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USERS' MANUAL

VIBRATING WIRE LOAD CELL

MODEL ELC-32V

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1 INTRODUCTION

The Encardio-rite model ELC-32V vibrating wire load cell is precision engineered and specially designed for use in severe environments associated with civil engineering applications and construction activity. The advantage of vibrating wire load cell over a more conventional electrical strain gage or semiconductor type load cell lies mainly in the use of a frequency, rather than a voltage, as the output signal. Frequency may be transmitted over long cable lengths of up to 2 km without appreciable degradation caused by variation in cable resistance that may result from water penetration, temperature fluctuations, contact resistance or leakage to ground.

The load cell is often used in series with a hydraulic jack for applying load. Consequently, it verifies load as applied by the hydraulic jack.

Encardio-rite model ELC-32V load cell is made in two configurations:

A **Hollow with center hole** - primarily used to load test an end anchored rock bolt or tie back or for monitoring their long term performance. It is also used in monitoring temporary or permanent loads in pre-stressing or other cables.

B **Solid construction without center hole** – used for measurement of compressive load between structural members like struts, tunnel supports or at junction between a beam and top of a pile strut.

Collapse of roof or falling of side wall in underground cavities is a factor of prime importance to geologists, design engineers and construction companies. Slope failures and landslides have been recognized as one of the several forms of natural disaster and can happen anywhere in the world without any discrimination. Whether it is giving away of roof of a mine or buckling of side wall of an underground power house cavity or a land slide or a slope failure, the disaster may cause mammoth loss of life, property, wealth and time. A large number of methods are available for taking preventive and corrective action. One of the methods is anchoring.

Anchoring has emerged as a powerful preventive method. Use of pre-stressed grouted anchors provides an active support system in all the above cases. In any optimum, safe and economic use of anchoring, anchor spacing and anchor load have to be determined. This is done by use of center hole load cell and a suitable read out unit. At locations where several sensors are installed, a datalogger may be used for ease in analysis and for studying cumulative effects.

1.1 General Considerations

Major source of error in data obtained from these load cells is due to off-centre loading, end effects and uneven bearing plates and their warping. These effects can result in a cumulative error of as much as ± 20 %, unless special precautions are taken.

1.1.1 Off-centre loading

Most compressive load cells have a solid central raised button such that load is uniformly distributed. In these load cells, load may be greater on one side than the other. Effect of eccentric loading can be minimised by using spherical bearing washers or soft washers. This however is rarely done as it is cumbersome and expensive. Effect of eccentric loading can be reduced by gaging the load cell at several places along the periphery. In vibrating wire load cells, normally three strain gage elements are used at 120^{o} along the periphery. For larger center hole load cells six strain gage elements are recommended. However, this makes taking of readings and averaging them more cumbersome.

1.1.2 End effects

Large height to diameter ratio is required in a columnar load cell to have uniform distribution of stress in the gaged area. A load cell that has a height of more than four times the wall thickness of the loaded columnar section is generally regarded as good. However, to make it easier to use, normally the height is somewhat reduced.

1.1.3 Uneven bearing plates and their warping

An uneven bearing or load distribution plate can affect the accuracy of the reading. So can the bending or distortion of the plates. It is essential to have bearing/load distribution plates of the correct thickness and finish. In case of a center hole load cell, hole in plates should match that of load cell.

When a center hole load cell is used in conjunction with a hydraulic jack, warping of bearing plates is caused primarily by a size mismatch between the hydraulic jack and the load cell. In case the jack is larger than the load cell bearing plates, it tends to wrap around them causing the vertical column of the load cell to distort inwards causing the load cell to give a different reading from the actual. The vice versa is true in case the hydraulic jack is smaller than the load cell bearing plates.

The effect is reduced by using thicker bearing plates. Refer to § 2.1.2 for recommended bearing plate sizes. Bearing plates should be flat and smooth. It is always better to have them machined or ground.

1.2 Conventions used in this manual

WARNING! Warning messages calls attention to a procedure or practice, that if not properly followed could possibly cause personal injury.

CAUTION: Caution messages calls attention to a procedure or practice, that if not properly followed may result in loss of data or damage to equipment.

NOTE: Note contains important information and is set off from regular text to draw the users' attention.

This users' manual is intended to provide you with sufficient information for making optimum use of vibrating wire center hole load cells in your application. To make this manual more useful we invite your valuable comments and suggestions regarding any additions or enhancements. We also request you to please let us know of any errors that you may find while going through this manual.

1.3 Handling of load cell

Load cell should be handled very carefully during transportation and installation. It should never be dropped as impact generated will almost certainly result in a shift of zero reading.

CAUTION: The load cell should not be dropped under any circumstances because this may lead to its permanent damage.

1.4 How to use this manual

The manual is divided into a number of sections. Each section contains a specific type of information. The list given below tells you where to look for in this manual if you need some specific information.

For general description: See § 2.1 'General description'.

For understanding principle of vibrating wire center hole load cell: See § 2.2 'Operating principle'.

For test certificate: See § 3 'Sample test certificate'.

For installation of center hole and solid load cells: See § 4 'Installation procedure'.

For trouble shooting: See § 4.6 'Trouble shooting'.

For evaluating thermistor data: See § 5 'Thermistor - temperature resistance correlation'.

2 VIBRATING WIRE LOAD CELL

2.1 General description

Each load cell is provided with three vibrating wire strain gage elements on the periphery at 120° to each other. Load cells with six elements are available when specifically ordered. A thermistor is incorporated in each vibrating wire load cell for monitoring temperature.

2.1.1 Stainless steel element

The vibrating wire and coil magnet assembly are mounted on periphery of a stainless steel columnar element.

2.1.2 Bearing and load distribution plates

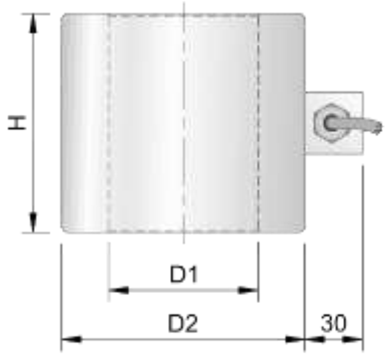


Figure 2.1

Vibrating wire load cells with a center hole are very susceptible to eccentric loading. The effect is reduced by providing bearing and load distribution plates of proper dimensions. The internal diameter of these plates is ALWAYS equal to the internal diameter of the load cell. The dimensions are as follows:

Capacity kN	D2 mm	D1 mm	H mm	Weight kg
250	58	27	75	1.5
500	88	52	85	3.0
1,000	127	78	115	7.5
1,500	160	102	120	12.0
2,000	190	127	130	16.5
2,000	210	152	130	17.5
3,500	275	202	140	31.0
1,000 – 3,500 kN capacity load cells are also available with no center hole and consequently reduced outside diameter				

Capacity	Bearing/load distribution plate			
kN	O.D. mm	I.D. mm	T mm	Wt. kg
250	60	27	23	0.5
500	95	52	30	1.2
1,000	130	78	35	2.5
1,500	165	102	42	4.5
2,000	195	127	48	6.7
2,000	215	152	48	7.0
3,500	280	202	60	14.3

2.1.3 Cable connection

Tri-polar plasma surge arrestors inside the transducer housing protects the vibrating wire pluck and read coils from electrical transients such as may be induced by direct or indirect lightning strikes.

Leads from the coil magnets of all gauges are terminated on a PCB inside the load cell housing. Six core/nine core 5 m cable is connected to PCB inside housing. The green and white leads of cable are used to connect the thermistor for measurement of temperature, black lead is common for one end of all coils and other lead colours are for other ends of coils of strain gauges.

2.2 Operating principle

The vibrating wire load cell basically consists of a hollow cylindrical columnar section on which are longitudinally mounted vibrating wire strain gages at equal angle to each other. Each strain gage consists of a magnetic, high tensile strength stretched wire, the ends of which are anchored to the columnar section that deflects in some proportion to the applied load. Any change in load, deflects the columnar section and this in turn affects the tension in the stretched wire. Thus, any change in the load, directly affects the tension in the wire.

The resonant frequency, with which the wire vibrates, induces an alternating current in the coil magnet. This is read by the read out unit.

In other words, any variation in the load on the load cell causes the columnar section to deflect. This changes the tension in the wires of the elements thus affecting the frequency of vibration. The load on each element is proportional to the square of the frequency and the read out unit is able to display this directly in engineering units. The sum of the load on the elements gives the average load on the center hole load cell.

2.3 Taking readings with the model EDI-54V vibrating wire indicator

The model EDI-54V vibrating wire indicator is a microprocessor-based read-out unit for use with Encardio-rite's range of vibrating wire sensors. It can display the measured frequency in terms of time period, frequency, frequency squared or the value of measured parameter directly in proper engineering units. It uses a smartphone with Android OS as readout having a large display with a capacitive touch screen which makes it easy to read the VW sensor.

The EDI-54V vibrating wire indicator can store calibration coefficients from 10,000 vibrating wire sensors so that the value of the measured parameter from these sensors can be shown directly in proper engineering units. Please note that the each vibrating wire load cell has 3-6 elements.

For transducers with built-in interchangeable thermistor, it can also display the temperature of the transducer directly in degree Centigrade.

The vibrating wire indicator has an internal non-volatile memory with sufficient capacity to store about 525,000 readings from any of the programmed sensors. Each reading is stamped with the date and time the measurement was taken.

Refer instruction manual WI-6002.112 of model EDI-54V for entering the transducer calibration coefficients. The gage factor of the model ELC-32V vibrating wire load cell is given in the individual test certificate provided with every supply of load cell. The gage factor and the factory zero reading (frequency) can directly be taken from the test certificate for setting up transducer coefficients in the read-out unit. The test certificate also gives the factory zero reading in frequency^2 for use with transducers provided with polynomial linearity correction.

An internal 6 V 4 Ah rechargeable sealed maintenance-free battery is used to provide power to the vibrating wire indicator. A battery charger is provided to charge the internal battery which operates from 90 V to 270 V AC 50 or 60 Hz V AC mains. A fully discharged battery takes around 6 hours to get fully charged. The indicator uses a smartphone as a readout that has its own internal sealed rechargeable Li-ion maintenance battery as a power source. A separate battery charger/adapter unit for the smartphone, operating from universal AC mains supply is supplied with each EDI-54V indicator unit.

3 SAMPLE TEST CERTIFICATE

Test Certificate

Customer			Date	
PO No.			Temp.	29°C
Instrument	VW Center hole Load Cell Model ELC-32V			
Serial No	0510192			
Capacity	500 kN			

Test Data:

Load Applied kN	Observed Values(digit)			Average (digit)	End point fit kN	Non-linearity (%fs)
	Element-1	Element-2	Element-3			
0	7088.9	7042.0	7692.0	7274.3	0.00	0.00
100	6787.8	6623.3	7469.9	6960.3	102.4	0.48
200	6482.1	6237.0	7247.3	6655.5	201.8	0.37
300	6167.0	5857.0	7010.0	6344.7	303.2	0.64
400	5866.9	5488.8	6782.2	6046.0	400.6	0.13
500	5559.8	5124.3	6540.0	5741.4	500.0	0.00

Maximum Non Linearity 0.64 % fs
Linear Gage Factor -3.262E-01 kN/digit (applicable for all the three elements)
Where 1 digit = frequency^2/1000

Wiring Configuration

Colour	Description
Black- Red	Element-1
Black- Brown	Element-2
Black- Blue	Element-3
Green- White	Thermistor

Cable Length: 5 m

Dimensional details:

	ID(mm)	OD(mm)	Height(mm)
Load Cell	27	58	75
Load distribution plate	27	60	23
Bearing plate	27	60	23

Checked by Tested by

Note: Format for six element load cell or with polynomial correction is different

4 INSTALLATION PROCEDURE

4.1 Preparation of three/six elements sensor before installation

The procedure described is for a three element load cell. For a six element load cell, please make the necessary modifications in the procedure.

4.1.1 Check working of sensor as follows:

- Coil resistance measured by a digital multimeter between red/black, brown/black, and blue/black leads, should lie between 130-170 Ohm. Determine resistance at room temperature from thermistor temperature resistance chart in § 5. This resistance should be equal to that between green and white leads. For example, in case room temperature is 25°C, this resistance would be 3,000 Ohm.
- The resistance between any lead and the protective armour should be > 300 M Ohm.
- Connect the red/black leads from the sensor to the Encardio-rite model EDI-54V portable readout unit and switch it on. The display will show something like:

  `Freq:  2629.8 Hz`

  Where, the actual figure will vary from transducer to transducer and will also depend upon the element connected to the indicator.

  This initial reading on the portable readout unit should be stable.
- Shift the read-out unit display to the frequency^2 mode. Each sensor is provided with a test certificate giving relationship between load and output.

NOTE: Check sensor for proper functioning before installation. Each load cell is provided with a test certificate giving relationship between applied load and output. The gage factor given is the average value as determined for the three/six vibrating wire elements.

4.1.2 Extend cable if required by using a suitable cable jointing kit. Alternatively, you can procure a junction box from Encardio-rite for this purpose. For long term outside usage seal junction box with a suitable cable jointing compound.

CAUTION: In case cable is used for extension, it should always be removed from a spool by rotating the spool. This will reduce chances of nicking, bending or twisting of the cable.

NOTE: For cable jointing compound, details are given below:

- For PVC cable: R-pack 3M Scotch Cast 450 resin and hardener MSH 283
- For PU cable: 3M Scotch Cast Electrical Kit 2131

Any suitable two component cable jointing compound available in your Country can be used in place of the above mentioned compounds used by us in India. The above two jointing compounds are included in the supplies made in India.

WARNING! Avoid skin and eye contact with the jointing compound. The compound is harmful if swallowed. Hands should be thoroughly washed with soap and water immediately after use. Use of latex gloves is recommended especially if a large number of joints are to be made. Empty jointing compound containers should be destroyed after pouring and should not be used for storing any other material.

4.1.3 After extension of the cable, check working of sensor again following procedure described above.

NOTE: Remember to add the cable resistance when checking the resistance between the leads after the cable jointing. For the model CS 0401 cable, the resistance is 84 Ohm/km (multiply by 2 for both leads). In case any other cable is used, make the necessary addition in the resistance value.

4.2 Installation on anchor bolt or cable anchor

4.2.1 Before installation of load cell take temperature and initial zero reading of all three/six elements in load cell. Subsequent readings will be compared against this initial zero reading to get the correct load. This data is used to feed the initial reading for the individual elements in the model EDI-54V.

4.2.2 Carefully grout seating pad perpendicular and concentric with anchor bolt/cable anchor. Inserting a suitable bush between the anchor bolt/cable anchor and the bored hole can do this. The bush should be subsequently removed.

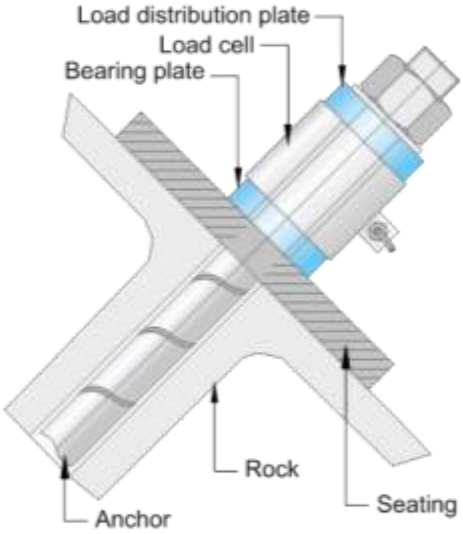


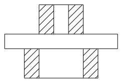
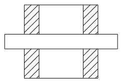
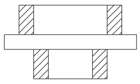
Figure 4.1

4.2.3 Install center hole load cell between flat bearing and load distribution plates. These plates should be parallel to each other and normal to the of load cell. The anchor can be centralized by carefully positioning the load cell over it. Alternatively, a suitable bush can be used in the annular space between the load cell and the anchor to centralize it. If a bush is used, care should be taken that it does not interfere with loading pattern of load cell. In case surface of flat bearing and load distribution plates cannot be maintained parallel, spherical settings or wedges or compensation washers made of copper/high density plastic material should be used.

NOTE: Effect of eccentric loading and uneven or warped bearing and load distribution plates has a profound effect on load cell reading. Having thicker plates reduces this effect. For recommended sizes of plates, refer to § 2.1.2. Careful mounting is required to reduce effect of eccentric loading. Load cell should be mounted between flat bearing and load distribution plates of proper thickness depending upon load cell capacity. Load should be centralized with respect to load cell axis. In case surfaces are not parallel, spherical settings or wedges should be employed.

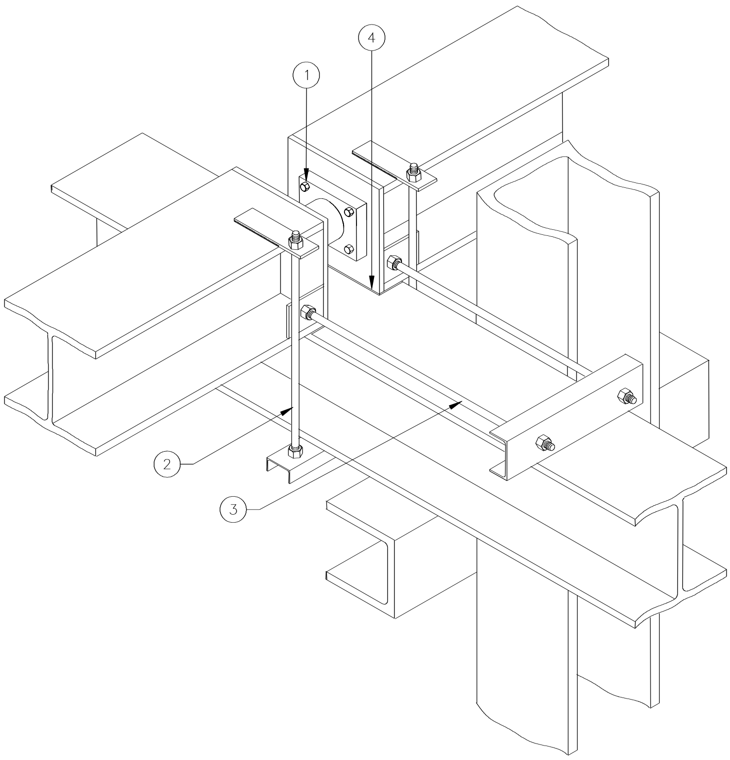
NOTE: An uneven bearing or load distribution plate can affect accuracy of reading. So can the bending or distortion of plates. It is essential to have bearing/load distribution plates of correct thickness and finish. Hole in these plates should match internal diameter of center hole load cell. Effect of bearing/load distribution plates bending is illustrated by an experiment performed on an Encardio-rite 1,000 kN anchor bolt load cell, loaded on an universal testing machine to full capacity. For purpose of the experiment a flat plate was placed on the load cell and the load was applied through bushes of different diameters. The result is displayed below.

It will be noticed that if bush is smaller, load cell over registers. Vice versa is also true. The effect is reduced in case the plate in-between is thicker. Theoretically also, this is how it should be, because the vibrating wire strain gages are mounted at the center of the hollow cylindrical columnar stress element.

		Load cell response to applied load (1,000 kN)	
		23 mm thick plate	35 mm thick plate
Smaller bush	 Load cell	105 %	101%
Same size bush	 Load cell	100 %	100 %
Larger bush	 load cell	96 %	99 %

4.3 Installation on struts

Installation of load cells (solid) for measurement of axial load should be carefully designed. It varies from installation to installation and also depends upon type of struts used. A typical installation is illustrated below.



1. Encardio-rite model ELC-32V load cell (solid type).
2. Stay rod for restrain in vertical direction (with required brackets etc.) - 2 no.
3. Stay rod for restrain in horizontal direction (with required brackets etc.) - 2 no.
4. Teflon pad – 2 no.

Figure 4.2

4.4 Pile load testing

Installation of load cells (solid type) for pile load testing should be carefully designed. A typical installation is shown in Figure 4.3 below:

Figure 4.3 Pile load testing

4.5 Cable laying

4.5.1 General precautions in the mounting of the cable

Careful and skilled cabling is required in installation of a load cell. The load cell/cable joint and a large part of cable may be exposed to blasting and construction work. Part of the cable may be permanently embedded and no future access may be available for any maintenance and corrective action. In general, take following precautions:

- Protect cable from damage by angular/sharp particles of material in which it is embedded.
- Cables may be spliced without affecting sensor reading; nevertheless, splicing should be avoided wherever possible. If necessary, use special cable jointing kits available from factory.

Take precaution that cables are properly tagged all along. With best possible precautions, mistakes may still occur. Tags may get lost due to cable getting accidentally cut. Encardio-rite uses convention that looking from junction box or observation room towards sensor, cable from most distant sensor is always at the left hand side. In that order, cable from closest sensor is at extreme right.

NOTE: A simple code for remembering this is "LL-SR". Longer (cable) left, shorter (cable) right when viewing the sensors from the observation room.

Similarly, cable from most distant sensor should be connected to extreme left socket in junction box. Succeeding cables from sensors are connected progressively towards right in junction box.

4.6 Trouble shooting

Once installed, remedial action is limited. Maintenance and trouble shooting is consequently confined to periodic checks of cable connection and functioning of the read-out unit. Refer to following list of problems and possible solutions should problems arise. For any additional help, consult factory.

4.6.1 Symptom: Load cell reading unstable

- Check insulation resistance. Resistance between any lead and the protective armor should be > 500 m Ohm. If not, cut a meter or so from the end of cable and check again.
- Does read-out work with another load cell? If not, read-out may be malfunctioning or have a low battery.

Consult manual of readout unit for charging or trouble shooting instructions.

- Use another read-out unit to take reading.
- Check if there is a source of electrical noise nearby? General sources of electrical noise are motors, generators, transformers, arc welders and antennas. If so problem could be reduced by shielding from the electrical noise.

4.6.2 Symptom: Load cell fails to read

- Cable may be cut or crushed? Check nominal resistance between the gage leads using an Ohmmeter. It should be within 130 - 170 Ohm. The correct value is given in test certificate. Please add cable resistance when checking. For model CS 0401 cable, the resistance is 26 Ohm/km and for the model ERC-12-15 cable, the resistance is 84 Ohm/km. (multiply by 2 for both leads). In case any other cable is used, make the necessary addition in the resistance value. If the resistance reads infinite or a very high value, a cut in the cable is suspected. If the resistance reads very low (<100 Ohm), a short in the cable is likely.
- Does read-out work with another load cell? If not, read-out is malfunctioning or may have low battery. Consult manual of readout unit for charging or trouble shooting instructions.
- Use another read-out unit to take the reading

5 THERMISTOR - TEMPERATURE RESISTANCE CORRELATION

Thermistor type **Dale 1C3001-B3**

Temperature resistance equation

$$T = 1/[A + B(LnR) + C(LnR)^3] - 273.2\ °C$$

T = temperature in °C

LnR = Natural log of thermistor resistance

A = 1.4051×10^{-3}

B = 2.369×10^{-4}

C = 1.019×10^{-7}

Ohm	Temp. °C	Ohm	Temp. °C	Ohm	Temp.°C
201.1k	-50	16.60K	-10	2417	+30
187.3K	-49	15.72K	-9	2317	31
174.5K	-48	14.90K	-8	2221	32
162.7K	-47	14.12K	-7	2130	33
151.7K	-46	13.39k	-6	2042	34
141.6K	-45	12.70K	-5	1959	35
132.2K	-44	12.05K	-4	1880	36
123.5K	-43	11.44K	-3	1805	37
115.4K	-12	10.86K	-2	1733	38
107.9K	-41	10.31K	-1	1664	39
101.0K	-40	9796	0	1598	40
94.48K	-39	9310	+1	1535	41
88.46K	-38	8851	2	1475	42
82.87K	-37	8417	3	1418	43
77.66K	-36	8006	4	1363	44
72.81K	-35	7618	5	1310	45
68.30K	-34	7252	6	1260	46
64.09K	-33	6905	7	1212	47
60.17K	-32	6576	8	1167	48
56.51K	-31	6265	9	1123	49
53.10K	-30	5971	10	1081	50
49.91K	-29	5692	11	1040	51
46.94K	-28	5427	12	1002	52
44.16K	-27	5177	13	965.0	53
41.56k	-26	4939	14	929.6	54
39.13K	-25	4714	15	895.8	55
36.86K	-24	4500	16	863.3	56
34.73K	-23	4297	17	832.2	57
32.74K	-22	4105	18	802.3	58
30.87K	-21	3922	19	773.7	59
29.13K	-20	3748	20	746.3	60
27.49K	-19	3583	21	719.9	61
25.95K	-18	3426	22	694.7	62
24.51K	-17	3277	23	670.4	63
23.16K	-16	3135	24	647.1	64
21.89K	-15	3000	25	624.7	65
20.70K	-14	2872	26	603.3	66
19.58K	-13	2750	27	582.6	67
18.52K	-12	2633	28	562.8	68
17.53K	-11	2523	29	525.4	70

5.1 Measurement of temperature

Thermistor for temperature measurement is provided in all Encardio-rite vibrating wire load cells. The thermistor is connected between the green and white leads and gives a varying resistance output related to the temperature (see § 5). The resistance can be measured with an Ohmmeter. The cable resistance may be subtracted from the Ohmmeter reading to get the correct thermistor resistance. However, the effect is small and is usually ignored.

The Encardio-rite model EDI-54V vibrating wire read-out unit gives the temperature from the thermistor reading directly in engineering units.