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Retrofication of Historical Monumental Structures with Fracture Mechanics Approach

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Abstract— **Heritage is of most important and prestige for a human kind. It is also very important to conserve and preserve it. After many decades of their construction now it is very necessary to retrofit them which should last to next generation. In the process of enhancement of strength and retrofication of the structures, it should not change its original form, shape, size, feel and heritage. It must be look like as it is originated and built.**

As in conventional methods of restoration there are so many methods / techniques for restoration of plaster, color, texture, surface etc. But here I am interested to conserve stone/brick masonry which is structurally damaged by some natural calamities like earthquake, flood, wind storm etc. or disrupted by war or some other attacks. The fundamental structural strength is focused on this subject.

The Fracture mechanics is new discipline as compare to other conventional branch of engineering. In fracture mechanics Griffith done lot of work in brittle material like glass and metal. Very less work has been done in stone fracture. The stone fracture mechanics as less focus on stone masonry and other stone construction.

Here I tried to explore horizons of new direction of stone monumental structures. I found very less back up for the subject. I tried to open it for further study and research in future

Introduction

There are so many structures constructed over the world since the existence of the human race. Some ancient structures are still maintained in their position, which were constructed during a time when there were no advanced techniques and composite materials available. These historical/monumental structures reflect our heritage, lifestyle, and culture. It is necessary to prevent them against deterioration, disintegration, environmental effects, natural calamities, and other factors, and preserve them for many years. We need to understand the geometry, construction methods, structural details, and joinery of structures from that era. This study on retrofitting and strengthening of historical structures encompasses the area of preservation and conservation. There were so many studies related to damage and retrofitting of the structures, but I have tried to justify this study with the help of the emerging field of fracture mechanics.

This study includes the history of structures, their construction, and methods of construction to understand historical/monumental structures. Further, it aims to understand damage, defects, and the deterioration of structures, including flaws and cracks, from the point of view of fracture mechanics. And it leads to its solution with appropriate retrofitting and strengthening methods of structural elements concerned with enhancing strength, stability, and importance

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2. DAMAGES TO STRUCTURES AND INTERPRETATION OFFRACTURE MECHANICS

2.1 Damage Identification and Structural Elements

2.1.1 Causes of damage to structures

Several factors and loading actions are responsible for the destruction of any structure, and that is also applicable for stone masonry structures. Any load and load combinations will affect the stability and life of the structure. Other conditions like weather, acid rain, temperature, delamination of stone, etc., should be considered as aspects for heavy damages. These factors damage the structural components in various manners.

2.1.2 Presence of Flaws and Irregularities in Stone

Natural stones have been obtained from rock masses, which contain embedded and surface cracks due to geological disturbances and irregular joinery. These generate natural flaws and irregularities in the rock, being a reason for the propagation of cracks through it, leading to structural collapse when excessive loading occurs.

2.1.3 Cracking of Stone

Macro-cracks may result from natural flaws in the stone, errors during quarrying, rust-jacking, or structural causes. While micro-cracks may be caused by fluctuations in wetting and drying and may seem inconsequential, they likely indicate more serious problems to follow, and consideration should be given to treating them with injection grout. Macro-cracks, on the other hand, may indicate more serious structural issues, especially if they occur in a structure such as a multi-storied building. Simply pointing out such cracks may overlook more critical problems associated with settlement, subsidence, or loading changes. Bonding large cracks can be problematic, but efforts should be made to seal out water that will cause additional problems.

2.1.4 Weathering of Stone

Fig.1. Weathering of Stone

Weathering of stones causes deterioration of the structure and damages its cultural value. It is non-uniform and local-specific deterioration is accordingly differentiated. It may be intentionally accelerated and proceed rapidly all over the structure, though for some stones this process is slow**.**

Weathering is a combination of three processes: Physical, Chemical, and Biogenic

Physical and chemical actions mostly occur as synergic effects. The causes of weathering action are:

- The decay of stone is complex, involving an interaction between dissolution, crack-corrosion, and expansion-contraction cycles triggered by the release of residual stresses.
- Thin spalls of stones are generally caused by a combination of stress relief and salt action.
- Vegetation, black staining, due to rain and bird extraction.
- Living organisms may contribute to mechanical weathering. Lichens and mosses grow on surfaces and create a more humid chemical microenvironment

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The attachment of these organisms to the surface enhances physical as well as chemical breakdown of the surface microlayer of the stone. On a larger scale, seedlings sprouting in a crevice and plant roots exert physical pressure as well as providing a pathway for water and chemical infiltration.

- Chemical weathering changes the composition of stones, often transforming them when water interacts with minerals to create various chemical reactions. Chemical weathering is a gradual and ongoing process as the mineralogy of the stone adjusts to the near surface environment. New or secondary minerals develop from the original minerals of the stone.
- Chemical weathering is enhanced by geological agents like the presence of water and oxygen, as well as biological agents such as acids produced by microbial and plant-root metabolism.
  - The process of mountain block uplift is important in exposing new rock strata to the atmosphere enabling important chemical weathering to occur; significant release occurs of *Ca^{2+}* and other ions into surface waters.
  - Acid rain* occurs when gases like sulfur dioxide and nitrogen oxides are present in the atmosphere. These oxides react in the rainwater to produce stronger acids and can lower the pH to 4.5 or even 3.0. Sulfur dioxide (*SO_2*) comes from volcanic eruptions or from fossil fuels, forming sulfuric acid within rainwater, which can cause solution weathering to the stones on which it falls.
  - Some minerals, due to their natural solubility, oxidation potential, or instability relative to surficial conditions, will weather through dissolution naturally, even without acidic water.
- Hydrolysis is a chemical weathering process affecting silicate and carbonate minerals. In such reactions, pure water ionizes slightly and reacts with silicate minerals. An example reaction:

$$Mg_2SiO_4 + 4\,H^+ + 4\,OH^- = 2\,\mathrm{Mg}^{2+} + 4\,\mathrm{OH}^- + H_2SiO_4$$

(Olivine (forsterite) + four ionized water molecules = ions in solution + silicic acid in solution)

- This reaction theoretically results in the complete dissolution of the original mineral if enough water is available to drive the reaction. In reality, pure water rarely acts as a H+ donor. Carbon dioxide, however, dissolves readily in water, forming a weak acid and donating H+ donor.

$$Mg_2SiO_4 + 4\,CO_2 + 4\,H_2O = 2\,\mathrm{Mg}^{2+} + 4\,\mathrm{HC}O_3^- + H_4SIO_2$$

(Olivine (forsterite) + carbon dioxide + water = magnesium and bicarbonate ions in solution + silicic acid in solution)

- This hydrolysis reaction is much more common. Carbonic acid is consumed by silicate weathering, resulting in more alkaline solutions because of the bicarbonate. This is an important reaction in controlling the amount of CO_2 in the atmosphere and can affect the climate.
- Aluminosilicates, when subjected to the hydrolysis reaction, produce a secondary

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mineral rather than simply releasing cations.

$$2KAlSi_3O_8 + 4\,H_2CO_3 + 9\,H_2O = AL_2Si_2O_5(OH)_4 + 4\,H_4SIO_4 + 2K^+ + HCO_3^-$$

- (Orthoclase (aluminosilicate feldspar) + carbonic acid + water = kaolinite (a clay mineral) + silicic acid in solution + potassium and bicarbonate ions in solution)

2.1.5 DISRUPTED BY WAR

Wars during ancient periods between Mughal rulers and Hindu rulers, and during British rule, took the form of destruction of religious structures. A few examples:

- In 1024, during the reign of Bhima I, the prominent Afghan ruler Mahmud of Ghazni raided Gujarat, plundered, and destroyed the Somnath temple and broke its jyotirlinga. In 1299, Alauddin Khilji's army under the leadership of Ulugh Khan defeated Karandev II of the Vaghela dynasty and sacked the (rebuilt) Somnath temple. By 1665, the rebuilt temple was once again ordered destroyed by Mughal emperor Aurangzeb.
- Around 1200 CE, one of the most prominent seats of learning in ancient India, Nalanda University, was sacked and destroyed by Turkish leader Bakhtiyar Khilji.
- In 1565 CE, after the Battle of Talikota, the magnificent capital city of Vijayanagara, with all its exquisite temples, palaces, mansions, and monuments, was sacked and completely destroyed by an invading Muslim army raised by the five Bahamani Sultanates. Now, only destroyed Hampi remained.
- A large number of Hindu and other (e.g., Jain) temples were destroyed during the Islamic invasions of India.
- On 6 December 1992, the "Babari Mosque," built in 1528, was destroyed by Hindu extremists

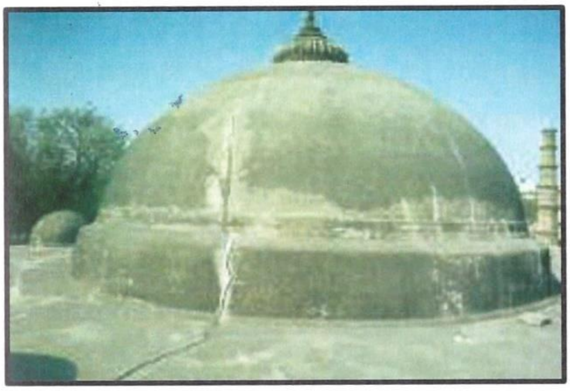

Fig. 2. Disrupted during war

2.1.6 NATURAL CALAMITIES

Earthquakes, floods, heavy rain, etc., are natural calamities that cannot be stopped by us. In such conditions, the structures suffer major damage, often leading to the destruction of the structure. Some minor damages include cracks on the surface of the structural component. These cracks start propagating throughout the structural elements and lead to the destruction of that portion. Major damages due to these actions include breakage of stones, weakening of the foundation, soil liquefaction, and collapse of the structure. These situations are vulnerable if better preservation measures are not taken.

Major damages to structures occur due to earthquakes. During an earthquake, the earth plates move, and with that, the foundation of the structure experiences dynamic effects. Since stone is not flexible material, the earthquake waves disturb its stability, leading to destruction

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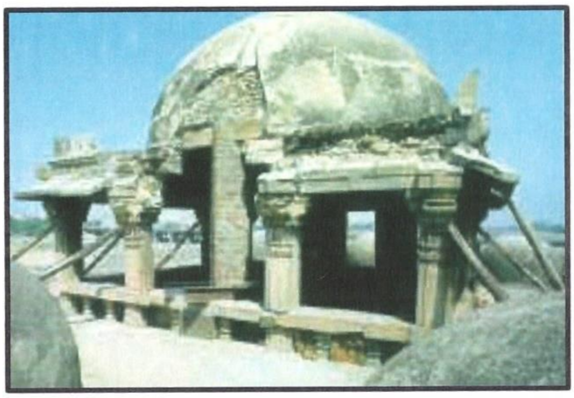

Fig. 3. Natural calamitie: seismic effect

3. CONCLUSION

Following are the conclusions obtained from the present study of the topic.

- Use of fracture mechanics will predict which crack is stable and which one is unstable.
- A stable crack cannot be disturbed, and it should be repaired with conventional techniques like non-shrink grout of cracks and filling of cracks. Unstable cracks can be retrofitted by end pinning, stitching of stones, replacing with equivalent stone, post-tensioning, jacking staples at joinery, wedging, or interlocking of stones, so that it should not compromise the strength of the structure.
- Fracture mechanics is the emerging technique for assessing the residual life of the structure, failure properties, and stable or unstable cracks.

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