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USERS' MANUAL

IN-PLACE INCLINOMETER SYSTEM

VERTICAL WITH DIGITAL (SDI-12 & MODBUS) O/P

MODEL EAN-56

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1 INTRODUCTION

This users' manual defines the procedure for long-term monitoring of lateral movement using Encardio-rite model EAN-56 digital in-place inclinometer (IPI) system (vertical) in the soil, earthworks, slopes or structures like retaining/diaphragm wall, embankment or dam etc. The in-place inclinometer system provides:

- significant quantitative data on the magnitude of inclination or tilt of a foundation, embankment or slope and its variations with time
- the pattern of deformation, zones of potential danger and effectiveness of construction control measures undertaken
- behaviour of ground movement after construction and indicates potentially dangerous conditions that may adversely affect the stability of the structure.

IPI system comprises of an array of tilt sensors with specific gage lengths that are installed inside a standard grooved inclinometer casing for real-time lateral movement monitoring in critical applications. Model EAN-56 IPI system uses tilt sensors with digital output. Both SDI-12 serial interface and Modbus (RS-485) output options are available.

Encardio-rite model ESDL-30 datalogger can be used for EAN-56 IPI system with SDI-12 serial interface output. Maximum distance of datalogger from the IPI gagewell can be up to 200 m. Data from the datalogger can be transmitted remotely to a central/cloud server via cellular (GSM/GPRS) network. The system with SDI-12 output can also be directly connected to suitable RF dataloggers (nodes) and gateway for wireless data transfer.

For IPI array with Modbus output, maximum distance from datalogger to IPI gagewell can be 1.2 km. Any suitable datalogger with either GSM/GPRS or RF transmission facility can be connected for datalogging and wireless data transmission.

Continuous data logging and online monitoring with instant alert messages helps to provide an early warning in case of an impending failure.

1.1 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.

1.2 How to use this manual

The manual is divided into a number of sections. Each section contains a specific type of information. Refer to the index for any specific information required.

To make this manual more useful, your valuable comments and suggestions are invited regarding any additions or enhancement. You are also requested to please point out any errors that are found while going through the manual.

NOTE: Videos on installation of model EAN-52 IPI with SDI-12 output, its connection to ESDL-30 datalogger and its configuration with the ESDL-30 datalogger are provided on Encardio-rite's YouTube channel. User can refer to these videos for better understanding.

1.3 General information

This users' manual is intended to provide sufficient information for installing and making optimum use of ABS inclinometer casing. The manual also contains instructions on how to set-up for lowering of the measuring instruments into the gage well for purpose of taking inclination/settlement readings.

NOTE: Installation personnel must have a background of good installation practices and knowledge of the fundamentals of geotechnics. Novices may find it very difficult to carry on the installation work. The intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

A lot of effort has been made in preparing this instruction manual. However, the best of instruction manuals cannot provide for each and every condition in the field, which may affect performance of the sensor. Also, blindly following the instruction manual will not guarantee success. Sometimes, depending upon field conditions, installation personnel will have to consciously depart from the written text and use their knowledge and common sense to find the solution to a particular problem.

This equipment should be installed, maintained and operated by qualified personnel. Any errors or omissions in installation, data or data interpretation are not the responsibility of Encardio-rite Electronics Pvt. Ltd. or its Group Companies.

1.4 Mandatory checks before installation of IPI sensors

We need to follow few essential guidelines for a proper operation of in-place inclinometer systems as explained below. These steps should be executed just after installation of casing (once grouting is set), before lowering the IPI system.

NOTE: Logically, the checks described below should have been given in section 3 of the manual (preparation before installation of IPI chain; after installation of casing). They are included in the first chapter only to emphasize that they should never be missed. Please read this section 1.4 once again once the installation of the casing is complete, before lowering the IPI chain.

NOTE: For instructions on installation of Encardio-rite inclinometer casing refer to Users' Manual # WI 6002.104 on Inclinometer casing installation, available on our website www.encardio.com/downloads.

1.4.1 With Encardio-rite model EAN-26 DP dummy probe

Lower dummy probe inside the inclinometer casing, first in grooves in one direction and then in the perpendicular direction to verify that the grooves are smooth with no concrete or foreign material stuck in them. Clean if necessary.

The inclinometer probe or IPI chain should never be lowered down in the gage well unless the installed casing is checked by the dummy probe. The monitoring instrument may get stuck in the gage well and you may permanently lose it in case this instruction is not followed.

NOTE: The model EAN-26DP dummy probe is not a part of the supply and has to be ordered separately.

Inclinometer gagewell being checked with dummy probe

1.4.2 With Encardio-rite model EAN-26M inclinometer probe

Take initial reading of x-y profile of borehole with model EAN-26M inclinometer system and store the data for future reference. This step is very important and should never be ignored.

The inclinometer probe gives the true x-y profile of the borewell with a gage length of 0.5 m. In case any abnormal movement is observed later on from the installed **IPI daisy chain**, the borehole profile can be verified by removing the **IPI chain** and taking a fresh set of readings with the model EAN-26M inclinometer probe (and comparing it with the reference readings to check any abnormality).

Digital inclinometer system

For details on using model EAN-26M digital inclinometer system, please refer to operating manual # WI 6002.103 available on our website www.encardio.com/downloads.

Inclinometer readings being taken with manual probe

NOTE: The model EAN-26M inclinometer probe is not a part of the supply and has to be ordered separately.

CAUTION: The initial x-y profile taken with the model EAN-26M inclinometer probe is a reference for future use. It should be carefully stored and never be lost till the borewell is used for monitoring.

1.4.3 X-Y coordinates with Prism target

Determine initial Northing (X) and Easting (Y) positions of casing top by surveying after the inclinometer casing is set. For this purpose a prism assembly with holder pin can be used for model EAN-AT-70 inclinometer casing. ERT-10P2 prism target can be directly mounted on the suspension bracket (which is an integral part of the IPI), with a precision prism holding pin adaptor, as shown in figure 1-1.

Readings should be taken with an accurate and precise total station. This data should be treated as a reference during verification of deflection at a later date.

Note: This step can be taken before IPI chain installation or just after the IPI chain is installed. In former case, place only the suspension bracket over the casing for mounting prism target.

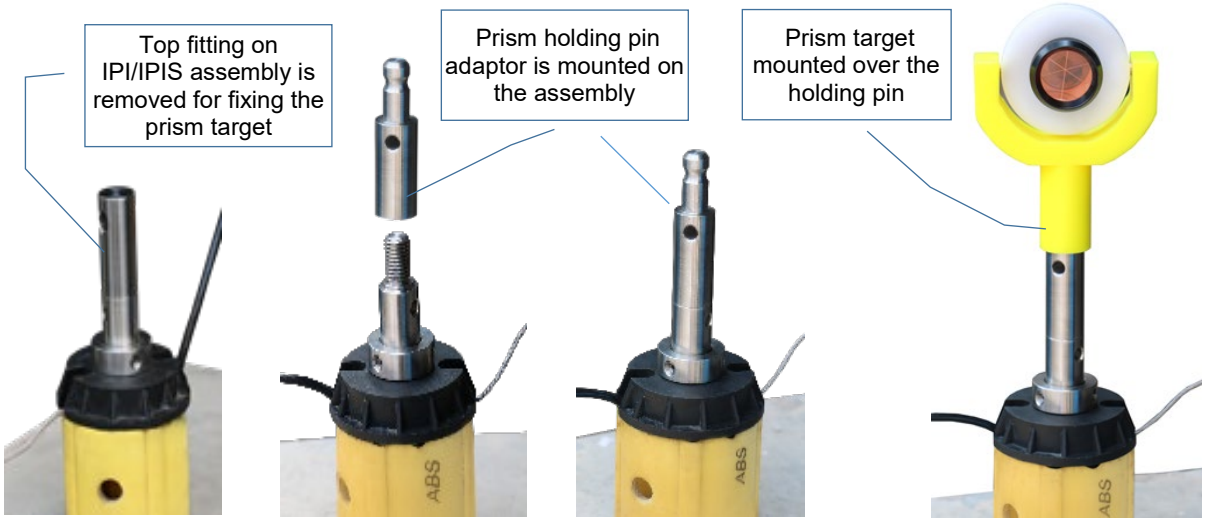


Figure 1-1 Prism target mounting accessories suitable for taking X-Y coordinates for IPI

1.4.4 Elevation by settlement point

Additionally, determine the elevation of the pipe top using a precision digital level. For this purpose, a settlement marker should be provided adjacent to top of inclinometer casing that will serve as survey reference point. The survey marker is illustrated in figure 1-3.

This will allow inclinometer profile to be referenced to an absolute reference (elevation above sea level) should the fixed bottom reference needs to be verified due to any reason.

NOTE: The prism target assembly with holding pin and the survey target are not a part of the supply and have to be ordered separately.

CAUTION: The Northing (X), Easting (Y) and Elevation (Z) of the casing top taken by the precision total station and digital level is a reference for future use. It should be carefully stored and never be lost till the borewell is used for monitoring.

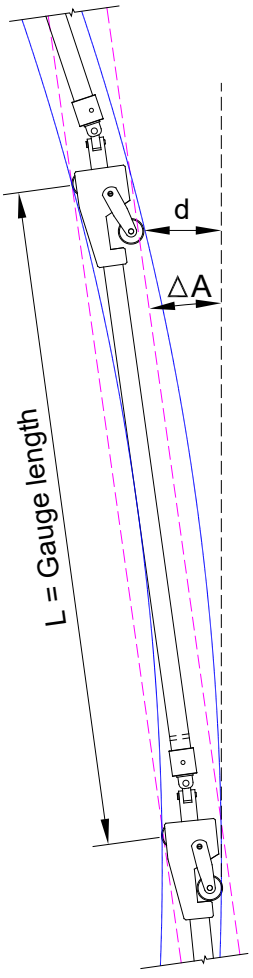
Figure 1-2 Survey target to be mounted on top concrete platform to determine elevation of casing top

1.5 Selection of gage lengths for the IPI chain

Sensors in an IPI chain consist of tilt sensors connected to rigid bars (gage tube) which are subsequently connected together end to end to form an array (or chain) of sensors. The total length of the tilt sensor plus the length of the gage tube forms the gage length for that particular tilt sensor. Encardio-rite provides IPI with gage lengths of 1, 1.5, 2 and 3 m as standard.

Although, sensors with long gage lengths can be employed in an IPI chain, there is a practical limit to the gage length that can be allowed at each sensor position. For best profiling of the borewell, it should be ensured that the entire gage length at each sensor position remains perfectly straight. If the borehole casing deforms too much over the gage length of any sensor position, the curvature introduced in the casing will foul the gage length of the sensor at that particular location. After a certain amount of allowed range of deformation, further deviation will cause the sensor gage tubing to touch the inclinometer casing and introduce a curvature in the gage tubing.

This will introduce an error while plotting the sub-soil displacement profile at that location, as the plotting assumes that each gage tubing is a perfect straight-line segment. The accompanying diagram shows at what deformation limit the gage tubing touches the casing and why.



Below we list the range of allowed deformation in the inclinometer casing (consequently the borehole itself) that will give proper result while plotting the displacement profile. If the allowed casing deformation is exceeded, it will result in an error while plotting the displacement profile - more the deformation more the error.

Sensor Gage Length L (m)	Maximum measurable angular deviation ΔA (deg)	Maximum allowed displacement over 1 m borehole length ΔA_m (deg/m)	Maximum allowed lateral movement d_{max} (mm per m)
1.0	9.6	9.6	167
1.5	6.4	4.8	111
2.0	4.8	2.4	84
3.0	3.2	1	56

The above values have been calculated using EAN-56 IPI chain in 70 mm od, 58 mm id inclinometer casing, assuming that the sub-soil movement is causing a circular bend in the inclinometer casing, for ease of calculation. For 85 mm od inclinometer casing, please contact factory for suitable IPI sensors and recommended gage lengths.

Summarising, if the expected ground displacement ranges is larger than displacement range allowed for any particular gage length, a shorter gage length should be used otherwise the plotted borehole displacement profile would be erroneous.

Another important point to be kept in mind is that the IPI chain measures displacement at the adjacent sensor points, considering that the gage tube is in a straight line. Any localized displacement between the sensor points will therefore not be measured by the IPI chain.

Gage length is the distance between the wheel assemblies of adjacent tilt sensors. Shorter gage lengths normally give more reliable and accurate data as compared to larger gage lengths. Sensor gage lengths should be optimized depending upon site conditions and important zones to have a reliable as well as cost effective system. Gage lengths can vary within an individual installation; for example - an IPI installed in an inclinometer casing in a landslide area may use 3 m gage lengths in the upper zone and 1 m gage lengths in the expected slip zone.

Designer must judiciously define the gage lengths taking the above factors into consideration.

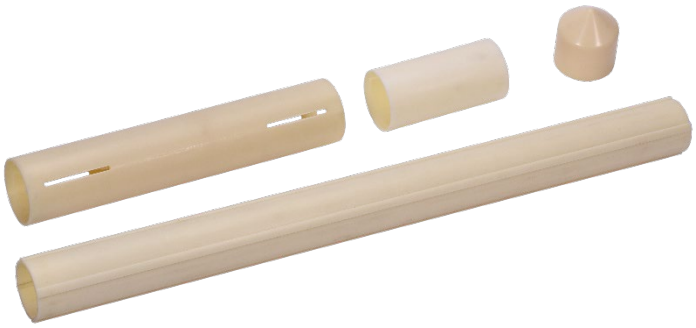
2 MODEL EAN-56M IPI SYSTEM

2.1 Overview

Model EAN-56 in-place inclinometer system consists of a string of digital tilt sensors installed inside standard inclinometer four grooved casing.

Each tilt sensor is fitted with a pair of pivoted sprung wheels, which rests inside the grooves of the inclinometer casing. The sensor is connected to rigid bars (gage tube) of desired length. The total length of the tilt sensor plus the length of the gage tube forms the gage length for that particular tilt sensor. The gage length determines the distance between each sensor over which the tilt is monitored. The IPI chain consists of tilt sensor and gage tube assemblies connected together end to end to form an array of sensors.

A series of inclinometer access tubes with four grooves at right angles, attached to each other with fixed couplings, are installed in a borehole or embedded in earth/rockfill or concrete structure during construction or fixed to the vertical face of a completed structure. One set of grooves is always aligned in the expected direction of movement and if this is not known, in the N-S direction.



Inclinometer ABS access casing with couplings and end cap

NOTE: For details on Encardio-rite inclinometer casing installation, refer to Users' Manual # WI 6002.104.

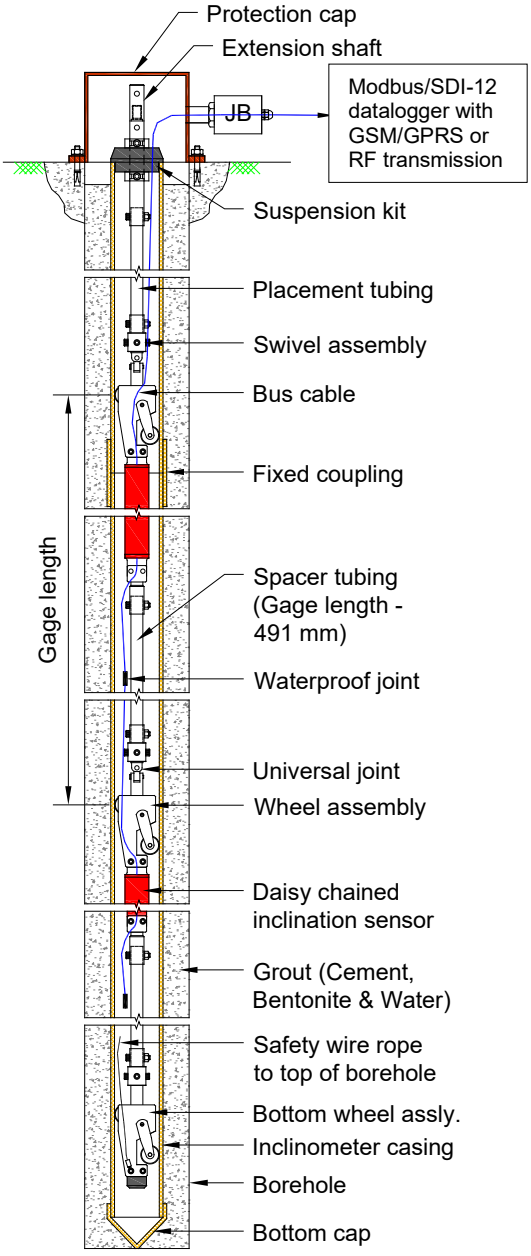


Figure 2-1 EAN-56M In-place inclinometer system (with SDI-12 and Modbus output)

The IPI chain is positioned inside the inclinometer casing in a continuous array to span the movement zone. The tilt sensors measure the tilt in successive segments to monitor change in the profile of inclinometer casing (gagewell).

When ground movement occurs, it displaces the inclinometer casing, causing a change in tilt of the in-place tilt sensors. This results in a change in the output of the sensors, proportional to the tilt i.e. the angle of inclination from vertical. The sensors with digital output (SDI-12 and Modbus) are connected to a suitable datalogger or data acquisition system for real-time monitoring of lateral movement. The tilt reading over gage length of each sensor can be converted to lateral deviation by:

"L sin A" where L is gage length; A is angle of tilt from vertical

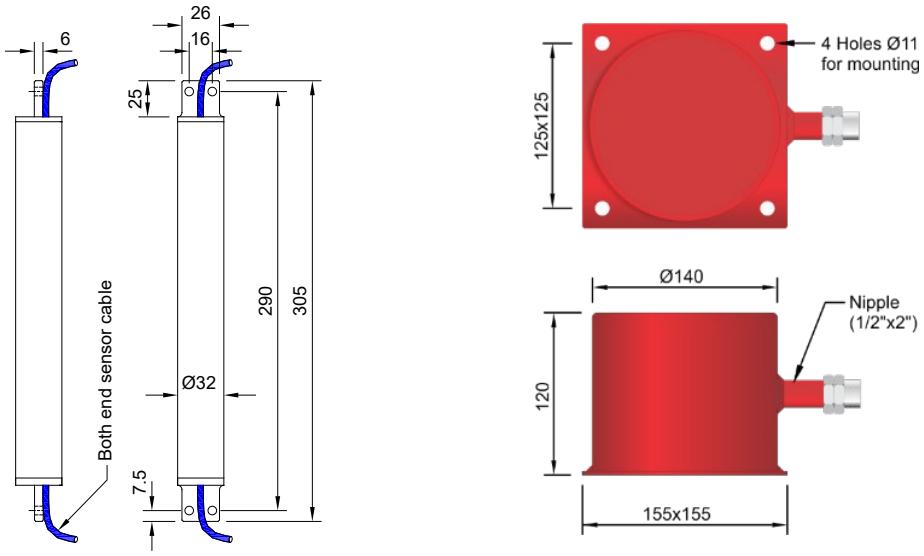
The lateral movement of the casing can be calculated by subtracting initial deviation from current deviation. Provided that one end of the casing is known to be fixed, it is possible to obtain a complete profile of the access tubing by summing readings from successive sensors. By comparing the profiles, the horizontal displacement of the gage well at different depths over a period of time may be determined.

2.2 In-place inclinometer system components

Following sub-assemblies are available in the Encardio-rite model EAN-56 in-place inclinometer system:

EAN-56/1	Biaxial MEMS sensor with digital output (SDI-12 and Modbus), housed in a waterproof stainless steel body, with a pair of wheels
EAN-52M/2-X	Gage tube assembly for 1 m, 1.5 m, 2 m and 3 m. 'X' suffix represents gage length required
EAN-52M/3	Wheel assembly
EAN-52M/4	Suspension kit with protective cap
EAN-52M/5	Placement tubing (specify length) for placing string of sensors
EAN-52M/6	Protective rope to prevent loss of sensor down hole
EAN-52M/7	Suspension stainless steel wire rope for positioning single or group of sensors in specific portion of borehole
CS-0703	6 core bus cable
Casings	ABS grooved casing with fixed/telescopic coupling, caps etc.

Figure 2-1 shows a typical in-place inclinometer string assembly, figure 2-2(a) shows tilt sensor details and figure 2-2(b) shows protective cover details.



(a) Dimensional details of tilt sensor **(b) Protective cover**

Figure 2-2 Tilt sensor and cover details

Following points need attention for in-place inclinometer system:

- The depth of borehole and the gage length specified by the user determines the number of sensors required.
- Gage tubing length is determined by the gage length specified.
    - Gage tubing length (mm) = specified gage length (mm) - 491 mm
    - Outside diameter of gage tubing = 16 mm
    - The sensor gage lengths can either be all of equal length in a chain or may have different lengths at different depths. Gage lengths varies from 1 m to 3 m.

- The depth at which first in-place sensor is to be placed from top of the borehole determines the length of the placement tube.
- A suspension stainless steel wire rope is available to position a single or group of sensors where profile of entire borehole is not of interest but only a specific portion needs monitoring.

2.3 Sensor output

The tilt sensors used in model EAN-56M IPI system are available with digital SDI-12 and Modbus output.

When used with SDI-12 output, a maximum of 61 sensors can be used in a chain and maximum distance of datalogger from the IPI gagewell can be up to 200 m.

When used with Modbus output, a maximum of 32 sensors can be used in a chain and maximum distance of datalogger from the IPI location can be 1.2 km.

The tilt sensors are connected in a bus chain through rugged and waterproof connectors, suitable for installation of sensors in an inclinometer casing, which may be filled with water. Each sensor is provided with a pair of bus cable terminating at either ends with male/female connectors – for connection to adjacent sensor. The bus cable from IPI chain can be used for both SDI-12 (3 core) and Modbus (4 core) output options.

2.4 Datalogger

Model EAN-56 IPI with SDI-12 output can be connected to Encardio-rite model ESDL-30 datalogger for remote online monitoring. ESDL-30 datalogger is a compact datalogger that can be mounted easily above the IPI gage well, or in a control room in close vicinity. The configuration of the system with datalogger is user friendly, which makes the commissioning of IPI system quite easy and fast. Data from the datalogger can be transmitted remotely to a central/cloud server via cellular (GSM/GPRS) network. The datalogger is housed in a rugged enclosure designed for use in harsh environments with wide temperature tolerance and with resistance to moisture and humidity.

The system with SDI-12 output can also be directly connected to suitable RF dataloggers (nodes) and gateway for wireless data transfer.

ESDL-30 datalogger for SDI-12 sensors

For EAN-56 IPI with Modbus output, any suitable datalogger with either GSM/GPRS or RF transmission facility can be connected for datalogging and wireless data transmission.

3 PREPARATION BEFORE INSTALLATION

3.1 Civil works

- Install casing as per Users' Manual # WI6002.104 on Inclinometer casing installation.
- Make a concrete platform at top (refer to figure 3-1) such that mouth of inclinometer casing is around 25 mm below the top of the concrete platform. Inside diameter of the cavity around the top of the casing in the platform should be around 150 mm.
- Place the protective cover (figure 2-2(b)) over the concrete platform and mark location for the Hilti HLC-M10x80 fasteners provided. Remove the cover and install the four mounting fasteners on the marked locations (for mounting of the protective cover later).

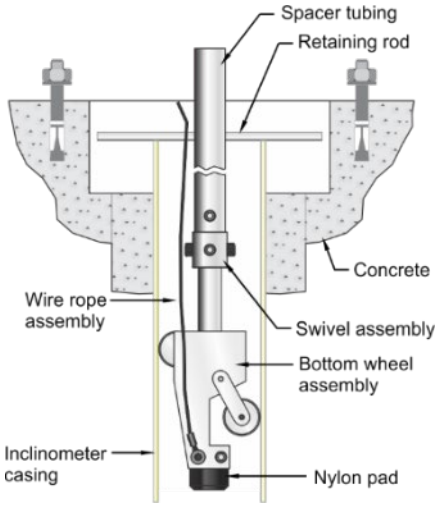


Figure 3-1 Concrete platform for protection

3.2 Pre-installation checks

- Check for any damage to cable/connector of each sensor.
- Each sensor bears a serial number and has two cables coming out of it.

NOTE: The bottom wheel assembly is to be considered as the reference point while analysing the monitored data.

- Identify the sensors to be lowered in order (lower most sensor to be numbered as sensor 1) and note down their serial number. Assign ID or address (0-9, a-z or A-Z) to each sensor. Ensure that no sensor in the chain has the same ID.
- One end of the cable from the topmost sensor is directly terminated in a junction box at the top of the borehole. The other end has a connector, which is mated with cable connector from the lower sensor.
- Locate A+ side i.e. the top wheel on all the sensors and it should be towards the expected direction of movement (refer to figure 3-2).

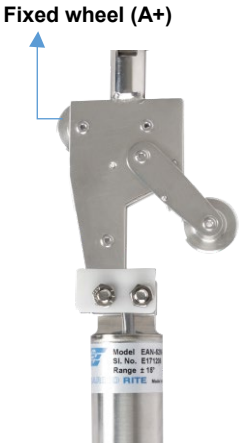


Figure 3-2 Top wheel

NOTE: Failure to place A+ side of each sensor of an IPI chain towards the expected direction of movement can result in misinterpretation of the data. This may have serious consequences.

3.3 Pre-assembly

3.3.1 Bottom assembly

- The supplied wire rope has two loops. Fix the smaller loop of the wire rope to the lower end of the bottom wheel assembly as shown in figure 3-3 and figure 3-4(a). Other end of wire loop is fixed to any secure structure at the top of the borehole to prevent the whole assembly from dropping down accidentally into the borehole during installation/removal.

Figure 3-3 Bottom wheel with wire rope connected

- Assemble the lower end of the spacer tubing to the bottom wheel assembly as shown in figure 3-3 and figure 3-5(a).

3.3.2 Sensor assembly

- Attach the bottom-most sensor to wheel assembly as shown in figure 3-4 & 3-5(b).
- Fix spacer (gage) tubing to other end of wheel assembly using coupler as shown in figure 3-4 & 3-5(b)
- Prepare such assemblies for all the sensors except for the top most sensor.

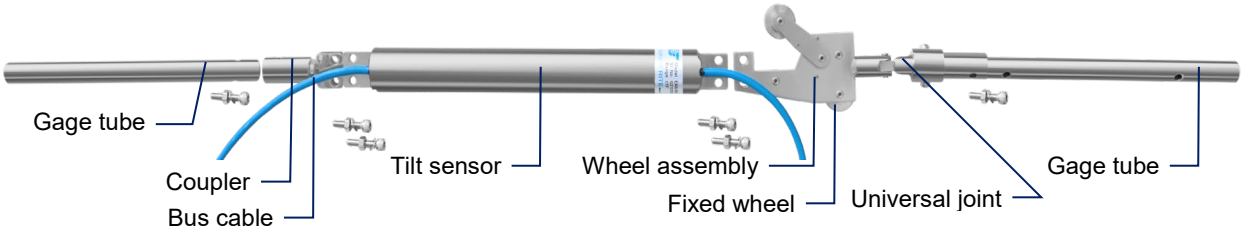
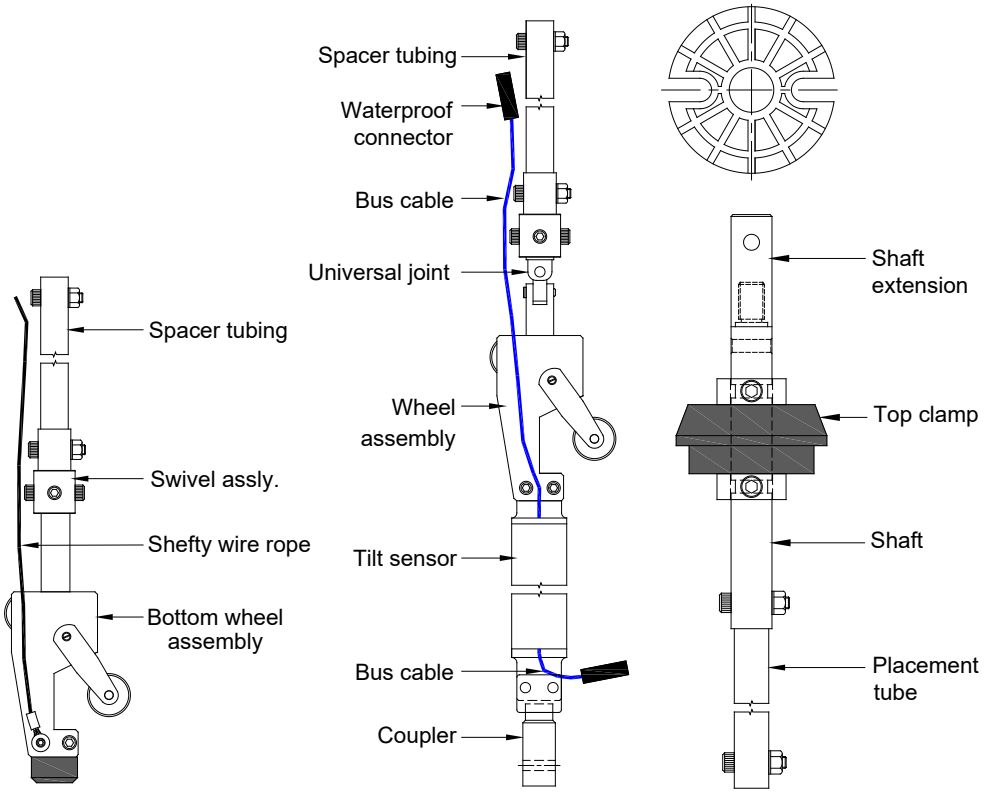


Figure 3-4

3.3.3 Top assembly/suspension bracket

- Attach a wheel assembly to the top most sensor.
- To the other end of the wheel assembly, fix the placement tube as shown in figure 3-5(c) and photograph in figure 3-6.
- Attach suspension kit to the other end of the placement tube as shown in figure 3-4(c).

NOTE: Required fasteners are supplied mounted on the assemblies except those used for fixing the IPI sensors to the gage tubing. These fasteners with some spares are packed separately.



(a) Bottom assembly **(b) Main (center) assembly** **(c) Top suspension assembly**

Figure 3-5 IPI chain assembly

Figure 3-6 IPI suspension bracket, with sensor & gage tube

4 INSTALLATION PROCEDURE

CAUTION: Please refer to section 1.4 for mandatory checks to be performed before lowering the IPI chain in the gagewell.

4.1 Lowering IPI chain in gagewell

- Place tilt sensor assemblies side by side in the order of installation.
- Lower the bottom assembly into inclinometer casing holding the safety wire rope such that assembly does not accidentally slip down into the casing.

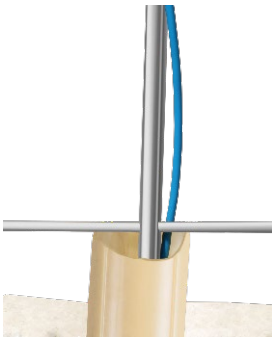
NOTE: Align wheels in casing grooves such that top/fixed wheel points towards the expected direction of movement.

- Insert a retaining rod (figure 4-1(a)) in the hole at the top end of the spacer (gage) tubing and rest assembly on the casing's top with the help of the retaining rod.
- Fix the bottom-most (1st) sensor assembly to the gage tubing using coupler (figure 4-1(b&c)). Use cable ties to tie the bus cable of sensor and wire rope neatly to the spacer tubing.
- Remove retaining rod and lower assembly into borehole carefully (figure 4-1(d)). Hold the assembly again in borehole using retaining rod.
- Fix the next (2nd) sensor assembly to the gage tubing of bottom-most sensor assembly. Fix the connectors of the bus cable tightly (figure 4-1(e)).

NOTE: Fix the connectors carefully; use only hands to make the connection.

- Repeat above procedure for all sensors taking care of orientation of wheels as mentioned above till suspension kit of the top assembly rests on the mouth of the inclinometer casing (figure 4-1(f)).

NOTE:
1. While lowering assemblies, make sure to use the retaining rod in every spacer tubing to prevent assemblies accidentally falling in to the borehole.
2. Take care of the sequence of sensors from bottom to top. Note the manufacturing serial and address of the sensors during assembly.
3. Prevent twisting of installed sensors during tightening of fasteners as this can damage the wheels and push them out of the grooves of inclinometer casing.



(a) Holding IPI bottom assembly with rod

(b) Connecting IPI sensor to gage tube

(c) Tightening the bolt with Allen key and spanner

(d) Inserting the sensor/wheel in gage well

(e) IPI sensor connectors

(f) Top assembly

Figure 4-1

CAUTION: Never let the IPI chain rest in borehole (gagewell) on the bottom wheel assembly. It should always be hanging such that all the gage tubes are in tension.

4.2 Mounting datalogger

The ESDL-30 datalogger can be mounted on a pole or concrete pillar above gage well, or in the control room in close vicinity. A typical mounting detail for installing datalogger on a vertical surface or wall is shown in figure below. Mark the position of fasteners. Drill 6 mm dia x 40 mm deep hole. Fix the datalogger using Hilti HPS-1 6/15x40 fasteners provided.

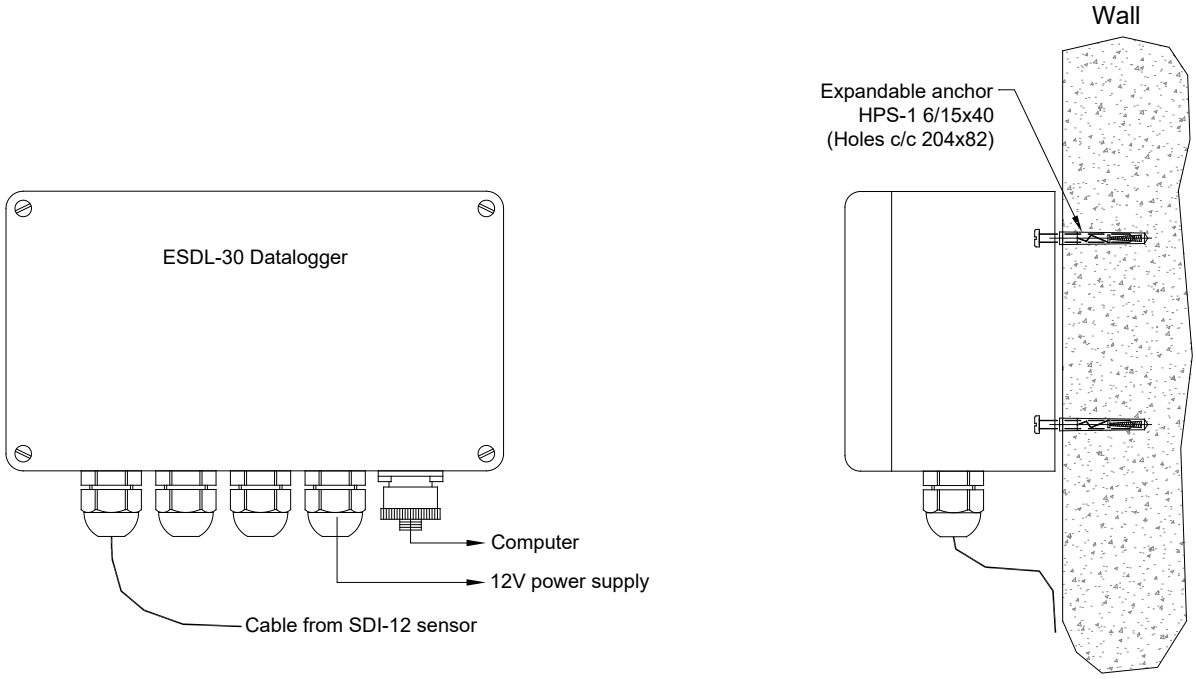


Figure 4-1 Mounting details for ESDL-30 datalogger installation on wall/vertical surface

4.3 Sign convention

Carefully orient the sensor during installation. Make a note of the orientation. 'A+' is marked on each sensor along the 'A' axis. Align wheels in the inclinometer casing grooves such that top/fixed wheel, i.e. 'A+', points towards the expected direction of movement

In biaxial tilt sensors, 'A' axis measures tilt in the plane of wheels and 'B' axis records data at 90 degrees to 'A' axis. Uniaxial sensor measures tilt only along 'A' axis.

Figure 4-2 shows a view from top and also convention used for assessing direction of movement for data interpretation.

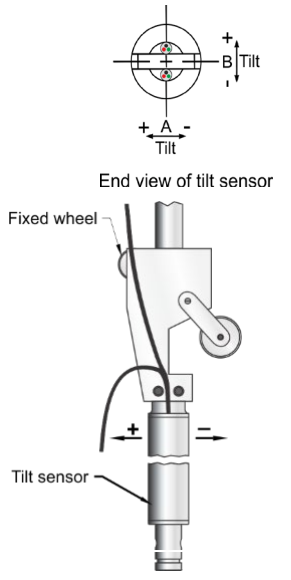


Figure 4-2 Sign convention

4.4 Maintenance of IPI sensors

The in-place inclinometer system requires careful maintenance after dismantling, if the whole set needs to be reused in another borehole in the future. Please implement the following maintenance steps:

- After dismantling the IPI chain, wheel assemblies, springs, pivots and axles should be cleaned and dried using compressed air.
- Oiling of the wheels, springs, pivots and axles to be performed subsequently.
- Bus cable connectors should be cleaned and dried. Cables should be free of any cuts.

As the dismantled IPI sensors were in use for a period of time, there may be a zero offset for each sensor. It should be removed before reusing. It is highly recommended that the sensors are sent back to the factory for re-calibration.

5 CONNECTING IPI WITH MODBUS DATALOGGER

5.1 Modbus output

For model EAN-56 IPI with Modbus output, any suitable Modbus datalogger with either GSM/GPRS or RF transmission facility can be connected for datalogging and wireless data transmission.

Encardio-rite model ESDL-30 datalogger can also be used with an additional Modbus card, if specifically ordered. However, maximum limit of Modbus IPI tilt sensors that can be connected to this ESDL-30 datalogger version is seven.

5.2 Wiring details

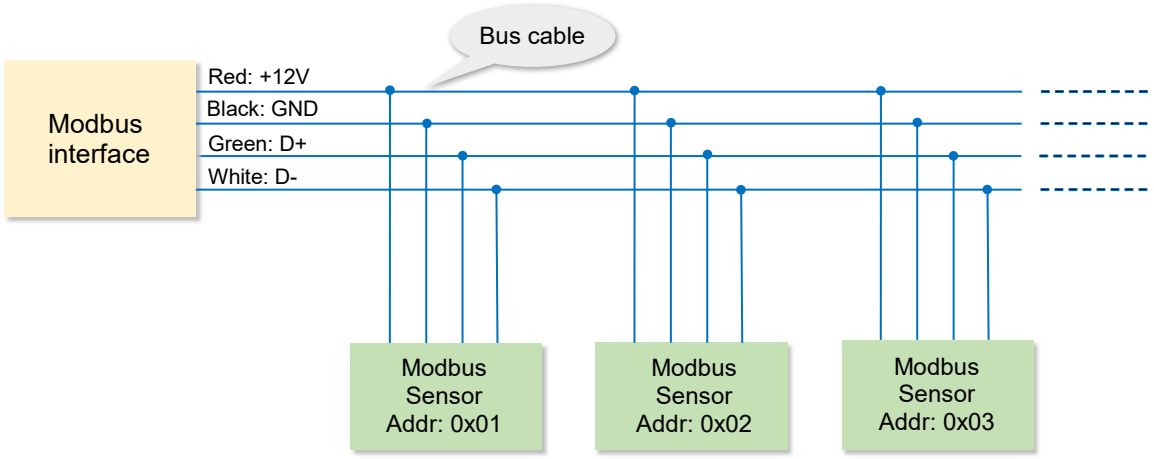


Figure 5-1 Wiring details to connect IPI with Modbus output to suitable datalogger

5.3 Modbus details for connection to datalogger

5.3.1 Modbus RTU Overview

EAN-56 IPI uses the industry standard Modbus Remote Terminal Unit (RTU) protocol to communicate with dataloggers. As the name suggests, Modbus was designed to work on what is known as a bus network, meaning that every device receives every message which passes across the network. Model EAN-56 uses the RS-485 electrical interface to communicate over long distance cables up to 1200 meters.

The Modbus RTU protocol uses packets (messages made up of multiple sections) to communicate and transfer data between devices on the network. The general format of these packets is as follows:

1 Modbus Address (1 byte) – The address of the specific device on the bus.

2 Function Code (1 byte) – The action to be carried out by the server device.

3 Data (multi-byte) – The payload of the function code being sent.

4 Cyclic Redundancy Check or CRC (2 bytes) – A 16-bit data integrity check calculated over the other byes in the packet.

5.3.2 Function Code

The Modbus RTU protocol uses following Function codes:

Function Code	Description
03	Read Holding Registers
06	Write Single Register

5.3.3 Modbus Register Table

Modbus tables (maps) define the memory locations within each EAN-56 interface and what information they contain. For example, the most recent sensor reading is stored in a table. This reading is presented in different formats in different sections of the table. The register location and size of these variables is detailed in the table below.

Modbus Register	Name	Data Length	Data Type	Description
0x00E0	Temperature Unit	2-bytes	16-bit Unsigned Integer	0 = deg C 1 = deg F
0x00E1	Tilt Unit	2-bytes	16-bit Unsigned Integer	0 = meters, 1 = degrees 2= mm/meter
0x00E2	Average Samples	2-bytes	16-bit Unsigned Integer	1 - 255
0x00E3	Settling Time	2-bytes	16-bit Unsigned Integer	0 – 255 seconds
0x00E5	Address of the Device	2-bytes	16-bit Unsigned Integer	0 - 247
0x00E6	Baud Rate	4-bytes	32-bit Unsigned Integer	1200, 2400, 4800, 9600, 19200, 38400, 115200
0x00E8	Endian Type	2-bytes	16-bit Unsigned Integer	0 = Little Endian Atomic 8 1 = Little Endian Atomic 16 2 = Big Endian Atomic 8 3 = Big Endian Atomic 16
0x012C	Ch-1 Status	2-bytes	16-bit Unsigned Integer	0 = Measurement Ready 1 = Busy in measurement
0x012D	Tilt Axis-X	4-bytes	32-bit float	± 90 degrees
0x012F	Ch-2 Status	2-bytes	16-bit Unsigned Integer	0 = Measurement Ready 1 = Busy in measurement
0x0130	Tilt Axis-Y	4-bytes	32-bit float	± 90 degrees
0x0132	Ch-3 Status	2-bytes	16-bit Unsigned Integer	0 = Measurement Ready 1 = Busy in measurement
0x0133	Tilt Axis-Z	4-bytes	32-bit float	± 90 degrees
0x0135	Ch-4 Status	2-bytes	16-bit Unsigned Integer	0 = Measurement Ready 1 = Busy in measurement
0x0136	Sensor Temp	4-bytes	32-bit float	-20 to +80 deg C

5.3.4 Default Settings

Sensor default settings are given below:

Device Address	0x01
Baud Rate	115200
Data	8-bit
Stop Bit	1
Parity	None
Endian	Big Endian Atomic 16
Measuring Time	1 Sec

5.3.5 Modbus Command Format

Followings are some examples of reading holding registers and writing single register.

5.3.5.1 Reading holding registers (Example: Reading sensor data)

BYTE	REQUEST	BYTE	ANSWER
(Hex)	Field name	(Hex)	Field name
01	Device address	01	Device address
03	Functional code	03	Functional code
01	Address of the first register Hi bytes	18	Number of bytes more
2C	Address of the first register Lo bytes	00 00	Register value Ch-1 Status 16-bit unsigned
00	Number of registers Hi bytes	BE 64 AB A4	Register value Tilt Axis-X 32-bit Float (-0.2233)
0C	Number of registers Lo bytes	00 00	Register value Ch-2 Status 16-bit unsigned
85	Checksum CRC	BE 0DC9 C5	Register value Tilt Axis-Y 32-bit Float (-0.1384)
FA	Checksum CRC	00 00	Register value Ch-3 Status 16-bit unsigned
		3C 45 26 0F	Register value Tilt Axis-Z 32-bit Float (2.93E-06)
		00 00	Register value Ch-3 Status 16-bit unsigned
		41 D6 24 C6	Register value Temperature 32-bit Float (26.76)
		DF	Checksum CRC
		20	Checksum CRC

5.3.5.2 Writing single register (Example: Changing device address from 0x01 to 0x02)

BYTE	REQUEST	BYTE	ANSWER
(Hex)	Field name	(Hex)	Field name
01	Device address	01	Device address
06	Functional code	06	Functional code
00	Address of the Register Hi bytes	00	Address of the Register Hi bytes
E5	Address of the Register Lo bytes	E5	Address of the Register Lo bytes
00	Data (write) Hi bytes	00	Data (value) Hi bytes
02	Data (write) Lo bytes	02	Data (value) Lo bytes
19	Checksum CRC	19	Checksum CRC
FC	Checksum CRC	FC	Checksum CRC

6 CONNECTING IPI WITH SDI-12 DATALOGGER

6.1 SDI-12 output

Encardio-rite model ESDL-30 datalogger can be used for EAN-56 IPI system with SDI-12 serial interface output. Data from the datalogger can be transmitted remotely to a central/cloud server via cellular (GSM/GPRS) network.

SDI-12 inputs have a unique ID (0-9, a-z or A-Z). Thus, the ID of sensors in the IPI chain have to be set accordingly during the installation process. Each of the 3 channels of the datalogger can have 61 sensors with ID 1-9 (ID 0 is used for factory purposes, hence not available for use), a-z or A-Z. For a given channel each sensor should have a different ID. For configuring the IPI chain with model ESDL-30 datalogger, please refer to Users' Manual # WI 6002.110 available at our website www.encardio.com/downloads

6.2 Wiring details

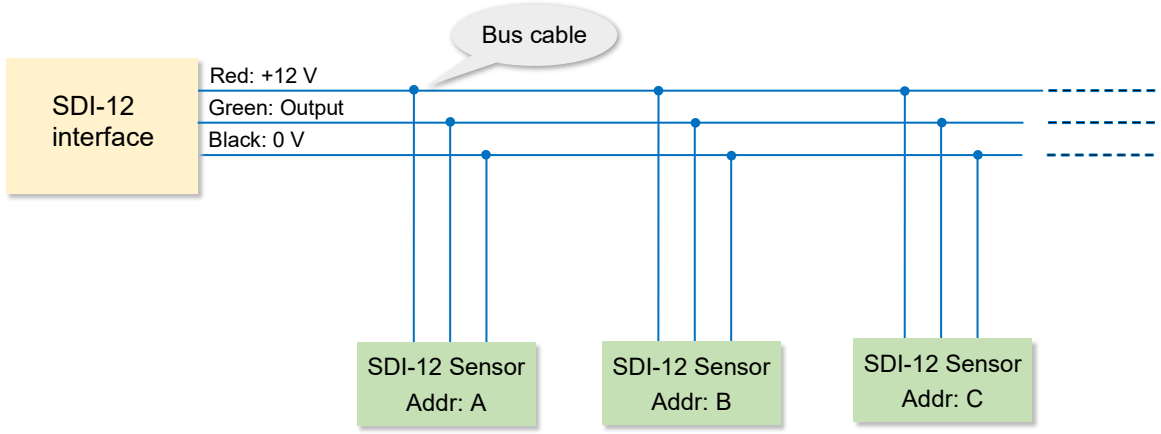


Figure 6-1 Wiring details to connect IPI with SDI-12 output to suitable datalogger

6.3 Connection to ESDL-30 datalogger

For extending cable from the top of an IPI chain, a junction box is required. Mounting details of the standard junction box from Encardio-rite are provided in figure 6-2 (left). If it is required to connect IPI sensor chains installed in two or more boreholes, a special junction box is required as shown in figure 6-2 (right).

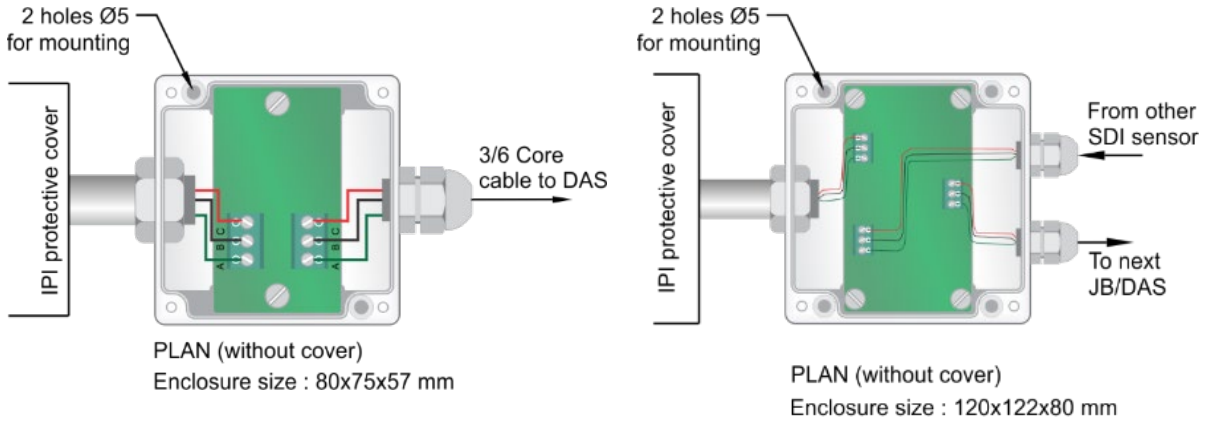


Figure 6-2 Junction Box

From IPI bus cable	Description	JB terminal
Red	+12 V	A
Green	Output	B
Black	0 V	C

Sensor cable can be directly terminated in the datalogger, in case datalogger is installed above IPI gagewell. ESDL-30 datalogger has three SDI-12 ports (channels). The IPI bus can be connected to any SDI-12 port of the datalogger. Connection detail is shown in figure below. Battery should be placed in the datalogger after the connections have been successfully done.

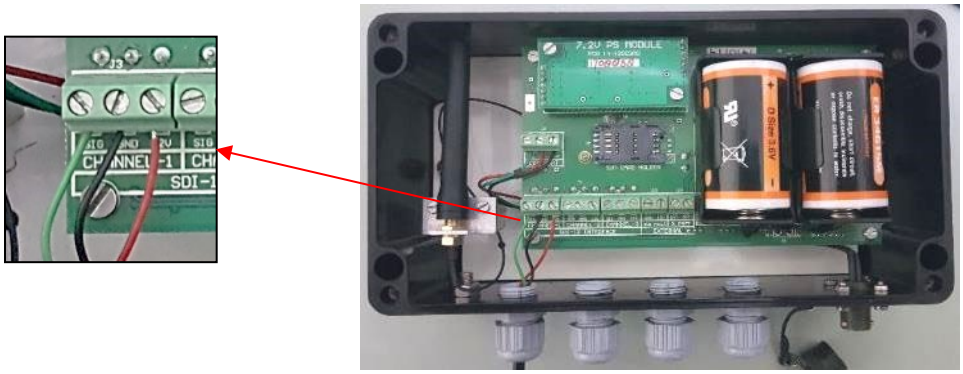


Figure 6-3 Connection of bus cable (from IPI chain) to ESDL-30 datalogger

NOTE: In an in-place inclinometer chain with SDI-12 interface connected to one port of a datalogger, IDs of the sensors cannot be repeated.

7 IPI CONFIGURATION WITH ESDL-30 DATALOGGER

7.1 Encardio-rite model ESDL-30 datalogger overview

ESDL-30 datalogger is designed to record data from the sensors connected to SDI-12 bus. The datalogger has 3 SDI-12 ports (channels). Sensors having SDI-12 interface can be connected on a common SDI-12 bus. This bus can be connected to any SDI-12 port of the datalogger. Each reading is stamped with date and time at which the measurement was taken. It has a non-volatile flash memory to store up to 2 million data points.

These data files can be downloaded to PC using Configuration Manager software by connecting logger with data cable or Bluetooth. The downloaded readings get stored in the PC's Home Directory in CSV format. The downloaded files can be transferred to FTP server using internet connection. It can be processed on any commonly available spreadsheet like Microsoft-Excel.

ESDL-30 with built in GSM/GPRS modem has capability to upload data records directly to remote FTP server. Upload schedule can be programmed in the datalogger using the software for automatic data upload to FTP server. Schedule can be set as fast as 5 minutes.

Model ESDL-30 datalogger

SDI-12 inputs have a unique ID (0-9, a-z or A-Z). Thus, the ID of sensors having SDI-12 output have to be set accordingly. Each of the 3 channels of the datalogger can have 61 sensors with ID 1-9 (ID 0 is used for factory purposes, hence not available for use), a-z or A-Z. For a given channel each sensor should have a different ID.

Connection of IPI sensor chain to ESDL-30 datalogger is shown in figure 5-2 in previous section. The IPI configuration with ESDL-30 datalogger is explained below in brief. For more details on configuration of model ESDL-30 datalogger, please refer to Users' Manual # WI 6002.110 available at our website www.encardio.com/downloads.

7.2 Sensor configuration with ESDL-30

1 Double click the SDI-12 Universal datalogger software icon on the Desktop. Then click "File" followed by "Create Site" as shown in figure 7-1 below:

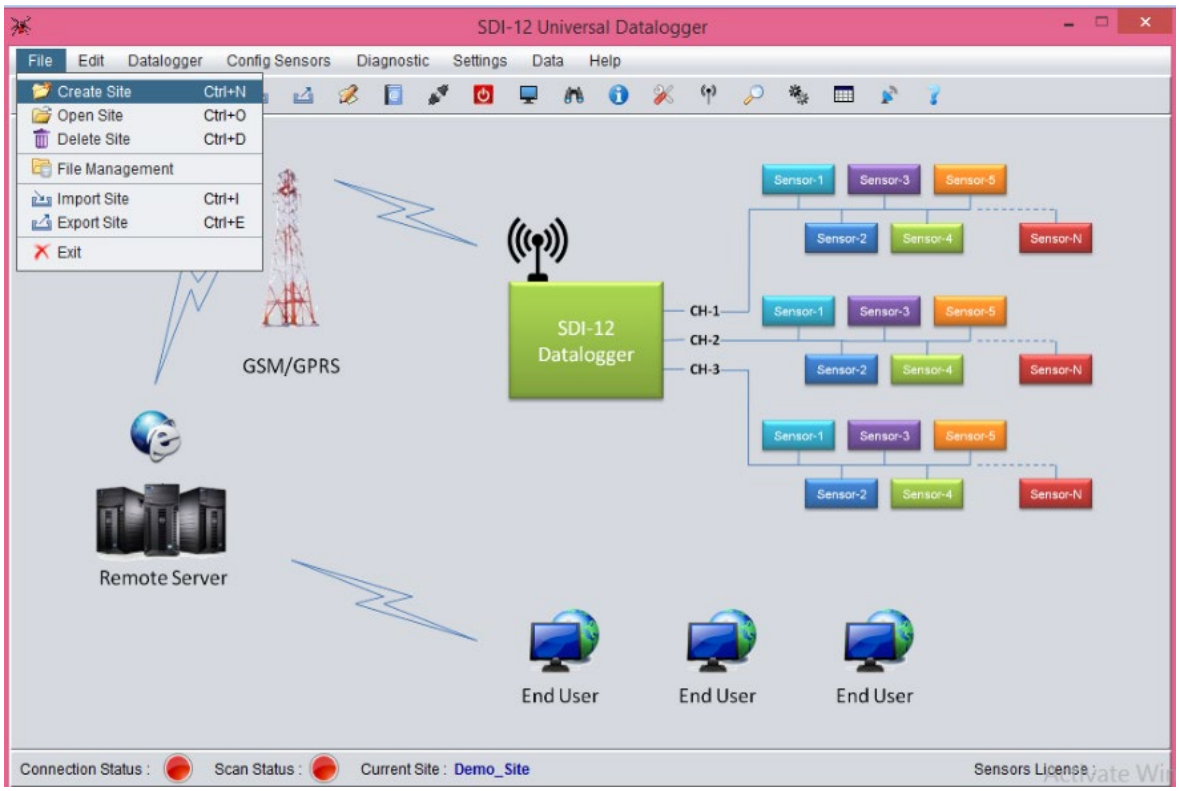


Figure 7-1 Home screen of EDSL-30UNI Configuration Manger Software

2 After clicking "Create Site", a "Create Site" window will appear as shown in figure 7-2 below. Enter "Site Name" and "Site Description". Then click "Save" button.

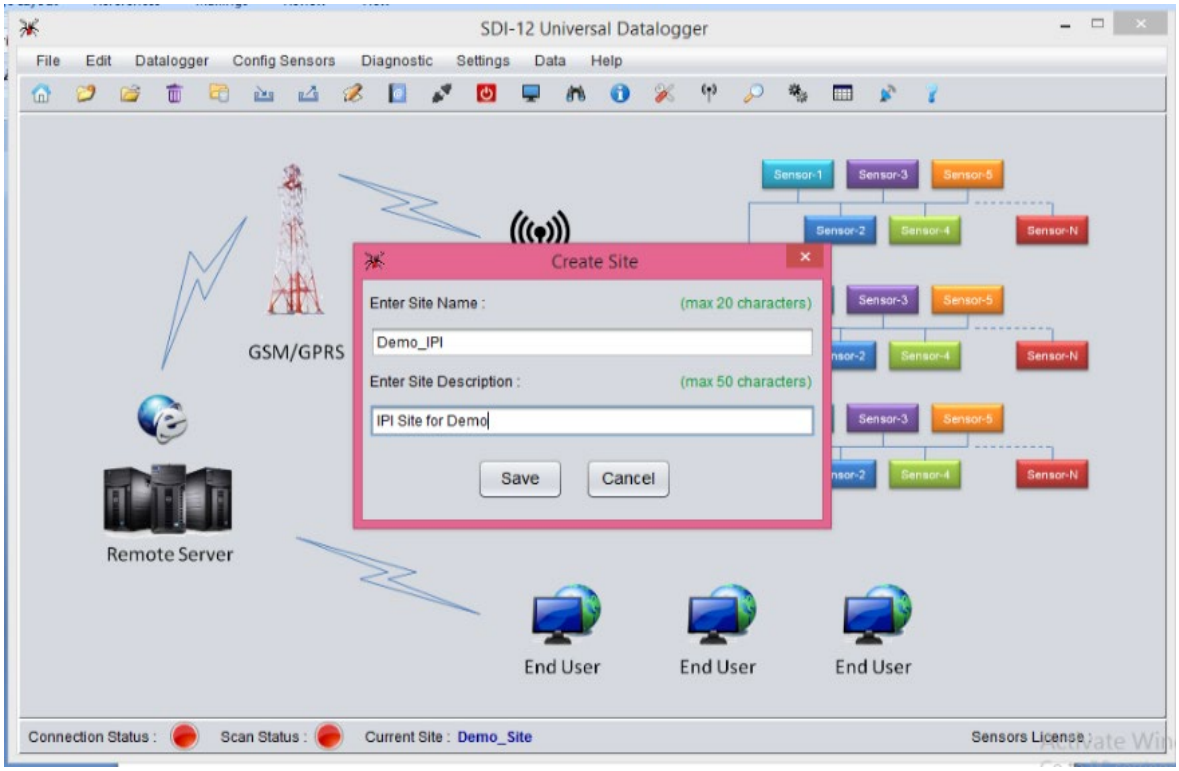


Figure 7-2 Create site window of EDSL-30UNI Configuration Manger Software

3 Then click "Datalogger" followed by "Connect/Disconnect Datalogger" as shown in figure 7-3 below.

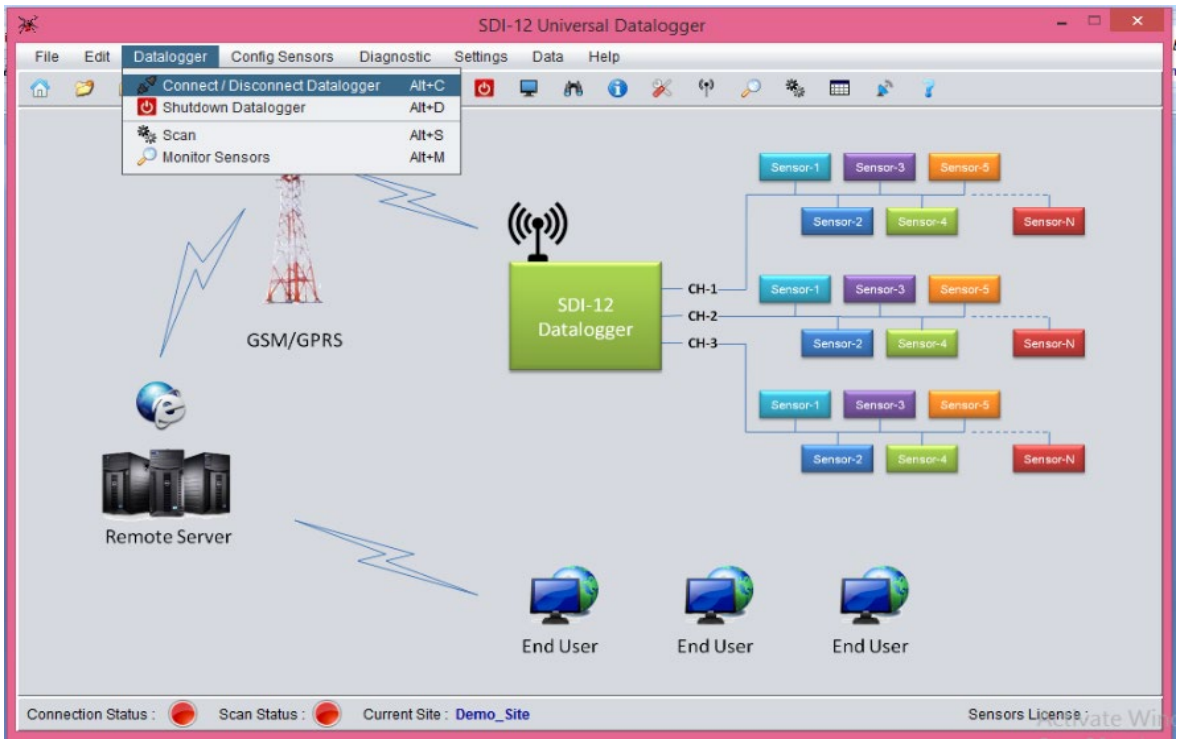


Figure 7-3 Datalogger menu of EDSL-30UNI Configuration Manger Software

4 After clicking "Connect/Disconnect Datalogger", a "Connection" window will appear as shown below. Select the usable "Com port" and then click "Connect" (figure 7-4).

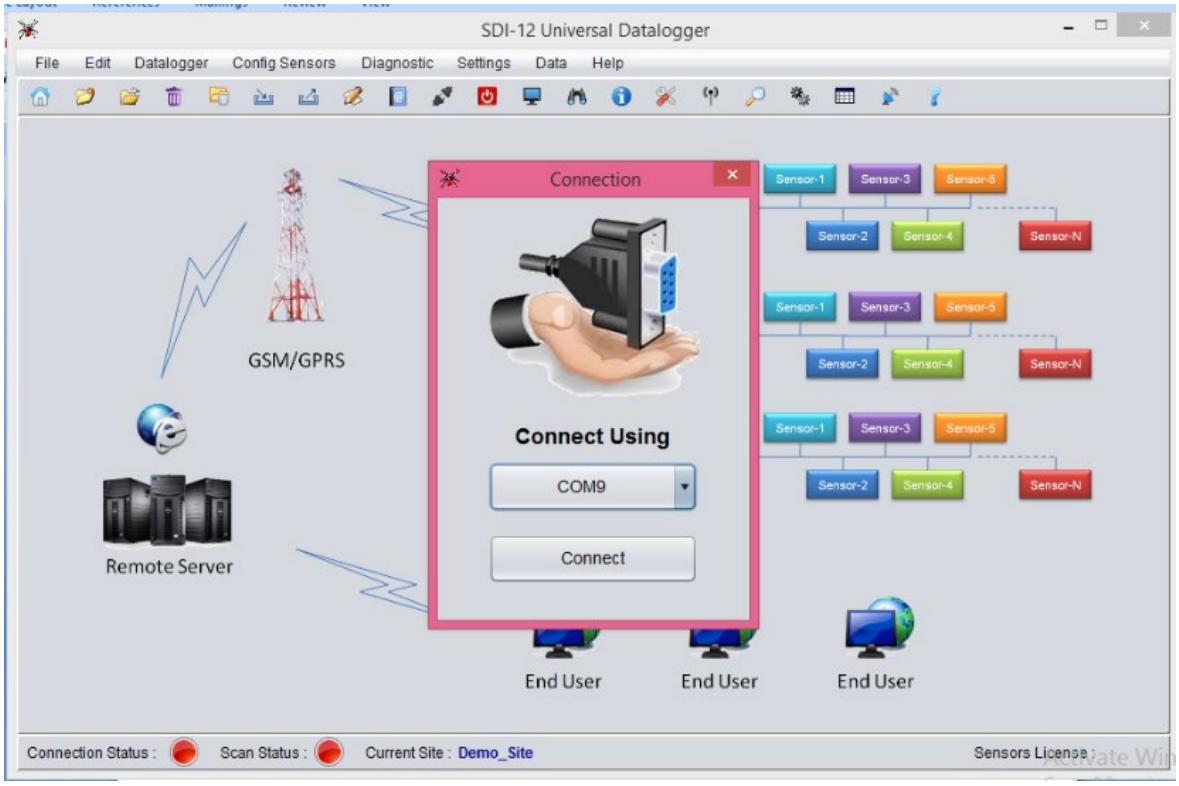


Figure 7-4 Dalalogger connection window of EDSL-30UNI Configuration Manger Software

5 Confirmation window showing Datalogger connection status will appear. Then click "OK" button. This will change the "Connection Status" from Red to Green (displayed at the bottom left in figure 7-5 below).

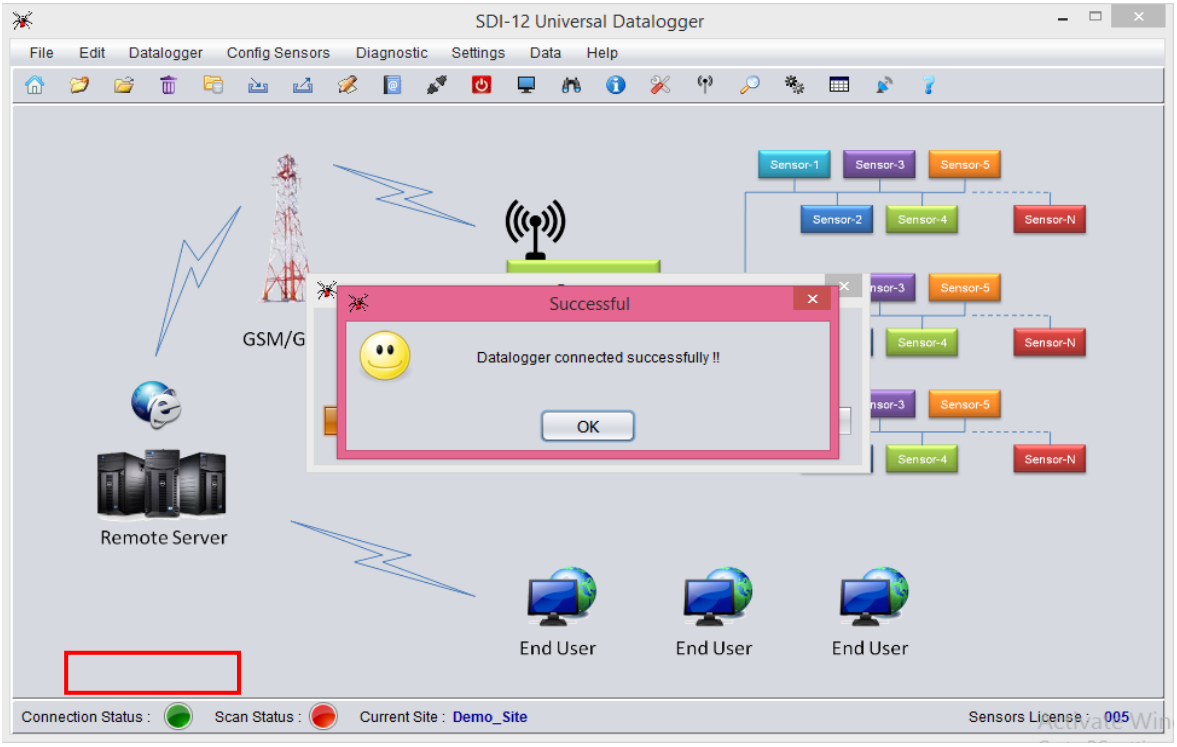


Figure 7-5 Datalogger connection status on EDSL-30UNI Configuration Manger Software

6 Then the Open Site window will appear automatically. Choose the created site file from "Select Site" dropdown menu and click "Open" (figure 7-6 and figure 7-7)

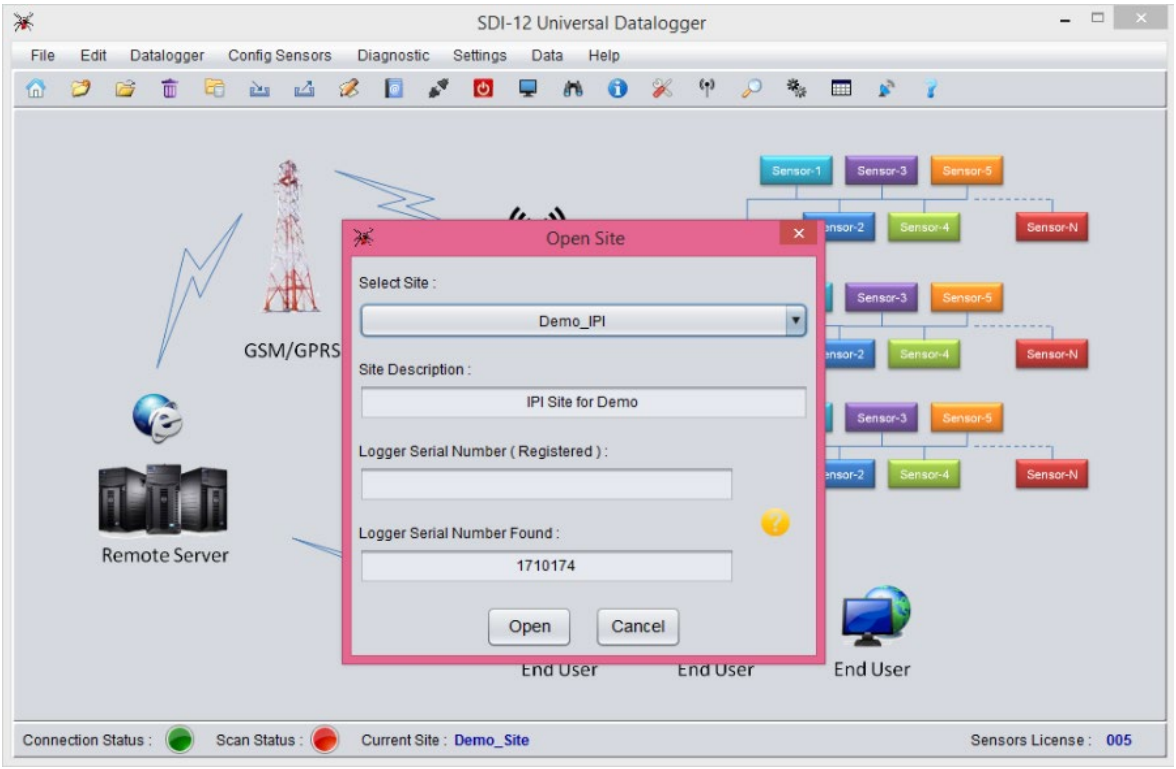


Figure 7-6 Open site window of EDSL-30UNI Configuration Manger Software

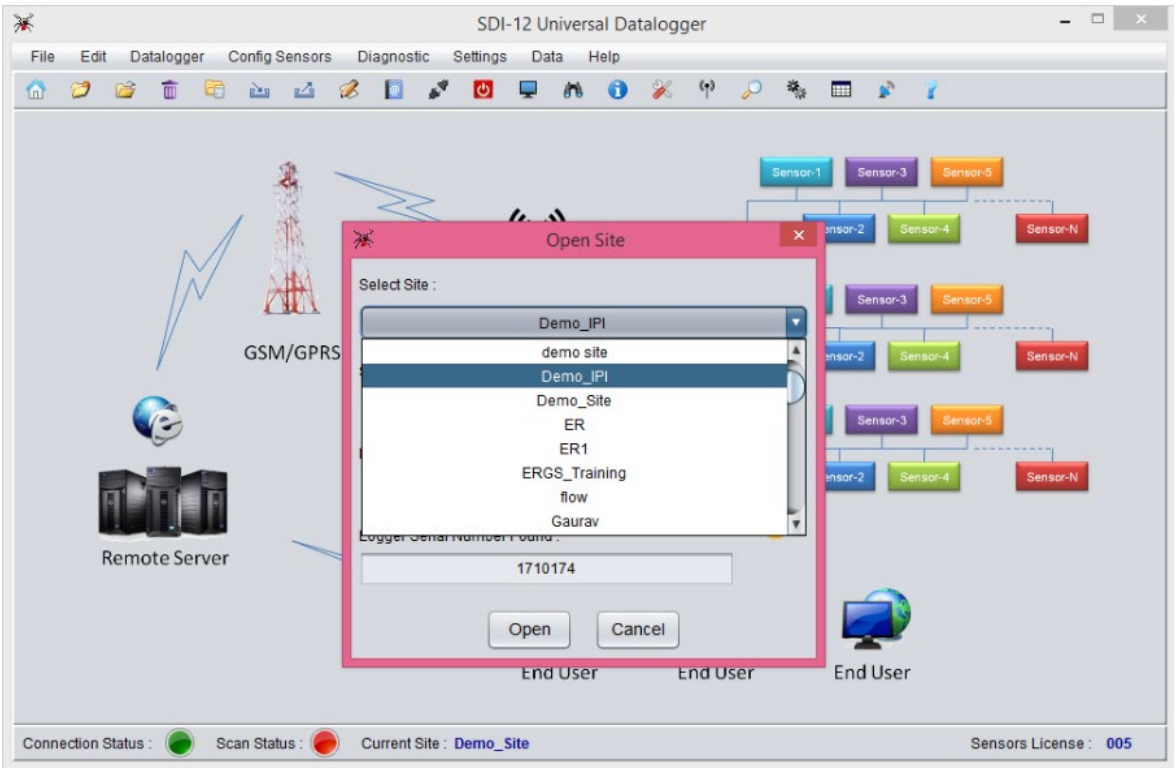


Figure 7-7 Open site window with dropdown list of sites of EDSL-30UNI Configuration Manger Software

7 Connect a single sensor to any Channel of the Datalogger physically. Click "Diagnostic" followed by "SDI-12 Terminal" to the set the ID of the sensor as shown in figure 7-8 below.

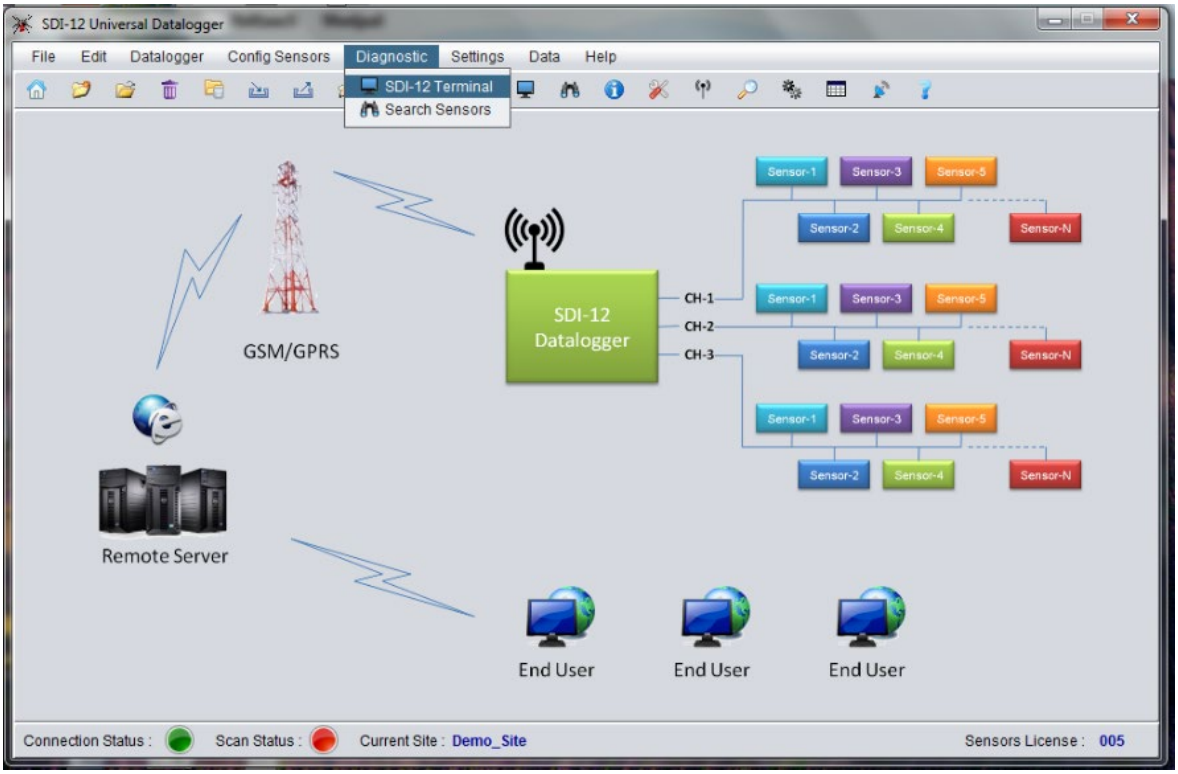


Figure 7-8 Assigning ID to SDI-12 sensor

8 In "SDI-12 Terminal" window (figure 7-9), select appropriate Channel number from the drop down list and then click "Update".

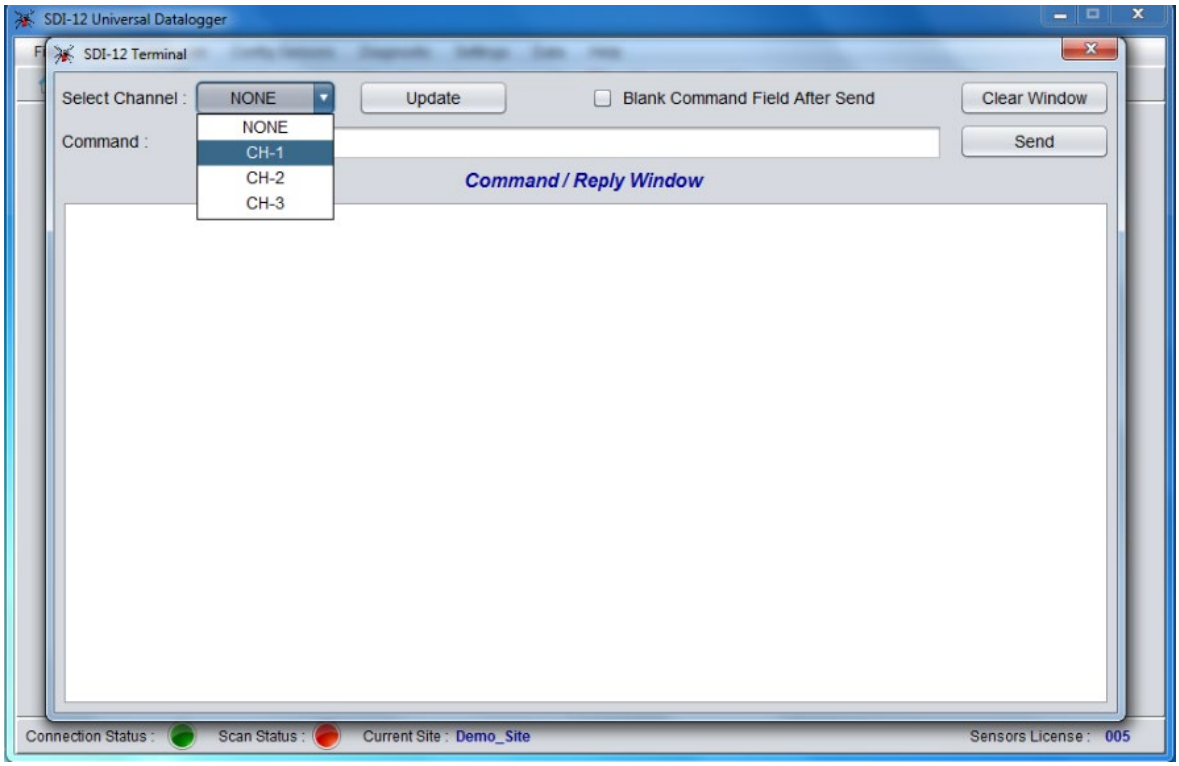


Figure 7-9 SDI-12 Terminal Window

9 Now type "?!" on the "Command" bar and click "Send" to read the sensor's present address (figure 7-10).

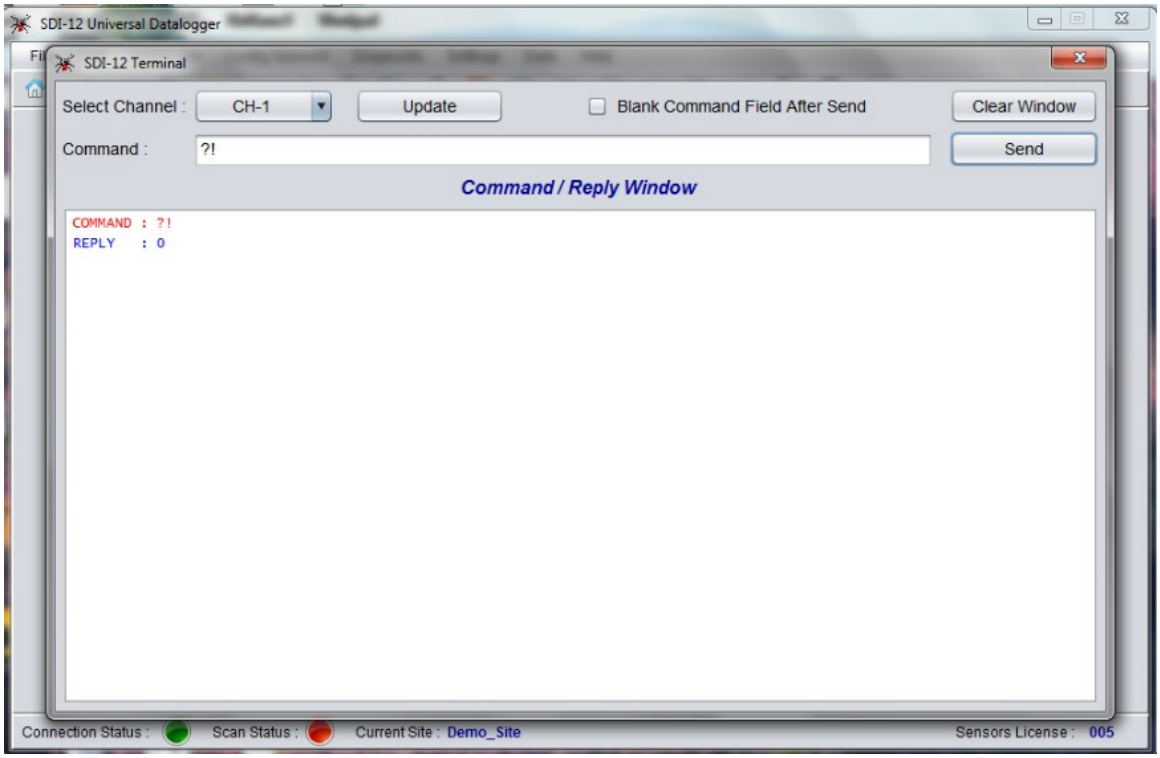


Figure 7-10 Command/Reply Window

10 To change the sensor address, type "oldaddr A newaddr !" then click "Send" as shown in figure 7-11 below. Now connect other sensors to the datalogger one by one and repeat the same procedure.

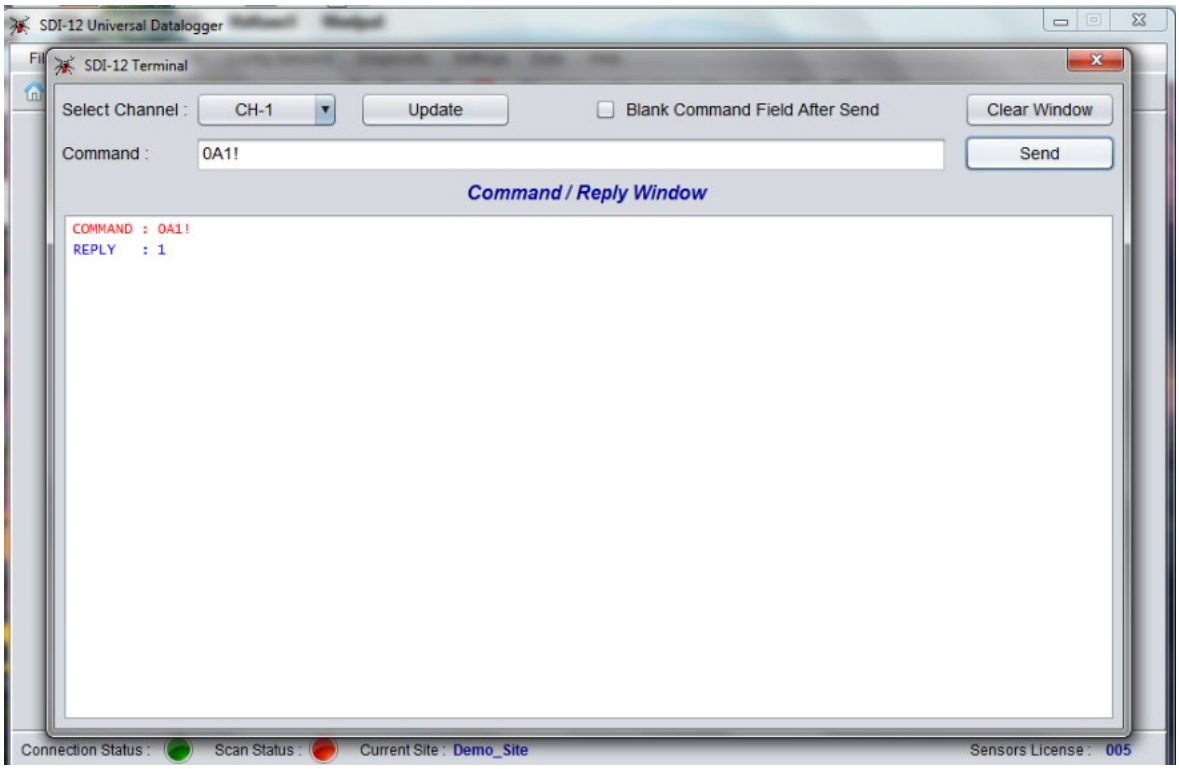


Figure 7-11 Command/Reply Window showing change in address

11 Click "Diagnostic" followed by "Search Sensors" to search the sensors connected with the Datalogger as shown in figure 7-12 below.

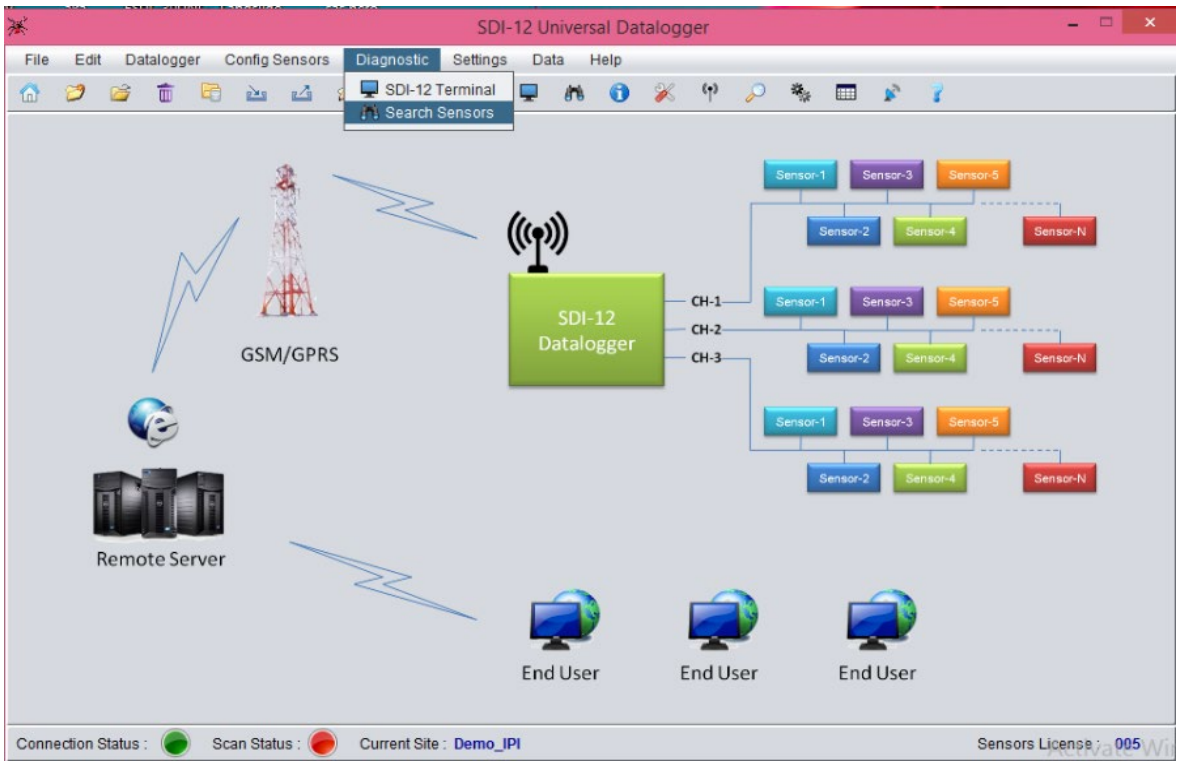


Figure 7-12 Diagnostic menu of EDSL-30UNI Configuration Manger Software

12 Click "Search Sensors" button to search all the sensors connected to the Datalogger.

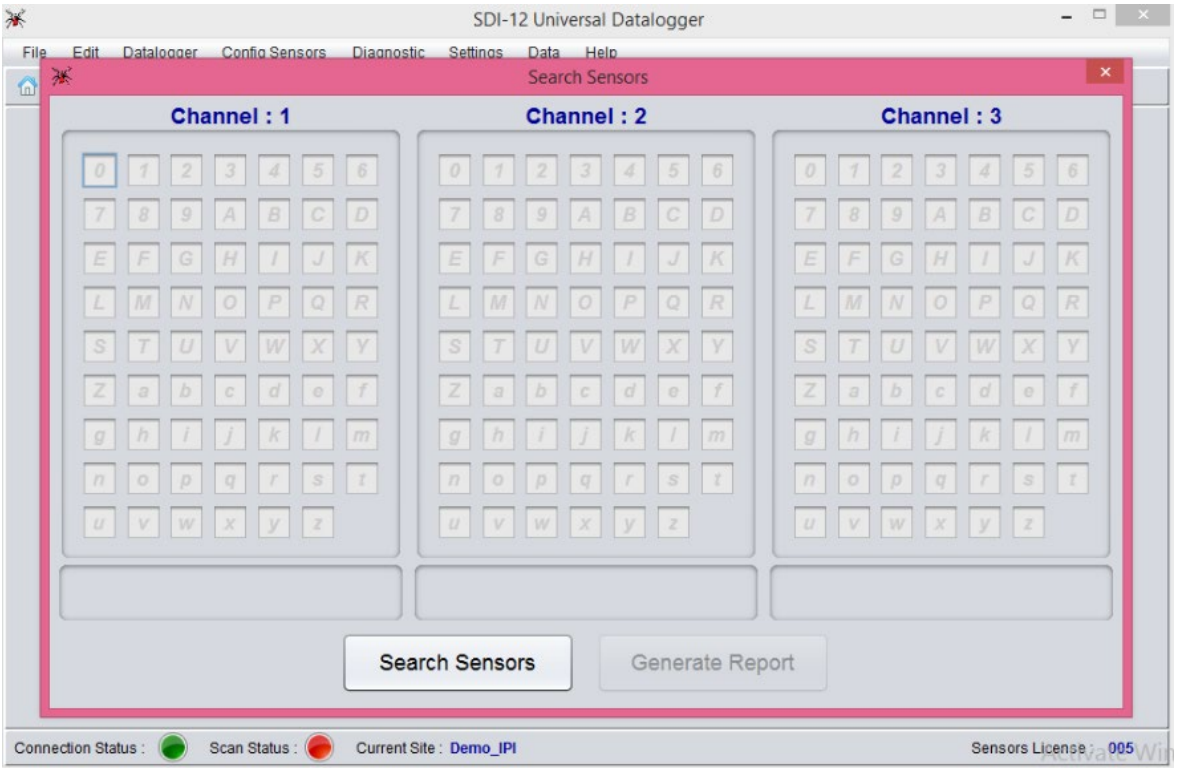


Figure 7-13 Search sensor window of EDSL-30UNI Configuration Manger Software

13 A message box showing progress of search will appear as shown in figure 7-14 below:

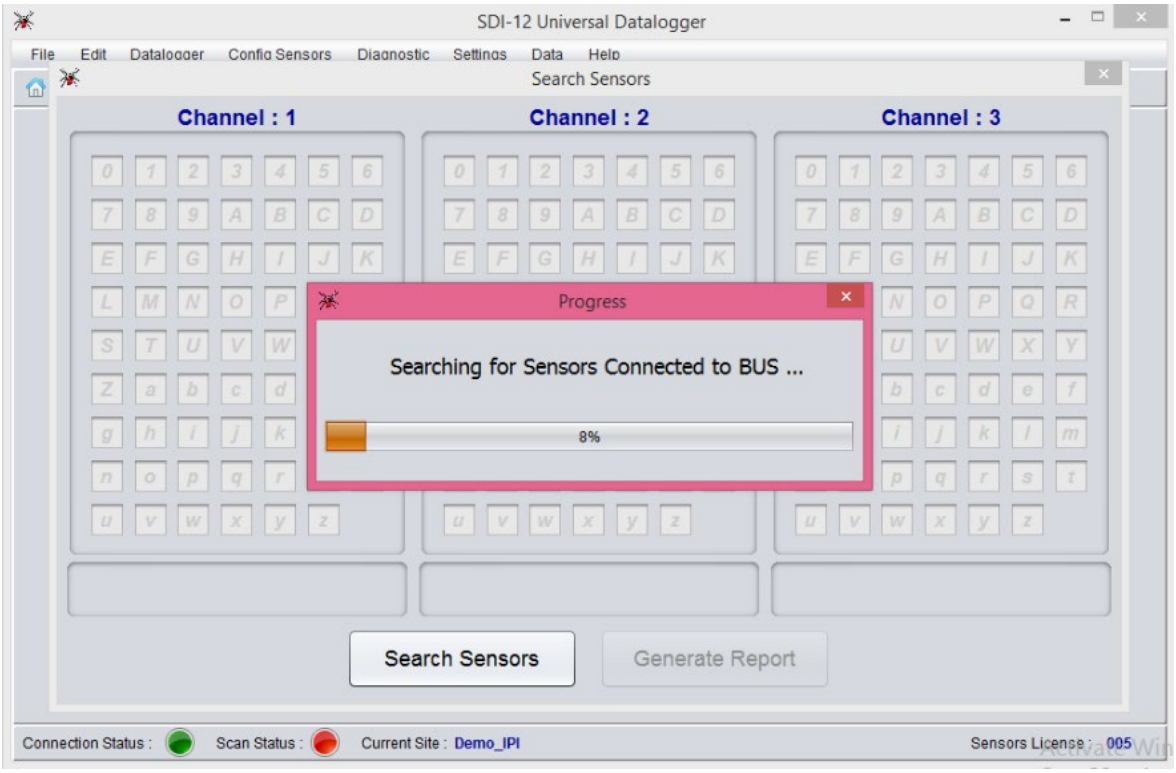


Figure 7-14 Message box showing sensor scan progress

14 On completion of search progress, addresses of sensor will be displayed (figure 7-15). Note down/generate report for later usage. Close "Search Sensors" window after use.

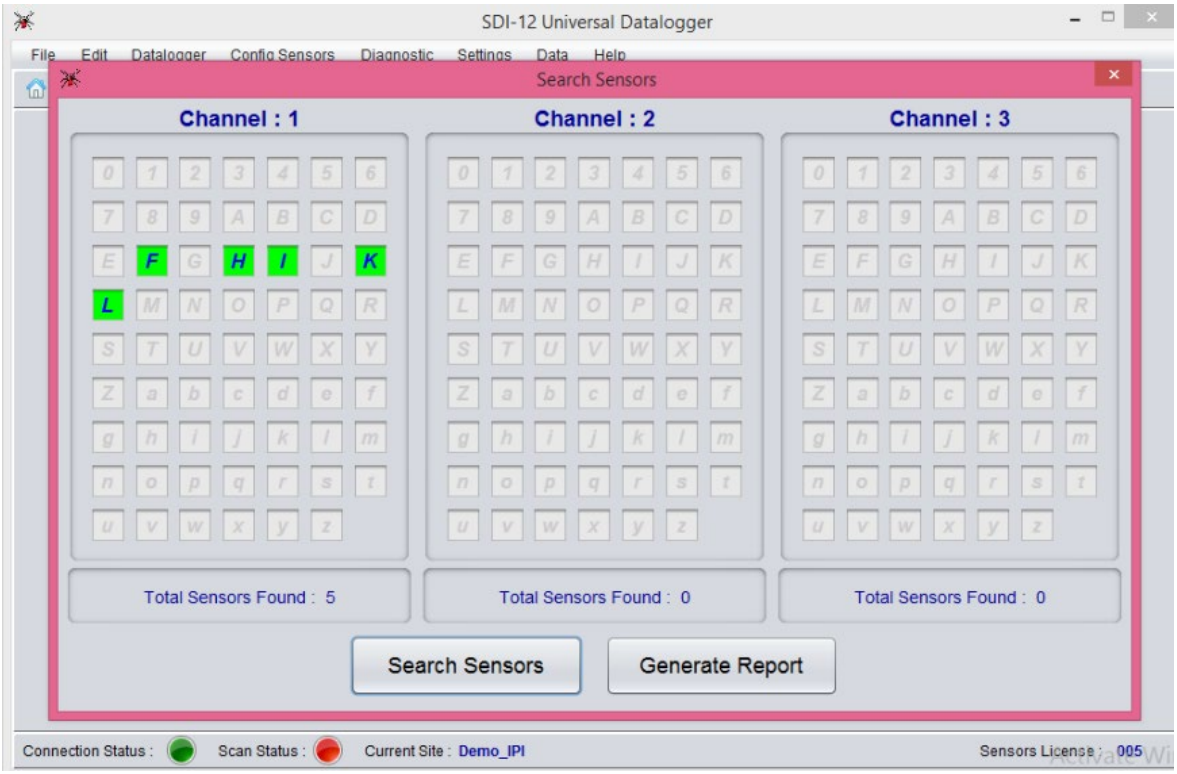


Figure 7-15 Search sensor window showing the detected sensors

15 Click "Edit" menu followed by "Sensor Table" as shown in figure 7-16 below to define the parameter name & unit of each sensor

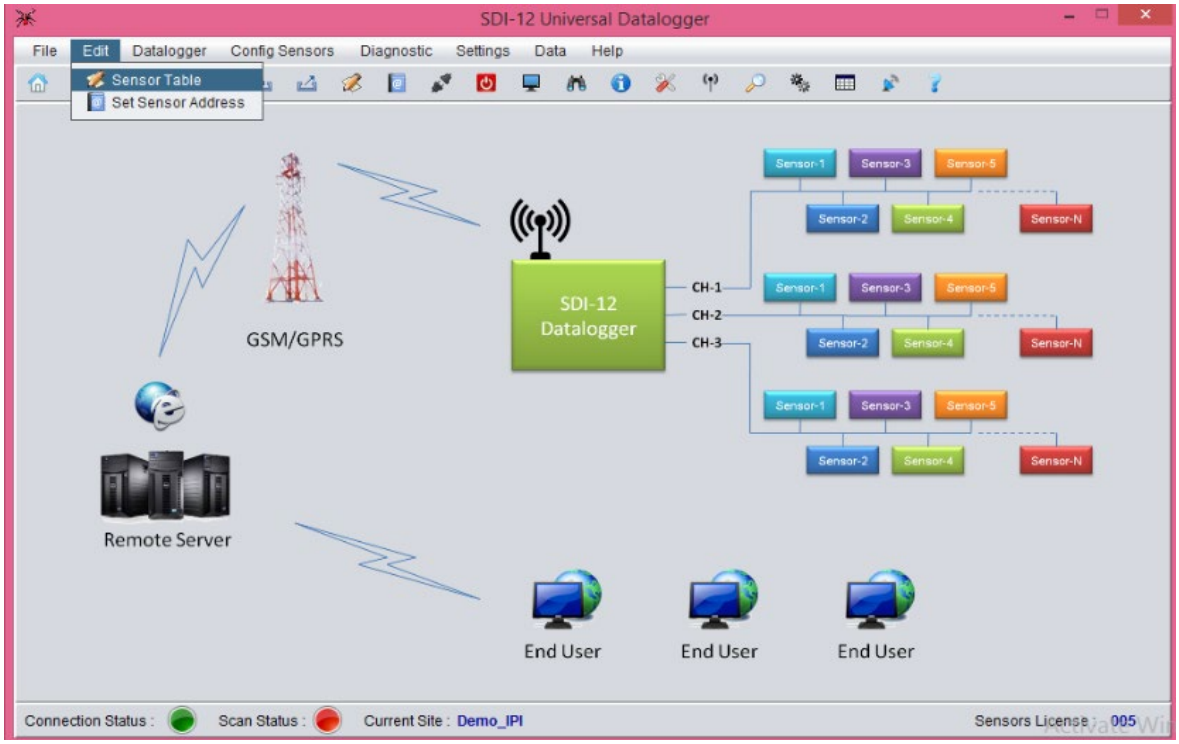


Figure 7-16 Edit menu with sensor table option of EDSL-30UNI Configuration Manger Software

16 In the "Sensor Table" window shown in figure 7-17 below, select appropriate channel from "Select Channel" & address from "Sensor Address" to which the sensor is connected. Then select the "Measurement Command Type" which is "M!" by default and "Select Number of Parameters" to be measured. Then click on "Edit Parameter Units"

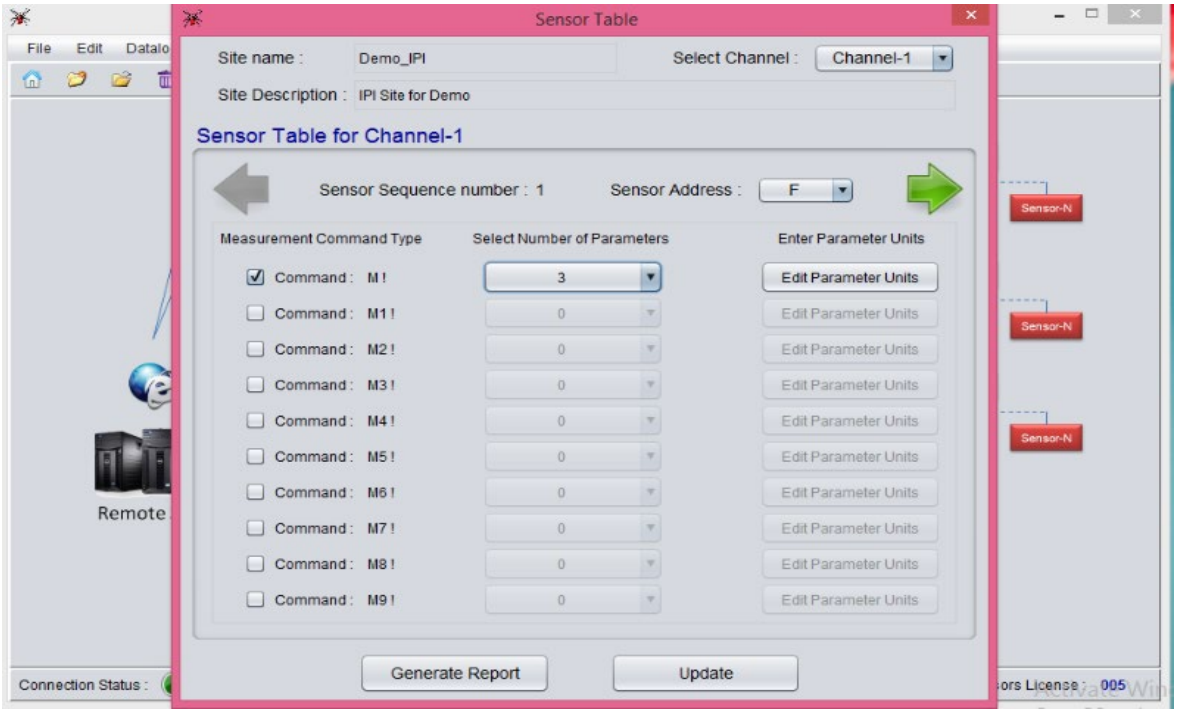


Figure 7-17 Sensor table window of EDSL-30UNI Configuration Manger Software

17 "Parameter Units" window will appear as shown in figure 7-18 below. Enter the required "Parameter Name" & "Parameter Unit". Then click "Exit"

Figure 7-18 Paramaters unit window of EDSL-30UNI Configuration Manger Software

18 Click  (figure 7-19) to define the parameters of next sensor connected and repeat the steps mentioned in Point no. 13 & 14 and so on. After defining parameters for all the sensors connected to the Datalogger, click "Update" button.

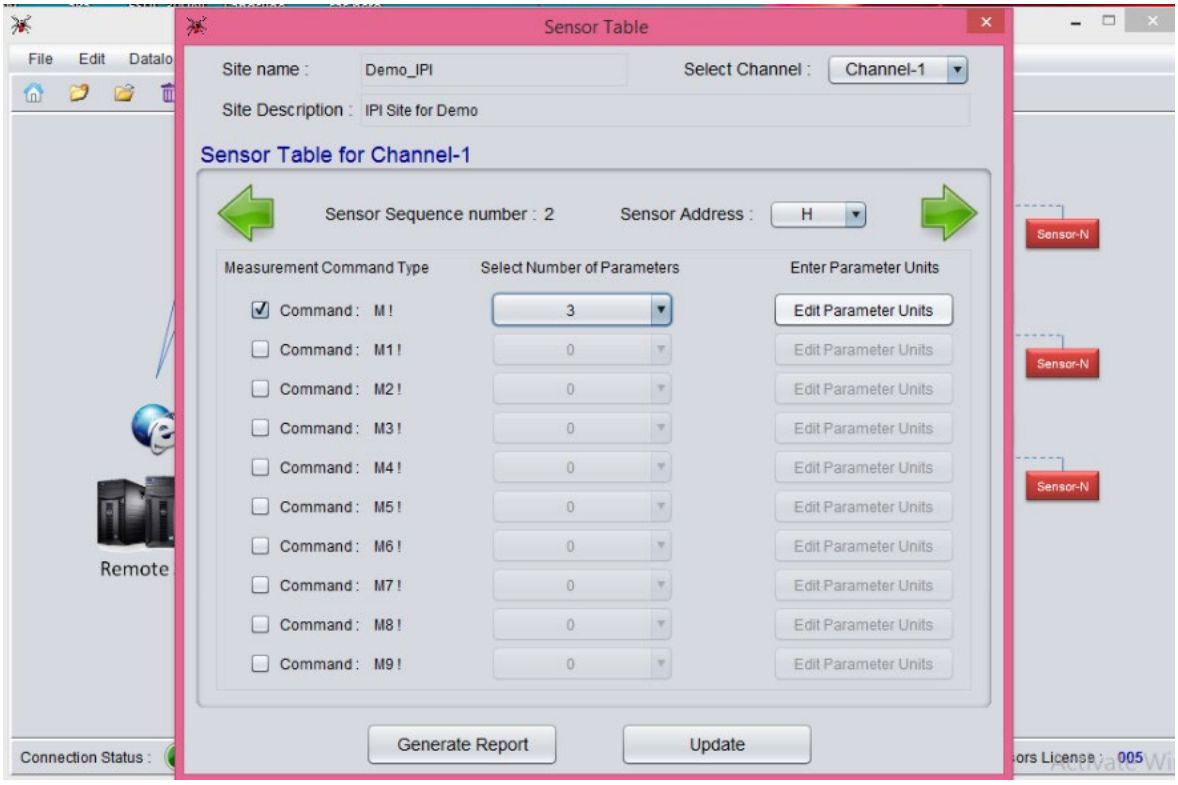


Figure 7-19 Selecting next sensor to be programmed in Sensor Table window

19 "Warning" message window will appear. Click "Yes"

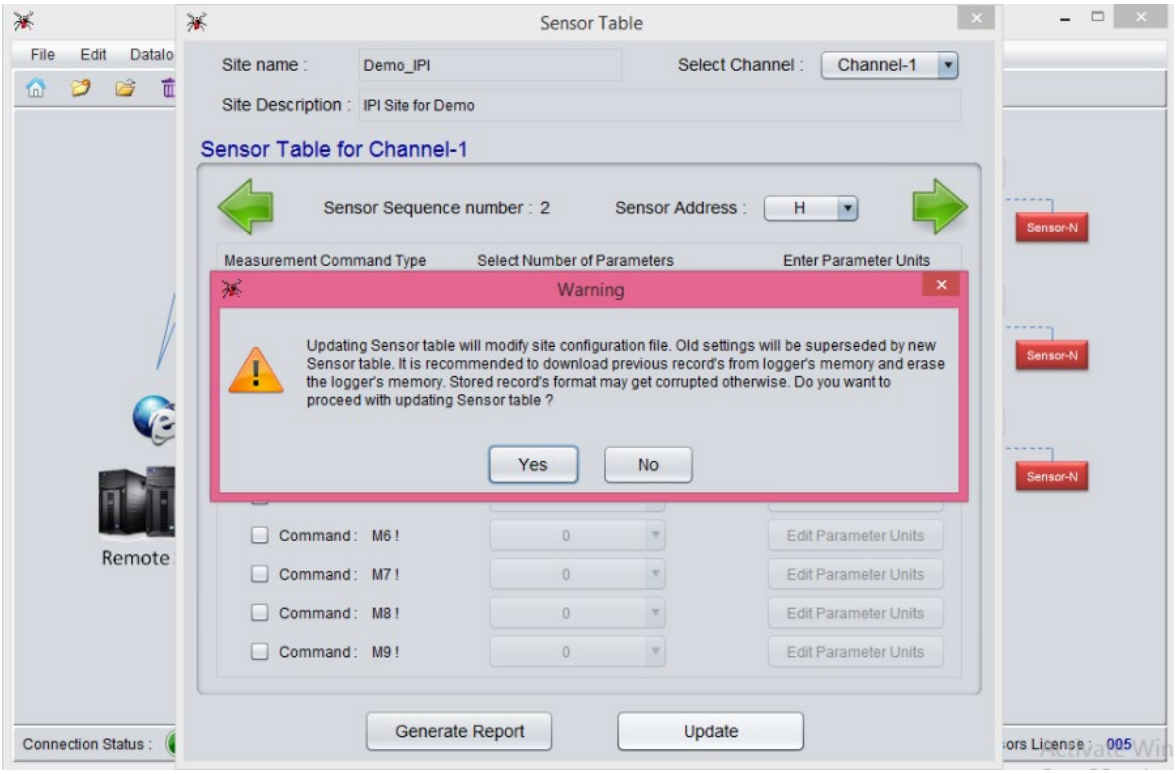


Figure 7-20 Warning message window appearing upon update of sensor table window

20 Now "Erase Memory" window will appear. Click "Yes".

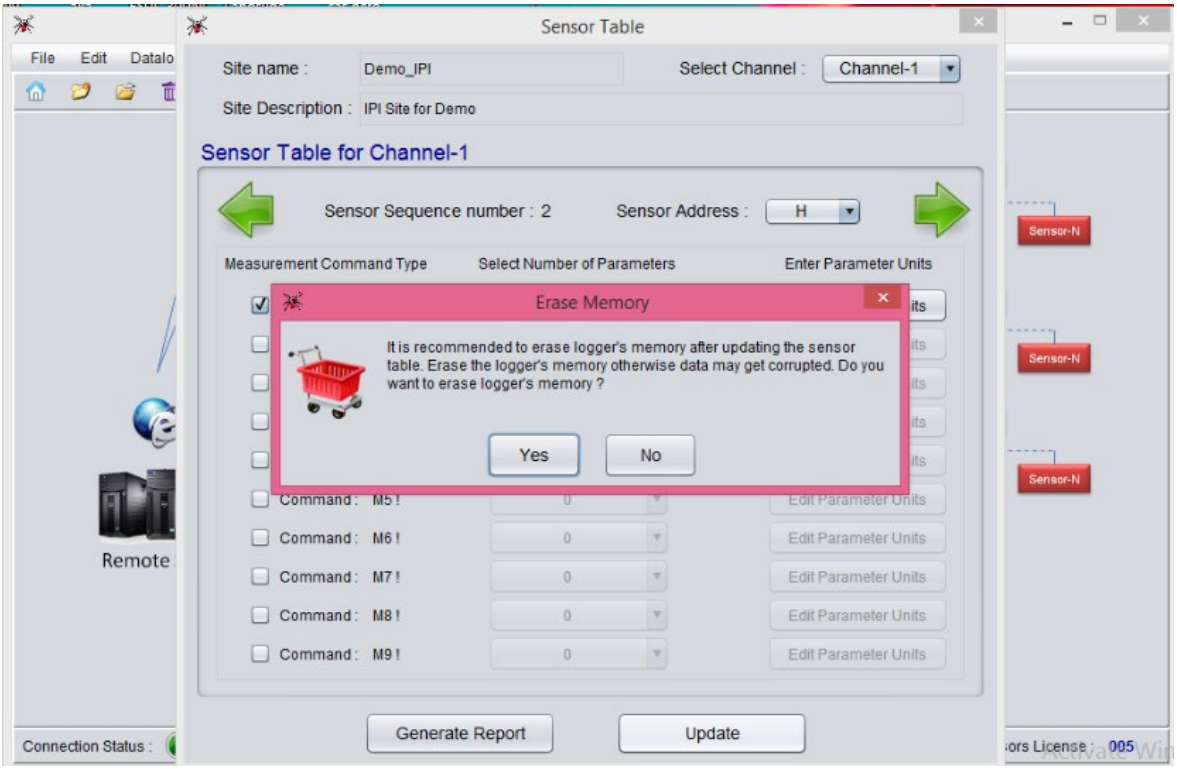


Figure 7-21 Erase memory window appearing upon update of sensor table window

21 Click on "Datalogger" menu followed by "Monitor Sensors" as shown in figure 7-22 below:

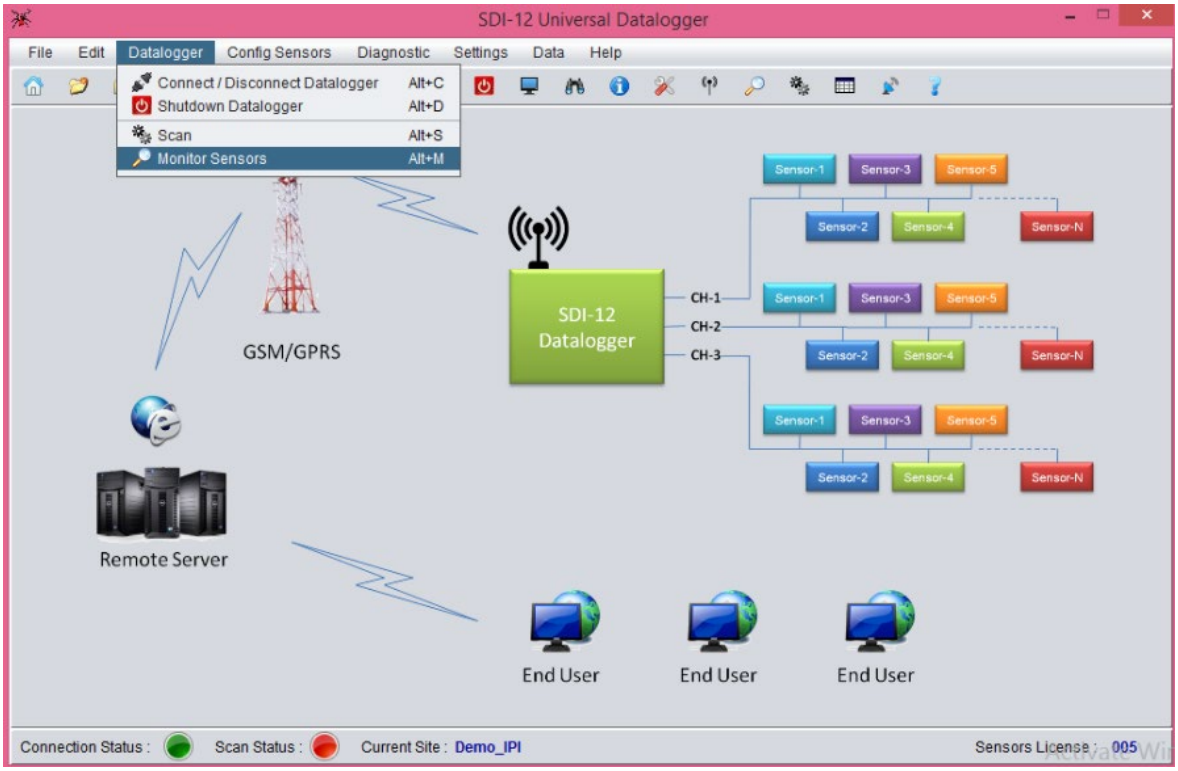


Figure 7-22 Monitor sensors option inside Datalogger menu

22 After clicking "Monitor Sensor" tab, a window will appear as shown in figure 7-23 below. Select appropriate Channel and click "Start" Button for sensor readings in Real Time

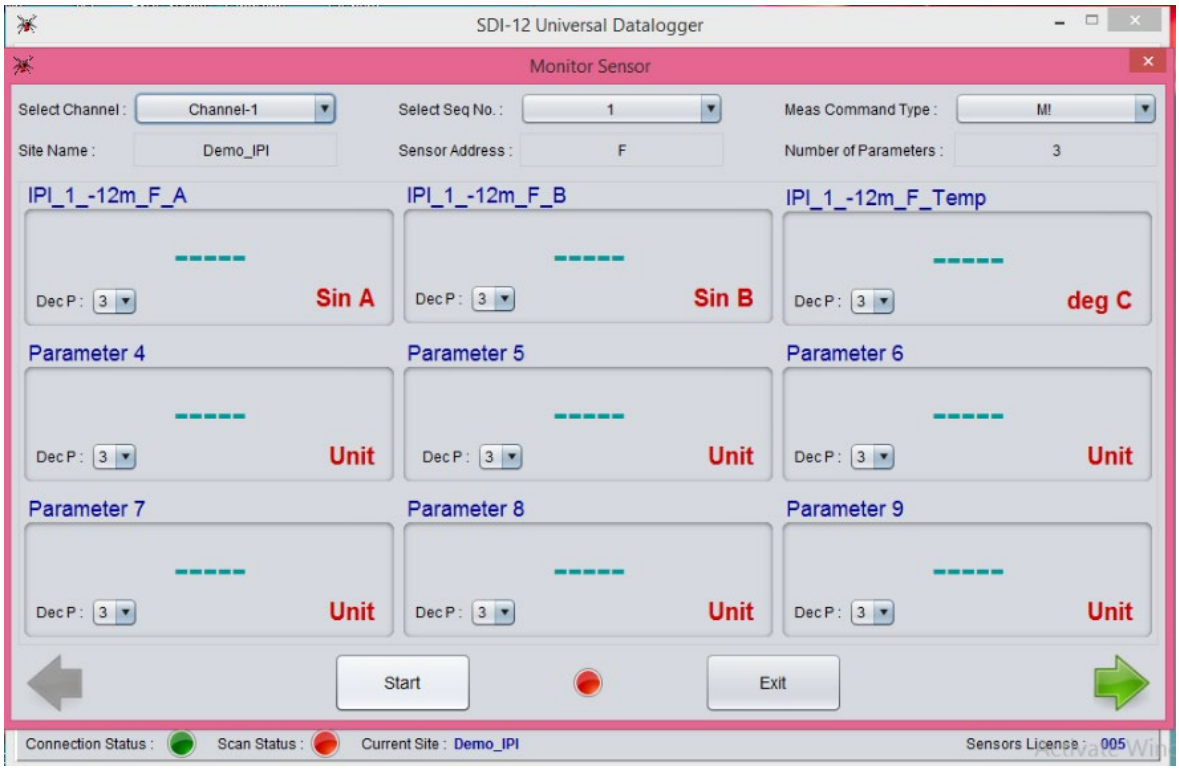


Figure 7-23 Monitor sensor window

23 Sensor readings for selected "Channel" & "Sequence no." will be displayed as shown in figure 7-24 below. Click "Exit" button to close this window.

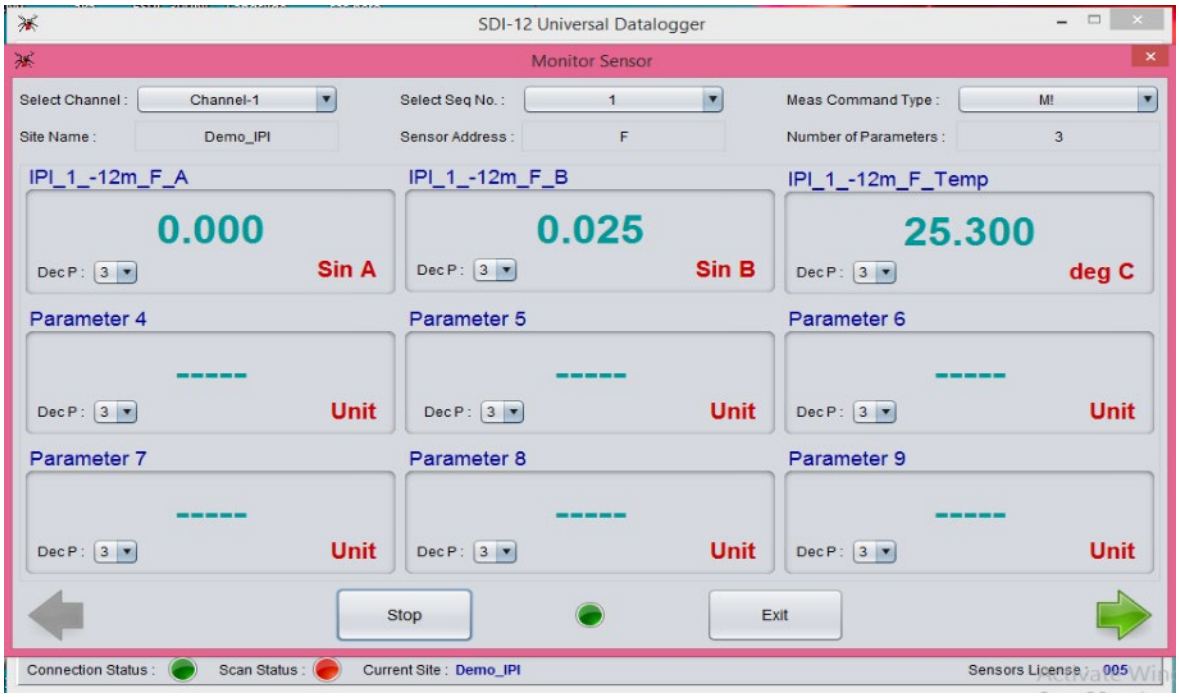


Figure 7-24 Measured sensor values appearing in Monitor Sensor window

24 Click "Settings" followed by "GPRS Modem" to configure FTP settings.

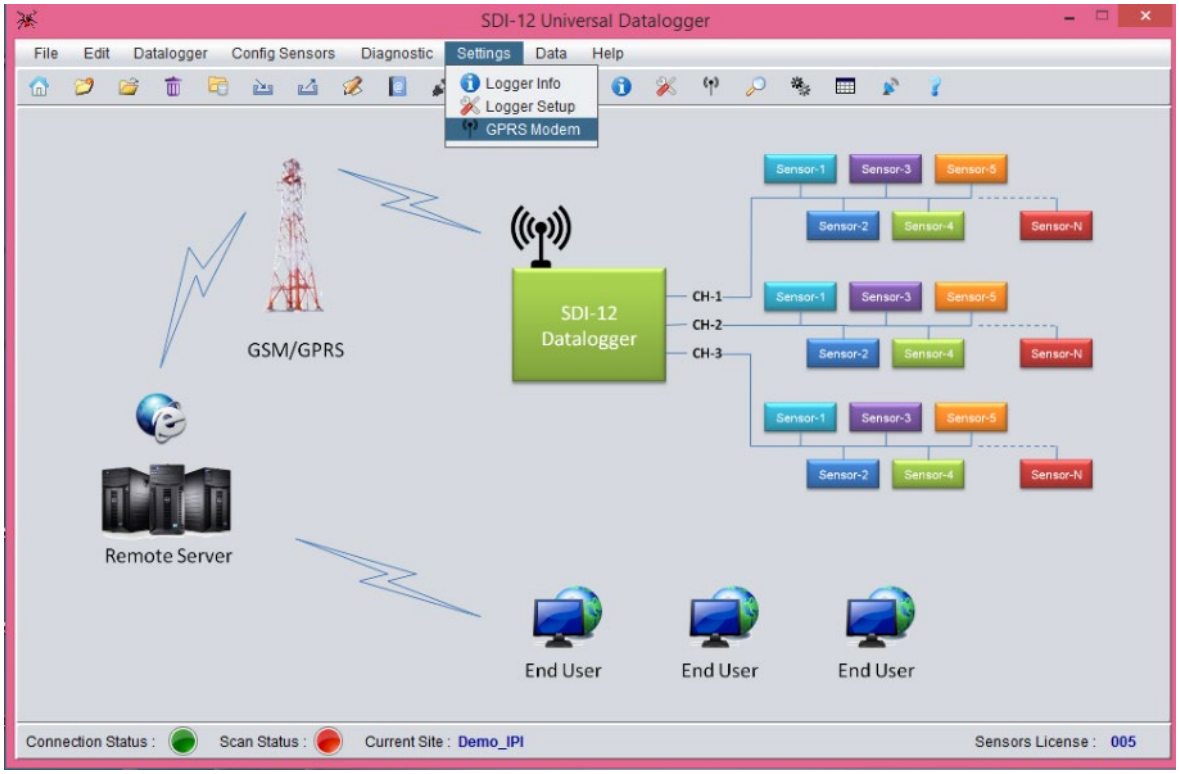


Figure 7-25 GPRS Modem option under Settings menu

25 Enter appropriate FTP credentials and click "Update". Then, set "Upload Time" as required and click update.

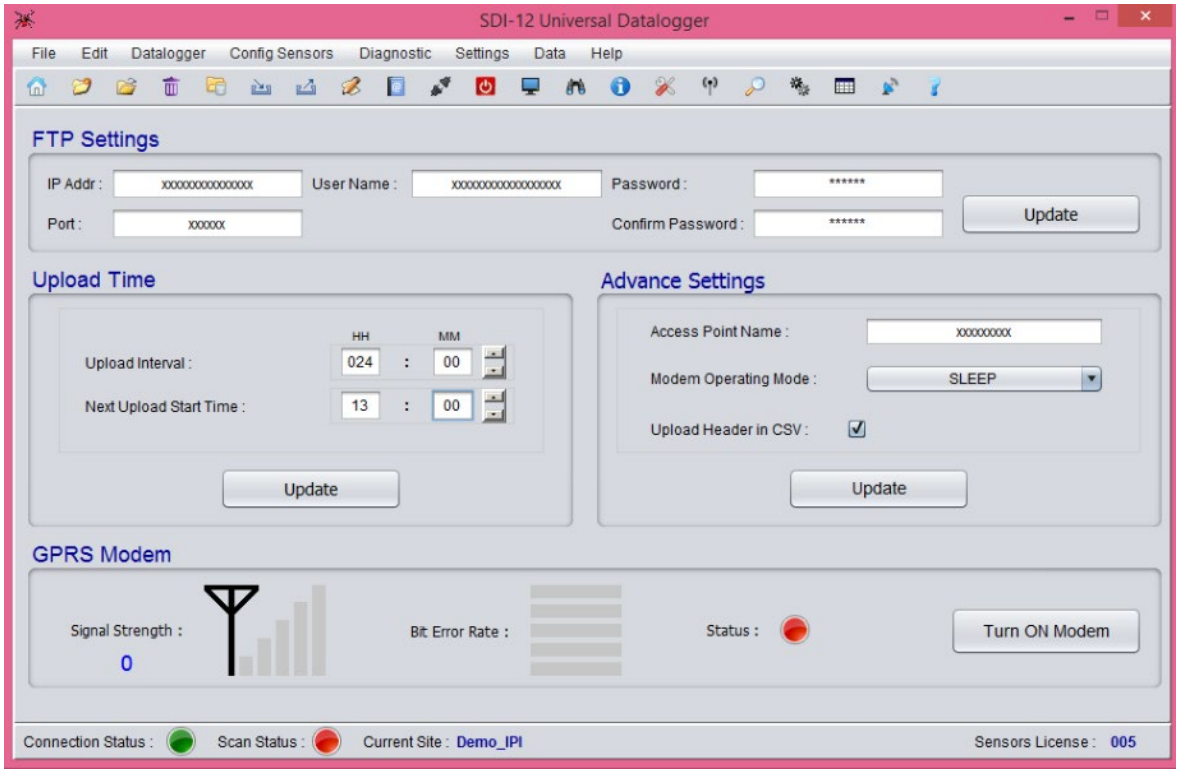


Figure 7-26 FTP settings window

26 After completing GPRS modem settings, click "Datalogger" followed by "Scan" to set the Datalogger Scan interval:

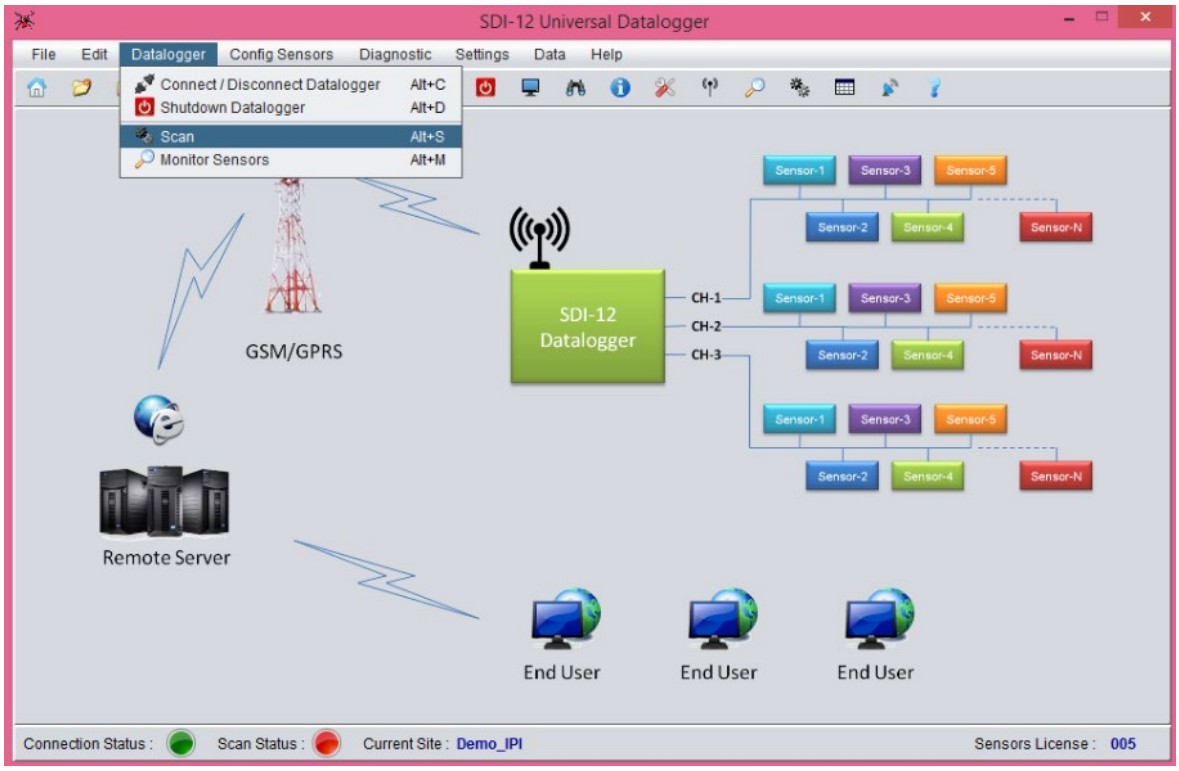


Figure 7-27 Scan option under Datalogger menu

27 Set "Scan Option" as required and click "Update"

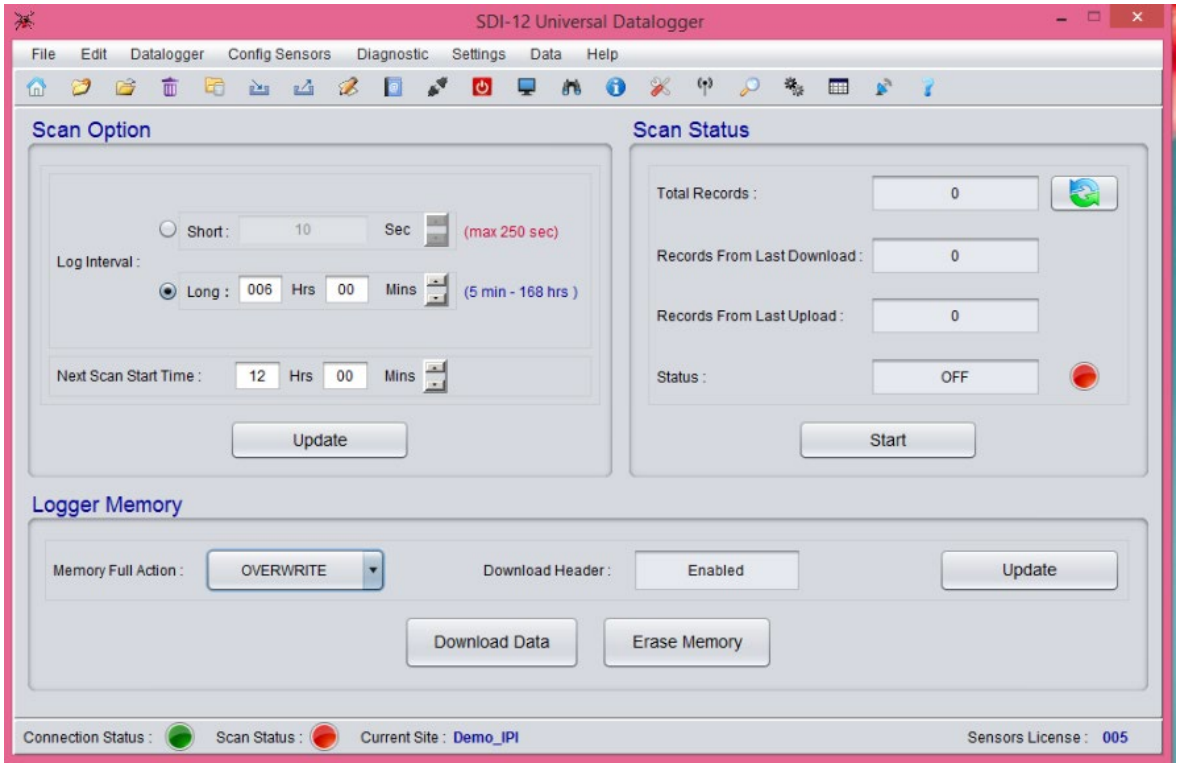


Figure 7-28 Configuring scan setting in Scan window

28 After updating, colour of "Scan Status" will change from Red to Green (as displayed at the bottom left corner of figure 7-29 below). Now click "Datalogger" followed by "Connect/Disconnect Datalogger"

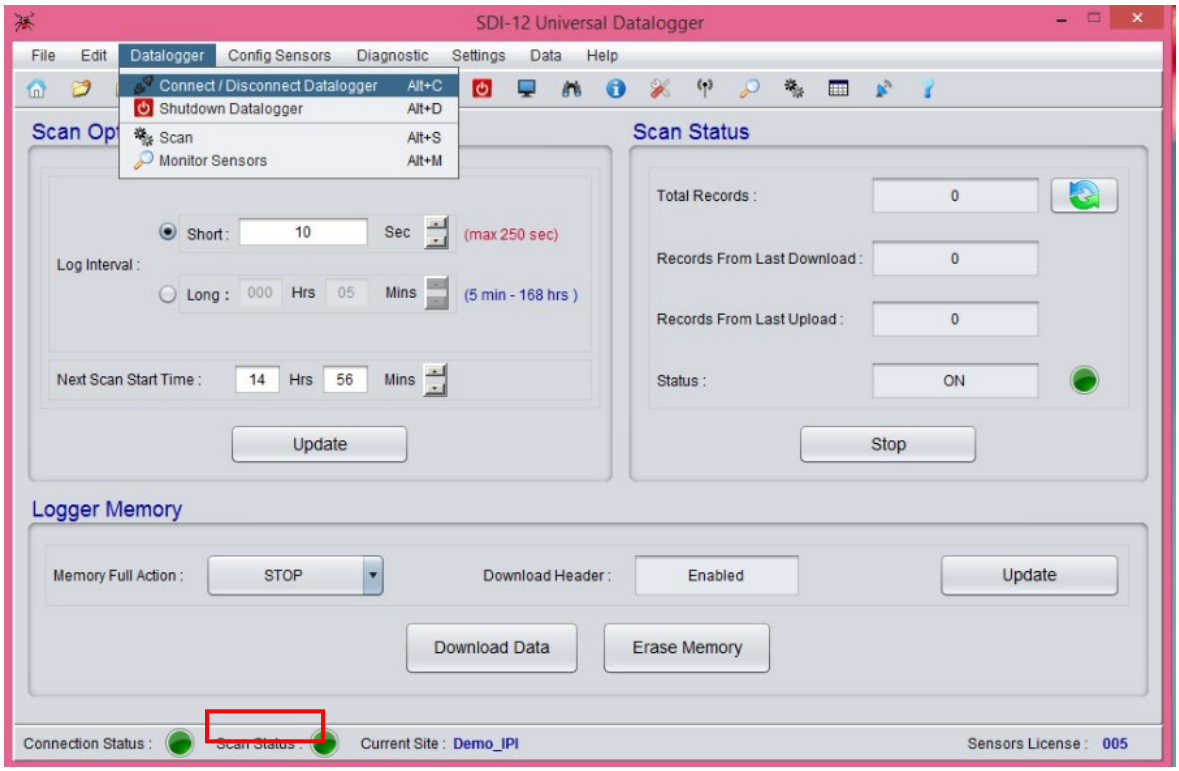


Figure 7-29 Scan status indicator in Scan window

29 Click "Disconnect" button to disconnect the Datalogger from Computer/ Laptop.

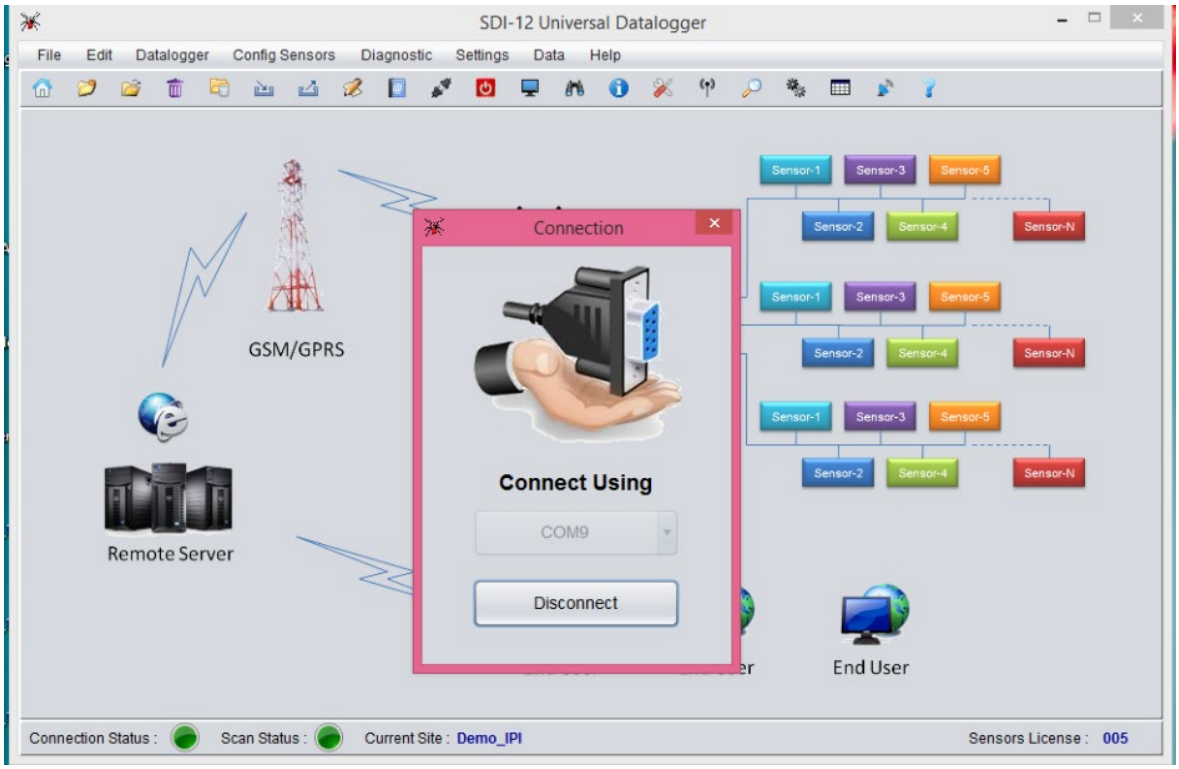


Figure 7-30 Disconnecting datalogger rom PC

8 CONNECTING IPI WITH RF NODES AND GATEWAY

Wireless sensor network are becoming vital in civil engineering and geotechnical field. Encardio-rite model EAN-56 in-place inclinometer system can be connected to any suitable RF datalogger and gateway system for real-time monitoring in challenging construction projects, with reliable data transfer over long distances without any delay.

The digital tilt sensors of the IPI chain are connected to RF datalogger (or node) that sends recorded data to the gateway, via long range, low power radio frequency with utmost reliability, eliminating the need for running lengthy cables. A single gateway can support a number of RF dataloggers/nodes and can be installed at a far distance. The gateway uploads all the collected sensor data to the central/cloud server at desired intervals, via cellular network or internet line.

A cloud-hosted data management and configuration software can be used to manage the network. The configuration can be done with an easy to use smartphone application.

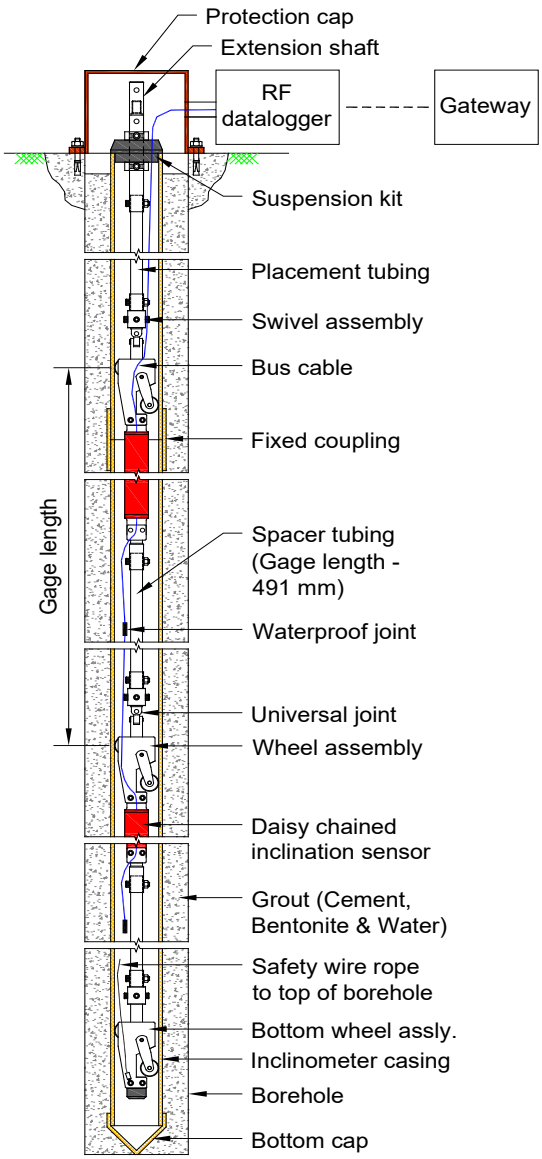


Figure 8-1 In-place inclinometer system with RF datalogger and gateway

9 WARRANTY

The Company warrants its products against defective workmanship or material for a period of 12 months from date of receipt or 13 months from date of dispatch from the factory, whichever is earlier. The warranty is however void in case the product shows evidence of being tampered with or shows evidence of damage due to excessive heat, moisture, corrosion, vibration or improper use, application, specifications or other operating conditions not in control of Encardio-rite. The warranty is limited to free repair/replacement of the product/parts with manufacturing defects only and does not cover products/parts worn out due to normal wear and tear or damaged due to mishandling or improper installation. This includes fuses and batteries

If any of the products does not function or functions improperly, it should be returned freight prepaid to the factory for our evaluation. In case it is found defective, it will be replaced/repaired free of cost.

A range of technical/scientific instruments are manufactured by Encardio-rite, the improper use of which is potentially dangerous. Only qualified personnel should install or use the instruments. Installation personnel must have a background of good installation practices as intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

The warranty is limited to as stated herein. Encardio-rite is not responsible for any consequential damages experienced by the user. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Encardio-rite is not responsible for any direct, indirect, incidental, special or consequential damage or loss caused to other equipment or people that the purchaser may experience as a result of installation or use of the product. The buyer's sole remedy for any breach of this agreement or any warranty by Encardio-rite shall not exceed the purchase price paid by the purchaser to Encardio-rite. Under no circumstances will Encardio-rite reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

A lot of effort has been made and precaution for accuracy taken in preparing instruction manuals and software. However best of instruction manuals and software cannot provide for each and every condition in field that may affect performance of the product. Encardio-rite neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damage or loss that results from use of Encardio-rite products in accordance with the information contained in the manuals or software.

Products described in Encardio-rite's catalogs are subject to modification and improvement as dictated by subsequent developments. Encardio-rite reserves the right to modify, change or improve products, to discontinue them or to add new ones without notice.