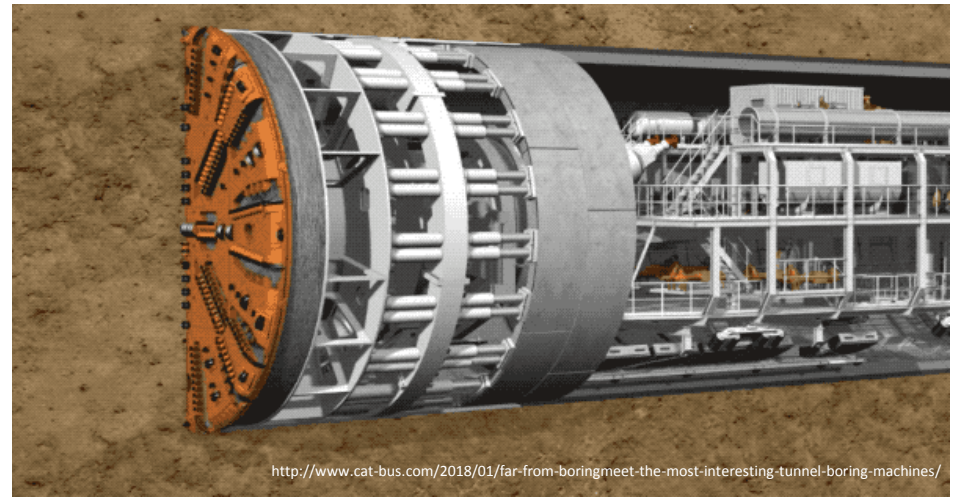




El evento del Cemento, el Concreto y los Prefabricados



<http://www.cat-bus.com/2018/01/far-from-boringmeet-the-most-interesting-tunnel-boring-machines/>

## *Innovation in Concrete Construction*

*Anne Ellis, P.E., FACI, F.ASCE*  
*Ellis Global*  
*USA*

## TOPICS

- Elon Musk
- Innovation
- Innovation + Concrete + Concrete Construction



# ELON MUSK

## INVENTOR – BUSINESS MAGNATE - INVESTOR

# Elon Musk Tackles BIG Problems . . .



**ELON MUSK**



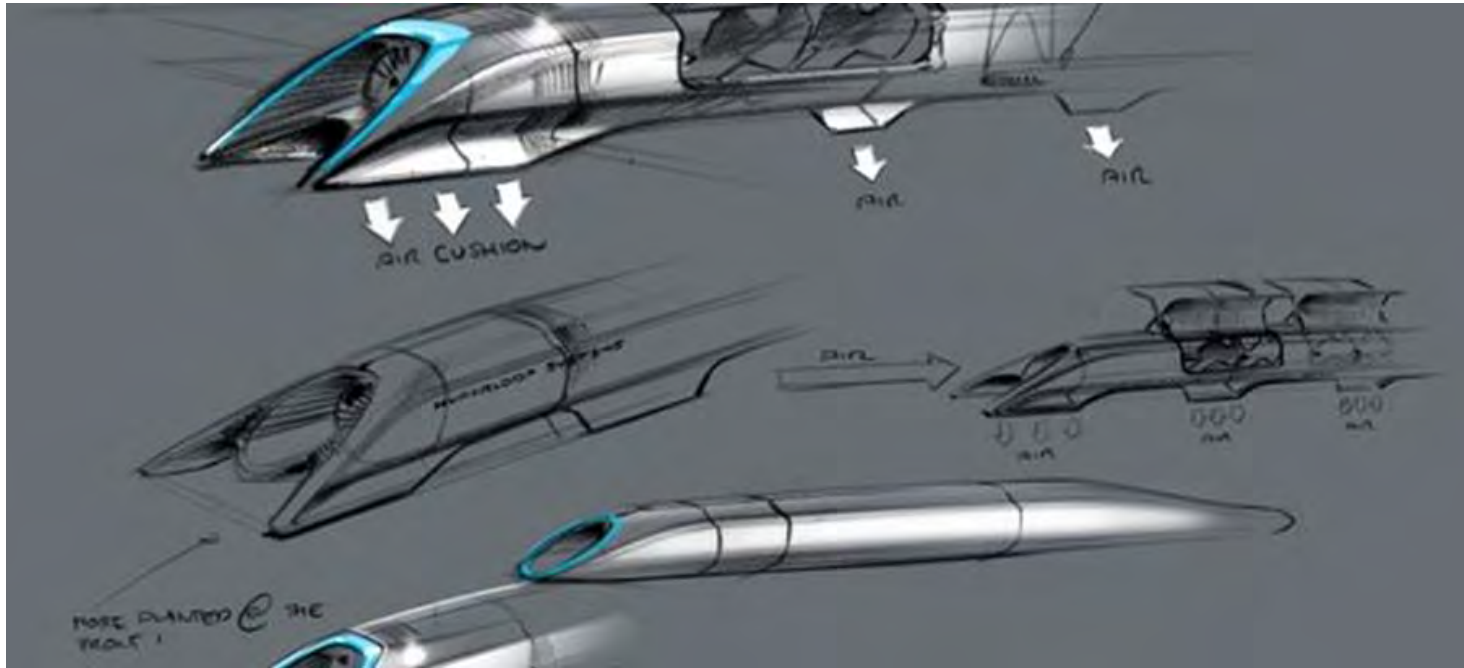
# **BIG PROBLEM**



**MOVING GOODS + PEOPLE**



# Elon Musk + The Fifth Mode of Transport



**MOVE GOODS AND PEOPLE: 760 MPH (1,200 KM/H)**

# Concept is open-source . . .



<http://www.arrivo-loop.com/mission/>

**HYPERLOOP**  
TRANSPORTATION TECHNOLOGIES

hyperloop | one  
BE ANYWHERE. MOVE ANYTHING. CONNECT EVERYONE.

TRANSPOND

**ARRIVO**

THE  
**BORING**  
COMPANY



<https://transpodhyperloop.com/media-kit/>



<https://www.theverge.com/2017/3/7/14840322/hyperloop-one-test-track-nevada-desert>



[http://www.motoraauthority.com/news/1112400\\_tesla-model-s-has-no-problem-fitting-inside-the-boring-companys-tunnels](http://www.motoraauthority.com/news/1112400_tesla-model-s-has-no-problem-fitting-inside-the-boring-companys-tunnels)

# Allows others to advance technology



**PROBLEM**



**TUNNELING  
TECHNOLOGY**

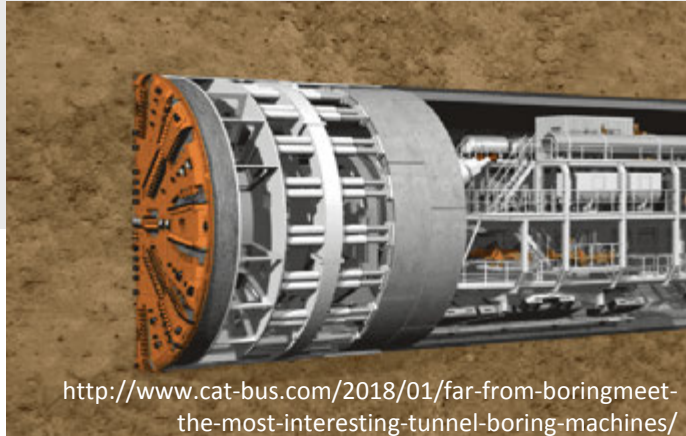
# Elon Musk + Tunnel Boring Machines

## Elon Musk Vision

*Build bigger  
and more efficient  
tunnel boring machine*

## SpaceX challenge

*Improve  
tunneling speed by  
500% to 1,000%*



<http://www.cat-bus.com/2018/01/far-from-boringmeet-the-most-interesting-tunnel-boring-machines/>

# Elon Musk + Tunnel Boring Machines

*"We're going to get this machine, take it apart,  
figure out how to make it go much **faster**  
while still being **safe** and  
**not affecting people on the surface.**  
We have no idea what we're doing."*

– *Elon Musk*

*January 2017*

# Elon Musk + Tunnels

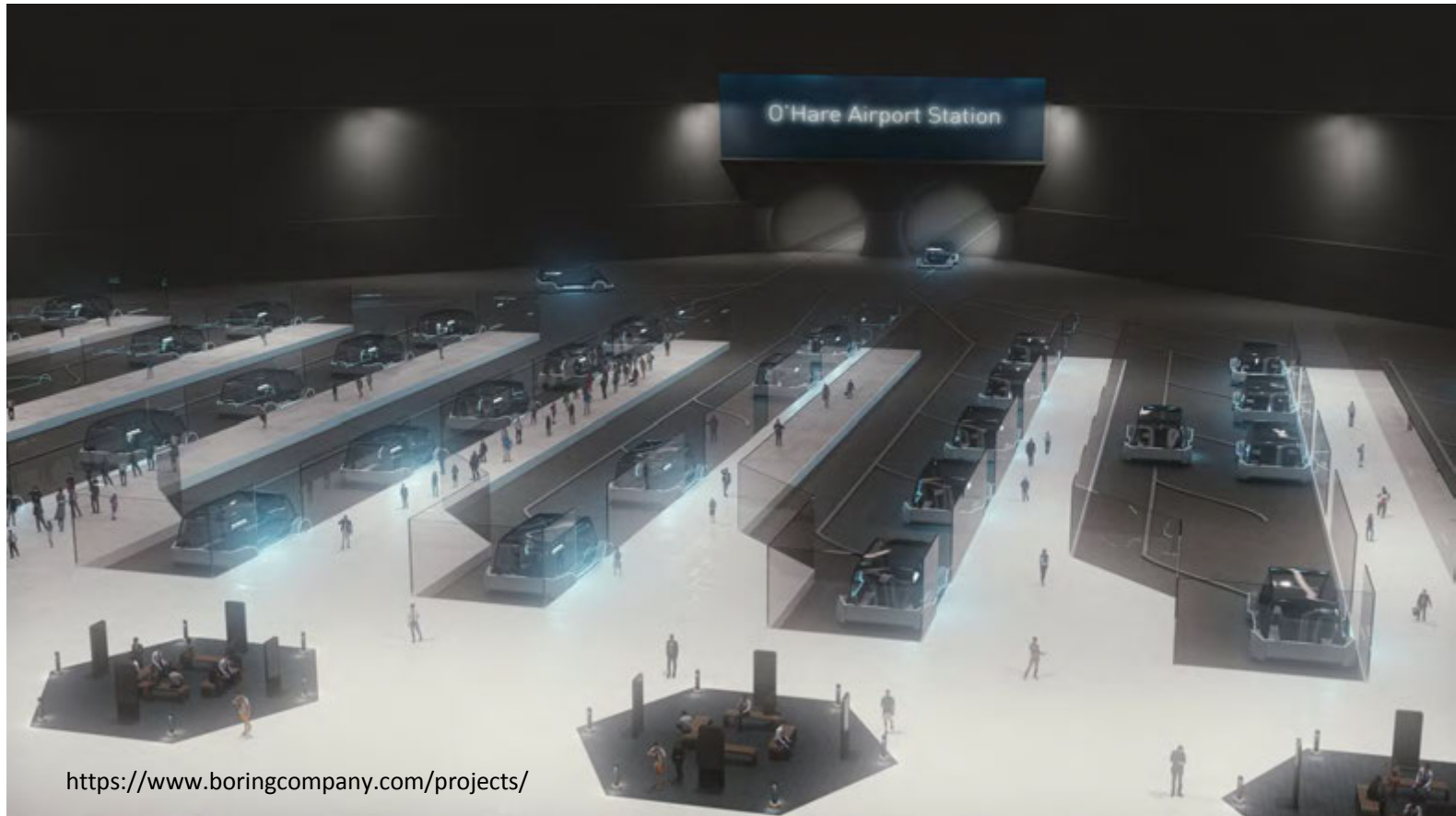


<https://www.boringcompany.com/projects/>

## The initial **Test Tunnel**

- Located in Hawthorne, CA, USA
- Being used for the research and development
  - Public transportation systems
  - Loop
  - Hyperloop.

# Elon Musk + Chicago Express Loop



<https://www.boringcompany.com/projects/>

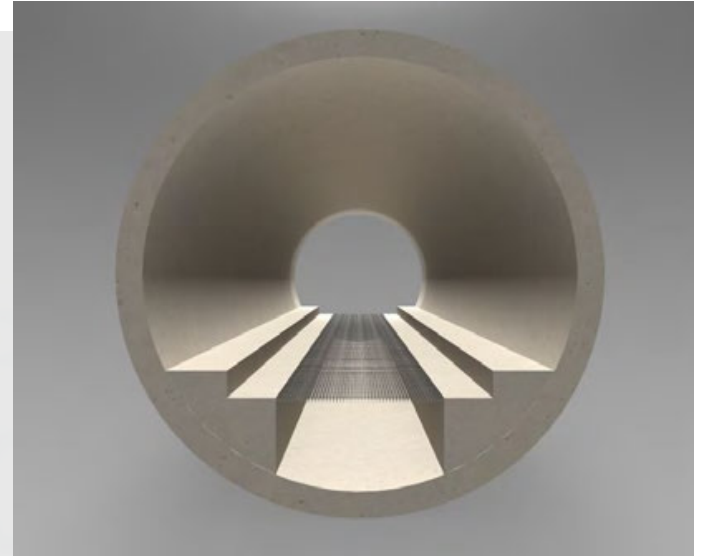
# Elon Musk + Concrete

## Precast concrete tunnel

“Advanced materials” concrete

- High-early strength
- Less permeable
- Added resistance to corrosion compared to the current industry standard

TBC – The Boring Company Application No. 17-SM056, Request to Approve Project for Sales and Use Tax Exclusion, California Alternative Energy and Advanced Transportation Financing Authority, Tuesday, December 19, 2017, Prepared By: Melanie Holman, Program Analyst, accessed July 8, 2018, <https://www.treasurer.ca.gov/caeatfa/meeting/2017/20171219/staff/4a3.pdf>



<https://www.boringcompany.com/projects/>



# Precast Concrete Tunnel Segments

## State of the art

- Compressive strength: C50/60
- Minimum strength at 5 hours: 11 MPa
- Steel fiber reinforcement
- Polycarboxylate-based high range water reducers
- 3d laser tolerance tracking systems



[http://vmt-gmbh.de/wp-content/uploads/2013/07/201105\\_vmtgmbh\\_3d\\_laser\\_tracker\\_system\\_lee\\_tunnel\\_gb.pdf](http://vmt-gmbh.de/wp-content/uploads/2013/07/201105_vmtgmbh_3d_laser_tracker_system_lee_tunnel_gb.pdf)

What might be the problem Elon Musk wants to solve?

# Problem Solving + Innovation

**CUSTOMER  
PROBLEM**

**PRODUCTION  
PROBLEM**

**HOW GREAT  
CAN WE BE  
PROBLEM**

# Related Definitions . . .

## CREATIVITY

NOVEL\* IDEA  
+  
USEFUL

## INNOVATION

NOVEL\* IDEA  
+  
USEFUL  
+  
VALUE\*\*

## ENTREPRENEURSHIP

NOVEL\* IDEA  
+  
USEFUL  
+  
VALUE\*\*  
+  
NEW ENTERPRISE

\* Novel: brand new or a new combination of old elements

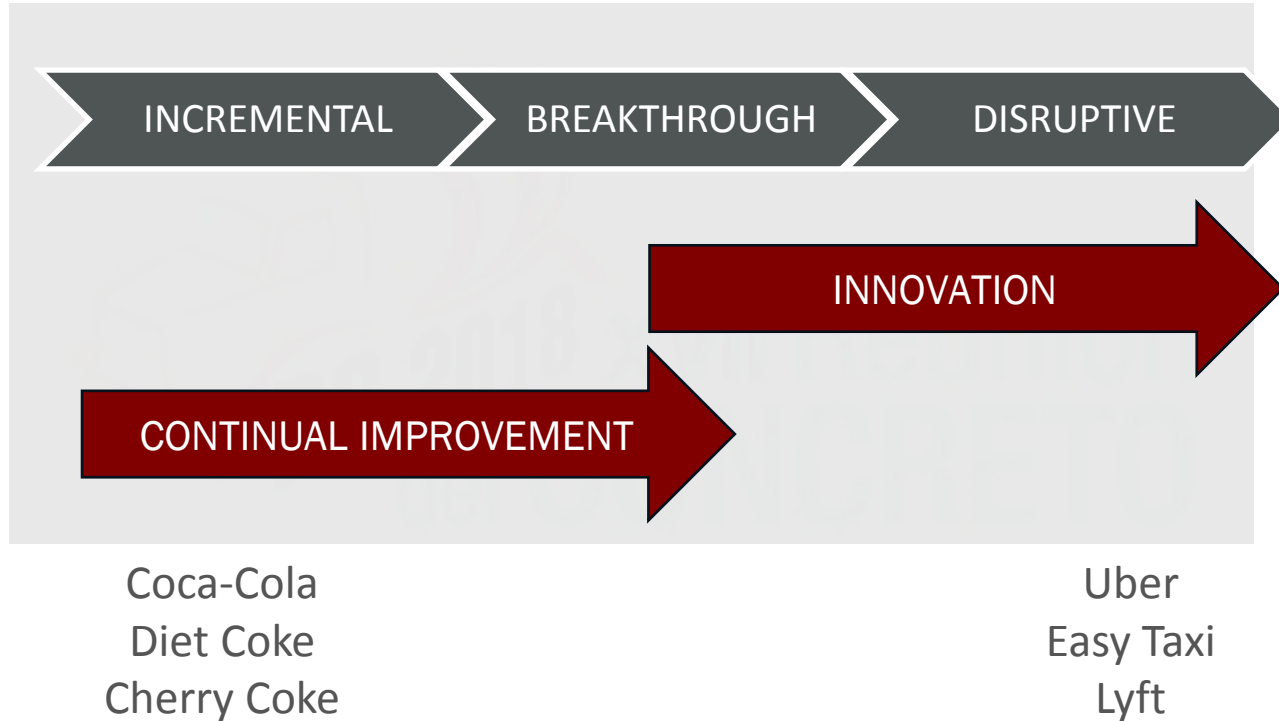
\*\* Value: operations, industry, society

# Innovation defined . . .

**INNOVATION**  
is the  
**PROCESS**  
of translating an  
idea or invention into a  
**good or service that creates value\***  
and/or for which customers will pay

\* Value: operational, industry, social

# Innovation spectrum



# The impact of innovation . . .

## DISRUPTIVE INNOVATION

Changes business models  
Initiates new markets  
Creates new customer habits





# Concrete



## REAL TIME MONITORING, INTERNET OF THINGS

- SLUMP
- TEMPERATURE
- LOAD SIZE
- REVOLUTIONS
- WATER
- DRUM SPEED
- LOCATION



<http://www.cptechcenter.org/ncc/TTCC-NCC-documents/Sp2014/SP14-3-Koehler%20Verify-sec.pdf>

# Concrete + Innovation

CUSTOMER  
PROBLEM



# Concrete + Innovation

HOW GREAT  
CAN WE BE  
PROBLEM



Fig. 2: Joints between reinforced concrete beams were replaced with UHPC. Dimension lumber portals and threaded rods held the bottom formwork tight against the beam flanges to prevent leakage of the UHPC

Table 4:  
Cost of Mixture 3 components

Component	Quantity, lb/yd <sup>3</sup>	Cost per yd <sup>3</sup> , % of total
Type I OPC	650	5.0
Slag cement	650	4.3
Silica fume	327	8
HRWRA	39	6.3
Sand A	395	1.2
Sand B	1580	4.8
Steel fibers	265	70.4
Total cost: \$892.70		

Note: 1 lb/yd<sup>3</sup> = 0.59 kg/m<sup>3</sup>

Ref. Concrete International, January 2018

Table 2:  
Mechanical properties of laboratory and field batches

Mixture no. or ID	Spread, mm (in.)	Compressive strength, MPa (psi)				Tensile strength, MPa (psi)	Strain at peak tensile stress, %
		7-day	14-day	28-day	56-day		
1	214 (8.4)	121.3 (17,600)	149.1 (21,600)	175.7 (25,500)	196.2 (28,500)	12.9 (1900)	0.41
2	215 (8.5)	118.2 (17,100)	147.8 (21,400)	169.2 (24,500)	187.4 (27,200)	11.1 (1600)	0.17
3	235 (9.3)	118.8 (17,200)	143.5 (20,800)	159.0 (23,100)	176.4 (25,600)	9.5 (1400)	0.18
4	238 (9.4)	113.4 (16,500)	137.1 (19,900)	151.9 (22,100)	—*	9.6 (1400)	0.14
Field	238 (9.4)	108.9 (15,800)	127.0 (18,400)	148.1 (21,500)	—*	8.3 (1200)	0.13

\*Specimens not tested. Not enough were made due to an oversight

ULTRA  
HIGH  
PERFORMANCE  
CONCRETE



# Concrete Construction Challenge

PRODUCTION  
PROBLEM



High-rise Shear Wall  
Coupling Beams  
in Seismic Zone  
**Time + Cost + Safety  
Issues**

Image courtesy of Webcor

# Concrete Construction Challenge

PRODUCTION  
PROBLEM

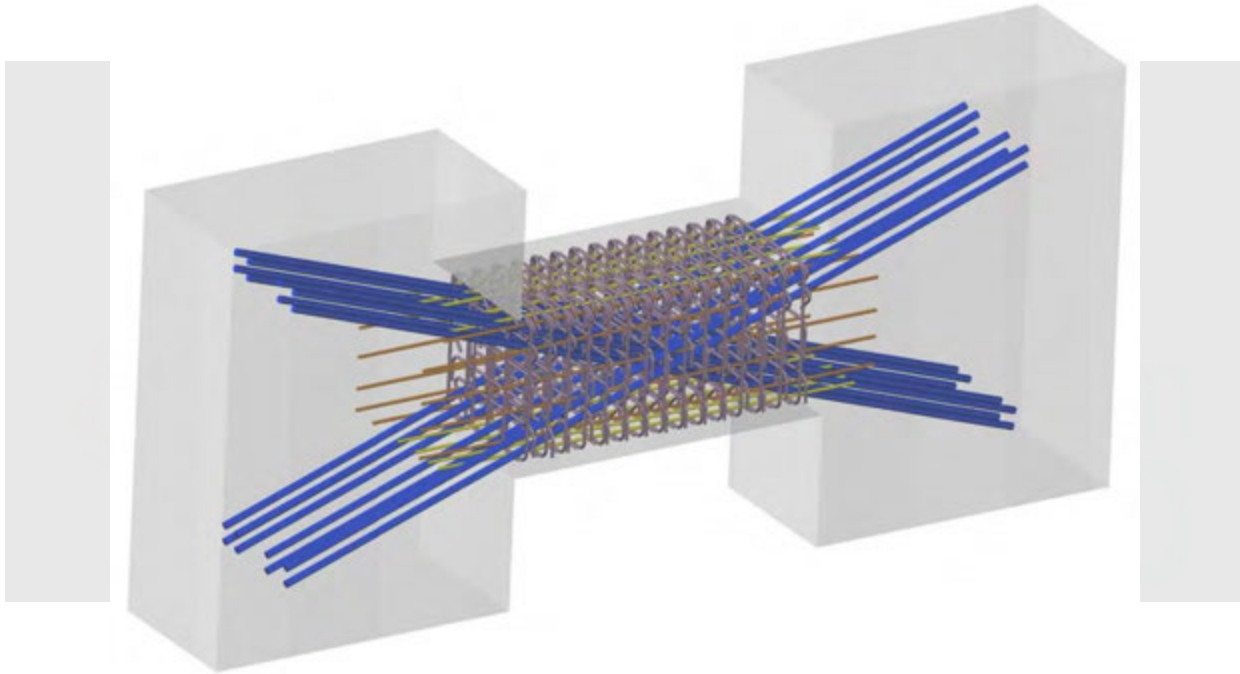


Image courtesy of CKC Structural Engineers



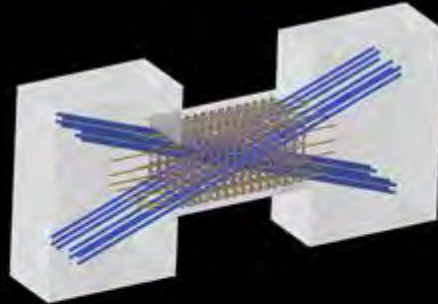
# Concrete Construction + Innovation

PRODUCTION  
PROBLEM

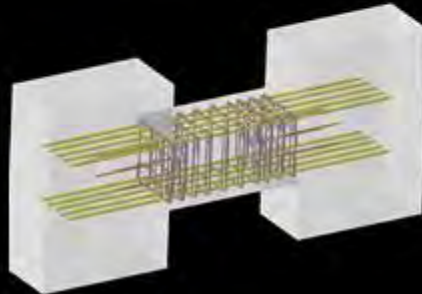


Image courtesy of Webcor

# Concrete Construction + Innovation



**Conventional Reinforced  
Concrete Coupling Beam**



**Steel Fiber Reinforced  
Concrete (SFRC)  
Coupling Beam**

Image courtesy of CKC Structural Engineers

# Concrete Construction + Innovation



Image courtesy of CKC Structural Engineers





# Concrete Construction + Innovation

## COUPLING BEAM TESTING UNIVERSITY OF MICHIGAN



Image courtesy of CKC Structural Engineers



## SAY HELLO TO THE INFORMATION SUPERHIGHWAY

Integrated Roadways is a technology developer, vendor, and network operator that delivers innovative self-funding smart infrastructure.



Smart Pavement™ connects Smart Cars and Smart Cities

Integrated Roadways, LLC - Proprietary and Confidential

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INTEGRATED  
ROADWAYS

# Concrete Construction + Innovation

HOW SMART  
CAN WE BE  
PROBLEM



Courtesy Integrated Roadways



# Concrete Maintenance Challenge

CUSTOMER  
PROBLEM

ADVANCED  
AUTOMATION  
+  
ADVANCED  
MANUFACTURING



~~JOINTS~~

# Concrete Maintenance + Innovation

## JOINT-FREE CONCRETE SLAB



Joint-free concrete slabs on grade. Image courtesy George Garber

# Concrete Construction Challenge

HOW SMART  
CAN WE BE  
PROBLEM

STABILIZE  
SOFT-  
GROUND  
CAVERNOUS  
TUNNEL



© Crossrail Ltd.

# Concrete Construction Challenge

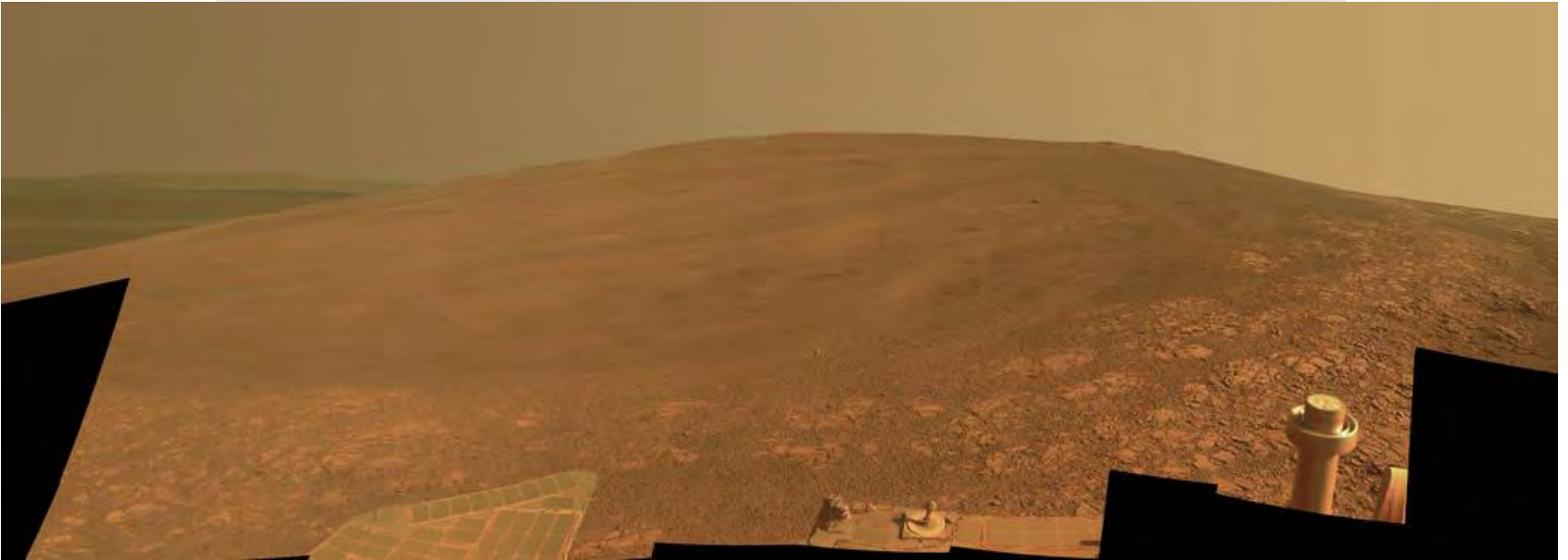


- SEMI-AUTONOMOUS SHOTCRETING
- FIBER REINFORCING
- TOPOGRAPHIC SURVEY EQUIPMENT



# Concrete Construction Challenge

HOW SMART  
CAN WE BE  
PROBLEM



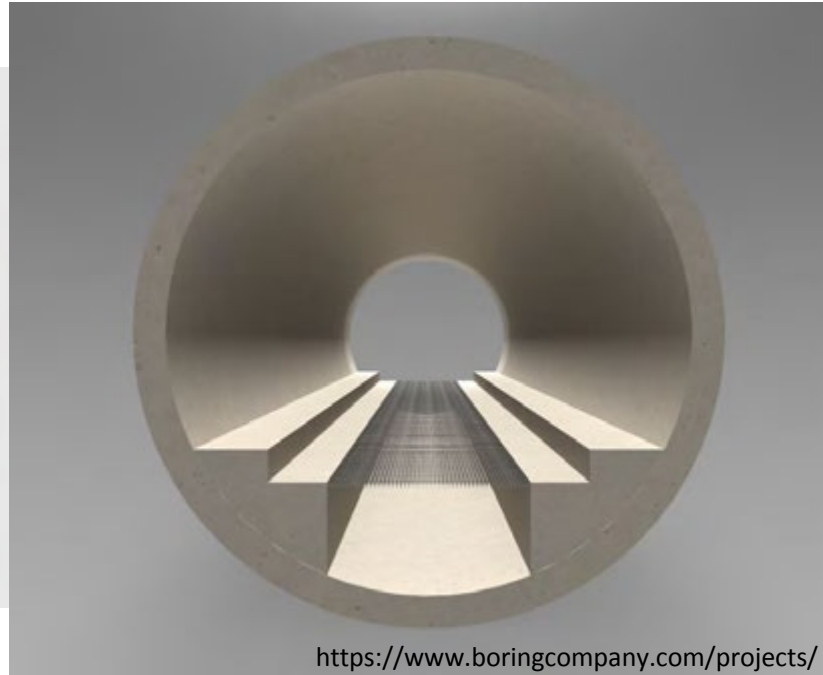
Sustainable Habitation on the Moon and Mars housing for deep space exploration





# 16:30: CONSTRUCTION OF HABITATS IN SPACE TONY KIM, NASA

# Elon Musk + Concrete



<https://www.boringcompany.com/projects/>