PE INTERNATIONAL
SUSTAINABILITY PERFORMANCE

LCA and LCC of the World's Longest Pier

A Case Study on Stainless Steel Rebar

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Progreso Pier, Mexico

A Compelling Case Study

Source: Nickel Institute

Progreso Pier, Mexico

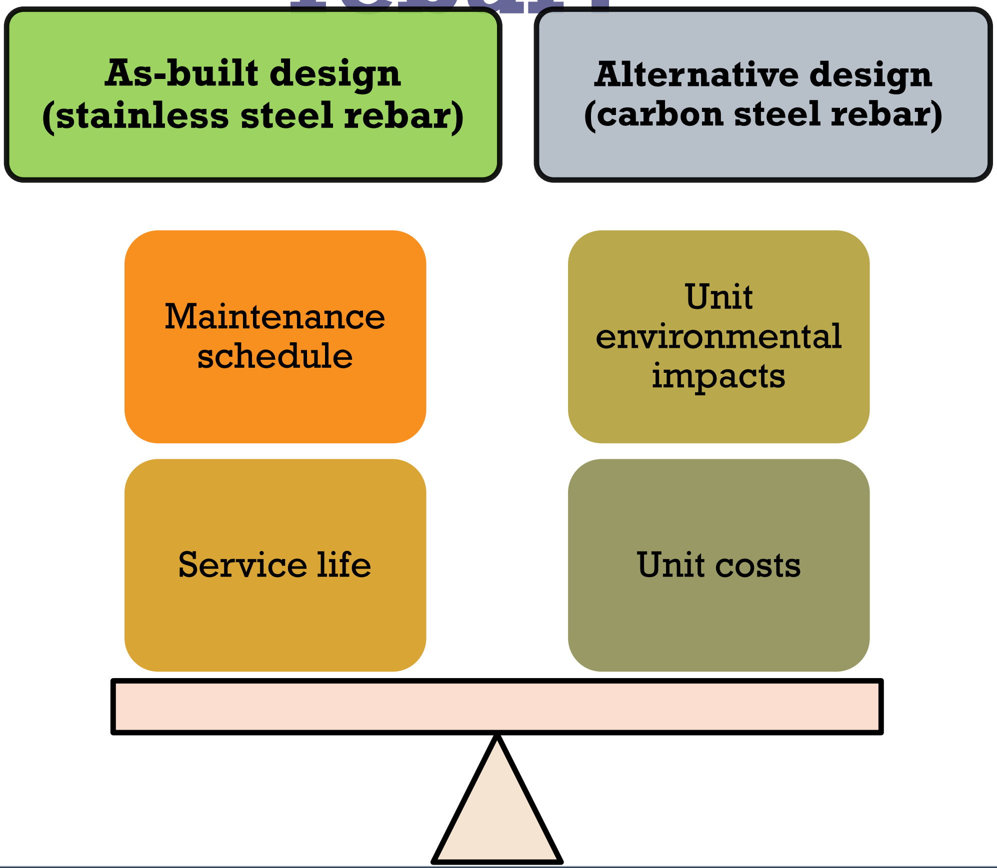
- **Longest pier in the world**
  - Built in 1941 at a length of 2100 meters
  - Extended in 1988 to 4000 meters
- **Innovative design**
  - One of the first major civil engineering structures to use stainless steel rebar
- **Resilient construction**
  - No significant maintenance has been performed

Image Source: Castro-Burgess et al.

It's All About the Rebar

- Provides tensile strength to reinforced concrete structures
- Common rebar is made of unfinished tempered steel (i.e., carbon or black steel) making it susceptible to corrosion
- More corrosion-resistant: epoxy-coated, galvanized or stainless steel

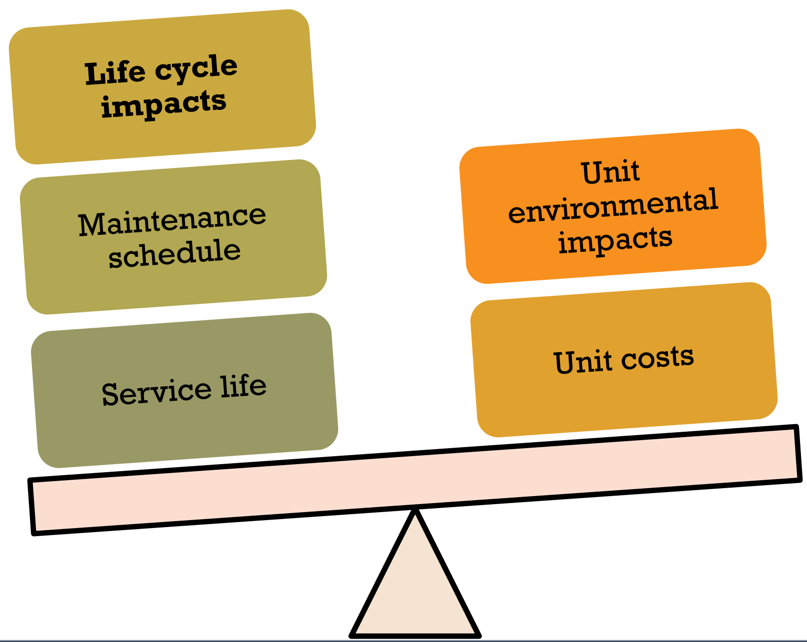
What if the Progreso Pier was built using carbon steel rebar?



What if the Progreso Pier was built using carbon steel rebar?

As-built design (stainless steel rebar)

Alternative design (carbon steel rebar)



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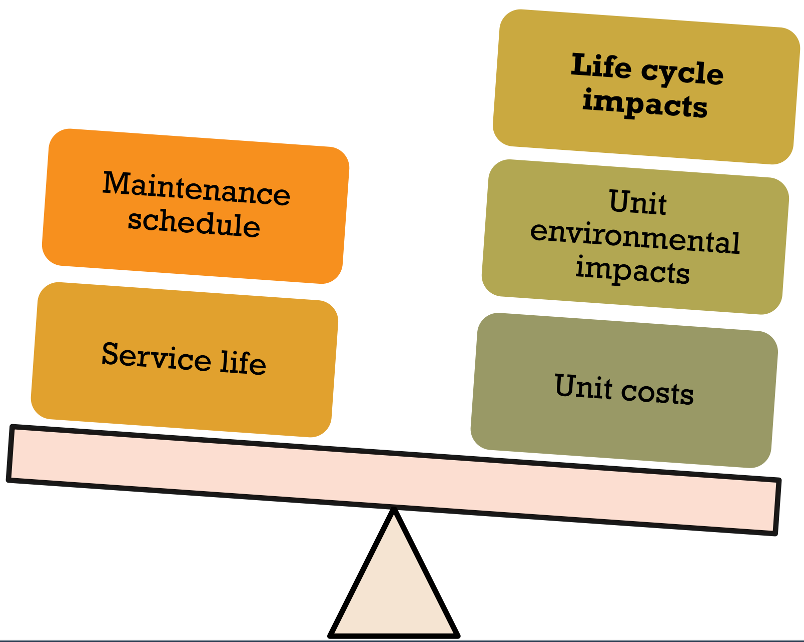


Comparison: Designs

As-built Design (stainless steel rebar)

- **Materials**
  - Concrete: 72,500 m^3
  - Stainless steel rebar: 220 tons
- **Maintenance:** to be determined
- **Service life:** to be determined

Alternative Design (carbon steel rebar)

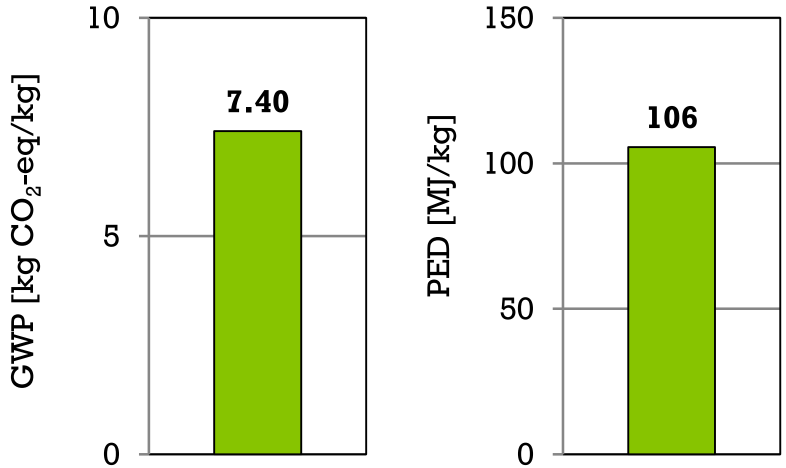
- **Materials**
  - Concrete: 72,500 m^3
  - Carbon steel rebar: 220 tons
- **Maintenance:** to be determined
- **Service life:** to be determined

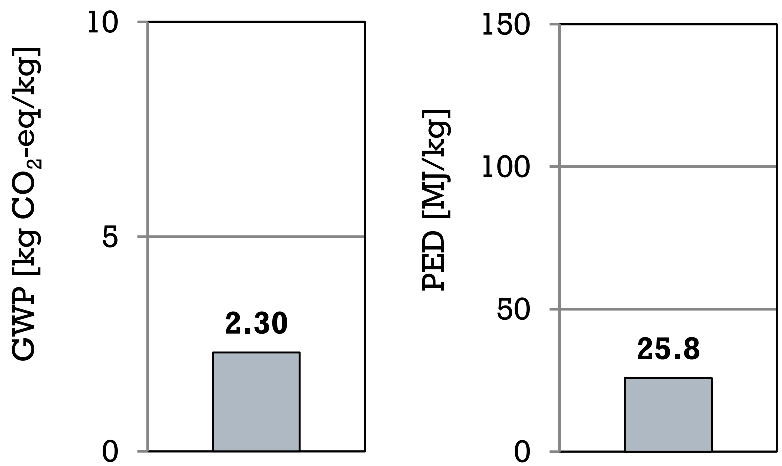
Comparison: Materials

Stainless Steel Rebar	***Carbon Steel Rebar***

Price (2013$): $6.59/kg

Price (2013$): $0.99/kg





Methodology: Overview

- **Comparative assertion**
  - Both designs serve the equivalent function
  - Stainless and carbon steel: same structural characteristics
  - Limited to the original 2100 meter pier (i.e., does not include 4000 meter extension)
- **Analysis period**
  - 79 years (1941–2020)
  - Provides estimate of past (1941–2013) and future (2013–2020) performance
- **System boundaries**
  - Included: materials, transportation, maintenance, and end-of-life fates
  - Excluded: construction, use, and demolition
- **Analysis methods**
  - Life cycle assessment (LCA) using GaBi (ISO 14040 series)
  - Life cycle costing (LCC) using Life-365 and Excel (ISO 15686-5)

Methodology: Service Life

- **Life-365 model**
  - Service life prediction model
  - Specific to reinforced concrete structures
- **Engineering analysis**
  - Performed by CTLGroup

Service Life

As-built Design
(stainless steel rebar)

Choride concentration threshold: **0.70% by weight**
Time to corrosion initiation and propagation: **44 Years**

Service life: **84 Years**

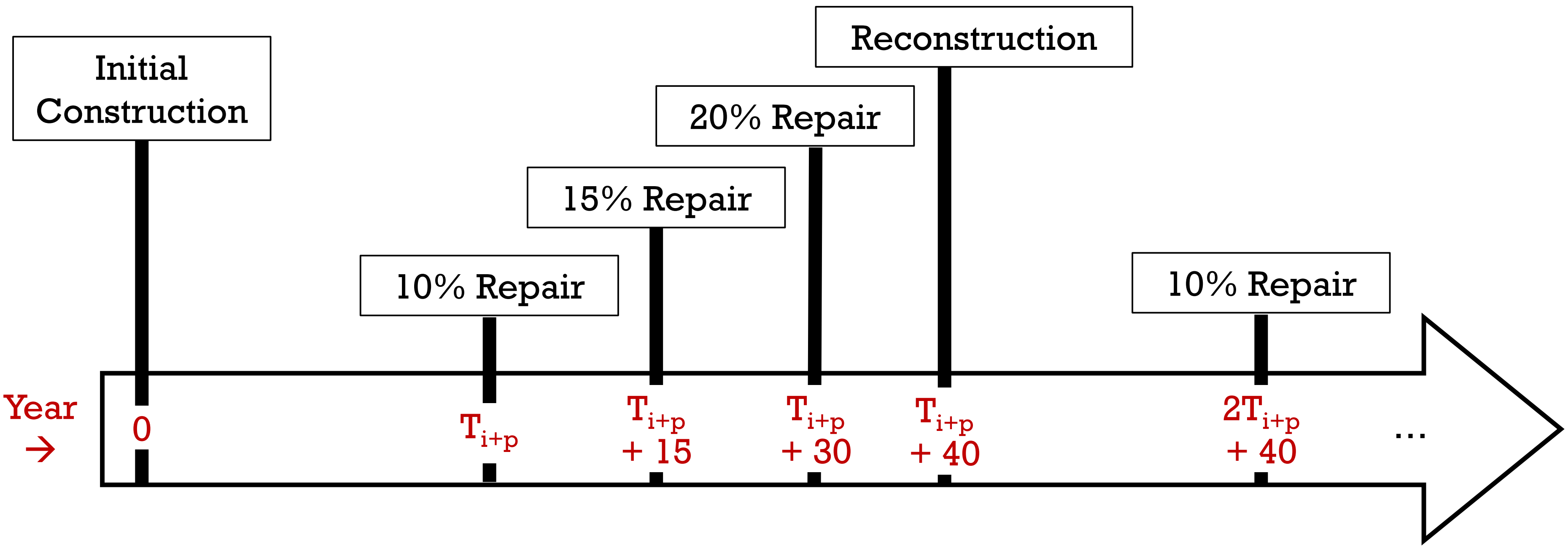
Life-365™

Alternative Design
(carbon steel rebar)

Choride concentration threshold: **0.05%** by weight
Time to corrosion initiation and propagation: **10 Years**

Service life: **50 Years**

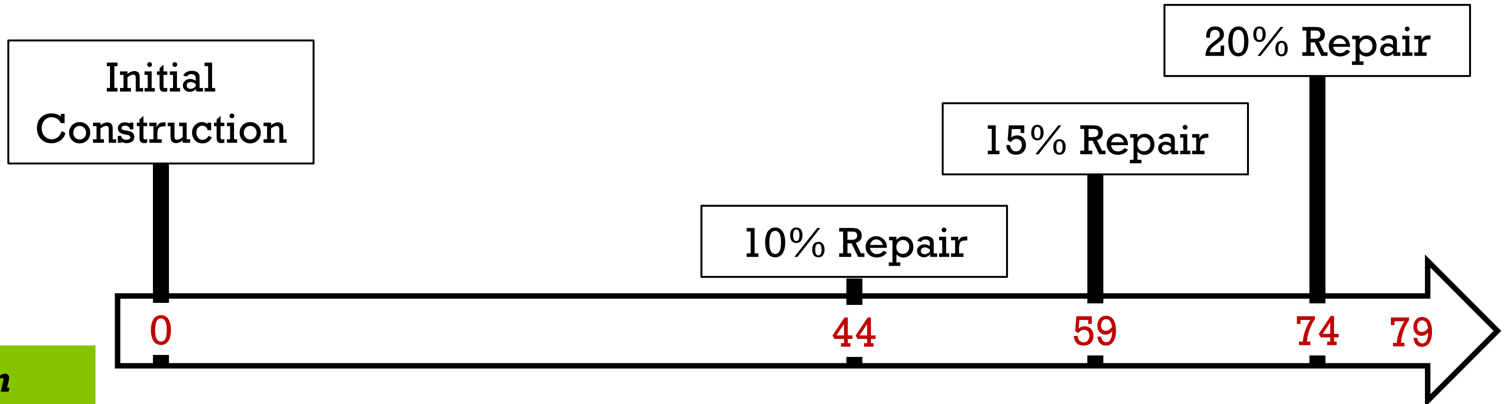
Methodology: Maintenance



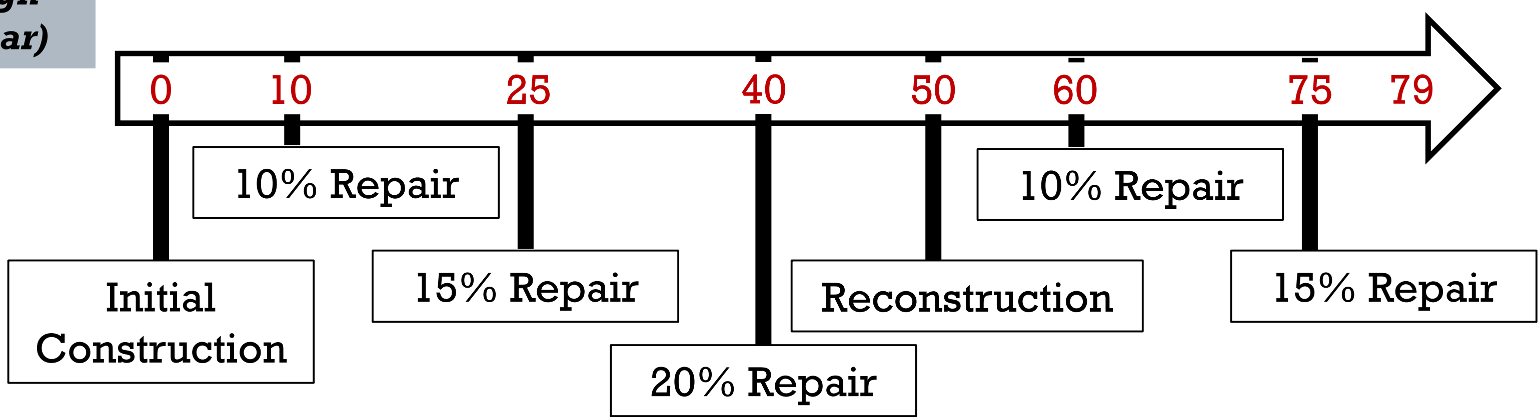
- T_{i+p} = time (years) to corrosion initiation and propagation of the rebar
- Service life and maintenance definitions follow United States Navy's engineering command (NAVFAC)

Maintenance

As-built Design (stainless steel rebar)

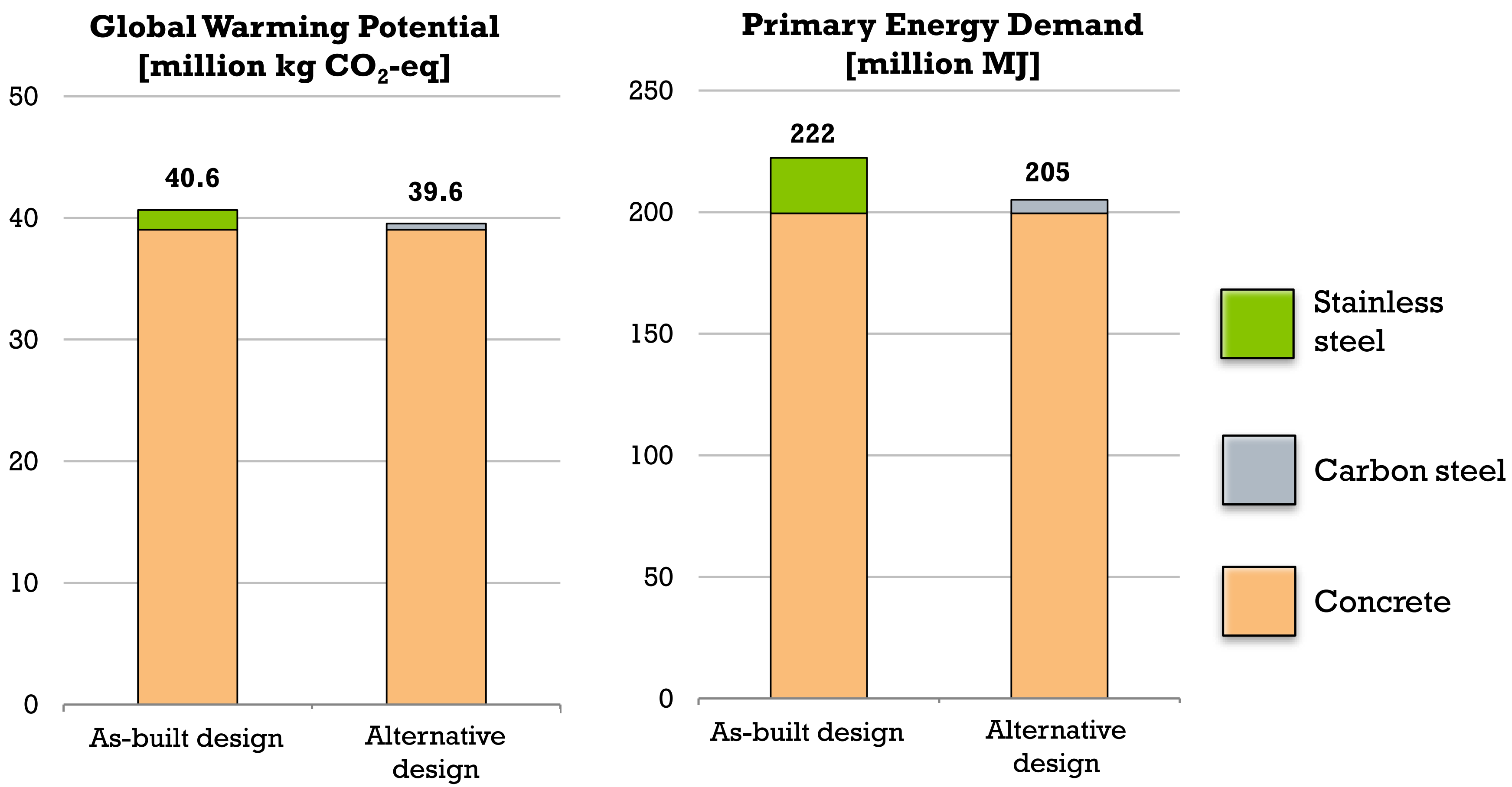


Alternative Design (carbon steel rebar)



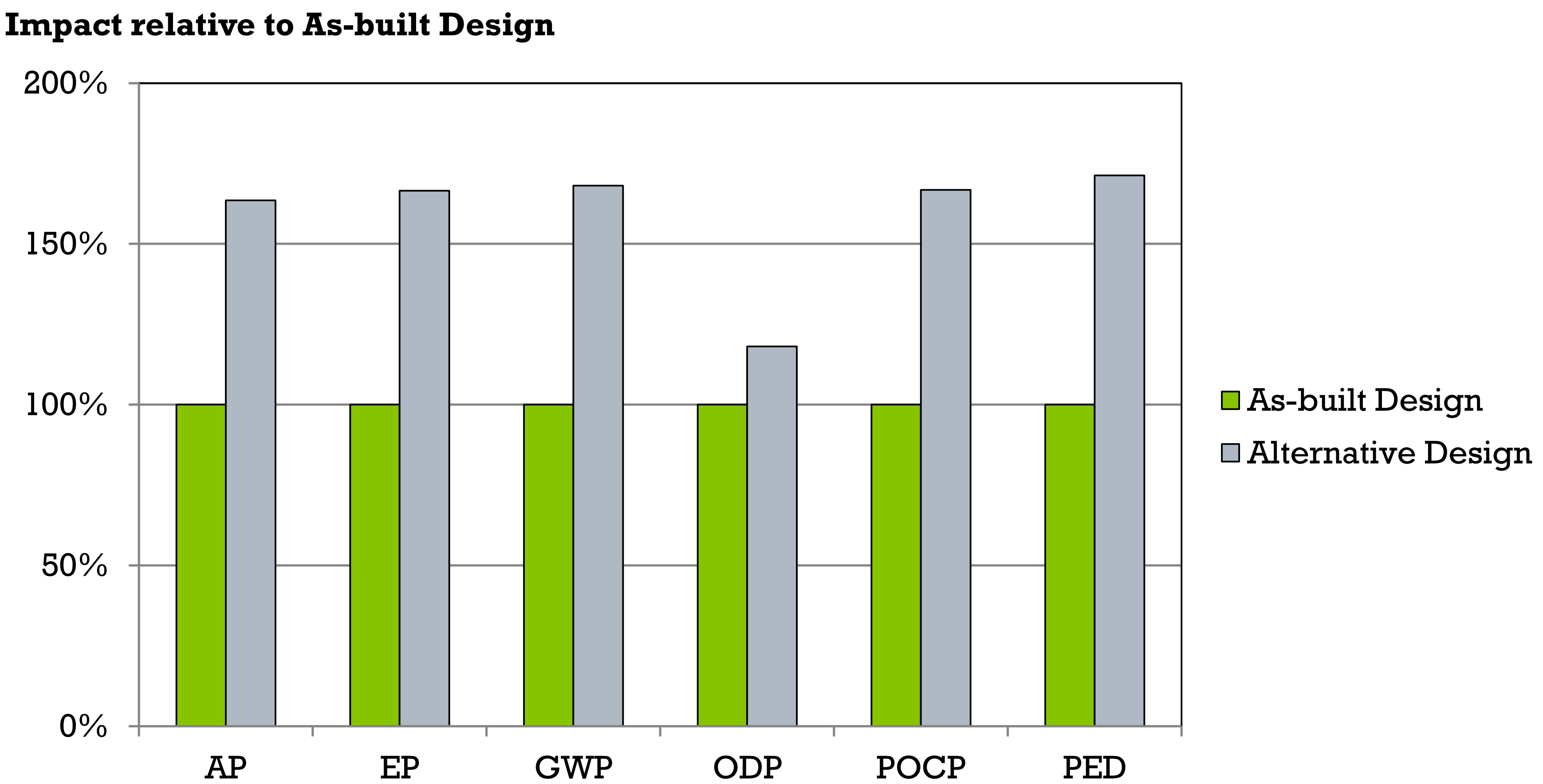
LCA Results

Breakdown of material contributions – initial construction



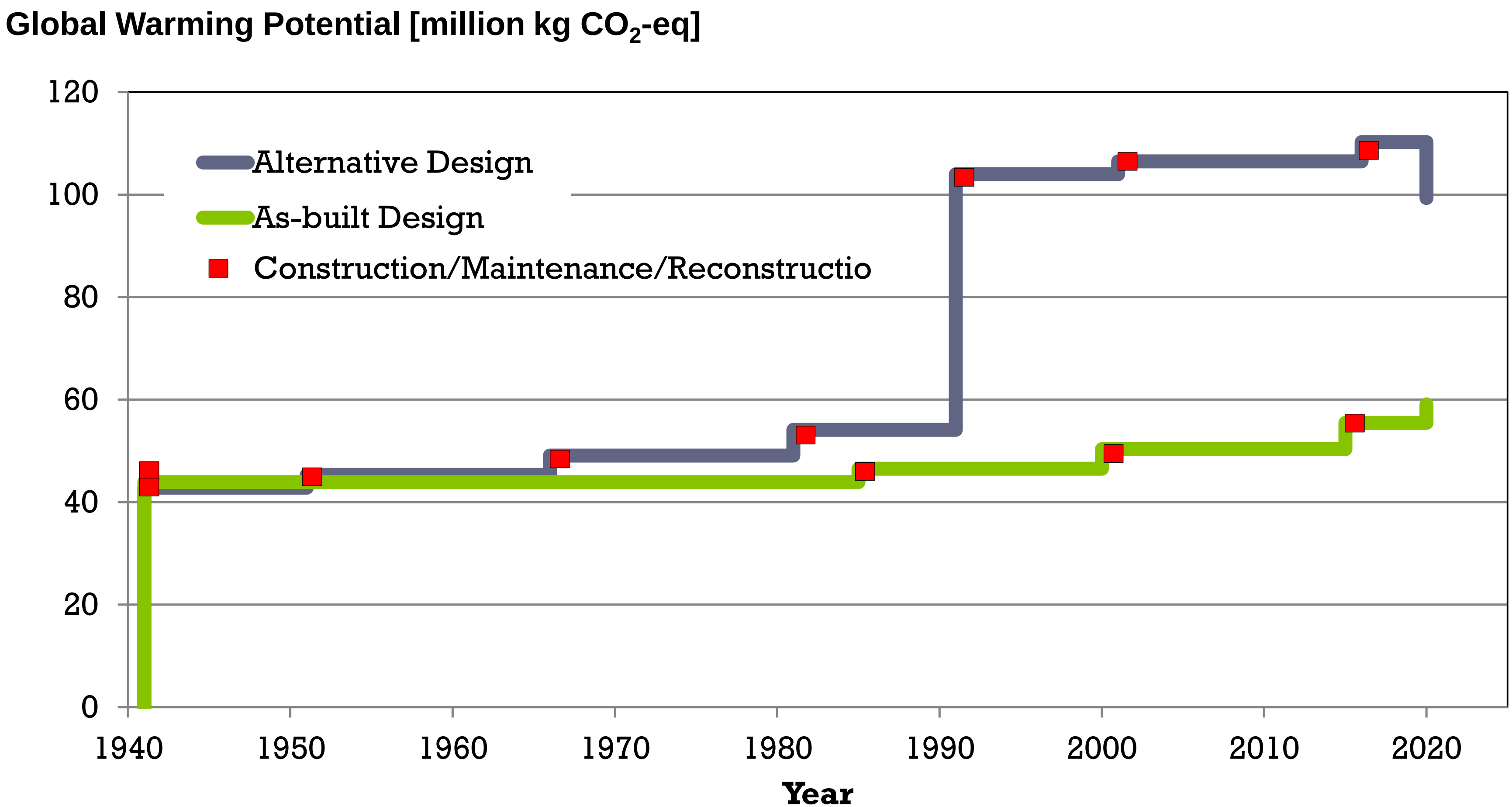
LCA Results

Total environmental impacts over 79-year analysis period



LCA Results

Comparison of GWP over 79-year analysis period



Sustainability Performance

Life Cycle Costing (LCC)

One-slide crash course

$$NPV = \sum_{n=0}^{P} C_n \left(\frac{1}{(1+i)} \right)^n - RV \left(\frac{1}{(1+i)} \right)^P$$

Where: P = analysis period

n = year, ranging from 0 to P

C_n = cost incurred in year n

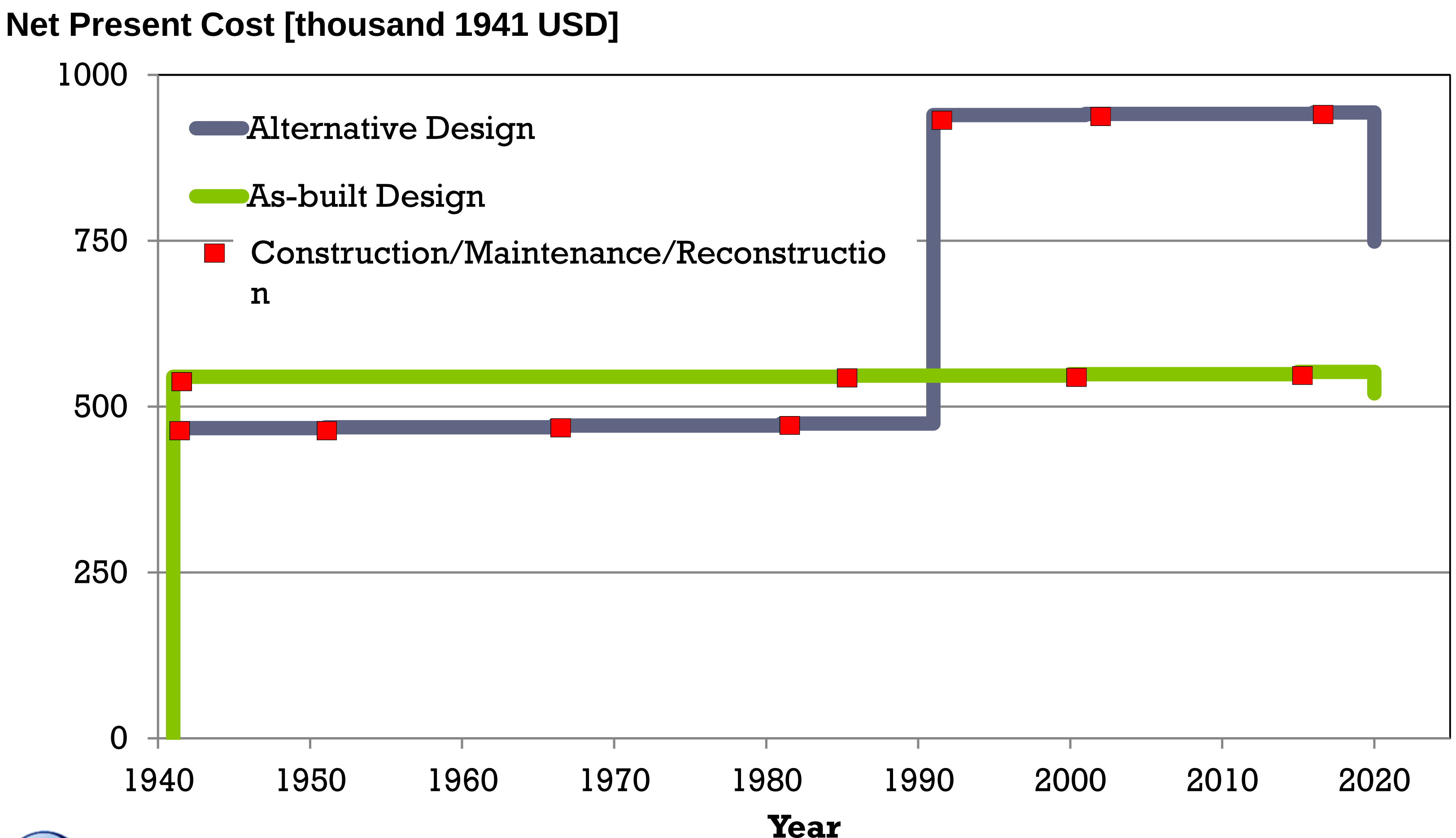
i = discount rate

RV = residual value

- Follows same concepts as life cycle assessment
  - Cost data collected for individual activities
  - Analyzed over the product life cycle
- Major difference between LCC and LCA is the consideration of the time
  - Future costs are discounted using the discount rate
  - Discount rate is variable and uncertain

Life Cycle Costing Results

Discount Rate of 0.01% (recommended by SETAC)



Life Cycle Costing

LCC is sensitive to discount rate

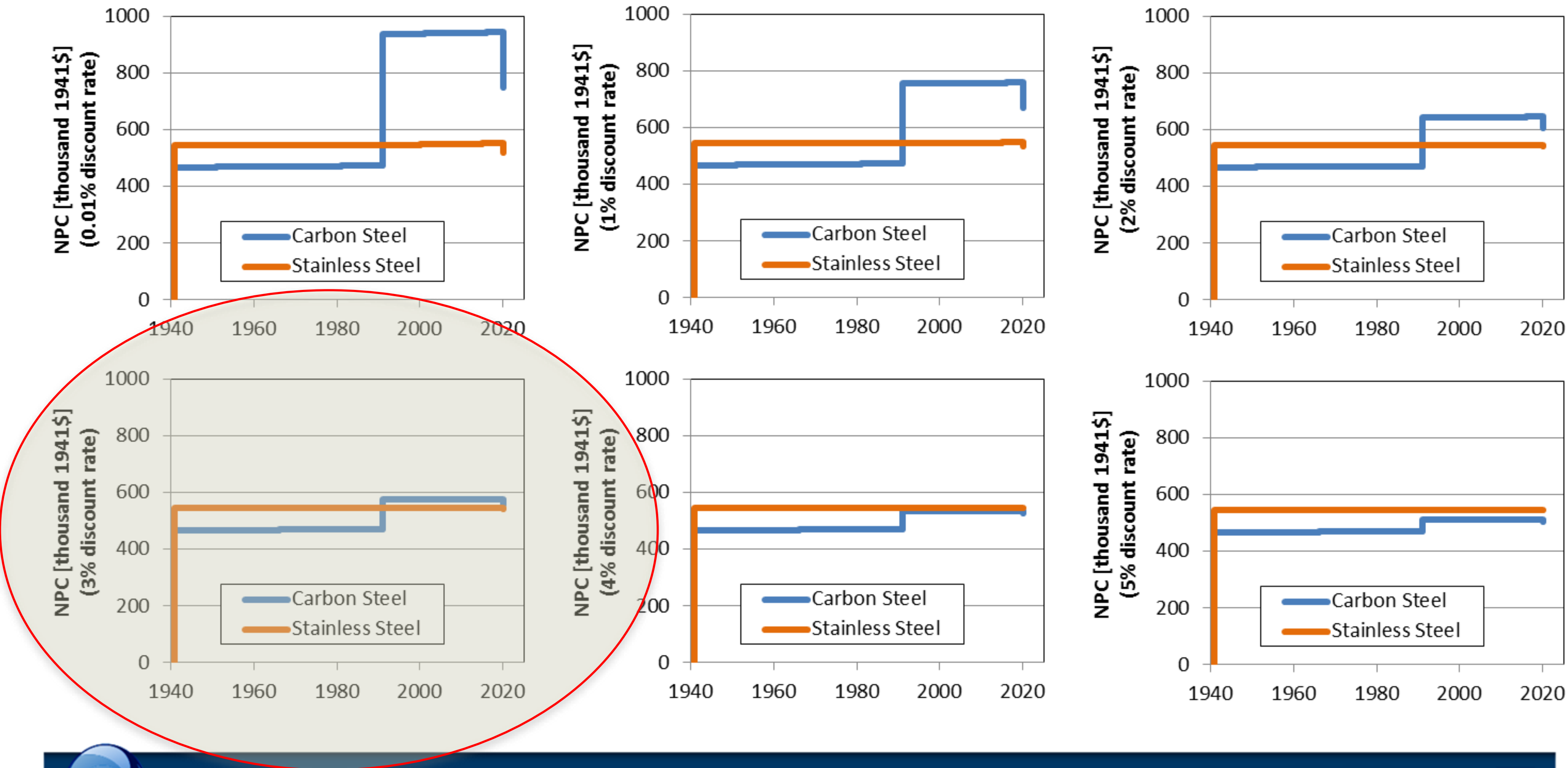
5%
4%
3%
2%
1%
0%

- **EU:** National ministries of finance specify the discount rates to be used in the economic analysis of publicly funded projects. These typically fall into the range of **3 to 5%**
- **EU:** “Use of a low (**3% or less**) or even a zero rate is recommended when LCC is used to assess the economic merits of alternative sustainability options.”*
- **US** Circular A94 currently uses **1.1%** based on the 30-year bond
- **US Navy** reports **0%, 1%, and 2.3%**
- **SETAC:** 0.01% discount rate for long-term investments (over 30 years)

*Source: *EU Guidance Document on LCC (2007)*

Life Cycle Costing

Sensitivity to the discount rate



Conclusions

- **The rebar material is a small part of the overall life cycle impact**
  - Concrete is dominant source of environmental and economic impacts
  - Structural performance and service life are key considerations
- **As-built structure (stainless steel rebar) has lower life cycle impacts**
  - Higher environmental impacts per unit of stainless steel outweighed by benefits related to corrosion resistance
  - Significant differences across all considered impact categories
- **As-built structure has lower life cycle costs**
  - Higher environmental impacts per unit of stainless steel outweighed by benefits related to corrosion resistance
  - Sensitive to the choice in discount rate

Final Notes

Consideration		Influence
• Construction/deconstruction activities not included	➡	Future activities are under-characterized
• Temporal representativeness is weak	➡	Similar uncertainty between each design
• Results are specific to the Progreso Pier case study	➡	Sweeping conclusions regarding stainless steel rebar are not proposed

Study currently undergoing peer review

Contact

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