ANNEXURE – XXI

Mahindra University's Research Labs

Images of Major Equipment

List of Research Labs

Supercomputer lab

Incubation Centre: Mahindra e-hub

Centre for Robotics: Robotics Lab

Wireless Innovation and 5G Research Lab

Fluidics and Heat Transfer Research Lab

Tribology and Materials Research Laboratory

Controls Research Lab

Geotechnical Research Lab

High Performance Computing Cluster

Smart Grid and Renewable Energy Lab

Automotive Systems Laboratory

Center for Sustainable Infrastructure and Systems

Chemistry Research Lab

Physics Research Lab

Electric Vehicle Research Laboratory

XRD Research Facility

Finance Research Lab

Digital Research Lab

Smart and Sustainable Materials Research Lab

Supercomputer Lab

The Supercomputer Lab of Mahindra University is created out of the baseline requirements for supporting high intensity computations for Artificial Intelligence research and applications, that incorporate Machine learning, Deep learning and Data Science.

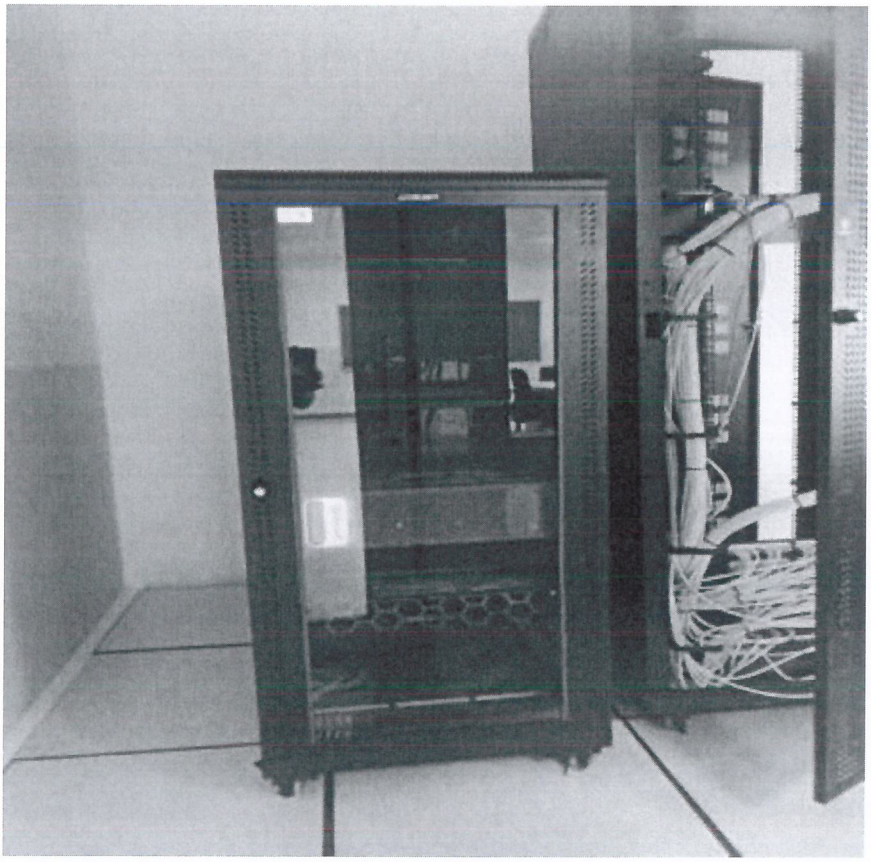
The core composition of this lab is the DGX-1 supercomputer platform, at whose kernel is a dual-core CPU server with 20 processors and 8 Tesla V100 GPU cards made up of 40,960 Nvidia CUDA cores, all connected through NVLink which minimizes internal communication overheads. On this kernel is built the platform that is a complex stack of components and software including AI Deep Learning frameworks, libraries and drivers.

This software stack is supported by DGX-1 cloud management services which continually provide updates and additional inputs. The software stack is composed of the most popular deep learning frameworks, as well as Nvidia DIGITS deep learning training application, third-party accelerated solutions, the Nvidia Deep learning SDK, Docker and drivers.

Deep Learning tasks, particularly training of complex Artificial Neural Network (ANN) architectures with many layers, hundreds of thousands of parameters, and tens of thousands of data samples, take enormous computing times if the task is performed serially on a single-thread. Instead, when launched on parallel threads, the training data can be split into multiple subsets and each launched on one thread so that the ANN training can be speeded up, ideally, by a factor equal to the number of threads. The GPU-based architecture of DGX-1 works on this principle to speed up AI applications.

The DGX-1 heart of the Mahindra University Supercomputer Lab is reinforced with a number of top-of-the-line CPU Servers that can be seamlessly scaled up in numbers. A fast Infiniband-based network connectivity is in the process of installation to connect these servers so that CPU-based parallelism can also be attained for simulations not attuned to GPU processing.

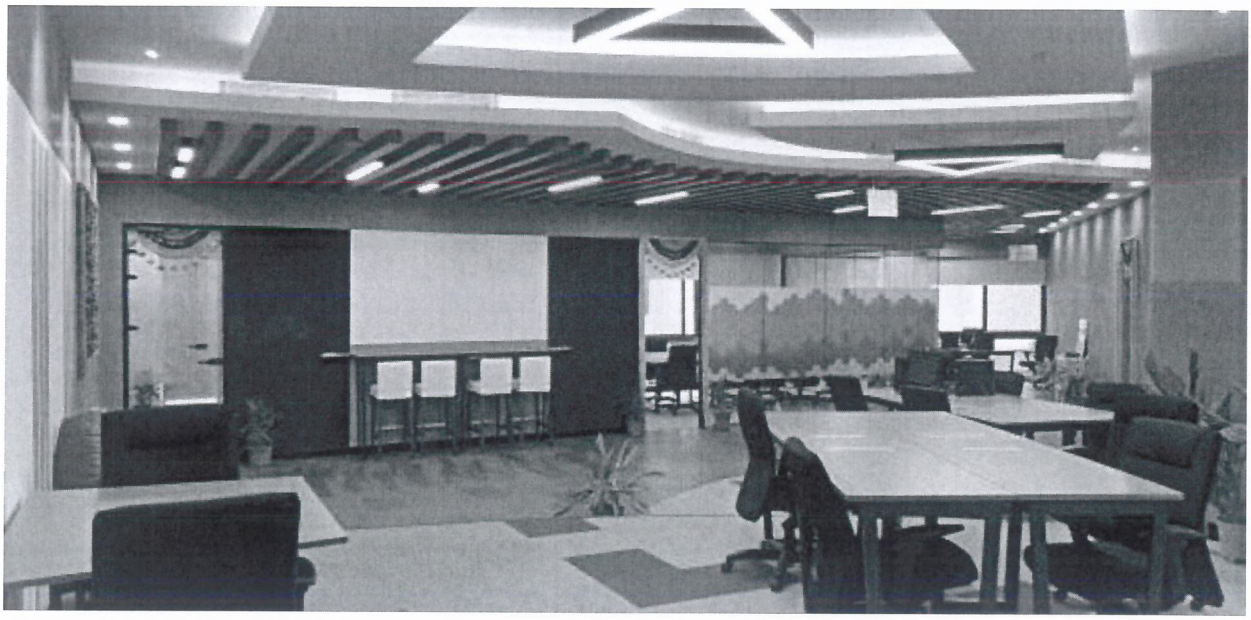
A Dassault-Systemes based 3D-Experience package is also installed in this lab. This package is an overlay on a suite of software that includes CATIA, DELPHI and other related modules, and facilitates Augmented Reality - Virtual Reality based immersive experience. A set of 30 Workstations coupled with a Server are installed and linked to the other platforms of this laboratory for facilitation of the complete 3D-Experience package.



Incubation Centre: Mahindra e-hub

The Incubation Centre is spread over 2000 square feet that can accommodate 15 entrepreneurs. It is fully equipped to facilitate the process of starting, shaping and scaling up new innovative ventures resulting from student-faculty research. In addition to providing a creative working space, the incubation centre also provides mentoring support in technology and business development, legal aspects and IPR, funding support, networking and go-to-market strategy. The incubation centre features an air-conditioned working space with a seating capacity of 34, a conference room, a discussion area, visitor's lounge, Wi-Fi connectivity, cafeteria and 24x7 security.

In addition, incubates have access to all labs, workshops and the seminar halls.



Centre for Robotics
Robotics Lab

Introduction:
Technology is changing the way people do things in every part of the world, and the sector continues to expand. Now, teaching robotics in MU is becoming an increasingly indispensable part of the curriculum. Apart from teaching we have a centre for robotics where students and researchers can flourish new ideas and innovation in the field of robotics. This centre can provide a base for the new research in MU

Proposed Activities:

The centre can provide facilities for the following activities but not the least.

- Research Wing Activities
  - Consultancy for Industries (M&M, Kuka, ABB, etc.)
  - Funded Projects (DST, DRDO, etc.)
  - Conferences / Workshop
- Student Wing Activities
  - Student Competitions
  - Project Displays
- Common Activities
  - Arranging Guest Lectures
  - Reading Groups

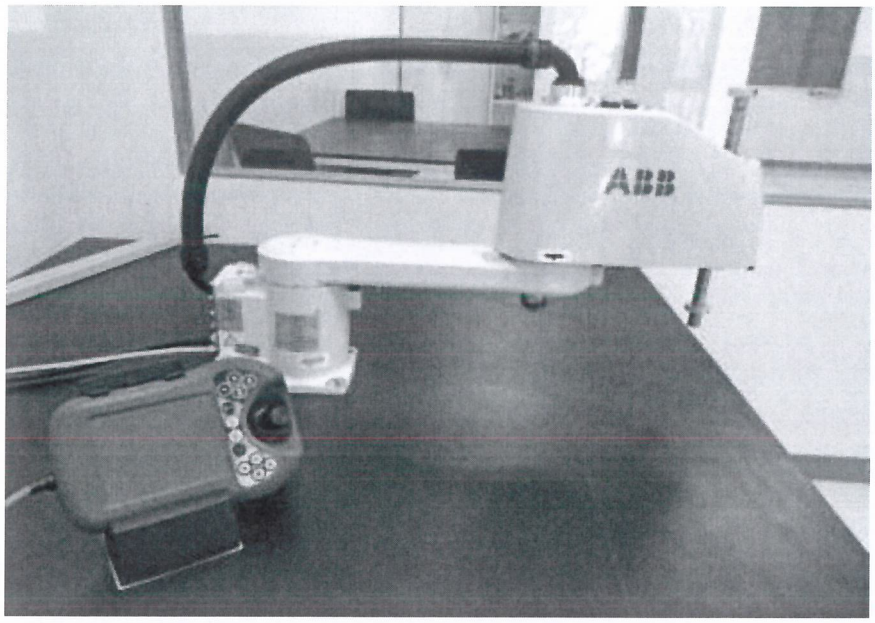
Equipment:

1. **ABB IRB1200 – Six Axis Manipulator**

Manufacturer: ABB

Application: Industrial robots have various axis configurations. The vast majority of articulated robots, however, feature six axes, also called six degrees of freedom. Six axis robots allow for greater flexibility and can perform a wider variety of applications than robots with fewer axes.

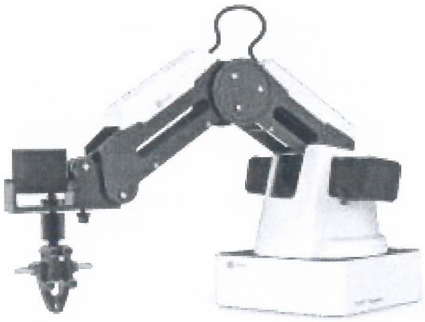
2. **ABB IRB 910SC – SCARA Robot**



Manufacturer: ABB

Application: SCARA Robots are a popular option for small robotic assembly applications. SCARA is an acronym for **S**elective **C**ompliance **A**rticulated **R**obot **A**rm, meaning it is compliant in the X-Y axis, and rigid in the Z-axis. The SCARA configuration is unique and designed to handle a variety of material handling operations.

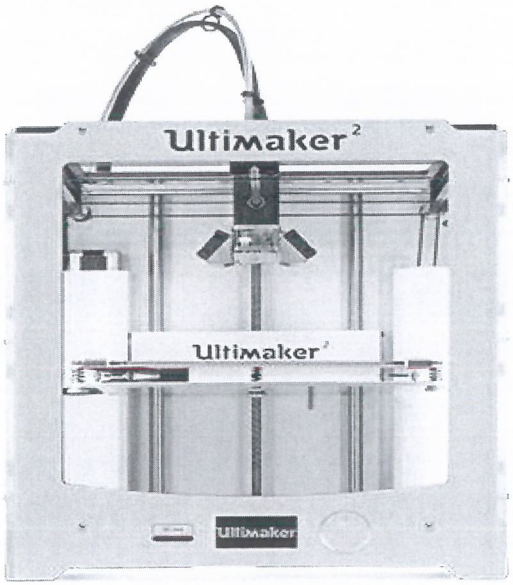
3. **DOBOT Magician – Educational**



Manufacturer: Dobot Inc.

Application: This is a 4-axis robot for educational and training purpose. DOBOT Magician is a multifunctional desktop robotic arm for practical training education. Installed with different end-tools, DOBOT Magician can realize interesting functions such as 3D printing, laser engraving, writing and drawing. It supports secondary development by 13 extensible interfaces and over 20 programming languages, which really makes anyones creativity and imagination increase without any limitation.

4. **Rapid Prototyping – Ultimaker 2+**



Manufacturer: Ultimaker USA
Application: Engineered to perform, the Ultimaker 2+ is reliable, efficient, and user-friendly. It can support of a wide range of materials, it's suitable for a huge variety of applications, from prototypes to customized tools. It's a great all-around 3D printer that delivers consistent results.

5. **Mobile Robots Platform –Robomuse 5.**

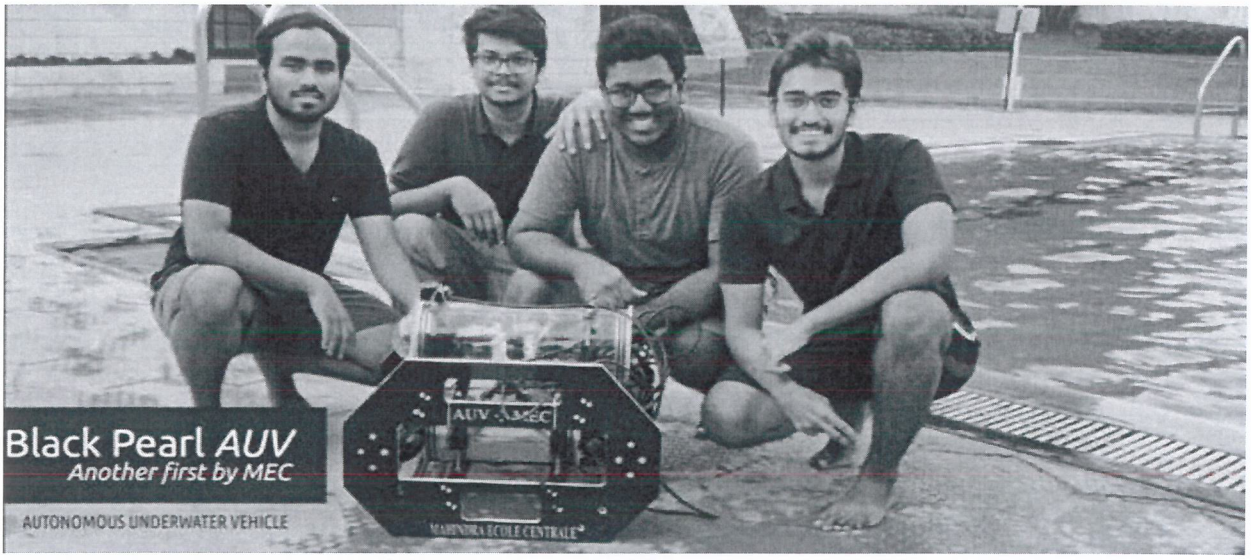
Built in IIT Delhi by MU students

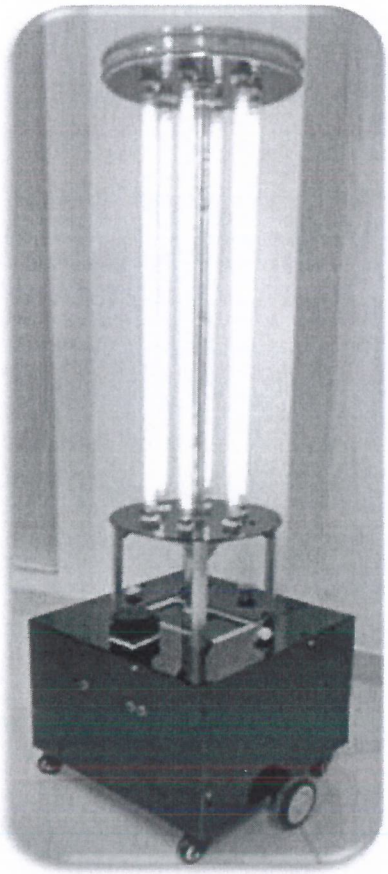
Application: To study and understand mobile robots based on various controllers to perform various tasks.

Proposed Projects

- Hyper-redundant robots
- Robotics in medical field
- Lunar Rover
- Humanoid
- Autonomous vehicles and robots
- Educational Robots
- Drones/Mobile Robots

Products from Robotics Lab





MUDRA- Autonomous UV Surface Disinfectant Robot

Wireless Innovation and 5G Research Lab

Wireless Innovation and 5G is a research lab at MU focusing on key aspects and challenges related to the future mobile networks and emerging wireless technologies. Active research can be conducted related to MIMO communication, radio resource & interference management, design of wireless systems using machine learning and artificial intelligence-based control and management algorithms, cognitive radio & spectrum management and address issues related to PHY & MAC layer.

Equipment available:

- 5-Nines Radio
- 5NR – IoT Bridge
- Wi-Guy

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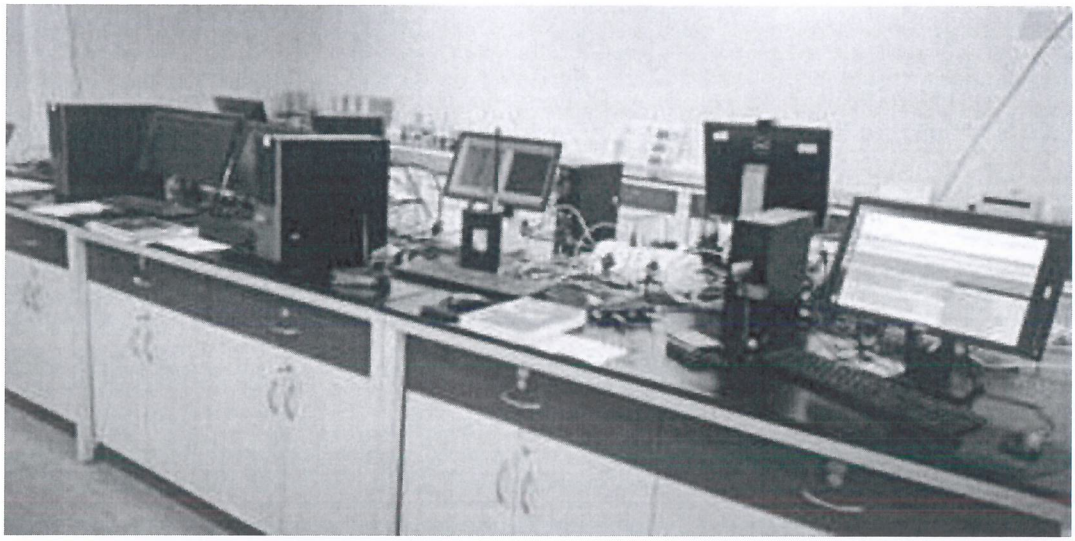
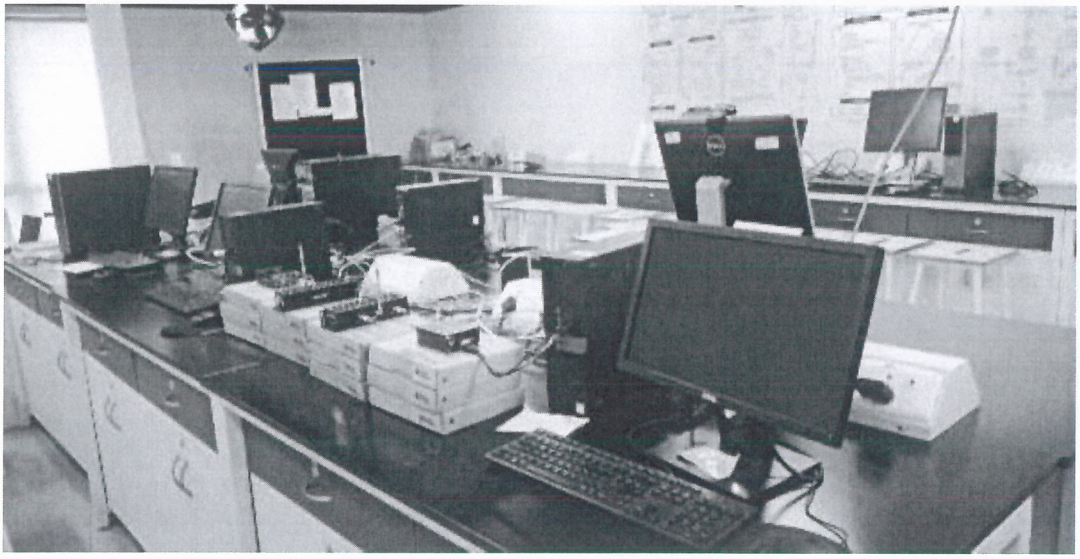
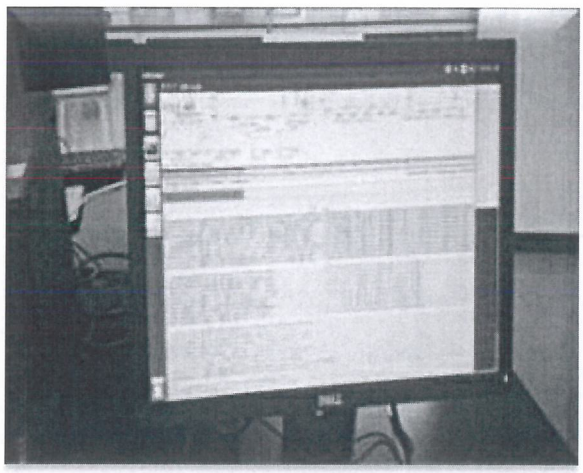
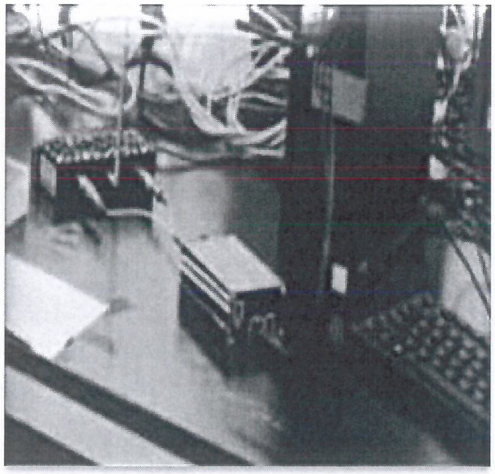
- IoT Network
- Spectrum Analyzer
- USRP

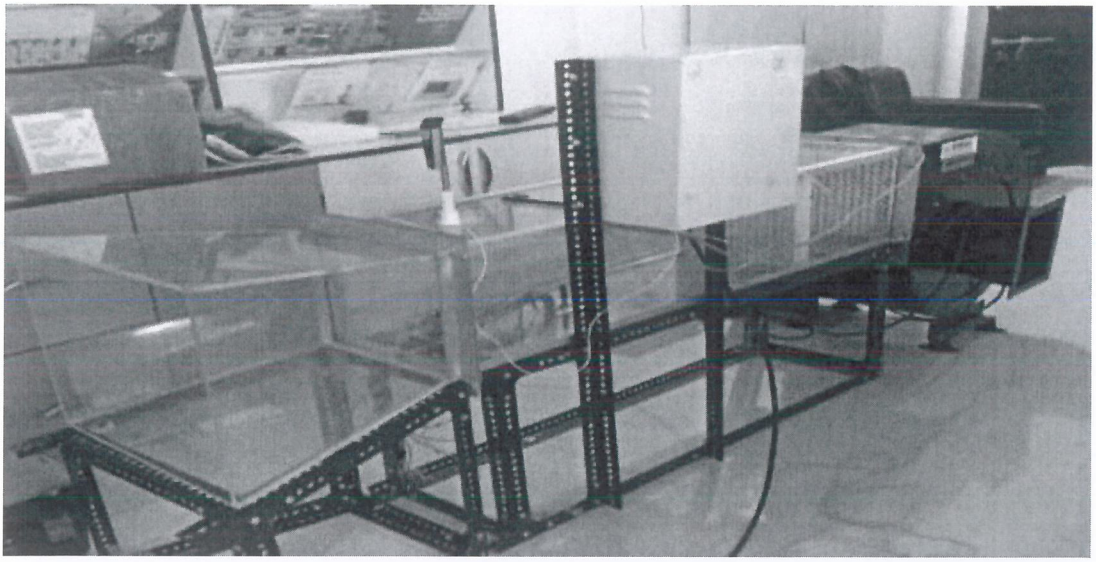


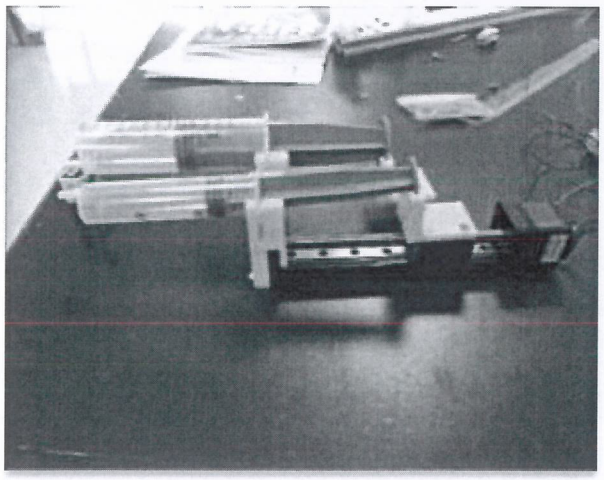


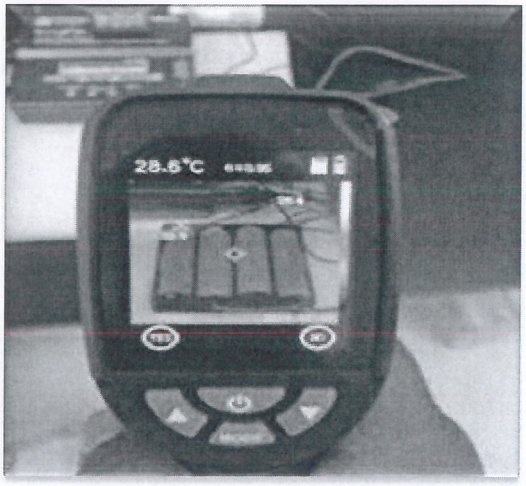


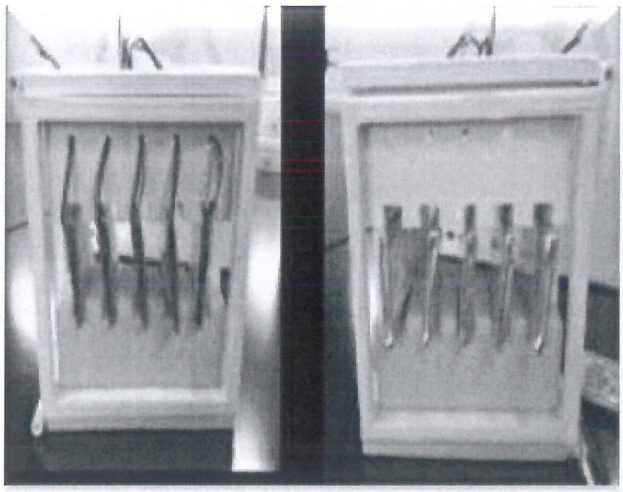


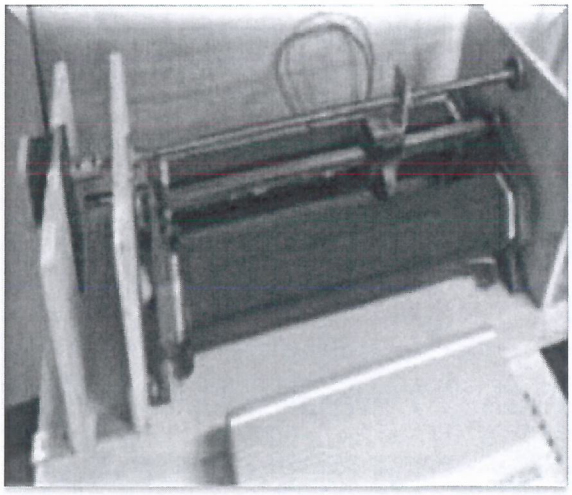
Fluidics and Heat Transfer Research Lab











Tribology and Materials Research Laboratory

Tribology and Materials Research Laboratory at Mahindra University is one of the facilities having the most advanced equipment that can facilitate research at par with the leading institutes of the country. It boasts of Industrial grade setups that helps characterize and assess the mechanical properties of a wide range of metallic as well as ceramic materials.

Typical experimental activities include: Cutting/sectioning of metallic samples, polishing, assessment of microstructure using optical microscope. Mechanical characterization includes measurement of bulk hardness (Rockwell, Vicker, Brinell) of metals/alloys, tensile/compressive stress-strain behavior, Young's modulus calculations, wear and tear measurement of metallic materials of moderate to high hardness at temperatures upto 500^{o}C.

Instruments

- Instron 5968 - Universal Testing Machine
- High Temperature Wear & Tear (Ducom)
- Specimen Mounting Press (Bainmount)
- Optical Microscope (Metascope)

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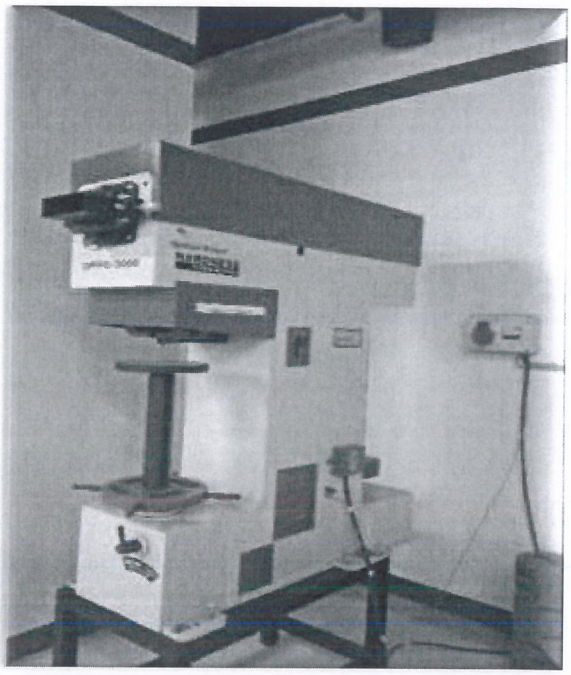
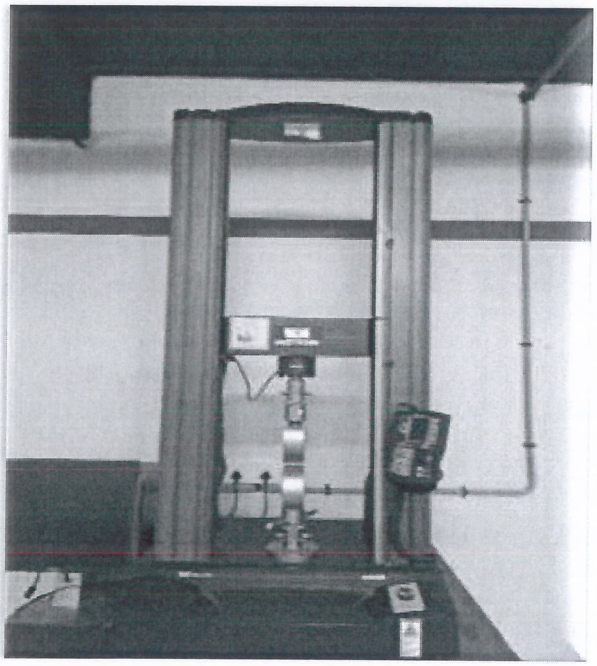
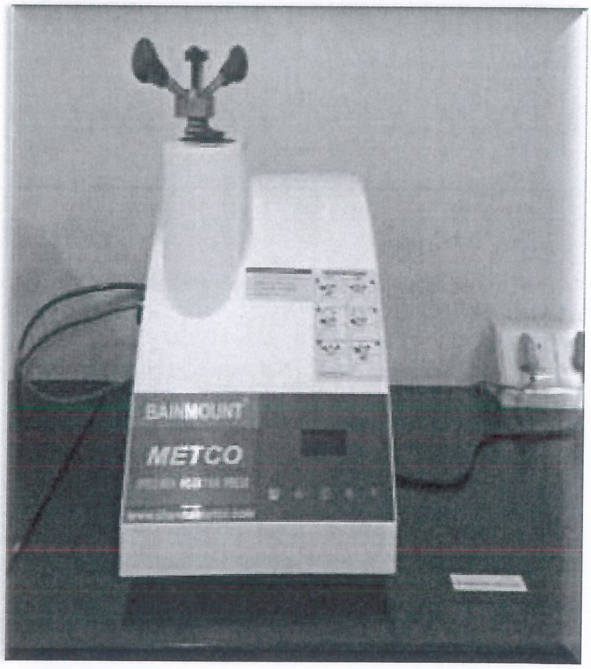
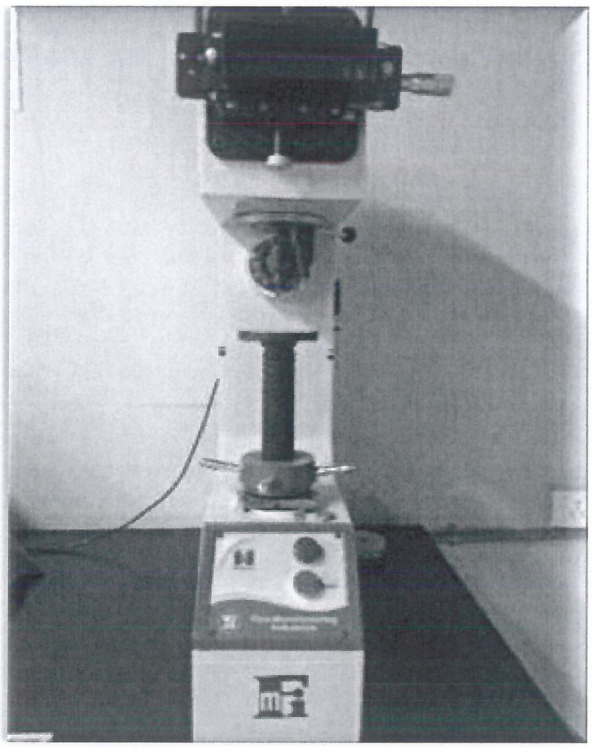
- Cutting/Grinding/Polishing Instrument (Metco- HSS)
- Hardness Testing: Rockwell (2 nos), Vicker, Brinell.



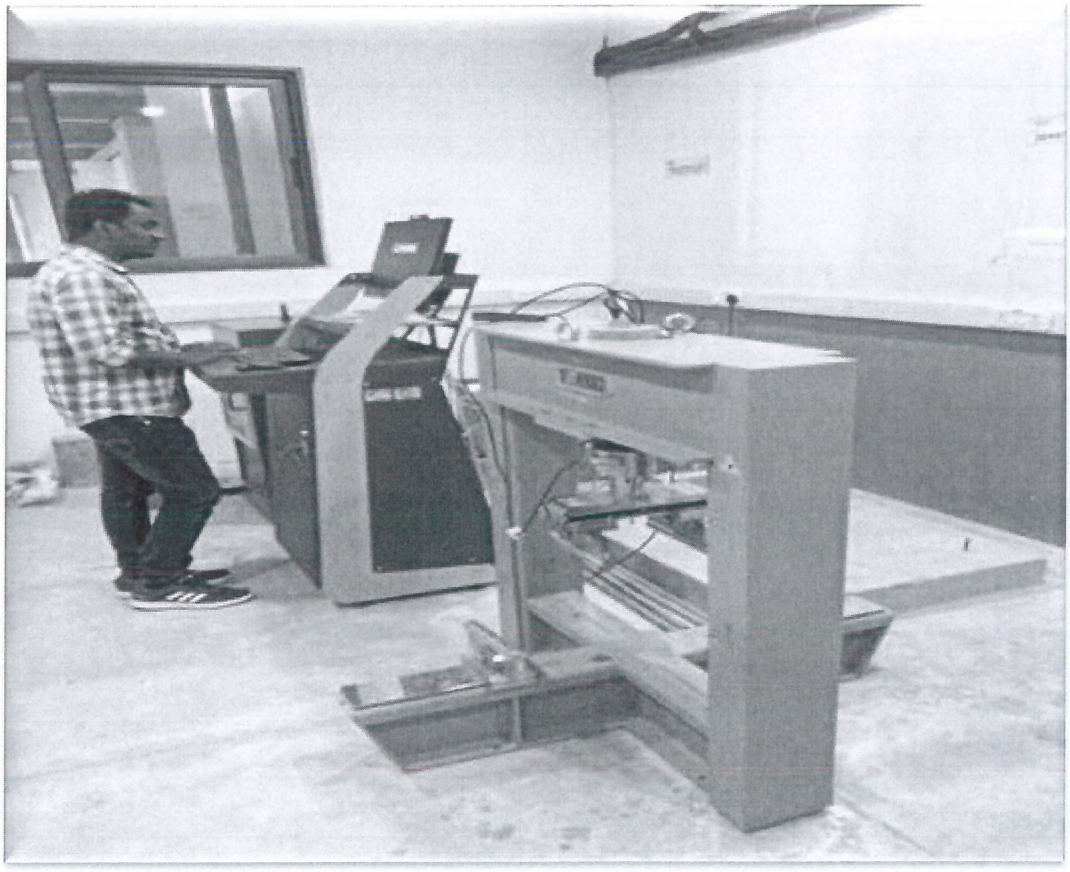






Controls Research Lab

- The CONTROLS® equipment for the civil/structural engineering laboratory, consists of a flexural testing machine and a compression testing machine.
- The FTM has a capacity of 200kN and the CTM has a capacity of 3000kN with capability to test with both load and displacement control.
- The high-stiffness flexural frame combined with AUTOMAX® Multi-test computerized control console accompanied with high precision LVDTs provide accurate readings for tests conducted on concrete beams.
- A high-end software namely DATAMANAGER® for simultaneous display of load, load rate and load/time graph, accompanies the equipment.
- The machine is equipped with modules to evaluate the Young's modulus and crack mouth opening displacements (CMOD).



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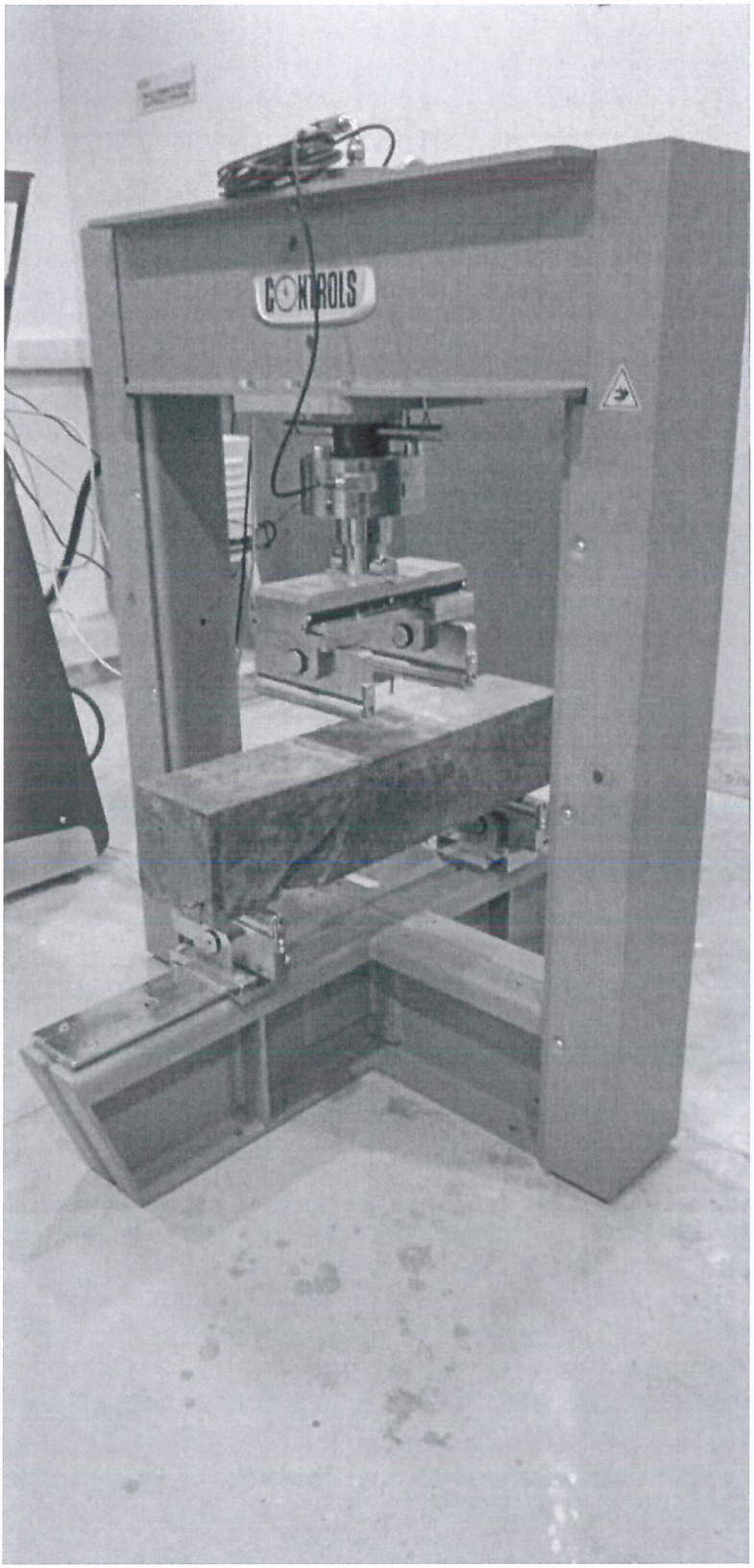
AutoMax Console



Flexural Testing Machine (200kN)

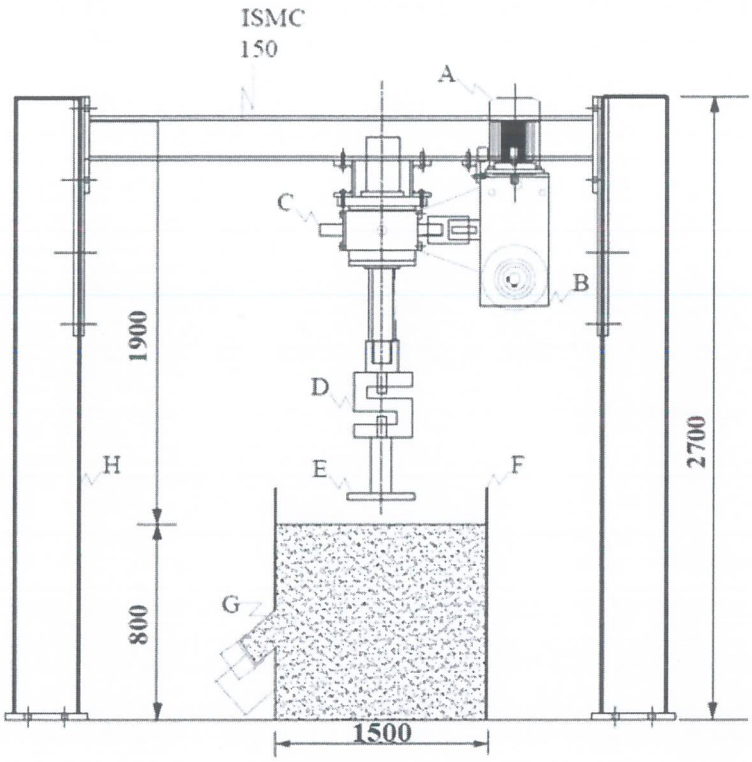
Compression Testing Machine (3000kN)

Operation of the equipment through AutoMAX Cosnole

Geotechnical Research Lab

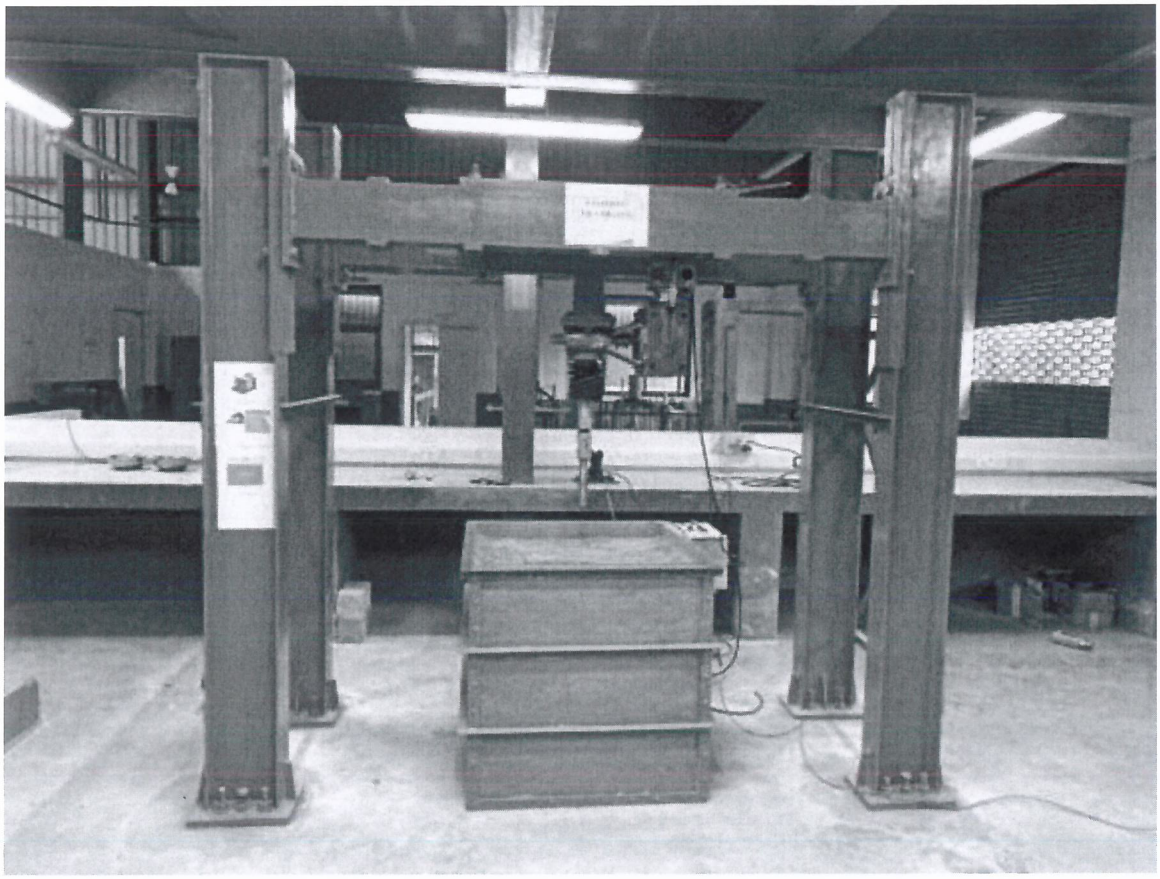
1.Large scale testing facility:

Test chamber of size equal to 0.9 m x 0.9 m x 0.9 m will be used to study the behavior of circular footing (to simulate the wheel load) resting on pavement layers. The reaction frame consists of four columns and two horizontal beam (Figure 1) to resists the applied loads. The diameter and thickness of the circular plate are equal to 150 mm and 30 mm, respectively. The static load tests will be conducted on the loading plate through an actuator.



A, B and C: Linear actuator with gear box set up, D: Load cell, E: Loading plate, F: Test chamber, G: Sand outlet, H: Reaction frame *(all dimensions given in the Figure are in mm)*

(a)



(b)

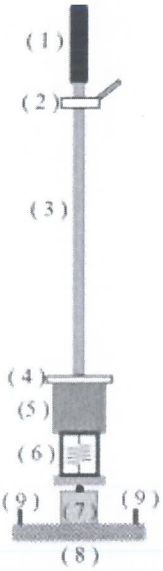
Fig. 1: Loading frame (a) cross sectional view and (b) photograph

The load applied on a circular plate in displacement-controlled mode with a rate of 1 mm/min. Displacement sensors linear variable displacement transducers (LVDT) are connected to measure the surface deformation. All sensors (load cell, strain gauges, and LVDT) will connect to the Data Acquisition system (DAQ) and the customized software records the data at every 30 seconds interval.

2. Modified Lightweight Deflectometer

LWD device is portable and used to calculate the deformation modulus of any layers of earthwork/pavement. The device consists of falling weight, loading plate, sensors, set of steel springs, etc. (as shown in Fig. 2). The falling weight is allowed to drop on a circular loading plate with a predetermined height of fall to measure the deformation

modulus. In the proposed modified LWD device, three sensors are used to measure the deformation of the bearing plate. Integrated results from the three sensors use to measure the deformation modulus.



(1) Grip
(2) Top fix and release mechanism
(3) Guide rod
(4) Round grip
(5) Falling weight
(6) Set of Steel springs (buffer)
(7) Measuring element that contains the sensor
(8) Loading plate
(9) Carry Grip

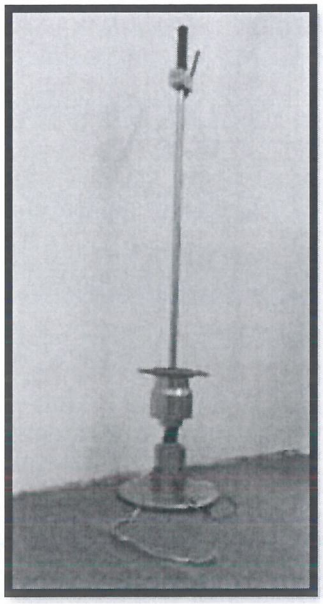


Fig. 2. Schematic diagram and photograph of LWD device

3. Dynamic cone penetrometer (DCP)

DCP device will be used to assess the quality of compacted soil. DCP consists of an 8-kg hammer with a standard height of fall equal to 575mm (Fig. 3). The hammer is dropped on the anvil of the lower shaft and it consists of a cone with an apex angle of 60°. The hammer directly transfers the energy to the cone through the lower shaft. The inverted scale engraved on the lower shaft is used to measure the penetration of the cone per each blow. Initially, seating blows are given to ensure that the wider portion of the cone is flush with the compacted surface, and the depth of penetration of cone corresponding to each hammer blow is recorded. The results are expressed in terms of dynamic penetration index, DPI.

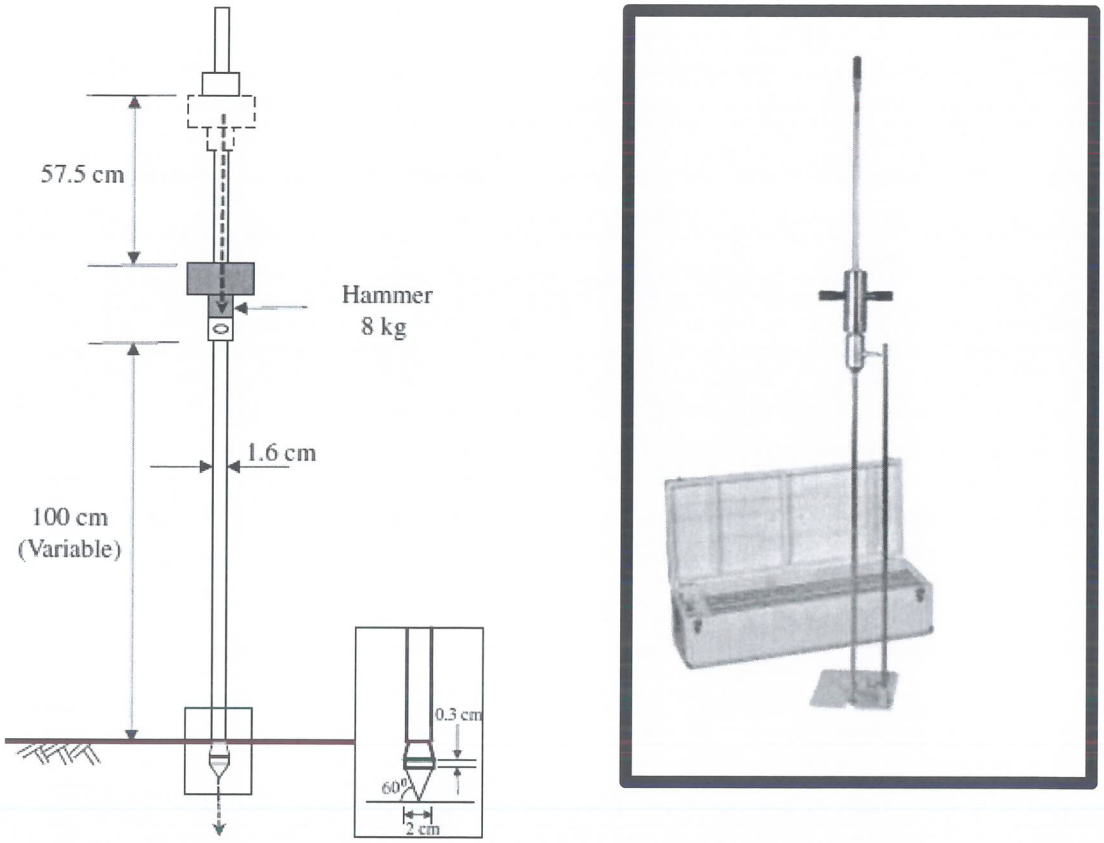


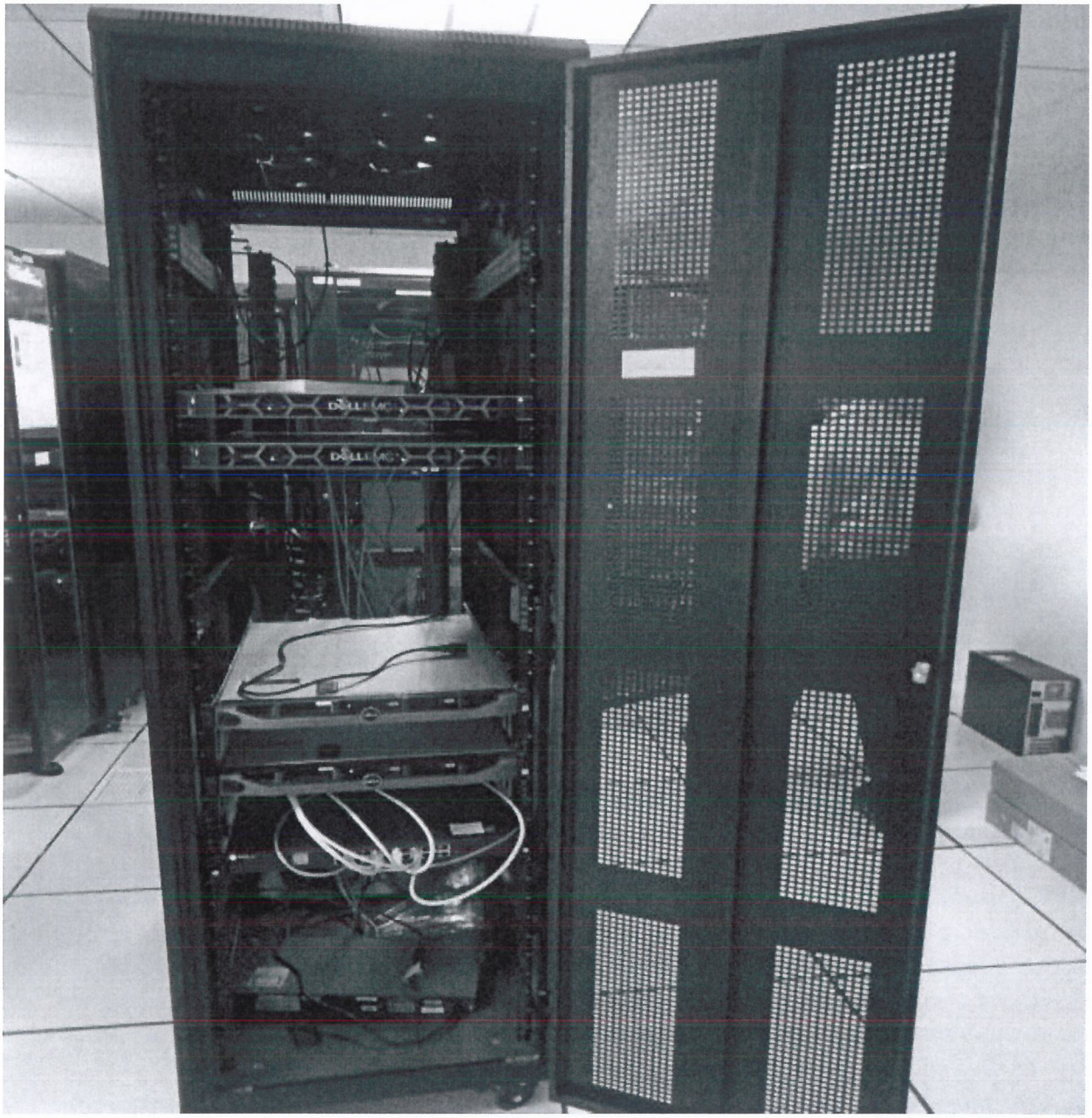
Fig. 3. Schematic view of dynamic cone penetrometer

4. Numerical modelling (Plaxis 2D)

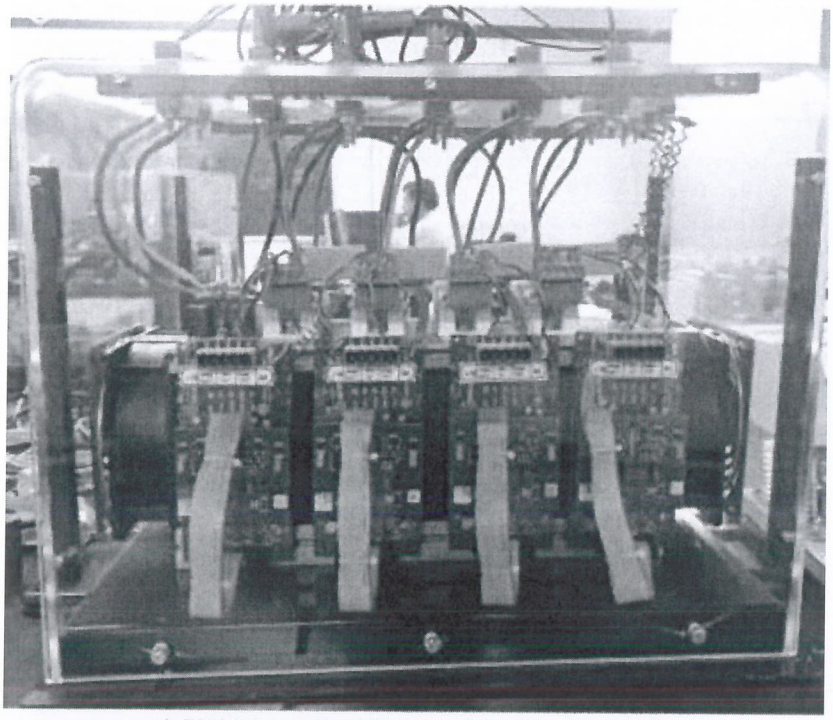
Plaxis 2D can be used to simulate the various geotechnical and transportation related problems.

High Performance Computing Cluster

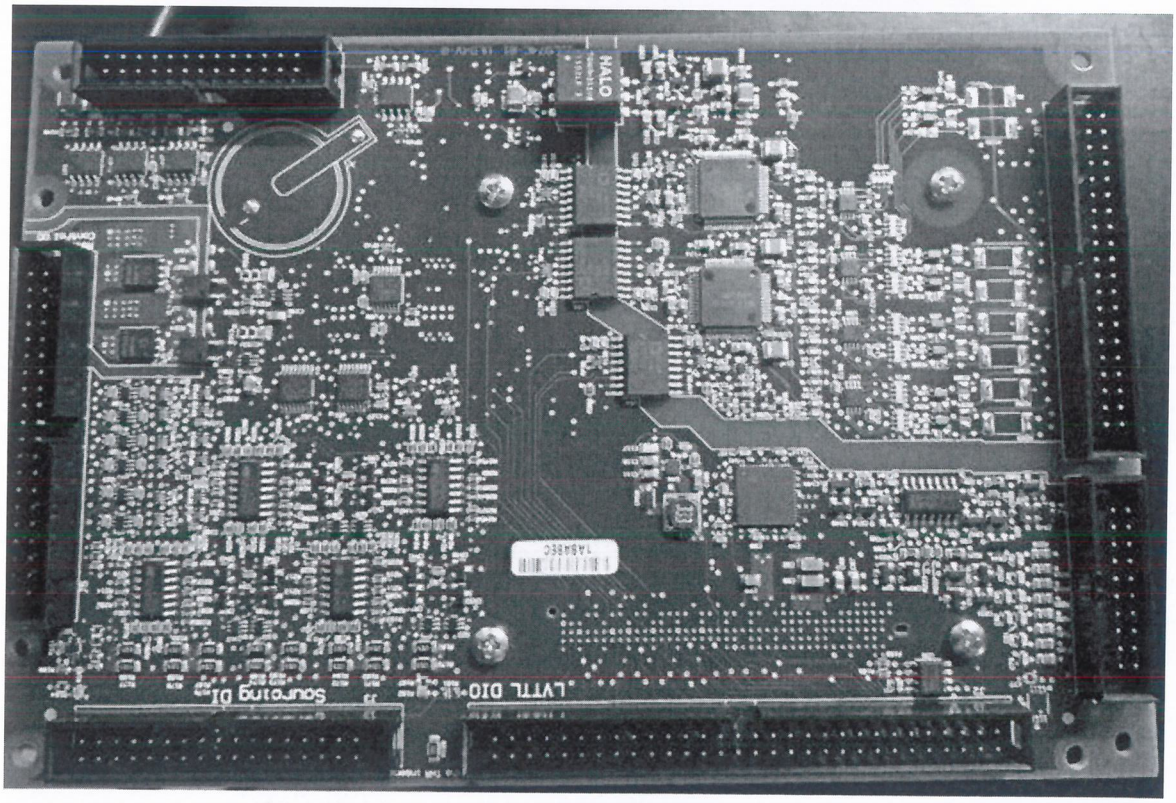
HPC cluster is made of 4 nodes. Two are Dell PowerEdge R430 rack servers and two are Dell PowerEdge R440 rack servers. A total of 8 processors and 80 cores are available in the cluster, with support for multithreading. 320 GB RAM and 16 TB Storage is available. Software installed include Matlab, Mathematica, ABAQUS, gfortran compiler and gnuplot.



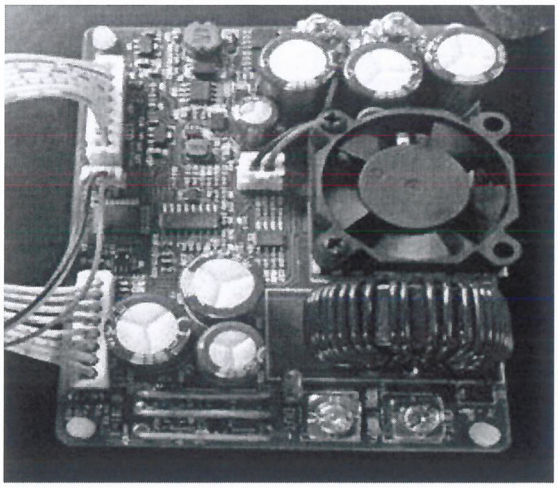
Smart Grid and Renewable Energy Lab



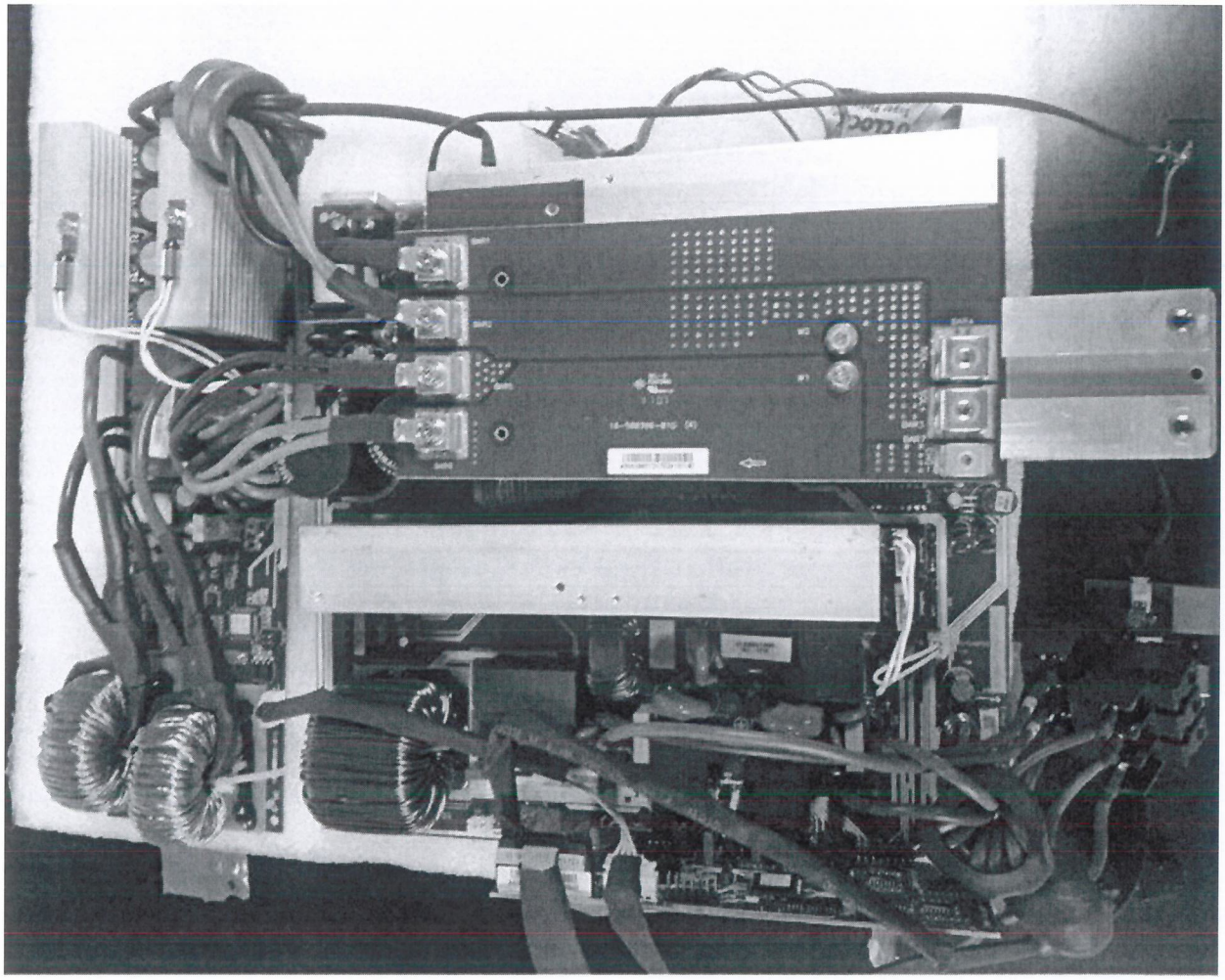
3 PHASE 4 LEG GRID CONNECTED INVERTER



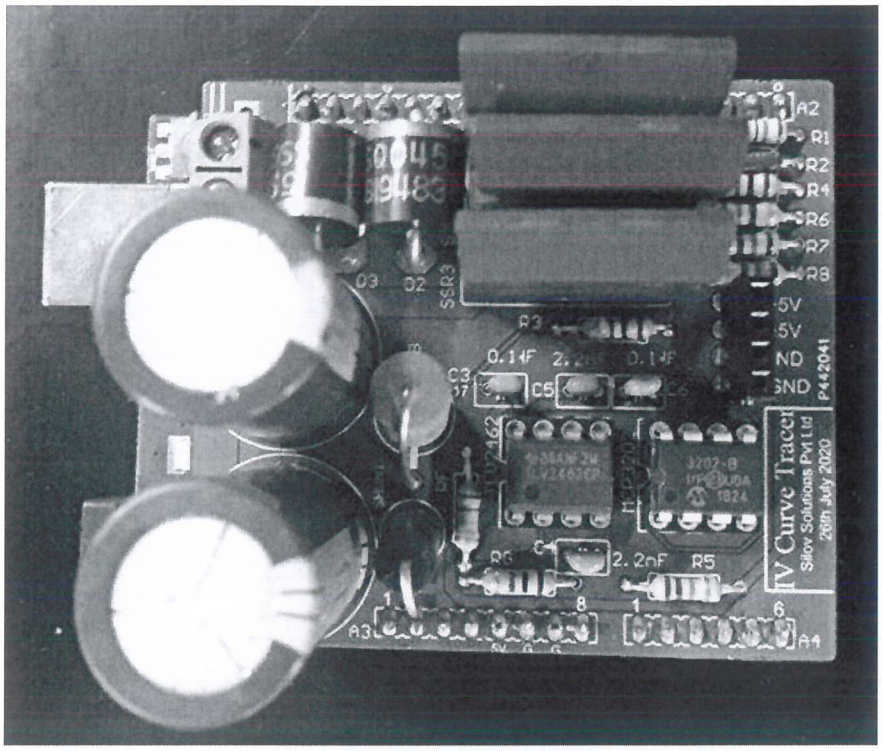
NI LABVIEW SB-RIO



1KW SOLAR PV EMULATOR

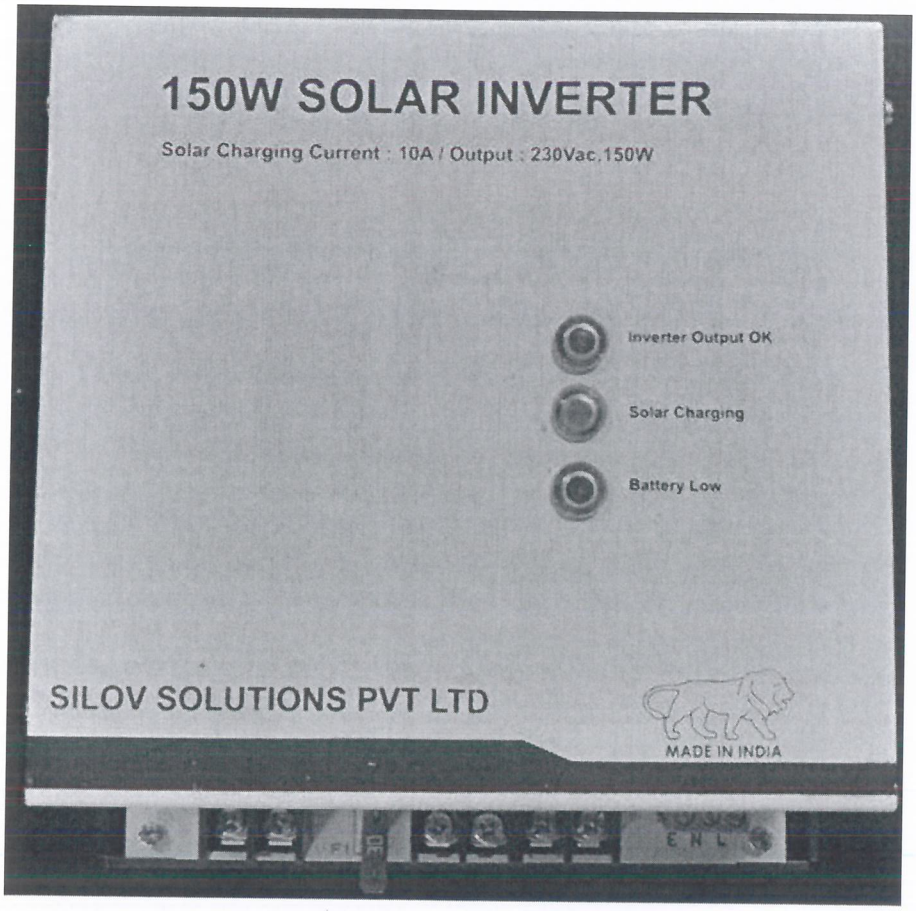


1KW HYBRID SOLAR INVERTER

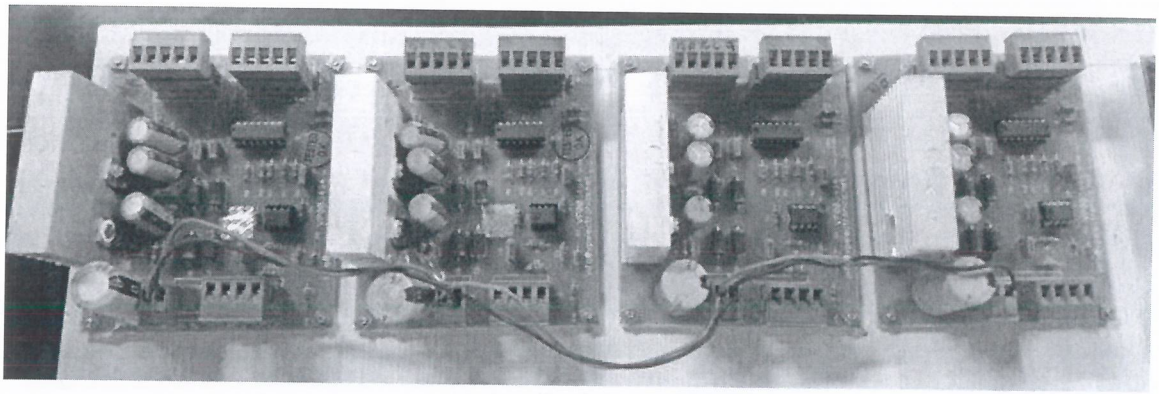


SOLAR IV CURVE TRACER

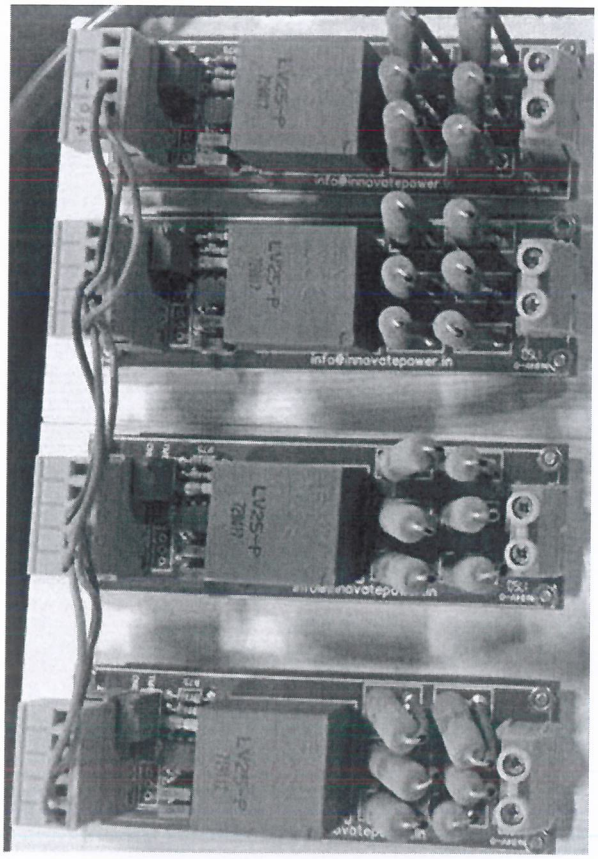
250W ELECTRONIC LOAD



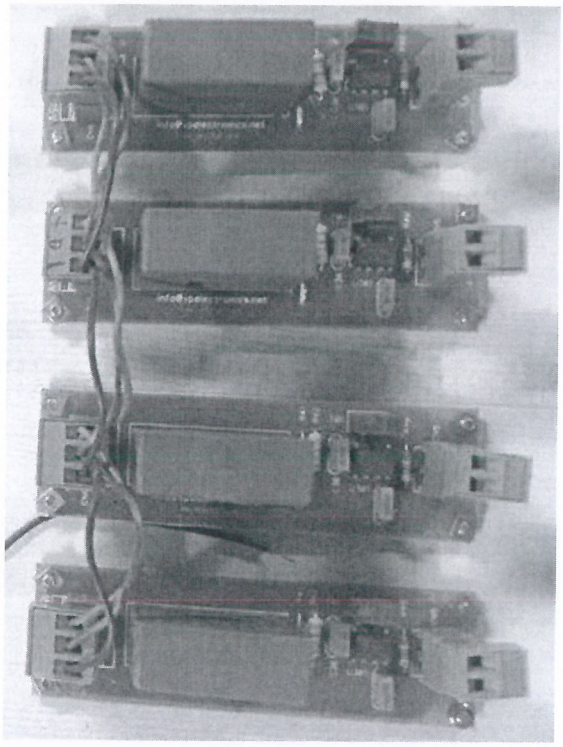
12V DC- 220V AC SOLAR INVERTER



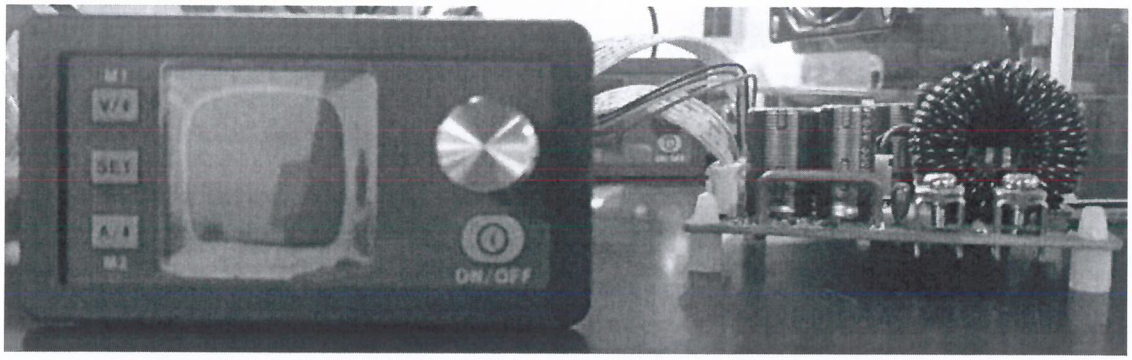
BOOSTER BOARDS



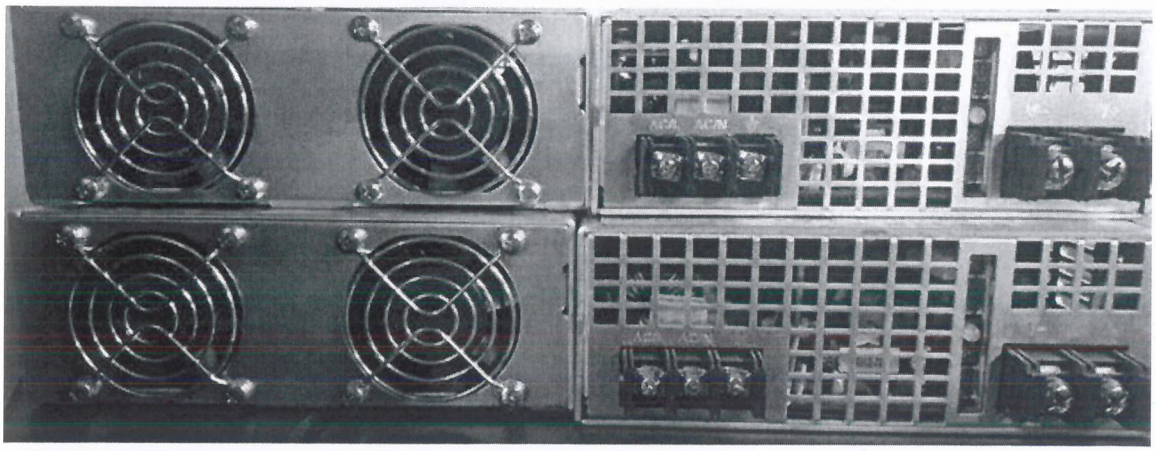
VOLTAGE SENSORS



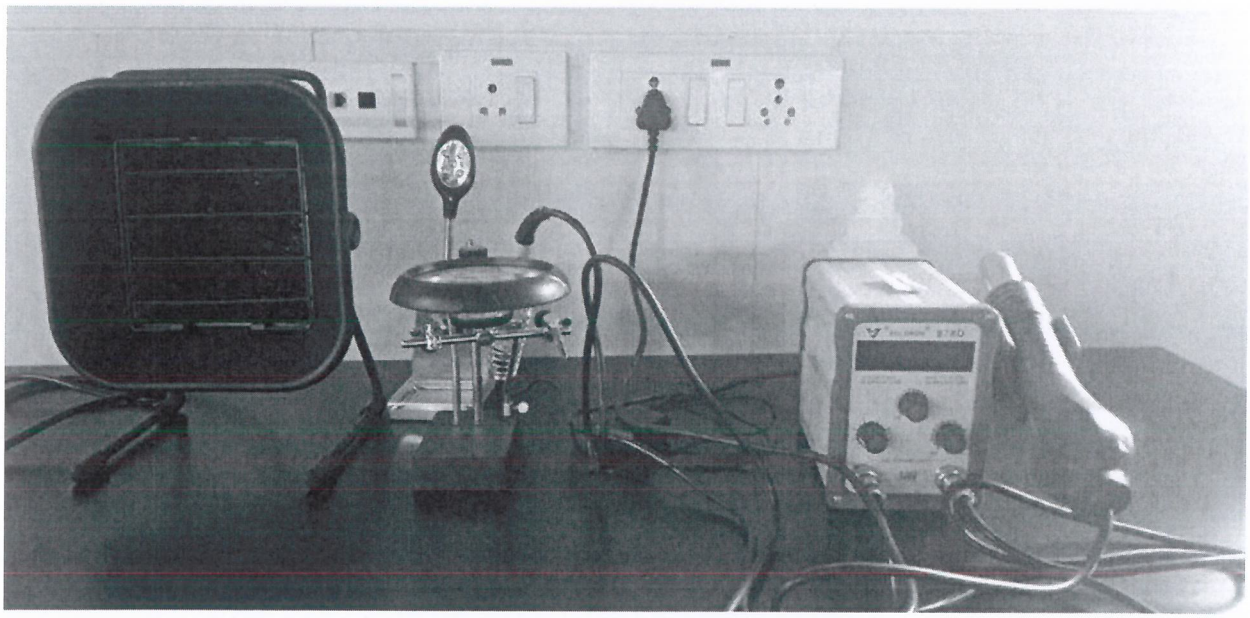
CURRENT SENSORS



VOLTAGE & CURRENT CONTROLLED DC-DC CONVERTER



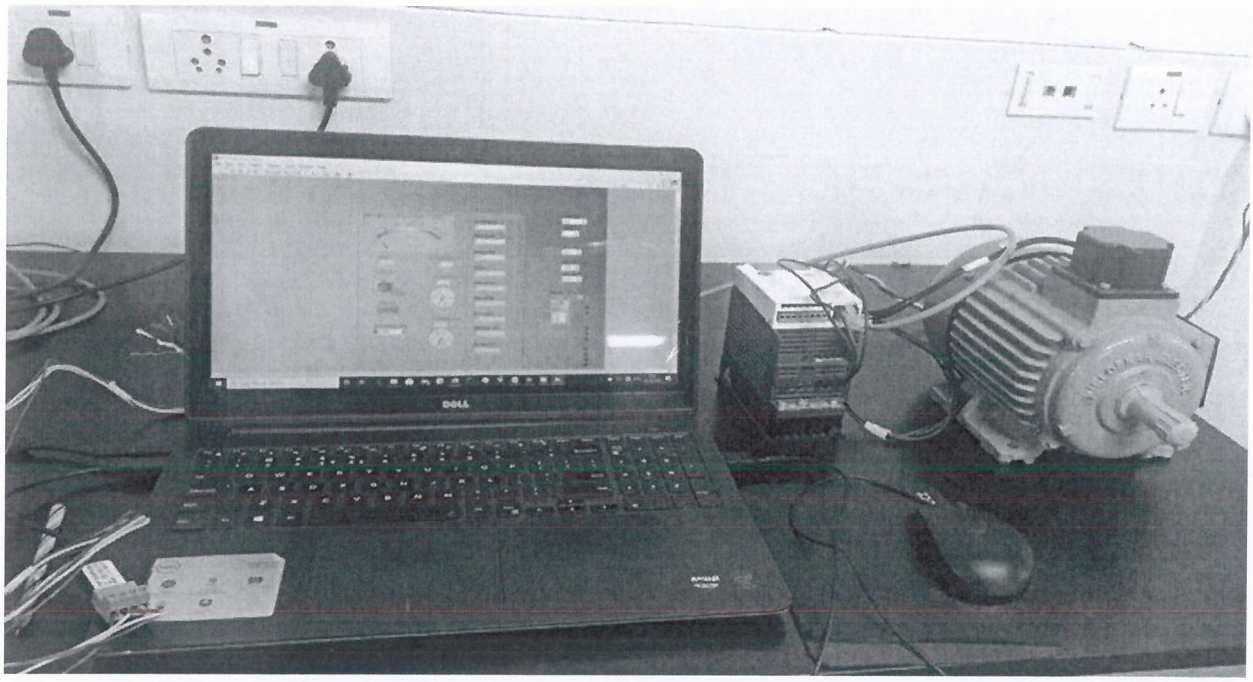
30 KW- SMPS



SOLDRON – SOLDERING STATION

STM32F407-DISCOVERY KIT

STM32F750 DISCOVERY KIT



CONTROLLING VFD OF AN INDUCTION MOTOR VIA PC

Automotive Systems Laboratory

This lab aims to introduce working of a traditional automobile and its powertrain. The primary equipment in this laboratory is a motorised cut-section of a 31 tonne Heavy Commercial Vehicle (Truck), which shows the entire drive train from the engine to the transmission and axles (including differential), in operation. Cut-sections of major components enable visualisation of the internals and their working. Apart from this, there is an LCV aggregate, and a truck cabin. The lab also has its own vehicle inspection pit and also a drivable 50 tonne HCV (trailer).

List of Equipment:

- Motorised cut-section of 31 tonne HCV, and Cabin mounted on a stand (separately)
- 6 tonne LCV Aggregates (Engine and Chassis)
- Driveable 50 tonne HCV (trailer truck)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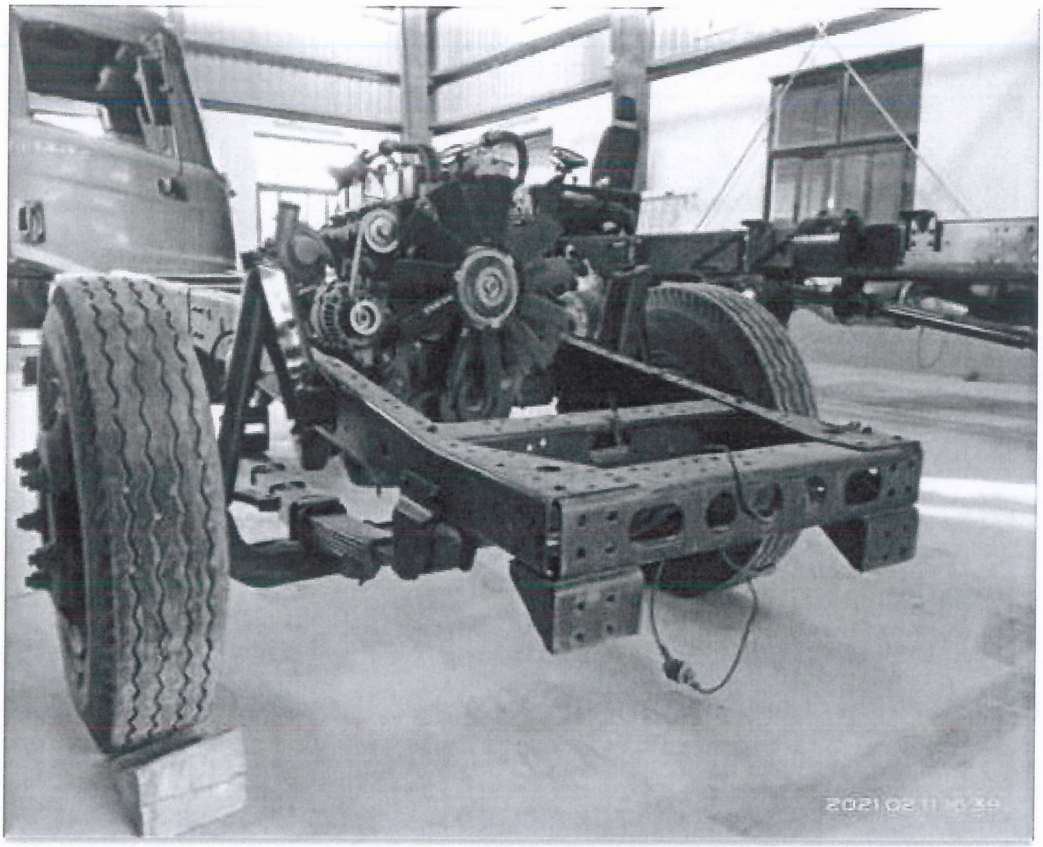


Center for Sustainable Infrastructure and Systems

Center for sustainable Infrastructure and systems (CSIS)

Infrastructure is very crucial for Nations development. Sustainability will decrease the environmental risk and increases the recycling of resources for bridges, hydraulic structures, pavements, sanitation networks and sky scrapers. It provides the services that enable society to function and economies to thrive. This puts infrastructure at the very heart of efforts to meet the sustainable development goals.

CSIS works towards achieving these goals by through its Three Dimensional (3D) mission and Five Dimensional (5D) vision.

3D mission:

Environment: Infrastructure assets play a key role in conserving natural resources and reducing the impact of climate change. So, usage of Traditional Materials in new construction can reduce greenhouse gases significantly and by minimizing the deterioration through regular maintenance (SHA and SHM), the functional utility of the structure can be increased to its design life. Deployment of sensors in the infrastructure will decrease consumption of energy.

Economy: Pre and post natural disaster effects on structural response makes serious impact on economy, so significant studies are being carried for earthquakes, cyclones, blast and vehicular-structural collisions damages.

Societal safety: Smart structures with hybrid solutions can predict the structural failures much advance and will be able to give enough warning.

5D vision:

Academic: Development of new academic courses while upgrading the existing courses in the line of sustainability. Adopting new technologies like Machine Learning and Artificial Intelligence in the domain areas of Earthquake Engineering, Structural Health Monitoring (SHM), Structural Design Optimization and Conservation of Heritage Structures. Focus on teaching the relevant courses with the exposure of real-time case studies are ongoing.

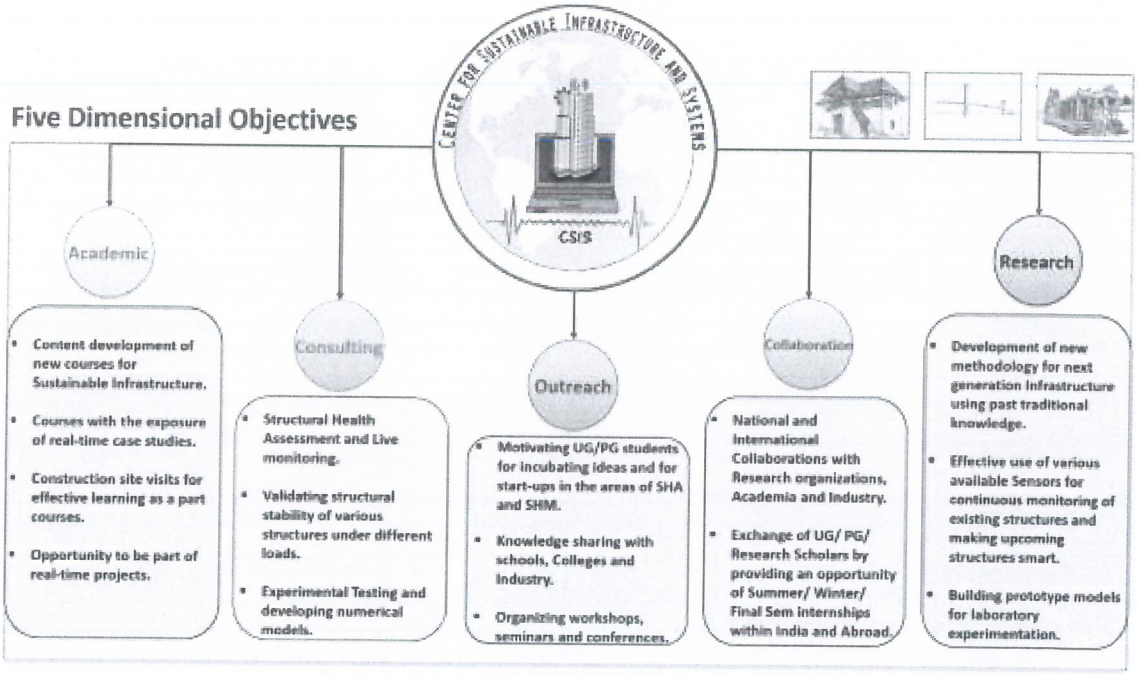
Research: Studies made on traditional techniques of rural housing motivated to the development of new methodologies for next generation's sustainable Infrastructure. Dwelling the possibilities in effective use of various Wireless Sensors for continuous monitoring of existing structures and making upcoming structures smart. Building the damage incorporated structural scaled models in view of experimental analysis. Modeling and mimicking the nature inspired structures for design optimization. Venturing into Augmented Reality (AR) and Virtual Reality (VR) for conservation of Traditional and Heritage structures. Artificial Intelligence for large seismic data analysis, prediction of

aftershocks and SHM. Product development for AI based damage identification, Bridge Management System, Tsunami wave propagation and crowd evacuation.

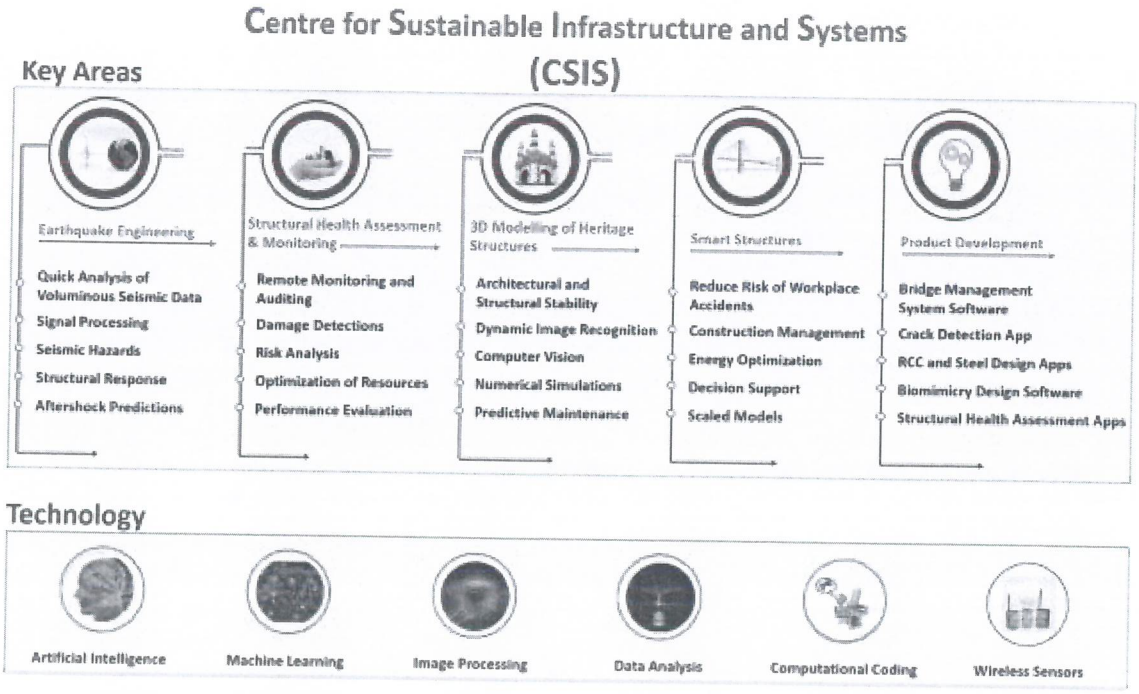
Consulting: Structural Health Assessment and Monitoring of RCC, steel and Heritage structures using advanced Nondestructive testing equipment's and wireless sensors.

Collaboration: For the greater impact and to cultivate the opportunities for the young minds, Center is collaborated with the Industry and Universities in India and abroad; KDM Engineering and Consulting India Pvt Ltd., NVLN Constructions Pvt Ltd., Vasaamaha Consultants; IIT Hyderabad, IIT Patna, IIT Mandi, IIT Bhubaneswar; ISEP Portugal, University Technology Malaysia, Brandenburg University of Technology Cottbus–Senftenberg Germany, Ulsan National Institute of Science and Technology South Korea, NTNU Norway.

Outreach: Center motivates UG, PG and research scholars for incubating ideas and for start-ups in the areas of SHA and SHM. Knowledge sharing with schools, Colleges and Industry through talks, lectures, workshops, seminars and conferences. Facilitate internship opportunities during summer and winter for students across the globe.



Mahindra University Hyderabad

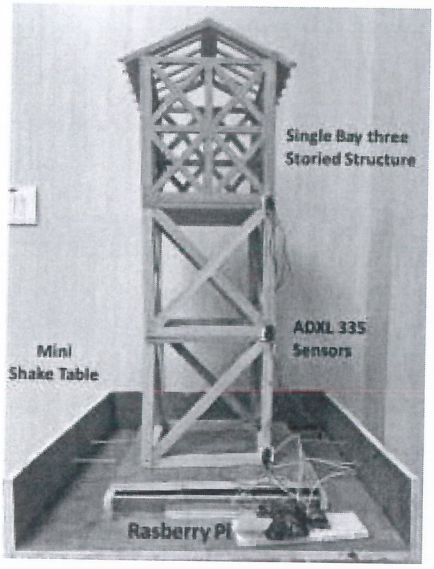


Ongoing Projects:

a. Structural Health Assessment and Monitoring of structures using wireless sensors and Artificial Intelligence. (Jan 2020 – Dec 2022)
b. Building Digi-Encyclopedia of Indian Traditional Houses using Augmented Reality. (Nov 2019 – Dec 2023)

Equipment/Prototype Models:

a. **Mini Shake Table:**

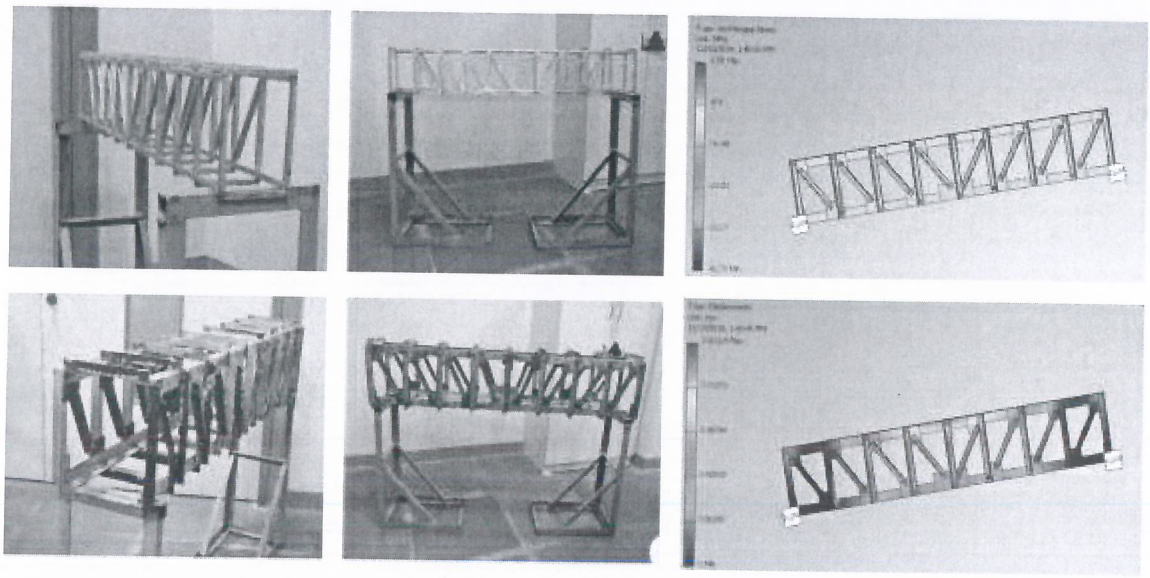


A Mini shake table developed in the lab to measure the response using accelerometer sensors of various heights of structures of single bay. The image shows all the components of the shake table. Also automation using machine learning (ML) models of the same is carried to see the response of the structure live on the mobile for human induced vibrations.

b. Prototype Foot Over Bridge

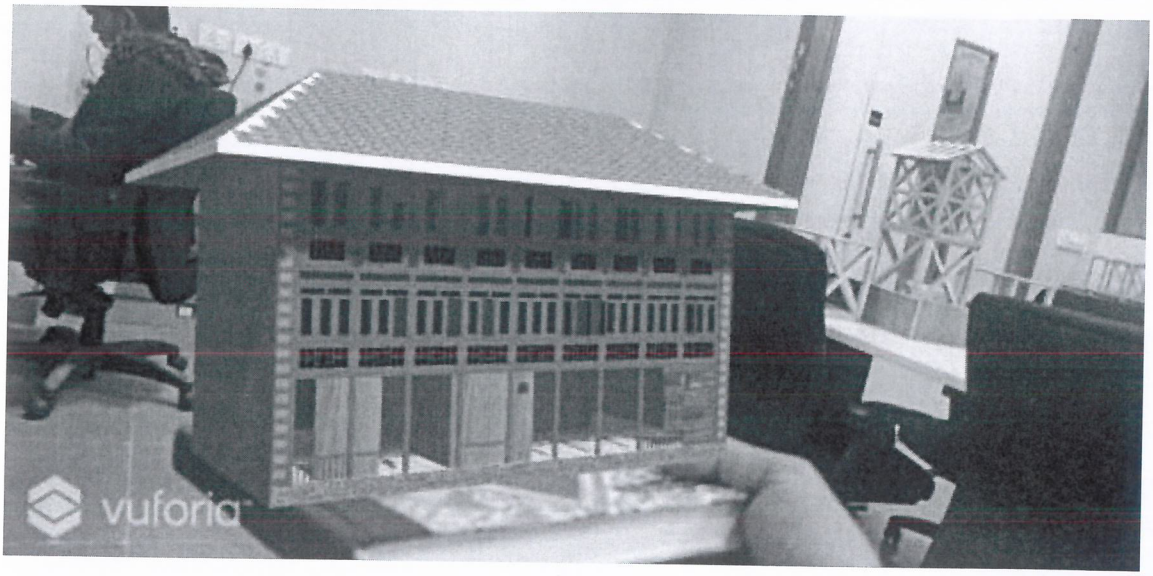
Foot over Bridge Prototype Model for Experiment

Numerical Model of prototype bridge



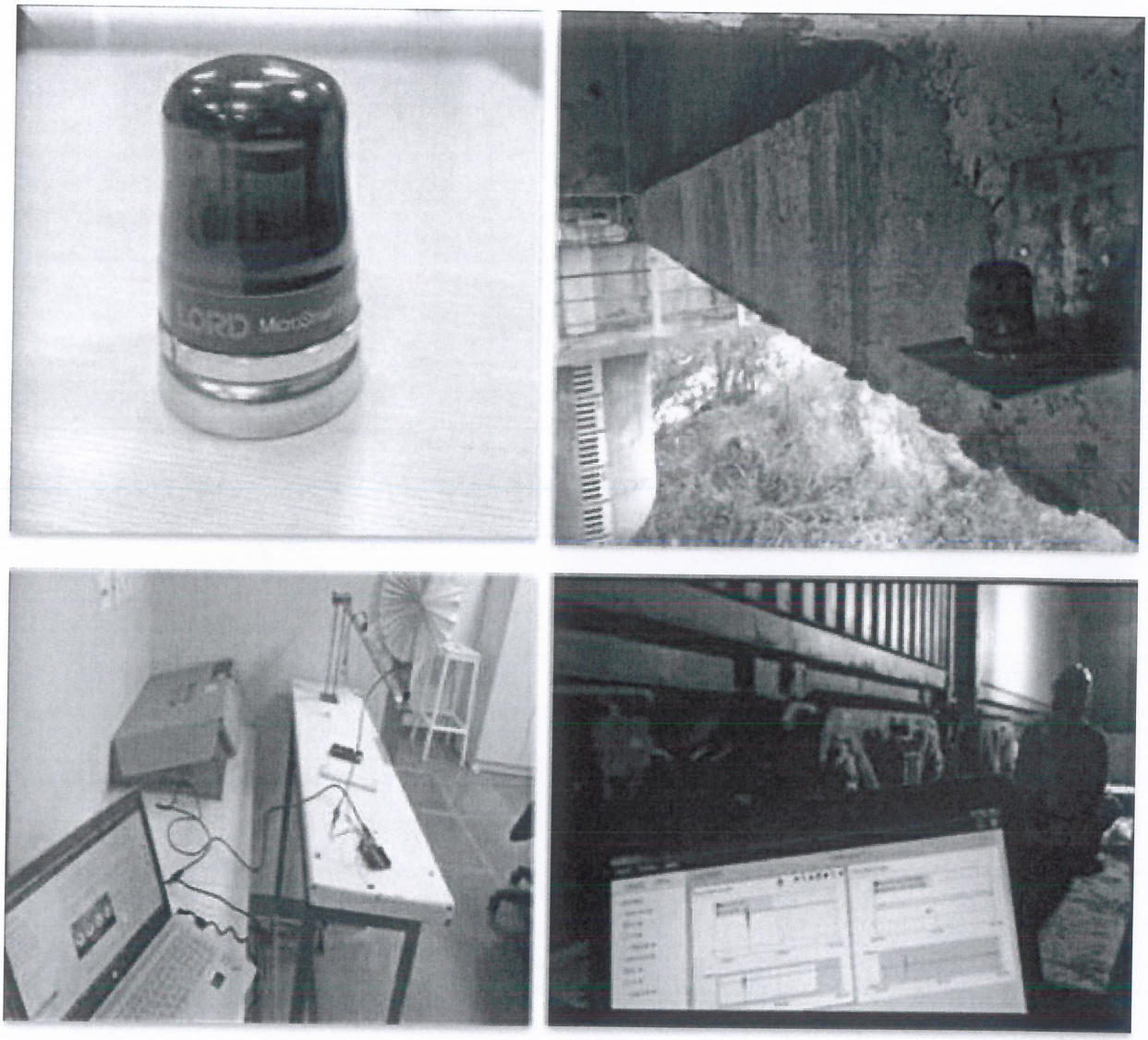
Prototype foot over bridge developed to understand the location of damage using wireless sensors, damage is induced manually at the element level and at the joints.

c. Digi-Encyclopedia of Indian Traditional Housing



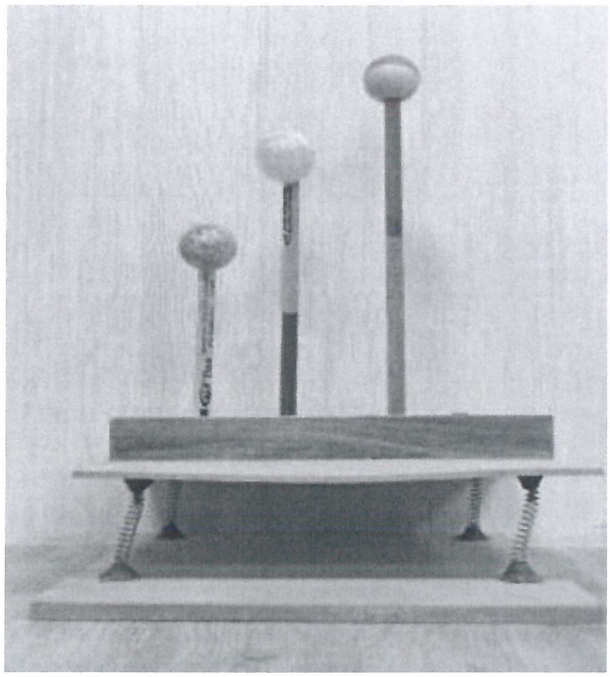
Sample 3D scaled traditional house model is built using conventional software and projected virtually on any surface using classical Augmented reality (AR) techniques, as part of making digital encyclopedia of the Indian traditional structures indicating the science and engineering behind the materials used and structural design.

d. Accelerometer Wireless Sensors during lab testing and real time bridge testing



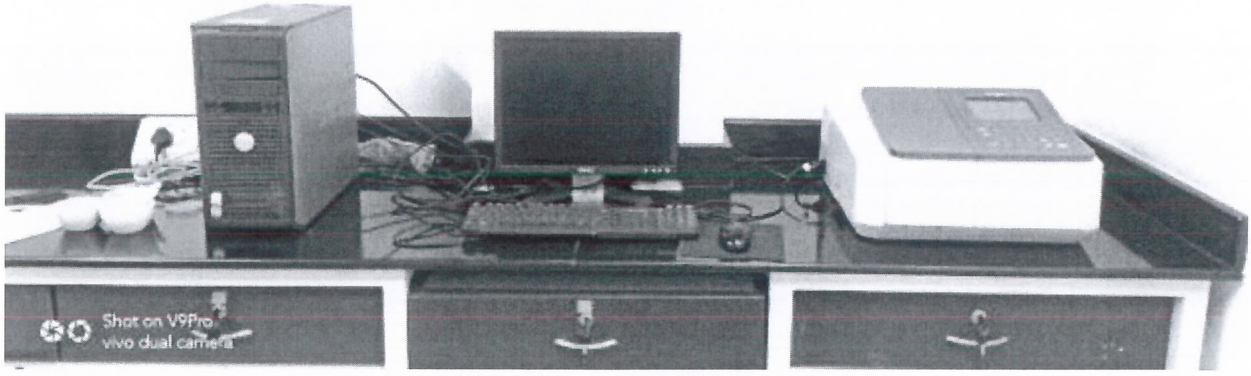
Glink 200 lord macrostrain accelerometer sensors to evaluate the characteristic properties of the given system.

e. **Resonance Prototype Model**



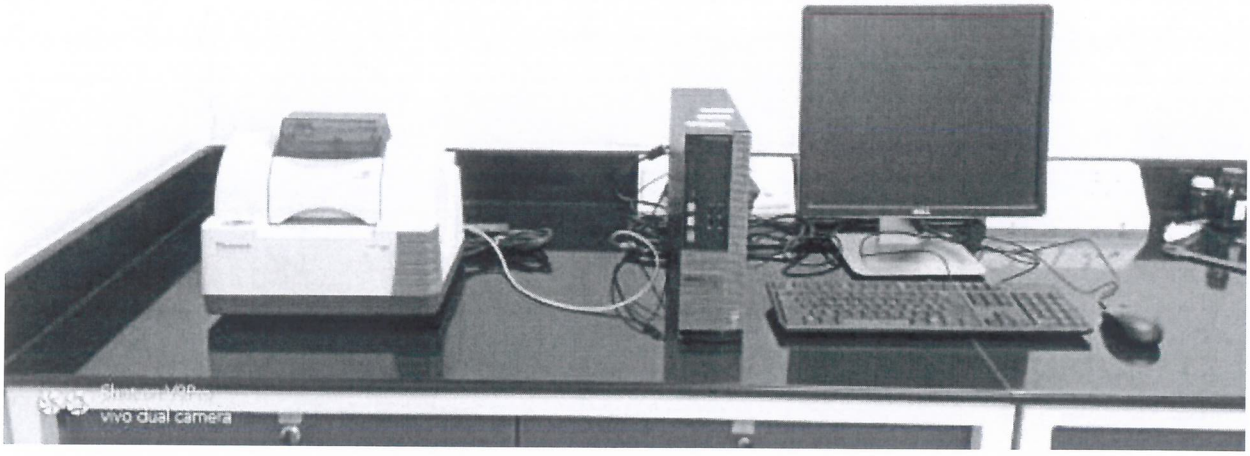
Prototype model to demonstrate the maximum response depends on the ground motion and not on the height of the structure.

Chemistry Research Lab



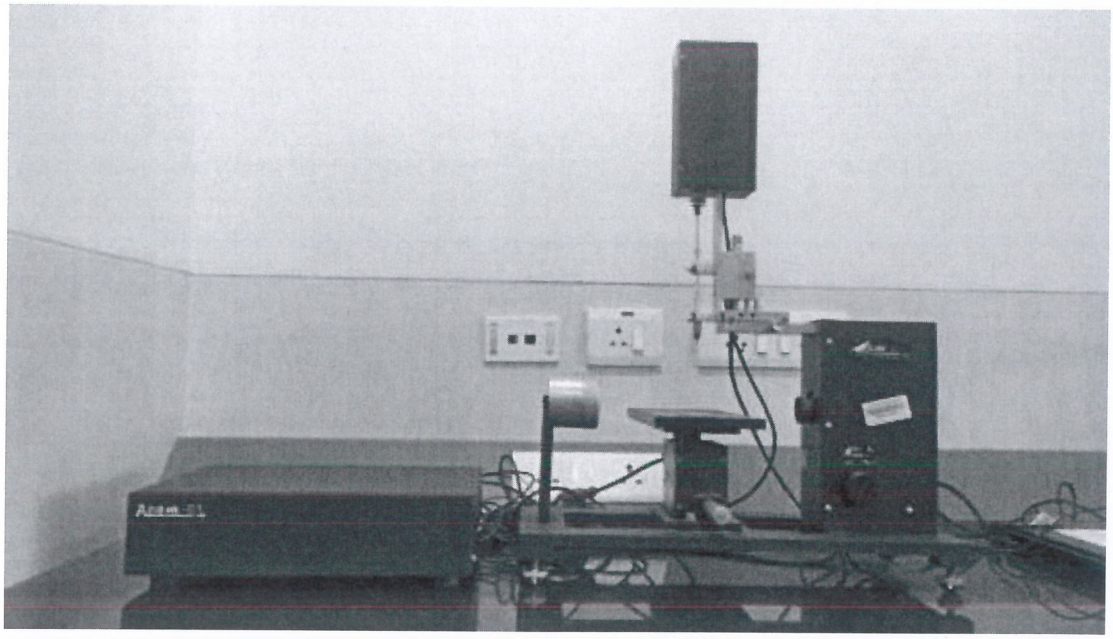
Ultra-Violet Visible Spectrophotometer

Make: Shimadzu



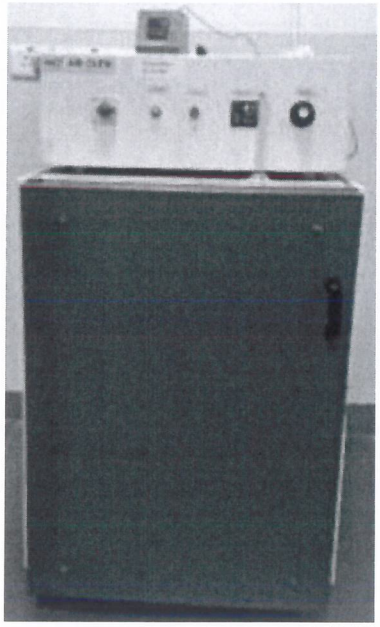
Infrared Spectrophotometer

Make: Nicolet iS5, Thermo Fischer



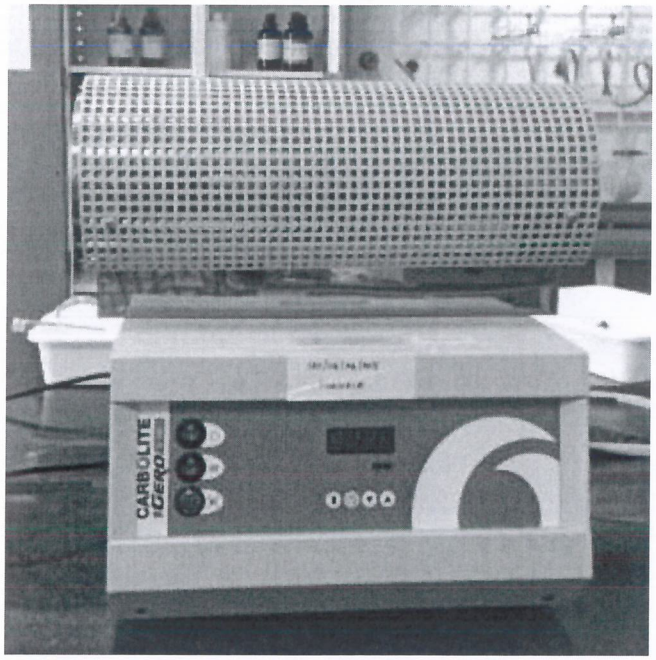
Contact Angle Meter

Make: Acam-D1



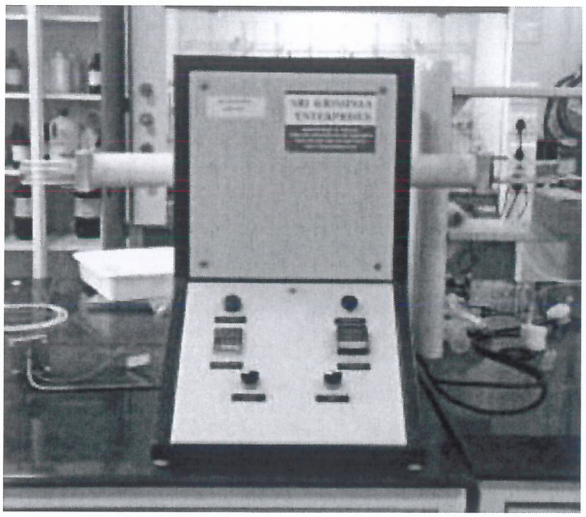
Hot Air Oven

Make: Thermocon



High Temperature Tube Furnace

Make: Carbolite

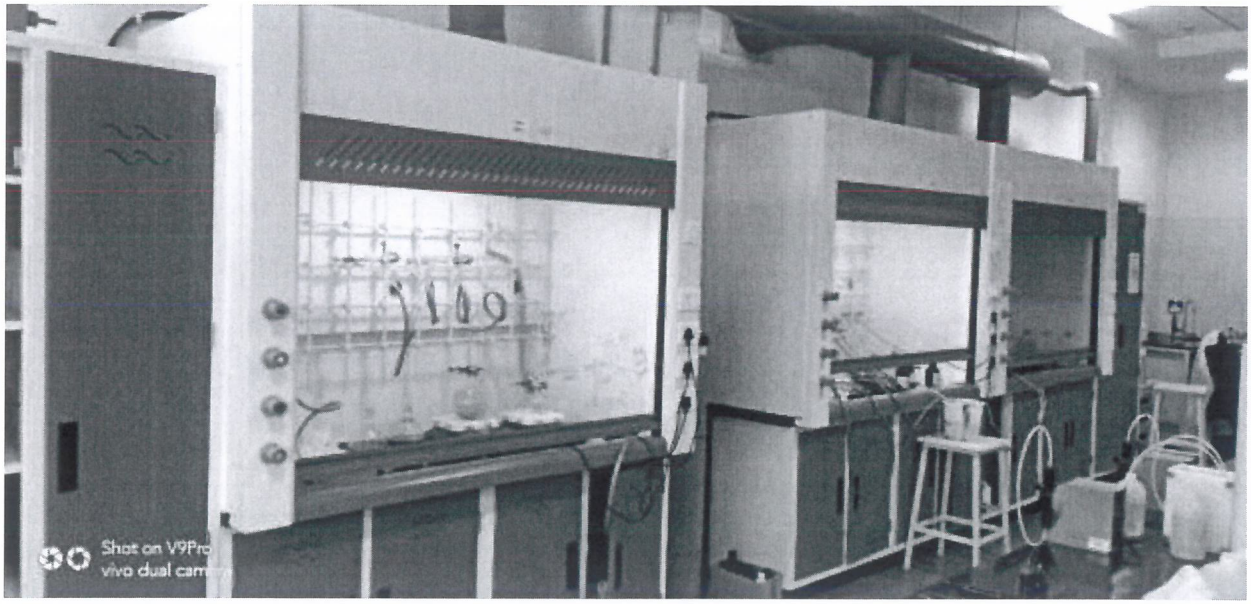


High Temperature Tube Furnace

Make: Sri Krishna Enterprises

High Temperature Muffle Furnace

Make: Sri Krishna Enterprises



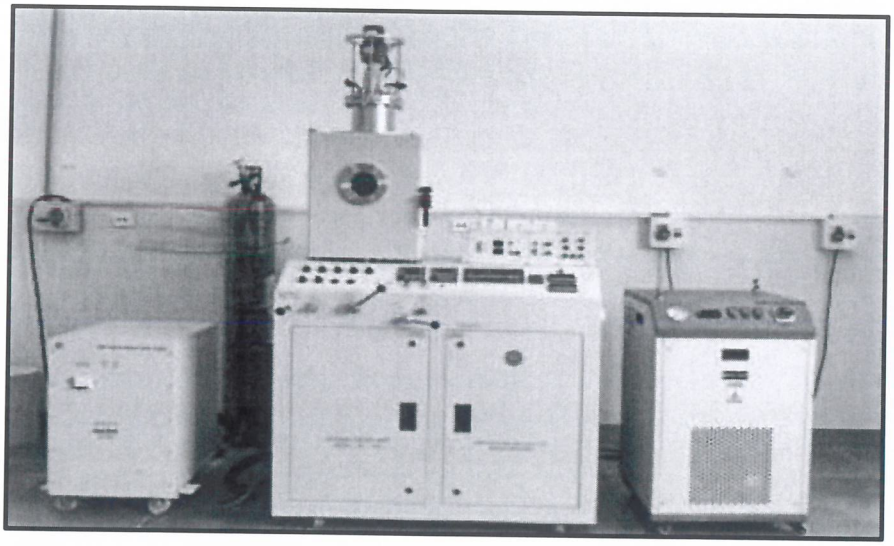
Ventilated Fumehoods and Fume cupboards

Make: ArtLab

Physics Research Lab

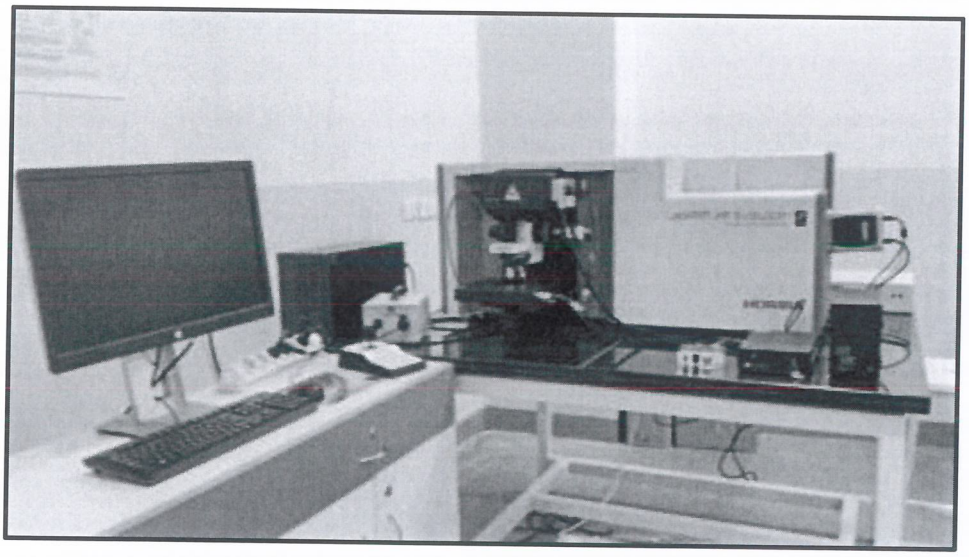
Electron Beam Evaporation

1. Electron Beam Evaporation is a physical vapor deposition technique.
2. Electron Beam bombarded on coating material will convert that material directly into vapor state and coated on substrate.
3. Higher deposition rate from 1nm to 100 nm per minute.
4. Only heats the target material and not the crucible, resulting in contamination free coating.
5. Company - Hind High Vacuum Bangalore.

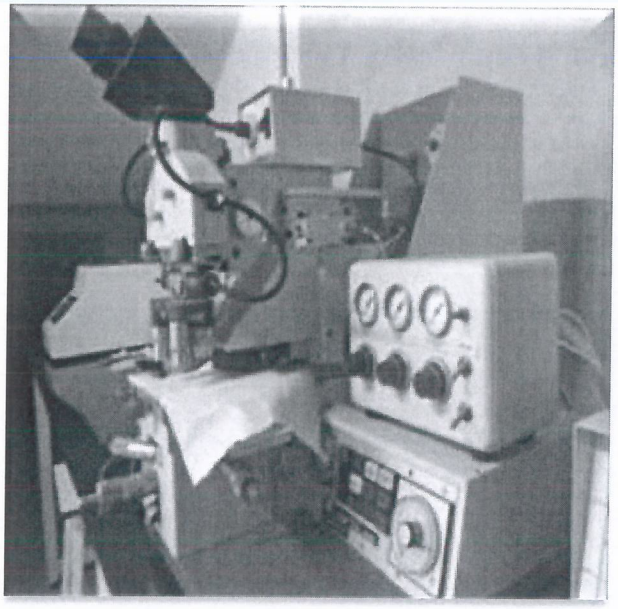


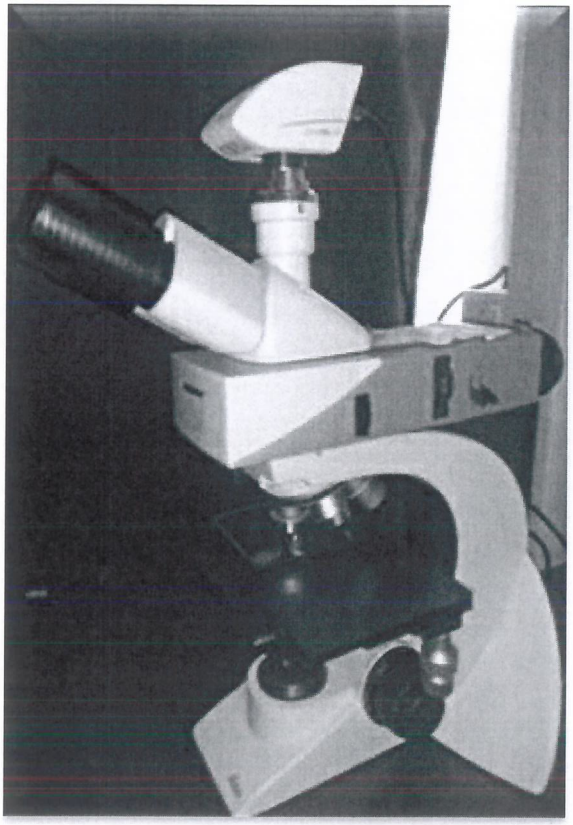
Raman Spectrometer

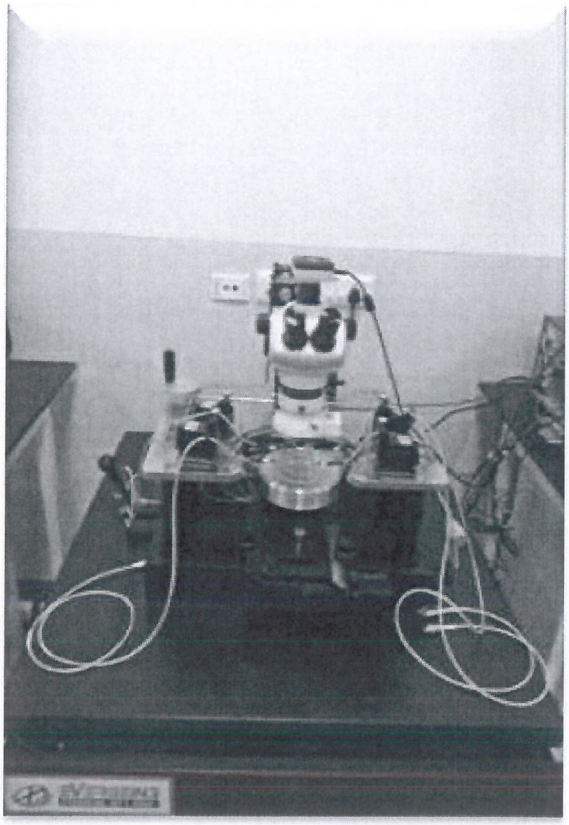
1. RAMAN Spectroscopy is a non destructive analysis technique which provides information about chemical structure, phase and polymorphy, crystallinity and molecular interactions.
2. It is based upon interaction of light with the chemical vibrational boding within the material.
3. RAMAN Spectroscopy is in-elastic light scattering technique.
4. System- LabRAM HR Evolution RAMAN Spectrometer HORIBA

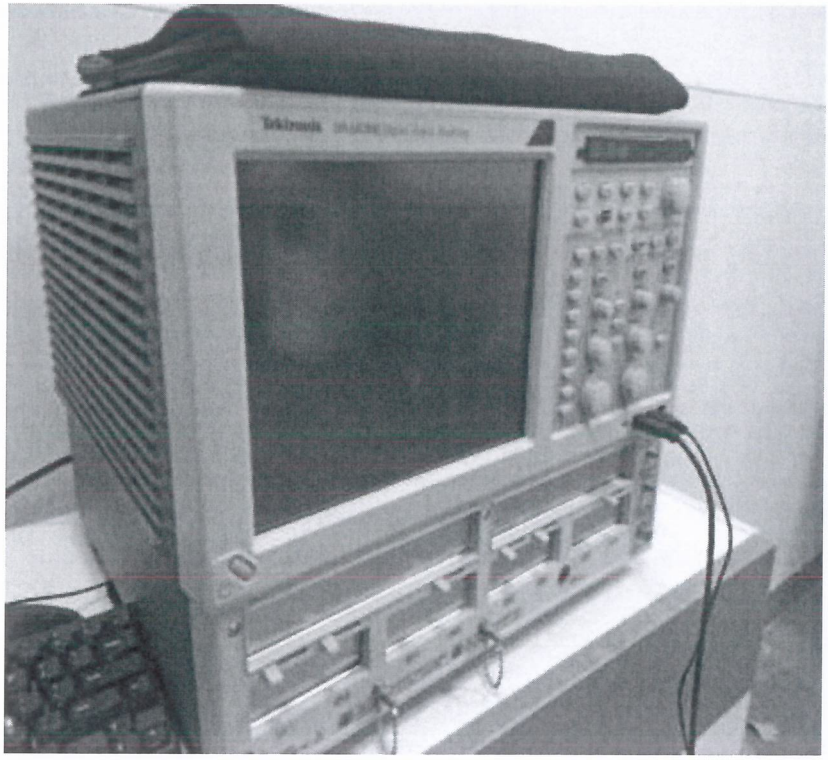


Other Major Equipment

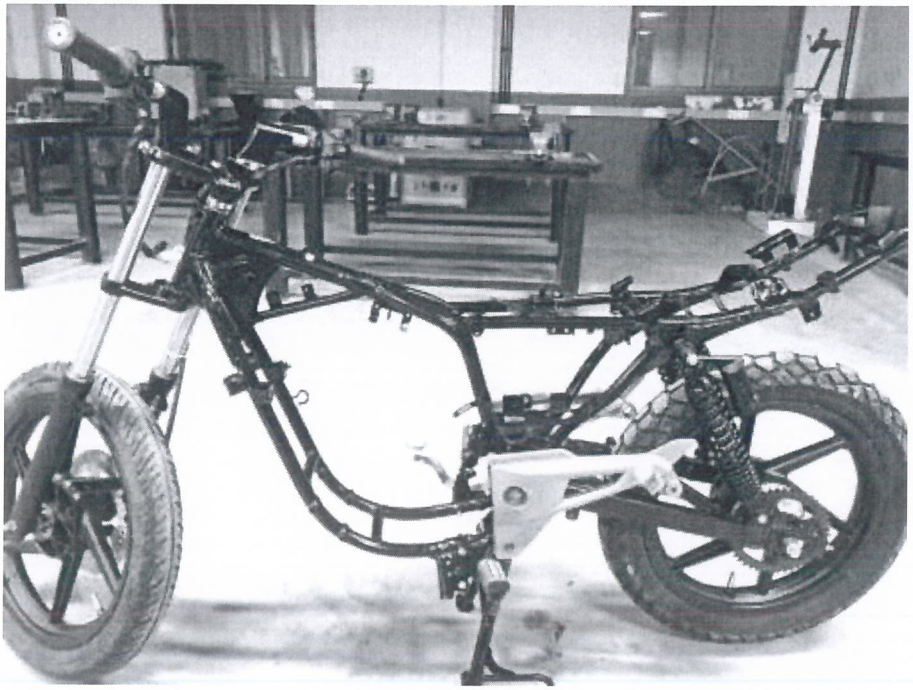




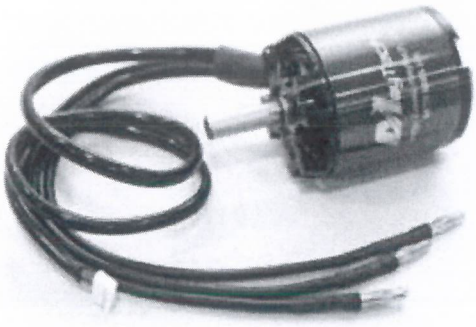




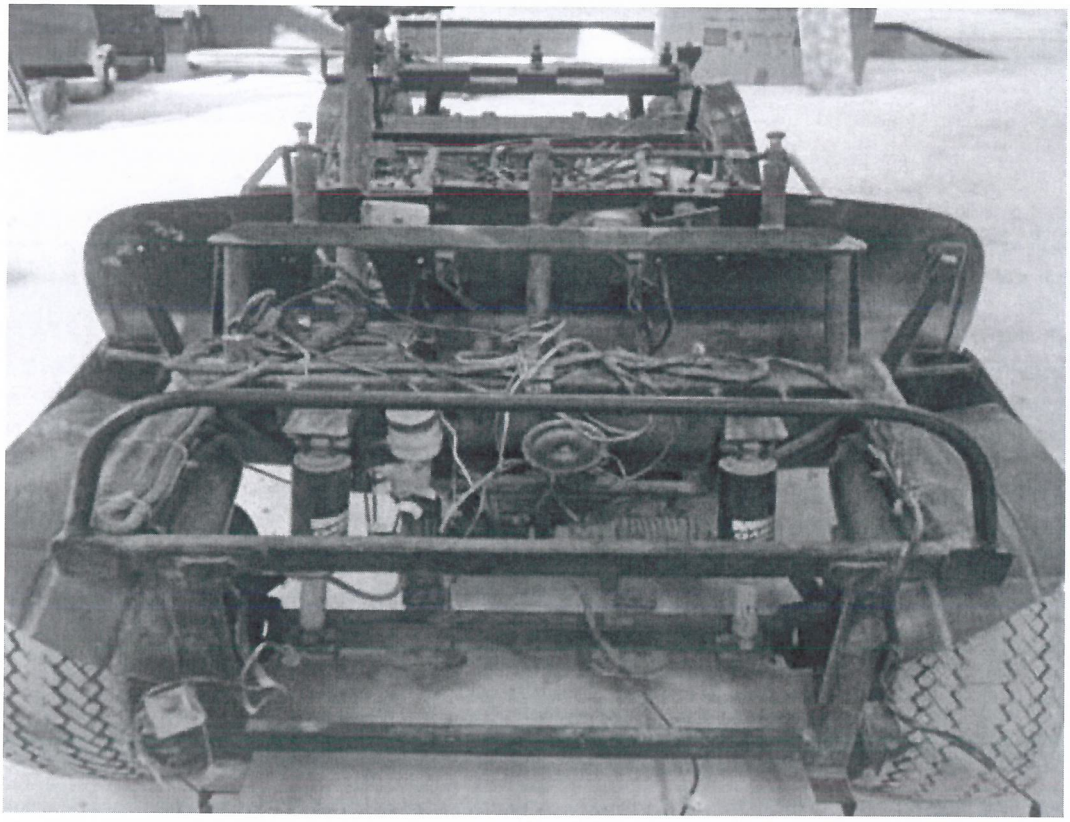
Electric Vehicle Research Laboratory



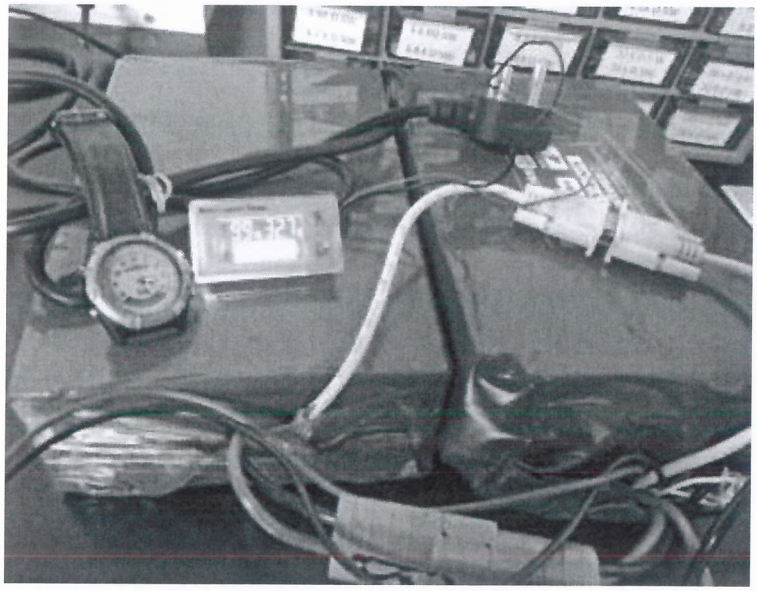
e-bike frame



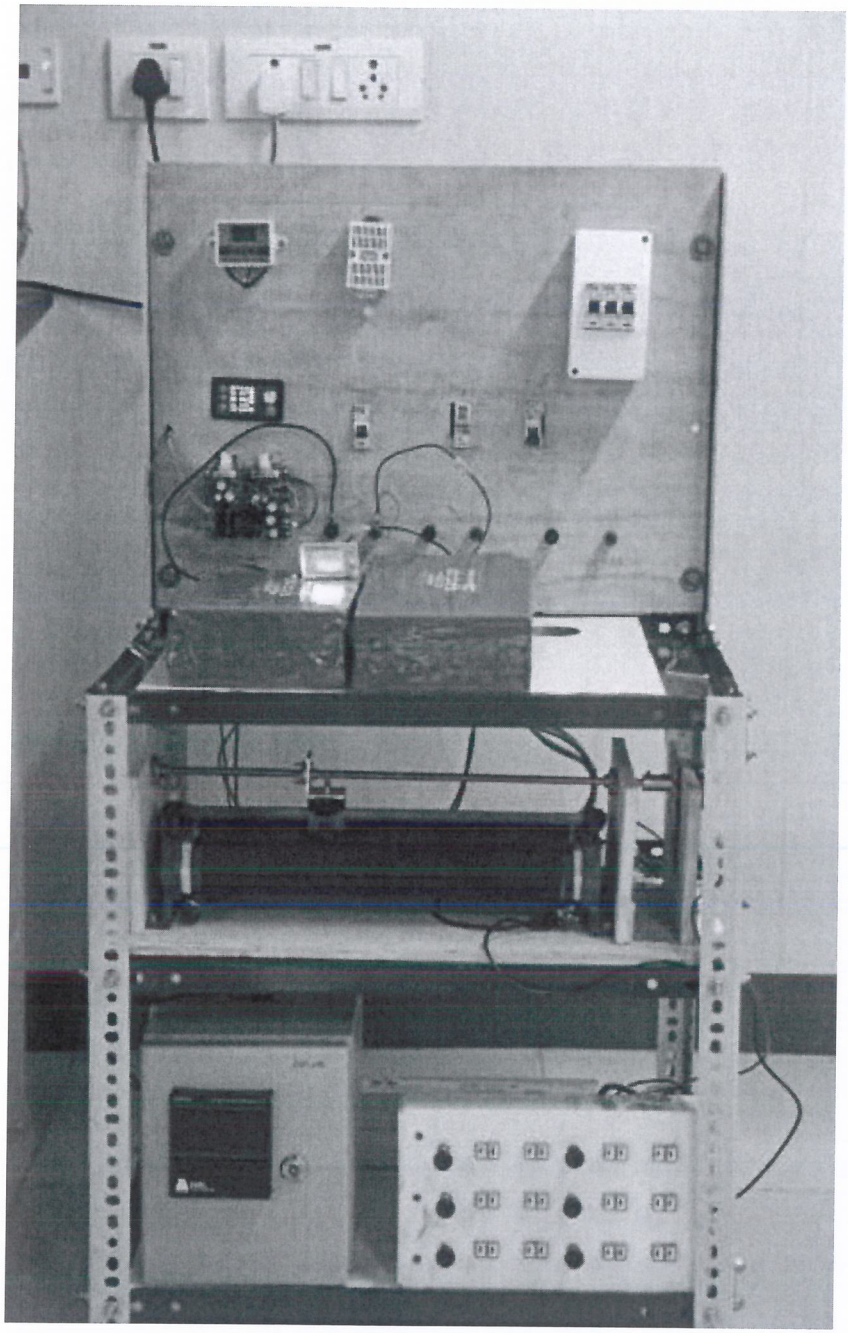
BLDC Motor



e-golf cart frame



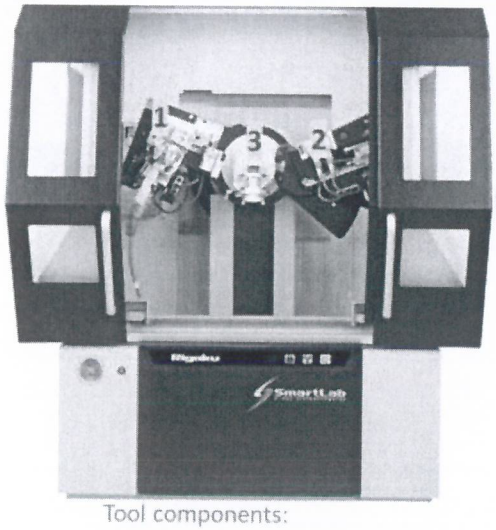
Battery Pack

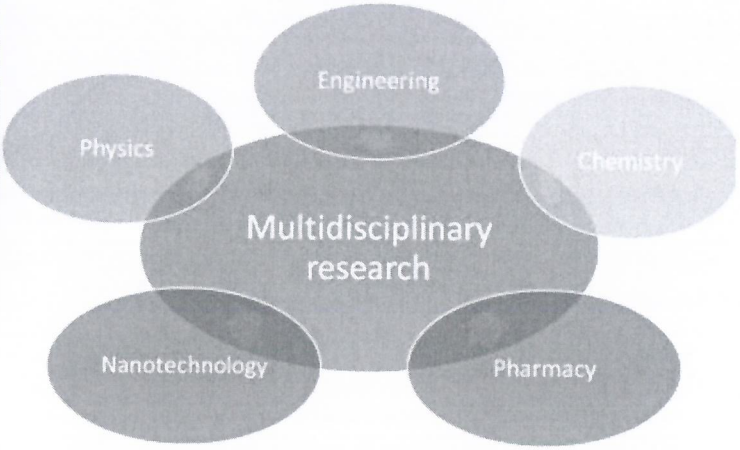


Sky RC battery tester

XRD Research Facility

X-Ray Diffraction (Rigaku-Smart Lab) Tool

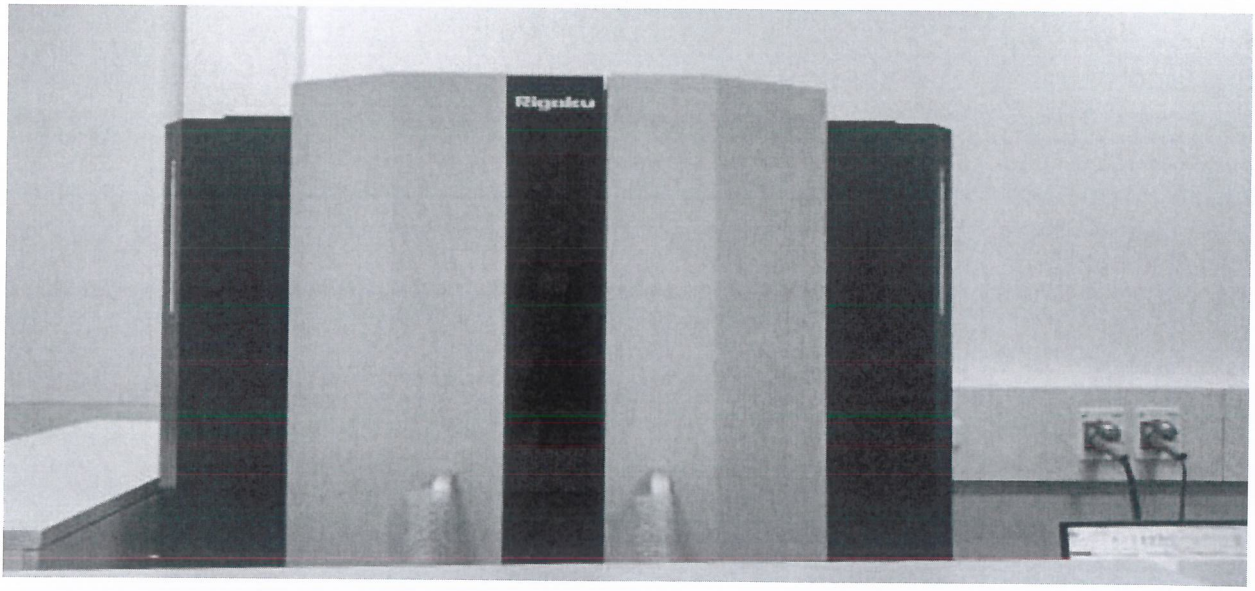




Tool components:

1. X-Ray source
2. Detector
3. Sample stage

State-of-the-art facility @ Mahindra University



Finance Research Lab

The Finance Research Lab at the School of Management, Mahindra University is a state-of-the-art facility designed to support cutting-edge research in finance. Our facilities are designed to support innovative and collaborative research in finance and to provide our researchers with the resources they need to advance the field. The Bloomberg terminal and NSE simulation software are two important tools available in the Finance Research Lab that help support research and analysis of financial markets and investments.

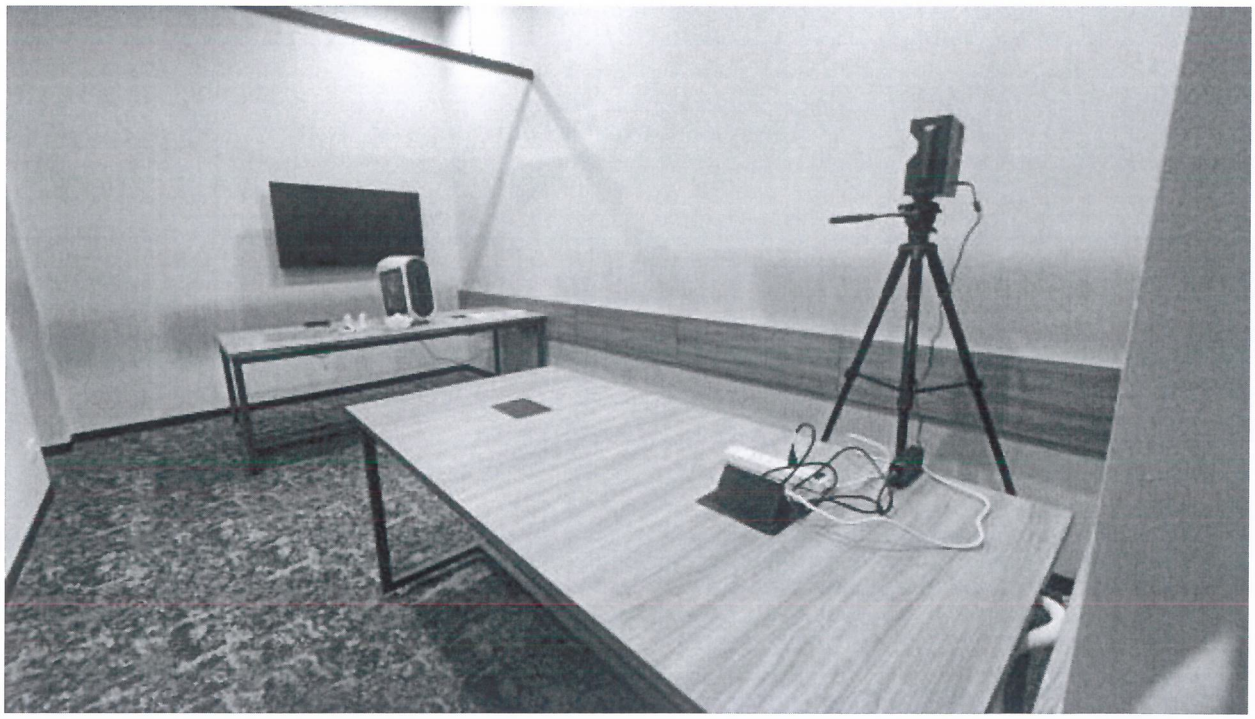
The Bloomberg terminal is a sophisticated financial data and news platform that provides users with real-time information and analysis on financial markets, investments, and economic news. It includes a wide range of features, such as news feeds, analytics, financial data, and trading tools, which are invaluable for researchers analysing financial markets and conducting investment research. The terminal also includes powerful analytical tools, such as charting and technical analysis, which can help researchers identify trends and patterns in financial data. Researchers can also use Bloomberg to perform financial modelling and to test investment strategies.

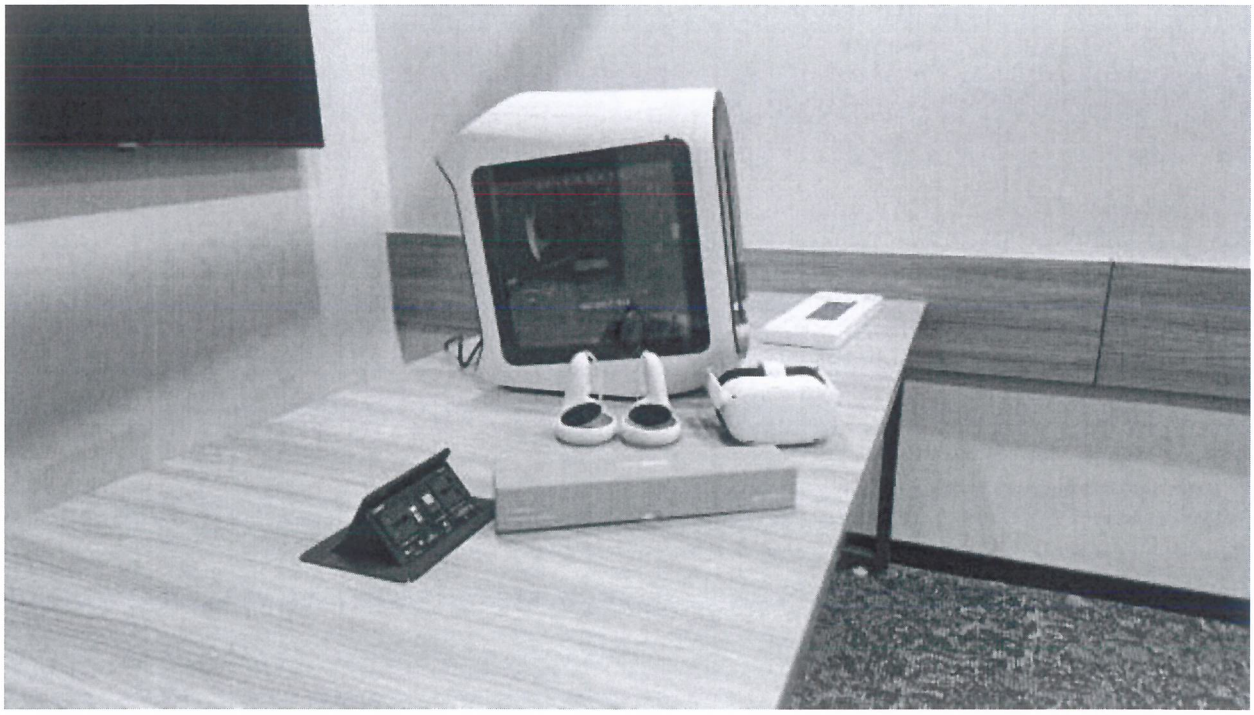
The NSE simulation software is a virtual trading platform that is designed to simulate a real trading environment in the National Stock Exchange (NSE), providing users with access to real-time market data, news feeds, and trading tools. Users can create and manage a virtual portfolio, execute trades, and monitor their performance in real-time. This software provides a hands-on experience for researchers and students to practice trading strategies and test their investment hypotheses in a simulated environment before investing real money. It provides a risk-free environment to experiment with different trading strategies and to learn from successes and failures.

Together, these tools are critical to supporting research and analysis of financial markets, investment strategies, and economic trends. The Finance Research Lab provides access to these tools to ensure that our researchers and students have the necessary resources to conduct innovative research and make informed investment decisions.

Digital Research Lab

The lab is powered by high capacity Alienware desktop and has equipment such as eye tracker and oculus headset to conduct marketing experiments. The current focus on the lab is to conduct Metaverse related consumer experiments.





Smart and Sustainable Materials Research Lab

1. LCR Meter

An LCR (inductance, capacitance, and resistance) meter is a device that measures the electrical properties of materials. In recent years, LCR meters have been used as a non-destructive testing tool for health monitoring of concrete structures. The electrical properties of concrete can provide valuable information about its structural integrity, including the presence of cracks, voids, and corrosion. The LCR meter works by applying an alternating current (AC) signal to the concrete and measuring its response. The meter can determine the impedance, or the opposition to the flow of electrical current, which is related to the inductance, capacitance, and resistance of the material. By analyzing the impedance data, the LCR meter can identify changes in the electrical properties of the concrete that may indicate the presence of damage or deterioration.

One of the main advantages of using LCR meters for health monitoring of concrete structures is their non-destructive nature. Unlike traditional testing methods, such as core sampling, LCR meters do not require physical damage to the structure, which can be costly and time-consuming. Additionally, LCR meters can provide real-time data, allowing for more frequent and accurate monitoring of the structure's condition.

LCR meters have been used in a variety of applications for health monitoring of concrete structures, including bridge decks, tunnels, and buildings. By detecting damage at an early stage, LCR meters can help prevent further deterioration and extend the lifespan of the structure. Overall, the use of LCR meters for health monitoring of concrete structures is an innovative and effective technique that can provide valuable information about a structure's condition. With their non-destructive and real-time monitoring capabilities, LCR meters are becoming increasingly popular in the field of structural health monitoring.

2. Waveform generator

A waveform generator is an electronic device that is used to produce various types of signals, including sine waves, square waves, and triangular waves. In the field of structural health monitoring of concrete structures. waveform generators are used as part of a non-destructive testing technique. The generator produces a signal that is amplified and sent to a transducer, which then converts the electrical signal into an acoustic wave that is transmitted into the concrete. By varying the waveform generated by the generator, different types of acoustic waves can be produced, allowing for more detailed analysis of the concrete structure. One of the advantages of using a waveform generator for impact-echo testing is its ability to produce repeatable and controlled signals. This allows for more accurate and reliable measurements of the concrete structure's properties over time. Additionally, waveform generators are relatively low-cost and portable, making them a practical tool for field testing of concrete structures.

3. Oscilloscope

An oscilloscope is an electronic device used to measure and display voltage signals over time. In the field of health monitoring of concrete structures, oscilloscopes are used as part of a non-destructive testing technique. One of the advantages of using an oscilloscope is its ability to provide real-time feedback on the condition of the concrete structure. By monitoring the voltage signal over time, changes in the structure's corrosion activity can be detected and addressed before they lead to significant damage or failure. Overall, the use of oscilloscopes is a valuable tool for monitoring the health of concrete structures.

4. Digital Multimeter

A digital multimeter (DMM) is an electronic measuring instrument that can measure multiple electrical properties such as voltage, current, and resistance. In the field of health monitoring of concrete structures, DMMs are often used in combination with other equipment to perform non-destructive testing techniques, such as half-cell potential

testing and electrical resistivity testing. DMM is used to measure the electrical potential between a reference electrode and a surface of a concrete structure. This potential is an indicator of the corrosion activity of the reinforcing steel in the concrete. The DMM is used to measure and display the voltage signal, which is then analyzed to assess the corrosion activity and potential deterioration of the structure.

In electrical resistivity testing, a DMM is used to measure the resistance of concrete between two electrodes. This measurement is used to calculate the electrical resistivity of the concrete, which is a key parameter in determining the likelihood of corrosion activity and potential deterioration of the reinforcing steel.

One of the advantages of using a DMM for health monitoring of concrete is its versatility. With the ability to measure multiple electrical properties, a DMM can be used for a variety of non-destructive testing techniques. This can save time and resources by eliminating the need for multiple specialized instruments.

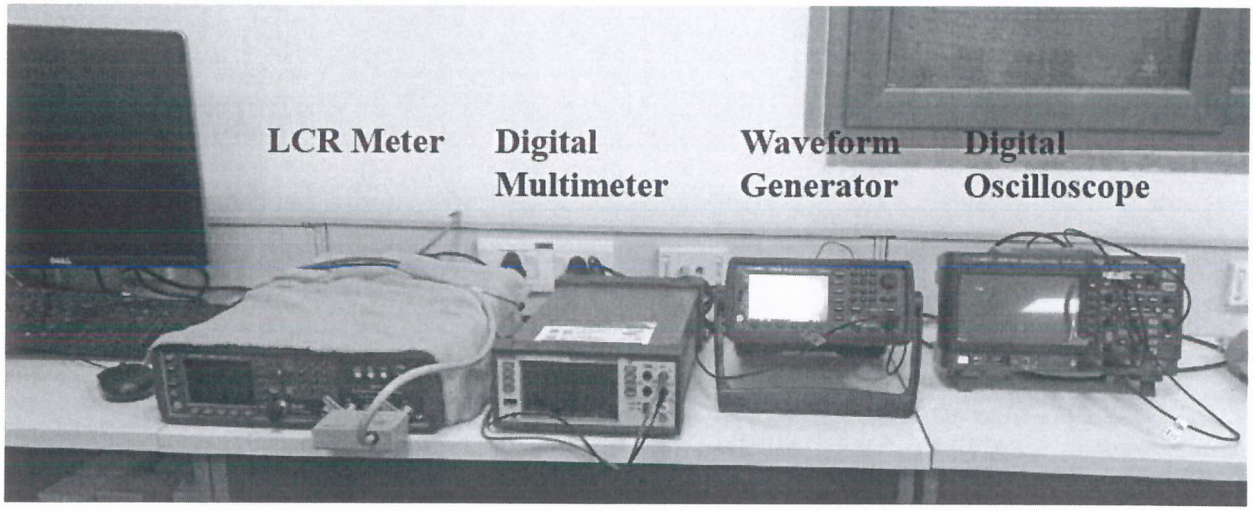


Fig. LCR Meter, Digital Multimeter, Waveform generator and Digital oscilloscope

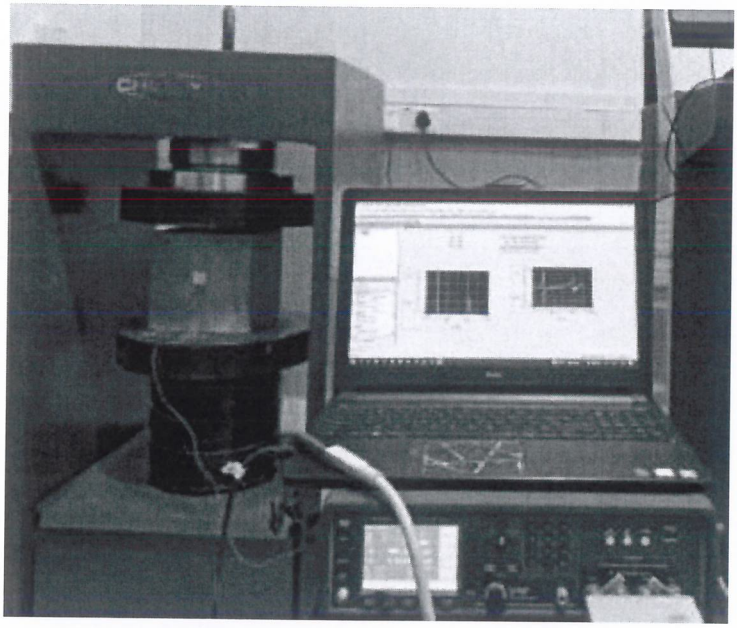


Fig. Experimental set-up of LCR Meter

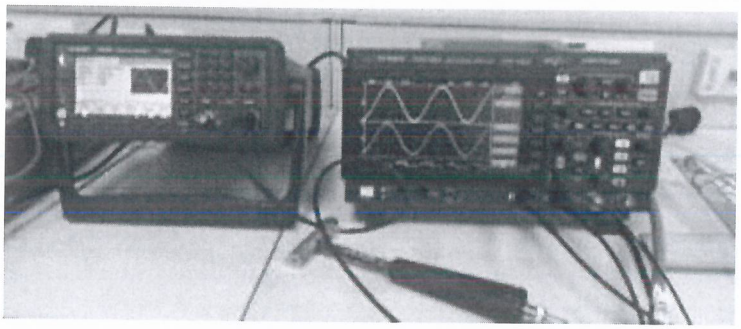


Fig. Experimental set-up of Waveform generator and Digital Oscilloscope

5. Carbonation chamber

In most cases of predicting the durability of reinforced concrete structures, only the dominant deteriorating process such as carbonation. This test method used for testing concrete carbonation under mechanical loading. The test procedure was proposed for the uniaxial compression, flexure and uniaxial tension. The compressive and flexural loads is recommended to be applied on a prismatic concrete specimen using a test rig. The test rig for uniaxial tension maintains the applied load by the bolt & spring method. Load monitoring by load cell is required to guarantee the stability of the external load during the entire test period. The carbonation chamber shall automatically adjust the inner environment and meet the precise requirement. The recommended test conditions are a temperature of 20 °C ± 2 °C, a relative humidity of 60% ± 5%, and a CO_2 concentration with 2% - 10%. The carbonation chamber should have abundant internal space that are

sufficient to accommodate at least one series of specimens vertically placed in the loaded rigs. The loaded specimen together with the test rig is recommended to be moved into a carbonation chamber with a temperature of 20 °C ± 2 °C, a relative humidity of 65% ± 5%, and a constant CO_2 concentration that much higher than the atmosphere. The temperature, relative humidity, and CO_2 concentration are recommended be monitored during the whole period of the experiment.

The carbonated prism or dumbbell specimens are to be split in the middle with a universal testing machine. The freshly split surface is recommended to be immediately cleaned of dust and lose particles, and then phenolphthalein solution should be sprayed on the split surface to determine the carbonation depth.

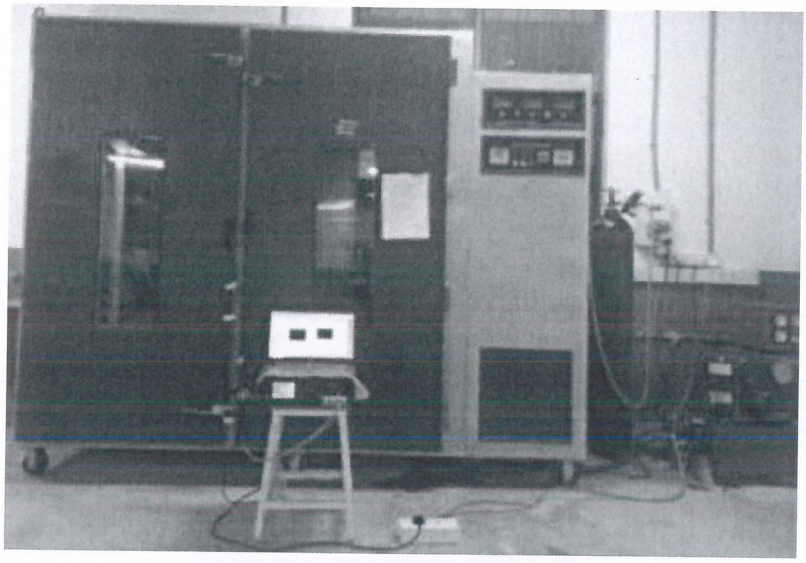


Fig. Carbonation chamber

Fig. Carbonation depth measurement of concrete samples

7. Dynamic Shear Rheometer

Rheometers are significant in concrete research and engineering because concrete is a complex material with unique rheological properties that are essential in achieving the desired performance and durability. Concrete rheology refers to the study of concrete and behaviour of fresh properties under stress can be optimized for specific applications. Rheometer can be used to optimize the mix design of concrete by measuring its flow behaviour, workability, and viscosity. By adjusting the mix design parameters, such as the water-cement ratio, aggregate gradation, and admixture dosage, the rheological properties of concrete can be optimized to achieve the desired performance and durability. Concrete is tested for strength, workability, and durability using rheometers to make sure it satisfies the standards. Quality control teams can make sure that the concrete satisfies the necessary performance requirements by monitoring the rheological characteristics of the concrete during mixing, transportation, and placement. Rheometers are used to predict the performance of concrete in real-world applications. For example, the shear rheology of concrete can be used to predict its resistance to shear forces in bridges and other infrastructure projects. By maximising its microstructure and porosity, rheometers are used to make concrete more durable. In order to attain the correct microstructure and porosity, which are important components in longevity of concrete, researchers can optimise the curing process by evaluating the rheological characteristics of the concrete during the curing process.

The Anton Paar Cup and Bob Rheometer is used in product development and optimization to improve the performance of different materials, including paints, adhesives, and coatings. By measuring the rheological properties of these materials, researchers can optimize their performance for specific applications and improve their durability and stability especially in case of 3D printable and pumpable concretes. Following are the pictures showing the apparatus and its working. Raw materials that were considered are shown in figure 1 and the sample is poured into the measuring cell as shown in the Figure 2. Figure 3 shows the test setup of rheometer and the sample during shearing after giving shear rate as input as shown in Figure 4 respectively.

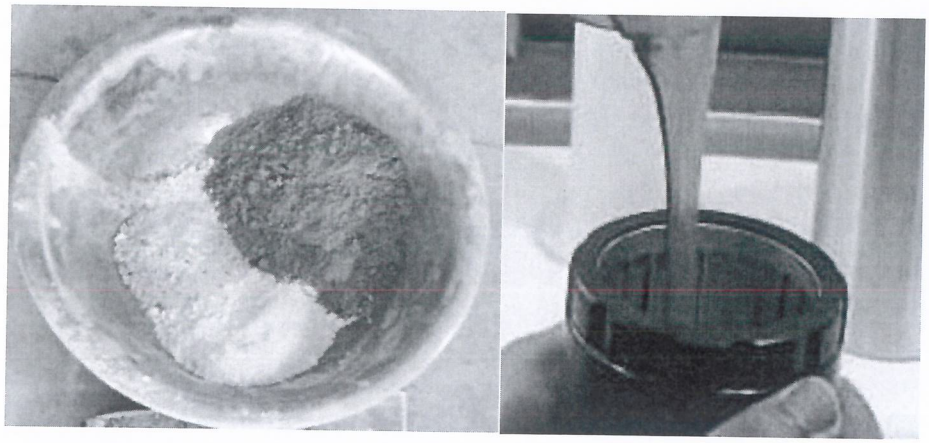


Figure 1 Raw materials

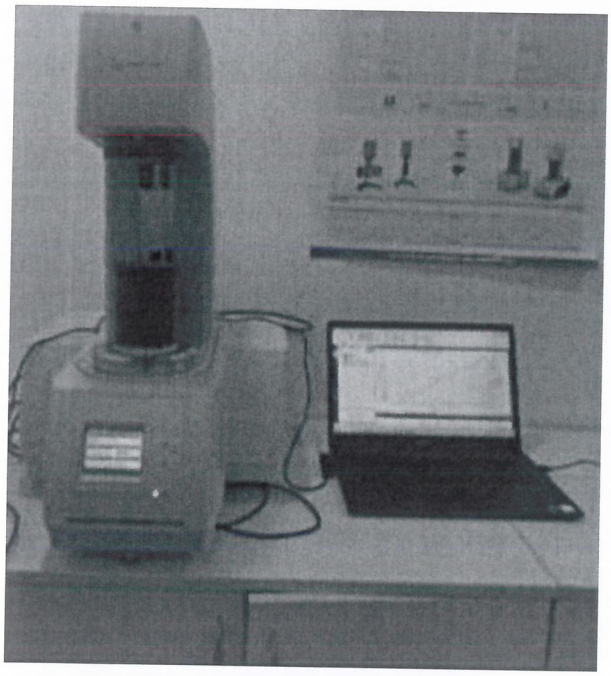


Figure 2 Sample collection

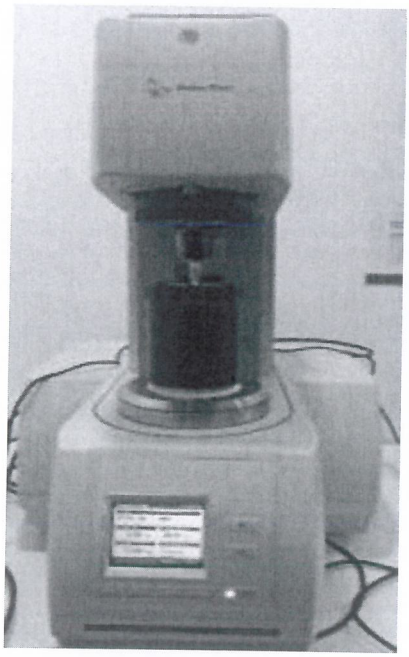


Figure 3 Anton-Paar Rheometer test setup

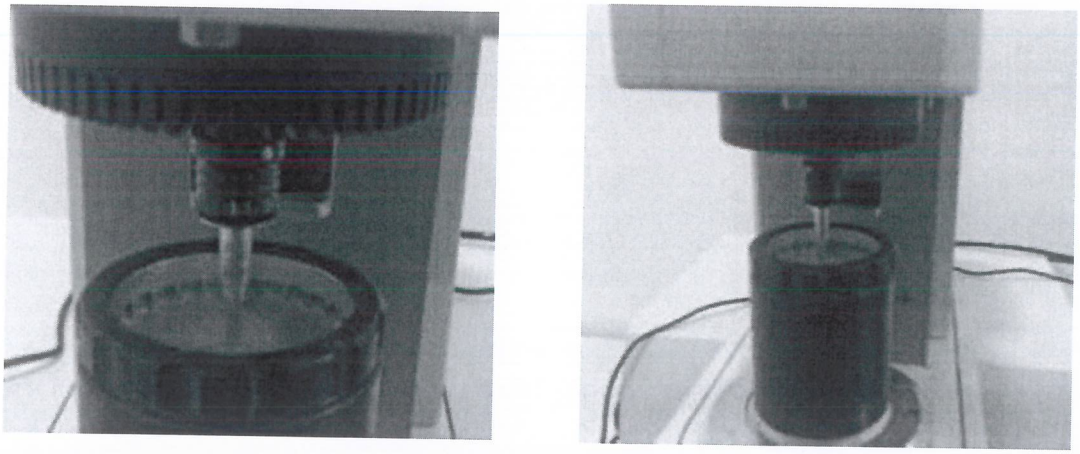


Figure 4 Shearing of sample