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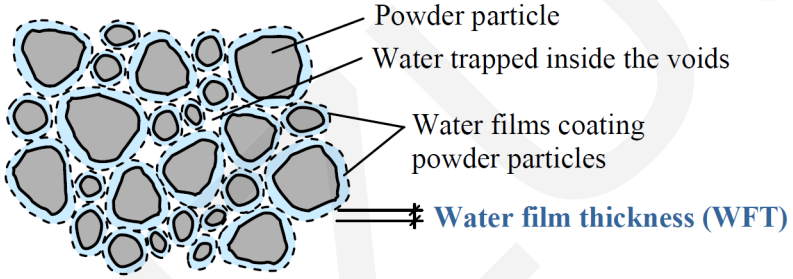
Packing and film thickness theories for the mix design of high-performance concrete

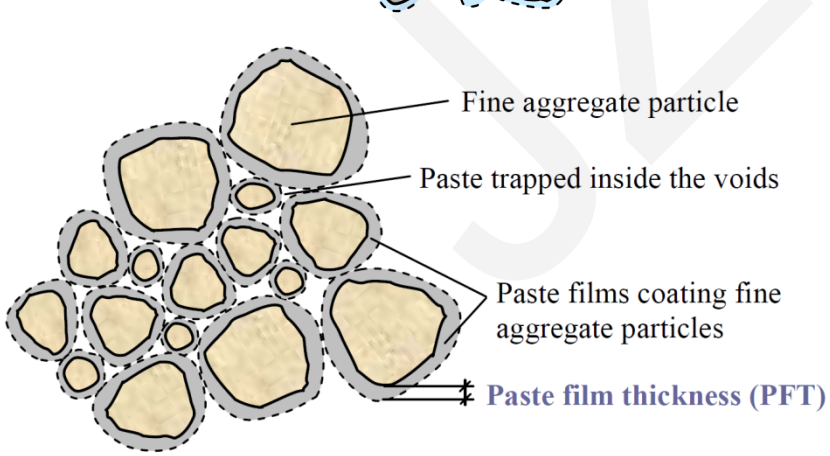
Pui-Lam NG, Albert Kwok-Hung KWAN, Leo Gu LI

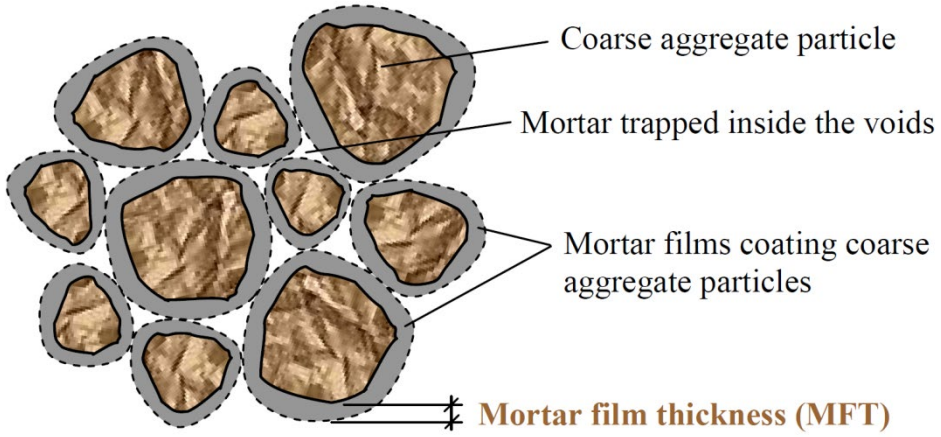
Keywords: Concrete mix design, concrete science, film thickness, high-performance concrete, packing density, sustainability

Introduction

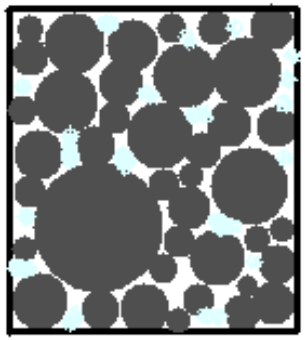
- The mix design of high-performance concrete (HPC) is complicated
- The packing density of solid particles has major effects on the performance of concrete, through its great effects on:
  - Water film thickness (WFT) coating the cementitious materials particles,
  - Paste film thickness (PFT) coating the fine aggregate particles, and
  - Mortar film thickness (MFT) coating the coarse aggregate particles

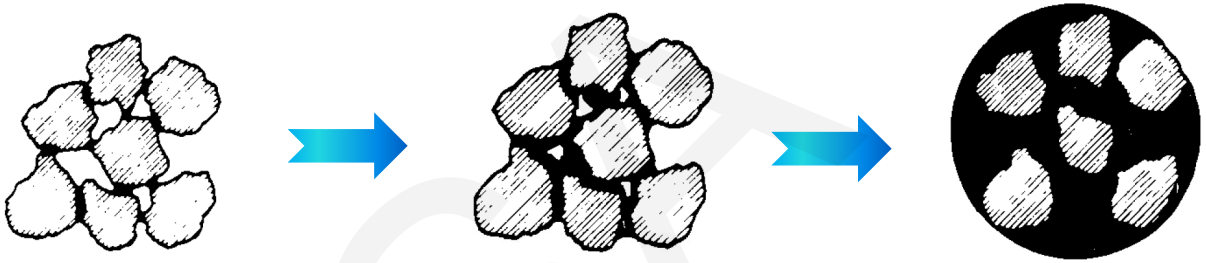


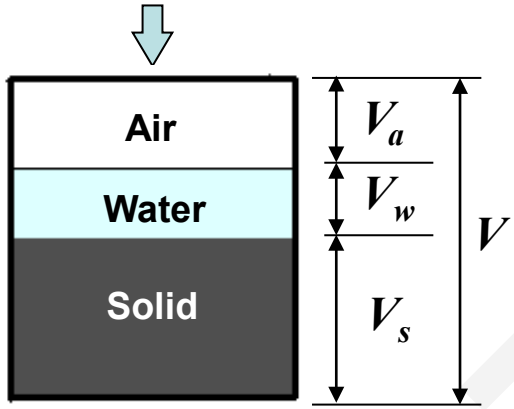


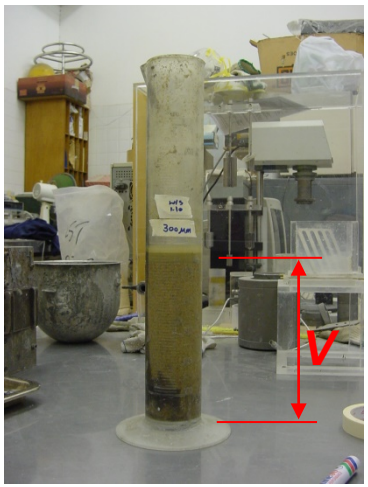


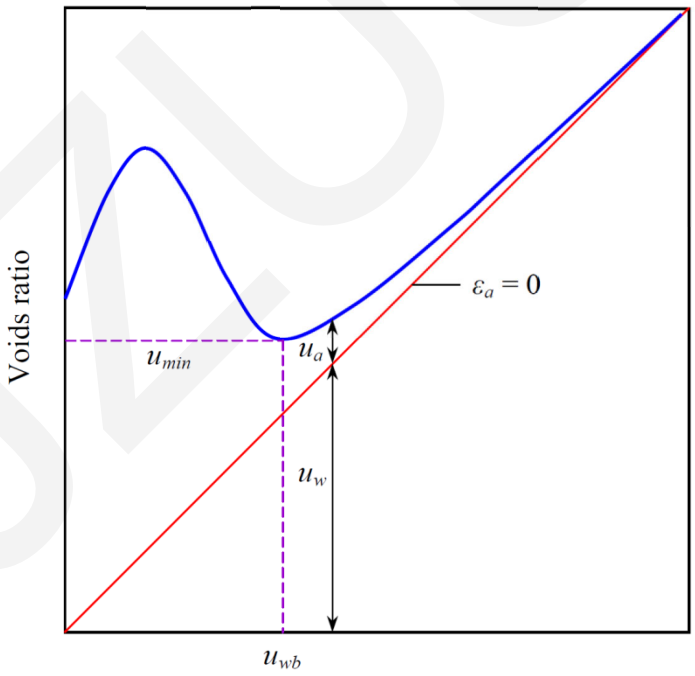
Wet Packing Test



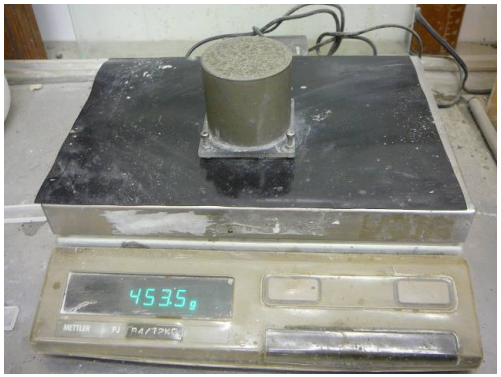












Experimental Investigation

- 32 trial concrete mixes

Material	Specific surface area (m^2/m^3)
OPC	1.55×10^6
Fine aggregate	5.12×10^4
Portion of fine aggregate > 75 μm in size (excluding the portion < 75 μm in size)	1.03×10^4
Portion of fine aggregate > 1.2 mm in size (excluding the portion < 1.2 mm in size)	2.04×10^3
10 mm coarse aggregate	642
20 mm coarse aggregate	398



Slump flow test



V-funnel test

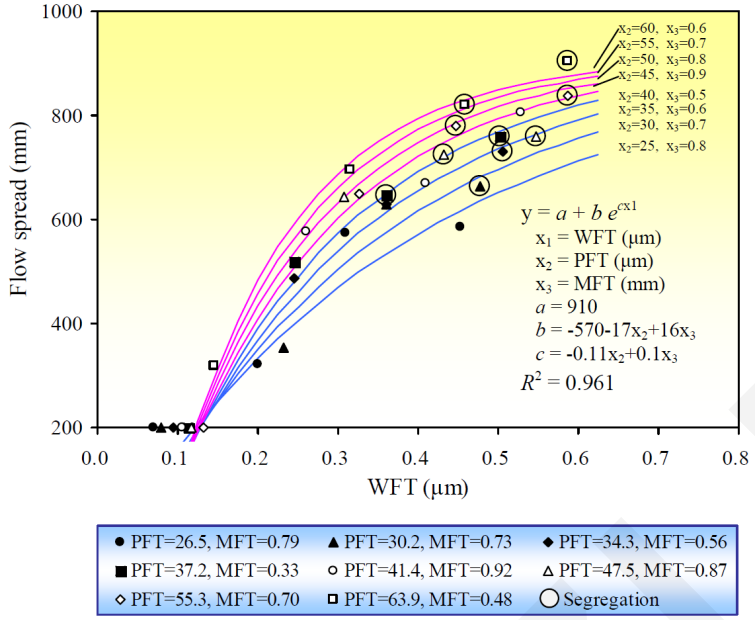


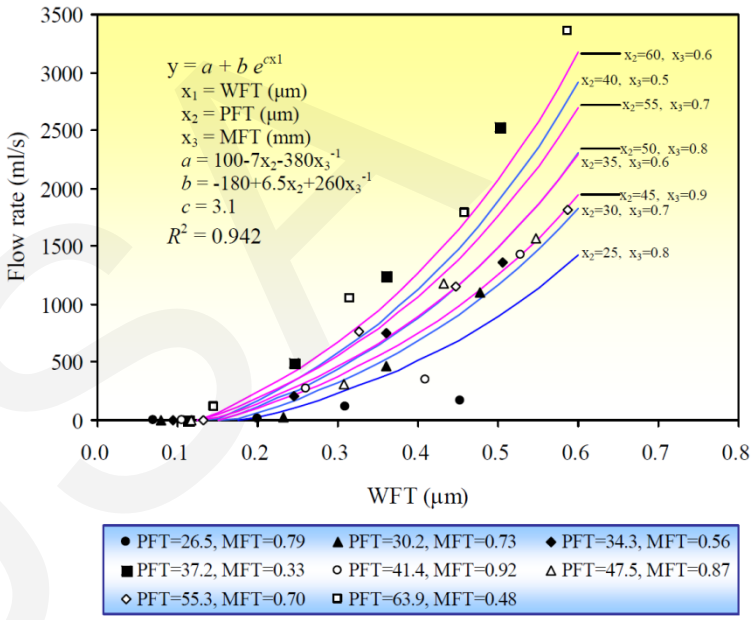
Sieve segregation test

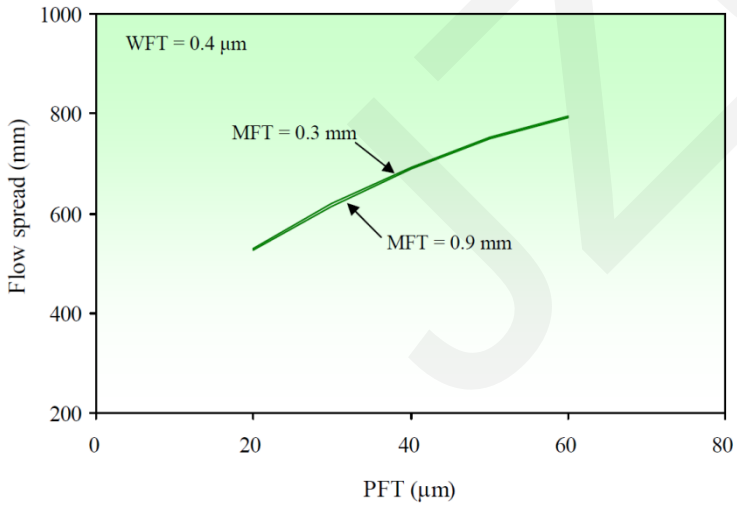


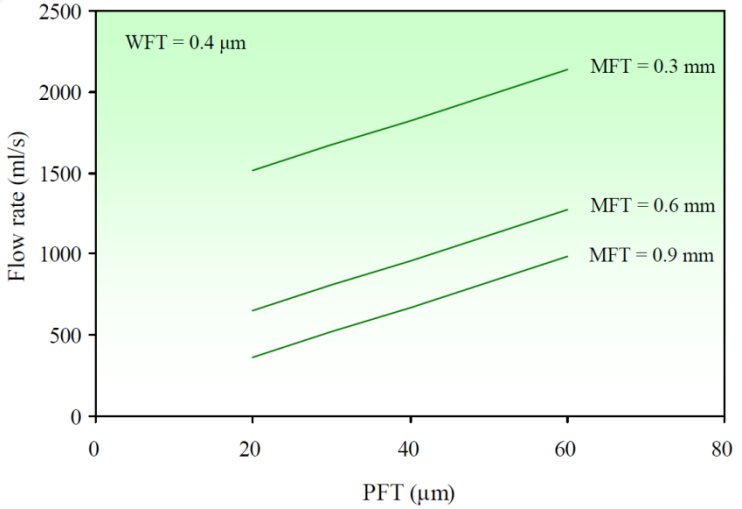
U-box test

Combined Effects of Film Thicknesses





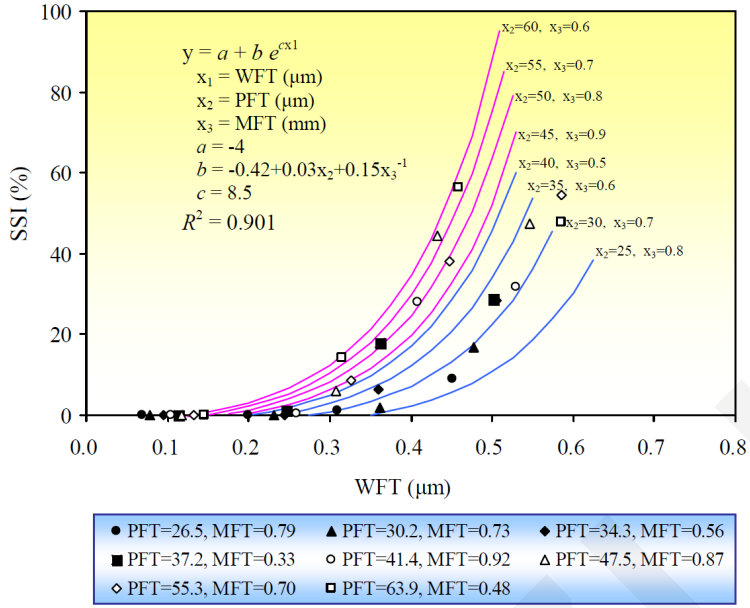


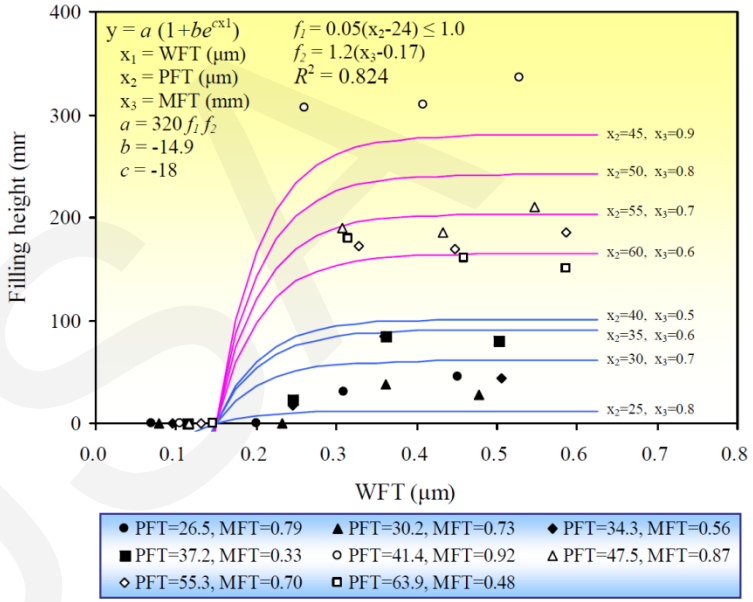


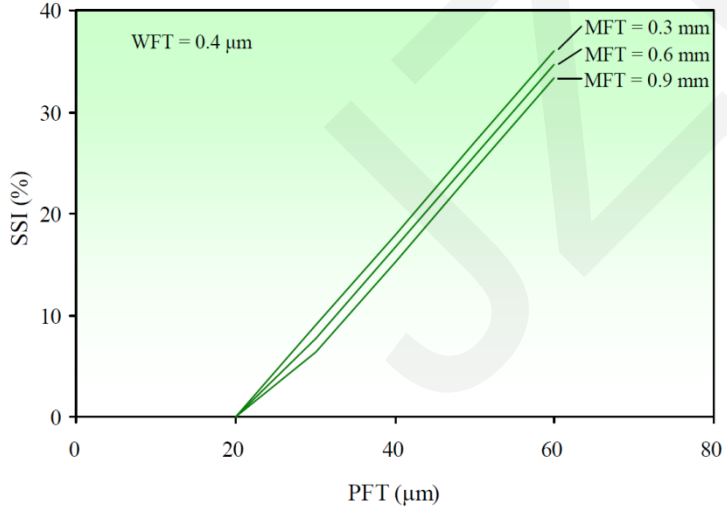
Effects on flow spread

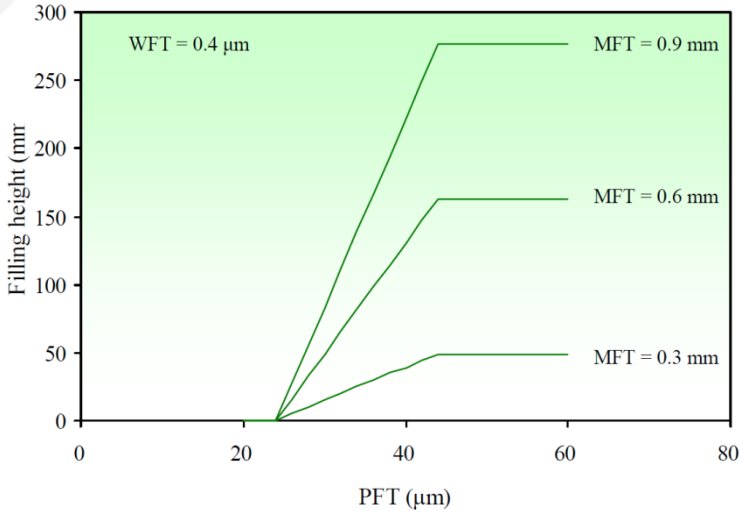
Effects on flow rate

Combined Effects of Film Thicknesses







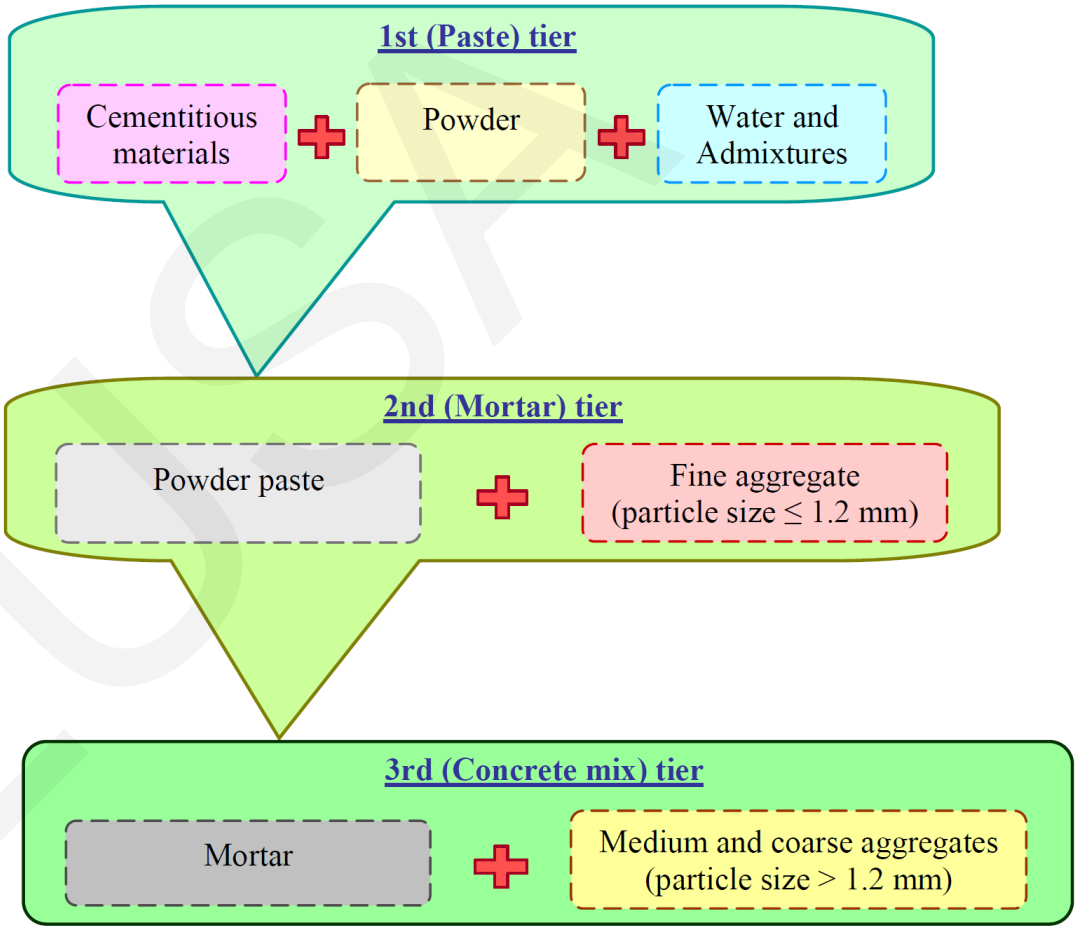


Effects on sieve segregation index

Effects on filling height

Three-tier Mix Design Method

- Design the concrete mix in 3 tiers of increasing particle size range:
  - First tier (paste tier): cementitious materials and powders (≤ 75 μm in size) which form the powder paste when mixed with water,
  - Second tier (mortar tier): fine aggregate particles (≤ 1.2 mm & > 75 μm in size) which form the mortar when mixed with the powder paste,
  - Third tier (concrete mix tier): medium aggregate particles (≤ 5 mm & > 1.2 mm in size) and coarse aggregate particles (> 5 mm in size) which form the concrete when mixed with the mortar



Conclusions

- The packing and film thickness theories for the mix design of HPC have been presented
- For accurate measurement of packing density of concrete materials, the wet packing test had been developed
- The WFT, PFT and MFT are governing factors of the rheological performance of concrete
- To illustrate the above, a series of concrete mixes with different combinations of water/cement (W/C) ratio, cement paste volume (CPV) and fine/total aggregate (F/T) ratio were tested for their flowability, cohesiveness, passing ability and packing density
- The experimental results have revealed strong correlation of flow spread, flow rate, sieve segregation index (SSI) and U-box filling height with film thicknesses
- Redefinition of aggregate classifications is advocated by the authors
- Framework of the three-tier concrete mix design method has been developed