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SAND • CEMENT
Back to Basics
WATER • AGGREGATE

2024 FALL CONVENTION

DENVER, COLORADO | OCTOBER 22-25, 2024

A Very Brief History of Time:

From Ancient Cementitious Materials to the Marvels of Modern Concrete

Presented by Jeremy Begley, PE

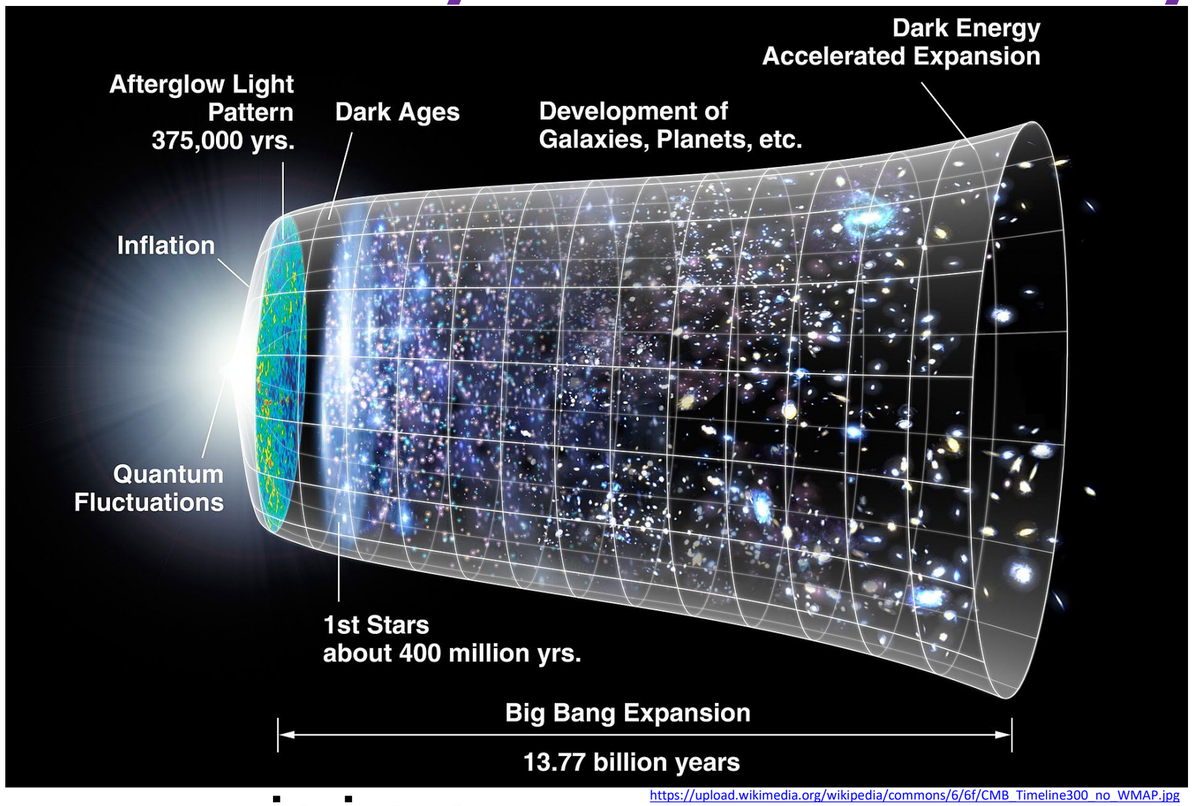
www.icri.org

Live Content Slide

When playing as a slideshow, this slide will display live content

Poll: What area of the repair industry do you represent?

A Very Brief History of Time



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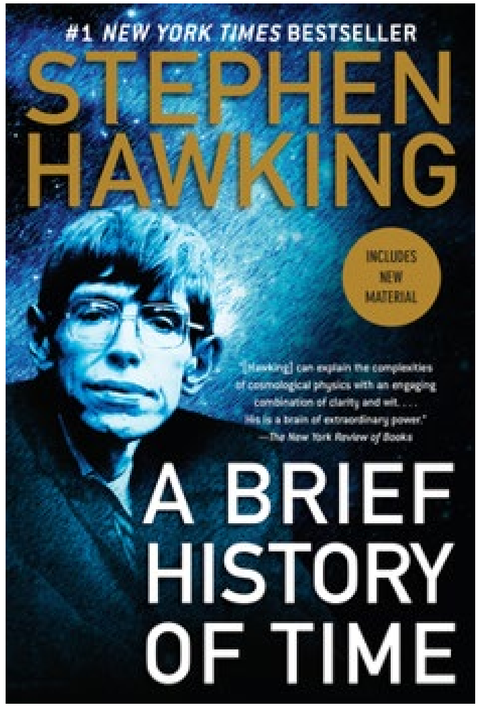

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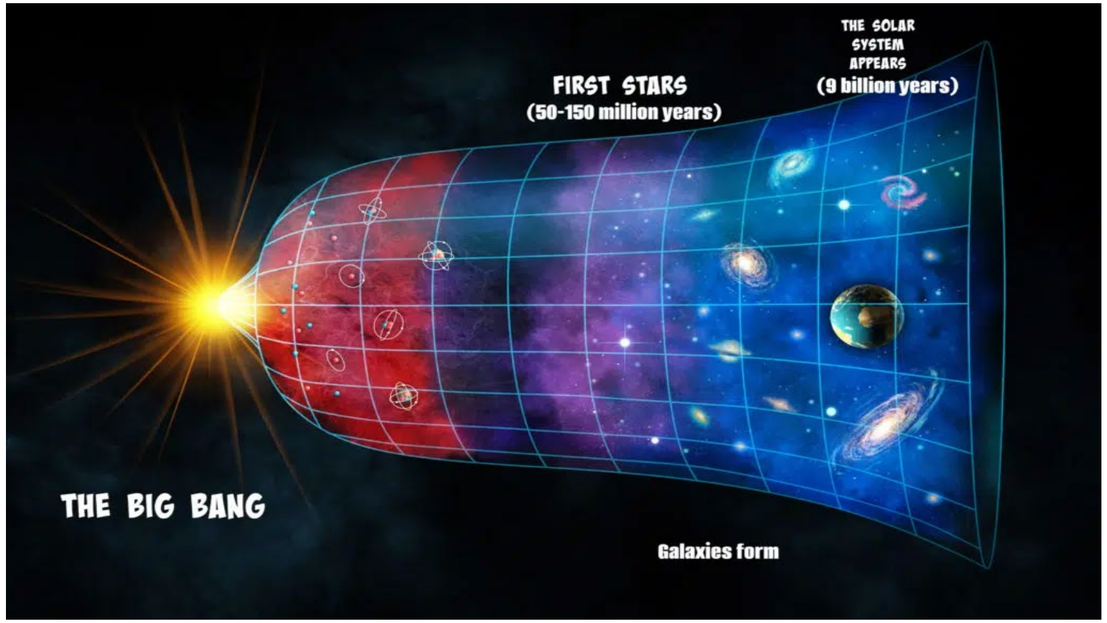

https://www.science-sparks.com/what-is-the-big-bang/

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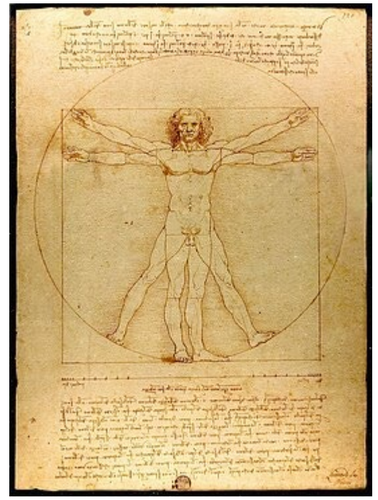

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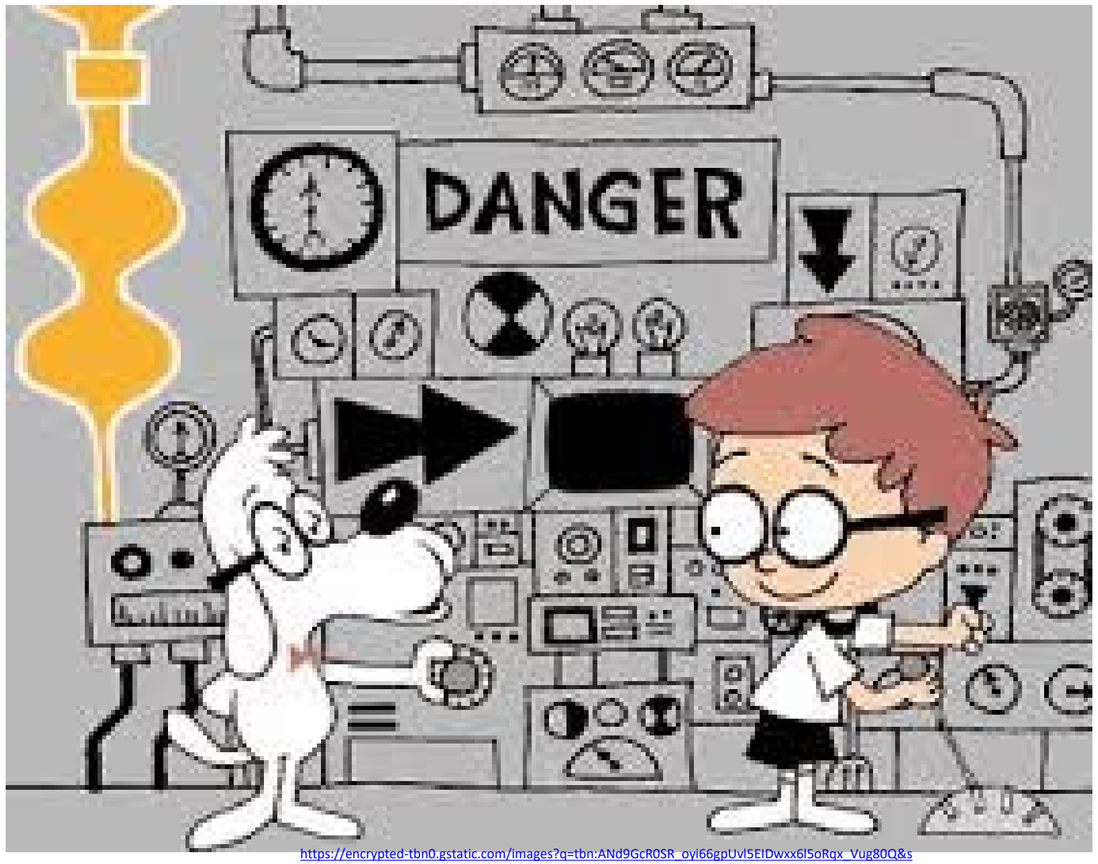

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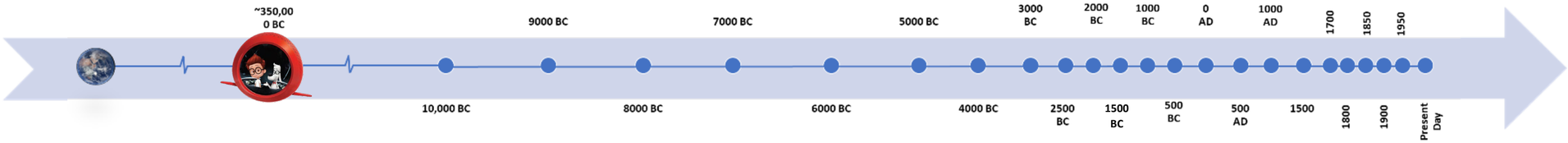

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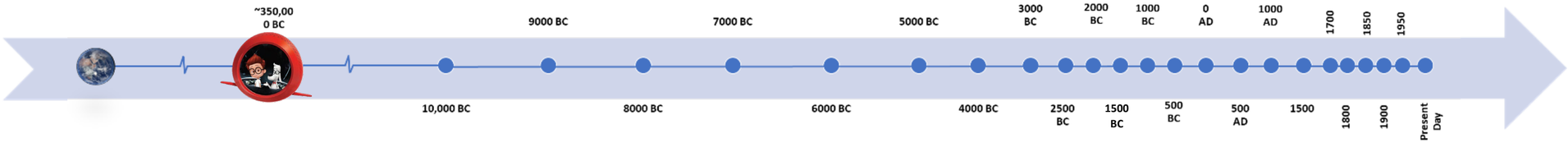

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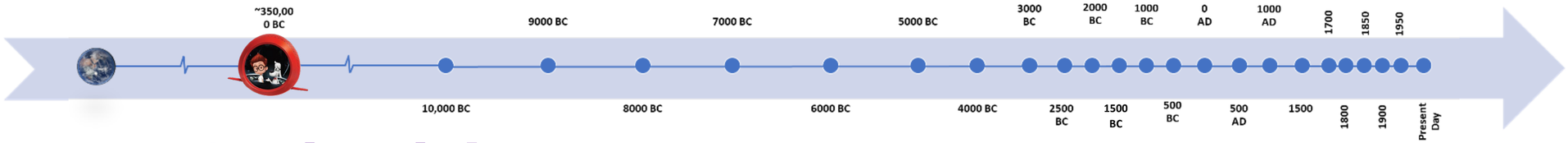
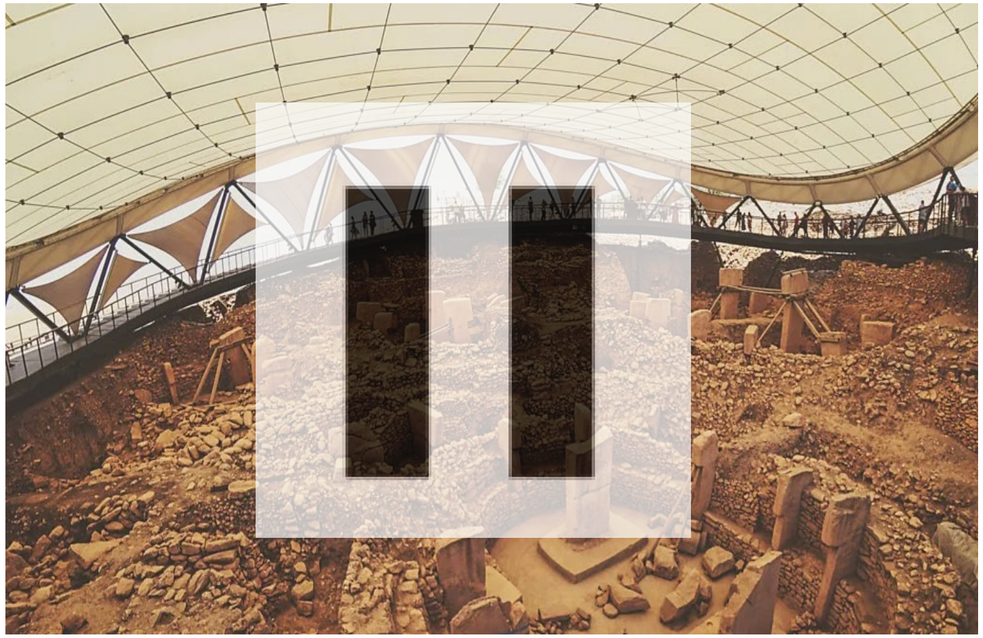
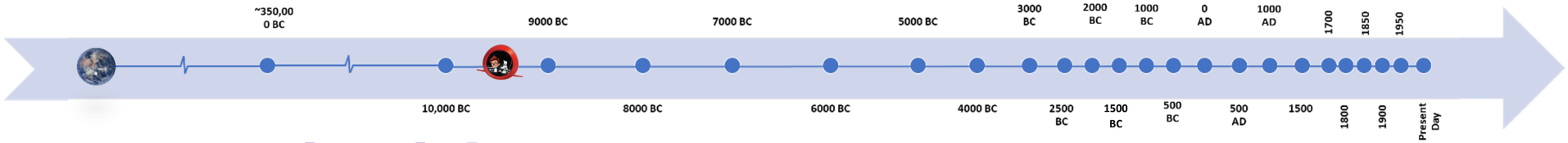


Gobekli Tepe Turkey: 10,000-9000 BC



https://www.bbc.com/travel/article/20210815-an-immense-mystery-older-than-stonehenge

https://www.smithsonianmag.com/history/gobekli-tepe-the-worlds-first-temple-83613665/



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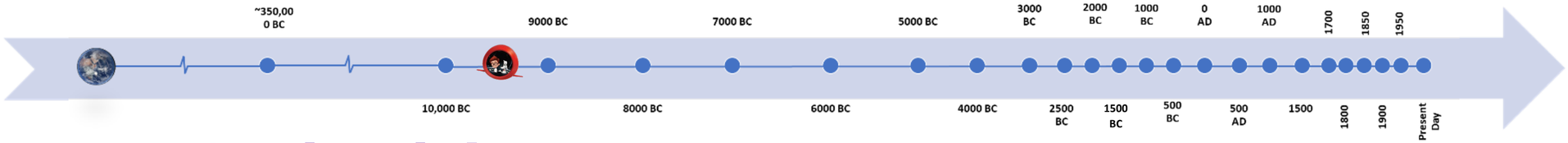
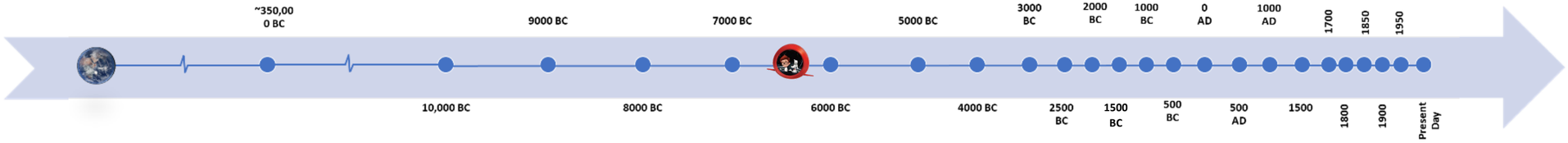


Gobekli Tepe Turkey: 10,000-9000 BC

- Gobekli Tepe
  - One of the world's oldest religious sites
  - Limestone structure
  - Neolithic Era
  - Predating Stonehenge by 6000 years
  - Lime mortar/plaster flooring

https://www.cambridge.org/core/journals/cambridge-archaeological-journal/article/geometry-and-architectural-planning-at-gobekli-tepe-turkey/2CBAF416E33AFE6496B73710A2F42FF9

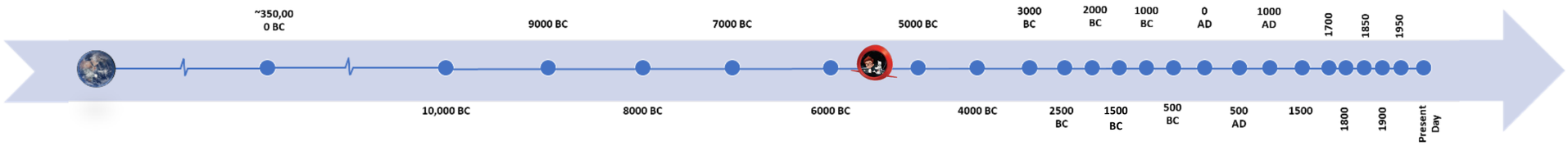


6500-3000 BC

~6500 BC

Middle East

- Mesopotamia / Syria region
- Limestone fire pits
- Accidental discovery of lime
  - Calcium oxide
- Lime kilns constructed for mortar
  - Rubble wall house construction
  - Concrete-like floors
  - Waterproof cisterns



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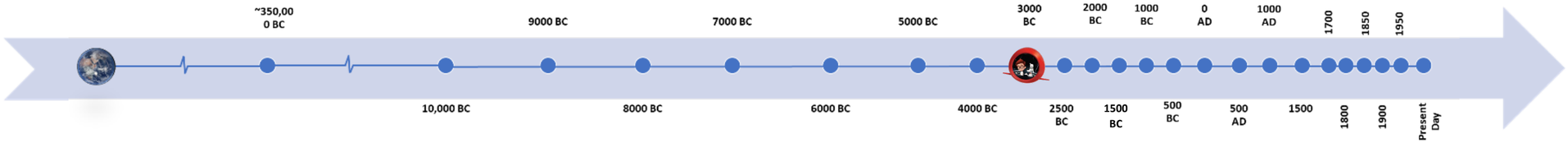
~5600 BC

Southern Europe

- Former Yugoslavia region
- Danube River
  - Lime cement deposit
- 10” early concrete floors in huts
  - Lime cement mixed with sand, gravel, and water
  - Similar mixture to modern concrete



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~3000 BC

China

- Northwest China
- Greenish/Black in color
- Concrete floors
  - Cement
  - Water
  - Sand
  - Broken pottery
  - Bones

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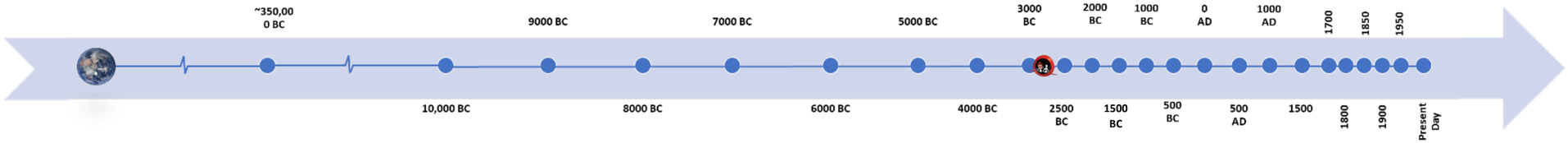
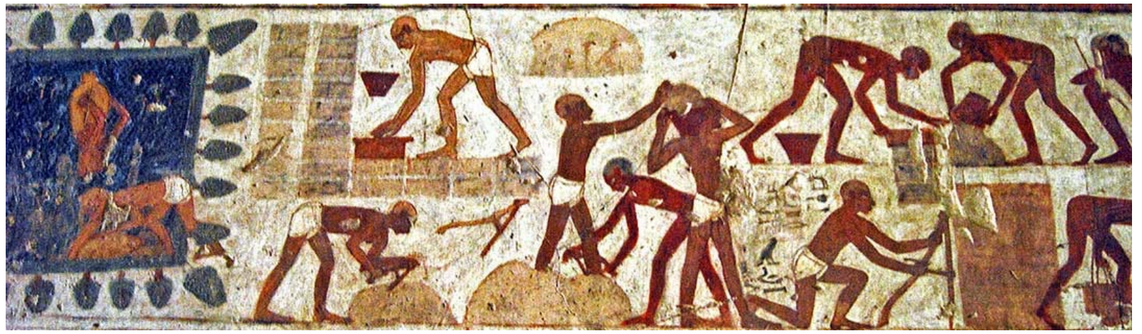


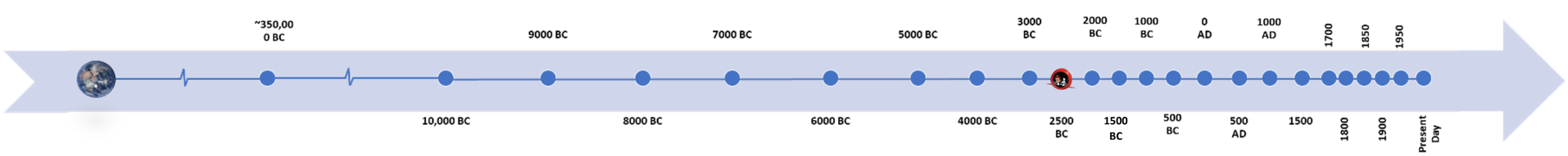
Egypt: 4300 – 2700 BC

- Ancient Egypt: Predynastic to Early Dynastic Era
  - Common building materials of this era
    - Bricks made with mud/straw

https://acropolis-wp-content-uploads.s3.us-west-1.amazonaws.com/mud-and-straw-bricks-1.webp



https://www.patternsofevidence.com/wp-content/uploads/2021/02/brick-making-rekhmire.jpg

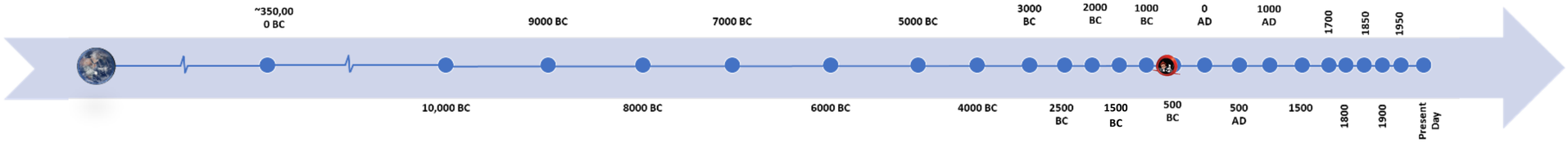


Egypt: ~2500 BC

- Old Kingdom Era
  - Limestone blocks
  - Concrete-like cementing materials
    - Burnt gypsum mortar
    - Lime concrete
  - Uppermost blocks may be cast-in-place
    - NSF studies using electron microscope
  - 1950 BC
    - Thebes mural depicting concrete mortar operation

https://www.thetimes.com/life-style/property-home/article/mystery-void-found-in-great-pyramid-of-giza-d002hr6kf

https://pita.ess.washington.edu/tswanson/wp-content/uploads/sites/9/2018/10/The-History-of-Concrete.pdf



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Greece: 600 BC

- Pozzolan Discovery
  - Santorini Island
  - Hydraulic properties when pozzolan mixed with lime
  - Ability to harden underwater
  - Protective coverings of walls of unburned bricks
- Pseudo-concrete
  - Rough broken stone held together with lime mortar and sand
  - Too weak for major projects

https://isabelbarrosarchitects.ie/blog/wp-content/uploads/2017/07/pozzolana.jpg

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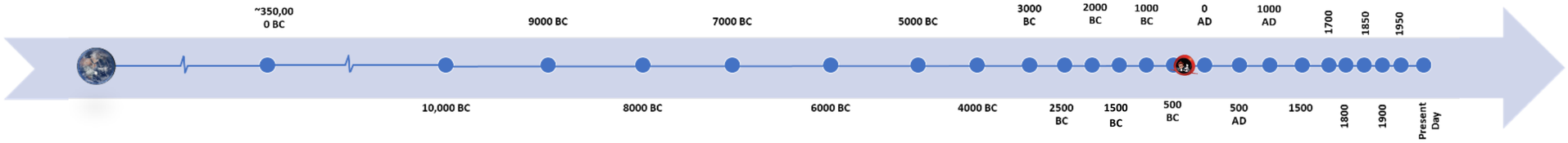

Rome: 300 BC

- 300 BC: First uses of Roman Concrete
  - Wall in Pompei
  - Similar chemical reaction to the Greeks
  - Sturdier concrete than Greek version
  - Submersion capability
  - Name derivation – Concretus
- Hydraulic Cement
  - Volcanic Ash & Lime
  - Ash found near Pozzuoli, Italy
  - Name Derivation: Pozzolanic Cement
- 75 BC: Further Examples
  - Theater at Pompei
  - Roman Baths
- Pozzolanic Concrete: Backbone of Roman Construction

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https://www.worldhistory.org/uploads/images/959.jpg

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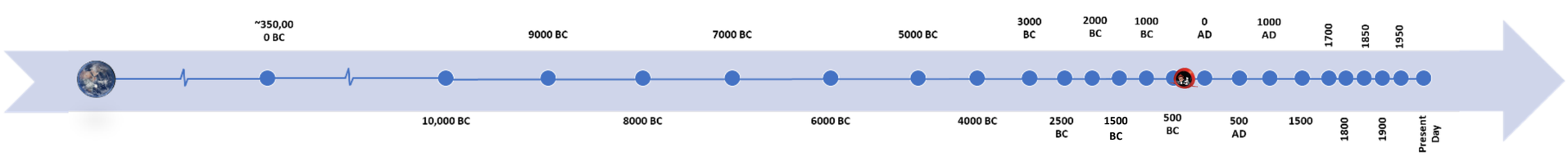

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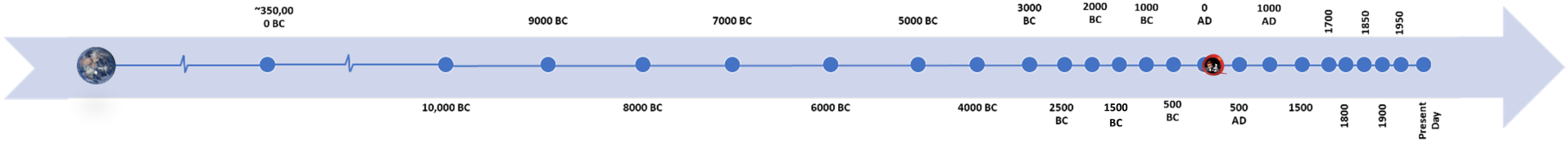
China: ~400-200 BC

- Great Wall of China
  - Begins between 400-220 BC
  - Continues through many centuries and dynasties to the 1600s
  - Built to defend against northern invaders
  - Early sections comprised of rammed earth, which are now mostly eroded away
  - Evolved into brick sections held together with inorganic/organic mortar
  - Lack of volcanic ash
  - Sticky rice mortar

https://www.wanderlustmagazine.com/wp-content/uploads/2023/11/5-1-scaled.jpg



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Rome: 200 BC - 476 AD

- Aqueducts / Bridges
  - Pont du Gard (France)
    - 40-60 AD
    - 3 stacked arch tiers
    - 11 million gallons of water/day over 31 miles
    - Later usage as toll bridge
  - Aqueduct Bridge of Segovia (Spain)
    - 98-112 AD
    - More concrete
    - Reduced arches with greater spans
    - 2 tiers
  - Later aqueducts
    - Tall slender piers
    - No stacked arches

Pont du Gard (40-60 AD)


Acueducto de Segovia
(98-112 AD)

Chabet Ilelouine (125-130 AD)

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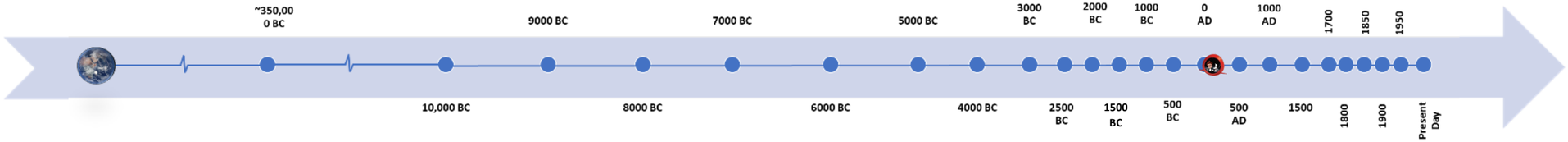

Rome: 200 BC - 476 AD

- Buildings
  - Colosseum
    - Iconic Amphitheater for variety of events
    - 80 AD
  - Pantheon
    - 126-128 AD
    - Massive unreinforced concrete dome
    - Remains largest of its kind today
  - Baths of Caracalla (Terme di Caracalla)
    - 212-216 AD
    - Large bath house with 1600-person capacity
    - Innovative heating and drainage/water supply


https://en.wikipedia.org/wiki/File:Colosseo_2020.jpg

Colosseum (80 AD)


https://www.italyromeguides.com/wp-content/uploads/2021/03/terme-di-caracalla-topolino.jpg

Baths of Caracalla (212-216 AD)

Pantheon (126-128 AD)

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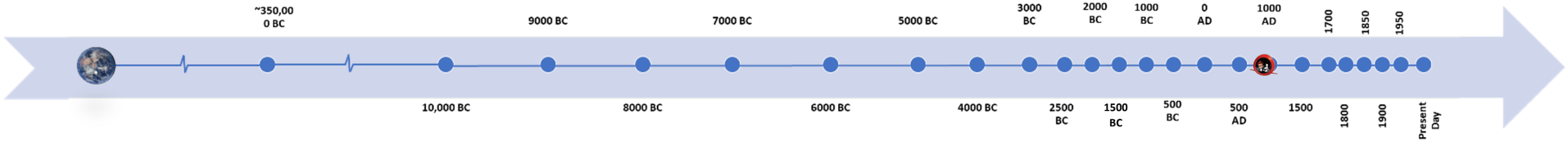

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Medieval Era: 476 – 1500 AD

- Fall of Roman Empire in 476 AD
- Decline in Concrete Use
  - Natural stone and lime cement mortar
- Roman Techniques Forgotten
  - Lost Concrete Mix Technology
  - Decline of Engineering Knowledge
- Rediscovery of Hydraulic Cement
  - Fortresses and Canals
- Gothic Architecture
- Outside Europe
  - Middle East & Asia

https://study.com/cimages/videopreview/videopreview-full/1apc97q1h0.jpg
Notre Dame Cathedral (1163-1260)

https://www.classicjourneys.com/wp-content/uploads/2021/07/ReplettImageServer-729.jpeg

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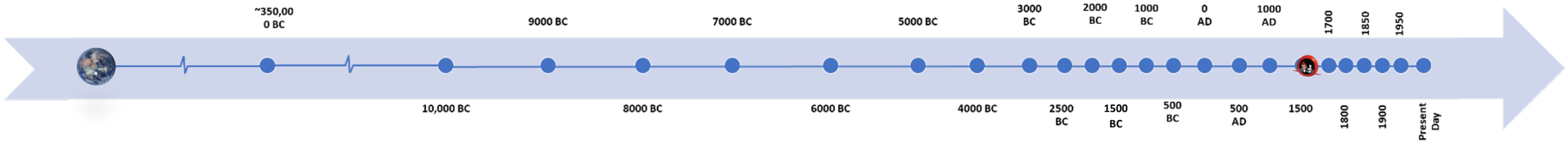

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The Renaissance: 1400 – 1600

- Revival of Roman Techniques
  - Rediscovery of ancient Roman texts
  - Particularly Vitruvius
- Pozzolanic Additives
  - Giovanni Giocondo
  - Experimented with recreating Roman concrete.
- Limited applications
  - Used but not prevalent
- Architectural Innovation
  - Classical Roman construction method applications

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St. Peter's Basilica (1506-1615)

Duomo di Firenze: Filippo Brunelleschi Dome (1420-1436)

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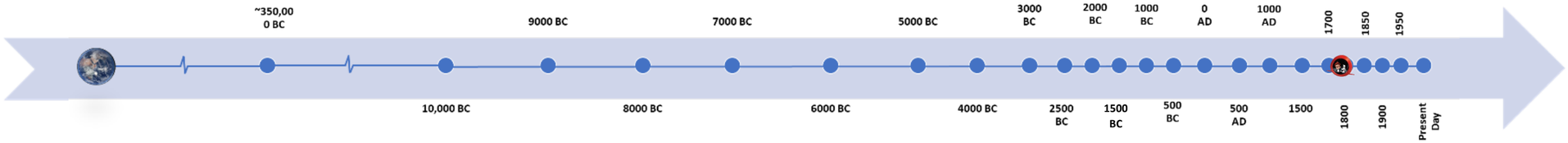

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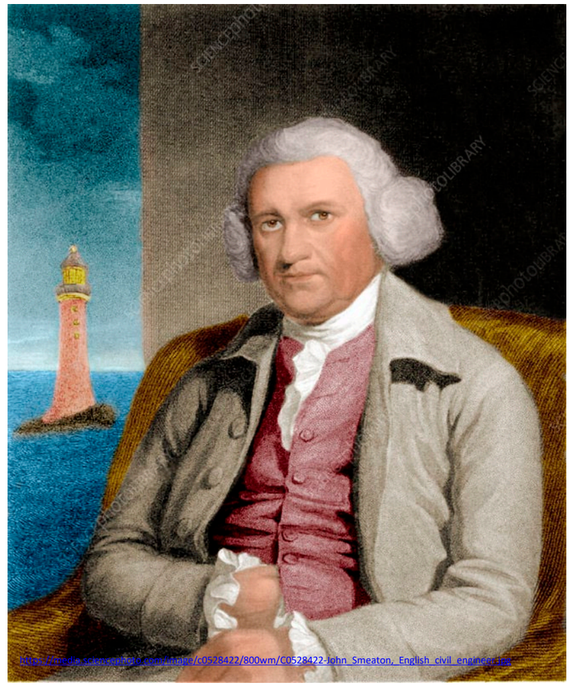
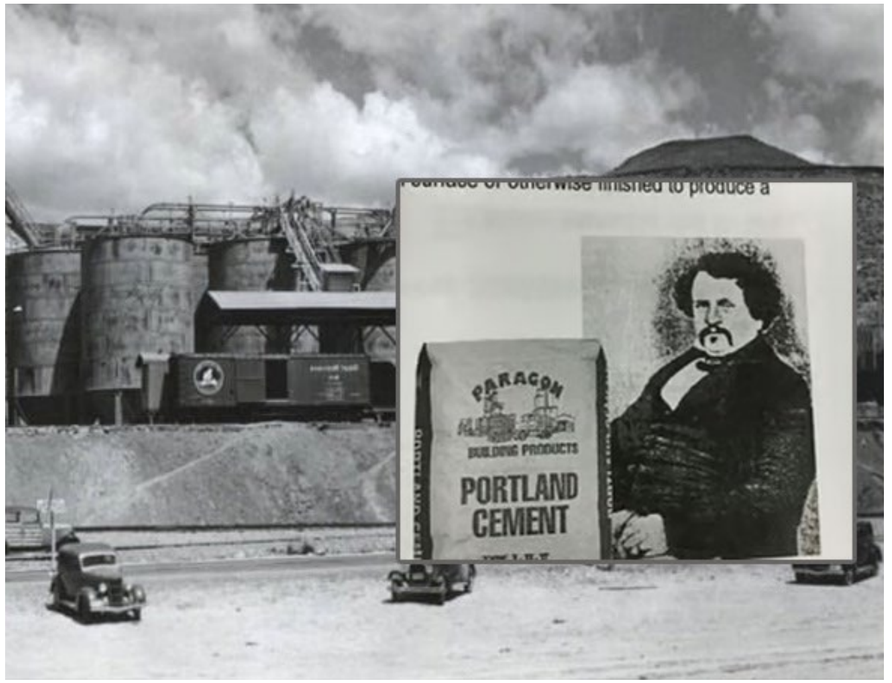
1st Industrial Revolution: 1750-1850

- John Smeaton (1759)
  - Reinvented hydraulic lime
  - Eddystone Lighthouse Rebuild
  - Limestone containing clay
  - Precursor to Portland Cement
- Joseph Aspdin (1824)
  - Father of Portland Cement
  - Heated mixture of limestone and clay
  - Most important ingredient in modern concrete
  - Large scale use possible



John Smeaton (1724-1792)



Joseph Aspdin (1778-1855)

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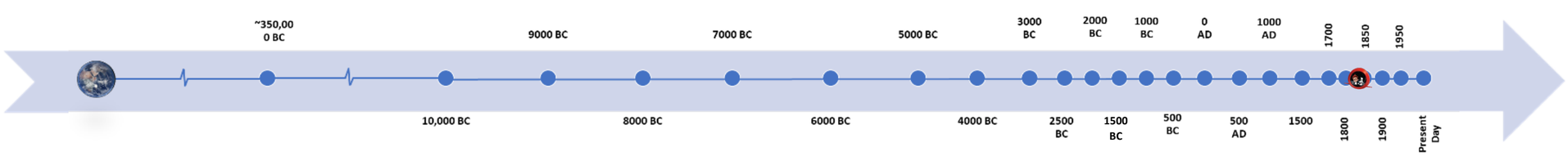
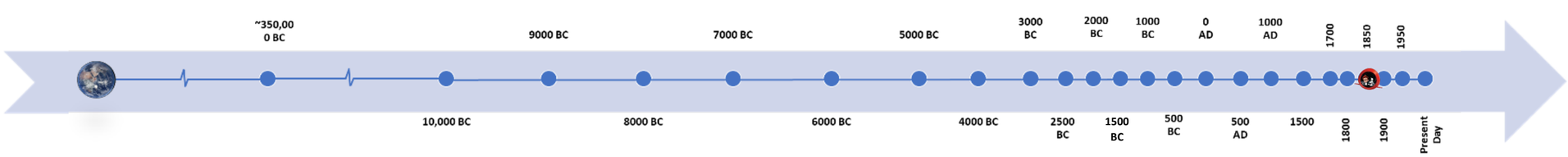


1st Industrial Revolution: 1750-1850

- Cement Production Advancements
- Improved kiln technology
  - More efficient
  - Consistent cement production
  - Improved quality
  - Scalability
- Isaac Charles Johnson (1845)
  - British cement manufacturer
  - Harder clinker
  - Stronger cement

Isaac Charles Johnson (1811-1911)



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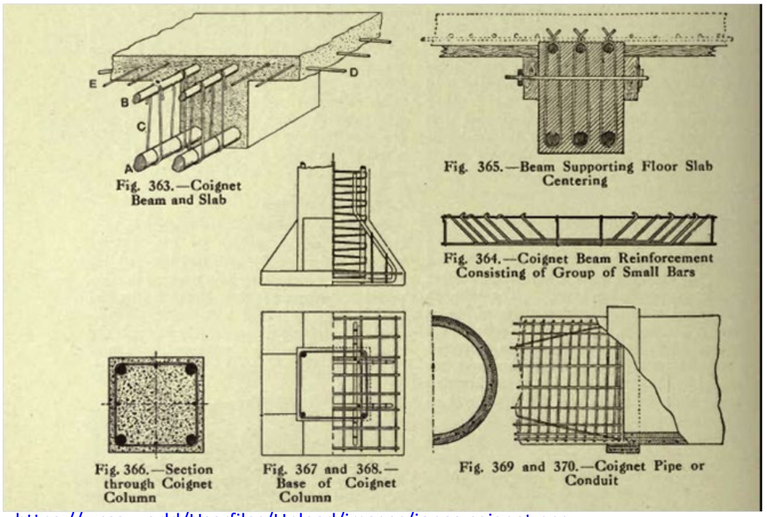
Reinforced Concrete: 1850s

- Joseph Monier (1849)
  - French gardner
  - Patented for garden pots
  - Applications for major projects
- François Coignet (1850s)
  - Iron bars
  - Construction projects
- Henry Bessemer (1856)
  - Steel production
  - Stronger & more ductile than iron
  - Mass production
- Reinforced Concrete
  - Major technological concrete breakthrough

https://wcsa.world/userfiles/upload/images/modules/news/2018/7/14/0_538ded37c07a803df400017e_zumtobel-group-award-2014.jpg



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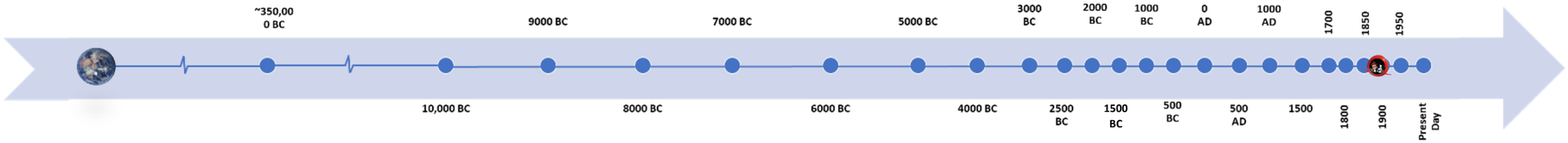

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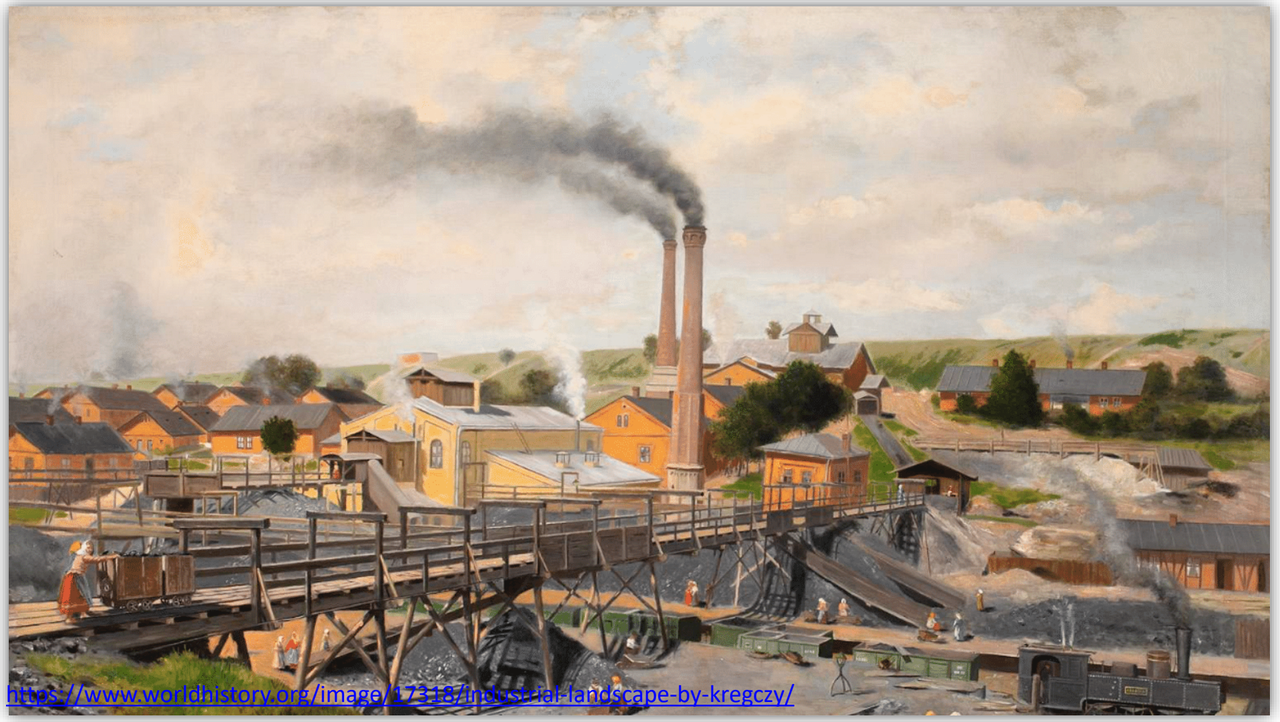
2nd Industrial Revolution: 1870-1914

- Reinforced concrete
  - Improved strength & versatility
  - Ideal for modern construction
- Cement industrialization
  - Large scale rotary kilns
  - Mechanized processes
  - Faster & Cheaper
  - Widespread availability
- Everyday Construction Material

https://wcsa.world/Userfiles/Upload/Images/lg_grandrochert.jpg

Industrialization: 1870s-1960s

- Exponential Growth of Infrastructure in US
- 1870s-1900s:
  - Railroad Expansion
  - Urbanization
- 1910s-1920s
  - Highway and Road Networks
  - Electrical Grid Systems
- 1930s: New Deal Programs
  - Schools, hospitals, bridges, dams, public buildings
- 1940s: WWII and Post-War Boom
  - War effort infrastructure: Military bases, factories, transportation networks
- 1950s-1960s
  - Interstate Highway System
  - Suburban Growth: Roads, schools, utilities



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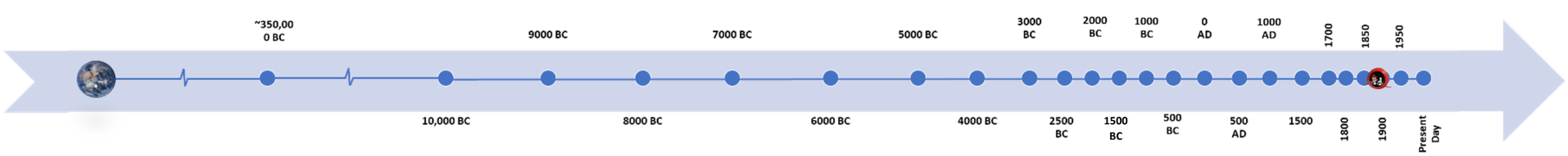

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Rise of Skyscrapers: 1885 & Beyond

- Home Insurance Building (1885: Chicago, IL)
  - First skyscraper, steel frame, 10 stories
  - Steel skeleton, enabled taller buildings
- Reinforced Concrete
  - Taller and more fire-resistant buildings possible
  - More design flexibility compared to steel alone.
- Ingalls Building (1903: Cincinatti, OH)
  - 1st reinforced concrete skyscraper in world
  - 16 stories
  - Demonstrated potential
  - Influenced future high-rise construction
- Changing Urban Skylines

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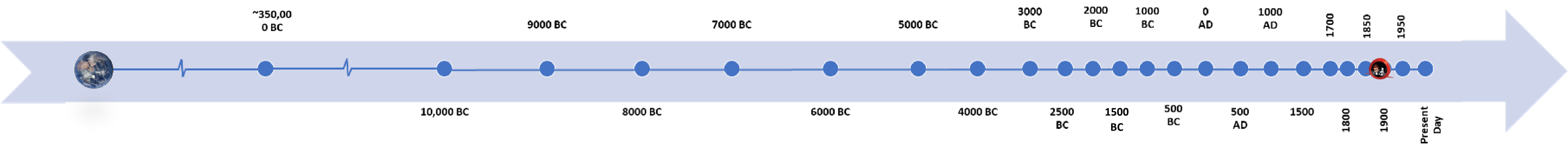
https://www.construction-today.com/wp-content/uploads/2020/08/the-history-and-legacy-of-the-ground-breaking-ingalls-building-in-cincinnati_02.jpg

The Ingalls Building (1903)



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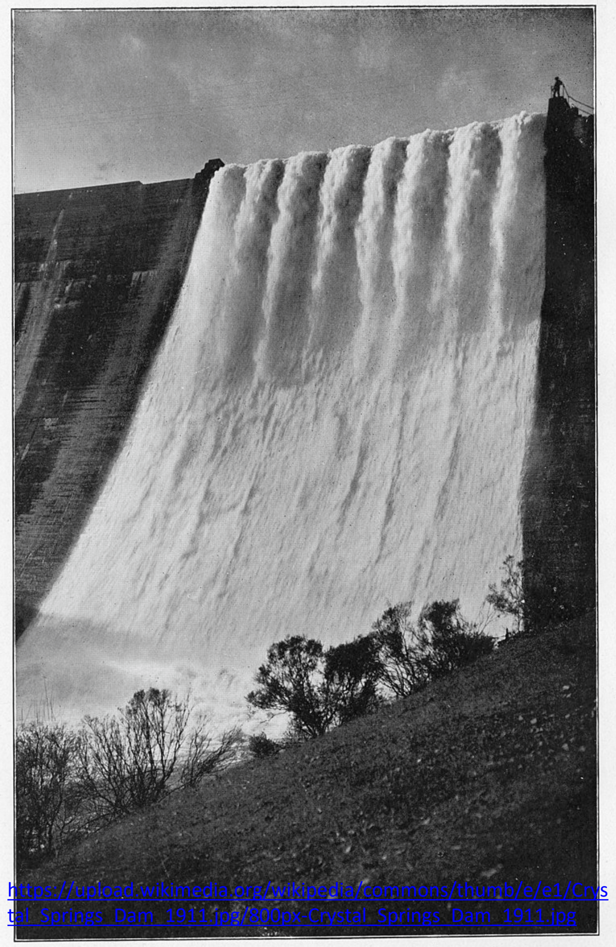
Large Concrete Dams: 1888 & Beyond

- Crystal Springs Dam (1888)
  - Gravity Dam in San Mateo County, CA
  - Set precedent for concrete use in dams
    - Shift from masonry to concrete
  - At time of completion, largest concrete structure in world
  - Withstood 1906 earthquake and Loma Prieta in 1989
- Hoover Dam (1931-1936)
  - World's first high dam
  - Arch-gravity dam
  - 726 feet
  - Hydroelectricity, irrigation, & flood control
- Dam building era (1930s-1960s)
  - 200 to 300 large concrete dams built


https://upload.wikimedia.org/wikipedia/commons/thumb/e/e1/Crystal_Springs_Dam_1911.jpg/800px-Crystal_Springs_Dam_1911.jpg

OVERFLOW OF CRYSTAL SPRINGS DAM. VIEW TAKEN IN FEBRUARY, 1911.
The year 1911 was one of about normal rainfall.


https://encrypted-tbn2.gstatic.com/licensed-image?q=tbn:ANd9GcQ4yxIc6rKBuCeJCczjatI_VNqG2RvyHsP8SoOnPy3xXhcaVf0W96oIF3QhowNTr9B3S5YFJjmuOjoEqVUKTDgWxDk-zocKOWrSOyrCbw

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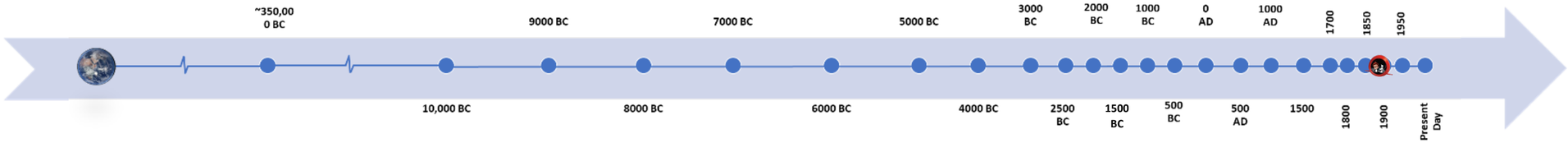

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Concrete Bridges: 1889 & Beyond

- Alvord Lake Bridge (1889)
  - First reinforced concrete bridge in US (San Francisco)
  - Milestone in civil engineering
- Bixby Creek Bridge (1931-1932)
  - Reinforced concrete engineering landmark
- By 1950
  - More than 1000 RC bridges built

https://historicbridges.org/california/alvordlake/little_day4_alvordlakebridge04830.jpg

Alvord Lake Dam (1889)

https://upload.wikimedia.org/wikipedia/commons/thumb/c/ca/Bixby_Creek_Bridge%2C_California%2C_USA_-_May_2013.jpg/1920px-Bixby_Creek_Bridge%2C_California%2C_USA_-_May_2013.jpg

Bixby Creek Bridge at Big Sur (1931-1932)

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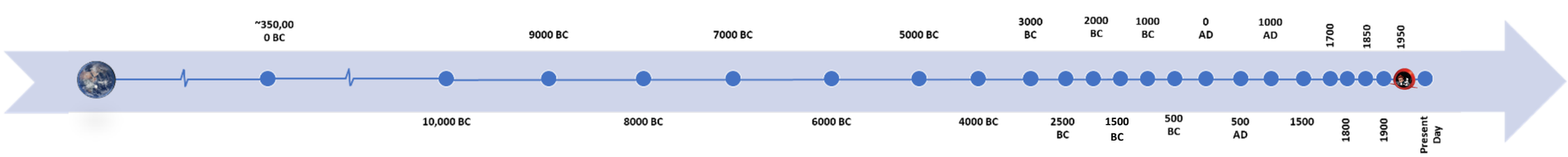

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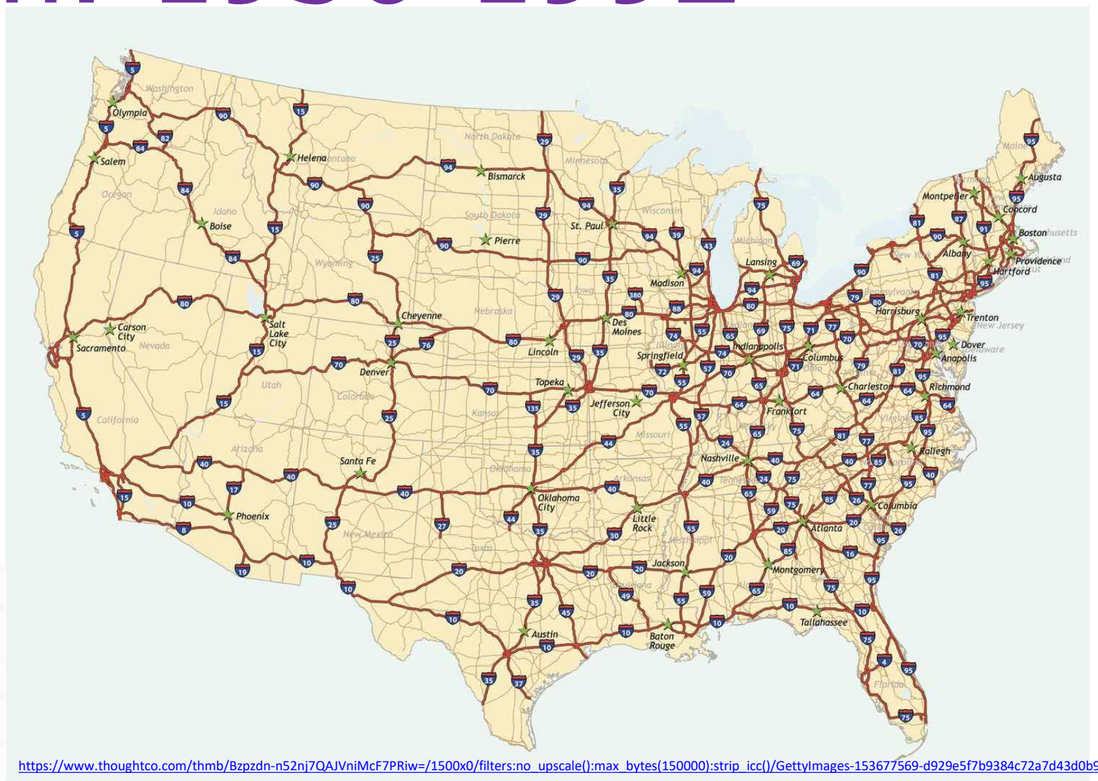
The Interstate System: 1956-1992

- US Interstate Highway System
  - Not possible without modern concrete
  - Inception
    - 1956 by President Eisenhower
  - Purpose: Military and civilian use
    - Enhancing national defense and economic growth
  - 47,000 miles of highways
  - Minimum of four lanes
  - Revolutionized travel and commerce in the U.S.
  - Facilitated suburban growth and regional connectivity.
  - Reduced travel times and improved road safety.
  - Symbol of American ingenuity and infrastructure development



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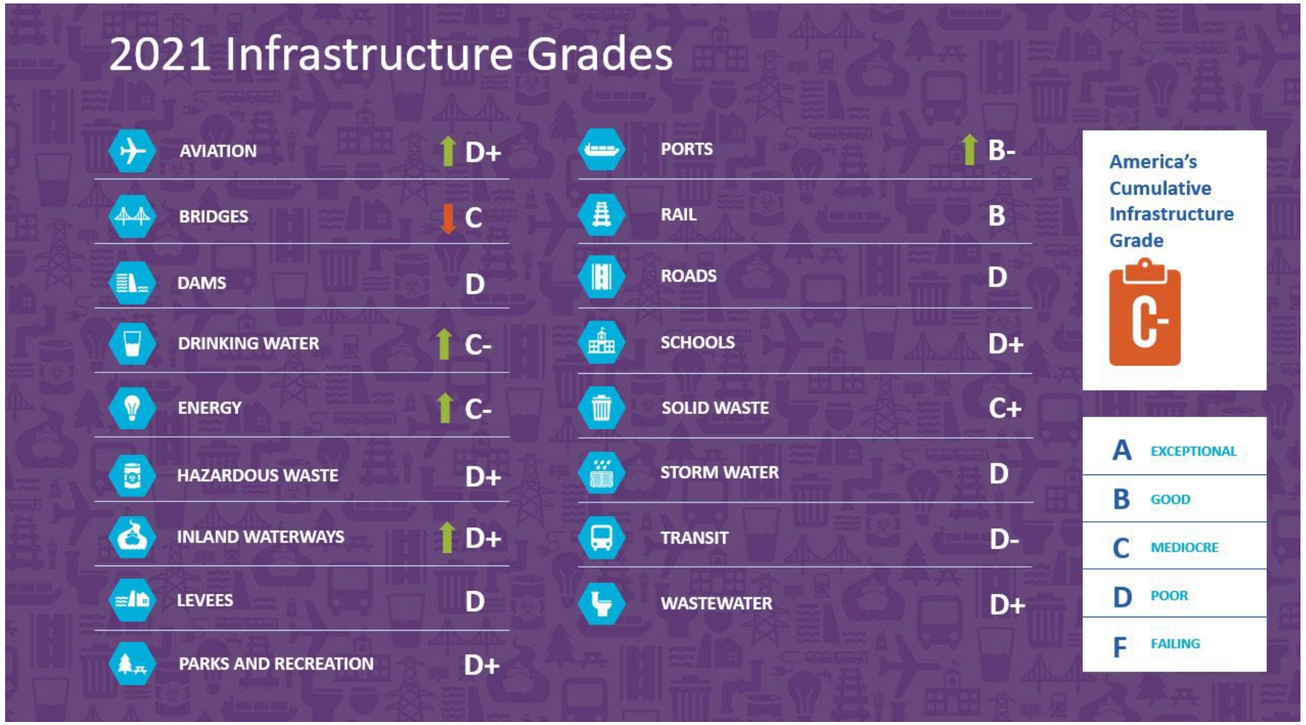
Modern Times: Aging Infrastructure

- US ASCE Report Card
  - Comprehensive assessment of US infrastructure
  - Unimpressive grades
- Toll on infrastructure
  - Wear & tear
  - Weather
  - Increased use from population growth
- Our Role
  - ICRI
  - Collective effort



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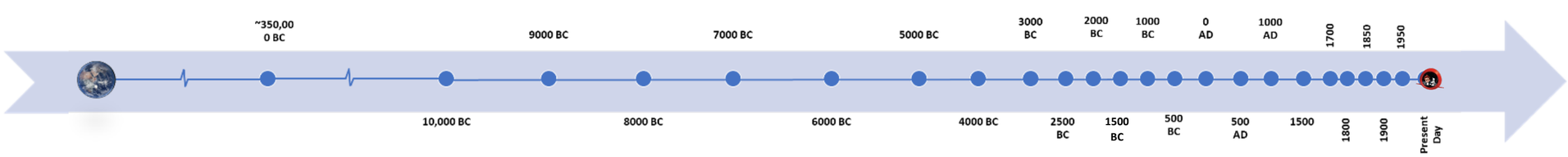

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Modern Times: Aging Infrastructure

- Key Signs
  - Cracking
  - Spalling & Delamination
- Typical Issues
  - New Structural Loading
  - Design Errors/Code Changes
  - Installation Defects
  - Poor mix design or consolidation
  - Carbonation
  - Corrosion of Reinforcement
  - Freeze-thaw
  - Alkali-Silica Reaction (ASR)

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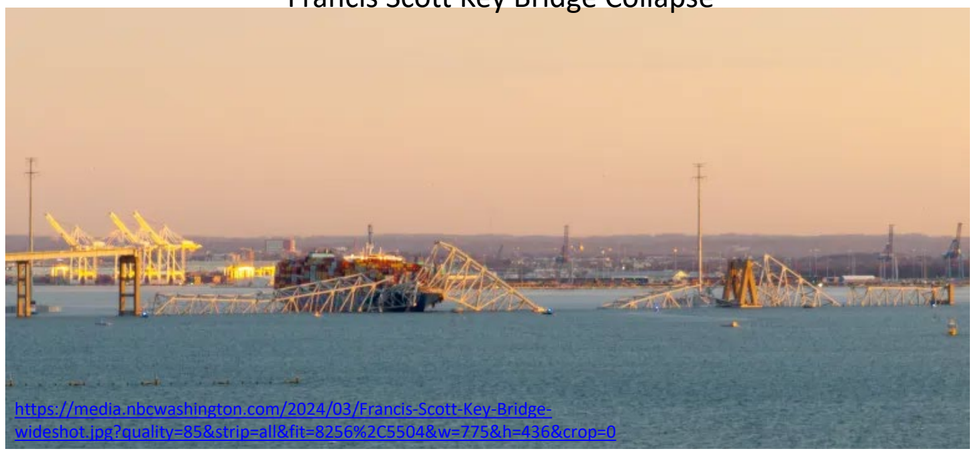
https://assets3.cbsnewsstatic.com/

Francis Scott Key Bridge Collapse


https://media.nbcwashington.com/2024/03/Francis-Scott-Key-Bridge-wideshot.jpg?quality=85&strip=all&fit=8256%2C5504&w=775&h=436&crop=0

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Repair & Rehabilitation Solutions

- Crack injection
  - Epoxy or polyurethane
- Surface / structural repair
- Overlay system
- Corrosion protection
  - Cathodic protection & corrosion inhibitors
- Strengthening solutions
  - FRP systems or steel plate bonding
- Grouting
  - Epoxy or cementitious
- Shotcrete
- Structural rehabilitation
  - Post-tensioning or jacketing
- Waterproofing
  - Membrane systems & crystalline treatment
- Joint repair and replacement
  - Sealants

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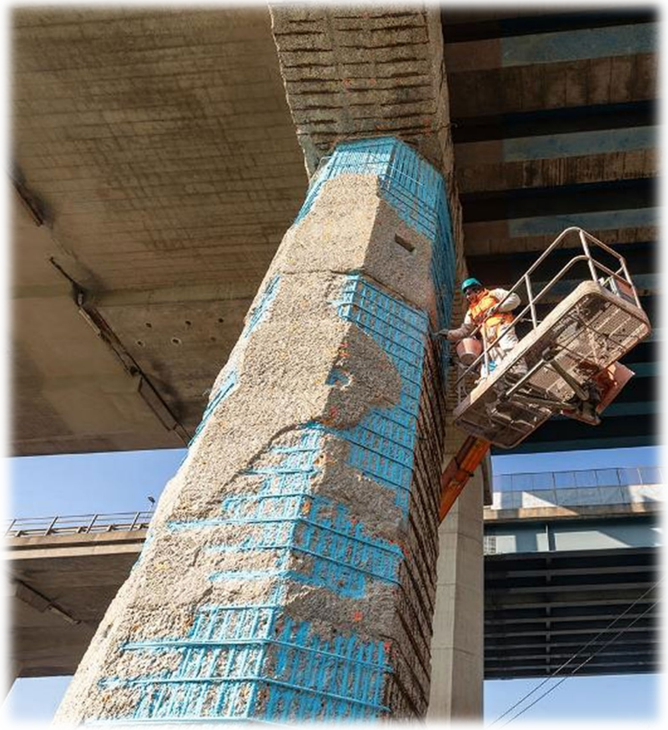

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Advancements of Materials

- Low-Carbon Solutions
  - Recycling and Reuse in Modern Concrete
  - Reconfiguring cement making processes to meet environmental regulations
  - Admixtures & Additives
    - Geopolymer concrete
      - Industrial waste material like fly ash and slag
    - Hemp: organic material
    - Biochar: carbon sequestering
    - Kaolinite: replicate volcanic ash properties
- Current & Future Advancements
  - Self-Healing Concrete
  - Ultra-high performance concrete (UHPC)
  - Graphene-enhanced concrete
  - 3-D Printing

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Extending Service Life

- Extending Service Life of Structures
  - Economic Benefits of Proper Rehabilitation
    - Cost Savings: 3-10X
    - Time Savings: Less disruption and delay
    - Less Regulation Permitting
  - Preservation
- Lack of maintenance
  - Reduction of service life
- Assessment importance
  - Monitoring & Surveillance
- Repair
  - Intervention
  - Service life extension
  - Could be a series of repairs

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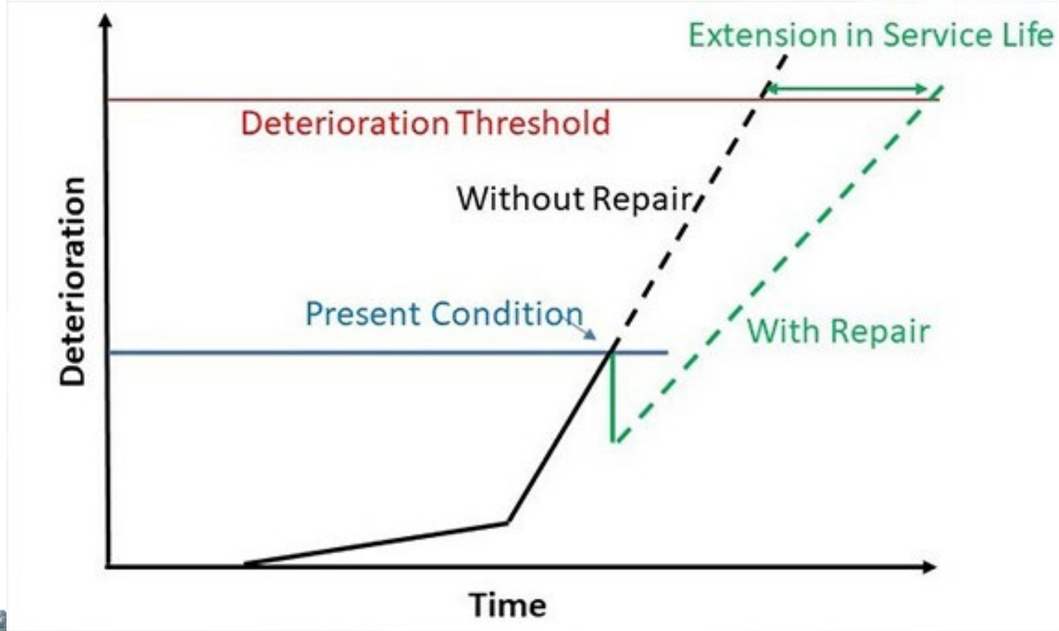

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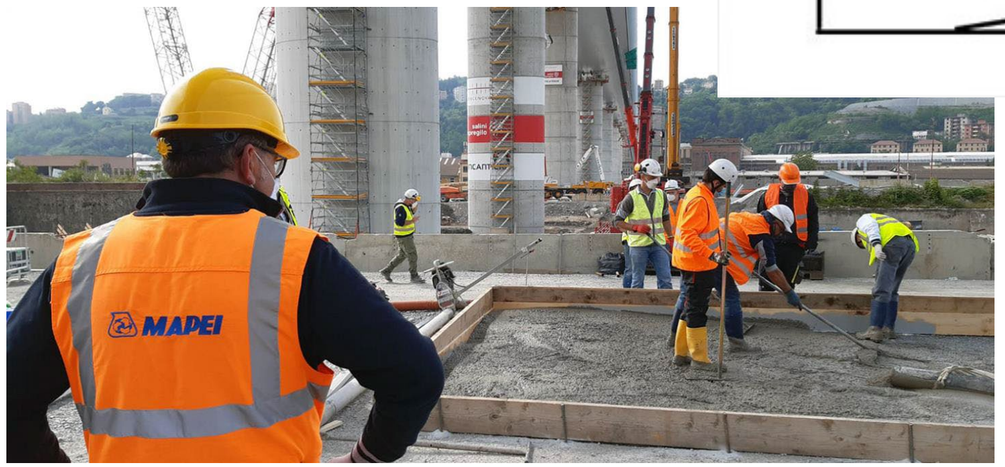

New Genoa Bridge Work: San Giorgio (2019-2020)

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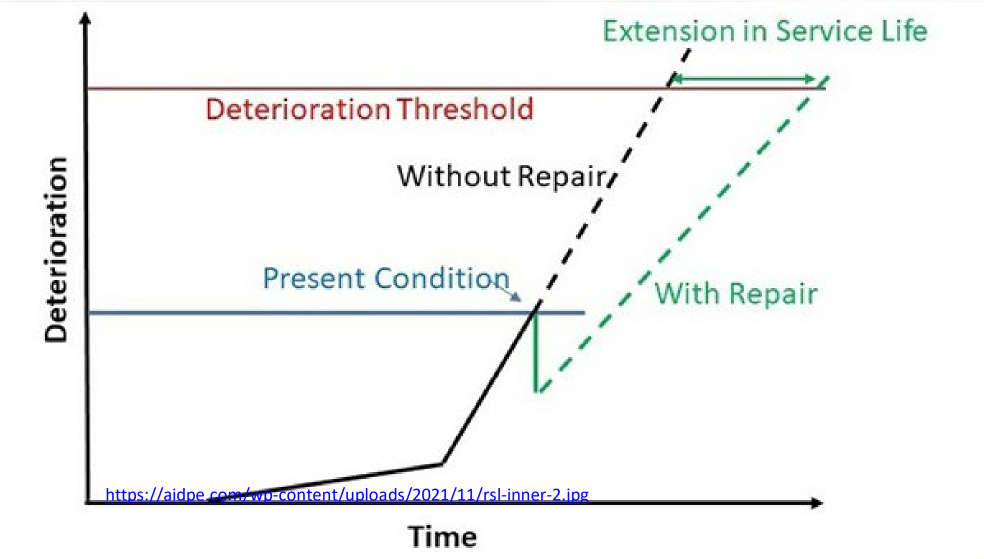

Extending Service Life

- Lake Lure Dam
  - Deferred maintenance
  - Funding
  - Rare large storm event due to Hurricane Helene

Lake Lure after Hurricane Helene (Sept. 2024)

Oroville Dam Spillway (Feb. 2017)

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Extending Service Life

- Extending Service Life of Structures
- Preservation & Carbon Savings
- Lower environmental impact
- 400 Million CY of new concrete placed each year in US
  - Contributes to 80 Million Tons of CO_2 to atmosphere
- 12 Billion CY of current inventory of existing concrete in US
  - 2.4 Billion Tons of CO_2
  - Each day of extended service life
    - Savings of ~6.6M Tons of CO_2

Center of Excellence for Preservation and Service Life Extension

P+Ex is a non-profit center of excellence organization focused on preserving and extending the service life of concrete structures.
www.pexcoe.org

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Case Study: Oroville Dam Spillway

- Oroville Dam (CA): 1961-1968
- Heavy precipitation in February 2017
  - Erosion of primary spillway
  - Undermining of emergency spillway
  - Evacuation
  - Forced to continue flow through primary spillway and endure more damage
- Repair (2017-2018)
  - Concrete lining of emergency spillway channel
  - Anchoring primary spillway to bedrock
  - Rebuilding eroded material
  - Creating new spillway channel

Case Study: I-80 Verdi Bridge

- Verdi Bridge (NV): 1995-1996
- Issues
  - Deteriorated concrete:
    - Columns, ledger beams and pile caps
- Repair solutions (2015-2016)
  - ICRI guidelines for Structural repair mortars followed
  - Cementitious fiber-reinforced fluid mortar
    - Form & pour application
  - Concrete repair mortar for overhead applications
  - Penetrating water repellant to protect against chloride ion intrusion
    - Pile caps and pedestals

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Case Study: Guggenheim Museum

- Solomon R. Guggenheim Museum (NYC): 1959
- Issues
  - Water intrusion
  - Concrete deterioration
  - Aesthetic Wear
- Repair solutions (2007-2008)
  - Epoxy injections
  - Sealants
  - Corrosion-inhibiting cementitious mortar on reinforcement
  - Repair mortars
  - Flexible cementitious waterproofing membrane
  - Elastomeric coating

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Case Study: Historic Rehabilitation

- Roman Coliseum (2000)
  - New performance stage
    - Partial reconstruction of arena floor
    - Anchoring
    - Masonry restoration
    - Archeological restoration
  - Solutions
    - Epoxy resin injections
    - Superfluid hydraulic binder for injection and consolidation of stone, brick, and tuff structures
    - High-flow, shrink-free grout for anchors
    - Superplasticizing pozzolanic admixture for quality concrete and resistance to chemical attack

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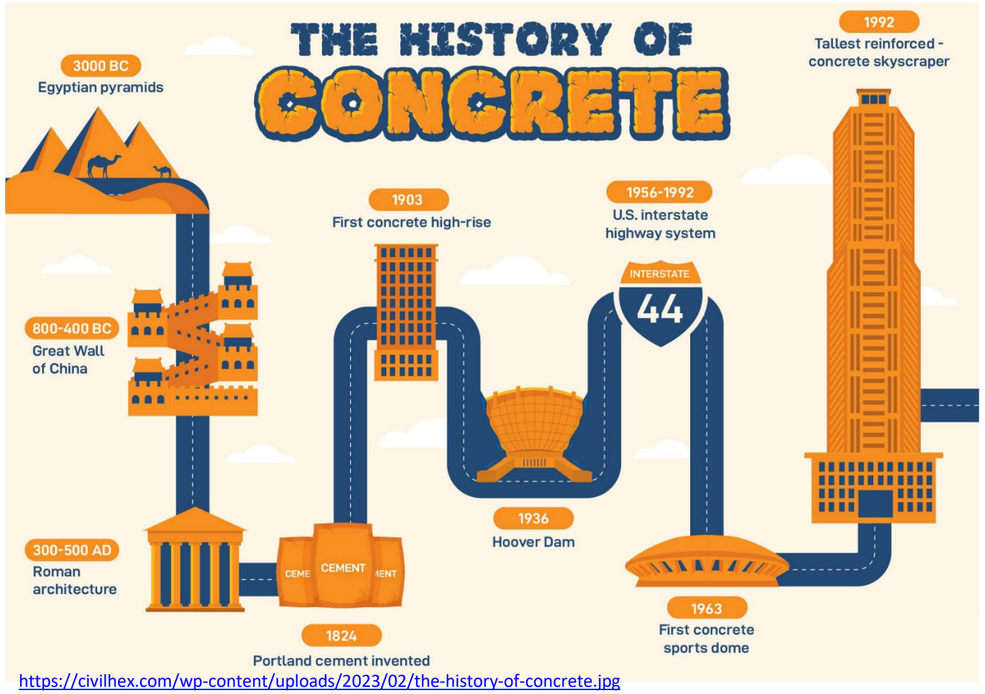
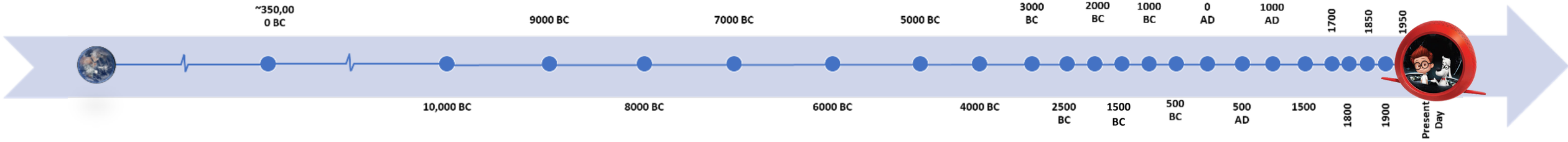
Conclusion

- Journey of Concrete through Time
  - Pre-history cementitious materials
  - Ancient Marvels
  - Middle Ages and Lost Technology
  - Portland Cement
  - Reinforced Concrete
  - Modern Iconic Concrete Infrastructure
- Aging Infrastructure
- Sustainability Challenges
- Future Innovations



https://civilhex.com/wp-content/uploads/2023/02/the-history-of-concrete.jpg



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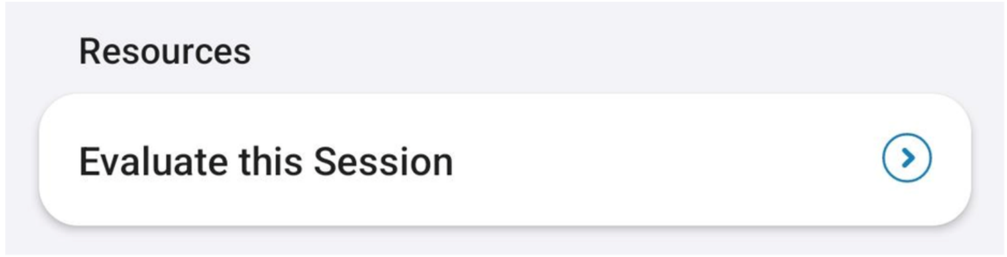
- Photography
  - Links from online sources provided below photos
  - MAPEI Corporation
  - Personal photos
- Case Studies
  - MAPEI Corporation

SESSION EVALUATION



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