INSTRUCTION MANUAL

HIGH STRENGTH VIBRATING WIRE INSTRUMENTED REBAR

Model IRHP & IRCL

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1 PRODUCT

1.1 INTRODUCTION

Grouted rebars and embedment reinforcing rebars have been used worldwide for the past fifty years both in mining and civil engineering. The High Strength Vibrating Wire Instrumented Rebar, model **IRHP**, has been especially developed for the remote monitoring of punctual load, and strain measurement into a rebar reinforcement system. The Instrumented Rebar worked exactly as a standard rebar and provides a high strength support in a structure in addition to its monitoring capability.

Its extremely rugged design and its high sensitivity make it a very reliable instrument to be embedded directly in concrete for use in a wide range of applications in rock bolting and reinforcement:

- tunnel lining
- foundations
- precast piles
- slurry wall
- caissons
- bridge abutments
- mining roof and wall stability
- structural behaviour

If the Instrumented Rebars are commonly used to secure structures, they can be used also as a warning device for the workers of the impending structure overloading. The monitoring of rebars is an important source of information on the structural behaviour and gives a significant economic advantage in reducing the amount of unnecessary bolting. Slope failure, strata dislocation and collapse of openings are some of the common hazards in strip mining, quarries and numerous civil construction projects, including road building, tunnelling and other excavations. Extensive tie-back wall bolting to stabilize the strata is a common practice in these operations. As rock mass reinforcement device, it can be used as a passive rebar or a pre-stress rebar. Once grouted or embedded in concrete, the full load will be applied along the ribbed surface of the rebar.

Various units in sizes and lengths are available to meet reinforcement requirements, from 13 to 51 mm (1/2 to 2 in) nominal rebar diameters depending of the application.

Small diameter such as 13 or 19 mm (1/2 or 3/4 in) nominal diameter rebars (model **IRCL**) are commonly used as “sister bars” which are attached along side existing rebars but not really to the structure itself. Larger models are generally bolted or welded into the rebar system.

Instrumented Rebar can be used also in boreholes to monitor the rock mass behaviour.

The Instrumented Rebar comes as is with an electrical cable. Different accessories and options are available also.

Usual sizes of Instrumented Rebars are 29 and 32 mm (1-1/8 and 1-1/4 in) nominal diameter rebars, and come generally in one meter lengths.

The sensing element is a miniature vibrating wire strain gage transducer model **SM-2**. The sensing element is clamped in a hole drilled along the central axis of the rebar by two setscrews. For small sizes of rebar such as 13 or 19 mm (1/2 or 3/4 in), the strain gage is fixed alongside the rebar and covered with a protection housing. Vibrating wire strain gages are well known for their ruggedness and long-term stability even in harsh environments. As the signal output is a frequency rather than a current or a voltage, there is no effect on the readings due to the contact resistance or the length of cable.

The Instrumented Rebar can be read with the standard MB-6TL Readout or MB-3TL or monitored remotely and automatically from a Data Acquisition System such as the SENS-LOG data logger.

Figures 1, 2 and 3 give different examples where the Instrumented Rebar is commonly used.

1.2 DESCRIPTION

Basically, the IRHP and the IRCL consist of three parts: the ribbed surface rebar, the strain gage and the cable. Different configurations exist depending of the model, with different accessories and options. Most of the rebars will reach their mechanical yield before reaching the sensor limit values.

The sister bar, model IRCL, is designed to be wire tied in parallel with the existing rebar. Also the small diameter (i.e. ½ in.) of the bar minimizes its affection of the sectional modulus of the concrete. As the sister bar is attached alongside existing rebar of all sizes with wire, we consider that the strains measured by the sister bar are the same as the existing rebar under study.

The vibrating wire transducer is plucked by a coil/magnet assembly. A frequency pulse is generated in the coil/magnet assembly causing the wire to vibrate at its natural resonant frequency. For applications using a portable readout the resultant resonant vibration is then sensed by the coil/magnet assembly when the readout is in its listening mode, and the signal is displayed on the readout as a digital output which is directly proportional to the tension in the rebar. With the SENS-LOG Data Acquisition System, the data memorized can be reduced directly in loading level in the bolt in units selected by the user.

For the specific application where a Single Point Instrumented Rebar System is grouted in a borehole, an optional hand-held probe with a mating contact can be used to temporarily connect the readout to the rebar head mounted with a recessed contact plug.

The construction of the gage does not appreciably change the appearance of the rebar. The IRHP model is installed and operated in the same manner as existing rebars and requires no special handling. It is rugged and robust, and is manufactured as an instrument ready to be installed. However, model IRCL requires some care since the coil/magnet assembly is slightly protruding the rebar and may be damaged. For both models, the weakest part is the cable, therefore care is recommended during handling.

An optional spherical bearing plate is offered (See Figure 2) in order to avoid bending moments of the rebar, due in particular to non-parallel strata face and rebar head.

1.3 CONNECTION

In most of applications, the electrical cable is potted directly in the Instrumented Rebar, making it totally sealed and waterproof. Depending of the model chosen and the application requirements, the cable is potted in the middle of the rebar or at one end.

In the specific case a Single Point Instrumented Rebar grouted in a borehole, the use of the optional hand-held probe may provide a convenient carry-on device by means of which electrical contact to the strain gage at the rebar head can be readily established. The taking of a reading is done automatically on the MB-6T Readout when the probe tip is pushed against the rebar contact plug recessed in its head. The center flat point on the rebar head and the probe spring tip provide contact points of one polarity. The stainless steel probe tubing and the rebar head external ring provide the other polarity contact points. A coiled cord with a connector for vibrating wire readout unit is attached to the probe handle. All contact points on the Instrumented Rebar and on the probe are made of non corrosive material (stainless steel).

An optional waterproof connector with a protection cap is available also for the Single Point Borehole Instrumented Rebar.

2 INSTALLATION PROCEDURE

2.1 PRE-INSTALLATION ACCEPTANCE READING

Readings of all gages should be taken as the instrumented rebars are received to ensure they have not been damaged during shipment or handling on site.

Take the readings in LINEAR units without any load. Then compare them with the factory readings shown on the calibration sheet. The differences should not exceed 50 LINEAR units.

For details about how to take readings or how to convert frequency into LINEAR units, please refer to next chapter (Reading procedure).

2.2 INITIAL READING

When the instrumented rebar is installed, take an initial reading in LINEAR units. If the sensor is provided with a thermistor, record temperature reading to be able to apply correction later.

Unless specified otherwise, all Instrumented rebars are delivered with the strain gage preset at the factory to the middle range of compression and tension.

2.3 INSTALLATION PROCEDURES

2.3.1 BOREHOLE INSTALLATION

The Instrumented Rebar can be installed as per a standard rebar in a borehole:

<u>as an active reinforcement rebar:</u>

- using an optional expansion shell anchor in order to preload the rebar prior to the grouting operation. This procedure gives rapid support action after installation, to be increased by friction load along the ribbed surface after curing time.
- cementing the bottom end of the rebar with resin or cement, wait for the curing time, until it is dry and has full strength, then preload the rebar prior to the final grouting operation. Curing time for resin is very fast. Curing time for cement grout requires several days before the rebar can take its maximum load.

as a passive reinforcement rebar:

- grouting the rebar into the borehole, the load being applied slowly in time with the rock mass convergence. This passive procedure cannot be used if a rapid support action is required immediately after installation of if important convergence is expected during the curing period. Curing time for resin can be very fast. Curing for cement grout requires several days before the rebar can take load.

A post-tensioning of the Instrumented Rebar can be applied later on after curing period.

The Instrumented Rebar can be installed as well as in a Single Point Rebar Configuration than in a Multipoint Rebar Configuration, using extension rebars with couplings if necessary.

Both left hand and right hand threads are available but left hand threads are mostly used.

2.3.2 EMBEDMENT IN CONCRETE MASS

The Instrumented Rebar can be bolted or welded directly on any reinforcement rebar system such as Pile Concrete, Pile Reinforcing cage or Concrete mass reinforcement structure. Generally, large sizes of Instrumented Rebars (over 19 mm (3/4 in) nominal diameter) contribute to structural reinforcement and refer to model IRHP.

A lot of care is required when the Instrumented Rebar must be welded to the reinforcement structure, in order to protect the cable and the strain gage against extreme heat.

Note: If sensor and cable are located in the middle of the rebar, weld only its extremities. When cable connection is located at rebar end, do not weld between middle section and connection end.

2.3.3 SISTER BAR INSTALLATION

The sister bar is usually installed along the rebar system using standard iron tie wire. Normally, tying at each end of the sister bar is acceptable, depending on the pouring procedure of the concrete. The electrical cable should also be tied along the rebar system but the wire should not be metallic in order not to damage the cable.

3 READING PROCEDURE

3.1 VIBRATING WIRE READOUT

Each Instrumented Rebar is tested before shipping, and a calibration sheet is supplied. Please refer to it.

Various models of readout can be used for reading the IRHP / IRCL. Please refer to the instruction manual of the type of readout you are using.

3.2 EQUATIONS

The relationship between applied load and the readout can be expressed by the equation:

$$\mathbf{P} = \mathbf{AL}^2 + \mathbf{BL} + \mathbf{C}$$

where: **P** = Applied load, in kN
L = Current Reding in Linear Units (LU)
A,B,C = Calibration factors (see calibration sheet)

Example:
The current reading is: **L** = 6618 LU

The calibration sheet gives: **A** = -2.0034E-06 kN/LU^2

B = 6.4444E-02 kN/LU

C = -2.9893E+02 kN

The calculated applied load is then: **P** = -2.0034E-06 (6618)^2 + 6.4444E-02 (6618) - 2.9893E+02 = 30.82 kN

Note that decreasing readings in LINEAR units indicate increasing load.

If the frequency is measured, convert it into LINEAR units using the following equation:

$$L = K\frac{F^2}{1000}$$

where L = reading in LINEAR units
K = gage constant for IRHP/IRCL rebars = 1.0
F = frequency in Hz

Example:
With F = 2 621 Hz,

We get: $L = 1.0 \times \frac{2621^2}{1000} =$ 6869.6 LU

3.3 TEMPERATURE EFFECT

The Instrumented Rebar sensor, model SM-2, behaves mechanically approximately as the rebar itself:

- under load because it simply follows the mechanical expansion or contraction imposed to the rebar,
- under temperature, because it has the same thermal expansion coefficient, which is 11.5 μstrains / °C, for steel material.

The interpretation of the readings may be a relatively complex issue and is beyond the scope of this manual, but it is imperative that the user has some idea of the pitfalls of trying to interpret structural stresses. Strains being measured to determine stresses should be measured so as to enable the strains due to stresses to be separated from those due to other causes. These other causes are temperature variations, humidity, moisture, strains induced from the setting of the concrete itself, etc.

The influence of most of these factors is not fully understood, especially in a hyperstatic structural system like a reinforcement rebar system.

The linear expansion coefficient of steel for the vibrating wire sensor at 11.5 μstrains / °C is very close to the structural factor which may vary between 7 and 20 μstrains/°C. Therefore, correction for temperature effect is usually considered as negligible. However, in some applications, it may be important to know the real load applied to the structure.

4 TROUBLESHOOTING

Maintenance and troubleshooting of vibrating wire instruments are required. Periodically verify cable connections and terminals. The transducers are sealed and not user serviceable. Following are typical problems and suggested remedial actions.

UNSTABLE READING

- Connect the shield drain wire to the readout unit.
- Isolate the readout from the ground by placing it on a piece of wood or similar non-conductive material.
- Check for sources of nearby noise as motors, generators, antennas or electrical cables. Move the rebar cables if possible.
- The sensor may have been damaged by over-ranging or shock.

NO READING

- Check the coil resistance. Nominal coil resistance is 45Ω ± 10Ω for IHRP rebars and 90Ω ± 10Ω for IRCL rebars, plus cable resistance (22 gage copper: approximately 0.07Ω/m).
  - If the resistance is high or infinite, a cut cable must be suspected.
  - If the resistance is low or near zero, a short must be suspected.

- If resistances are within the nominal range and no reading is obtained, the transducer is suspect and the factory should be consulted.

- Check the readout with another rebar.
- The sensor may have been over-ranged or shocked.

THERMISTOR RESISTANCE IS TOO HIGH

- Likely, there is an open circuit. Check all connections, terminals and plugs. If a cut is located in the cable, it should be spliced. The vibrating wire output signal is a frequency rather than current, variations in cable resistance have little effect on gage readings and, therefore, splicing of cables has no effect either and in some cases, may be beneficial.

THERMISTOR RESISTANCE IS TOO LOW

- Likely, there is a short. Check all connections, terminals and plugs. If a short is located in the cable, splice the cable.

5 MISCELLANEOUS

5.1 ENVIRONMENTAL FACTORS

Since the purpose of instrumented rebar installation is to monitor site conditions, factors which may affect these conditions should always be observed and recorded. Seemingly minor effects may have a real influence on the behaviour of the structure being monitored and may give an early indication of potential problems. Some of these factors include, but are not limited to: blasting, rainfall, tidal levels, excavation and fill levels and sequences, traffic, temperature and barometric changes, changes in personnel, nearby construction activities, seasonal changes, etc.

5.2 CONVERSION FACTORS

	To Convert From	To	Multiply By
LENGTH	Microns Millimetres Meters	Inches Inches Feet	3.94E-05 0.0394 3.2808
AREA	Square millimetres Square meters	Square inches Square feet	0.0016 10.7643
VOLUME	Cubic centimetres Cubic meters Litres Litres	Cubic inches Cubic feet U.S. gallon Can–Br gallon	0.06101 35.3357 0.26420 0.21997
MASS	Kilograms Kilograms Kilograms	Pounds Short tons Long tons	2.20459 0.00110 0.00098

FORCE	Newtons Newtons Newtons	Pounds-force Kilograms-force Kips	0.22482 0.10197 0.00023
PRESSURE AND STRESS	Kilopascals Bars Inches head of water* Inches head of Hg Pascal Kilopascals Kilopascals Kilopascals	Psi Psi Psi Psi Newton / square meter Atmospheres Bars Meters head of water*	0.14503 14.4928 0.03606 0.49116 1 0.00987 0.01 0.10197
TEMPERATURE	Temp. in °F = (1.8 x Temp. in °C) + 32 Temp. in °C = (Temp. in °F – 32) / 1.8		

* at 4 °C E6TabConv-990505

Table 2: Conversion factors

5.3 SCHEMATICS

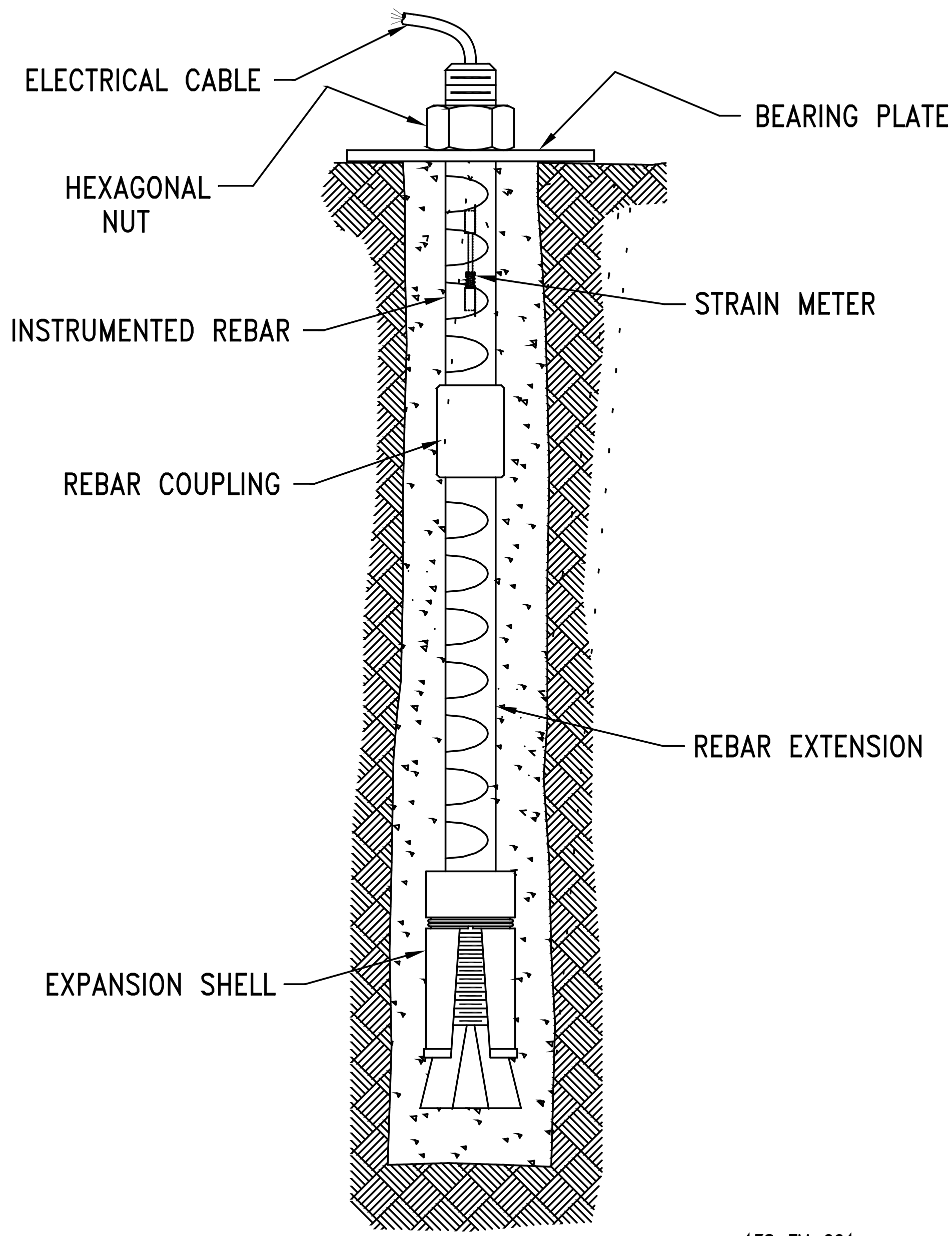

Figure 1: Single Point Instrumented Rebar
Typical Borehole installation

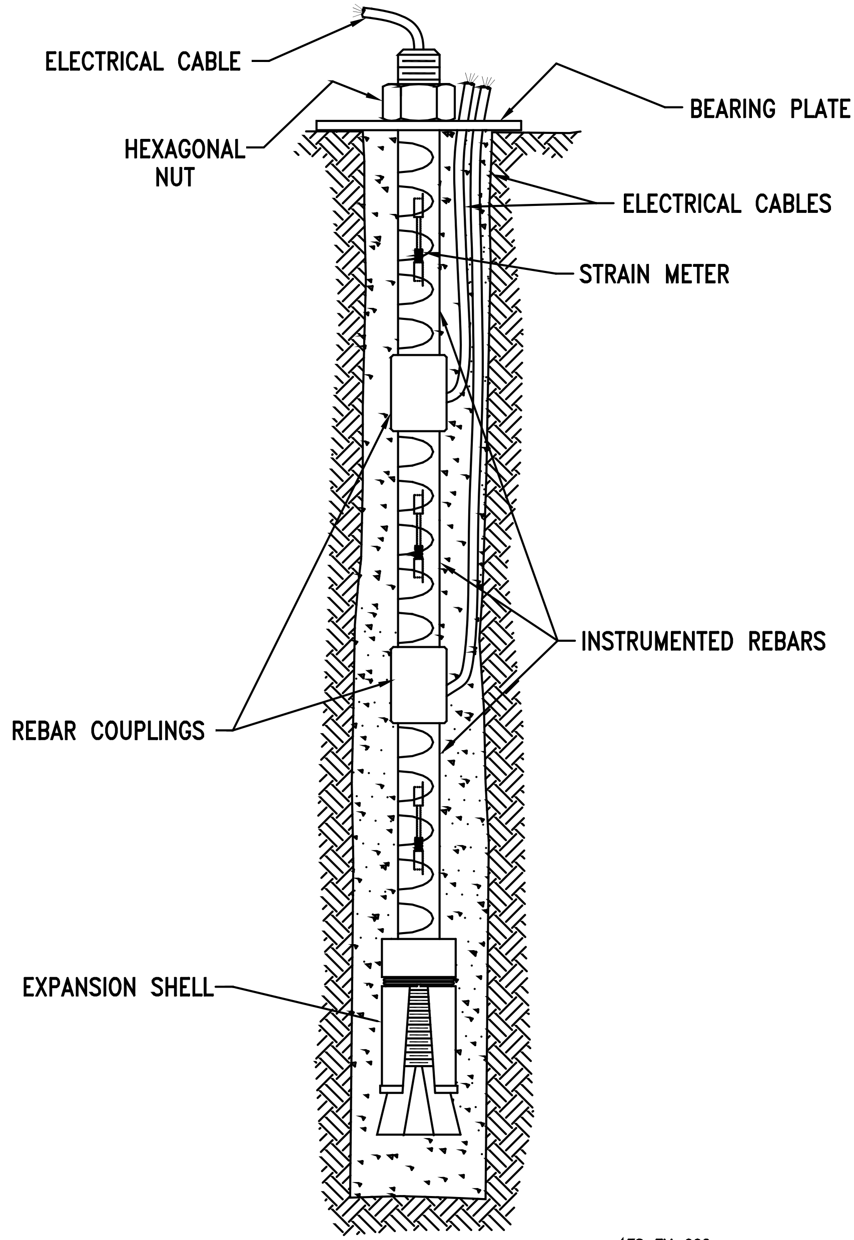

Figure 2: Multiple Instrumented Rebar System
Typical Borehole installation

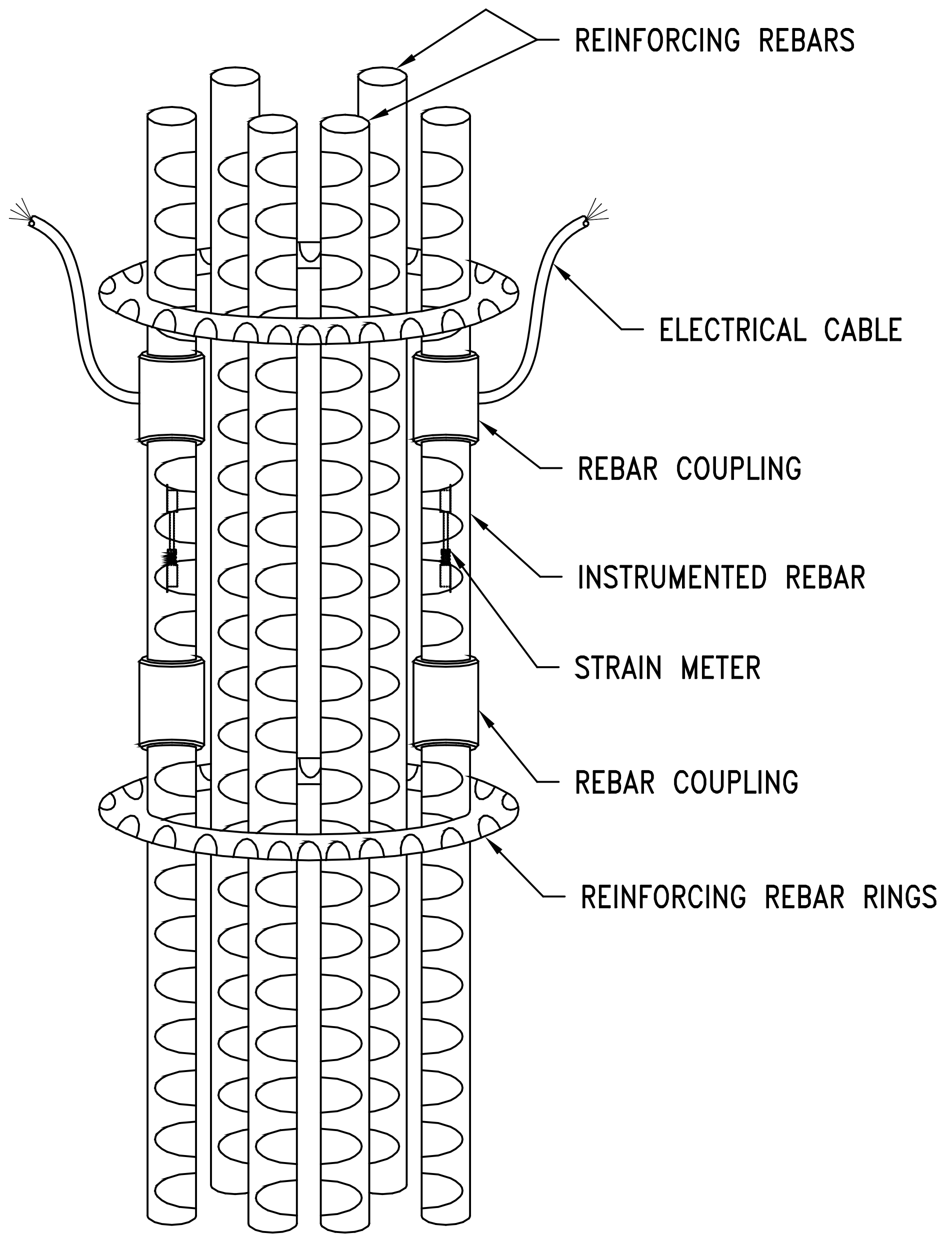

Figure 3: Instrumented Rebar System in concrete
Pile reinforcing gage