KAEDAH PEMBAIKAN STRUKTUR

Emmy Sherina Ismail Hashim
Bahagian Perkhidmatan Forensik Struktur
Cawangan Kejuruteraan Awam dan Struktur (CKAS)

Kandungan

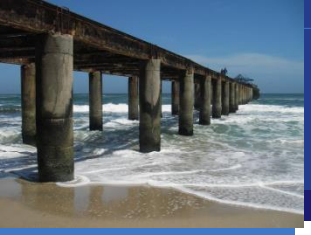
- Proses Pembaikan
- Keperluan Bahan
- Pelbagai Bahan Pembaikan
- Kaedah Pembaikan

PEMBAIKAN / PEMULIHAN

Untuk memulihkan sebahagian atau keseluruhan struktur yang rosak kepada tahap khidmat rekabentuk dan untuk meningkatkan ketahanlasakan.

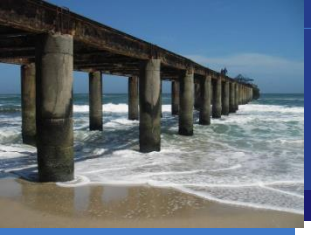
PENGUKUHAN (STRENGTHENING)

Untuk menaik taraf struktur kepada tahap khidmat rekabentuk yang lebih tinggi – meningkatkan keupayaan menanggung beban.



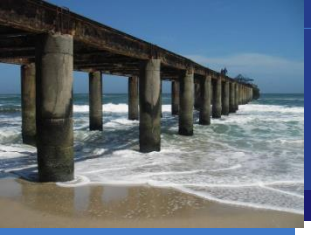
PROSES PEMBAIKAN

- Detailed Investigation
  - Visual Inspection
  - Defect Mapping
  - Non Destructive Test
  - Structural Analysis
- Diagnose Cause(s) of Defects
  - Durability problem
  - Structural problem
- Select Repair Method
  - Good Knowledge in Material Products and Repair Methods



JENIS KEROSAKAN

- Keretakan/delamination/pengupasan (spalling) disebabkan oleh pengaratan tetulang
  - Pengkarbonatan
  - Serangan klorida

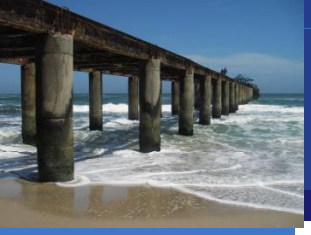


JENIS KEROSAKAN

- Keretakan disebabkan oleh pergerakan hakiki
  - pengecutan (*shrinkage*)
  - rayapan (*creep*)
  - penghidratan (*hydration*)
  - perubahan suhu

JENIS KEROSAKAN

- Kemerosotan Bahan
  - serangan asid
  - serangan sulfate

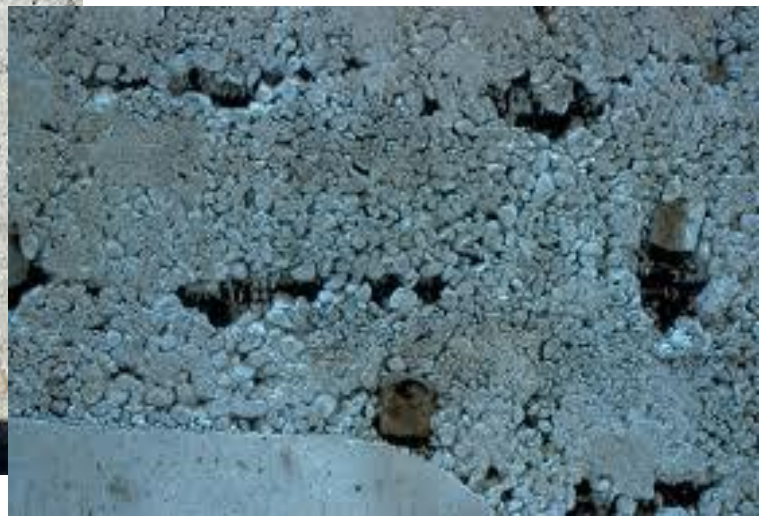


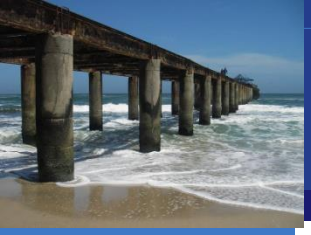
JENIS KEROSAKAN

- Keretakan disebabkan oleh kerosakan struktur
  - penambahan beban
  - kekurangan dalam rekabentuk & spesifikasi
  - mutu kerja yang tidak baik
  - pergerakan pada asas struktur

KEPERLUAN BAHAN

- Mesti mempunyai kebolehkerjaan yang baik
  - *Honeycomb*



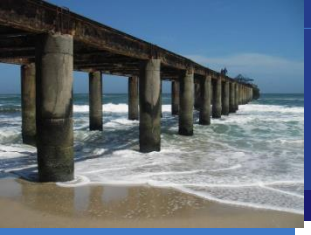


KEPERLUAN BAHAN

- Mesti mempunyai batu baur bukan reaktif
  - *Map-cracks*

KEPERLUAN BAHAN

- Rintangan yang baik terhadap ejen agresif
  - Pengkarbonatan – pengaratan tetulang

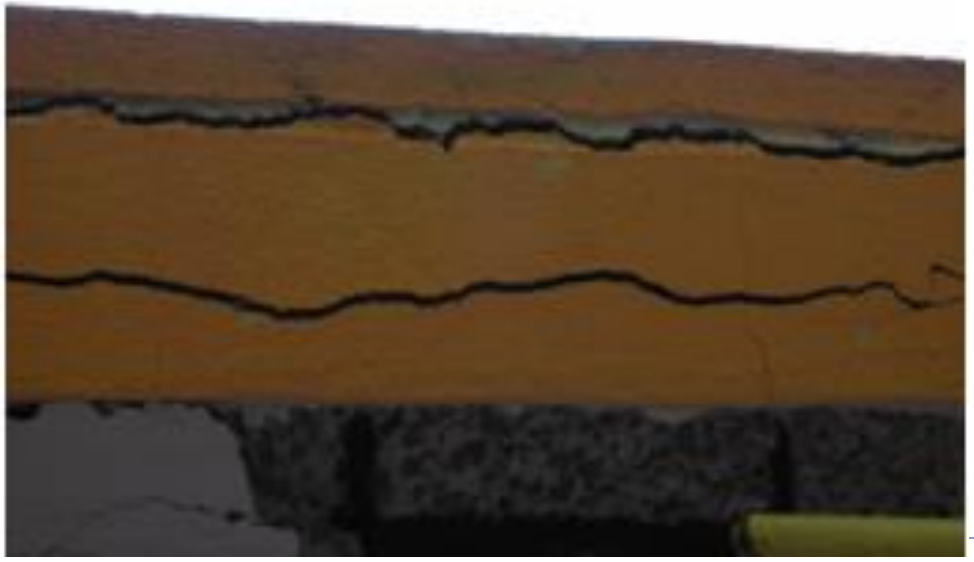


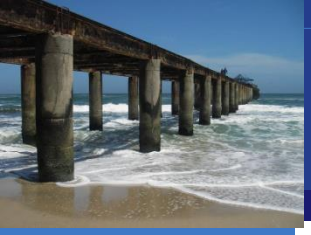
KEPERLUAN BAHAN

- Rintangan yang baik terhadap ejen agresif
  - Serangan Klorida– pengaratan tetulang

KEPERLUAN BAHAN

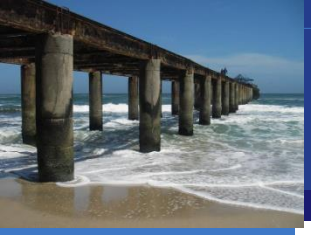
- Ikatan yang baik / pengecutan terpampas
  - *Delamination /* keretakan





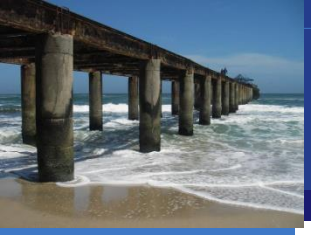
PELBAGAI BAHAN PEMBAIKAN

- **Kriteria Pemilihan Bahan**
  - Memahami keadaan khidmat
  - Memahami keadaan dedahan
  - Teknik pemasangan
  - Sifat bahan dalam pengawetan dan keadaan plastik



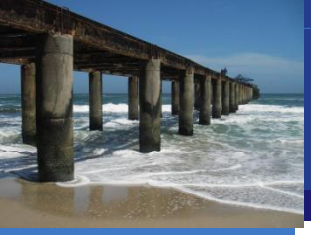
PELBAGAI BAHAN PEMBAIKAN

- **Prestasi Keperluan Bahan Pembaikan**
  - Ikatan yang baik untuk substrat konkrit
    - bersifat rencam (*compositely*)
  - Kekuatan
    - Sekurang-kurangnya kekuatan seperti konkrit yang sedia ada
  - Pengecutan yang rendah
    - Mengurangkan tekanan dalaman dan keretakan



PELBAGAI BAHAN PEMBAIKAN

- **Prestasi Keperluan Bahan Pembaikan**
  - Kebolehtelapan yang rendah
    - meningkatkan ketahanlasakan
  - Nisbah air-simen yang rendah
    - Meningkatkan ketahanlasakan
  - Kebolehkerjaan yang baik
    - Kebolehkerjaan di dalam ruang yang kecil



PELBAGAI BAHAN PEMBAIKAN

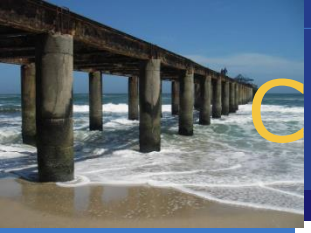
- **Prestasi Keperluan Bahan Pembaikan**
  - Pengembangan dan keanjalan
    - sesuai dengan konkrit sedia ada
  - Warna dan tekstur
    - adunan sama dengan konkrit sedia ada

PELBAGAI BAHAN PEMBAIKAN

- **Bahan-Bahan Biasa Bagi Pembaikan Konkrit**
  - ***Cementitious material***
    - *Cement-based mortar or concrete*
    - *Cement-based polymer modified concrete*
    - *Superfluid micro-concrete*
  - ***Resin-based material***
    - *Epoxy mortars*
    - *Resin-based polymer concrete*

Repair Materials – The Choice

- Cementitious material
  - Most widely used
  - Very close mechanical properties to the structure
  - Relatively cheaper
- Resin mortars
  - Very rapid high strength development
  - Higher resistance to physical attack such as high impact or abrasion
  - Provide less permeable cover
  - Higher resistance to chemically aggressive environment



Cement-Based Mortar or Concrete

- Wide availability and low cost
- Cement mortars for small repair and concrete for large repair
- Portland cement – high early strength or sulfate resistant
- Appropriate admixtures impact improved qualities

Epoxy Mortars

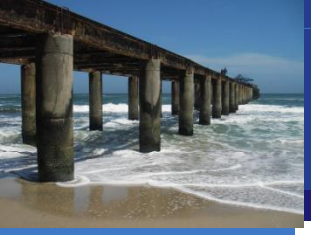
- Excellent bond properties
- High strength and rapid strength development
- Fast cure
- Excellent chemical resistance
- Insensitivity to moisture or a wet environment
- High resistance to impact and abrasion

Application for Epoxy Products

- Pressure grouting
  - Low-viscosity resins to fill fine cracks
- Concrete repair
  - An epoxy resin is mixed with filler aggregates
- Providing doweling action
- Repair of deck joints and concrete surfaces
- High resilience and strength under bearing pads
- Adhesion between fresh and old concrete

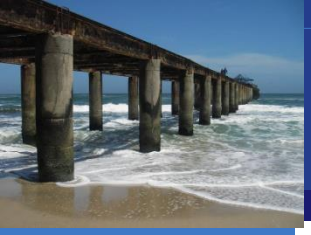
Cement-Based Polymer Concrete

- Polymer mixed with a cement-based mortar
- Emulsion
  - small, spherical plastic particles, disperses throughout the cement paste
- Concrete mix are blocked
  - Reducing permeability and shrinkage and improving chemical resistance, flexural strength, adhesion and resistance to abrasion

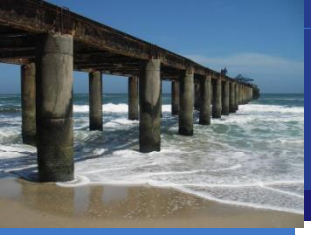


Superfluid Microconcrete

- Specialist formulator product
- High strength, polymer modified, free flowing cementitious material
- Pre-packed
  - Factory controlled quality
- Main used – Formwork repair
- Fluid cement grouts mixed with small aggregate (10mm)
  - Contain no metallic expansion system
  - Self compacting
  - Shrinkage compensated in both liquid and cured states



KAEDAH PEMBAIKAN



5 Repair Steps of Concrete Repair

Step (1) Reinforcement Protection

Step (2) Repair Mortar and Application Method

Step (3) Corrosion Inhibitor

Step (4) Re-profiling of Surfaces

Step (5) Protective Coating

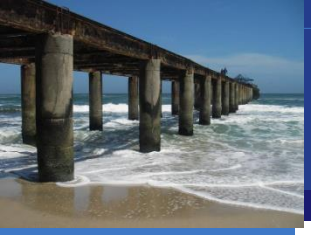
KAEDAH PEMBAIKAN

- Crack repair
- Patching repair / handplaced
- Formwork repair
- Sprayed Concrete

Crack repair methods

- Non-structure cracks
  - Wide crack- sealed with epoxy resin / cementitious grout injection(>0.25mm)
  - Fine crack- sealed with epoxy resin (<0.25mm)

- Structure cracks
  - Sealed with resin injection
  - Add reinforcement
  - Add steel plate

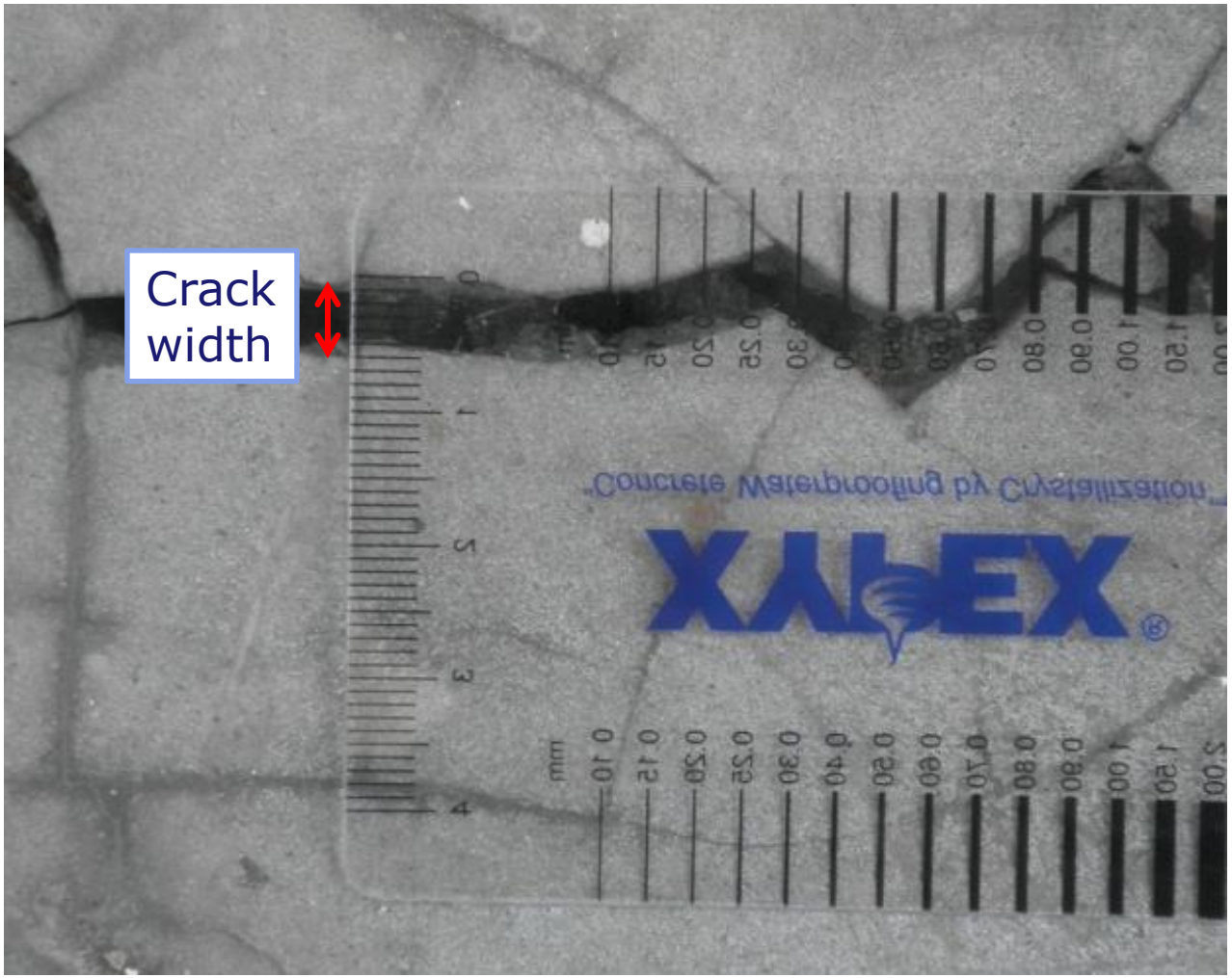


Why Cracks Need to be Sealed?

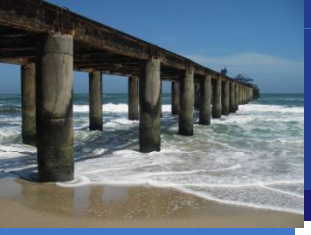
Cracks may be considered as a failure if they

- Are aesthetically unacceptable
- Make the structure non-watertight
- Affect the durability of the structure

Crack repair methods

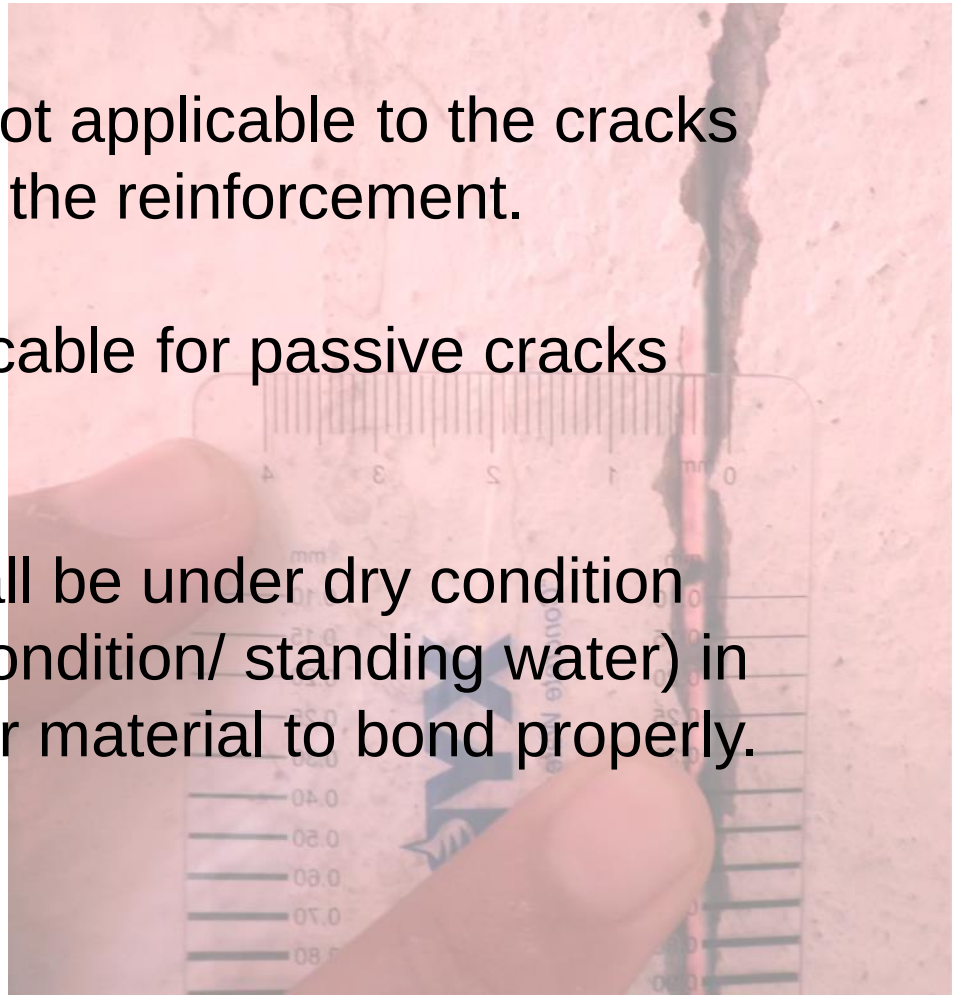


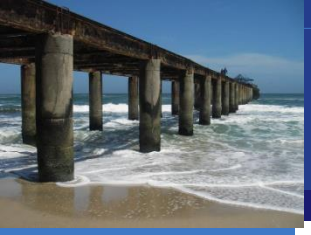
Crack Width	Repair Method
<0.25mm	Method 1
0.25mm – 5mm	Method 2
>5mm	Method 3



Crack repair methods

- This repair method is not applicable to the cracks caused by corrosion of the reinforcement.
- Repair Method is applicable for passive cracks (inactive cracks) only.
- All concrete cracks shall be under dry condition (strictly no damp/wet condition/ standing water) in order to allow the repair material to bond properly.





Classification of Cracks

Dormant Cracks

- Do not increase in size and length
- Result from shrinkage, initial movement of supports, previous structural overload
- May or may not need repair

Fine cracks – up to 1mm wide

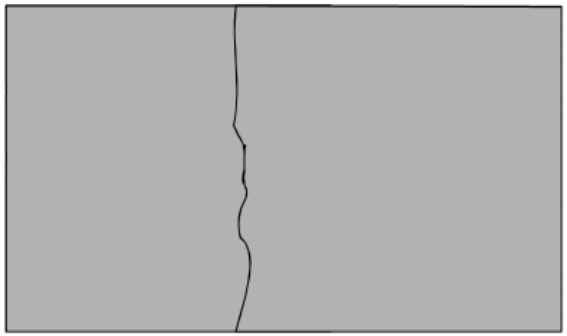
Wide cracks – from 1 to 6mm wide

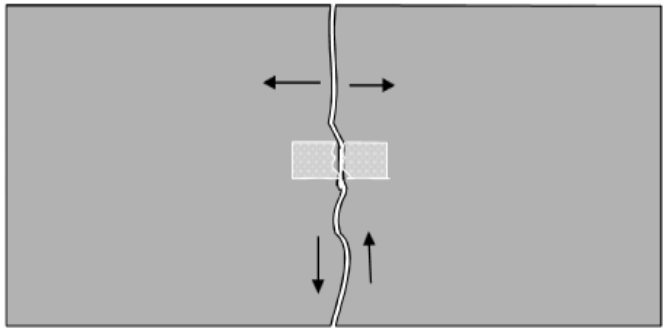
Fractures – over 6mm wide

Active Cracks

- Changed in width and length under load
- Formed in response to a continuing movement or to present overload
- Need to repair but difficult

Cracks width depends on movement

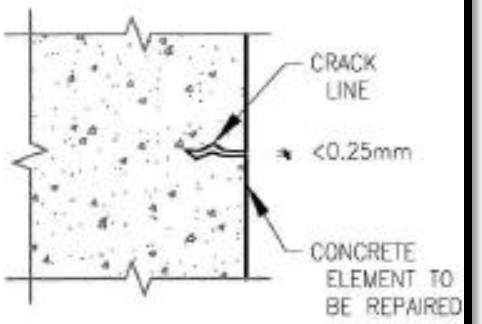




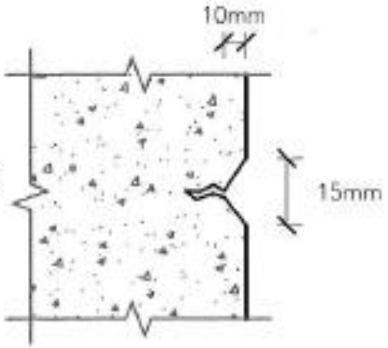
Crack repair methods

METHOD 1
CRACK WIDTH LESS THAN 0.25mm

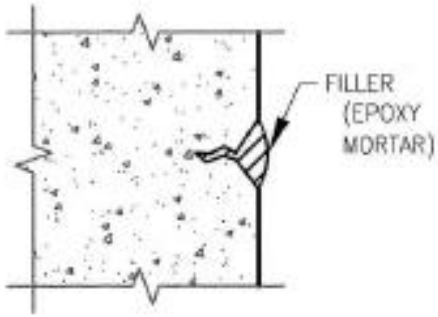
1. SURFACE PREPARATION
   - REMOVE ALL LAITANCE/UNSOUND PLASTER/EXISTING PROTECTIVE COATING.



2. SAW CUT "V" SHAPE GROOVE
   - CUTTING THE CONCRETE ALONG THE CRACK FOR DEPTH AND WIDTH OF 10mm AND 15mm RESPECTIVELY.



3. APPLY EPOXY GROUT AS A SURFACE SEAL
   - CRACK LINE TO BE FILLED UP WITH EPOXY MORTAR FILLER/GROUT.

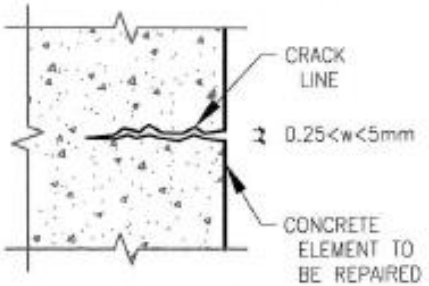


4. FINISH THE REPAIRED SURFACE TO AN EVEN SURFACE BY GRINDING.

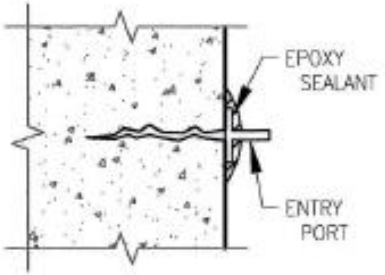
Crack repair methods

METHOD 2
CRACK WIDTH FROM 0.25mm UP TO 5.0mm

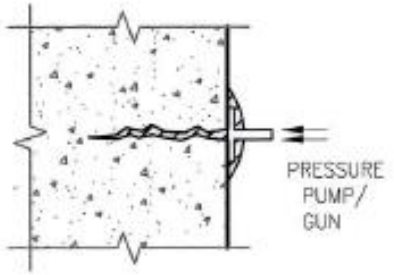
1. **SURFACE PREPARATION**
   - REMOVE ALL LAITANCE/UNSOUND PLASTER/EXISTING PROTECTIVE COATING.



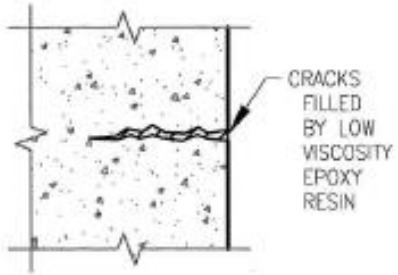
2. **ENTRY PORT INSTALLATION AND SEAL THE CRACK LINE USING EPOXY SEALANT.**
   - ENTRY PORTS SHALL BE SPACED 100mm APART.



3. **LOW VISCOSITY EPOXY RESIN INJECTION**
   - CRACK LINE TO BE FILLED UP WITH LOW VISCOSITY EPOXY RESIN.



4. **CLEAN AND FINISH THE REPAIRED SURFACE TO AN EVEN SURFACE BY GRINDING.**

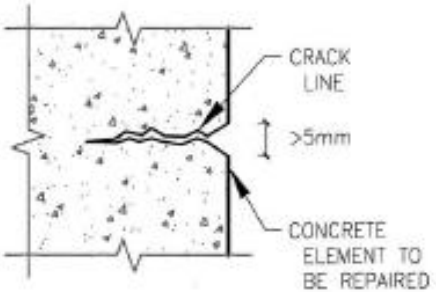


1. HORIZONTAL CRACKS – THE INJECTION OF THE LOW VISCOSITY EPOXY RESIN SHALL BEGIN AT THE WIDEST SECTION.
2. VERTICAL CRACKS – THE INJECTION OF THE LOW VISCOSITY EPOXY RESIN SHALL BEGIN AT THE LOWEST ENTRY PORT.
3. THE INJECTION OF THE LOW VISCOSITY EPOXY RESIN SHALL COMMENCE AT THE FIRST PORT UNTIL THE EPOXY RESIN FLOWS OUT FROM THE NEXT ADJACENT PORT.

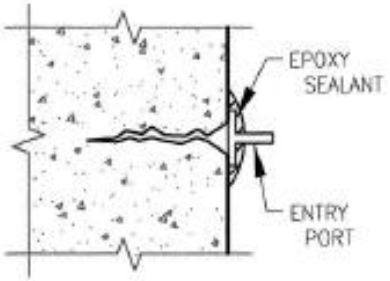
Crack repair methods

METHOD 3
CRACK WIDTH MORE THAN 5.0mm

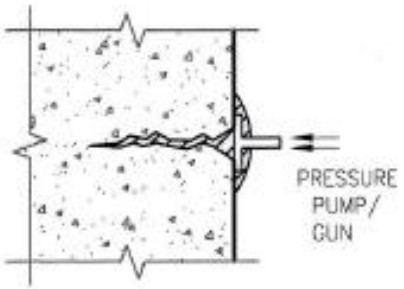
1. **SURFACE PREPARATION**
   - REMOVE ALL LAITANCE/UNSOUND PLASTER/EXISTING PROTECTIVE COATING.



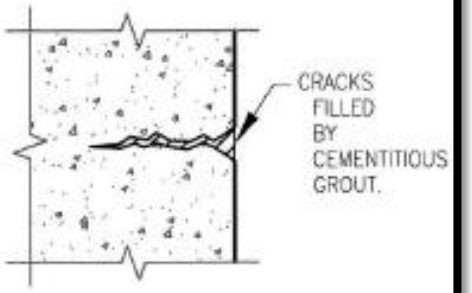
2. **ENTRY PORT INSTALLATION AND SEAL THE CRACK LINE USING EPOXY SEALANT.**
   - ENTRY PORTS SHALL BE SPACED 150mm APART.



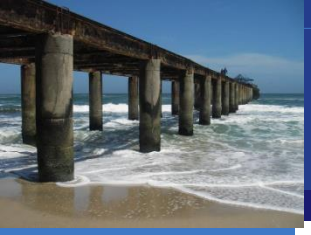
3. **CEMENTITIOUS GROUT INJECTION**
   - CRACK LINE TO BE FILLED UP WITH CEMENTITIOUS GROUT.



4. **CLEAN AND FINISH THE REPAIRED SURFACE TO AN EVEN SURFACE BY GRINDING.**

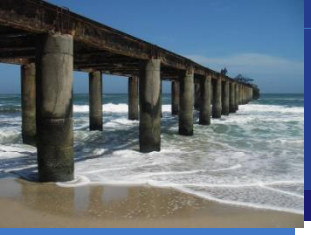


1. HORIZONTAL CRACKS – THE INJECTION OF THE CEMENTITIOUS GROUT SHALL BEGIN AT THE WIDEST SECTION.
2. VERTICAL CRACKS – THE INJECTION OF THE CEMENTITIOUS GROUT SHALL BEGIN AT THE LOWEST ENTRY PORT.
3. THE INJECTION OF THE CEMENTITIOUS GROUT SHALL COMMENCE AT THE FIRST PORT UNTIL THE CEMENTITIOUS GROUT TO FLOWS OUT FROM THE NEXT ADJACENT PORT.



The epoxy grout resin should satisfy the following properties:

Tensile strength (BS 6319: Part 7, ASTM D-638)	equal or more than 20 N/mm2
Compressive strength (BS 6319: Part 2, ASTM D-638)	equal or more than 80 N/mm2
Slant shear strength (BS 6319: Part 4, AASHTO T-237)	equal or more than 30 N/mm2
Flexural strength (BS 6319: Part 3, ASTM 0790)	equal or more than 50 N/mm2

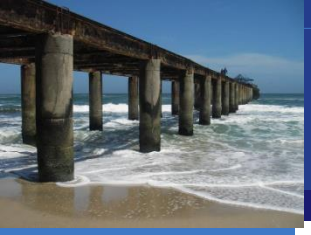


CRACK INJECTION

- Apply to repair cracks by injection epoxy grout into the cracks to 'locked' the concrete

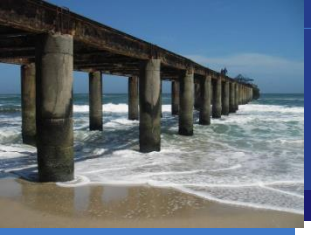
General Work Procedure

1. Surface treatment of crack
2. Seal crack surface and mark injection pipes
3. Fit injection pipes
4. Commence injection work
5. Final surface treatment



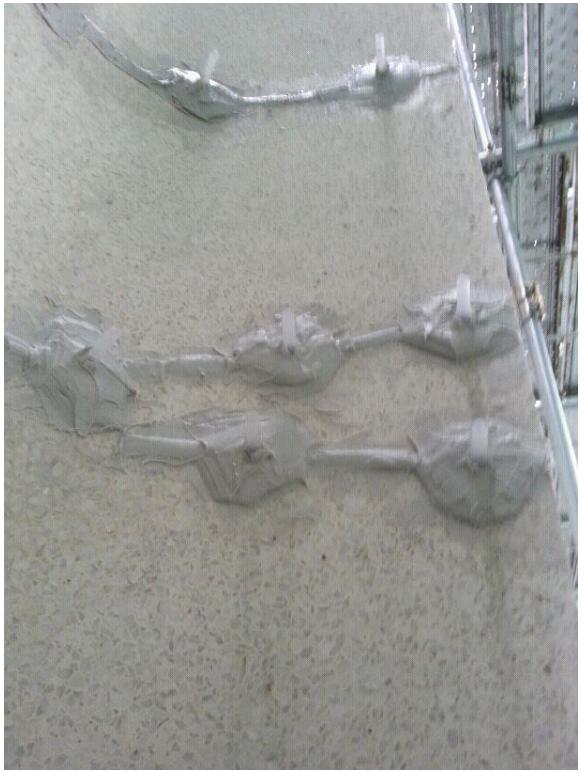
Epoxy Injection Work Sequence

1. Mark crack locations and remove any loose material with wire brush.
   Oil and grease should be clean with a piece of Cloth dipped into thinner.



Epoxy Injection Work Sequence

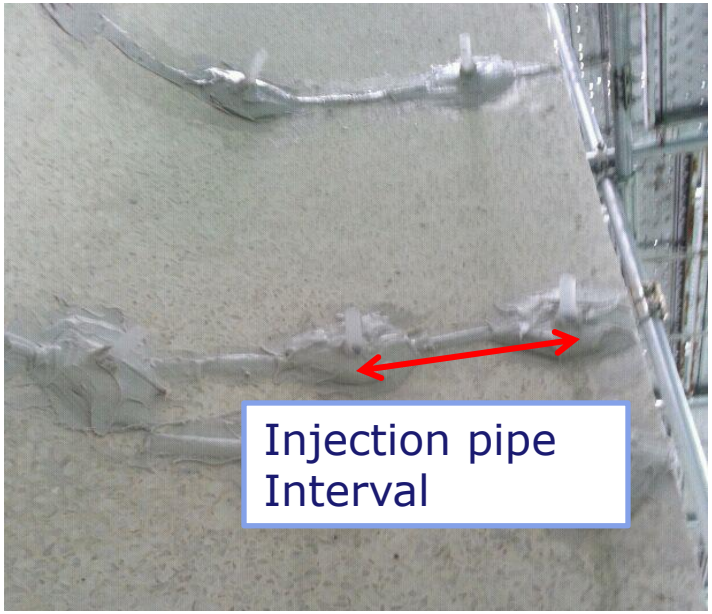
2. Attach fitting pipes at Injection points.



* spacing between injection points differ with crack width

Spacing between injection points differ with crack width

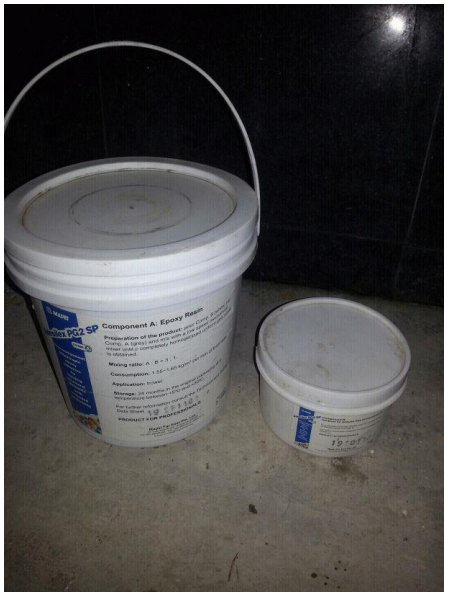
Crack Width (mm)	Injection Pipe Interval (mm)
< 0.3	50 - 100
0.3 – 0.5	100 - 200
0.5 – 1.0	150 - 250
> 1.0	200 - 300



Epoxy Injection Work Sequence

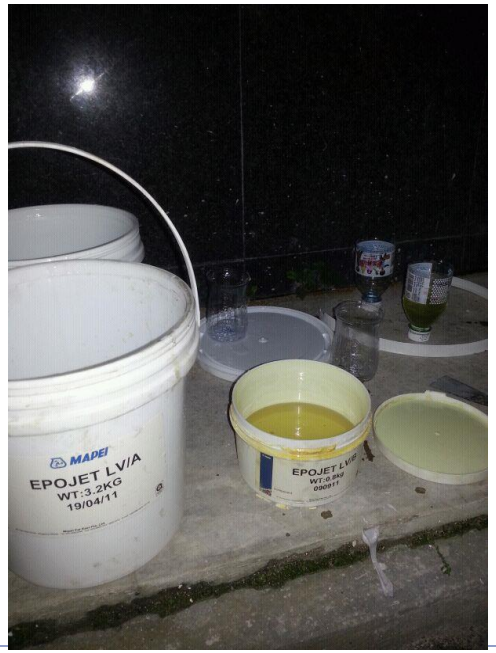
3. Seal crack surface to a thickness of about 3mm and width of 50mm and cure until it harden.

4. Screw in the INJECTION into the fitting pipes



Epoxy Injection Work Sequence

5. Pour the mixed grout into the pump and commence injection work after fixing pump hose to the injection pipe.



Epoxy Injection Work Sequence

6. Cure the injection material until it has hardened.

7. Remove the fitting pipe by hammering it off.

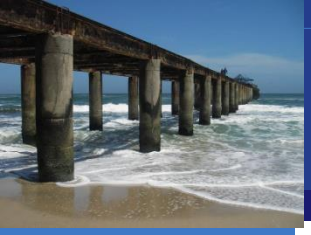
8. Finish the repaired areas to a flat surface using disc grinded.

Concrete Repair Process

- Removal of defective concrete
- Reinforcement preparation
  - Removal of corrosion products
  - Lap new reinforcement
  - Priming
- Place repair material
  - Patch repair
  - Formwork repair
  - Guniting
  - Prepacked grouting
- Protective coating

Removal of Defective Concrete

- Mark areas to be removed
- Saw cut edges of repair area by 10 mm – 20 mm deep
- Concrete removal by jack hammers or waterjet
  - Removal must not damage rebar
  - Removal must be 20mm behind rebars
    - Remove contaminated concrete
    - Provide access for cleaning corrosion
  - Removal additional 50mm beyond corroded rebar



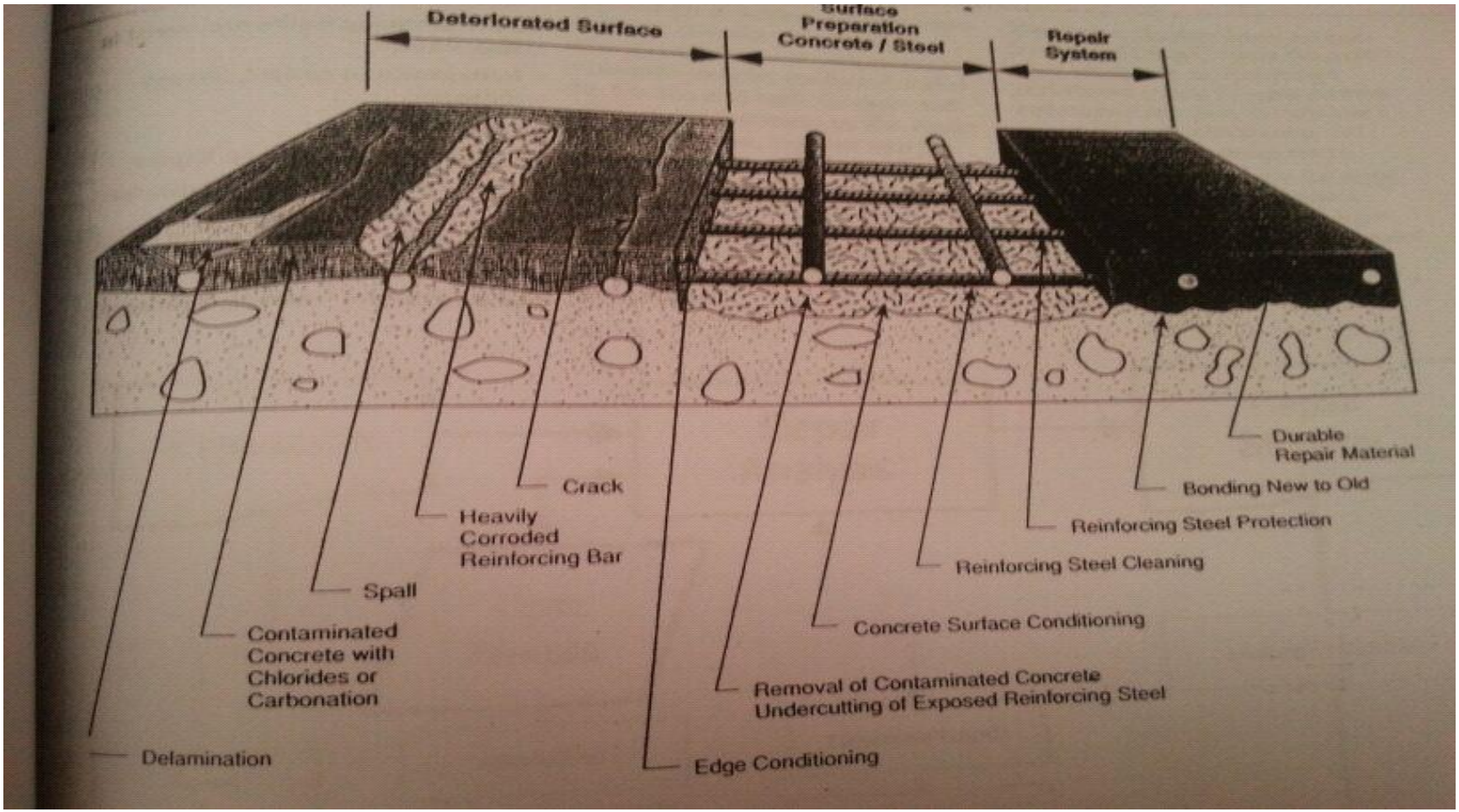
Removal of Defective Concrete

- Clean remaining concrete surface
  - High pressure air
  - High pressure water jet
- Removal only on alternate columns / beams within same span
  - No imposed load directly above

Reinforcement Preparation

- Remove all corrosion products
  - Wire brush
  - Sand/grit blasting
- Rebar corrosion more than 10% has to be supplemented
  - Minimum lap length = 42 Dia
- Prime rebar within 2 hours of cleaning using zinc-rich type primer

Sequence of Concrete Repair Process



Application Criteria for Patching

- Inactive defects due to honeycomb, spalling, cavity etc.
- Spalling/ defective area not more than 0.5m2
- Localised / small defect
- Causes
  - Poor workmanship
  - Minimal carbonation
  - Inadequate cover

Concrete Patch Repair

NOTES

1. Marking and removal of defective concrete :

(a) Locate the damaged areas.

(b) Mark the perimeter of repair area.

(c) Cut back the concrete surface to prevent feather edges. Remove all damaged concrete to expose sound concrete substrate using appropriate tools.

(d) Remove all fragments or other contaminants to fully expose surface.

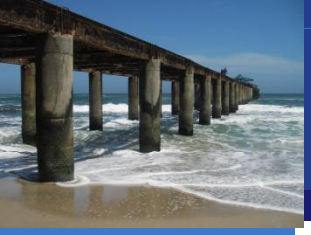
(e) Remove the damaged concrete behind the reinforcements with minimum of 20 mm clearance.

2. Surface treatment to reinforcement :

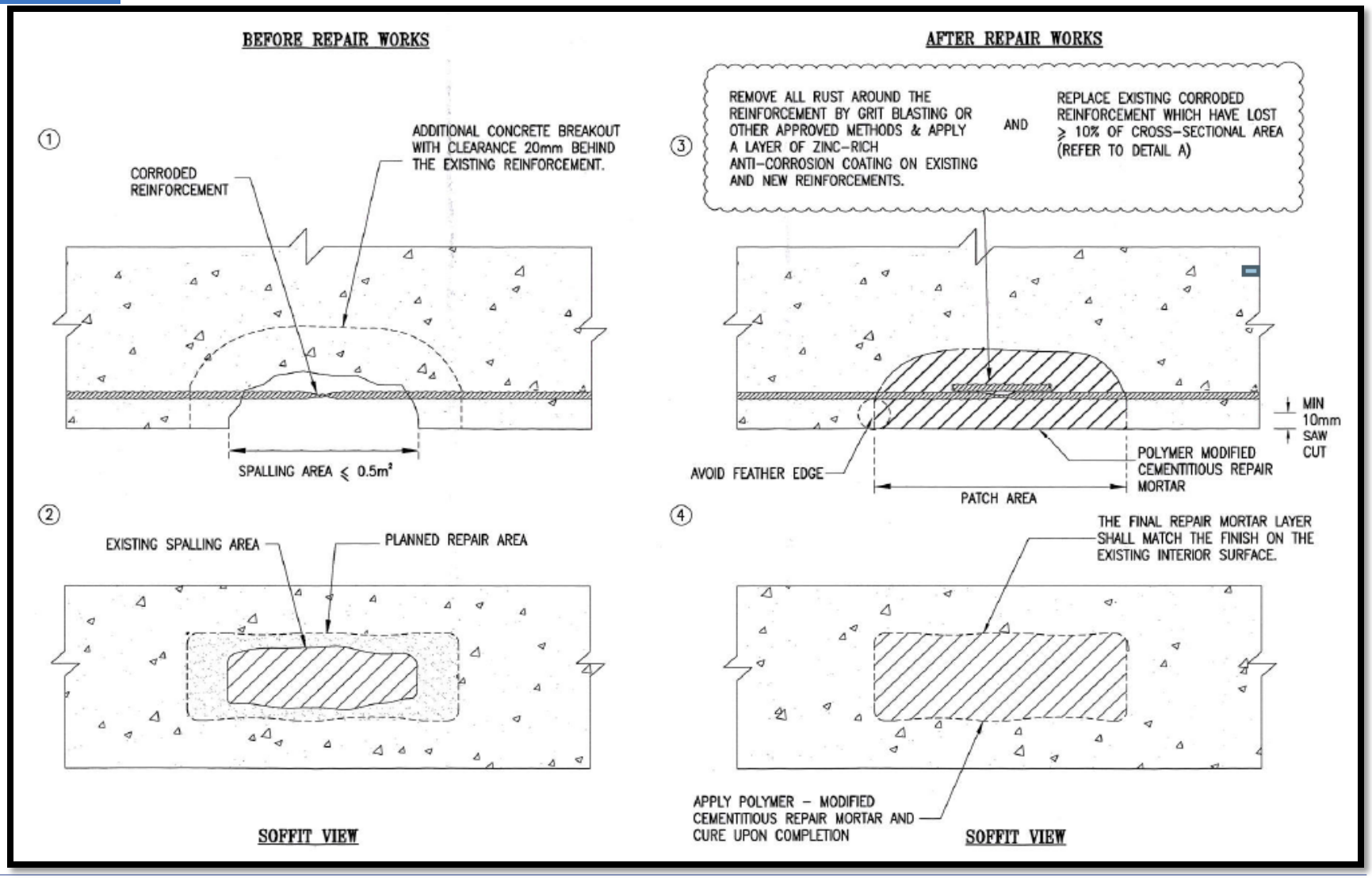
(a) Remove all rusts around corroded reinforcements using approved appropriate tools.

(b) For heavily corroded reinforcements with $\geqslant$ 10% reduction in cross-sectional area, add supplemental reinforcements.

(c) Apply a layer of zinc-rich anti-corrosion coating to all existing and new reinforcements.

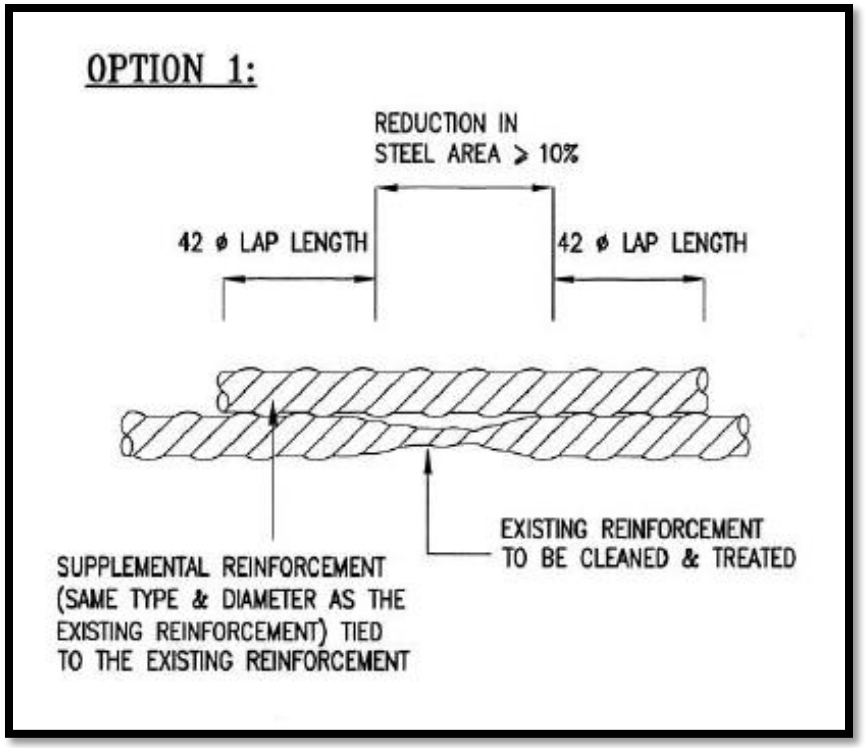


Concrete Patch Repair

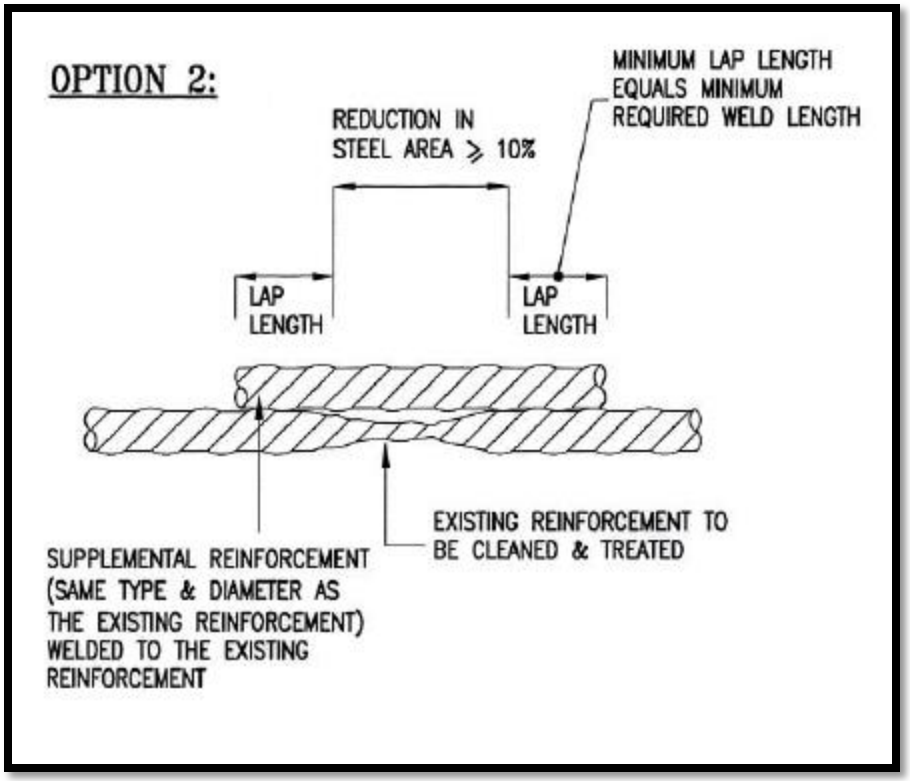


Concrete Patch Repair

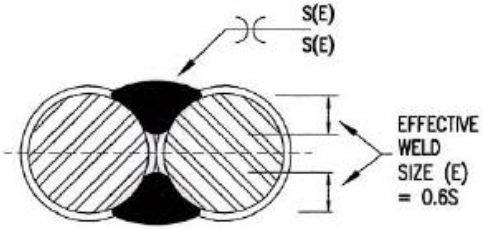
LAPPING FOR NEW REINFORCEMENT



Concrete Patch Repair



MINIMUM REQUIRED WELD LENGTHS FOR STEEL REINFORCEMENT	
BAR SIZE (mm)	DOUBLE FLARE V-GROOVE WELD (mm)
10	80
12	100
16	130
20	160
25	200
32	260



DOUBLE FLARE V-GROOVE WELD

LAPPED, WELDED SPLICE DETAIL

NOTES:

1) RADIUS OF STEEL REINFORCEMENT = S.
2) THESE ARE SECTIONAL VIEWS. BAR DEFORMATIONS ARE SHOWN ONLY FOR ILLUSTRATIVE PURPOSES.

Patch Repair Work Sequence

1. Mark out repair area
    * Define defective location

Patch Repair Work Sequence

2. Break out concrete using jack hammer or other mechanical means
   * Remove behind corroded steel

3. Saw cut edges of repair zone
   * No feather edges

Patch Repair Work Sequence

4. Clean corrosion products by grit blasting or wire brushing

Patch Repair Work Sequence

5. Prime reinforcement within 2 hours of preparation using zinc-rich type primer

Patch Repair Work Sequence

6. Wet substrate with clean water

7. Apply a thin layer of bonding agent

Patch Repair Work Sequence

8. Hand applied repair mortar in layers of about 10 mm each

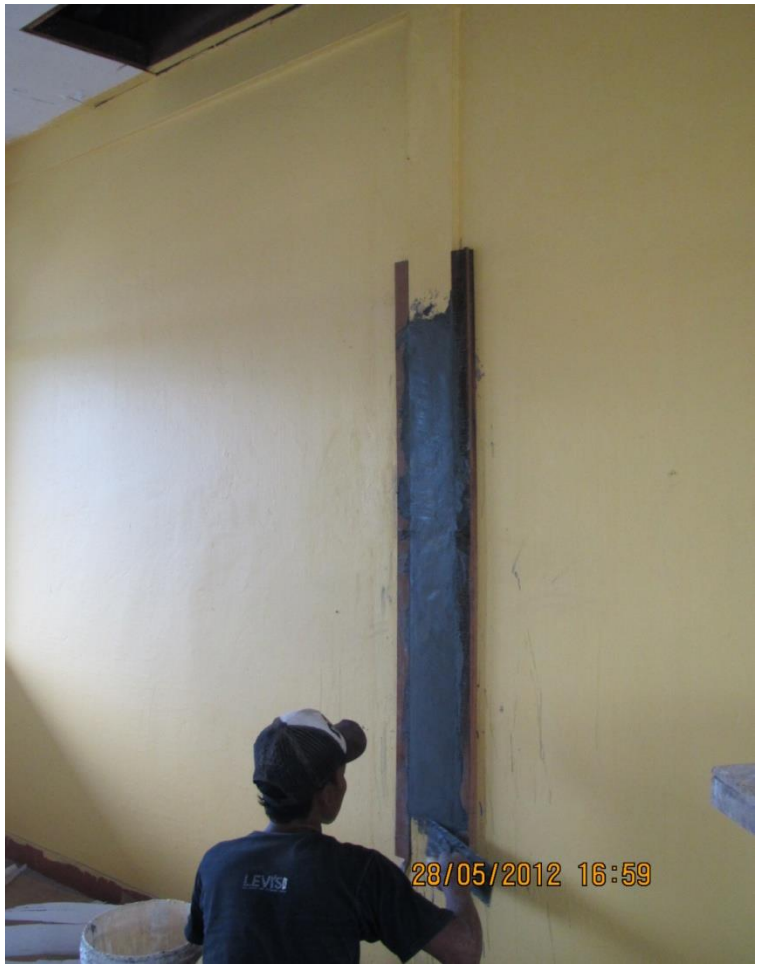
Patch Repair Work Sequence

9. Remove surplus repair mortar using a wooden float

Patch Repair Work Sequence

10. Make good the finish surface using a trowel or sponge

11. Cure immediately to the entire repair area

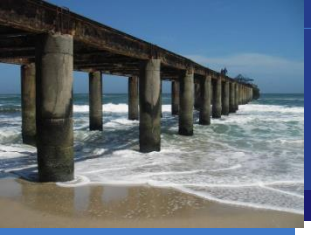


Application Criteria for Formwork Repair

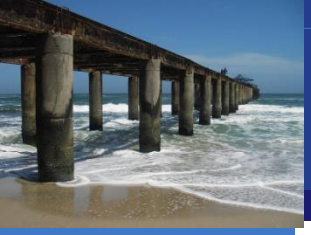
- Cracks / delaminations / spalling resulting form corrosion of rebar
  - Chloride ingress and carbonation
- Adraded concrete surface with loss of cement matrix
- Material deterioration due to sulfate or acid attack
- Large repair area

Formwork Repair Material

- Specialist formulator's Micro-Concrete
  - Free-flowing
  - Self compacting
    - Advantageous as space is confined
  - High strength
    - Rapid strength development
  - Shrinkage compensated
  - Abraded concrete surface with loss of cement matrix
  - Prepacked
    - Factory controlled quality
    - Only add water at site



Formwork Repair



Formwork Repair

NOTES

1. Marking and removal of defective concrete :

   (a) Locate the damaged areas.

   (b) Mark the perimeter of repair area.

   (c) Cut back the concrete surface to prevent feather edges. Remove all damaged concrete to expose sound concrete substrate using appropriate tools.

   (d) Remove all fragments or other contaminants to fully expose surface.

   (e) Remove the damaged concrete behind the reinforcements with minimum of 20 mm clearance.

2. Surface treatment to reinforcement :

   (a) Remove all rusts around corroded reinforcements using approved appropriate tools.

   (b) For heavily corroded reinforcements with $\geqslant$ 10% reduction in cross-sectional area, add supplemental reinforcements.

   (c) Apply a layer of zinc-rich anti-corrosion coating to all existing and new reinforcements.

Formwork Repair

3. Placing of repair materials:

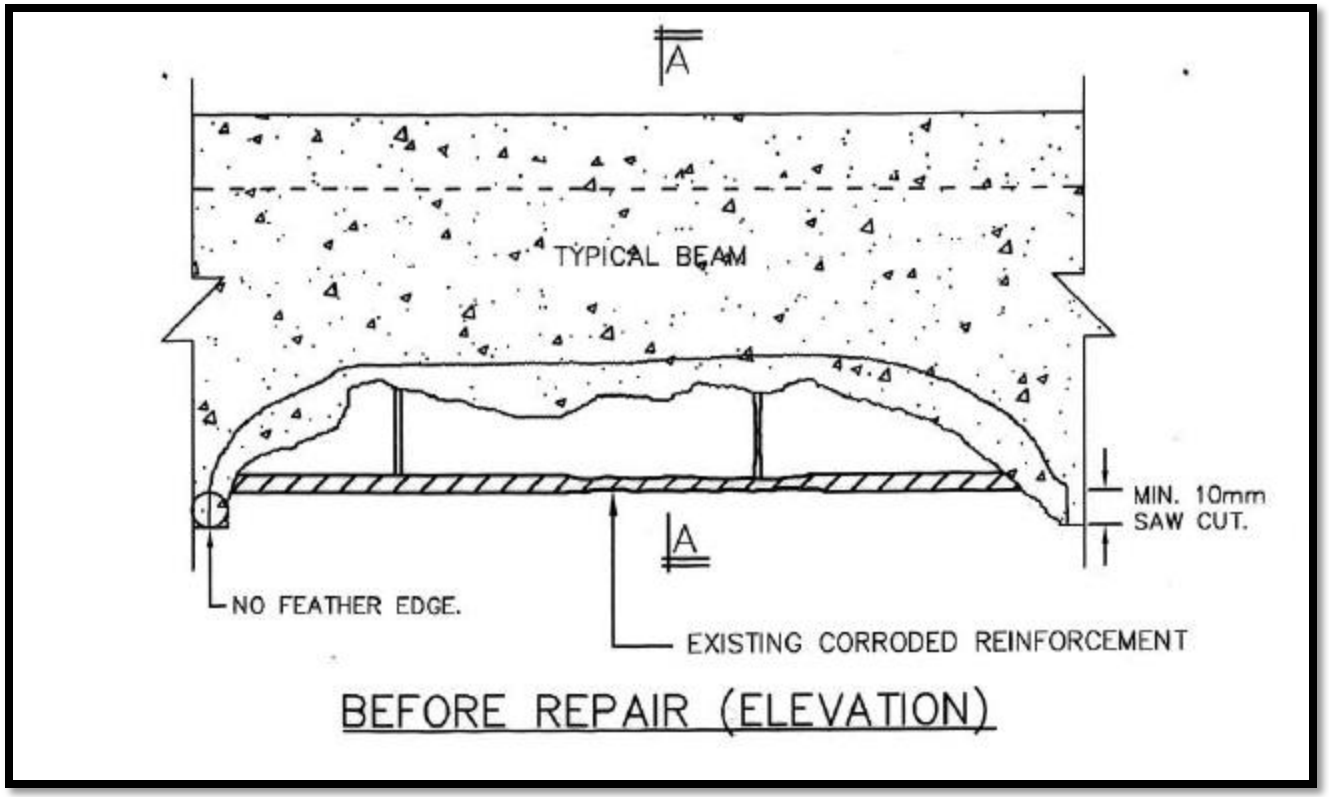
(a) Install formwork (air–tight) along the length of the member and secure by using suitable tie rods and anchor bolts.

(b) Install grout pipes along the length of member (entry port should be levelled lower than outlet port). Seal the edges of formwork using fast setting epoxy.

(c) Inject repair material into the tight formwork via entry ports using hydraulic injection pump with pressure up to 0.275 N/mm^2 (40 psi).

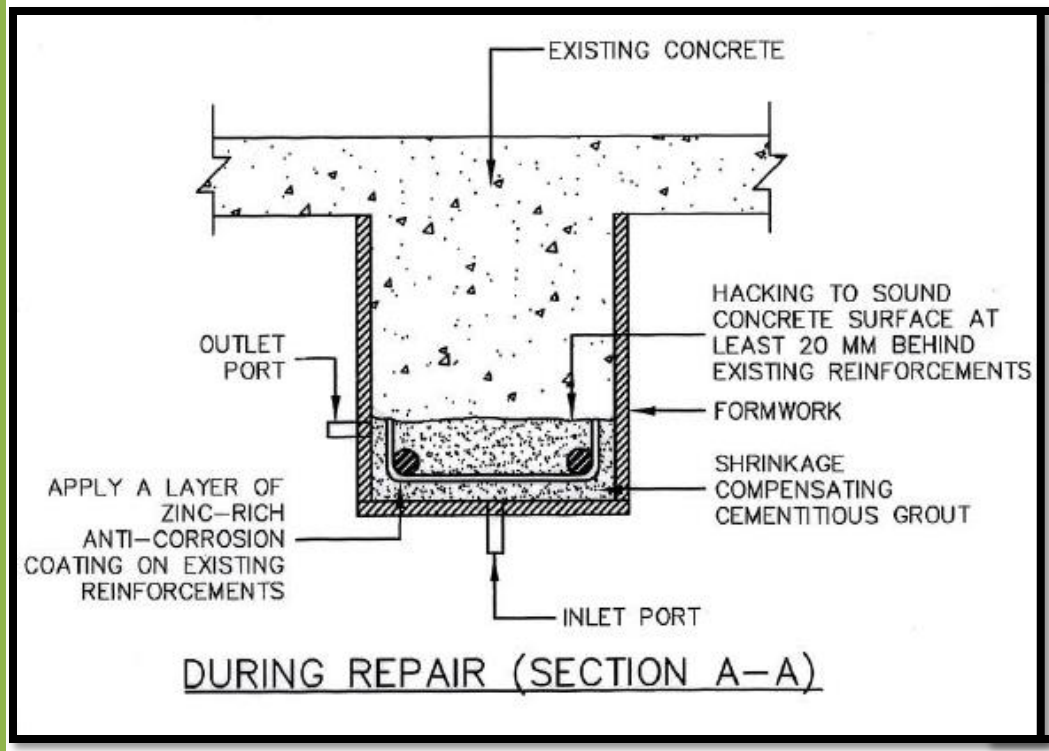
(d) After removing the formwork, cure the repair material appropriately to ensure there is no rapid loss of moisture.

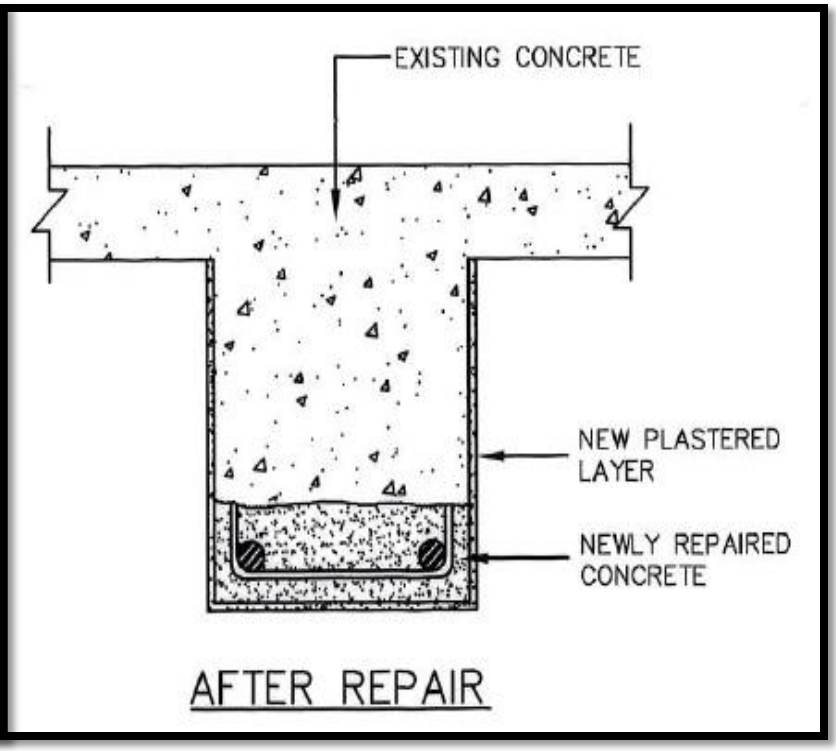
Formwork Repair



BEFORE REPAIR (ELEVATION)

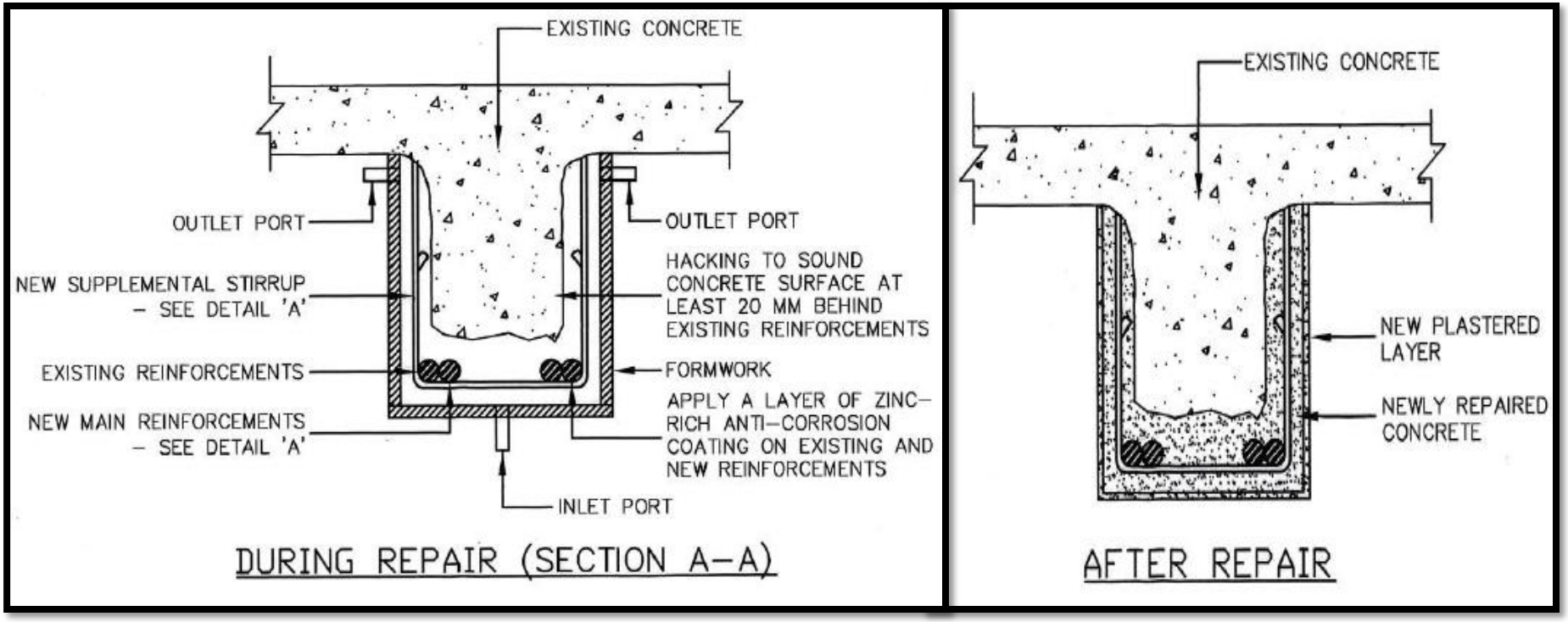
Formwork Repair





CASE 1: CORROSION OF REINFORCEMENT
WHERE REDUCTION IN STEEL AREA < 10%

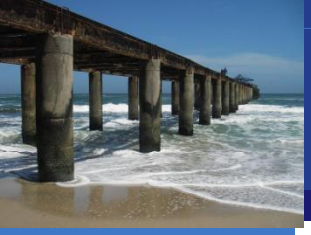
Formwork Repair



CASE 2: CORROSION OF REINFORCEMENT
WHERE REDUCTION IN STEEL AREA $\geqslant$ 10%

Formwork Repair Work Sequence

1. Remove defective and unsound concrete to 20 mm behind reinforcement

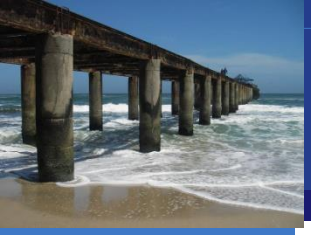


Formwork Repair Work Sequence

2. Clean corrosion products by grit blasting or wire brushing

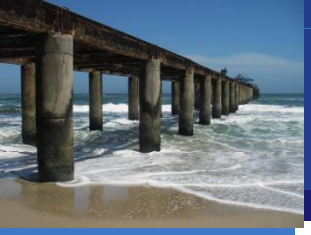
Formwork Repair Work Sequence

3. Prime reinforcement within 2 hours of preparation using zinc-rich type primer



Formwork Repair Work Sequence

4. Erect formwork to specified finished dimension and ensure it is watertight



Formwork Repair Work Sequence

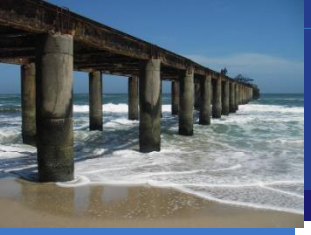
5. Mix grout – high strength, polymer modified,

   prepackaged free flowing cementitious material – superfluid microconcretes

Formwork Repair
Work Sequence

6. Place superfluid microconcrete into formwork

   * ensure that grout fully filled the funnel to avoid air entrapment



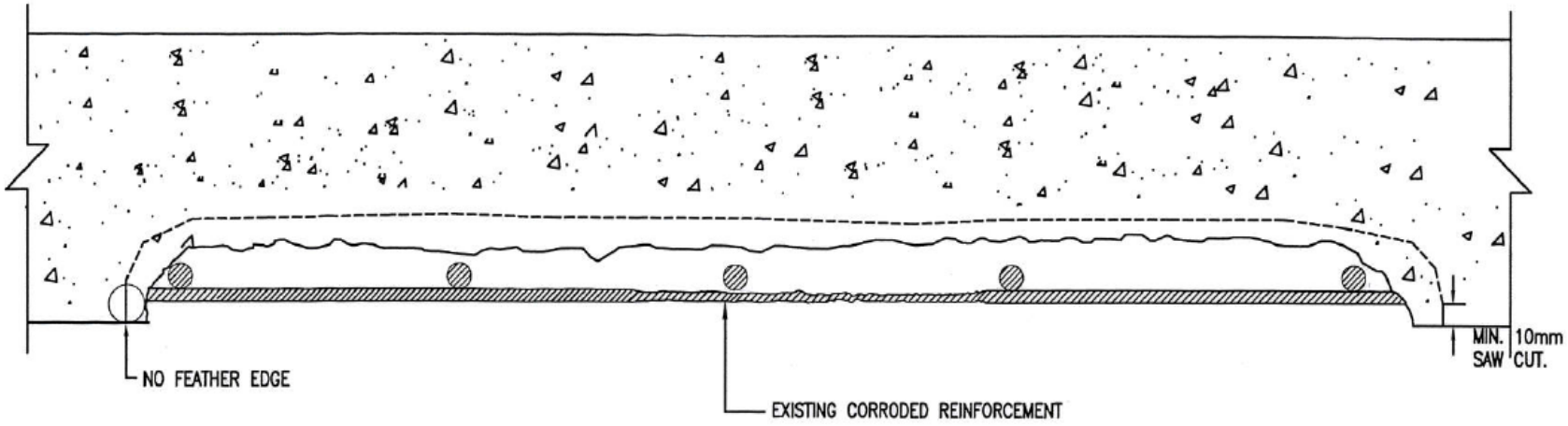
Formwork Repair Work Sequence

6. Reinstated column

Sprayed Concrete

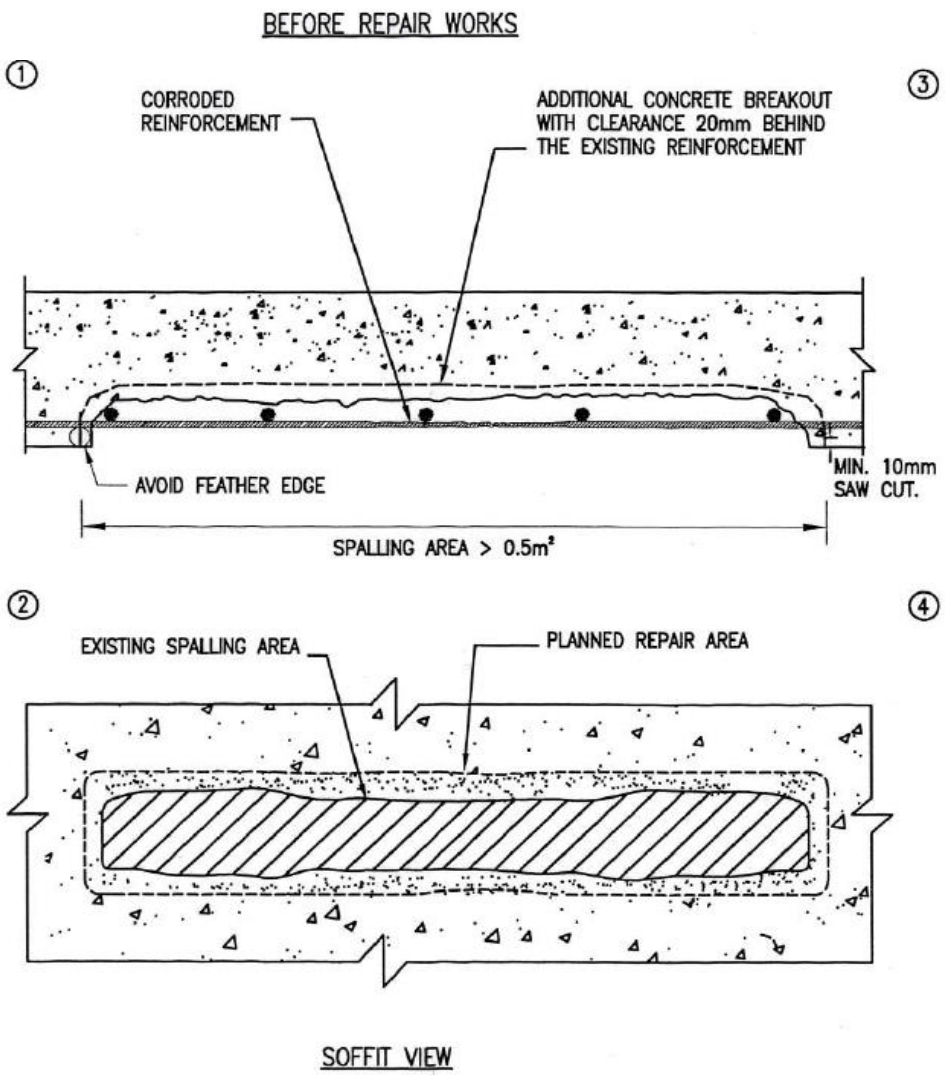
Sprayed Concrete

CONCRETE REPAIR BY SPRAYED CONCRETE FOR CORRODED RENFORCEMENT

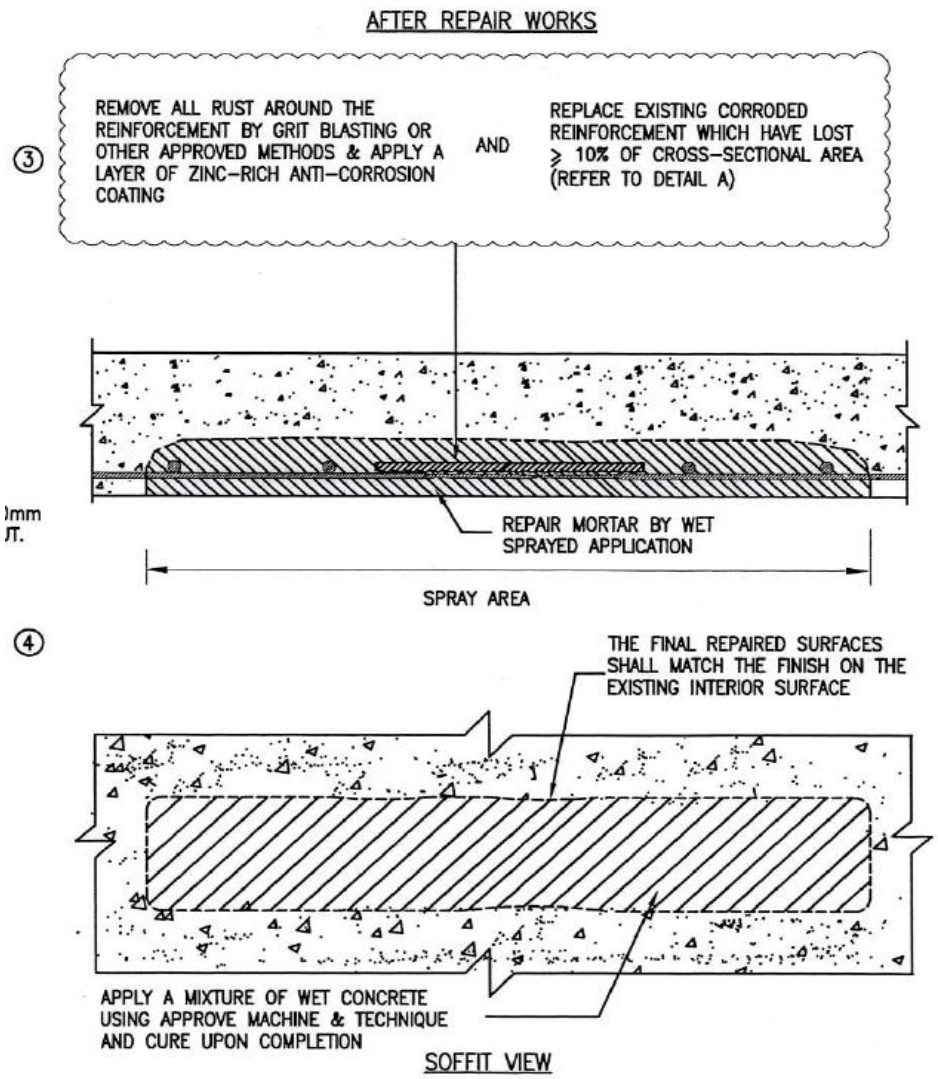


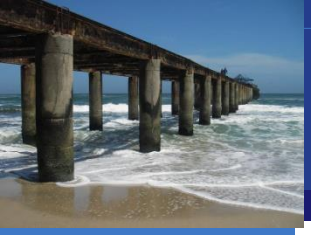
BEFORE REPAIR (ELEVATION)

Sprayed Concrete



Sprayed Concrete





Sprayed Concrete Work Sequence

1. Existing concrete surface need to be roughened to a profile necessary to achieve mechanical interlock

Sprayed Concrete Work Sequence

2. Sprayed concrete (wet process)

Sprayed Concrete Work Sequence

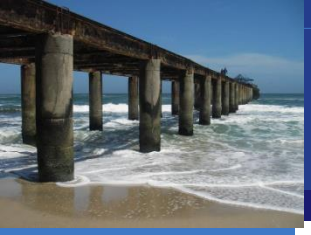
3. Make good the finish surface using a trowel

Sprayed Concrete Work Sequence

4. Apply skim coating to the entire repair area

Sprayed Concrete Work Sequence

5. Final output



TERIMA KASIH