Non-brittle concrete

Concrete is brittle: beyond its elastic limit, it fractures under tensile stress. The high brittleness of concrete is revealed as cracks on sidewalks, on building walls, on bridge decks and in practically any structure, even if it is not the designer's intention to subject the concrete elements to tensile stress.

Under earthquake or bomb blast loading, collapse of structures can often be traced back to the brittle response of concrete.

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New development

In the past, non-brittle concrete has been created by using a lot of fibers, typically more than 5% by volume, and often aligned. The limitation of such non-brittle concrete is that the high fiber content and aligned configuration make it difficult for it to be applied in the field and it has therefore remained an academic curiosity. Recently, a version of non-brittle concrete has been developed at the University of Michigan with relatively low fiber content, known as Engineered Composites Concrete (ECC). By using ECC, a building behaves in the field with normal construction equipment such as ready-mix concrete trucks and to have self-consolidating characteristics, so that vibration is not required. The modulus of elasticity of ECC is similar to that of the concrete mix, thus allowing a more uniform distribution of stresses throughout the structure.

Characteristics and applications of ECC

The non-brittle nature of ECC overcomes the numerous limitations of normal concrete. For example, steel reinforcement is typically used to control crack widths in structural concrete members. However, the corrosion of such steel reinforcement may lead to a shortened service life. The non-brittle behavior of ECC means that it is no longer a necessary concern for structures subject to cracking. Moreover, in ECC, the composite material subjected to high shear loads require the use of special steel reinforcement. As ECC is non-brittle, it bears no danger in this matter. Even under severe loading, such as a bomb blast, ECC's ductile behavior allows for a sequence of bond-splitting, cover spalling, and core crushing. The concrete in the supporting columns will suffer these types of brittle failure when subjected to large imposed cyclic deformation. As a result, ECC is more likely to remain intact after an earthquake. Under severe non-mass loading, such as a bomb blast, severe fragmentation of the brittle concrete cover may occur. For example, when a compression wave reflects as a tensile wave reaching the free surface of a wall panel. No amount of steel reinforcement can eliminate this failure mode, but ECC may offer a solution.

The high deformability of ECC can be used to advantage in those situations where excessive deformation is essential. For example, it is necessary to place joints some distance apart in long concrete slabs in order to limit cracking of the concrete. In many instances, the use of ECC may mean the elimination of movement joints and hence joint maintenance.

Apart from new structures, ECC may be expected to be of benefit in repairs, due to its ability to eliminate surface cracking and interface delamination, which are typical modes of failure in many concrete repairs. The above is only a short list of possible applications that would take advantage of the non-brittle characteristics of ECC. Many have been demonstrated either in the laboratory or in practice. The possibilities are limitless. Clever use of ECC can make the infrastructure safer, more durable and less expensive, and maintenance costs. There are an increasing number of full-scale uses of ECC in large engineering projects. For example, Minato Bridge in Hokkaido, Japan (see Figure 5) has a composite ECC deck (underlain by a steel plate) and was completed in 2002. The estimated service life for this bridge deck is 100 years. Figure 5 shows the Rogun power station building in central Tokyo, expected to be completed by early 2008. This 27-story building uses two precast ECC coupling beams on every storey for seismic energy absorption during earthquakes.

Special ECCs

ECCs with special characteristics have been developed. These include lightweight versions with density in the range of 250 to 1780 kg/m³, and a high early strength version with compressive strength reaching 20 MPa in three hours. These characteristics are achieved without sacrificing the tensile ductility of the composite. In addition, ECCs with self-healing capability and self-sensing capability are being researched.

Conclusion

The civil engineering infrastructure faces several challenges in terms of safety under extreme natural and man-made loads and durability under normal service and environmental loads. In addition, sustainable development of the infrastructure in harmony with the natural environment is in question. It is not difficult to argue that the brittle nature of normal concrete is an important contributor to these concerns. Non-brittle ECC may provide a viable material solution to enhance the safety, durability and sustainability of the next generation of civil infrastructure.

Additional reading:

1. U. Li, Improved Composites Concrete, in Proceedings, Concrete Cover, Vancouver Canada, August 2000, pp. 293-299.

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