Accelerated Construction of new banks by using Nuclear Gauges for checking in-place Dry Density of Earthwork

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Synopsis

To achieve the required in-service performance of an embankment, proper control has to be exercised on the compaction of each layer of the fill material laid, which is ascertained by checking the "Degree of Compaction" or "Relative Density" of the each layer of fill material, at specified intervals. This requires in-place measurement of "bulk density" and "moisture content", which was conventionally done by "Sand Replacement Method/Core Cutter Method" and "Sand Bath Method/Calcium Carbide Method" respectively. These conventional methods take considerable time for each of the test, causing hindrance in laying subsequent layer of fill material, which can be done only after testing and clearance of underlying layer, in case of projects involving large quantity of earthworks. One of the solutions to this, which can facilitate accelerated construction of new banks, is use of "Nuclear Gauges" for rapid and non-destructive in-place measurement of "bulk density" and "moisture content" of compacted layers. Use of Nuclear Gauges gives the test results in 3-4 minutes time and it is an accepted method world over, as well as National Highways and Airport projects in India. This paper presents the basic features/principles of working of Nuclear Gauges, Working Procedure for using these gauges and feedback received from field wherein these gauges were used in Railway Projects in India.

1. Introduction

Proper compaction of fill material during construction of an embankment is one of the important parameter which decides its' in-service performance. Therefore, the compaction of each layer of compacted soil needs to be ascertained at the specified locations, in a specified pattern. Depending on the type of soil being used, the quality of compaction is ascertained in terms of "Degree of Compaction" or the "Relative Density" (ratio of "in-place dry density" of the compacted soil and "maximum dry density" obtained in the laboratory for the same soil). The "in-place dry density" of the compacted soil is calculated based on measured values of "bulk density" and "moisture content".

The conventional methods for measuring the "in-place bulk density" of the compacted soil are "Sand Replacement Method" as per IS:2720 (Part XXVIII) – 1974 and "Core Cutter Method" as per IS:2720 (Part XXIX) – 1975. For some of coarse grained soils with little fines, where taking core cutter samples is difficult, only sand replacement method can be used. But both these methods take about 20-30 minutes time. The conventional methods for measuring the "in–place moisture content" of the compacted soils are "Sand Bath method" or "Calcium Carbide Methods" as per IS:2720 (Part-II) – 1973. The "Sand Bath Method" takes 10 minutes or more time depending upon the moisture content of the soil. The "Calcium Carbide Method" takes lesser time of about 2-3 minutes. Thus, ascertaining the "in-place dry density" by the conventional methods requires about minimum 30 minutes time.

As per RDSO Guidelines, minimum one dry density test has to be conducted for every 500 m^2 surface area of compacted earthwork. The top width of newly constructed embankment for BG will be about 8.85m (including 500mm extra width on both sides for trimming off later on). For a 10m high embankment, the bottom width of the embankment will be 28.85m (with 2H:1V Side Slope), requiring one dry density test for every 17m length and the next layer of the fill material can be laid only when the underlying layer is tested & cleared. In case of projects with large quantity of earthwork, carrying out these tests by conventional methods requires deployment of multiple testing batches and causes hindrance in accelerated construction of embankments. For an example, the Dedicated Freight Corridor (DFC) had reported that in their work of Western Corridor between Rewari – Iqbalgarh total quantity of earthwork & blanketing is assessed as 512.0 Lakhs m^3 and use of conventional methods was taking more than a day to give clearance for laying of next layer of embankment.

One of the alternatives to facilitate accelerated construction of new banks is to use Nuclear Gauges for in-place measurement of "bulk density" and "moisture content" of compacted layers, which is an accepted method world over for more than 20-30 years. The non-destructive nature of the test allows repetitive measurements at a single test location and statistical analysis of test results.

2. Basic Features and Working Principle of Nuclear Gauges

2.1 General

Fig. 1: Nuclear Moisture Density Gauge

Nuclear moisture/density gauges use low level radiation to measure the bulk/wet density and moisture content of soil and granular construction materials, to conduct quality checks on railway formations. It is simple equipment with computer backup to assess moisture content, density and degree of compaction in the field. Most of the gauges now-a-days combine the facilities for determination of density and moisture content both in the same gauge. Large number of tests with data acquisition and storage facilities can be done in short time with lesser manpower as compared to the conventional methods.

2.2 Apparatus

Nuclear gauges contain a source of Gamma rays for density measurement and a source of Neutrons for moisture measurement. Density measurement is based on the scattering and absorption of gamma radiation which in-turn can be related to the density of the material being tested. Moisture measurement is based on the slowing down (thermalisation) of fast neutrons, which is a function of the hydrogen content of the material being tested. The measurements are made by detectors built into the gauges which are displayed as counts. While exact details of construction of the apparatus may vary, the system shall consist of:

(i) Gamma Source: A sealed source of high-energy gamma radiation, such as Cesium or Radium.

(ii) Gamma Detector: Any type of gamma detector such as a Geiger-Mueller tube(s).

(iii) Fast Neutron Source: A sealed mixture of a radioactive material such as Americium, Radium and a target material such as Beryllium, or a neutron emitter such as Californium-252.

(iv) Slow Neutron Detector: Any type of slow neutron detector such as Boron Trifluoride or Helium-3 proportional counter.

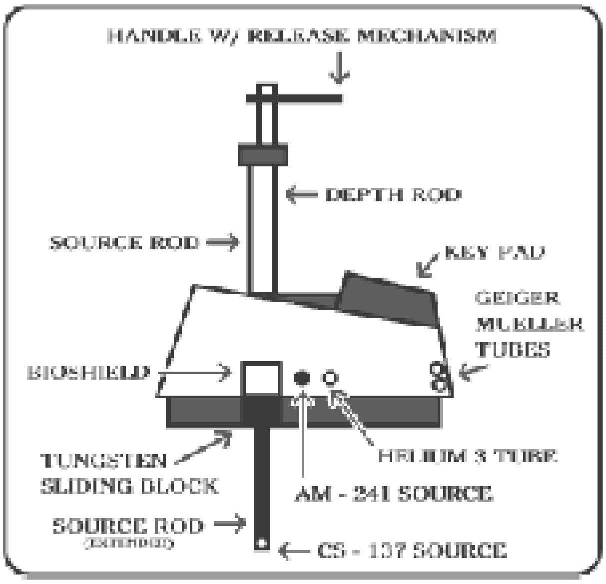

Fig. 2 : Parts of a typical Nuclear Gauge

(v) Reference Standard: A block of material used for checking instrument operation, correction of source decay, and to establish conditions for a reproducible reference count rate. Each nuclear gauge is provided with a standard reference block which needs to be kept with the gauge, and is used for determining standard counts both in the laboratory and in the field. Use of a standard reference block from another nuclear gauge is not technically valid.

(vi) Site Preparation Device: A plate or straightedge or other suitable leveling tool used for levelling the test site to the required smoothness, and in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.

(vii) Drive Pin: A pin of slightly larger diameter than the probe, used to prepare a hole in the test site for inserting the probe:

(viii) Drive Pin Guide: A fixture that keeps the drive pin perpendicular to the test site. Generally part of the site preparation device.

(ix) Drive Pin Extractor: A tool that is used to remove the drive pin in a vertical direction so that the pin will not distort the hole in the extraction process.

(x) Hammer: Heavy enough to drive the pin to the required depth without undue distortion of the hole.

Fig. 3 : Site preparation Device with Drive Pin and Hammer etc.

2.3 Modes of working

Two alternative modes of working are provided in these gauges:

(i) Direct Transmission Mode

This mode involves placing the detector on the surface and the source at a known depth up to 300 mm within the material. The gamma source rod extends through the base of the gauge into a pre-formed hole to a desired depth. Measurement positions are normally provided to a depth of 300 mm in increments of 25 mm. The wet density of soil is measured by the attenuation of gamma radiation. This is preferred mode for Density Measurement and should be used where possible because of its deeper zone of influence.

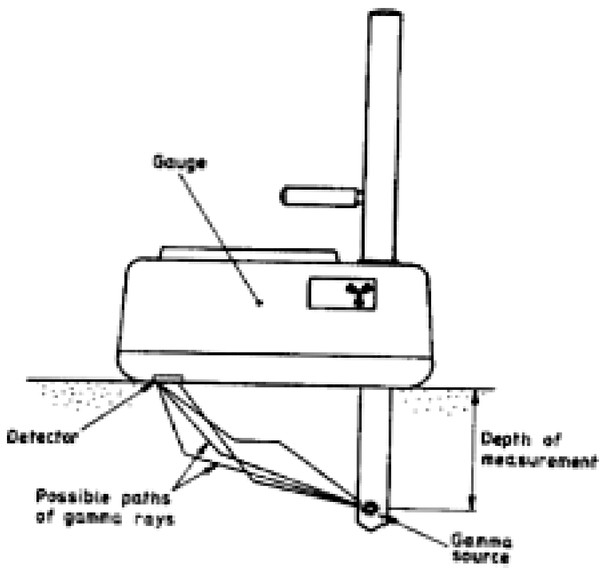

Fig. 4 : Direct Transmission Mode

(ii) Backscatter Mode
In this mode, the gamma and neutron sources and the detectors are kept at the surface. The gamma radiation emitted from the source is scattered back towards the detector to be measured. Moisture Density can be determined only by using the backscatter mode. This mode is less precise than the direct transmission method and is not used for the measurement of soil density. However, some gauges permit measurement of moisture density while at the same time measuring bulk density by either mode of operation. The effective measurement depth for moisture content varies according to the moisture content of the material and decreases with increasing moisture content. The gauge is calibrated to read the water mass per unit volume of soil.

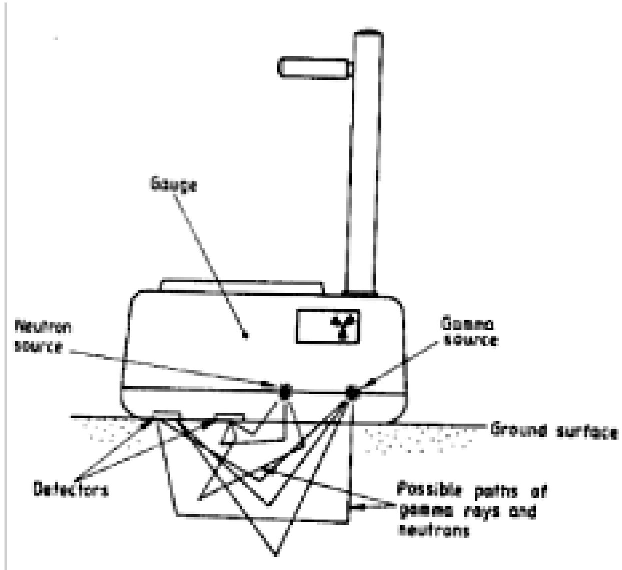

Fig. 5 : Backscatter Mode

2.4 Interferences

2.4.1 In-situ Density Interferences

The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material test is homogeneous.

(i) Measurements may be affected by the chemical composition of the material being tested.

(ii) Measurements may be affected by non-homogeneous soils and surface texture.

(iii) Measurements in the Backscatter Mode are influenced more by the density and water content of the material in close proximity to the surface.

(iv) Measurements in the Direct Transmission mode are an average of the density from the bottom of the probe in the soil back up to the surface of the gauge.

(v) Oversize particles or large voids in the source-detector path may cause higher or lower density measurements. Where lack of uniformity in the soil due to layering, aggregate or voids is suspected, the test site should be excavated and visually examined to determine if the test material is representative of the in-situ material in general.

(vi) The zone of influence including the depth below the surface for density as well as water content measurements is not precise and will depend on the design of the gauge and, in case of bulk density determination will vary with the type of transmission. Typically, the measurement depth for bulk density is between 50 mm and 300 mm.

2.4.2 <u>In-situ Water Content Interferences</u>

The fundamental assumption inherent in the test method is that the hydrogen present is in the form of water and that the material under test is homogeneous.

(i) The chemical composition of the material being tested can affect the measurement and adjustments may be necessary (see Section 3.3.6). Hydrogen in forms other than water and carbon will cause measurements in excess of the true value. Some chemical elements such as boron, chlorine and cadmium will cause measurements lower than the true value.

(ii) The water content measured by this test method is not necessarily the average water content within the volume of the sample involved in the measurement. The value is biased by the water content of the material closest to the surface, but this bias will not adversely affect the accuracy of moisture content measurement, provided that the water within the material is evenly distributed. The volume of soil represented in the measurement is indeterminate and will vary with the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. Approximately 50% of the moisture content determination may refer to the uppermost 50 mm of soil.

2.5 <u>International Standards on use of Nuclear Gauges</u>

Following established standards are available on use of Nuclear Gauges for in-situ determination of Density and Water Content of soil:

(i) American Standard ASTM D-6938 - 10.
(ii) British Standard BS 1377 : Part IX : 1990
(iii) CETANZ Technical Guideline No. TG3 of New Zealand, issued in Dec'2014.

2.6 <u>Use of Nuclear Gauges in India</u>

The Nuclear Gauges were hitherto not being used generally in India in Railway Projects for in-place measurement of Density and Moisture Content in earthworks. However, they are being used for this purpose in National Highway projects of NHAI and Airport Projects of AAI.

3. <u>Working Procedure for use of Nuclear Gauges</u>

Para 7.2.2.1 (c) of the RDSO Guidelines for "Earthwork in Railway projects" stipulate that Nuclear Density Moisture Gauge (NDMG) can be used for in-situ dry density measurements, in consultation with RDSO and as per "Test Procedure" issued by RDSO. The Dedicated Freight Corridor Corporation (DFCCIL) had made a reference to

RDSO for use of NDMG in the Rewari – Iqbalgarh Section of Western Corridor. The fill material being used at this site was of Granular (predominantly Sandy) type (Category SQ2 as per Guidelines of GE:G-0014), wherein the field checks of compaction were being done using Sand Replacement Method. Based on this reference from DFCCIL, a team from RDSO carried out site inspection in which inter-alia the results given by NDMG were checked vis-à-vis results given by Sand Replacement Method, at the same locations. Based on checks and provision of various International Standards, a Working Procedure was issued for determination of in-situ density and water content of soil by means of a Nuclear Gauge designed to operate on the ground surface. The quality of the result produced is dependent on the competence of the personnel using the gauge and the suitability of the equipment and facilities used. The salient features of the Working Procedure issued are as under:

3.1 Calibration of the Gauge

(i) Calibration of the gauge should be done by an Accredited Agency or by the Manufacturer of the gauge, in accordance with procedure given in Annex-A1 and Annex-A2 of ASTM D6938-10.

(ii) Gauges shall be calibrated initially and after any repairs that can affect the gauge geometry or the existing calibration. To be within specified tolerances, calibration curves, tables, or equivalent coefficients shall be verified, at periods not to exceed 12 months. If the tolerances cannot be met at any time, the gauge shall be calibrated to establish new calibration curves, tables, or equivalent coefficients. If the owner does not establish a verification procedure, the gauge shall be calibrated at a period not to exceed 12 months.

(iii) Record of calibration shall be maintained, in conformity with procedure given in Annex-A1 and Annex-A2 of ASTM D6938-10 and before use of any gauge it should be ensured that the gauge is having valid calibration certificate issued in conformity with stipulated standard.

3.2 Standardization of the Gauge

Nuclear moisture density gauges are subject to long-term aging of the radioactive sources, which may change the relationship between count rates and the material density and water content. To correct for this aging effect, Standardization of the gauge is required to be carried out periodically.

(i) Standardization of the gauge shall be performed at the start of each day's work and a record of this data should be retained. This procedure shall also be repeated after 8 Hours of continuous use.

(ii) Standardization should be done with the gauge located at least 9 m away from other nuclear moisture density gauges and clear of large masses of water or other items which can affect the reference count rates.

(iii) Procedure for Standardization

(a) Turn on the gauge and allow for stabilization according to the manufacturer's recommendations.

(b) Using the reference standard block, whose serial number matches with the serial number on the gauge, take a reading that is at least four times the duration of a normal measurement period (typically one minute). Use the procedure recommended by the gauge manufacturer to establish the compliance of the standard measurement to the accepted range. Without specific recommendations from the gauge manufacturer, use the procedure given in Para (c) below.

(c) If the values of the current standardization counts are outside the limits set by Eq. 1 and Eq. 2, repeat the standardization check. If the second standardization check satisfies Eq. 1 and Eq. 2, the gauge is considered in satisfactory operating condition.

$$0.99(N_{dc})e^{\frac{-(ln(2))t}{T_{d(1/2)}}} \leq N_{d0} \leq 1.01(N_{dc})e^{\frac{-(ln(2))t}{T_{d(1/2)}}} \quad (1)$$

and

$$0.98(N_{mc})e^{\frac{-(ln(2))t}{T_{m(1/2)}}} \leq N_{m0} \leq 1.02(N_{mc})e^{\frac{-(ln(2))t}{T_{m(1/2)}}} \quad (2)$$

Where:

$T_{d(1/2)}$ = the half-life of the isotope that is used for the density determination in the gauge.
$T_{m(1/2)}$ = the half-life of the isotope that is used for the water content determination in the gauge.
N_{dc} = the density system standardization count acquired at the time of the last calibration or verification.
N_{mc} = the moisture system standardization count acquired at the time of the last calibration or verification,
N_{d0} = the current density system standardization count,
N_{m0} = the current moisture system standardization count,
t = the time that has elapsed between the current standardization test and the date of the last calibration or verification.
ln(2) = the natural logarithm of 2, which has a value of approximately 0.69315,
e = the inverse of the natural logarithm function, which has a value of approximately 2.71828.

(d) If for any reason the measured density or moisture becomes suspect during the day's use, another standardization check should be performed.

3.3 Procedure for measurement

3.3.1 When possible, select a test location where the gauge will be placed at least 600 mm away from any object sitting on or projecting above the surface of the test location, when the presence of this object has the potential to modify gauge response. If measurement is to be made at a specific location and the aforementioned clearance cannot be achieved, such as in a trench, follow the gauge manufacturer's correction procedure(s). Keep all other radioactive sources at least 9m away from the gauge to avoid any effect on the measurement.

3.3.2 Prepare the test site in the following manner:

(i) Remove all loose and disturbed material and additional material as necessary to expose the true surface of the material to be tested.

(ii) Prepare an area sufficient in size to accommodate the gauge by grading or scraping the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

(iii) The depth of the maximum void beneath the gauge shall not exceed 3 mm. Use native fines or fine sand to fill the voids and smooth the surface with a rigid straight edge or other suitable tool. The depth of the filler should not exceed approximately 3 mm.

(iv) The placement of the gauge on the surface of the material to be tested is critical to accurate density measurements. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. The total area filled should not exceed approximately 10% of the bottom area of the gauge.

3.3.3 Turn on and allow the gauge to stabilize (warm up) according to the manufacturer's recommendations.

3.3.4 <u>Direct Transmission Mode</u>

(i) Make a hole perpendicular to the prepared surface using the rod guide and drive pin. The hole should be a minimum of 50 mm deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area. Care must be taken in the preparation of the access hole in uniform cohesionless granular soils. Measurements can be affected by damage to the density of surrounding materials when forming the hole.

(ii) Remove the hole-forming device carefully to prevent the distortion of the hole, damage to the surface or loose material to fall into the hole.

(iii) Place the gauge on the material to be tested. Lower the probe into the hole to the desired test depth. As a safety measure, it is recommended that the probe not be extended out of its shielded position prior to placing it into the test site. When possible, align the gauge so as to allow placing the probe directly into the test hole from the shielded position.

(iv) If the gauge is so equipped, set the depth selector to the same depth as the probe.

(v) Secure and record one or more one-minute bulk density and water content readings. Read the in-situ bulk density directly or determine one by use of the calibration curve or table previously established.

(vi) Read the water content directly or determine the water content by use of the calibration curve or table previously established.

(vii) Retract the probe into the housing and check that the radioactive source is safely housed.

3.3.5 Backscatter Mode:

(i) Seat the gauge firmly. Set the gauge into the Backscatter position.

(ii) Secure and record one or more set(s) of one-minute density and water content readings. When using the backscatter mode, follow the manufacturer's instructions regarding gauge setup.

(iii) Read the in-situ bulk density or determine one by use of the calibration curve or table previously established.

(iv) Read the water content or determine one by use of the calibration curve or previously established table (see Section 3.3.6).

3.3.6 Water Content Correction and Oversize Particle Correction:

(i) For getting accurate values of water content and bulk density, both of these corrections need to be made when applicable.

(ii) Prior to using the gauge-derived water content on any new material, the value should be verified. As part of a user developed procedure, occasional samples should be taken from beneath the gauge and comparison testing done to confirm gauge-derived water content values. All gauge manufacturers have a procedure for correcting the gauge-derived water content values.

(iii) When oversize particles are present, the gauge can be rotated about the axis of the probe to obtain additional readings as a check. When there is any uncertainty as to the presence of these particles, it is advisable to sample the material beneath the gauge to verify the presence and the relative proportion of the oversize particles.

(iv) When sampling for water content correction or oversize particle correction, the sample should be taken from a zone directly under the gauge. The size of the zone is approximately 200 mm in diameter and a depth equal to the depth setting of the probe when using the direct transmission mode; or approximately 75 mm in depth when using the backscatter mode.

3.4 Calculation and expression of Results

In most of the gauges, the Bulk Density, Water Content and Dry Density are calculated and displayed directly. Otherwise, calculate the Dry Density (ρ_d) as under:

$\rho_d = (100 \times \rho) / (100 + w)$

where:

ρ = Bulk Density of the soil determined by Nuclear Gauge

w = Moisture Content of the soil (in %)

If the Nuclear Gauge determines the Water Content of the soil per unit volume of the soil, then the Dry Density is calculated as under:

$\rho_d = \rho - W$

Where,

ρ = wet density

W = Moisture Density i.e. water mass per unit volume of soil

The Moisture Content (in %) "w" can be calculated as: $w = (W \times 100)/(\rho - W)$

3.5 Reporting of Results

The Field Data Records shall include, as a minimum, the following:

(i) Make, Model and Serial Number of the Nuclear Gauge.
(ii) Validity date of Gauge calibration.
(iii) Data for Standardization of the gauge.
(iv) Data/details about daily Verification of Gauge Results (see Para 3.6)
(v) Location of test (e.g. Chainage and Lift/Layer No.).
(vi) Visual description of material tested.
(vii) Name of the operator(s).
(viii) Test mode (i.e. Direct transmission or Backscatter) and depth of test.
(ix) Any corrections made in the reported values and reasons for these corrections (i.e. over-sized particles, water content).
(x) Maximum Laboratory Density value.
(xi) Bulk Density measured.
(xii) Water Content in percent.
(xiii) Dry Density Calculated/measured.
(xiv) Degree of Compaction/Percent Compaction.

3.6 Daily Verification of Gauge Results

In the Nuclear Gauges, the results directly displayed by the gauge are used straight away. Therefore, it is necessary that the results displayed by the gauge are reliable. To ensure this, a daily verification of gauge results was introduced in the working Procedure, in addition to the Calibration and Standardization stipulated in various International Standards.

(i) At the start of each day's work, the Degree of Compaction (% compaction) should be measured at minimum 3 locations by the Nuclear Gauge and compared with the results given by the conventional methods like Sand Replacement Method or Core Cutter Method at the same locations.

(ii) If the difference in Degree of Compaction (%) at any of the location is more than 6%, the reason for the difference should be examined in detail.

(iii) If the difference in average Degree of compaction (%) of all the locations, ignoring its' sign, is more than 4%, the standardization of the gauge shall be repeated.

(iv) After standardization, the procedure given in Para (i) to (iii) above shall be repeated again. If the difference in average Degree of compaction (%) of all the locations, ignoring its' sign, is still more than 4%, the nuclear gauge shall be re-calibrated, to bring the difference in average Degree of compaction (%) of all the locations within 4%.

3.7 Precautions

(i) These gauges utilize radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of these gauges must become familiar with applicable safety procedures and government regulations.

(ii) Effective user instructions, together with routine safety procedures and knowledge of and compliance with Regulatory Requirements, are a mandatory part of the operation and storage of these gauges.

(iii) The presence of moisture inside the gauge cavity will cause malfunctioning of the gauge. Hence, they should be stored in a warm and dry place and not used in the rain.

(iv) This procedure does not purport to address all of the safety concerns, if any, associated with its use. The user of this standard should establish appropriate safety and health practices and ensure compliance to all regulatory limitations.

4. Feedback received from Field

The feedback received from the Rewari – Iqbalgarh Section of Western Corridor, for which the Working Procedure for use of Nuclear Gauge was issued, is as under:

(i) By using Nuclear Gauge, Field Dry Density check takes about 6 minutes in Sandy Soils, 7 – 7.5 minutes in Granular Type of soils and about 8 - 8.5 minutes in Blanket Layer vis-à-vis about 20-30 minutes time required for Sand Replacement Method.

(ii) In Daily Verification Checks, the difference in Degree of Compaction obtained using Sand Replacement Method and Nuclear Gauge varies between 1% and 2.36%.

(iii) More number of Field Density Checks per team are being performed by using Nuclear Gauge, which would help in enhancing progress of earthwork.

5. Condusion

Nuclear Moisture Density Gauge is a non-destructive testing equipment which enables very quick measurement of Density and Moisture Content of the earthwork in field, as compared to other conventional methods hitherto being used. This equipment has facility for calculation of all relevant derived parameters and storage of test data. Thus, more number of tests can be conducted and data can be stored with same power. However, the aspects of deployment of trained/suitable operator, calibration of gauge, standardization of gauge, daily verification of gauge results and proper safety precautions should be taken care at the site. These gauges are being world over, for more than 20 - 30 years and in India also they are in use in projects of National Highway and Airports etc. Thus, it is expected that use of Nuclear Moisture Gauges for Field Dry Density Checks of earthwork will contribute in accelerating the Railway projects of New lines/Doubling/Gauge Conversion.

References

(i) ASTM D6938-10: Standard Test Method for "In-place Density and Water Content of Soil and Soil-aggregates by Nuclear Methods (Shallow Depth)".

(ii) BS 1377: Part-9: 1990 – British Standard Method of test for Soils for Civil Engineering Purpose: Part-9 : In-situ Tests.

(iii) AASHTO: T310-02: Standard Specifications for "In-place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depths)".

(iv) National Association of Testing Authorities (NATA) Australia: Technical Note 32, March'2013: Use of Nuclear Gauges for testing Soils and Asphalts.

(v) IS:2720 (Part XXVIII) – 1974: Indian Standard "Method of Test or Soils – Determination of Dry Density of soils in-place, by the Sand Replacement Method".

(vi) IS:2720 (Part XXIX) – 1975: Indian Standard "Method of Test or Soils – Determination of Dry Density of soils in-place, by the Core Cutter Method".

(vii) "Guidelines for Earthwork in Railway Projects", Guideline No. GE:G-1, July'2003, issued by RDSO.

(viii) "Guidelines and Specifications for Design of Formation for Heavy Axle Load", Report RDSO/2009/GE:G-0014, November'2009, issued by RDSO.

(ix) A Booklet on "Geotechnical Testing for Railway Engineers – Laboratory and Field Tests", issued by RDSO in December'2004.

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