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Technical and sustainability aspects of Lightweight Concrete Bridges

April 12, 2021

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Learning Objectives

1. Determine adequate construction materials to upgrade aging infrastructure

2. Identify pros and cons of lightweight concrete

Technical and Sustainability Aspects of Lightweight Concrete Bridges

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TRB WEBINAR: Apr 12, 2021

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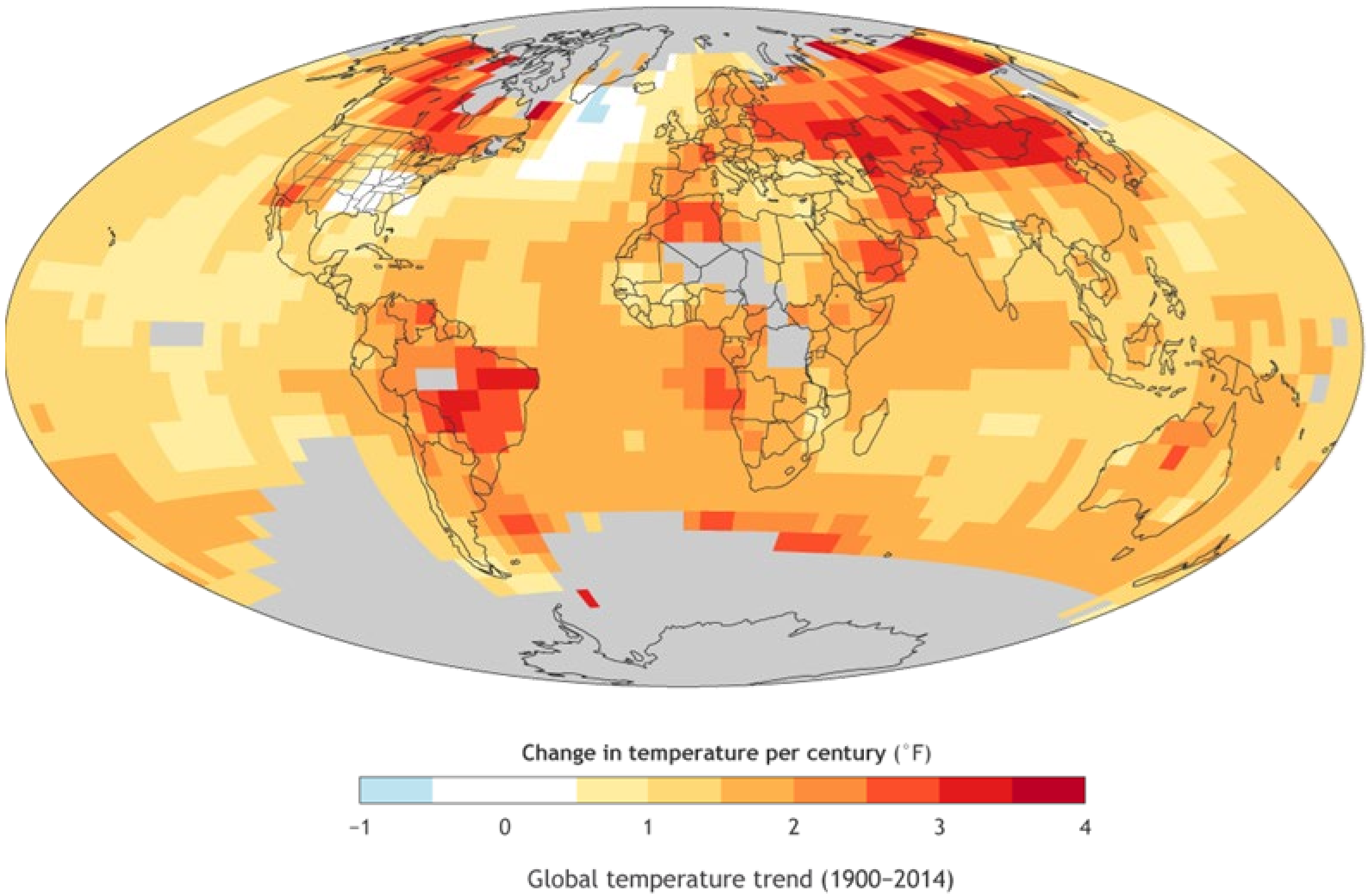
OUTLINE

- INTRODUCTION - MH
- PART 1: TECHNICAL ASPECTS OF LWC - AM
- PART 2: SUSTAINABILITY GAINS OF LWC - MH
- PART 3: MARKET DEMAND OF LWC - MH
- PART 4: PRIME BARRIERS FACING LWC - AM
- Q/A SESSION

GLOBAL WARMING



Source: NOAA

GLOBAL CLIMATE CHANGE

X 3

The number of climate-related disasters has tripled in the last 30 years *

X 2.5

Rate of global sea-level rise was 2.5 times faster than all of the 20th century between 2006 and 2016 *.

45M

Drought in Africa: More than 45 million people are struggling to find enough food across 14 countries will in 2019 §.

$110B

Damages from the 2019-2020 Australian wildfires cost $110 billion cost ¥.

*Oxfam International. “5 Natural Disasters That Beg for Climate Action.” Oxfam International, 7 Apr. 2020, www.oxfam.org/en/5-natural-disasters-beg-climate-action.

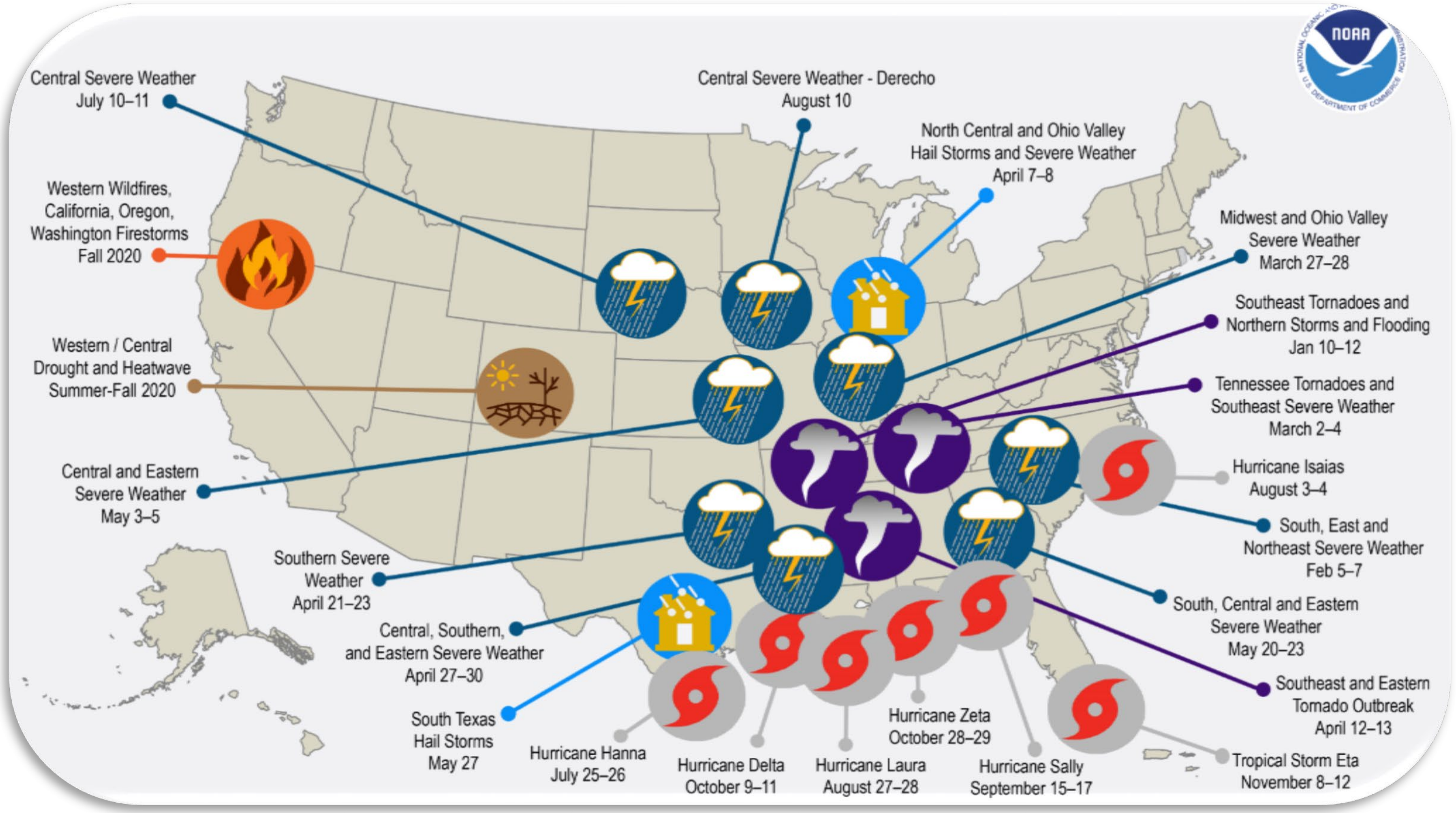
¥ Read, Paul, and Richard Denniss. "With costs approaching $100 billion, the fires are Australia’s costliest natural disaster." *The Conversation* 17 (2020).

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

§ Anyadike, Obi. “Drought in Africa Leaves 45 Million in Need across 14 Countries.” *The New Humanitarian*, 10 June 2019, www.thenewhumanitarian.org/analysis/2019/06/10/drought-africa-2019-45-million-in-need.

U.S. WEATHER AND CLIMATE DISASTERS IN 2020

- Since 1980, 285 weather and climate disasters where overall damages exceeded $B1
- Total cost is approx. $1.875 trillion ($78.1B per year)
- New annual record of 22 events in 2020



Source: NOAA National Centers for Environmental Information

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

PARIS CLIMATE AGREEMENT

- Global framework to reduce risks and the impacts of climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C.

- Long-term efforts of keeping the increase in global average temperature.

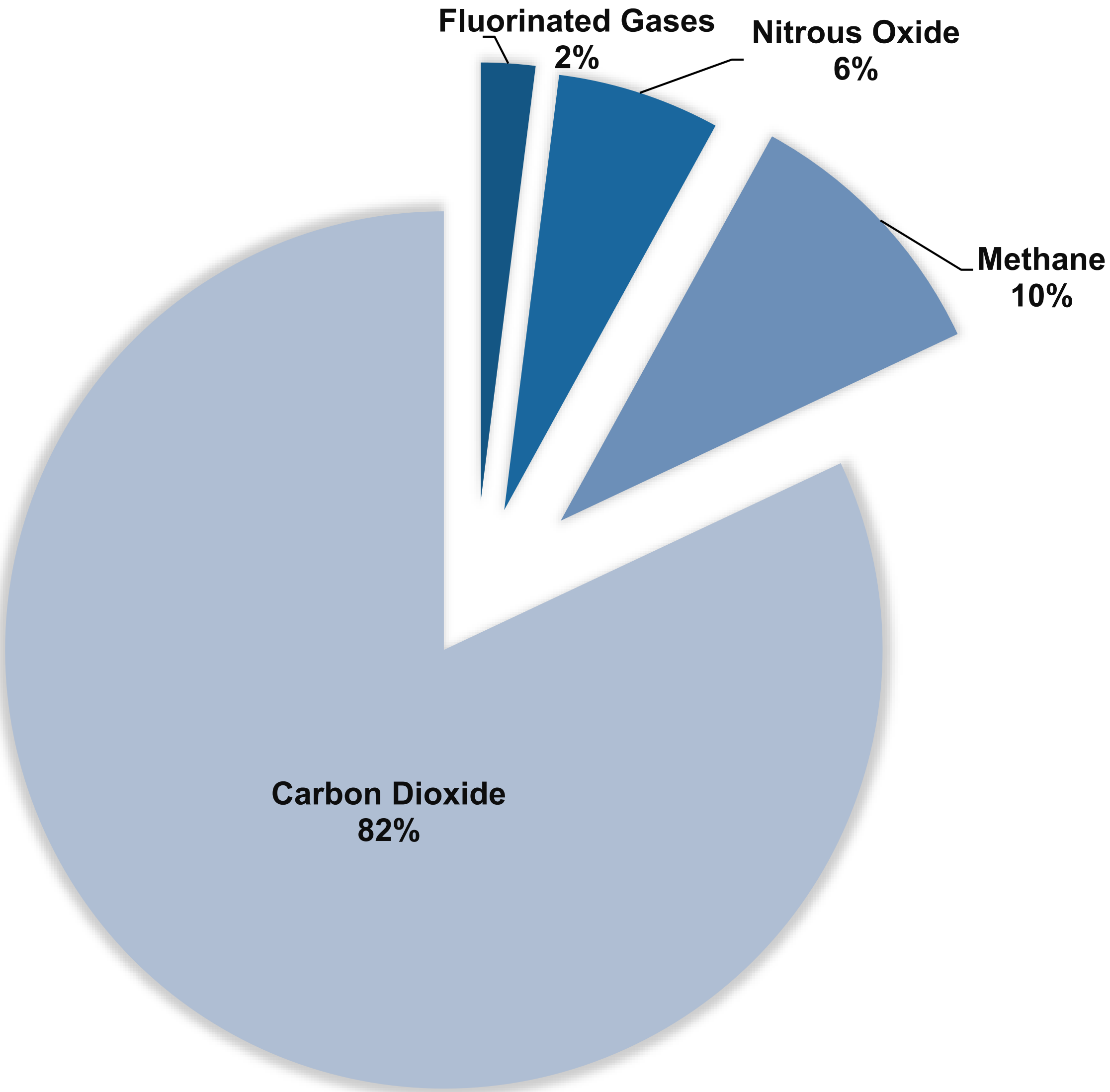
- EU is committed to reduce greenhouse gases (GHGs) emissions by at least 40% and 60% by 2030 and 2040 respectively, compared to 1990[¥].

- U.S. is committed to reduce greenhouse emissions by 26%-28% below 2005 levels by 2025[§].

¥ Kijewska, Anna, and Anna Bluszcz. "Analysis of greenhouse gas emissions in the European Union member states with the use of an agglomeration algorithm." Journal of Sustainable Mining 15.4 (2016): 133-142.
§ White House. "Fact Sheet: US Reports Its 2025 Emissions Target to the UNFCCC." (2015).

GREENHOUSE GASES IN USA

- We produce 55 billion tons (50 billion tons) of CO2e each year worldwide.
- US emissions of GHGs in 2019 amounted to 6.577 million metric tons.
- Primary GHG emissions are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and fluorinated gases.
- CO2 at approximately 82% contribution is the largest primary source of GHG.



U.S. EPA. "Inventory of US greenhouse gas emissions and sinks: 1990–2017." US Environmental Protection Agency (2019).

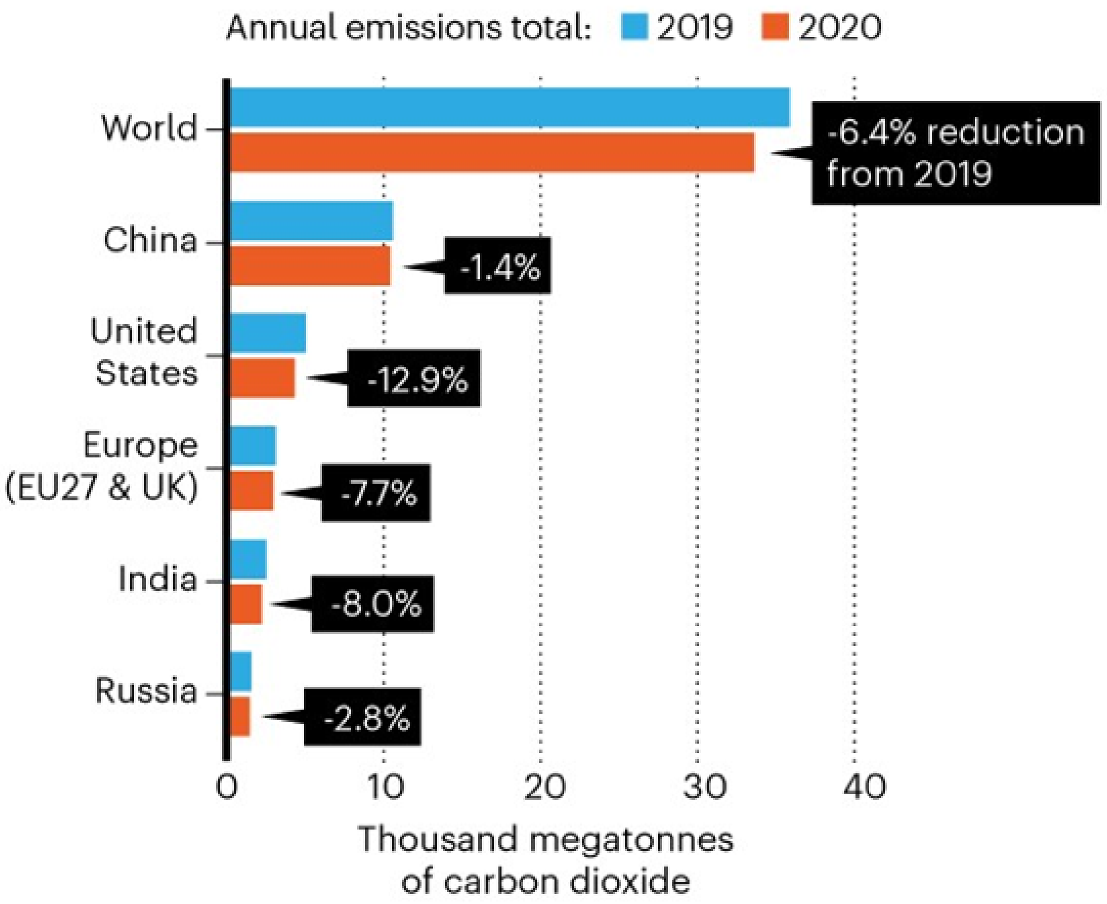
Ritchie, Hannah, and Max Roser. "CO_2 and greenhouse gas emissions." Our world in data (2017).

GHG and COVID-19

- ❑The transport industry is responsible for the highest share of GHG in U.S.

- ❑ Motor fuel consumption decreased by 24 per cent in the second quarter of 2020 compared to 2019.

- ❑ U.S. GHG emissions in 2020 was approximability 12.9% lower than 2019.



Source: Carbon Monitor Program

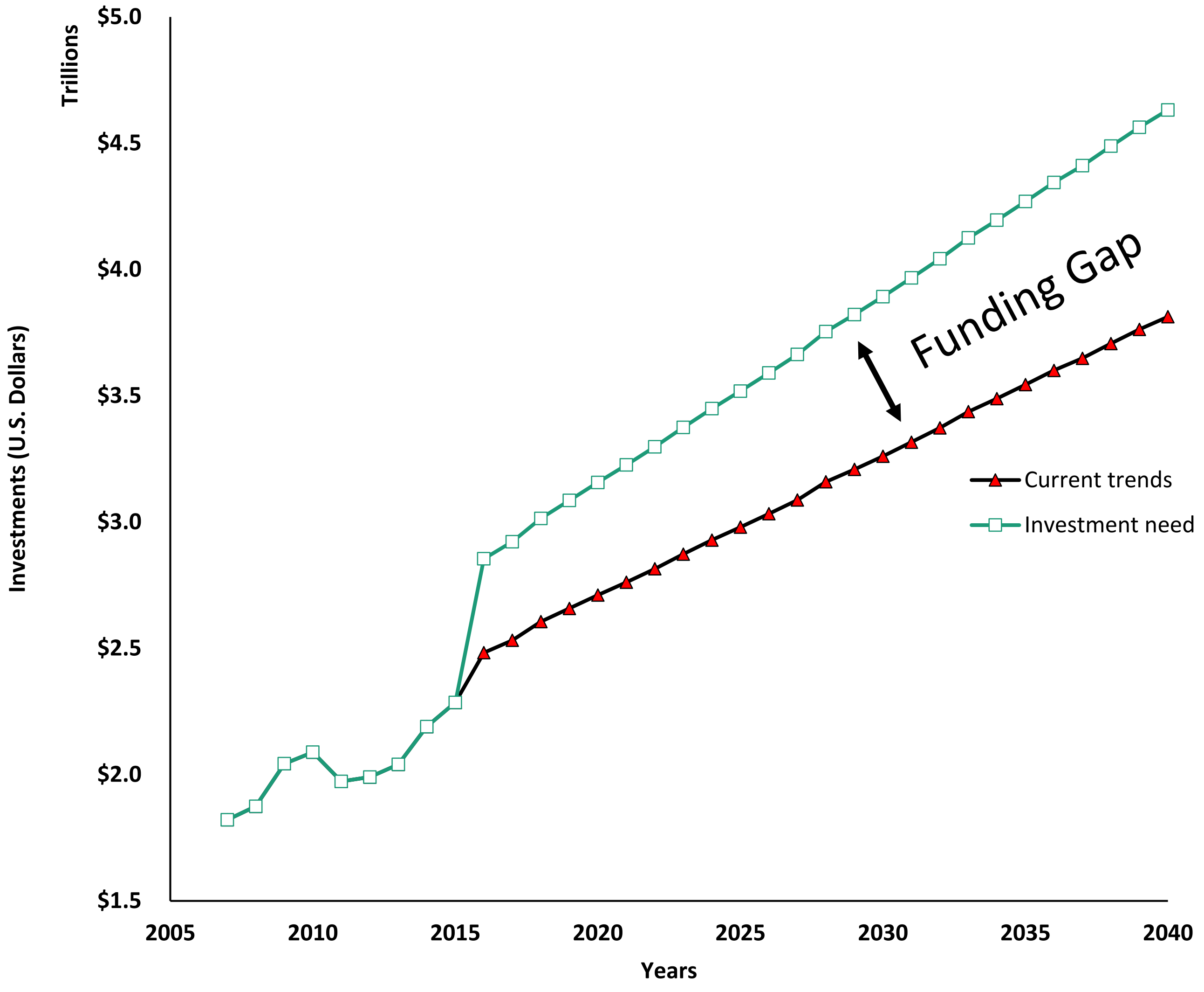
Shan, Yuli, et al. "Impacts of COVID-19 and fiscal stimuli on global emissions and the Paris Agreement." Nature Climate Change (2020): 1-7.

INFRASTRUCTURE INVESTMENT

- Global infrastructure investment needs to be $79[¥] trillion between 2021 and 2040. This is an average of $3.9 [¥] trillion per year.

- 2021 Report Card rates infrastructure as "C-" [§].

- Investment of $5.9[§] trillion is needed by 2029 to improve the U.S. Infrastructure.



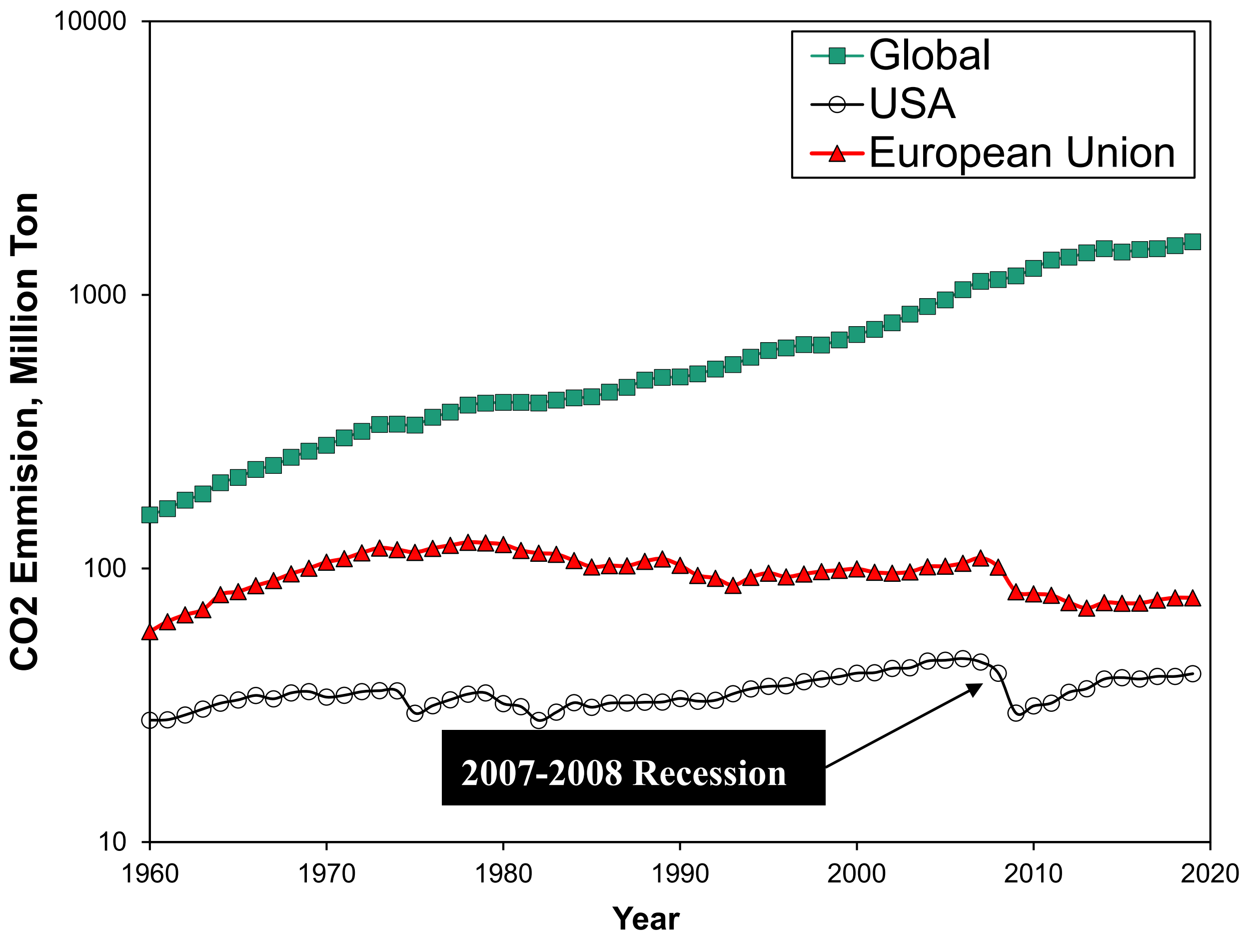
¥ Outlook, Global Infrastructure. "Infrastructure investment needs 50 countries, 7 sectors to 2040." July, A G20 Initiative. Sydney: Global Infrastructure Hub (2017).
§ American Society of Civil Engineers. 2017."America's Infrastructure Grades Remain Near Failing." American Society of Civil Engineers (ASCE) (2021)

CO2 EMISSIONS OF CEMENT SECTOR

- ❑ Cement production accounts for 0.33% of the total energy consumption in the USA, as compared to 1.8% for steel.

- ❑ Energy needed to manufacture cement amounts to approximately 85% of the total energy used to make concrete.

- ❑ Emissions dipped 6.3% during Great Recession of 2009.



Our World In Data. "Annual CO_2 Emissions from Cement." *Our World in Data*, 2020

Poll Question 1

Which of the following best describes your background/role?

a) State DOT
b) Local MPO
c) Federal government
d) University
e) Other

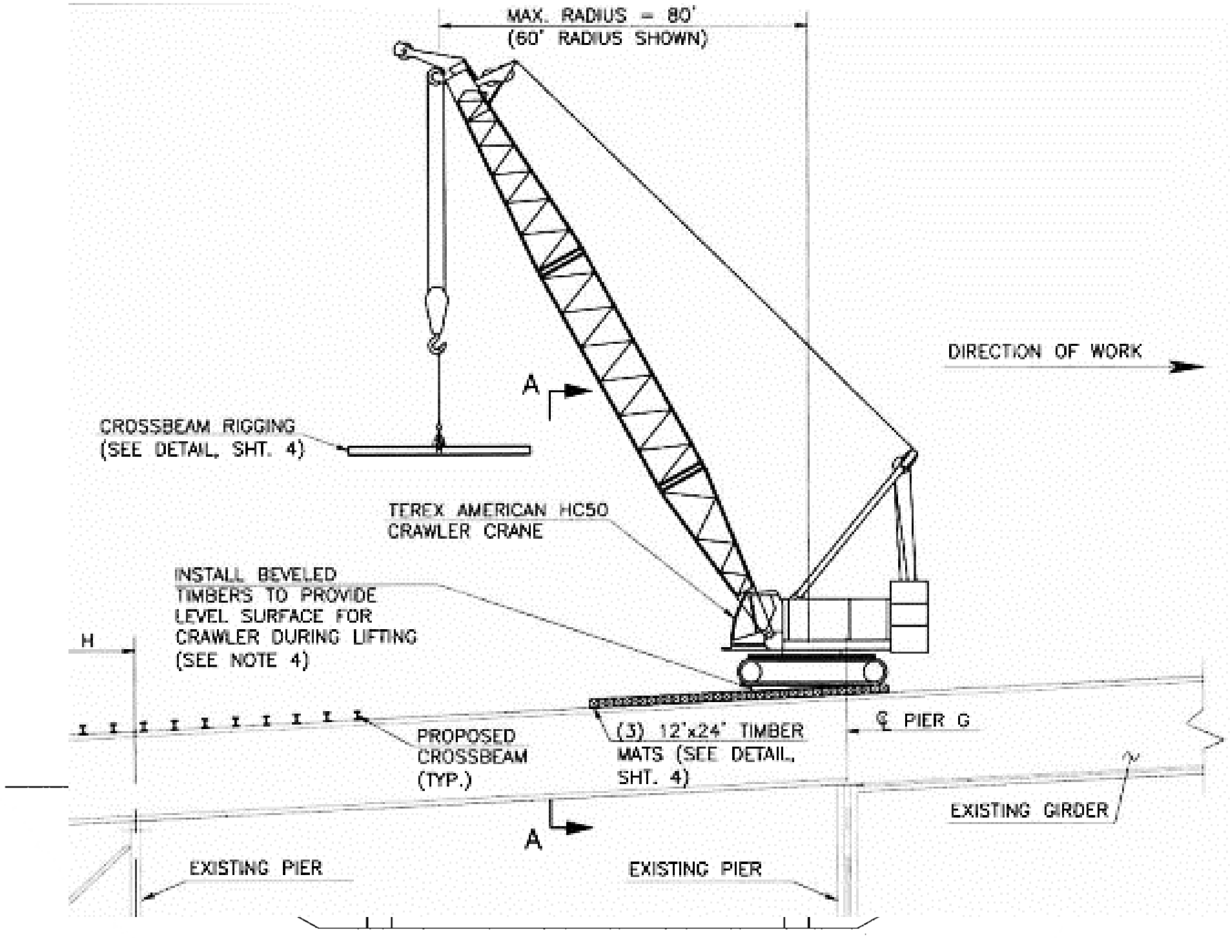
TYPES OF LWC

- Semi-lightweight concrete: Mix of NWA and LWA. Unit weight of 105-120 lb/ft^3 (1680-1920 kg/m^3) and compressive strength comparable to normal concrete.
- High strength lightweight concrete (HSLWC): Structural LWC with a 28- day compressive strength of 8ksi (55 MPa) or greater.
- Insulating concrete - compressive strength of 100 to 500 psi (0.69 to 6.89 MPa) with high thermal resistance. Not intended for weather exposure.

Mousa, Ahmad, Mohamed Mahgoub, and Mohab Hussein. "Lightweight concrete in America: presence and challenges." *Sustainable Production and Consumption* 15 (2018): 131-144.

COMMON APPLICATIONS

- ❑ Weak soils
- ❑ Reuse of Foundation
- ❑ Bridge widening
- ❑ Lower shipping and handling
- ❑ Reduced inertial seismic forces
- ❑ Higher fire resistance compared to NWC
- ❑ Rehabilitation and upgrade
  - ❑ HS20 ➔ HL93
  - ❑ WSD ➔ LRFD
  - ❑ Simple spans ➔ continuous beams



PART 1: TECHNICAL ASPECTS OF LWC

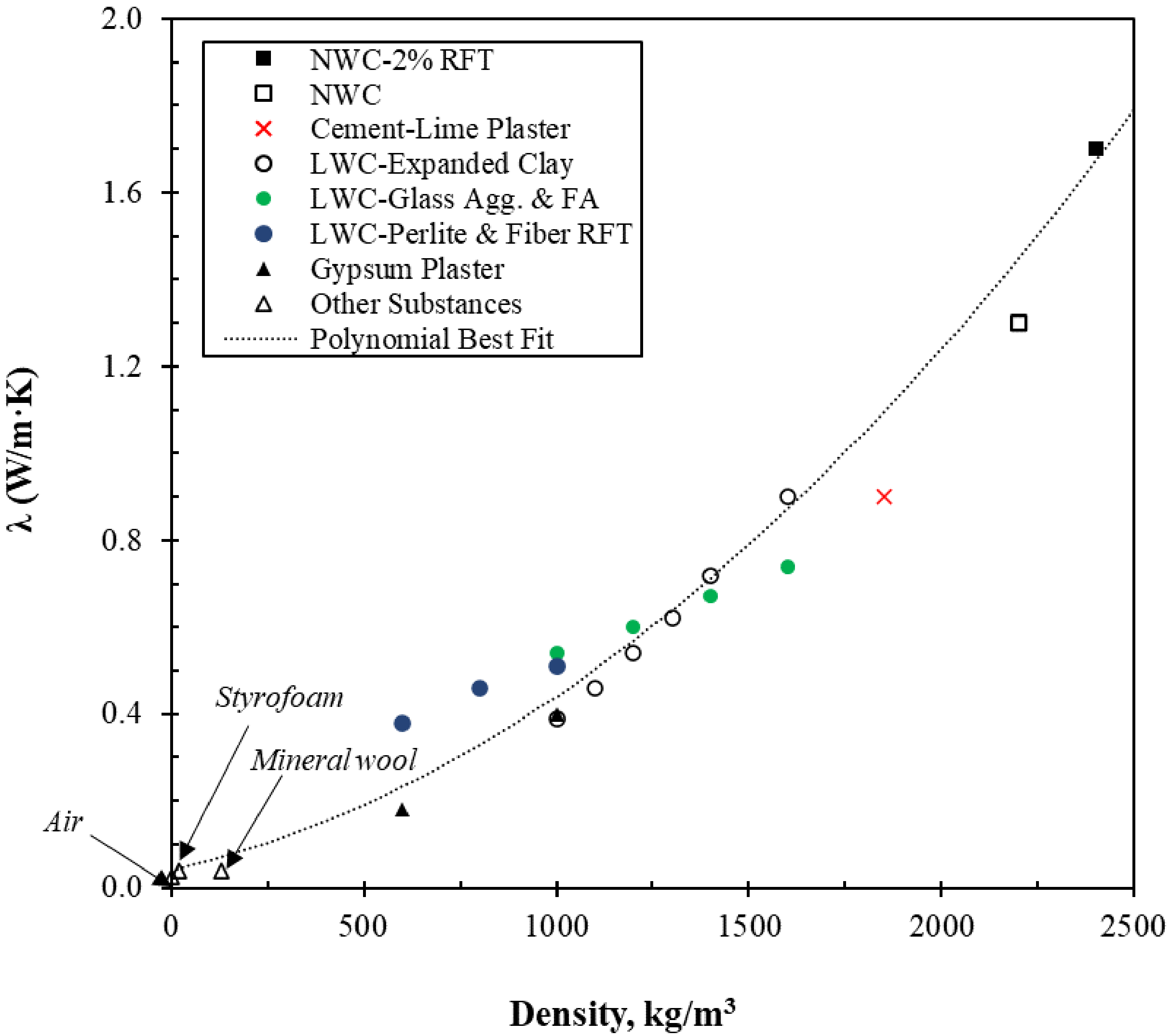
Poll Question 2

Which is the key hurdle(S) that impacts the use/specify/recommend LWC? (*multiple choice allowed*)

a) Price or Life cycle cost
b) Performance of placed concrete (likelihood cracking, delamination, etc.)
c) Structural strength
d) Placement of concrete (ease of pumping, placing and finishing)
e) Supply

THERMAL CONDUCTIVITY

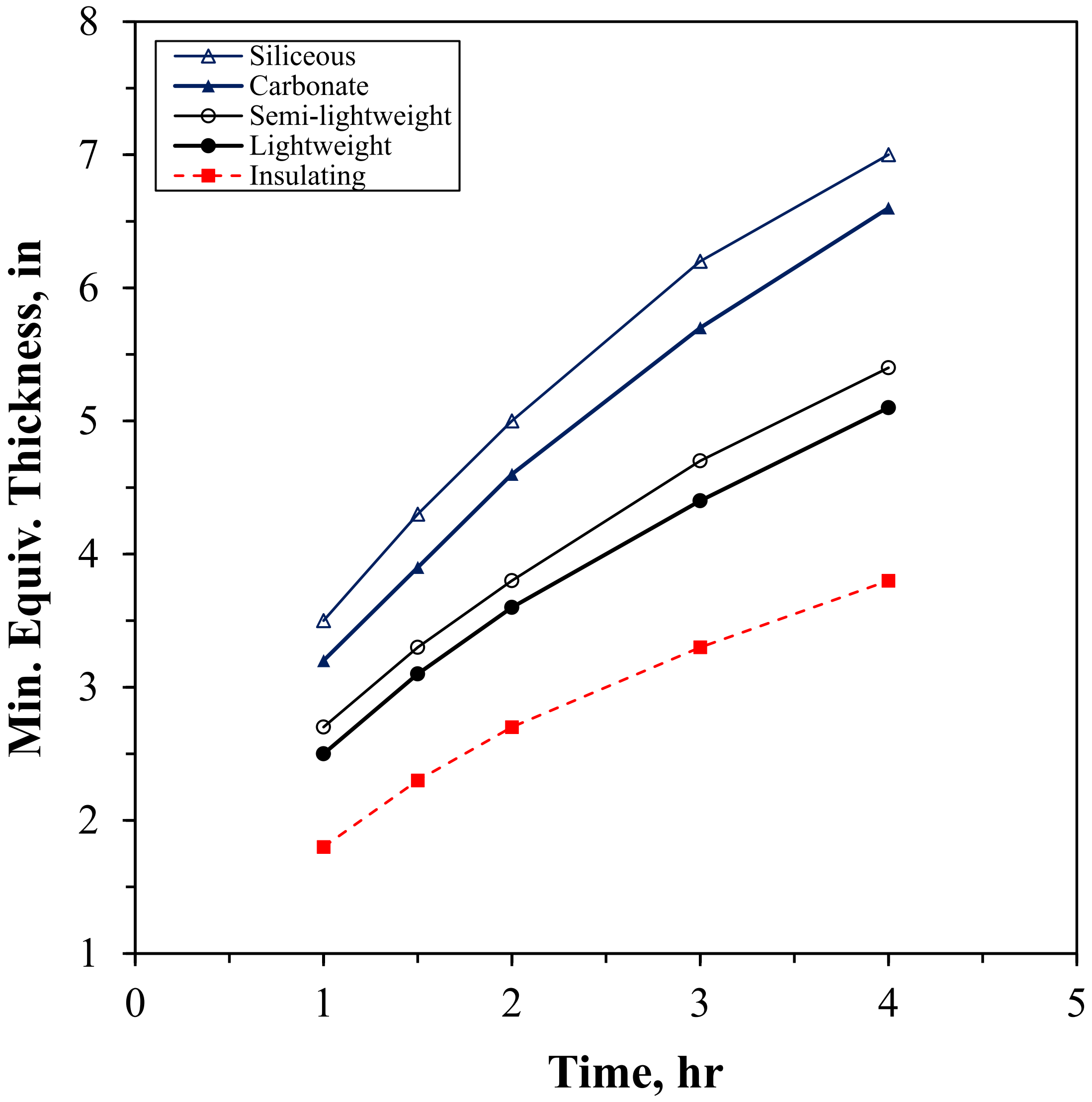
- Thermal conductivity (λ) is the quantity of heat transmitted through a unit thickness.
- LWA significantly reduces the thermal conductivity of concrete due the pores, which increases the porosity of concrete.
- Perlite and fiber-reinforced LWC (avg. λ=0.5) is approx. one third the thermal conductivity of NWC (avg. λ=1.5).



Mousa, Ahmad, Mohab Hussein, and Mohamed Mahgoub. "Merits and Future of Lightweight Concrete: Insights from USA Construction Market." Unpublished manuscript

FIRE RATING

- Modulus of elasticity drops with the increase in temperature.
- Fire resistance of concrete elements (e.g., floor and roof slabs) is measured by either the heat transmission or the structural failure end point.
- LWC has lower coefficient of thermal expansion, which offers a superb rating for fire resistance and provides a higher R-value.

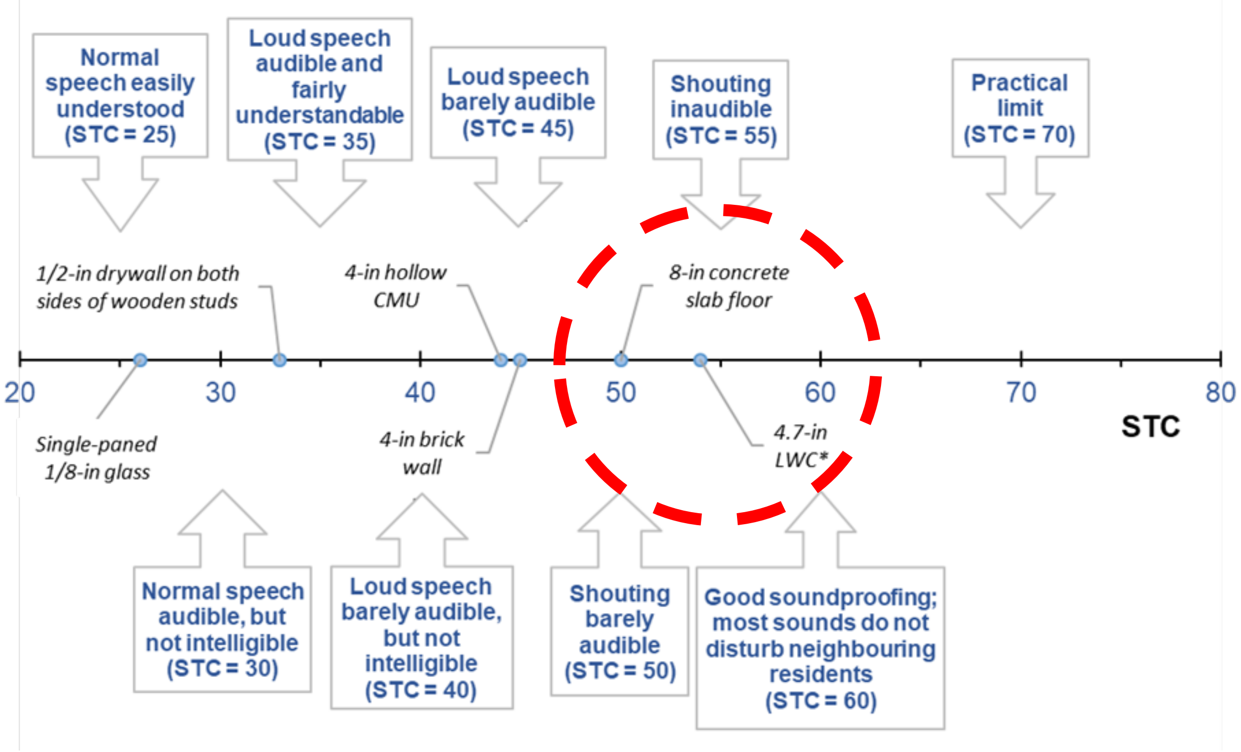


Mousa, Ahmad, Mohab Hussein, and Mohamed Mahgoub. "Merits and Future of Lightweight Concrete: Insights from USA Construction Market." Unpublished manuscript

SOUND INSULATION

- Sound Transmission Class (STC) >> measure for rating sound isolation.
- Acoustic insulation for LWC units containing closely textured surface aggregates perform better than predicted by their mass.

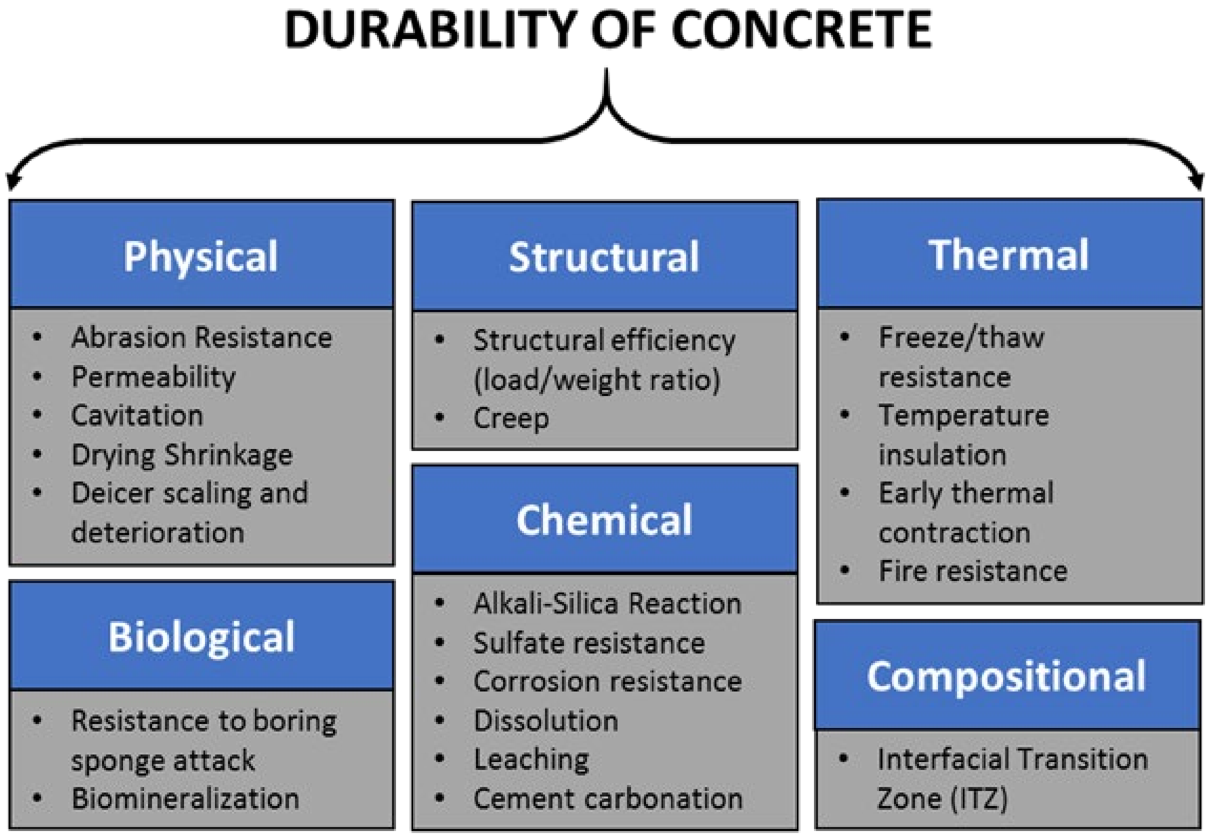
A sound insulation of a 4.7-in LWC panel acoustically outperforms that of an 8-in thick NWC slab floor.



Mousa, Ahmad, Mohab Hussein, and Mohamed Mahgoub. "Merits and Future of Lightweight Concrete: Insights from USA Construction Market." Unpublished manuscript

KEY DURABILITY ASPECTS OF LWC

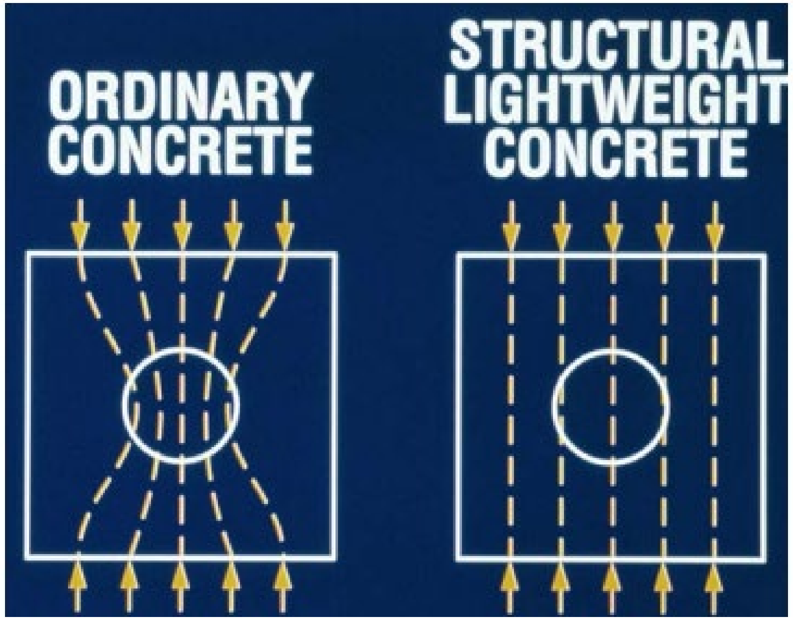
Critical durability of LWC are absorption, permeability, freezing and thawing resistance, alkali-aggregate reaction and chemical resistance, carbonation and corrosion resistance, and abrasion resistance



Mousa, Ahmad, Mohab Hussein, and Mohamed Mahgoub. "Merits and Future of Lightweight Concrete: Insights from USA Construction Market." Unpublished manuscript

FREEZING AND THAWING RESISTANCE

- Air-entrained LWC is comparably or even better than NWC with respect to freezing and thawing.
- LWC has elastic compatibility of the constituents and enhanced bond between the LWA and the cement paste.
- LWA pores reliefs the hydraulic pressure that develops as the chemically uncombined water freezes.



Elastic Compatibility
Source: Ozyildirim (2008)

Mousa, Ahmad, Mohamed Mahgoub, and Mohab Hussein. "Lightweight concrete in America: presence and challenges." *Sustainable Production and Consumption* 15 (2018): 131-144.
Ozyildirim, C., 2008. Durability of structural lightweight concrete. In: Proceedings of 2008 Concrete Bridge Conference, St Louis, MO, p. 142.

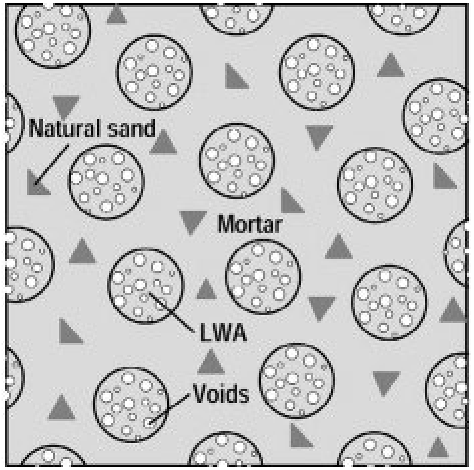
PERMEABILITY

- Permeability controls the long-term durability of concrete as it influences the rate of entry of aggressive liquids and the movement of water during wetting or drying.

- LWC has equal to or less permeability than NWC!

- The mechanical and physical properties of LWA directly affects the strength and permeability of LWC.

- High porosity of LWA enhances its absorption capacity, which subsequently creates a compatibility in moisture content between LWA and the surrounding water-rich cement binder (hygral equilibrium).

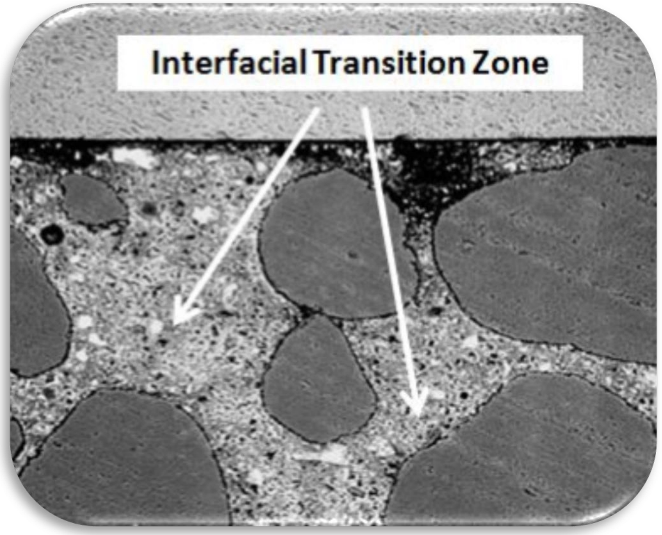


LWA particles in concrete
Source: Liu et al. (2011)

¥ Mousa, Ahmad, Mohamed Mahgoub, and Mohab Hussein. "Lightweight concrete in America: presence and challenges." *Sustainable Production and Consumption* 15 (2018): 131-144.
§ Liu, Xuemei, Kok Seng Chia, and Min-Hong Zhang. "Water absorption, permeability, and resistance to chloride-ion penetration of lightweight aggregate concrete." Construction and building Materials 25.1 (2011): 335-343.

INTERFACIAL TRANSITION ZONE (ITZ)

- ❑ Low permeability values are attributed to the superior ITZ between the aggregate and cement binder in LWC.
- ❑ As internal curing continues, ITZ reduces permeability by extending the hydration process – forming additional hydrated products in the pores and capillaries of the binder.
- ❑ The improved aggregate–cement binder interface in LWC is a result of mechanical interlocking between the LWA and the cement binder, combined with a chemical interaction.
- ❑ Low absorption of NWA causes a high disparity in water content on the opposite sides of ITZ, which could lead to bleeding and an increase the permeability of NWC.



Source: DeFord and Lange

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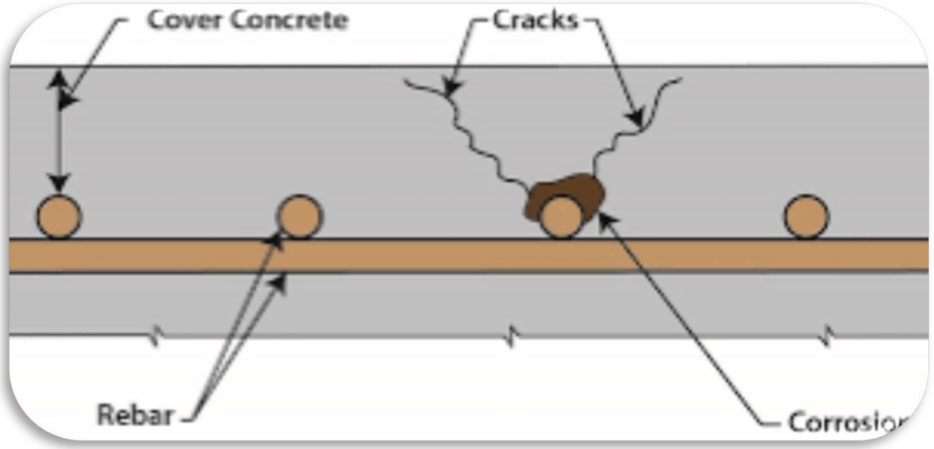
ITZ: A 50-YEAR-OLD LWC BRIDGE

- ❑ Nanjing Yangtze River Bridge is double-decked road-rail truss bridge in Jiangsu Province in China.
- ❑ It is 5,171 ft and approx. 80,000 vehicles and 190 trains per day. Opened for traffic in 1968.
- ❑ Potential pozzolanic reaction in LWC is effective over a long time, which not captured by the typical laboratory testing.
- ❑ After 50 years of hydration, the pores of the interfacial transition zone (ITZ) of LWC and LWA voids are filled up.
- ❑ Makes it difficult to define ITZ according to porosity or chemical element distribution.

Source: Global Times

Huang, Liming, et al. "Composition and microstructure of 50-year lightweight aggregate concrete (LWAC) from Nanjing Yangtze River bridge (NYRB)." *Construction and Building Materials* 216 (2019): 390-404.

CORROSION



- ❑ Two primary factors control rebar corrosion in concrete elements:
  - ✓ Thickness of concrete cover
  - ✓ Quality of concrete cover
- ❑ High permeability allows easy penetration of deleterious agents into concrete which accelerate rebar corrosion.
- ❑ U.S. Navy reported the lowest permeability with high-strength LWC compared to NWC.
- ❑ The higher freeze and thaw resistance of LWC leads to a more durable concrete, which can resist steel corrosion more effectively.

Mousa, Ahmad, Mohamed Mahgoub, and Mohab Hussein. "Lightweight concrete in America: presence and challenges." *Sustainable Production and Consumption* 15 (2018): 131-144.

ALKALI-AGGREGATE REACTION & CHEMICAL RESISTANCE

- ❑ LWC is not affected by long-term interaction between silica-rich aggregates and the alkalies in the cement, or from the ingress of alkalies from natural sources such as seawater.
- ❑ Porous nature of LWA provides the necessary space to minimize the deleterious expansion of reactive materials to precipitate in a non-harmful manner.
- ❑ Replacement of reactive NWC with LWC appears to significantly reduce the disruptive expansions associated with alkali-aggregate reaction.

Source: Portland Cement Association

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CARBONATION

- Carbonation is the reaction of carbon dioxide from the air with the calcium hydroxide from the hydration process.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

- Carbonation is associated with a reduction in pH values, which in turn neutralizes the protective layer over the reinforcing steel, render it vulnerable to corrosion.
- Carbonation of concrete surfaces can absorb 33% to 57% of the CO_2 produced during the calcination process of cement over a 100-year lifecycle.
- LWC mixtures yielded lower carbonation than NWC – despite their same strength rank.
- Superiority of LWC in terms of carbonation level is attributed to the lower w/c needed to achieve the required strength, and the lower "carbonatable" constituents (less cement) in NWC mixes, which increases their carbonation potential compared to LWC.

Mousa, Ahmad, Mohamed Mahgoub, and Mohab Hussein. "Lightweight concrete in America: presence and challenges." *Sustainable Production and Consumption* 15 (2018): 131-144.

ABRASION RESISTANCE

- Abrasion resistance of depends on strength, hardness, and toughness of the cement matrix and the aggregates as well as on the bond between these two phases.

- Most LWA suitable for structural concrete are composed of solidified glassy material with a hardness comparable to quartz.

- LWA Resistance of to wearing forces is expected to be lower than that of a NWA, due to the former's porous nature. This is compensated by the outstanding bond on ITZ.

- LWC bridge decks that have been subjected to more than 100 million vehicle crossings, including truck traffic, show wearing performance similar to that of NWC.

- Ice abrasion of LWC demonstrated similar performance to that of NWC exposed to arctic conditions.

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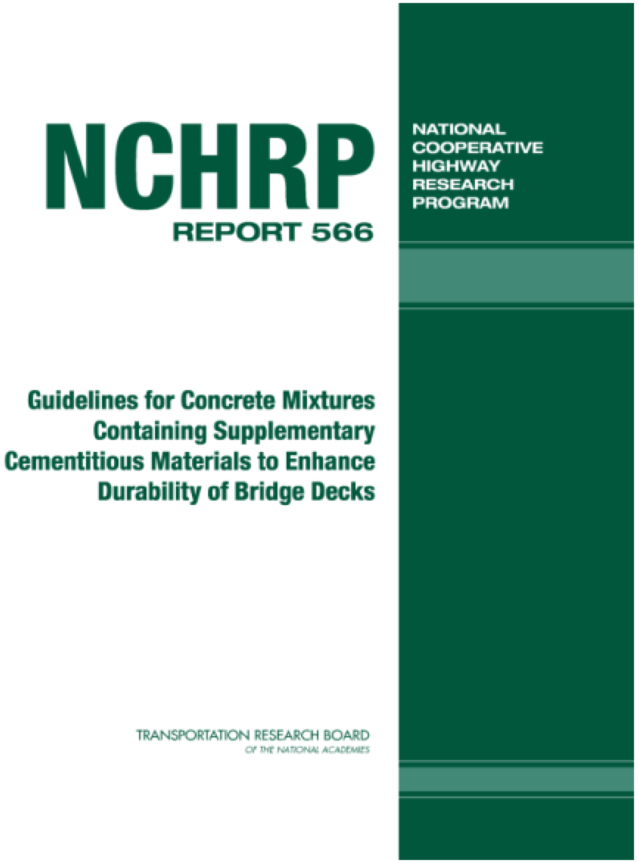
PART 2: SUSTAINABILITY GAINS OF LWC

ENERGY

- LWC can gradually save energy shares of intensive manufacturing industries due smaller structural elements and reduced cement and aggregate.

- Energy consumption can be further reduced by replacing cement with supplementary cementitious materials (SCMs).

- Every 1% replacement of cement with SCM can result in approximately 1% reduction in energy consumption per unit of concrete.



Source: Transportation Research Board

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LEED GAINS for LWC

Concentration	Maximum Points[1]	LWC Contribution Points
Integrative Project Planning and Design	1	-
Location and Transportation	16	-
Sustainable Sites	10	1[2]
Water Efficiency	11	1[3]
Energy and Atmosphere	33	1[2]
Materials and Resources	13	7[2]
Indoor Environmental Quality	16	1[2]
Innovation	6	1[2]
Regional Priority	4	-

- ❑ Most owners seem to be unaware of the benefits that LEED certification could bring them.
- ❑ LEED strategies can aid the property owners to decrease operating costs, obtain tax incentives, advance the efficiency of occupants, and improve lifecycle performance over the building service life.

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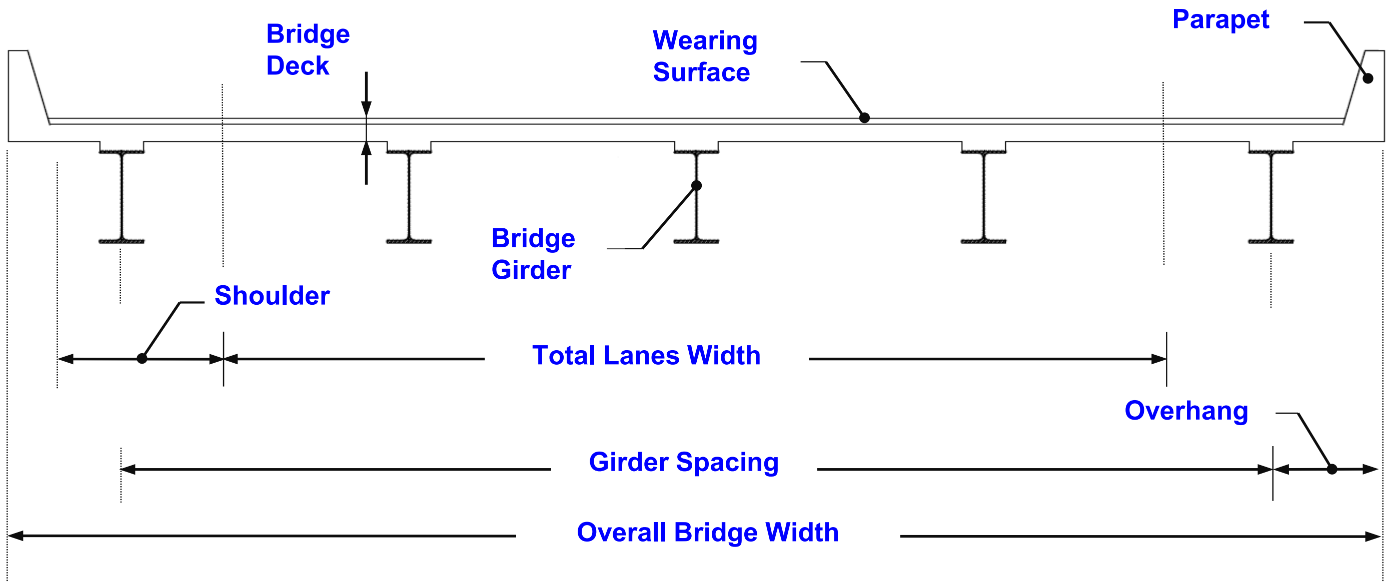
CASE STUDY



- ❑1.1-mile-long roadway crossing the Rahway River.
- ❑ The Rahway River is a navigable river used for commerce regulated by the United States Coast Guard (USCG).
- ❑ Total bridge length is 3,340-ft long and at 57.5 feet wide in North NJ.
- ❑ Located in tidally influenced and freshwater wetlands, saline marshes, contaminated site, aquatic environment, chemical and petroleum facilities, wildlife habitats, and threatened or endangered species.

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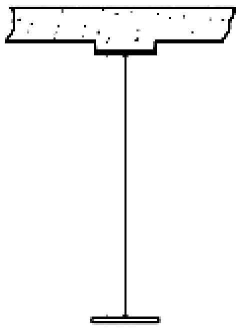
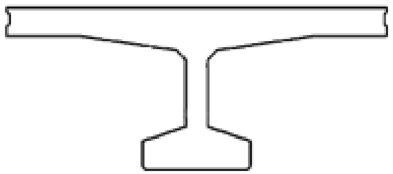
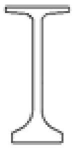
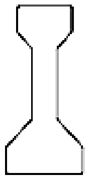
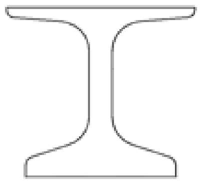
CASE STUDY: CONSIDERED ALTERNATIVES

Alternative	Description	Typical Superstructure Section
PPA	Steel Plate Girder with HPC Deck	
V1a	Steel Plate Girder with HPLWC Deck	
V1b	Steel Plate Girder with HPC Exodermic® Deck	
V1c	Steel Plate Girder with HPLWC Exodermic® Deck	
V2	HPSLWC Deck Bulb-Tees (DBT)	
V3	HPLWC Florida-I Beams (FIB) with HPLWC Deck	
V4	HPLWC AASHTO-PCI Bulb-Tees with HPLWC Deck	
V5	HPLWC AASHTO Prestressed Precast Girders	
V6	Nebraska NU2000 Pre-tensioned Prestressed Concrete Beam (PPCB) with HPLWC Deck	

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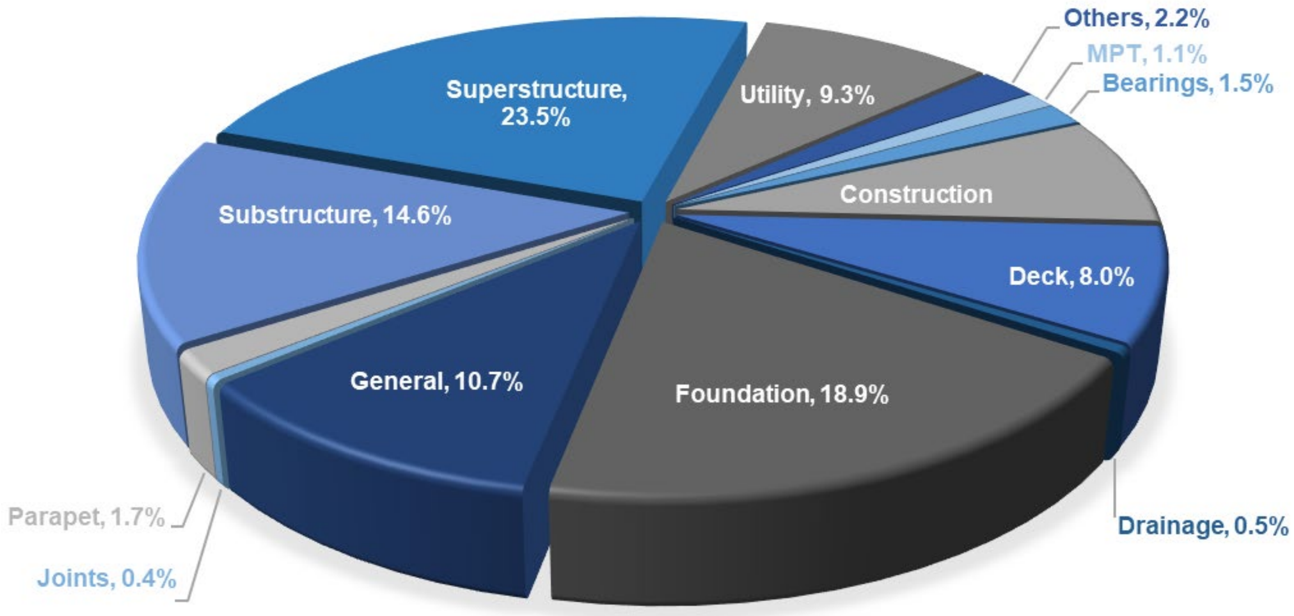
CAPITAL COST BREAKDOWN: BASE DESIGN

- ❑ 6-foot in diameter drilled shafts, socketed 15 feet into rock.
- ❑ Base Design/Preliminary Preferred Alternative (PPA) is made of 8 A709 50W steel plate girders steel plate girders with an overall beam depth of 78 inches
- ❑ 8-inch-thick reinforced high-performance concrete (HPC) deck slab with epoxy coated rebar.
- ❑ Fifty inches high heavy truck normal weight concrete (NWC) parapets.



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SUMMARY OF ANALYSIS

Alternative	PPA	V1a	V1b	V1c	V2	V3	V4	V5	V6
Deck Type	HPC	HPLWC	HPC Exodermic®	HPLWC Exodermic®	N/A	HPLWC			
Girder Type	Steel Plate Girder				HPLWC Deck Bulb-Tees (DBT)	HPLWC Florida-I Beams (FIB)	HPLWC AASHTO-PCI Bulb	HPLWC AASHTO Type VI	Nebraska NU2000 Beam
No. of Girders	8	8	8	6	10	6	6	8	7
Overall Depth (inches)	78	78	80	84	65	96	72	72	79
Spans	18	15	12	10	17	18	19	20	18
Max. Increase in Pier Load (%)	N/A	3%	-13%	-15%	-2%	13%	-12%	1%	6%
Max. Increase in Abut. Load (%)	N/A	11%	-6%	-7%	5%	**15%**	-3%	16%	**15%**

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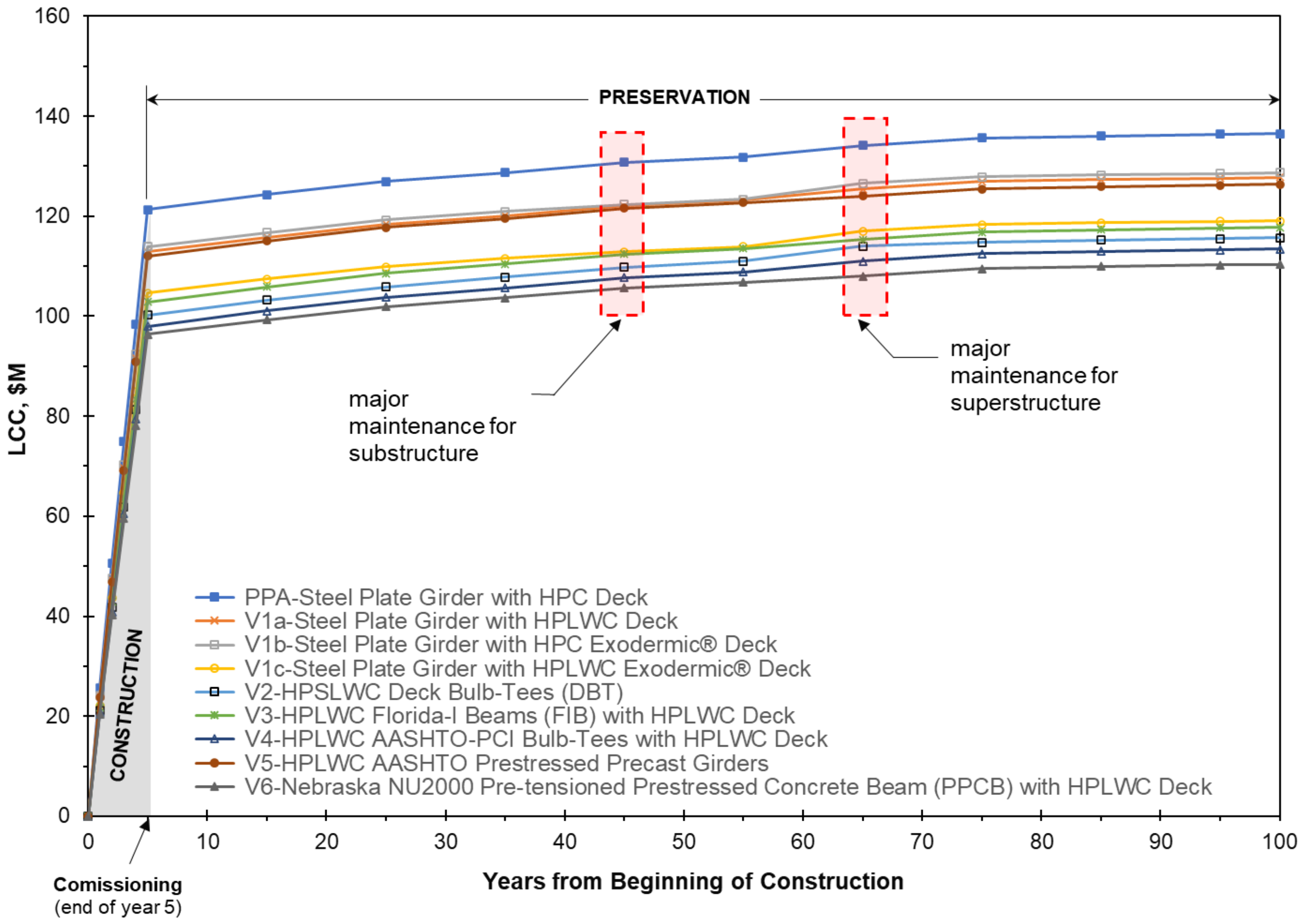
LIFE CYCLE COST (LCC)

- ❑ 2020 dollars as net present value (NPV).
- ❑ LCC (3% rate) in this study includes the initial construction and operational (inspection, preservation) costs over 100 years.
- ❑ Measurable increase at years 45 and 65 at which major maintenance takes place for the substructure and superstructure, respectively.



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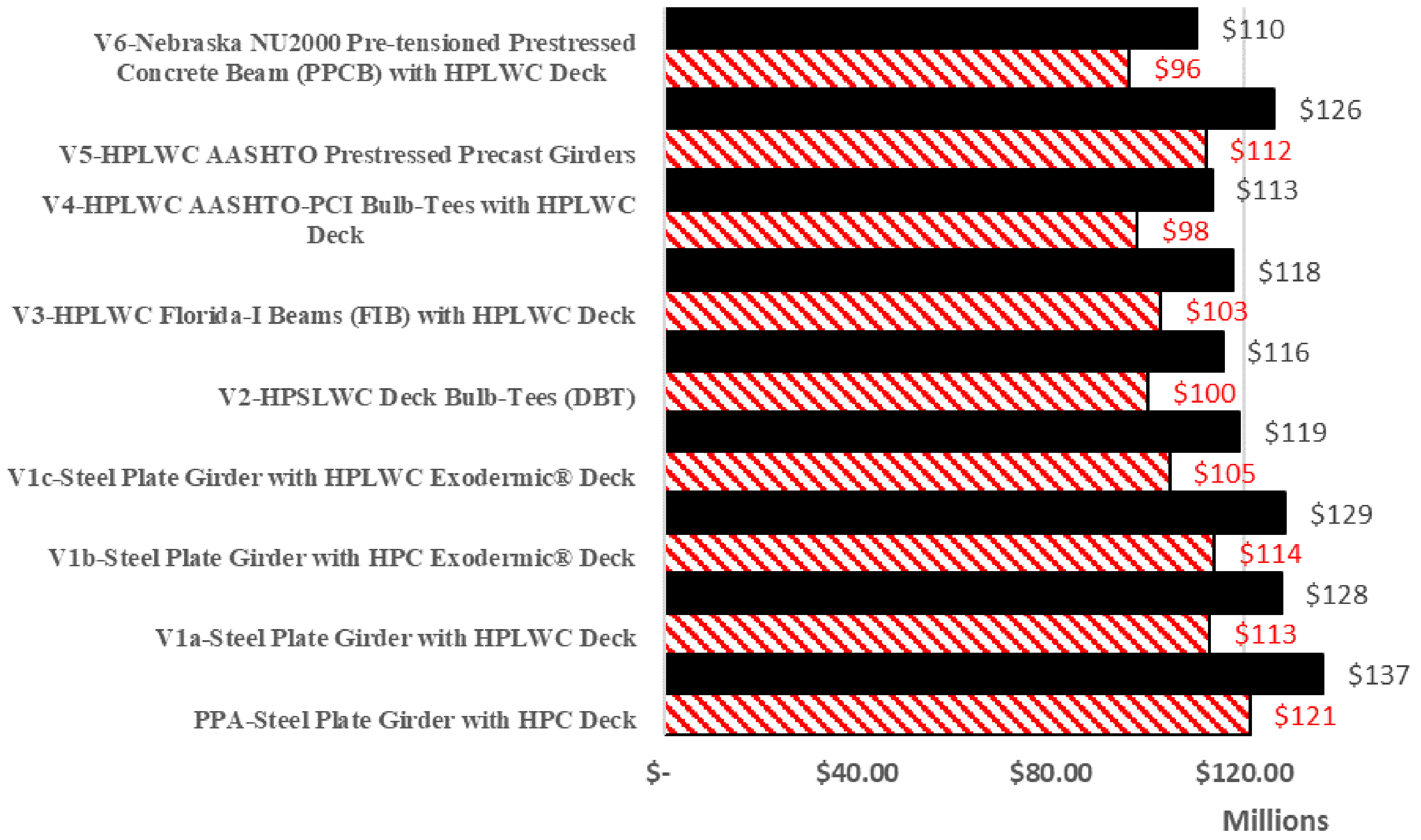
MONETARY SAVINGS

- All proposed alternatives have consistently shown less LCC than those of PPA over the 100-year period.

- Service life is expected to be 120 to 150 years with the suggested routine and periodical maintenance. Therefore, demolition, replacement, disposal, and salvage values were not included.



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VALUE INDEX

- Bridge designer tend to focus on monetary savings (To keep the client Happy).
- Value/ Performance capture non-monetary aspects:
  - Environmental impact
  - Constructability
  - Schedule
  - Road users' impact
  - Material savings
  - Load efficiency
  - Operational performance
  - Likelihood of acceptance

$$Value\ Index\ (VI) = \frac{Performance}{Cost} \times 100$$

- A relative value index (VI) was used as an unbiased measure for the selection of the optimal structural system.

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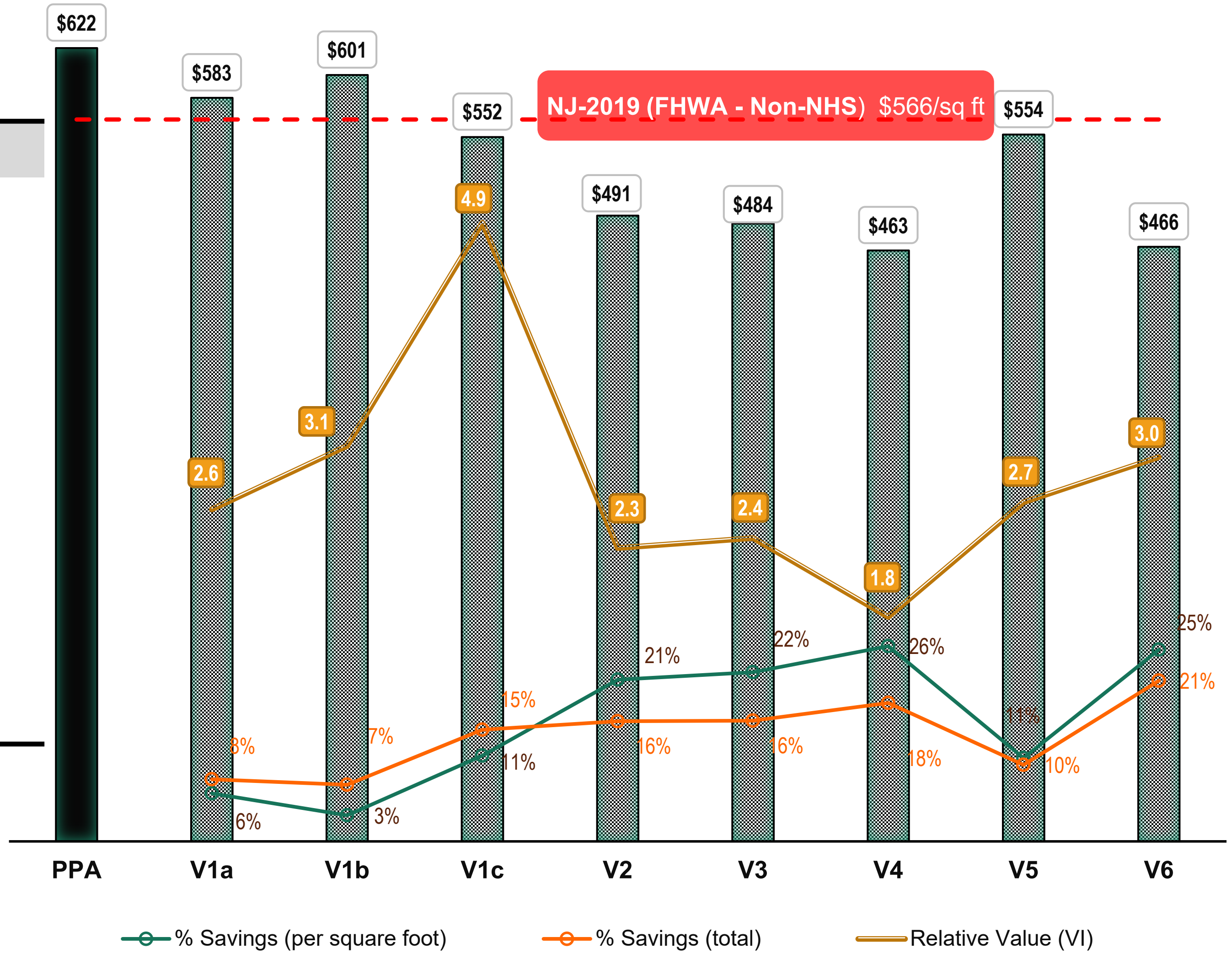
VALUE ENGINEERING STUDY

Alter.	Description
V1a	15 Spans of Steel Plate Girder with HSLWC Deck
V1b	12 Spans of Steel Plate Girder with NWC Exodermic® Deck
V1c	10 Spans of Steel Plate Girder with HSLWC Exodermic® Deck
V2	17 Spans of HSLWC Deck Bulb-Tees (DBT)
V3	18 Spans of HSLWC Florida-I Beams (FIB) with HSLWC Deck
V4	19 Spans of HSLWC AASHTO-PCI Bulb-Tees with HSLWC Deck
V5	20 Spans of HSLWC AASHTO Prestressed Precast Girders
V6	18 Spans of Nebraska NU2000 Pre-tensioned Prestressed Concrete Beam (PPCB) with HSLWC Deck



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HOW MUCH ARE WE REALLY SAVING?

Alter.	Description	Contaminated Soils	Steel	Concrete	Rock Sockets	CO_2	Energy
V1a	**15** Spans of Steel Plate Girder with HSLWC Deck	-12%	-1%	-3%	-13%	-3%	-2%
V1b	**12** Spans of Steel Plate Girder with NWC Exodermic® Deck	-26%	10%	-12%	-28%	-12%	1%
V1c	**10** Spans of Steel Plate Girder with HSLWC Exodermic® Deck	**-35%**	-12%	**-14%**	**-37%**	**-14%**	-13%
V2	**17** Spans of HSLWC Deck Bulb-Tees (DBT)	-3%	-77%	12%	-4%	12%	-43%
V3	**18** Spans of HSLWC Florida-I Beams (FIB) with HSLWC Deck	2%	-81%	19%	0%	19%	-43%
V4	**19** Spans of HSLWC AASHTO-PCI Bulb-Tees with HSLWC Deck	7%	-81%	13%	5%	13%	**-45%**
V5	**20** Spans of HSLWC AASHTO Prestressed Precast Girders	9%	-81%	23%	11%	23%	-42%
V6	**18** Spans of Nebraska NU2000 Pre-tensioned Prestressed Concrete Beam (PPCB) with HSLWC Deck	1%	**-82%**	14%	3%	14%	**-45%**

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SAVINGS ?

X Alt. V2: Saves of 497 Concrete Truck

X Alt. V1c: Saves emissions $\cong$ driving 235 million times around the earth

X Alt. 6: Saves $\cong$ 1.1 times the amount of steel in the Eiffel Tower

X Alt. 6: Saves energy $\cong$ 113 thousands houses for a whole year.

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PART 3: CURRENT MARKET OF LWC

LIGHTWEIGHT AGGREGATES (LWA)

- Aggregates account for 70–85% of the weight of concrete and amount to 5–10% of the cost of modern transportation projects.

- The properties and price of LWC are highly controlled by the availability of suitable LWA.

- Total amount of water that can be absorbed into the LWA to saturate the pores (typically 30%–35%) >> natural water available in aggregate at delivery (typically 5%–10%).

LWA AVAILABILITY AND COST

Type	Annual production¥	Price ($/ton)	Availability	Source
Common clays and Shale	12,000	36	38 States	Manufactured
Crushed glass aggregates	5,533	2	50 States	Byproduct
Scoria	2,700	7	12 States	Natural
Diatomite	920	10	4 States	Natural
Perlite	670	72	28 States	Manufactured
Pumice and pumicite	610	33	5 States	Natural
Vermiculite	220	916	11 Sates	Manufactured
Slate	43	12	6 States	Manufactured

¥ Thousands metric tons

LWA can be categorized to naturally occurring materials (e.g., scoria, diatomite, pumice and pumicite, slag stone, etc.), manufactured aggregates (e.g., common clay, perlite, vermiculite, slate, shale, etc.), industrial byproducts (e.g., recycled glass, cinders, fly ash, etc.), and lightweight synthetic particles (LSP).

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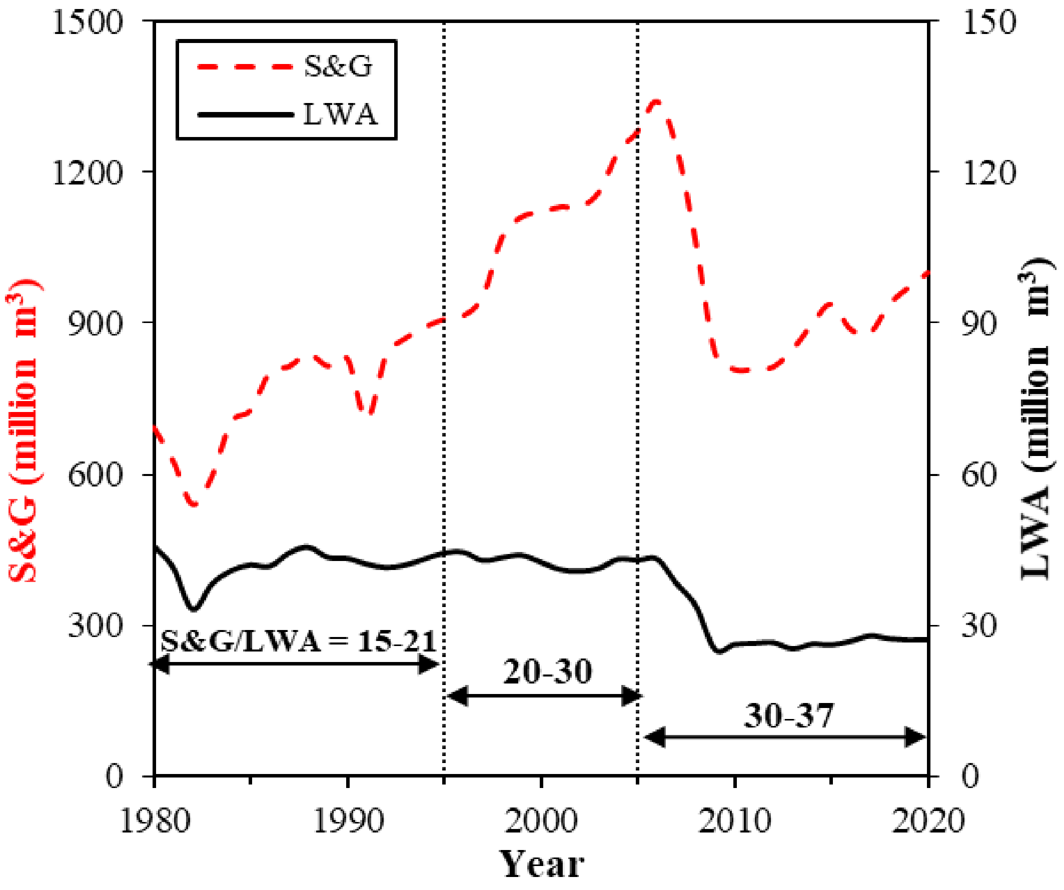
RATIO OF SAND & GRAVEL TO LWA PRODUCTIONS

- The ratio of S&G to LWA productions has gone through three phases over the last 40 years.
- Between 1975 and 1995 the ratio was 15–21 and increased to 20–30 between 1995 and 2005.
- The ratio increased again to 30–36 in favor of S&G in the last decade, thus signifying the stagnation of LWA production.



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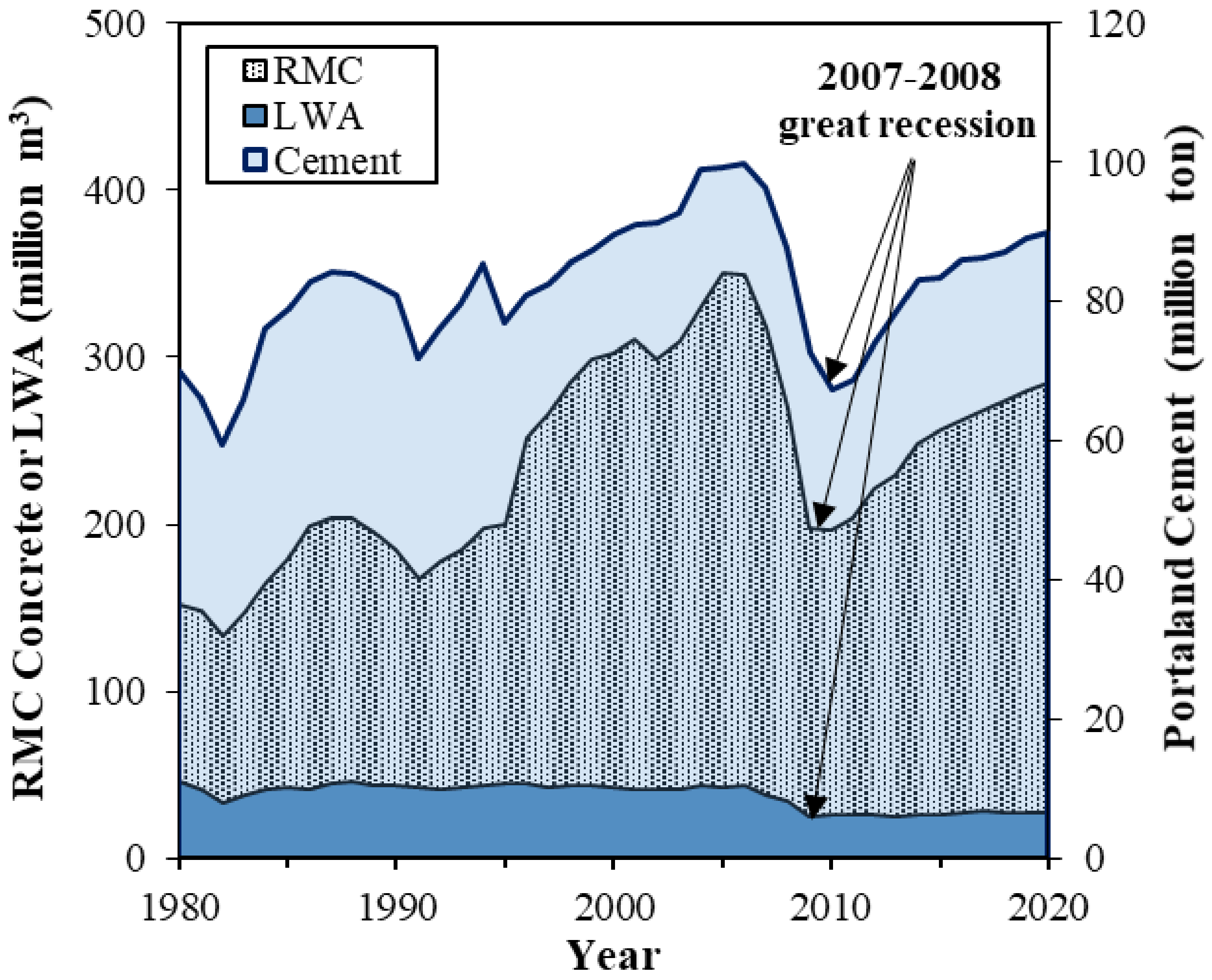
ANNUAL PRODUCTION OF LWA VS. CEMENT AND RMC



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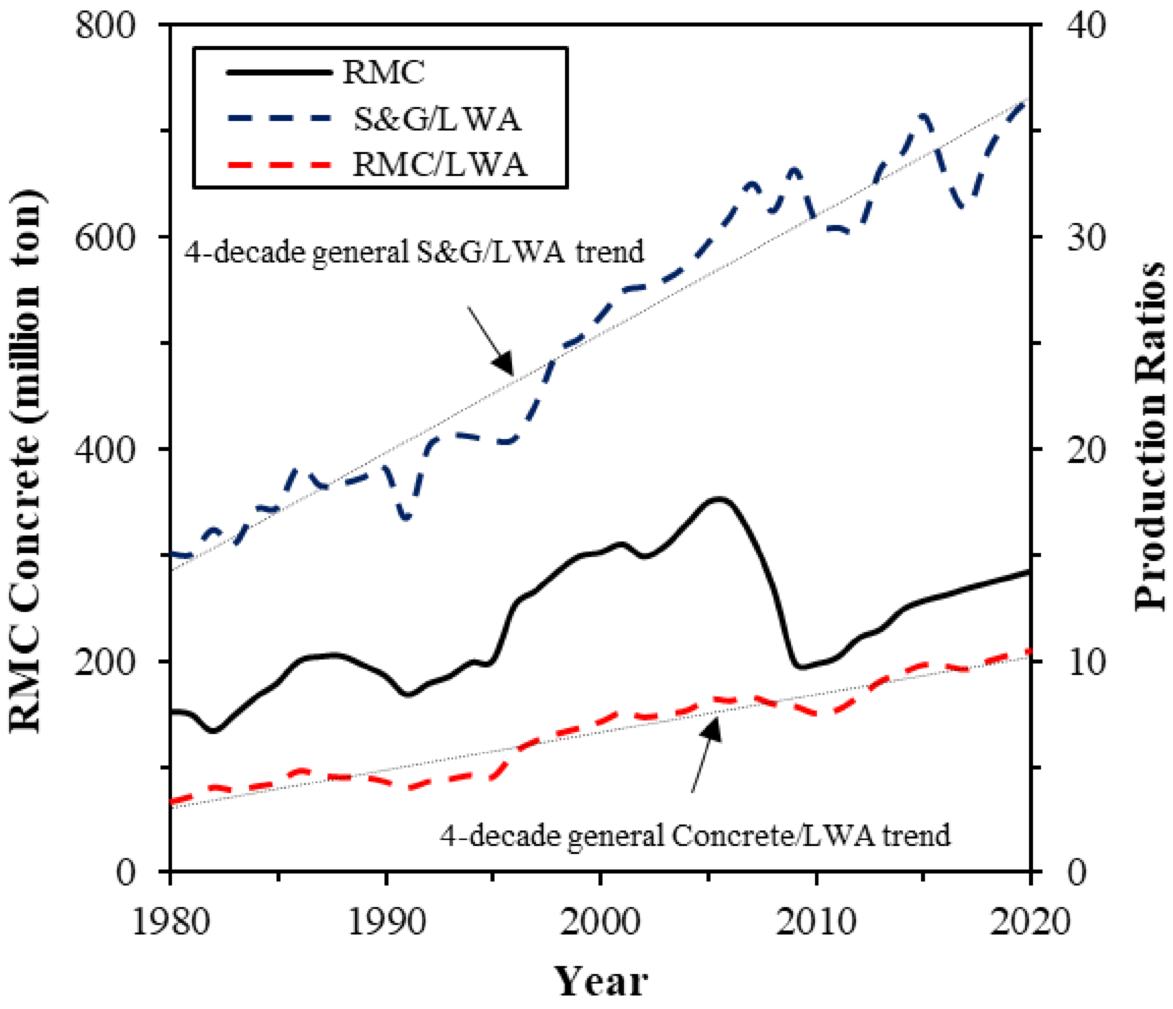

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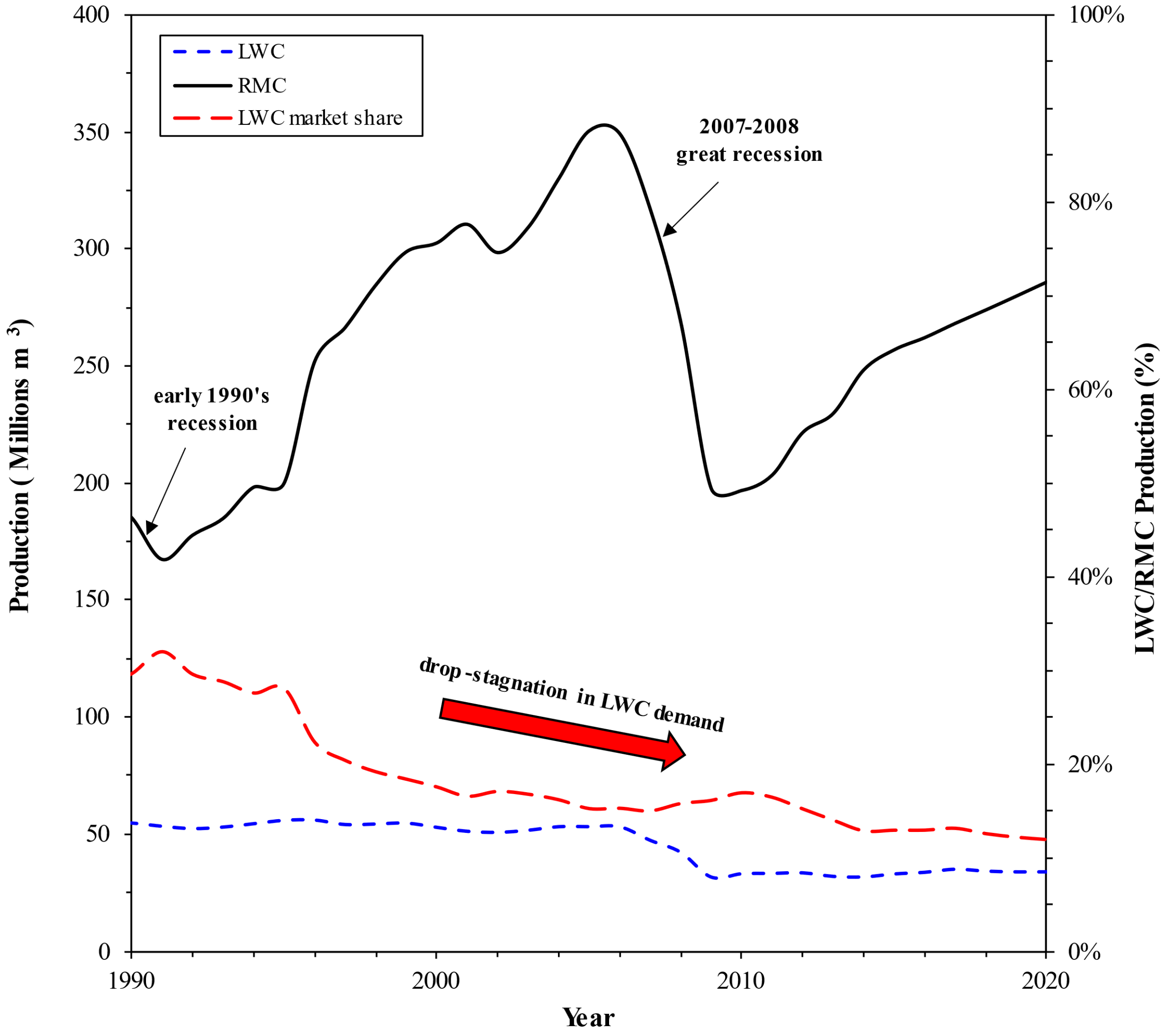
ESTIMATION OF LWC PRODUCTION

- No data!!
- LWA were used to estimate the representative production of LWC.
- Calculated LWC market share has dropped from approx. 30% in 1990 to merely 12% in 2019 on average.
- True market share is believed to be even smaller due to unavailable data on precast concrete and site-mixed concrete.



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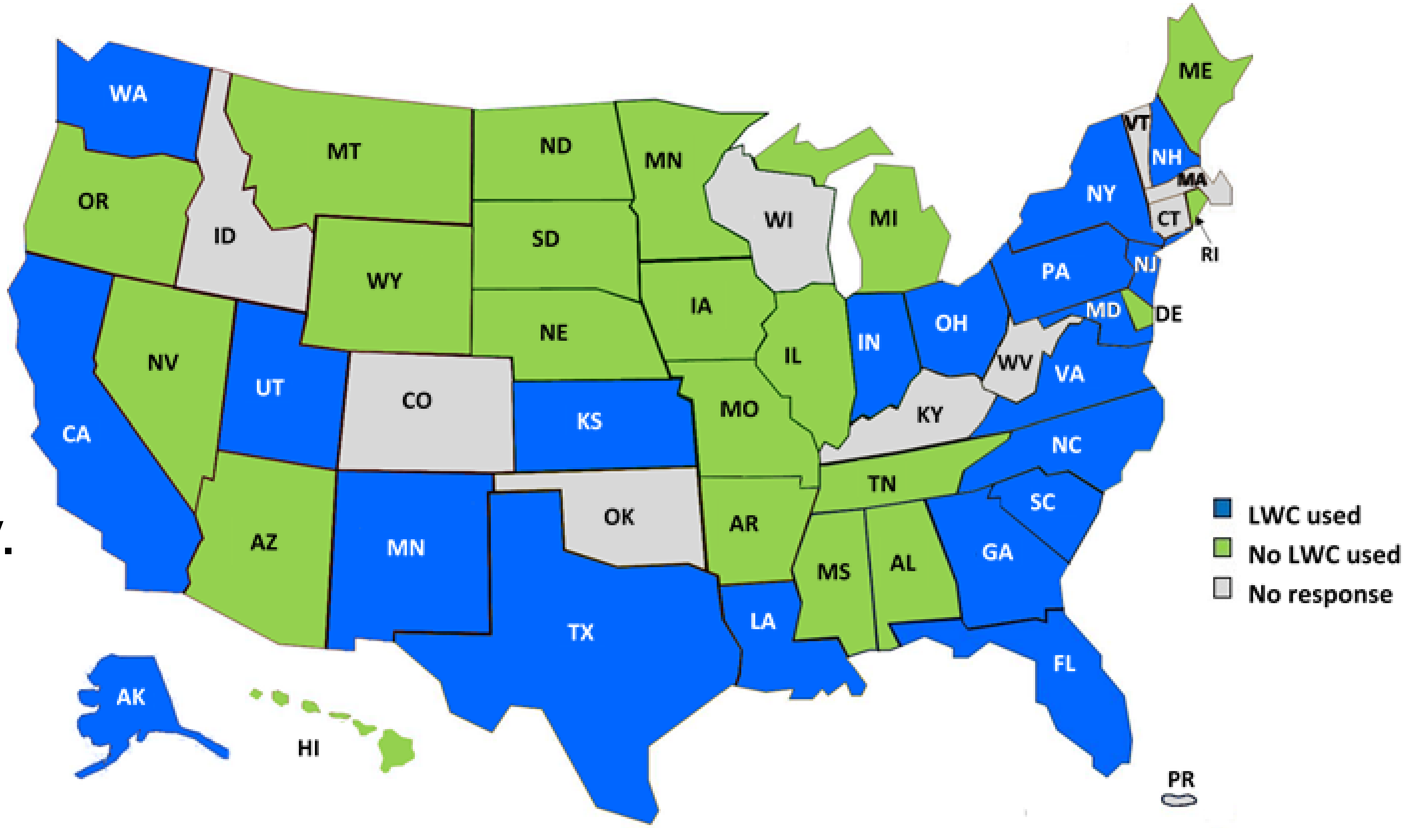
LWC BRIDGES IN USA

- Distribution of LWC bridges is indicative of the geographic interest.
- 228 LWC deck bridges (15 states) were constructed.
- Two states have used LWC prestressed girders (Virginia and Alaska)
- 33 LWC girders bridges (13 in Alaska and 20 in Virginia).

- Updated after NCHRP 733 Study.



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NOTABLE LWC BRIDGES IN U.S.

Bridge	State	Year	Length (ft)	Max. Span (ft)	Replacement Type
Governor William Preston Lane Jr. Memorial Bridge EB	MD	1952	21,279	1,600	Full
Coronado Bridge	CA	1969	11,179	660	Full
Governor William Preston Lane Jr. Memorial Bridge WB	MD	1973	21,051	1,500	Full
Antioch Bridge	CA	1978	9,437	460	Full
Parrotts Ferry Bridge	CA	1979	1293	640	Full
Arthur Ravenel Jr. Bridge	SC	1991	16,450	800	Deck
Brooklyn Bridge	NY	1999	5,989	1,596	Full
Neuse River Bridge	NC	1999	10,560	3,200	Superstructure
James River Bridge Restoration	VA	2002	4,185	415	Full
Benicia-Martinez Bridge	CA	2007	8,976	528	Full
Sam White Bridge	UT	2011	354	177	Emergency Repair
Skagit River Bridge	WA	2013	160	757	Deck
Thaddeus Kosciusko Bridge (I-87)	NY	2013	764	550	Full
I-40 Bridge	TN	2015	2,411	312	Deck
Pulaski Skyway	NJ	2016	18,491	550	Full

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NOTABLE LWC BUILDINGS

Project	State	Year	Floors	Height (ft)	Total footage (sq.ft.)
One Shell Plaza	TX	1971	52	714	1,300,000
North Pier Apartment Tower	IL	1991	61	581	550,000
Bank of America Corporate Center	NC	1992	60	871	1,400,000
First National Center	NE	2002	45	633	730,000
Goldman Sachs Tower	NJ	2004	42	781	1,600,000
Comcast Tower	PA	2008	60	**1176**	1,399,997
Duke Energy Center	NC	2010	48	786	1,500,000
Panasonic Headquarters	NJ	2013	20	unknown	340,000
Prudential Tower	NJ	2014	20	313	744,000
Wilshire Grand Center	CA	2017	73	**1100**	1,500,000

Project	Location	Year	Floors	Height (ft)	Total footage (sq.ft.)
Standard Bank Centre	Johannesburg, South Africa	1968	39	456	322,917
Central Square Building	Sydney, Australia	1972	26	302	Unknown
Guy's Hospital (400 beds)	London, England	1974	34	488	Unknown
Picasso Tower	Madrid, Spain	1988	51	515	1,302,000
Guggenheim Museum Bilbao	Abando, Spain	1997	3	187	350,000
CityLife Residential Buildings	Milan, Italy	2013	13	194	409,029

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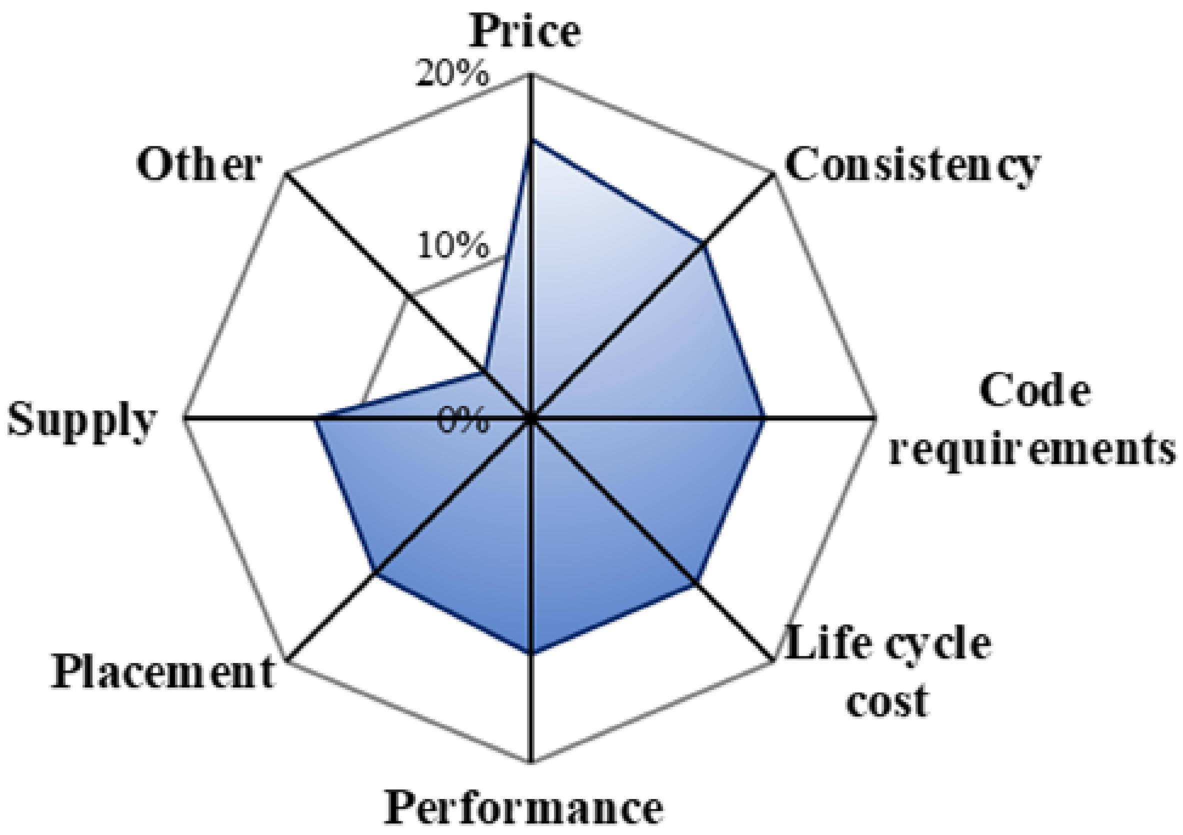
PART 4: PRIME BARRIER FACING LWC

LWC PERCEPTION

Survey from a broad spectrum of stakeholders with a total of 517 participants from the entire country.

- ❑ Concrete Suppliers
- ❑ Manufacturers
- ❑ Structural Engineers
- ❑ Architects
- ❑ Concrete Contractors
- ❑ LWA Suppliers



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Code Adherence

High Lifecycle cost

Insufficient Supply

Low Structural Strength

Unsuitable in Cold Weathers

Constructability

Performance Inconsistency

Inadequate Durability

Increased Delamination

Difficult to Finish

Pumpablility Issues

Very Expensive

CONSTRUCTABILITY

Shipping and Handling:

- ❑ Increase the beam length up to 25%.
- ❑ Reduce the load up to 30% (even more for Strength IV Limit State, 37%).
- ❑ Permits and escort vehicles are typically required for beams longer than 120 ft and/or heavier than 80 kips.
- ❑ Increase the load radius and/or decrease crane capacity.

Field Splices:

- ❑ Reduce the number of splices and/or temporary support.

Precast vs Cast-in-place:

- ❑ Accelerated Bridge Construction (ABC)

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PUMPABILITY

- Pumping LWC is often being considered problematic by contractors due to a range of factors, including inconsistent mixtures, slump loss, segregation, and the need for excessive pump pressures.

- Bringing the LWA to its saturated surface dry condition (SSD) prior to mixing typically requires a minimum of 24 h of presoaking to minimize most pumping issues of LWC.

- Pumping structural LWC could be as efficient as that of NWC in any project with a record height of 1,030 feet (approx. 314 m).

- Excessive mixing water can enhance pumpability but can cause segregation.

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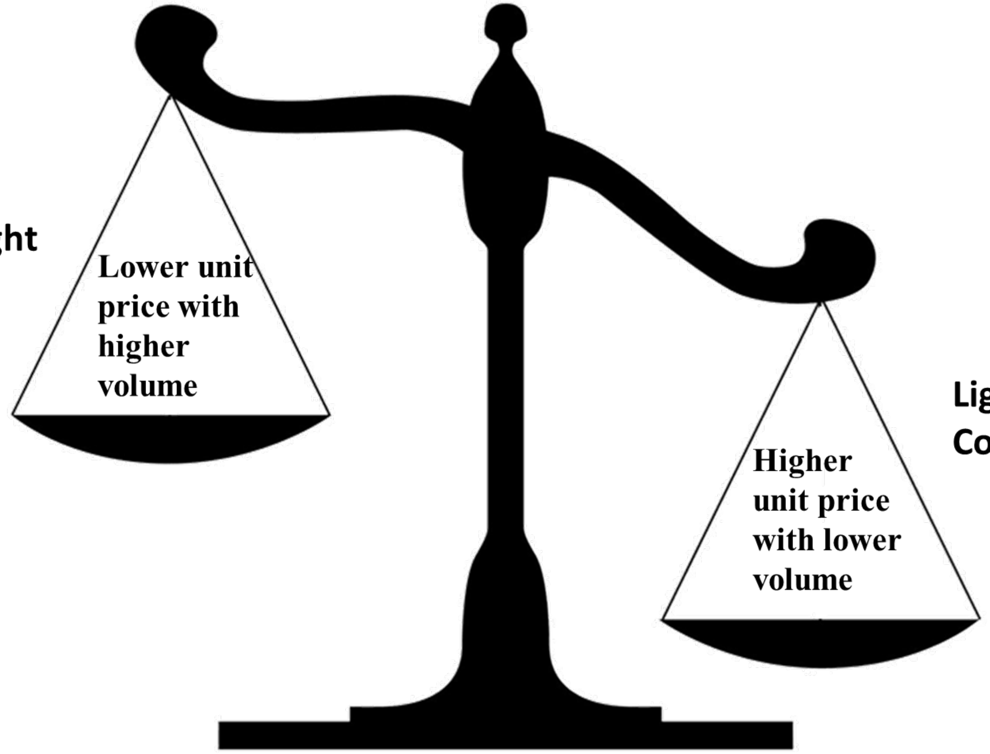
UNIT PRICE VS TOTAL PRICE

Lower Unit Weight → Less Dead Load → Smaller Members → Less Volume → Less Total Cost

Normal Weight Concrete



Lightweight Concrete

COLD WEATHER CONCRETING

- Presoaking of aggregate is clearly a major concern in the winter season.
- Freshly mixed LWC loses heat more slowly compared to NWC.
- Some LWC are still susceptible to damage from surface freezing when exposed to cold temperatures.
- The lack of experience of many contractors and ignoring LWA presoaking requirements were found to be the most common reasons behind the claimed unsuitability of LWC in cold weathers.

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STRENGTH

- Structural LWC is about as strong as NWC, which together with the reduced weight allows builders to place smaller columns and footings.

- Compressive strength values for LWC can reach above 8,000 psi (55.2 MPa), and up to 83 MPa (12,000 psi).

- A mixture reaches its strength ceiling when it possesses a slightly higher strength with a higher cement content. Reducing the maximum size of coarse aggregate can increase the strength ceiling (max comp. strength).

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PERMEABILITY AND DURABILITY

- ❑ Reduced permeability by stronger aggregate/cement paste bond induced by the porous nature of LWA.

- ❑ Improved durability by prolonged cement hydration driven by the increased moisture absorbed in LWA (internal curing).

- ❑ Lower coefficient of expansion of LWC reduces thermal cracks.

- ❑ Increased tensile strain capacity and reduced early drying shrinkage.

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GOOD PRACTICES

- Proper material selection and evaluation, adequate mix design, and high-quality workmanship.

- Technical and practical misconceptions about LWC stem from the partial understanding of a few but critical aspects of this material.

- Consistency of the batched LWA is difficult to control, particularly if aggregate is obtained from different sources. Routine characterizations and QC on the LWA at site is of great importance to account for absorption variation and to control the mechanical properties of the produced concrete.

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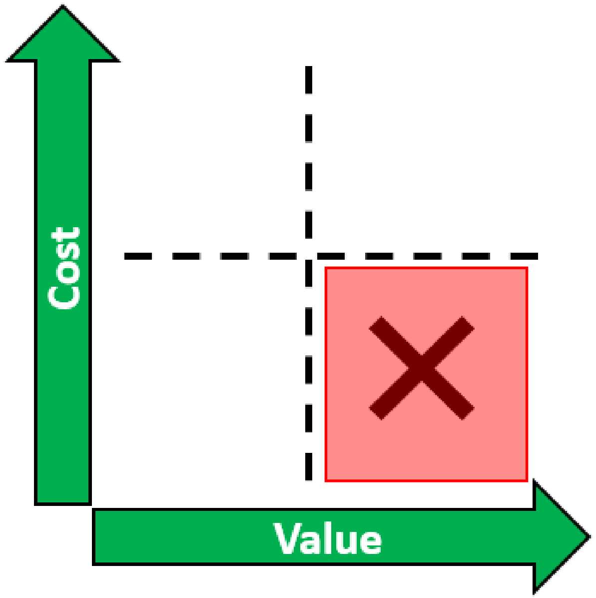
VALUE vs COST

- ❑ Imperative to distinguish between value and cost in assessing alternatives.

- ❑ Value is a measure of worth and observing the return on investment.

- ❑ Value is typically captured or perceived as a direct monetary gain.
- ❑ The value (worth) are subject to the liking and interest!

- ❑ The dollar amount of the environmental and ecological impact, resource depletion, aesthetics, and quality of life (e.g. road user cost, noise) is often unaccounted for.



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DECISION-MAKING CULTURE

- Minimum content recycled or recyclable, natural or renewable materials including the environmental impacts to produce and transport of the material.
- Bridge design engineers are typically oblivious to the importance of the environment, sustainability aspects and conservation of natural resources. They are by default concerned with technical aspects of the structural design. In this context, environmental bridge design merely abides by the required environmental permits and adheres to current regulations.

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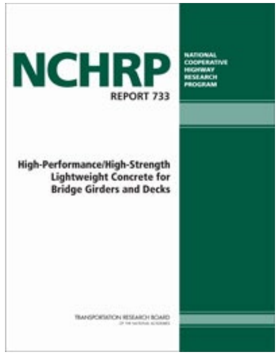
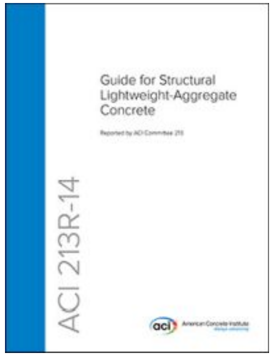
SUGGESTED REFERENCES

- ❑ NCHRP 733: High-Performance/High-Strength Lightweight Concrete for Bridge Girders and Decks

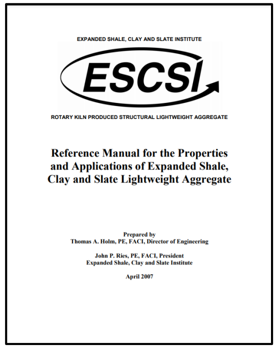


- ❑ ACI PRC-213-14 Guide for Structural Lightweight-Aggregate Concrete

Source: American Concrete Institute



- ❑ ESCSI's Reference Manual for the Properties and Applications of Expanded Shale, Clay and Slate Lightweight Aggregate



Source: Expanded Shale, Clay And Slate Institute (ESCSI)

Poll Question 3

Would you consider using/recommending LWC in projects?

a) Definitely No

b) Probably No

c) Neutral (Neither Yes nor No)

d) Probably Yes

e) Definitely Yes

Q/A SESSION

Any Questions?

?

THANK YOU!

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Today’s Panelists
#TRBWebinar

Moderator: Mohamed Mahgoub, *New Jersey Institute of Technology*

Ahmad Mousa, *Monash University Malaysia*

Mohab Hussein, *New Jersey DOT*

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