REPAIR METHODS FOR CONCRETE CRACKS
&
STRUCTURAL DAMAGES

Prepared by

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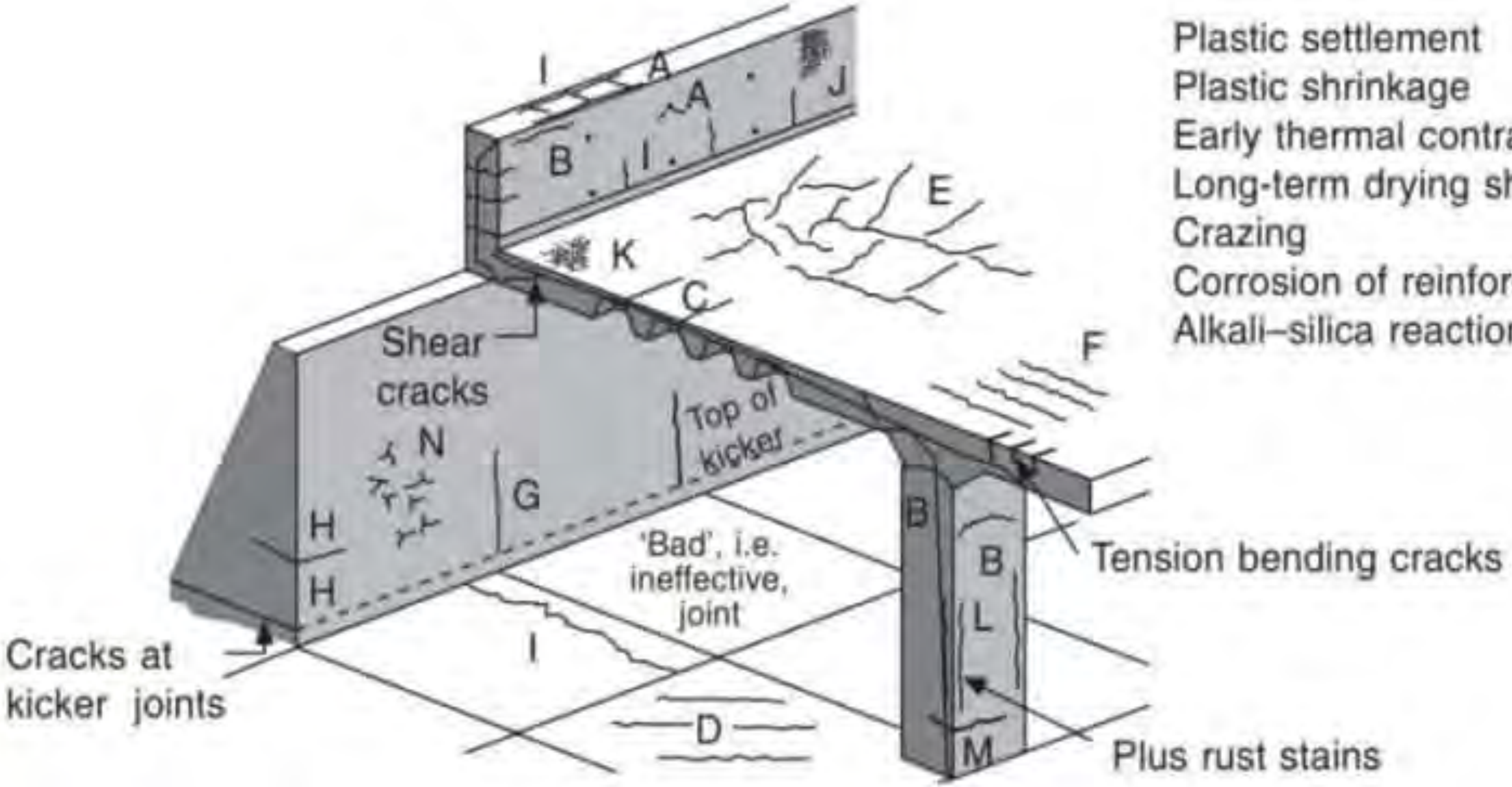
I. INTRODUCTION TO CRACKS (NON-STRUCTURAL)

COMMON TYPES OF NON-STRUCTURAL CRACKS



Type of cracking

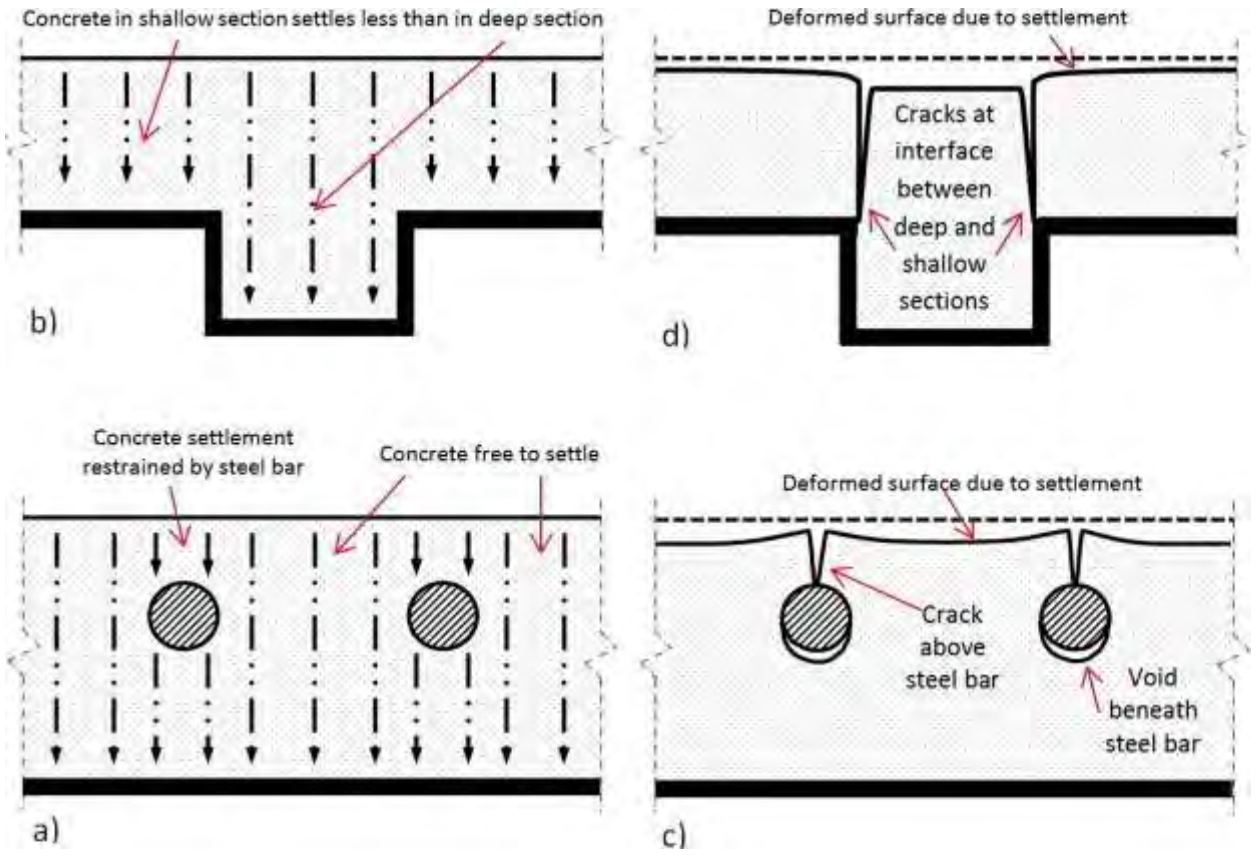
Plastic settlement	A, B, C
Plastic shrinkage	D, E, F
Early thermal contraction	G, H
Long-term drying shrinkage	I
Crazing	J, K
Corrosion of reinforcement	L, M
Alkali–silica reaction	N

Types of Cracking and Their Information

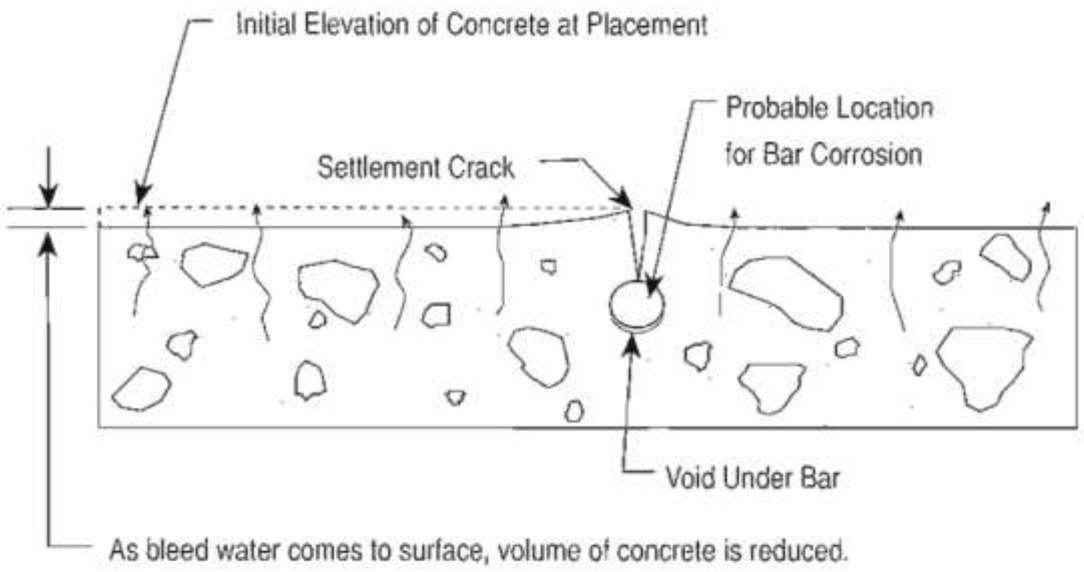
Letter	Type of Cracking	Subdivision	Most Common Location	Primary Cause (excluding restraint)	Secondary Causes/Factors	Time of Appearance
A	Plastic settlement	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Ten minutes to three hours
B		Arching	Top of columns			
C		Change of depth	Trough and waffle slab			
D	Plastic shrinkage	Diagonal	Roads and slabs	Rapid early drying	Low rate of bleeding	Thirty minutes to six hours
E		Random	Reinforced concrete slabs			
F		Over reinforcement	Reinforced concrete slabs	Ditto plus steel near surface		
G	Early thermal contraction	External restraint	Thick walls	Excess heat generation	Rapid cooling	One day or two or three weeks
H		Internal restraint	Thick slabs	Excess temperature gradients		
I	Long-term drying shrinkage		Thin slabs (and walls)	Inefficient joints	Excessive shrinkage inefficient curing	Several weeks or months
J	Crazing	Against formwork	"Fair faced" concrete	Impermeable formwork	Rich mixes	One to seven days, sometimes much later
K		Floated concrete	Slabs	Over troweling	Poor curing	
L	Corrosion of reinforcement	Natural	Columns and beams	Lack of cover	Poor quality concrete	More than two years
M		Calcium chloride	Precast concrete	Excess calcium chloride		
I	Alkali-aggregate reaction		Damp locations	Reactive aggregate plus high-alkali cement		More than five years

1. Plastic Settlement Cracking

- Plastic Settlement cracking occurs as a result of differential settlement during the plastic state of concrete. Differential settlement is always caused by a restraining factor, such as steel reinforcement or a varying concrete section depth. Concrete settles due to the influence of gravitational forces.



Plastic Settlement Cracking (Continued)



Probability of Subsidence Cracking (%)*

Cover	2″ Slump			3″ Slump			4″ Slump		
	#4	#5	#6	#4	#5	#6	#4	#5	#6
¾″	80.4	87.8	92.5	91.9	98.7	100	100	100	100
1″	60	71	78.1	73	83.4	89.9	85.2	94.7	100
1½″	18.6	34.5	45.6	31.1	47.7	58.9	44.2	61.1	72
2″	0	1.8	14.1	4.9	12.7	26.3	5.1	24.7	39

*NCHRP 297, Table 4, p. 11.

After initial placement, vibration, and finishing, concrete tends to continue to consolidate. During this period, the plastic concrete may be locally restrained by reinforcing steel, a prior concrete placement, or formwork. This local restraint may result in voids and/or cracks adjacent to the restraining element.

When associated with reinforcing steel, settlement cracking increases with increasing bar size, increasing slump, and decreasing cover. The degree of settlement cracking may be intensified by insufficient vibration or by the use of leaking or highly flexible forms.

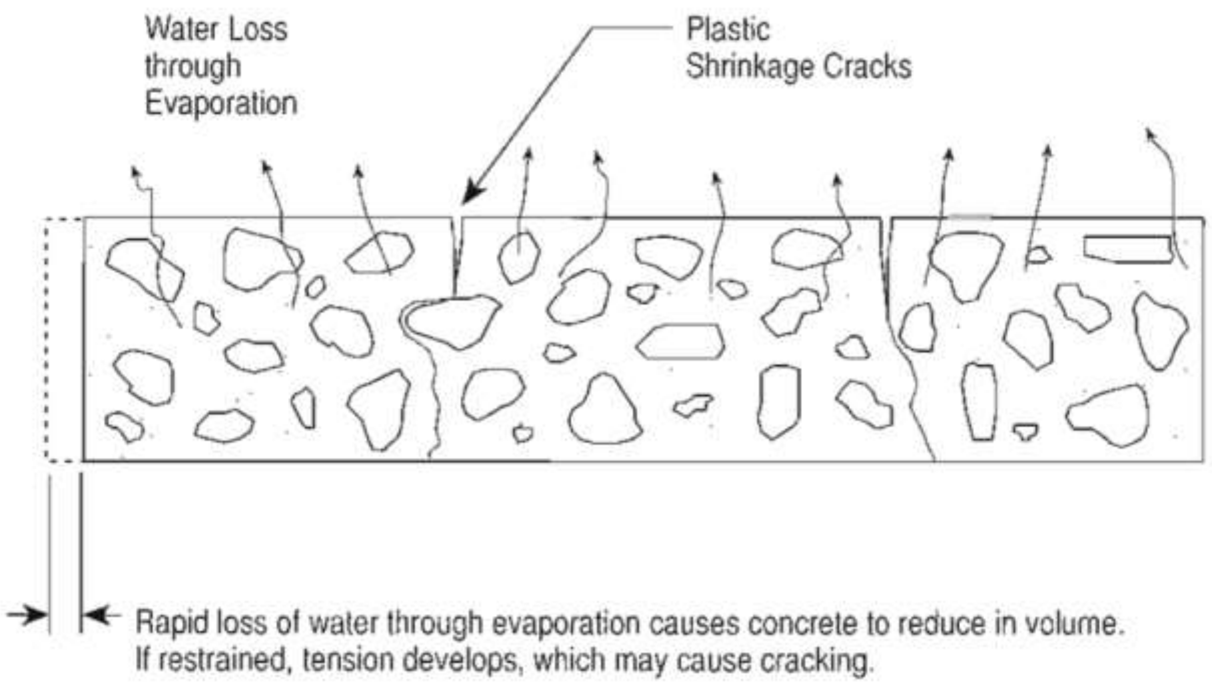
The use of the lowest possible slump, and an increase in concrete cover will reduce settlement cracking.

Plastic Settlement Cracking (Continued)

- The tendency for plastic settlement cracking to form may be reduced by adjusting the concrete mix, for example by avoiding gap-graded fine aggregate and reducing the water content, and by appropriate workmanship and control of vibration.
- The Plastic shrinkage/Plastic Settlement cracking may be repaired in plastic state by reworking the concrete surface using surface vibrators to close the cracks over their full depth and then completed by surface finishing.

2. Plastic Shrinkage Cracking (PSC)

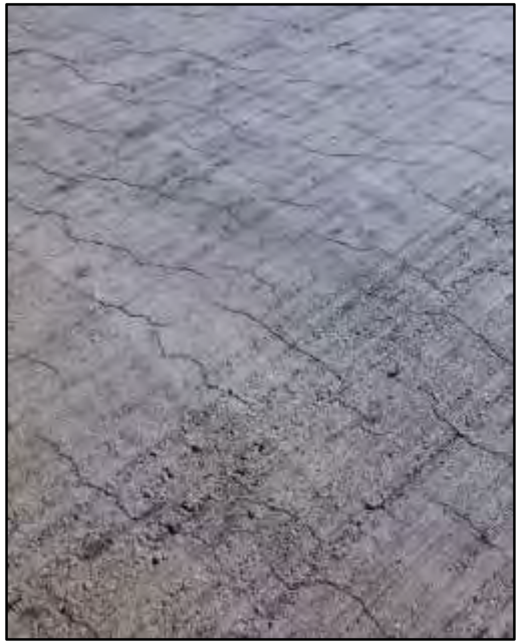
- Plastic shrinkage is caused by the loss of water by evaporation from the surface of newly laid concrete or by suction of dry concrete underneath. At the surface, plastic shrinkage occurs when the rate of evaporation exceeds the rate of bleeding.



Follow These Rules to Prevent Plastic Shrinkage Cracking

1. Dampen the subgrade and forms when conditions for high evaporation rates exist.
2. Prevent excessive surface moisture evaporation by providing fog sprays and erecting windbreaks.
3. Cover concrete with wet burlap or polyethylene sheets between finishing operations.
4. Use cooler concrete in hot weather & avoid excessively high concrete temperatures in cold weather.
5. Cure properly as soon as finishing has been completed.

Plastic Shrinkage Cracking (Continued)



PSC occurs when subjected to a very rapid loss of moisture caused by a combination of factors which include air and concrete temperatures, relative humidity, and wind velocity at the surface of the concrete in either hot or cold weather. When moisture evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete, resulting in shallow cracks of varying depth which may form a random, polygonal pattern, or parallel to one another.
They range from a few inches to many feet in length and are spaced from a few inches to as much as 10 ft apart. Plastic shrinkage cracks begin as shallow cracks but can become full-depth cracks.

Since **PSC** is due to a differential volume change in the plastic concrete, successful control measures require a reduction in the relative volume change between the surface and other portions of the concrete. It can be taken to prevent a rapid moisture loss due to hot weather and dry winds. These measures include the use of fog nozzles to saturate the air above the surface and the use of plastic sheeting to cover the surface between finishing operations. Windbreaks to reduce the wind velocity and sunshades to reduce the surface temperature are also helpful. At the start of cracking while the concrete is still responsive, a vigorous effort should be made to close the cracks by tamping or beating with a float. If, firmly closed, they are unlikely to reappear. Nevertheless, curing should be started as soon as possible.

3. Early Thermal Contraction Cracking

Early-age thermal cracking (ETC) occurs when the tensile strain, arising from either restrained thermal contraction or a temperature differential within the concrete section, exceeds the tensile strain capacity of the concrete.

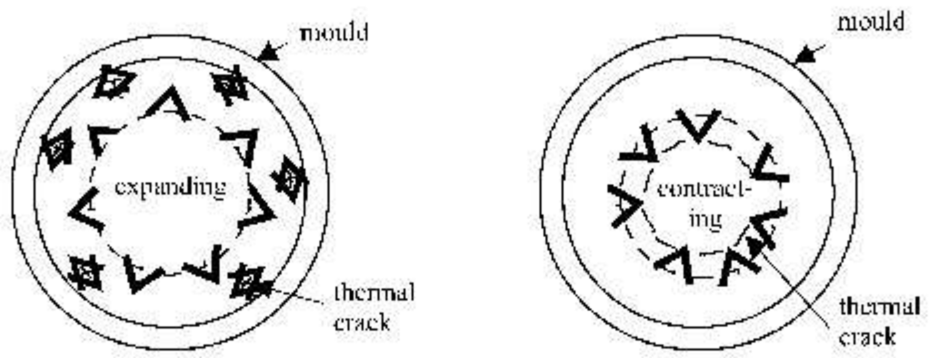
The main cause of ETC is the release of Heat of Hydration from the cement paste in concrete. Heat of Hydration causes differential expansion within the section leading to an internal restraint or an external restraint which will restrict contraction during the cooling or curing.

ETC can be evident in thinner sections within a few days. For thicker sections, it may take longer to develop cracks as the cooling is gradual. In situations where the use of reinforcement to restrict acceptable crack widths is uneconomical or impractical.

Other measures to minimize the risk of cracking include proper selection of materials and mix design (This usually involves replacing some of the Portland cement in the mix with class F fly ash, slag cement, or a combination of both), use of insulation to reduce thermal gradients, Introducing movement joints, cooling concrete before placing or in situ.

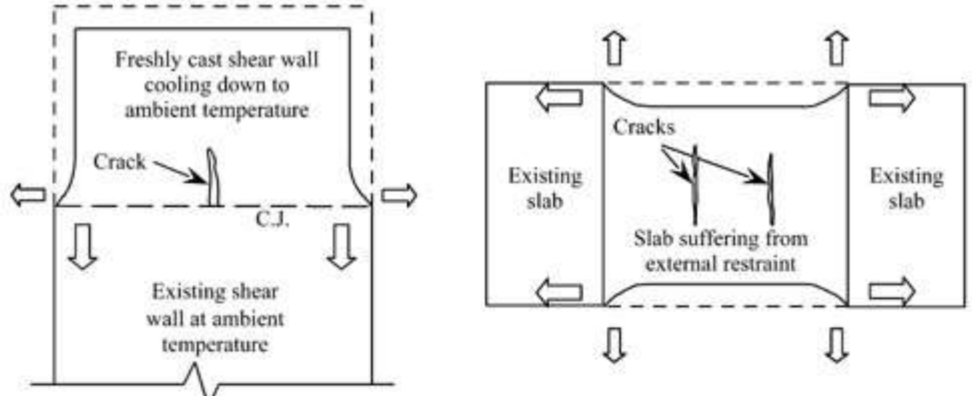
ETC can also be minimized by limiting temperature differences or using shrinkage reducing admixtures. Low-heat cement has been used to limit the temperature induced cracking in concrete. Also, shrinkage reducing admixtures have been used to decrease the stresses resulting from autogenous shrinkage

Early Thermal Contraction Cracking (Continued)



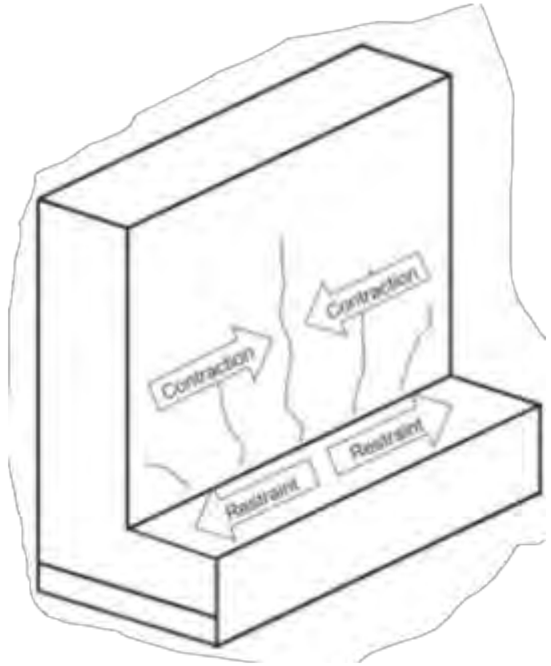
(a) when temperature is rising (b) when temperature is dropping

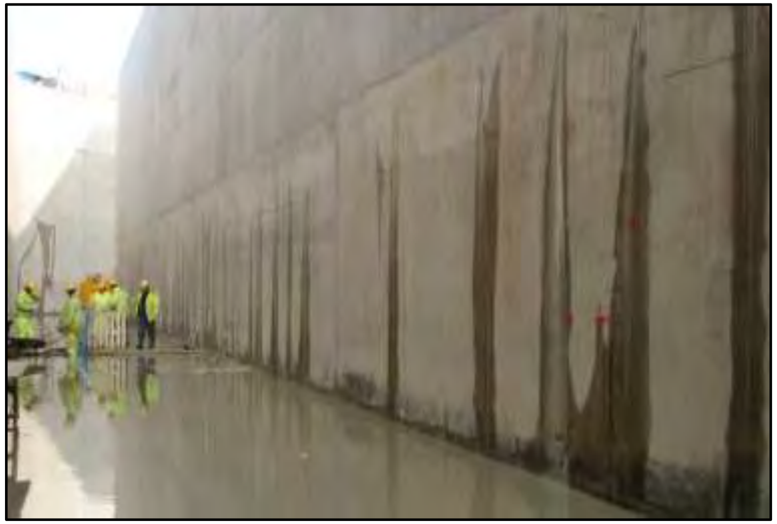
Thermal cracks induced by internal restraint



(a) edge restraint (b) end restraint

Thermal cracks induced by external restraint





4. Long-Term Drying Shrinkage Cracks

Surface drying will occur except when the surface is submerged or below grade. The amount of shrinkage cracking depends on factors such as surface dryness; mixture proportions, especially mixing water; the character and degree of restraint; and the extensibility (tensile-strain capacity) of the concrete.

The prime objective of crack-control procedures is to keep the concrete wet as long as possible so that the concrete will have time to develop more strength to resist cracking forces. To accomplish slow drying, wet curing should remain for several days. The specified curing period is preferably 7 or 10 days. Drying shrinkage can also be reduced by increasing the amount of aggregate and reducing the water content.

Shrinkage cracking can be controlled by using contraction joints and steel detailing. Shrinkage cracking may also be reduced by using shrinkage-compensating cement.

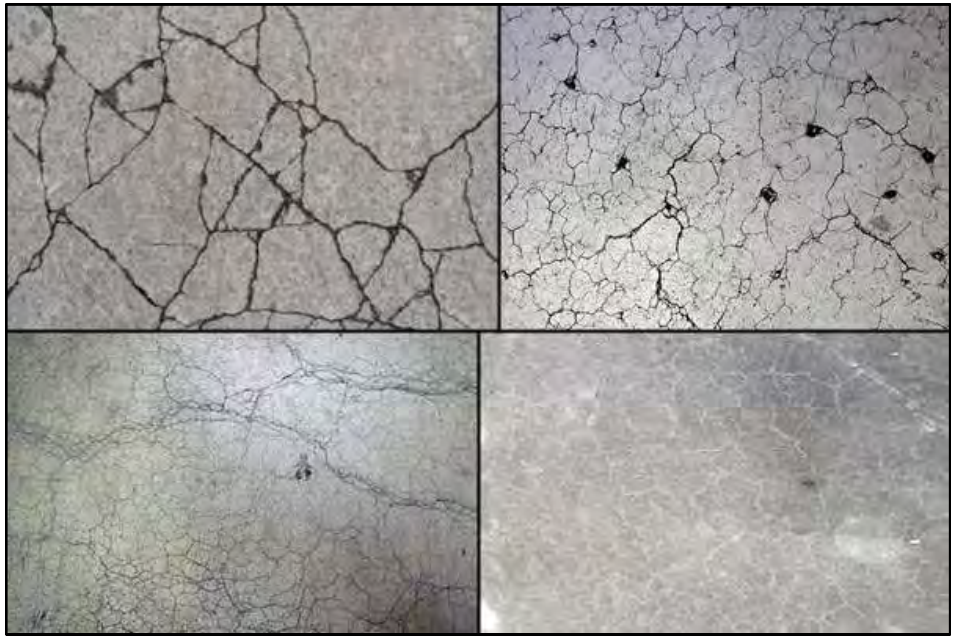
Long-Term Drying Shrinkage Cracks (Continued)

- Drying shrinkage is a consequence of loss of moisture (Capillary Water) from hardened concrete to the environment. Due to the emptying of the fine pores in the concrete, negative capillary pressure develops, which causes a volume reduction of the concrete. This shrinkage causes an increase in tensile stress, which may lead to cracking before the concrete is subjected to any kind of loading.
- The time at which shrinkage cracks occur depends on the rate of drying but is usually several months to three or four years after casting.

Preventive Measures for Long Term Shrinkage Cracks:

- Use of minimum water content
- Use of plasticizer for compensating workability due to lesser water
- Use of highest possible aggregate content and hence smaller quantity of cements
- Use of shrinkage compensating concrete
- Eliminate external restraints (e.g., smooth polythene sheet on the sub grade for base slab)
- Sufficiently close spaced reinforcement (e.g., generally 15 cm in slabs & walls)

5. Crazings



Surface crazing (alligator pattern) on walls and slabs is an example of drying shrinkage on a small scale. Crazing usually occurs when the surface layer of the concrete has a higher water content than the interior concrete. The result is a series of shallow, closely spaced, fine cracks. Crazing cracks are sometimes referred to as shallow map or pattern cracking. They do not affect the structural integrity of concrete and rarely do they affect durability or wear resistance. However, crazed surfaces can be unsightly.

Crazings (Continued)

Crazing develops within the first week of a concrete mixture's placement, and typically do not become visible until after the concrete is dried and set. If the water in the concrete mixture evaporates too quickly, the surface tends to shrink unevenly. This results in the formation of these cracks.

Prevention measures for concrete crazing

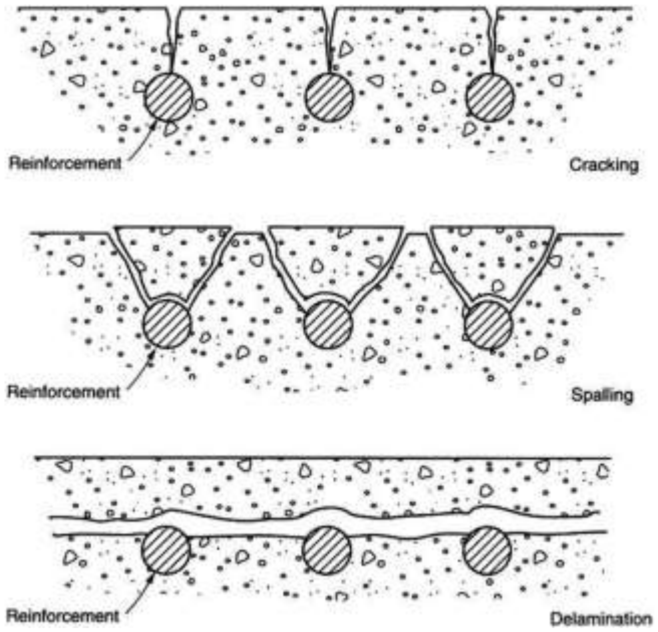
The surface should be kept wet by either flooding the surface with water or, covering the surface with damp burlap and keeping it continuously moist for a minimum of 3 days or, spraying the surface with a liquid membrane curing compound.

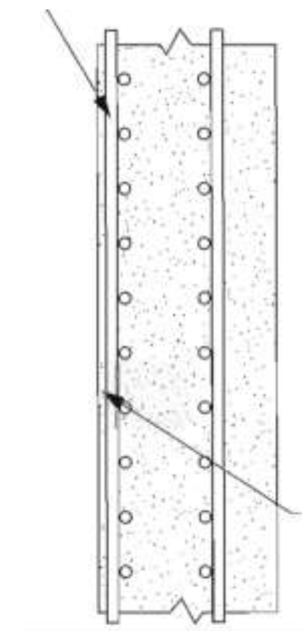
Some remedial measures to remove crazing cracks

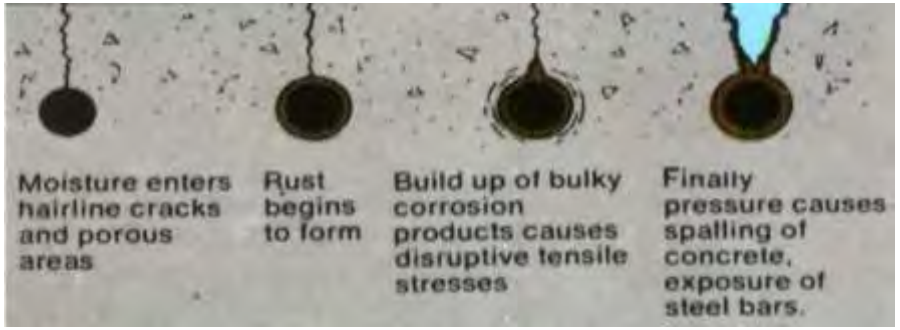
The monolithic appearance of the slabs can be corrected by the application of epoxy and silica sand. This will change the color and look of the surface, which can be corrected using any re-surfacing products.

Crazing can often be eliminated simply by applying a thinner glaze coat (over with a smooth, shiny coating). With some glazes, a thinner coat is not an option, but often a slight decrease in glaze thickness will stop crazing.

6. Corrosion of Reinforcements







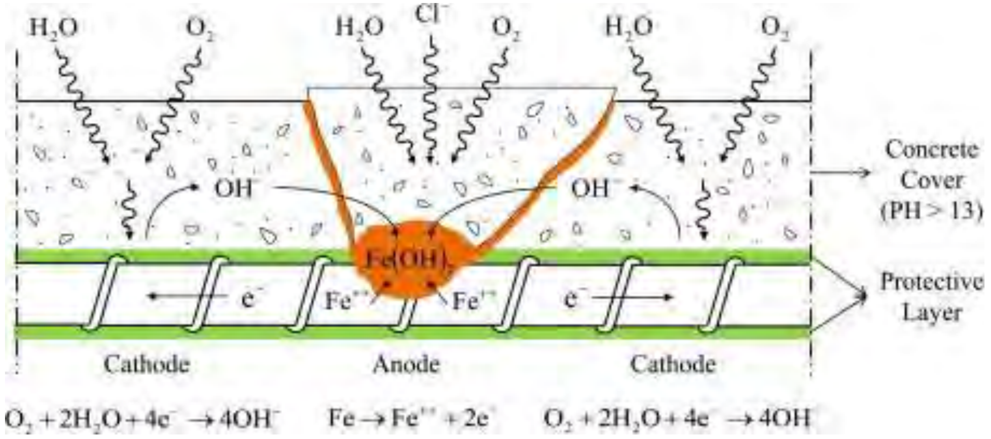
Prone to Spalling

Spalling

Delamination

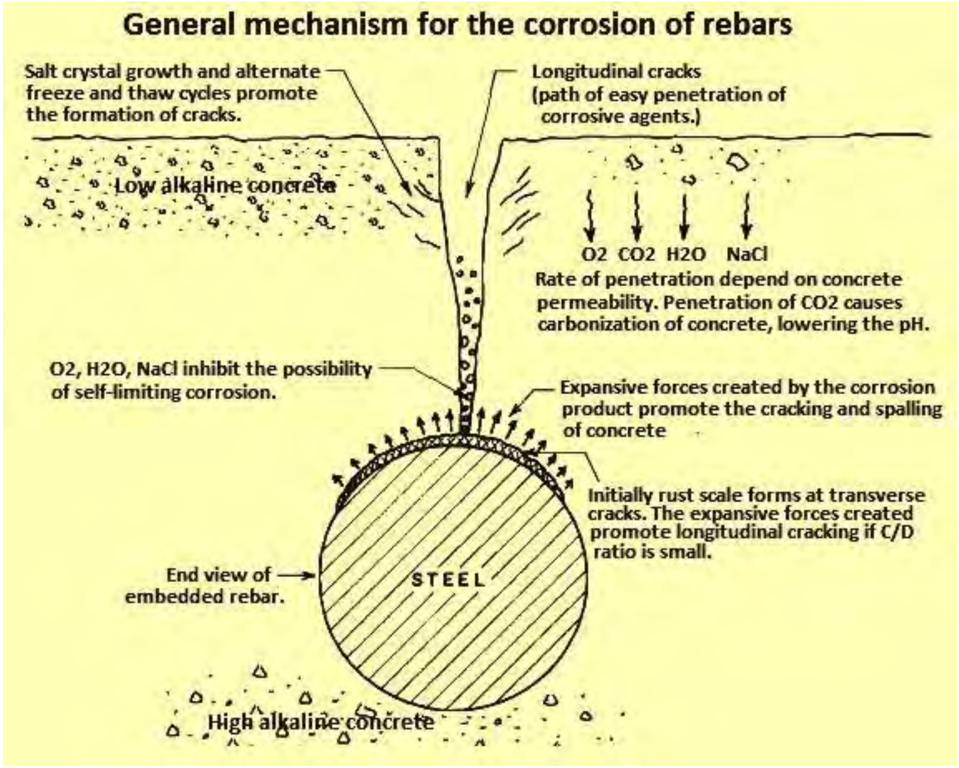
Corrosion of Reinforcements (Continued)

As the reinforcing steel corrodes, it expands and exerts pressure on the surrounding concrete cover, causing tensile stresses in concrete. This ultimately leads to cracking and spalling of the concrete cover, further exacerbating the durability problems of a structure and increasing the rate of its deterioration.



Remedial Measure

Remove concrete along the bar length until the corrosion product cannot be observed. Utilize abrasive blasting techniques to remove corrosion, expose new clean steel, and prepare the original hardened concrete for bonding. Apply a rebar coating to re-passivate the reinforcing steel. Selecting a pourable or pumpable low shrinkage concrete or pre-bagged cement-based repair material will provide a clean-formed finish. Improving the waterproofing detail to prevent water from entering the concrete pore structure will add additional durability.



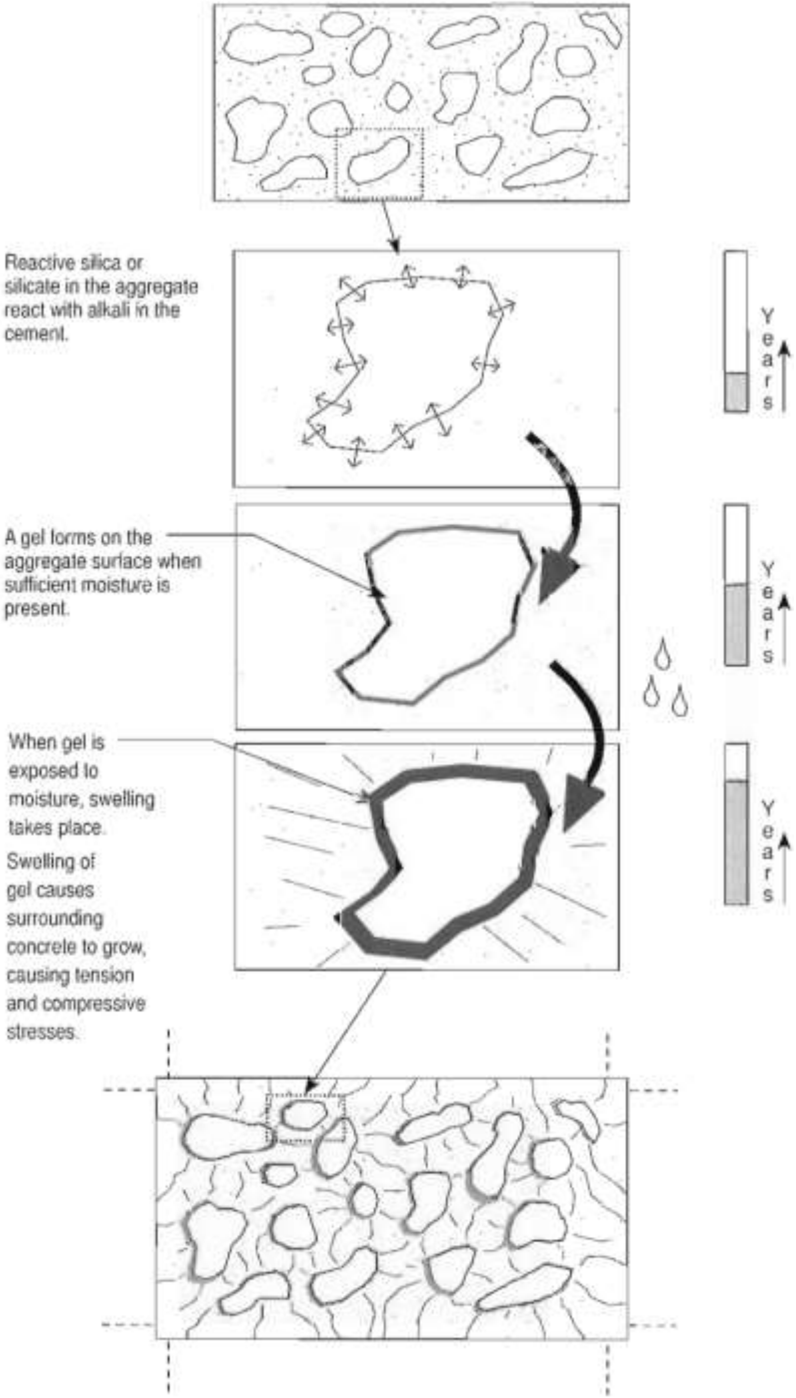
7. Alakali-Silica Reaction

Concrete may crack with time as the result of slowly developing expansive reactions between aggregate containing active silica and alkali derived from cement hydration, admixtures, or external sources (e.g., curing water, ground water, alkaline solutions stored or used in the finished structure).

The alkali-silica reaction results in the formation of a swelling gel, which tends to draw water from other portions of the concrete. This causes local expansion and accompanying tensile stresses and may eventually result in the complete deterioration of the structure.

Control measures include proper selection of aggregates, use of low alkali cement, and use of pozzolans, which themselves contain very fine, highly active silicas. The first measure may preclude the problem from occurring, while the later two measures have the effect of decreasing the alkali to reactive silica ratio, resulting in the formation of a nonexpanding calcium alkali silicate.

Alakali-Silica Reaction (continued)



II. REPAIR TECHNIQUES FOR CRACKS

METHODS OF CRACK REPAIR

1. EPOXY SEALING OR INJECTION
2. ROUTING AND SEALING
3. STICHING
4. EXTERNAL STRESSING
5. OVERLAYS
6. BLANKETING
7. AUTOGENOUS HEALING

Table 4.1 Guide to reasonable* crack widths, reinforced concrete under service loads

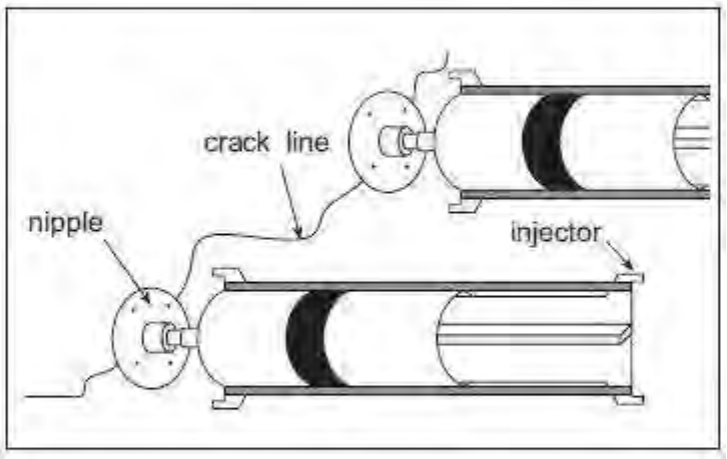
Exposure condition	Crack width	
	in.	mm
Dry air or protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray, wetting and drying	0.006	0.15
Water-retaining structures†	0.004	0.10

*It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgement *[sic]*.

†Exclusing *[sic]* nonpressure pipes.

Note: Table 4.1, Guide to Reasonable Crack Widths, Reinforced Concrete Under Service Loads, was reproduced from ACI 224R-01 (Reapproved 2008) *Control of Cracking of Concrete Structures* with permission from the American Concrete Institute.

1. EPOXY SEALING OR INJECTION

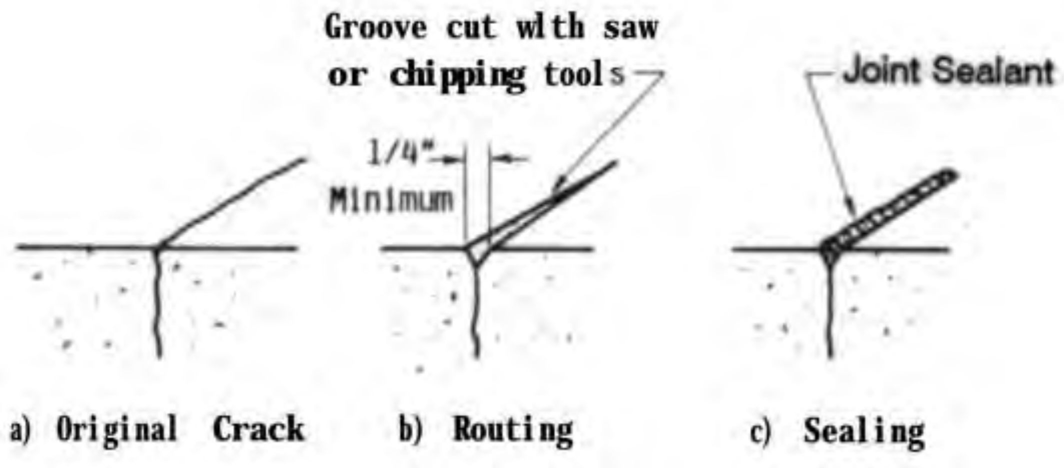


- Injecting Epoxy Bonding Compounds with High Pressure into the Cracks.
- Cracks as Narrow as 0.002 in. (0.05 mm) can be Bonded by Injection of Epoxy.
- Can be Used for Structural Repairs.
- However, Unless the Cause of Cracking has been Corrected, it will Probably Recur Near the Original Crack.

PROCEDURE

1. Clean the Cracks by Vacuuming or Flushing with Water or Other Effective Cleaning Solutions.
2. The Crack is then Flushed Out using Compressed Air and a Neutralizing Agent or Adequate Time is Provided to Air Drying.
3. Surface Cracks shall be Sealed to Keep the Epoxy from Leaking Out.
4. Install the Entry & Vending Ports.
5. Mix the Epoxy in Accordance with the Manufacturer's Instructions.
6. Inject the Epoxy.
7. Remove the Surface Seal After Injected Epoxy has been Cured.

2. ROUTING AND SEALING

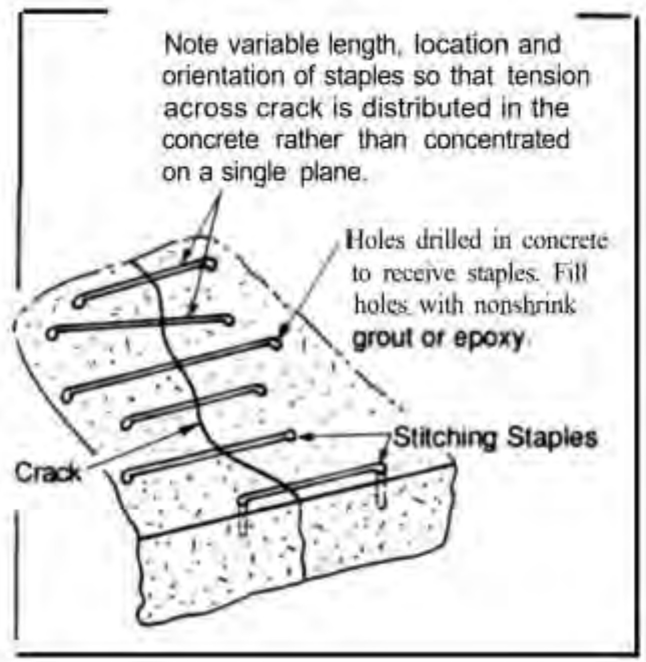


- Simplest, Most Common & Inexpensive Method.
- Can be used in Conditions Requiring Remedial Repair & Where Structural Repair is not Necessary.
- Most Applicable to Approximately Flat Horizontal Surfaces such as Floors & Pavements.
- Cement Grouts should be Avoided due to the Likelihood of Cracking.
- Epoxies, Silicones, Asphaltic Materials, NSG or Polymer Mortars can be Used.

PROCEDURE

1. Prepare a Groove at the Surface Ranging in Depth, Typically from ¼ to 1 in. (6 to 25 mm) using Concrete Saw, Hand Tools or Grinder.
2. Groove is then Cleaned by Air-blasting, Sand-blasting or Water-blasting and Dried.
3. A Sealant is Placed into the Dry Groove and Allowed to Cure.

3. STICHING

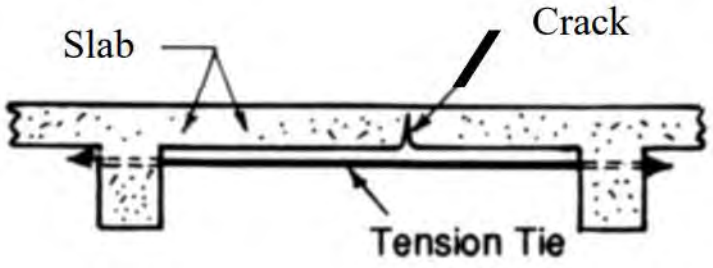


- Stitching Involves Drilling Holes on both Sides of the Crack and Grouting in U-Shaped Metal Units with Short Legs.
- Stitching Shall be Used where Tensile Strength must be Re-established across Major Cracks.
- Stitching a Crack Tends to Stiffen the Structure but Concrete can Crack Else-where. Thus, It maybe Necessary to Strengthen the Adjacent Section or Sections Using Technically Corrected Reinforcing Methods.

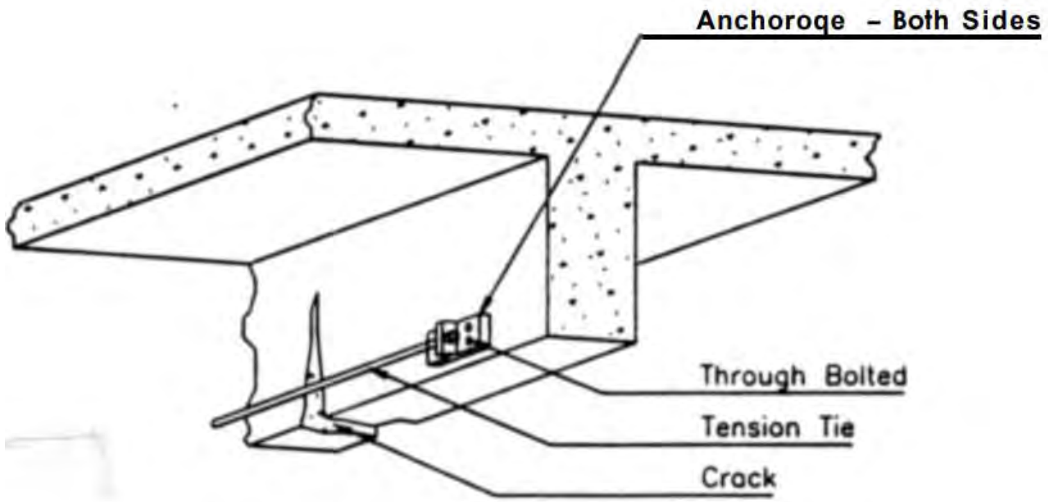
PROCEDURE

1. Drill the Holes on Both Sides of the Crack.
2. Clean the Holes.
3. Anchor the Legs of the U-Shaped Metal Units in the Holes with either a Non-Shrink Grout or an Epoxy Resin-Based Bonding System.
4. The Stables should be Installed in Variable in Length, Orientation, or Both. They should also be Located so that the Tension Transmitted Across the Crack is not Applied to a Single Plane within the Section.

4. EXTERNAL STRESSING



a) To Correct Cracking of Slab



b) To Correct Cracking of Beam

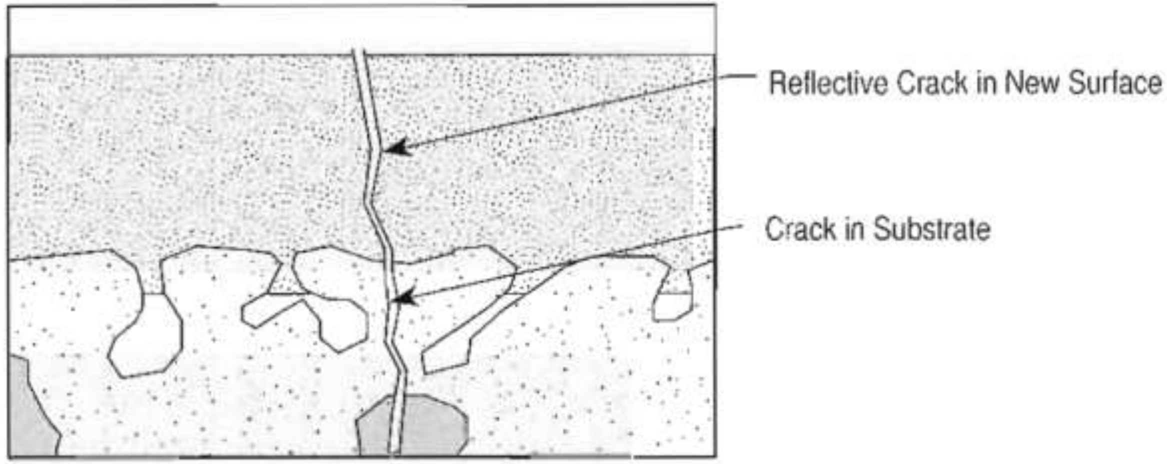
- The Development of Cracking is due to the Tensile Stress, thus can be Fixed by Suppressing this Stress.
- Cracks can be Closed by Inducing a Compression Forces to Overcome the Tensile Stresses.
- This Technique uses Pre-Stressing Strands or Bars to Apply a Compressive Force.

5. OVERLAYS

- Used to Seal Cracks if Further Significant Movement Across the Cracks are not Found.
- Used when Large Number of Cracks, Treating each Crack is Expensive.
- Active Cracks-Overlays Done with Materials which Are Extensible but not Flexible.

(E.g. – Polymeric Membrane with Topcoat of Tars)

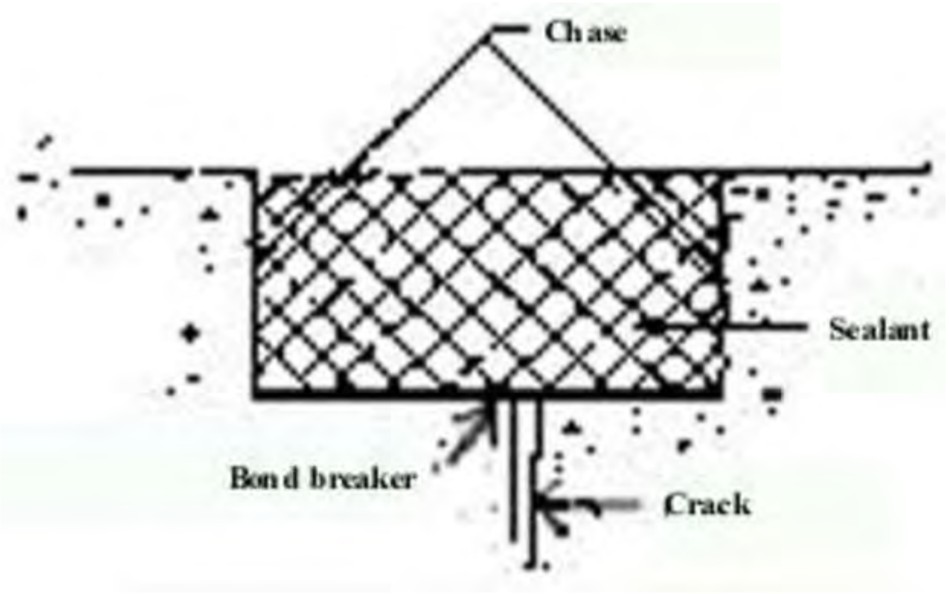
- Dormant Cracks – Any Type of Overlays may be Used.



Potential Problem of Overlays if Wrong System was Chosen for the Specific Condition

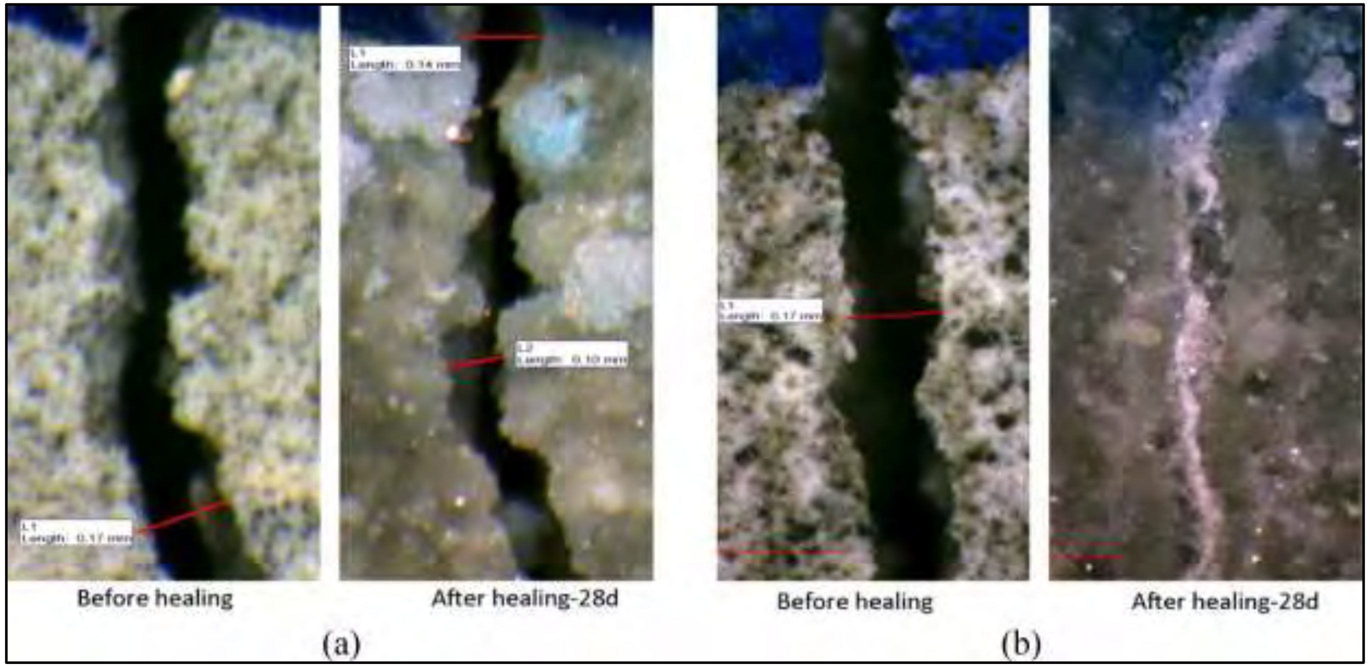
6. BLANKETING

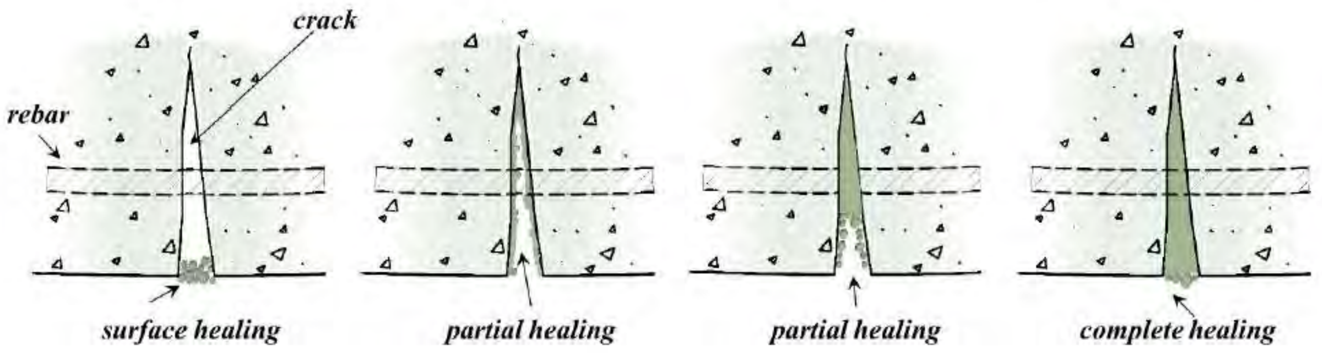
- Blanketing is similar to routing and sealing, used on a larger scale and is applicable for sealing active as well as dormant cracks.
  This is the simplest and most common technique for sealing cracks and is applicable for sealing both fine pattern cracks and larger isolated.
- Preparing the chase is the first step
- Usually, the chase is the cut square
- The bottom of the chase should be chipped as smooth to facilitate breaking the bond between the sealant and concrete. The sides should be prepared to provide a good bond with the sealant.
- Selection of sealant materials is the amount of movement anticipated and the extremes of temperature at which such movements will occur



Sealed Chase

7. AUTOGENOUS HEALING





Different level of self-healing

- A Natural Process which can Occur in Concrete in the Presence of Moisture and the Absence of Tensile Stresses.
- Healing Occurs through the Continued Cement Hydration and the Carbonation of Calcium Hydroxide in the Cement Paste by Carbon Dioxide which is Present in the Surrounding Air and Water.
- However, Healing will not Occur if the Crack is Active and is Subjected to Movement During the Healing Period. It will also not Occur if there is a Positive Flow of Water Through the Crack as it Washes Away the Lime Deposit.

III. DEFECTS & DAMAGES IN REINFORCED CONCRETE STRUCTURES

1. Honeycombs
2. Cold Joints
3. Fire Damage
4. Water Leakage
5. Chloride Penetration
6. Carbonation
7. Concrete Erosion
8. Freeze Thaw Attack
9. Sulphate Attack
10. Exposure to Aggressive Chemicals
11. Settlement

1. Honeycombs

Primary Causes of Honeycomb

Design of members

- Highly congested reinforcement
- Narrow section
- Internal interference
- Reinforcement splices

Properties of fresh concrete

- Insufficient fines
- Low workability
- Early stiffening
- Excessive mixing
- Aggregate that is too large

Construction conditions

- Reinforcement too close to forms
- High temperature
- Accessibility

Forms

- Leaking at Joints

Placement

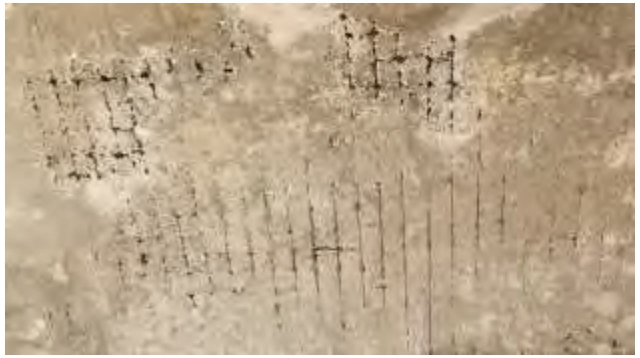
- Excessive freefall
- Excessive travel in forms
- Lift that is too high
- Improper tremie or drop chute
- Segregation

Consolidation

- Vibrator too small
- Frequency too low
- Amplitude too small
- Short immersion time
- Excessive spacing between insertion
- Inadequate penetration

Honeycomb is the rough pitted surface or voids in concrete formed due to improper compaction or incomplete filling of the concrete.

Honeycomb in Column

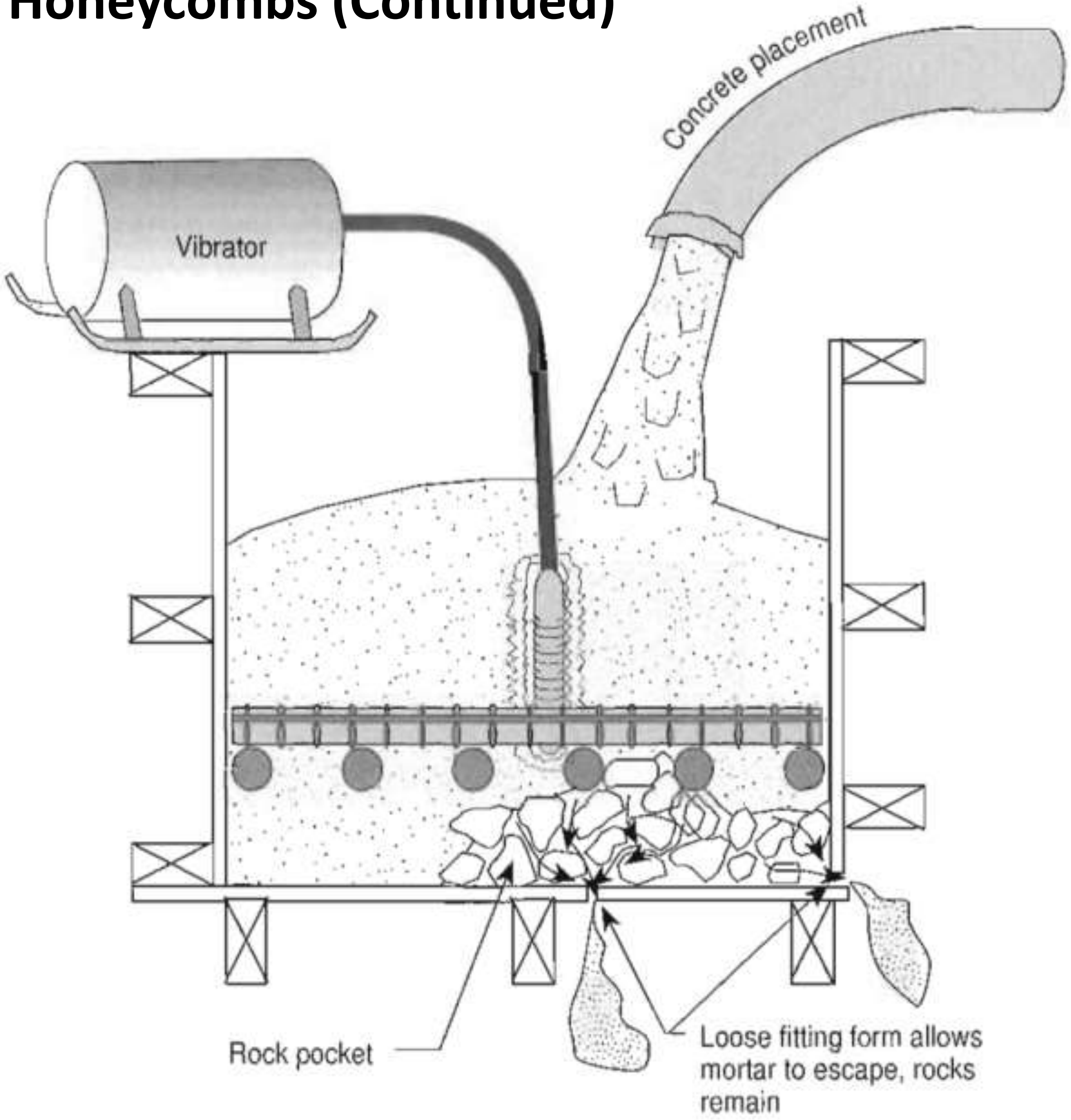


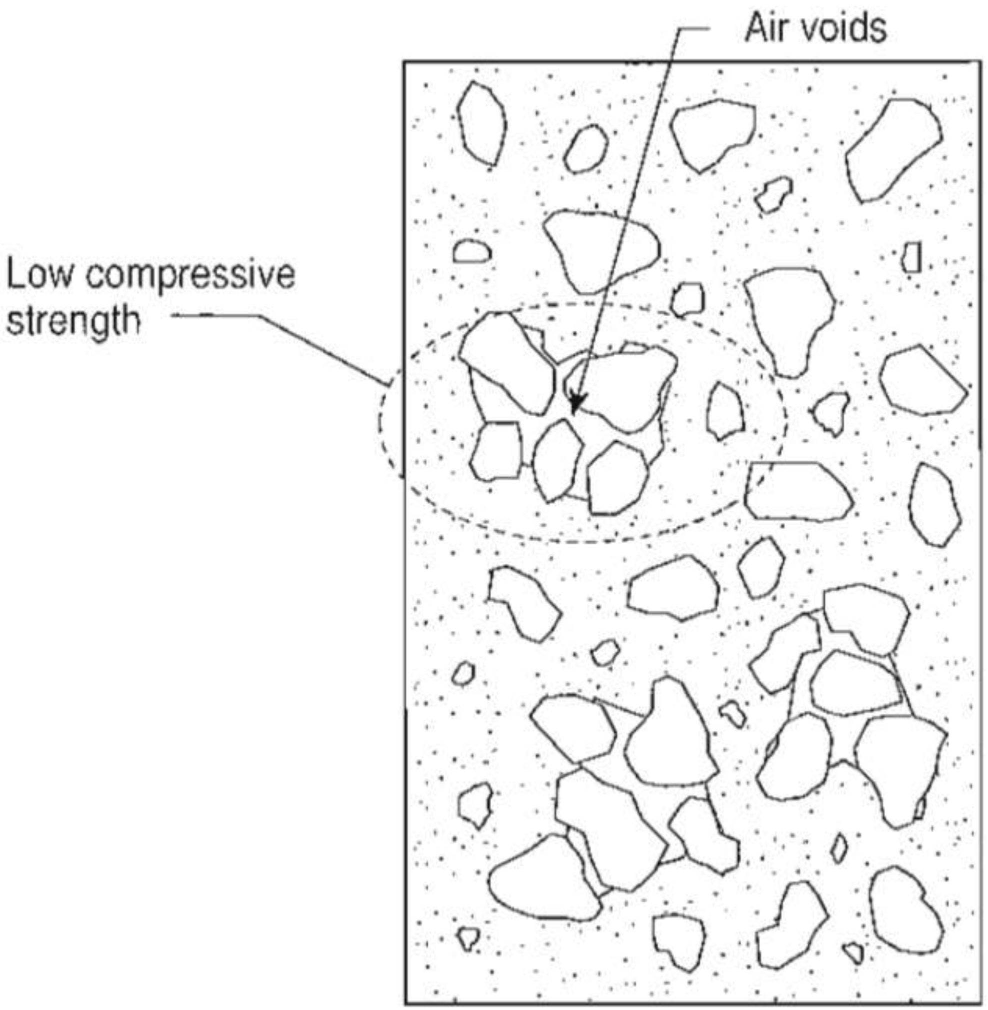
Honeycomb in Slab

Honeycomb in Beam

Honeycomb in Wall

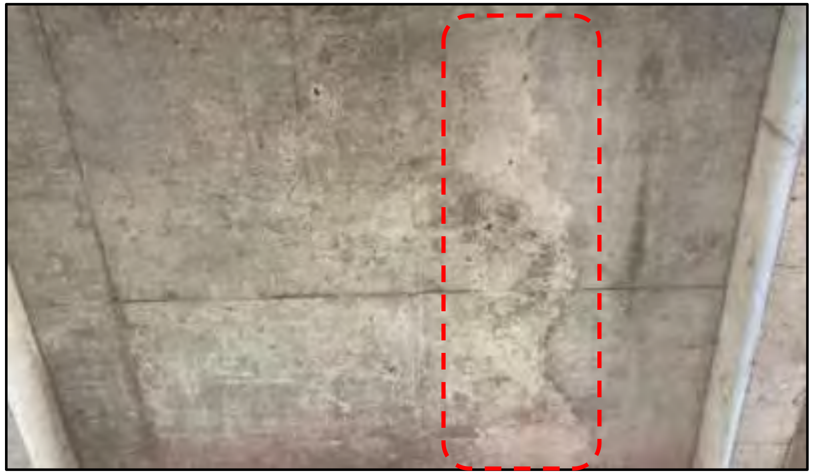
Honeycombs (Continued)



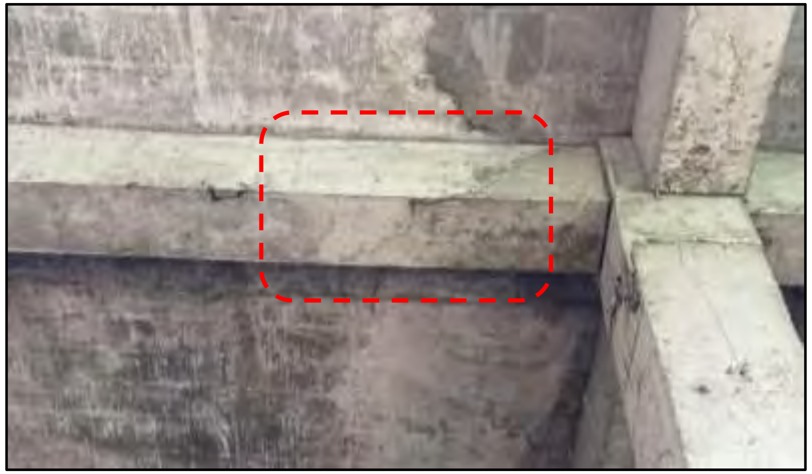


2. Cold Joints

A cold joint is a joint that is formed between two pours of concrete when the second concrete pour is placed after starting the setting of the first pour. After the initial setting time of the concrete, concrete starts setting. When new concrete is poured after that there will be a separation in the layers.



Cold Joint in Slab



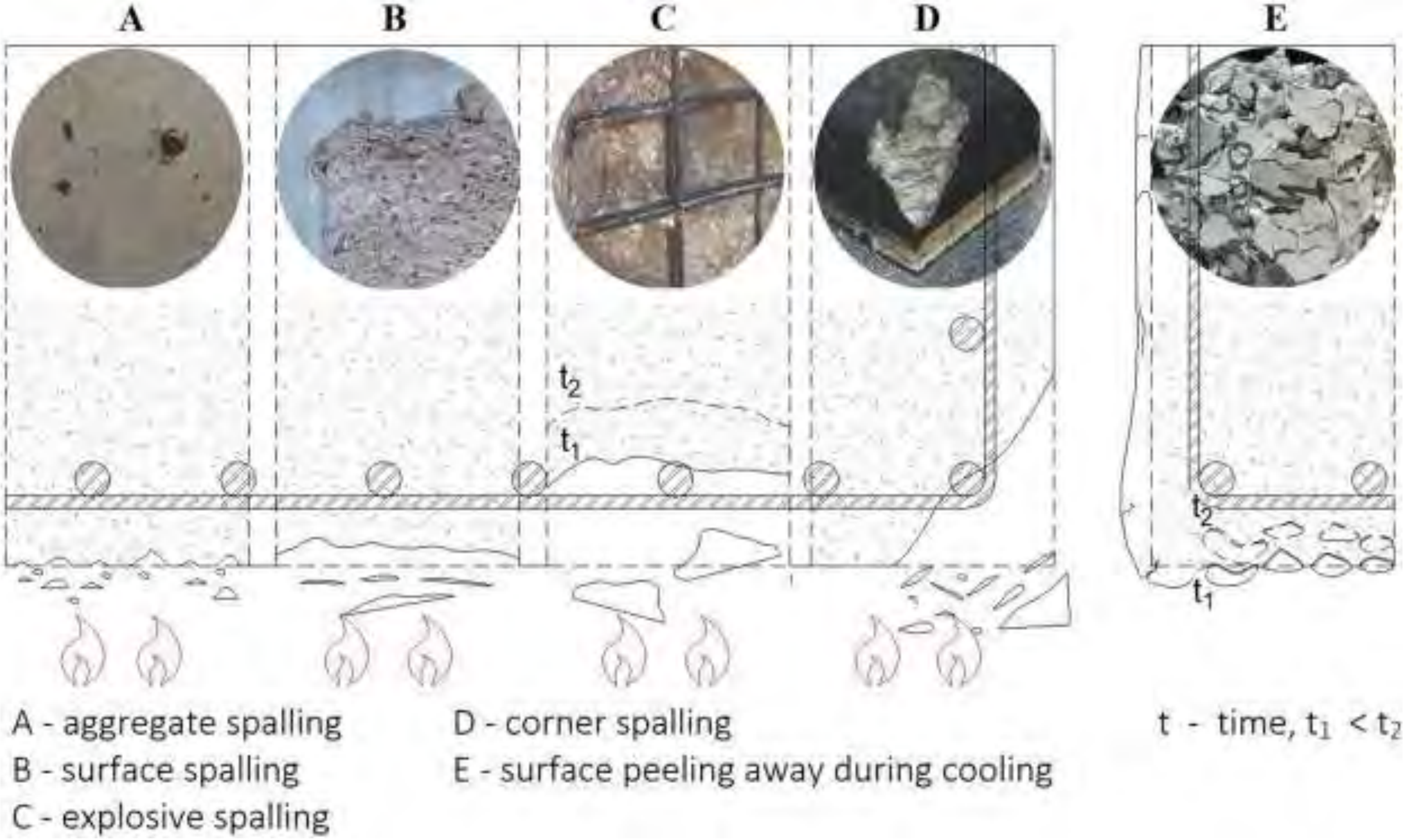
Cold Joint in Beam

Cold Joint in Wall

3. Fire Damage

Concrete is non-flammable and offers fire protective qualities for preventing the spread of fire. However, concrete loses most of its structural strength characteristics when exposed to extreme heat from a long burning fire.

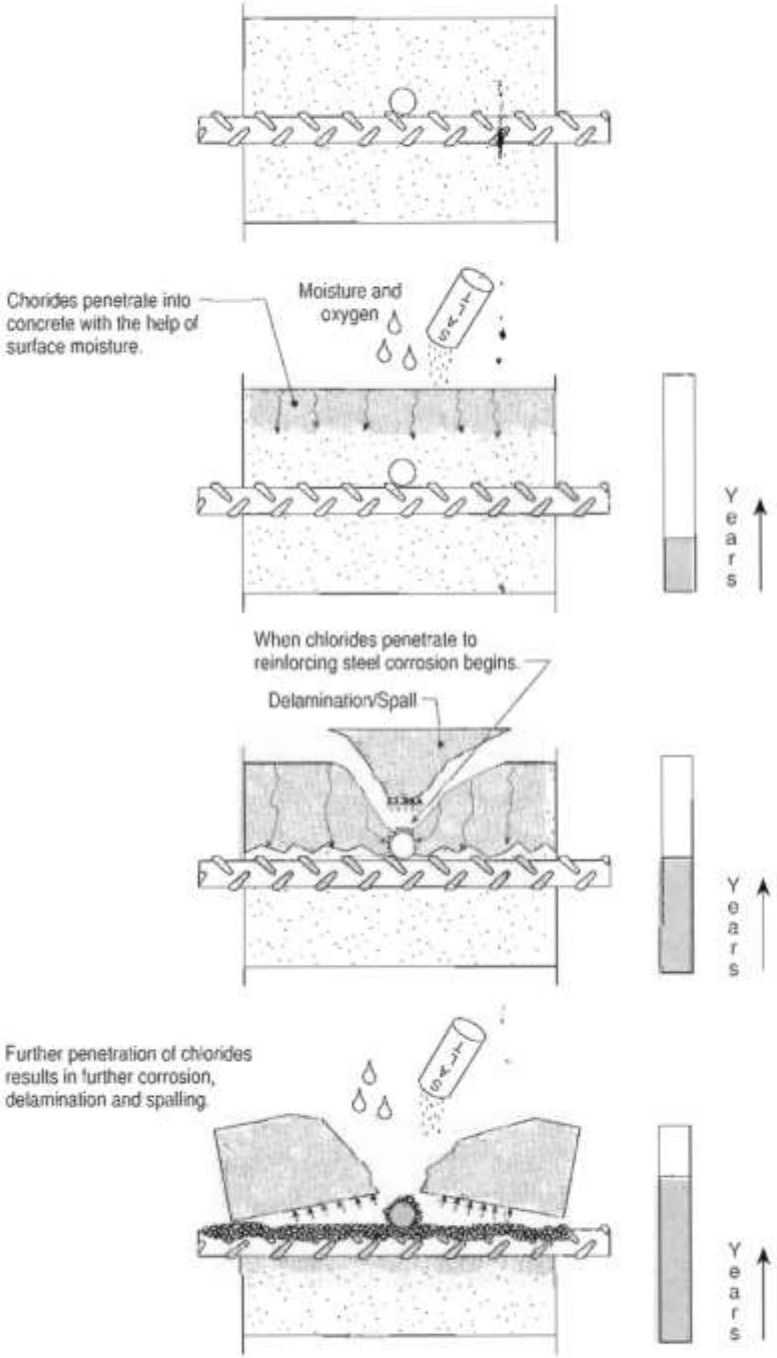
Fire Damage (Continued)



4. Water Leakage

5. Chloride Penetration

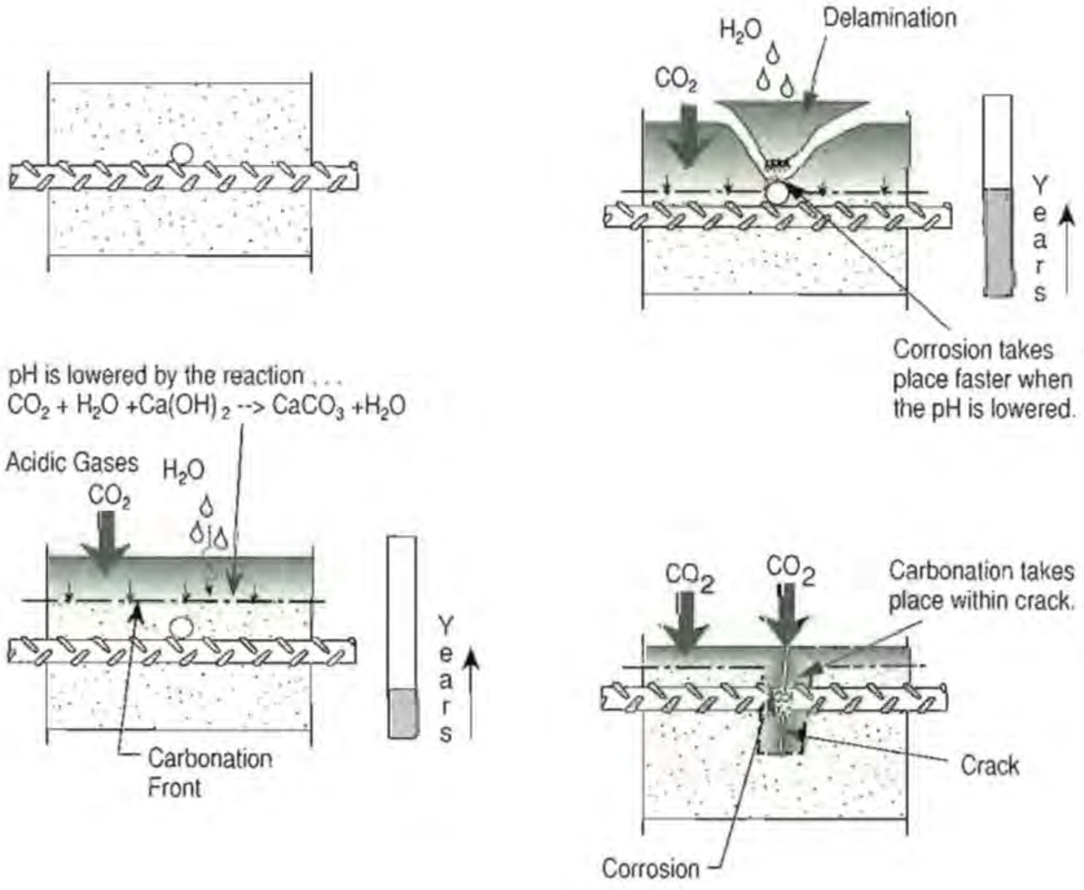
Chloride penetration refers to the depth to which chloride ions from the environment penetrate into the concrete. This can lead to corrosion in RCC structures, and thus study of chloride permeability is an important aspect that affects the durability of the concrete.

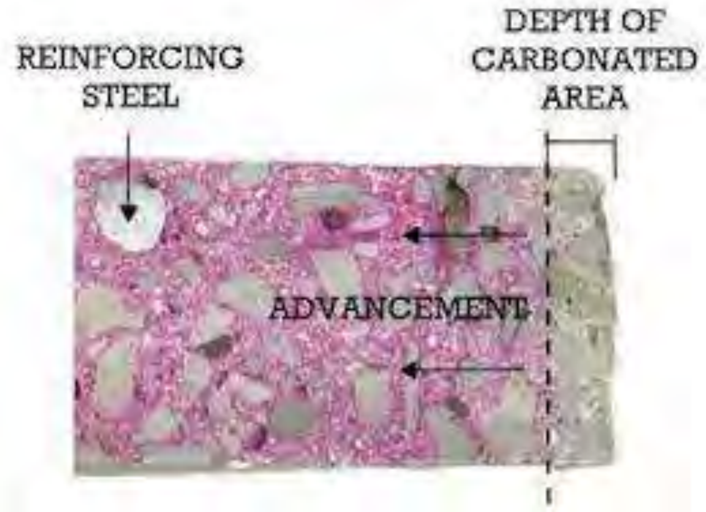


6. Carbonation

Carbonation of concrete is the chemical reaction between carbon dioxide in the air and calcium hydroxide and hydrated calcium silicate in the concrete to give mainly carbonates.

Carbonation significantly lowers the alkalinity of concrete via the consumption of $Ca(OH)_2$. This decrease in alkalinity destroys the passive protective oxide film around steel, causing it to start corroding.





Pozzolan

- Pozzolans are a broad class of siliceous or siliceous and aluminous materials which in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide (by product from the cement hydration) at ordinary temperature to form compounds possessing cementitious properties.

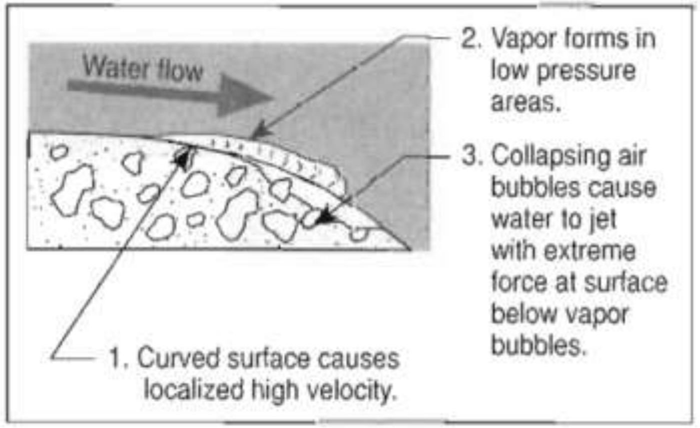
$$\text{Cement} + H_2O \Rightarrow CaH_2SiO_4H_2O + Ca(OH)_2$$

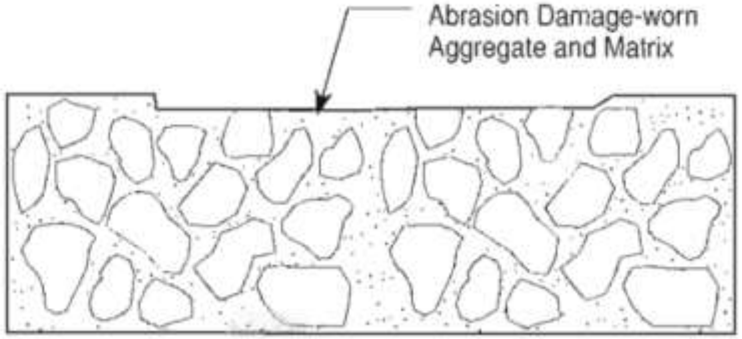
$$Ca(OH)_2 + Si(OH)_4 \Rightarrow CaH_2SiO_4H_2O$$

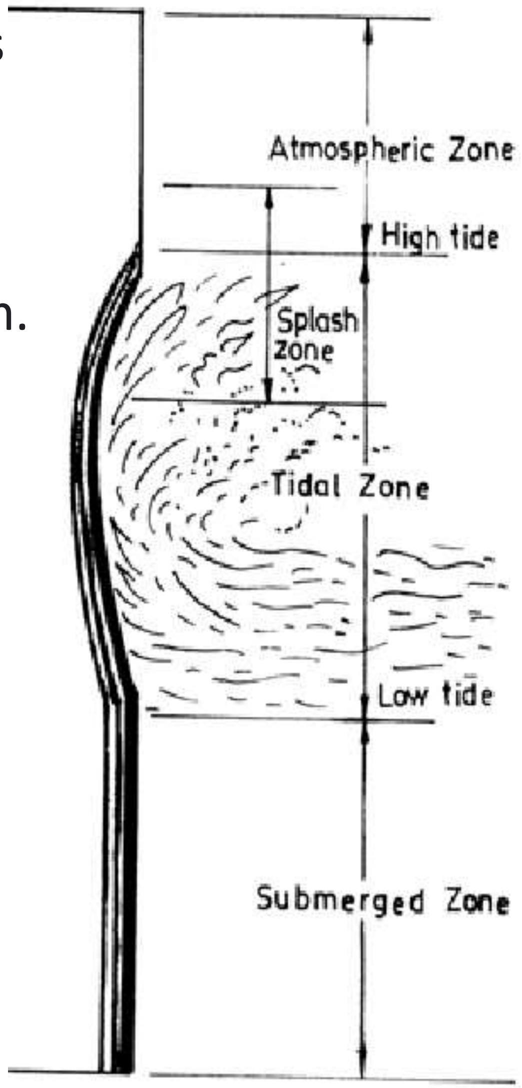
$CaH_2SiO_4H_2O$ is a calcium silicate hydrate, also abbreviated as C-S-H.

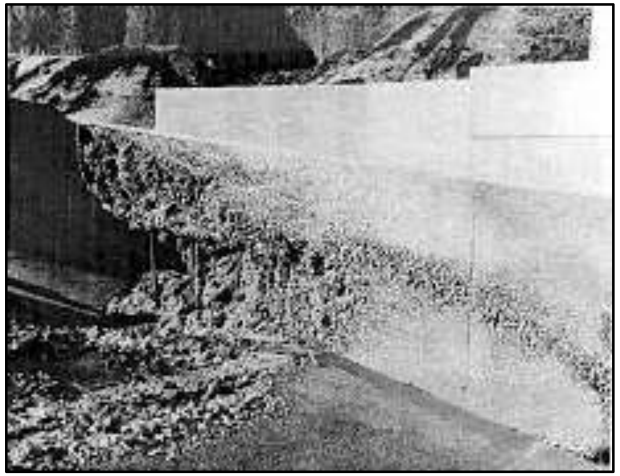
7. Concrete Erosion

Erosion is a mechanical damage of concrete which is frequently associated with corrosion. With this corrosion effects, erosion is happened when mechanical damage to concrete is occurred by the waves of water with gravel and sand carried by them.





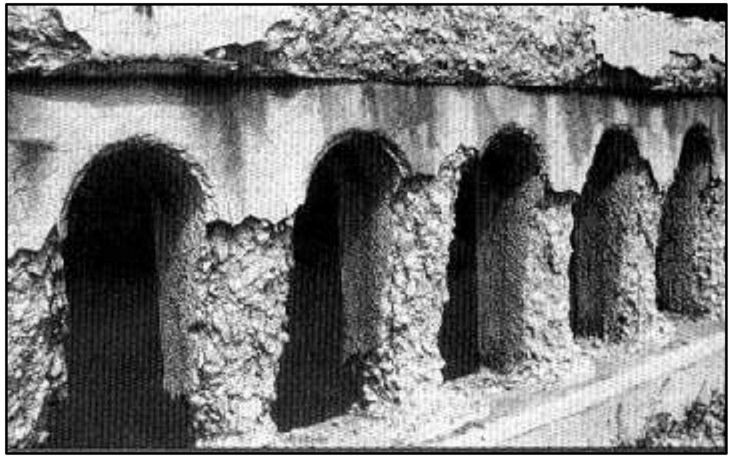


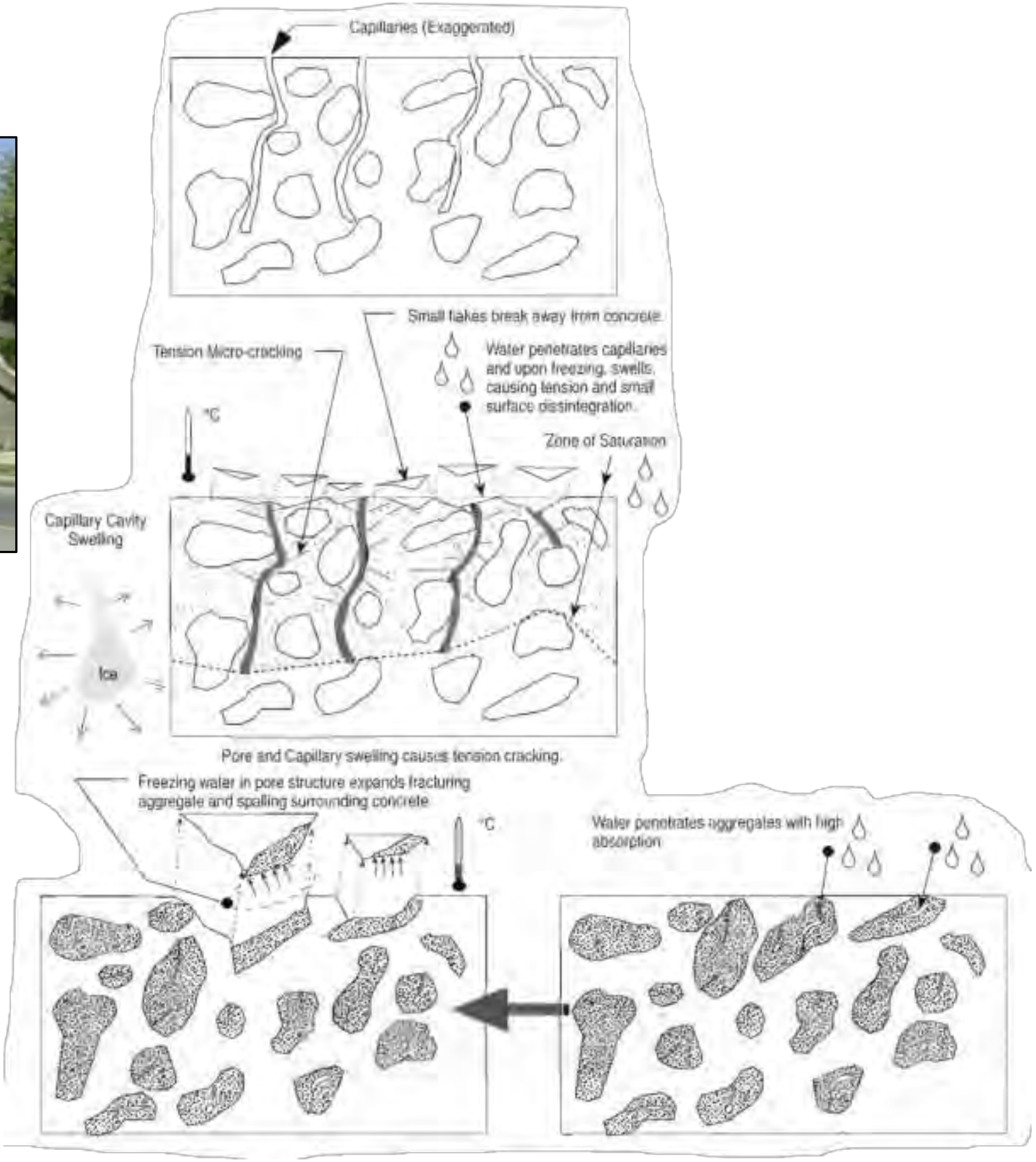


8. Freeze Thaw Attack

- Common in cold weather countries. The freeze-thaw cycle is a major cause of damage to construction materials such as concrete and brick assemblies.
- Freeze-thaw damage occurs when water fills the voids of a rigid, porous material and then freezes and expands. The volume of frozen water is 9% greater than liquid water, so when water freezes pressure is exerted on the surrounding material, and when the pressure exceeds the tensile strength of the material, cracks will result.
- During this process, the voids are enlarged, enabling the accumulation of additional water during the next thaw; this results in additional cracking during the next freeze. Substantial damage can occur over subsequent freeze-thaw cycles.

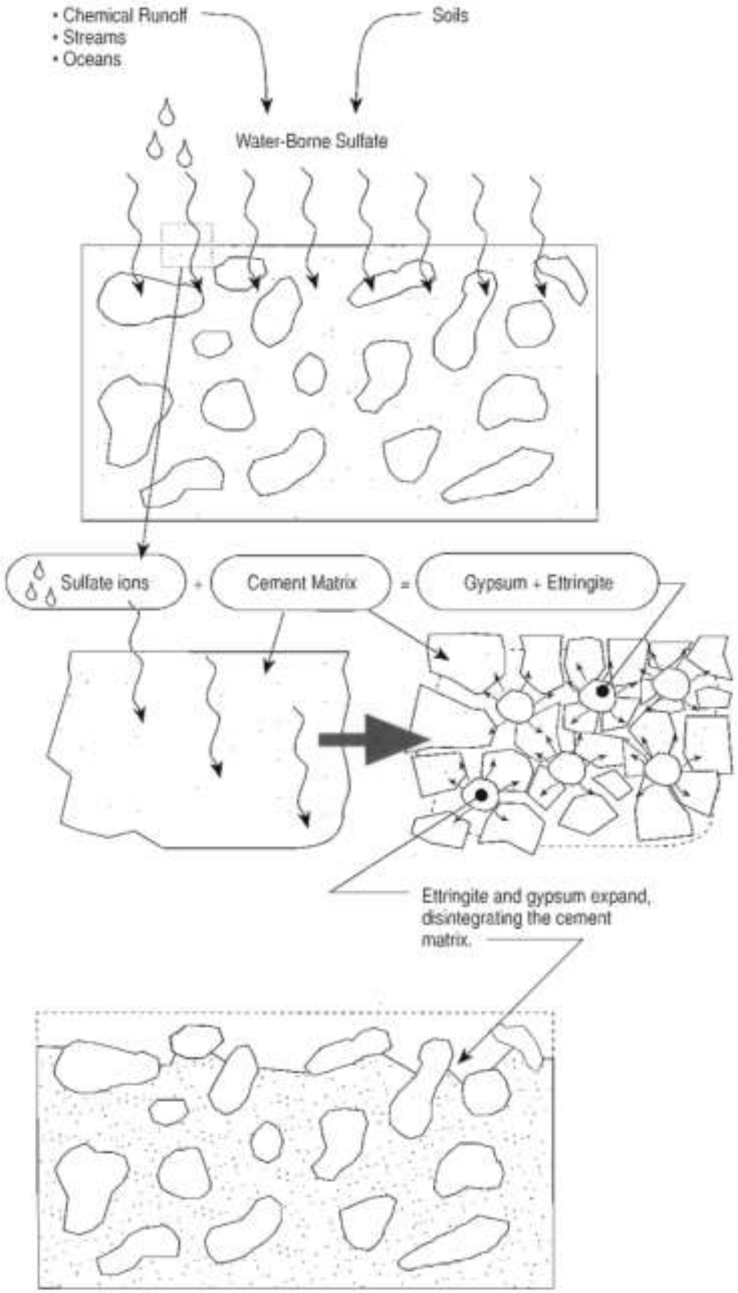
Freeze Thaw Attack (Continued)



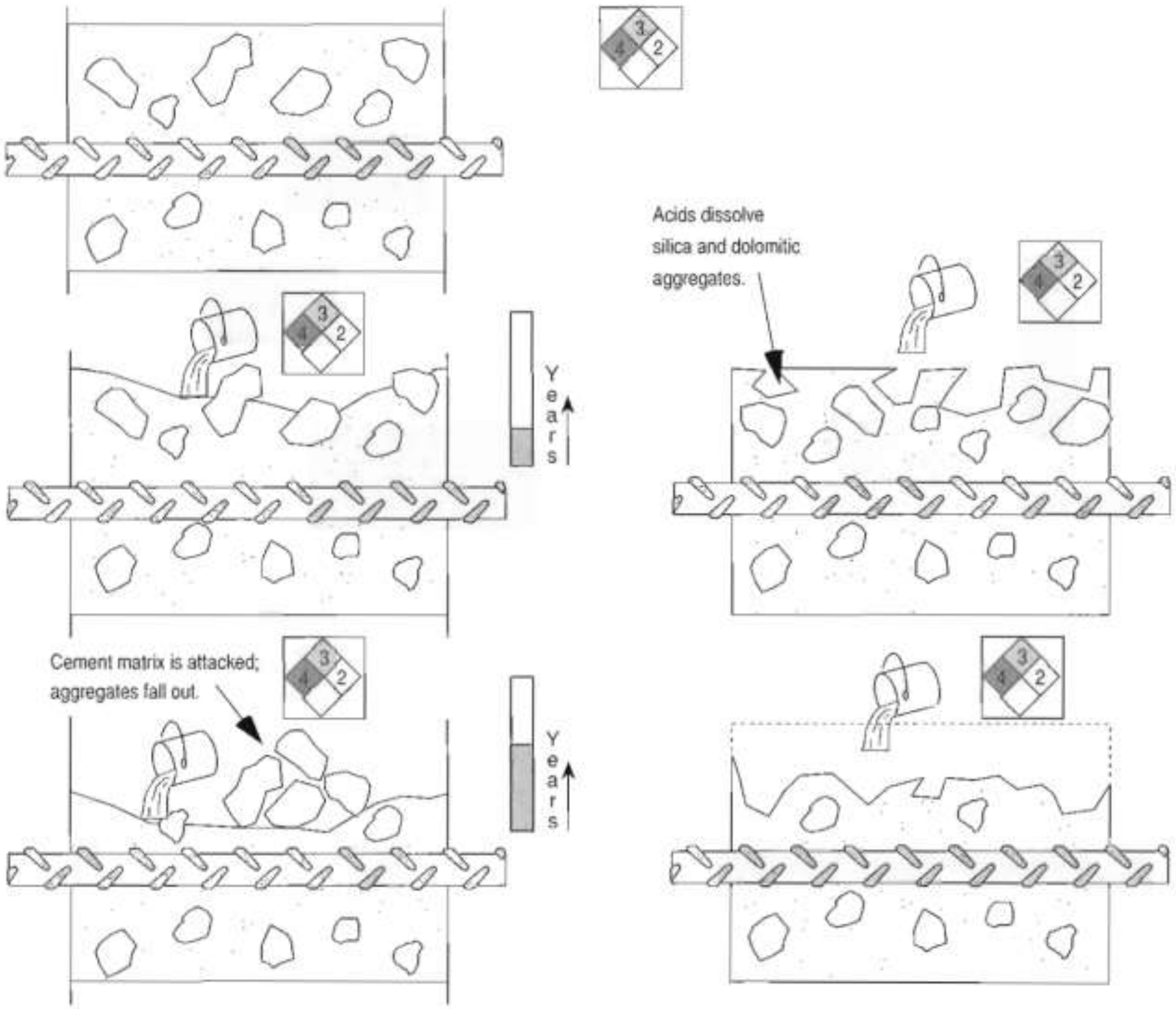


9. Sulphate Attack

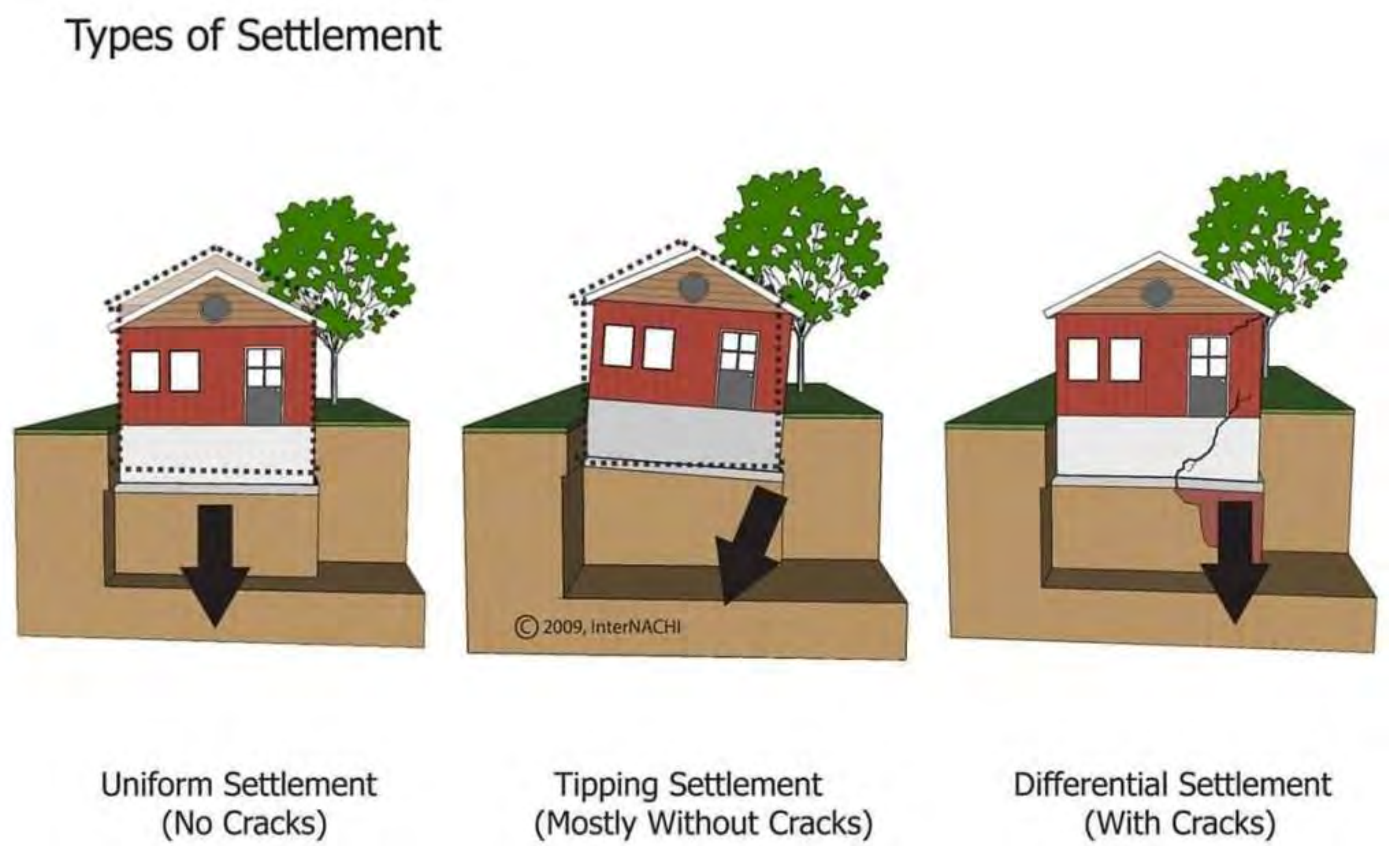
Sulfate attack of concrete is a complex process, which includes physical salt attack due to salt crystallization and chemical sulfate attack by sulfates from soil, groundwater, or seawater. Sulfate attack can lead to expansion, cracking, strength loss, and disintegration of the concrete.



10. Exposure to Aggressive Chemicals



11. Settlement



Settlement (Continued)

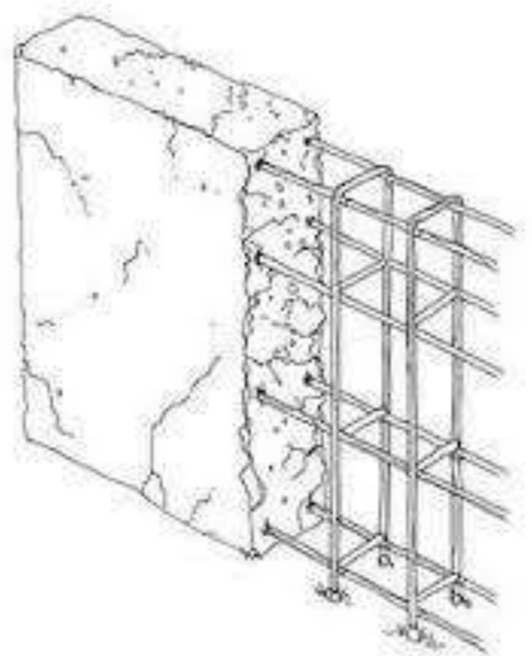
Wall Settlement

Building Settlement

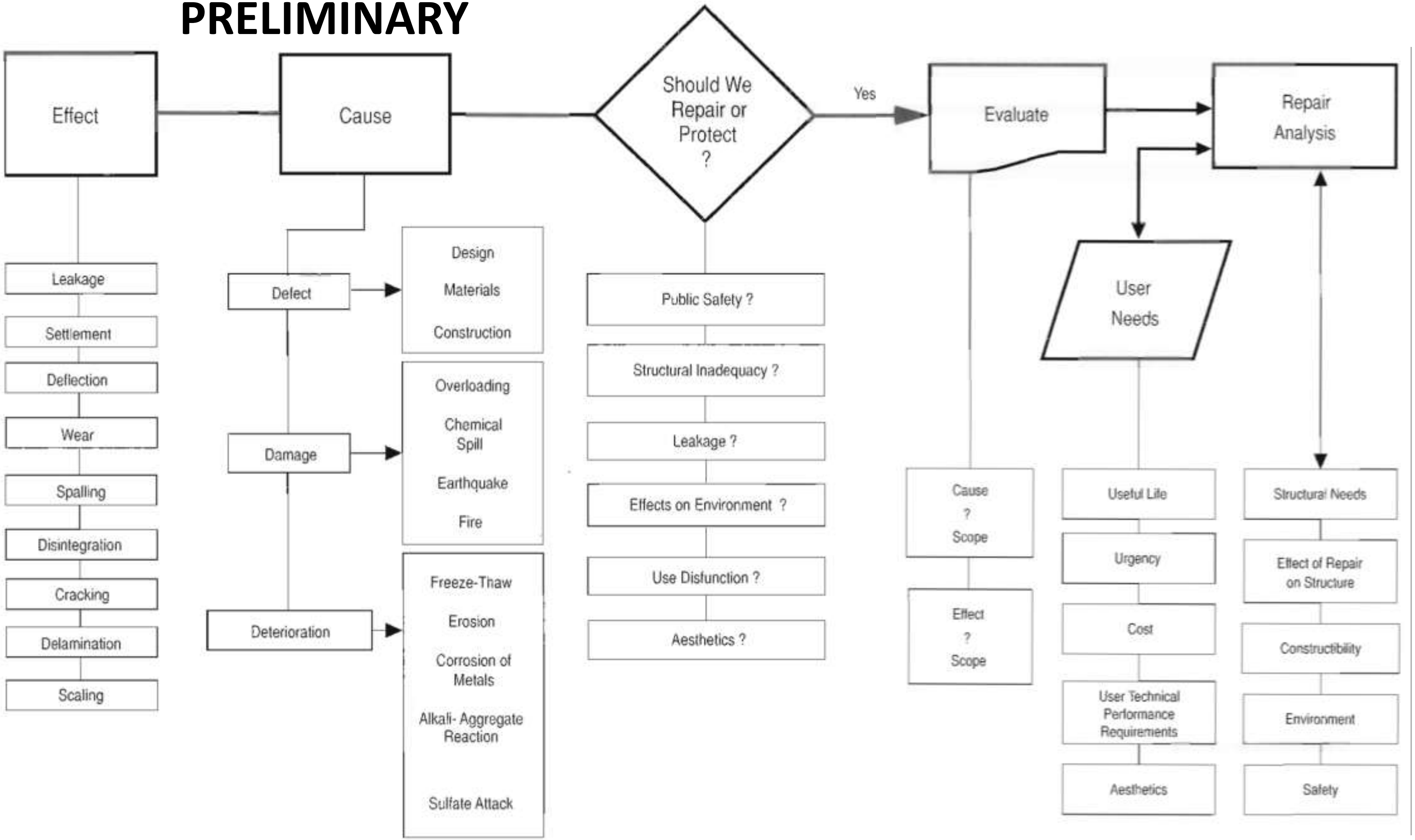
Floor Settlement

IV. PRELIMINARY PROCESS OF REPAIRS & RETROFITTING

- A Thorough and Logical Evaluation of the Current Condition of the Structure is the First Step of Any Repair or Rehabilitation Project.
- Concrete can be Defective for Several Reasons, Including Inadequate Design, Materials Selection and/or Workmanship. Concrete can also Deteriorate or be Damaged in Use.
- Consequently, Existing Reinforced Concrete may not be Functioning as Originally Intended and Designed.
- Reinforced Concrete is a Composite Material Consisting of Concrete and Reinforcing Steel. The Bond Between the Individual Constituents is the most Critical for the Properties of the Composite Material. Embedded Reinforcing Steel must be Adequately Bonded to the Surrounding Concrete Carrying the Anticipated Design Loads.
- The Evaluation Process is Important in Determining such Factors as Cause of Disfunction and Structural Safety, & for Establishing General Scope of Problems Found.



PRELIMINARY



EVALUATION

Visual Inspection

1. Walk-Through and Overall Visual Check of the Site Condition

Review of Engineering Data

1. Design & Construction Documentation
2. Operation & Maintenance Records
3. Concrete & Rebars (Including Other Materials Used) Records
4. Inspection Reports by Other Parties

Condition Survey

1. Mapping of the Various Deficiencies
2. Monitoring
3. Joint Survey
4. Sampling & Testing
5. Non-Destructive Testing
6. Structural Analysis

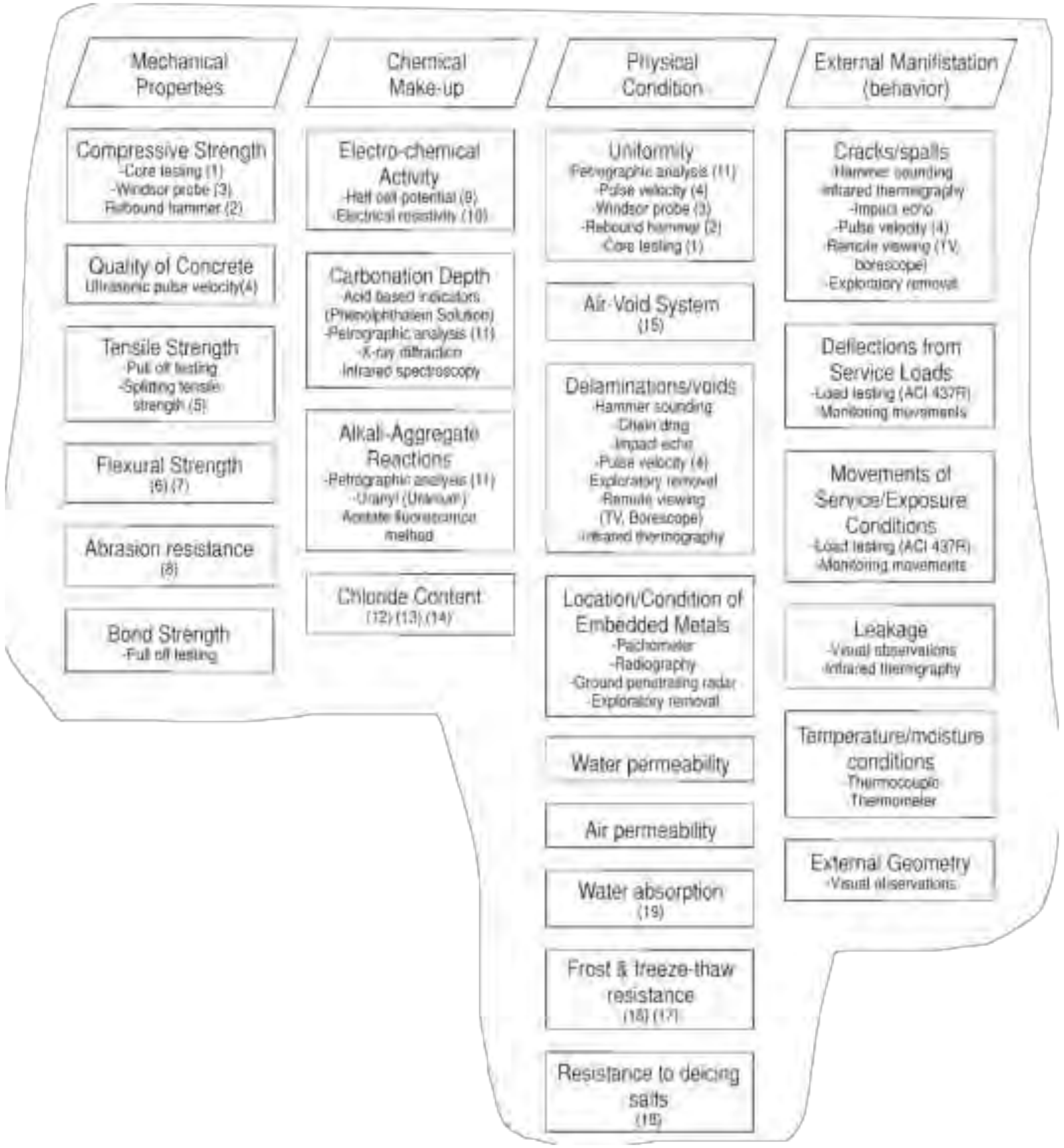
Final Evaluation

1. Evaluate the Root Causes of the Problem/s Based on Experience and Findings

Condition Survey Report

1. Report for Submission to the Requesting Parties with Further Procedure and Recommendations

TESTING METHODS FOR CONCRETE EVALUATION



NO.	DESIGNATION	TITLE
1	ASTM C 42	Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
2	ASTM C 805	Rebound Number of Hardened Concrete
3	ASTM C 803	Penetration Resistance of Hardened Concrete
4	ASTM C 597	Pulse Velocity Through Concrete
5	ASTM C 496	Splitting Tensile Strength of Cylindrical Concrete Specimens
6	ASTM C 78	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
7	ASTM C 293	Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)
8	ASTM C 418	Abrasion Resistance of Concrete by Sandblasting
9	ASTM C 876	Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete
10	ASTM D 3633	Electrical Resistivity of Membrane-Pavement Systems
11	ASTM C 856	Standard Practice for Petrographic Examination of Hardened Concrete
12	AASHTO T 259	Resistance of Concrete to Chloride Ion Penetration
13	AASHTO T 260	Sampling and Testing for Total Chloride Ion in Concrete and Concrete Raw Materials
14	AASHTO T 277	Rapid Determination of the Chloride Permeability of Concrete
15	ASTM C 457	Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete
16	ASTM C 666	Resistance of Concrete to Rapid Freezing and Thawing
17	ASTM C 671	Critical Dilation of Concrete Specimens Subjected to Freezing
18	ASTM C 672	Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
19	ASTM C 642	Specific Gravity, Absorption, and Voids in Hardened Concrete

V. CONCRETE REPAIR PROCESS & PROCEDURES

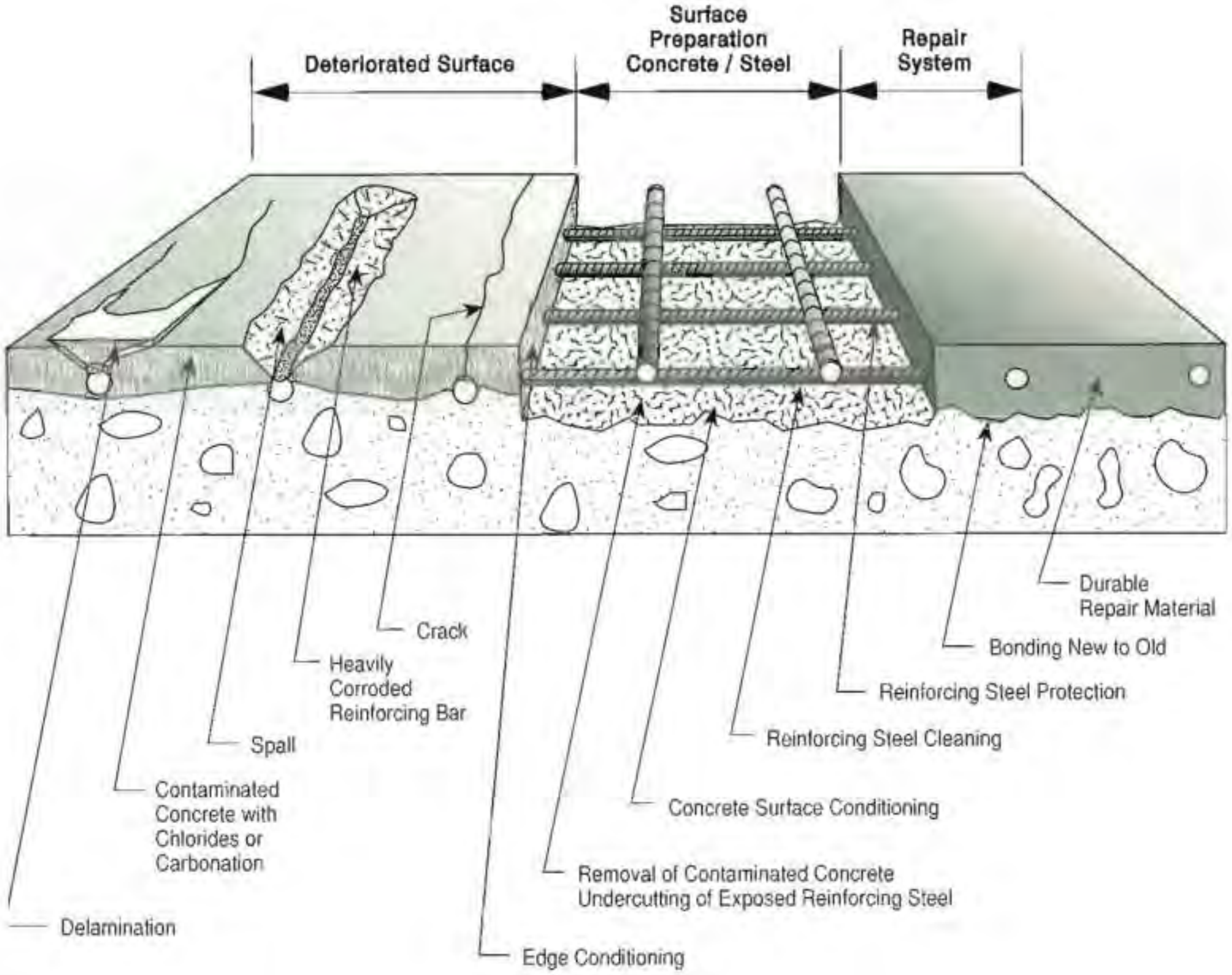
Objectives of Reinforced Concrete Repairs

- RESTORE AND INCREASE STRENGTH
- RESTORE AND INCREASE STIFFNESS
- IMPROVE FUNCTIONAL PERFORMANCE
- PROVIDE WATERTIGHTNESS
- IMPROVE APPEARANCE OF CONCRETE SURFACE
- IMPROVE DURABILITY
- PREVENT DEVELOPMENT OF CORROSIVE ENVIRONMENT AT REINFORCEMENT

Strength measures how much stress can be applied to an element before it deforms permanently or fractures.

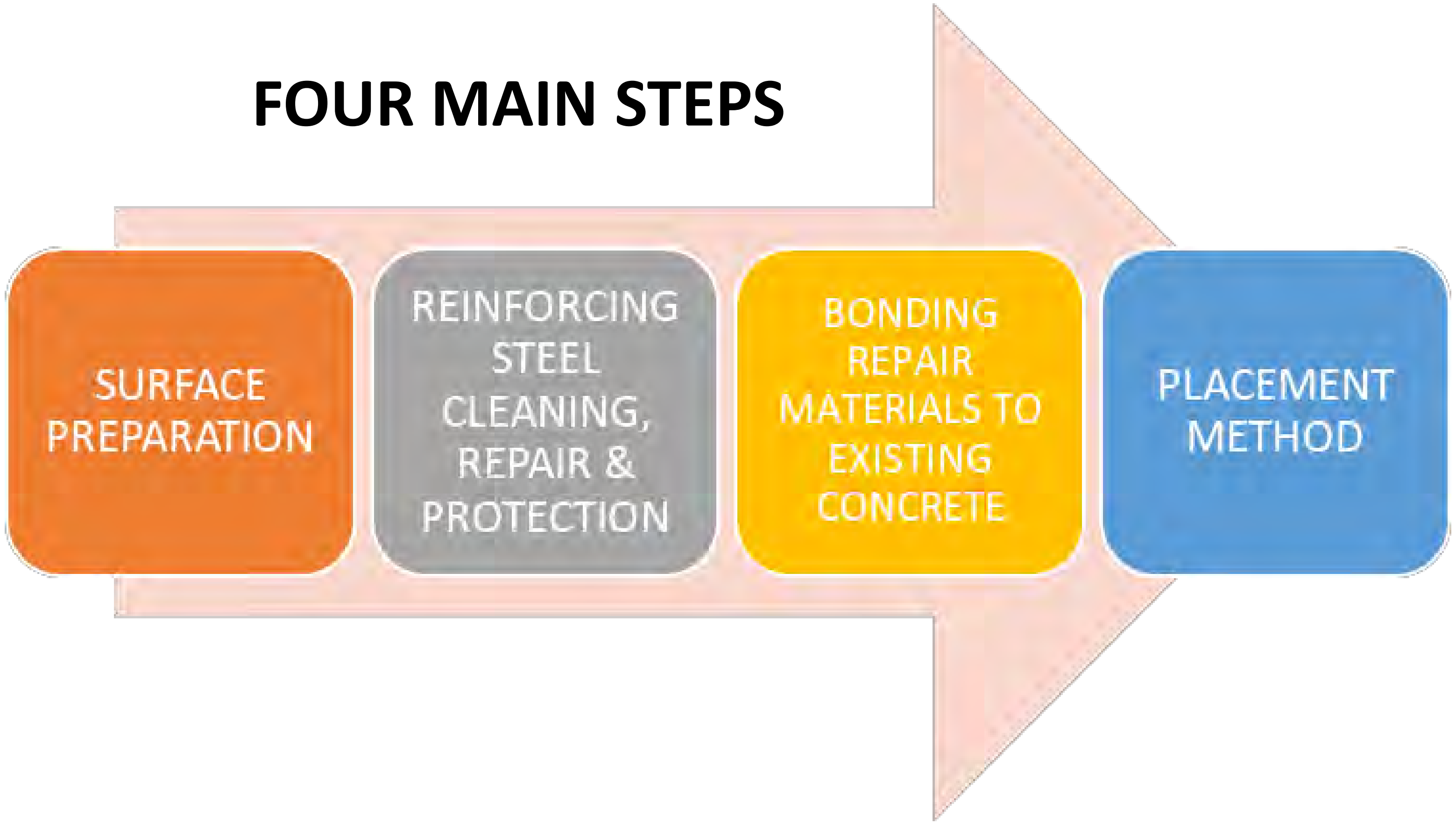
Stiffness is an indicator of the tendency for an element to return to its original form after being subjected to a force.

ANATOMY
OF
SURFACE REPAIRS

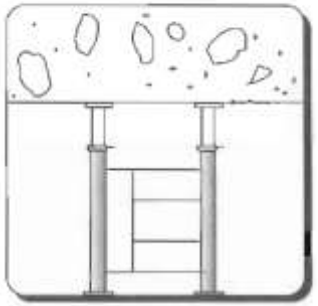


GENERAL PROCEDURES FOR REINFORCED CNCRETE REPAIRS

FOUR MAIN STEPS



1. SURFACE PREPARATION

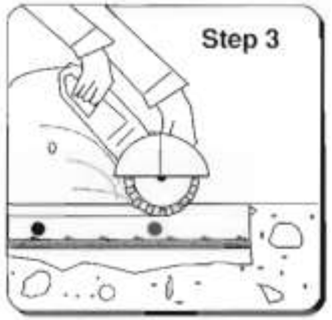


- Locate Area to be Repaired.
- Install Temporary Support Systems Prior to any Concrete Removals with an Engineering Judgement for Safety.

- Any Concrete Areas found to be Un-sound should be Re-Chipped.

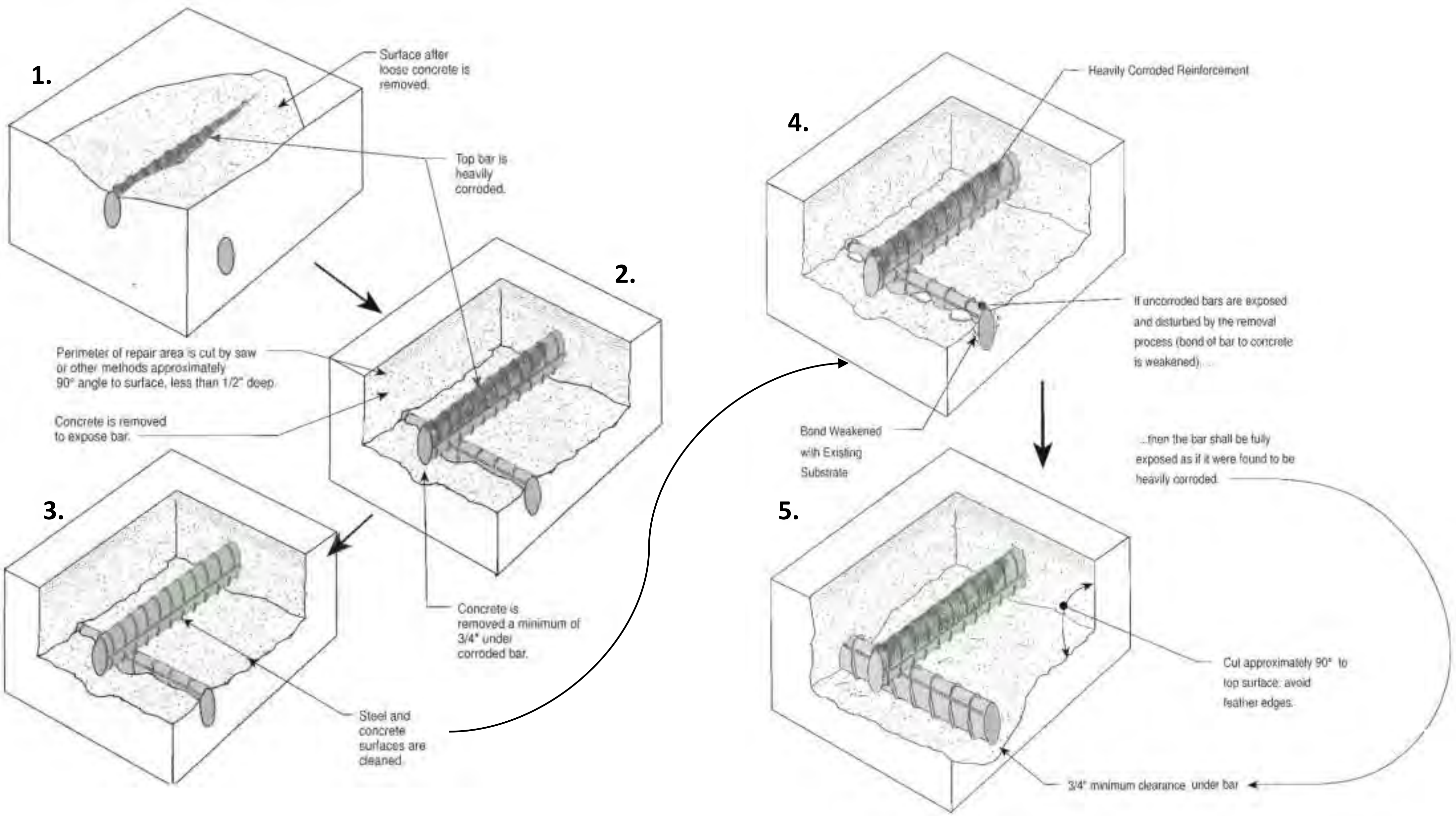
- Remove Deteriorated Concrete Using Acceptable Methods.
- Undercut Exposed Bars as they are Critical to Long-Term Success of Surface Repairs.
- Care Must Be Taken not to Damage the Reinforcing Bars.

- After Initial Removal, Surfaces should be Sounded for Delamination and Voids.



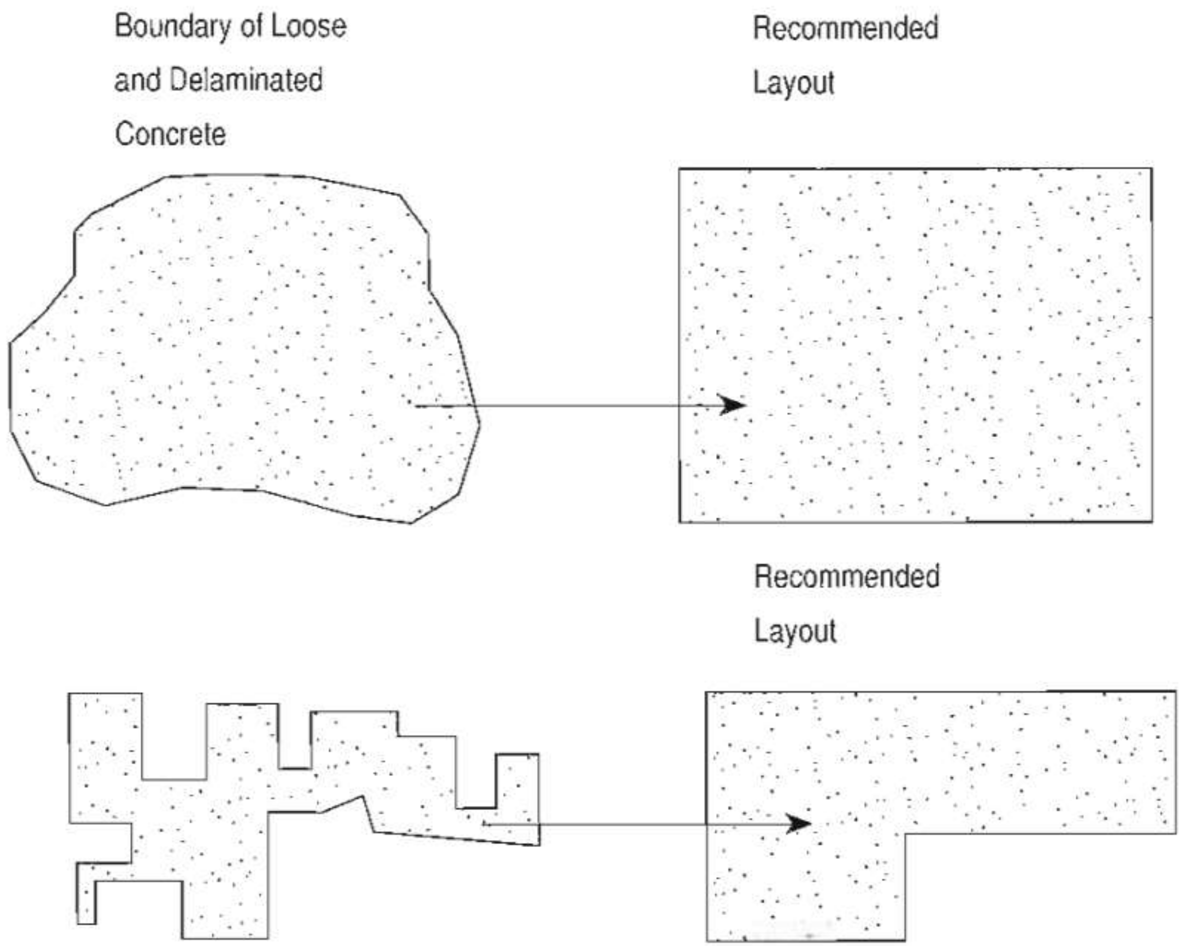
- Prepare Surface Repair Boundaries to Prevent Feather Edged Conditions.

WHEN CORRODED REINFORCEMENT IS ENCOUNTERED

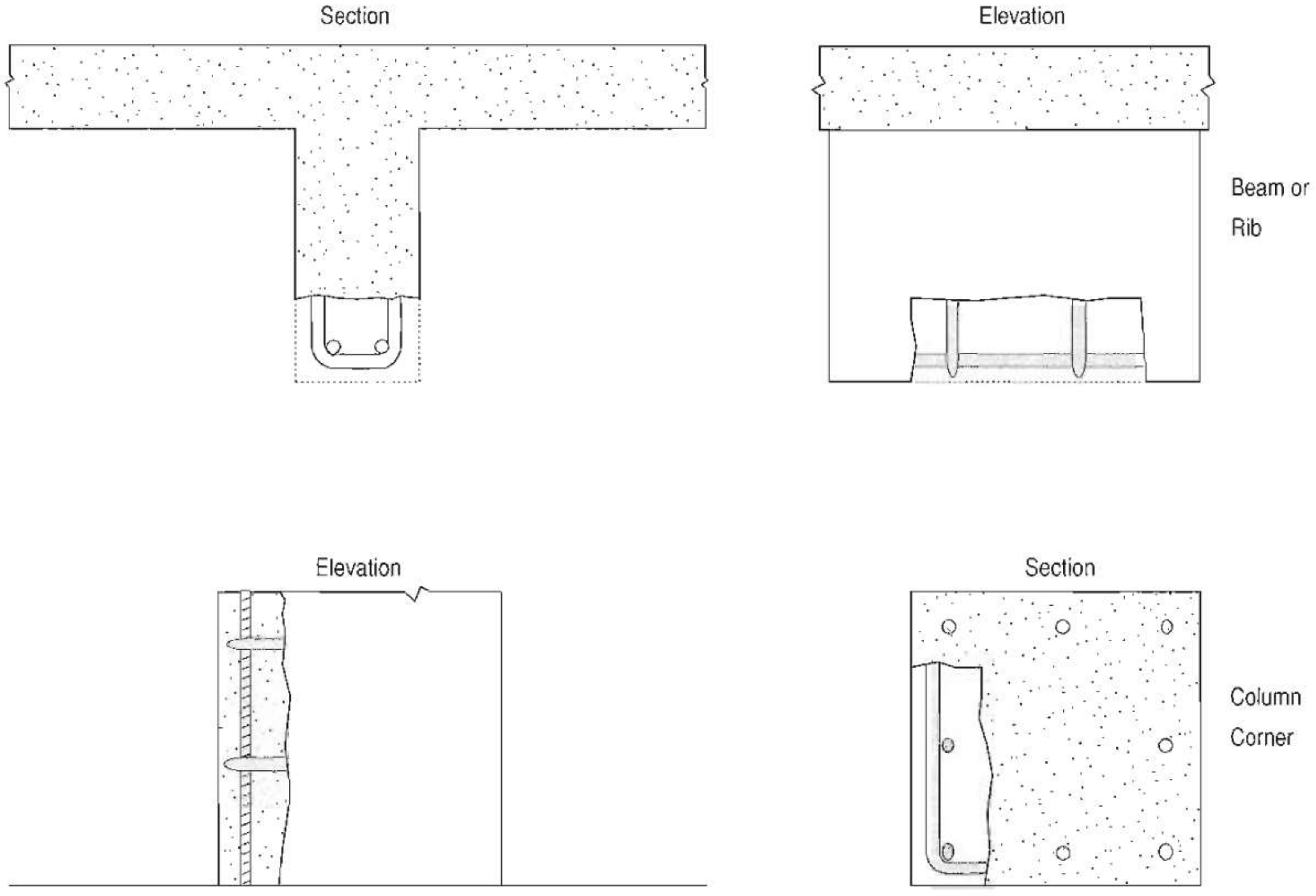


RECOMMENDED LAYOUTS OF SURFACE REMOVAL

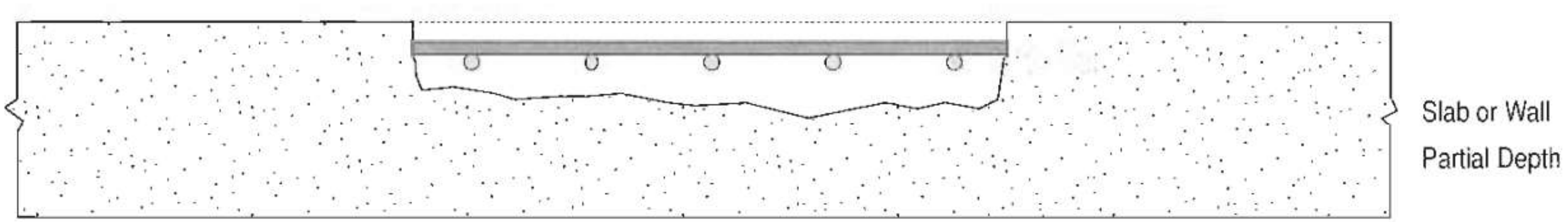
Layouts should be made as simple as possible.

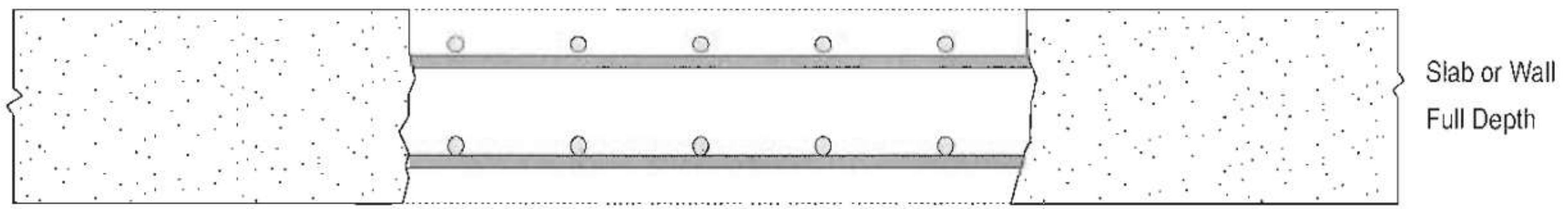


RECOMMENDED REMOVAL GEOMETRY

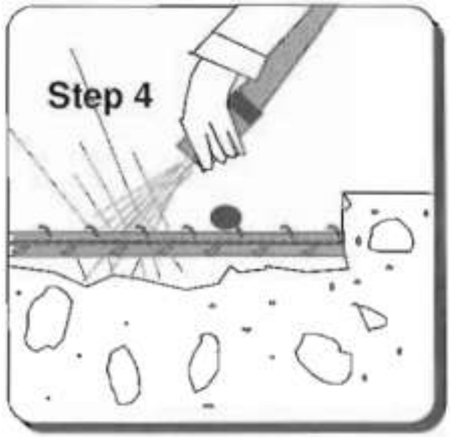


RECOMMENDED REMOVAL GEOMETRY (Continued)



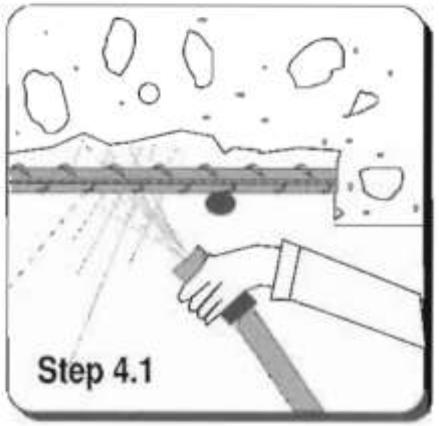


2. REINFORCING STEEL CLEANING REPAIR & PROTECTION

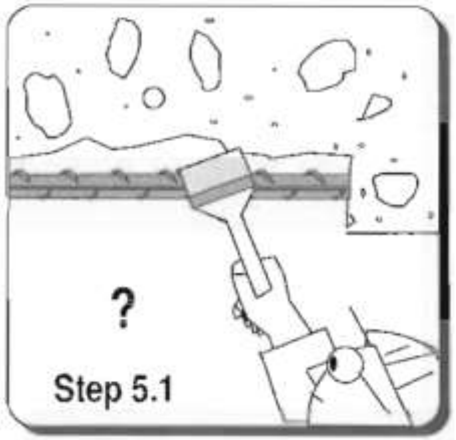


- Clean the Surface of the Exposed Reinforcing Steel & Concrete.
- Surface Cleaning is Critical to Achieve an Adequate Bond between the Repair and the Existing Concrete.

- Bars Damaged During Removal Operations or with Critical Section Loss may Require Repair or Replacement.

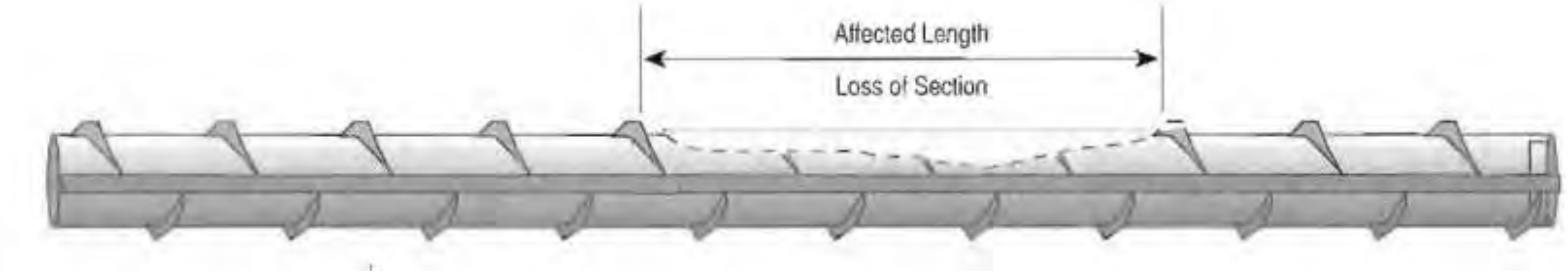


- Heavy Rust or other Bond-Inhibiting Materials must be Removed by any Acceptable Cleaning Methods.



- In Certain Situations, Special Coatings may be Applied to add Additional Protection to the Reinforcing Bars.

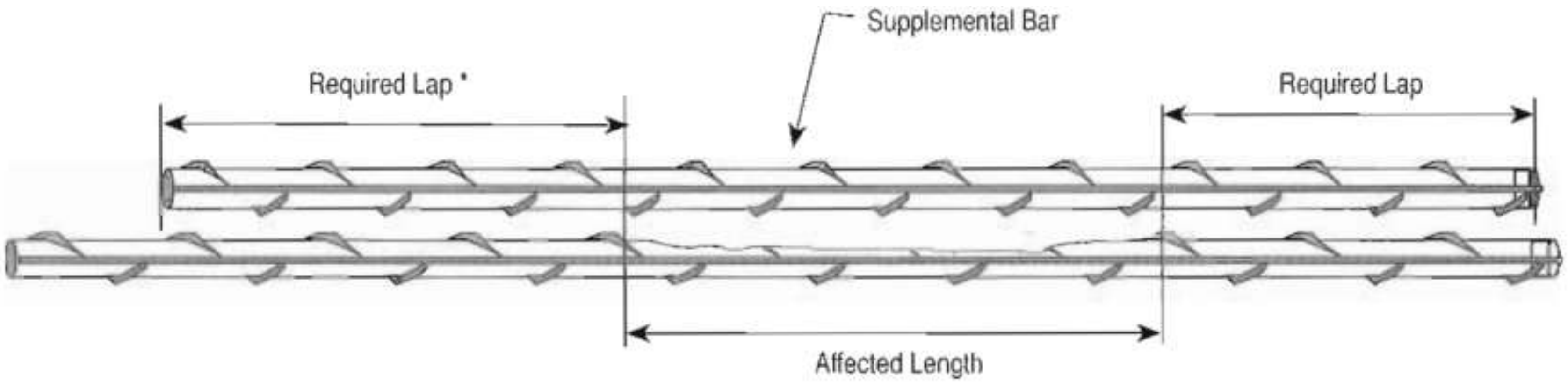
REINFORCING STEEL REPAIR (FROM SECTION LOSS)

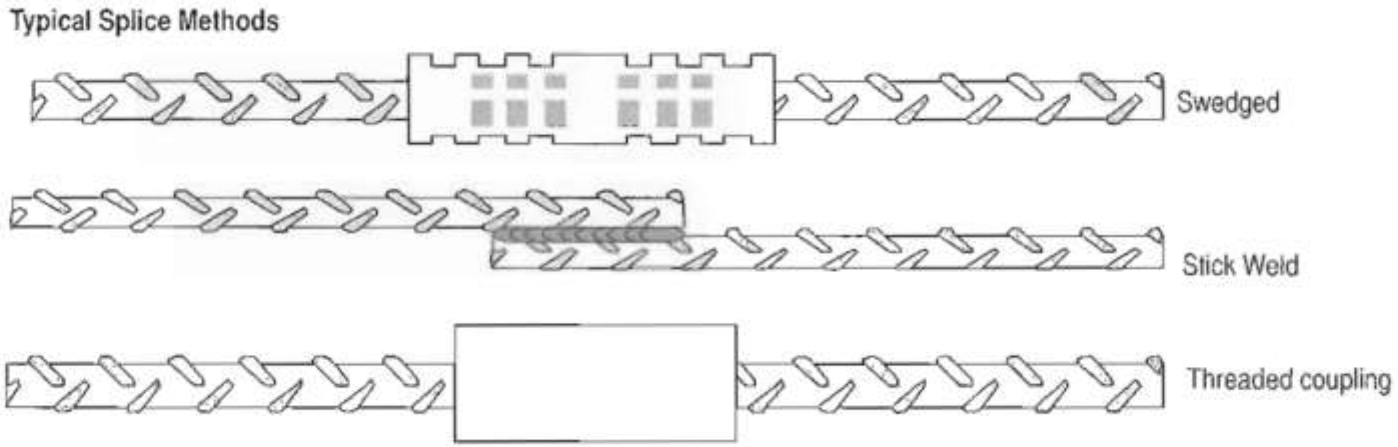


IF THE REINFORCING STEEL HAS LOST MORE THAN 25% OF ITS CROSS SECTION (OR 20% IF TWO OR MORE ADJACENT BARS ARE AFFECTED), THEN REINFORCING STEEL REPAIR IS GENERALLY REQUIRED.

METHODS OF REPAIRS FOR REINFORCING STEEL

1. Supplemental Bar over Affected Length. New Bar may be Mechanically Spliced to the Affected Bar or Placed Parallel to the Existing Bar.
2. Complete Bar Replacement.





REINFORCING STEEL CLEANING

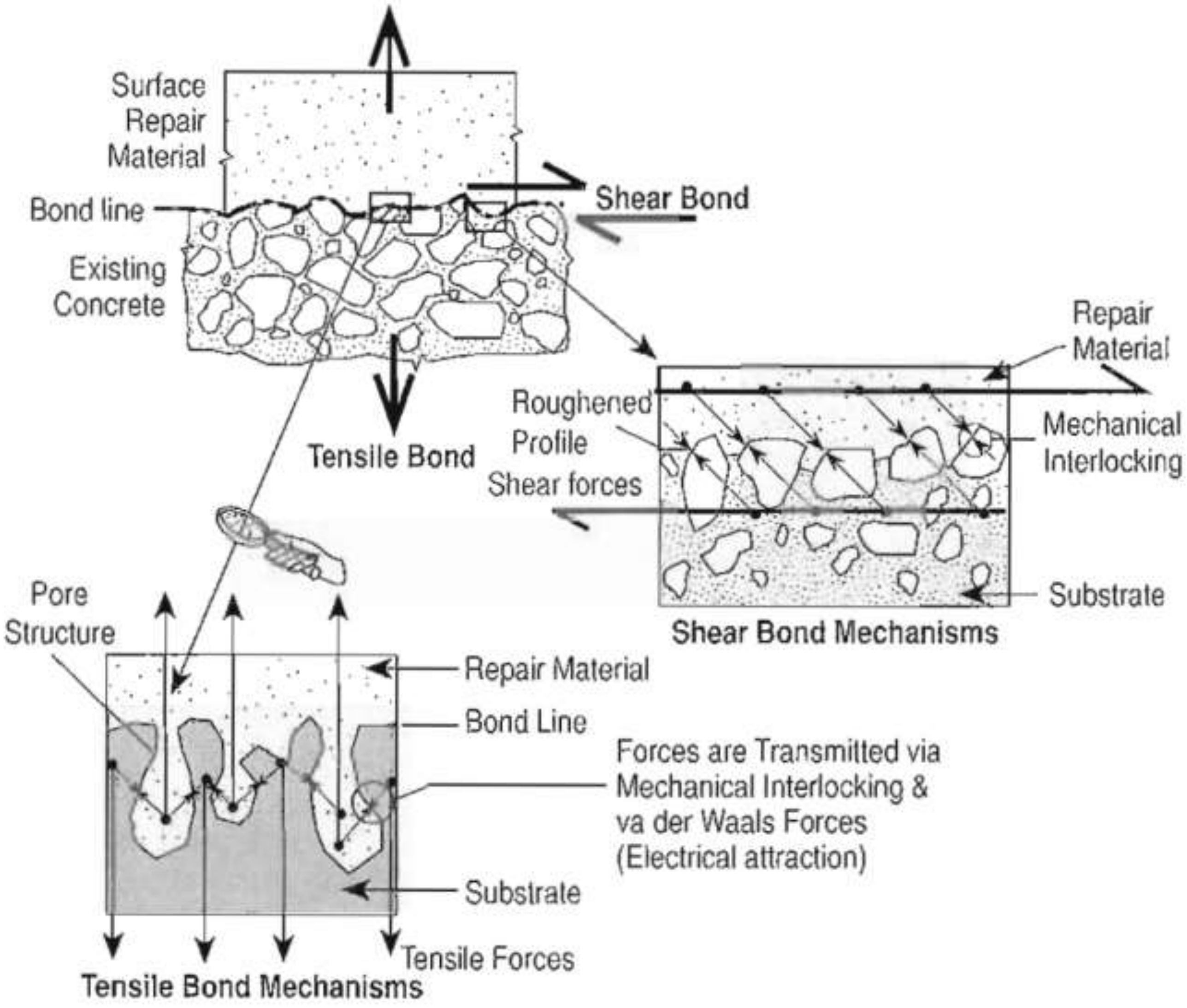
High Pressure Water Cleaning

Abrasive (Sand) Blast Cleaning

Power Wire Brushing

Manual Wire Brushing

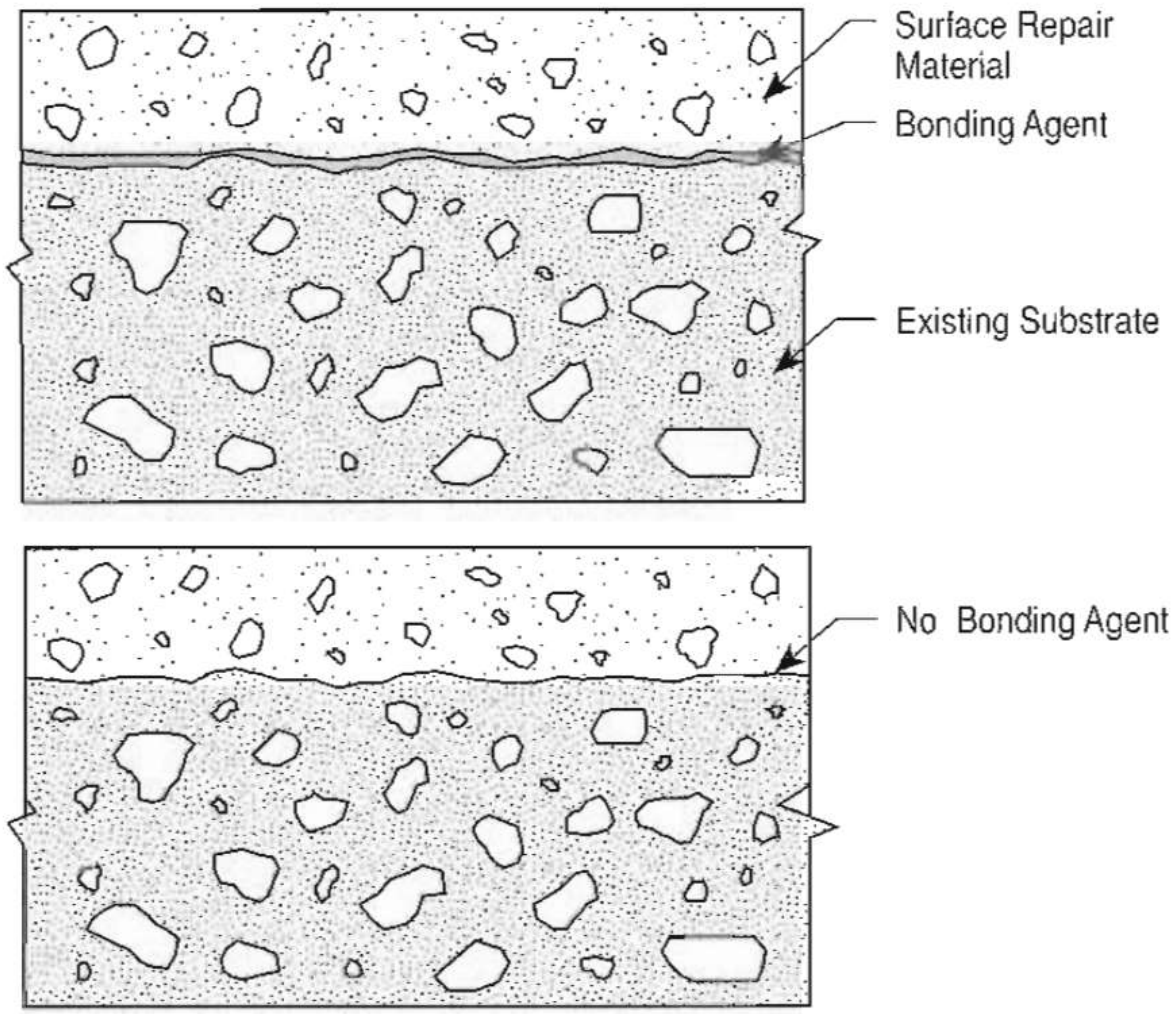
3. BONDING REPAIR MATERIALS TO EXISTING CONCRETE



Keys to Developing Bond

1. Clean, Sound Substrate.
2. Roughened Profile of Substrate for Mechanical Interlock.
3. Open Pore Structure in Substrate
4. Repair Material/Bonding Agent with Sufficient Paste for Absorption into Substrate Pores.
5. Repair Material is Applied with Sufficient Pressure to Facilitate Contact Between the Repair Material and the Substrate at the Bond Line.

BONDING AGENTS



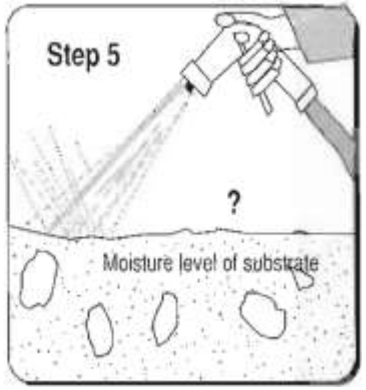
- Adequate Bonding can be Achieved by Placing Repair Material Directly Against Properly Prepared Substrate.
- Three Main Types of Bonding Agents;
    1. Cement-Based Slurries
    2. Epoxies
    3. Latex Emulsions

PREPARATION BEFORE BONDING MATERIAL APPLICATION

- The Surfaces of Existing Concrete must have an Open Pore Structure.
- The absorption of the Repair Material into the Substrate's Pore Structure is a Critical Bonding Mechanism.
- If the Pore Structure is Clogged with Dust, Slurry or Water, the Absorption Process will be Hindered, and Bond Strengths will be Reduced.

- Shot-blasting or Abrasive-blasting or Hydro-blasting and Vacuuming can Open the Pore Structure.

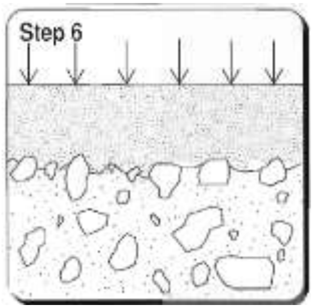
- The Open Pore Structure will Provide Capillary Suction of the Repair Material, or Bonding Agents, into the Substrate Concrete.



- The Moisture Level of the Substrate is also Critical to Achieve Bond.
- An Excessively Dry Substrate may Absorb too much Water from the Repair Material which can Result in Excessive Shrinkage.
- Also, Excessive Moisture in the Substrate can also Clog the Pores.
- **SSD (Saturated Surface Dry)** Condition should be Considered as a Best Solution.

BONDING MATERIAL APPLICATION

- The Repair Material must Contain a Sufficient Amount of Fluid Paste for Absorption into the Open Pore Structure of the Substrate.
- It is Important that the Bonding Agent should be Applied just before the New Concrete Placement or Casting.

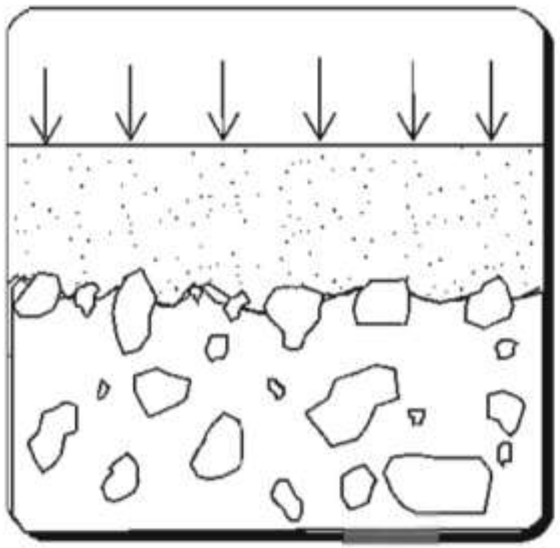


- The Bonding Agent must be Easily Absorbed into the Pore Structure and must be Compatible with the Repair Material and Substrate.
- It is also a Good Practice to Follow the Manufacturer's Instructions Depending on the Type of Work as Specified.

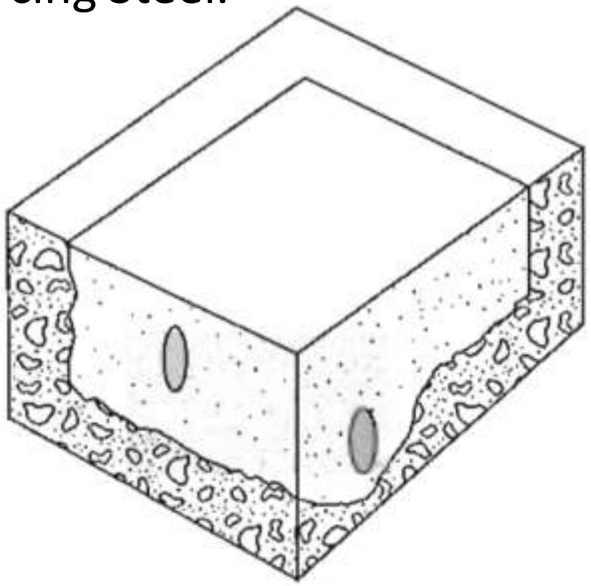
4. PLACEMENT METHODS

SELECTION OF REPAIR PLACEMENT METHOD

1. Selected Method of Placement will Successfully Deliver the Repair Material onto the Prepared Concrete Surface.
2. Constructability of Repair Method with the Site or Surrounding Current Condition.
3. The Repair Material must Achieve Satisfactory Bond to the Existing Substrate and must Fill the Cavity without Segregation, Sagging and Fully Encapsulating Exposed Reinforcing Steel.



The placement method must consolidate the repair material and create intimate contact between the repair material and the substrate.

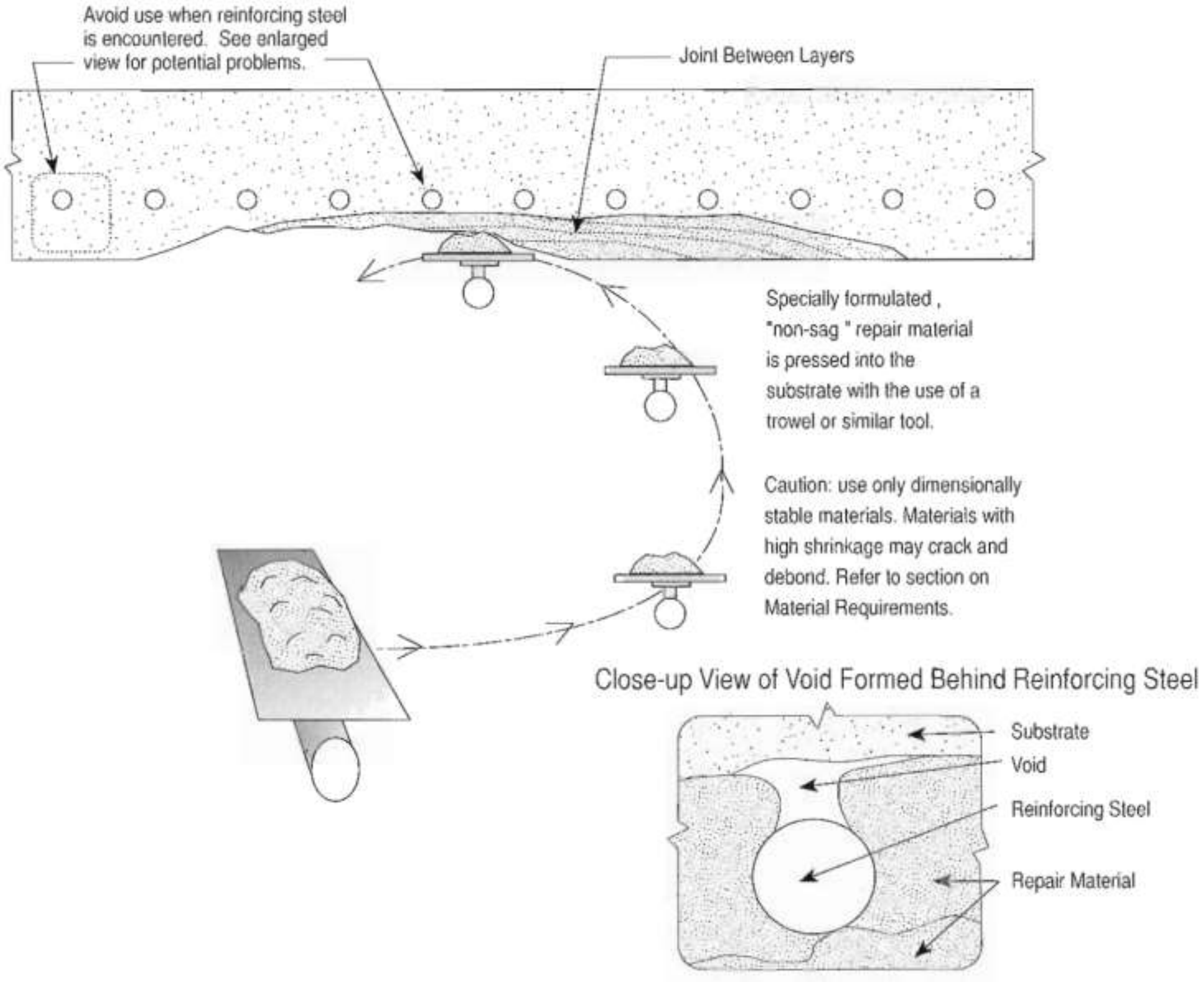


The placement method must also fully encapsulate any exposed reinforcing steel and produce a uniform cross section without segregation, cold joints, or voids.

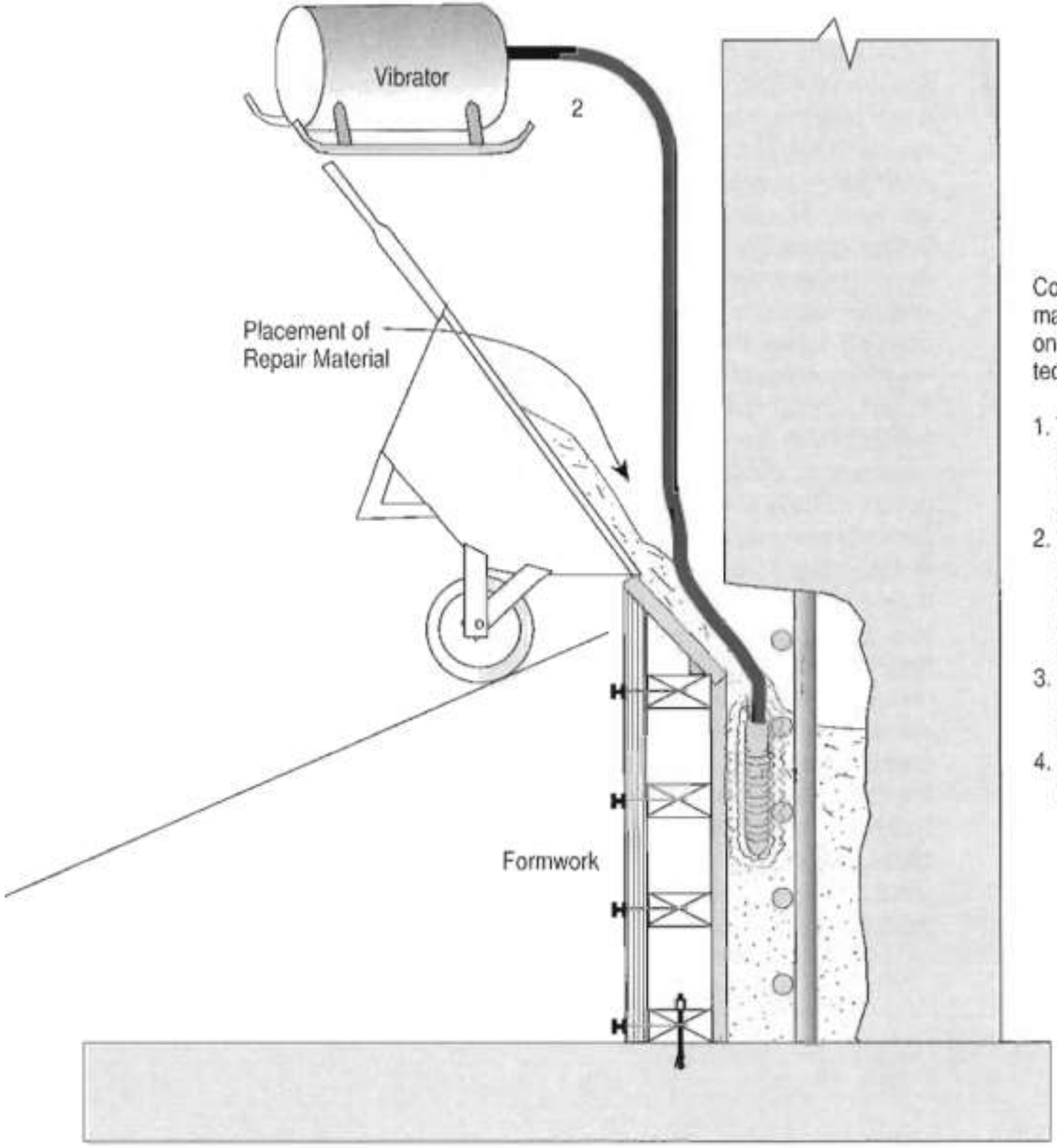
SUMMARY OF PLACEMENT METHODS

i. Hand-Applied
ii. Form and Cast-in-Place
iii. Form and Pump
iv. Full-Depth Repair
v. Grouted Preplaced Aggregate
vi. Shotcrete

(i) Hand Applied



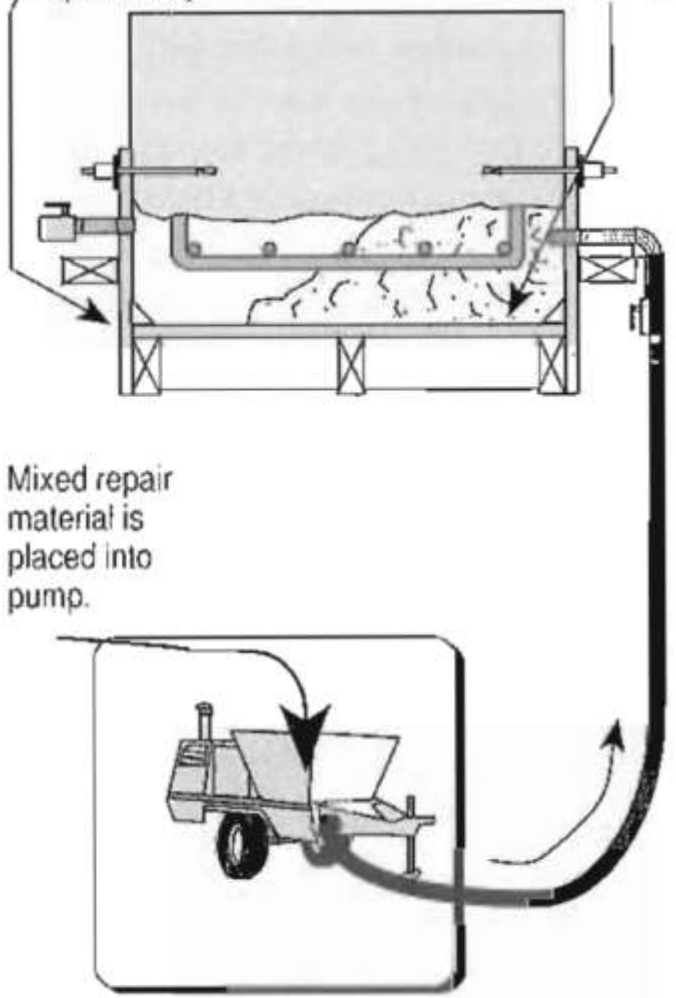
(ii) Form and Cast-in-Place



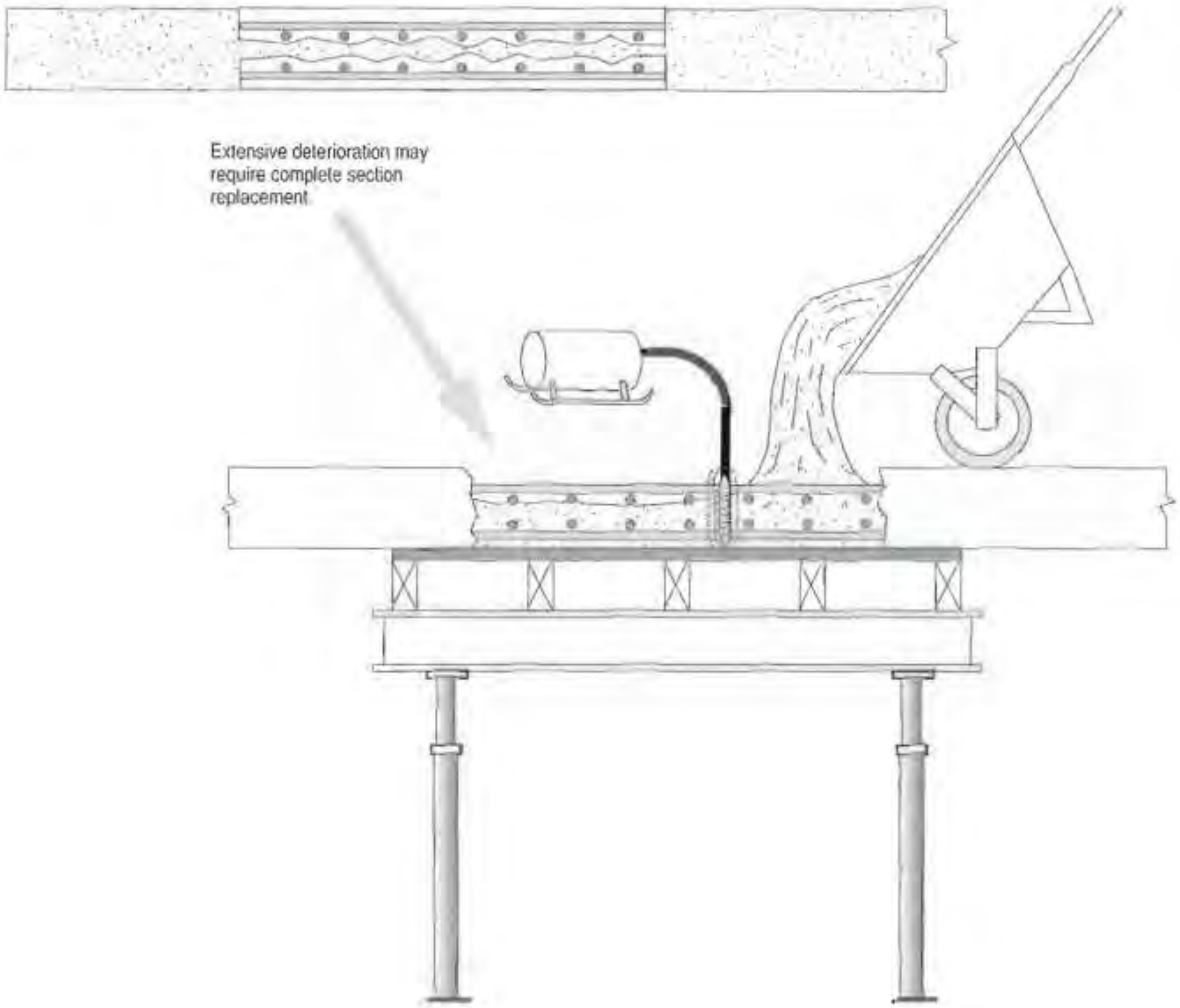
Consolidation of the repair material is accomplished with one of the following techniques:

1. The repair material is formulated to be extremely flowable and self-consolidating, or...
2. the repair material is placed into top of form and free falls into the prepared cavity where conventional internal vibrators are used, or...
3. rodding of the repair material from an access point in the formwork, or...
4. external vibration of formwork.

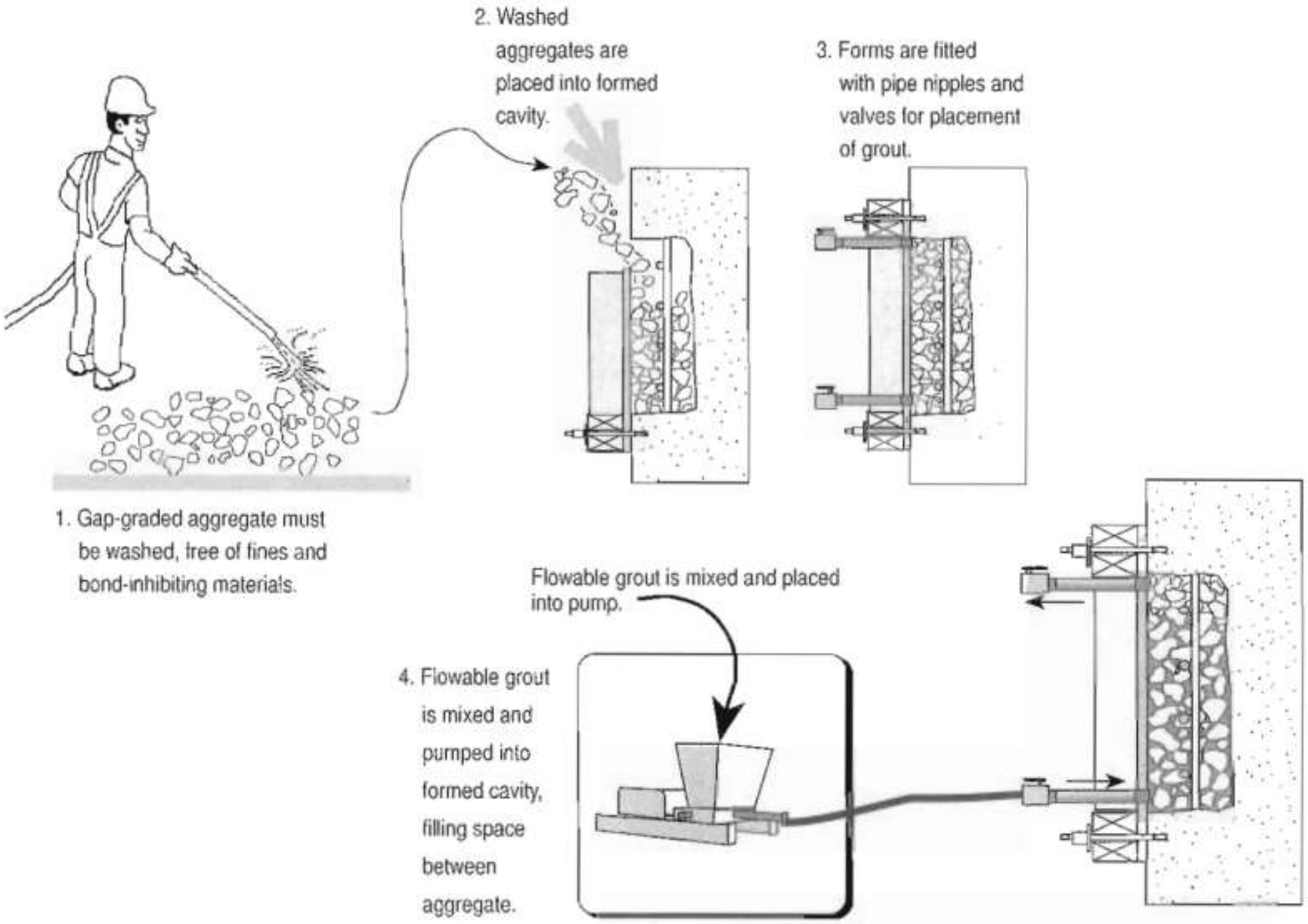
(iii) Form and Pump



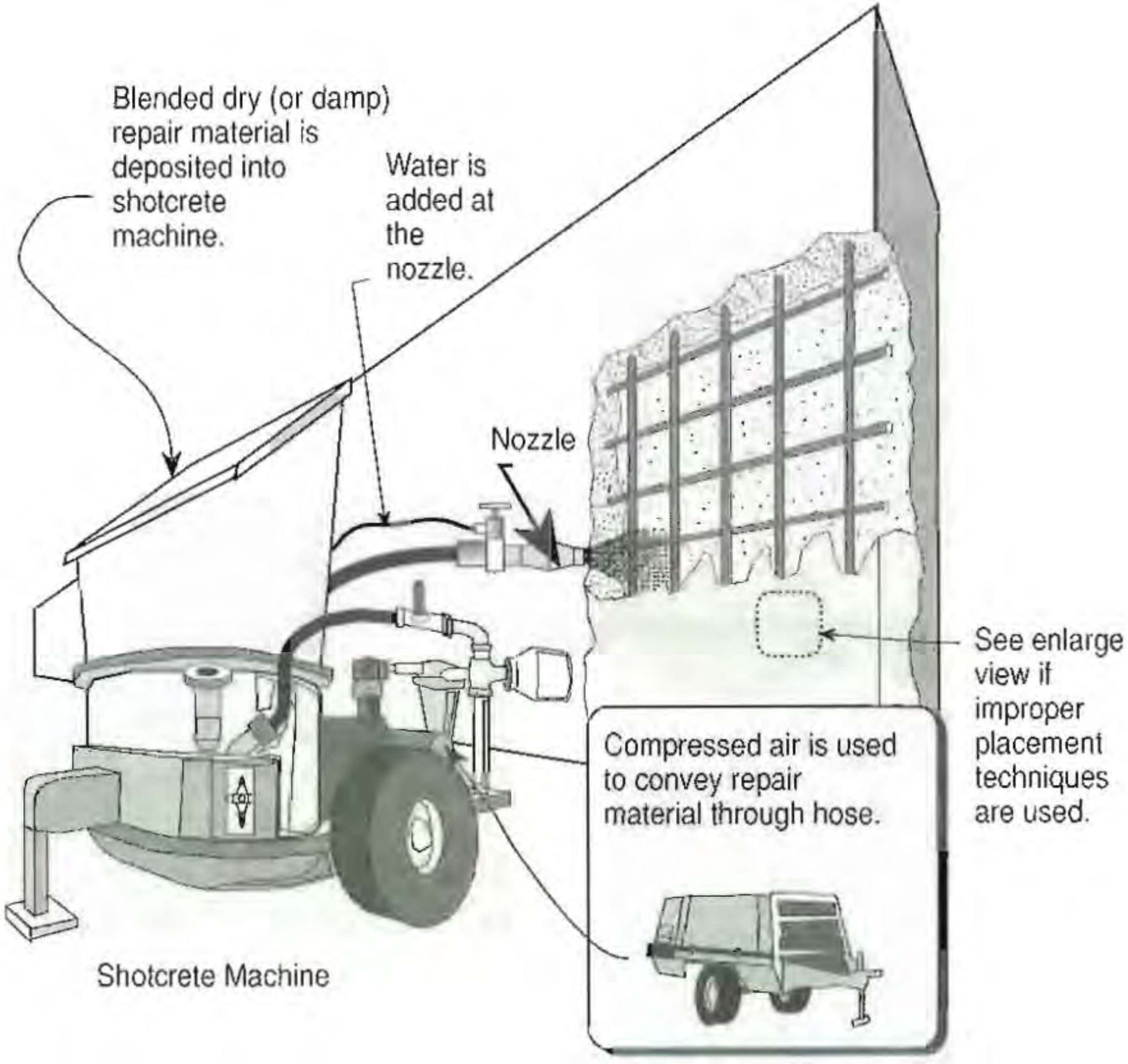
(iv) Full Depth Repair



(v) Grouted Preplaced Aggregate



(vi) SHOTCRETE



THANK YOU FOR YOUR ATTENTION

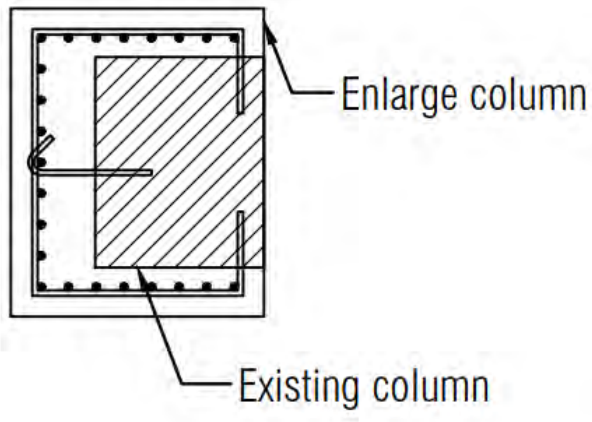
Questions are Welcomed

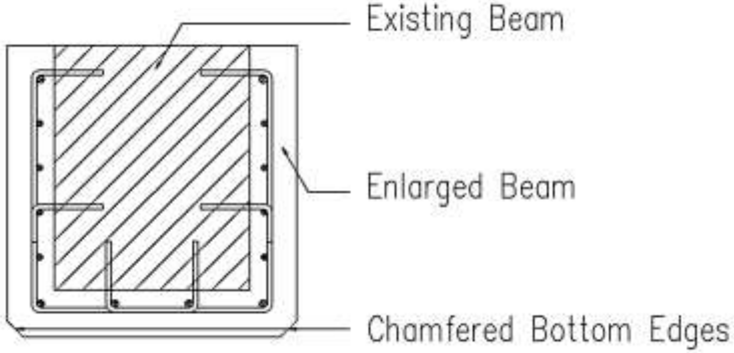

STRENGTHENING
METHODS OF
RC STRUCTURES

STRENGTHENING METHODS OF RC STRUCTURES

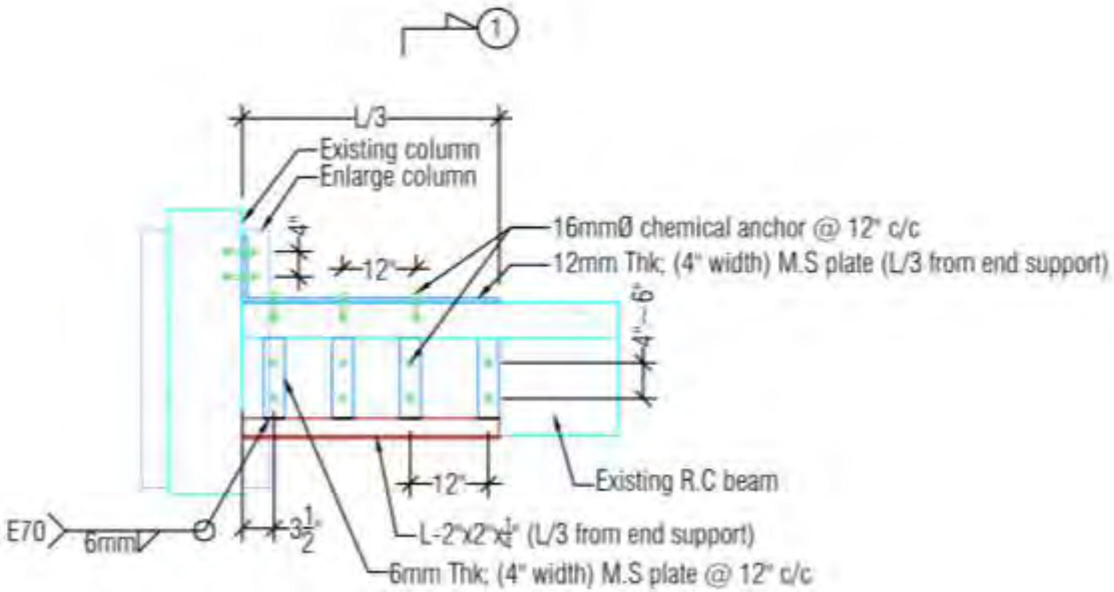
1. SECTION ENLARGEMENT (CONCRETE JACKETING)
2. STEEL JACKETING
3. EXTERNAL POST-TENSIONING
4. CARBON FIBRE REINFORCEMENT
5. OVERLAYING STRENGTHENING
6. STRESS REDUCTION METHOD
7. SPAN SHORTENING METHOD
8. FOUNDATION STRENGTHENING

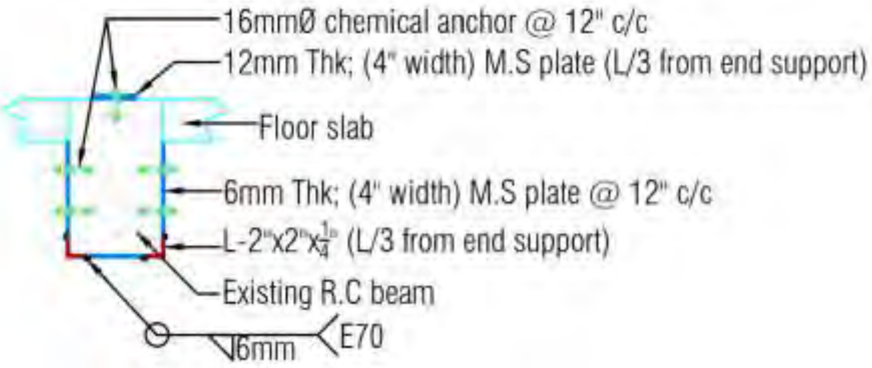
SECTION ENLARGEMENT (CONCRETE JACKETING)

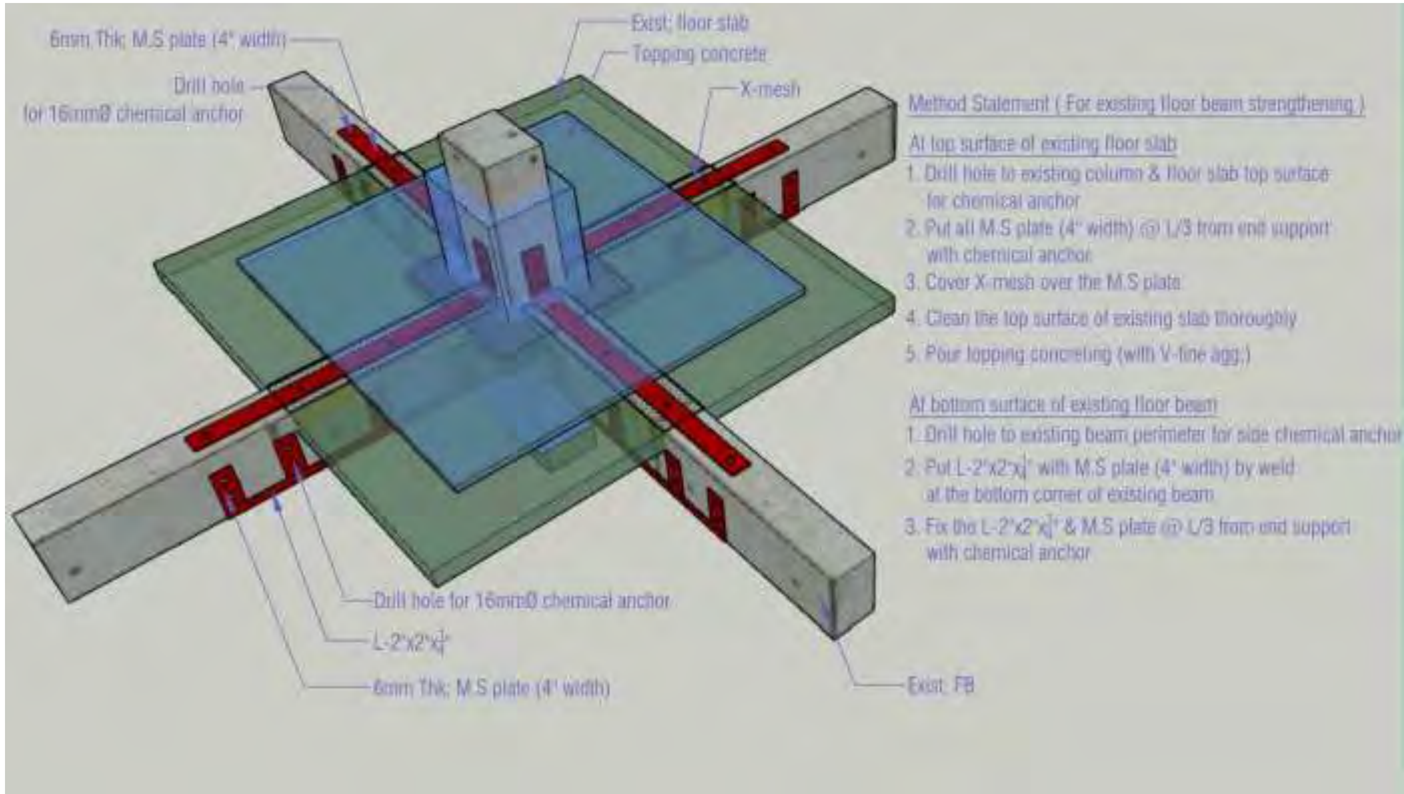




STEEL JACKETING (BEAMS & SLABS)

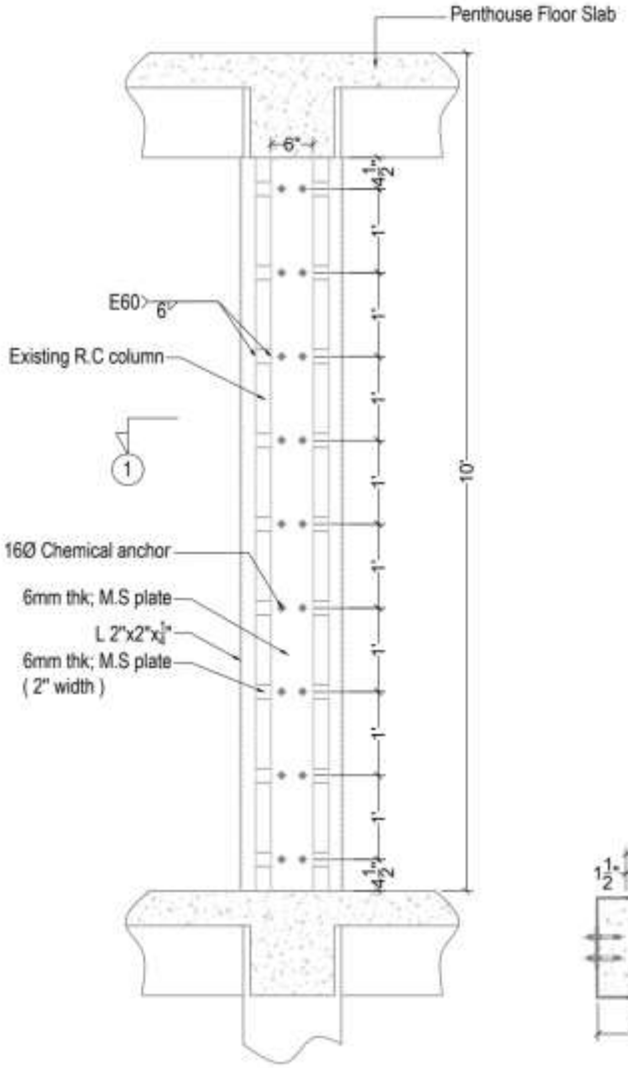




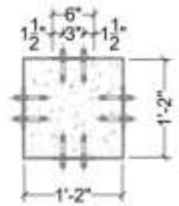


STEEL JACKETING (BEAMS) - CONTINUED

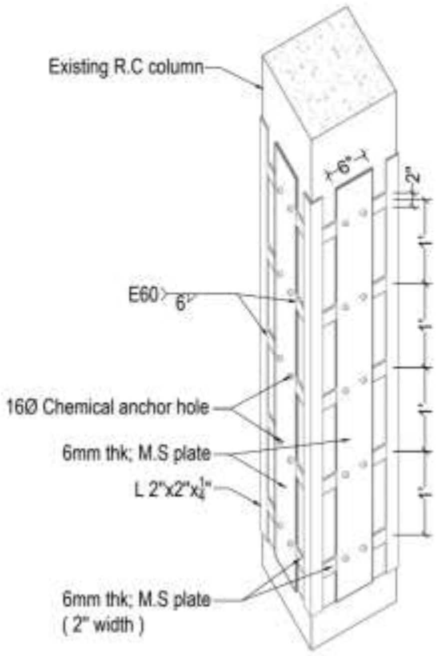
STEEL JACKETING (COLUMNS)



Column Elevation



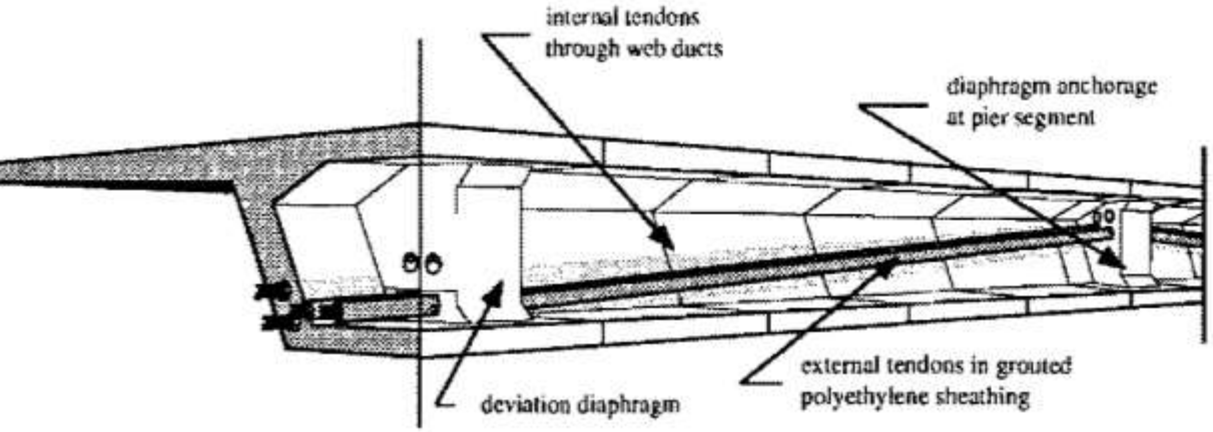
Section - 1

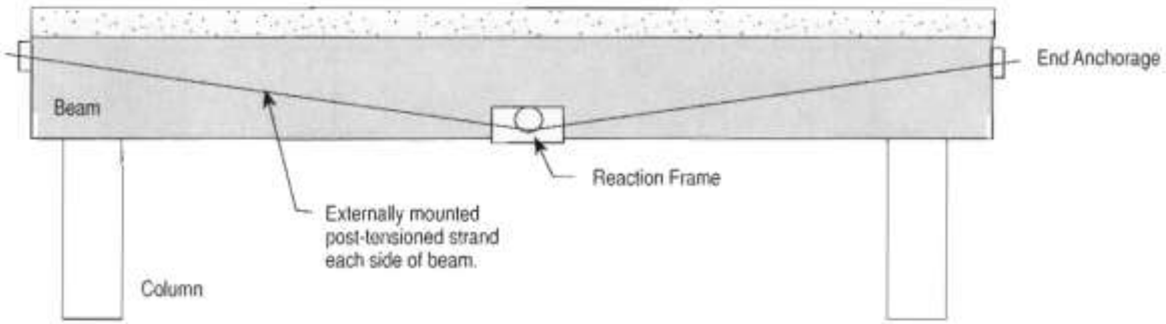


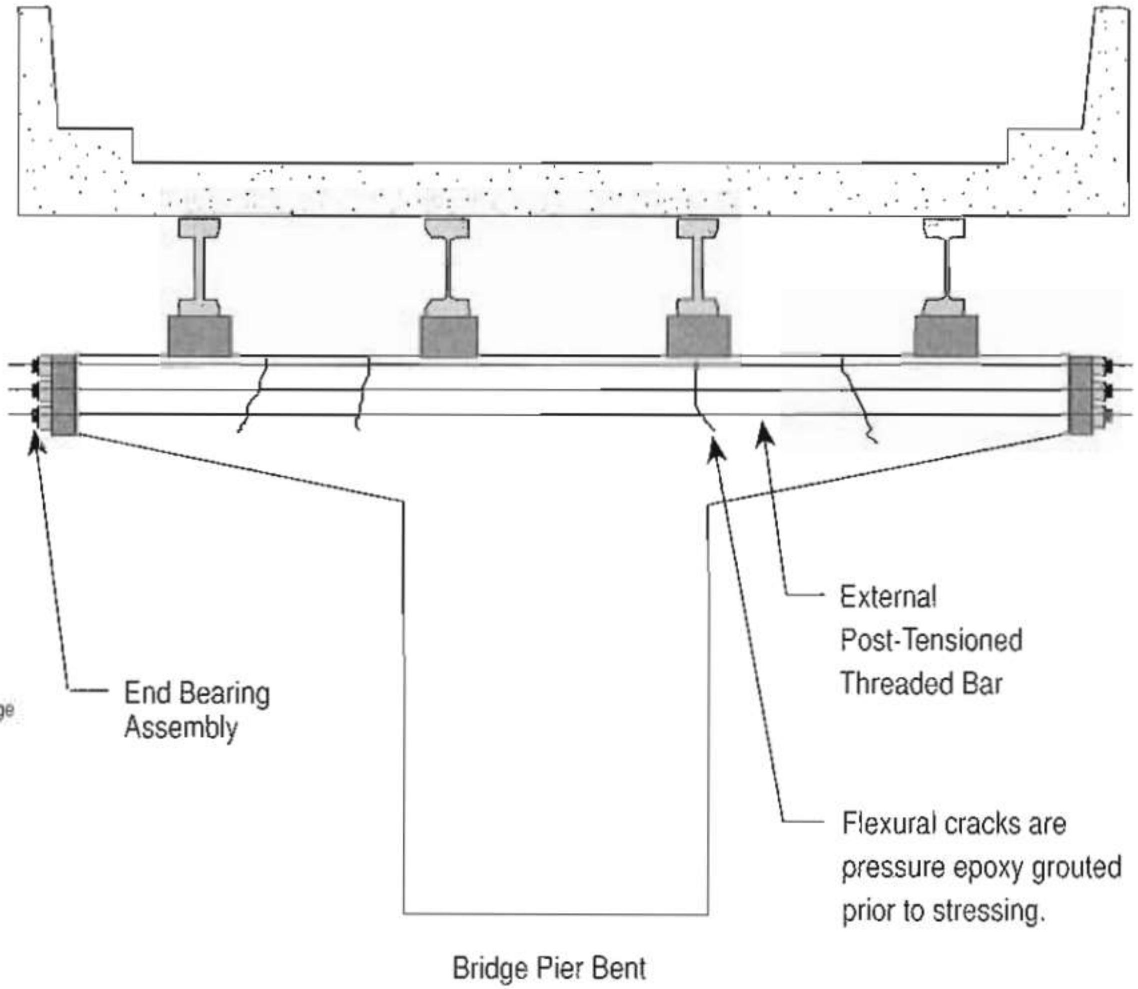
Typical Iso-view
(for column strengthening)

STEEL JACKETING (COLUMNS) - CONTINUED

EXTERNAL POST-TENSIONING

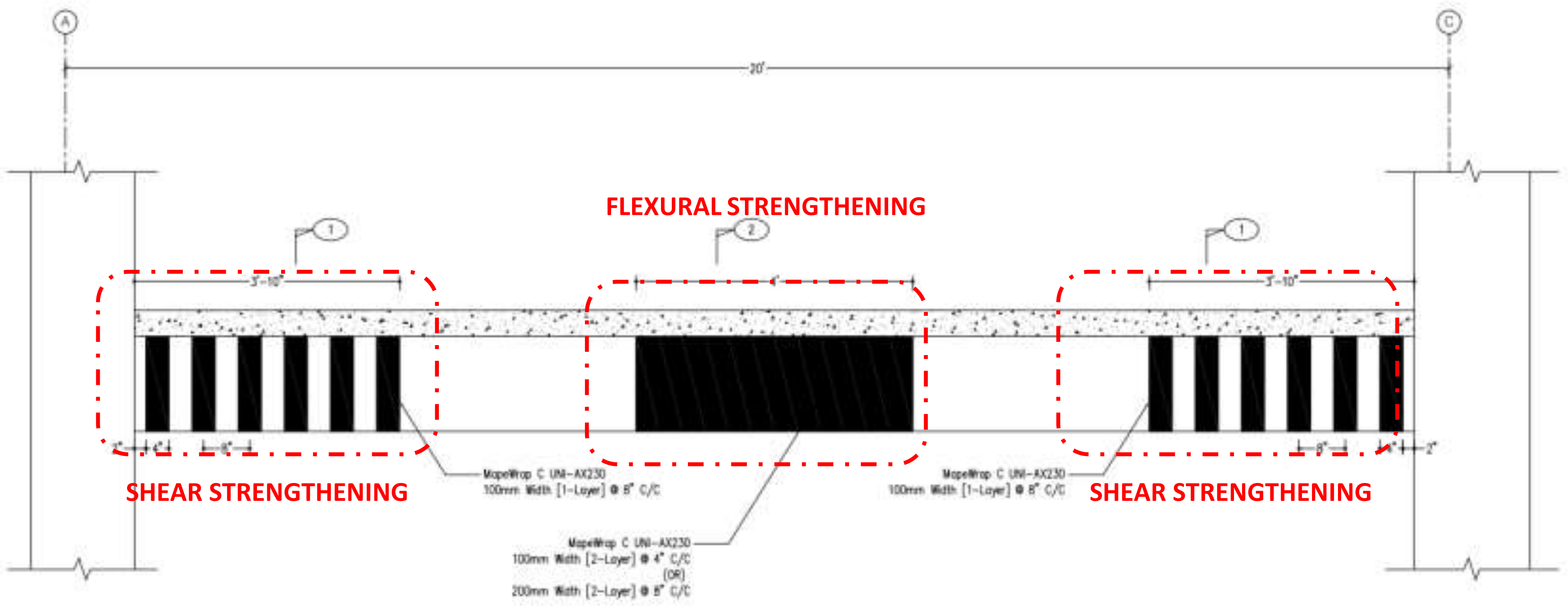


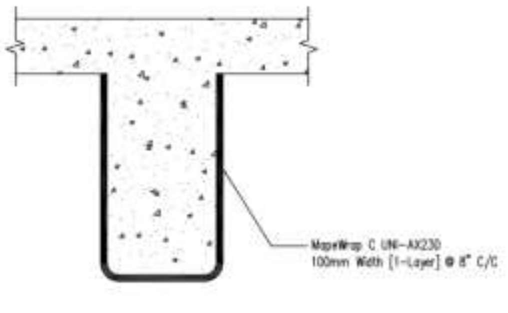




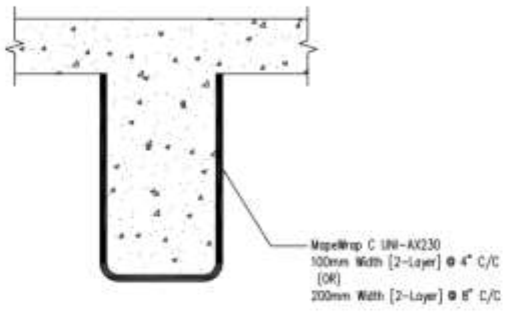
EXTERNAL POST-TENSIONING - CONTINUED

CARBON FIBRE REINFORCEMENT





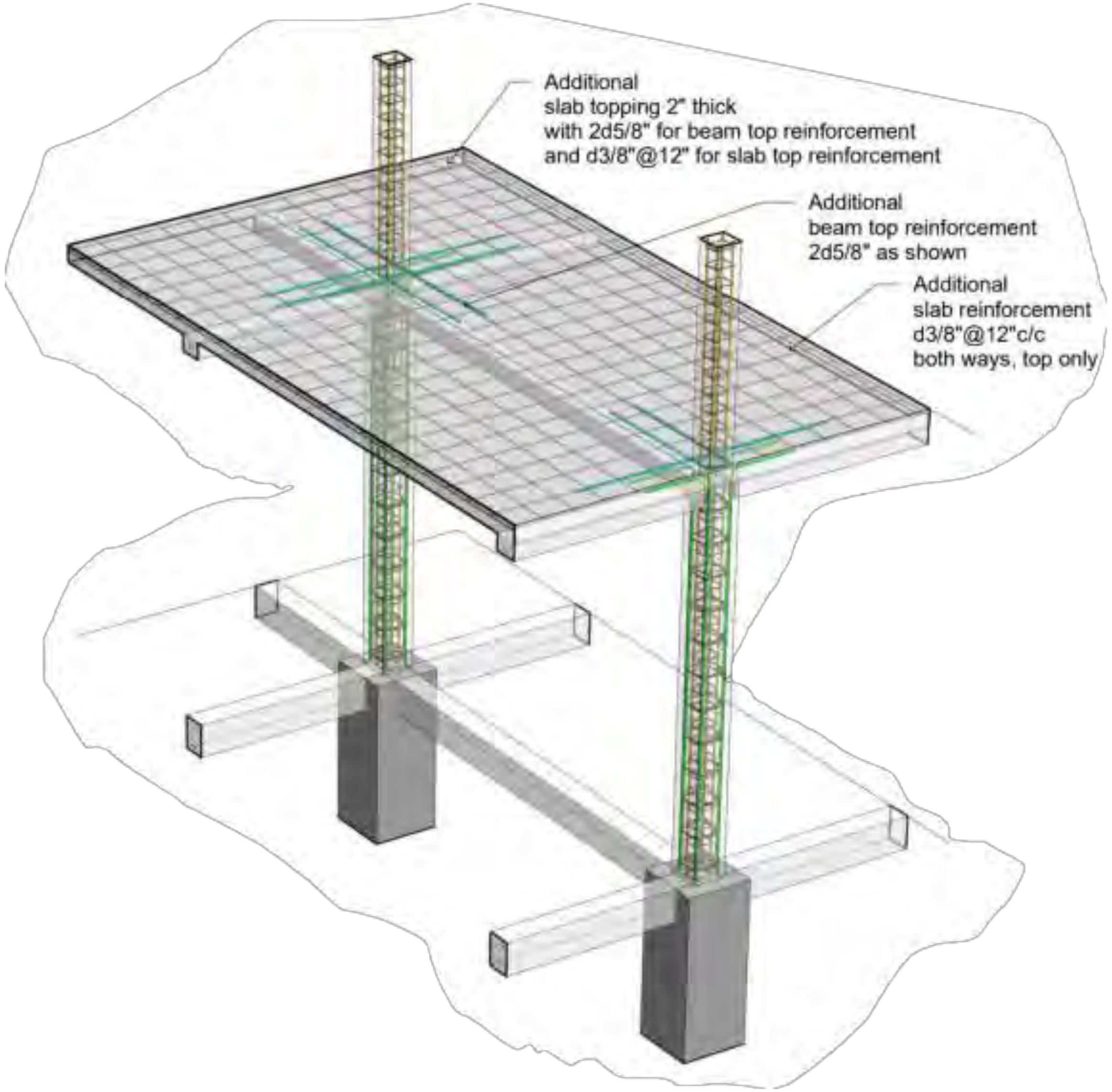
SECTION - (1)

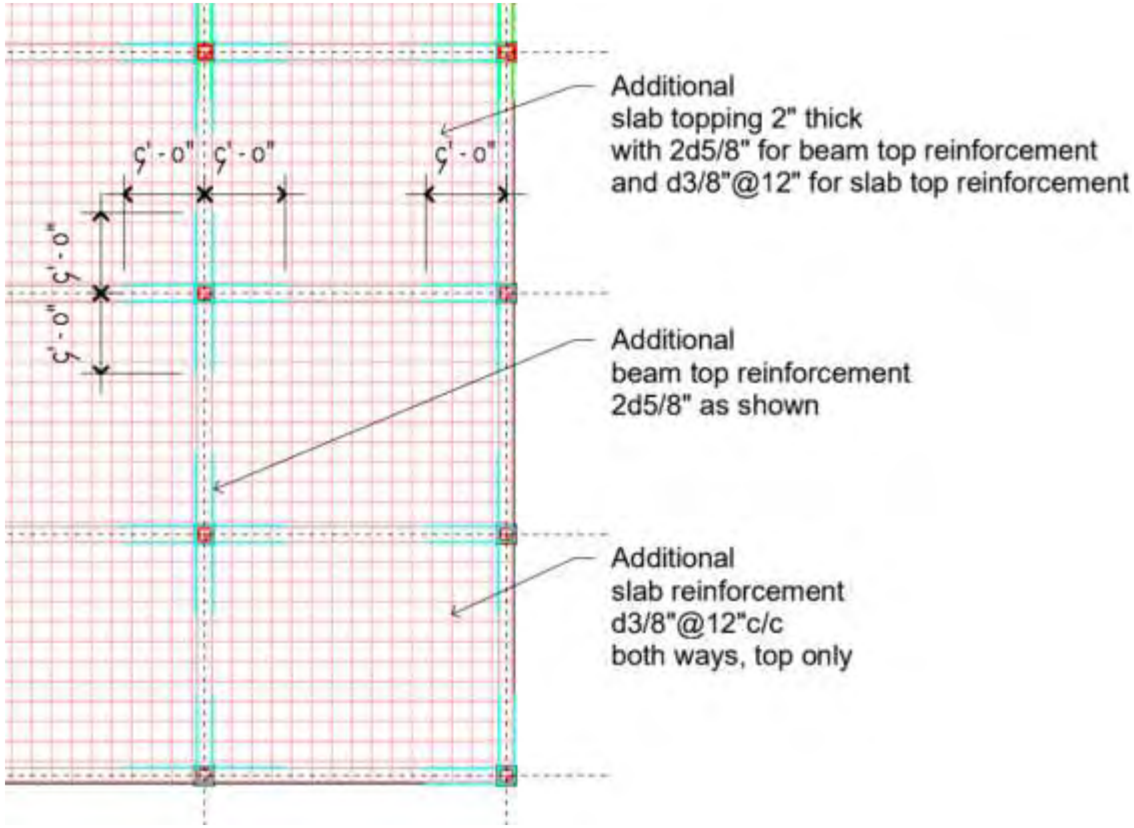


SECTION - (2)

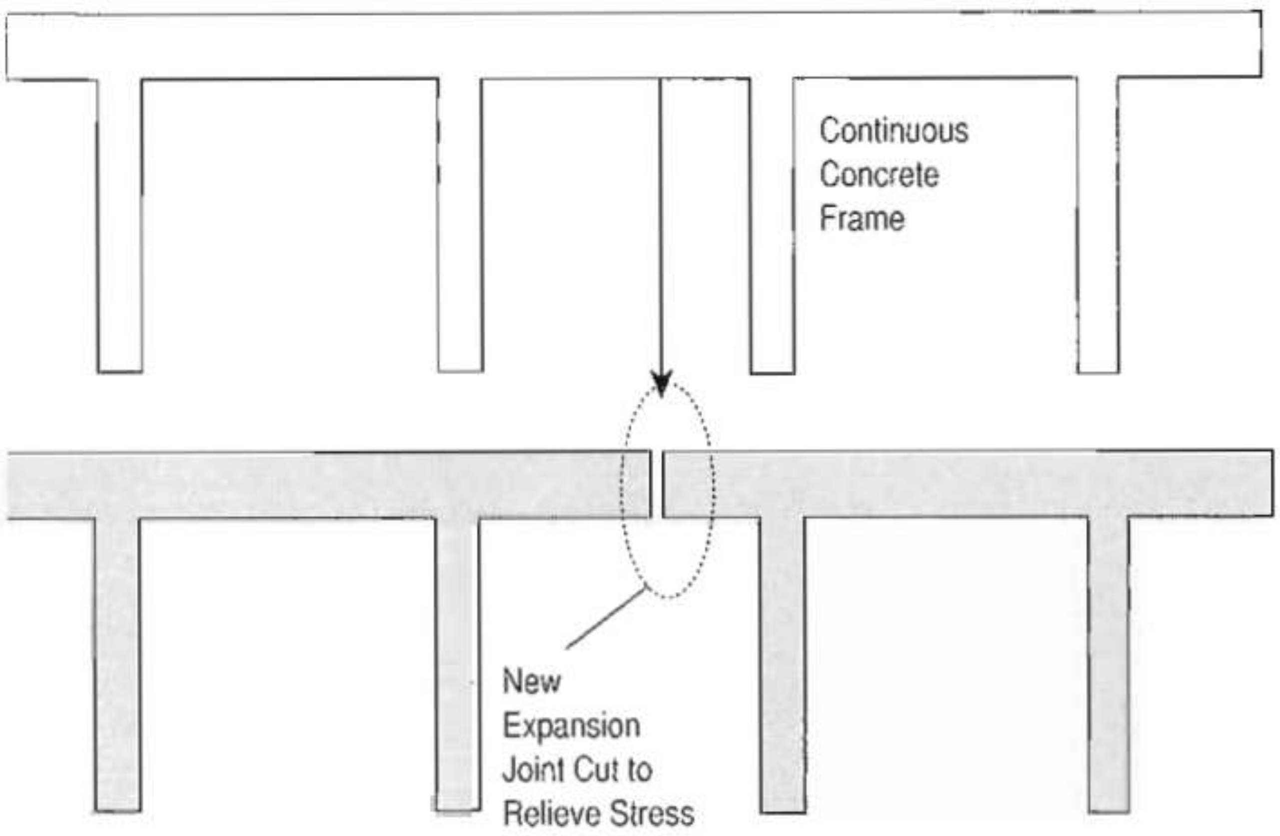
CARBON FIBRE REINFORCEMENT - CONTINUED

OVERLAYING STRENGTHENING

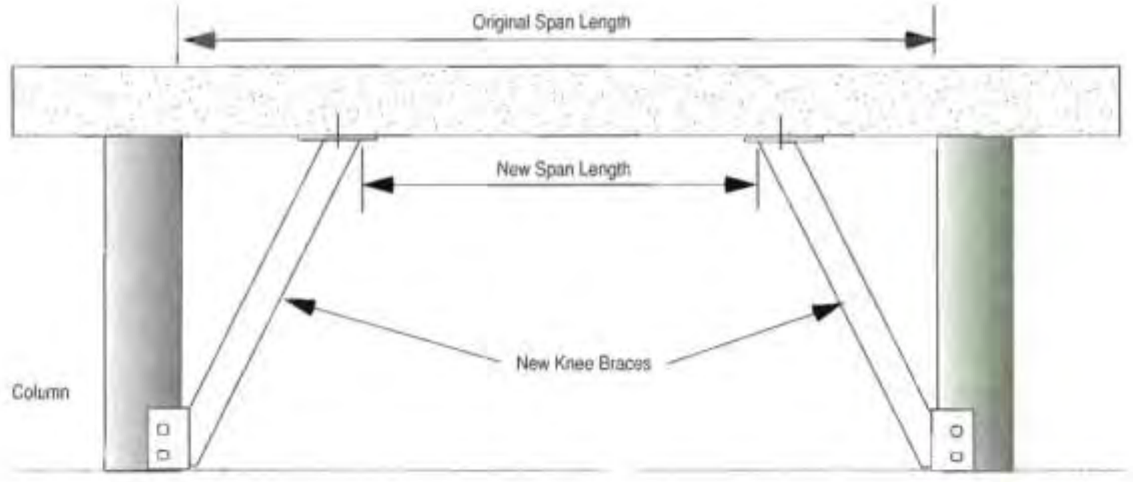


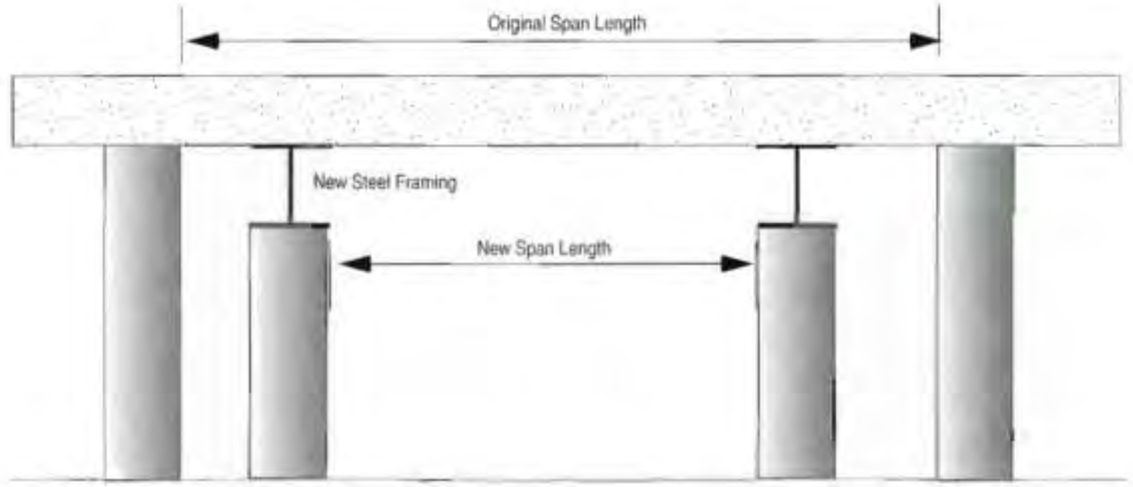


STRESS REDUCTION METHOD

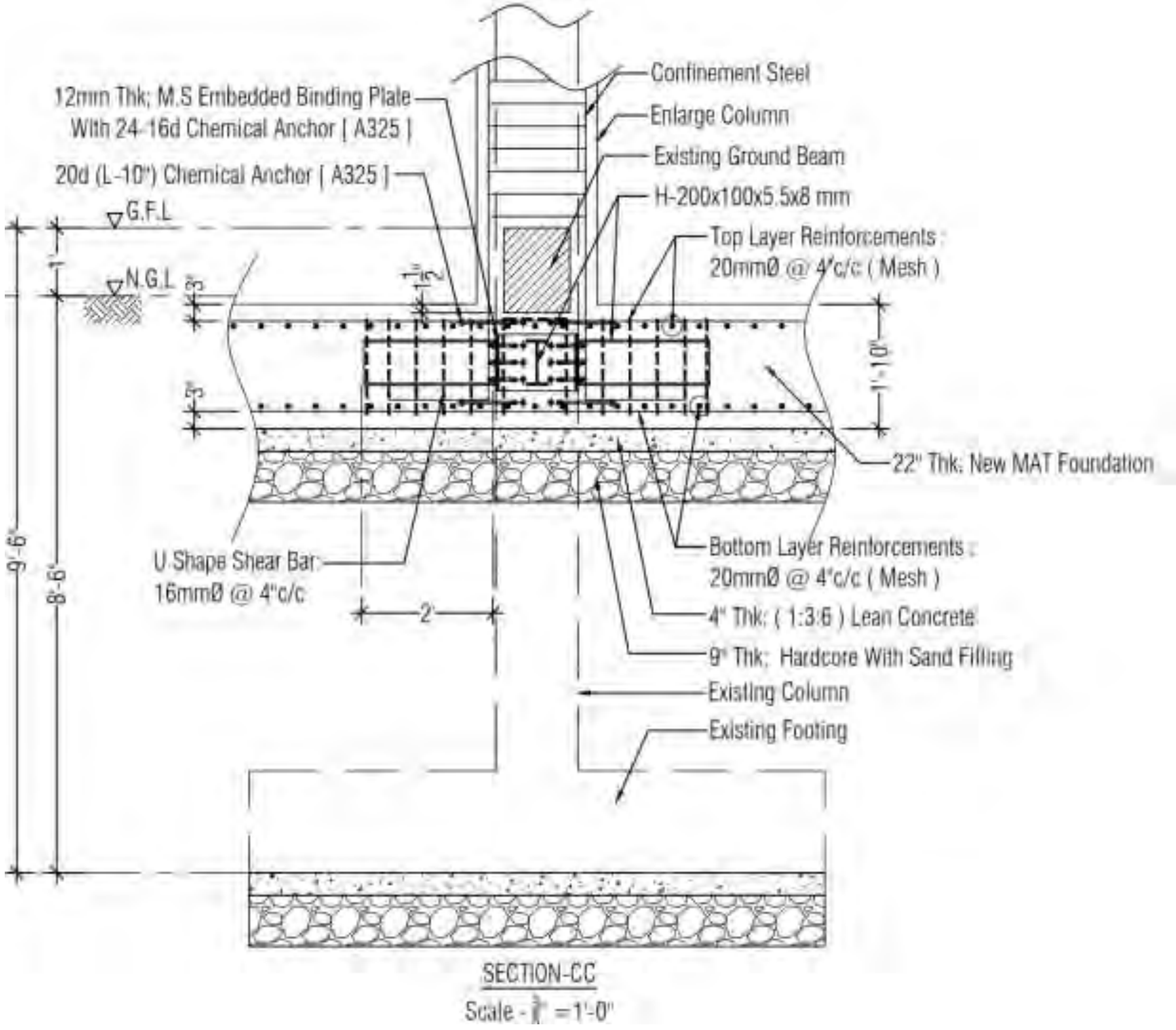


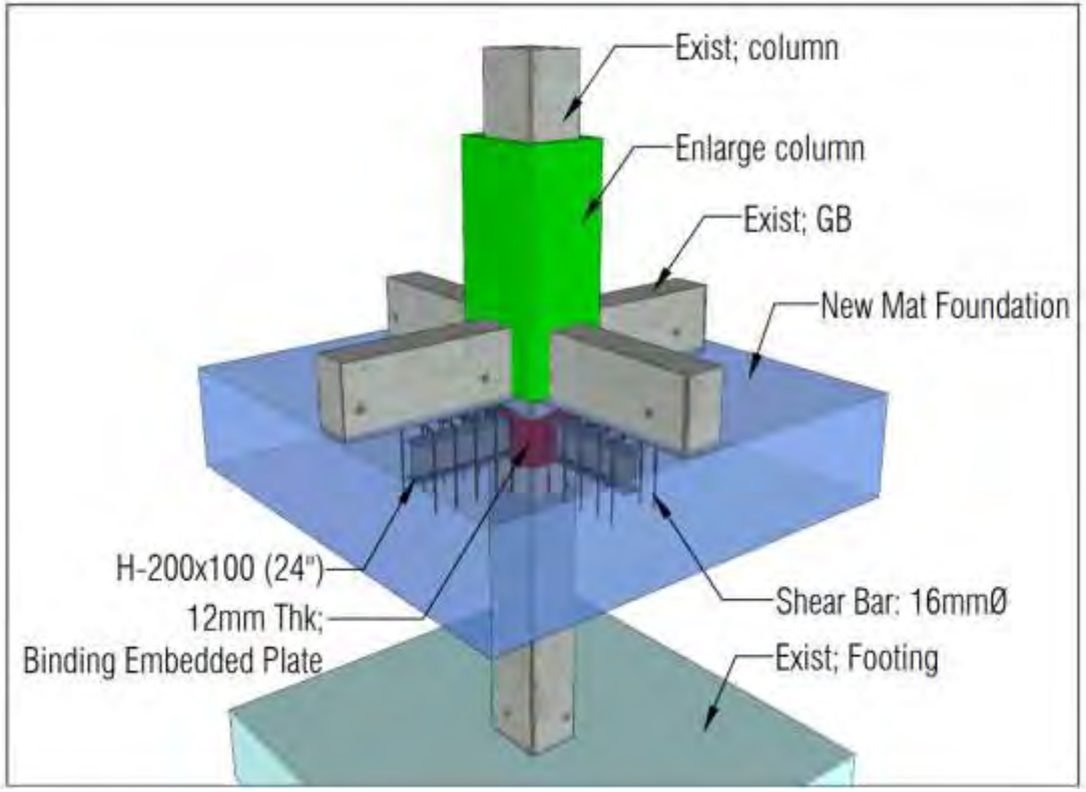
SPAN SHORTENING METHOD



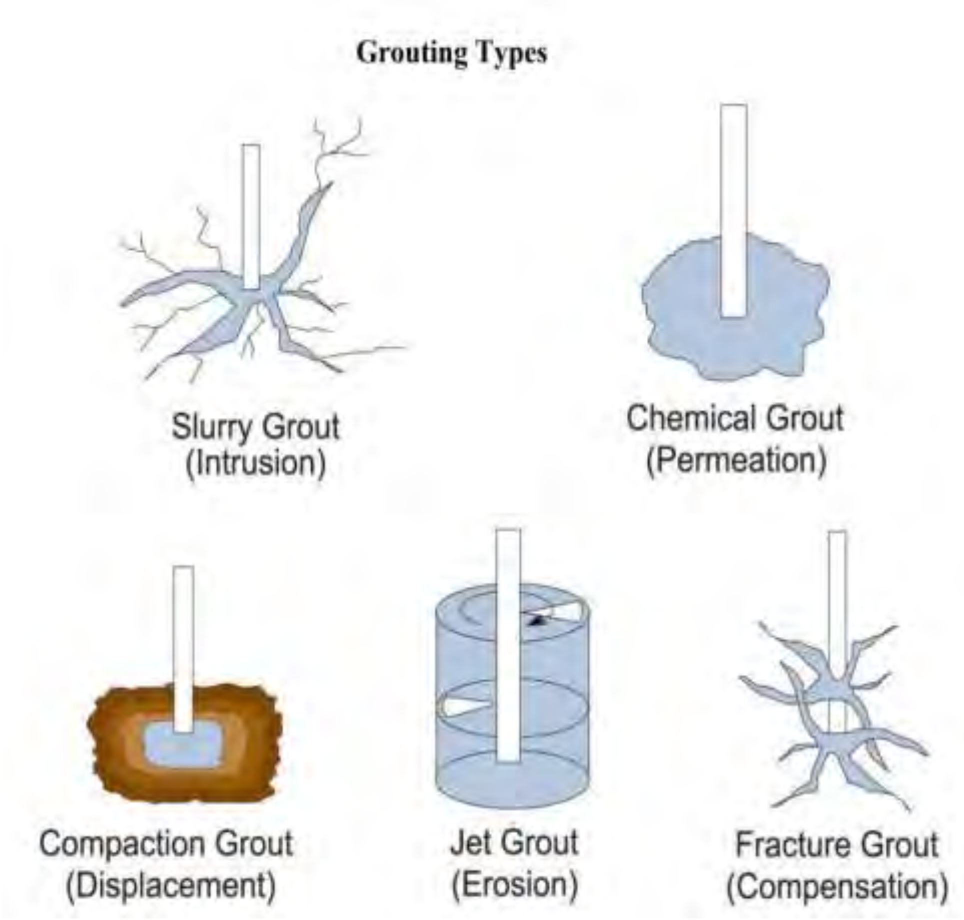


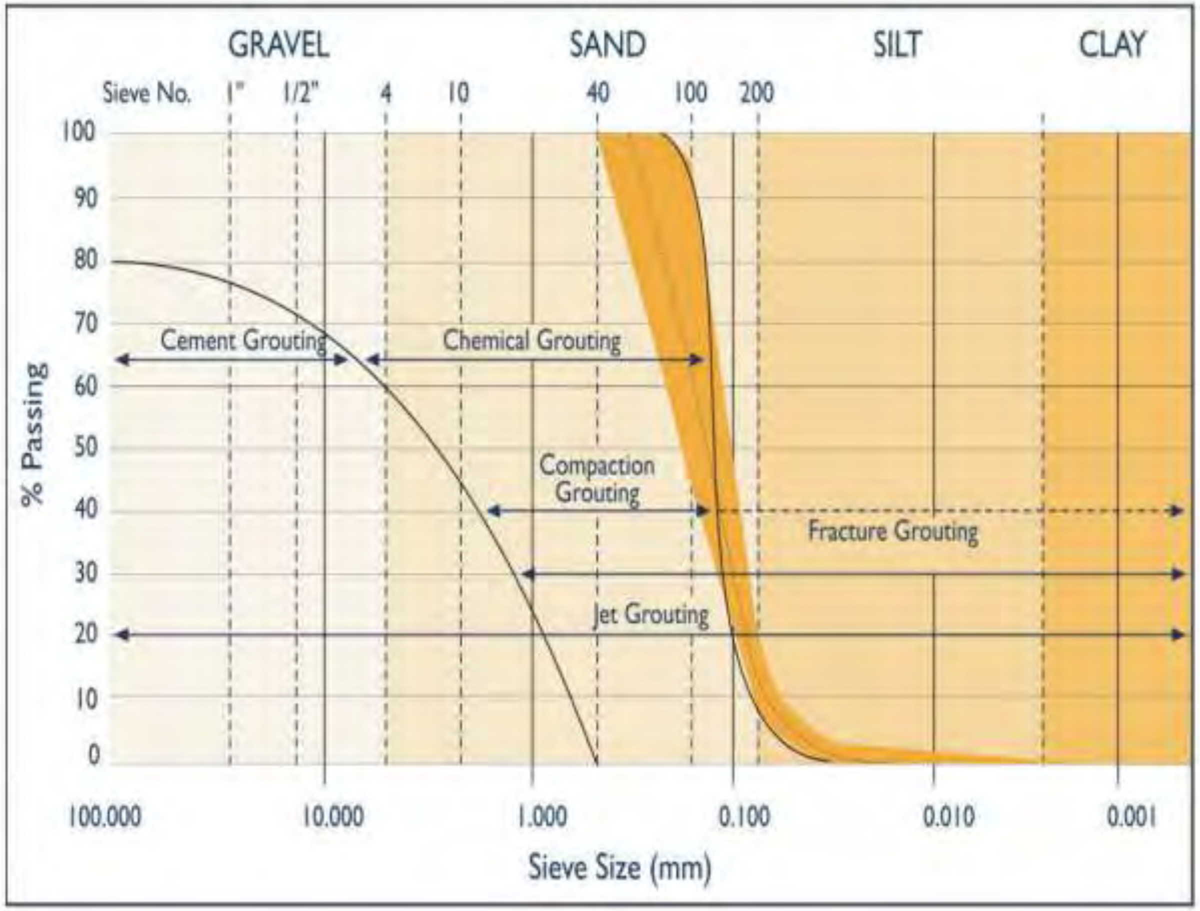
FOUNDATION STRENGTHENGING 1 – ADDITION OF NEW MATT FOUNDATION



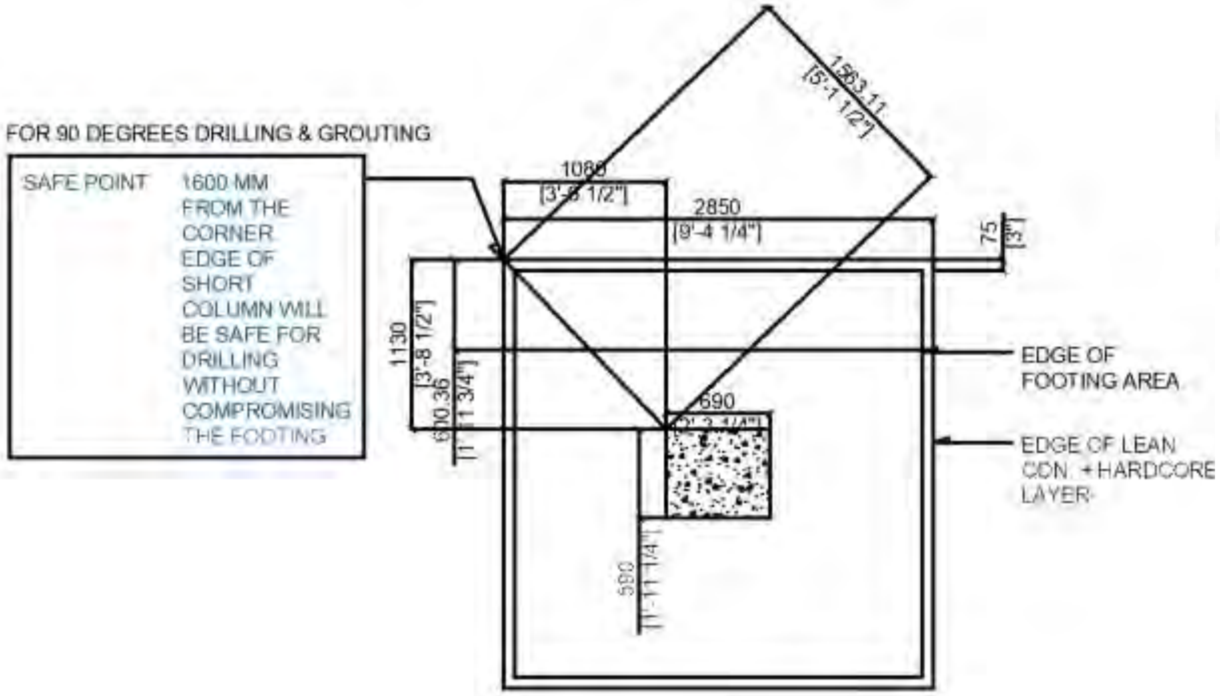


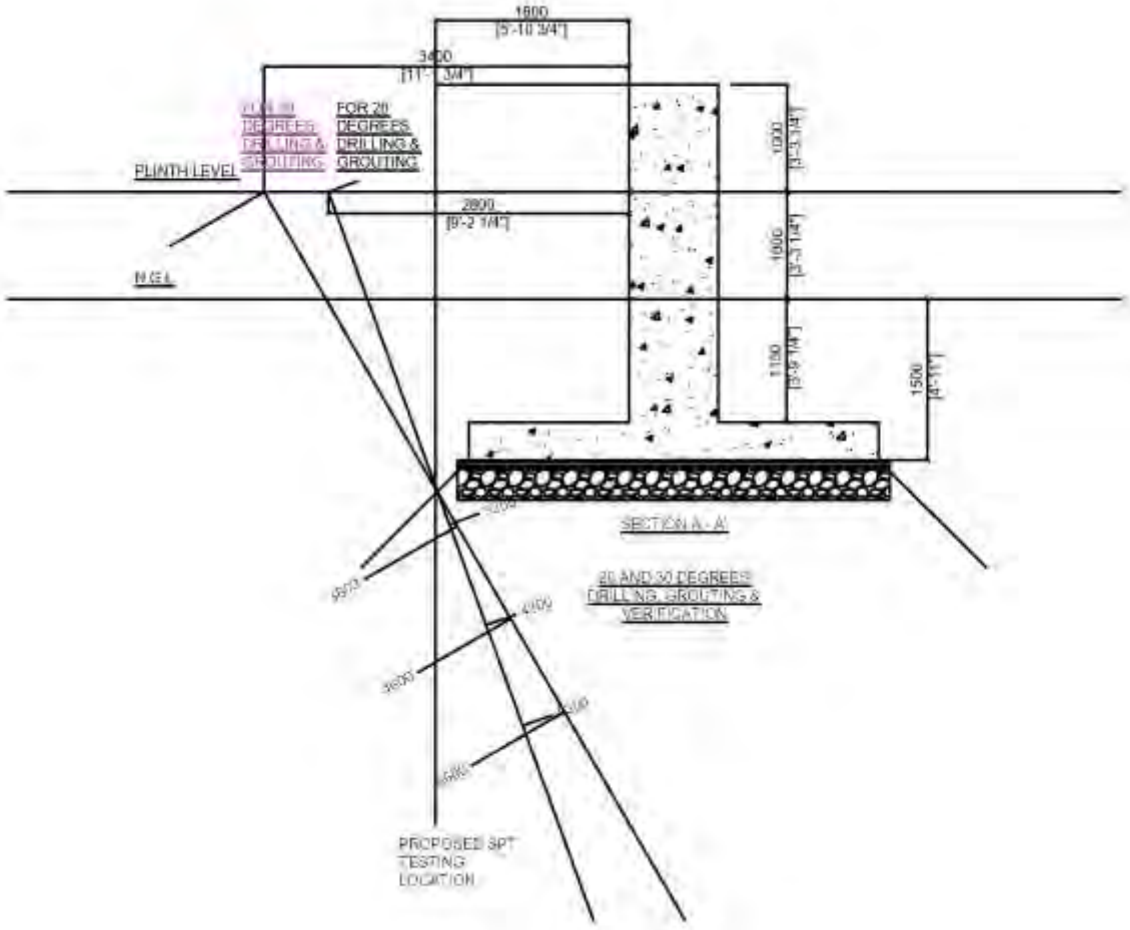
FOUNDATION STRENGTHENGING 2 – CEMENT GROUTING



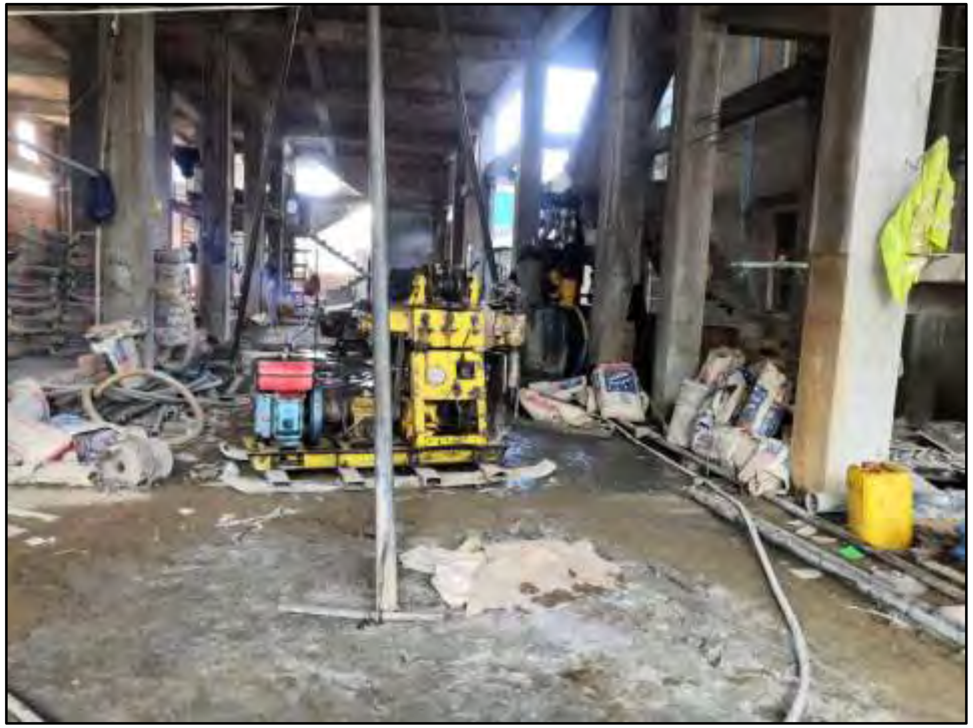


FOUNDATION STRENGTHENGING 2 – CEMENT GROUTING (CONTINUED)

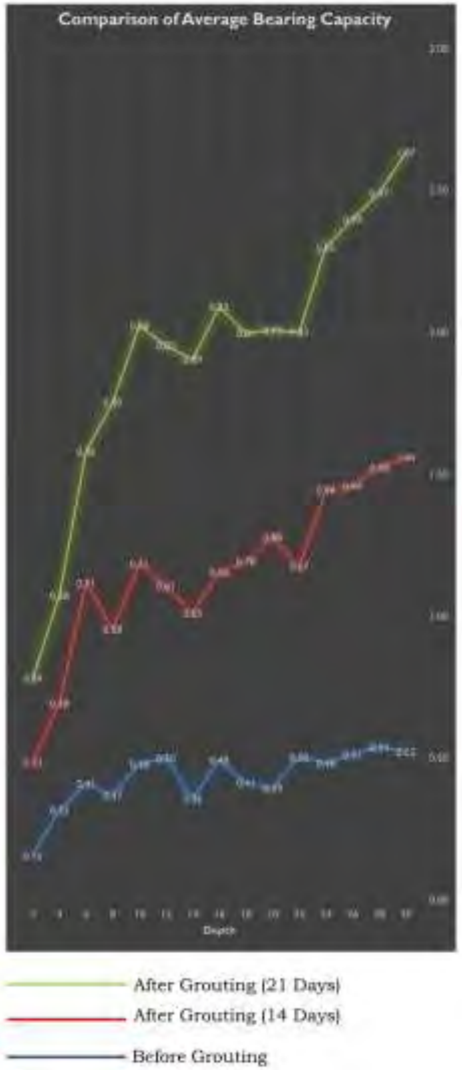




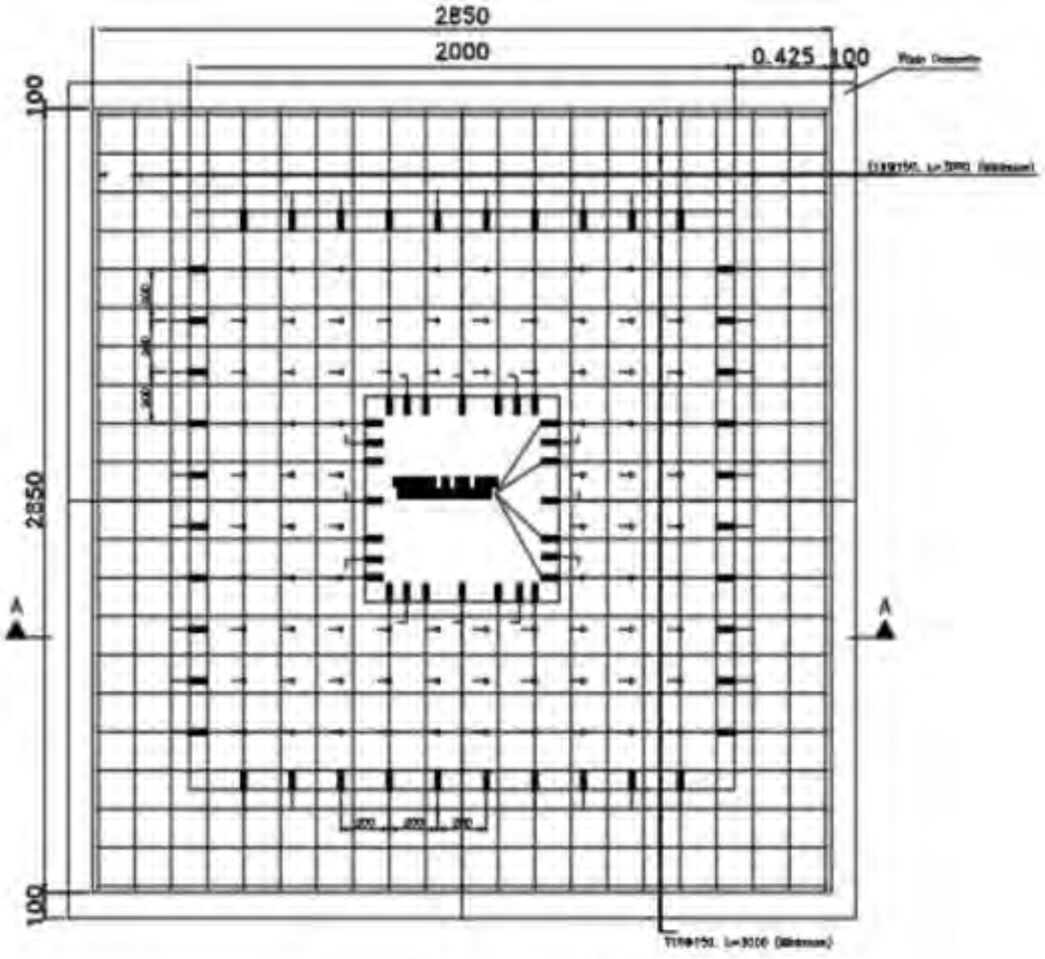
FOUNDATION STRENGTHENGING 2 – CEMENT GROUTING (CONTINUED)



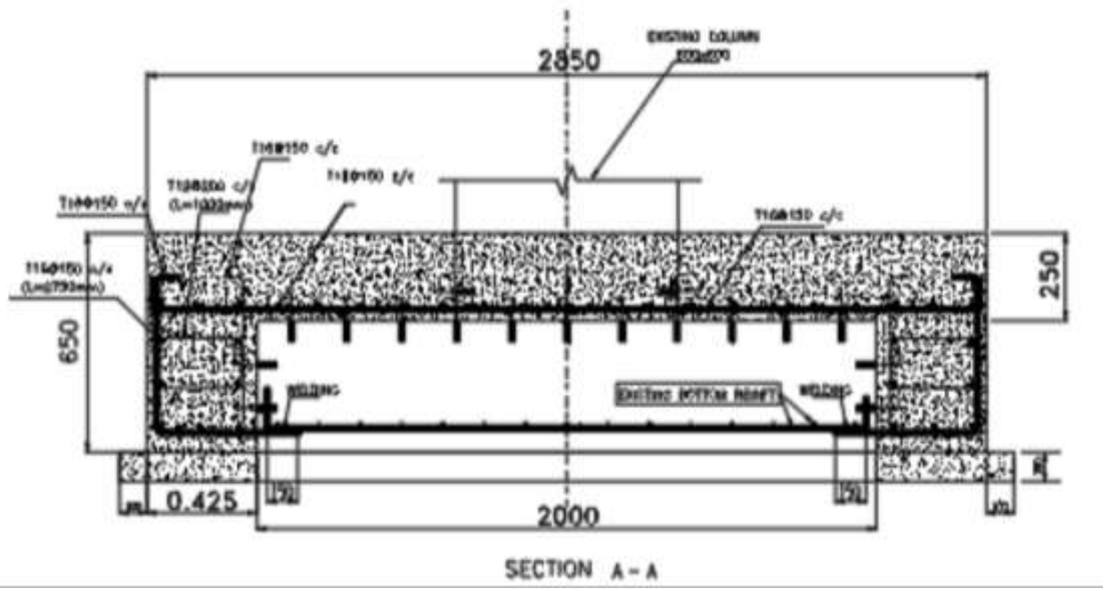
FOUNDATION STRENGTHENGING 2 – CEMENT GROUTING (CONTINUED)



FOUNDATION STRENGTHENGING 3 – FOOTING ENLARGEMENT



(a) Reinforcement plan



FOUNDATION STRENGTHENGING 3 – FOOTING ENLARGEMENT (CONTINUED)

FOUNDATION STRENGTHENGING 3 – FOOTING ENLARGEMENT (CONTINUED)

Thank You

For Your Attention!

Any Questions