ISH0306 - Consultancy for the Development of Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries

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Final Regional Workshop
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SUSTAINABLE HYDROPOWER CONSTRUCTION
Energy delivered / energy invested
Embodied energy
Zero Emissions

Typically 45% of lifetime energy in a traditional house is consumed during construction.

Zero energy house (BRE Watford UK).

Solar PV, south facing roof, LED lighting and a heat pump. Exports energy to the grid.

100% emissions in construction
Whole life thinking

Designers and regulators need to take embodied energy and carbon into account and move from a vision where controlling operational emissions is the ultimate aspiration to one where minimising whole life carbon emissions is the norm.

Institution of Civil Engineers (UK) – May 2015
Cradle to grave energy

Comprises:

a) Initial embodied energy – abstraction, processing, transportation and assembly at site.

b) Recurring embodied energy – needed to refurbish and maintain the structure (does not include operational energy)

c) Demolition energy – needed to demolish and remove the structure.
Embodied carbon

A similar approach can be adopted when assessing embodied carbon but with additional consideration of:

1. Sequestration of carbon in some building materials such as timber;
2. Emission of carbon (dioxide) in the production of materials such as cement; and
3. Long term sequestration of carbon by materials such as concrete.
# Energy & carbon of typical materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied energy (MJ/kg)</th>
<th>Embodied carbon (kgC/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>4.6</td>
<td>0.226</td>
</tr>
<tr>
<td>Concrete (general)</td>
<td>0.95</td>
<td>0.035</td>
</tr>
<tr>
<td>Concrete (pre-cast)</td>
<td>2</td>
<td>0.059</td>
</tr>
<tr>
<td>Glass</td>
<td>15</td>
<td>0.232</td>
</tr>
<tr>
<td>Steel (42.3% re-cycled)</td>
<td>24.4</td>
<td>0.428</td>
</tr>
<tr>
<td>Steel (primary)</td>
<td>35.3</td>
<td>0.749</td>
</tr>
<tr>
<td>Steel (stainless)</td>
<td>56.7</td>
<td>1.676</td>
</tr>
<tr>
<td>Steel (plate)</td>
<td>48.4</td>
<td>0.869</td>
</tr>
</tbody>
</table>

Construction emissions
Construction emissions - assessment

It is good practice to audit energy use and carbon emissions during construction to identify where improvements can be made.

- Consider material selection – use recycled materials if possible
- Use locally available sources and efficient transport options
- Consider energy sources – use standard industry software to assess options
### Embodied Carbon dioxide by location

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (t)</th>
<th>CO₂ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof and mega columns</td>
<td>52,800</td>
<td>4.9</td>
</tr>
<tr>
<td>Above ground structure</td>
<td>14,600</td>
<td>1.3</td>
</tr>
<tr>
<td>Below ground structure</td>
<td>870,200</td>
<td>80.2</td>
</tr>
<tr>
<td>Foundations</td>
<td>124,900</td>
<td>11.5</td>
</tr>
<tr>
<td>Excavations</td>
<td>23,200</td>
<td>2.1</td>
</tr>
</tbody>
</table>

### Embodied Carbon dioxide by material

<table>
<thead>
<tr>
<th></th>
<th>CO₂ (t)</th>
<th>CO₂ (%)</th>
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</thead>
<tbody>
<tr>
<td>Steel</td>
<td>138,500</td>
<td>12.1</td>
</tr>
<tr>
<td>Concrete</td>
<td>539,500</td>
<td>49.7</td>
</tr>
<tr>
<td>Reinforcement</td>
<td>387,700</td>
<td>35.7</td>
</tr>
<tr>
<td>Façade</td>
<td>3,200</td>
<td>0.3</td>
</tr>
<tr>
<td>Glass</td>
<td>600</td>
<td>0.1</td>
</tr>
<tr>
<td>Excavation</td>
<td>23,200</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Construction emissions – Mersey Barrage

The Mersey Tidal Power Project would be the largest tidal range project in the World.

- Installed capacity 700 MW
- Ave annual energy 900 GMh

Construction emissions 783,174 tCO₂
Emissions saving (20 yrs) 9,774,540 tCO₂ (positive after 1.6 years – typical HEP = 6 months)

<table>
<thead>
<tr>
<th>% CO₂ Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced concrete structures</td>
</tr>
<tr>
<td>Structural steel and plant</td>
</tr>
<tr>
<td>Aggregates and sand</td>
</tr>
<tr>
<td>Materials and plant transport</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>
Construction emissions – design decisions

Choice of slope engineering options can be informed by carbon calculators: e.g. Washington Dules Airport

Examining the carbon footprint and reducing environmental impact of slope engineering options – O’Riordan et al – Ground Engineering Feb 2011
Construction plant – power & lighting

a) Monitoring & targeting – sub metering will identify where energy is being used;
b) Grid connection – generator supplied energy is typically double the cost of grid energy and has considerably higher carbon emissions;
c) Lighting – specifying lower wattage and LED lighting could reduce energy use by 20%;
Construction plant - generators

a) Avoid oversizing – a generator should not be run at less than 30% load. Peak efficiency will be above 70% load;
b) Power factor – balance load across all three phases, minimise harmonic distortions;
c) Monitor efficiency – fit fuel and output meters, use a digital inverter for part loads.
Construction plant - compressors

a) Match demand – up to 90% of energy used by a compressor is wasted in heat and noise;
b) Efficiency – use sealed for life bearings, avoid re-conditioned units, replace filters;
Construction plant – earth moving equipment

Specifying modern high efficiency earth moving plant makes sense commercially and is better for the environment.

Performance Handbooks specify:

• Production figures and cycle times
• Capacity data
• Owning & operating costs
• Typical fuel consumption data
Data for fuel consumption and emissions is typically based on steady state engine dynamometer tests and does not take account of cycle times.

Estimators pay little attention to the environmental impact of plant selection.

CO₂ emissions have become the focus of taxation policy and better methods of estimation at the planning stage are required.
CO$_2$ from earthworks

- Traditionally balancing cut and fill was the objective but improved efficiency can be achieved by:
  - Addition of lime to overly wet, marginal, site won materials;
  - Finding use for construction waste in landscaping;
  - Classifying materials by class to optimise haul distances.

- Variables such as material density, gradient and haul distance make CO$_2$ estimating difficult for earthworks. A specific earthworks carbon calculator is required.

Construction materials from waste

- PFA can be moistened, formed into pellets and sintered to form light weight concrete aggregate (1,000 kg/m$^3$) – Lytag;

- Reinforcing steel can be made entirely from scrap resulting in a 35% drop in embodied CO$_2$;

- Crushed construction waste can be used for low quality concrete aggregates;

- Cement replacement products such as granulated blast furnace slag could achieve a 34% reduction in embodied CO$_2$.

Embodied Carbon Dioxide as a design tool – Knight & Addis – ICE Proceedings November 2011 – 164 Paper 1100021
Concrete Gravity Dams
Design

Power potential ~ height

Stability, and therefore mass requirement ~ height^2
Design

Conduct whole life energy and carbon audits to inform basic project design decisions. Can material use be reduced while producing the same result?
Ordinary Portland Cement

50 kg cement bag

Embodied energy ~ 4.6 MJ/kg
= 64 kWhr per 50 kg bag

Embodied carbon ~ 0.226 kgC/kg
= 11.3 kgC per 50 kg bag

Hydration will produce:
\[ C_3S + C_2S + C_3A + C_4AF + \text{hydroxides} \]
Ordinary Portland Cement

Cement kilns can be part fired with:
- Used tyres;
- Paint sludge from the car industry;
- Waste solvents and lubricants;
- Slaughter house waste (BSE precaution);
- Waste plastics;
- Sewage sludge;
- Rice and sugar cane waste;
- Used wooden railway sleepers

The cement industry can also provide a use for:
- Blast furnace slag – smelters
- Fly ash – coal fired power stations
- Silica fume – steel industry
- Synthetic gypsum – de-sulphurisation
RCC dam construction

Roller Compacted Concrete will usually provide the lowest cement content solution.

- Placed in 300 mm layers using conventional construction plant
- Cement + pozzolan ~ 150 kg / m³
- Fines content = 12 - 14% of total solids for cohesion (comprising cement + pozzolan + added stone powder + <75μ aggregate fines)
RCC dam construction - pozzolan

Mae Moe (Thailand) annual pozzolan production = 1.9 Mt from burning 16 Mt of lignite.

Limestone is added in the final process to remove nitric acid.

No separation of clinker, cinder and fly ash, but sieved < 45 μm.

ASTM C618-93 compliant, finely divided reactive silica to produce stable calcium silicate precipitates if alkalinity is sufficiently high.
RCC dam construction – lift joints

Hot joint ~ 3 hours (without retarder)
Cold joint ~ 24 hours
Avoid warm joints
RCC dam construction – lift joints

Nam Ngiep 1 – Lao PDR
RCC dam construction – lift joints

Sloping layer method
RCC dam construction – temperature

Temperature (long term)

Water filling completion
RCC dam construction – block joints

Upstream face – GERCC zone + double water bar & vertical drain at joints

Monolith joint induced in hot layer + GERCC zone at downstream face
Cement contents in RCC dams can be progressively reduced as confidence increases that design strengths can be achieved.
RCC dam construction – energy in the dam

Cement content at Nam Ngiep 1 has been progressively reduced from 80 to 60 kg/m$^3$.

Total volume of dam = 2.3 M m$^3$

Total potential cement saving at 10 kg/m$^3$ = $23 \times 10^6$ kg

Total energy saving = 29.5 GWh

Total embodied energy from cement in the dam (at 70kg/m$^3$)

= $2.3 \times 10^6 \times 70 \times 1.28 = 206$ GWh

Equivalent to a 24 MW power station at continuous full output for one year
Design lifetimes
Durability – hydro-mechanical

Low quality paint system on carbon steel

Unserviceable gate guides and step irons

High specification stainless steel guides and sealing faces
Durability - concrete

Damage to Concrete Structures – Geert de Schutter – CRC Press
Durability - concrete

Damage to Concrete Structures – Geert de Schutter – CRC Press 2013
Design life

Laggan Dam
(1934)
Conclusions

• Whole life thinking is required to inform basic design decisions;

• Estimates of embodied energy and carbon can be used as a design tool and should be a requirement;

• A site for a hydropower scheme is a unique opportunity. The energy is re-newable – the site is not.

Considerations of sustainability and durability should become key considerations in river basin development and project design.
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