Construction Materials and Safe Construction Practice in Corrosion-Prone Areas

DR MD TAREK UDDIN

Corrosion-prone areas can be defined as the areas where chloride ions are available around a structure from seawater or other sources, such as de-icing salt which is used for melting of ice from the road surface to facilitate vehicle movement.

Bangladesh is a tropical country; therefore, the main source of chloride ions here is seawater. The salt content is about two to three percentage of seawater. Airborne chlorides from seawater can fly several kilometres inland from the sea. The concentration of airborne chlorides is higher near the sea and reduces gradually as the distance from the sea increases. A structure constructed near the sea will face a relatively harsher corrosion environment compared to that which is constructed far from the sea. In seawater, the exposure environment for a structure can also vary. For example, the exposure of the part of a structure under seawater is defined as submerged exposure; the part of a structure in the tidal zone is called tidal exposure; and the part over the high tide level is known as seawater atmospheric exposure. Chloride ions enter the reinforced concrete structural elements which leads to corrosion over the steel bars in concrete. The process of corrosion over the steel bars in concrete initiated by chloride is known as chloride-induced corrosion. The corrosion of steel in concrete can also be initiated due to carbonation (reaction of atmospheric carbon dioxide and calcium hydroxide of concrete). The process of corrosion initiated by carbonation is called carbonation-induced corrosion.

In this article, only the chloride ion induced corrosion is focused on. The economic loss due to corrosion of steel is quite enormous. The loss is estimated at USD 2.5 trillion globally. For awareness of mass people, April 24 is observed as the Corrosion Awareness Day. The loss due to corrosion in corrosion-prone areas is a great concern to engineers and, therefore, engineers are trying to reduce this loss through the selection of proper materials and implementation of appropriate construction practice.

Concrete is a porous material. Harmful agents like chloride ions can enter concrete through the capillary pores in concrete. The capillary pores are formed due to the presence of free water remaining in concrete after reaction of cement particles with water (known as hydration of cement). The more free water, the more the volume of capillary pores. For hydration of cement, only 23 percent of water (with respect to the weight of cement) is required. The chemically bound water with cement particles will create nano-scaled pores that prevent chloride ions from entering the concrete. On the other hand, the free water (remaining after hydration of cement) creates capillary channels in concrete and allows harmful agents like chloride ions to enter concrete. The more the volume of capillary pores, the higher the rate of chloride ingress into concrete. Therefore, in corrosion-prone areas, it is necessary to produce dense concrete by limiting the amount of water. The reduction of water in concrete makes concrete less workable. However, the flow ability of concrete can be increased with the use of water reducing chemical admixture. Nowadays, self-levelling concrete can be produced with the use of water reducing chemical admixture even for a very low amount of water with respect to the cement. With the reduction of water in concrete, the strength of concrete will also be increased. Therefore, in corrosion-prone areas, it is essential to use high-strength concrete. The more the strength of concrete, the stronger the barrier against chloride ingress into concrete.

Deterioration of concrete due to corrosion of steel in concrete (Top – Slab, Bottom Left – Column, Bottom Right – Beam).

The other important parameter for protection against corrosion of steel in corrosion-prone areas is concrete cover around the steel bars. Based on the severity of environmental exposure conditions, a thicker high-quality concrete cover is required.

Recently, a study was conducted to understand the rate of chloride ingress into concrete made with different aggregates available in Bangladesh, such as brick chips, stone chips, shingles, etc. Concrete made with clay burnt brick aggregates shows more chloride ingress compared to the other aggregates. It indicates that in corrosion-prone areas, brick chips should not be used for making concrete due to its high porosity and greater absorption of water.

A further laboratory based research study was carried out on chloride ingress into concrete made with different types of cement. It was found that slag based cement reduces chloride ingress into concrete by producing a relatively denser micro-structure within the concrete. It produces a stronger barrier against chloride ingress into concrete. This observation was also verified with the research results of long-term exposure tests in marine environment conducted over a timespan longer than 30 years.

Based on the laboratory as well as long-term exposure investigations of concrete specimens made with slag cement, it was concluded that slag cement is the best cement against protection of chloride ingress into concrete. Therefore, it is recommended to use slag based cement in corrosion-prone areas. By using slag cement and increasing cover and reducing the amount of water (water-to-cement ratio), it is possible to design a reinforced concrete structure in a corrosion-prone area which can last more than 150 years. As concrete is weak in tension, it is likely that concrete structural members will be cracked due to the imposed service and environmental loads. Nevertheless, the crack widths are to be kept as narrow as possible. The opening path of narrower cracks will be healed due to the deposition of chemical reaction products formed due to the reaction between concrete and environmental agents. This process is called self-healing of concrete.

During mixing of concrete, corrosion inhibitors can also be used to prevent corrosion over the steel bars. Epoxy-coated bars can also be used in concrete to delay the initiation of corrosion. However, epoxy-coated bars are to be handled carefully during transport and placement in structural members. If coating is damaged, it should be re-applied before casting concrete. Otherwise, pitting type corrosion will occur at the damaged locations. As an alternative reinforcement, stainless steel can also be used. However, it will increase the cost of the project significantly. Surface coating on the concrete structures can also be used to form a barrier against chloride ingress into concrete.

Due to the harsh exposure environment (due to the presence of chloride), the construction work in the corrosion-prone areas is to be executed very carefully. The mixing water as well as curing water of concrete should be free from salt. Aggregates should be angular (not flaky and not elongated), strong, non-reactive, properly graded, and free from salt and dust (silt and clay). Concrete should be mixed properly with a minimum amount of water as per the mix design of concrete. The amount of cement should not be lower than the specified minimum limit. Water reducing chemical admixture is to be used to enhance the flow ability of concrete. Concrete should be transported to the construction sites as soon as possible before cement starts setting. Formwork should be watertight to avoid the formation of honeycomb (concrete with large interconnected voids due to the leakage of water through formwork) in concrete. Concrete should be placed carefully to avoid segregation and should be compacted properly without causing segregation. Immediately after casting, concrete should not be allowed to dry. Proper curing (a process to stop evaporation of water from concrete) is to be ensured. Curing should be done continuously without any interruption for the specified period. The structural health should be monitored and recorded periodically. A guideline related to the maintenance and repair of the structure should be prepared and followed accordingly. The condition of structural health is to be monitored through the service life of structures. An early decision on repair of structure (if necessary) is essential to reduce the cost of repair as well as overall safety of the structure. The parameters related to the materials and construction practices are to be considered holistically to make a long-term durable concrete structure in corrosion-prone areas and it will eventually safeguard the investment of the construction project as well as sustainability of construction materials. The experiences acquired from our local exposure environment should be incorporated in the durability design guideline.

Dr Md Tarek Uddin, *PEng., is Professor, Department of Civil and Environmental Engineering, Islamic University of Technology (IUT).*