Functionally Graded Concrete for the Civil Infrastructure – A Multifunctional Material System Approach

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Structural Materials and Mechanics
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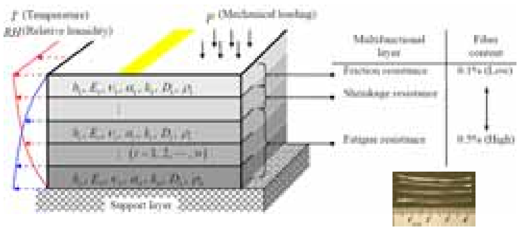
Motivation

- Functionally Graded Concrete to achieve multi-objectives
- Layers of specific material properties placed at optimal location and thickness to enhance overall performance
- Achieving high performance rigid pavement system



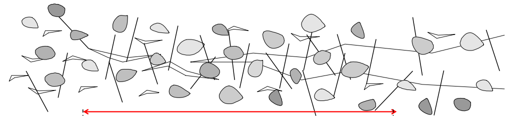
- **Fibers**: provide toughening mechanisms in concrete

Research Objectives

- Constitutive modeling for fracture mechanisms of fiber reinforced concrete (FRC) through cohesive zone model
- Study the placement and thickness of concrete materials in order to optimize the fracture resistance and behavior

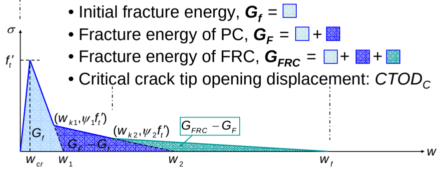
Cohesive Zone Model Approach

Fracture Mechanisms of FRC



Softening model for FRC

- Tensile strength : f_t'
- Initial fracture energy, G_f = □
- Fracture energy of PC, G_F = □ + ■
- Fracture energy of FRC, G_{FRC} = □ + ■ + ■
- Critical crack tip opening displacement: $CTOD_C$



$$w_1 = \frac{2G_f}{f_t'} \qquad w_{k1} = CTOD_C$$

$$\psi_1 = 1 - \frac{CTOD_C f_t'}{2G_f}$$

$$w_2 = \frac{2}{\psi_1 f_t'}\left[G_F - (1-\psi_1)G_f\right]$$

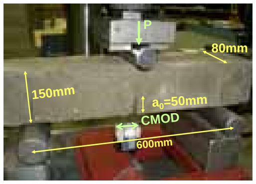
$$w_f = (Fiber\ \ length)/4 \sim (Fiber\ \ length)/2$$

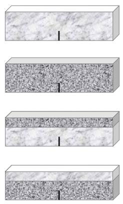
$$\psi_2 = \frac{2(G_{FRC} - G_F)}{f_t'(w_f - w_2)}$$

$$w_{k2} = w_2 - \frac{\psi_2}{\psi_1}(w_1 - w_{k1})$$

Experimental & Computational Setup

Test Program

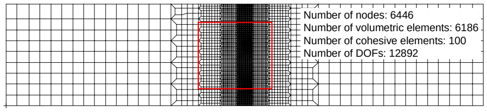


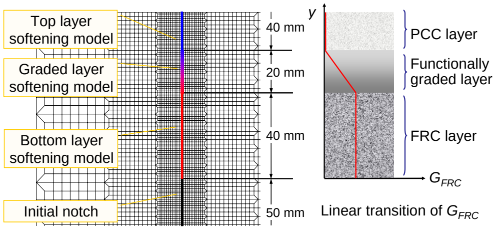


Material Properties

Elastic modulus	f_t'	G_f	G_F	G_{FRC}	$CTOD_c$	Fiber length
26.9 (GPa)	3.9 (MPa)	38.1 (N/m)	145 (N/m)	2562 (N/m)	0.0157 (mm)	40 (mm)

Finite Element Modeling

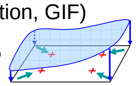




Graded cohesive surface element

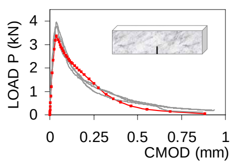
(Generalized Isoparametric Formulation, GIF)

$$u = \sum_{i=1}^{m} N_{(i)} u_{(i)} \qquad x = \sum_{i=1}^{m} N_{(i)} x_{(i)} \qquad G_{FRC} = \sum_{i=1}^{m} N_{(i)} G_{FRC(i)}$$

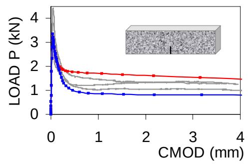


Computational Results

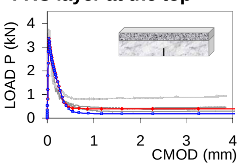
Plain concrete



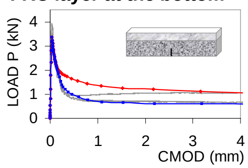
Fiber reinforced concrete



FRC layer at the top

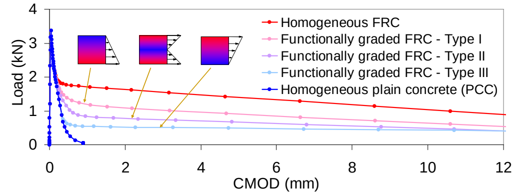


FRC layer at the bottom

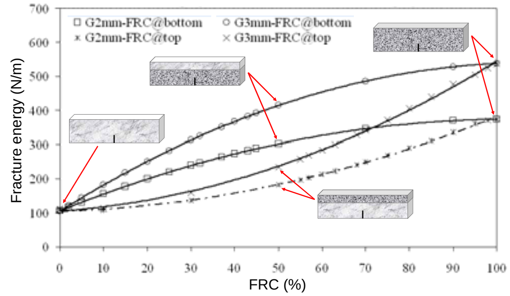


—— Experimental results
—◆— Numerical predictions: w_f = (fiber length) / 4
—◆— Numerical predictions: w_f = (fiber length) / 2

Functionally Graded FRC



Effect of Material Thickness Variation



Cost Benefit Analysis

FRC (%)	0	10	30	50	70	90	100
PCC (%)	100	90	70	50	30	10	100
Cost	1.00	1.02	1.05	1.08	1.11	1.14	1.15
FRC layer at the top							
G_{2mm}	1.0	1.4	2.2	2.8	3.2	3.7	3.5
FRC layer at the bottom							
G_{2mm}	1.0	1.0	1.1	1.6	2.4	3.2	3.5

Conclusions

- Proposed softening model captures fracture behavior of PCC, FRC, and layered FRC
- Fracture process zone is divided into aggregate bridging zone and fiber bridging zone
- This investigation can lead to optimal thickness and position of materials in concrete pavements increasing cracking resistance while minimizing costs

Acknowledgement

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