Material, Methodology and Inspection Technology for Structural Joints in Modular Integrated Construction

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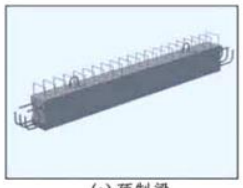
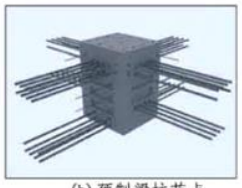
Contents

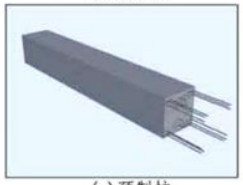
PART 01

Background and Significance

Prefabricated building


(a) 预制梁


(b) 预制梁柱节点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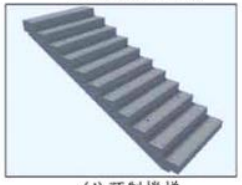

(d) 预制楼梯

《Outline of the Modernization Development of Construction Industry》

2020, above 20%
2025, above 50%

of new constructions will be **Prefabricated building**

Government support policy

Solve current problems

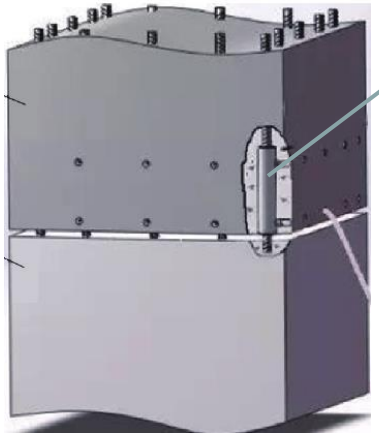
Industrialization
Fast construction speed
Reduce labor
Green
Environment friendly
Good overall benefit

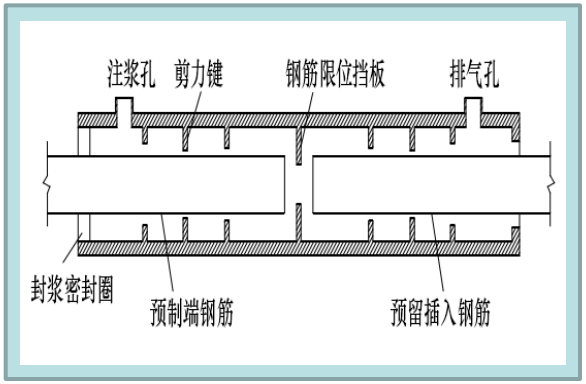
Advantages

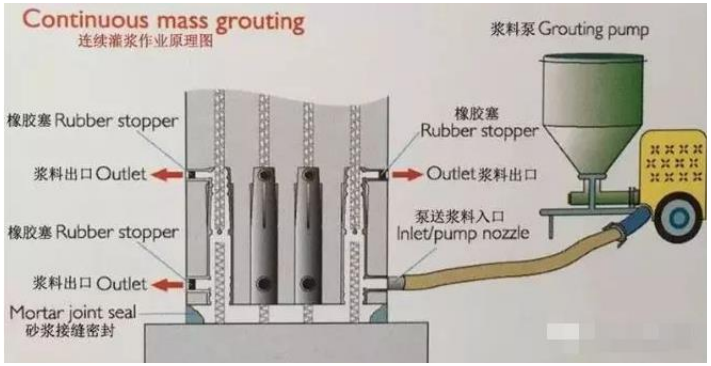
Joint connection

Connection method

- **Grout sleeve splicing**
- Grout anchor overlap
- Bolt connection
- Welding connection







The most common connection method

↓ Above 60%

Grout sleeve splicing

↓ Performance

Stability Safety Durability Seismic performance

PART 02

Introduction

Grout sleeve splicing

Grout sleeve

Rebar

Cementitious grout

灌浆套筒

- 结构形式
  - 全灌浆（整体式、分体式）
  - 半灌浆（整体式、分体式）
- 材料
  - 球墨铸铁

  - 钢
    - 碳素结构钢
    - 低合金结构钢

- 加工方式
  - 铸造
  - 机械加工
    - 切削加工
      - 滚压
      - 锻造挤压
      - 锻造滚压
    - 压力加工

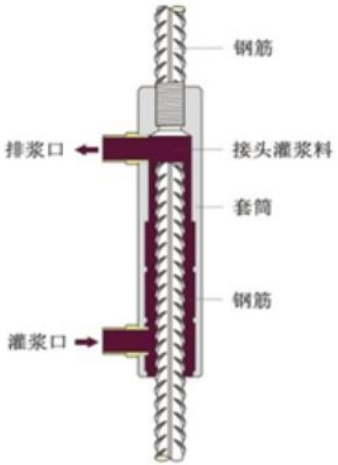
→ **Equivalent to cast-in-place**

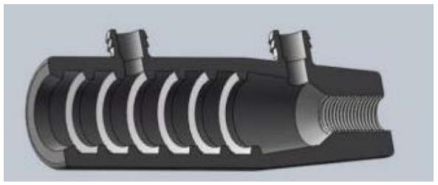
Good fluidity
Early strength
High strength
Slight expansion

Grout sleeve

Half grout sleeve

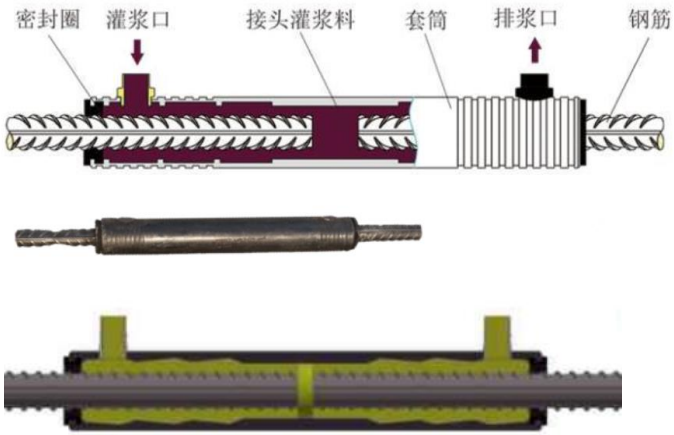
Grout + Mechanical connection
Prefabricated wall
Prefabricated column





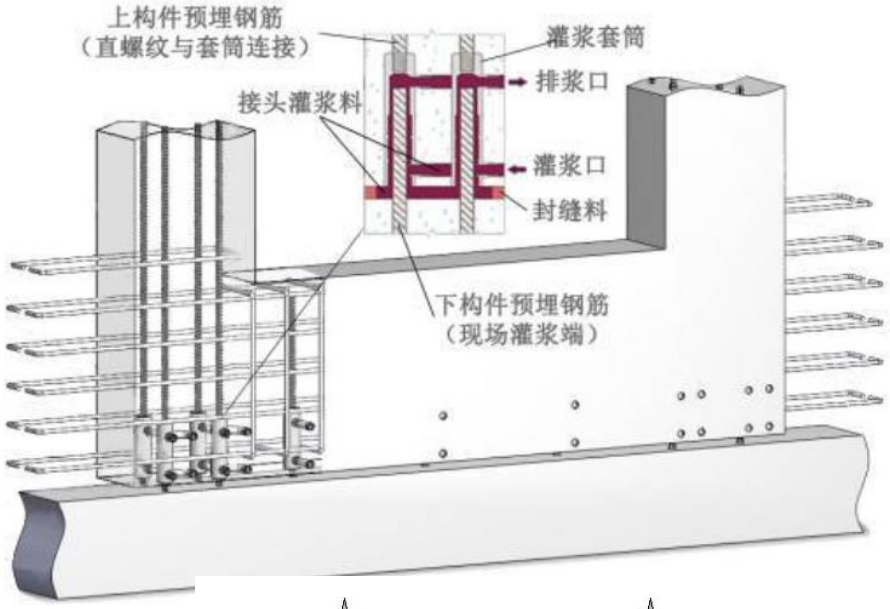
Complete grout sleeve

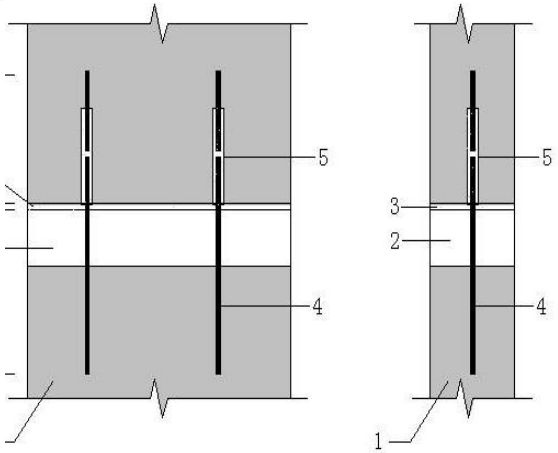
Grout + Grout connection
Mainly
Prefabricated beam



Application

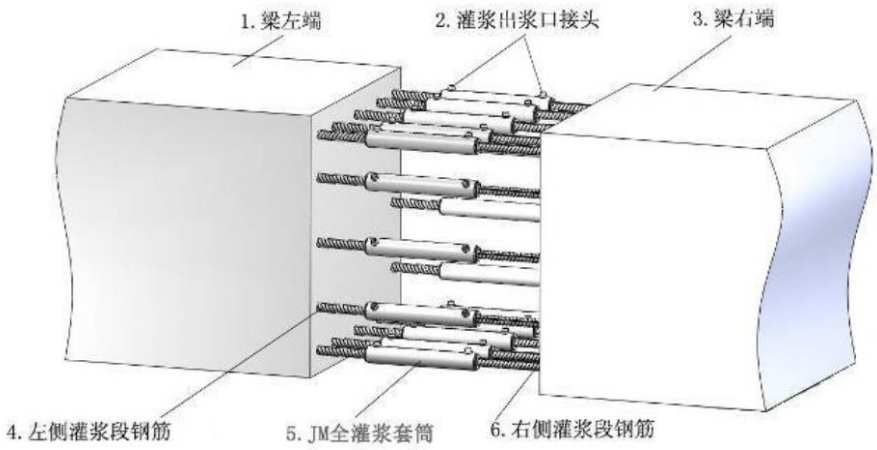
Prefabricated concrete shear wall

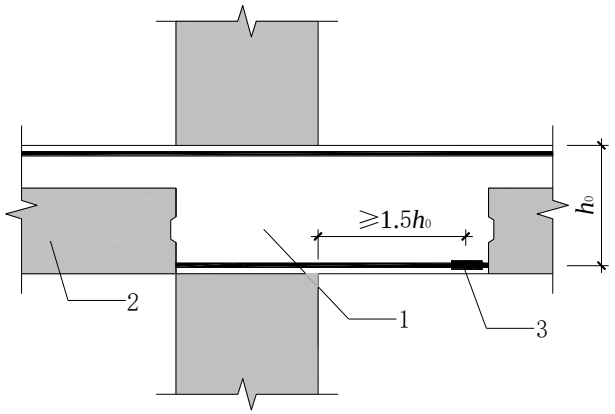




Application

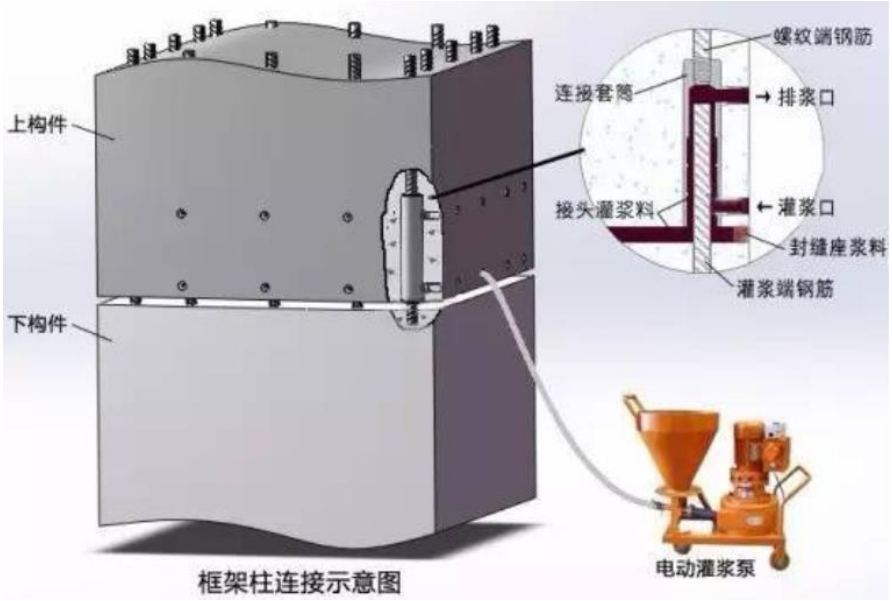
Prefabricated concrete frame beam



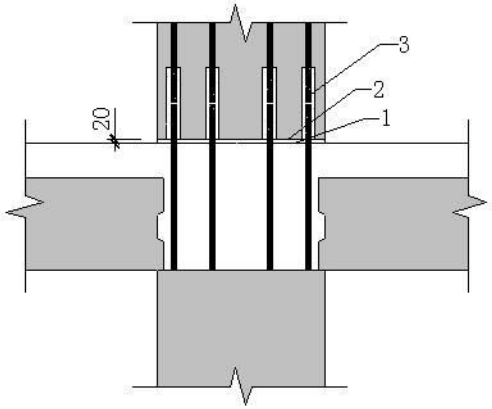


Application

Prefabricated concrete frame column



框架柱连接示意图

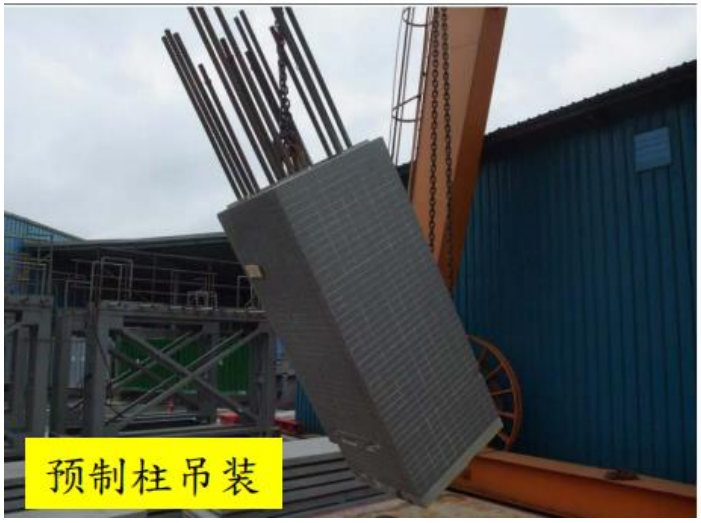


Installation process of frame column

Location

Gasket

Hoisting



Support

Installation process of frame column

Verticality

Airflow

Sealing

Grouting

Installation process of frame column

Mechanical grouting

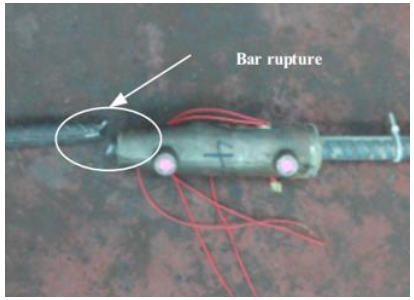
Manual grouting

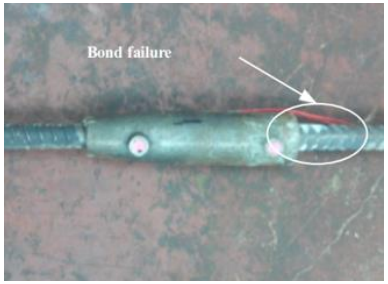
Influencing factors of connection quality

- Connection material
- Equipment and auxiliary
- Connection method

Construction and management person

Influencing factors of grout sleeve splicing





- Cementitious grout
  - Strength
  - Grouting defect
- Grout sleeve
- Rebar
  - Diameter
  - Anchor length

Related standards

《装配式混凝土建筑技术标准》GB/T 51231-2016 Architecture

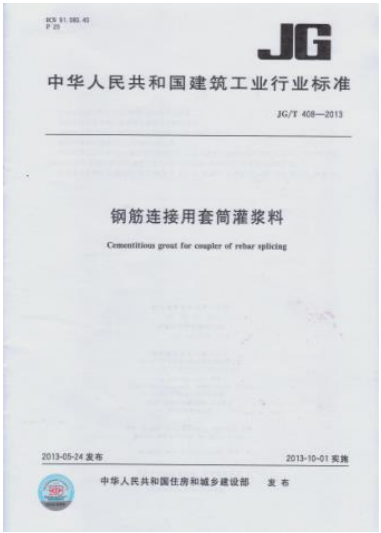
《装配式混凝土结构技术规程》JGJ 1-2014 Structure

《钢筋机械连接通用技术规程》JGJ107-2003 Mechanical connection

《钢筋连接用套筒灌浆料》JG/T 408-2013 Cementitious grout

《钢筋连接用灌浆套筒》JG/T 398-2012 Grout sleeve

《钢筋套筒灌浆连接应用技术规程》JGJ 355-2015 Application standard



PART 03

Standard requirements

Cementitious grout

Good fluidity　　High strength

Early strength　　Slight expansion

表 3.1.3-1　灌浆料抗压强度要求

Curing time 时间（龄期）	抗压强度（N/mm²）Compressive strength
1d	≥35
3d	≥60
28d	≥85

Cementitious grout

表 3.1.3-2 灌浆料竖向膨胀率要求

项目	竖向膨胀率（%）Vertical expansion rate
3h	≥0.02
Difference value 24h 与 3h 差值	0.02～0.50

表 3.1.3-3 灌浆料拌合物的工作性能要求

项 目		工作性能要求
Liquidity 流动度（mm）	Initial 初始	≥300
	30min	≥260
泌水率（%）		0

Grout sleeve

球墨铸铁灌浆套筒的材料性能 Cast iron

项　　目	性能指标
Tensile strength 抗拉强度 σ_b/MPa	≥550
断后伸长率 δ_5/%	≥5
球化率/%	≥85
硬度/HBW	180～250

钢质机械加工灌浆套筒的材料性能 Steel machining

项目	性能指标
Yield Strength 屈服强度 σ_s（N/mm²）	≥ 355
Tensile strength 抗拉强度 σ_b（N/mm²）	≥ 600
断后伸长率 δ（%）	≥ 16

Rebar

Anchor length of Rebar ≥ 8 times of rebar diameter

3.1.2 灌浆套筒应符合现行行业标准《钢筋连接用灌浆套筒》JG/T 398 的有关规定。灌浆套筒灌浆端最小内径与连接钢筋公称直径的差值不宜小于表 3.1.2 规定的数值，用于钢筋锚固的深度不宜小于插入钢筋公称直径的 8 倍。

表 3.1.2 灌浆套筒灌浆段最小内径尺寸要求

钢筋直径（mm）	套筒灌浆段最小内径与连接钢筋公称直径差最小值（mm）
12～25	10
28～40	15

The connection

3.2.2 钢筋套筒灌浆连接接头的抗拉强度不应小于连接钢筋抗拉强度标准值，且破坏时应断于接头外钢筋。

3.2.3 钢筋套筒灌浆连接接头的屈服强度不应小于连接钢筋屈服强度标准值。

3.2.4 套筒灌浆连接接头应能经受规定的高应力和大变形反复拉压循环检验，且在经历拉压循环后，其抗拉强度仍应符合本规程第 3.2.2 条的规定。

表 3.2.6 套筒灌浆连接接头的变形性能

项目		变形性能要求
对中单向拉伸	残余变形（mm）	$u_0 \leqslant 0.10\ (d \leqslant 32)$ $u_0 \leqslant 0.14\ (d > 32)$
	最大力下总伸长率（%）	$A_{sgt} \geqslant 6.0$
高应力反复拉压	残余变形（mm）	$u_{20} \leqslant 0.3$
大变形反复拉压	残余变形（mm）	$u_4 \leqslant 0.3$ 且 $u_8 \leqslant 0.6$

Centring

uniaxial tension

Elongation

Off-center

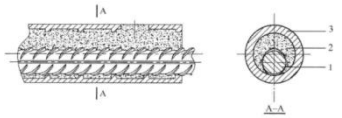


图 2 偏置单向拉伸接头的钢筋偏置示意图
1—在套筒内偏置的连接钢筋；2—灌浆料；3—灌浆套筒

High stress

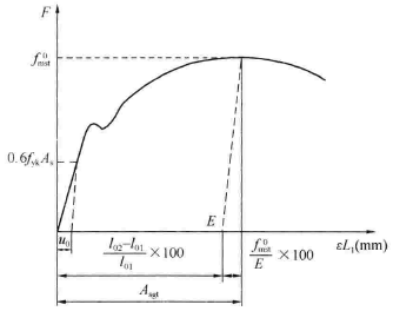
Large deformation

repeated tension and compression

The connection

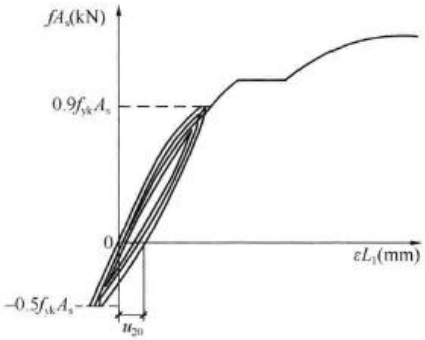
表 A. 1. 3　接头试件型式检验的加载制度

试验项目		Loading system 加载制度
单向拉伸		0→0.6f_{yk}→0（测量残余变形）→最大拉力（记录极限抗拉强度）→破坏（测定最大力下总伸长率）
高应力反复拉压		0→(0.9f_{yk}→−0.5f_{yk})→破坏（反复 20 次）
大变形反复拉压	Ⅰ级 Ⅱ级	0→（2ε_{yk}→−0.5f_{yk}）→（5ε_{yk}→−0.5f_{yk}）→破坏（反复 4 次）（反复 4 次）
	Ⅲ级	0→（2ε_{yk}→−0.5f_{yk}）→破坏（反复 4 次）



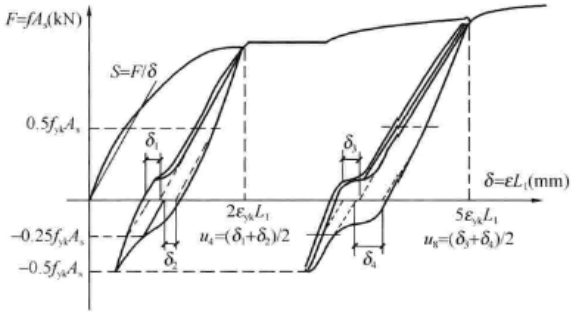
单向拉伸

Uniaxial tension



高应力反复拉压

High stress repeated tension and compression



大变形反复拉压

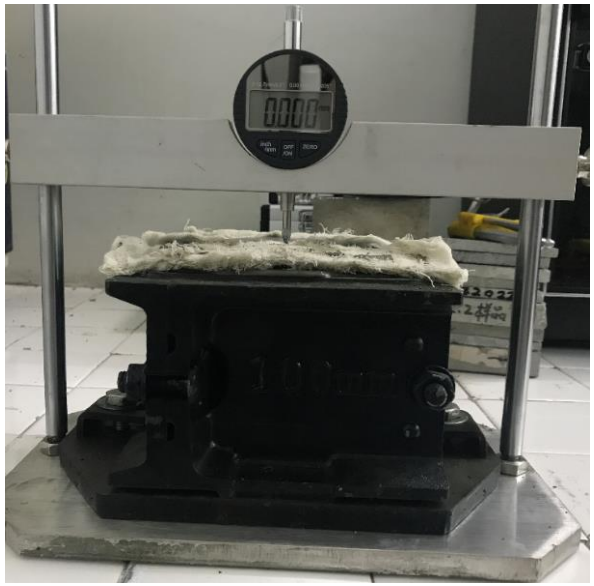
Large deformation repeated tension and compression

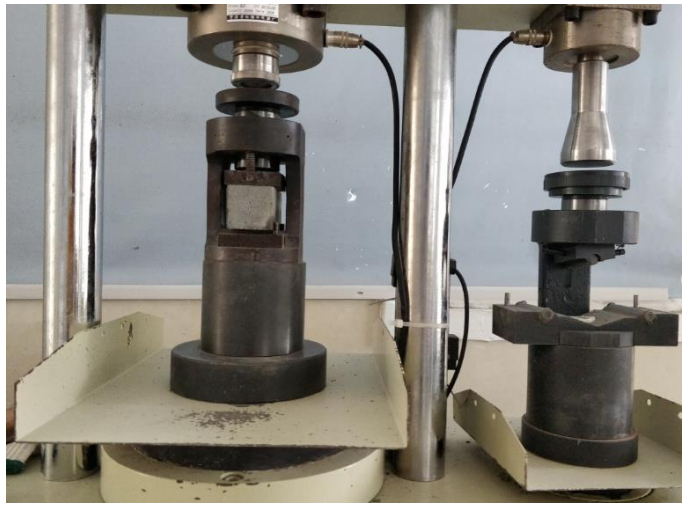
PART 04

Research on cementitious materials

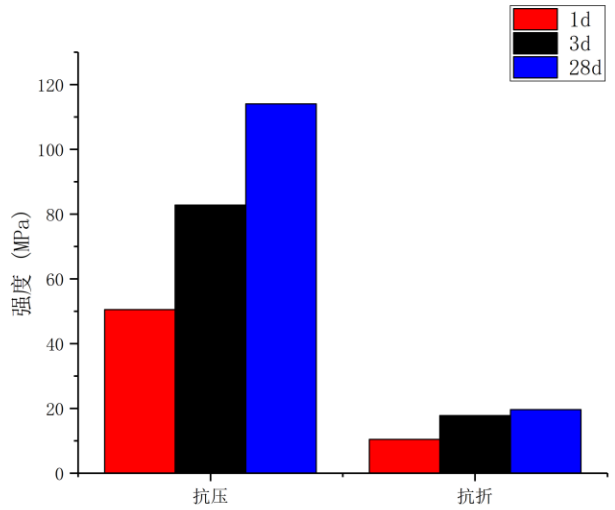
Research on cementitious materials

Cementitious grout



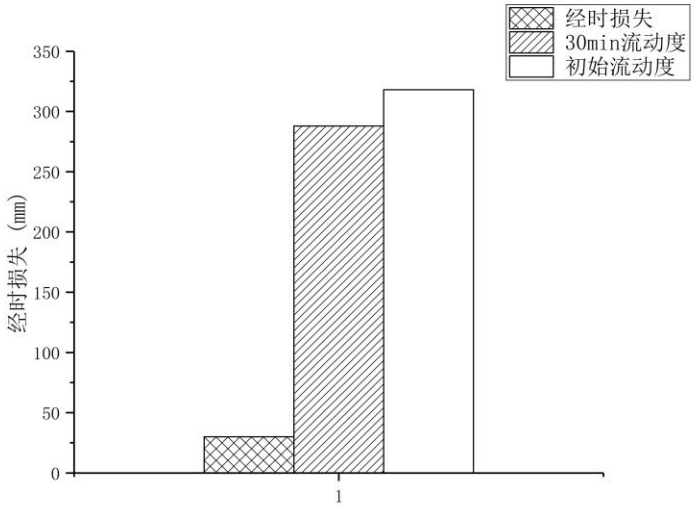


Cementitious grout



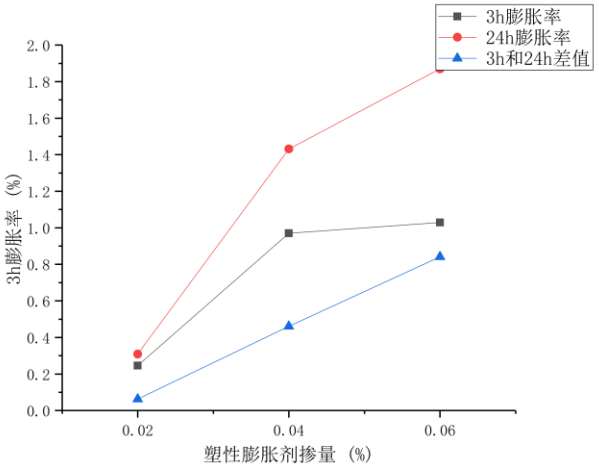
Early strength

High strength

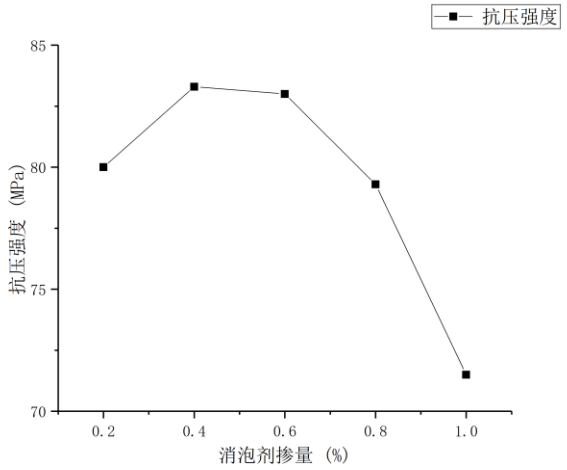


Good fluidity

Cementitious grout



Mixing amount of expanding agent

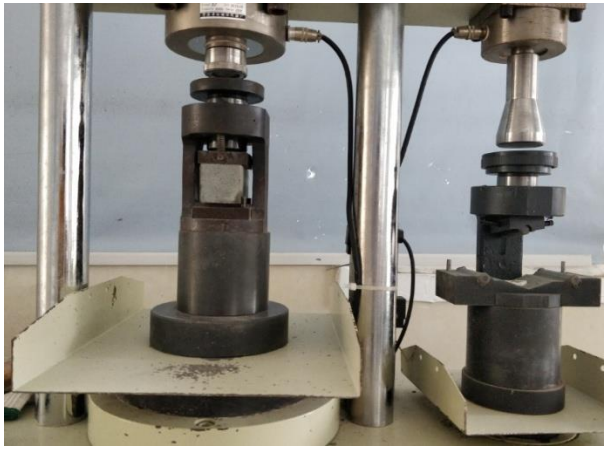


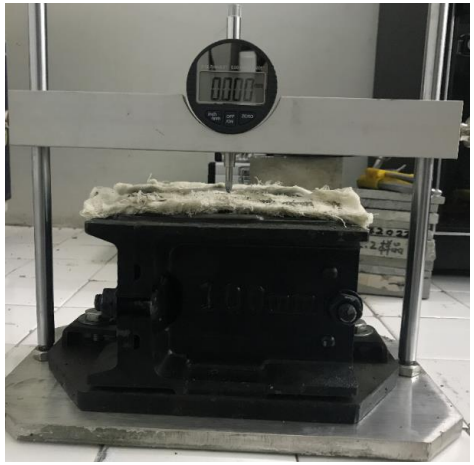
Mixing amount of defoamer

Balance between expansion and porosity

Cementitious grout

	Compressive strength / MPa			Fluidity / mm		Vertical expansion rate / %	
	1d	3d	28d	Initial	30min	3h	Difference 24h and 3h
Produced	38.6	71.8	102.6	347	315	0.2	0.04
Requirement	35	60	85	≥300	≥260	≥0.02	0.02~0.50

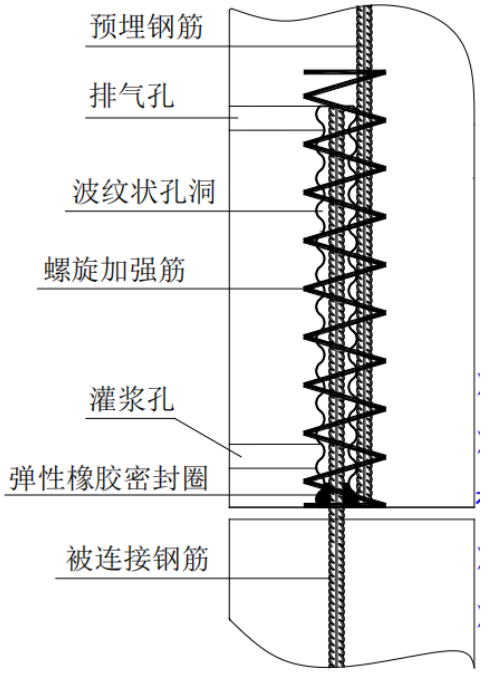




Cementitious materials for overlap joint

钢筋浆锚搭接连接接头用灌浆料性能要求

项　目		性能指标	试验方法标准
泌水率（%）		0	《普通混凝土拌合物性能试验方法标准》GB/T 50080
流动度（mm）	初始值	≥200	《水泥基灌浆材料应用技术规范》GB/T 50448
	30min 保留值	≥150	
竖向膨胀率（%）	3h	≥0.02	《水泥基灌浆材料应用技术规范》GB/T 50448
	24h 与 3h 的膨胀率之差	0.02～0.5	
抗压强度（MPa）	1d	≥35	《水泥基灌浆材料应用技术规范》GB/T 50448
	3d	≥55	
	28d	≥80	
氯离子含量（%）		≤0.06	《混凝土外加剂匀质性试验方法》GB/T 8077



Cementitious materials for sealing

封浆料抗压强度、抗折强度要求

项目		技术指标
抗压强度（MPa）	1d	≥30
	3d	≥45
	28d	≥65
抗折强度（MPa）	28d	≥7

封浆料竖向膨胀率要求

项目		技术指标
竖向膨胀率（%）	3h	≥0.02
	24h 与3h 差值	0.02~0.30

封浆料工作性能及氯离子含量要求

项目		技术指标
流动度（mm）	初始	130~170
氯离子含量（%）		≤0.03
泌水率（%）		0

PART 05

Influence by grouting defects

Influence by grouting defects

Experiment
--- Making defects

Influence by grouting defects

Experiment
--- Grouting

Influence by grouting defects

Experiment
--- Tensile test


Rebar


Grout sleeve splicing

Influence by grouting defects

Experiment
--- Results

No.	Anchor length of Rebar	Test result	No.	Anchor length of Rebar	Test result
1-1	8d	Rebar break	2-1	8d	Rebar break
1-2	7d	Rebar break	2-2	7d	Rebar break
1-3	5d	Rebar break	2-3	6d	Rebar break
1-4	3d	Rebar pullout	2-4	4d	Rebar pullout
1-5	7d	Rebar break	2-5	7d	Rebar break
1-6	5d	Rebar break	2-6	6d	Rebar break
1-7	3d	Rebar pullout	2-7	4d	Rebar pullout
1-8	8d	Rebar break			

Influence by grouting defects

Experiment
--- Results

No.	Anchor length of Rebar	Test result	No.	Anchor length of Rebar	Test result
1-1	8d	Rebar break	2-1	8d	Rebar break
1-2	7d	Rebar break	2-2	7d	Rebar break
1-3	5d	Rebar break	2-3	6d	Rebar break
1-4	3d	Rebar pullout	2-4	4d	Rebar pullout
1-5	7d	Rebar break	2-5	7d	Rebar break
1-6	5d	Rebar break	2-6	6d	Rebar break
1-7	3d	Rebar pullout	2-7	4d	Rebar pullout
1-8	8d	Rebar break			

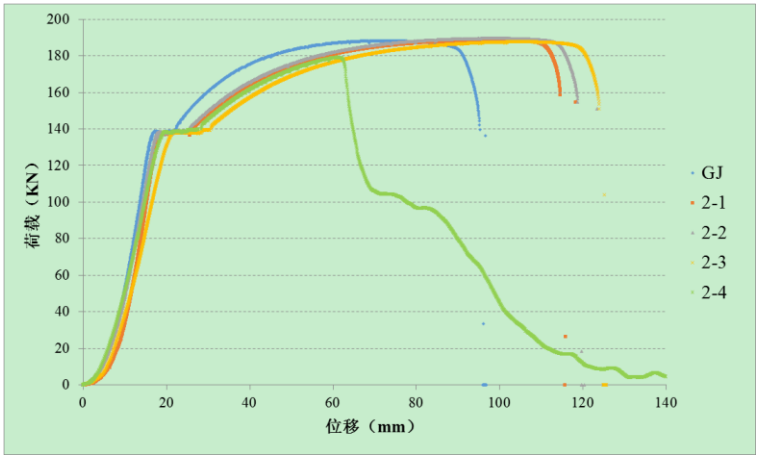
Influence by grouting defects

Experiment
--- Results

No.	Anchor length of Rebar	Test result	No.	Anchor length of Rebar	Test result
1-1	8d	Rebar break	2-1	8d	Rebar break
1-2	7d	Rebar break	2-2	7d	Rebar break
1-3	5d	Rebar break	2-3	6d	Rebar break
1-4	3d	Rebar pullout	2-4	4d	Rebar pullout
1-5	7d	Rebar break	2-5	7d	Rebar break
1-6	5d	Rebar break	2-6	6d	Rebar break
1-7	3d	Rebar pullout	2-7	4d	Rebar pullout
1-8	8d	Rebar break			

Influence by grouting defects

Experiment
--- Results



No.	Anchor length of Rebar	Test result	No.	Anchor length of Rebar	Test result
1-1	8d	Rebar break	2-1	8d	Rebar break
1-2	7d	Rebar break	2-2	7d	Rebar break
1-3	5d	Rebar break	2-3	6d	Rebar break
1-4	3d	Rebar pullout	2-4	4d	Rebar pullout
1-5	7d	Rebar break	2-5	7d	Rebar break
1-6	5d	Rebar break	2-6	6d	Rebar break
1-7	3d	Rebar pullout	2-7	4d	Rebar pullout
1-8	8d	Rebar break			

Anchor length: at least 5d for this test condition

Influence

Grouting strength

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PART 06

Detecting techniques

Detecting techniques

The problems:

Sleeve grouting is not full

The strength of cementitious grout is low

The position deviation of reserved rebar is large

The embedded rebar is cut off

Cracks occur during lifting and transportation

. → **Detecting is very important!**

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The related standards:

Shanghai:《装配整体式混凝土建筑检测技术标准》
（DG/T 08-2252-2018）

Beijing：《装配式混凝土结构工程施工与质量验收规程》
（DB42T 1225-2016）

Shandong：《装配式混凝土结构现场检测技术标准》
（DB37/T 5106-2018）

Tianjing：《装配式建筑预制混凝土构件质量与检验标准》
（DB/T29-245-2017）

Guangdong：《装配式混凝土建筑工程施工质量验收规范》
（DBJ/T 15/71-2019）

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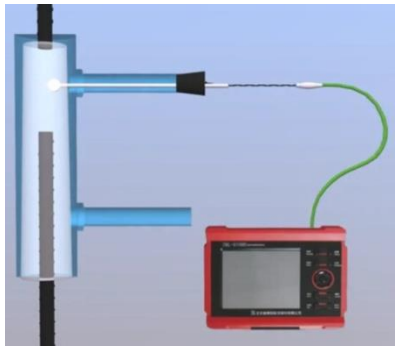
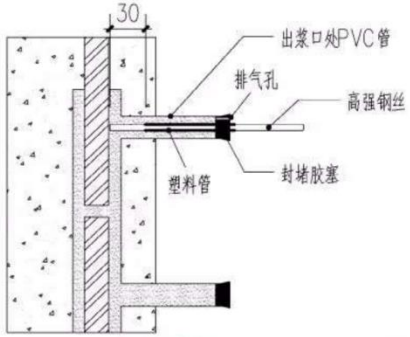
Filling fullness of grouting

1) Pre-embedded detecting techniques





2) Nondestructive detecting techniques

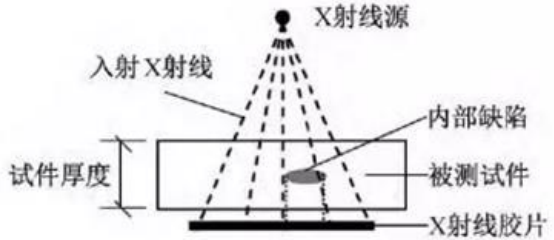


图 1　X 射线胶片成像原理

3) Partial-destructive detecting techniques

At present,
no widely nondestructive testing method is available yet!

1) Pre-embedded sensor

Vibrational energy is different

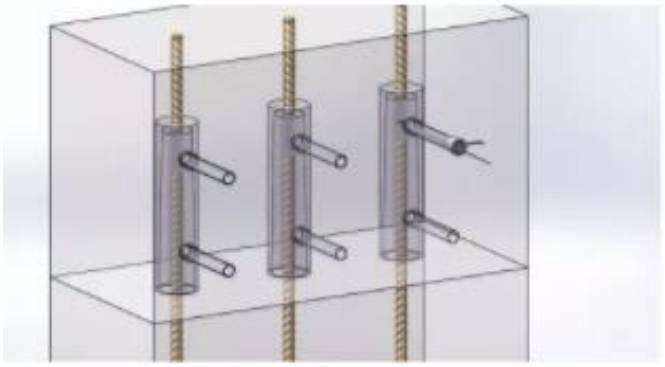
空气中
Air

流体灌浆料中
Fluid grouting

固化灌浆料中
Solid grouting

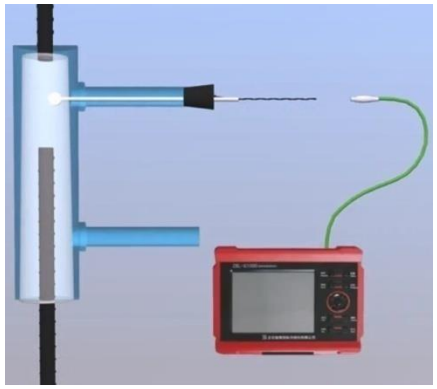
饱满（能量值0~150）

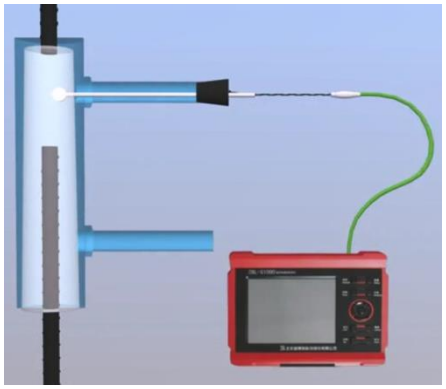
不饱满（能量值151~255）

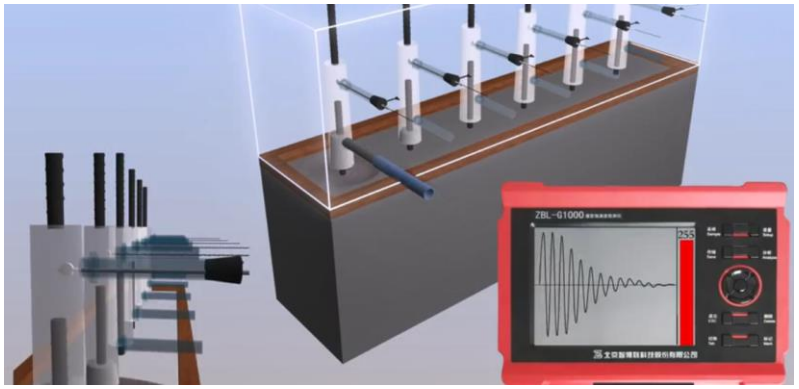


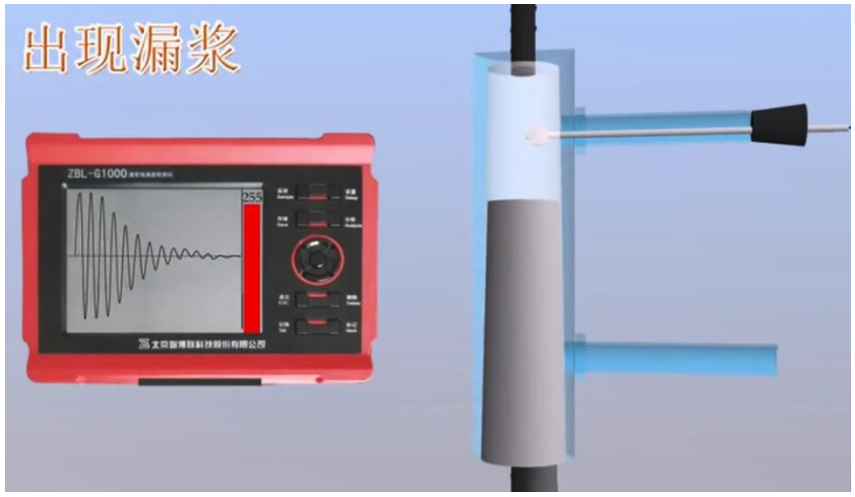
Detecting techniques

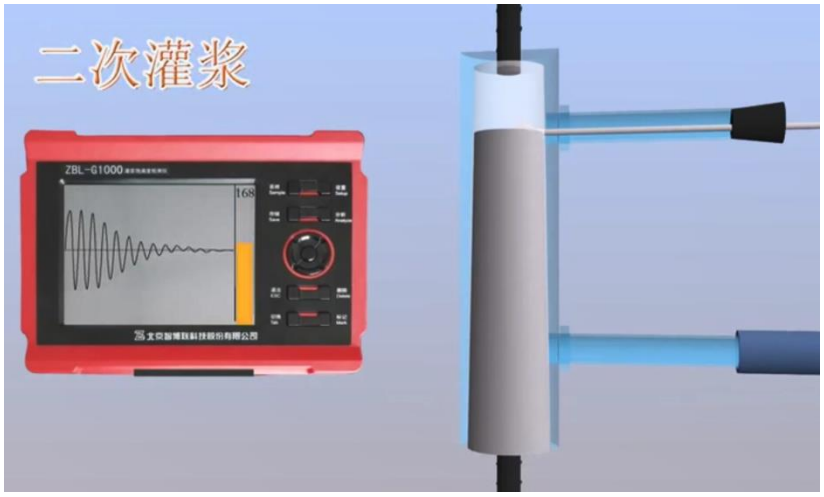
1) Pre-embedded sensor







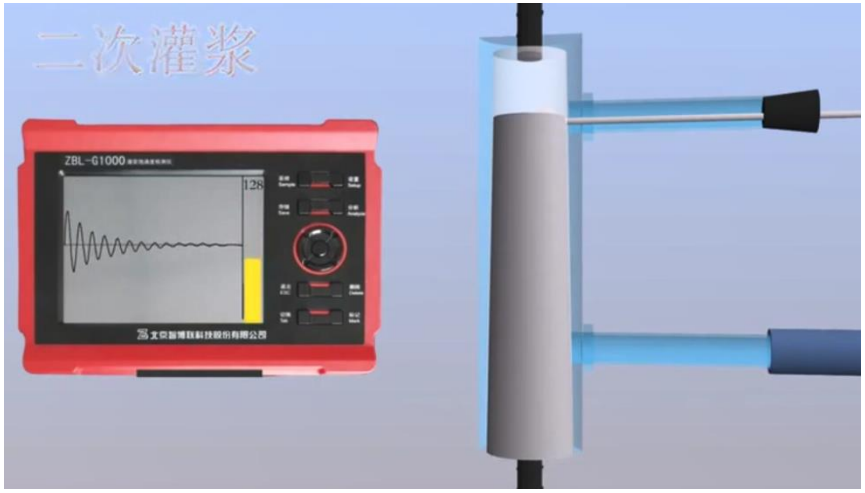


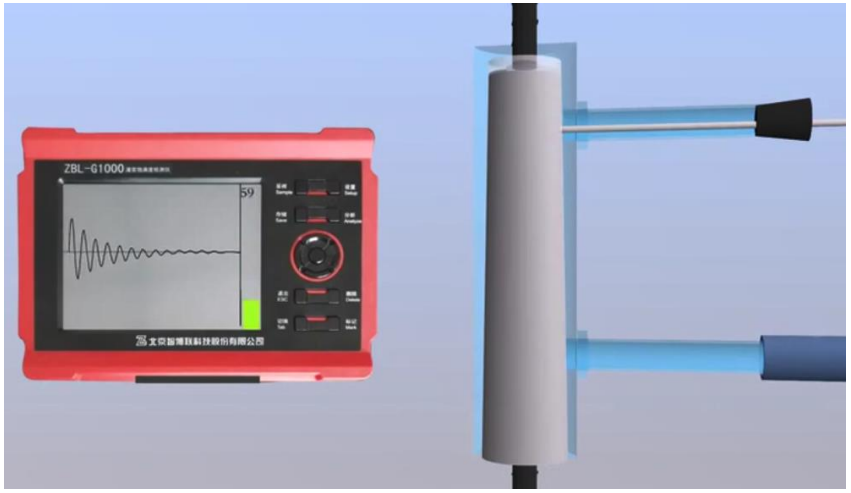


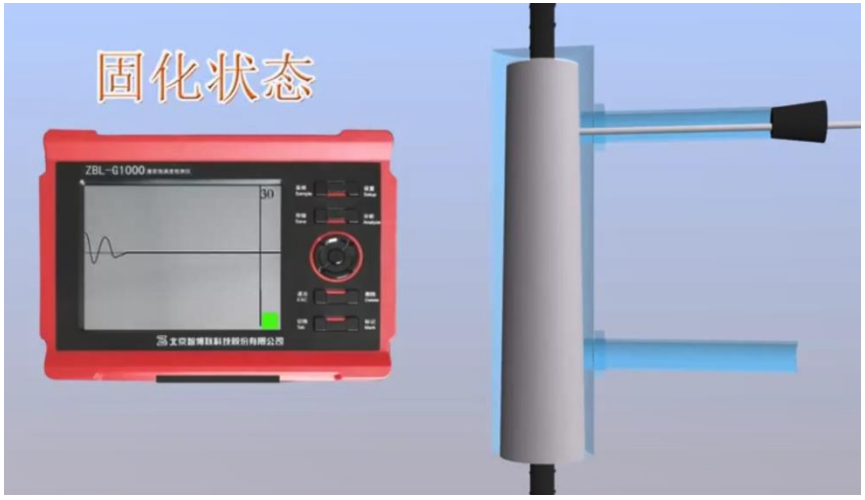
Detecting techniques

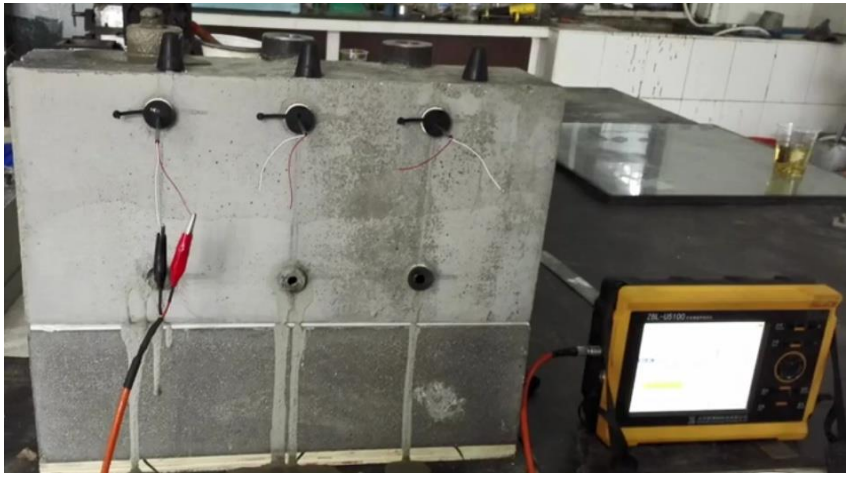
1) Pre-embedded sensor

Need to be installed in advance!

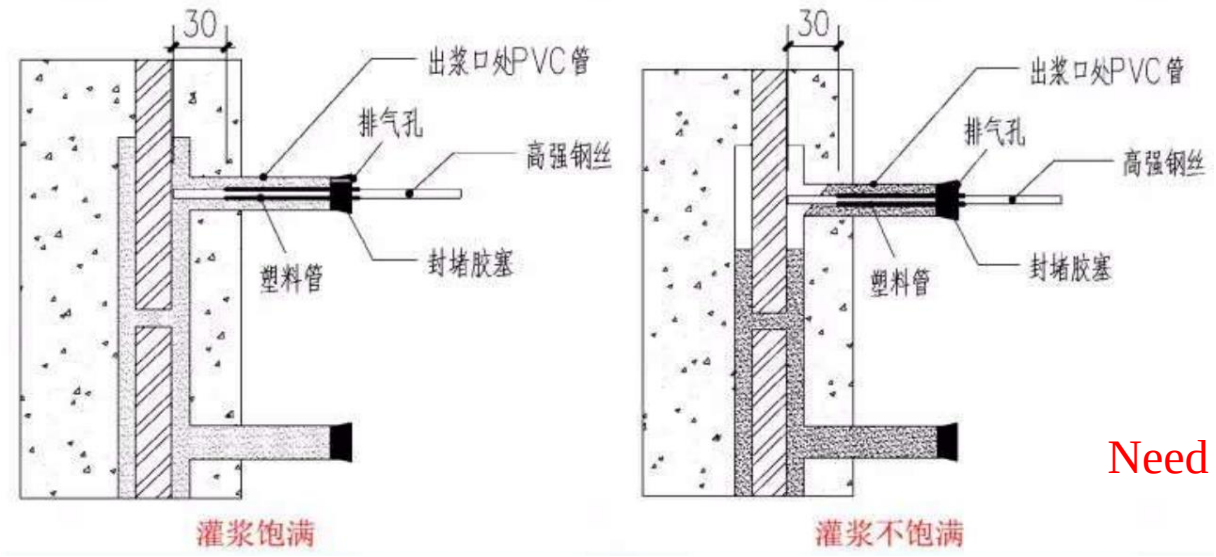








2) Pre-embedded steel pull-off method



Need to be installed in advance!

The pull-off pressure is different

3) X-ray technique（CT）

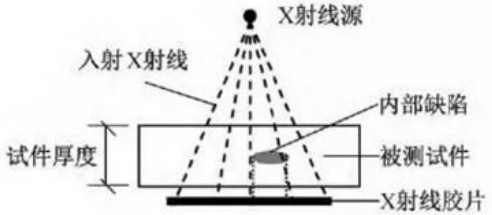
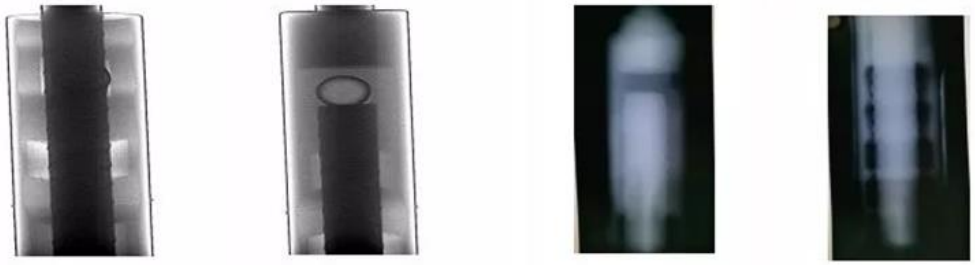


图1　X 射线胶片成像原理

Radiation problem!

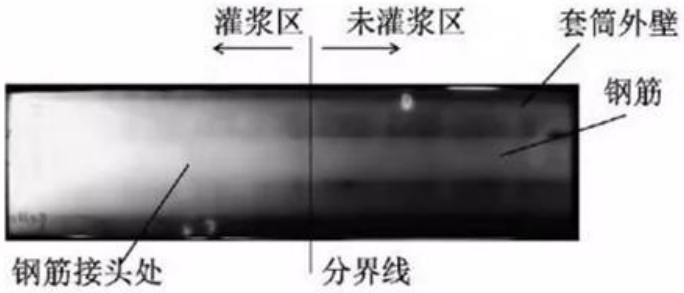
（ at least 30 m away）

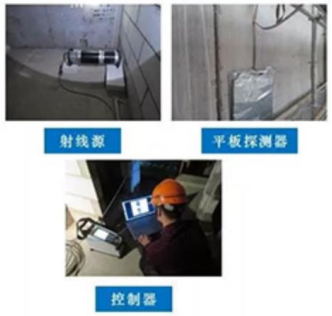


Thickness below 200mm is applicable for now.

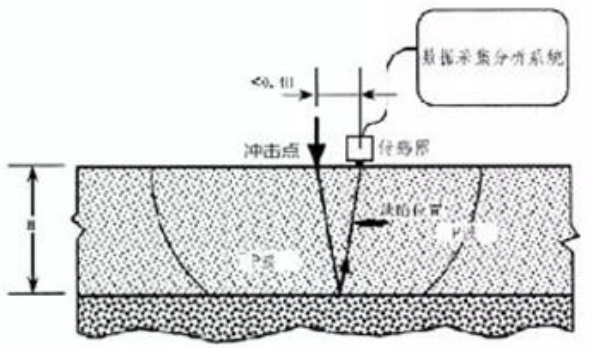
a 射线机定位

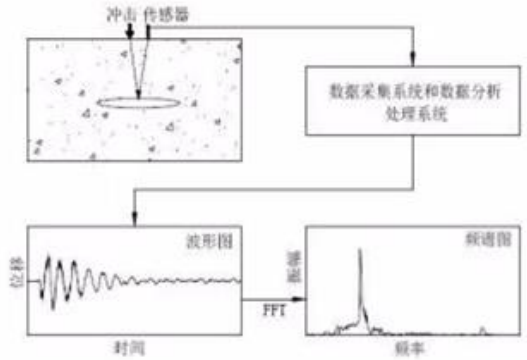
b 墙体背面粘贴暗袋





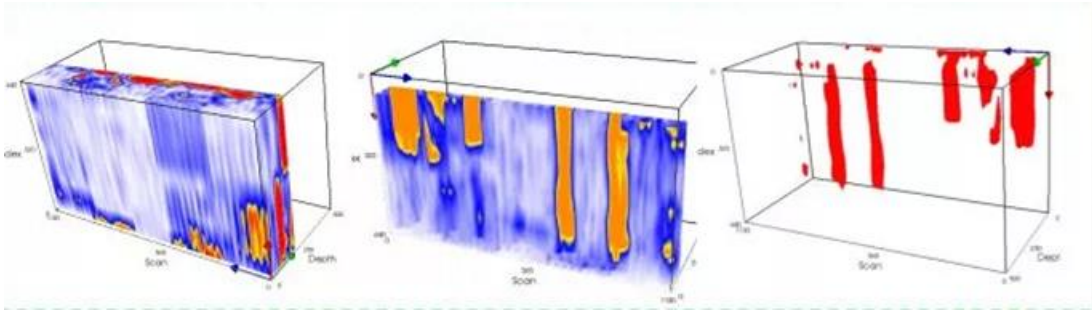
4) Impact-echo method





Failure to effectively identify internal defects at present!

5) Ultrasonic method



Failure to effectively identify internal defects at present!

Detecting techniques

At present, the quality control is mainly focused on the construction process and manufacturing process.

Concealed work after construction is difficult to be effectively detected.

Effective detecting technique is lacking!

A combination of multiple detecting techniques

The development of new equipment and detecting techniques

A combination with machine learning , wireless transmission, 5G network …

PART 07

Summary

7 Summary

- Prefabricated building will be more and more popular.
- Joint connection is the most important part, which influence the safety and durability of the building.
- Grout sleeve splicing is the most common connection method, but problems exist at present.
- The effective detecting techniques for grouting defects is lacking.
- We can make the cementitious grout with a good quality.

Thanks For Your Attention !

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