping, friction coefficient and lower occlusal force among ballast particles.
- 国外高速铁路中所采用的防治对策有：采用洒水、加热器、特殊涂料等融雪措施；停车时铲除落雪；加高轨枕，使轨枕高出道床面 100mm；采用道砟网、道砟屏栅或合成树脂等措施。日本高铁采用了道砟防护垫
  The prophylaxis and treatment countermeasures adopted by abroad the high speed railway are: use the snowmelt measures such as watering, heater, special coatings; root out snow when parking; higher than that of heightening the sleeper, the sleeper track surface is 100 mm; use ballast net, ballast screen grid or synthetic resin. Japan's high-speed rail adopted ballast protection pad.
- 桥上有砟轨道结构道砟液化现象
  Ballast liquefaction of ballasted track on bridge
  出现液化现象主要是列车以一定速度（不一定是最高速度）通过桥梁引起的垂向加速度超过 0.7～0.8g 引起的；当梁体与道砟间铺设弹性垫层（称为道砟垫）后，将增加道床的加速度，结果会使液化现象更加严重；另外，具有按规则和重复分布的轮对以一定速度运行时，将与梁体可能产生共振现象，也是产生液化现象的主要根源。
  Liquefaction occurs mainly trains at a certain speed (not necessarily the highest speed) caused by bridge caused by the vertical acceleration of more than 0.7 ~ 0.8 g; When laying the elastic cushion between the girder and ballast(called ballast pad), will increase the acceleration of ballast, the result can make the liquefaction phenomenon is more serious; In addition, according to the rules and repeat the distribution of the wheel to a certain speed, will have a resonance phenomenon, and the beam body may also produce liquefaction phenomenon of primary sources.

- 道砟垫、道砟胶
  Ballast pad, Ballast glue

三、教学重点

1. 有砟轨道结构中的钢轨、扣件、轨枕等结构；

2. 有砟轨道与无砟轨道在结构上的区别；

四、专业思想培养

1. 根据对有砟轨道结构的介绍，掌握轨道各个结构部分的作用；

3. 了解工务养护维修工作的重点以及养护维修对铁路运营的重要作用。

五、布置作业

1. 有砟轨道结构有哪几部份组成？

Which parts are composed of ballast track structure？

2. 混凝土轨枕技术特点是什么？

What is the technology characteristics of concrete sleeper？

3. 道床飞砟的危害。

4. 预习相关无砟轨道结构知识；

5.使用 AutoCAD 完成有砟轨道结构的三维绘图，加深对轨道结构的认识。

第四章 线路几何形位

Chapter 4 Track geometry

一、教学目标 Course purpose

1. 了解如何设置的外轨超高在曲线。

A) Know: Purpose and how to set of superelevation of outer rail on curve.

2. 掌握直线上轨道几何形位的基本元素、意义和标准

B)Master: Basic elements, meaning and standard of straight-line track geometry.

3. 掌握直线和曲线上的轨道空间几何形位和主要特征

C) Master: geometric spaces and the main features of the straight and curved track.

二、教学过程 Teaching procedure

第一讲 轨道几何形位概述

Part1：Overview of track geometry

1. 几何形位定义及影响

Definition and effect of track geometry

- ◆ 几何形位定义 **Definition:**
- ■ 轨道各部分的几何形状、相对位置和基本尺寸
  The geometry, the relative position and basic dimensions of the various parts of the track
- ■ 平面：轨向（直线、曲线）和缓和曲线
  Plan: alignment of track (lines, curves), transition curve
- ■ 横断面：轨距（曲线轨距加宽）、轨底坡、水平（曲线外轨超高）
  Cross-section： gauge(curve gauge widening), rail cant, horizontal(outer rail superelevation in curve)

- 纵断面：前后高低
  Profile: the vertical profile (height of front and rear)

◆ 影响 Effect：

- 机辆几何形位—轨道几何形位→密切配合，产生动荷载
  Locomotive geometry and track geometry cooperate closely, otherwise resulting in dynamic load.
- 影响机车车辆及轨道的安全运行、设备寿命、舒适度、养护费用
  Affecting the operation safety, equipment life, comfort and maintenance costs of locomotives and track.
- 机辆几何形位—轨道几何形位→密切配合，产生动荷载
  Locomotive geometry and track geometry cooperate closely, otherwise resulting in dynamic load.
- 影响机车车辆及轨道的安全运行、设备寿命、舒适度、养护费用
  Affecting the operation safety, equipment life, comfort and maintenance costs of locomotives and track.
- 影响安全运行因素：轨距、水平、轨向、外轨超高→机辆掉道、爬轨 、倾覆
  the locomotive off track， climbing rail and capsize
- 影响舒适度因素：轨距、外轨超高顺坡及其变化率、轨向、缓和曲线线形、前后高低→机辆横向、竖向加速度→惯性力
  →horizontal of locomotive and Vertical acceleration→inertial force
- 影响设备寿命因素：轨距、水平、轨向、前后高低、外轨超高→钢轨磨耗、轨道受力→养护维修工作和费用
  →Rail abrasion, track force→maintenance and repair work and cost

第二讲 机车车辆走行部构造

Part2: The running gear structure of locomotive

1、走行部构造

The structure of running gear

- 机车走行部分：车架+轮对+轴箱+弹簧装置+转向架及其他部件
  Locomotive running parts: frame +wheel + axle box+ spring device+ bogie ,etc.
- 车辆走行部分：转向架+ 轮对+轴箱+弹性悬挂装置+ 制动装置
  Vehicle Traveling parts: bogie +wheel + axle box + elastic suspension system + braking device

2、轮对构造

Wheel-set structure

轮对：一根车轴+两个相同的车轮
Wheel-set: Axle+Wheel

- 整体轮（整体辗钢轮，主要类型）：踏面+轮缘+轮辋+幅板+轮毂
  monolithic wheel: tread+ flange+ rim+ spoke+ hub
- 轮箍轮：轮心+轮箍
- **tire wheel: Wheel center+ Wheel tire**
- 轮缘（**flange**）：踏面内侧制成凸缘，防车轮脱轨
- 踏面（**tread**）：车轮和钢轨的接触面
- 车轮内侧面**(The inner surface of the wheel)**：轮缘一侧竖直的一面，钢轨内侧
- 车轮外侧面**(The outer surface of the wheel)**：踏面一侧竖直的一面，钢轨外侧

3、轮对踏面
Wheel-set tread

锥形踏面 **Tapered tread**；磨耗型踏面 **The worn tread**

4、轮对尺寸
Wheel-set dimension

- 车轮宽度（轮幅宽)：车轮内侧面与外侧面间距离
  Wheel width: The distance between the wheel inner side and outer side.
- 踏面测量线：通过踏面上距车轮内侧面一定距离的一点划出的水平线
  Tread measuring line: From the wheel side within a certain distance through tread point draw a horizontal line.
- 轮缘高度：由踏面测量线至轮缘顶点的距离
  Flange height: The line is measured by the tread to rim vertex distance.
- 轮缘厚度：由踏面测量线向下 10mm 处量得的厚度
  Flange thickness: The line is measured by the tread down quantity at 10 mm thickness.
- 车轮直径：取踏面上距轮内侧面一定距离的一点为基点测直径、测轮箍厚度
  Wheel diameter: Take the tread is apart from the wheel side within a certain distance of base diameter measurement, measuring the thickness of the tire
- 轮对宽度计算公式**(The formula to calculate of wheel width)**：q=T+2d
  q——轮对宽度 **wheel width**（mm）
  T——轮对的轮背内侧距离 **the distance of wheel back inside surfaces**（mm）
  d——轮缘厚度 **flange thickness**（mm）
-

5、车辆尺寸
Vehicle size

全轴距（**Total wheelbase**）→同一车体最前位、最后位车轴中心水平距

固定轴距（**Fixed wheelbase**）→同一车架或转向架上始终保持平行的最前位、最后位车轴中心水平距离

车辆定距（**Vehicle fixed distance**）→车辆前后两走行部分车体支撑间的距离

第三讲 轨道几何形位基本要素
Part3: Track geometry elements

1、轨道几何形位基本要素
Track geometry elements

- 轨距 **gauge**、水平 **horizontal**、轨向 **alignment of track** 、前后高低 **the rail height**、轨底坡 **rail base slope**
- 静态检查：道尺、弦绳、轨检仪
  Static checking: Road ruler, string rope, track inspection instrument.
- 动态检查：轨检车、动检车
  Dynamic checking: Track inspection car, moving inspection car.
- 动态不平顺大于静态不平顺
  Dynamic irregularity is larger than static.
- 惯性基准测量原理
  Inertial benchmark measurements principle.

2、轨距
Gauge

- 定义：钢轨顶面下 16mm 处两股钢轨作用边间最小距离，不受肥边磨耗影响
  Definition: Under the rail top 16mm in function and minimum distance between two rails, is not affected by fat side abrasion
- 欧洲国家在 14mm 处测量
  European countries measure in the 14 mm
- 标准轨距（**Standard gauge**）：1435mm
- 宽轨距/窄轨距：1670/1067（俄罗斯/南非）
  Wide/Narrow gauge: 1670mm/1067mm(Russia/South Africa)
- 由于扣件不良、轨枕挡肩失效、轨头侧面磨耗等造成的
  Caused by abnormal fasteners, sleepers shoulder block failure and the rail head side abrasion, etc.
- 偏差标准**(deviation standard)**：普通铁路+6、-2mm，高速铁路+1、-1mm
- 变化率**(change rate)** ：正线**(main line)**、到发线**(receiving-departure track)**≯2‰（或 2mm/m），高速为 1‰
- 游间**(moving clearances)** ：轮对一个车轮轮缘紧贴一股钢轨作用边时，另一个车轮轮缘与另一股钢轨作用边之间所形成的一定间隔
  When a wheel flange close to a rail surface, another wheel rim and another rail between edge formed by a certain interval

3、水平
Horizontal

- 定义：指线路左右两股钢轨顶面的相对高差
  Definition: The relative elevation between the top surface of the left rail and the right rail.

- 直线地段：应在同一水平面上→荷载均匀行车平稳
  Straight Line: same horizontal plane→load uniformly and ride smoothly.
- 曲线地段：外轨应均匀和平顺超高
  Curve: outer rail should be uniform and smooth superelevation.
- 道尺测量
  Road ruler measure
- 普通铁路容许偏差 4mm
  Common rail allowable deviations is 4mm.
- 两轨高低不平顺所引起的
  Caused by irregularity of the two rail.
- 两种类型的不平顺 ：水平差、平顺扭曲
  Two types of irregularity: Horizontal error, Ride twist (twist or warp)

4、轨向
Alignment of track

- 定义：指轨道中心线在水平面上的平顺性
  Definition: Refers to the center line of the orbit in the horizontal plane ride comfort

- 产生原因：轨排横向残余变形积累和轨头侧面磨耗不均匀、扣件失效、轨道横向弹性不一致等
  Cause: track skeleton Residual deformation accumulation and rail head side section of track horizontal uneven abrasion, fastener failure, rail lateral elastic inconsistencies, etc
- 要求：直线方向必须目视平顺，曲线圆顺
  Demand : Rails straight direction must be visual smooth, curve coordinately
- 测量 **Measure**：10m 弦绳 **String string**
- 影响：蛇行运动→行车平稳性；无缝线路高温季节胀轨跑道
  Effect : Sinusoidal movement→The driving stability; CWR high temperature season expansion and rail
- 偏差 **Deviation**：普通铁路**(Common rail)** 4mm
- 形成：左右轨方向不平顺平均
  Consequence: Direction of two rails irregularity on average

5、前后高低
The rail height

- 定义：轨道沿线路方向的竖向平顺性
  Definition: Vertical comfort of railway track direction along the route

- 产生原因:线路施工和大修作业的高程偏差，桥梁挠曲变形，道床和路基残余变形沉降不均匀，轨道各部件间的间隙不相等，存在暗坑、吊板，以及轨道垂向弹性不一致等
  Cause: Line construction and elevation deviation of major repair, bridge deflection, uneven residual deformation of ballast bed and subgrade settlement, track of the gap between parts are not equal, exist covertly pit and hanging board, and the track vertical elastic inconsistencies, etc
- 要求 **Demand**：目视平顺
- 测量 **Measure**：10m 弦绳
- 偏差 **Deviation**：普通铁路 4mm
- 形成 **Consequence**：分左右轨高低不平顺
- 静态：路基状态、捣固坚实程度、扣件松紧、 枕木腐朽、磨耗不一致性导致不均匀静态下沉
  Static: subgrade state, tamping degree ,tightness of fasteners, sleepers rot and inconsistent abrasion result in uneven static sink.
- 动态：从表面上看平顺，实际上动态不平；轮轨动力作用→轨道动态下沉→冲击动力增大→加速道床变形→扩大不平顺 → 加剧车辆对轨道破坏
  Dynamic: It looks like smooth on the surface, but dynamic irregularity; wheel-rail dynamic action→track sink dynamically→impact dynamic force increases→accelerates ballast bed deformation→expansion of irregularity→exacerbate the destruction of vehicles on the track.
- 破坏作用同不平顺长度成反比，同深度成正比
  Destructive effect is inversely proportional to the length of the irregularity, the same proportional to its depth.
- 轨面短波不平顺
  Shortwave irregularity on rail surface
- 焊缝区短波不平顺
  Shortwave Irregularity in weld zone
- 钢轨扎制中形成的垂向周期性不平顺
  Vertical periodic irregularity cased in the rail rolling process
- 基础沉降引起的长波不平顺，1Hz 共振问题
  The long-wave irregularity caused by foundation settlement, 1Hz resonance problems

6、轨底坡 **Rail base slope**

- 定义：轨底与轨道平面之间所形成的横向坡度
- **Definition: Between rail flange and rail plane formed by the transverse slope**
- 目的：与车轮踏面匹配，钢轨轴心受力，轮轨接触居中，提高横向稳定性，减轻轨头不均匀磨耗，延长使用寿命
  Purpose: Match the wheel tread, stress in the axis of rail, Wheel/rail contact center, improve the lateral stability, reduce the rail head uneven abrasion, prolong the service life.

- 设置值 Settings：1965 年前 1/20；1965 年后为 1/40，法铁建议采用 1：20
- 偏差 Deviation：不大于 1：12，不小于 1：60
- 根据光带判断轨底坡是否合适，光带偏内，轨底坡不足
  The appropriateness of rail base slope is judged according to the light band , and it is deficiency when the light band is biased inside.
- 曲线内轨可适当加大轨底坡
  The inner rail can increase the rail base slope appropriately in curve lots.

第四讲 曲线轨道轨距加宽
Part4: Track gauge widening in curve

1、加宽原因与方法
reasons and methods for widening

- 加宽原因：曲线半径小时，为使机车车辆顺利通过曲线；不致被楔住或挤开轨道；减小横向作用力；减少磨耗
  Reasons: To get through the curve smoothly for locomotive when the Curve radius is small; not to be wedged or crowded out track; reduced lateral forces; reduce abrasion.
- 加宽方法：将曲线轨道内轨向曲线中心方向移动，外轨位置则保持与轨道中心半个轨距不变
  Methods: The inner rail curved track moves along to the center of the curve, while the outer rail remains half of gauge to the track.
- 加宽值：与机车车辆转向架在曲线上的几何位置有关
  Widening values: depending on the geometric position of locomotive bogies in the curve

2、转向架内接形式
Internal Connection from of bogie

- 类型：斜接、自由内接 、楔形内接、正常强制内接，游间存在所引起
  Type: Diagonal inscribing, free inscribing, wedge inscribing, normal forced inscribing, it is caused by moving clearances
- 斜接：转向架外侧最前位车轮轮缘与外轨作用边接触，而内侧最后位车轮轮缘与内轨作用边接触
  Diagonal inscribing: The outer front wheel flange on the frame or bogie of the rolling stocks is in contact with the gauge line of the outer rail, while the inner rear wheel flange is in contact With the gauge line of the inner rail
- 原因：轨距过宽，也称强制内接
  Too broad gauge, also known as forced internal
- 自由内接：转向架的外侧最前位车轮轮缘与外轨作用边接触，其它各轮轮缘无接触地在轨道上自由行驶，理想状况
  Free inscribing: The outer front wheel flanges on the frame or bogie of the rolling stocks is in contact with the gauge line of the outer rail while

all other wheel flanges run freely along the track without any con-tact with the rail and with its rear axle coincides with the perpendicular radius of the curve

- 楔形内接：转向架最前位和最后位外侧车轮轮缘同时与外轨作用边接触，内侧中间车轮（轴数为奇数）或靠近中间的两轮（轴数为偶数）轮缘与内轨作用边接触，轨距过小
- **wedge inscribing :The outer front and outer rear wheel flanges on the frame or bogie of the rolling stocks are in contact with the gauge line of the outer rail simultaneously while the inner middle wheel flange (with odd number of axles) or the inner two wheel flanges nearest to the center of the rolling stocks (with even number of axles) are in contact with the gauge line of the inner rail and with the perpendicular radius of the curve passes through the middle point of the frame or bogie**
- 正常强制内接：为避免楔形内接，对楔形内接所需轨距增加 δ min/2
  Normal forced inscribed: To avoid wedge inscribing , add a half moving clearances on the wedge inscribing on the required

3、轨距加宽原则
Gauge widening principle

- 保证大多数的车辆能以自由内接形式通过曲线
  Ensure that the majority of vehicles get through the curve in the form of freedom inscribing.
- 保证固定轴距较长的机车通过曲线时，不出现楔形内接，但允许以正常强制内接形式通过
  Ensure that when the locomotive with a longer fixed wheelbase get through the curve , wedge inscribing is not allowed, but the normal forced inscribing is ok.
- 保证车轮不掉道，即最大轨距不超过容许限度
  Ensure that the wheels cannot be off the track, namely, the maximum gauge does not exceed the permissible limit.

4、根据车辆条件确定轨距加宽
Determined the gauge widening according to vehicle conditions

- 以自由内接形式通过曲线所需最小轨距
  The minimum required in the form of free inscribed by curve track

$$S_f = q_{\max} + f_0;\quad f_0 = \frac{L^2}{2R};\quad e = S_f - S_0$$

S_f —— 自由内接所需加宽（**Needing widen of free inscribing**）
q_{max} ——最大轮对宽度（**Maximum width of wheel**）
f_0 ——外矢距（**The vector distance**）
S_0 ——直线轨距（**Track gauge of Straight line**）
L ——转向架固定轴距（**Bogie wheelbase**）
R ——曲线半径（**Radius of the curve**）
e ——轨距加宽值（**Slacking of gauge**）

5、根据机车条件检算轨距加宽

Review the gauge widening according to locomotive conditions

- 许机车按正常强制内接形式通过曲线
  Locomotive get through the curve in form of normal forced inscribing
- 楔形内接 **Wedge inscribing**

$$S_w = q_{\max} + f_0 - f_1 \quad ; \quad f_0 = \frac{L_{01}^2}{2R} ; \quad L_{01} = \frac{L_1 + L_2 + L_3}{2}$$

f_0—前后两端车轴外轮在外轨处所形成的矢距

f_1—中间两个车轴的内轮在内轨处形成的矢距

- 正常强制内接 normal forced inscribing

$$S_w' = S_w + \frac{1}{2}\delta_{\min}$$

6、曲线轨道的最大允许轨距

The maximum allowable track gauge in curve

- 原则：保证安全、不掉道
  Principles: ensure safety and not be off the track
- 最不利条件：一侧车轮轮缘贴靠钢轨时，另一车轮 1:10 斜坡段，应全部在轨头顶面范围内滚动
  The most adverse conditions: when the one side of the wheel flange abuts rails, the other wheels, 1:10 ramp segment, should roll fully within the scope of the rail head surface.
- 计算公式 **Formula**

$$S_{\max} = d_{\min} + T_{\min} - \varepsilon_r + a - r - \varepsilon_s$$

d_{min} —车辆轮最小轮缘厚度 22mm（**Minimum vehicle wheel rim thickness is 22mm**）

T_{min} —车轮最小轮背内侧距离 1350mm（**Minimum distance between wheel back inside of the wheel is1350mm**）

ε_r —车轴上弯时轮背内侧距离缩小量 2mm（**Amount of axle wheel back distance inside corner is 2mm**）

a —轮背至踏面斜度为 1:20 与 1:10 变坡点的距离 100mm（**Round back to tread gradient is 1:20 and 1:10, Changing slope distance is 100mm**）

r —钢轨顶面圆角宽度 12mm（**Rail surface fillet width is 12mm**）

ε_s —钢轨弹性挤开量 2mm（**Rail elastic pushed out is 2mm**）

S_{max}=22+1350-2+100-12-2=1456mm

- 各标准间的统一
  The unified standards
- 轨距偏差允许值 6mm
  Allowable value of gauge deviation is 6mm
- 最大加宽允许值 15mm
  Maximum allowable widening value is 15mm
- 标准轨距 1435mm
  Standard gauge is 1435mm

- 合计 1456mm
  Total is 1456mm

三、教学重点

1. 轨道几何形位的基本元素、意义和标准；

   The basic elements of track geometry, meaning and standard;

2. 轨道曲线轨距加宽和外轨超高的计算方法；

   The calculation method of track gauge widening and Outer rail superelevation in curve;

3. 缓和曲线的计算方法。

   The calculation method of easement curve.

四、专业思想培养

1. 根据具体的轨道几何形位结构，重点介绍轮轨关系，轨道曲线结构的设计思想；

Depending on the track geometry structure, emphasis on the wheel/rail relationship and rail curve structure design idea;

3. 了解轨道几何形位的重要性以及轨道曲线的设计严格标准的意义。

Understand the importance of track geometry and the meaning of rail curve design strict standards.

五、布置作业

1. 根据车辆条件计算轨距加宽；

Calculate according to the condition of vehicle gauge widening;

2. 计算缓和曲线长度。

Calculate length of easement curve.