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Monitoring of Load Bearing Structures with Optical Fiber Sensors

Surveillance des constructions à l'aide de capteurs à fibres optiques

Bauwerksüberwachung mit Lichtwellenleitersensoren

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SUMMARY

Optical fibers, known as signal transmitters in the field of communications, are also used as sensors for the monitoring of structural elements. Optical fiber strain sensors, which are embedded directly in the concrete, provide at any time information, e. g. on nascent cracks in the monitored structural element and any change in these. Optical fiber sensors integrated into prestressing tendons made of composite fiber materials provide information on the functionality of these prestressing tendons.

RÉSUMÉ

Les capteurs à fibres optiques, connus comme signal transporteur en technique de communication, sont aussi utilisés comme détecteurs pour la surveillance des structures porteuses. Des détecteurs d'allongement à fibre optique sont directement incorporés au béton de l'ouvrage, indiquant en permanence l'état de fissuration et son évolution dans le temps. Les capteurs à fibres optiques, intégrés aux unités de précontrainte de matériaux composites, contrôlent le bon fonctionnement du système de précontrainte.

ZUSAMMENFASSUNG

Lichtwellenleiter, aus der Nachrichtentechnik als Signalübermittler bekannt, werden auch als Sensoren für die Überwachung von Bauteilen verwendet. Lichtwellenleiterdehnungssensoren, die direkt in den Beton eingebettet werden, geben zu jeder Zeit z. B. Auskunft über entstehende Risse im überwachten Bauteil und deren Veränderung. In Spannglieder aus Faserverbundwerkstoffen integrierte Lichtwellenleitersensoren geben Auskunft über die Funktionsfähigkeit dieser Spannglieder.

1. THE OPTICAL FIBER STRAIN SENSOR

In the field of communications the optical fiber is primarily and principally a signal transmitter. A prerequisite for its great significance is the excellent light transmitting capacity achieved. The attenuation of light undesired in the field of communications, dependent upon the mechanical load on the optical fiber, is utilized as a sensor effect for the monitoring of structures. In contrast to the field of communications, efforts in the development of the optical fiber sensor are directed towards obtaining as large a measuring signal as possible as a consequence of mechanical changes in the optical fiber.

Gradient fiber with a refraction coefficient diminishing away from the radius of the core, is employed as a rule for such sensor applications. The inner core is enclosed by external sheathing upon which the reflexion of light takes places. However, it is also capable of transmitting light with a lower refraction coefficient. If a ray of light is transmitted by an optical fibre, leakages occur in the range of micro-deflexions. The light leakage incurred is reported by a measuring technique as a change in attenuation in dB (decibels).

By fitting the optical fiber with a thin spiral wire (fig.1) the finding is put to use that micro-deflexions are also able to be generated as a consequence of radial pressure. Upwards of a certain length laid, the spiral wire, when pulled longitudinally, presses radially upon the optical fiber and creates micro-deflexions on it, which then cause corresponding changes in attenuation and turn the optical fiber into an optical fiber strain sensor.

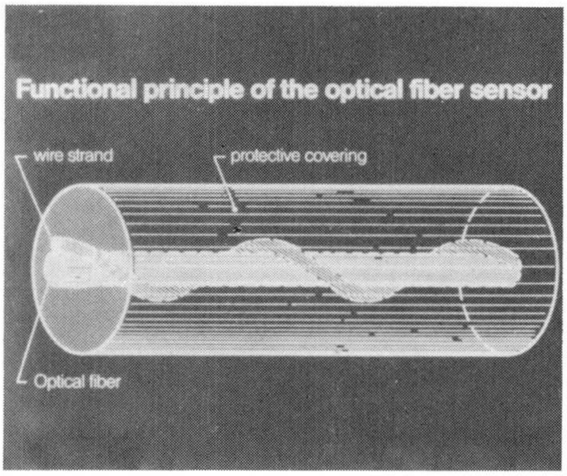

Fig. 1: Functional principle of the optical fiber sensor

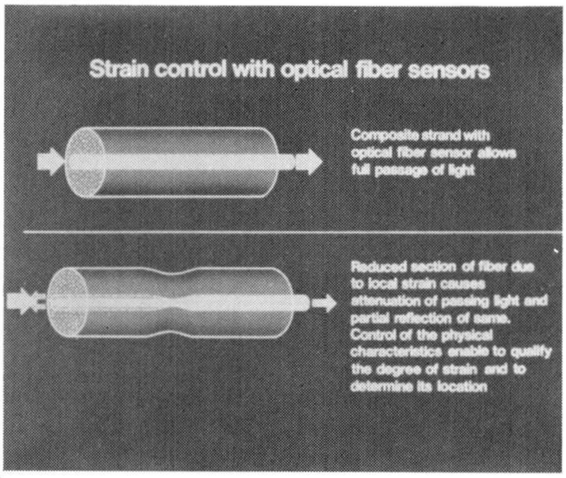

Fig. 2: Measurement principle of the optical fiber sensor

The optical fiber strain sensor displays changes in attunuation as a function of the strain producted. Since loads on concrete structures do not occur evenly, but can take place due to localized inconstancies, e.g. due to cracks, in addition to the integral attenuation measuring process, the localized fault ought also to be identifiable. For this purpose the attenuation signal which occurs more strongly at the fault's location is recordable using the backscatter measuring technique well-known in communication engineering (fig.2). The type of fault and over the localized change in strain are detectable by superimposing the attenuation curves of sensor when subjected to a load or no load.

2. MODEL EXPERIMENTS FOR THE TESTING OF OPTICAL FIBER SENSORS

Nowadays two measuring principles are available for integral monitoring, depending on whether both ends or just one end of the sensor are accessible (fig.3 and 4). The optical reference fiber serves to compensate the temperature and to correct any changes in transmitter power or in receptor sensitivity.

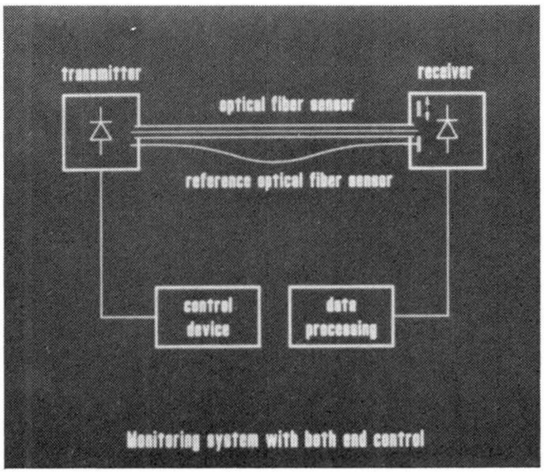

Fig. 3: Monitoring system with both end control

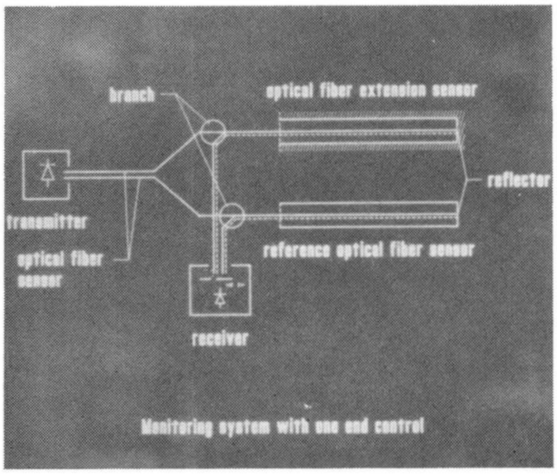

Fig. 4: Monitoring system with one end control

There are two fundamentally different possible applications in the monitoring of structures using optical fiber sensors. Firstly, the monitoring of concrete structures, e.g. during the formation of cracks and during their continued development, and secondly, the monitoring of prestressing tendons made of composite fiber materials. In the case of crack monitoring in concrete structures where these are new structures, sensors specially designed for this application are placed directly in the concrete in those positions in the structure known from static principles to be subject to a heavy load, in order to obtain evidence of any requisite repair measures at a very early stage, and hence, by this means to reduce this work considerably. In the case of existing structures, particularly in the case of structures which are already damaged, these optical fiber sensors are retro-applied to the structural elements to be monitored, in order to continue observation of the cracks which have been incurred by them, or in order to monitor repair measures which have already been performed with respect to the loadbearing capability of the structural element. In the case of composite fiber prestressing tendons, optical fiber sensors are integrated directly into the composite fiber bar, in order to indicate its undamaged condition.

In order to record evidence that these optical fiber sensors comply with the requirements made of them, initially, extensive experiments were performed in the laboratory, with the object of determining the fundamental suitability. The next stage was experiments with small prestressed beams at the University of Gent, with a span of 2,0 mtrs and an overall height of 60 cm (fig.5). In these experiments (prestressing with and without bond) all sensor applications developed to date were checked in the prestressing tendon, inside the concrete and with retro-attachment. The final field suitability test was an experiment with a 20 mtr long prestressed beam (overall height 1 mtr),

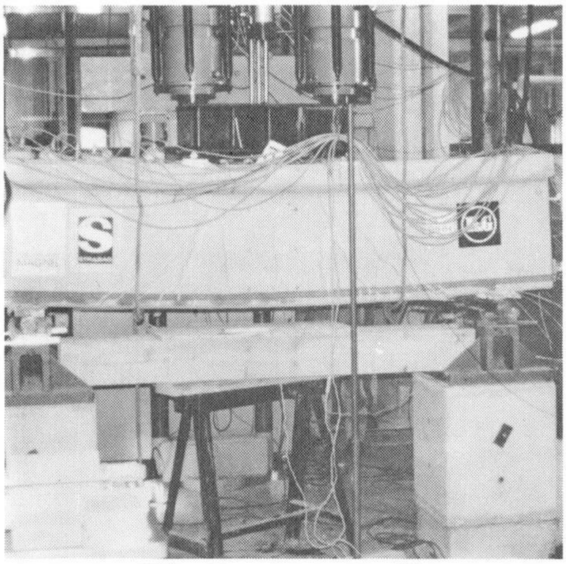

Fig. 5: 2 m-beam

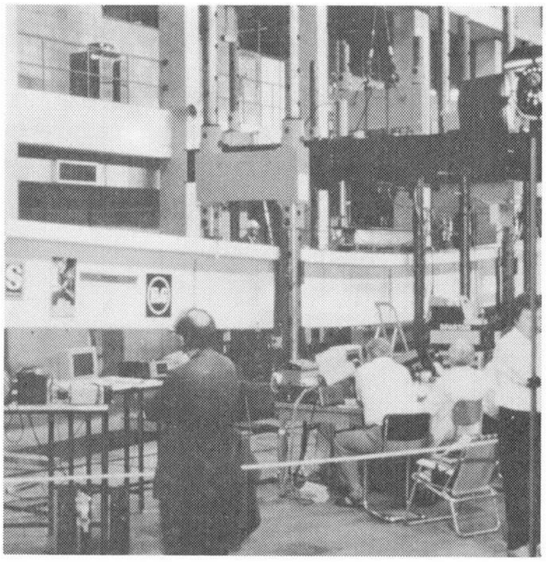

Fig. 6: 20 m-beam

likewise at the University of Gent (fig.6). In this case the suitability of these sensors for the tasks set and the selected application techniques was able to be proven impressively. With the aid of optical fiber both the transition from non-crack to cracked state and the exceeding of the steel reinforcement's yield limit were able to be determined (fig.7). These changes were equally detectable by means of optical fiber sensors in the prestressing tendon up to the failure of the beam (fig.8).

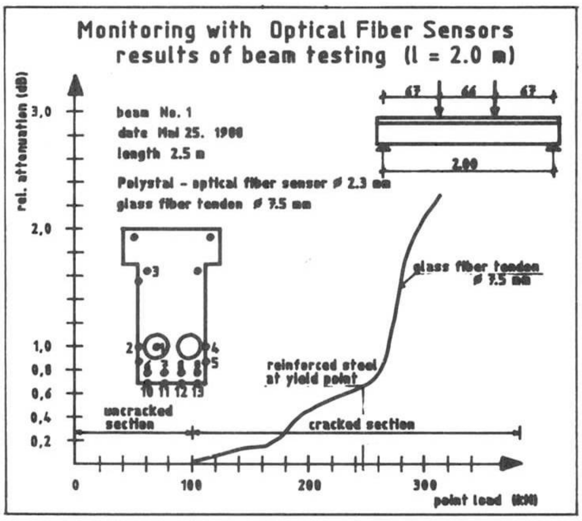

Fig. 7: Results of beam testing with optical fiber sensor in the tendon

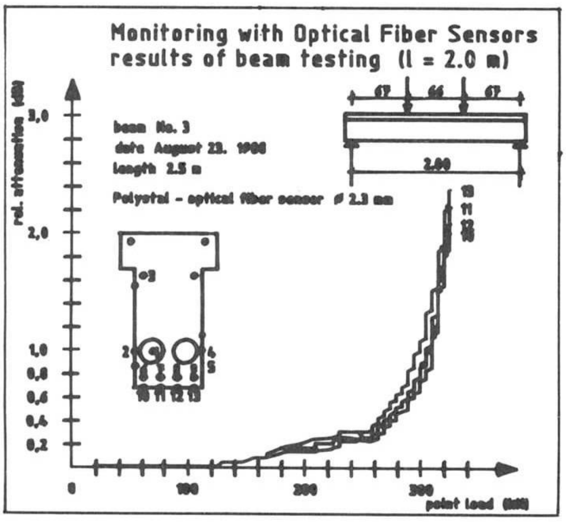

Fig. 8: Result of beam testing with optical fiber sensor in the concrete

3. THE APPLICATION

On the Ulenbergstrasse Bridge [4], the first bridge worldwide for extremely heavy road traffic loads (bridge classification 60/30) to be completed with glass fiber prestressing tendons) besides the direct embedding of optical fiber sensors in the concrete, several prestressing tendons were also equipped with optical fiber sensors. The measurements which have been carried out to date for almost 3 years now, show no change whatsoever in the structure of the bridge (fig.9).

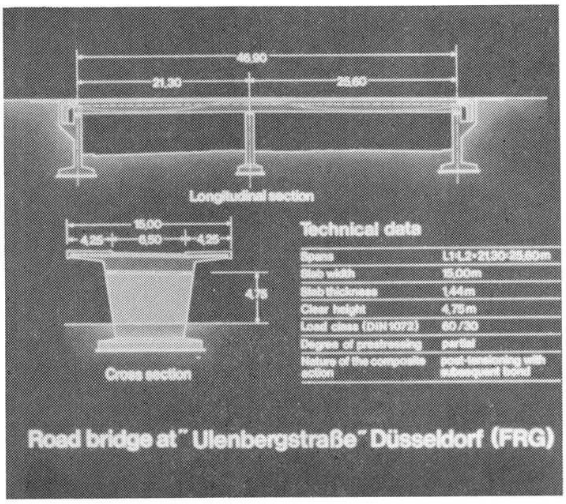

Fig. 9: Technical data
Bridge Ulenbergstrasse

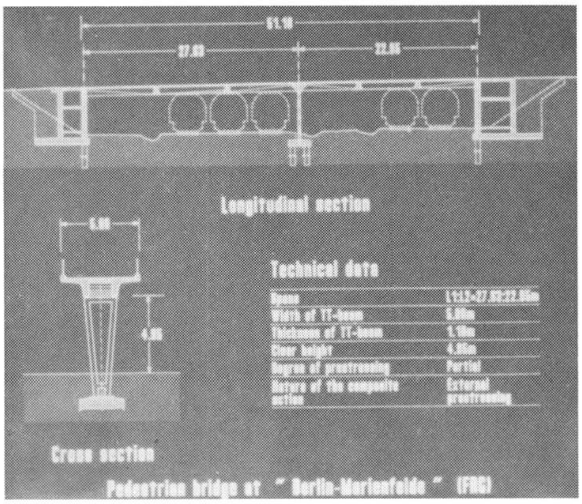

Fig. 10: Technical data
Bridge Marienfelde

The design of the Berlin-Marienfelde pedestrian bridge (fig.10), a two span slab/beam bridge, is an example of the first fully monitored bridge structure. The prestressing of this bridge, designed as external prestressing withon bond, is generated by seven 19-bar composite fiber glass prestressing tendons. In addition to all those prestressing tendons in which sensors are integrated, a whole series of optical fiber sensors have been embedded directly inside the concrete or have been retro-applied. During a trial loading carried out in November using 250 concrete slabs (weight per slab 1 to.) this trial loading was able to be monitored with the aid of sensors. By using particulary highly sensitive sensors, evidence was even able to be recorded on the dynamic behaviour of this bridge.

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