第六章 结构防火技术
Chapter 6 Fire-resistance Structure

火灾和建筑防火基本知识

Introduction to Fire Disaster and Fire Protection of buildings

结构、构件的耐火性能

Fire Resistance of Structures and Structural Components

建筑防火设计

Fire Protection Design of buildings

结构抗火设计

Fire Resistance Design of Structures

6.1 Introduction to Fire Disaster and Fire protection of buildings

Introduction

人类进步、社会发展离不开火，但是火如果失去控制，反过来会危害人类。Fire is indispensable to the development of human society. However, fire will be harmful to human if it is out of control.

Definition：

火灾是**由于在时间和空间上失去控制的燃烧所造成的灾害。Fire hazards are the disaster caused by burning out of control over time and space.**

6. 1. 1 火灾分类 Types of Fire hazards

- **火灾分类 Types of Fire hazards**
  - 按照物质燃烧特性将火灾分为A、B、C、D E五类
  - **A类火灾：**固体物质火灾，具有有机物质，产生灼热的灰烬，如木材、棉、毛、麻和纸张等
  - **B类火灾：**液体火灾和可熔化的固体物质火灾。如汽油、煤油、沥青和石蜡等

  Fire hazards are classified into A, B, C， D and E five types according to the characteristics of burning materials

  - Type A: Burning of solid materials such as wood, cotton, linen, and paper that contains organic substances and produces hot ashes.
  - Type B: Burning of liquids and melting solids such as Gasoline, kerosene, asphalt and paraffin.

6. 1. 1 火灾分类 Types of Fire hazards

- **火灾分类 Types of Fire hazards**
  - **C类火灾：** 气体火灾。如煤气、液化气、甲烷、乙炔等
  - **D类火灾：** 金属火灾。如钾、纳、镁、锂等
  - E类火灾**：** 指带电设备火灾
  - Type C: Burning of gases such as gas, liquefied petroleum gas, methane, acetylene etc.
  - Type D: Burning of metal such as Potassium, sodium, magnesium, lithium etc.
  - Type E: Burning of electrical equipment

火灾发生次数最多、损失最为严重的当属建筑火灾

However, the most common and devastating Fire hazards are building fire.

●火灾的巨大危害 Devastation of Fire hazards

- **case1: Fire hazard of Dongdu commercial building In Luoyang**

time：2000年12月25日19时；
地点：河南洛阳东都商厦；
起火原因：违章电焊火花落入沙发起火；
火灾损失：不详；
火灾伤亡：造成309人死亡；

- **case 2: Fire hazard of friendship hotel in Kelamayi Xinjiang火灾**

时间：1994年12月8日16时；
发生地点：新疆克拉玛依友谊馆；
起火原因：电线短路引燃舞台幕布起火；
火灾损失：不详；
火灾伤亡：造成325人死亡（其中288人是8－14周岁中小学生）；

Case 3: fire in Petrochemical Plant in Lanzhou

发生时间：2010年1月7日；

发生地点：中石油兰州石化303厂；

起火原因：原料罐区石油罐发生闪爆；

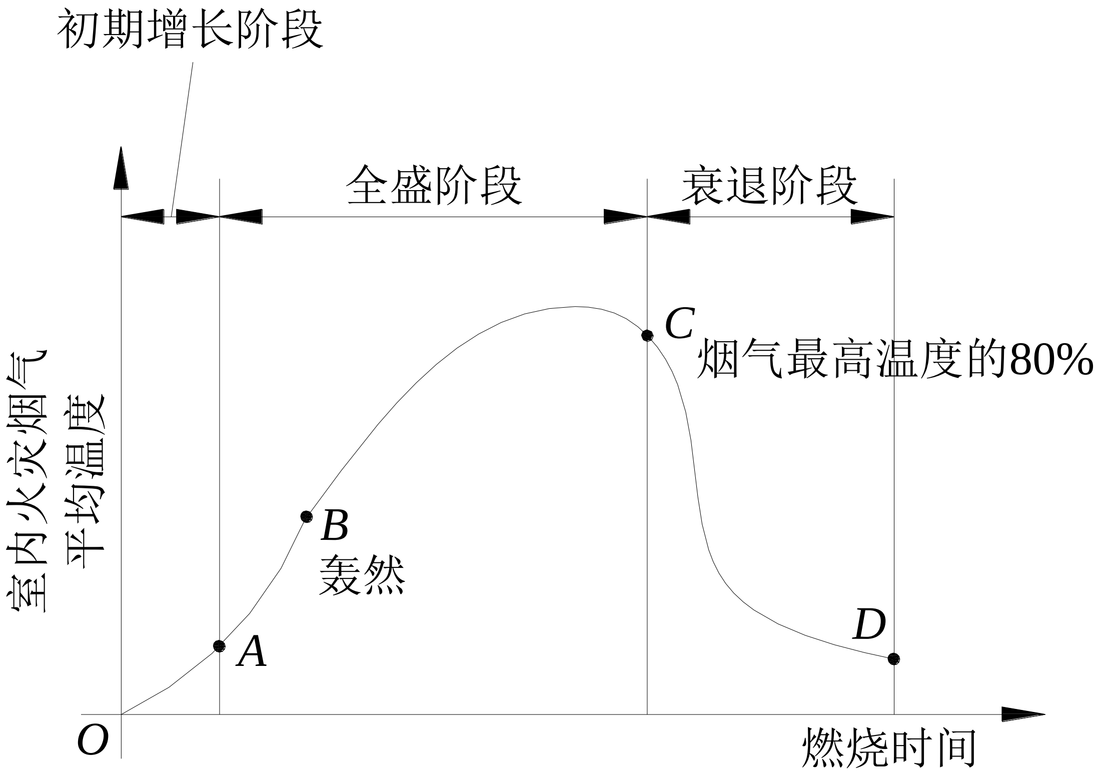
火灾伤亡：造成6人死亡，五人失踪

6.1.2 Characteristic of building fire

- **建筑起火的原因 Causes of building fire**
  - 生活和生产用火不慎
    Careless usage of fire in life and production
  - 违反生产安全制度
    Violation of safety production rule
  - 电气设备设计、安装、使用及维护不当
    Inappropriate design, installment, usage and maintenance of electrical equipment
  - 自然现象引起
    Natural phenomenon
  - 人为纵火
    Arson
  - 建筑布局不合理
    Unreasonable building layout

火灾的发展过程 Development of fire

- 火灾初期增长阶段、火灾全盛阶段、火灾衰退阶段
  initial growth stage, full burning stage， fire recession stage .



- **火灾的发展过程 Development of fire**
  - □初期增长阶段特征：火灾燃烧范围不大，火灾仅限于初始起火点附近；室内温度差别大，在燃烧区域及其附近存在高温，室内平均温度低；火灾发展速度较慢，在发展过程中火势不稳定；火灾发展时间因受点火源、可燃物质性质和分布以及通风条件影响，其长短差别很大。Characteristics of initial growth stage: The fire is limited to the initial fire point. The temperature indoor is very different that the temperature in the combustion area and its vicinity is higher while the average temperature indoor is lower. The development of fire is slow and unstable and its duration is greatly influenced by the ignition source, the properties and distribution of combustible materials and the ventilation conditions.
  - □初期增长阶段是灭火的最有利时机，也是人员安全疏散的最有利时段 The initial growth stage is the most favorable time for fire fighting and safe evacuation of peoples.

- full burning stage:

在火灾初期增长阶段后期，火灾范围迅速扩大，当火灾房间温度达到一定值时，聚积在房间内的可燃气体突然起火，整个房间都充满了火焰，房间内所有可燃物表面部分都卷入火灾之中，燃烧很猛烈，温度升高很快。

In the end of initial growth stage, the fire area expanded rapidly. When the room temperature reaches a certain value, the combustible gas accumulated in the room suddenly caught fire and the room is full of flame. All the fuel surface are involved in the fire. The combustion is fierce and the temperature rises rapidly.

□房间内局部燃烧向全室性燃烧过渡的这种现象称为轰燃。轰燃是室内火灾最显著的特征之一，它标志着火灾全面发展阶段的开始。对于安全疏散而言，人们若在轰燃之前还没有从室内逃出，则很难幸存。

This phenomenon, commonly called flashover, is the transition from the local combustion to the whole combustion. Flashover is one of the most prominent features of indoor fire, it marks the beginning of the full burning stage. For safe evacuation, it is difficult to survive, if people have not been out of the room before the flashover.

轰燃的特征 Characteristics of flashover：

- 室内可燃物猛烈燃烧:

  Fierce burning of the indoor fuel

- 火灾温度呈直线上升并达到最高点

  The temperature rise straightly up to the highest point.

- 燃烧稳定，燃烧速度几乎不变。可燃物烧毁质量占火灾烧毁总质量的80%

  The combustion is stable with a constant speed. The burning mass is 80% of the total mass in fire.

- 火灾衰退阶段 fire recession stage

随着室内可燃物的不断减少，火灾燃烧速度递减，进入熄灭阶段。With the decrease of indoor fuel, the burning rate is decreasing and enters the quenching stage.

- 特征 Characteristics：
  - 室内可燃物减少，温度开始下降
    the indoor fuel decreases and the temperature starts to drop
  - 温度下降的速度与火灾持续时间有关，火灾持续时间长，温度下降速度小，火灾持续时间短，温度下降速度大
    The drop speed of temperature is related to the duration of fire, the longer duration of fire is, the lower the temperature drops. Conversely, the temperature drops faster, when the fire duration is short.
  - 火灾衰退阶段的初期，温度仍然很高，火势很猛，仍对周围有很多威胁。
    In the early stage of fire recession , the temperature is still high and the fire is fierce, which is still a lot of threats to the surroundings

6.1.3.建筑材料的耐火性能
Fire-resistance of building materials

- **材料的耐火性能** Fire resistance of the materials

- 材料的燃烧性能 Combustion properties

  可燃性，火焰特征，燃烧速度，发热量，燃烧方式等

  combustibility, flame characteristics, combustion speed, calorific value, combustion mode etc.

  可分为非燃烧体、难燃烧体、可燃燃烧体 和易燃烧体

  Building materials are classified as non-combustible , difficult-burning, combustible and easy-combustible materials.

- 材料的导热性 Thermal conductivity

  导热性好的非燃烧材料，往往耐火防火性能差

  Non-combustible material with good thermal conductivity often has a poor fire resistance performance such as steel.

- 材料的隔热性能 thermal insulation performance

6.1.3. Fire resistance of building materials

- Fire resistance of the materials

□材料在高温下的物理力学性能

Mechanical properties of materials at high temperature

高温下或高温后，材料的力学性能随温度的升高而变化规律。当达到一定温度时，结构丧失承载力，构件失稳，或爆裂。

The mechanical properties of material will change with the temperature increase. When the temperature reaches a certain value, the structure loses its bearing capacity, the components is unstable and even burst.

□ 材料的发烟性能 Smoking properties of materials

一方面使人窒息，另一方面遮挡视线而影响扑救和人员疏散

The smoke can choke people, block the sight and hamper the rescue and evacuation of people

□ 材料的毒性性能 toxicity of materials

材料热分解产生有毒物质随烟气扩散，将会产生更严重的危害

The toxic produced by the thermal decomposition of materials diffuses with the smoke, which will cause more serious damage.

6.1.4.建筑火灾对结构的破坏
Damage of building fire structures

- **火对结构的损伤 Damage of fire to structure**

- 建筑火灾对结构的破坏 Damage of building fire to structure

  timber structure:

  结构本身发生燃烧并不断削弱结构构件的截面，势必造成结构倒塌

  The burning of structure will continuously weaken the cross-section of structural components, which definitely leads to the collapse of structure

  Reinforced Concrete Structure and Steel Structures:

  材料本身并不燃烧, 强度和弹性模量降低，造成截面破坏或变形较大而失效、倒塌

  The material itself is not-burning. But the decrease of strength and elastic modulus will cause the failure and collapse of the cross section or larger deformation.

6.1.4. Damage of building fire to structures

- **火对结构的损伤 the damage of fire to structure**

□建筑火灾对结构构件的破坏

Damage of building fire to structural components

□ 常温下的适筋梁变为超筋梁;

The under-reinforced beam at normal temperature will change to over-reinforced beam

□ 连续梁抗火性能比简支梁好得多;

The continuous beam has much better fire resistance than the simply supported beam

□ 梁板构件的承载力明显降低，刚度虽然没有明显变化，但延性明显降低，发生脆性破坏;

The bearing capacity of the beams and slabs is obviously reduced. While the stiffness is not obviously changed, the ductility is greatly reduced and the brittle failure occurs;

楼板是火灾中最薄弱的环节 Floor is the weakest part in the fire.

6. 1. 4. Damage of building fire to structures

- **耐火极限 Fire-resistance limit**

□ 建筑构件的耐火性能 Fire resistance of building components

构件的燃烧性能和抵抗火焰燃烧的时间（耐火极限）

The combustion performance and the duration of resistance to flame burning of components (the limit of fire resistance)

耐火极限：对任一建筑构件按照标准时间-温度曲线进行耐火试验， 从受到火起作用时起，到失去稳定性或完整性被破坏或失去隔火作用时为止的时间

Fire resistance limit: the duration from the time when the fire acts on the building component to the time when it losses stability, integrity, fire insulation, or is destroyed by the fire when a building component is tested on a fire resistance test under the standard time-temperature curve,

6. 1. 4. Damage of building fire to structures

- **耐火极限 Fire resistance limit**

□耐火极限判定条件 criterion of fire resistance limit

非承重结构：丧失完整性；失去绝热性

Non-bearing structure: loss of integrity; loss of thermal insulation.

承重结构： 是否失去承载能力和抗变形能力

Bearing structure: lose the bearing capacity or the anti-deforming capacity

墙：发生坍塌，失去承载能力

Walls: Collapse ,or lost bearing capacity

梁或板：坍塌，失去承载能力，最大挠度超过L/20cm，失去抗变形能力

Beam or slab: collapse, loss of bearing capacity, the maximum deflection exceeds L/20cm and thus lose or the anti-deforming capacity

柱：坍塌，失去承载能力，轴向收缩变形速度超过3Hmm/min，失去抗变形能力，H为受火高度

Column: collapse, loss of bearing capacity, axial shrinkage deformation rate exceeds 3Hmm/min and thus lose the ability to resist deformation, H for the height of the fire

6.1.4. 建筑火灾对结构的破坏
Damage of building fire to structures

- **建筑的耐火等级 Fire-resistance Ratings**

《建筑设计防火规范》将多层建筑物的耐火性分为：一级、二级、三级和四级。

Design Code for building fire protection and prevention classified fire resistance ratings of building into 4 classes, class 1, class 2, class 3 and, class 4.

- 楼板直接承受荷载，受火影响大，因而耐火等级的评判以楼板为基准。
  The floor is subjected to the fire load directly, which is influenced mostly by the fire, so the fire resistance rating of building is based on that of floor.
  据统计：火灾持续时间2h内的占火灾总数95%，1.5h内的占88%，1h内扑灭的占80%；
  According to statistic data: The fire with a duration less than 2h accounts for 95% of the total fires, Fire with a duration less than 1.5h accounts for 88%, and fire that was extinguished within an hour accounts for 80%

6. 1. 4. 建筑火灾对结构的破坏
Damage of building fire to structures

- **建筑的耐火等级 Fire-resistance Ratings**

- 现浇混凝土楼板耐火极限为1.5h，为一级耐火等级。普通钢筋混凝土空心板耐火极限为1h，为二级耐火等级，达0.5h的为三级耐火等级。

  The fire resistance limit of cast-in-place concrete slabs is 1.5h, the first class. The fire resistance limit of ordinary reinforced concrete hollow slabs is 1h, class 2, and the limit is 0.5h,class 3.

- 《建筑设计防火规范》分级的标准为：大多数情况下能保持结构的支撑能力，再按构件的结构安全性大小分别确定梁柱构件的耐火极限。

  The classification standard of Fire-resistance ratings in the code is that the support ability of the structure can be maintained in most cases, and the fire resistance limit of the beam and column components can be determined according to its effect on structural safety.

表 3.2.1 厂房和仓库建筑构件的燃烧性能和耐火极限（h）

构件名称		耐火等级			
		一级	二级	三级	四级
墙	防火墙	不燃烧体 3.00	不燃烧体 3.00	不燃烧体 3.00	不燃烧体 3.00
	承重墙	不燃烧体 3.00	不燃烧体 2.50	不燃烧体 2.00	难燃烧体 0.50
	楼梯间和电梯井的墙	不燃烧体 2.00	不燃烧体 2.00	不燃烧体 1.50	难燃烧体 0.50
	疏散走道两侧的隔墙	不燃烧体 1.00	不燃烧体 1.00	不燃烧体 0.50	难燃烧体 0.25
	非承重外墙	不燃烧体 0.75	不燃烧体 0.50	难燃烧体 0.50	难燃烧体 0.25
	房间隔墙	不燃烧体 0.75	不燃烧体 0.50	难燃烧体 0.50	难燃烧体 0.25
柱		不燃烧体 3.00	不燃烧体 2.50	不燃烧体 2.00	难燃烧体 0.50
梁		不燃烧体 2.00	不燃烧体 1.50	不燃烧体 1.00	难燃烧体 0.50
		不燃烧体	不燃烧体	不燃烧体	难燃烧体

表 5.1.2 建筑物构件的燃烧性能和耐火极限（h）

构件名称		耐火等级			
		一级	二级	三级	四级
墙	防火墙	不燃烧体 3.00	不燃烧体 3.00	不燃烧体 3.00	不燃烧体 3.00
	承重墙	不燃烧体 3.00	不燃烧体 2.50	不燃烧体 2.00	难燃烧体 0.50
	非承重外墙	不燃烧体 1.00	不燃烧体 1.00	不燃烧体 0.50	燃烧体
	楼梯间、前室的墙 电梯井的墙 居住建筑单元之间的墙和分户墙	不燃烧体 2.00	不燃烧体 2.00	不燃烧体 1.50	难燃烧体 0.50

	疏散走道两侧的隔墙	不燃烧体 1.00	不燃烧体 1.00	不燃烧体 0.50	难燃烧体 0.25
	房间隔墙	不燃烧体 0.75	不燃烧体 0.50	难燃烧体 0.50	难燃烧体 0.25
柱		不燃烧体 3.00	不燃烧体 2.50	不燃烧体 2.00	难燃烧体 0.50
梁		不燃烧体 2.00	不燃烧体 1.50	不燃烧体 1.00	难燃烧体 0.50
楼板		不燃烧体 1.50	不燃烧体 1.00	不燃烧体 0.50	燃烧体
屋顶承重构件		不燃烧体 1.50	不燃烧体 1.00	燃烧体 0.50	燃烧体
疏散楼梯		不燃烧体 1.50	不燃烧体 1.00	不燃烧体 0.50	燃烧体
吊顶（包括吊顶搁栅）		不燃烧体 0.25	难燃烧体 0.25	难燃烧体 0.15	燃烧体

6. 2　建筑结构的耐火性能
Fire resistance performance of building structures

6.2.1 建筑材料的燃烧性能 Combustion performance of building materials

- 燃烧性能分级 Classification of Combustion performance
  - 燃烧性能：材料燃烧或遇火时所发生的一切物理、化学变化。着火的难易程度、火焰传播快慢及燃烧时的发热量，对研究火灾的发生和发展有重要意义。
  - 分级：非燃烧材料，难燃烧材料，可燃烧材料和易燃烧材料
  - Combustion performance: All physical and chemical changes that occur when the material is burning or exposed to fire. The difficulty of combustion, the spreading speed of the flame and the heat produced in combustion are of great value to the study of the occurrence and development of fire hazards.
  - Building materials can be classified as non-combustible , difficult-combustible, combustible and easy-combustible materials

6. 2 Fire resistance performance of building structures

6.2.1 建筑材料的燃烧性能 Combustion performance of building materials

- **非燃烧材料：**受到火烧或高温作用时不起火，不燃烧，不碳化，如花岗岩，水磨石水泥制品，钢材等。

  non-combustible materials: materials that can’t catch fire, burn, or carbonize when exposed to flame or high temperature in air. Examples: granite, terrazzo, cement products and, steel etc.

- **难燃材料：**在空气中受到火烧或高温作用时难起火，难碳化，火源移走后，燃烧或微燃立即停止。如刨花板，石膏板。

  difficult-combustible materials: Materials such as strand boards and plasterboards which are difficult to catch fire or carbonize in air when exposed to flame or high temperature in air. Or the combustion will stop if the fire source is moved away .

6. 2 Fire resistance performance of building structures

- 燃烧性能分级 Classification of Combustion performance
- **可燃烧材料：**受到火烧或高温作用时立即起火或微燃，离开火源后仍能燃烧或微燃，如天然木材，竹材。

  Combustible Materials: Materials including woods or bamboos that start to burn immediately when exposed to flame or high temperature and continue burning when the fire source is moved away。
- **易燃材料：**受到火烧或高温作用时，立即起火，且火焰传播速度快，如有机玻璃，泡沫塑料。
- Easy- combustible materials: Materials including organic glasses and foam plastics that starts burning immediately when exposed to fire or high temperature, and the fire spreads rapidly.

- 建筑用材
  - 无机材料
    - 混凝土、胶凝材料类
    - 砖、天然石材与人造石材类
    - 建筑陶瓷、建筑玻璃类
    - 石膏制品类
    - 无机涂料类
    - 建筑金属、建筑五金类
  - 有机材料
    - 各种功能性材料类等
    - 建筑木材类
    - 建筑塑料类
    - 装修及装饰性材料类
    - 有机涂料类
  - 复合材料
    - 各种功能性材料等
    - 各种功能性复合材料等

有机材料都具有可燃性，无机材料一般是非燃烧体。

Organic materials are all combustible, and inorganic materials are generally non-combustible

6.2.1 Combustion performance of building structures

- 常用材料的燃烧性能 Combustion performance of popular building materials
  - 钢材：非燃烧材料，在300~400℃时，钢的抗拉强度很快下降，600℃时失去承载能力。并且，在温度和应力的共同作用下，随时间推移会发生蠕变。冷加工钢筋和高强钢丝的耐火性能比低碳钢差。常采用隔热材料进行包封，散热，形成防火保护层。
  - Steel: Steel is non- combustible burning material. Its tensile strength will soon decline when the temperature is between 300~400℃ and the structures lose its bearing capacity when the temperature reaches 600 ℃. Moreover, steel will creep over time under the joint action of temperature and stress. The fire resistance properties of cold working steel and high strength steel wire are worse than those of low carbon steel. So heat insulation materials are often used for sealing, cooling, and form a fire protection layer.

- Combustion performance of popular building materials
  - 混凝土：非燃烧材料，混凝土的骨料决定它的耐火性能，是较好的耐火材料。
  - Concrete: concrete is a non-combustible burning material with a good fire resistance. And the aggregate of concrete determines its fire resistance.
  - 钢筋混凝土：非燃烧材料，但在温度升高时钢筋蠕变加大，温度升高更为明显，600 ℃后钢筋的粘结强度几乎丧失。
  - Reinforced concrete: reinforced concrete is non-combustible material. The creep of steel increases when the temperatures rise. the higher the temperature, the more obvious creep is. The cohesive strength of steel almost lose completely when the temperature is higher than 600 ℃.

- Combustion performance of popular building materials
  - 木材：可燃烧材料. 预热干燥：150℃以下，自由水，吸附水蒸发，木材干燥；热分解：200-500 ℃，半纤维素，木质素，纤维素化学分解；燃烧：260 ℃ 为木材起火的危险温度，400-460 ℃木材自行起火。

wood: a combustible material

Preheating and drying: When the temperature is below 150℃, free water and absorbed water evaporates and the wood dries.

Thermal decomposition: When the temperature reaches 200-500 ℃, the hemicellulose, lignin, cellulose in the wood decomposes chemically

Burning: 260 ℃ is the dangerous temperature of bursting into flame for wood. When the temperature reaches 400-460 ℃ the wood will starts to burn spontaneously.

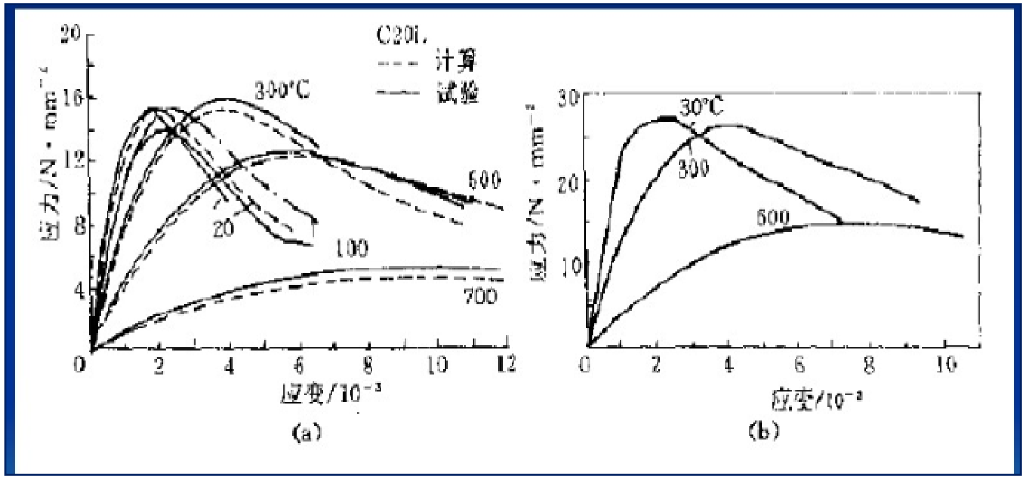
6.2 Fire resistance performance of building structures

6.2.2 建筑材料的高温性能 Mechanical properties of building materials at high temperature

□混凝土的高温性能（concrete）

随着温度的升高:

- 强度降低
- 弹性模量减小
- 应力-应变曲线趋于扁平
- 峰值应变增大



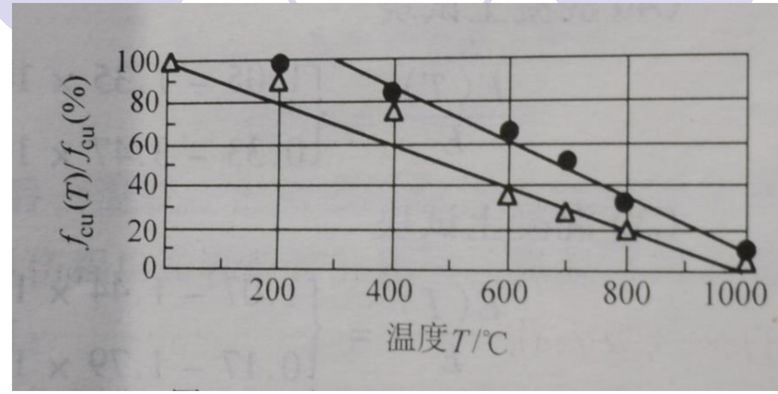
混凝土棱柱体, 圆柱体的受压应力-应变全曲线

With the temperature increases, the compression strength, elastic modulus of concrete decreases, the strain peak increases, and the stress-strain curve tends to be flat.

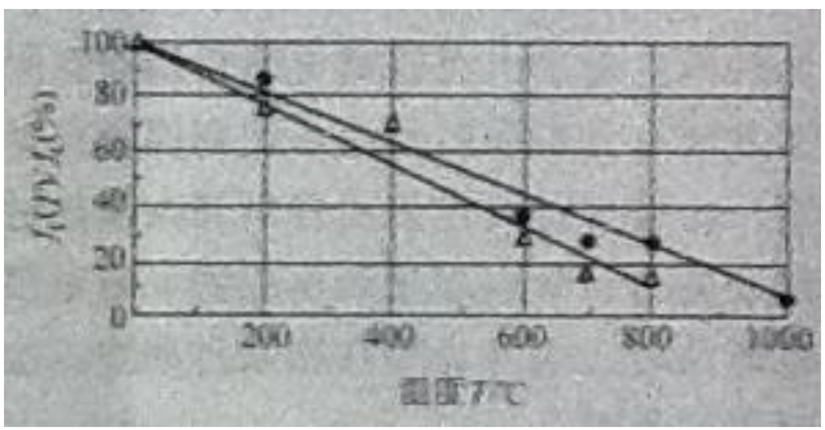
- 钢筋的高温性能
  - 在300~400℃时，其强度略有提高但塑性降低
  - 超过400℃时，强度降低，塑性增加，温度越高强度降低越显著，
  - 高温后钢筋强度有较大幅度恢复
  - 高温时弹性模量降低，高温后弹性模量无明显变化。
- Mechanical properties of steel bar
  - When the temperature is at 300~400℃, Strength increases slightly and plastics decreases.
  - When the temperature is over 400℃, Strength decreases, but plastics increases. The higher the temperature, the more obvious the decrease of strength is.
  - The strength recover greatly after high temperature.
  - The elastic modulus of steel bar decreases at high temperature, but almost has no changes after high temperature

6.2.3 建筑材料的高温后性能 Mechanical properties of building structures after high temperature

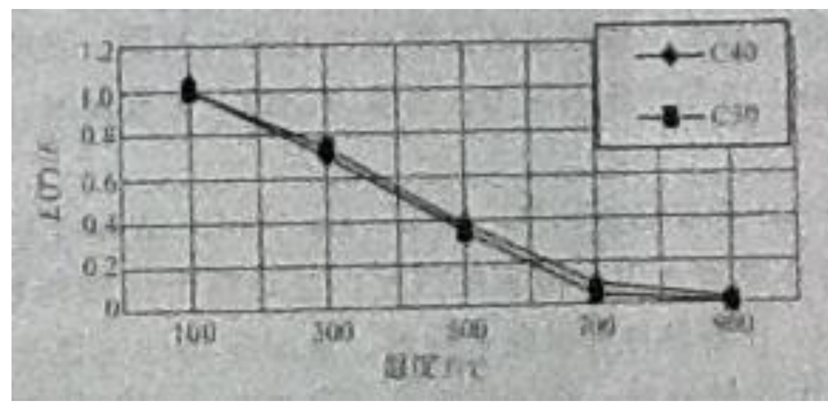
- mechanical properties of concrete after high temperature
  - 抗压强度 compressive strength：
    - 弹性模量: modulus of elasticity
    - *抗拉强度 tensile strength*



Compression strength-temperature curve



Tensile strength-temperature curse



Elastic modulus-temperature curve

6.2.3 建筑材料的高温后性能 Performance of building structures after high temperature

- Concrete:
  - 原因 Causes

    水化矿物脱水

    Dehydration of mineral water

    水化水泥内部组成部分变形不协调产生内应力

    The uncoordinated deformation of internal components of cement hydration induces internal

    骨料受热破坏

    Aggregates are damaged when heated

    水泥石与骨料间联系破坏

    Connections between cement stones and aggregates are damaged

mechanical properties of steel bar after high temperature

屈服强度 Yield strength

光圆钢筋在500℃前屈服强度较常温有所提高。500 ℃以后自然冷却和炉内冷却屈服强度下降。喷水冷却反而升高。

The yield strength of plain steel bars at less 500℃ increases compared to that of normal temperature. However the yield strength of steel bars at over 500℃ decreases after natural cooling or furnace cooling, while increases when cooled by spraying water.

螺纹钢筋在500 ℃前屈服强度较常温变化不大。500 ℃以后屈服强度下降。

The yield strength of rebar bars at less 500℃ almost keeps the same with that of normal temperature, while decreases when the temperature is over 500℃.

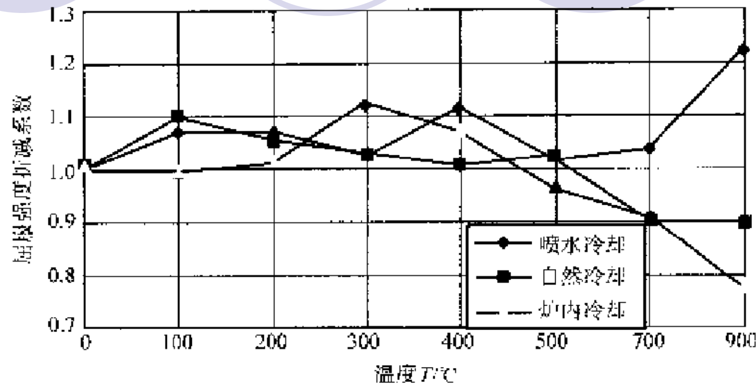
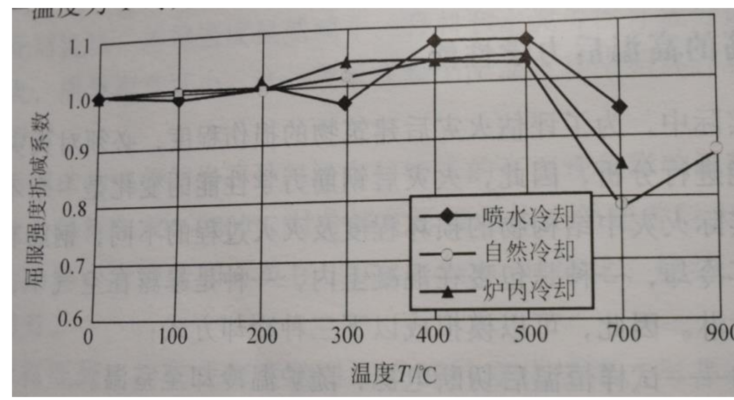


图 8-8　光圆钢筋屈服强度折减系数与温度的关系



螺纹钢筋屈服强度折减系数与温度的关系

mechanical properties of steel bar after high temperature

极限强度 Ultimate strength

500度之前有不同程度的提高，500度后，光圆钢筋的有下降趋势，900度时喷水冷却骤然上升.

The ultimate strength of plain bar increases when the temperature is less 500 ℃. When the temperature is above 500 ℃, the strength starts to decrease. And rises rapidly when cooled by spraying water at 900 ℃

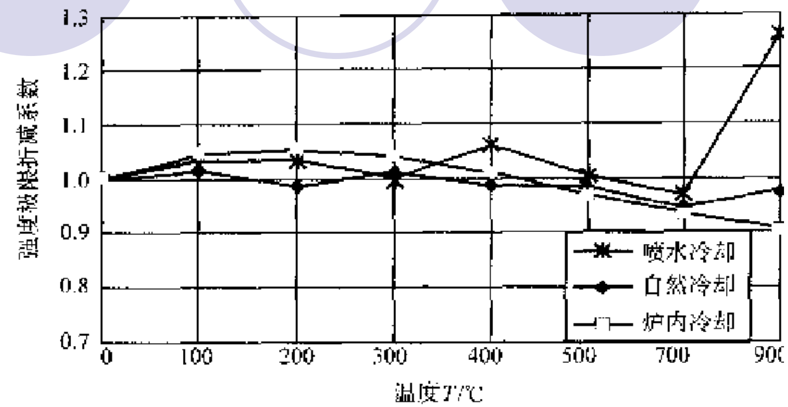


图 8-11 光圆钢筋极限强度折减系数与温度的关系

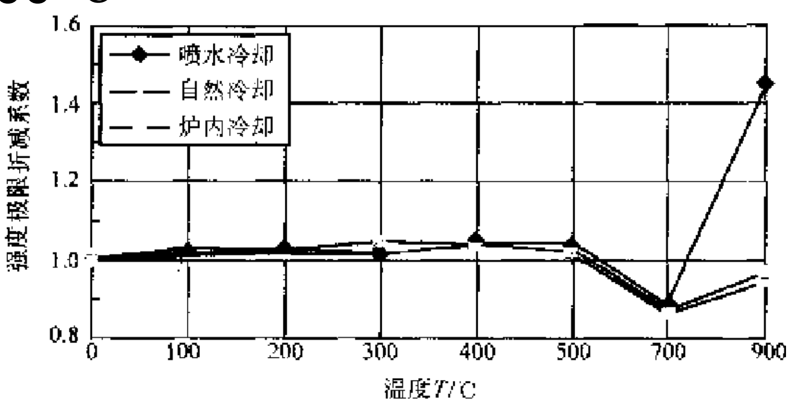


图 8-12 螺纹钢筋极限强度折减系数与温度的关系

Ultimate strength of rebar increases when the temperature is less 500 ℃. When the temperature is above 500 ℃, the strength starts to decrease，then increases when over 700 ℃, rises rapidly at 900 ℃ when cooled by spraying water

mechanical properties of steel bar after high temperature

弹性模量 Modulus of elasticity

- 高温冷却后弹模与常温基本相同
- The modulus of elasticity when cooled after heating is almost the same as that of normal temperature

钢筋应力-应变关系

- 温度小于500 ℃时，冷却后的应力-应变关系基本不变，大于500 ℃后，冷却后屈服段消失。
- Stress-strain relationship：When the temperature is less 500 ℃, the stress-strain relationship is almost keep same. When steel bar is heated over 500 ℃, then cooled, the yield stage disappears.

Bond strength of reinforced concrete

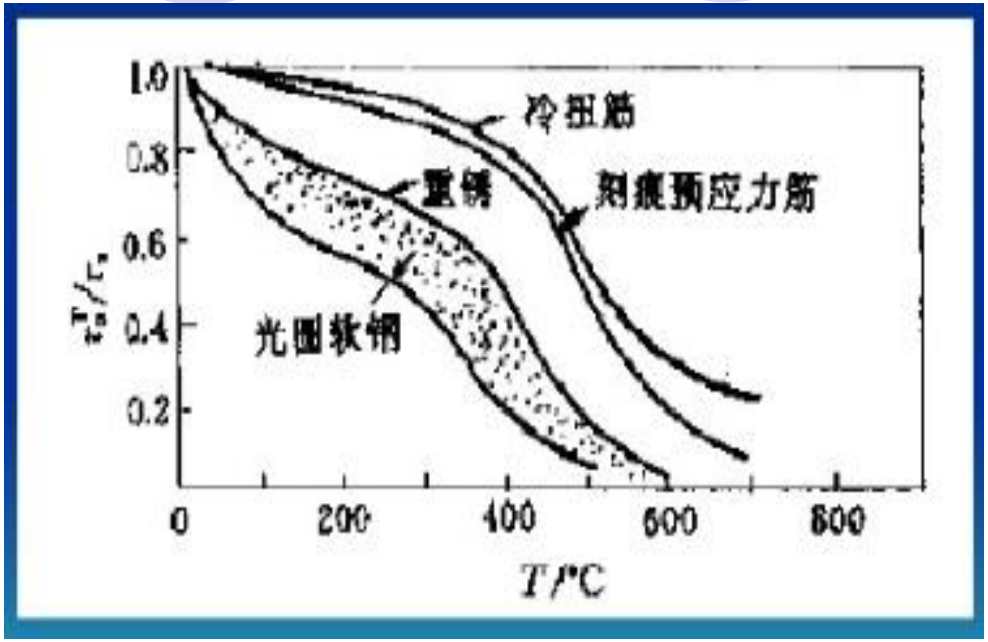
- 高温时和高温后混凝土强度降低，故粘结强度降低。

  The strength of concrete decreases at and after high temperature，so the bond strength decreases correspondently.
- 变形钢筋的粘结强度比光圆钢筋大得多。

  The bond strength of deformed bars is much greater than plain bars
- 高温下的粘结强度比冷却后的稍高。

  The bond strength is slightly higher at high temperature than after cooling
- 采用高温后损伤系数考虑火灾的不利影响。

  Therefore the unfavorable influence of fire hazards on bond strength should be considered by damage factor.



高温下钢筋与混凝土的粘结强度

Bond strength between steel and concrete at high temperature

6.3 建筑防火设计
Design of fire protection and prevention

- 建筑物耐火等级的确定 Determination of fire resistance class of buildings
- 建筑总平面布局与防火间距 The general layout of the building and the fire resistance distance
- 划分建筑内的防火分区和防烟分区 Division of the fire protection zone and the smoke protection zone
  - 防火分隔物：防火墙，防火门，防火窗等

    Fire barrier: fire wall, fire door, fire window, etc.
  - 对高层，重要公共建筑或无窗建筑及地下建筑的重要部位进行防烟设计

    Anti-smoke design is necessary for the important parts of high rise buildings, important public buildings, the buildings without windows and underground buildings.

6.3 建筑防火设计
Design of fire protection and prevention

- 设计避难层，避难通道，计算避难出口
  Design the evacuation floor and the evacuation passageway and the evacuation exit
- 设立防、排烟系统
  Set up smoke control system
- 设立火灾自动报警、广播和疏散诱导系统
  Set up fire automatic alarming, broadcast and evacuation guidance system
- 消火栓系统和自动灭火系统
  Fire hydrant system and automatic fire extinguishing system
- 建筑内部装修设计防火设计
  Fire prevention design of interior decorations

耐火等级由建筑物的重要性，高度及火灾荷载等因素决定，常根据建筑物的占地面积，长度和层数确定

The fire resistance rating is determined by the importance of building, the height and the fire load and other factors, which are often determined by the floor area, length and number of the building.

民用建筑的耐火等级、层数、长度和建筑面积

Fire resistance ratings, number of layers, length and area of civil buildings

耐火等级	最多允许层数	防火分区间		备注
		最大允许长度（m）	每层最大允许建筑面积（m^2）	
一、二级	不限	150	2500	1. 体育馆、剧院、展览建筑等的观众厅、展览厅的长度和面积可以根据需要确定 1. 托儿所、幼儿园的儿童用房及儿童游乐厅等儿童活动场所不应设置在四层及四层以上或地下、半地下建筑内
三级	5层	100	1200	1. 托儿所、幼儿园的儿童用房及儿童游乐厅等儿童活动场所和医院、疗养院的住院部分不应设置在三层及三层以上或地下、半地下建筑内 2. 商店、学校、电影院、剧院、礼堂、食堂、菜市场不应超过二层
四级	2层	60	600	学校、食堂、菜市场、托儿所、幼儿园、医院等不应超过一层

建筑总平面布局与防火间距
The layout of building and fire separation distance

- 建筑总平面布局 general layout of building
  - 进行居住小区规划时，考虑消防车的通行且设置消防车道，道路中心线间距不宜超过160m，消防车道穿过建筑物的门洞时，其净高和净宽不应小于4m，门垛之间的净宽不应小于3.5m；

    When planning residential building, the fire lanes should be considered, and the spaces between the centerline of fire lanes should not exceed 160m. When a fire lane runs through the door of building, its net height and width should not be less than 4m and the width between the gate stacks should not be less than 3.5m;

The layout of building and fire separation distance

- 建筑总平面布局 general layout of building
  - 设计小区院门时，考虑消防车通行所需的宽度和净高，并具有重型车辆的通行能力，考虑设回车道。

    When designing the gates of a residential community, the net height and width required by fire trucks should be considered, the roads should have the bearing capacity for heavy truck. And also the return path should also be taken into consideration
  - 室外消火栓的防护半径不应超过150m，消火栓的间距不应超过120m

    The radius of protection of outdoor fire hydrants should not exceed 150m, the fire hydrant distance should not exceed 120m.

The layout of building and fire separation distance

- 建筑总平面布局 general layout of building
  - 建筑物的封闭内院或天井，若短边超过24m，宜设进入内院的消防车道。
  - If the short side of an Enclosed courtyard or a patio building is more than 24m, it is necessary to set a fire lane leading to the inner courtyard.

The layout of building and fire separation distance

- 建筑物的防火间距 Fire separation distance of buildings

  建筑物之间留出的用于防止火灾蔓延的安全距离

Safe distance between buildings should be kept to prevent the spreading of fire hazards

一般民用建筑的防火间距

Fire separation distance between civil buildings

表 5.2.2 民用建筑之间的防火间距（m）

建筑类别		高层民用建筑	裙房和其他民用建筑		
		一、二级	一、二级	三级	四级
高层民用建筑	一、二级	13	9	11	14
裙房和其他民用建筑	一、二级	9	6	7	9
	三　级	11	7	8	10
	四　级	14	9	10	12

表 3.4.1 厂房之间及其与乙、丙、丁、戊类仓库、民用建筑等之间的防火间距（m）

名称			甲类厂房	乙类厂房（仓库）			丙、丁、戊类厂房（仓库）				民		
			单层或多层	单层或多层		高层	单层或多层			高层	裙房，单层或多层		
			一、二级	一、二级	三级	一、二级	一、二级	三级	四级	一、二级	一、二级	三级	四
甲类厂房	单层、多层	一、二级	12	12	14	13	12	14	16	13	25		
乙类厂房	单层、多层	一、二级	12	10	12	13	10	12	14	13	25		
		三级	14	12	14	15	12	14	16	15	25		
	高层	一、二级	13	13	15	13	13	15	17	13	25		
丙类厂房	单层或多层	一、二级	12	10	12	13	10	12	14	13	10	12	1
		三级	14	12	14	15	12	14	16	15	12	14	1
		四级	16	14	16	17	14	16	18	17	14	16	1
	高层	一、二级	13	13	15	13	13	15	17	13	13	15	1
丁、戊类厂房	单层或多层	一、二级	12	10	12	13	10	12	14	13	10	12	1
		三级	14	12	14	15	12	14	16	15	12	14	1
		四级	16	14	16	17	14	16	18	17	14	16	1
	高层	一、二级	13	13	15	13	13	15	17	13	13	15	1

6.4 结构抗火设计 Fire resistant design of structures

- 钢筋混凝土结构抗火设计 Fire resistant design of reinforced concrete structure

- 混凝土结构抗火设计要求：火灾下，结构达到承载力极限状态时的温度 T_d 应不小于耐火极限时间内结构的最高温度 T_m

  Fire resistance design requirements of concrete structure: During fire hazard, T_d, the temperature of a structure when it reaches bearing capacity limit, should not be less than the highest temperature T_m the structure reaches within the fire resistance limit.

$$T_d \geq T_m$$

或：在结构耐火设计极限时间内，结构的承载力应不小于各种作用产生的组合效应，即：

Or in the fire resistance limit the bearing capacity of structure should not be less than the combined effects of different actions, that is:

$$R_d \geq S_m$$

6.4 结构抗火设计 Fire resistant design of structures

- Fire resistant design of reinforced concrete structure

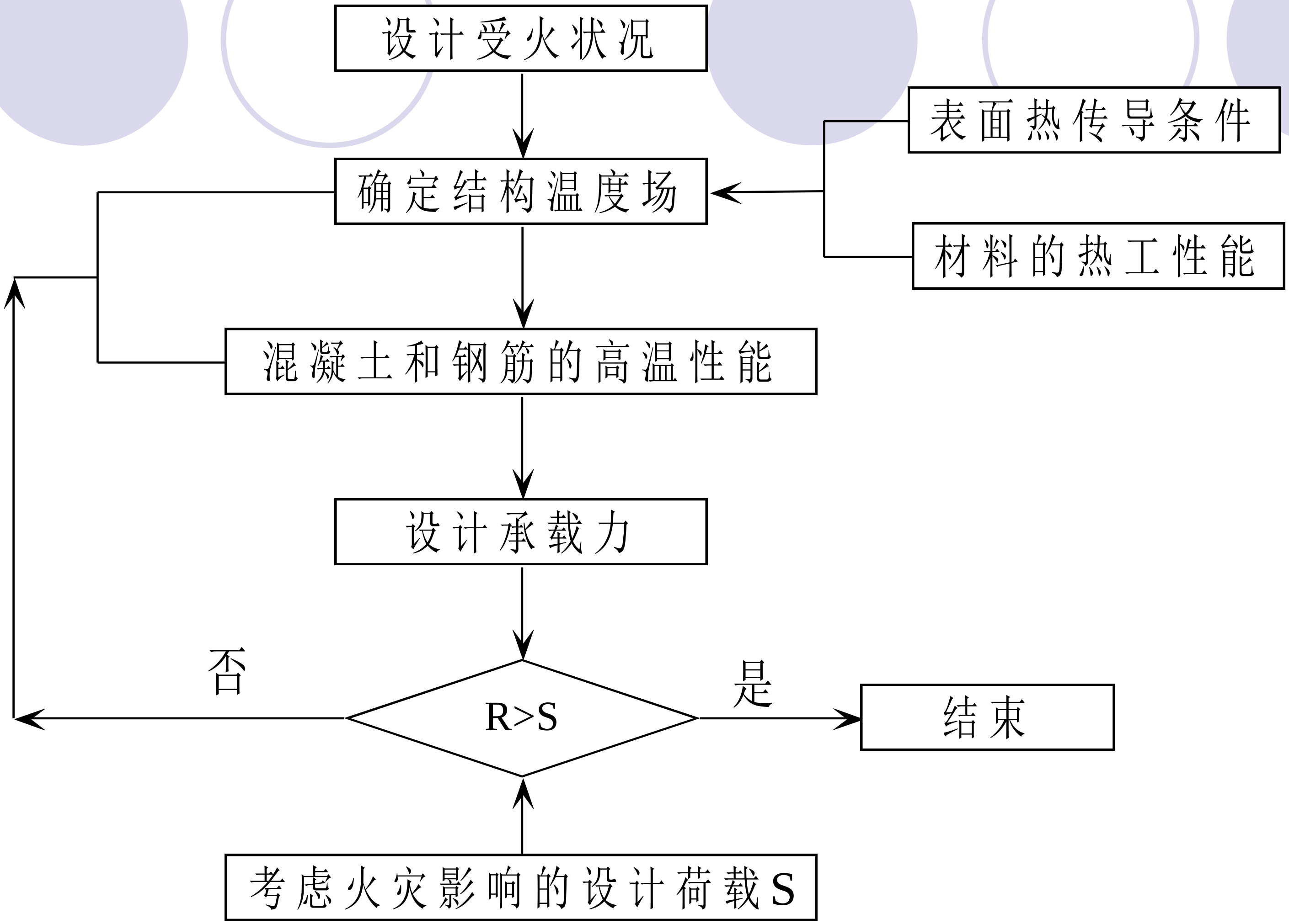
- 混凝土结构抗火设计计算流程

  Fire resistance design process of reinforced concrete structure

- 火灾荷载的确定 Determination of the fire load（热量Q/受火面积A）

火灾荷载指火空间内所以可燃物燃烧时产生的总热量值。分为固定性荷载，活动性荷载和随机性荷载

Fire load is the total heat quantity produced by the burning of all the combustible materials in the fire space. It is divided into dead loads, live loads and random loads



结构抗火设计流程

Fire resistant design procedure of structures

6.4 结构抗火设计 Fire resistant design of structures

- Fire resistant design of reinforced concrete structures

- 混凝土结构抗火设计方法 Fire resistant design method of reinforced concrete structure
- 基本假定 Basic assumptions：
  - 截面温度场已知 temperature field in cross section is given
  - 忽略截面初始裂缝和应力状况 the initial cracks and stress are neglected
  - 平截面假定 Plane section assumption
  - 钢筋与混凝土之间无相对滑移作用 There is no relative slip between steel bar and concrete
  - 忽略混凝土的高温抗拉作用
    The tensile strength of concrete at high temperature is neglected

6.4 结构抗火设计 Fire resistant design of structures

- Fire resistant design of reinforced concrete structures

□近似计算方法 Approximate calculation method

假设低于500℃时混凝土的高温抗压强度同常温抗压强度，高于500℃时强度为零，将原截面简化为与常温混凝土强度相等，面积较小的匀质截面，然后按普通混凝土构件进行设计。

If the temperature is lower than 500 ℃, the compressive strength of the concrete at high temperature is same as normal compressive strength. When the temperature is higher than 500 ℃, the compressive strength drops to zero. The original cross section is simplified as an equivalent smaller section with the same strength of normal concrete. It is designed same as normal concrete structural component.

- 钢结构抗火设计 Fire resistant design of steel structures

- 基于实验的传统抗火设计方法 Conventional fire resistant design method based on experiment
- 基于计算的构件抗火设计方法 Fire resistant design method based on calculation of structural component
- 基于性能的抗火设计方法 performance-based fire resistant design

（1）以性能为基础的防火设计方法是运用**消防安全工程学**的原理和方法，考虑火灾本身发生、发展和蔓延的基本规律，结合实际火灾中积累的经验，通过对建筑物及其内部可燃物的火灾危险性进行综合分析和计算，从而确定性能指标和设计指标。

The performance and design target are determined by analyzing and calculating the fire threats by buildings and the combustibles inside, combined with the experience accumulated in the real fire hazards, using the principles and methods of fire safety engineering, and considering the basic rules for the occurrence, development, and spreading.

- 钢结构抗火设计 Fire resistant design of steel structures

- 基于性能的抗火设计方法 performance-based fire resistant

（2）预设各种可能起火的条件和由此所造成的火、烟蔓延途径以及人员疏散情况，选择相应的消防安全工程措施，并评估消防安全目标是否已达到要求。

Preset potential conditions that cause burning, the subsequent fire hazards, their spreading routes and people evacuation; select the corresponding fire safety engineering measures to cope with; and assess if the fire safety engineering target is achieved.