Prefabricated vs. in-situ concrete bridges in a whole life perspective

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Agenda

1. Prefabricated vs. in-situ concrete bridges
2. Tools for Life Cycle Costs (LCC) and Life Cycle Assessment (LCA)
3. Example (comparison)
4. Summary
Prefabricated vs. in-situ concrete bridges

Selected factors that influences the choice (in random order):

- Contractual setup
- Functional requirements
- Boundary conditions (e.g. location, exposure, soil)
- Execution methods
- Structural design
- Costs
- Execution period
- Risk
- Traffic
- Life Cycle Costs
- Maintenance
- Materials
- Environmental impacts
- Durability, sustainability
Prefabricated bridges

<table>
<thead>
<tr>
<th>Pros:</th>
<th>Cons:</th>
</tr>
</thead>
<tbody>
<tr>
<td>› Shorter construction time at site</td>
<td>› Every element needs a support (requires bearings and/or cross beams)</td>
</tr>
<tr>
<td>› Traffic disturbance and associate accidents are often minimized</td>
<td>› Deck height is often higher than when cast-in-situ</td>
</tr>
<tr>
<td>› Use of scaffolding is minimized (risk reduction)</td>
<td>› More joints are required (larger maintenance costs)</td>
</tr>
<tr>
<td>› Concrete elements are produced in a controlled environment (high quality)</td>
<td>› Limited lengths and widths due to transport</td>
</tr>
<tr>
<td>› Construction is independent on the weather situation</td>
<td></td>
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<tr>
<td>› Large spans are possible</td>
<td></td>
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In-situ cast bridges

<table>
<thead>
<tr>
<th>Pros:</th>
<th>Cons:</th>
</tr>
</thead>
<tbody>
<tr>
<td>› Extensive architectural degrees of freedom</td>
<td>› Longer period of construction (imposes risks)</td>
</tr>
<tr>
<td>› Monolithic structures are possible (static advantageous)</td>
<td>› Execution require more man-power</td>
</tr>
<tr>
<td>› No need for cross beams</td>
<td>› Scaffolding is required (imposes risks)</td>
</tr>
<tr>
<td>› Interface management is minimized</td>
<td>› Period of traffic disturbance is longer when compared to prefabricated bridges (imposes risks)</td>
</tr>
<tr>
<td></td>
<td>› Quality level is dependent on the weather situation</td>
</tr>
<tr>
<td></td>
<td>› Many site operations at the same time (imposes risks)</td>
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Recent study in Sweden...(Larsson & Simonsson, 2012)
US initiative...(2009-)

"...the FWHA's goal is to shift the paradigm of our industry so that the use of PBES (Prefabricated Bridge Elements & Systems, red.) becomes the standard method of construction and the use of conventional construction methods, such as on-site CIP (Cast-In-Place, red.) operations are used in a limited manner"
US initiative – some statements...

Accelerated Bridge Construction (ABC) comprise:
- Slide-in Bridge Construction
- Prefabricated Bridge Elements and Systems

**BENEFITS**

Benefits to employing ABC technology include:

- **Mobility impacts on bridge construction or replacement projects can be reduced to 48 to 72 hours with planning and bridge construction reduced by years.** Decreasing construction time directly benefits the public by significantly reducing traffic delays and road closures.

- **Reduced agency costs.** ABC can be the most cost-effective means of construction, especially when total project costs, including right-of-way acquisition, project administration, maintenance of traffic, environmental mitigation utility relocation, escalation or railroad flagging costs are considered.

- **Reduced user costs.** ABC dramatically reduces work zone road user costs associated with bridge construction projects on existing roadways.

- **Improved motorist and worker safety.** Each year 2,000 fatal crashes occur in work zones. Forty-four percent of bridge construction worker injuries involve a vehicle traveling through a work zone and two-thirds of these injuries are fatal. Limiting the duration of traffic impacts reduces the exposure to work zone crashes, increasing safety for both the construction worker and the traveling public.

- **More durable, longer-lasting bridges.** As our Nation faces the prospect of crumbling infrastructure, this innovation is not only effective, but also incredibly important to addressing this serious, time-sensitive challenge.

- **An effective solution to environmentally sensitive areas.** ABC technologies may also be an effective solution or alternative in areas where construction may be constrained or delayed by environmental considerations or limitations.

- **Public support.** Post-construction surveys of residents and businesses indicate high levels of customer satisfaction for ABC projects.
Decisions made early has the greatest impact...

![Graph showing the impact of decisions over time from planning to execution to operation. The graph illustrates that decisions in planning have a high impact on performance, while decisions in operation have a high impact on costs and operational disturbance.](image-url)
Contractual setup

**Common**: Contracts shall support low life cycle costs, stable budgets, right timing and innovation where appropriate.

- **Design and build**
  - functional requirements shall ensure low life cycle costs
  - including other LCC-based requirements can be difficult / requires a robust evaluation model
  - contractors degree of freedom shall be maintained

- **Public-Private-Partnership (PPP)**
  - ex. for a 30 year period, risks are spilt btw. partners

- **others...**
Tendering – Functional requirements

- Often they concern *initial quality* because of warranty period
- How to deal with a 10% reduction in service life?

- A LCC model as part of the tender evaluation could supplement functional requirements, on component level it could favor:
  - low initial cost
  - low maintenance and replacement costs
  - low quantity (very transparent)
  - high service life
LCC in a tender framework

› Contractors job (objectivity)?
› Owners job (robust and transparent model as part of tender)?
› Step-wise procedure:
   › LCC (Owner) of Conceptual Design
   › LCC (Contractor) as part of the offer (model as part of tender)
   › LCC (Owner) comparison of offers
   › LCC (Owner) during construction as a reality check
› Requires country specific and realistic O&M costs
› Keeping Contractors degrees of freedom
Tools for LCC and LCA ... for bridges
Choosing the Best Bridge Alternative

Compromise

LCC
LCA
"LCE"

ETSI

Statens vegvesen

NTNU

TRAFIKVERKET

Vejdirektoratet

COWI
MAINLINE

MAIN TENTANCE, RENEWAL AND IMPROVEMENT OF RAIL TRANSPORT INFRASTRUCTURE TO REDUCE ECONOMIC AND ENVIRONMENTAL IMPACT
Example (comparison)

Overpass "Vindingevej"

Overpass "Vesterled"
Example (comparison)

› Construction costs:
  › In-situ: 11.4 mio. DKK.

› Prefab: "same level"

Recent study from Netherlands support this for "typical" bridges (Bakker, 2014) +/- 10%
Example (comparison)

> O, M and R budget (in-situ):

Routine Maintenance (yearly)
Principal Inspection (every 5th year)
Special Inspection (every 10th year)
Road user disturbance not included

Primarily: Wearing course, surfacing+ waterproofing, conc. rep., railings and edge-beams
Example (comparison)

- We do not have sufficient data...
- However, construction joints in prefab. bridges increase O&M costs
- But Net Present Values during a 100 year period are expected to be roughly the same.
Example (comparison)

- Road user disturbance cost (NPV, 5%):

<table>
<thead>
<tr>
<th></th>
<th>ADT</th>
<th>Speed (km/h)</th>
<th>Detour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overpass</td>
<td>10.000</td>
<td>50 -&gt; 30</td>
<td>1 km</td>
</tr>
<tr>
<td>Underpass</td>
<td>40.000</td>
<td>110 -&gt; 70 (6 -&gt; 4 lanes)</td>
<td>-</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Duration (years)</th>
<th>Cost (MDKK)</th>
<th>Remark</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-situ</td>
<td>Prefab</td>
<td>In-situ</td>
<td>Prefab</td>
</tr>
<tr>
<td>Execution</td>
<td>1</td>
<td>7/12</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
<td>Operation</td>
<td>100</td>
<td>100</td>
<td>0.27</td>
<td>~0.27</td>
</tr>
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</table>
Example (comparison)

- Other society cost, ex. accidents:
  - 1 death: ~20 MDKK.
  - Risk = Probability x Consequence

- In-situ (1 year):
  - Execution: 24.000 kr.

- Prefab (7 month):
  - Execution: 14.000 kr.

- Additional risk due to scaffolding and other effects

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number of deaths per hour per 10^3 persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountaineering (int.)</td>
<td>2700</td>
</tr>
<tr>
<td>Travel by plane (int.)</td>
<td>120</td>
</tr>
<tr>
<td>Travel by car</td>
<td>5</td>
</tr>
<tr>
<td>Construction sites</td>
<td>7.7</td>
</tr>
<tr>
<td>Accidents at home</td>
<td>2.1</td>
</tr>
<tr>
<td>Structural damage</td>
<td>0.002</td>
</tr>
</tbody>
</table>

UK, 1970's based on (Thoft Christensen et al, 1982)
Environment – (How) do we take this into consideration?

According to MAINLINE investigation, it is limited due to:

› Bridge projects consist of many different elements
› Long service life
› Significant uncertainties
› Complexity (not only CO₂ and waste)
› Lack of local data
› Lack of rules for monetization (balancing discount rate, tax etc.)

Global Warming Potential – Overpass Vindingeøj
(ETSI, 2013)
Summary

› We see a growth in number of prefabricated bridges
› Growth is primarily driven by society costs (road user disturbance)
› Some reservations related to aesthetics
› Tools and data for LCC and LCA are needed
› Tendering and contractual setup shall support the above
› Gathering of data/experience is needed from all partners and especially for infrastructure managers
Thank you

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