Demountable and reusable composite floor systems

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Principles of demountable composite beams

- Shear connectors can be disconnected from the beams and the steel beams are reused
- Composite slab may be cut into segments, demounted and reused in the same sequence as in the original design
- Shear connectors are more flexible than welded shear connectors
- Long span secondary beams are more efficient and the shear connector arrangement may be varied to optimise performance
- Primary beams may be designed as non-composite to facilitate demounting of the slab
Types of shear connector - bolted

- 20mm dia. bolts have nuts above and below the flange
- Shear connectors may have threaded ends
- Close fit holes (21mm diameter)
Types of shear connector - coupler

- Bolts are fixed above and below to couplers
- Coupler is left cast into slab
- Close fit holes
Types of shear connector - friction

- Cylinders are cast in the slab
- Friction grip bolts are used
- Normal clearance holes
Ways of re-using the composite slab

- Use a full depth edge trim along the beams
- Partial depth edge trim to form a pre-determined cut line through the mesh reinforcement
- In demounting, make a transverse cut through the topping
- Slab segments should be suitable for lifting and transportation – 2.7m width x 3 to 4m span is proposed
- Slab segments are re-used by grout filling the cut lines (see later presentation by Prof Lam)
Typical push test results

Load (kN) vs. Slip (mm)

- $k_{sc,ini} = 28.7$ kN/mm
- $P_{d,6mm}$
- $k_{sc,sec} = 20.9$ kN/mm
- $P_{d,2mm}$
Tests on composite beams

- Shear connector tests at Univ. Bradford and Univ. Luxembourg
- Composite beam tests at TU Delft and Univ. Luxembourg
- Cellular beam test with bolted shear connectors at Univ. Bradford
- Assembly, demounting and re-assembly of composite car park structure at TU Delft
Test on composite cellular beam -11.2m span
Details of cellular beam test

- Cellular beam is composed of:
  - 305x 165 x 46 kg/m top Tee
  - 305x 305 x 97 kg/m bottom Tee
  - Asymmetry of 2.4:1

- Beam dimensions
  - Span of 11.2m
  - Slab width of 2.8m (= L/4)
  - Beam depth of 427mm (L/h = 26)
  - Slab depth of 150mm (using 80mm decking)
Cellular beam section

305x165 x 46 kg/m UB top Tee

305x305 x 97 kg/m UC bottom Tee
Beam details with edge trim to form cut lines for demounting
Cellular beam test at failure
Cellular beam load-deflection curve
Cellular beam – bolted shear connector slip

Graph showing the relationship between total load (kN) and slip at the 2nd bolt from the beam end (mm). The graph indicates a significant increase in slip at around 700 kN, followed by a decrease as the load decreases.
Cellular beam test – key results

- Failure load is 24.1 kN/m² plus self-weight of 3 kN/m²
- Deflection at 5 kN/m² = 16mm (=L/700)
- End-slip at failure = 6 to 8mm
- Degree of shear connection was 38% (for 70 kN shear connector resistance) < 84% to Eurocode 4 for 2.4:1 asymmetry
- Failure mode by yielding of the bottom Tee in tension
- Evidence of web-post yielding in shear between the openings
Cellular beam test at failure
## Summary of cellular beam test results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test</th>
<th>Theory</th>
<th>Ratio</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending resistance</td>
<td>1190 kNm</td>
<td>1073 kNm</td>
<td>1.11</td>
<td>Based on shear connector resistance of 70 kN and steel mill certs.</td>
</tr>
<tr>
<td>Pure vertical shear resistance</td>
<td>425 kN at support 318 kN at first cell</td>
<td>340 kN at cell 3</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>Vierendeel bending resistance</td>
<td></td>
<td>318 kN</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Web-post shear or buckling resistance</td>
<td>Horizontal shear= 257 kN at web-post 3/4</td>
<td>229 kN-shear 275 kN-buckling</td>
<td>1.12</td>
<td>Horizontal shear failure of the top web controls</td>
</tr>
<tr>
<td>Deflection under self-wt. of concrete</td>
<td>29.5mm wet and 28.3mm dry</td>
<td>28.3mm</td>
<td>1.0</td>
<td>Close using the bending stiffness at the opening</td>
</tr>
<tr>
<td>Deflection under 5 kN/m² imposed load</td>
<td>16.0mm</td>
<td>16.8mm</td>
<td>0.95</td>
<td>Theory is based on shear connector stiffness of 30 kN/mm</td>
</tr>
</tbody>
</table>
Design methods for demountable composite beams

- Plastic method to Eurocode 4 with modifications due to the load-slip relationship of the shear connectors
- Utilisation factor, UF < 0.9 to avoid permanent deformation in first cycle of use
- Minimum degree of shear connection taking account of UF
- Elastic method is used for serviceability to calculate deflections and end slip
- Elastic method may also be used at the ultimate limit state (as a lower bound for all cases and also for Class 3 or 4 sections)
Effective inertia of composite section

\[ I_{\text{eff}} = I_s + \frac{I_c}{n} + \left( \frac{n A_s}{A_c} + \left( \frac{\pi}{L} \right)^2 E_s A_s \left( \frac{s_{sc}}{k_{sc}} \right) \right) \]

- \( k_{sc} = \) shear stiffness of shear connectors
  \( \approx 30 \text{ kN/mm} \) for bolted shear connectors
- \( s_{sc} = \) equivalent spacing of shear connectors
Load-slip distribution along beam
Elastic limits for demountable composite beams

- Stresses depend on un-propped or propped construction
- End slip at serviceability ≤ 1.2mm
- End slip at ultimate limit state ≤ 2mm, so that deformations are not permanent in the first use cycle
- Additional deflection due to the flexibility of the shear connectors is calculated
- Equivalent spacing of shear connectors is dependent on their distribution
Reuse of demountable composite beams

- Beam and slab are re-used
  - The composite slab is cut into segments and re-used in the same order on the same beam
  - The beams are re-used in the same configuration i.e. the building is moved

- Beam is re-used
  - The beam is disconnected from the slab
  - The slab is demolished
  - The beam can be re-used with a new slab
Reuse of composite slabs in demountable construction

Composite slabs and steel beams with bolted shear connectors

- IPE or UB steel beams
- Cellular beams of asymmetric section

Second cycle of use

- Type 1 construction
  - Beams are salvaged and reused but the slab is not reused and demolished
  - New on-site concrete slab and new shear connectors
  - Welded shear connectors in second cycle of use

- Type 2a construction
  - Cement grout between the reused slab segments for compression transfer
  - Bolted shear connectors; further cycles of use are possible

- Type 2b construction
  - Additional concrete layer is placed on the slab segments for compression transfer
  - Additional design checks on composite beam for second cycle of use
Use of precast slabs in demountable composite construction
Conclusions on demountable composite construction

- Use long span composite construction to optimise performance and to minimise the components
- Demountable shear connectors have equivalent shear resistance to welded studs
- But they are more flexible, and so deflection calculations should include this effect
- Utilisation in first use, $UF \leq 0.9$ to avoid permanent deformation
- Minimise the degree of shear connection for most economic use
- Elastic design may be used with optimised shear connector distribution for both Serviceability and Ultimate limit states
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