Innovative Concrete Technology for Zero Maintenance

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CONCRETE has always been a widely used civil engineering material in the construction industry. For years, researchers and engineers have worked hand in hand to create new types of concrete using alternative ingredients with the objective of improving its properties. The effort to revolutionise concrete construction has taken place in recent years and is being spearheaded by scientists and researchers all over the world. Special effort is needed to create a much less brittle (or rather ductile) concrete, and one that is tougher and more durable compared to conventional concrete.

The durability of conventional concrete has always been an issue especially for facilities that are subjected to harsh environments. Aggressive and harmful chemicals and substances in the oil and gas environment, and the extreme conditions of the marine environment can reduce the durability and affect the performance of the concrete material.

Conventional concrete requires adequate vibration during pouring, otherwise honeycombs and voids form in the concrete, which will lead to internal and external cracks that can adversely affect concrete durability. Adding more super-plasticiser to enhance the workability of concrete to ease compaction could also lead to segregation. Apart from the harsh environment, dynamic load effects could also cause cracks to develop and propagate. The common problems of conventional concrete have led to requests for concrete with better durability throughout the lifespan of the structure, but yet economical to produce.

To date, concrete specifications in many projects have yet to address the adoption of innovative concrete technology simply because it may be difficult to convince the industry to shift from conventional concrete to a new type of concrete as the initial cost of the latter might be a bit higher. However, as the main objective of ductile concrete is to minimise maintenance by improving crack resistance, the long term performance and benefit could be very attractive to maintenance engineers.

Various studies have been conducted in recent years by experts to analyse the performance of ductile and other innovative concrete materials. Figures 1 and 2 show examples of laboratory tests being conducted on high strength ductile concrete. A lot more effort is needed to instill awareness among the engineers and to realise the implementation of innovative concrete materials. This article is dedicated towards creating awareness within the industry on the benefits of the use of innovative concrete and to instill value engineering through knowledge sharing.

Figure 1: High strength ductile concrete loaded to failure

Figure 2: Crack monitoring of high strength ductile concrete

THE NEED FOR AN INNOVATIVE CONCRETE BLEND

Maintenance cost is a cost that could eat into the profit of an organisation. A lot of money is allocated for maintenance work every year, however, very often the performance of a structure does not return to its designed value even after maintenance work, due to the fact that it is almost impossible to totally remedy any defect that appears after years of operation. With a variety of root causes that can contribute to the defects, it is difficult to rectify and isolate the cause of the failure.

From time to time, civil engineers undertake structural integrity assessment to assess the current load bearing capacity of structural components and the effect of concrete defects on such capacity. In many cases, relieving the structure of the loads or the strengthening of structural components would be necessary to ensure that the structure can continue to serve its designed function.

As such, the question is, could we have a type of concrete that needs almost zero maintenance work? Could there be a concrete that does not crack easily when subjected to vibration, or one that could seal its own cracks and pores such that no moisture would be able to penetrate through them and cause reinforcement corrosion? It is high time scientists and engineers redefine and redesign concrete composition.

BENEFITS OF IMPROVING CONCRETE

Being a brittle material, concrete is prone to cracks under tensile loads. Continuous vibrations, exposure to high temperature that induces thermal stresses, chloride and sulfate penetration, carbonation, lime leaching, and even blasts and impacts could lead to cracks and other defects in concrete. Water and moisture ingress through cracks could further expedite the corrosion process of the reinforcement. Once the reinforcement is corroded, it needs quite substantial repair work and the possibility of strengthening work to ensure the structure continues its function of sustaining the applied loads.

In oil and gas plants, it is not uncommon for concrete structures to be subjected to vibration and differential temperature profiles along the structure. Seismic activity may not be a problem in this country, but oil and gas investments in countries prone to seismic loadings could further justify the use of ductile concrete. A concrete structure with good fatigue resistance, good vibration damping and cracking resistance is desired when subjected to continuous dynamic and cyclic loadings.

In many cases, a concrete structure cracks due to excessive deformation. The addition of structural members to increase the total mass of the structure and, hence, amend its natural frequency may not be an easy task due to constructability issues. Cracks and corroded reinforcement repairs and strengthening seem to be the common solution under such circumstances. Partial shutdown may also be needed to provide a safe environment for the repair and strengthening work to proceed.

It is also not uncommon that repairs need to be done repetitively due to the reappearance of the defects. Since mechanically applied loads might not be varied easily, and structural strengthening and modification may not be an easy task to carry out in a live plant, the short-term repair of structural defects can be considered routine work for many maintenance engineers.

The current problems and high expenses for maintenance justify the use of a concrete that is adequately ductile, to minimise cracks and to prevent the ingress of water, moisture, chloride and other substances in order to achieve almost zero maintenance. When the passage of water, moisture, chloride, sulfate, etc, is cut off from reaching the reinforcement, we could permanently have zero corrosion of the reinforcement. When this is achieved, the requirement for the repair and rejuvenation of a structure is minimised and the designed service life of the structure is extended.

APPLICATION OF DUCTILE CONCRETE AND CRYSTALLINE WATERPROOFING TECHNOLOGY

Over the years, concrete technology has evolved from conventional normal strength concrete to high strength concrete and, currently, ductile concrete. Ductile concrete is somewhat new in the market and its application is not yet popular. However, its future remains bright, at least in the oil and gas industry.

With so much money spent on structure and facilities maintenance, including unit shutdowns for repairs and structural integrity work, it is time to embark on developing a construction material that could offer zero maintenance. The design life of a plant has always varied between 20 to 30 years, but in so many cases, the design life has been prolonged for extended plant operation. For the first 20 to 30 years of operation as designed originally, the structures and facilities could easily satisfy the required design life even with little maintenance by the plant crew.

However, in many cases, towards the end of the design life of the plant, when the decision to extend plant operation is made, the condition of structures, concrete fireproofing, buildings, foundations, etc, may no longer be satisfactory. This could be due to budget constraints during routine maintenance as well as budget constraints at the end of the asset's lifetime, in addition to normal deterioration of concrete. Rust stains, corroded reinforcement, structural and non-structural cracks, detachment, etc, can normally be seen, as shown in Figures 3, 4, 5 and 6.

Figure 3: Structural cracks on a concrete deck

Figure 4: Structural cracks in concrete fireproofing

Figure 5: Structural cracks due to vibration

Figure 6: Widespread structural cracks

In extreme cases, some structures and supports could partially fail before it reaches its design life. To ensure structural integrity, including prolonging the remaining capacity of the structure as well as other facilities, it requires many man-hours to inspect, assess and analyse the structure. Structural repairs and strengthening that incur high costs need to be performed. Partial plant shutdown needs to be done to allow for structural repair and strengthening work to take place.

In view of this problem, ductile concrete is seen as the right material that can provide the negligible maintenance concept for the multiple design life of the plants. Ductility is provided by the use of steel fibres. Such fibres improve the tensile strength of concrete and control concrete cracking by providing cracking resistance due to the matrix constituents. Sustainable concrete construction is also provided by the use of steel fibres in lieu of normal steel rod reinforcement.

Apart from ductile concrete, waterproofing technology by means of crystallisation is also an area that should be further investigated by maintenance engineers. Marine structures as well as structures and foundations subject to freezing and thawing conditions and concrete tanks in oil and gas plants are the best candidates for the application of crystalline waterproofing technology.

The technology was founded on the concept that supplementary concrete admixtures will react with water and moisture and the by-product of cement hydration to form a permanent network of non-soluble crystalline structure within concrete pores, tiniest pathways and capillaries, hence preventing the passage of water and other potentially damaging chemicals from reaching the reinforcement. Once the waterproof property is achieved, the reinforcement is forever protected from potential corrosion.

Liquid retaining structures such as concrete basins, chemical treatment plants, underground tanks and containment structures are best waterproofed through the crystallisation concept. Although waterproof coatings and membranes could also be used, such coatings and membranes have limited service life and need to be renewed to ensure their continued effectiveness. Crystalline waterproofing serves the structure both ways in terms of protecting from possible chemical leakage through capillary action and preventing the intrusion of chemicals and substances from the surrounding soil in the case of underground structures.

Crystallisation also provides for the self-sealing of cracks through the formation of crystals within cracks and pores. The self-sealing property is important to prevent the ingress of water and the worsening of cracks through the freezing and thawing process, and the formation of chloride precipitates within cracks and pores.

The superior properties of concrete through its ductility and effective crystalline waterproofing capability provide the plants with almost zero concrete maintenance requirement and readiness to multiply concrete design life for extended operation as required by the stakeholders.

CONCLUSION

The minimisation of concrete deterioration is possible through the use of ductile concrete and crystalline waterproofing technology. Extra effort to review and reassess the concrete specification for the oil and gas industry should be initiated. Cost savings due to zero maintenance could be an attractive investment return for stakeholders. Nevertheless, more research work is needed for a more cost effective solution by developing an optimal concrete composition in order to attain the additional property of self-compacting concrete.

The self-compacting high strength ductile concrete with crystalline waterproofing property could be a superb advancement for the easier placement of concrete, as well as save on labour, avoid noise pollution and, most importantly, able to produce high quality zero maintenance concrete due to its superior durability. Research also suggests that innovative concrete could be a green technology due to the possible reduction in the consumption of non-renewable raw materials (aggregate, sand and cement), hence reducing overall CO_2 emissions and global warming impacts.

The future of this generation of concrete appears to be extremely promising. ■