Strengthening of building structures

Mon 14.03.2016
Introduction & Conservation

Repair methods of the roofing structures

Repair methods of the window and the door structures

Repair of fire damage

Repair methods for wooden structures

The use of ICT for condition assessment of structures

Building information modelling BIM

HVAC-renovation

Strengthening of building structures

Course Content
# Outlines

**• Strengthening**  
  - The need of structural strengthening  
  - Factors affecting selection of strengthening method  
  - Strategies for structural strengthening  

**• Strengthening techniques**  
  - Section enlargement  
  - External plate bonding  
  - External Post-Tensioning  
  - Ferrocement laminates  
  - Sprayed concrete  

**• Strengthening of concrete structures**  
  - Foundations  
  - Slabs  
  - walls  
  - Beams  
  - Columns  
  - Masonry walls  

**• Strengthening using FRP**  
  - Sprayed FRP  
  - FRP plates / strips  

**• Case study: Section enlargement using SCC**
Strengthening

The aim of strengthening is to increase the capacity of an existing structural element.

Strengthening can be achieved by:
- Replacing poor quality or defective material by better quality material
- Attaching additional load-bearing material
- Redistribution of the loading actions through imposed deformation of the structural system

The new load-bearing material:
- High quality concrete
- Reinforcing steel bars
- Thin steel plates and straps
- Post-tensioning tendons
- FRP composite materials
### The need of structural strengthening

- **Load increases due to:**
  - higher live loads,
  - increased wheel loads,
  - installations of heavy machinery
  - vibrations.

- **Damage to structural parts due to:**
  - aging of construction materials
  - fire damage,
  - corrosion of steel reinforcement
  - impact of vehicles.

- **Improvements in suitability for use due to:**
  - limitation of deflections,
  - reduction of stress in reinforcement
  - reduction of crack widths.

- **Modification of structural system due to:**
  - elimination of walls/columns
  - openings cut through slabs.

- **Errors in planning or construction due to:**
  - insufficient design dimensions
  - insufficient reinforcing steel
Factors affecting selection of strengthening method

<table>
<thead>
<tr>
<th>Factors</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude of strength increase</td>
<td></td>
</tr>
<tr>
<td>Effect of changes in relative member stiffness</td>
<td></td>
</tr>
<tr>
<td>Size of project</td>
<td>methods involving special materials and methods may be less cost-effective on small projects</td>
</tr>
<tr>
<td>Environmental conditions</td>
<td>methods using adhesives might be unsuitable for applications in high-temperature environments</td>
</tr>
<tr>
<td>Dimensional/clearance constraints</td>
<td>section enlargement might be limited by the degree to which the enlargement can encroach on surrounding clear space</td>
</tr>
<tr>
<td>Accessibility</td>
<td></td>
</tr>
</tbody>
</table>

- **In-place concrete strength and substrate integrity**
  - the effectiveness of methods relying on bond to the existing concrete can be significantly limited by low concrete strength

- **Environmental conditions**
  - methods using adhesives might be unsuitable for applications in high-temperature environments
  - external steel methods may not be suitable in corrosive environments

http://theconstructor.org/practical-guide/
Factors affecting selection of strengthening method

• **Operational constraints**
  – methods requiring longer construction time might be less desirable for applications in which building operations must be shut down during construction

• **Availability of materials, equipment, and qualified contractors.**

• **Construction cost, maintenance costs, and life-cycle costs**

• **Load testing to verify existing capacity or evaluate new techniques and materials**

http://theconstructor.org/practical-guide/
Strategies for structural strengthening

1. **Design faults**
   - Lower performance before taken into service
   - Strengthening slightly above the desired performance level

2. **Damaged due to an accident**
   - Collision, fire or overload that damaged the system to a level where performance requirements were not fulfilled
   - Repaired and strengthened to a new performance level

3. **Structure demands changes**
   - Higher load bearing capacity was required

   - Strengthening to meet the performance level
   - possible to keep the structure in service

---

Performance History of a Structure

http://theconstructor.org/structural-engg/strengthening-structures
Strategies for structural strengthening
Strengthening techniques

- Section enlargement
- External plate bonding
- Post-Tensioning
- Ferrocement laminates
- Sprayed concrete
- FRP
Section enlargement (Jacketing)

- **Jacketing**
  - Adding R.C. jacket section
  - Achieve the desired section properties and performance

- **Advantages**
  - Increasing of the load-carrying capacity
  - Increasing of the stiffness.

- **Disadvantages**
  - Increase in the concrete member size obtained after the jacket
  - The need to construct a new formwork.
Stages of section enlargement

i. Temporary supports

ii. Removal of the deteriorated concrete

iii. Corrosion removal from the exposed reinforcement

iv. Surfaces cleaning and preparation to ensure bonding with the repair material

v. Replacement or addition of the supplementary reinforcement

vi. Reinforcement protection (in some cases)

vii. Formwork and applying of the repair material
External plate bonding

- **Steel plates** or **steel flat bars** are bonded to the structural elements
- **Widely appear in strengthening of bridge structures.**
- **The bonding is ensured by:**
  - the use of epoxy adhesives
  - additional fastening by means of dowels or bolts glued to the holes drilled in the concrete members.
- **Disadvantages:**
  - it can be applied only to the relatively sound structures.

http://www.chemcosystems.com/tech_platebond.html
Post-Tensioning

- Effective in increasing the **flexural and shear** capacity
- Applied to **reinforced and pre-stressed** concrete members
- The post-tensioning forces are delivered by:
  - **Standard pre-stressing tendons**
  - **High-strength steel rods**
- Usually located outside the original section.
- The repair system supplements **minimal additional load** to the structure thus being an effective economical strengthening technique.

**Internal Post-Tensioning**

**External Post-Tensioning**
Stages of the post-tensioning strengthening

i. If there are existing spalls patching must be done, because this repairs must ensure that the pre-stressing forces are distributed uniformly across the section of the member

ii. The existing cracks must be repaired by means of epoxy injecting or other known methods

iii. The tendons are connected to the structure at anchor points, typically located at the ends of the member
Ferrocement laminates

- Thin composite material made of cement mortar reinforced with wire meshes.
- The wire meshes are uniformly distributed in continuous layers with relatively small diameters.
- The Ferro cement is used to replace the damaged concrete.
- Strengthening with Ferro cement improves:
  - cracking resistance
  - flexural stiffness
  - the ultimate loads compared to the original un-strengthened element.

- These improvements depend on the full composite action between the Ferro cement layers.

Sprayed concrete (shotcrete)

- It is one of the oldest materials and the most common techniques of repairing and strengthening of reinforced concrete structures.
- Sprayed concrete has been used in that field for almost 90 years.
- There are two processes for applying sprayed concrete:
  - **dry mix sprayed concrete** in which most of the mixing water is added at the nozzle.
  - **wet mix sprayed concrete** in which the ingredients, including water, are mixed before introduction into the delivery hose.
- Both dry mix and wet mix sprayed concrete are used in concrete repair/strengthening work, but the use of dry mix sprayed concrete is more common.
Shotcreting

Dry injection method

Wet injection method
Strengthening using Fibre Reinforced Polymer (FRP)
Strengthening using Fibre Reinforced Polymer (FRP)

- Lightweight
  - Easy to install

- High Strength
  - 5x steel

- Corrosion resistant
  - Durable structures

- Highly versatile
  - Suit any project

FRP Materials

Rak-43.3313 Repair Methods of Structures, exercise (4 cr)
Esko Sistonen & Fahim Al-Neshawy
Strengthening using Fibre Reinforced Polymer (FRP)

- Plastic and polymer materials that are reinforced with structural fiber such as
  - fiberglass (GFRP)
  - carbon fiber (CFRP)
  - aramid fiber.

**Common methods**

- Externally bonded FRP (EBR).
  - FRP plate bonding.
  - FRP Confining or jacketing

- Sprayed fiber reinforced polymers

Strengthening using Fibre Reinforced Polymer (FRP)

### Typical densities of FRP materials, kg/m³ (ACI Committee 440, 2002)

<table>
<thead>
<tr>
<th>Material</th>
<th>GFRP</th>
<th>CFRP</th>
<th>AFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>7,900</td>
<td>1,200 – 2,100</td>
<td>1,500 – 1,600</td>
</tr>
</tbody>
</table>

### Typical properties of prefabricated FRP strips and comparison with steel (FIB 2002)

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic modulus (GPa) - $E_r$</th>
<th>Tensile strength (MPa) - $f_r$</th>
<th>Ultimate tensile strain (%) - $\varepsilon_{fu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prefabricated strips</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low modulus CFRP</td>
<td>170</td>
<td>2800</td>
<td>1.6</td>
</tr>
<tr>
<td>High modulus CFRP</td>
<td>300</td>
<td>1300</td>
<td>0.5</td>
</tr>
<tr>
<td>Mild steel</td>
<td>200</td>
<td>400</td>
<td>25 ($Yield strain = 0.2 %$)</td>
</tr>
</tbody>
</table>

### E-glass fiber properties

- **Tensile strength (MPa):** 2410
- **Elastic modulus (GPa):** 79.0
- **Elongation (%):** 3.04

Strengthening using sprayed FRP

- Sprayed carbon or glass chopped fiber with **vinyl ester resin** upon concrete structures

- Benefits of using vinyl ester resin:
  - it takes shorter time to harden the resin than epoxy resin
  - the mechanical properties of vinyl ester resin are the same as the one of epoxy resin
## Typical FRP strengthening applications

<table>
<thead>
<tr>
<th>Type</th>
<th>Application</th>
<th>Fibre Dir.</th>
<th>Schematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural</td>
<td>Tension and/or side face of beam</td>
<td>Along long. axis of beam</td>
<td><img src="http://www.construction-innovation.info/images/pdfs/Research_library/ResearchLibraryC/Project_Reports/Review_of_Strengthening_Techniques_using_Externally_Bonded_Fiber_Reinforced_Polymer_Composites.pdf" alt="Section" /></td>
</tr>
<tr>
<td>Shear</td>
<td>Side face of beam (u-wrap)</td>
<td>Perpendicular to long. axis of beam</td>
<td><img src="http://www.construction-innovation.info/images/pdfs/Research_library/ResearchLibraryC/Project_Reports/Review_of_Strengthening_Techniques_using_Externally_Bonded_Fiber_Reinforced_Polymer_Composites.pdf" alt="Section" /></td>
</tr>
</tbody>
</table>
Typical FRP strengthening applications

- Flexural strengthening of slab
- Flexural strengthening of beam
- Wrapping of concrete tank
- Shear strengthening of beam-column joint
- Shear strengthening and confinement of column

Strengthening of concrete structures

- Foundations
- Slabs
- walls
- Beams
- Columns
- Masonry walls
Strengthening the foundations

Piling

Ref. www.lemcon.fi

Shotcreting
Concrete casting

Rak-43.3313 Repair Methods of Structures, exercise (4 cr)
Esko Sistonen & Fahim Al-Neshawy
Strengthening the foundations

- Columns foundations need strengthening in the case of applying additional loads.
- Widening and strengthening of existing foundations may be carried out by constructing a concrete jacket to the existing footings.
- The new jacket should be properly anchored to the existing footing and column neck in order to guarantee proper transfer of loads.
- This can be accomplished by drilling holes into existing concrete of footing and epoxy grouting the longitudinal reinforcement of jacket.
Strengthening the foundations

Column strengthening by casting new foundation

Temporary supporting with steel columns

WeeGee-house, ESPOO


Esko Sistonen & Fahim Al-Neshawy
Strengthening the foundations

WeeGee-house, ESPOO

Esko Sistonen & Fahim Al-Neshawy
Adding new steel bars to RC slab using section enlargement technique.
(a) from bottom, (b) from top

strengthening of reinforced concrete slab by removing the concrete cover and applying new bottom steel rods to flexural zones of slab to enhance its positive flexural capacity

applying new top steel rods to flexural zones of cantilever slab to enhance its negative flexural capacity

Ferrocement strengthening technique by adding wired steel mesh to R.C. slab

Strengthening of R. C. slabs

Strengthening a slab by increasing its depth from bottom

1. Supporting the slab, removing the concrete cover, cleaning the steel bars and coating them with epoxy.
2. Installing vertical and horizontal dowels at 25cm spacing in each direction.
3. Installing the new steel mesh.
4. Casting the surface with epoxy.
5. Pouring the required new layer of concrete.

Strengthening a slab by increasing its depth from top

1. Removing the concrete cover and roughening the surface.
2. Installing steel dowels at 25-50cm spacing in both directions.
3. Installing the new mesh and fasten it with the dowels.
4. Pouring the required new layer of concrete.

http://theconstructor.org/structural-engg/strengthening-techniques-r-c-slab/
Strengthening of R. C. slabs

- Strengthening the slab with stressing method
- Increasing punching shear capacity of the slab
  - Bolting through the slab
  - Strengthening hollow-core slabs
Strengthening the R.C. walls

The dimensions of the wall and its reinforcement are increased by the following steps:

1. Roughing the total area of the concrete surface.
2. Installing steel connectors for the whole surface at 25-30cm spaces in both directions.
3. Installing steel connectors into the wall footings, with the same number and diameter of the main vertical steel bars, using an epoxy material.
4. Installing the steel mesh and fasten it by steel wires to the steel connectors.
5. Coating the surface of the wall with an appropriate epoxy material.
6. Pouring the concrete jacket using low shrinkage concrete before drying of the epoxy material.

http://theconstructor.org/structural-engg/strengthening-of-r-c-walls/
Strengthening of R. C. beams

- Reinforced concrete beams need strengthening when the existing steel reinforcement or cross section in the beam is unsafe or insufficient

  or

- when the loads applied to the beam are increased due to the reasons mentioned before

Strengthening of R. C. beams

- Adding reinforcement steel bars to the main steel without increasing the beam’s cross sectional area
- Increasing both the reinforcing steel bars and the cross-sectional area of concrete
- Tensile and/or shear capacity is to be increased by gluing steel sheets / carbon fiber reinforced laminates into a lower and/or side surface of the beam
- Reinforced concrete beam is to be strengthened by adding new steel bars
**Strengthening of R. C. beams**

**ADDING STEEL PLATES TO THE BEAM**

1. Roughing and cleaning the concrete surfaces where the plates will be attached.
2. Coating the concrete surfaces with a bonding epoxy material.
4. Putting a layer of epoxy mortar on top of the plates with a 5mm thickness.
5. Attaching the steel plates to the concrete using bolts

**Strengthening of R. C. beams**

- Concrete beam is to be substituted with steel beam
- Steel profile is to be fixed into a concrete beam
- Steel profile is to be wedged below the beam

Reducing the load on the beam using steel beam

Strengthening of R. C. beams

Post-tension by external tendons

Share and Flexural Strengthening of Beam Using FRP

Rak-43.3313 Repair Methods of Structures, exercise (4 cr)
Esko Sistonen & Fahim Al-Neshawy
Strengthening of R. C. columns

- Strengthening of reinforced concrete columns:
  - Load increasing due to the increasing in floors number
  - Load increasing due to design mistakes
  - Compressive strength of concrete is not according to the code requirements
  - Percent or type of reinforcement is not according to the code requirements
  - Column inclination is more than allowable
  - Foundation settlement is more than allowable.

Strengthening of R. C. columns

• Entirely or partly jacketing
• Strengthening the column with the steel form
• Increasing cross sectional surface with steel profiles
• Substituting the concrete column with the steel column
Strengthening of R. C. columns

Rehabilitation Using Distributed Sacrificial Anode CP System

Memorial Bridge
Daytona Beach, Florida
181 Pile Jackets

ref: www.norcure.com
Strengthening of R. C. columns (Video)
Strengthening of masonry walls

Strengthening of Masonry Walls by Application of Single and Double sided reinforced concrete (RC) jackets

Strengthening of Masonry Walls using FRP Structural Repointing: (a) Grinding of masonry joints, (b) Masking of masonry to avoid staining, (c) Application of epoxy based paste to masonry joint, (d) Installation of GFRP Rods

http://theconstructor.org/building/strengthening-of-masonry-walls
Case study: Section enlargement using SCC
Case study: Section enlargement using SCC

Repairing process of the supporting walls, parapet and slab of the balcony using self-compacting concrete. (Batch 1, October 2004, laboratory condition)

Moulding work

Condition before casting

Condition after repairing
Case study: Section enlargement using SCC

Repairing process of the supporting column and slab of the balcony using self-compacting concrete (Batch 2, November 2004, outdoors condition)

Condition before casting

Moulding work

Condition after repairing
Case study: conclusions

- An objective with the work was to find the minimum cover depth of the self-compacting concrete (SCC) suitable for the repair method studied.
- Fresh and hardened concrete tests for the self-compacting concrete used showed that the concrete fulfilled the requirements for balcony repairing.
- The results of slab frost resistance tests show the scaling and flexural strength change of self-compacting concrete was very small after 300 cycles and the changes in ultrasound transmission time were small, so there is no sign of inner deterioration.

- Drying shrinkage of self-compacting concrete was higher than the theoretical shrinkage for the normal concrete because self-compacting concrete contained more fine aggregate. Using reinforcement mesh reduces the shrinkage of self-compacting concrete.
- The bond between the old concrete, which has a lower strength than the repairing self-compacting concrete, is poor specially, when casting concrete in the lower surface of concrete slab.
Summary

Lecture summary
- Introduction
- Strengthening techniques
- Strengthening of concrete structures
- Strengthening using FRP
- Case study: Section enlargement using SCC

Next Events:
- 21.03.2016: First excursion to the renovation site (Dipoli)
- 04.04.2016: Midcourse seminar
- 11.04.2016: Second excursion to the renovation site (Parliament house)

Next Lecture:
- Building information modelling BIM