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Government of India

Ministry of Road Transport & Highways

(S&R (P&B/New Technology) Zone)

Transport Bhawan, 1, Parliament Street, New Delhi-110001

2600.11

Dated: 23rd June, 2025

CIRCULAR

To

1. The Chief Secretaries of all the State Governments/ UTs.
2. The Principal Secretaries/ Secretaries of all States/ UTs Public Works Department/ Road Construction Department/ Highways Department (dealing with National Highways and other centrally sponsored schemes).
3. The Chairman, National Highways Authority of India, G-5 & 6, Sector-10, Dwarka, New Delhi-110 075.
4. The Managing Director, NHIDCL, World Trade Centre, New Delhi-110029.
5. The Director General (Border Roads), Seema Sadak Bhawan, Ring Road, New Delhi-110 010.
6. All Engineers-in-Chief and Chief Engineers of Public Works Department of States/ UTs/ Road Construction Department/ Highways Departments (dealing with National Highways and other centrally sponsored schemes).
7. The Secretary General, Indian Roads Congress
8. The Director, IAHE, Noida, UP
9. All CE-ROs, ROs and ELOs of the Ministry.

Subject: Adoption of Automated & Intelligent Machine-aided Construction (AI-MC) in National Highways Projects -reg.

Madam/Sir,

While a significant growth in the National Highway (NH) network has been seen in the last decade, there have also been substantial greenfield NH constructions or greenfield/brownfield NH with high embankments requiring significant amount of earthwork and proper compaction.

2. Initially highways were constructed manually but with advancement of technology, highway construction has evolved to mechanized and machine-controlled construction. Considering the availability of intelligent road construction machines, it has been felt appropriate to induct **Automated & Intelligent Machine-aided Construction** (**AI-MC**) in highway construction involving significant greenfield segments with high embankments. The benefits of AI-MC are as under:

- Automatic Machine Guided Construction
- Repository of Digitized Construction Data
- Adherence to Design Specification

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- Time efficient and wastage reduction
- **Time bound construction without compromising quality of construction**
- Improved rideability
- Enhanced performance durability & longevity
- Real time documentation & monitoring and
- Better transparency to control highway construction activities.

3. NHAI had taken up one pilot project of AI-MC in Lucknow-Kanpur Expressway Project, wherein Automated & Intelligent Machines such as GPS-aided Motor Grader, Intelligent Compactor and stringless Paver have been used. On the basis of evaluation of efficacy of AI-MC demonstrated in this project alongwith feedback of the project stakeholders and considering the International Guidelines/specifications in this regard, it is decided to begin with adoption of AI-MC in NH construction. List of Projects is given in **Appendix-A**.

4. In Schedule-B of such project should have the provision of automated & intelligent construction machinery such as GPS-aided Motor Grader to be used for earthworks, subbase & base (Details given in **Annex-I**) and Intelligent Compaction Roller (IC Roller) - Single Drum/Tandem Vibratory Roller to be used for soil/subbase/base layer compaction (Details given in **Annex-II**). Also, a flow-chart of the work flow for AI-MC is given in **Annex-III**. Calibration of Compaction Meter Value (CMV) or similar parameters shall be done with respect to conventional method of density measurement i.e. sand replacement method for each borrow area soil as well as each design of different mixes of subbase and base. Concessionaire/Contractor should get license of required Radio Frequency 403-473MHZ. Ministry will facilitate to get license of the radio frequency range 403-473MHZ from Department of Telecommunications (DoT). Concessionaire/Contractor has to submit the duly filled requisite application along with license fee to Ministry or its executing agency well in advance.

5. Contractor/Concessionaire shall submit AI-MC report (in hard copy & soft copy) of grade control as well as IC roller of each layer in addition to the test results submitted conventionally for approval of request of inspection (RFI) of that particular layer. It is to be noted that whatever conventional QA&QC is being done will be continued. QA&QC as per Contract Provisions and specification will also continue as usual as the aim of introduction of AI-MC is for aiding the quality management at the end of Contractor/Concessionaire and AE/IE rather than substituting the laid down quality checks in the Specification. These AI-MC data & report are in addition to those. Also, data access i.e. login id and password is to be facilitated to respective PIU/RO/HQ until the back end facility for data storage facility will be created. Once it is created, the real time data will be stored therein.

6. Contractor/Concessionaire shall ensure signing of agreement between the Contractor/Concessionaire and the Machine Control Technology Provider before use of AI-MC in NH project. The agreement shall have the provision of involvement of the Machine Control Technology Provider during execution.

7. The contents of the Circular may be brought into the notice of all concerned for needful compliance. Also, it is requested to kindly share the feedback while using AI-MC so that Indian Roads Congress Guideline for AI-MC will be formulated.

8. This issues with the approval of Competent Authority.

Enclosures: Appendix-A, Annex-I, II & III

Bidur Kant Jha.

Yours sincerely,

Bidur Kant Jha
23.06.2025

(Bidur Kant Jha)

Director (New Technology for Highway Development)

For Director General (Road Development) & Special Secretary

Copy to:

1. All CEs in the Ministry of Road Transport & Highways
2. All ROs of the Ministry of Road Transport & Highways
3. All CE(NH) of PWD/R&B dealing with National Highways
4. Technical circular file of S&R (P&B) Section
5. NIC-for uploading on Ministry's website under "What's new" & "Comprehensive Compendium Circulars with **CODE 2600.11**.

Copy for kind information to:

1. PS to Hon'ble Minister (RT&H)
2. PS to Hon'ble MOS (RT&H)
3. Sr. PPS to Secretary (RT&H)
4. Sr. PPS to DG (RD) & SS
5. Sr. PPS/ PPS to Addl. Secretary (Road Safety)/ Addl. Secretary (RT&H & LA)
6. Sr. PPS/ PPS to AS&FA
7. Sr. PPS/ PPS to all ADG (KB)/ ADG (SC)/ ADG (RS)
8. Sr. PPS/ PPS to JS (RT&MVL)/ JS (EIC) / JS (Logistics)/ JS (NHIDCL)

Appendix-A

- **Projects (which are already been sanctioned and yet to be awarded) envisaged for implementation of AI-MC in FY 2025-26:**

Sr. No.	Name of Project Corridor	Approx. Length (in km)	Executing Agency	Remarks
1	Western Bypass of Gwalior - MP	29.0	NHAI	-
2	Construction of New Sambalpur Bypass - Odisha	35.0	NHAI	-
3	6-lane Greenfield Southern Ludhiana Bypass	25.0	NHAI	-
4	Construction of 4-lane Greenfield Northern Patiala Bypass	29.0	NHAI	-
5	Deoghar Bypass - JH	49.0	NHAI	-
6	Southern Bareilly Bypass - UP	30.0	NHAI	-
7	Sagar Bypass	25.0	NHAI	Included in bid documents
8	Rahatgarh to Barkhedi	10.0	NHAI	-do-
9	Aerocity Road-Ramgarh (Zirakpur Bypass)	19.0	NHAI	-do-
10	Shillong-Silchar Corridor	167.0	NHIDCL	Approved by Cabinet and bids to be invited.
11	Patna-Arrah-Sasaram, Bihar	125.0	NHAI	-
12	Pagote-Chowk, Maharashtra	29.0	NHAI	-
13	4- Laning of Bendordem to Canacona Bypass of NH-66	22.1	Road Wing, RO Maharashtra	In the State of Goa
14	Upgradation to 4L PS of Kalavad- Jamnagar section (Package-II) of NH-927D	47.6	Road Wing, RO Gujarat	-
15	Vrindavan Bypass	15.0	Road Wing, RO Uttar Pradesh	-
16	Colonelganj bypass NH-330B	14.0	Road Wing, RO Uttar Pradesh	-
Total Length (in Km)		**671.0**	-	-

- **Projects (submitted for Cabinet Approval) envisaged for implementation of AI-MC in FY 2026-27:**

Sr. No.	Name of Project Corridor	Approx. Length (in km)	Executing Agency	Remarks
1	Satellite Township Ring Road of Bengaluru (STRR), Karnataka	144.0	NHAI	Appraised by PPPAC,

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Sr. No.	Name of Project Corridor	Approx. Length (in km)	Executing Agency	Remarks
				Pending with Cabinet for approval
2	Badvel Nellore, Andhra Pradesh	108.0	NHAI	Approved by Cabinet
3	4-lane access controlled Sirhind-Sehna section of NH-205AG, Punjab	107.0	NHAI	Appraised by PPPAC, Draft Cabinet note to be circulated
4	Capital Ring Road of Bhubaneswar	111.0	NHAI	Appraised by PPPAC, Draft Cabinet note to be circulated
5	Parmakudi to Ramanathpuram	47.0	NHAI	Appraised by PPPAC, Draft Cabinet note to be circulated
6	Rameshwar to Paradeep- Coastal Highway	163	NHAI	Sent to PPPAC for appraisal
7	AP-KN-Raichur and Gudebellur-Marikal	155.0	NHAI	Sent to PPPAC for appraisal
8	Mahabalipuram-Puducherry Package-III	46.0	NHAI	Sent to PPPAC for appraisal
9	Sahebganj-Arreraj-Bettiah	103.0	NHAI	Sent to PPPAC for appraisal
10	Nashik-Aehmednagar-Solapur-Akkalkot segment of the Surat-Chennai Expressway	374.0	NHAI	Pending appraisal by PPPAC
Total Length (in Km)		**1358.0**	-	-

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Annex-I: Machine Control Technology Components and Specifications

1. General specifications of Grade Control Technology in Motor Grader

Road projects require embankment, subgrade, subbase, base and other pavement layers to be graded to a defined 3D model with varying depth and slope. The ideal way to control depth and slope of motor grader blade in relation to the 3D model during the grading process is by using 3D machine guidance system. The machine guidance system needs to guide the operator to grade to the required depth and slope. The machine guidance system needs to be as flexible and efficient as possible for earthworks but highly accurate on pavement layers. Therefore, the machine requires dual mast GPS guidance for earthworks/other pavement layers. The requirement includes the finishing of final subgrade, final embankment and subbase/base/other pavement layers as per the IRC specification Clause 902.

The system should include GNSS receivers and GNSS antennas. These components can be integrated into a single unit or may provide as separate units, depending on the OEM design and specifications with an operating range of 40 Gs for 10 milliseconds duration, +/-5 PSI sealed housing, be 20.4 gRMS vibration resistant and have an operating range of at least -40°C to +70°C to minimise damage to the receiver. The GPS antenna must use CAN based cabling rather than coaxial to minimise downtime due to cable failures. Accuracy of the Real Time Kinematic GPS needs to be at least 8mm + 1ppm RMS horizontally and 15mm + 1ppm RMS vertically.

The GPS receiver must have support for all GNSS constellations including but not limited to GPS, GLONASS, Galileo, BeiDou, NAVIC/IRNSS.

The operator needs to be 100% confident they have graded to the 3D model across their entire working zone. By monitoring the cut/fill map on-screen the operator can be confident the correct elevation and slope has been graded.

As an option, to ensure the blade is cutting material when recording data, the machine needs to have a CAN based 'blade on ground' sensor installed that measures the elevation change from the blade being in a cutting position or not. The blade on ground sensor needs to have at least +/-45° operating range, 100% sealed housing with 5PSI, IP68 rating, 0.05° resolution with repeatability of +/-0.1°, and an operational temperature range of -40°C to +85°C.

Metrics

- Ability to get visual guidance to depth and slope of a 3D model on the motor grader via a machine guidance system
- Ability to display a cut/fill map
- Ability to record and store the as-graded surface during machine operation
- Dual mast GPS guidance for earthworks with integrated GPS receiver and antenna in one housing or may provide as separate units, depending on the OEM design and specifications

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2. Components of 3D Machine control Dual GNSS Motor grader system

3D machine control technology for graders typically consists of several key components that work together to enable precise grading operations:

A. **Operator Display and controller**: 3D machine control system processes data from the GNSS receivers and angle sensor. It calculates the precise position and orientation of the grader's blade in real-time and compares it to the desired design surface or grade specified in the digital design plans. The on-board control box determines the position of each tip of the blade and compares it to the design elevation to compute cut or fill to grade. The cut/fill data is used to drive the valves for automatic blade control or is shown on in-cab lightbars that provide visual guidance for manual operation.

Specification: -

- Display: Min 7.0-inchLCD brightness is adjustable over a suitable range to accommodate different working conditions or better.
- Windows CE 5.0 Operating System or Android 6.0.1 Marshmallow or Linux or Ubuntu for easy software extensibility or better.
- USB Host Port on Front Face protected with self-closing Protective Cover
- Lightbars for cut/fill.
- buzzer (with adjustable levels) for Operator feedback and warning
- Operating Temperature: -20°C to +65°C
- Humidity: 90% Relative Humidity
- Sealing: IP66 for dust, rain and pressure wash or better
- Electrical Input voltage: 9V-32V
- Real time data display: Provides real-time feedback on grading operations, including blade position and terrain surface information.
- Diagnostics tools: Includes diagnostic tools for troubleshooting and maintenance purposes.

B. **GNSS Receivers (Global Navigation Satellite System)**: High-precision GNSS receivers to provide accurate positioning data to the grader. These receivers receive signals from multiple satellite constellations (like GPS, GLONASS, Galileo, BeiDoU, NAVIC/IRNSS, etc.) to calculate the grader's position in three dimensions.

Specification: -

- An advanced RTK engine for faster initialization times when satellite lock is lost and enhanced performance near obstructions
- Support for All GNSS constellations including but not limited to GPS, GLONASS, Galileo, BeiDou, NAVIC/IRNSS, etc.
- Single Integrated GNSS receiver with antenna in Alloy/metal casing (not plastic) or separate, rugged cab or blade mountable unit.
- Single cable connector (high cycle count connector)
- Real Time Kinematic (RTK) positioning:
  Horizontal accuracy: 8 mm + 1 ppm RMS (0.032 ft +1 ppm)
  Vertical accuracy: 15 mm + 1 ppm RMS (0.05 ft +1 ppm)

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- Operating Temperature: -40°C to +70°C (-40°F to +158°F)
- Sealing +/- 5 psi sealing
- Shock - Survival: 75 Gs, 6 milliseconds duration, 3 shocks in each of the three mutually perpendicular axes
- Shock - Operating: 40 Gs, 10 milliseconds duration
- Vibration 20.4 gRMS
- Electrical Input Voltage: 9 to 32 VDC

C. **Hydraulic Control Valves**: These valves are responsible for adjusting the grader's blade height, tilt and based on the commands received from the control system. They ensure that the blade conforms to the desired grade profile with high accuracy.

Specification: Hydraulic valve should be suitable as per OEM grader and Hose should withstand the hydraulic pressure of grader.

D. **Communication**: 3D machine control technology often includes capabilities for data management and communication. This may involve storing as-built data for quality control purposes and possibly transmitting real-time progress updates to project managers or stakeholders. There are 2 communication system installed in the grader Internet gate way device for office to field and vice versa communication and UHF radio for receiving signal correction from base station.

Specifications:

Rugged Machine Mountable Radio:

- Power: 12 and 24V operation
- Two RS232 serial ports, One CAN (J1939) bus port (250kbps)
- LED provides information on radio status
- Rugged machine mounted radio
- Operating temperature: -40°C to +70°C
- Humidity: 100% fully sealed, waterproof
- Sealing: IP67
- Vibration: 9.8 gRMS
- Transmit power: Receive only
- Receive sensitivity: - -108 dbm
- Frequencies: 403-473Mhz Worldwide
- Over the air data rate: 19200 bps, 9600 bps, 4800bps

Internet Modem:

- Power: 9 V DC to 32 V DC
- Adhesive Mount GNSS/ Wi-Fi / Cellular combo
- Operating Temperature: -40 °C to +85 °C
  Wi-Fi -20 °C to + 85 °C
- IP Rating: 67
- Humidity / Enclosure: SAEJ1455
- Shock / Vibration: SAEJ1455
- Cellular as an option: LTE bands 1,3,7,8,20, UMTS 900/1800/2100 and GMS 900/1800
- Technology: LTE (LTE with fallback to UMTS/HSDPA and GPRS), v WCDMA(HSPA), GSM (EGPRS, GPRS) data only, no voice support as an option.

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- Serial: Three wire RS-232
- CAN bus: 2 CAN Bus support for communications up to 250kb/s
- Wi-Fi: 2.4GHz & 5GHz Wi-Fi Support Supported Protocols
- Supported Modes: Access Point

E. **Power Module as required /optional:** Power Module delivers clean, conditioned DC power for systems used on mobile machinery. The compact, standalone module delivers load dump and over-current protection. Power control is implemented in the module and managed remotely via electrical connection. Designed to the toughest industry standards, the Power Module delivers even in the harshest conditions.

Specifications:

- 9.5 to 32 VDC input/output
- Load dump and over-current protection
- Up to three separate output circuits (peak 15 amp each)
- Input connector - 8-pin bulkhead connector
- Output connector - 8-socket bulkhead connector
- Environmentally sealed enclosure
- Electrically switched on/off control
- Operating temperature: -40°C to +85°C
- Vibration: 15.32 G-RMS
- Sealing: IP67

F. **Valve module as required:** The Valve Module is used to simultaneously control up to 3 hydraulic valves from a CAN network. The Valve module is compatible with Proportional Voltage (PV), Proportional Time (PT) and Pulse Width Modulation (PWM) valve types.

Specifications:

- Support for PV, PT+ and PWM valve types
- Controls up to 3 valves simultaneously
- Input voltage 9 - 36 Vdc
- Function Instance support (up to 4 units on same CAN bus)
- Operating: -40°C to +70°C
- Humidity: IEC 60068-2-78, IEC 60068-2-30;
- Electrical Input Voltage: 9 to 36 VDC

G. **RTK Base station**: The portable RTK base station communicates with RTK-enabled GPS receivers on the grader, providing real-time corrections to the GPS signals. This ensures that the grader knows its exact position relative to the desired grade, preventing errors and ensuring accuracy in the grading process. RTK technology enhances the accuracy of GPS positioning from meters to centimetres. This is crucial in machine control for graders where precise positioning is essential for grading tasks.

Specification:

- GNSS Receiver with Integrated Antenna
- RTK Position accuracy: Min. H: 8mm + 1ppm & V:15mm + 1ppm
- No of Channels: Min. 500 channels or more

- Satellite Signal tracking: System must have facility to track GPS, GLN, BDS, GAL, NAVIC/IRNSS, etc
- Position update rate: Min. 20 Hz or better.
- Communication device: Bluetooth, Radio modem fully integrated, receive and transmit, external antenna minimum 1 W output power or more, with provision to attach High Power Radio.
- Battery: Minimum 4-5 hours operation with single internal battery & provision to attached external Power Source.
- Operating Temperature: -40°C to +65°C
- Dust & waterproof: IP-68 or better.

H. **Office software**: Office software serves as a powerful software tool in machine control technology for design and data preparation in construction and earthmoving projects. One of the primary functions of office software is to facilitate the design and preparation of surfaces and alignments for machine control systems. Engineers and designers can use to create 3D models of terrain surfaces, road alignments, drainage systems, and other features essential for construction projects. These designs can then be exported to machine control systems to guide equipment operators accurately during earthmoving operations.

I. **Cloud based real time software:** Cloud based Real time monitoring software should have the ability to send design updates to the field and ensure all crews are working from the same design. It is also important that all field data be sent back to the office for later use in the validation process. Data should be accessible from any location. It is essential that surface elevation information recorded on machines along with can be seen in the office. From the office it is also important for management to be able to see where any survey crew or machine is on site at any given time via an online portal. The software should enable data storage, analysis, and reporting, allowing owners, engineer and project team to track surface data over time and optimize future operations based on historical data.

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Annex-II: Intelligent Compaction Technology

India has presently about 1.46 lakh km length of National Highways Network. Progress of about 34km per day was achieved for development works on NHs during 2023-24. Out of total NH Network, there is about 3000km is high speed corridors and there is a vision to construct further 45,000km till 2047. Most of the high-speed corridors are greenfield and new construction on embankment. It is expected and desirable that the newly constructed embankment fill will consolidate with time. Therefore, to minimise the post-construction consolidation, the earthwork or other pavement layer/s shall be compacted to the maximum possible extent initially i.e. during construction itself.

2. Compaction is one of the principal mean available to the highways engineers for the substantially increasing the strength of materials used in construction of roads. There is marginal increase in CBR (the indirect indicator of shear strength of soil) for compaction up to 85%. But thereafter the increase is exponential. For practical purposes, it is important that the highest practical level of density (in terms of Maximum Dry Density, or MDD) be achieved from embankment upwards in order to minimize subsequent deformations due to further densification under the traffic loading. Clearly if insufficient compaction is achieved during construction then the long-term performance of the road is likely to be adversely affected, so it is critical to ensure that specified compaction is attained.

3. The life of the road depends on its structural strength. Optimum compaction is essential to achieve designed structural strength, long term performance, reduced maintenance costs and enhances life of roads. Compaction of soil minimizes water seepage and helps the soil to acquire better strength. As strength increases it is possible to reduce the pavement thickness. Considerable economy in construction cost can, thus, be brought about. On account of better packing of soil grains by expelling air after compaction, the permeability of soil reduces. The densely packed soil grains do not allow water from external source to enter and hence can resist erosion. Even though compaction may account for less than 4% of the total construction cost, the benefits accrue in terms of longevity and riding quality are immense. To achieve long span of the road and to protect the investment made i.e. the economic returns from the project developments, it is essential that its structural strength is maintained. Compaction of soil helps in increasing the load bearing capacity, wear resistance, impermeability and life. Similarly, optimal compaction of bituminous layer/s helps in improving the interlocking of aggregate particles resulting in reduction in permeability and improving the durability of road.

4. The purpose of compaction is to improve its engineering properties by increasing its density to make it strong enough to resist displacement or movement under loads that may be applied to it. Principal properties affected by compaction are following:

i) Structural strength.

ii) Load bearing capacity.

iii) Stability of fills.

iv) Impermeability.

v) Shear resistance.

5. Specifications for Road & Bridge works, MORT&H Specification (fifth Revision) 2013 stipulates that "The different layer/s shall be compacted to minimum 95 to 98% of

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Laboratory Maximum Dry Density (MDD) as per IS: 2720(part 8) in case of soil/base/subbase layer, whereas minimum 92% of Maximum Theoretical density of loose bituminous mixture G_{mm} as per ASTMD 2041 for bituminous layer/s. Further, it stipulates that field compaction has to be determined at every 1000sqm for soil/base/subbase layer/s and at every 700sqm for bituminous layer/s". One of the serious limitations of existing procedure is that it is point test only gives the compaction value of the test location does not give continuous compaction confirmation. Further, it is biased with the selected location if not randomly selected the test point. Also, it does not give lift thickness the compacted layer. **Current quality-control and quality-assurance conventional test methods for roadway compaction cover less than 1% of the actual compacted area**. Also, it is said that the premature pavement failure of newly constructed road is primarily contributed by workmanship 79% and material related 21.0%.

5. Intelligent Compaction technology is one way to combat the workmanship issues that result in future pavement performance issues. Intelligent compaction (IC) offers a method to measure 100% of a roadway compacted area. Benefits of IC technology are as under:

- Assured Quality as it is Continuous Compaction Measurement System or Continuous Compaction Control (CCC)
- Ensures right number of passes
- Avoid over or under compaction
- Maintain consistent & uniform compaction to design standard
- Real-time Compaction map and measurable records

6. There is an AASHTO PP81-2020 Standard Practice for 'Intelligent compaction Technology for Embankment and Asphalt Pavement applications which defined IC as a process that uses rollers that equipped with a measurement-documentation system that automatically records compaction parameters (e.g., spatial location, stiffness in terms of intelligent compaction measurement value ICMV, temperature, pass count, vibration amplitude and frequency) in real-time during the compaction process. IC rollers equipped with accelerometers use roller vibration measurements to assess mechanistic material properties and to ensure that optimum compaction and uniformity is achieved through continuous monitoring of operations.

7. Also, Indian Roads Congress IRC: SP: 97-2013 "Guidelines on Compaction Equipment for Road Works" detailed about intelligent compaction system alongwith its advantages such as imparts uniform compaction for full width of the road, documentation of real time roller location, no. of passes, speed of roller, amplitude, frequency and Compaction Meter Value (CMV) to measure degree of compaction. Further, it stipulates the vibratory roller should be fitted with GPS, accelerometer for CMV and tablet to store data as well as it can keep data on cloud for real time alerts and the tandem vibratory roller should also fitted with infra-red sensor to measure laying compaction temperature while rolling. However, IRC guideline is silent about whether the road roller is to be fitted with Intelligent compaction system or not.

8. In view of aforementioned discussions, considering consistency & uniformity, continuous compaction measurements in entirety, assured quality, bring real time visibility, minimize human intervention, to bring transparency and to have enhanced performance durability, it is decided to begin with adoption of Intelligent Compaction Technology for the roller/compactor to be used for soil, subbase and base layer .

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9. Intelligent compaction Roller(IC Roller)-a self-propelled roller integrated with a navigation satellite system and onboard documentation system that can display real-time, color-coded maps of roller location, number of passes, roller speeds, color-coded maps of stiffness response and amplitude and vibration frequencies of the roller drum.

The Single Drum/Tandem Vibratory Roller to be used for soil/subbase/base layer compaction shall have either in-built or retrofitted with hardware and software to measure/record/report of the following parameters:

- Global Navigation Satellite System (GNSS) coordinates along with date & time stamp of the location,
- Roller Pass Count- the area covered by one width of the roller in a single direction,
- Roller Speed,
- Compaction vibration amplitude and frequency,
- Compaction Meter Value (CMV),
- Ability to Set Target Pass Count & CMV based on trial section,
- Modem or Wi-Fi, and
- Onboard Data Acquisition/Documentation system and real-time display

10. The instrumented Intelligent Roller/Compactor should have the hardware and software components with the following features and specifications:

10.1 **GNSS Receiver for pass count mapping fitted on Roller**: GNSS receivers in IC systems provide accurate positioning information with few centimetre-level accuracy. This precise positioning is essential for mapping the location of compaction equipment on the work site.It shall support for all GNSS constellations including but not limited to GPS, GLONASS, Galileo, BeiDou, NAVIC. It has the accuracy of +/-3cm in X and Y direction and operating temperature range -20°C to +60°C. GNSS has the capability to use the agency specified Co-ordinate System file for site calibration and ability to connect to a RTK-GPS either using either a local ground-based station or VRS network (use the VRS network only when coverage is available throughout the project limits) or satellite correction hub.

10.2 Real Time Kinematic (RTK) **Rover**-Remotely operated Video enhanced Receiver-used to determine GPS coordinates for given point location and setup to reference the local, ground-based base station. RTK enhances the precision of GPS. This might only be required during correction or may be dispensed with if cost increased much. The same has been done with GPS receiver fitted on roller by temporary removal of the same.

10.3 **Angle Sensor or IMU sensor: Corrects horizontal position of compactor for mapping. Installed on machine body, calculates body pitch and roll. If machine features Horizontal Steering Control, an additional angle sensor is required on the drum.**

10.4 **Accelerometer/Compaction Sensor**: Intelligent Compaction Measurement Value (ICMV) - the stiffness of the materials based on the response of the roller drum vibrations and underlying material responses. The Compaction sensor results, CMV (Compaction Meter Value), are based on a development of Geodynamik engineers in 1978 and subsequent research over the decades. They found that the comparison of the resonance amplitude of the 1st harmonic with the amplitude of the base frequency is directly related to the stiffness of the underlying soil material. A second value called RMV (Resonance Meter Value) is an indicator for the amount of bouncing of the vibratory drum, often also called double jump or drum bounce. CMV has no dimension and needs to be calibrated with spot measurement techniques to get a dimension like measurements like sand

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replacement, cone penetration, nuclear gauge, ... M.N. /sqm. Compaction sensor should have operating range: -40 °C to +70 °C, Storage range: -40 °C to +85 °C, Humidity: 100% fully sealed, waterproof; Sealing: ± 5 psi sealing; Vibrations: 8.0 gRMS and Input Voltage: 9 to 32 VDC.However, it may vary as well or as recommended by IC system provider.

10.5 **Onboard Document System/Display/Control Box**: The controller manages and processes data from various sensors and systems integrated into the compactor. This includes data from GNSS receivers and compaction meters. It continuously monitors key parameters such as compaction effort (measured in terms of vibration frequency and amplitude) and position data from GNSS. The display logs compaction data for documentation and reporting purposes. It records data such as compaction meter value, % CMV change, Vibratory pass counts, and which are essential for quality control and project documentation. Use an onboard documentation system with a minimum of the following capabilities:

- Display real-time, color-coded maps of linework (alignment file), roller drum location, number of roller passes, and Intelligent Compaction Measurement Value (ICMV) for systems with an accelerometer.
- Display and store current value for roller speed, vibration frequency, vibration amplitude, GNSS co-ordinates and pass count.

Operator Display and controller should have sunlight readable optically bonded screen with capacitive multi-touch interaction, easy software extensibility ,Powerful processor platform with dedicated graphics processor, integrated Bluetooth and Wi-Fi for wireless connectivity, Quick-release RAM mounting for daily theft protection removal and Rugged design for construction and paving machine environments.

10.6 **Modem or Wi-Fi**: IC should have data management and communication capabilities. This may involve storing as-built data for quality control and transmitting real-time progress updates to project managers or stakeholders. The grader Internet gateway device has 2 communication systems installed for office-to-field and vice versa communication. Modem or Wi-Fi is used for getting/transferring data to cloud storage.

10.7 **IC Software**: This software interprets the data collected by the hardware components and provides operators with real-time feedback on compaction. It displays compaction metrics such as coverage, CMV values, CMV change, allowing operators to make informed decisions during the compaction process.

10.8 **Required Instrumented Roller Equipment Accuracy for best performance and documentation**:

Operating Parameter	Accuracy
Global Positioning system	+/- 30mm in the X and Y direction
Rolling Speed	+/-0.5kmph
Frequency	+/-2Hz
Amplitude	+/-0.2mm

10.9 **Office software for data preparation for Field systems and Processing results**: The Office software plays a crucial role in the construction process. It is used to prepare design data that can be carried in construction grade survey instruments and 3D Machine control tools. The software should be capable of generating a 3D model from the provided

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design, including a Triangulated surface model and 3D Linework. It should also be able to overlay machine guidance as-built records and generate reports. Site calibration/GNSS localization should be done as per site conditions. The software should be capable of sending data to machines via the cloud and generating sectional and longitudinal drawings based on alignment geometry. It should also be able to adjust the control point network adjustment and localized coordinate system.

11. **Intelligent Compaction Workflow**: The workflow involves several key steps to ensure accurate and efficient operation. Throughout this workflow, effective communication and collaboration among project stakeholders (engineers, surveyors, equipment operators, etc.) are prefer to ensure successful implementation of the 3D machine control connected site configuration. This approach helps optimize construction processes, improve accuracy, and minimise rework, ultimately leading to more efficient and cost-effective project delivery. The general outline of the workflow is as under:

11.1 **Training and Certification of the Personnel**: Supervisors and operated need to be trained by the Technology provider. Also, technology provider shall involve during execution.

11.2 **Control Points Establishment**: Begin by establishing control points on the construction site using surveying equipment. These control points should be accurately measured, traversed and documented. Control points serve as a reference point with known local coordinates. Two control points, two at the start and two at the end (totaling 4 control points) should be established for site calibration. Control points spaced at spacing of 5km within 45m of the centerline or depend on project ROW. Alternate the control point on each side of the alignment. All control points have clear line of site to satellites to allow for calibration.

Three Dimensional 3D, accuracy<=30mm in the X, Y and Z direction.

11.3 **Collect GNSS Data**: Use GNSS receivers to collect precise positioning data at the control points across the construction site. This data includes latitude, longitude, and Ellipsoid height information.

11.4 **Site calibration/localization**:

GNSS data in Latitude, Longitude, and Ellipsoid Height

Local coordinates in Northing, Easting, Elevation (MSL).

Site calibration or " localization" refers to the process of adjusting or fine-tuning the positioning data received from the GNSS receivers to match the specific conditions and coordinates of the construction site. Based on the data collected from GNSS Rover and survey control points, the GNSS system adjusts its calculation to minimise errors and ensure that the equipment operates according to the intended design specifications.

11.5 **Digital Model Preparation**:

11.5.1 **Conversion to 3D Model**: Convert the CAD design/2D design data into a 3D digital model that accurately represents the project site.

11.5.2 **Data Integration with site calibration**: Design of different layers and chainage need to be aligned with the respective site calibration/localization file.

11.6 **Machine Control System Setup**:

11.6.1 **Hardware Installation**: Install machine control systems on the roller.

11.6.2 **Local Calibration/Verification of Roller Position**: Calibrate the equipment to ensure accurate positioning and alignment with the project model. This step is crucial for maintain precision throughout the process. GNSS accuracy on the instrumented IC rollers is verified each day prior to start the work. The accuracy of Roller MV position reporting should be verified when the Instrumented Roller is stationary. When the roller is stationary, the roller-mounted GPS position can be compared with the position from a RTK GNSS unit (i.e., rover) placed at the drum center or left or right. This can also be accomplished by establishing a marker of known position on the ground and approaching the marker with the roller from different directions. The different steps are as under:

- Move the machine on to a level pad. Remove any articulation from the machine.
- Set the drum focus to the left or right.
- Drive in a straight line for approximately 5m.
- Stop the machine and record the Northing, Easting and Elevation values for the left or right.
- Use spray paint to mark a "T" on the ground on the drum's left or right side comprising a line along the side of the drum.
- Use a ROVER (total station or GNSS) to record the position on the "T" and compare the readings. The readings should be within +/- 5cm.

11.7 **Data Management and Transfer**:

11.7.1 **Data Transfer/Design Files**: Transfer the 3D digital model of design files and site coordinates data to the machine control systems using appropriate communication protocols (e.g. Wi-Fi, cellular networks). Ensure the alignment file is loaded onto the onboard documentation system of each instrumented roller.

11.7.2 **Data Updates**: Ensure that any updates or changes to the 3D model are promptly transferred to the machine control systems to maintain alignment with the project's evolving needs.

12. **Report Submittal**: Contractor/Concessionaire shall submit the IC report along with whatever conventionally submitted i.e. field density test results to AE/IE for finally accepting the compacted layer. The different steps of operational work flow are as under:

12.1 **Setup of Target Pass and CMV Value**: For any particular borrow area material for embankment/subgrade/subbase mix/base mix, the first bed shall be done conventionally and once it passed in compaction test results, the no. of passes given and the CMV obtained shall be set as target no. of passes and CMV for that particular material to be subsequently laid.

12.2 **Satellite Reception**: Receive signals from GNSS satellites to determine the compactor's precise position.

12.3 **3D Mapping**: Use GNSS data to create a 3D map of the area being compacted, showing the vibration status in real-time.

12.4 **Pass Count Analysis**: Analyse the number of passes made over each area to ensure uniform compaction and identify any missed spots or over-compacted areas.

12.5 **Data Storage**: Store pass count data for future reference and analysis.

12.6 **Reporting**: Required Dashboard Reporting of all passes:

Date Stamp	
Time Stamp	
Roller ID	
Longitude(decimal degrees) or Easting(m) or local Easting Co-ordinate	
Latitude(decimal degrees) or Northing(m) or Local Northing Co-ordinate	
Height on ground above WGS84 geoid(Z) in m previous compacted or underneath laid layer (Z1) or Local Elevation	
Height on ground above WGS84 geoid(Z) in m after complete compaction(**Z2**) or Local Elevation	
Lift Thickness(mm) **Z2-Z1**	It will be used as an indicator and not insisted in case of non-compliance or Height/Elevation of all the passes so that lift thickness can be calculated within the specification tolerance.
GNSS mode	RTK-fixed
Roller Pass Number	
Roller Direction	Forward/Reverse
Roller speed	
Vibration On	Yes/No/On/Off
Frequency	
Amplitude	
ICMV	

13. **Quality Control and Verification**:

13.1 **Verification Checks**: Conduct periodic checks to verify the accuracy of the compacted surface against project specifications.

13.2 **Adjustments**: Make necessary adjustments to the machine control systems or operational procedures based on feedback and verification results.

14. **Maintenance and Support**:

14.1 **Maintenance**: Regularly maintain and update the machine control systems to ensure continued accuracy and reliability.

14.2 **Technical Support by Technology Provider**: Provide ongoing technical support to operators and project teams to address any issues that may arise during construction.

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Annex-III: Work Flow