Summary of Final Report, BC-796
April 2002

DEVELOPING GEOTECHNICAL APPLICATIONS FOR THE FIBER OPTIC PORE WATER PRESSURE SENSOR PHASE I

PROBLEM STATEMENT

One of the considerations that bridge design engineers must factor into the bridge design process is the amount of pressure that will be exerted against the supporting piles. Pressure will come from a variety of sources, including the loads applied by the weight of vehicles driving upon the bridge, and the pressures applied by wind, wave, and soil. Consequently, engineers estimate the total stress, or effective stress, that will be applied to the piles, which, in turn, determines the depth to which the piles will be driven. Among the stressors is a temporary phenomenon known as pore water pressure. Pore water pressure occurs after the pile has been driven into the soil below the water table: the water cannot easily or quickly escape from the soil displaced by the driving process. The consequence is that the escaping water temporarily increases the stress. Because pore water pressure is factored into the effective stress, piles may be driven further than necessary or, worse, spliced and driven further than designed (resulting from on-site stress measurements). By calculating the pore water pressure, engineers can more accurately determine the effective stress. The challenge is finding an effective means for measuring pore water pressure.

Fiber optic pore pressure sensors may prove to be more accurate than the piezometers and more durable and economical than the pore pressure transducers currently used for field monitoring. In addition, they could be used in the laboratory to replace existing pore pressure transducers. These fiber optic sensors would be immune to electromagnetic interference and corrosion.

The fiber optic pore pressure sensor was developed using a concept known as the fiber optic microbend theory. Although there are many types of fiber optic sensors used for measuring pressures or strains, the most economical ones are those based upon the microbend principals. If properly designed, these sensors can be constructed with relatively inexpensive components. The light source, for example can often be a light emitting diode (LED), while the fiber needs little or no preparation before placement in the sensing region.

OBJECTIVES

The objective of this research was to develop geotechnical applications, including the ability to measure either pore pressures or total stresses, for fiber optic sensors.

FINDINGS

A 12-month study was completed that enabled the fabrication and laboratory testing of prototype fiberoptic pore pressure sensors. Forty circular sensors were fabricated. Various combinations of materials were used, and eight types of sensors were developed. Size, stiffness, and internal materials were varied to produce the types shown in ***Table 1***.

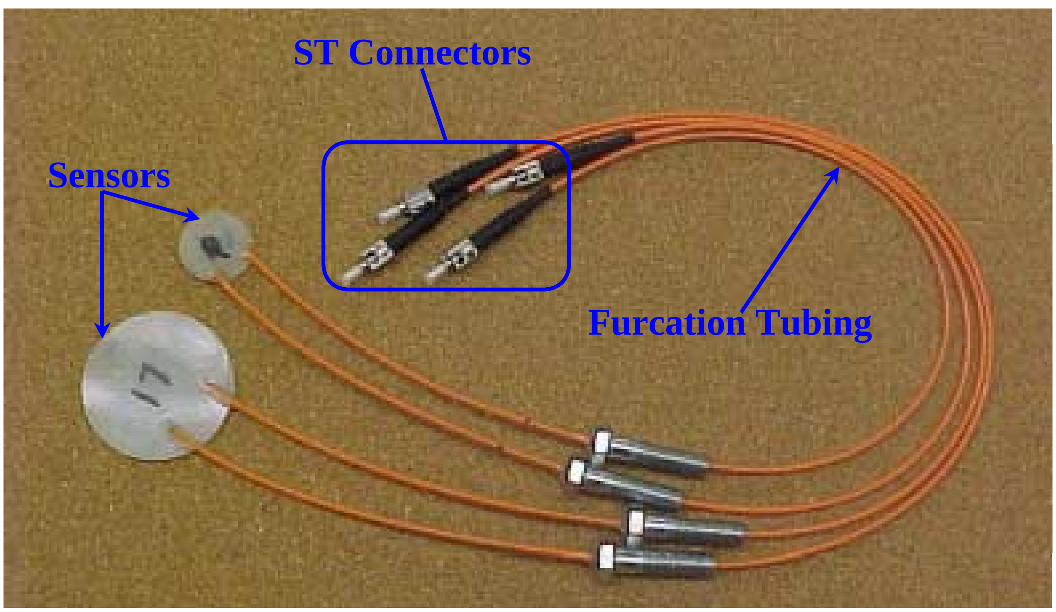
<u>Table 1</u> Sensor Testing Variable Combinations

G-10 Diameter (inches)	G-10 Thickness (mils)	Mesh	No. of Microbenders	Average Thickness (inches)
2.25	20	Polypropylene	24	0.073
2.25	10	Polypropylene	24	0.052
2.25	20	FluortexETFE	24	0.064
2.25	10	FluortexETFE	24	0.043
1.25	20	Polypropylene	11	0.073
1.25	10	Polypropylene	11	0.052
1.25	20	FluortexETFE	11	0.064
1.25	10	FluortexETFE	11	0.041

Two mesh types with approximately 20 openings per inch were used. The stiffness of the meshes used varied by a factor of 2 with the polypropylene being the stiffer material. Sensors were constructed in 1.25 and 2.25 inch diameters using 10 mil and 20 mil G-10 fiberglass protective outer plates. During compression, light intensities decreased and were measured using opto-electronic equipment with photodiodes that convert light intensity to voltage.

A basic sensor consisted of two circular plates, with microbending mesh and optical fiber sandwiched between them. The optical fiber lead ends were fitted with ST type connectors for protection and to allow light to pass from a light source. ***Figure 1*** shows typical 1.25 and 2.25 inch diameter sensors.

<u>Figure 1</u> Photograph of 1.25 and 2.25 inch diameter sensors.



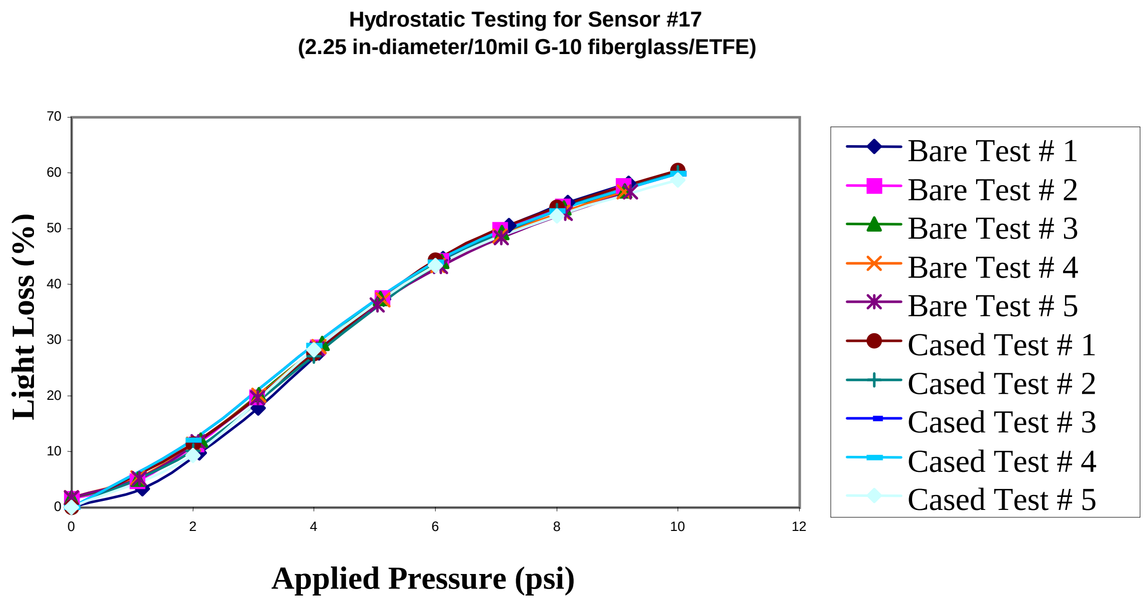
Upon completing the sensor characterization, researchers developed a testing program to determine how the microbend sensors would perform if they were used as pore pressure sensors. Sensors were tested after they were encased in a porous shell using pneumatic pressures to simulate the pore water pressures. ***Figure 2*** shows data from Sensor 17 (with ETFE mesh). The results, when the sensors were subjected to hydrostatic pressure up to 35 psi, showed no variation between bare and encased sensors, which indicates that the sensor can be used to measure pore water pressures up to this value.

Table 2 Summary of Regression Analysis for Hydrostatic Testing of Sensors

Sensor No.	Diameter (inches)	Cover Plate (mils)	Mesh Type	Coefficient of Determinination R^2 1st Deg	2nd Deg	3rd Deg	4th Deg	5th Deg	6th Deg
1	2.25	20	PP	0.87	0.97	0.97	0.98	0.99	0.99
2	2.25	20	PP	0.75	0.92	0.96	0.97	0.97	0.97
7	2.25	10	PP	0.98	0.98	0.98	0.98	0.99	0.99
8	2.25	10	PP	0.92	0.94	0.99	1.00	1.00	1.00
12	2.25	20	ETFE	0.96	1.00	1.00	1.00	1.00	1.00
13	2.25	20	ETFE	0.97	0.97	0.99	0.99	0.99	0.99
17	2.25	10	ETFE	0.98	0.99	1.00	1.00	1.00	1.00
18	2.25	10	ETFE	0.99	0.99	1.00	1.00	1.00	1.00
21	1.25	20	PP	0.96	0.99	0.99	0.99	0.99	0.99
23	1.25	20	PP	0.92	0.98	0.99	0.99	0.99	0.99
26	1.25	10	PP	0.96	0.98	0.98	0.99	0.99	0.99
27	1.25	10	PP	0.99	0.99	1.00	1.00	1.00	1.00
33	1.25	20	ETFE	0.99	0.99	0.99	1.00	1.00	1.00
34	1.25	20	ETFE	0.98	0.99	0.99	1.00	1.00	1.00
36	1.25	10	ETFE	0.98	0.98	0.99	0.99	0.99	0.99
37	1.25	10	ETFE	0.98	0.98	1.00	1.00	1.00	1.00

Average PP	0.92	0.97	0.98	0.99	0.99	0.99
Average ETFE	0.98	0.99	1.00	1.00	1.00	1.00
Percent Differen	94%	98%	99%	99%	99%	99%

Figure 2 Typical data from bare and encased sensor showing application for pore water pressure testing



CONCLUSIONS

Researchers built and evaluated four variations of circular fiber optic microbend sensors for use in geotechnical engineering. The sensors demonstrated working ranges up to 70 psi (490 kPa). They were calibrated using both axial compression and pneumatic pressurization.

The testing program showed that pneumatic or hydrostatic testing yielded the best calibration curves. The data obtained showed that poorly constructed sensors can be identified. If hydrostatic testing is not available, axial compression with rubber pads on each side of the sensor can yield acceptable calibration curves, but poorly constructed sensors then may be difficult to identify.

The calibration curves were nonlinear with percent light loss on the y-axis and pressure on the x-axis. The curves have a hyperbolic shape; therefore, linear calibration curves can only be used to predict light losses to 40%. Subsequently, researchers developed a data analysis procedure that indicated that third order polynomials yielded promising calibration curves with regression coefficients nearing unity.

Of the four construction variables evaluated during the testing, mesh stiffness caused the most variation in sensor response. Sensors constructed with the softer ETFE mesh yielded more consistent calibration curves than those constructed from polypropylene. The smaller sensors had a better working range than the larger sensors when evaluating the results at 40% light loss. This range was nearly double that of the larger sensors. The thickness of the sensor cover plates indicated that the 10 mil G-10 fiberglass produced more variability than the 20-mil thickness.

BENEFITS

This project developed and tested under laboratory conditions a fiber optic sensor capable of measuring both pore pressures and total stresses. The sensor's cost and its immunity to corrosion and to electromagnetic and vibrational interference make it a highly attractive alternative to currently available methods. The fiber optic pore water pressure sensor developed in this study needs to be field tested. If successful, the benefits will include potentially significant time and cost savings. With pore water pressure data, bridge designers can more accurately determine the effective stress—that is, reduce it according to the amount of temporary stress resulting from pore pressure. The result would be to reduce overdesign and to eliminate the associated time and material costs.

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