Our R&D Journey on MiC: Materials, Designs & Implementation

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NAMI
Your *Materials* Expert

Outline

- Intro of NAMI
- Update of NAMI Gen-1 Lightweight Concrete & Impacts
- R&D towards Sustainability
  - Structural-grade Lightweight Concrete with GGBS
  - Foaming Technologies with Recycled Glass & Flue Gas
- Innovative Structural Designs
  - New Materials for Structural Applications
  - New Design for Concrete MiC Interlocking
- Implementation: First Lightweight Concrete-Steel MiC in HK
- Concluding Remarks

Introduction

NAMI, incorporated in 2006, is designated by the Hong Kong Government as a Research and Development Center for nanotechnology and advanced materials

R&D Investment
>HK$1 Billion

Equipment
(>HK$300M)

Technical Talents
>250
(>50% PhD)

Lab Area
(48,000 ft^2)

Filed Patents
(>500)

Sponsors
(>300)

NAMI - Strong and Strategic Collaboration

- *>48,000 sq ft lab area*
- *>HK$300M Equipment*
- *R&D & Marketing*

Healthcare

Environmental

Electronics

Energy

Battery

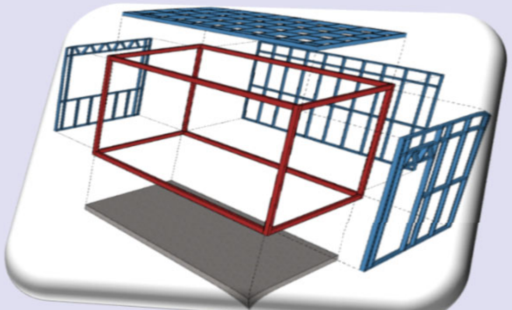
Construction

NAMI Lightweight Concrete & MiC Technology Roadmap

Current Issues of Steel Frame based Modules

- **Current practice** – based on traditional materials with limitations

Steel MiC



Hollow wall system

❑ **Features:**
- Lightweight (e.g. 12m long <20 tons)
- Flexible internal partitioning structure
- De-mountable modules

❑ **Issues:**
- Conventional drywall system (i.e. fire resisting board sandwiched with mineral wools in the core)
  - Hollow structure
  - Unable to mount heavy components on walls
  - Limited durability
  - Difficult for future re-use

We have developed a new *lightweight structural-grade concrete* to replace conventional drywall!

Features of Revolutionary Structural-grade Lightweight Concrete Materials for Steel-concrete Modular Construction

Structural-grade, lightweight & 50 years design-life concrete as floor slab and external wall

- ❑ **40% lighter** in weight, **C25 grade** compressive strength, **50 yrs** design life ➔ favorable for logistics and reusability ➔ **MORE SUNSTAINABLE**
- ❑ **Larger module size**, e.g. <25 tons for 12m module.
- ❑ **Direct high-level wall cupboard installation** (4KN anchorage), **fire** (2 hrs), better **thermal insulation** (3 times*), and **acoustic** (STC 42@75mm).
- ❑ **Sustainable fabrication process at ROOM TEMPERATURE**
- ❑ **Approved for structural use (slab + external wall) since 2022**

* cf. C30 normal concrete

Impacts

- This ITF*-funded lightweight concrete and module system design is now available for non-exclusive licensing.
- Currently, four local companies have obtained licenses to utilize the technology and design for bidding tenders in Hong Kong.
- One licensee has been constructing a 10-storey tower with 137 modular units using this innovative lightweight concrete.

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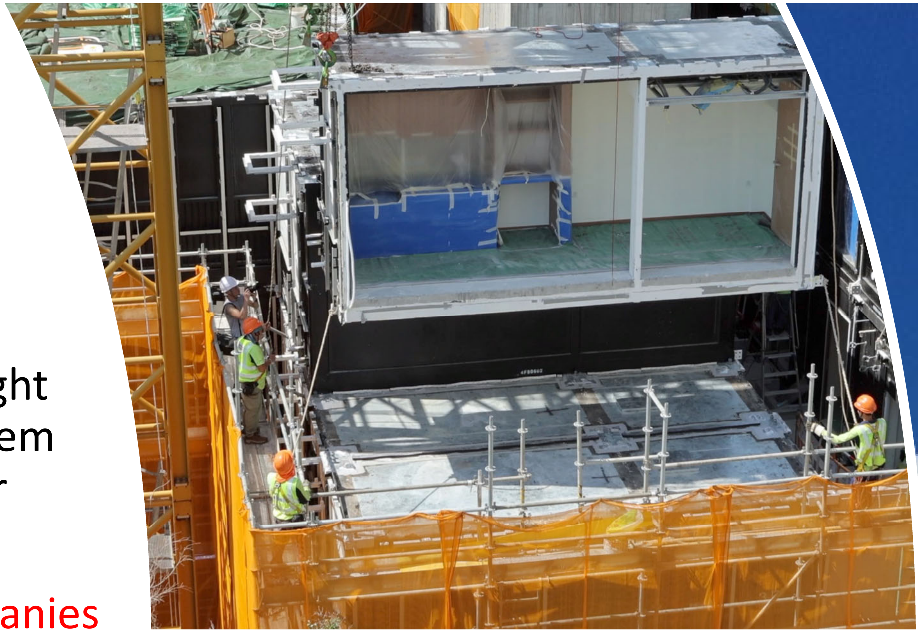

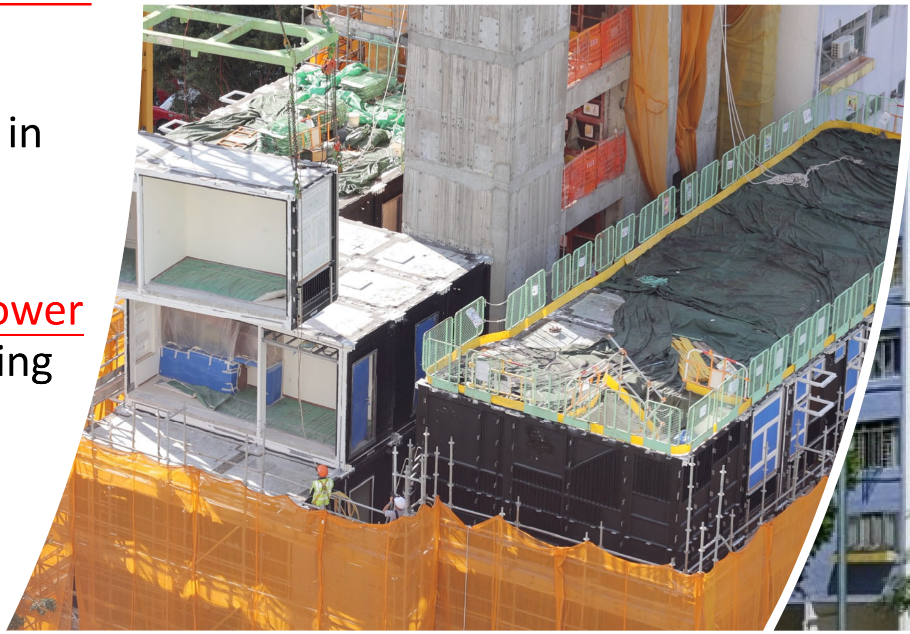

* ITF - "Innovation and Technology Fund" under the Innovation and Technology Commission (ITC) of the

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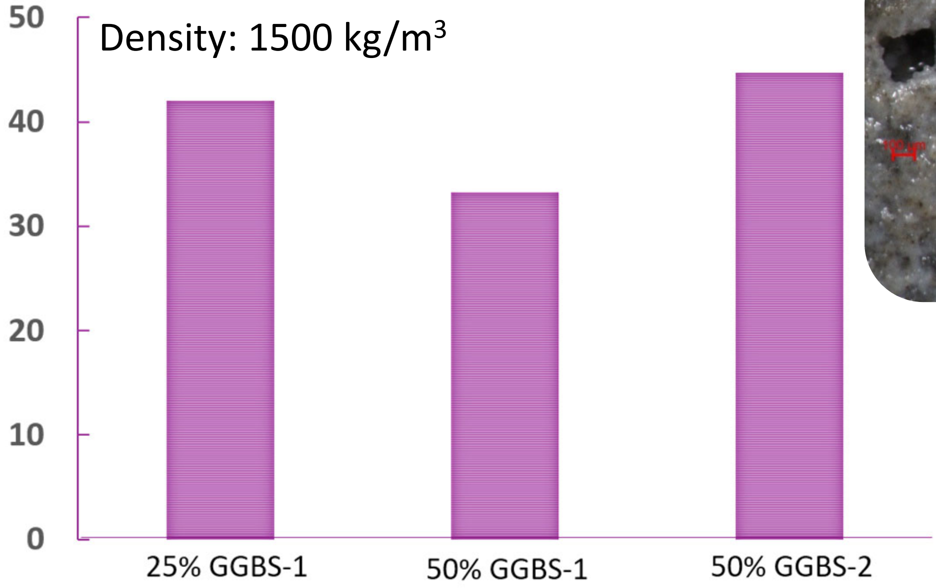
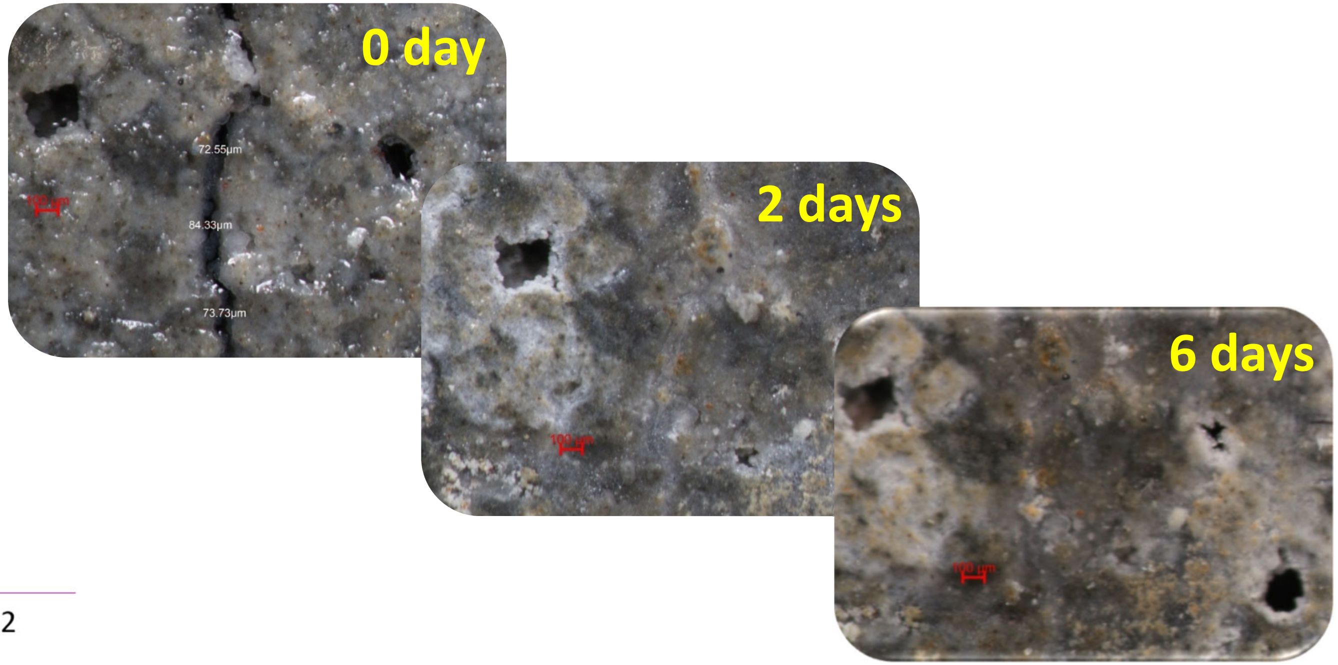
Structural-grade Foamed Concrete with GGBS





- Up to 50% GGBS replacement of structural grade foamed concrete is under development
- Different GGBS sources would determine the properties of the concrete
- Self-healing of foamed concrete has been observed in the presence of water

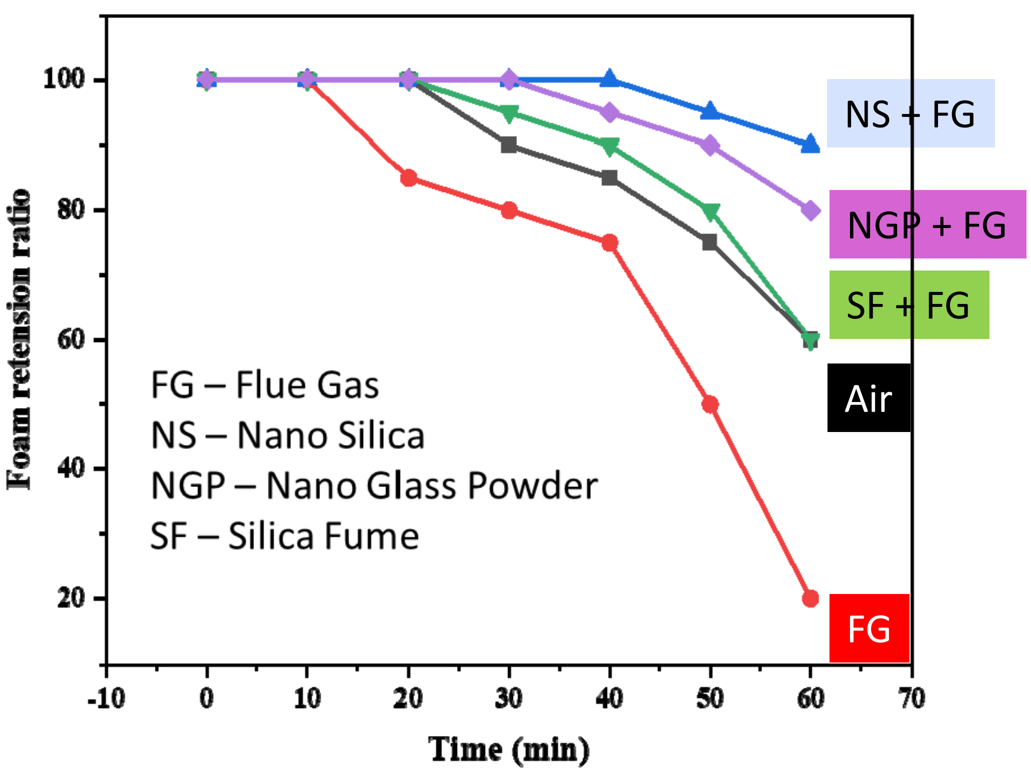
Potential Use of Nano Glass Powder for Foam Stabilization under Flue Gas (1/2)

- **Silica fume is commonly used in cementitious materials and is primarily made of silica with nano-size**
- **Disposed glass bottle can be grounded into powder (~400nm), which is similar to silica fume.**
- **This glass powder is adopted as foam stabilizer.**

- **Flue gas is approx 80% N_2 + 20% CO_2, which is released to atmosphere by power plants and gas suppliers.**
- **This flue gas can be adopted for foaming gas during the production of foamed concrete.**
- **The CO_2 can be captured inside the concrete during the curing process.**

Potential Use of Nano Glass Powder for Foam Stabilization under Flue Gas (2/2)

Effect of flue gas on foam stability



- Foam stability is critical in determining the consistency of foamed concrete properties
- Foams under flue gas are very unstable due to the formation of carbonic acid (H_2CO_3) which affects the pH of water thence the stability of the surfactant for the foams.
- Nano Silica are able to stabilize the foams even under flue gas
- Nano glass powder from recycled glass demonstrated reasonable foam stability
- Foamed concrete fabrication based on is undergoing.

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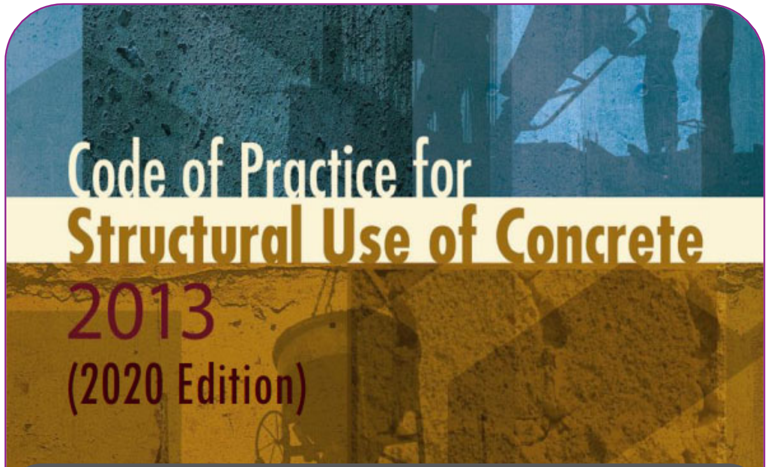
Design Code and Methodology



Clause 1.1 of the Code of Practice for Structural Use of Concrete 2013 (Concrete Code) stated that the followings are **outside of this Code of Practice:**

- no fines concrete
- aerated concrete
- glass fibre reinforced concrete
- concrete containing lightweight or heavy aggregate

International Code/Spec Research

- Eurocode
- American code
- China code
- Related guidance / research

Design Methodology

- Selected code
- Test results
- In accordance with local practice
- BD coordination

- Module design
- Wall panel design
- Connection design
- Simulation of wall elements
- Simulation of wall-frame connections
- Material parameters
- Analysis parameters

Design Code Consideration For IPA

Structural Use of Lightweight Concrete

- Not included in CoP_SUC2013

> **1 GENERAL**
>
> **1.1 SCOPE**
>
> This Code of Practice provides recommendations for the design, construction and quality control of reinforced and prestressed concrete buildings and structures where the concrete is made with normal weight aggregates. It covers the requirements for strength, serviceability, durability and fire resistance, but not other possible requirements such as thermal or acoustic properties.

- Following ACI codes adopted
  - ✓ ACI 318-14 Building Code Requirements for Structural Concrete

> **concrete, all-lightweight**—lightweight concrete containing only lightweight coarse and fine aggregates that conform to ASTM C330.
>
> **concrete, lightweight**—concrete containing lightweight aggregate and having an equilibrium density, as determined by ASTM C567, between 90 and 115 lb/ft^3.

  - ✓ ACI 523.3R-14 Guide for Cellular Concretes above 50lb/ft^3 (800kg/m^3)

> *This guide addresses the materials, properties, design, production, and placement of cellular concretes with as-cast densities greater than 50 lb/ft^3 (800 kg/m^3). The usual density range of cellular concrete is 20 to 120 lb/ft^3 (320 to 1920 kg/m^3). Cellular concretes in the lower portion of this range are used for many applications, such as roof thermal insulation and geotechnical fills. Cellular concretes in the higher density range are used for cast-in-place, precast applications and nonstructural floor fills.*

Bending Capacity

Concrete Modulus of Elasticity	10,000 N/mm^2
Poisson's Ratio	0.2-0.3
Concrete Minimum Characteristic cube strength	25 N/mm^2
Rebar Modulus of Elasticity	200,000 N/mm^2
Rebar Minimum Yield Strength	500 N/mm^2

Test Setup

Sample	**Loading capacity**	
	Design required	Measured
125-W/O conduit	13.6kN	66kN
125-with conduit	13.6kN	72kN
135-with conduit	13.6kN	78kN

Deflection Check

Concrete Modulus of Elasticity	10,000 N/mm^2
Poisson's Ratio	0.2-0.3
Concrete Minimum Characteristic cube strength	25 N/mm^2
Rebar Modulus of Elasticity	200,000 N/mm^2
Rebar Minimum Yield Strength	500 N/mm^2

Deflection Check

Table 24.2.2—Maximum permissible calculated deflections

Member	Condition		Deflection to be considered	Deflection limitation
Flat roofs	Not supporting or attached to nonstructural elements likely to be damaged by large deflections		Immediate deflection due to maximum of L_r, S, and R	$\ell/180$[1]
Floors			Immediate deflection due to L	$\ell/360$
Roof or floors	Supporting or attached to non-structural elements	Likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements, which is the sum of the time-dependent deflection due to all sustained loads and the immediate deflection due to any additional live load[2]	$\ell/480$[3]
		Not likely to be damaged by large deflections		$\ell/240$[4]

Span = 2.5m
Thickness = 125mm
E = 10,000N/mm^2

Dmax = 9.39mm
< l/240=10.42mm, OK

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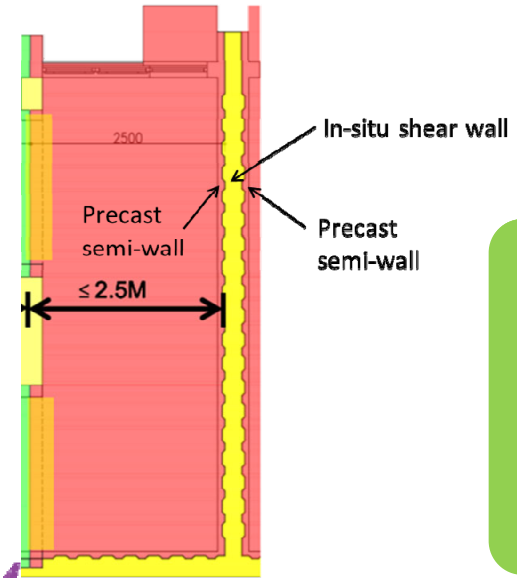
Initiative: Composite Wall Design

Conventional 3-layer Sandwich Structure (400mm)

- Precast semi-wall
- In-situ middle shear wall
- Shear loop to enhance binding between lost form and in-situ wall



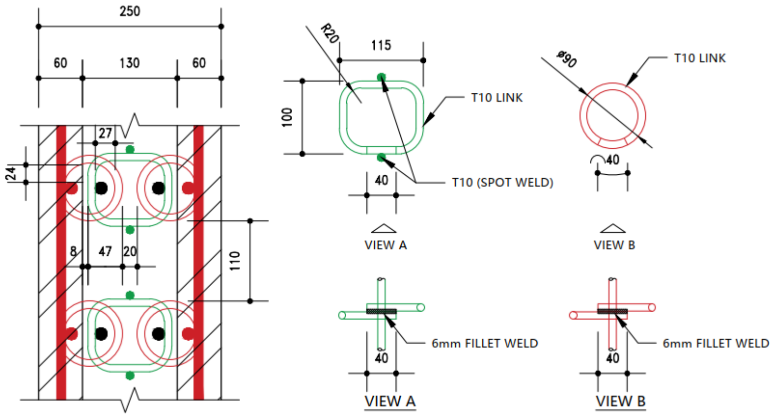
HA-NAMI composite structural walls (250mm)

- Alternative links and transverse reinforcement and tie details (*called TB-Link*) for vertical reinforcement of the reinforced concrete structural walls
- Enhance the structural efficiency
- Reduce the wall thickness

Our Targets:

- **Precast semi-wall considered as structural part**
- **Thinner wall:**
  - **↑ carpet areas**
  - **↓ total building weight**

➔ MORE SUSTAINABLE



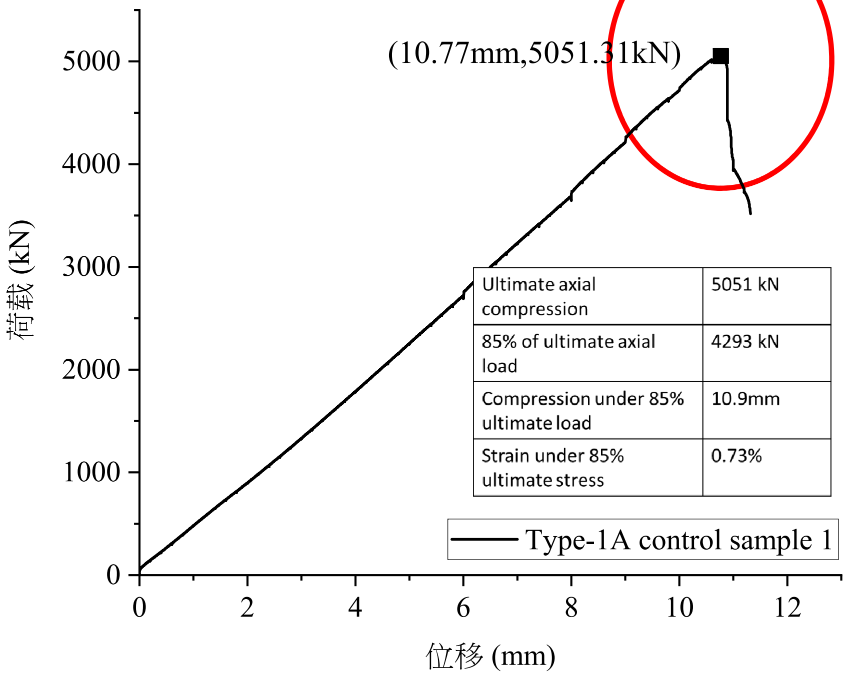
TYPICAL DETAILS FOR
CONFINED BOUNDARY ELEMENTS TYPE 1 & 2
(1 : 5)

HA-NAMI TB-Link Specimen Fabrication


Installation of the middle rebars

Comparison of Loading Curve

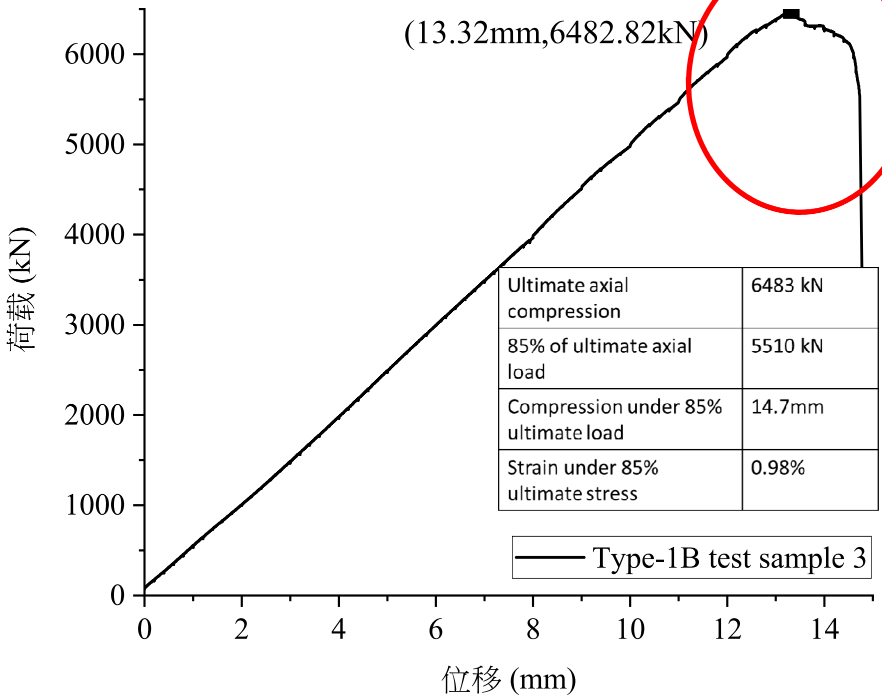
Control without Sandwiching



Ultimate axial compression	5051 kN
85% of ultimate axial load	4293 kN
Compression under 85% ultimate load	10.9mm
Strain under 85% ultimate stress	0.73%

Sandwiched Panels with HA-NAMI TB-Link

better confinement



Ultimate axial compression	6483 kN
85% of ultimate axial load	5510 kN
Compression under 85% ultimate load	14.7mm
Strain under 85% ultimate stress	0.98%

- Dissemination of project results with the Housing Department to the industry stakeholders including contractors and precasters (Sep 2023)
- Full scaled mock-up of concrete MiC based on TB-Link is under fabrication

Implementation: First Lightweight Concrete-Steel MiC in HK

(Video)

Concluding Remarks

- Either in steel-MiC or concrete-MiC, **innovative material is the key enabler** inspiring better design, productivity and durability
- More **R&Ds** are needed to address the concerns/uncertainties in MiC, from **design, construction to maintenance**
- NAMI has been proactively conducting materials-structural related R&Ds to support the MiC development in HK, and we welcome the industries to **give us questions** for investigation

Let's Forge a Future of Continuous Innovation & Build the Tomorrow We Envision

Thank you for your kind attention!