CONCRETE DETERIORATION

What is concrete deterioration?

Concrete, despite its relative durability, does deteriorate over time. This can be caused by material limitations, design and construction flaws, and exposure to environmental conditions. The deterioration of concrete may result in aesthetic, functional, and/or structural problems that impact the safety and service of the structure.

Different types of deterioration

Corrosion

The leading cause of deterioration in concrete structures is the corrosion of embedded metals like steel. Steel is not stable under normal atmospheric conditions. The materials in concrete create a basic environment around the steel. At this basic pH, an oxide layer forms on the steel that prevents corrosion from advancing at a fast rate. The passive layer around the steel can be ruined due to chemical reactions between the steel and environmental elements.

Cracking

A complete or incomplete separation of concrete into two or more parts produced by breaking or fracturing. Cracks have been categorized into large and small sized cracks. Small cracks are less than 3 millimeters, as seen in Figure 1 and a large crack is larger than 3 millimeters, as seen in Figure 2.

Spalling

A phenomenon where concrete breaks, peels and chips away from the structure usually due to rusting of steel within the concrete which expands outwards causing cracks. The cracks begin below the surface and lead to surface damage.

Major: characterized by breaking, peeling, and chipping that exposes the steel reinforcement of the concrete. Major spalling requires exposed steel reinforcement as seen in Figure 3.

Figure 1. Small Crack

Figure 2. Large Crack

Figure 3. Major Spalling

Figure 4. Minor Spalling

Minor: characterized by peeling and chipping that does not expose the steel reinforcement of the concrete. Minor spalling is superficial and does not have exposed steel reinforcement. An example of minor spalling can be seen in Figure 4.

Chipping

Defined by the breaking away of concrete in small sections from the structure, usually at an edge or corner, due to external factors as opposed to from spalling.

Figure 5. Concrete Chipping

In order to rehabilitate the deteriorating concrete structures at the Mrigadayavan Palace, restoration methods were explored. Different types of restoration methods can be used based on the extent and location of the deterioration. Some factors that are used to select the method included the presence of steel rebar throughout the column, type of deterioration, size of the cracks. More information about the different restoration methods can be found using the link below.

REHABILITATION METHODS

REHABILITATION METHODS

Rehabilitation vs. Preservation

Preservation and rehabilitation are two applicable procedures for the Mrigadayavan Palace. The goal of **rehabilitation** is to maintain a building's historical character while still making the necessary changes or repairs in order to meet the needs of its current usage. Rehabilitation focuses on maintaining as much of the original character and usage as possible with minimal and effective changes. In rehabilitation the goal is to repair, not replace. The goal of **preservation** is to provide a building with ongoing maintenance and repair for whatever form the building currently takes. This method focuses on retaining a building's existing form, materials, and integrity. Any changes made over time will be preserved as part of the building's history and no new exterior additions will occur.

Areas of focus

The Mrigadayavan Palace has experienced the effects of external and internal deterioration on concrete structures over the course of time. Three main concrete structures are deteriorating, including the concrete walkways, concrete columns, and concrete ceiling panels.

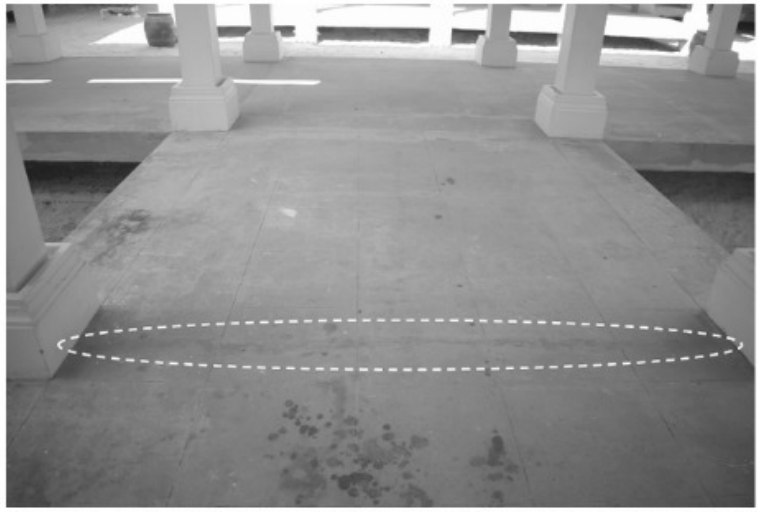


Figure 1. Cracks in the concrete walkway between two columns

Walkways

The walkways on the ground floor of the Mrigadayavan Palace were made of concrete which has no steel reinforcement (rebar) inside and there are no expansion joints presented in the concrete walkways. Cracks on the concrete walkways or concrete floor base were observed to be mainly on the surface. The areas with the most deterioration problems were in the Samutphiman (area 6) and Pisansakorn (area 14). The majority of the cracks were mostly near or between the concrete columns. Some cracks on the concrete floor extended from one column across to the other columns as shown in *Figure 1*.

The concrete walkways were rehabilitated using the following methods:

PARTIAL DEPTH REPAIR

CONCRETE OVERLAY

Columns

There are 831 concrete columns at the Palace, in which approximately 30% of these columns had small cracks. Approximately 10 columns were severely corroded with major cracks in them. From the observations and the collected information, the possible factors that could affect the corrosion of concrete columns and the most probable cause of corrosion of concrete columns were discussed. The possible factors include ocean sea spray, humidity, wind, architectural deterioration, and architectural errors.

Figure 2. Cracks from inadequate load carrying capacity

Architectural errors are one of the most mentioned external factors in terms of factors that cause cracks in concrete columns. Based on consultations with an architect and observations at the Palace, the crack patterns and corrosion that existed on the majority of the concrete columns might have been different if they were caused by the excessive load of the roof tiles. Furthermore, the cracks that existed on the concrete columns were merely outer surface cracks that did not relate or affect the stability of the concrete columns.

Since the palace is situated on the seaside, an assumption was made that **wind speed** would relatively be stronger than normal. It could be a cause of corrosion by making the concrete column unstable because the strong wind would add parallel directional force towards the concrete structures, creating shear stress in the columns.

Humidity is not the cause of cracks in concrete columns. However, the humidity was one of the main factors that increased the rate of corrosion for the steel reinforcement. Once minor cracks formed in concrete columns due to other factors, humidity from the sea and the surrounding area could seep through those small cracks. Thus, there could be rust in those reinforced steel bars which could build up and cause a more extensive cracking. Eventually, the concrete was pushed away from the steel bars, resulting in spalling of the concrete columns.

The concrete columns *with* steel rebar were rehabilitated using the following methods:

PATCHING	SEALANT
REINFORCED JACKETING	CONCRETE CASTING

The concrete columns *without* steel rebar were rehabilitated using the following methods:

EPOXY INJECTION

SEALANT

CONCRETE CASTING

Ceiling Tiles

Other than the deterioration in the concrete walkways and columns, cracks and discoloration were also observed in the concrete ceiling panels. These steel reinforced ceiling panels have been supported by wooden frames. The ceiling panels were built in the same pattern in every building at the palace. In each grid of the modular system, one grid (three by three meters) consists of nine ceiling panels with slight differences in designs and dimensions. From the observations, minor cracks at the edge of the concrete ceiling panels were observed. There was also some discoloration on the surface of the ceiling panels showing more pale color as in Figure 3. A metal detector was used to scan for the existence of the steel reinforcement to determine that the pattern of the inner steel reinforcement was a four by four metal bar grid.

Even though most of the cracks are relatively small, **roof leakage** is also one factor that could cause the cracks to grow larger and more intense. The degree of corrosion in concrete ceiling panels at its highest point in buildings contains leakage in the roof. This is due to water that leaks through the roof and acts as a catalyst that speeds up the process of steel reinforcement corrosion. However, the effect of roof leakage would not play a part if there are no cracks contained.

Aside from the cracks, another aspect that was affected was the discoloration. The concrete ceiling panel itself contained the inner steel reinforcement inside to support the structure. The inner steel reinforcement is a four by four metal bar block, which correlates with the pattern of discoloration on the panels. Rust from the steel rods created a mark on the panels in a yellow-like color plus sign mark. Over time, humidity causes rust on the steel rods. **Rust** on the steel affected both the appearance of the concrete panels and their physical state in terms of cracks.

Because the main deterioration of the ceiling panels is caused by issues in the wood beams as opposed to the concrete, no rehabilitation methods were recommended.

Figure 3. Plus sign marks due to rust on the steel rods

CONCRETE CASTING

What is concrete casting?

A method of fixing chipped concrete by either taking a mold of a missing section and filling it with concrete or by filling the holes that can easily be sectioned off with concrete directly. Concrete around the deterioration will need to be removed and the area will need to be cleaned. A bonding material may be necessary.

Type of deterioration rehabilitated

This rehabilitation method was used on concrete columns where no steel reinforcement was present and chipping was the only type of deterioration observed.

Criteria

Availability of Materials: Steel rebar is widely available and pre-cast concrete/ shotcrete is low- cost
Expertise Needed: Qualified and experienced engineers or specialists
Manpower: Up to 17 days of work
Time until Usability: 28 Days
Longevity: Typical service life - 50 years
Aesthetics: New concrete will be lighter in color than the existing concrete, column width will be increased
Historical Accuracy: Concrete can be matched in material and color
Deterioration Type: Spalling, cracking, major deterioration
Advantages: Columns gain 100% of initial strength
Disadvantages: High increase in space around column

Before Rehabilitation vs. After Rehabilitation

CONCRETE OVERLAY

What is concrete overlay?

The application of a thin concrete layer (at least 51 mm thick) to a walkway slab. Cracks may require patching before-hand and if using an unbonded overlay (for areas of greater deterioration) then a geotextile material will need to be laid down first. Concrete overlays require uniform support conditions and effective management of movement in the design process. There are both bonded and unbonded overlay options.

Type of deterioration rehabilitated

This rehabilitation method was used on concrete walkways where cracking was seen throughout the entirety of it.

Criteria

Availability of Materials: Materials bought from a concrete manufacturer, geotextile material easily bought as well
Expertise Needed: Workers with experience in concrete mixing, placing, and curing
Manpower: Hours, cracks may need patching beforehand, if using unbonded overlay a geotextile material will need to be laid down
Time until Usability: 24-48 hours until set and 28 hours until fully set
Longevity: 20+ years
Aesthetics: Concrete material and color can be developed to match the former concrete, 51-254 mm
Historical Accuracy: Materials can potentially be found that are from the time period desired,
Deterioration Type: Cracks and spalling, bonded overlay needs good conditions and is for surface distress, unbonded overlay can work for more major deterioration
Advantages: Accurately restores the look of concrete as well as the function in a asthetically pleasing way
Disadvantages: Potentially adds thick concrete to a walkway. Needs to repair all sidewalks to keep even structure

Before Rehabilitation vs. After Rehabilitation

Chloride Extraction & Cathodic Protection

What is chloride extraction?

A temporary process that extracts or removes chloride ions from chloride-contaminated reinforced concrete structures to restore the passivation layer.

What is cathodic protection?

A method of reversing the damage caused to the passivation layer and preventing further corrosion of steel through the delivery of a positive current to the reinforcing steel.
Passivation Layer: A positively charged oxide film surrounding the steel rebar which protects against corrosion.
Impressed Current Cathodic Protection (ICCP): Consists of permanent inert galvanic anodes and an external DC power source to supply the current.
Galvanic Corrosion Protection: Utilizes galvanic anodes which are metals with sufficient voltage difference with respect to the corroding steel that a protective current will be discharged from the anode through the concrete to the corroding structure through deterioration of the anode and without an external power supply
Fusion Anodes: Hybrid system that combines the efficiency and longevity of impressed current cathodic protection with the maintenance-free performance of galvanic anodes

Type of deterioration rehabilitated

This rehabilitation method was used on concrete columns with steel reinforcement. Chloride extraction and cathodic protection should be used when there is any form of spalling in the column to prevent further damage.

Criteria

Chloride Extraction

Availability of Materials: DC power supply is connected to the reinforcing steel, positive terminal of an anode in electrolyte medium is applied to the surface of concrete
Expertise Needed: Minimal
Manpower: Hours - 1 day
Time until Usability: 3-8 weeks until full chloride extraction
Longevity: 5-20 years depending on further exposure
Aesthetics: No change to physical appearance
Historical Accuracy: Preserves the existing concrete from discoloration and corrosion
Deterioration Type: Mitigates active corrosion
Advantages: Non-destructive
Disadvantages: Dependent on treatment density, distribution of chloride ions, permeability, electrical resistivity

Impressed Current Cathodic Protection (ICCP)

Availability of Materials: Requires state-of-the-art power supplies and monitoring equipment capable of delivering milliamp precision protection currents
Expertise Needed: Qualified and experienced engineers or specialists
Manpower: Time to apply permanent galvanic anodes and connected power source, on-going monitoring and maintenance
Time until Usability: Immediate polarization with power source
Longevity: 20-30 years with maintenance
Aesthetics: Wiring may be visible, anodes can be placed discreetly or be embedded
Historical Accuracy: Not for historical accuracy, no need for physical alterations of material
Deterioration Type: Significant signs of leaks, cracks, delaminated concrete, and corrosion
Advantages: No other method is capable of reversing the damage caused to the the passivation layer of the steel reinforcement with such efficiency for an extended period of time
Disadvantages: Impressed current cathodic protection systems are not recommended for general usage on prestressed concrete structures because hydrogen produced can make the high-strength steels brittle in nature

Before Rehabilitation vs. After Rehabilitation

REINFORCED CONCRETE JACKETING

What is reinforced concrete jacketing?

This method reinforces columns with steel rebar by adding a layer of concrete reinforced by longitudinal steel reinforcements and traversing steel ties around the original column in the form of a jacket. Reinforced concrete jacketing is used when there is damage to a reinforced concrete due to environmental wear and tear as well as poor construction, poor maintenance or accidents. Jacketing is a process that restores deteriorated concrete to original dimensions or increased in size by encasement using suitable materials.

Type of deterioration rehabilitated

This rehabilitation method was used on concrete columns with steel reinforcement present and major spalling was seen.

Criteria

Availability of Materials: Steel rebar is widely available and pre-cast concrete/ shotcrete is low-cost
Expertise Needed: Qualified and experienced engineers or specialists
Manpower: Up to 17 days of work
Time until Usability: 28 Days
Longevity: Typical service life - 50 years
Aesthetics: New concrete will be lighter in color than the existing concrete, column width will be increased
Historical Accuracy: Concrete can be matched in material and color
Deterioration Type: Spalling, cracking, major deterioration
Advantages: Columns gain 100% of initial strength
Disadvantages: High increase in space around column

Before Rehabilitation vs. After Rehabilitation

PATCHING

What is patching?

The application of concrete over minor cracks and holes in existing concrete structures. Concrete around the deterioration will need to be removed and the crack will need to be cleaned. A bonding material may be necessary.

Type of deterioration rehabilitated

This rehabilitation method was used on concrete columns with steel reinforcement present and cracks larger than 3mm.

Criteria

Availability of Materials: Materials bought from a concrete manufacturer
Expertise Needed: Minimal
Manpower: Hours - 1 Day
Time until Usability: 24-48 hours until set and 28 hours until fully set
Longevity: 5-20 years depending on further exposure
Aesthetics: New concrete will be lighter in color than the existing concrete
Historical Accuracy: Concrete can be matched in material and color
Deterioration Type: Cracking, major deterioration
Advantages: Columns will gain partial strength
Disadvantages: N/A

Before Rehabilitation vs. After Rehabilitation

SEALANTS

What are sealants?

Plastics or other polymers applied in joints or over surfaces to serve as protection against water and chemical attacks. Sealants work by filling in fine cracks or pores, creating a waterproof seal to prevent additional moisture from attacking the concrete.

Type of deterioration rehabilitated

This rehabilitation method was used on concrete columns with and without steel reinforcement present. These columns also contained cracks smaller than 3mm.

Criteria

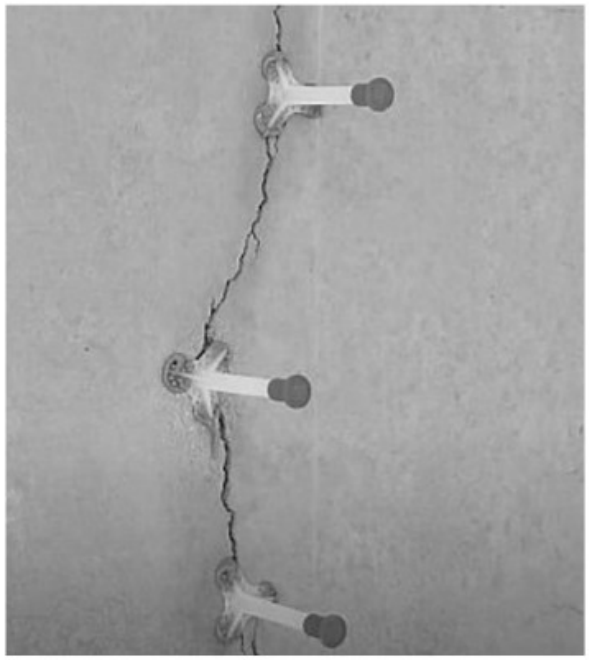
Availability of Materials: Somewhat expensive material but low labor and equipment costs and very little time required each day, requires cleaning and applying
Expertise Needed: Absolutely no expertise needed
Manpower: Less than a day
Time until Usability: Minutes to hours
Longevity: 4-7 years, silicone may last longer and has strong resistance to weathering
Aesthetics: Relatively thin, different material than the concrete, overlay may be used as historically accurate cover
Historical Accuracy: Not for historical accuracy, overlay may be used as historically accurate cover
Deterioration Type: Preventative - reduces moisture and chemical attacks, most effective when performed on concrete pavements that exhibit minimal structural deterioration and when the cracks are relatively narrow with minimal spalling and faulting, width <13 mm
Advantages: Easy to implement and acts as a preventative solution from further damage
Disadvantages: Does not strengthen material, purely for waterproofing and filling surface cracks

Before Rehabilitation vs. After Rehabilitation

EPOXY INJECTION

What is epoxy injection?

The injection through mounted ports of an epoxy to fill surface level cracks and provide minor reinforcements to deteriorated areas. The epoxy injection must take into account aspects like pressure of the seal, type of resin used, and also if the crack is horizontal or vertical.



Type of deterioration rehabilitated

This rehabilitation method was used on concrete columns without steel reinforcement present and cracks larger than 3mm.

Criteria

Availability of Materials: Cleaning equipment, surface-mounted injection ports, injection equipment - easily found, may be expensive
Expertise Needed: Experience preferred but not required
Manpower: A day
Time until Usability: Up to 12 hours
Longevity: 5 years
Aesthetics: Epoxies are not concrete and will look different than the surrounding concrete, may need finish and paint
Historical Accuracy: Epoxies can not be matched to concrete and are not historically accurate, they do not change the makeup or style of the column
Deterioration Type: Floor and column cracks without further deterioration - cracks 0.002 in. (0.05 mm) in width or greater
Advantages: quick solution with minimal experience necessary for full rehabilitation
Disadvantages: If the cause of cracking is corrosion of the reinforcing steel or if movement of the concrete is anticipated after repairs, epoxy injection may not be the best solution to the problem

Before Rehabilitation vs. After Rehabilitation

PARTIAL DEPTH REPAIR

What is partial depth repair?

Removal of small areas of deteriorated concrete found in only the top half of a walkway slab followed by the insertion of a compressible material between the new concrete and the old and then the subsequent application of a patching material to the area. A bonding material may be necessary and the concrete will need to be cleaned after the initial removal process.

Type of deterioration rehabilitated

This rehabilitation method was used on concrete walkways where cracking was seen only in the top half of the concrete

Criteria

Availability of Materials: Materials include compressible material, cement, light jack hammers and milling machines, cleaning equipment - actual repair materials can eaily be bought from a concrete manufacturer
Expertise Needed: Workers with experience in concrete removal, mixing, placing, and curing
Manpower: 1-3 days
Time until Usability: Curing time dependent on type of concrete
Longevity: 5-15 Years
Aesthetics: May be rougher than surrounding pavement, concrete color can be matched, can be smoothed down
Historical Accuracy: Concrete can be matched in material and color
Deterioration Type: Cracks, spalling, and joint deterioration in top half of walkways
Advantages: Solves issue of thermal expansion by inserting compressible materials between new concrete and old slab
Disadvantages: Not useful for spalling of transverse or longitudinal cracks caused by shrinkage, fatigue, or foundation movement

Before Rehabilitation vs. After Rehabilitation