同济大学 TONGJI UNIVERSITY | 土木工程学院 COLLEGE OF CIVIL ENGINEERING

# Application of recycled concrete in sponge city construction

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Research Group for Recycled Concrete Structures and Construction

# Contents

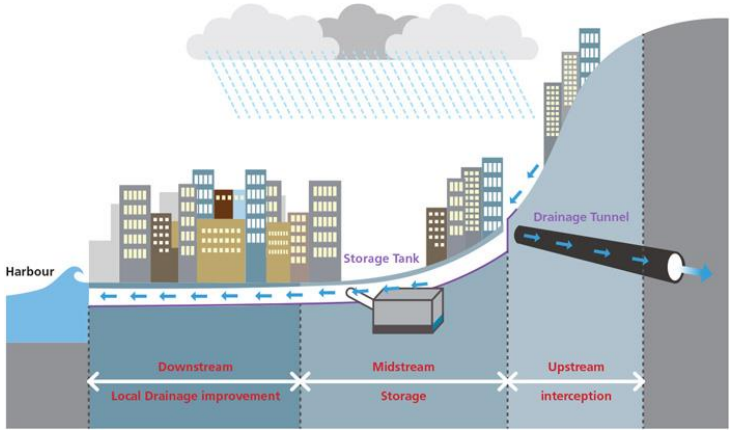
# 1.Background

## 1.1 Urban flooding

- Urban flooding has become one of the most frequent natural disasters in recent years.
- Urbanization converts natural land into urban infrastructure, which is mostly impervious and produces considerable hydrological effects.
- The most direct impact are the increases in flood frequency and volume, which intensify the risk, frequency, and extent of urban flood disasters.

# 1.Background

## 1.1 Urban flooding




- In the context of urban flood mitigation, traditional controls of urban stormwater mostly comprise municipal pipe network based on the strategy of removing runoff from a site as quickly as possible and then storing it at downstream facilities.
- Municipal pipe network is necessary to deal with extreme rain storms. However, simply continuing to increase the capacity of municipal pipe is considered unsustainable because of the pressure associated with ongoing climate change and urbanization.

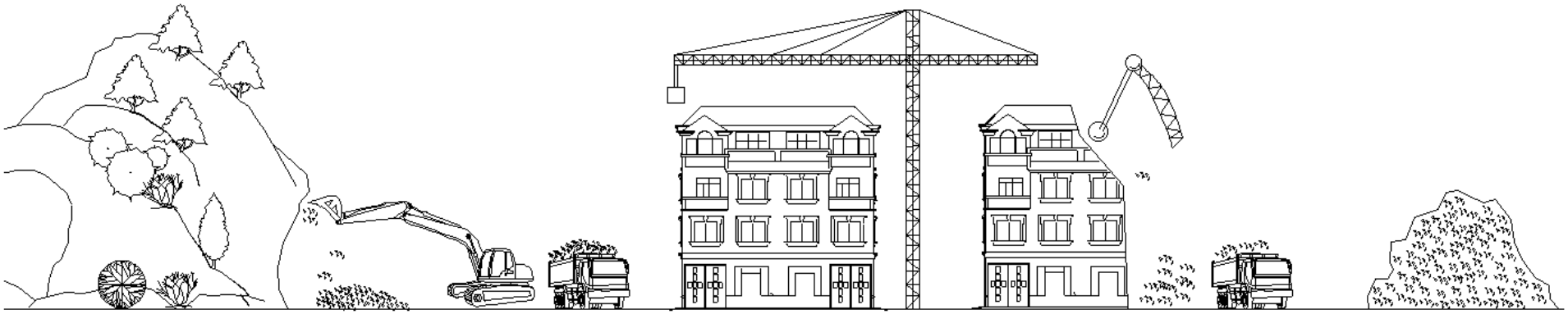
# 1.Background

## 1.2 Sponge city


- In 2013, China proposed a new strategy for integrated urban water management named the Sponge City Program, deviating from the traditional rapid-draining approach.
- The new paradigm calls for natural systems such as soil and vegetation to be incorporated in urban runoff control strategies.

# 1.Background

## 1.3 Traditional model of construction industry



**Raw material exploration** → **Building** → **Demolition** → **C&D Waste**

In the **traditional model** of construction industry, from the raw materials exploration to the C&D waste production, a small portion can be used as recycling materials. Most of the construction waste is **directly discharged** to the natural world, and the whole process rarely considers the **adverse effects** on the resources and the environment.

# 1.Background

## 1.4 C&D waste production

The amount of C&D waste significantly increases with urbanization, which has a serious impact on environment. In 2014, the amount of C&D waste reached **1.5 billion** tons in China

How to treat the C&D waste?

# 1.Background

## 1.5 Disposal of C&D waste

### Building up stockpiles

Effect:
Occupy a large amount of valuable land leaving a bad effect on environment.

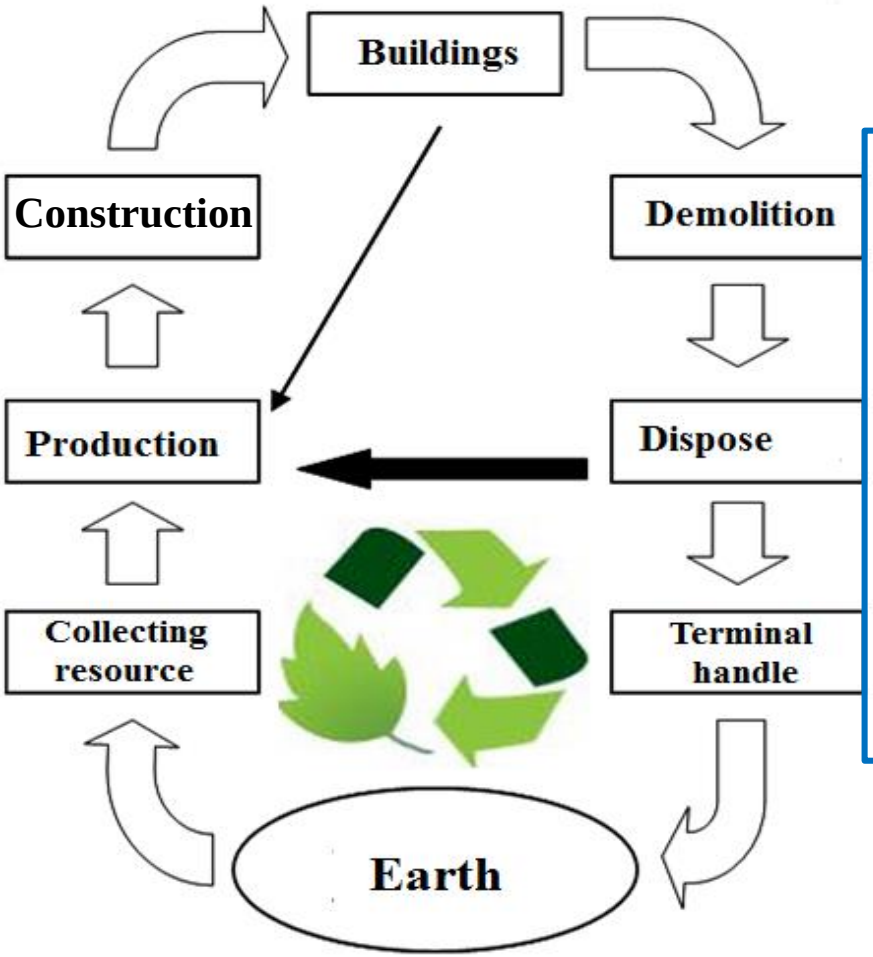
### Disposing off the grid

Effect:
Consumption of resources, leading to pollution due to transshipment.


In recent years, land resources are becoming more scarce. The simple landfill and transfer to the field have greatly increased the disposal costs and brought about serious environmental impacts.

# 1.Background

## 1.6 Sustainable development of construction industry




- Recycling the C&D waste into **recycled materials**, which can be used as the building materials in the new construction, immediately.
- Following the development patterns titled **"Resource - Product - Recycling resource"**, and it can well meets the sustainable development of construction .

# 1.Background

## 1.7 Recycling technology

- There are two ways for the C&D recycling in China.

  The first way is the production of **recycled aggregates (RA)** and **recycled aggregates concrete (RAC)**.

  The second way is the production of **recycled powder (RP)** and recycled **powder concrete (RPC).**

- The properties of **RA and RAC** have been studied, systematically. However, the studies on the **RP and RPC** are only beginning.

# 1.Background



## 1.8 Sponge city & recycled concrete

Benefits of sponge city:

- Reducing runoff
- Minimizing pollutant discharge
- Decreasing erosion
- Maintaining the base flows of receiving streams

+

Benefits of recycled concrete:

- Saving arable land
- Reducing industry energy consumption
- Reducing natural aggregate consumption
- Decreasing the potential impact of pollution
- Reducing $CO_2$ emission

↓

**Application of recycled concrete in the construction of "sponge city"**

# 2. C&D waste Reclamation

# 2. C&D waste Reclamation

## 2.1 Main ideas

Localization

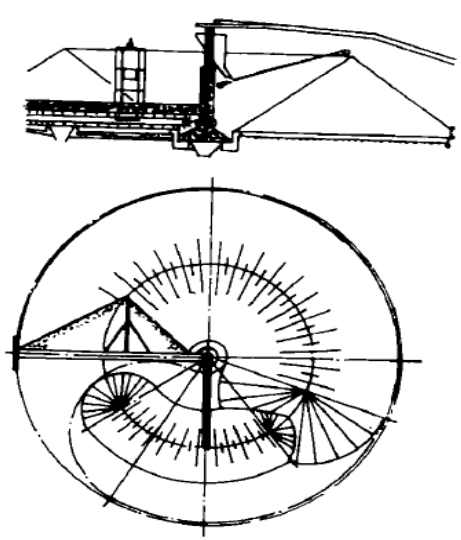
Energy conservation

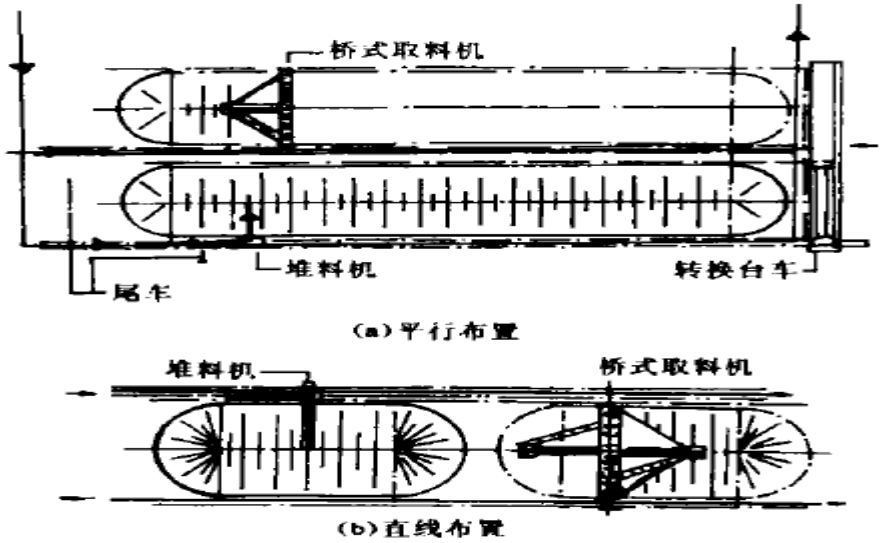
Reduction of $CO_2$ emission

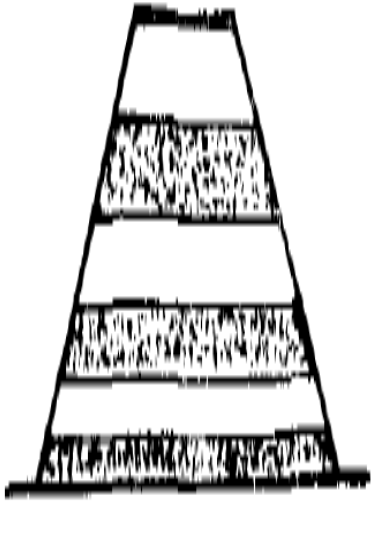
# 2. C&D waste Reclamation

## 2.2 Pre-homogenization process

In order to make the ingredients of the raw materials become more uniform before being officially put into production, the ingredients of the raw materials are made more uniform by a certain stacking and taking method, and **this process is called pre-homogenization of raw materials.**





Construction waste pre-homogenization yard

# 2. C&D waste Reclamation

## 2.3 Crushing equipment

The main methods of crushing are: crushing, grinding, chopping, and impact. The crushing can be carried out by a single method, but generally, **a crushing mechanism of two or more joint operations** is used.

Crushing equipment
- Jaw Crusher
- Impact Crusher
- Hammer crusher
- Cone crusher

Jaw Crusher

Impact Crusher

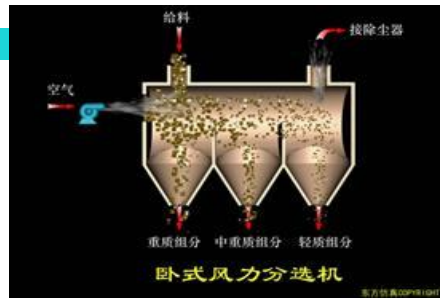
Hammer crusher

Cone crusher

# 2. C&D waste Reclamation

## 2.4 Sorting

Vibrating screen




Wind sorting

Sorting equipment

- Particle size sorting equipment
- Wind sorting equipment
- Magnetic sorting equipment
- Inertial sorting equipment

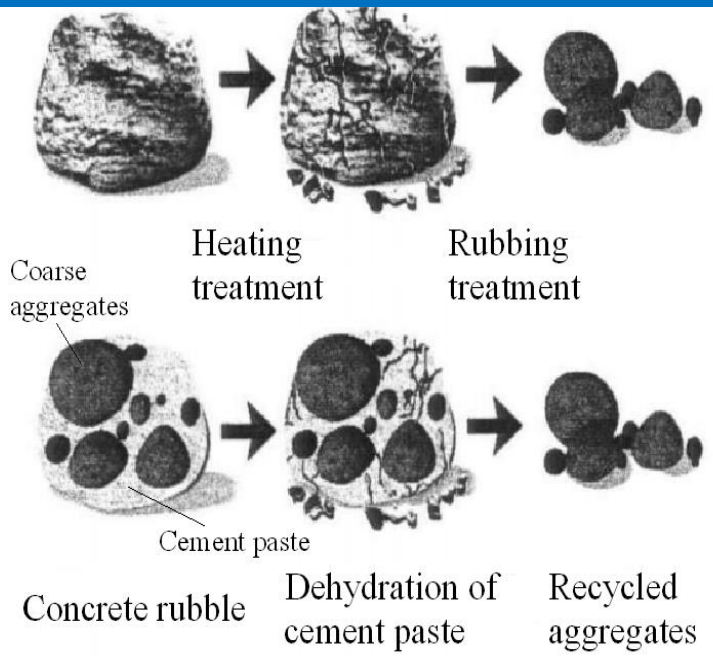
Magnetic sorting

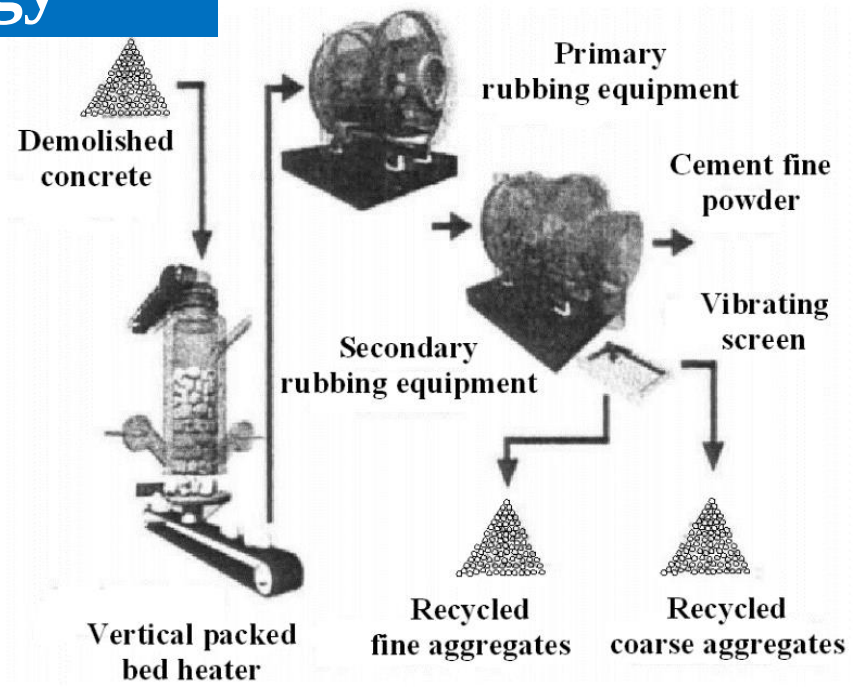
Inertial sorting

**Particle size sorting equipment:** Separating **small size particles** in construction waste.
**Wind sorting equipment:** Separating **light materials with less density**.
**Magnetic sorting equipment:** Separating **steel and metal** from construction waste.
**Inertial sorting equipment:** Separating **large and light materials** such as paper and plastic film.

# 2. C&D waste Reclamation

## 2.5 Heated grinding technology

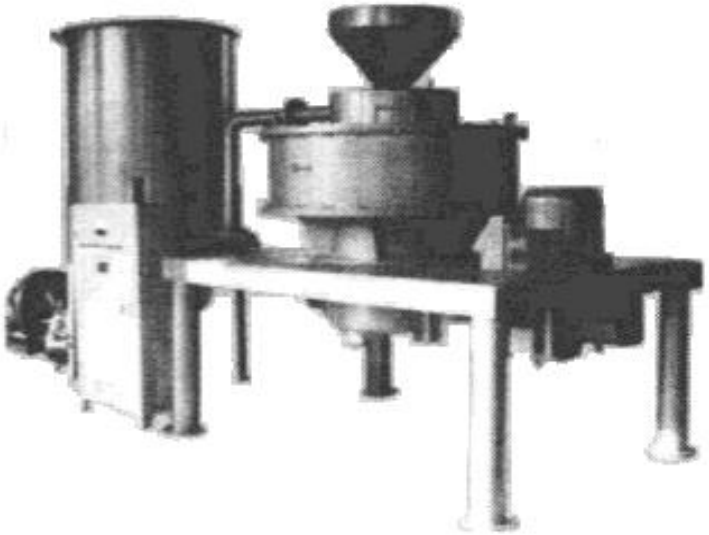


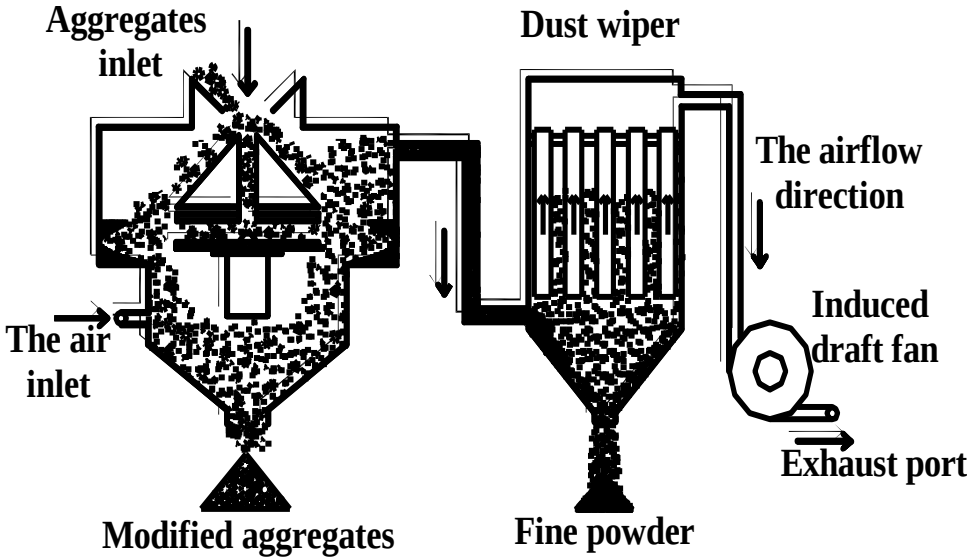




The initially crushed waste concrete block is subjected to high-temperature heat treatment to dehydrate and embrittle the cement stone, and then impacted and ground in the mill **to effectively remove the cement stone residues** in recycled aggregates. The heated grinding process can recover high-quality construction waste **recycled coarse aggregates**, high-quality **recycled fine aggregates** and **micro aggregates (powder)** from C&D waste.

# 2. C&D waste Reclamation

## 2.6 Aggregate particle shaping






**Recycled aggregate particle** shaping technology **can significantly increase** the particle bulk density and apparent density of recycled aggregates, **reduce** the void content, water absorption rate and crushing index values of recycled aggregates. Moreover, **the bulk density, compact density and needle-like aggregate content are superior to natural gravel aggregates, which can fully meet the requirements of preparing ordinary concrete.**

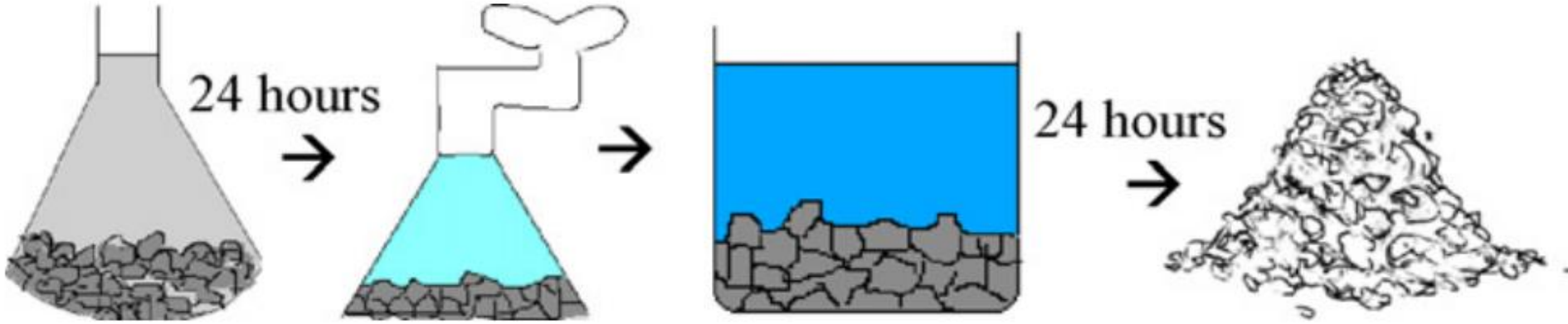
# 2. C&D waste Reclamation

## 2.7 Microwave heating modification

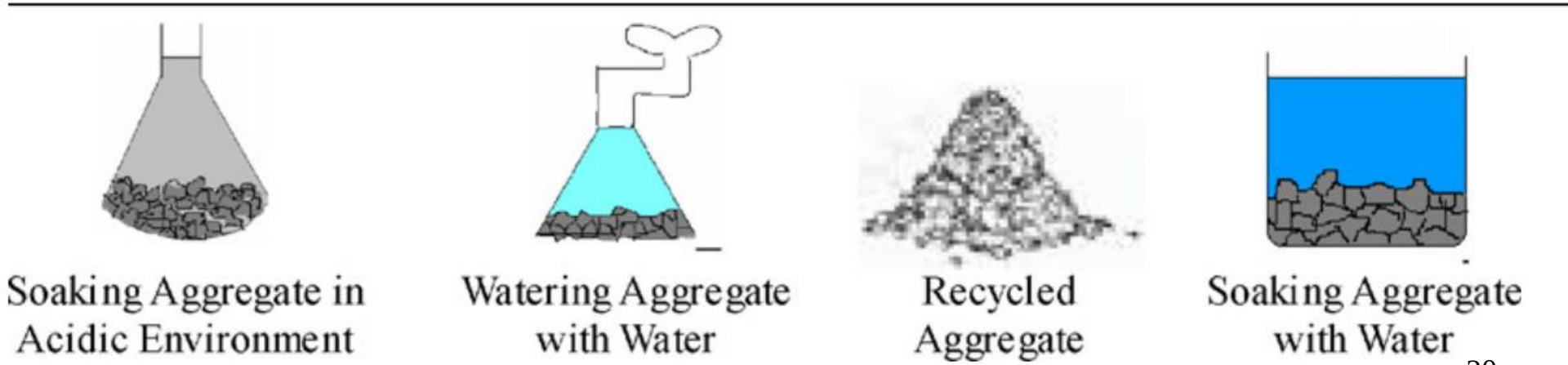
**Microwave heating** provides a new way to improve the performance of recycled coarse aggregates (RCA) and concrete prepared by RCA. After microwave heating, the old mortar content, water absorption rate and crushing index of the RCA can **be significantly reduced**, and the physic and chemical indices of RCA are closer to natural aggregates.

# 2. C&D waste Reclamation

## 2.8 Pickling modification

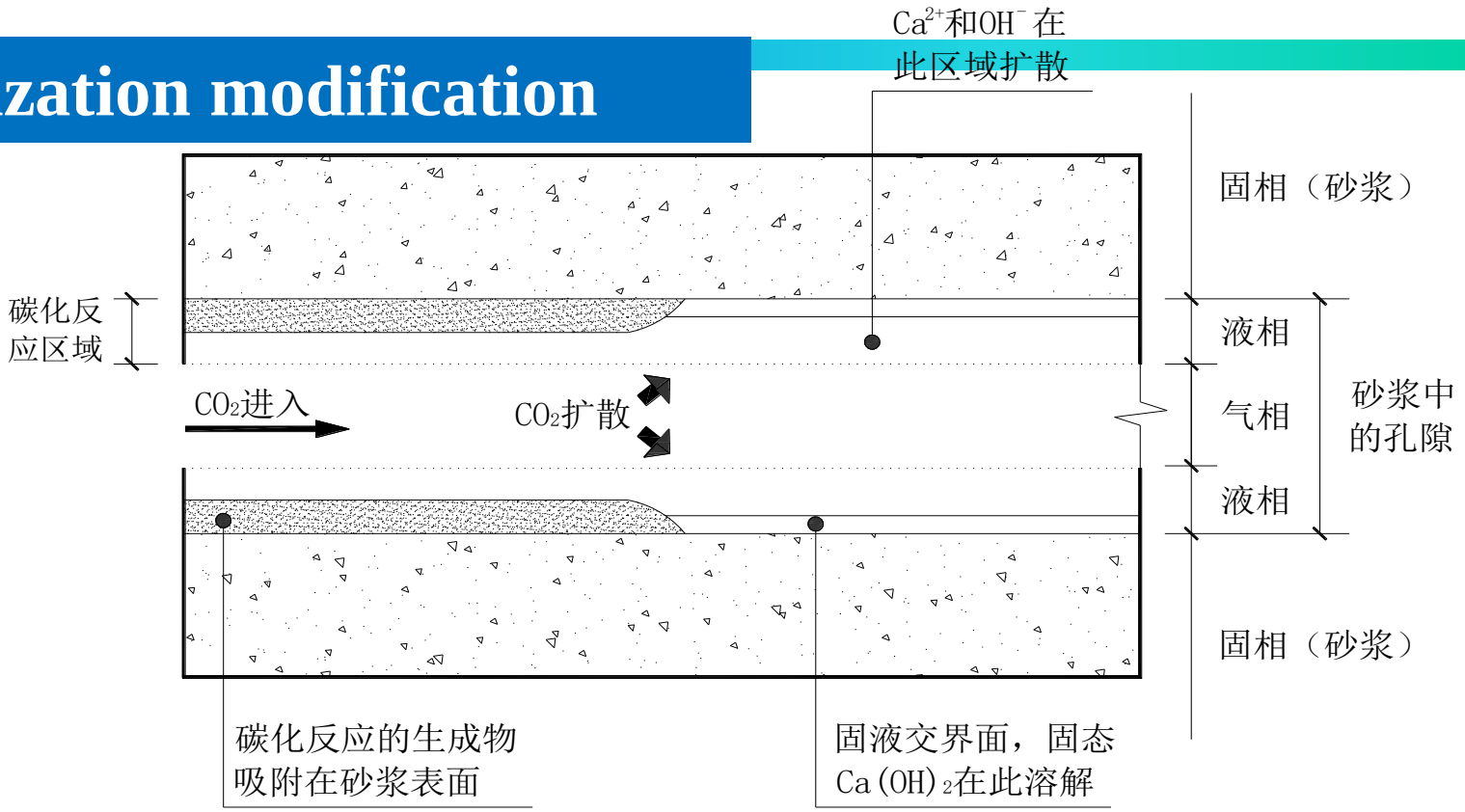



Process of pickling modification of recycled aggregates



# 2. C&D waste Reclamation

## 2.9 Carbonization modification




Carbonization mechanism of cement-based materials

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

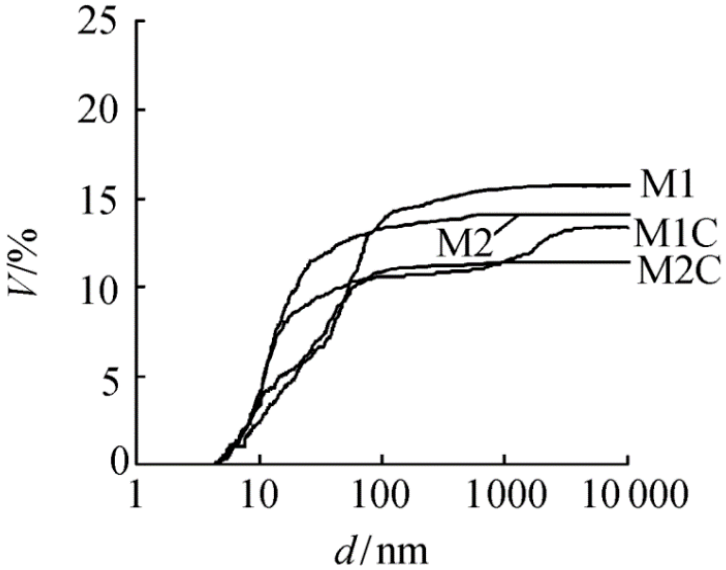
$$C\text{-}S\text{-}H + 2CO_2 \rightarrow SiO_2 + 2CaCO_3 + H_2O$$

$$C_3S + (3 - x)\ CO_2 + yH_2O \rightarrow C_xSH_y + (3 - x)\ CaCO_3$$

$$C_2S + (2 - x)\ CO_2 + yH_2O \rightarrow C_xSH_y + (2 - x)\ CaCO_3$$

# 2. C&D waste Reclamation

## 2.9 Carbonization modification

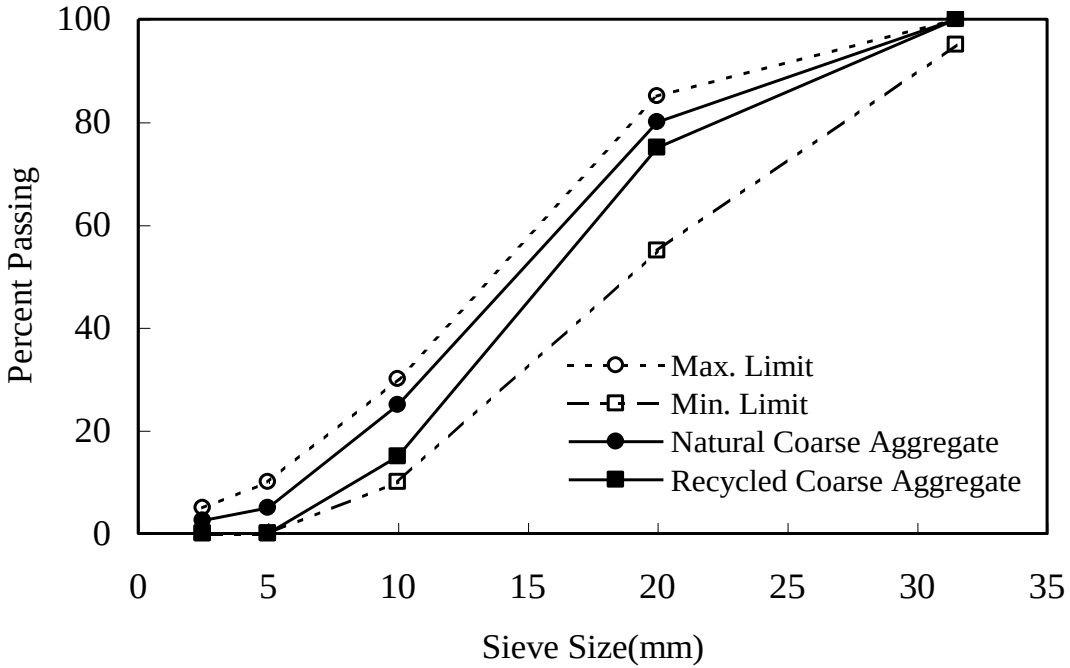



Effect of carbonation on pores of cement mortar

Carbonization of recycled aggregates can **improve** the compactness of recycled aggregates, **reduce** the porosity and crushing index of recycled aggregates, and **effectively improve the mechanical properties of recycled aggregates and recycled concrete**. Meanwhile, **environmental benefits can be achieved**.

# 2. C&D waste Reclamation

## 2.10 Particle grading adjustment

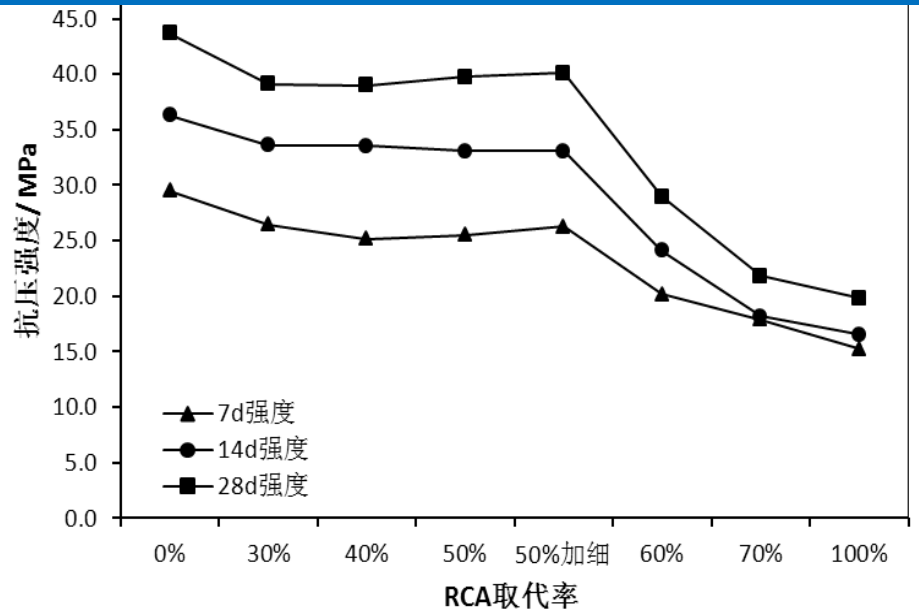



天然骨料和再生骨料的颗粒级配曲线

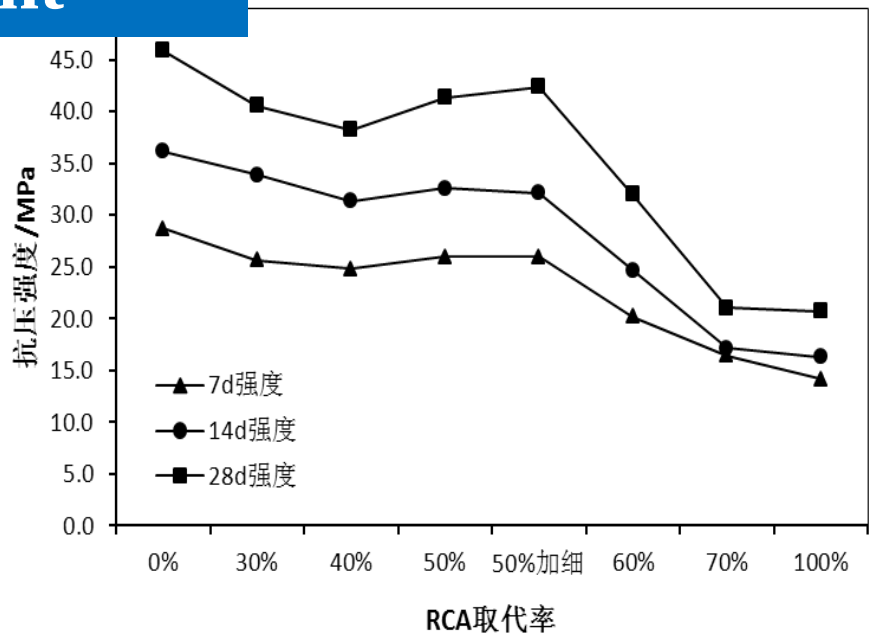
Compared with natural aggregates, recycled aggregates have lager size and poor gradation continuity, which are unfavourable for the performance of recycled concrete.

# 2. C&D waste Reclamation

## 2.10 Particle grading adjustment




Compressive strength before grading adjustment

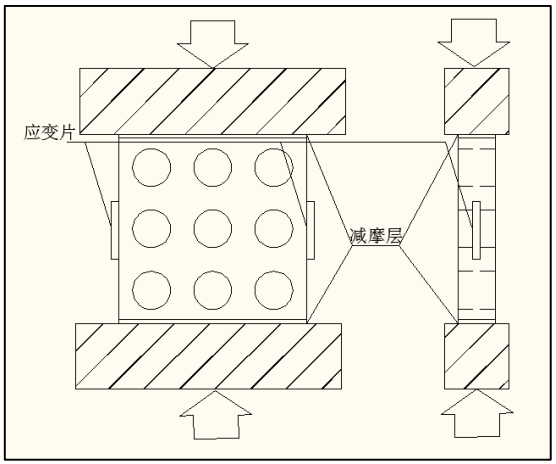



Compressive strength after grading adjustment

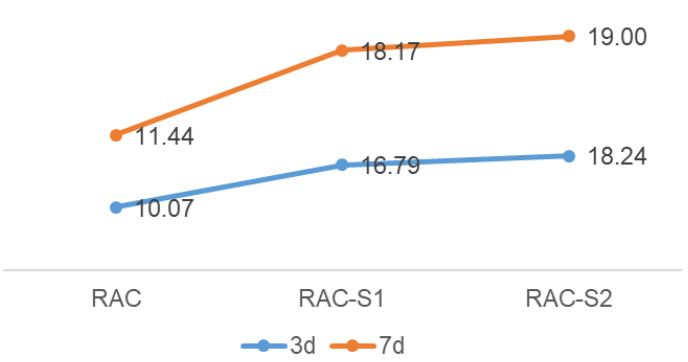
Suitable grading adjustment of recycled aggregates can **significantly improve the compressive strength of recycled concrete**.

# 2. C&D waste Reclamation

## 2.11 Nano modification



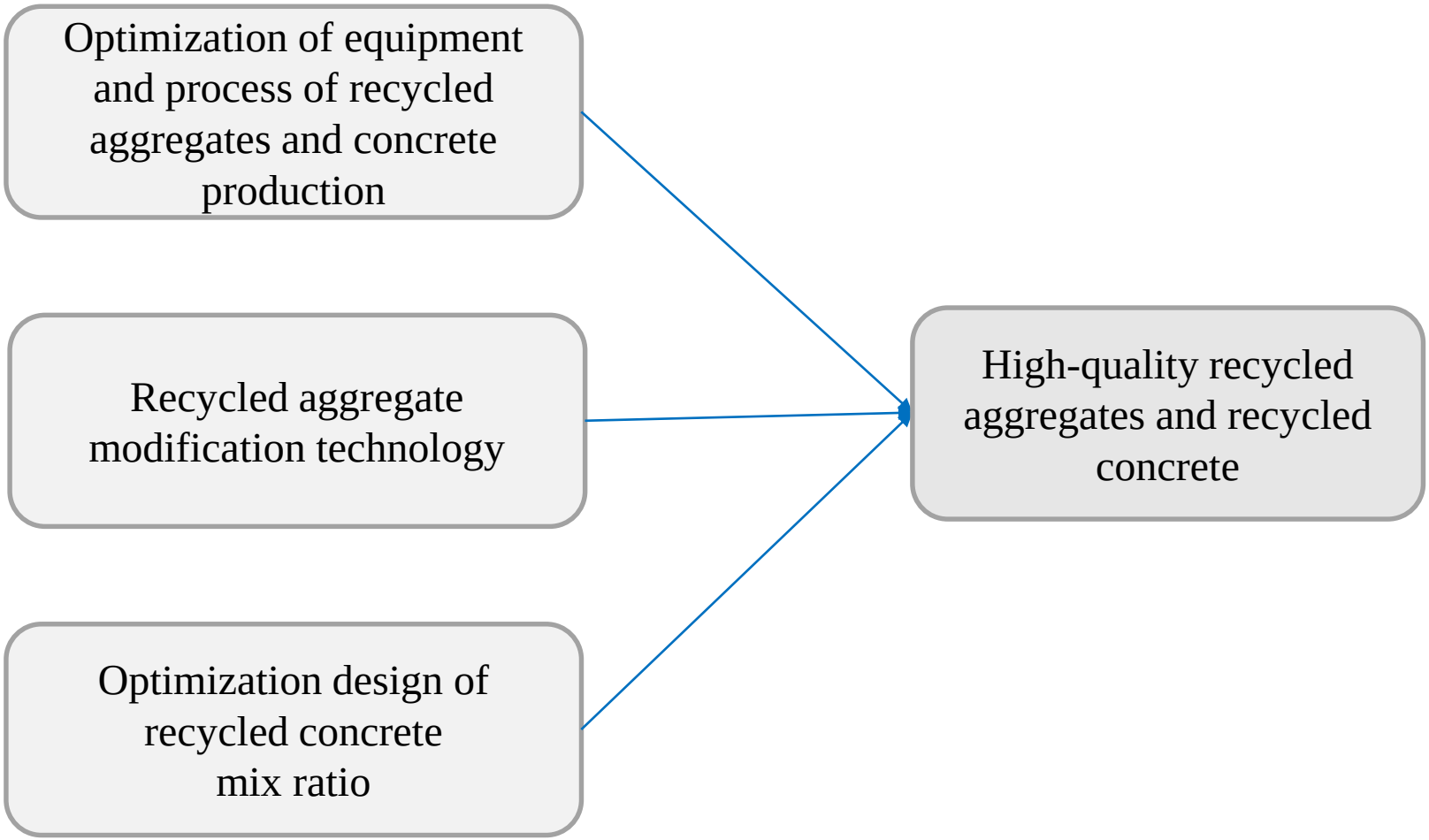





Using nano-modification to strengthen the old ITZ of recycled coarse aggregate, improving the static and fatigue properties of recycled concrete.

# 2. C&D waste Reclamation

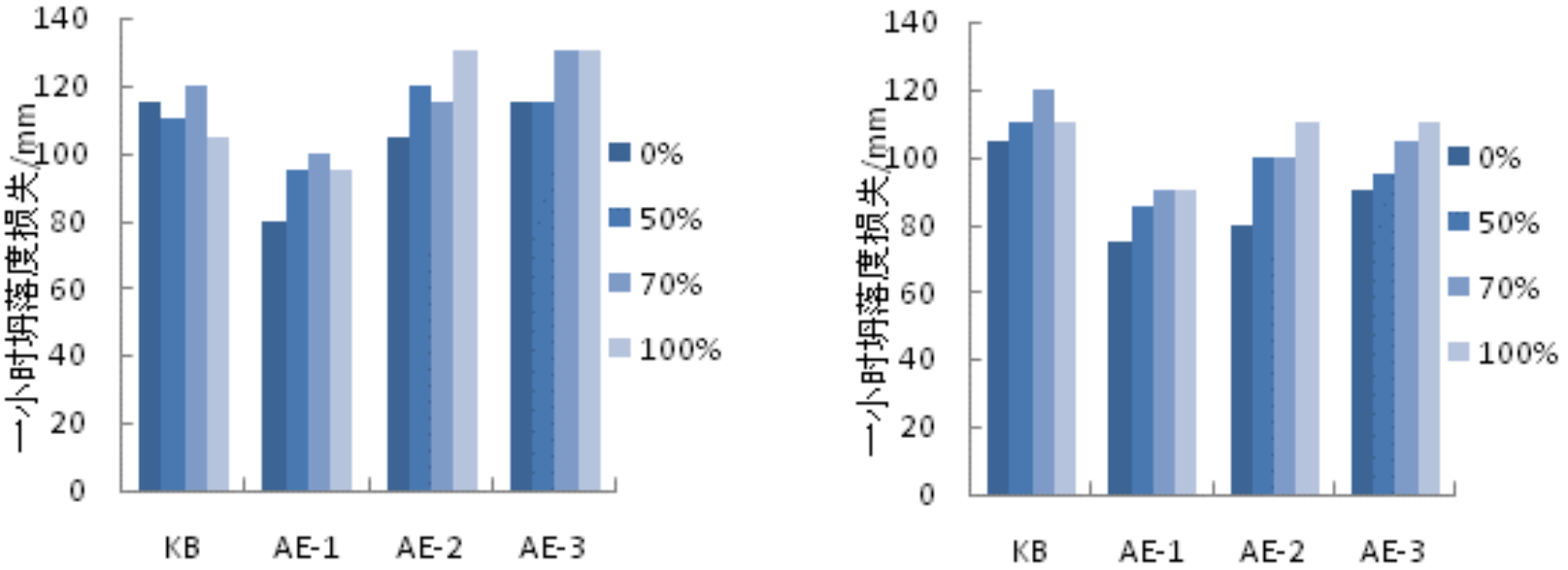
## 2.12 Summary of reclamation technologies



# 3. Properties of recycled concrete

# 3. Properties of recycled concrete

## 3.1 Workablity



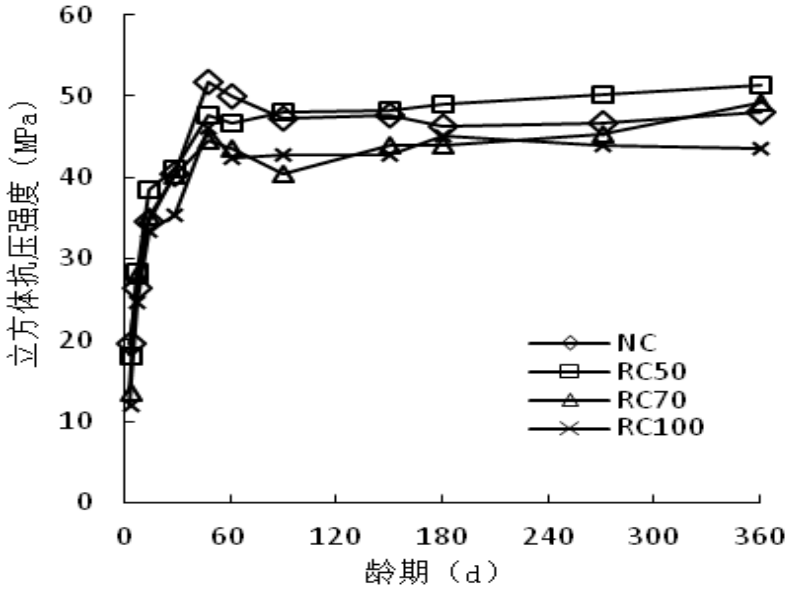

（a）60min absolute slump loss （b）60min slump loss as opposed to 180mm

Effect of Recycled Aggregate Replacement Rate on Slump Loss

With the increase of the replacement rate of recycled aggregates, **the slump loss of recycled concrete increases**, because recycled aggregates absorb more free water under the same conditions.

# 3. Properties of recycled concrete

## 3.2 Mechanical property (compressive strength)



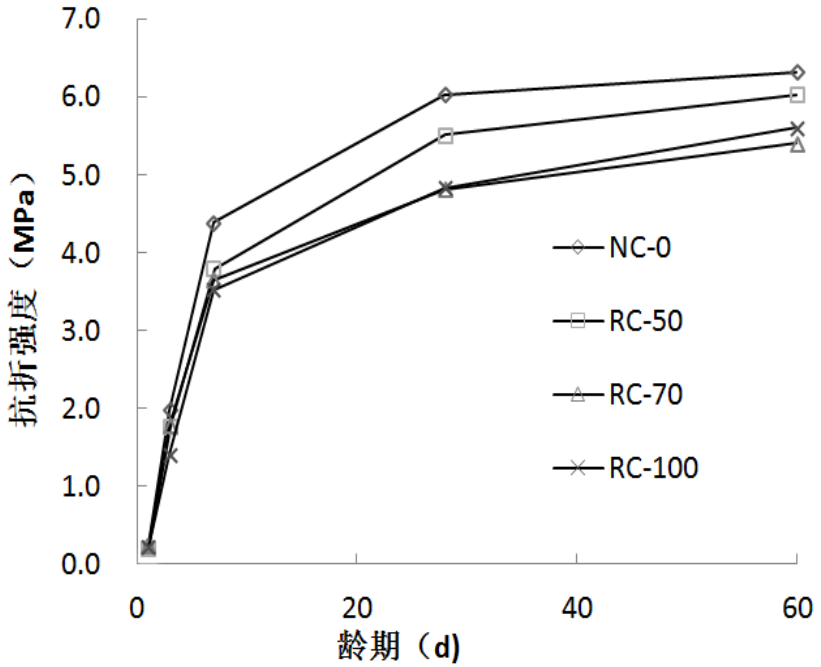

Effect of replacement rate and concrete age on compressive strength

（1）Cubic compressive strength of ordinary concrete and recycled concrete change **in the basically same trend** under long-term age

（2）The strength of recycled concrete still has **more growth in the later period**.

# 3. Properties of recycled concrete

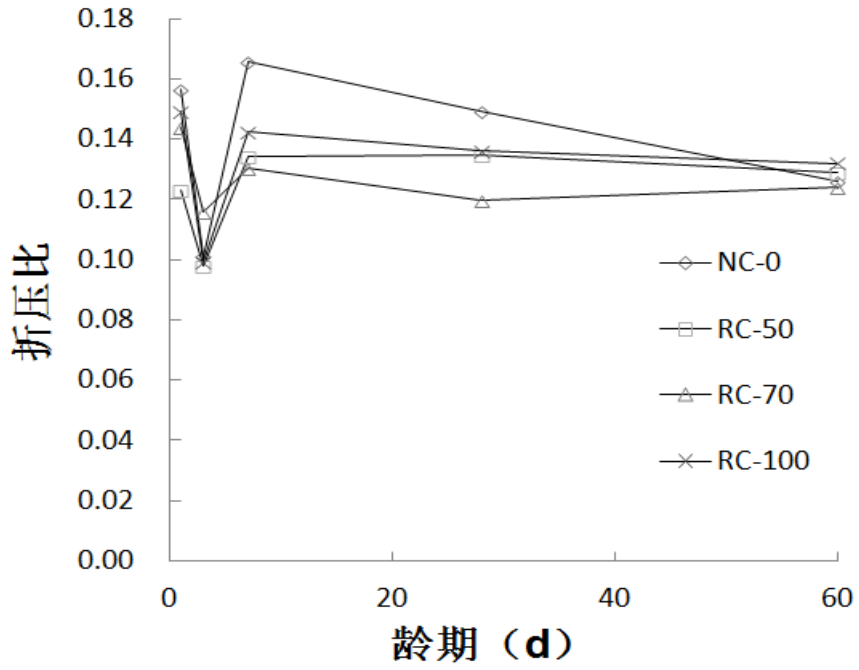
## 3.3 Mechanical property (flexural strength)




Effect of replacement rate and concrete age on flexural strength

Recycled concrete has **lower flexural strength** than ordinary concrete. The flexural strength of recycled concrete with a replacement rate of 70% and 100% is **relatively close**.

# 3. Properties of recycled concrete



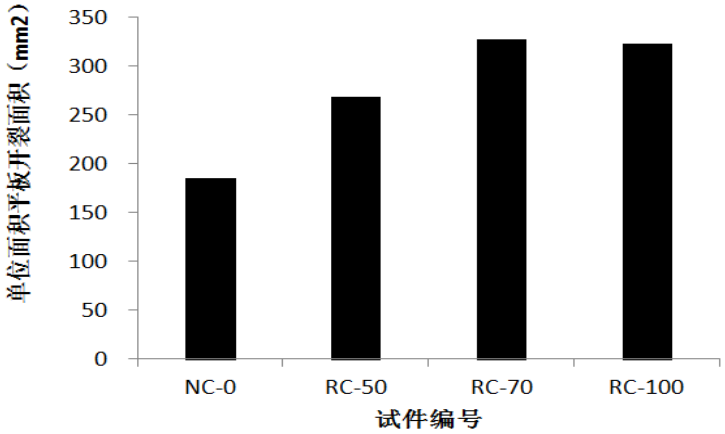

The trend of the development of compression-bend ratio

The **cracking resistance** of recycled concrete under load remains at a level close to that of ordinary concrete.

# 3. Properties of recycled concrete

## 3.4 Volume stability - plate cracking test

(a)诱导式开裂平板



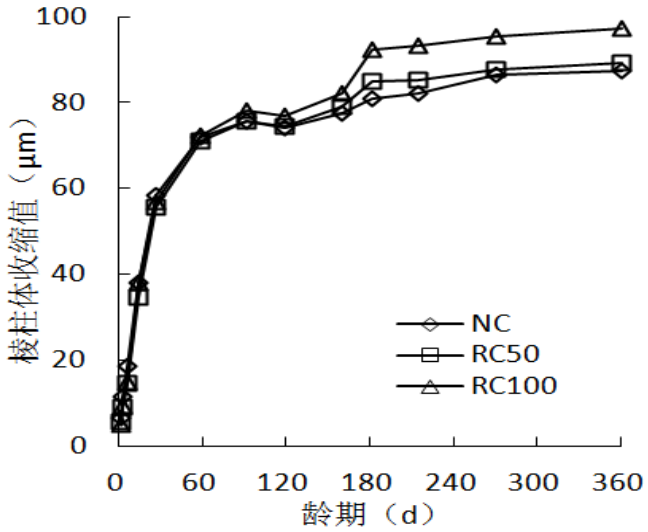

Effect of replacement rate on crack resistance

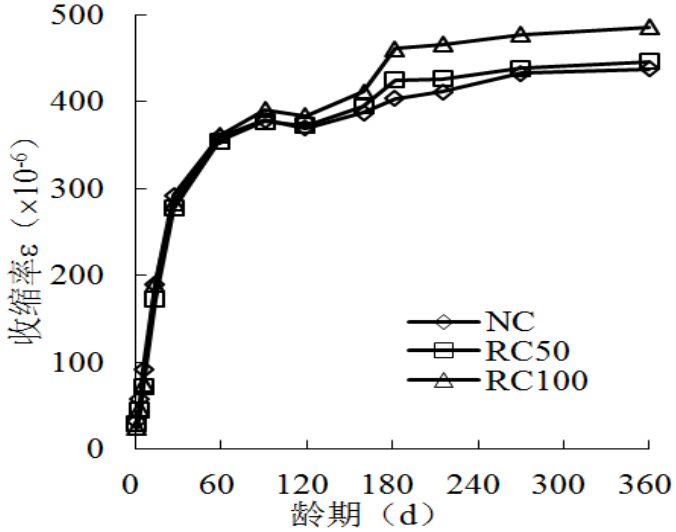
(b)试件成型

With the increase of the replacement rate of recycled coarse aggregate, **the cracking area of recycled concrete is increased**, and **the crack resistance is lowered.**

# 3. Properties of recycled concrete

## 3.5 Volume stability - shrinkage test



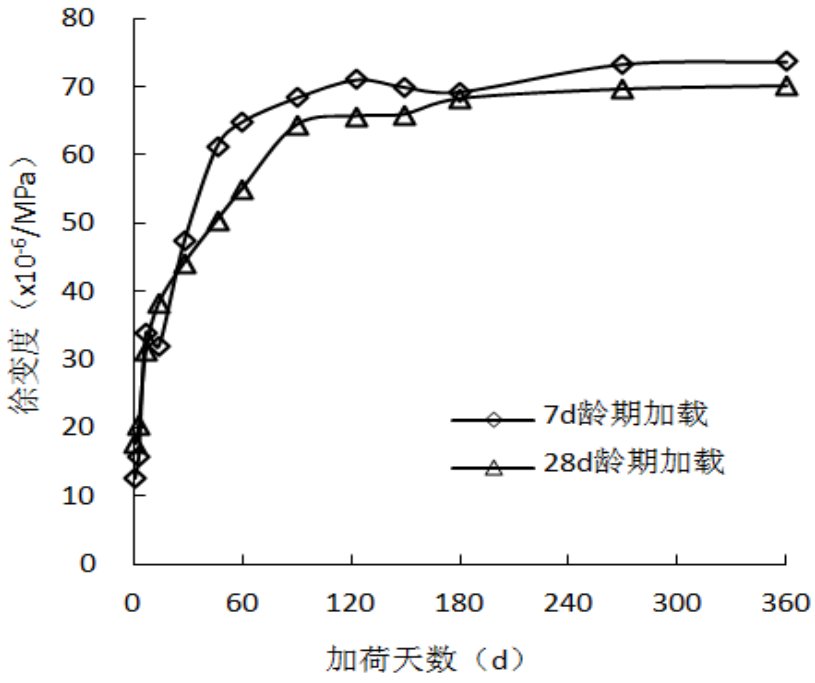

（1）**The shrinkage of concrete specimens grows faster at the early age**；

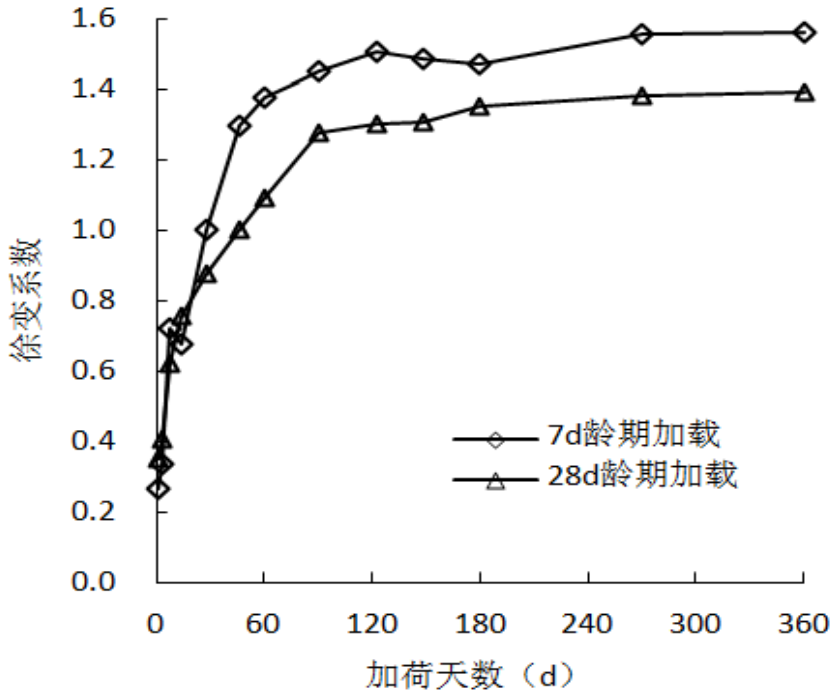
（2）**The shrinkage rate of recycled concrete slowly increases** with the increase of the replacement rate of recycled aggregates;

（3）The recycled concrete with **added fly ash and mineral powder** can be **greatly improved** in shrinkage.

# 3. Properties of recycled concrete

## 3.6 Volume stability - creep test

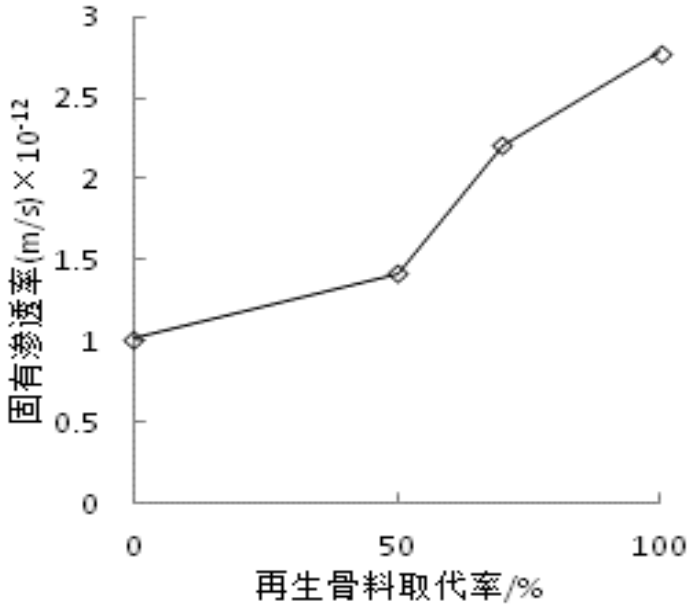



When recycled concrete is subjected to load at **7d age**, the creep deformation tends to be **stable at earlier age**, but **the creep value will be larger**.

# 3. Properties of recycled concrete

## 3.7 Durability - permeability

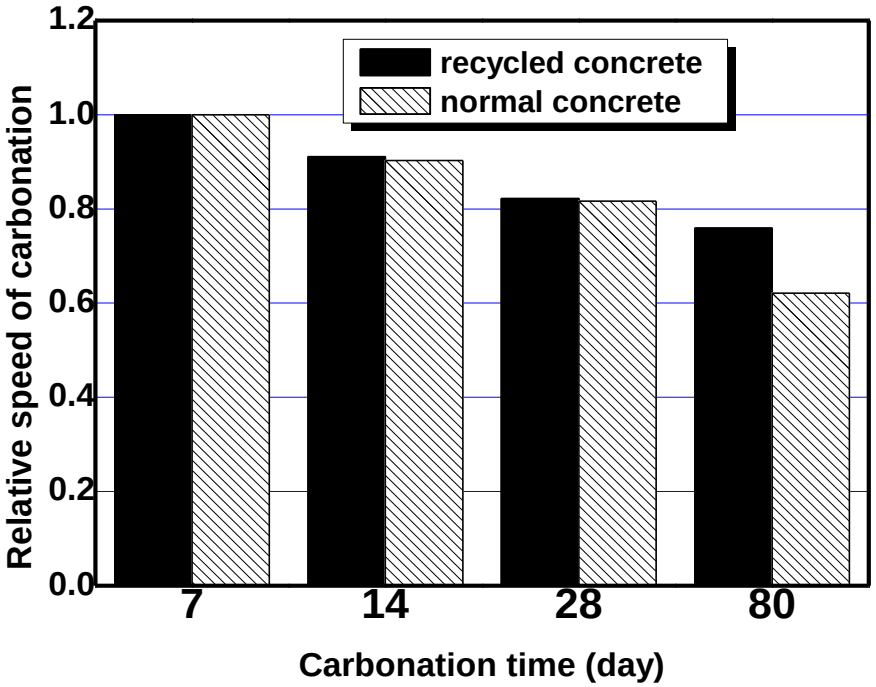



Effect of replacement rate on intrinsic permeability

As the replacement rate of recycled aggregate increases, the **impermeability of recycled concrete decreases**.

# 3. Properties of recycled concrete

## 3.8 Durability - anti-carbonization performance

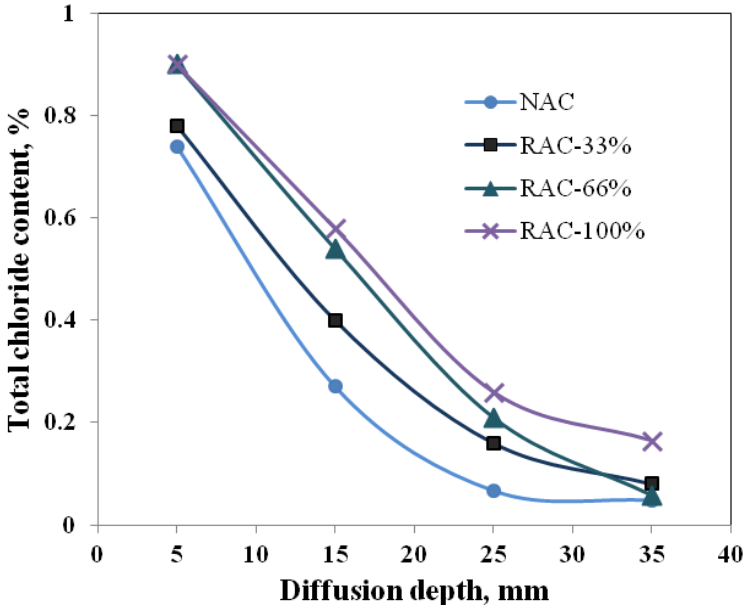



Carbonation speed of concrete under different carbon ages

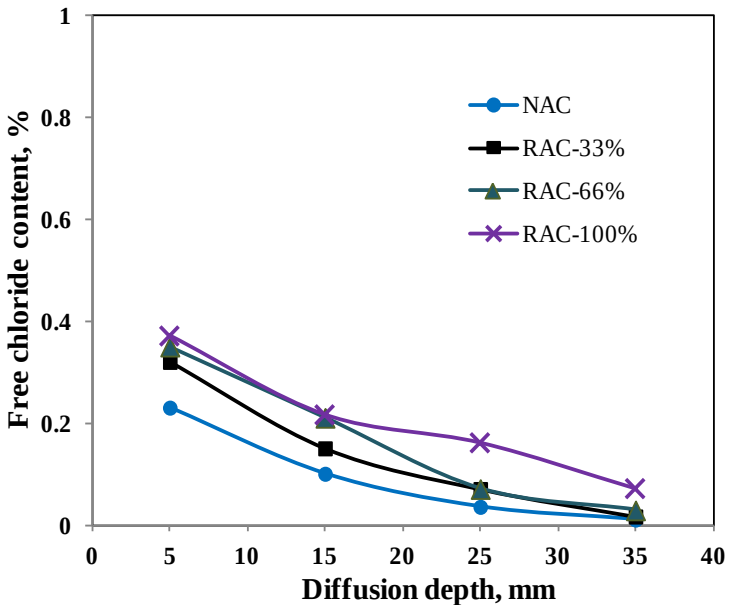
In long period, **recycled aggregate concrete has a higher relative carbonization rate** than normal concrete.

# 3. Properties of recycled concrete

## 3.9 Durability - resistance to chloride intrusion




Total chloride ion content



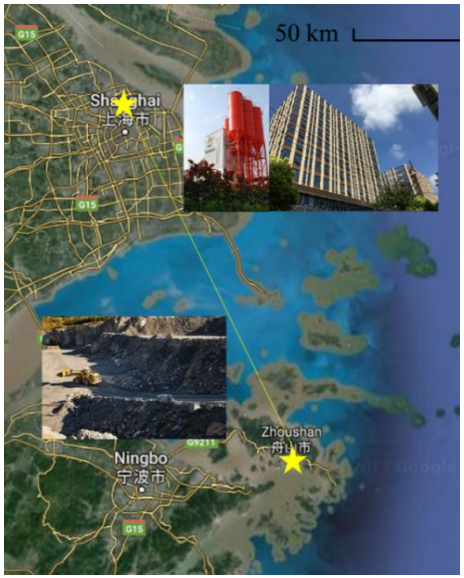

Free chloride ion content

Both the **total chloride ion and free chloride ion intrusion increase** with the replacement rate of recycled aggregate.

# 4. Application in sponge city

# 4. Application in sponge city

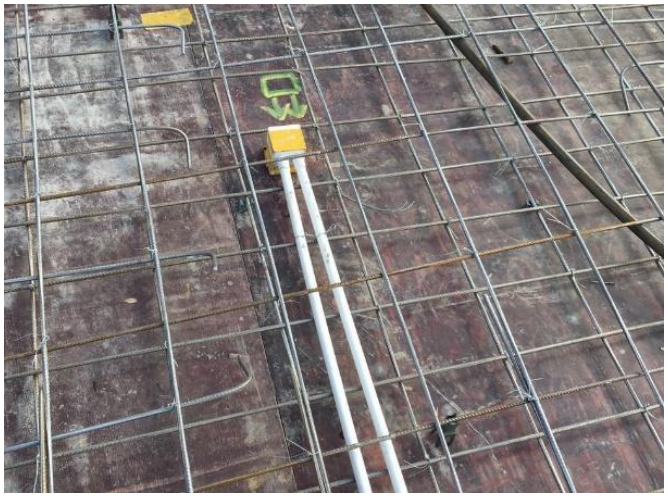
## 4.1 Application of recycled concrete in structure


- World Square 133 is a commercial building located in Shanghai, China.
- Consisting of two 12-storey reinforced concrete frame-shear wall structures, one made with RAC while the other one made with NAC.
- Both towers have 12 floors above the ground with a 49.2m height, and have the similar arrangement of structural components, as shown in Figure.
- The replacement percentage of RCA in the RAC was limited to 30%.

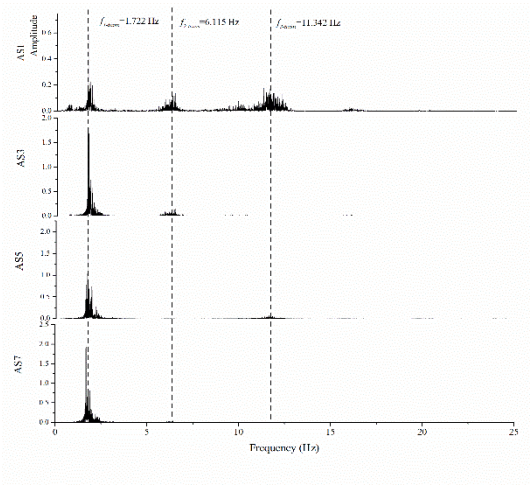
# 4. Application in sponge city

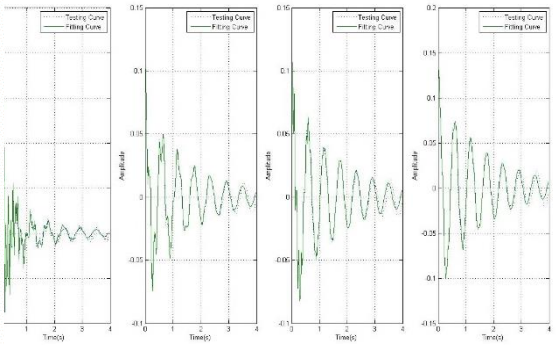
## 4.1 Application of recycled concrete in structure

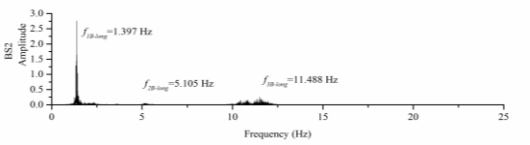


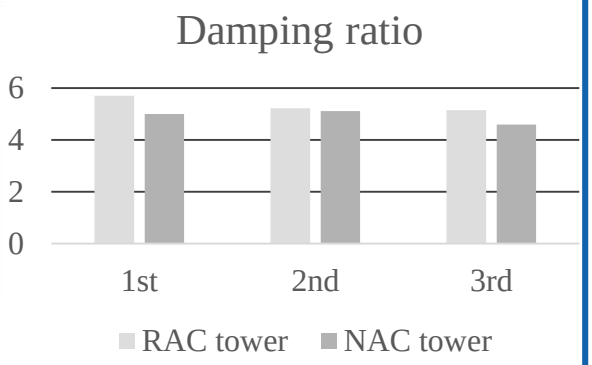
# 4. Application in sponge city

## 4.1 Application of recycled concrete in structure



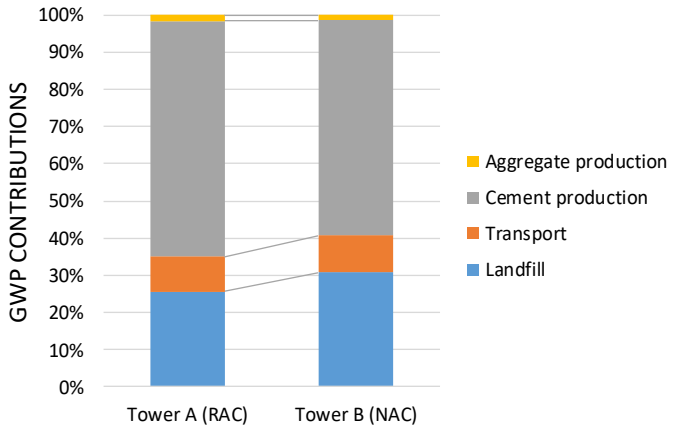



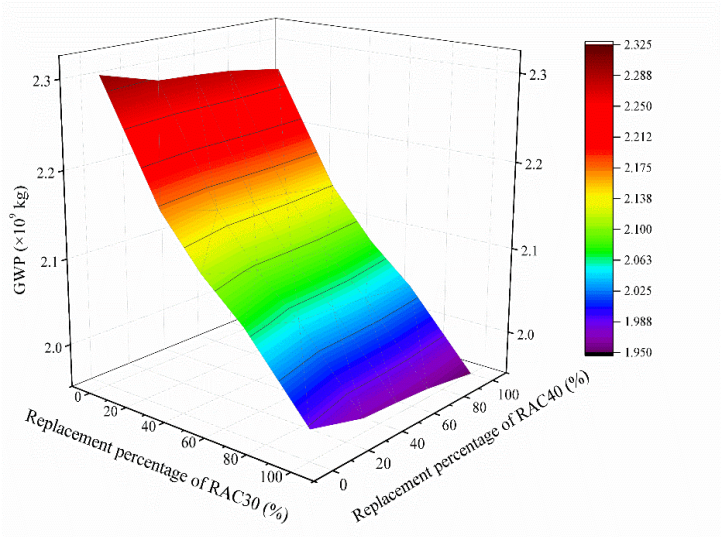




- The comparison of fundamental frequencies in transitive direction demonstrates 7% decrease in the first-order frequency and 13 % reduction in stiffness of RAC structure compared to NAC structure.
- A 14% damping ratio improvement was observed by using RCA in the RAC tower.

# 4. Application in sponge city

## 4.1 Application of recycled concrete in structure




- The $CO_2$-equivalent of the RAC structure were found to be respectively 6.51 and 6.31%, lower than those of the NAC structure.
- Considering the RAC's environmental benefits including reducing the embodied carbon footprint, energy consumption, the need for natural resources, C&D wastes processing and its competitive structural performance, the result highlights RAC as a sustainable alternative to NAC.

# 4. Application in sponge city

## 4.1 Application of recycled concrete in structure

In Jiangsu

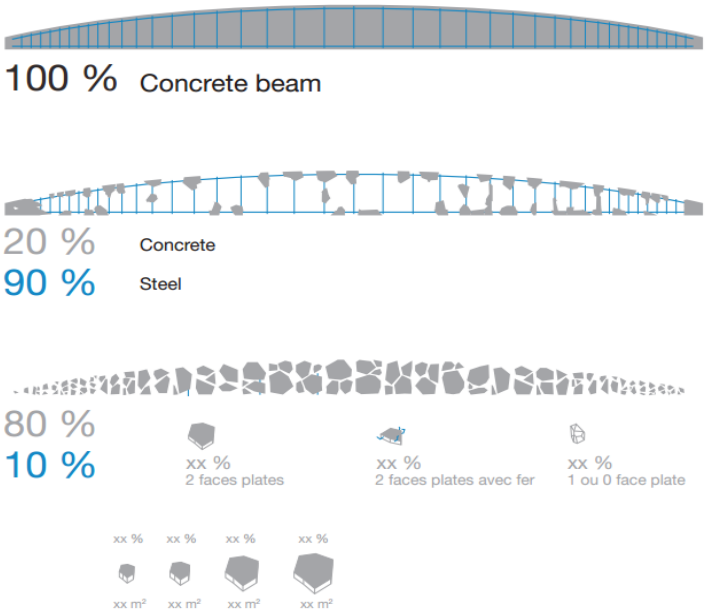
In Beijing

In Guizhou

In Zhejiang

# 4. Application in sponge city

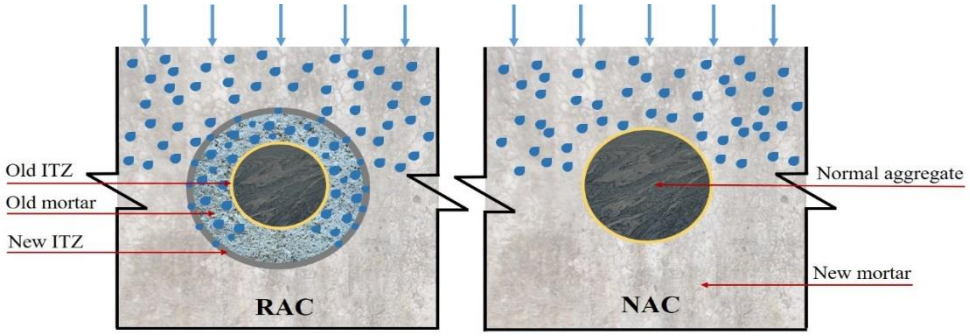
## 4.2 Application of recycled concrete in pavement



# 4. Application in sponge city

## 4.3 Use of recycled concrete in permeable products

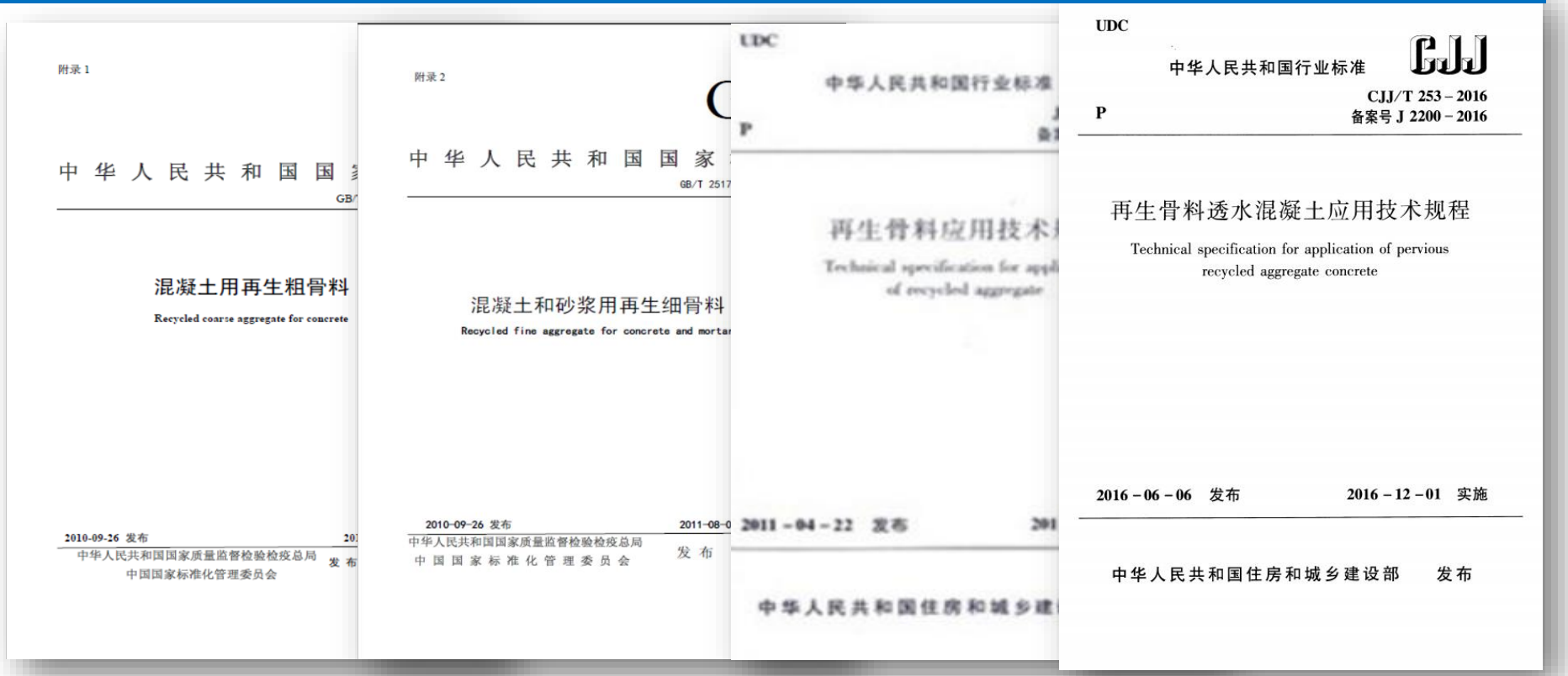
| Properties | Recycled aggregate | Natural aggregate |
|---|---|---|
| Adhesive rate of old mortar (%) | 33 | 0 |
| Loose packing density (kg/m$^3$) | 1280 | 1360 |
| Tight packing density (kg/m$^3$) | 1440 | 1480 |
| Apparent density (kg/m$^3$) | 2530 | 2660 |
| Crushing value index (%) | 11.0 | 5.13 |
| Clay content (%) | 1.80 | 0.80 |
| Water content (%) | 1.60 | 0.40 |
| Water absorption (%) | 4.08% | 1.03 |




1. The RA and RAC possess the higher water absorption as well as the water-retaining property, than natural aggregate (NA) and natural aggregates concrete (NAC)
2. Through the rational design, the RAC can have a good ability of **permeable characteristic.**
3. **Sponge city construction** provides the new way of the utilization of RA and RAC.

# 4. Application in sponge city

## 4.3 Use of recycled concrete in permeable products




**The code standard** on recycled aggregates (RA) and recycled aggregate concrete (RAC) have been published in recent years, promoting **the utilization of RA and RAC in sponge city**.

# 4. Application in sponge city

## 4.3 Use of recycled concrete in permeable products

Ground brick and water permeable brick prepared by recycled aggregate
CJ/T 400-2012

ICS 91.100.15
Q 13

CJ

中华人民共和国城镇建设行业标准

CJ/T 400—2012

再生骨料地面砖和透水砖

Ground brick and water permeable brick prepared by recycled aggregate

2012-05-16 发布　　2012-10-01 实施

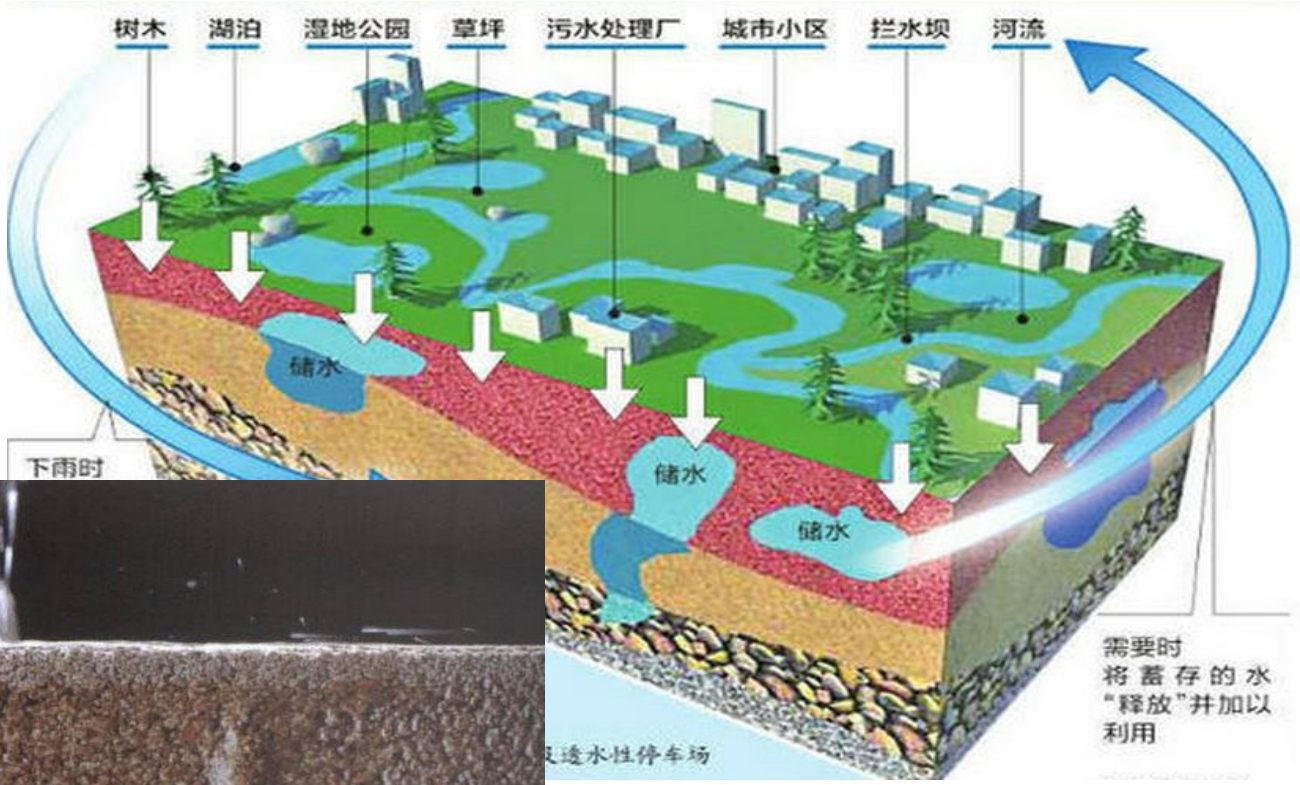
中华人民共和国住房和城乡建设部　发布

**Recycled aggregate floor tiles** : Recycled aggregate concrete floor tiles take recycled aggregate, cement as the main raw material, adding the right amount of admixture, adding water to mix and after natural conservation or steam curing to form.

**Recycled aggregate permeable bricks** : Floor tiles with larger water permeability take waste recycled aggregate, cement as the main raw material, adding the right amount of admixture, adding water to mix and after natural conservation or steam curing to form.

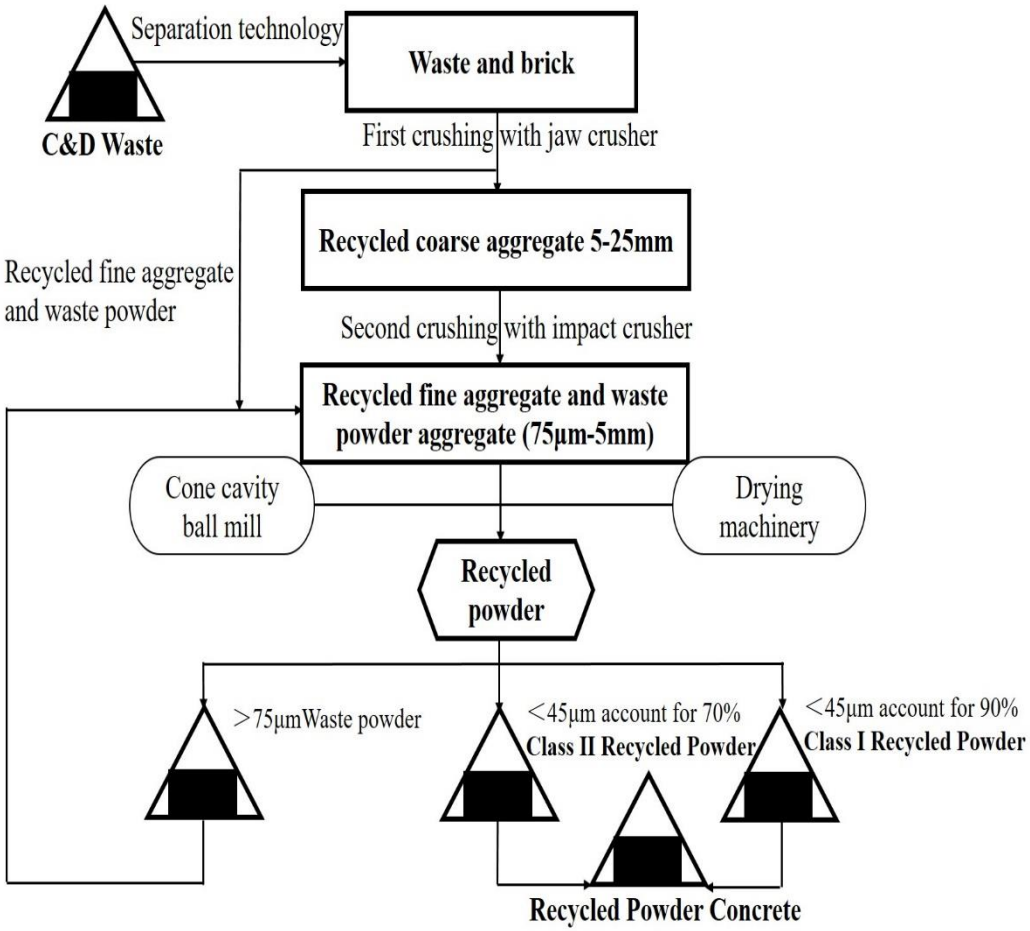
# 4. Application in sponge city

## 4.3 Use of recycled concrete in permeable products




# 4. Application in sponge city

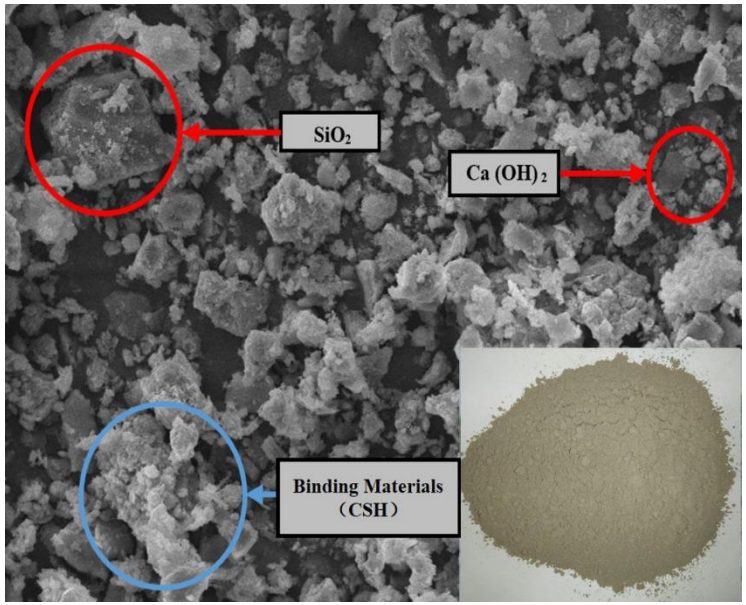
## 4.4 Use of recycled powder in permeable product




- There has already been a Chinese standard CJJ/T 253-2016 about the application of pervious recycled aggregate concrete.
- We're trying to replace Portland cement with recycled powder (RP) obtained from construction and demolition (C&D) waste.

# 4. Application in sponge city

## 4.4 Use of recycled powder in permeable product

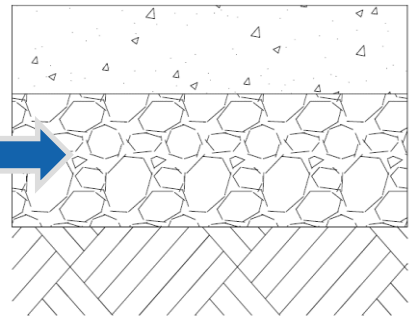



- **The appearance of RP(recycled powder) is similar to that of cement and fly ash.** The Scanning Electron Microscope (SEM) images of RP. As can be seen, the SiO2 crystal obtained from the crushing of waste concrete in CDW are easily distinguishable. Moreover, the calcium silicate hydrate (CSH) and hexagonal crystal titled Ca(OH)2 derived from the cement paste in waste concrete can also be observed.

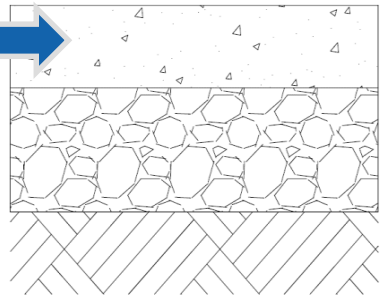
# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Cement Stabilized recycled aggregate serve as base



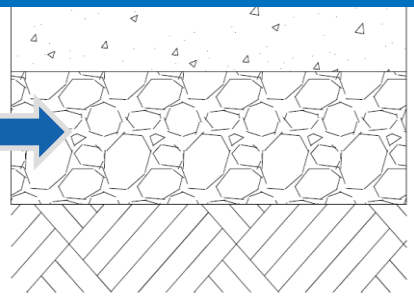
Replacing Portland cement by recycled powder in pervious recycled aggregate concrete



# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Cement Stabilized recycled aggregate serve as base



Recycled aggregate gathered from the demolition site was divided into 3 groups roughly: coarse aggregate; medium-size aggregate; fine aggregate

Particle gradation of recycled aggregate

| Particle size(mm) | 31.5 | 25 | 20 | 16 | 10 | 5 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mass percentage | 100 | 94.24 | 83.64 | 55.44 | 50.02 | 40.61 | 28.10 | 20.60 | 15.74 | 8.27 | 4.08 | 1.99 |

Mixture proportions(kg/m³)

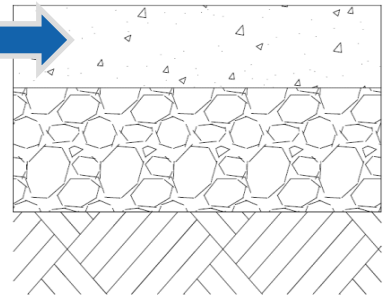
| C/A | Cement | Water | Recycled Aggregate | | |
|---|---|---|---|---|---|
| | | | Coarse | Medium-size | Fine |
| 0.03 | 53.274 | 165.503 | 480.306 | 480.306 | 960.612 |
| 0.04 | 67.264 | 166.649 | 476.522 | 476.522 | 953.044 |
| 0.05 | 87.098 | 168.274 | 471.157 | 471.157 | 942.314 |
| 0.06 | 103.532 | 169.619 | 466.712 | 466.712 | 933.424 |
| 0.07 | 119.658 | 170.940 | 462.350 | 462.350 | 924.701 |

unconfined compressive strength specimen

# 4. Application in sponge city

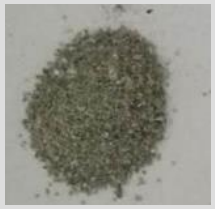
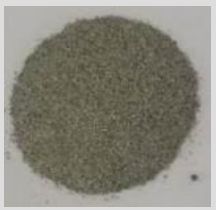
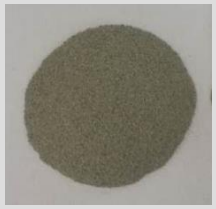
## 4.5 Design of pervious pavement by recycled materials

Replacing Portland cement by recycled powder in pervious recycled aggregate concrete



Strength activity index $H_{28}$ $H_{28} = R/R_0 = \frac{18.2}{25.2} = 72.2\%$

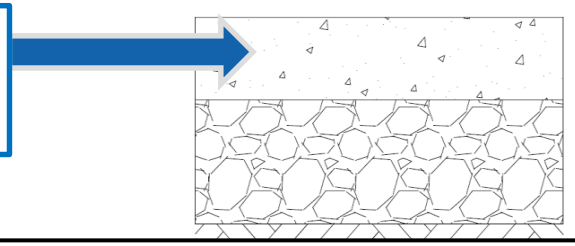
Particle gradation of recycled powder

| |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Particle Size | >0.6mm | >0.3mm | >0.15mm | >0.075mm | >0.045mm | <0.045mm |
| Weight (100g in total) | 0.4g | 1.1g | 12.7g | 33.0g | 19.8g | 33.3g |
| Percentage | 0.4% | 1.1% | 12.7% | 33.0% | 19.8% | 33.3% |

# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Replacing Portland cement by recycled powder in pervious recycled aggregate concrete



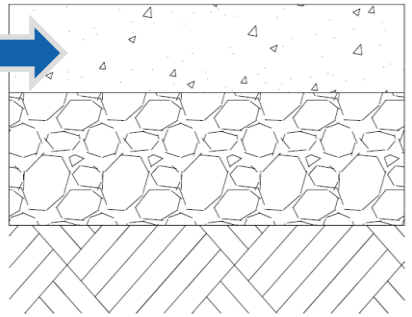
Mixture proportions(kg/m³)

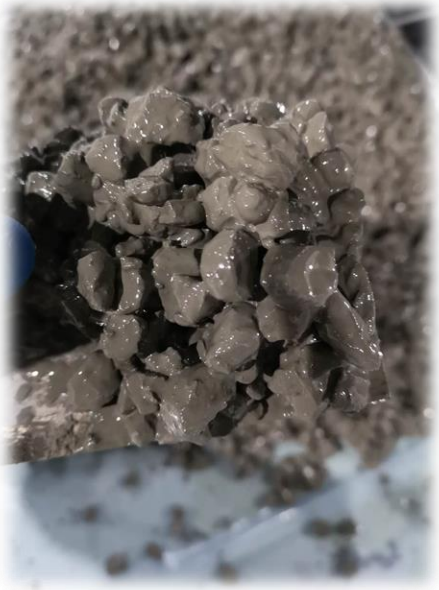
| Specimens | w/b | Water | | Binding Material | | Recycled Aggregate | Water Reducing Agent |
|---|---|---|---|---|---|---|---|
| | | Mixing Water | Additional Water | Cement | Recycled Powder | | |
| PRAC25-RP0 | 0.25 | 91.38 | 55.66 | 365.52 | 0.00 | 1391.60 | 1.46 |
| PRAC25-RP15 | 0.25 | 91.38 | 55.66 | 310.69 | 54.83(15%) | 1391.60 | 1.46 |
| PRAC25-RP30 | 0.25 | 91.38 | 55.66 | 255.86 | 109.65(30%) | 1391.60 | 1.46 |
| PRAC30-RP0 | 0.30 | 105.44 | 55.66 | 351.46 | 0.00 | 1391.60 | 1.41 |
| PRAC30-RP15 | 0.30 | 105.44 | 55.66 | 298.74 | 52.72(15%) | 1391.60 | 1.41 |
| PRAC30-RP30 | 0.30 | 105.44 | 55.66 | 246.02 | 89.62(30%) | 1391.60 | 1.41 |
| PRAC35-RP0 | 0.35 | 118.45 | 55.66 | 338.44 | 0.00 | 1391.60 | 1.35 |
| PRAC35-RP15 | 0.35 | 118.45 | 55.66 | 287.67 | 50.77(15%) | 1391.60 | 1.35 |
| PRAC35-RP30 | 0.35 | 118.45 | 55.66 | 236.91 | 101.53(30%) | 1391.60 | 1.35 |

# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Replacing Portland cement by recycled powder in pervious recycled aggregate concrete





PRAC30-RP0

PRAC30-RP30

Water-absorbing quality of recycled powder has an important effect on the flowability of cement paste.

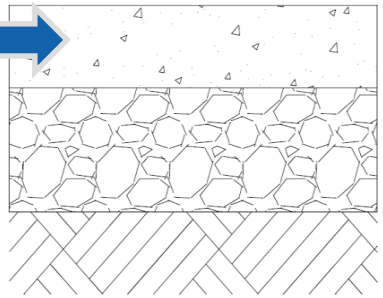
Diameter of pores distributed in the bottom of pavement is relatively larger.

Permeability is improved.

# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Replacing Portland cement by recycled powder in pervious recycled aggregate concrete



PRAC30-RP0

PRAC30-RP30

Same amount of:

- Water consumption
- Water reducing agent

Same modeling method

Water-absorbing quality of recycled powder has an important effect on the flowability of cement paste.

Diameter of pores distributed in the bottom of pavement is relatively larger.

Permeability is improved.

# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Replacing Portland cement by recycled powder in pervious recycled aggregate concrete

图 1　试件横截面图

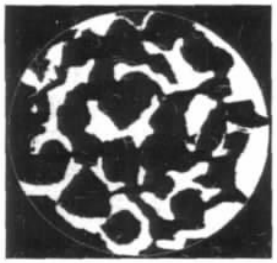


图 2　截面图像灰化图

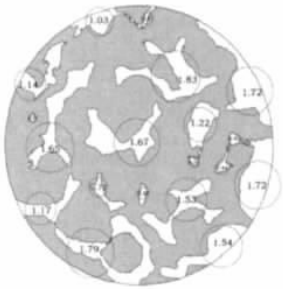
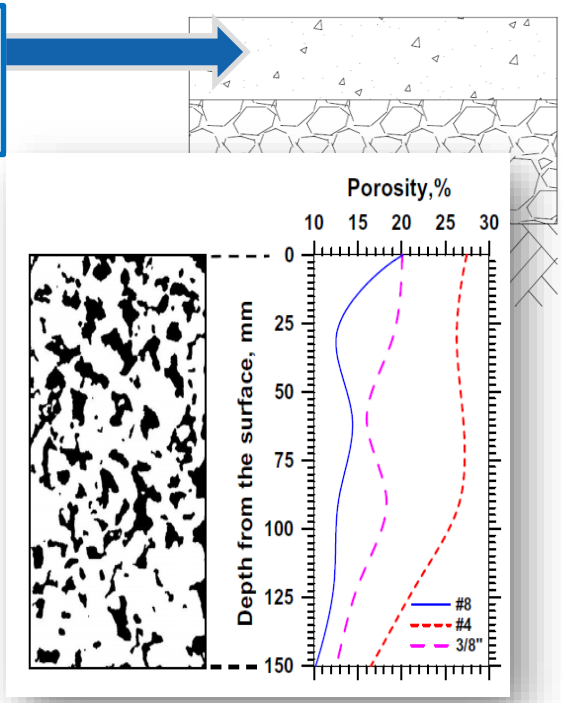


图 3　截面等效孔径示意图




**Horizontal cutting**

**Equivalent aperture**

**Plane porosity**

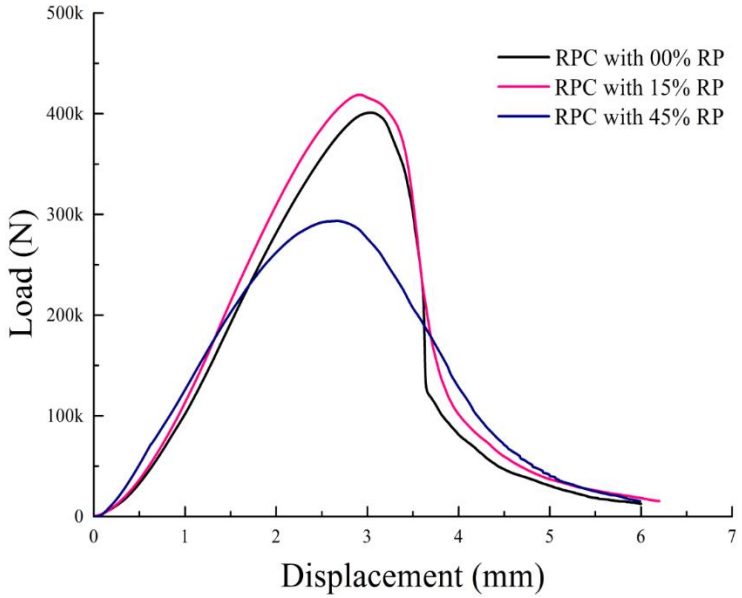
**Vertical cutting**

**Paste distribution**

# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Using recycled powder in pervious pavement

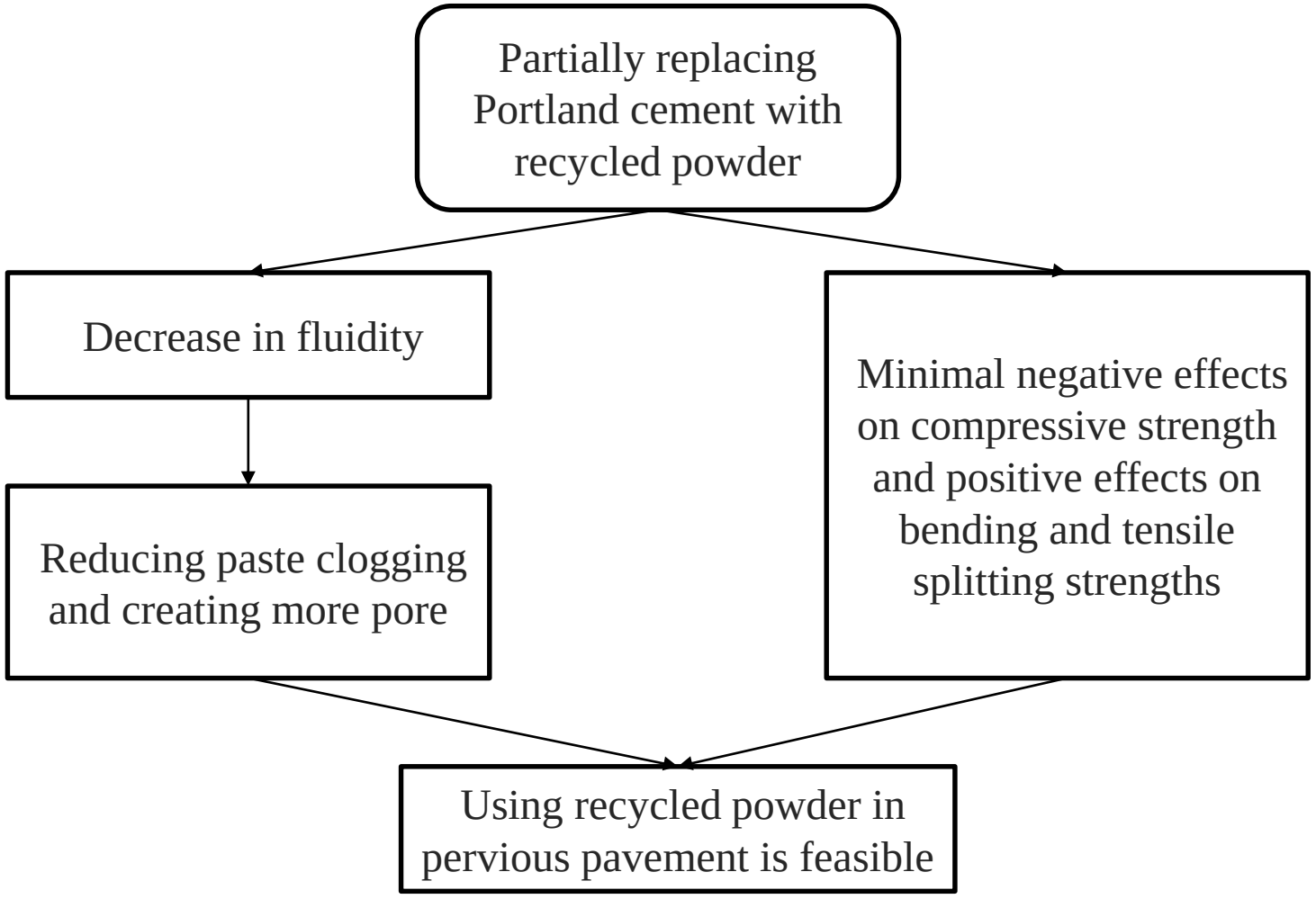



- Replacing up to **30%** of cement with RP was found to have **minimal negative effects** on compressive strength. All the mechanical properties of RPC were found to decrease considerably with further increase in the RP replacement percentage to 45%.

# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

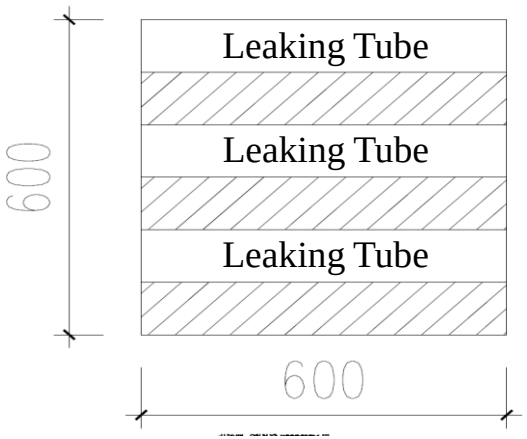
Using recycled powder in pervious pavement



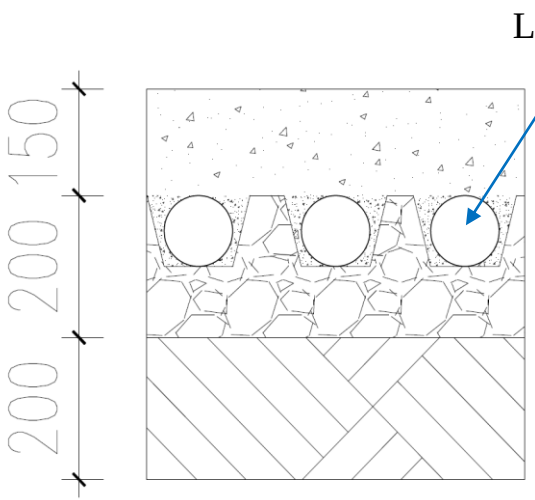
# 4. Application in sponge city

## 4.5 Design of pervious pavement by recycled materials

Plan to create a permeable pavement system model containing **leaking tube**




Model Plan

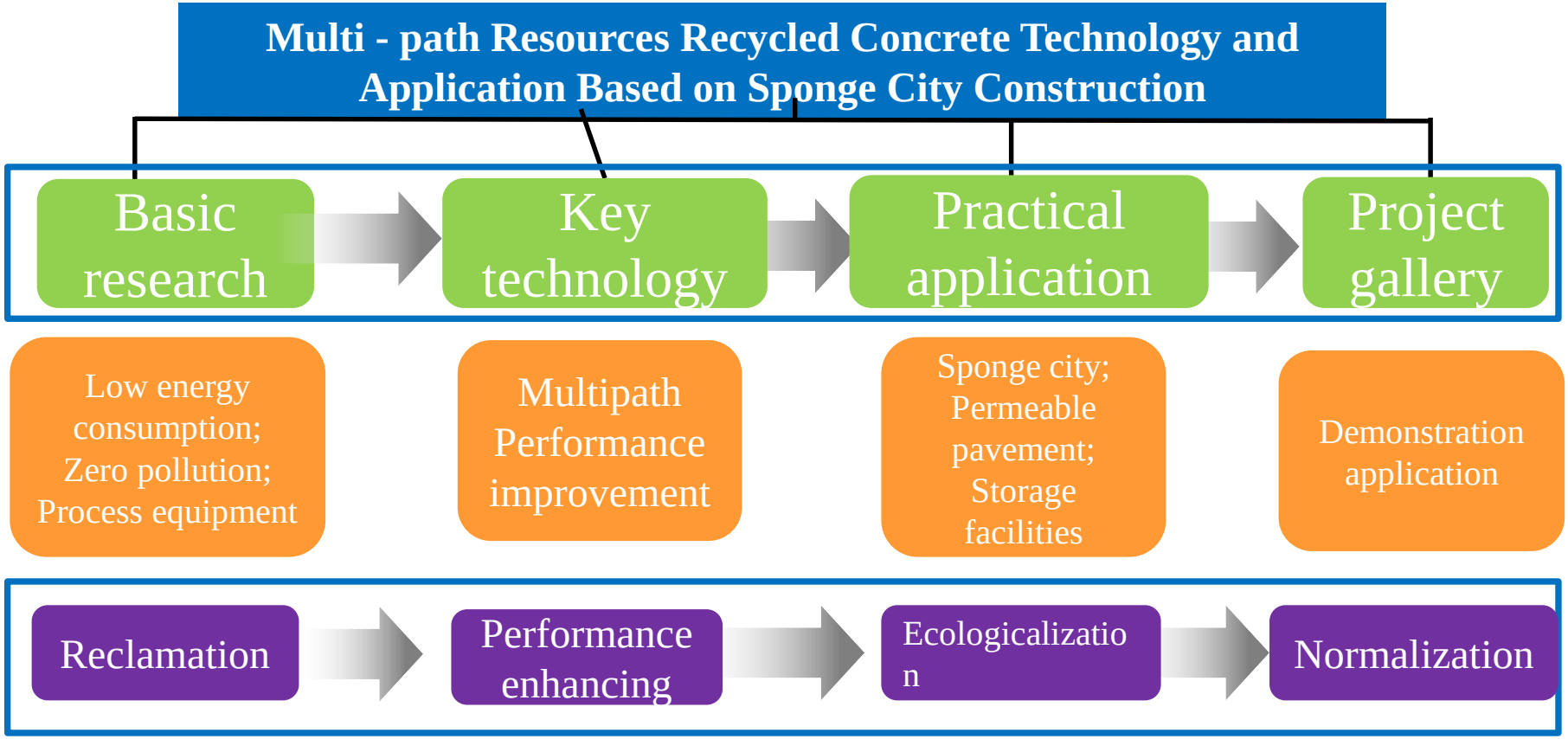



Model Section

There are great possibilities to improve the permeability of the pavement and postpone the appearance of runoff.

# 4. Application in sponge city

## 4.6 Research content



# 4. Application in sponge city

## 4.7 Demonstration project


Permeable pavement using recycle materials in Lingang District

# 4. Application in sponge city

## 4.7 Demonstration project

**Six roads in national pilot area of sponge city**

**Pervious concrete using recycled aggregate serving as basement**

**Pavement structure**

- 60mm Permeable brick
- 30mm medium-coarse sand
- 100mm recycled pervious concrete
- 100mm macadam

Permeable pavement using recycle materials in Lingang District

# 4. Application in sponge city

## 4.7 Demonstration project


Permeable pavement using recycle materials in Citizen's Park, Taicang

# Conclusions

1. Recycled aggregate concrete is one type of sustainable concrete. Research on RAC is encouraged from recycled aggregates to recycled concrete material and then recycled concrete structures.
2. A complete set of reclamation equipment and technologies are available to produce high-quality recycled aggregates and recycled concrete.
3. Recycled coarse concrete can be a structural concrete after proper design and construction, under static loadings, dynamic loadings and seismic loadings. Recycled fine aggregates and recycled powder need further research.
4. Recycled aggregates and recycled powder are suitable to make permeable products. Using recycled materials to build permeable pavement is promising.

# *Thanks for your attention!*

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