HIGH DUCTILITY CONCRETE WITH POLYMER FIBERS FOR BRIDGE DECK LINK SLABS

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ABSTRACT: Conventional joints between bridge decks have become a significant durability issue in the past decades. Concrete damage near the joints results in negative impacts on the underlying substructure such as reduced water tightness due to cracking. Elaborate maintenance of the joints is necessary to prevent serious structural deterioration. Hence, economic considerations favour jointless constructions to accomplish long-term durability and improved overall performance. A jointless bridge deck involves a link slab that replaces the conventional joint. This link slab ties two bridge decks positively. Hence, the link slab is subjected to loads. Bending and elongation form cracks in the link slab. Restricting crack development and crack width within the link slab is crucial for the performance.

Within the structural repair of highway bridges in northern Italy the existing joints and the adjacent concrete are removed. Concrete link slabs are cast in place instead. The concrete used was designed specifically to meet the requirements for cracking control. This paper describes the function of this innovative concrete that complies with the requirements of bridge deck link slabs. The application of this concrete for the repair of numerous deck links on a highway bridge in northern Italy is described in detail.

1. INTRODUCTION

Not particularly strength, but ductility is one of the main characteristics of a cementitious material when it comes to repair of existing concrete structures. Either restraints or dynamic loading require a certain amount of deformability. Otherwise cracks will occur within short time, which damages the quality and durability of the repair. In addition to the material itself, the whole concrete structure must feature a certain ductility to withstand deformation controlled loadings such as hygral and thermal shrinkage, soil-settlements or earthquakes.

The ductility of a structure is characterized by the capacity of the structure to absorb large deformations without collapsing. The ductility of a material is defined as the capacity of the material to be plastically deformed by performing large inelastic deformation prior to fracture.

Joints are the traditional way to allow deformations to take place in a structure without causing any damage. The ductility of such a structure is localized within its joints.

Joints are a very sensitive part of a structure. They require continuous care and maintenance. In addition they are often the starting point of greater damages, as they give access for harmful substances.

Jointless constructions require other measures to assure sufficient ductility of a given structure. One example for this is the replacement of bridge deck joints by so called bridge deck link slabs, which are made of a high ductility concrete, which is capable to provide the necessary ductility.

2. CAUSES FOR CRACK FORMATION

Under standard atmospheric conditions (no chemical attacks) reinforced concrete elements (RC elements) are subjected to different kind of loads.

- Mechanical loads
- Loads induced by restraints (eigenstresses)

- Hygral:	endogenous shrinkage
	drying shrinkage
- Thermal:	heat of hydration
	thermal gradients

In addition to mechanical loads such as static and dynamic loads as well as dead weights there are hygral and thermal loads: Hygral loads are generated during the time dependent drying process of the concrete. This process generates moisture gradients normal to the exposed surface. As moisture loss leeds to a volume reduction, this differential drying causes differential deformations. If these deformations are partially restrained, tensile stresses (eigenstresses) are induced. Their maximum values occur at the exposed surface. When these stresses exceed the tensile strength, surface micro crack formation starts. As the drying process continues, cracks propagate further along the cross section of the element.

Not only drying shrinkage but also natural atmospheric temperature variations cause alternating differential volume changes within the RC element. Sudden temperature drops caused by heavy rain showers on heated overlay surfaces due to solar radiation can induce large gradients of thermal eigenstresses.

In reality a certain superposition of hygrally and thermally induced eigenstresses and external loads can lead to crack formation of the RC element.

Fig. 1 illuminates the mechanics of a RC element regarding the superposition of the different types of loads mentioned above. A crack formation takes place when the loads (restrainments) can not be absorbed by the system. The capacity of the materials to absorb restrainments is contained in its elastic deformation, fracture energy and creep ability. The competition between loads and material is illustrated in Fig. 1

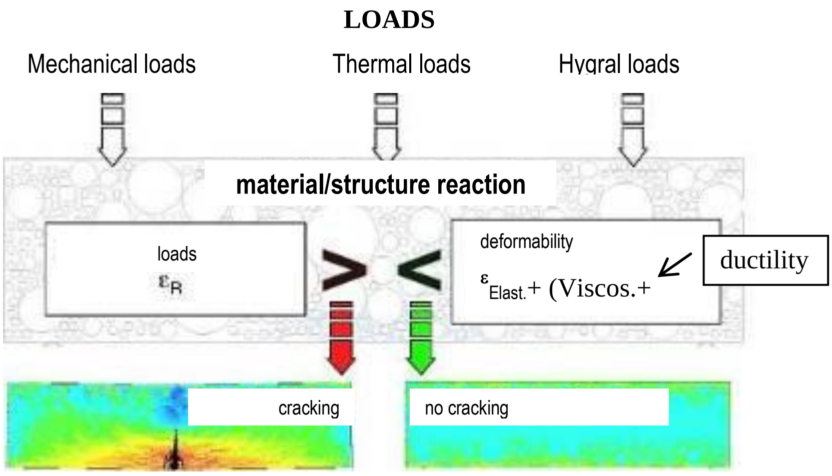

Figure 1: Causes of Crack Formation

3. FRACTURAL BEHAVIOUR OF CEMENT BASED MATERIALS LOADED IN TENSION

The limited tensile strength of concrete makes the material particularly sentitive to crack formation. The way how the crack develops is influenced by the type of loads acting on the material. If a specimen is loaded in tension with a force and the resulting stress is gradually increased an uncontrolled and fast crack formation occurs after reaching the tensile strength. The specimen breaks in a brittle way.

If the specimen is loaded with a deformation induced for instance by hygral shrinkage the specimen behaves in a different way. After reaching the tensile strength the material is still able to transfer forces. A so called fracture process zone develops containing microcracks. The crack formation is controlled by the deformation. After the cosumption of the fracture energy (see fig. 2 area below the stress-strain curve) of the material the specimen is completely broken.

Fig.2 shows the difference between the crack formation in a force (stress) controlled and a deformation controlled direct tensile test**:**

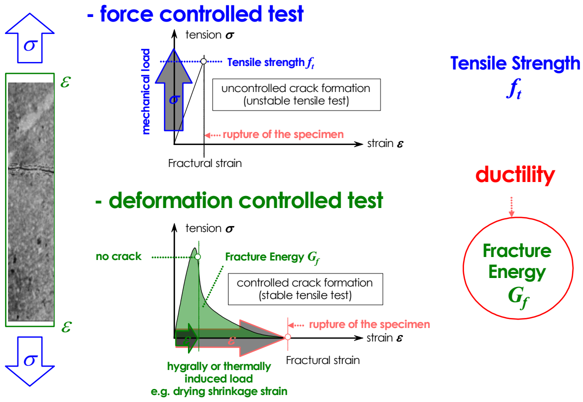

Figure 2 : Force controlled test and deformation controlled test

The fracture energy of the material can be strongly influenced with the use of proper fibers. Fiber reinforced materials are able to absorb deformations redistributing the crack formation and controlling the crack opening.. The type and the amount of fibers within the cementitous matrix influences strongly the post peak behaviour and the ductility of the material by increasing its resistance against crack formation.

4. EXAMPLES OF DUCTILE CEMENT BASED MATERIALS

4.1 Introduction

Compared to normal concretes or mortars, very high ductile cement based materials contain 1 to 2-% Vol. of high modulus polymer fibers. The particularity of these materials is their behaviour under tensile loading. After the appearance of the first crack they behave similar to metal: With increasing deformation the materials' load bearing capacity increases while microscopic cracks are formed. Unlike in common concretes and mortars there is no brittle failure after first crack formation as the fibers manage to bridge the cracks and arrest them.

Fig. 3 compares the stress deflection curves and crack patterns of a high ductility mortar (Tecnochem HFE-tec pav 360) and a standard mortar. The behaviour described above is very obvious. One of the many possible applications of HFE-tec pav 360 is the repair of concrete bridge decks where it is used to replace the existing covercrete.

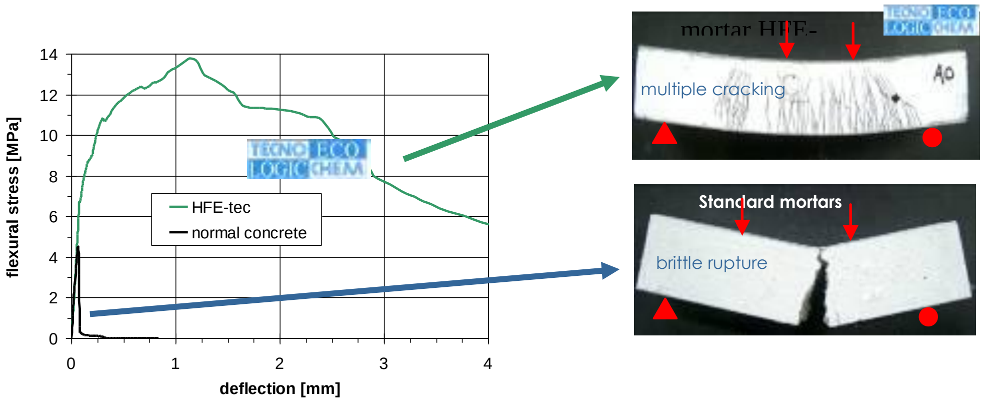

Figure 3: Flexural behaviour of the repair mortar HFE-tec pav 360

Fig. 4 shows the load deflection curve of another high ductility mortar (Tecnochem HFE-tec SHCC1). Compared to the material shown in fig. 3, this one features an even higher deformability. This comes from a different composition which uses finer sand and higher amounts of finer high modulus polymer fibers. By this tensile strains of up to 5% prior to collapse become possible. Compared to the maximum elastic strain of standard mortars of just about 0.01% this value is tremendous and opens a whole variety of new applications.

Figure 4: flexural behaviour of the mortar HFE-tec SHCC1

One possible application of such high ductility mortars is the construction of concrete buildings with a high level of earthquake resistance. Fig. 5 compares the behaviour of a conventional RC column with a column made of high ductility RC. The illustration shows how the performance of such materials can be used to create structural nodes within high ductility concrete structures.

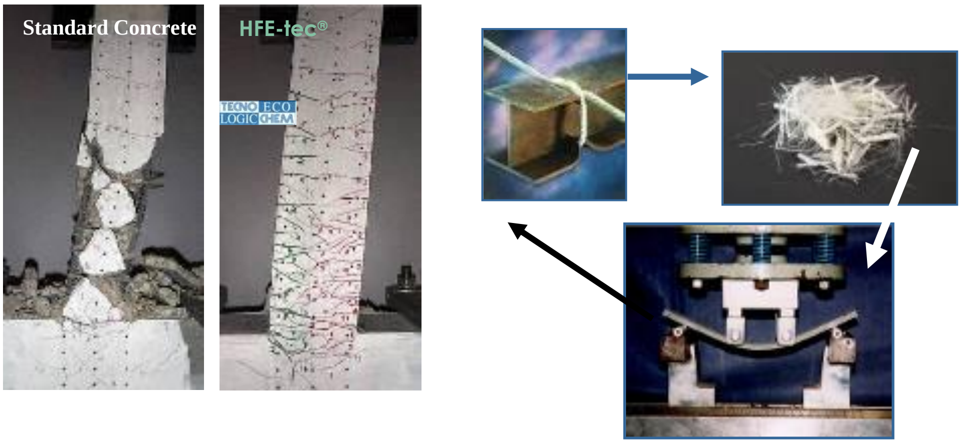

Figure 5: very high deformability induced by the interaction matrix- high modulus synthetic fibres

5. CASE HISTORY: DUCTILE LINK SLABS

5.1 Introduction

As described above the replacement of conventional bridge deck joints by so called bridge deck link slabs is an optimum application for high ductility concretes. The following case history describes the successful application within the repair of the Autobrennero (Highway A22), a highway in northern Italy which comprises of many bridges. The general informations regarding the project are given in fig. 6.

Infrastructure:
Viaduct,San Maurizio

Locality:
Chiusa

Repairing Works:
15 link slabs

Material Quantity:
150 cubic meters

Type of Material:
Fiber Reinforced Concrete
with low Young's Modulus and
High Ductility

Figure 6: Retrofitting Highway A22

5.2 Description of Case History

Within the structural repair of the viaduct San Maurizio 15 linking slabs have been built using approximately 150 cubic meters of high ductility concrete. Fig. 7 shows the construction detail of the old joint.

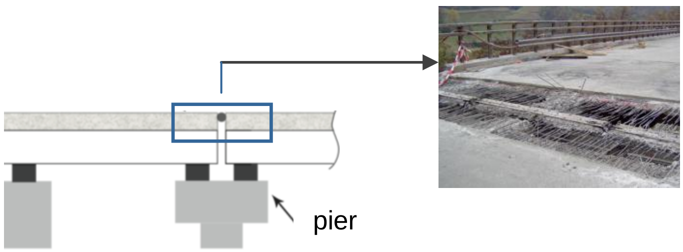

Figure 7: Existing joints (scheme and photo)

The existing joints and the adjacent concrete have been removed and concrete link slabs have been cast in place instead. Fig. 8 shows a schematic representation of the link slab including a picture showing the reinforcement of the link slab. The concrete used was designed specifically to meet the requirements for cracking control.

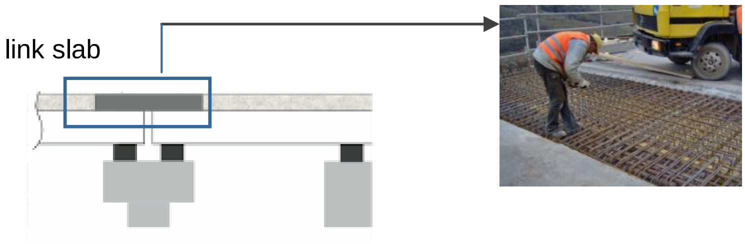

Figure 8: New bridge deck link slab as replacement of joints (scheme and photo)

Fig. 9 shows the concreting works on site.

Figure 9 : Surface Finish of high ductility concrete for bridge deck link slab.

5.3 Main Properties of the Ductile Concrete

The fiber reinforced concrete is characterized by an extremely low elasticity modulus but, at the same time, by rather high strength due to the addition of polymeric fibres with a very high elasticity modulus. The material is able to absorb the stresses of the structure, preventing the formation of localized macro cracks and generating very small and well distributed micro cracks, which have no influence on the slabs' durability.

The used fibres (12 kg per cubic metre, length 20 mm, diameter 0,3 mm) have a very high Young's modulus and a tensile strength close to 2000 MPa, comparable to that of steel.

Although the w/c ratio is very low, the concrete can be poured during a period of two hours. Once hardened, the mechanical properties evolve rapidly. The flexural tensile strength at 7 days reaches 12MPa. The hardened material has an elasticity modulus below 25 GPa, a fracture energy of about 50 times greater than common concretes, and a final hygral shrinkage less than 0,05%.

The following list summarizes the main properties of the concrete used for the link slabs:

- rheology: rheoplastic
- workability: over 3.5 h
- loadable after 10 h
- Young's Modulus: < 25 GPa
- compressive strength: 60 MPa
- fracture energy: 12'500 N/m
- density: < 2180 g/l
- pull out: 25% higher than standard concrete
- hygral shrinkage < 0.5‰
- durability: high (w/c-ratio < 0.33)

Fig. 12-15 show the evolution of several mechanical properties of the high ductility concrete used for the bridge deck link slabs at Brenner highway.

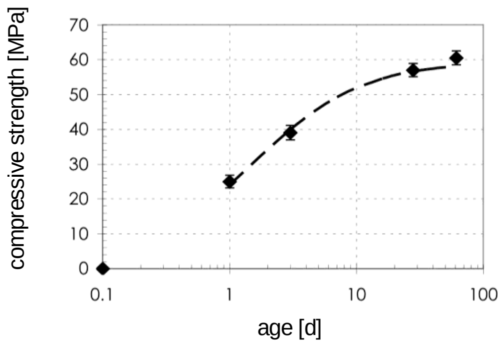

Figure 10 : evolution of the compressive strength

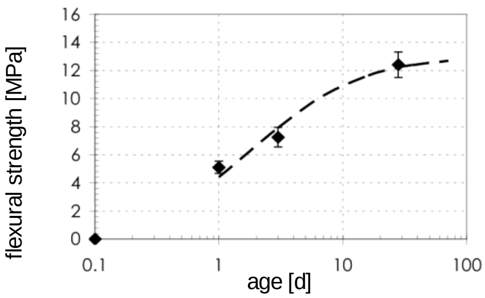

Figure 11 : evolution of the flexural strength

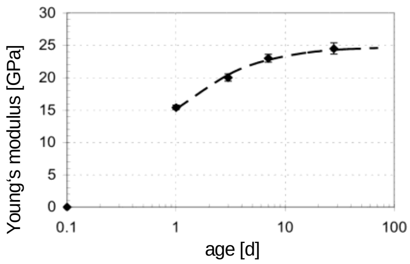

Figure 12: evolution of the Young's Modulus

CONCLUSIONS

During the last years several new high performance fiber reinforced cement based materials have been developed thanks to new materials and new design methods. These materials will provide the possibility for engineers and architects to design and build economic, durable and technically matured structures and buildings. In order to provide maximum benefits from the above mentioned developments the construction materials industry has already begun to investigate and to produce these new generations of materials. Pilot projects have been started last year.

The repair of numerous deck links on a highway bridge in northern Italy using ductile concrete has been succesfully realized. Ductile cement based materials could be produced and successfully cast on site. Other site applications are scheduled this year.

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