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Freeze-Thaw Cycle in Concrete and Brick Assemblies in cold regions in north India

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I. Introduction

India is a country with a large land mass, the 7th largest in the world. Its population is huge, it being the second most populous country in the world after China. Being a developing country with a huge population, there is an intense focus on construction activities which range from residential to commercial or infrastructure augmentation like bridges, roads, etc. Construction has changed from traditional to modern with the mud and mortar giving way to concrete and steel structures.

Located 8 and 37 degree North latitudes, India is as a whole located in the Northern hemisphere but the climatic conditions are diverse, with most of the country experiencing a tropical/subtropical geography with warm to hot summers and pleasant winters. However, there are different climatic conditions with certain areas experiencing temperate climate with intense winters, especially those in the northern most regions of the country like in Ladakh and Jammu and Kashmir. The temperatures in these regions drop to sub-zero levels, touching as low as -60 C in certain areas like Drass in the Ladakh region. While these climatic factors pose challenges to life, the possible adverse of such extreme climatic conditions are often ignored and people resort to using the same construction materials as are used elsewhere in the country where climatic conditions are not so challenging. We herewith discuss the effect on intense cold on the construction materials used in temperate Indian settings which result in settings that are detrimental to the modern construction materials like brick and concrete assemblies that are integral to the modern constructions.

Intense cold and freeze-thaw damage:

Cold temperatures result in icy conditions and as a result freezing is common.

This can result in damage to common construction materials like concrete and brick assemblies. The volume of frozen water is upto 10% greater than liquid water. When water seeps in to the voids of a porous and rigid material, it expands and exerts lateral pressure on the surrounding material. formation and growth of ice crystals within the pores of cementitious materials can create hydraulic, osmotic, and crystallization pressures high enough to induce microscale cracks. When the pressure exerted exceeds the tensile strength of the material, cracks result. Apart from causing a reduction in the strength of the material, it also results in a larger void which serves as a nidus for the accumulation of water in the next seepage and if frozen, additional cracks and expansion of the previous cracks appear. Cracking accelerates deterioration by reducing bulk mechanical integrity, exacerbating water and ion penetration, and increasing susceptibility to damage upon exposure to subsequent freeze-thaw cycles.

Thus these freeze-thaw cycles result in substantial damage to the construction material. The damage occurs primarily due to 2 processes viz surface spalling and Internal cracking.

Surface spalling results from recurring accumulation of water or snow on surfaces, both horizontal and vertical, causing them to remain wet for extended periods to time. Humid conditions during winter result in moistening of the surfaces and the water can seep into the available pores and can get subjected to the freeze-thaw process. As a result of the freezing, the external layer of the construction material fractures to the depth of water penetration and falls off. The spalling of the surface of the concrete results in the exposure of the underlying aggregate and the repetition of the vicious cycle. Repeated spalling can even expose the reinforcing bars, leading to further deterioration. In case of bricks, surface spalling also results in fractures and falling off of the superficial layers with direct exposure of the deeper surfaces, that are softer and considerably more porous, which puts these to a greater susceptibility to the freeze-thaw damage.

Internal cracking occurs when internal cracks and voids are filled with water and subject to freezing. Unlike surface spalling, the cracking starts on the interior, which may not be evident to visual inspection. Upon further freeze-thaw cycles, the damage may propagate to the surface.

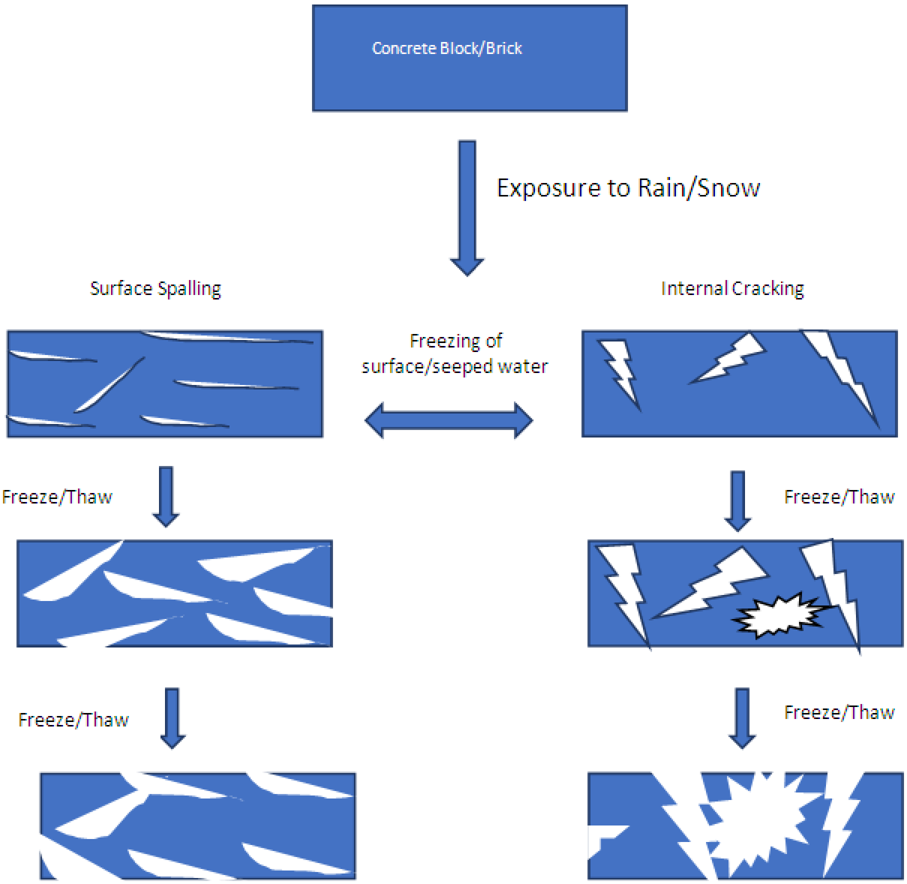

Figure 1. Schematic representation of the effects of Freeze-Thaw Damage to Concrete/Brick blocks

Kashmir experiences a harsh winter and the capital city of Srinagar observes temperature average high and low temperatures in January are 28 and 49 F (fig 2), so freezing and thawing can occur frequently. Such kind of recurrence of freeze-thaw are more destructive than in colder climates where below-freezing temperatures throughout the days would result in less frequent freeze-thaw cycles.

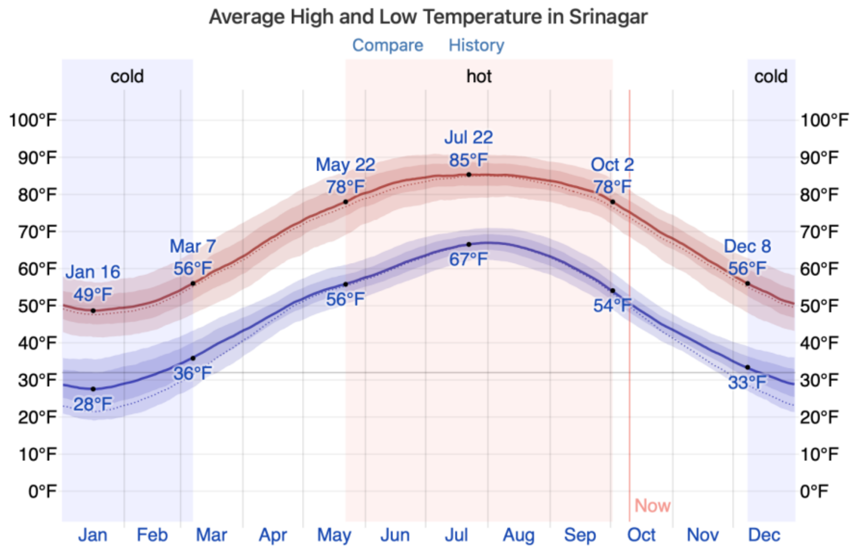

Figure 2. Average High and low temperature in Srinagar. *The daily average high (red line) and low (blue line) temperature, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures. (Source: https://weatherspark.com/y/108076/Average-Weather-in-Srinagar-India-Year-Round)*

II. Prevention of Freeze-Thaw Damage

Since both the processes associated with the freeze-thaw cycles are progressive, they can be intensely damaging if not effectively prevented. There are numerous strategies for preventing damage, including the following:

1. Control penetration of water: One way to prevent freeze damage is controlling environmental water in the form of water, ice and snow. Properly detailed parapets, copings, roof edges, and other critical connection points prevent water penetration in concrete and brick assemblies. Overhangs, drip edges, and other details also prevent water from saturating wall surfaces. These should be judiciously employed to reduce the penetration of water into the construction assemblies.

2. Control of groundwater. Capillary action from the damp ground can also lead to water seeping into the concrete and brick assemblies. Dampness of the ground should be eliminated. A proper drainage of Earth, sloping away from the constructed structure will help reduce the water contact of the assemblies. Flashing or other methods should be utilized so as to reduce water from being drawn up into wall assemblies.

3. Use water-resistant brick.

Bricks appropriately graded for resistance to freezing damage can be helpful in reducing the freeze-thaw damage. Grades of bricks that are appropriate for severe weathering and moderate weathering should be used in situations where resistance to cyclic freezing is desired or where moderate resistance to cyclic freezing damage is permissible, respectively.

4. Use appropriate concrete.

Concrete should be designed with properties that will minimize freeze-thaw damage. A low water to cement ratio reduces permeability, which will in turn reduce both surface and internal water absorption. High strength concrete ($\geq$6,000 psi) has increased tensile strength and will withstand the high internal pressures exerted by freezing and consequent expansion of volume.

Concrete is air-entrained concrete (4% or more of concrete volume) which contains microscopic bubbles which allow the concrete to expand with less likelihood of cracking. Conventional air-entraining admixtures (AEAs) create stabilized air void systems within cementitious matrices via surfactant mechanisms. Despite enhancing freeze-thaw resistance, the introduction of an air void system results in reduced mechanical strength, which can be as high as 5% per 1% entrained air and an increase in permeability that is proportional to the amount of introduced air. Furthermore, recent research has indicated that, if a critical water saturation level is reached in air-entrained concrete (~86%–88%), entrained air void systems are rendered ineffective and freeze-thaw damage is inevitable. While the time to reach this critical water saturation level can be years, the propensity for unavoidable damage in saturated air-entrained concrete is a limitation to the use of AEAs.

As such further strategies are employed to mitigate these influences of air entrainment. Such strategies include (1) densifying and strengthening cement paste using nanoparticles or supplementary cementitious materials, (2) incorporating superabsorbent hydrogel particles as a non-surfactant method to achieve an entrained air void system, and (3) using macroscale polymeric fibers for mitigating crack propagation due to frost-induced damage.

Antifreeze proteins (AFPs) and antifreeze glycoproteins (AFGPs) are ice-binding proteins (IBPs) produced by plants, fish, insects, and bacteria that enable a variety of organisms to resist freezing temperatures. These substances have been isolated from the freeze-tolerant organisms and have been incorporated into cementitious materials. Use of these molecules may help counter other deleterious disadvantages that coincide with the use of AEAs. The disadvantages of air entrainment are significantly reduced by the use of biomimetic substances like PEG-PVA in cement paste.

III. Conclusion

The freeze-thaw cycle is a concern in most cold climates and should be addressed during design. With proper detailing and specification freeze-thaw damage to assemblies can be reduced or eliminated.

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