

# From Research to Reality: 3D Printing Concrete Developments in Japan

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Professor, Department of Civil Engineering

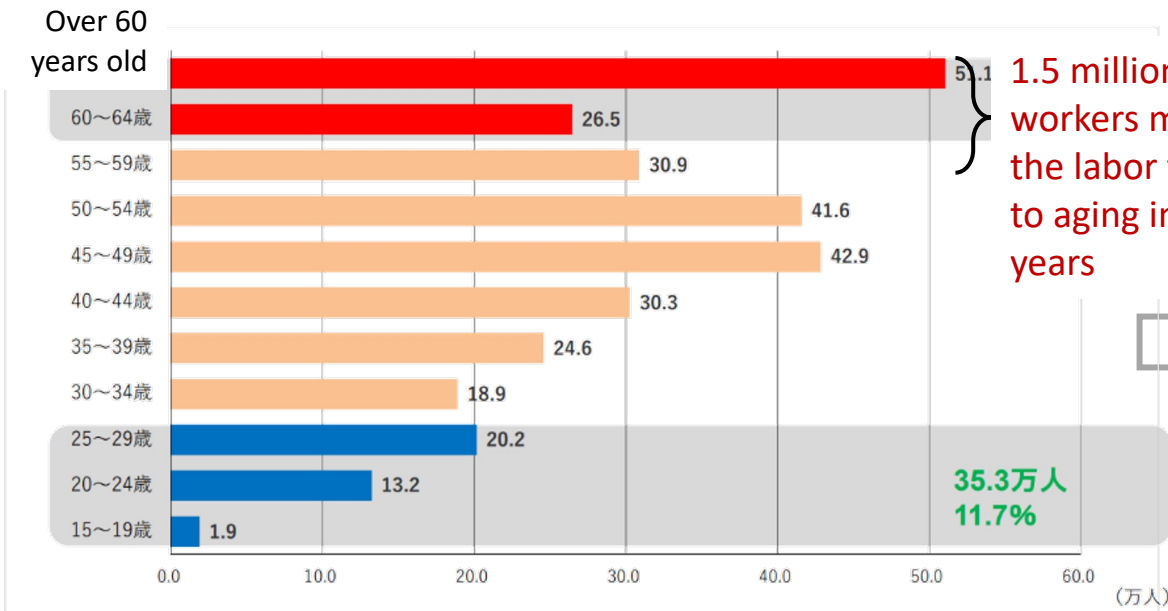
The University of Tokyo, Japan

# Recent Government Initiatives in Japan's Construction Sector (since 2016)



-A Productivity Revolution in Construction-

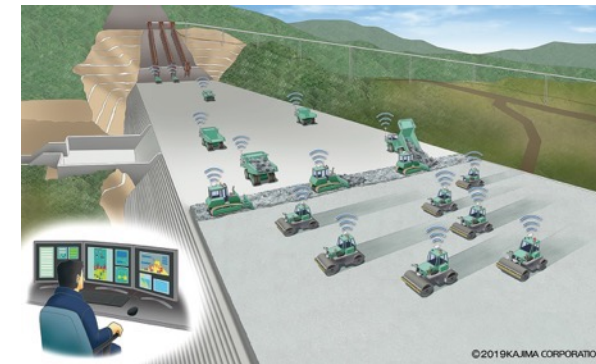
Age structure of the workforce in 2023 (MLIT)



1.5 million skilled workers may leave the labor force due to aging in next 10 years

**Promoting digital technologies** is essential to **increasing productivity** in the construction sector, fostering innovation in the design, construction, and maintenance of infrastructure.

Next generation construction systems through automation of construction machinery (Kajima Corporation, 2019)



- ❑ Of the 3.4 million skilled workers, approximately 1.5 million are expected to leave the workforce within the next 10 years due to aging.
- ❑ Fewer young people are entering the workforce, with only 12% of workers being under the age of 29.



Unmanned construction of structures using 3D printing technology (Shimizu Corporation, 2024)

# JCI Technical Committee on the Construction of Concrete Structures using 3D Printing technology (JCI-TC192A)

Duration of the committee's activities: From 2019 April to 2021 June

Number of members: 22

Chair Prof. Tetsuya Ishida, The University of Tokyo

Secretary-general Dr. Koji Kinomura, Taisei Corporation

Secretary Dr. Yoshikazu Ishizeki, Obayashi Corporation

Dr. Yoji Ogawa, Taiheiyo Cement

Dr. Ken Saito, Japan Sika

Prof. Minoru Kunieda, Gifu University

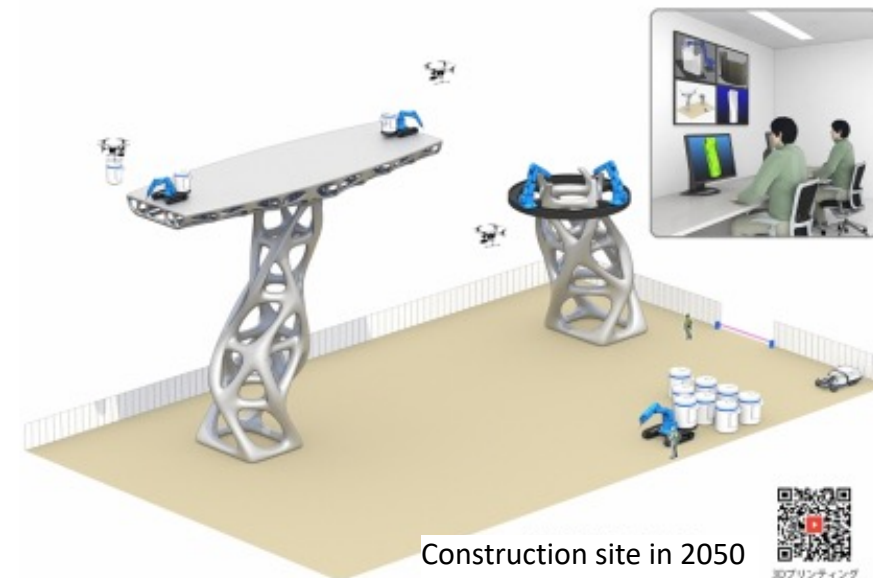
Advisor Dr. Tsuyoshi Maruya, Taisei Corporation



Construction site at present  
By Shimizu Corporation

## Japan's First Technical Committee on Concrete 3D Printing

- Composed of experts in concrete engineering and digital fabrication from academia, industry, and government.
- Conducted domestic and international literature reviews on 3D printing technology.
- Organized workshops with international guest speakers.
- Carried out joint testing using 3D printers from multiple organizations
- Developed a roadmap for technological advancement.



Construction site in 2050  
By Shimizu Corporation



# JSCE technical subcommittee on the application of 3D printing technology to civil engineering structures

## ■ Member

Chair: Prof. Tetsuya ISHIDA (The University of Tokyo)  
Secretary-General: Mr. Shigenobu IGUCHI (East Japan Railway Company)  
Secretary: Dr. Motohiro ONO (The University of Tokyo)  
Dr. Koji KINOMURA (TAISEI Corporation)  
Prof. Minoru KUNIEDA (Gifu University)  
Mr. Takuya TAKAMIZAWA (East Japan Railway Company)

Number of members : 51 (Academia: 10, Government: 9 , Industry: 32)



## ■ Activity period

2021 June – 2023 October

## ■ 3 Working groups

Design/Material/Print WG

Performance evaluation  
/Quality assurance WG

Contract/Standardization WG

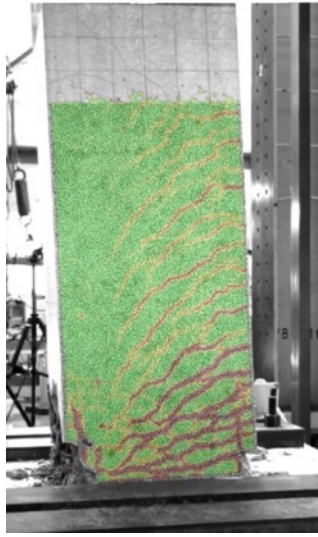
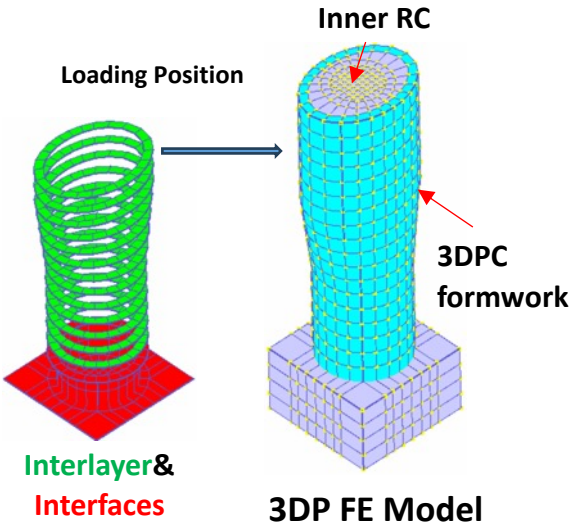
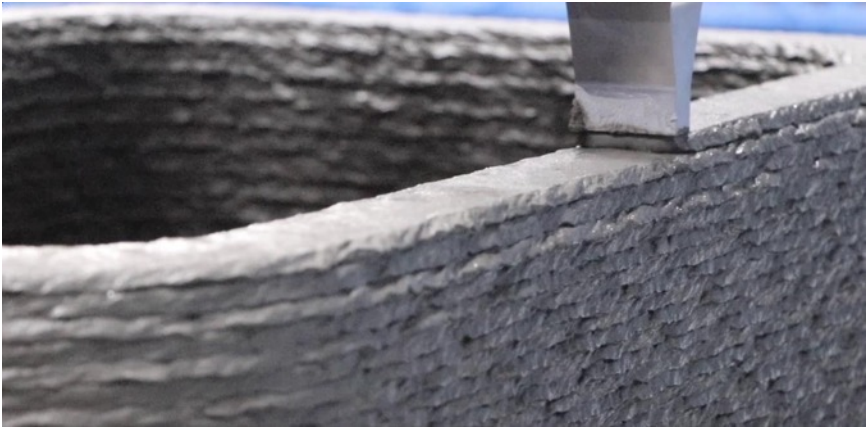
- Discussed the potential of 3D printing in the civil engineering field.
- Identified challenges unique to 3D printing across the planning, design, construction, and inspection processes, using benches for railway stations as a case study.
- Proposed the necessity of **design and construction guidelines**, focusing on **embedded formwork produced by 3D printers**, which is commonly applied in Japan. Based on this, a successor committee has completed a draft of the guidelines (introduced at the end of this presentation).

# 3D Printing Technologies Developed by Japanese Companies and Research Institutions

Today's Work, Tomorrow's Heritage



KYOTO UNIVERSITY



# 3D printing technology developed by Taisei Corporation

By courtesy of Dr. Kinomura, Taisei Corporation

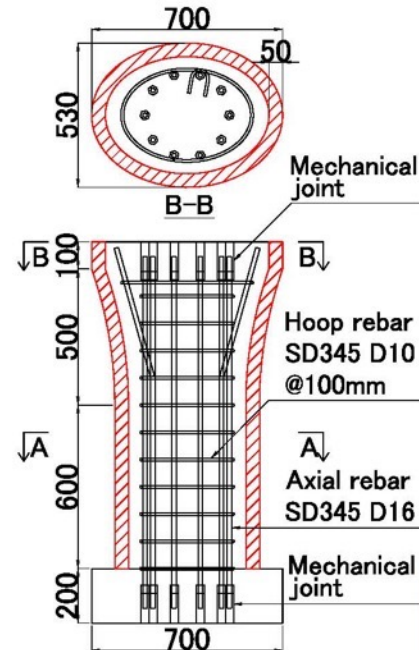
# Bridge Using 3D Concrete Printer

## Superstructure: A Girder Designed with Topology Optimization



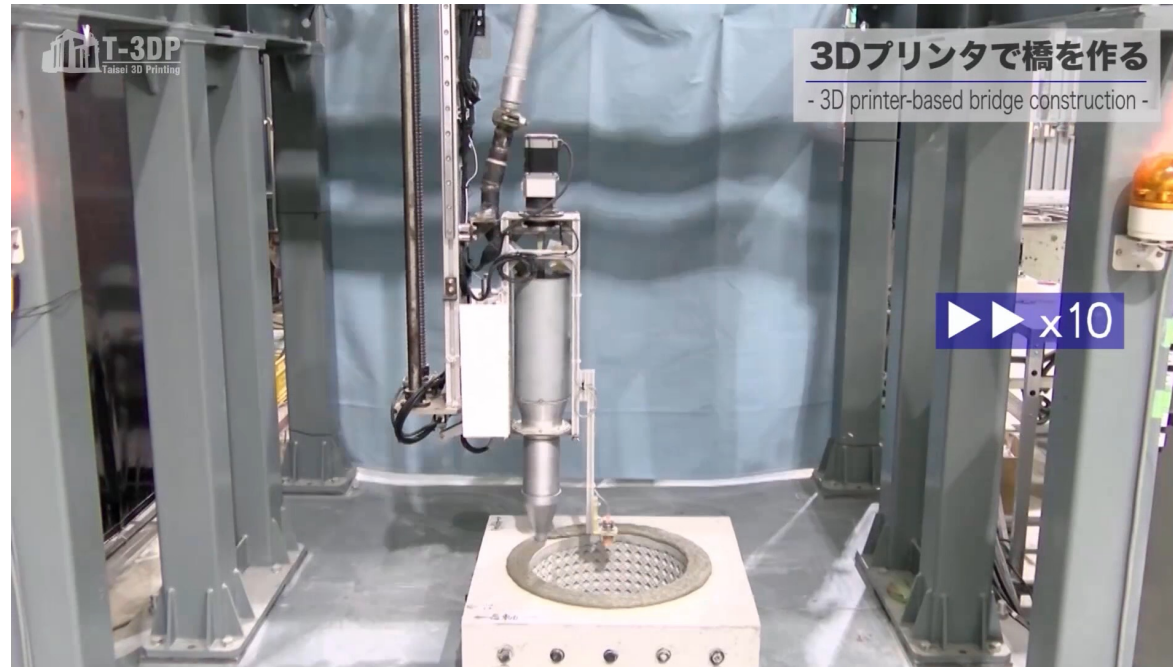
1/4 weight as much as the original shape

## Substructure: Application of 3D Printed Embedded Formwork



- ✓ The outer shell, depicted with red stripes, is formed using 3D printing with short-fiber reinforced mortar.
- ✓ Pre-assembled rebars are placed, and high-fluidity concrete is cast into the outer shell, aiming for future automation.

# ■ Manufacturing Process



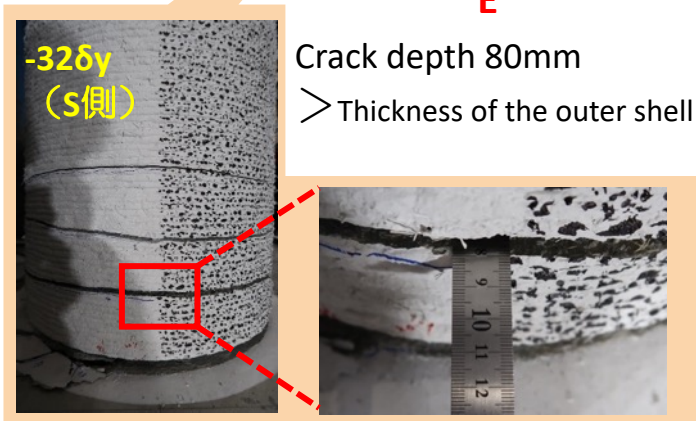
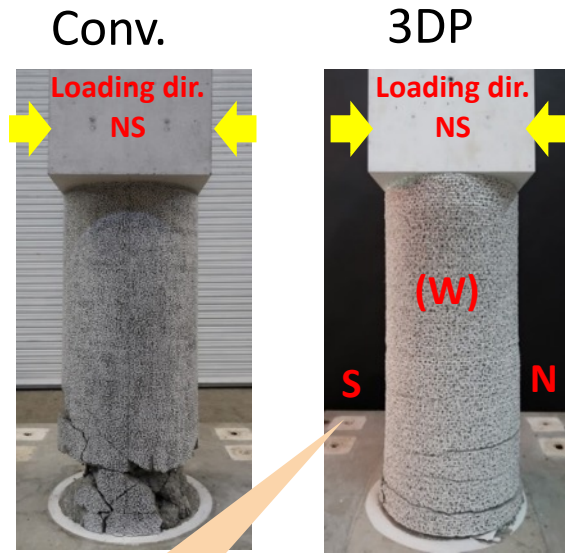
## ■ Cyclic loading test



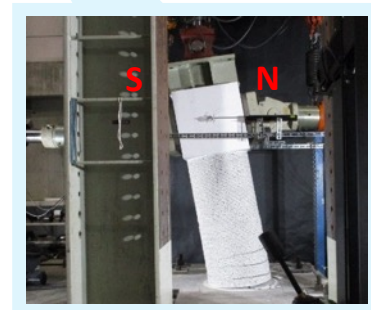
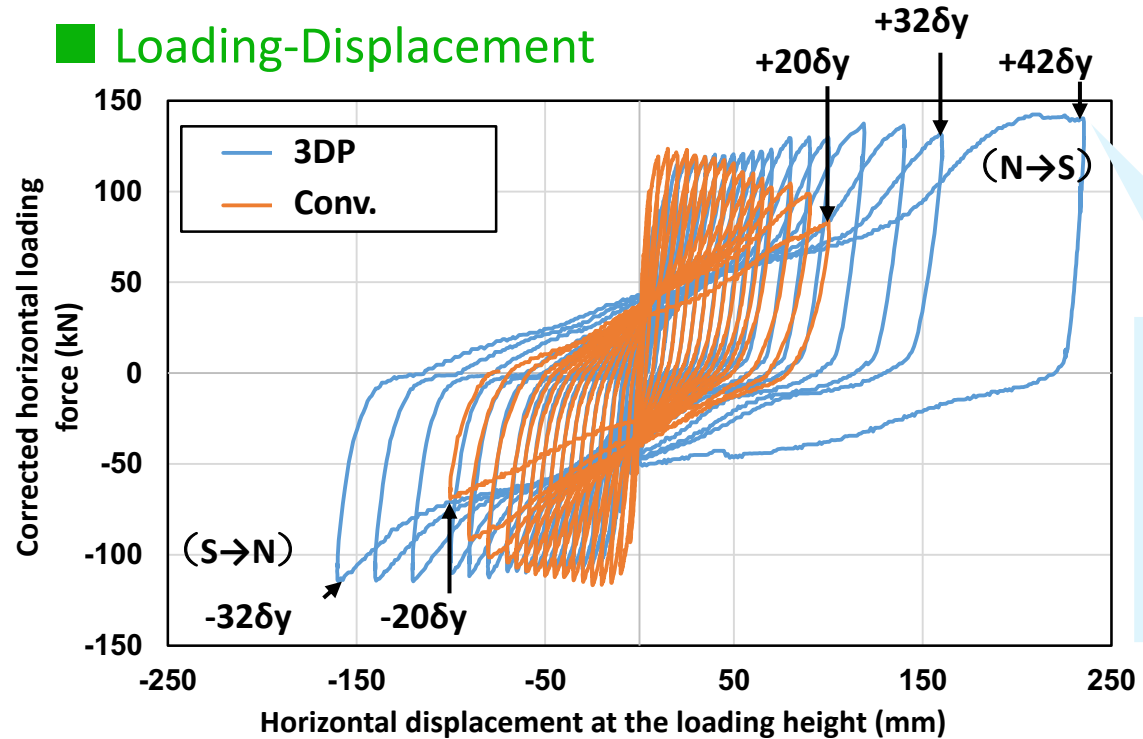
# ■ Experimental Results: The 3DP Bridge Pier Demonstrated Improved Ductility Compared to Conventional Ones

- Cyclic loading tests were conducted to evaluate structural performance
- 1) Conventional one    2) 3D-printed Pier (Each Size :  $\Phi 530\text{mm}$ ,  $H1200\text{mm}$ )

## ■ After loading



## ■ Loading-Displacement



- The outer shell and inner concrete behaved as a unified structure.
- The results suggest that the uniaxial distribution of short fibers in the outer shell enhances shear reinforcement and confines the cover concrete, resulting in higher ductility in the case of 3DP.

# 3DPC Formwork Composite Column Behavior (3DPCF composite specimen)

3D-RC solid elements are used to model the behavior of the column and foundation, while 2D interface elements with a shear transfer model represent the interlayer and interface behaviors. The interlayer thickness is assumed to be 10 cm, considering critical stress locations.

**Material properties**

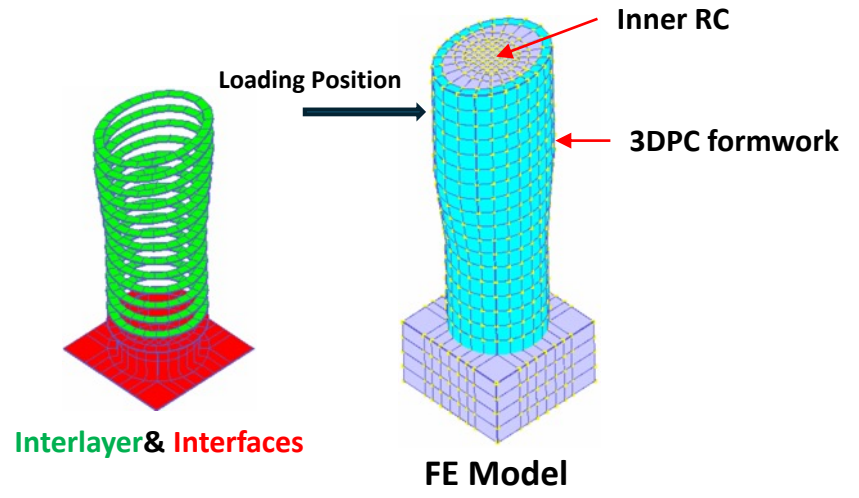
Materials	Compressive strength (MPa)	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)
Inner concrete	41	3.5	–	30
3DPCF mortar	52	4.5	–	33
Axial rebar	–	785	386	206
Hoop rebar	–	785	346	206

**Interlayer Properties**

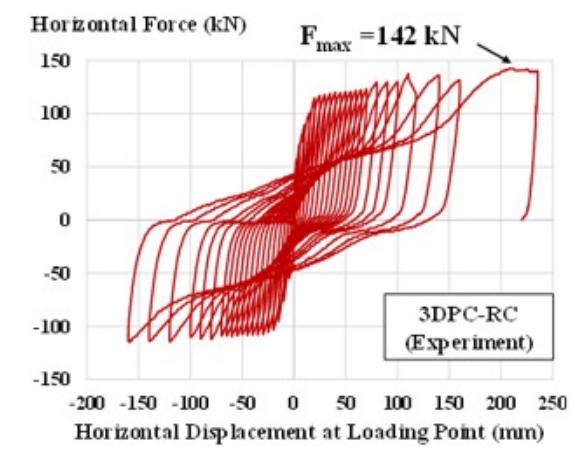
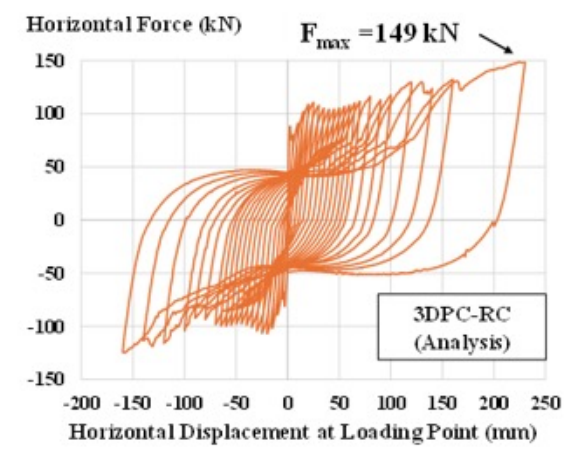
Interlayer Interfaces Property	Value
Average compressive strength (MPa)	52
Bonding strength (MPa)	2.77
Tension Opening Stiffness (MPa)	33600
Shear Stiffness (MPa)	14000
Max of Roughness size (cm)	0.1

**Interfaces Properties**

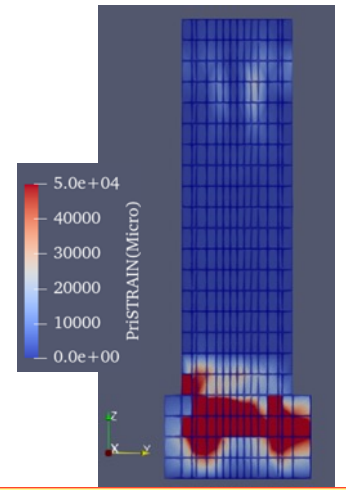
Interlayer Interfaces Property	Value
Average compressive strength (MPa)	41
Bonding strength (MPa)	3.5
Tension Opening Stiffness (MPa)	30000
Shear Stiffness (MPa)	12500
Max of Roughness size (cm)	0.5



**Load-displacement cyclic hysteresis**



**Strain Distribution**



**Crack Propagation**

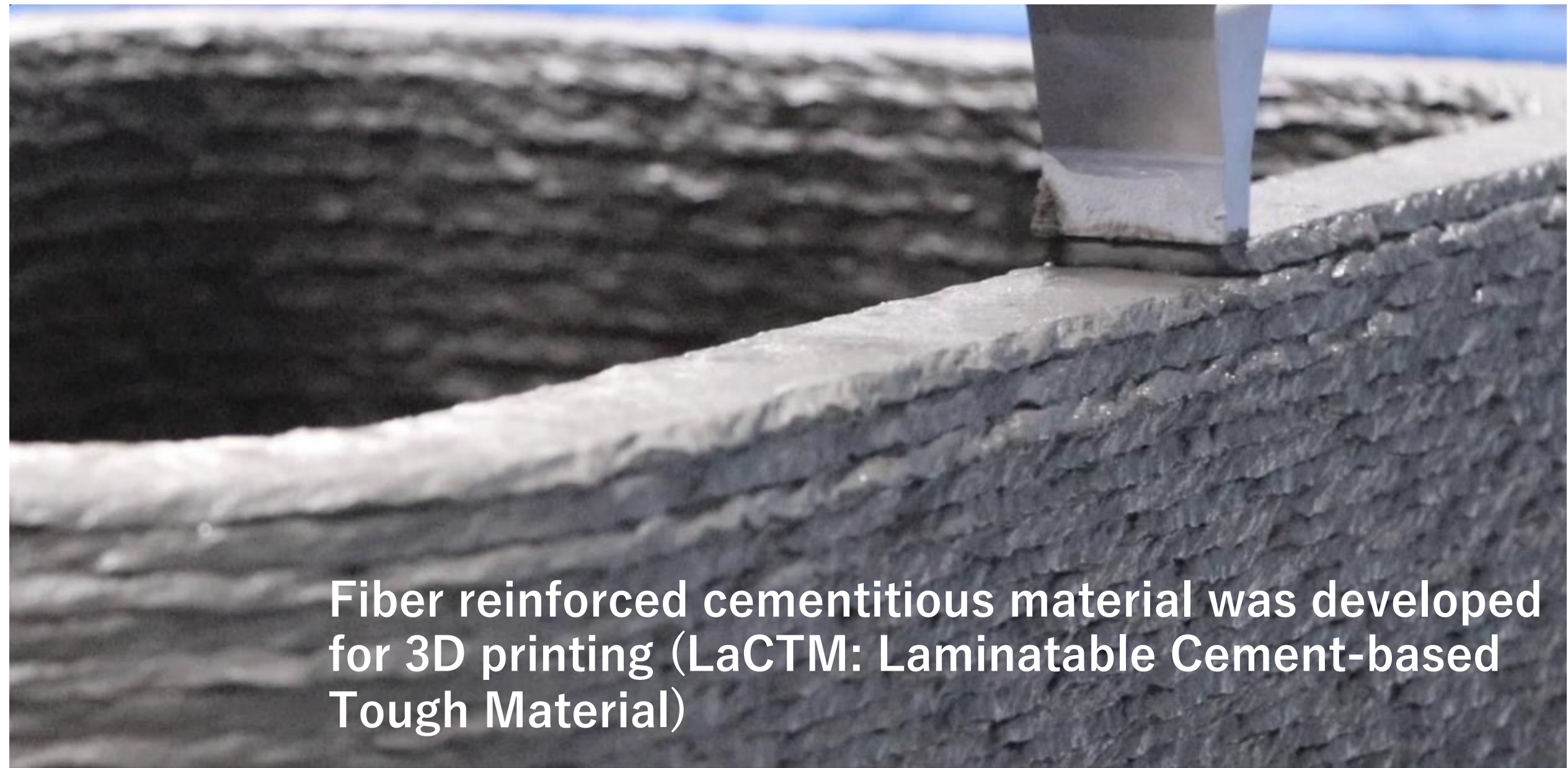


The finite element model results closely matched the experimental results for both ultimate capacity and deformation level.



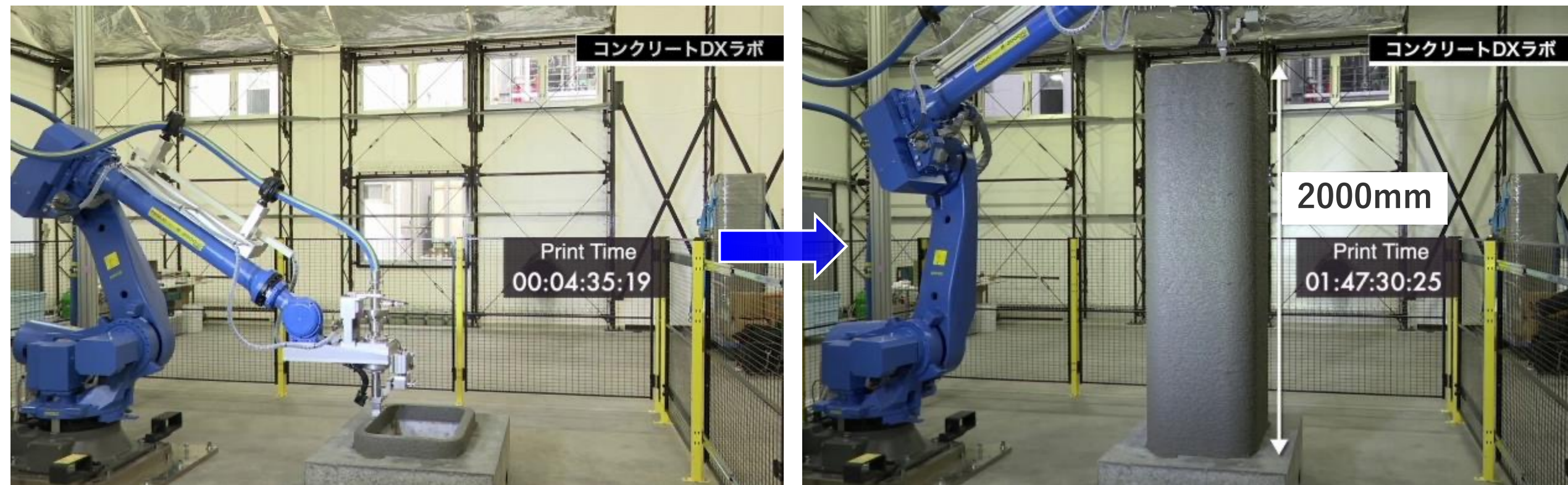
# 3D printing technology developed by Shimizu Corporation

By courtesy of Dr. Ogura, Shimizu Corporation



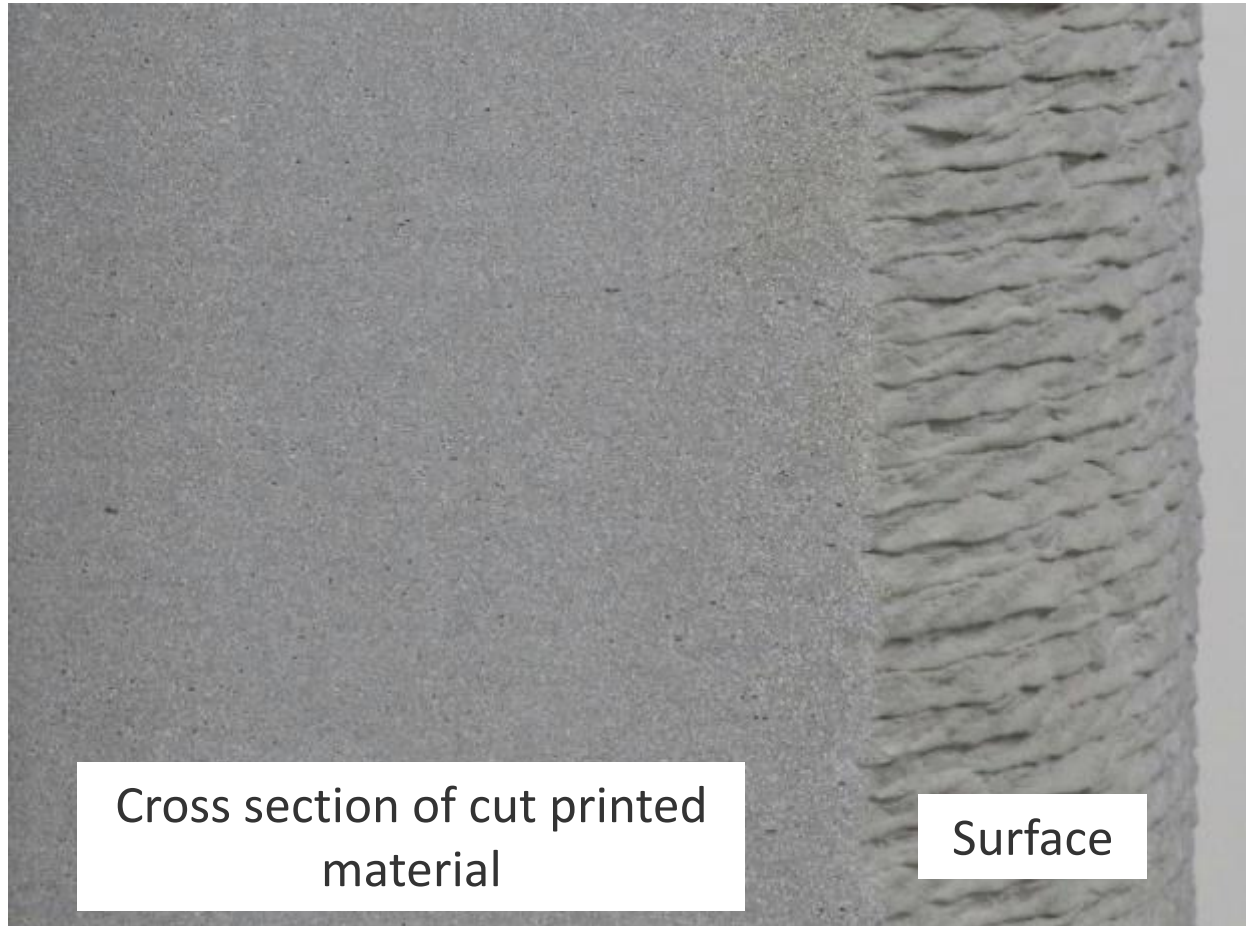
Fiber reinforced cementitious material was developed for 3D printing (LaCTM: Laminatable Cement-based Tough Material)

## Feature of LaCTM #1: High Buildability with Optimized Pumpability



- A 2-meter-high formwork can be 3D-printed in just 2 hours

## Feature of LaCTM #2: Uniform quality in printed members



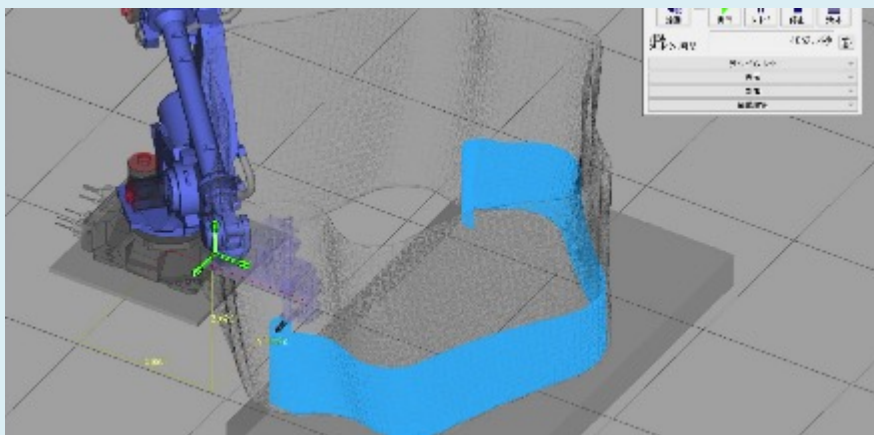
A printed specimen in past research



R.A. Buswell et al.:  
3D printing using  
concrete extrusion:  
A roadmap for  
research, Cement  
and Concrete  
Research, 2018.

# Feature of LaCTM #3: High ductility





Robot control based on 3D CAD data



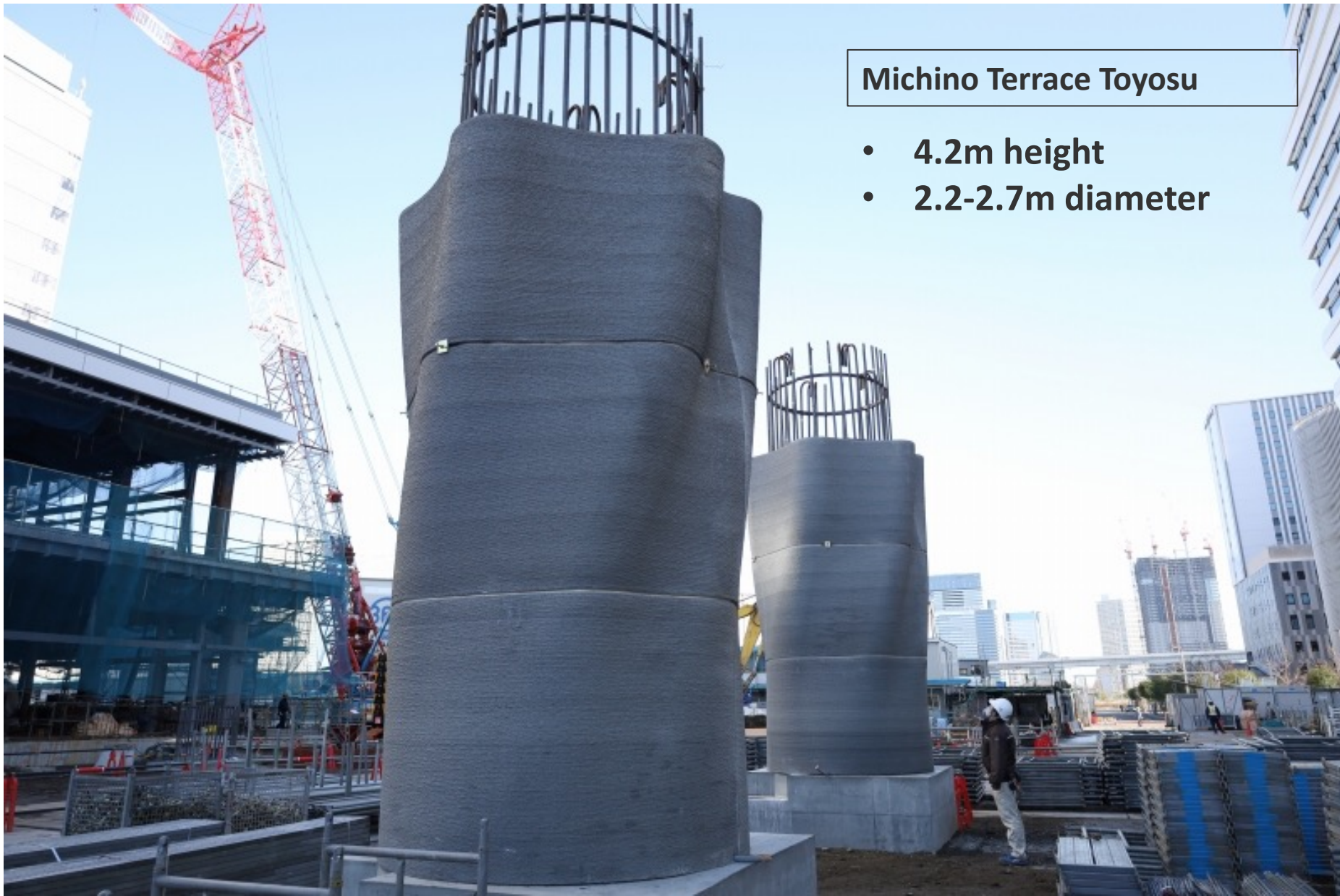
Rapid Manufacturing of Freeform Surfaces



Rebar installation and concrete casting  
at construction site



Transport and assemble the formwork the  
day after 3D printing



## Michino Terrace Toyosu

- 4.2m height
- 2.2-2.7m diameter



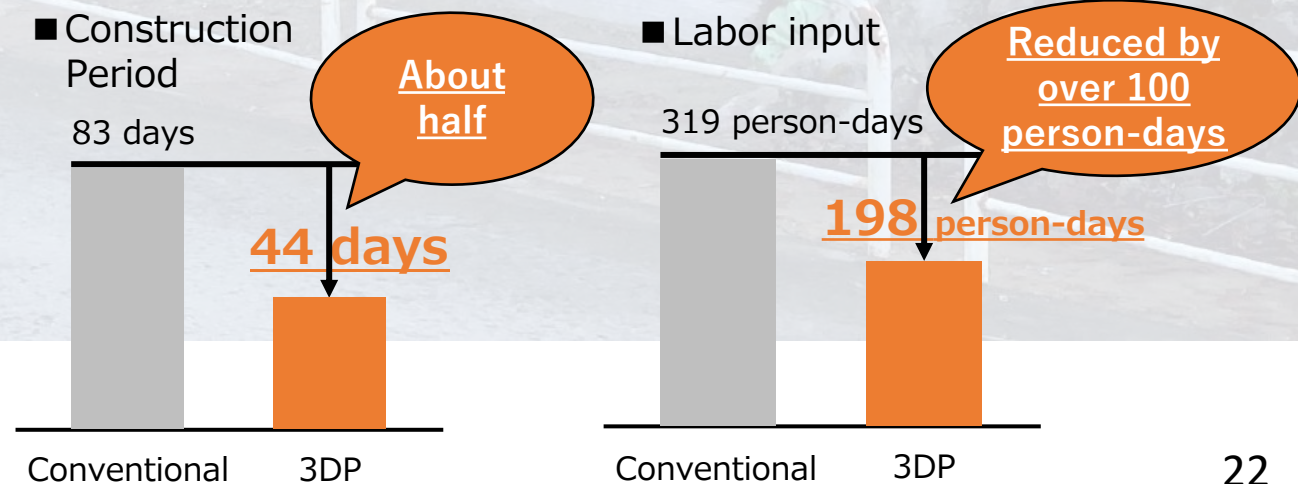
**Update  
the construction industry  
with technology**



# Disaster Recovery Construction for Rockfall Site, Provided by Polyuse Co. Shinjo City, Yamagata



Formwork for a gravity retaining wall produced with a 3D printer.  
By creating curved sections with the 3D printer to match the road alignment, the construction period has been significantly reduced compared to conventional methods.

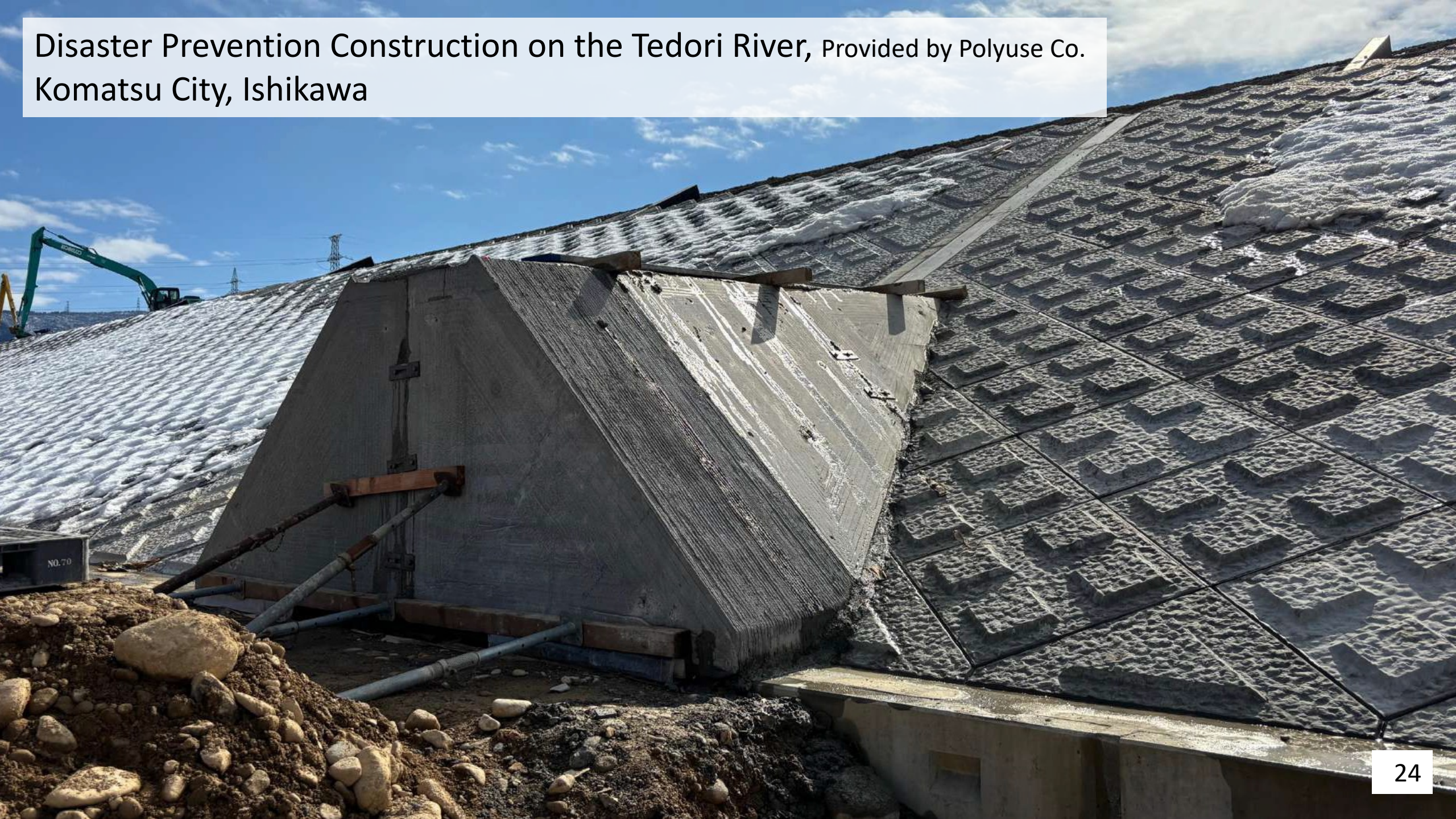




Standardized precast U-shaped gutters are used for the channels, but catch basins need to be customized to fit the local terrain, making 3D printing advantageous. 2022 October




Disaster Prevention Construction on the Tedori River, Provided by Polyuse Co.  
Komatsu City, Ishikawa



# Rapid Expansion of Construction Use Cases for 3D Printers Across Japan

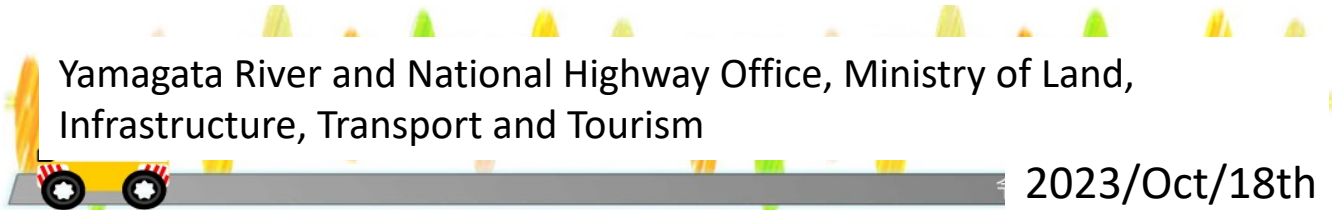
(Cited from posts on X, formerly Twitter)

 The Tosa National Highway Office, Ministry of Land, Infrastructure, Transport and Tourism

..

Yamagata River and National Highway Office, Ministry of Land, Infrastructure, Transport and Tourism

2023/Oct/18th



Today, a site visit was held at the Aki Road construction site to observe the use of a 3D printer for construction. This project site marks a new milestone as it is set to become **“the first application in public works in Japan”** by utilizing this technology in the substructures of bridges in collaboration with relevant stakeholders. We are committed to further enhancing productivity in construction sites!

## Application of 3D Printers in the Construction Industry



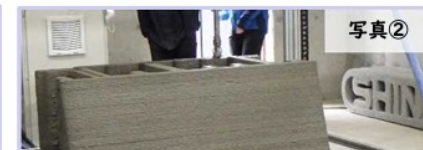
令和5年10月6日(金)新庄国道維持出張所の工事を受注している(株)新庄砕石工業所 主催の3Dプリンター印刷の見学会が行われました。

見学会には、工事関係者など約30名が参加し、3Dプリンターの実演を見学しました。

(株)新庄砕石工業所の柿崎取締役管理部長は、現在の建設業の課題となっている人手不足や生産力の低下、働き方改革への遅れなどを延べ、これらの課題を3Dプリンターで克服していきたいと話していました。

## Constructing a Gravity Retaining Wall with a 3D Printer

で、3Dプリンターで造形しています。

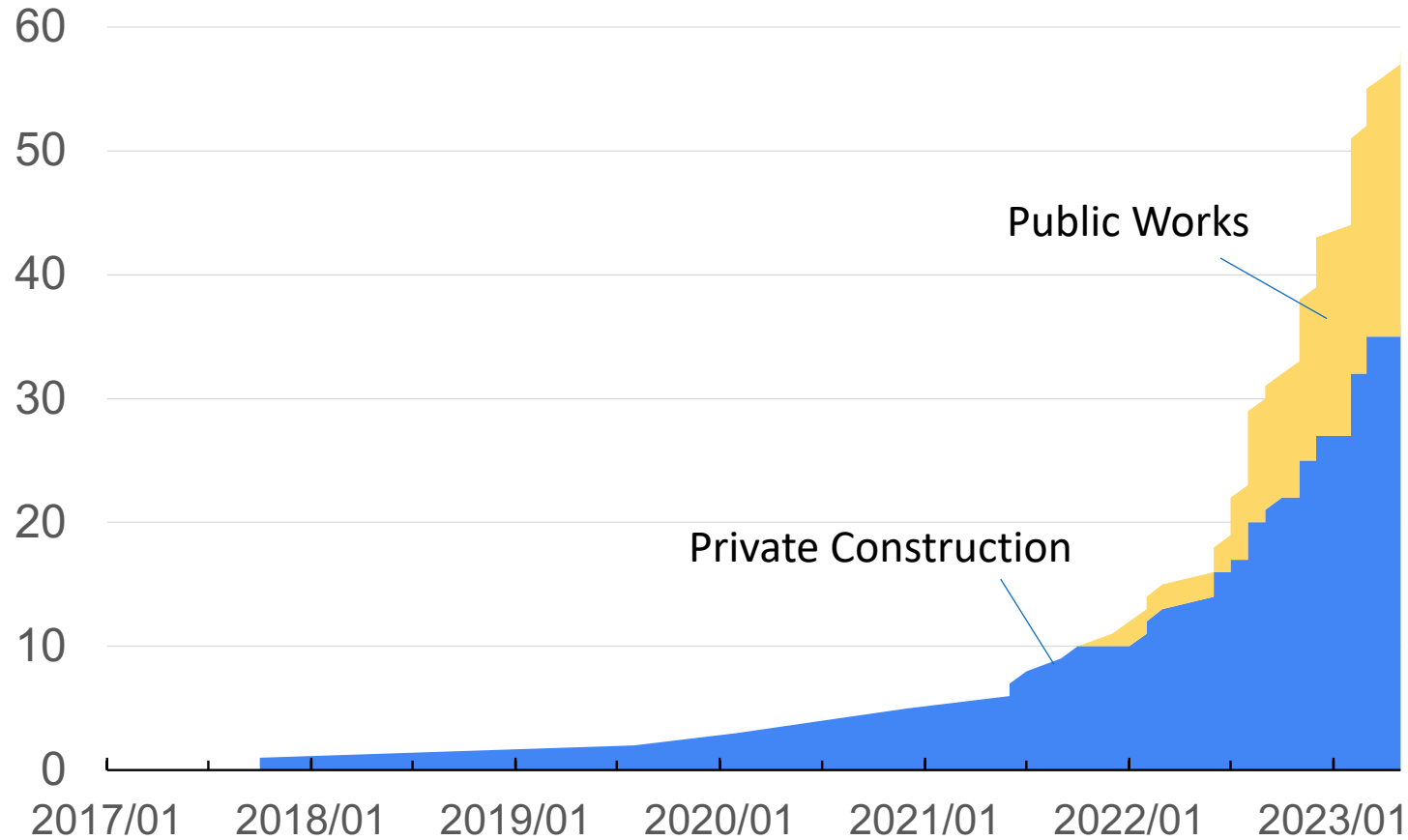


午後7:01 · 2023年10月18日 · 3,305 件の表示

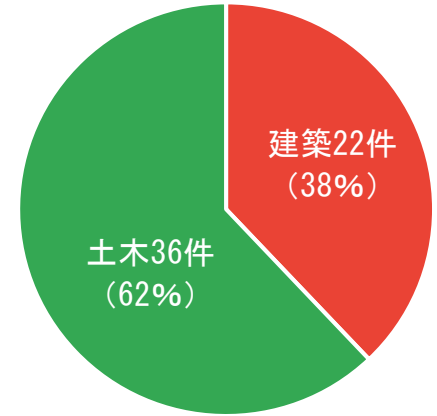


**Application Example in National Highway Construction in Kochi Prefecture:** Components produced with a 3D printer were utilized as formwork for bridge footings. This marks **the first instance of such use in a major structure** in Japan. Provided by Polyuse Co., 2023 November

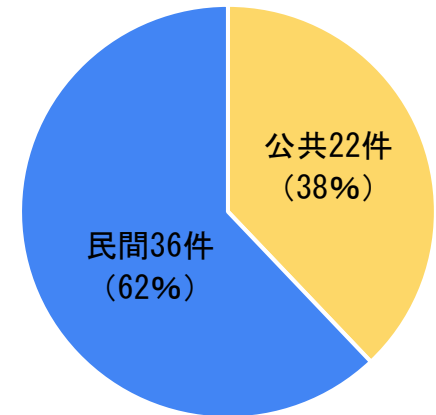
### Total Number of 3DP constructions



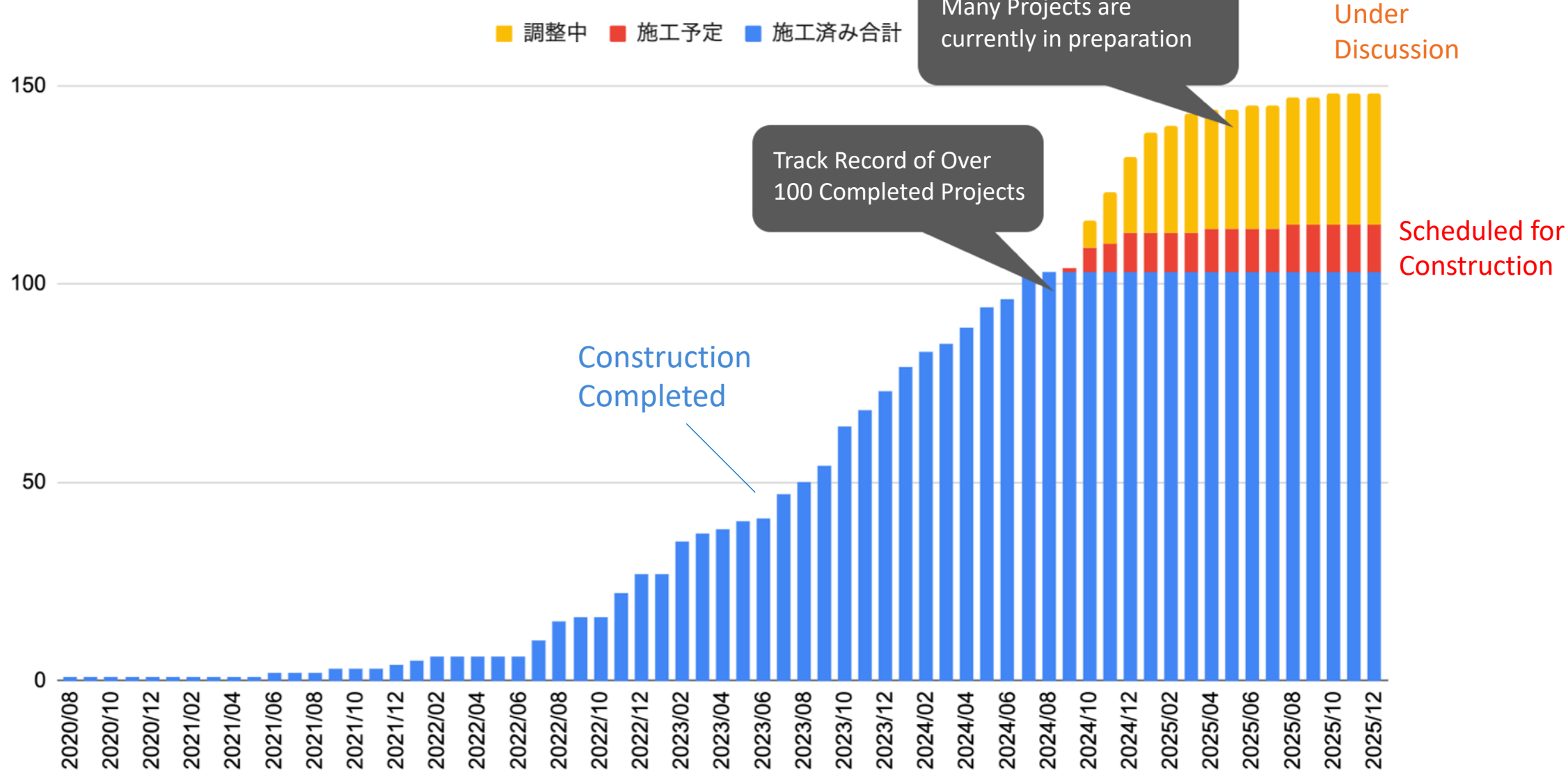
### 施工実績に占める土木・建築用途の割合 (2023年6月時点)



### 施工実績に占める民間・公共工事の割合 (2023年6月時点)



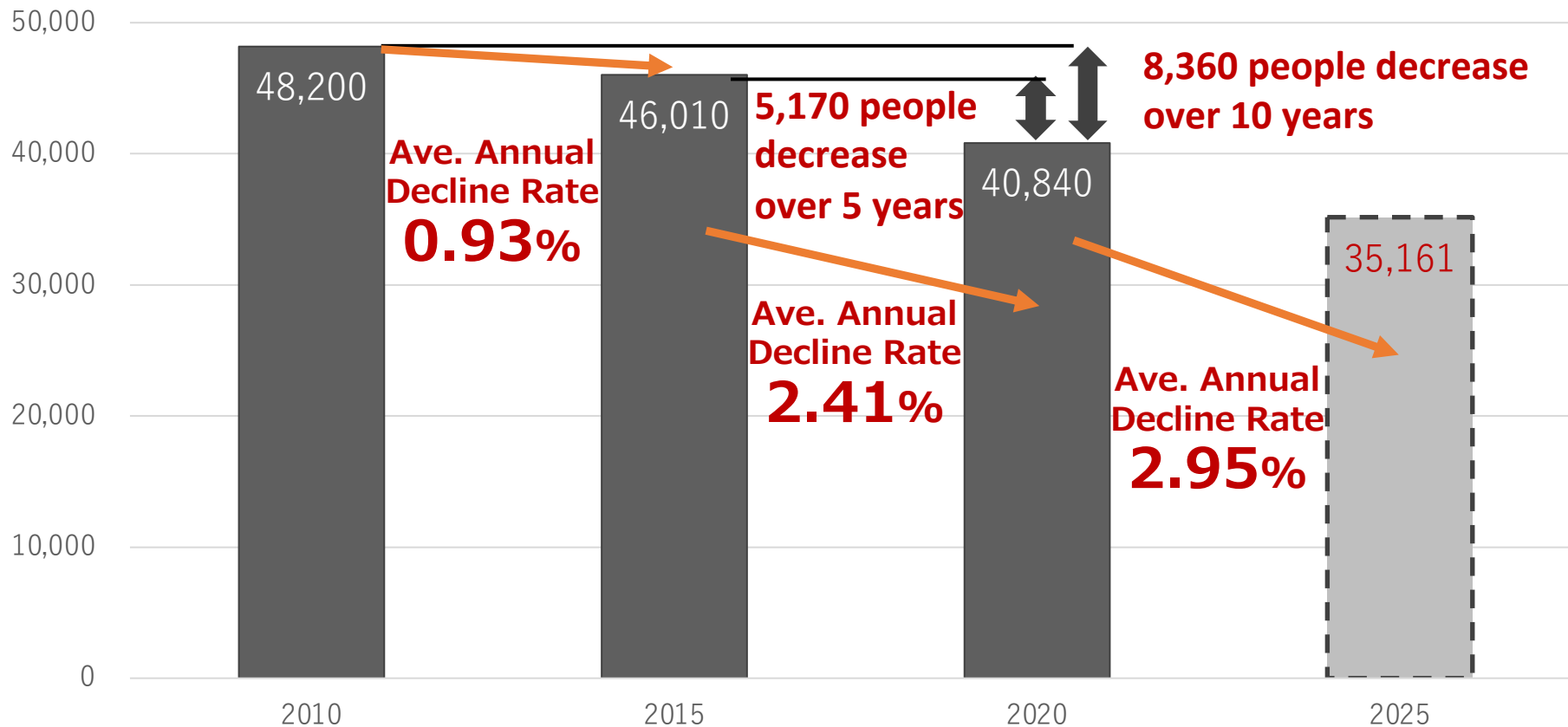
# Cumulative Polyuse Construction Projects



# ■ Why Is 3D Printing Becoming Increasingly Adopted?

## Trends in the Decline of Formwork Carpenters in Japan

- According to the national census, the number of craftsmen engaged in formwork production has decreased by 8,360 over the past 10 years and by 5,170 in the last 5 years.
- The average annual decline rate was 0.93% between 2010 and 2015, whereas it accelerated to 2.41% between 2015 and 2020, indicating a faster decrease in the number of formwork carpenters.



The declining number of formwork carpenters has created a significant bottleneck in concrete construction. 3D printing technology offers a transformative solution to address labor shortages and enhance productivity.

# Reduction in Construction Time and Labor Savings through 3D Printing

■ In the case of a gravity retaining wall in a public works project

In the case of construction using a 3D printer, on-site work by skilled craftsmen is no longer necessary, enabling a reduction in **the construction period**.

91%減 ↓

In the case of construction using a 3D printer, the reduced labor hours contribute to **labor savings**.

79%減 ↓

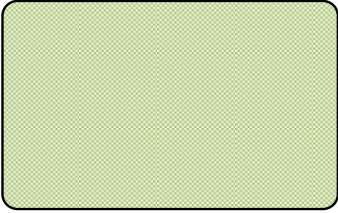

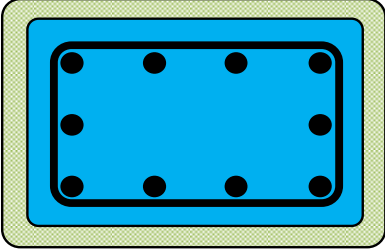


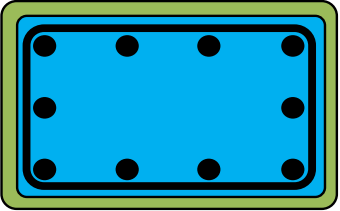

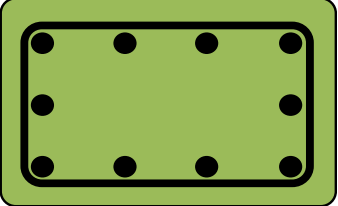


## 建設用3Dプリント埋設型枠を用いた コンクリート構造物の技術指針(案)



Recommendations for the design, construction, and maintenance of 3D-printed permanent formwork applications, 2025 August, JSCE.

**Target of the guidelines**

Category	A	B	C	D
	Non-structural member	Non-Structural Permanent Formwork	Structural Permanent Formwork	Structural member
	Monuments, benches, catch basins, curbstones, and other auxiliary structures, etc.	Permanent formwork designed <b>solely to resist lateral pressure</b> during concrete casting.	Permanent formwork that <b>carries forces and serves as cover concrete.</b>	Key structural components
Design	Designed to meet the required performance of the target (structural calculations performed as necessary).	Not considered as an effective cross-section in the design.	<b>Evaluation of durability, safety, and other factors is required.</b>	<b>Evaluation of durability, safety, and other factors is required.</b>
Cross-Section Diagram	 <p>  : Printed section (Non-structural member)                 </p>	 <p>  : Cast Concrete   : Re-bar                 </p>	 <p>  : Printed section (Structural member)                 </p>	
Examples	Benches, Curbstones, Catch Basins, Stairs, Monuments	Wall and Column Members, Foundation Members	Column members, etc	Beam members, etc

# Table of Contents for the Recommendations

## Chapter 1: General Principles

- 1.1 General
- 1.2 Definition of Terms
- 1.3 Policy for Adopting 3D Printed Permanent Formwork

## Chapter 2: Structural Planning

- 2.1 General
- 2.2 Investigation
- 2.3 Performance Requirements
- 2.4 Considerations for Manufacturing 3D Printed Permanent Formwork
- 2.5 Considerations for Constructing Concrete Structures Using 3D Printed Permanent Formwork
- 2.6 Considerations for Maintenance of Concrete Structures Using 3D Printed Permanent Formwork
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- 3.1 General
- 3.2 Basics of Printing Materials
- 3.3 Design Values for Structures Made by 3D Printers
- 3.4 Actions
- 3.5 Calculation of Response Values
- 3.6 Verification
- 3.7 Ensuring the Integration of 3D Printed Permanent Formwork and Cast-in-Place Concrete
- 3.8 Joining of 3D Printed Permanent Formwork

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- 4.1 General
- 4.2 Manufacturing Plan
- 4.3 3D Printers
- 4.4 Printing Materials
- 4.5 Measurement and Mixing
- 4.6 Layered Fabrication
- 4.7 Curing and Storage

## Chapter 5: Construction of Concrete Structures Using 3D Printed Permanent Formwork

- 5.1 General
- 5.2 Construction Planning
- 5.3 Transportation to the Site and On-Site Storage
- 5.4 Erection and Installation
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- 5.6 Construction of the Main Structure

## Chapter 6: Quality Control

- 6.1 General
- 6.2 Quality Control During Manufacturing
- 6.3 Quality Control During Construction

## Chapter 7: Inspection

- 7.1 General
- 7.2 Inspection During Manufacturing
- 7.3 Inspection During Off-Site and Near-Site Printing
- 7.4 Inspection Records

## Chapter 8: Maintenance

- 8.1 General
- 8.2 Maintenance Planning
- 8.3 Diagnosis
- 8.4 Countermeasures
- 8.5 Documentation

**The Recommendations, structured into 8 chapters, explain technical items covering all aspects from structural planning to maintenance.**

# Concluding remarks

- **3D printing adoption in construction is accelerating in Japan.**  
Driven by labor shortages, government initiatives, and technological advancements.  
Expanding from national infrastructure to private-sector applications.
- **New recommendations provide a clear framework for implementation.**  
Approved by the Japan Society of Civil Engineers (JSCE).  
Ensure safe and effective use of 3D-printed embedded formwork.
- **Future outlook: Expanding applications and continuous improvement.**  
Enhancing structural performance and construction efficiency.  
Further integration with digital technologies and automation.

Thank you for your kind attention!



The University of Tokyo,  
Hongo Campus (Main campus)