75 YEARS LEGACY

Building a Better World & Inspiring the Future

CIVIL ENGINEERING
INDIAN INSTITUTE OF SCIENCE

Department of Civil Engineering

INDIAN INSTITUTE OF SCIENCE
भारतीय विज्ञान संस्थान

Indian Institute of Science

Foreword

Anticipating that Indian independence was around the corner at the end of World War II, the Indian Institute of Science (IISc) established the Department of Power Engineering with three sections namely, Electrical Engineering, Mechanical Engineering, and Civil and Hydraulic Engineering. The last of these was established in the year 1950 to harness the copious amounts of water from our rivers for irrigation in order to meet agricultural needs and for power generation and drinking water supply for the rapidly growing urban centres, through the development of multipurpose river valley projects. It is believed that on the recommendation of Sir M Visvesvaraya, who served the Institute in various capacities in the Court and Council between 1913 and 1948, Prof MS Thacker, the then Director of the Institute, appointed Prof NS Govinda Rao, who was working in the Karnataka Engineering Research Station (KERS) – formerly known as the Mysore Engineering Research Station and Hydraulic Research Station – as the head of the Civil and Hydraulic Engineering section.

Commencing with research in hydraulics engineering with financial support from the central government in the 1950s and 1960s, the department diversified and developed vibrant research programmes in Geotechnical, Structural, and Water resources and Hydraulics Engineering over the years, and established course and research-based Master's and a doctoral programme in these three areas. Despite its relatively small size of about 25-30 faculty members, the department has consistently emphasised precise experimentation, rigorous theoretical analysis, and meticulous simulations. Additionally, the department has actively contributed to major national research initiatives and fostered significant international research collaborations. The department's faculty members have also been instrumental in capacity-building educational initiatives, reflecting their dedication to teaching and mentorship.

The Department of Civil Engineering has been pivotal in establishing interdisciplinary research centres such as the Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP), the Centre for Earth Sciences (CEaS), and the Interdisciplinary Centre for Water Research (ICWaR) at IISc. Following the establishment of CiSTUP, the department launched comprehensive programmes in transportation systems engineering, offering both course-based and research-based Master's degrees as well as doctoral programmes from 2010 onwards. Faculty members have also significantly contributed to the growth and success of the Centre for Sustainable Technologies (CST), established by the Institute to address critical issues affecting rural areas and communities.

Over the past 75 years, the Department of Civil Engineering has proudly served the nation with distinction, pushing the boundaries of research in cutting-edge areas, delivering vibrant and engaging teaching programmes, and providing essential consultancy services in critical sectors.

This brief volume offers readers an insightful journey through the department's remarkable 75-year history, meticulously compiled by the Office of Communications from archival records and enriched through interviews with a few former and current faculty members. We hope this narrative provides an inspiring glimpse into our storied past, celebrating the department's achievements as we move forward into an exciting future of continued excellence, innovation, and service to society.

Prof Ananth Ramaswamy
Chair,
Department of Civil Engineering

Department of Civil Engineering
Indian Institute of Science (IISc)

(As on 1 August 2024)

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Prof P Anbazhagan
Prof Ashish Verma
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Dr Keshav Bharadwaj Ravi
Prof G Madhavi Latha
Prof D Nagesh Kumar
Dr KS Nanjunda Rao
Prof Narayan K. Sundaram
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CIVIL ENGINEERING

Photo: IISc Photography Club

Laying the Foundation

- Ranjini Raghunath

Tracing the growth and contributions of the Department of Civil Engineering

At 11.45 am on the morning of 8 July 1954, standing on the bank of the Sutlej river, Prime Minister Jawaharlal Nehru pressed a button. Immediately, the sluice gates of the newly-constructed Bhakra Nangal canal system opened, and the roaring river waters raced towards millions of acres of dry land in west India. It was one of the first river valley development projects launched after India's independence.

The Bhakra Nangal project was a landmark, Nehru said in his speech at the event, but not just because it would irrigate large portions of Punjab and Rajasthan and provide electricity for thousands of factories and cottage industries. "It is a landmark because it has become the symbol of a nation's will to march forward with strength, determination, and courage." Nehru and other nation builders realised that harnessing the rivers crisscrossing the country was crucial for providing water and power for millions of its citizens.

India's independence also coincided with a shift in IISc's priorities. Wartime contributions were winding down. The Institute's Governing Council constituted a committee under physicist Meghnad Saha to propose new plans and directions for its growth. In 1947, this committee recommended that a Power Engineering department be set up at the Institute, with three sections: Electrical Engineering, Mechanical Engineering, and Civil and Hydraulic Engineering. The last of these became the Department of Civil Engineering (CiE).

In the past 75 years, CiE has carried out fundamental and applied research in four major areas: geotechnical engineering, structural engineering, water resources engineering, and transportation engineering. Faculty members have consulted on hundreds of regional and national civil engineering projects, developed new models and tools to study the behaviour of materials, designed large structures like dams and bridges, and provided sustainable solutions for environmental challenges. The department has also helped incubate various other centres at the Institute, including the Centre for Infrastructure, Transportation, and Urban Planning; the Centre for Earth Sciences; and the Interdisciplinary Centre for Water Research.

When the department was initially set up, the hope was that faculty members in the other sections of Power Engineering would focus on power generation and distribution. A major expectation from the civil engineers, however, was that they begin working on designing dams – structures that encompass many core aspects of civil engineering.

"In the initial years, the department's focus was more on water supply and dams," recalls Nanjunda Rao, Chief Research Scientist at CiE. "Subsequently, people recognised that when you want to build a dam, it has to be founded on strata, so soil mechanics became important. When it came to the design of the dam cross-section itself, it then became a structural engineering problem."

Early pioneers

For the first few years, faculty positions under the Civil and Hydraulic Engineering section remained vacant. KR Narayana Rao was the first to be appointed as Assistant Professor in 1949. The following year, MS Thacker, the Institute's director, invited NS Govinda Rao, an engineer at the Karnataka Engineering Research Station, to head the section.

Govinda Rao's appointment was in some ways the real starting point for the department. He not only initiated several areas of research, but also used his extensive contacts at the Central Board of Irrigation and Power (CBIP) to bring large funding and projects to the department. "Govinda Rao developed it into a big department," recalls KS Subba Rao, former faculty member at CiE. "He built it up from CBIP schemes."

Photo courtesy: IISc Archives

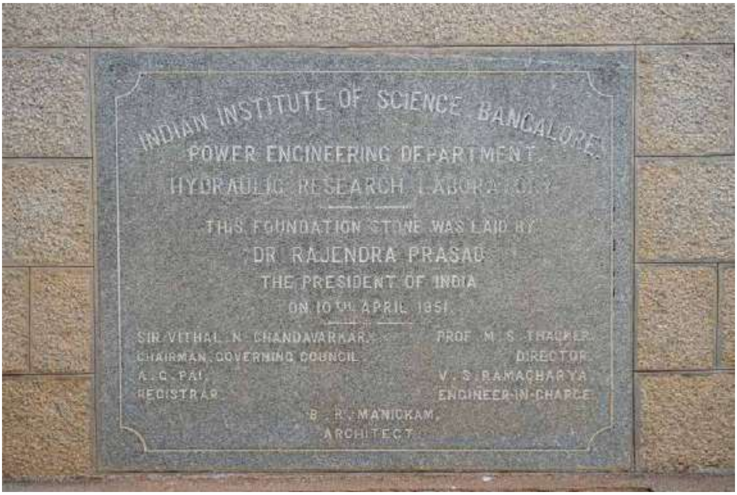
Civil and Hydraulic Engineering building (right) in the 1950s

One of the first areas that Govinda Rao focused on was cavitation research – the study of how air bubbles form and collapse in liquids flowing under low pressure. “For about 10 years, there was vigorous work on cavitation. He also wanted to start research on centrifugal pumps,” recalls Rama Prasad, former faculty member at CiE.

The foundation stone for the department’s first building – the hydraulics lab – was laid by Rajendra Prasad, the then President of India, in 1951. By then, the department had started admitting students for a two-year post-graduate diploma programme. A flurry of new faculty hires happened in 1951-52. Several research assistants were also appointed – one of them was KTS Iyengar, who eventually became a faculty member, and like Govinda Rao, had a huge influence on the department’s growth.

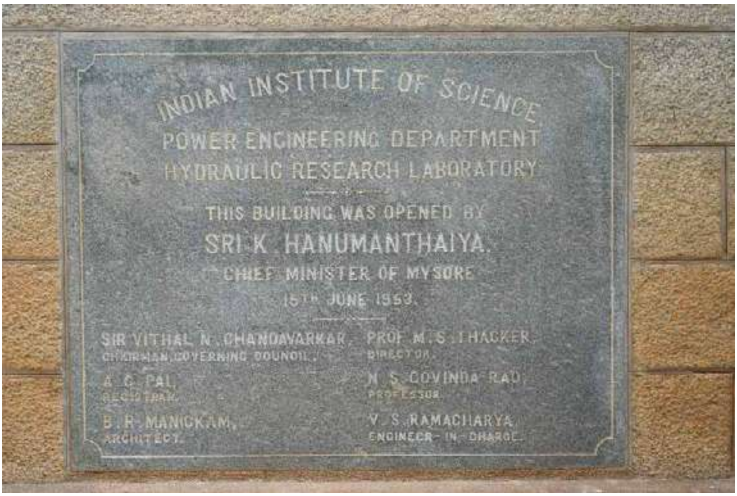
“KTS Iyengar was like a grandfather who brought together people working in different areas,” Nanjunda Rao recalls. “He had a Bachelor’s degree when he joined IISc as a research assistant. Govinda Rao encouraged him to do his PhD in Germany (University of Hannover), where he worked on elasticity solutions for anchorage zones. After KTS Iyengar returned to IISc, he was given a free hand to develop structural engineering disciplines.” KTS Iyengar and Govinda Rao even collaborated on testing the strength of prestressed concrete – which can reduce the use of steel drastically compared to normal reinforced concrete – and on designing a concrete mix of high early strength from local materials.

Photo: KG Haridasan



The foundation stone for the hydraulic research laboratory laid by Rajendra Prasad, the then President of India, in 1951

Photo: KG Haridasan



Hydraulic research laboratory building inauguration by Sri K Hanumanthaiya, the then Chief Minister of Mysore, in 1953

"KTS Iyengar and NS Govinda Rao – these were the two who had their stamp on this department," says Ananth Ramaswamy, the current Chair of CiE.

Strengthening structures

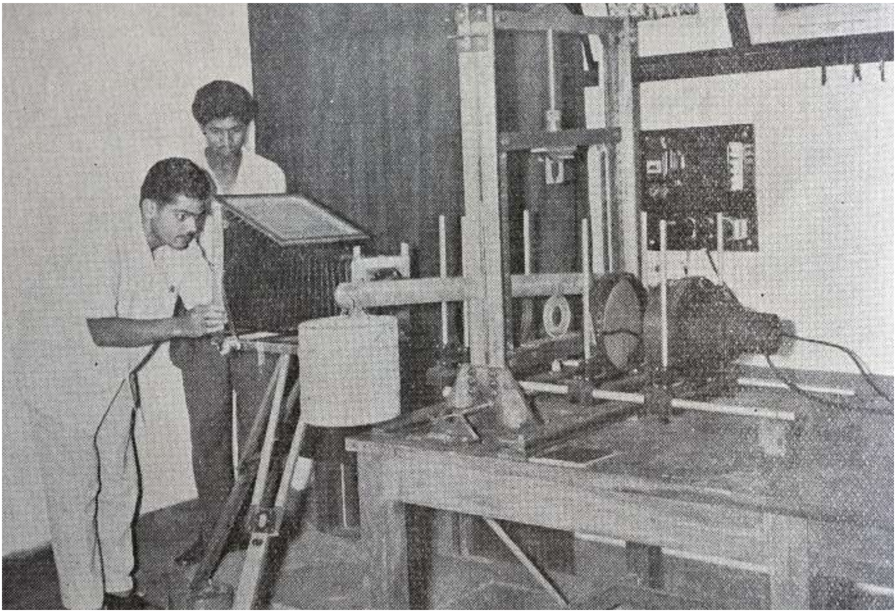


Image courtesy: IISc golden jubilee souvenir, 1959

Studies with photoelasticity apparatus

KTS Iyengar's primary interests lay in structural engineering. He established a photoelasticity lab to analyse stresses in scaled down models of structures like dams. One of his students, K Chandrashekhara, recalls using novel optical techniques in that lab to solve structural problems related to layered soils. He also recalls working on an interesting project of testing the strength of metallic wires used to pull up cages carrying workers who were mining deep down in the Kolar Gold Fields. "If the rope cuts off, and the whole cage suddenly drops, people would die. It was a human problem," he explains.

KTS Iyengar also encouraged students to work on earthquake engineering. "There were no earthquakes in the south, so nobody was interested. I was the one who first started work on earthquake engineering [in the department]," says KS Jagadish, former student and faculty member at CiE.

"KTS Iyengar also encouraged experimental work on concrete structures," Nanjunda Rao adds. "Two of his students (B Vijaya Rangan and N Ramprakash) contributed to the understanding of the behaviour of reinforced concrete beams under combined bending, shear and torsion, which is even today used in the Bureau of Indian Standards. Vijaya Rangan, currently Emeritus Professor of Civil Engineering, Curtin University, Perth, Australia, visited CiE in 2010 and shared his research on 'Fly ash based Geopolymer concrete.'"

Photo courtesy: K S Nanjunda Rao

B Vijaya Rangan (second from right) during his visit to CiE in 2010

In the 1970s, S Anantharamu, a new faculty member who came to the department, introduced many new tools for analysing structures. "Anantharamu, for the first time, did work on finite element analysis, which was just then beginning," recalls former faculty member BK Raghu Prasad. "In the early 1980s, he worked on expert systems and AI. Now, people only talk of AI."

Nanjunda Rao recalls that when IISc's then Director Satish Dhawan was visiting USA to identify faculty candidates, he was impressed by Anantharamu, who was pursuing his postdoctoral research there at the time and issued him an offer letter for a faculty position on the spot. "The department Chair was initially unhappy at not being consulted," Nanjunda Rao recalls with a chuckle (Anantharamu recounted this anecdote to Nanjunda Rao several times during casual discussions).

After Anantharamu's demise, Raghu Prasad continued to expand on the former's work in emerging areas, like neural network modelling for mixed design of concrete.

"[The department] started the area of fracture of concrete in India for the first time in IISc," Raghu Prasad recalls. "IITs and other universities had not even made an attempt to think of fracture of concrete [at that time]."

Another faculty member, RN Iyengar, developed techniques in earthquake prediction, specifically ground motion prediction equations for different parts of the country. "It was extremely original work … I regard it as a breakthrough work in the country," says Madhavi Latha, faculty member at CiE.

Faculty member Prakash Desayi also made fundamental contributions to the understanding of the behaviour of materials like reinforced concrete, prestressed concrete, and ferrocement. "He did a lot of work on the analysis of reinforced concrete. He came up with a celebrated equation for the stress-strain curve for concrete confined in circular steel spirals. It has found application in many areas," recalls former PhD student Balaji Rao. "He also carried out remarkable fundamental work on ferrocement … He studied the fracture behaviour of ferrocement elements using double cantilever beams. At that time, it was very new." Prakash also tested the use of replacing cement and sand with various types of eco-friendly materials like fly ash.

Balaji Rao also recalls Prakash being dedicated to his work and teaching. "He would not attend conferences to present his papers. I once asked him why. He said, 'If I keep going to conferences, who will guide the students?'"

In later years, structural engineers at the department have also been called in to carry out forensic analysis of failed or damaged structures, such as railway bridges and retention walls. Since the time of Govinda Rao, the department has also "come full circle" with the launch of a major collaboration in 2024 with the Central Water Commission – called the International Centre of Excellence for Dams (ICED) – to test and strengthen the country's ageing dams, Ananth says. "There are about 5,000 dams. We need to understand their current condition, for intervention and to do a comprehensive risk assessment."

Scrutinising soil

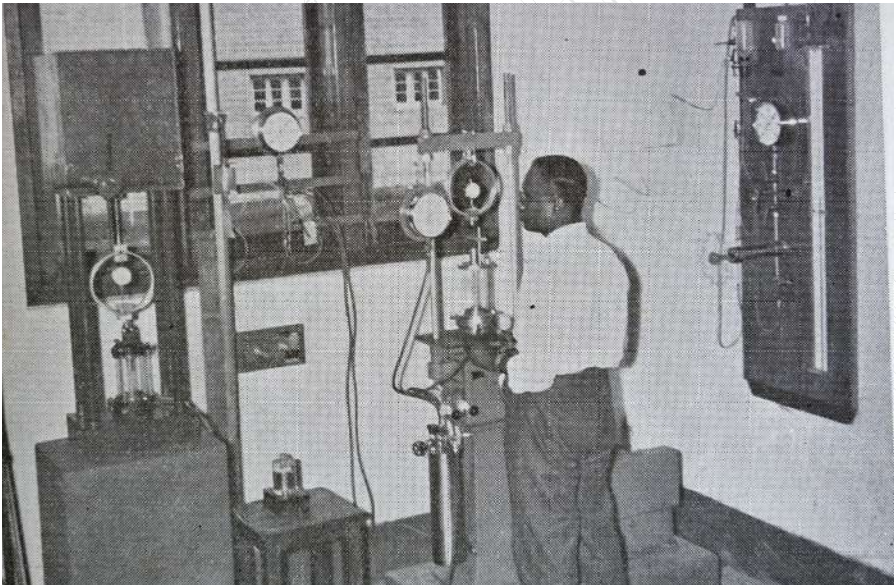
When Madhavi was doing her MTech at NIT Warangal, she recalls referring to several papers published by CiE faculty to learn about new ways of reducing the swelling potential of soils like black cotton soils. "They developed a chemical-based method which became the most widely-used technique," she remembers. Madhavi later joined the department as a postdoctoral fellow and eventually became a faculty member. She and other colleagues have been working on studying the behaviour of soils and ways to reinforce them.

"Earlier the soil mechanics lab was only a matchbox – it had no first floor, it was only a stone building with one hall, and two rooms on either side," recalls Subba Rao. In the initial years, research focused largely on soil chemistry and characterisation. Researchers also carried out several consultancy projects on soil foundations in and around Bengaluru.

"Consultancy used to be one-third of our work," says A Sridharan, former faculty member at CiE. He recalls working with government agencies on testing the quality of soil in a Kudremukh iron ore mining project, and analysing the foundation used for anchoring large guns to protect naval installations in Kochi.

Researchers also worked on grouping different kinds of soils depending on how they behaved under different conditions. "They were very basic experiments, but they provided clearly established insights into soil mechanics," Madhavi says.

Image courtesy: IISc golden jubilee souvenir, 1959



Triaxial shear and permeability apparatus in the soil mechanics lab

In the 1990s, faculty member BR Srinivasa Murthy developed a unique box jacking technique that involved using hydraulic jacks to push reinforced concrete sections or boxes through the soil to build a tunnel without disrupting traffic on the road above. The technique was used to build an underpass that connected the main IISc campus to the other side across CV Raman Road. "It cost less than a crore and was completed in two years," says Nanjunda Rao. "Not a single tree was cut during this construction."

After the Bhuj earthquake struck in 2001, researchers began paying attention to how soils behave under seismic stress. "Faculty and students from the department went to Bhuj, collected soil samples, and tested them," Madhavi recalls. "Students also started working on problems like dam failures in earthquakes and the liquefaction potential of the Bhuj soil." With the efforts of TG Sitharam, Professor (on lien) at CiE and current Chair of the All India Council for Technical Education, the area of earthquake geotechnical engineering began at CiE, an area that Madhavi and colleagues have continued to work on.

"[Soil mechanics] has been a very vibrant group from the beginning," Madhavi says. "Many people [in the department] were regarded as pioneers in these areas."

That vibrancy has continued to this day, thanks to enthusiastic and passionate students, she adds. "For example, we are now working on a setup that can make transparent soils. It is a very new thing that has not been explored much across the world."

Chasing water

"Water is quite different from soils and structures," explains S Vedula, former faculty member at CiE. "It is governed by principles which are quite different from solids."

In the early years, due to Govinda Rao's "clout", many faculty members were involved in large-scale river valley projects. But some of them also carried out fundamental studies on water hydrology – studying water movement, properties, and distribution. "In the 1950s-60s, hydrology was not a well known subject," Vedula recalls. "There was no research going on in many areas of water resources … like sediment transport or groundwater. Prof Govind Rao encouraged us to branch off [into these areas] around the late 1960s."

During the 1960s, Govinda Rao also oversaw the construction of a high-speed water tunnel facility that was used to study the effects of cavitation on objects like underwater missiles and marine propellers. When cavitation bubbles collapse, they send out tiny shockwaves that can seriously damage the object or surrounding walls. Faculty member Vijay Arakeri, who had done his PhD at Caltech, was recruited to run the facility and carry out cavitation experiments, on a joint appointment at the civil and mechanical engineering departments. His group also developed a novel technique of "synthetic cavitation" that used electrodes to artificially generate oxygen and hydrogen bubbles in the water flow.

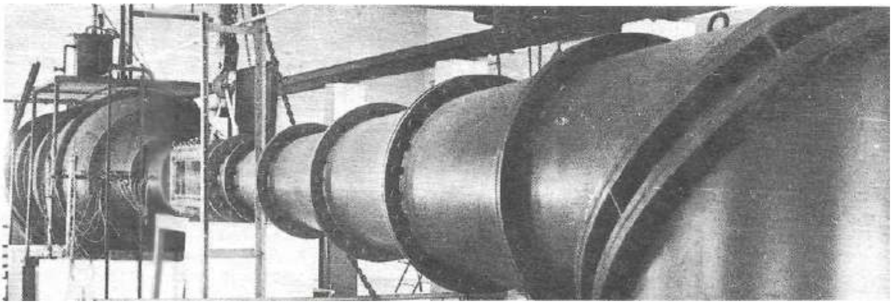


Image courtesy: Vijay Arakeri/Current Science

Portion of the water tunnel used for cavitation research

"The first LCA [Light Combat Aircraft] model was tested in the water tunnel," Vijay recalls. Another challenging project was testing models of underwater missiles for the Defence Research and Development Laboratory (DRDL). "We also took on a large consultancy project involving 10 faculty members from IISc to design a water tunnel for the naval science and technology lab at Visakhapatnam," he says. "But they didn't go for our design, and finally imported one from Russia."

In later years, researchers were also called to consult on a number of riverwater-sharing disputes in south India. Rama Prasad was asked to consult on the division of waters from the Krishna river among Maharashtra, Karnataka and Andhra Pradesh. He also served on the Kaveri Tribunal constituted in 1990 to resolve the water-sharing dispute between Tamil Nadu and Karnataka.

Groundwater was another focus area. “The first groundwater model for the country was developed here in the 1980s,” recalls Mohan Kumar, former professor at CiE. “It was a computational model of the Vedavathi river basin.”

“People here have developed a lot of mathematical models looking at the optimisation of water supply,” Mohan Kumar adds. He led a multidisciplinary project called EQWATER that combined Internet-of-Things (IoT) sensing with computer models and algorithms to figure out how to optimise water supply and demand in Bengaluru. “You can prepare a water balance for the city almost at a war level,” he says.

Researchers led by faculty member Pradeep P Mujumdar have also developed models of urban floods in cities like Bengaluru. Using high-resolution satellite data, his team reconstructed a “digital twin” of the city to track how water would flow during floods and help civic agencies test out future flooding scenarios. Some of these efforts culminated in a new centre being spun off from CiE called the Interdisciplinary Centre for Water Research (ICWaR) at IISc in 2015. Faculty members like Mohan Kumar, Pradeep Mujumdar, Nagesh Kumar, VV Srinivas, and others have been focusing on out several water-related areas including climate modelling, ocean dynamics, and urban floods management via this centre.

But one challenge, Mohan Kumar points out, is that government agencies should have the “absorption capacity” to implement such solutions. “You develop a wonderful model … and you show it is working. Everything is perfect. Then, when you hand it over, they must be ready and able to run that model, or modify it. That is not simple.”

Social impact

Apart from fundamental studies, researchers in CiE have also worked on many projects that have had significant social impact, says Sudhakar Rao, former Chair of the department.

Sudhakar himself has worked on projects related to water contamination. He recalls how cases of “blue baby syndrome” – infants exposed to excess nitrate who developed low oxygen levels – cropped up in the 1990s. One of the main reasons was the use of pit toilets which contained nitrate that leached into the groundwater. “The presence of nitrates in groundwater is a ticking time bomb,” he says.

Sudhakar and others did extensive work in a village called Mulbagal, about 100 km from Bengaluru. “They use onsite sanitation – solid waste is not treated but disposed on site – plus they depend on groundwater for drinking water. It was a very lethal combination.” The permissible level of nitrate in groundwater is 45 mg/L, but Sudhakar and others were shocked to see that in Mulbagal the levels were as high as 200 mg/L. They decided to modify the pit toilet design into a twin system in which nitrate is removed on site, and the waste released is free of the chemical.

Sudhakar and others also came up with an alternative approach to remove fluoride from drinking water. “Earlier, there was the Nalgonda technique in which activated alumina was used to remove fluoride,” he explains. “But if you overshoot by adding [excess] alumina, you may introduce aluminium into the water, which is very toxic. Plus, once the column is exhausted, you need to regenerate the activated alumni using caustic soda, which is again toxic.”

The team instead turned to magnesium oxide – found in milk of magnesia that humans consume – to absorb fluoride. They designed a simple defluoridation unit that was installed in a few villages in Karnataka, Andhra Pradesh, and Rajasthan. “To be environmentally friendly, we also converted the residue into an earth brick,” Sudhakar explains. “We did a lot of leaching studies and showed that it was robust, and did not release any fluoride into the environment.”

Photos courtesy: Sudhakar Rao

Fluoride contaminated sludge being converted (left) into safe building brick (right)

Sudhakar and faculty member BV Venkatarama Reddy were also involved in a project testing mining waste from the Kolar Gold Fields – which was shut down by 2001 – for cyanide. “They had left behind millions of tons of waste. We picked up samples from the mountains, and also tested the water in the surrounding areas,” he says. “Our main concern was whether there was any residual cyanide. Fortunately, it had all evaporated … We also didn’t find any other heavy metals.”

In later years, Sudhakar, Venkatarama, and others also began working on earth-based building materials that can cut down the use of carbon-emitting concrete, as well as the use of natural products like plant fibers as stabilising agents in bricks.

Sudhakar points out that many department faculty have been involved in such projects of social relevance. “For example, Muddu Sekar’s group has devoted 20-30 years to study watersheds,” Sudhakar adds. “It is one of the longest running projects in the department.” Sekar’s team, in collaboration with French researchers, has set up study sites in the Bandipur National park to track and analyse water, soil moisture, and a host of other requirements in forest ecosystems over decades. The project was an outcome of a collaboration with the French government that began in the 1990s and resulted in the formation of an Indo-French Cell for Water Sciences housed at the department. “It's one of the best collaborations, going on for about 25 years,” Mohan Kumar adds.

Scaling up

“Whenever government agencies think of a very big project, they first reach out to IISc,” Madhavi says.

In the early 2000s, Sitharam, Madhavi and others were contacted by the Indian Railways to consult on their most ambitious project: a new railway bridge stretching across the Chenab river from Udhampur to Baramulla in Jammu. Because it was a treacherous and seismically active zone, they had to test the stability of the soil and foundation, design rock anchor systems, and strengthen them against earthquakes.

Ananth recalls another project with the Board of Research on Nuclear Sciences to assess risk in existing nuclear power plants and predict possible failures. “It was a large coordinated project that looked at half a dozen different areas and risk-related issues,” he explains. The CiE team developed a model to predict the level of prestress in the heavy density concrete used to build the primary containment unit. “Because it was already grouted, they don’t know what the prestress levels are now. Studies can predict this, so that they can find out how long the plant can continue to operate … [because] the cost of decommissioning an existing plant can be as much as setting up a new plant.”

CiE researchers also worked on a major project with ISRO to suppress acoustic waves created during a rocket launch. The team designed a water injection system that would use high-speed jets to pump water into the rocket bore as the rocket took off. “The whole process happens in 15 seconds, during which the water conductance system has to work. The solution [we designed] was implemented in 2014,” recalls Mohan Kumar. “It was one of the flagship projects of the department … We are very proud of it.”

The department is also working on setting up a futuristic laboratory facility for fire safety evaluation of building components in IISc’s Challakere campus, with support from the Department of Science and Technology (DST). It will test how materials and structures respond to fire inside a building. “What building codes are silent about is what will happen to elements and connections as a fire spreads. The calculated evacuation time may be based on the construction material, but not on the support systems," Ananth explains. "We will test structures under mechanical as well as thermal load … to enhance safety."

Photo courtesy: Raghuveer Rao

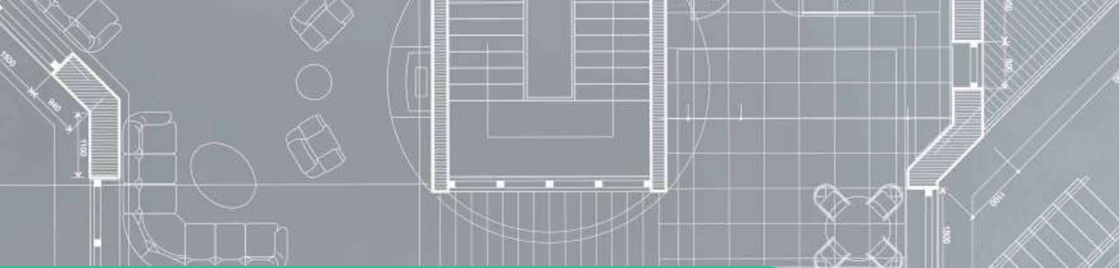
Current faculty members at CiE

In recent years, CiE has not only continued to expand its research interests but also keep up with changing and emerging areas. "The idea that civil engineering should only focus on building materials or help the construction industry is changing," Sudhakar says.

"New areas in civil engineering have emerged," Ananth says. "We used to have onsite structural health monitoring. Now we have remote monitoring using IoT and sensors … structures like bridges, nuclear plants, and dams – in which consequences of failure are significant – are heavily instrumented."

In 2010, CiE launched an academic review of their department (with expert members from India and abroad) – one of the first in IISc to start this practice, Madhavi points out. "We came together as a group, and we called in really top people in the world to come and assess where we stand. We all presented our work, and got to know what everyone else is working on. It was a wonderful experience," she recalls. The review not only prompted the department to plan its future directions, like working on large-scale collaborative projects like ICED, but also think of ways to share resources among groups of researchers cutting across the three traditional areas.

"I joined more than 20 years ago and have seen the department change a lot, in a good way … I am sure this will continue," Madhavi adds. "Twenty years down the line, we will have a totally changed department."



Building a Department

- Sandeep Menon

How NS Govinda Rao laid the foundation for civil engineering

A photo of a moustachioed bespectacled man looks down from the wall of the office of the Department of Civil Engineering at IISc. A few steps further, in the Chairperson's office, another portrait watches on from above the door. It is fitting that NS Govinda Rao has a watchful eye on the department's proceedings and decision-making. Although the man never worked in these offices (he sat in a ground floor room of the Department of Power Engineering), Rao played a pivotal role in the nurturing and growth of the Department of Civil Engineering. It has been more than half a century since Rao left the department, but his name still reverberates in these halls, kept alive by those who knew him and others who know of him.

There are stories of Rao's benevolence, of his love for science, and justified anger. There are also tales of Rao calling the Registrar and demanding that he sort out a clerical error regarding a student's nonpayment of tuition fee and slamming down the phone receiver. Other chronicles talk of Rao securing money and scholarships for his students out of thin air. There are several more interesting tales, many are true, others made true apocryphally. The picture that is painted is that of a man who was accomplished, capable, and humane. He was also the reason the Department of Civil Engineering became a cornerstone of the Institute.

Photo courtesy: Vinay Sriram, grandson of Govinda Rao

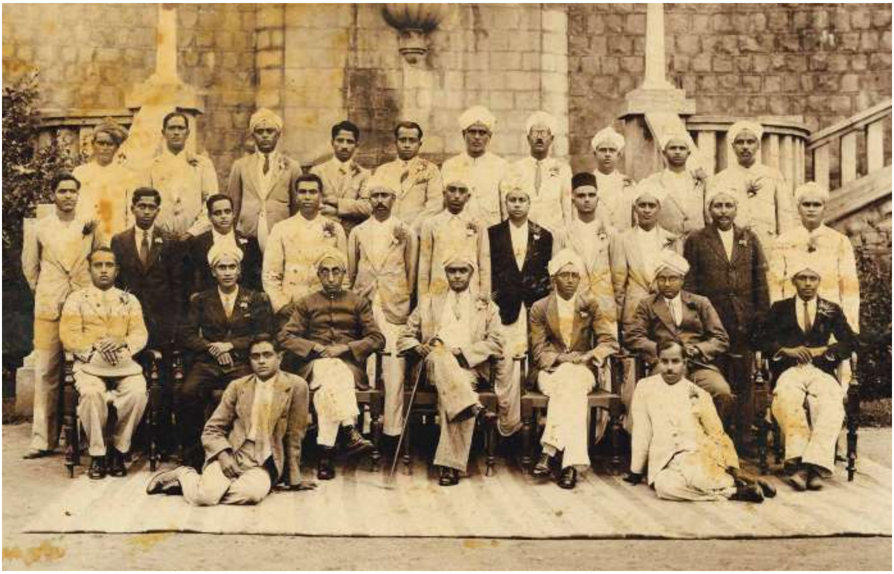
NS Govinda Rao

From industry to the Institute

Rao was born on 6 February 1907 to Radha Bai and NK Srinivasa Rao in a high-achieving family in Mysore city, to which place his great-grandmother had migrated from the small Maharashtra town of Naladurga in 1860. His great-grandfather was the deputy commissioner, and his father a high court judge. As the second child with five sisters, Rao had the environment and aptitude for academic excellence, influenced by his father's intellectual pursuits that extended to mathematics, astronomy, philosophy, and agriculture among others. After he completed his BE with honors from Mysore University in 1928 (he secured the first rank and two gold medals), he eventually joined the Public Works Department as an assistant engineer.

Rao was jarringly thrust into the real world when he lost his father and had to shoulder the responsibility of his family at the young age of 24. Despite personal hurdles, Rao grew in his career. He worked extensively on cavitation, siphons, and other areas of hydraulics, and he also pioneered research in the area of soil dynamics.

Photo courtesy: Vinay Sriram, grandson of Govinda Rao



Govinda Rao (seated on chair, second right) with his colleagues at the project subdivision, Krishna Raja Sagara in 1934

He played a major role in the survey, design, and construction of several irrigation projects such as the Krishna Raja Sagar Dam, Visvesvaraya Canal, and Markandeya Dam. He also taught at the Government Engineering Diploma School in Bengaluru for two years. In 1945, he became the Assistant Director of the Karnataka Engineering Research Station (KERS), Krishna Raja Sagara.

His elevation at his work was the result of his nearly two decades of research publications, particularly his association in the design of the Ganesh Iyer Siphon, which is a special kind of domed volute siphon that ensures excess inflow into a reservoir is safely disposed of. This gave him a reputation as a leading voice in hydraulics research and caught the eye of celebrity engineer M Visvesvaraya. It is said that it was upon Visvesvaraya's recommendation that the then IISc director, MS Thacker, appointed Rao as the head of the Civil and Hydraulic Engineering section, which was established as part of the Department of Power Engineering in 1950.

It was a time of great turmoil and flux. The country was thrust into independence and was trying to find its feet. Power and water were major areas of focus, and several structural, geotechnical, and hydraulic problems needed to be solved for the smooth functioning of the country. Rao was seen as an ideal candidate because he married industry knowledge with academic rigour. Though he did not have a doctorate to his name, his research during his time in the KRS Research Station had shown that he had the aptitude to lead a department.

Under his watch, the Civil and Hydraulic Engineering section grew and became the Department of Civil Engineering in 1972, five years after he retired. He developed three research streams within the department – Hydraulics, Structural Engineering, and Soil Mechanics. He also started Master's programmes in in these areas. His tenure saw several degrees awarded and many research papers published in leading national and international journals. The department grew from strength to strength and was recognised as a Centre for Advanced Studies by the University Grants Commission, in recognition of the quality of work that came out from the department led by Rao.

The visionary "non-academic"

Rao was a curious and capable researcher. He published over 100 papers in reputed journals and frequently attended international conferences. His significant contributions were in the areas of cavitation, laminar and turbulent flows, flood adsorption, design of dams and canals, siphons, and more. He also served as the editor of the *Journal of the Civil Engineering Division*, published by the Institution of Engineers between 1962 and 1965, and as a member of the panel of editors for *Hydraulic Research* published by the International Association for Hydraulic Research in 1963. In 1965, he was elected president of the Institution of Engineers, and the Indian Society of Soil Mechanics and Foundation Engineering.

As good as Rao was at science, he was perhaps a better administrator. The Civil and Hydraulic Engineering section at IISc started with fewer than a dozen people. To build it, he needed workforce, expertise, and finances. The finances were straightforward. He dug into his little black book, which had several contacts from his years in government service.

Photo courtesy: Vatsala Ramamurthy, daughter of Govinda Rao

Govinda Rao (centre) with dignitaries during Prime Minister Jawaharlal Nehru's visit to IISc

At the Institute, there was plenty of technical know-how. This, combined with Rao's ability to consider real-world impact and outreach, turned out to be a fruitful union. Being a "non-academic" in an academic institute, as he frequently quipped, he was able to make the best of both worlds.

"His contacts at the Central Board of Irrigation and Power (CBIP) got him projects [to work on]. Then, he could get additional research funds for students of the department under the CBIP scheme. He brought in a buoyant research atmosphere in the department through the CBIP schemes," says KS Subba Rao, former professor in the department.

"The civil department had a lot of money because of the projects they were involved in," says K Chandrashekhara, former professor of structural engineering at IISc. "Rao's contacts within the government and his rapport with people helped a lot with getting projects, consultancies for dams and other works, and funding."

With the finances sorted, Rao built a department filled with capable scientists. He encouraged his team to build equipment and was willing to fund it. The high-speed closed-jet water tunnel facility, the first of its kind in India, was designed, fabricated, and established due to Rao's vision, which helped with research in cavitation. "He travelled around the world to learn how to build it, and finally it was built based on a design from Caltech (California Institute of Technology)," says Rama Prasad, another faculty member in the department at the time. The reason for choosing the design was that it was the most suitable for the rocky crust found in the Institute.

The hydraulics laboratory was also built during his time. Research around soil mechanics, hydraulics, and structural engineering developed with his active support.

Leaving behind a legacy

Rao maintained an open-door policy in his office. When KS Jagadish, a former student of Rao in 1961 who later became a professor of structural engineering at the department, approached him to change his post graduate course-based degree programme (ME in Power Engineering) to post graduate research-based degree programme (MSc (Engineering)), Rao was highly encouraging. “He was very open-minded that way,” Jagadish admits. Thanks to its close association with power engineering, the department had an interdisciplinary feel to it since its inception. Rao encouraged his students to seek advice from other heads of departments – and even from the director Satish Dhawan himself – if required.

Rao had an eye for talent and was not averse to accommodating talent that he spotted to the advantage of the system. One anecdotal story talks about Rao encouraging a student who had received a second-class in his Bachelor of Engineering degree to author a research paper and publish it in the *Journal of Institution of Engineers (India)*, upon which he was promptly admitted to a research programme in the department.

His students also remember him as a teacher who went beyond books. “He imbibed a spirit of inquiry and helped build self confidence in his students, encouraged them to believe in their research, and to speak out,” says S Vedula, a former faculty member at the department.

Once part of his department, everyone was treated as an extended family. Conceivably, the role of the patriarch came to him naturally, having had to take over as the head of the family at an early age and then having a family of nine children himself. His daughter describes him as a loving and pleasant father. “He was a great storyteller ... talkative, easygoing. All the children found him approachable and he never lost his temper,” says Vatsala Ramamurthy, his daughter.

His love for animals and gardening also shows a certain want to nurture. Due to his extended family, dinner time attendance sometimes hit more than two dozen people in the kitchen.

In one instance, when one of the department’s faculty members was given a promotion over the others, he was able to placate the irate parties by securing scholarships for higher studies in foreign universities. The benefits were two-fold, it ensured harmony in the department and more knowledge as well.

When Rao retired in 1967, the funds and schemes from CBIP also slowly waned, but the department had already established itself as a powerhouse and was more than capable of standing on its own. Since then, the department has grown rapidly, spawning several groups, laboratories, and branches, and contributing to several nation-building projects that are shaping the country. Though the current department might be far from the one Rao was familiar with, he remains a central figure in its collective memory, commemorated by the bi-annual Prof NS Govinda Rao Memorial Lectures held on his birth anniversary.

Rao passed away on 22 December 1995. In his long journey, he was known for multiple pursuits. Following his retirement, he served as an advisor to the CBIP till 1971. He was invited to various countries, such as Australia and Germany, to

Photo courtesy: Krishna Mohan Desai, son of Prakash Desayi, former Professor at CiE

Group photo with faculty, students, and staff of the Civil and Hydraulic Engineering Department on the eve of Govinda Rao's (bottom row, ninth from left) superannuation in 1967 deliver specialist lectures. He was also a member and consultant for various bodies in the power and infrastructure field, even serving as the president of a few, such as the Indian Geotechnical Society and the Institution of Engineers (India). But perhaps one of his most lasting legacies was developing the core ideals of rigorous research, consultancy, and an inclination towards social welfare, which has been foundational to the success of the Department of Civil Engineering. To this day, the department continues to research, develop, and advise on grand projects for the nation.

A department of civil engineering having a mandate for research was almost unheard of at the time when Rao took over. That vision of his is now reality.

A Tribute from the Department of Civil Engineering

The affection, regard and respect his faculty colleagues had for him is reflected in the following para quoted from the address presented to Professor Govinda Rao on the eve of his superannuation from IISc in 1967:

"Sir, you have lit many a candle. All of them put together may be no match to the serene brightness of your beacon light. But we will assure you, sir, that we will strive our utmost to keep the high traditions set by you ...".

Srisailam dam backwaters in the Krishna River

Photo courtesy: Wikimedia Commons/Amit Chattopadhyay

From Rivers to Reservoirs

- Parth Kumar and Rohini Subrahmanyam

How CiE researchers oversaw dam operations and managed water disputes

NS Govinda Rao, the first head of the Department of Civil Engineering (CiE), was one of the engineers working on the colossal Krishna Raja Sagara (KRS) Dam on the Kaveri River, before he came over to IISc. Under his guidance, work on hydraulics and water resources engineering flourished at CiE. He was also on the advisory boards of many multipurpose river valley projects in the country. From 1950 to 1967, he worked on power generation, storage of water for supply to urban areas through canal systems, and crop processing during non-rainy seasons to bring arid areas under an irrigated framework.

Then, in the 1970s, the introduction of desktop computers helped engineers at CiE move away from experimental hydraulics research and towards mathematical and computational methods to study water storage and supply from reservoirs.

This was around the time when S Vedula, a former faculty member at CiE, got an opportunity to do a fellowship at Harvard University for a project based on systems engineering. Back then, he did not even know the "spelling of systems engineering," he says. He had previously worked on water resources planning and floods, but mostly with a focus on hydraulics.

During his fellowship, he worked on reservoir operations in the Upper Cauvery Basin, focusing on figuring out the best configuration such that the irrigation demands of the states of Karnataka and Tamil Nadu can be met.

"[That was] systems engineering in a general sense, but what I did after coming back [to IISc] is the formal application of systems analysis techniques to reservoir planning and management," he says.

Photo courtesy: Wikimedia Commons/Vaishu2

The Krishna Raja Sagara dam beside the Brindavan gardens in Karnataka, India

Reservoir sizing and operation

In the late 1970s, Vedula and another former CiE faculty member, Rama Prasad, carried forward much of Govinda Rao's legacy. They acted as consultants on the Upper Krishna project and played an instrumental role in sizing the Almatti Reservoir and the integrated operation of Almatti and Narayanpur reservoirs.

"Water from the [reservoir's] storage gets diverted into the canals. And these canals go far and wide in the downward direction and branch off into several sub-channels, to supply water for irrigation," Vedula explains. "[Irrigation] is the major purpose of any dam construction in this country." After computing irrigation demands, the idea is to build a reservoir in a way as to store water when there is rainfall – during the monsoon, for example – and then supply water to meet the demands when water inflow is low.

Two major factors come into play while building and operating a reservoir, according to Vedula. One is how big the reservoir should be. "You can use mathematical programming techniques to find out the minimum capacity of the reservoir for a given demand," he says.

Given a certain reservoir capacity, one can find the level of reliability of that reservoir in meeting the specified demands. Both these factors need to be kept in mind. "If you build a higher capacity than what is required for the desired reliability level, you are wasting your resources," says Vedula.

Dissolving disputes

As dams have generally been built along large rivers like the Krishna and Kaveri, their operations generally affect water availability to various states that surround the dam areas. This can lead to many conflicts and disputes, and engineers like Vedula have been called upon to consult in such cases.

One such instance was when the Karnataka government decided to increase the height of the Almatti dam, a major dam in the Krishna River and part of the Upper Krishna Irrigation Project. Raising a dam's height is beneficial to the people downstream of it, as they can get more water diverted via the canals. But at the same time, it can flood areas upstream of the dam. "This is where the conflict comes up," says Vedula. "In the context of an interstate river like Krishna, there will invariably be resistance to raising the height of the dam from both the upstream and downstream people for different reasons. "

The proposal to raise the height precipitated a major conflict between the states of Karnataka, Maharashtra, and Andhra Pradesh, with both Maharashtra and Andhra Pradesh objecting to raising the height. Maharashtra was upstream of the dam and the government was worried about increased flooding in its lands, and the people of Andhra Pradesh were concerned about Karnataka having more control over the water's release once the height is raised, impacting their water availability.

To settle this dispute, Vedula and others had to step in and analyse whether raising the height of the dam would truly inundate Maharashtra's lands. With the help of technical studies of the backwaters, they were able to show that even if more water is stored, it will stay within Karnataka and not spread out into Maharashtra. The dam's height has since been approved by the concerned

Krishna Water Disputes Tribunal (KWDT-II) to be increased to 524.25 meters from the current 519.6 meters, but objections between the states are still on.

Since the Krishna River flows through all three states – Maharashtra, Karnataka, and Andhra Pradesh – another major question that is up for dispute is how much water each state should get. Rama Prasad helped with relevant calculations when the Krishna Tribunal was set up to resolve this dispute.

In the 1990s, Rama Prasad played a similar role in calculating the amount of water to be released at different points in the river when the Kaveri Tribunal was set up to settle another water-sharing dispute between Tamil Nadu and Karnataka.

Photo courtesy: Wikimedia commons/Purvi Puranik

In 2016, all the gates of the Almatti dam in Vijayapura district, Karnataka, were opened to release excess water

"Though the tribunal gave its judgement in 2006, the dispute still hasn't been resolved since the tribunal never said what would happen if the rainfall wasn't enough," says Rama Prasad. The Kaveri river originates in the Kodagu district of Karnataka, and water gets collected in four reservoirs – Harangi, Hemavathy, KRS on the Kaveri, and another on the Kabini, a tributary – before it reaches Tamil Nadu. "Karnataka captures most of the water when there isn't enough rain, so the water reaching Tamil Nadu is less than what the tribunal has ordered." In such situations, the Kaveri River Management Authority helps the states reach an agreement.

In yet another case, Vedula, after retirement, helped the technical team of Karnataka in the Mahadayi Water Disputes Tribunal proceedings. The Tribunal's primary function was to determine the quantitative allocation of the total Mahadayi river basin's water among the basin states – Karnataka, Goa and Maharashtra. Projectwise allocations were not addressed. The Tribunal's final report came out in August 2018, and the judgement was gazetted in February 2020. Legalities still remain to be resolved at the Supreme Court.

Lifelines of the land

Rama Prasad has remained engaged in dam-related projects even after his retirement in 2001, particularly those focused on securing water supply for Bengaluru. At present, the city draws water from Tore Kudala, near the confluence of the Kaveri and Shimsha rivers, upstream of the KRS dam. The KRS dam is the last point within Karnataka where water can be stored; Mettur, the next reservoir, is in Tamil Nadu. As a result, water from Kaveri's tributaries, which join the river between these two dams, cannot be tapped for Bengaluru's needs.

Photo courtesy: Wikimedia commons/Abhiram24

Kaveri river runs through a deep and narrow gorge at Mekedatu, which translates to "goat's leap" in Kannada

"During the monsoon, there is plenty of water," explains Rama Prasad. "But after the monsoon is over, there is a problem because if water is released for Bengaluru, then the irrigated lands, like in Mandya, will get less water, and the farmers will object to this."

To address this problem, the Karnataka government has proposed constructing a dam in Mekedatu, downstream of KRS, where the Arkavathy meets the Kaveri. Rama Prasad has played a key role in determining the dam's proposed storage capacity – one more chapter in a long career spent harnessing, directing, and maintaining the flow of rivers.

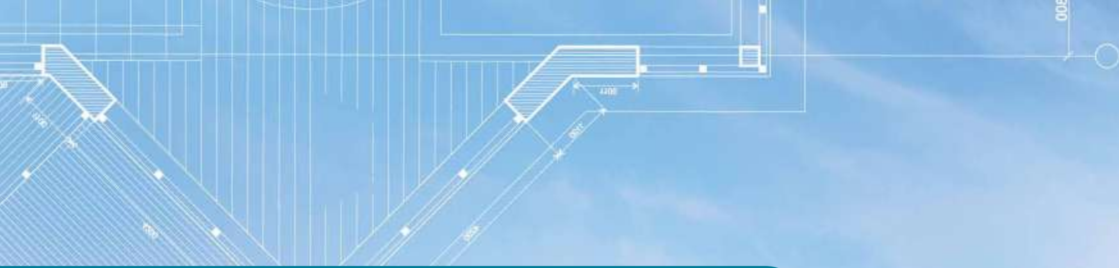
Photo courtesy: VV Srinivas

Yaragol dam is built to supply drinking water to Bangarpet, Malur, and Kolar towns and 45 villages on the way

VV Srinivas, Professor at CiE, is also involved in important dam-related work. The Karnataka Water Resources Development Organisation (WRDO) and Karnataka Urban Water Supply & Drainage Board (KUWS & DB) called upon him as an expert, to estimate the amount of dependable flow in the ungauged Markandeya River – at a site proposed for the construction of the Yargol dam project. In an ungauged river, one doesn't have measuring equipment in place to check how much water is flowing at specific locations along the river. Undeterred, he made recommendations on the scope for constructing a dam at the location.

Building and managing reservoirs is a tricky task, made more complicated by environmental concerns and disputes over shared water. But these reservoirs are our “lifeline,” says Vedula.

“You want water to satisfy drinking demands, municipal and industrial demands, heavy irrigation demands, and then power generation – hydro power generation,” lists Vedula. “We are eating today comfortably because of the reservoirs that were built during the period of 1960-1980.”



Built to Last

- *Parth Kumar*

How CiE researchers played a role in building and maintaining megastructures

It was a chilly April day in 2005. Madhavi Latha stood at the edge of the overlook, the wind tugging at her coat as her eyes swept across the sprawl of the Kashmir Valley. After a gruelling 14-hour journey in a rattling jeep, she had finally reached the site. Below her, the Chenab River wove through the landscape, steep mountains rising on either side. She had been called in to help realise an extraordinary vision: bridging this chasm with a colossal arch bridge – 359 metres high and stretching a full kilometre without support. Looking at the rock masses, the unforgiving terrain and the daunting gradient of the hills, she realised the true scale of the task – it appeared almost impossible.

"Of course, nothing is impossible in today's world," says Madhavi, Professor at the Department of Civil Engineering. "We have advanced so much in civil engineering that we can certainly do things which seem impossible."

Throughout its history, the Department of Civil Engineering (CiE) at IISc has played a central role in the conception and construction of some of India's most ambitious megastructures. From colossal bridges that bring distant regions together to massive dams that store monsoon waters and power cities with hydroelectricity, these engineering feats are essential for a nation's development. Though bridges and dams differ greatly in their structural demands and design principles, they pose the same challenges – building stable foundations, ensuring long-term durability, minimising environmental impact, and addressing the concerns of the local communities. Balancing technical precision with social sensitivity is no small task, but the impact can be far-reaching and transformative, shaping the infrastructure and future of the country.

Photo courtesy: Wikimedia Commons/Ojhayogesh

Aerial view of Chenab Bridge, the world's tallest railway arch bridge over the Chenab river, under construction in 2017

A Himalayan task

For decades, the Kashmir Valley remained disconnected from the rest of the country, accessible only by winding, mountainous roads. In 2005, the Northern Railways decided to take up this Herculean task of connecting Jammu and Srinagar by rail. One critical section, the Udhampur-Srinagar-Baramula Rail Link (USBRL), would require more than 927 bridges over rugged terrain in a seismically active zone with complex, anisotropic rock formations. One of these was the Chenab Rail Bridge – slated to be the tallest, longest, and most technically demanding.

AFCONS, the construction partner for Northern Railways, approached over 50 experts from institutes like IISc, NIRM Bangalore, IIT Delhi and IIT Roorkee for this project. TG Sitharam, Professor (on lien) at CiE, IISc, was part of the team that worked towards the completion of the bridge foundation in 2021. AFCONS also turned to Madhavi for her expertise in geotechnical engineering to contribute to the bridge's design, planning, and execution.

Though the overall design of the bridge had been decided already, Sitharam, Madhavi and the team had to decide the dimensions of the arch, the number and locations of the piers (the vertical load-bearing columns) and the type of foundation. A major task was to study the slope profiles on either side, come up with different strategies to excavate the slopes, and make them stable enough to support the bridge foundations and the train load. This was a long and tedious process, but by 2013, the slopes had been carved to perfection and the foundations had been laid. Now, the construction of the bridge's arch and piers could begin.

Photo courtesy: Madhavi Latha G

Madhavi Latha supervising slope stabilisation at the Chenab Rail Bridge

A large portion of Madhavi's work was computational, so she could work remotely for the most part – but she had to visit the site multiple times a year. Reaching the site was a struggle in itself – Madhavi had to take a series of flights and trains, followed by a long road journey to get there. In the early days, there was virtually nothing at the bridge site, and the team had to build camps and live with basic facilities.

"Once, during the COVID-19 pandemic, I had to visit the site urgently because there was a slope stability issue and we had to make a decision immediately," Madhavi narrates. "Every day, the work involved huge equipment which is mobilised from a low-lying area to the heights where we were working, and keeping them at the site is an expensive proposition. Any decision has to be taken very quickly, otherwise we lose out on a lot of money."

Stressing on foundations

Austrian geologist Karl Terzaghi, widely regarded as the "father of soil mechanics," once said that foundations have always been treated as "stepchildren" in civil engineering. "Their acts of revenge for lack of attention can be very embarrassing," he wrote.

Historically, most failures in megastructures have rarely occurred in the superstructures above ground. Instead, they often originate in the foundations hidden below. A major issue is differential settlement – the uneven sinking or settling of different parts of a foundation due to compaction, expansion or irregular shifting of the soil below. This is dangerous and can lead to structural damage, cracking, or even tilting of the building, as we see in the Leaning Tower of Pisa.

With the Chenab Rail Bridge, building a stable foundation was a challenge since the slope that the arch rested on was made of fragmented rock, making it very prone to differential settlement. Madhavi and the team had to make a lot of modifications to the rock. They pumped a mixture of cement, sand, and water into the gaps between the fragments to keep them together as a monolith – a process called grouting. Subsequently, they carefully planned and designed the foundations, making them wider instead of deeper so as to spread the load over a larger area.

Researchers in CiE have also worked extensively on dam engineering, an area that ties in all three focus areas of the department – structural engineering, hydraulics, and soil engineering for building stable foundations.

The way bridges are designed, their main support comes from piers. In contrast, dams are constantly in contact with the soil, making the design of the dam completely different – the soil bearing capacity becomes paramount. In the early 1970s, the Karnataka Power Corporation wanted to build a 55 metre-high dam on the Savehaklu river, a tributary of the Sharavathi. The plan was to supply the stored water to the nearby Linganamakki dam on the Sharavathi to generate hydroelectricity. But when they conducted tests on the soil, they concluded that the site was poor and they could not possibly build a dam more than 10 metres tall.

But the dam had to be built. So, they decided to call upon KS Subba Rao, who was then a Professor at the Department of Civil Engineering. “I was not a dam engineer – I was a foundation engineer,” exclaims Subba Rao. He noticed at once that the tests had not been done correctly and decided to take up the project. He roped in his ME (Master of Engineering) students, and they carried out all the experiments and verification tests once again, finally concluding that it was indeed possible to build the dam.

When Subba Rao first visited the dam site, he was surprised to see that the Karnataka Power Corporation had dug 40 feet-deep pits in the soil, which had been standing without any damage for the past four years, in a place which receives over 150 cm of rainfall. “I called the engineers and asked them: ‘Don’t you think the soil is good? Looking at these pits, who would accept that the soil isn’t good enough to build the dam?’” he narrates. “And the engineers told me, ‘We also felt that way, but we aren’t qualified enough to say anything, only your words are trusted here.’ That gave me a lot of confidence!”

Listening to cracks

Building a bridge or dam is only half the battle: ensuring its health over time is equally critical. A structure’s longevity depends on how well it is monitored and maintained.

Concrete, the primary material used in dams and bridges, is brittle: it shows high strength under compression, but it has low tensile strength, meaning that it easily cracks and breaks when stretched even a little bit. To help concrete withstand tensile stresses, it is often reinforced with steel. “But concrete itself is weak, and micro-cracks can still emerge,” explains JM Chandra Kishen, Professor at the Department of Civil Engineering. “This can allow the ingress of water along with pollutants, which can then find their way to the reinforcement and corrode it, eventually leading to the failure of the structure.”

In large concrete dams, tensile stresses emerge at the heel – the interface between the dam and the rock foundation. This region is prone to cracking because the materials on either side of the interface – rock and concrete – have different elastic properties. KTS Iyengar and BK Raghu Prasad, former faculty members at the Department of Civil Engineering, led pioneering efforts to understand these problems, laying the groundwork with the softening beam model and the fractal theory. Engineers still rely on these tools today to understand how cracks behave and propagate inside materials – a field of study called fracture mechanics. Chandra Kishen joined the department in 1996 and carried forward this work, promoting experimental research in interfacial fracture mechanics.

Over the years, the department's expertise in fracture mechanics was carried forward by graduating doctoral students to other reputed institutions in India. Students trained at IISc have gone on to win acclaim at global events, such as the International Conference on Fracture Mechanics of Concrete and Concrete Structures (FraMCoS). It all came full circle when Chandra Kishen hosted the conference at IISc in September 2023.

CiE boasts the largest fatigue testing laboratory in the world. At its heart is a mighty servo-hydraulic Universal Testing Machine (UTM) equipped with advanced sensors, high-speed data acquisition systems and digital imaging tools. Acoustic emission sensors, which "hear" the tiny ultrasonic whispers of cracks under stress, also play a key role in effective crack analysis.

And that's not all – in 2017, a bi-axial fatigue testing machine joined the lineup, enabling researchers to probe how concrete behaves under fatigue loading – when it is subject to repeated stresses. CiE's state-of-the-art infrastructure makes all the difference because in the world of concrete and steel, understanding how things break is the first step to building things that last.

Photo courtesy: Ananth Ramaswamy

Stone arch bridge at Dudhsagar Falls

Maintaining structures

The department's strong foundation in fracture mechanics underpins many modern approaches to maintaining ageing infrastructure, where a robust and regular maintenance protocol is crucial. This can range from daily visual inspections and sensors placed on the structure to periodic monitoring of deformation, strain, and tilt. Insights from these inspections help engineers take timely action, such as filling up micro-cracks which appear on the surface, to prolong the structure's life and ensure its continued safety.

Cracks can originate from within the concrete as well. Recently, the Ministry of Jal Shakti approached IISc and IIT Roorkee to look at various problems they were facing in over 5,000 dams across India, with one such issue being the alkali-silica reaction (ASR). The chemistry of concrete is such that there is reactive silica present, which is prone to volumetric expansion. When the material around it prevents that expansion, there is a buildup of stress leading to possible cracking and damage to the dam. "There are dams in the country where ASR is happening," says Ananth Ramaswamy, the current chair of the Department of Civil Engineering. "We want to figure out a mechanism by which this can be addressed to minimise water seepage and damage to the dam."

Researchers at CiE have also contributed to other projects under the Ministry of Jal Shakti, evaluating the vulnerability of dams by examining hydrological, seismic, and human-induced hazards. These included analysing the risk of dams breaking in climate change scenarios, studying the impact of blast waves from a nearby quarry on the KRS dam, and studying the ground conditions at the VV Sagar dam using surface wave testing.

Photo courtesy: Ananth Ramaswamy

Truss bridge outside Hospet station with a displacement gauge mounted to measure the deflection as the train passes

Bridges are also prone to damage due to fatigue. Chandra Kishen has worked on assessing the residual life of megastructures. “Many bridges in the country were built 50-70 years ago and have been subjected to changing magnitudes of loads, coming and going over several decades. We call this fatigue loading, and it can cause small micro-cracks to grow larger,” he says. “Our job is to assess if we need to do any kind of repair or retrofitting to the structure, and also determine how many [more] years it can serve us.”

In 2006, Southwestern Railways was looking to increase the axle load of railway bridges (the weight carried by a single axle on a vehicle) from 18 tonnes to 25 tonnes. The critical points they needed to analyse in their existing infrastructure were bridge bearings and supports. They approached IISc, among other institutes, to examine these bridges, some of which dated back to the 1870s.

The rail section that the department researchers looked at was in the Hospet and Toranagallu region in the iron ore belt, where ore was excavated and put on goods trains to be sent to the port in Vasco via Hubli, Castle Rock, and Londa. “They wanted us to instrument the bridges under current loading, and since there are live sections there, they did not allow us to go to higher loads like 25 tonnes that they were interested in,” says Ananth, who was part of the team. “They wanted us to find out whether the current performance was under the elastic regime and whether an enhanced load can be put on these sections.” A structure’s elastic regime is the range of stresses and deformations that it can tolerate while still returning to its original shape once the load is removed.

The team visited five bridges and spent 3-4 days at each site, monitoring the trains and measuring strains, displacement, and acceleration. None of the original drawings existed for any of these bridges, so the team had to construct numerical models based on field measurements, which was not easy. Over a three year period, they made predictions based on the model, reconciled the predictions with their measurements, and gave feedback on the feasibility of going up to higher axle loads.

“Accessing distressed areas within bridges or dams can be very difficult at times,” Chandra Kishen says. “We have to give solutions which are practically implementable and optimal at the same time.”

Photo courtesy: Ananth Ramaswamy

Chandra Kishen at the site of the Escarpment Viaduct Bridge 102 in Braganza Ghats, a plate girder bridge with sensors mounted inside

Learning on the ground

Civil engineers who work on large-scale structures often need to think on their feet. While working on the Chenab Rail Bridge, not all of the things that Madhavi's team had planned initially ended up materialising, and they had to continuously evolve all the design parameters – something she describes as the 'design-as-you-go' approach.

"The rock types changed from dolomite to quartzite to shale (a softer rock) as we dug deeper," narrates Madhavi. Since they could not rely on a low-strength material like shale, they had to change the foundation from a single block to two connected blocks in some places. They also used long, slender columns called pile foundations, which provided the optimal bearing capacity in unsteady terrain. In many cases, they had to change the locations of the foundations entirely when they discovered open cavities in the rocks below.

"When you are working on a project of this scale, you cannot just depend on one method," explains Madhavi. "You need to adapt to different methods and see which one works better for you. All methods that you adopt are not written in books – you often need to find solutions then and there, spontaneously." The team also had to take a lot of risks during construction by subjecting the bridge to every possible extreme condition and applying every possible load to make sure it would remain stable for over a century.

In recent years, CiE has taken on a more prominent role in major infrastructure projects, such as the Chenab Rail Bridge, marking a shift in approach since the

1990s, when Sitharam first joined the department. “Back then, our department was sort of conservative and rarely took on large consulting projects. We mostly did small-scale testing here and there,” he recalls. “But we moved towards a concept of complete design. For the Chenab Bridge, the entire design – from the foundation to the top – was done by us, except for the steel superstructure, which was handled by an international consultant. The foundation design, slope stability analysis, the choice of construction schemes, strengthening methods, grouting techniques – all of that selection was done here at IISc.”

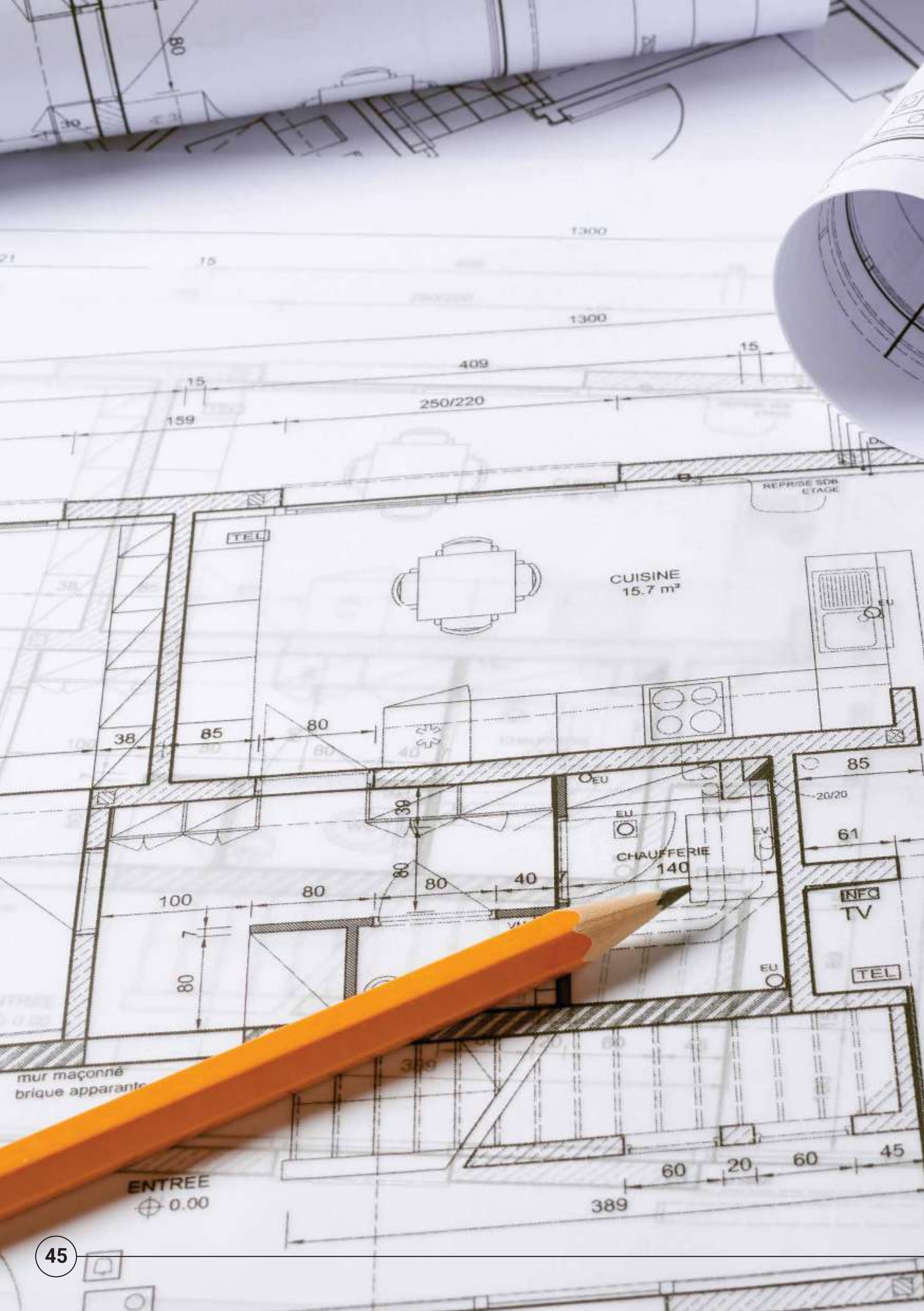
While the work can be long and demanding, there’s nothing quite like the pride and satisfaction of seeing a megastructure take shape before one’s eyes. “For hundreds of years, the local people had wanted the Chenab Rail Bridge [to be constructed], for easy conveyance from Jammu to Srinagar,” says Madhavi. “There is a lot of change from when I first saw the hills to what I see now – it is beautiful how it has changed the lifestyle of the people around there.”

The deck of the bridge was completed in 2022. Standing 359 metres tall as the world's highest railway bridge, the Chenab Rail Bridge is an engineering marvel – designed to last 120 years, resist blasts, and withstand temperatures ranging from –10°C to 40°C and wind speeds of up to 266 km/h. Trains began operating on the bridge in February 2025. On 6 June 2025, Prime Minister Narendra Modi officially inaugurated the bridge, opening it up for regular traffic.

“When I first saw the train moving on the deck at 120km/h, I got goosebumps,” Madhavi recalls. “It was a really fulfilling moment.”

Photo courtesy: Madhavi Latha G

Completed Chenab Rail Bridge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Engineering Her Way

- Bitasta Das

Not long ago, a woman in civil engineering was seen as an exception. At the Department of Civil Engineering (CiE), IISc, women engineers are rewriting this narrative. They are leading projects, shaping policies, and challenging long-held gender norms in the field, paving the way for future generations to enter the field with more ease.

Opening the doors

Photo courtesy: Ranganayaki

Ranganayaki Mallur Krishnaswamy, former Draughtswoman at CiE

Ranganayaki Mallur Krishnaswamy was working at an architecture firm in Bengaluru when she came across a job opening for a draughtsman position at the Department of Civil Engineering, IISc. As she had a diploma in civil engineering from the Government Women's Polytechnic College in Bengaluru, she took her chances and applied for it. "I was aware of IISc's reputation as a premier institution for research and higher education, and so I felt drawn to being part of such a community," she says. She excelled in the interview and heralded a new beginning by becoming the department's first draughtswoman in 1976.

In this role, her work revolved around the preparation of figures, machine drawings, and plans for building components in an era before digital tools such as MS Excel and AutoCAD. Those were the times when hand-drawn figures and preparation of visuals for presentations were an integral part of academic life. Her responsibilities included assisting faculty members during consultations and contributing to reinforcement detail drawings and other civil engineering sketches, which are crucial for on-site execution. Besides these, she had several administrative duties like managing the department library, designing and creating the annual calendars, and coordinating and managing logistics during interviews and conferences.

As the sole woman staff member at that time, Ranganayaki actively built a supportive network of women faculty, staff and students, both within her department and across others. Among the friendships she formed was one with the late Rajeswari Chatterjee, the first woman engineering faculty member at IISc and later Chair of the Department of Electrical Communication Engineering. She also contributed illustrations to several of Rajeswari's books.

In her career that spanned close to three decades, Ranganayaki witnessed many significant moments at IISc, including the inauguration of the JN Tata Auditorium and listening to an inspiring speech by JRD Tata. Over the years, she also got opportunities to meet many dignitaries at the Institute, such as Prince Charles, Rajiv Gandhi, and APJ Abdul Kalam.

Ranganayaki retired from the Institute in 2003, but it was not the end of her professional journey. She committed herself to mastering AutoCAD and continued to work with an architect for several more years. Besides that, she discovered her passion for quilting. She now professionally teaches the craft and also creates commissioned quilts.

Making a beginning

A Vatsala joined the Department of Civil Engineering in 1982 as an MSc (Engg) student in the Soil Mechanics group. In 1984, she applied for a Scientific Assistant position that had opened up and successfully cleared the interview. That same year, she submitted her MSc thesis and later went on to pursue her PhD as a staff registrant, which she completed in 1988. Over the years, through regular evaluations and promotions, she rose through the ranks and eventually retired voluntarily as a Principal Research Scientist in 2004.

As a member of the scientific staff, her responsibilities were diverse. She supported faculty in their research activities, managed the procurement and maintenance of laboratory and computer equipment, and assisted in organising workshops and conferences. After obtaining her PhD, she also taught courses for MTech and research students and co-guided several doctoral scholars.

She regards her years at the institute as the most fulfilling phase of her career.

Photo courtesy: Raghuveer Rao

A Vatsala sitting at her desk at CiE

Unlike the scientific staff in the other two divisions of the department, who had limited time and opportunity for personal research, she had the flexibility to actively pursue research alongside her official responsibilities. For most of her career, she was the only woman on the academic staff in the department, although there were a few female students.

Her research was on elasto-plastic modelling of soil behaviour under a general three-dimensional stress system. She was the only one in the country working on this topic at that time. The area was considered complex compared to others because soil, being a particulate porous medium, exhibits coupling of plastic volumetric and shear response. Though modelling was quite well developed by then for normal saturated clayey soil systems.

After years of dedicated research, she began to feel that her area of work offered limited scope for fundamental breakthroughs, with most developments amounting to minor advances. She explored the possibility of shifting her research focus, but she was not satisfied with the outcome. At the same time, she increasingly felt the need to connect with the world beyond academic research. These circumstances eventually led her to take voluntary retirement.

Since then, she has been actively engaged with rural communities and volunteers with various NGOs and civil society organisations. Her work spans a wide range of issues, including sustainable agriculture and food systems, rural livelihoods, water and energy efficiency, natural resource management, marketing challenges, and the implementation of government policies and programs. She is also involved in advocacy related to land rights and other grassroots concerns.

Vatsala recalls, “Ratan Tata, in his lectures at IISc, always used to advocate for the addition of humanities and social science departments, which never happened during my time. I feel this paradigm is extremely necessary for the institute”.

Claiming the space

When Sridevi Jade joined IISc as a postgraduate student in 1986, she was the only woman across the three civil engineering disciplines: structural engineering, geotechnical engineering, and hydrology. Initially, life at IISc was a cultural shock for her; having come from a state university, Osmania University, she found IISc much less conservative. It was safe for girls to walk from the labs to their hostel as late as 3 am. On the flip side, she often felt lonely during discussions around assignments and projects, as the men would form their own groups. During her time on campus, Sridevi successfully requested a few changes, such as separate swimming pool hours for women and designated meeting areas for visitors at the women's hostel.

Photo courtesy: Sridevi

Sridevi Jade in a field site in Kashmir, with the GNSS station behind her

After completing her Master's degree in 1988, Sridevi returned to IISc in 1995 as a PhD student in the same department. This time, she was an external student while working with the Council for Scientific and Industrial Research (CSIR). She worked in the area of geotechnical engineering, where she delved into numerical modelling as applicable to rocks. Sridevi pioneered data intensive, global navigation satellite system (GNSS)-based multidisciplinary research in the country resulting in estimates of crustal motion, atmospheric water vapor, and ionosphere variability in the Indian subcontinent for the past 30 years. She led several multi-institutional hazard mitigation projects in challenging terrains such as Ladakh, Kashmir, northeast India and the Andamans. This has resulted in precise estimates of the crustal motion and strain models for the Indian plate interior and boundaries, thus providing an estimate of the recurrence rate of large earthquakes in the Himalayas. She has also been instrumental in setting up a national network of GPS stations for monitoring seismotectonic activity in India to assess earthquake hazards.

Sridevi recently retired as the Director and Outstanding Scientist at the CSIR-Fourth Paradigm Institute (4PI). Though she faced several challenging moments in her career, including discrimination and carrying out surveys in harsh landscapes, she relied on hard work and determination to navigate these obstacles. "My advice to the younger women is to keep working, regardless of the recognition and rewards, they will come by when you keep doing what makes you happy," she says.

Laying the ground

Madhavi Latha Gali completed her PhD in Civil Engineering from IIT Madras, a postdoc at IISc, and a year-long stint as an Assistant Professor at IIT Guwahati. She returned to teach at IISc in 2004 and became the first woman faculty member at the Department of Civil Engineering.

Madhavi's research focuses on geosynthetics (polymeric materials used to reinforce soil), earthquake-resistant design, and rock engineering. Her interest in geosynthetics began during her BTech, driven by a desire to explore alternatives to traditional construction materials such as cement and concrete. Being one of the few experts in rock engineering problems, today she is a leading contributor to India's growing infrastructure projects. The landmark Chenab bridge project of the Indian Railways was one such example. "My role was to assess the stability of slopes under various critical conditions of earthquakes and design rock anchor systems to make the slopes resistant to earthquake forces," she recalls.

Photo courtesy: Madhavi Latha Gali

Madhavi adjusting the loading plunger in a large diameter cyclic triaxial test setup – used to check for soil liquefaction

She currently serves as Chair of the Centre for Sustainable Technologies at IISc – a role that has further shaped her research trajectory. In her current work, she investigates the use of natural fibers and sustainable techniques for soil reinforcement as alternatives to synthetic polymers. This presents a significant challenge, as natural fibers are prone to degradation when exposed to water and microorganisms. Her research aims to develop methods to enhance their durability and extend their lifespan.

Alongside her research, Madhavi places equal importance on ensuring gender parity within the department. She recalls that it was not as easy when she joined the department, as it is now. From securing exclusive women's restrooms in the geotechnical engineering building to promoting inclusivity within the labs, Madhavi has consistently worked to improve the presence and participation of women in a department that has historically lacked gender balance. She is happy that currently there are almost as many female students as males in the department.

The nature of work in civil engineering poses challenges for women students, especially when it requires staying on site. These can be remote construction sites with less accessibility to resources and poor safety. On such occasions, being a woman and having tread those paths, she makes sure that she understands what her students need and helps them continue their work.

Pushing the frontiers

Swetha Veeraraghavan joined as an Assistant Professor in the Department of Civil Engineering, IISc, in 2020 after her PhD at the California Institute of Technology and postdoc at Idaho National Laboratory, both in the USA. Her areas of research include earthquake engineering, computational mechanics and wave propagation.

Photo courtesy: Swetha

Swetha Veeraraghavan, Assistant Professor of geotechnical engineering at CiE

Her urge to learn new things and her positive experiences during her BTech internships and term projects led her to pursue an MS/PhD degree. A fulfilling research experience during the PhD prompted her to pick a career where she could continue learning and discovering new things. So, for her, R&D labs and academia were the clear choices. "I chose academia since it allowed me to have the freedom to choose the kind of questions I wanted to pursue," she says. Since IISc is one of the finest research institutions in India, with a well-accomplished peer group and a beautiful campus, she felt that the Institute would provide the perfect research environment for her to grow in academics.

Right before she started her BTech in naval architecture and ocean engineering at IIT Madras, an earthquake followed by a devastating tsunami struck the coast of Chennai, her hometown. After moving to California, which contains a large section of the San Andreas fault that had caused many earthquakes, she learnt how seismic wavefields have the potential to destroy entire cities, and how the damage can be mitigated through intelligent engineering design. This is when she became interested in the field.

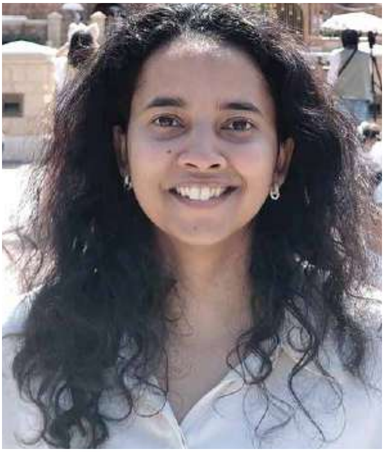
Her current research focus is on the seismic safety of structures, with particular emphasis on the Indian scenario. More than 50% of the land in India experiences moderate to high-intensity earthquakes. She is developing numerical frameworks and experiments to simulate the rupture of earthquake faults and analyse the response of critical infrastructure such as tunnels, dams and nuclear power plants to these seismic wavefields. She also works on developing new composite seismic metamaterials that can effectively shield these sensitive structures from moderate to large earthquakes.

As the only woman in her BTech classes, Swetha initially faced issues adjusting. But with support from her classmates, she excelled, graduating at the top of her class. The experience affirmed her belief that gender does not define one's capabilities.

Paving the path

Satyavati Komaragiri is among the new faculty members who joined the Department of Civil Engineering. She is an Assistant Professor, about a year old at the Institute. After her BTech from IIT Guwahati, she worked in the industry for close to a year. This was when she realised that her heart was in academics. She decided to pursue her master's degree and subsequently her PhD from the University of Texas at Austin. Her work until this time primarily involved building and structural mechanics, and materials.

Photo courtesy: Satyavati



Satyavati Komaragiri, Assistant Professor of structural engineering at CiE

Satyavati's research interests began to shift during her Master's, when she took up a research assistantship at the University of Texas that focused on concrete pavements. However, the project supervisor retired, and the new project supervisor specialized in asphalt roads. This change sparked a natural and organic transition in her focus, leading her to pursue a PhD on asphalt pavements.

The fact that no faculty at IISc works primarily in the area of asphalt pavements convinced her that this opportunity needs to be explored. She applied for a position at the Institute, and today she conducts studies on how to build durable roads at a low cost using sustainable materials. "Something I realised after coming back to India is that there is a lot of interest among the general public when I say that I work on roads, so there is a lot to be done in that area," she says.

Hailing from Kota and moving to Guwahati for BTech, followed by working in Mumbai before going to Austin for graduate studies, and then finally shifting to Bengaluru has given her a rounded perspective on life and work. Navigating a historically male-dominated field has brought both challenges and opportunities. While there are obstacles such as unconscious bias, the need to prove expertise, and the pressure to conform to established norms, it has also enabled her to break barriers, introduce new perspectives, and foster a more inclusive workplace, both for herself and the future generations. She sees this as a platform for leadership and growth.

Soil Sleuths

- Ranjini Raghunath

Geotechnical engineers, who investigate soils and their properties, play an important and sometimes overlooked role in civil engineering

A vacation on a Spanish beach in the 1960s sparked a revolution in the construction industry.

French engineer Henri Vidal was piling up sand to build a sand castle when he realised that no matter how hard he tried, he could not make the angle of the mound steeper than its natural incline. This is because sand, like all soils, has poor tensile strength – it comes apart easily as the individual particles don't cling tightly to each other. But when he stuck pine needles into the sand, he found that the friction between the needles and sand helped stabilise it and allowed him to make steeper mounds. Excited by this discovery, he went on to develop a construction technique and later a multi-billion-dollar company called "Reinforced Earth" that changed the way many modern structures are built.

The idea was simple: If you alternate layers of soil with strips made of materials like steel, you could make the layers strong enough to build walls, bridges, even dams. Since the 1980s, engineers have switched from steel to polymers called geosynthetics that are more lightweight, cost-effective and corrosion-free. Today, thousands of structures are being constructed with such polymer-blended soils using the reinforced earth technique.

Photo: Vibha S

Mohit Jadav, a former MTech student in the Department of Civil Engineering, investigating a slope failure due to rainfall in Chikkamagaluru district

“Even the engineers building the new airport terminal in Bengaluru are using this technique for expanding the access roads,” says G Madhavi Latha, Professor in the Department of Civil Engineering. “If you see most of the abutments of bridges or flyovers these days, from the outside, they all look like [they are made of] concrete, but inside it is all soil.”

Madhavi’s lab studies reinforcement techniques using a variety of sophisticated instruments. With a universal tensile testing machine, they are able to stretch geotextiles – fabrics made from polymers – to test their tensile strength, the maximum load they can support when stretched. A 3D printer helps them print not only geosynthetics but also sand particles in desired shapes, sizes and textures using polymers. One of her forme PhD students, Rizwan Khan, used video cameras set up in the lab to track how the interfaces between different soil layers, and between soil and geosynthetic layers, behave as they rub against each other. Madhavi is particularly proud of the digital microscope she has set up that helps her students peer at the tiniest of grains in a soil sample. Such digital imaging-based explorations, she says, have brought a lot of “freshness” and innovation to the more traditional field of civil engineering.

“When you say civil engineering, people think of huge structures like dams or buildings,” points out Raghuveer Rao Pallepati, Principal Research Scientist at the Department of Civil Engineering. “All these structures have to rest on the ground. How good the ground is to support the structures is assessed by geotechnical engineers.”

Geotechnical engineers like Madhavi and Raghuveer are fascinated by how various soils behave under different conditions. Soils are classified into different types – clay, silt, sand or gravel – depending on the fraction of the different-sized particles that they contain. With concrete now being recognised as the most destructive material on the planet, soil is rapidly making a comeback as a construction material. Soils with clay-sized particles are also being explored as liner materials to stop leaching from landfills and hazardous waste pits. Crucially, soil is at the heart of many natural and climate-change induced disasters – its collapse can bring buildings to the ground and lead to landslides and flooding.

“Superstructures like concrete buildings are [made of] manufactured materials. We know their properties and we can control them,” says Raghuveer. “But the ground is naturally formed with different-sized particles, mineral content and conditions. We have no control over that.”

On solid ground

If you take a spoonful of sand and sugar side-by-side, you might think that the individual particles are of the same size. This is true for sugar, but not sand, explains Raghuveer. Soils are an uneven mix of particles of different shapes and sizes. The texture and colour of the soil varies depending on the type of material that weathered over millions of years to give rise to it. A soil patch in the IISc campus is usually red in colour because of minerals rich in iron, whereas the cotton-growing soils found in North Karnataka's Gulbarga and Bidar districts are pitch black due to the presence of iron and aluminium as well as the soil's ability to retain a lot of water.

This variability is a major reason why soils "cannot be taken for granted," says Sudhakar Rao, former Professor in the Department of Civil Engineering. If you dig up the soil at a specific spot, and then dig at another site just 100 metres away, there is no guarantee that the composition will be the same, he explains.

Another important feature of soils is how much water they can retain, called the level of saturation, which determines their ability to support structures built on top of them, like buildings or walls.

"Imagine you have constructed a structure when the soil was unsaturated [devoid of water]," says Raghuveer. When it rains and the ground water level rises, filling the air pockets between the soil particles, the weight exerted by the structure on the ground will initially be taken up by the water, which forms an interconnected matrix inside the soil. Later, when the water dries up, the weight gets transferred to the soil particles, which causes them to deform, and makes the building "settle", developing cracks or sagging floors. "In the lab, we can estimate and extrapolate how much will be the settling for a building over time, before construction begins," he explains.

Some expansive soils, like the black cotton soil, swell when they are in contact with water during the rainy season, and shrink during the summer as the water evaporates from the ground surface, adds Raghuveer. "If you construct buildings

Photo: Prince Kumar

Kalore Shubham Arun, a former PhD student in Sivakumar Babu's lab, studies geocomposites that can reinforce pavements at a shallow depth in North Karnataka, most of them will get cracks. To prevent that, you have to rest the foundation at a depth where the moisture changes are minimal."

Soil stability is especially critical when it comes to earthquakes. When tremors travel through the ground, the shockwaves loosen and separate the soil particles, making the soil flow, almost like a liquid – a process aptly called liquefaction. Two of Madhavi's former students, Balaji Lakkimsetti and Prerana Krishnaraj, are currently creating earthquake-like conditions in the lab using cyclic simple shear and shaking table experiments, and trying to understand how soils liquefy and how they can be strengthened to withstand various degrees of shaking.

With advances in technology in recent years, even the weakest of soils can be reinforced before constructing any structure. "If you look at the Burj Khalifa, people never thought about the fact that it is so close to the sea, that marine soils have a lot of problems," says Madhavi. "Because there are solutions which can make soils take any amount of load."

One of those solutions is using geosynthetics, like the polymers in the reinforced earth technique. Geogrids, for example, are rectangular mesh-like structures that can strengthen the aggregates used for roads and pavements, and reduce the thickness of the layers paved. For a 100 km-long road, reducing the height by one-fourth of a metre can save a few thousand tonnes of natural soil, Madhavi explains. A large cyclic triaxial setup in her lab – the only one of that size in the country – helps her study the strength of these reinforced aggregates under simulated vehicular loads.

Photos: Indra Prasad Acharya and Sudhakar M Rao

Fly ash (left), a by-product of coal-fired power stations, can be converted to geopolymer sand (right) to use in construction

Such geosynthetics can also be made from recycled materials. Kalore Shubham Arun, a former PhD student in the lab of Sivakumar Babu, Professor in the Department of Civil Engineering, is using geocomposites produced from crude oil waste to design improved pavements that can help drain water faster, and prevent water logging and potholes. “Not much research has gone into this area for Indian conditions,” he says, adding that results from such studies can contribute to road and highway management policies.

With land space becoming scarce in cities like Bengaluru, such reinforcement techniques are only gaining momentum.

“Earlier, if you found a piece of land that was not conducive to construction, you could ignore it. Land was available in plenty. Now, it is no longer that situation,” says Sudhakar.

Sudhakar, who has studied soils for decades, also laments the loss of many traditional practices that involved using soil for construction. Centuries ago, villagers in North Karnataka used to mix the black cotton soil with grass, hay and cow dung and let it age for decades to build strong walls for their houses. “We went to those sites, brought these samples to the lab and examined them to figure out how the villagers did it. We got some interesting results,” he says. But the practice has long since been abandoned, and none of the local people the team spoke to was able to remember what their ancestors used to do. “Unfortunately, with the advent of easy construction technologies, people forget about these things.”

Leaks and landfills

In the late 1990s, a few years before Sudhakar started working on the black cotton soils, many countries were waking up to the looming problem of disposing nuclear waste safely. For highly radioactive waste, the plan was to bury them deep into the bedrock (more than 1-2 km below the surface) in canisters made of steel or a similar strong material. But what if this steel cracks, and radioactive waste begins leaching into the ground, making its way to the groundwater? The answer lay in a type of clay that you might find in your acne face mask – bentonite. Bentonite is nearly impervious to water and has excellent self-healing – it can absorb liquids that may leak, and swell, plugging any holes or punctures. It can also remain stable for millions of years. Bentonite blocks surrounding the steel canisters can therefore provide a rugged and long-lasting barrier.

“We had a project with the Board of Research in Nuclear Sciences to identify the type of bentonite that could be used for a high-level waste repository,” recalls Sudhakar. “We scouted around the country, identified a type of bentonite in a place called Barmer in Rajasthan, brought the soil to the lab and did a lot of tests to evaluate its usefulness as a waste containment material. The lab was very successful in identifying, characterising, and comparing it with bentonites in other countries.”

While such repositories are still way off into the future, a more immediate challenge is staunching leaks in urban landfills. Anjali Pillai, a former PhD student in Madhavi’s lab, is trying to figure out how a combination of a material called geosynthetic clay liner (GCL) – which contains bentonite at its core – and M-sand

– artificial sand made from crushed rocks like granite – can be used to line landfill slopes. “Sand mining is illegal now, and causes a lot of environmental problems. Instead of sand, we can lay this material as the bottom-most layer to line landfills,” she says. Anjali is particularly interested in understanding how efficiently the M-sand particles interact with GCL. This ‘interfacial strength’ is important because many landfill failures have been linked to poor interactions between the various layers that line its slopes. “Once you prepare [the landfill], there is no going back, because its lifespan can be 30-50 years,” she says.

Photo: KG Haridasan

Anjali Pillai, a PhD student in Madhavi Latha’s lab, using an optical microscope to study the interaction between geosynthetic clay liner and M-sand particles

Some geotechnical engineers are not only interested in building such landfills but also in managing the waste inside them. “Solid waste ultimately degrades into a soil-like material … that’s the reason why we apply the same principles of soil behaviour to it,” explains Sivakumar Babu. Several of his students are working on various aspects of landfill management. “We have 300 acres of dumpsites in Bengaluru … there are significant problems like leachate, methane emissions, and water contamination. We have to solve these problems as well.”

“If you visit any landfill in Bengaluru, you rarely find any that have a proper lining system. Most of them are not engineered,” says Prince Kumar, one of his PhD students who is working on models to estimate the amount of toxic gas generated from landfills, and design effective gas extraction systems. Another student, Anusree N, is focusing on ways to enhance the breakdown of materials in landfills by using natural enzymes. “Waste management is an area in which people are usually hesitant to work,” she says. “At the same time, this is also one of the most burning issues.”

Saving soil

The image of a burning Bellandur lake is something that Bengalureans have become uncomfortably familiar with in recent years.

But it is not the only area in the city where both water and soil are being polluted by effluents from industries. Soil pollution, a serious issue in many urban areas, is also something that people like Sivakumar Babu are working on. Two of his students, Kalyani Kulkarni and Prathima Basavaraju, have been collecting soil samples from the Bellandur lake area and Peenya industrial district to determine the levels of pollutants like chromium, nickel, cadmium and zinc, and come up with ways to reduce them. “Chromium contamination is one of the more serious problems as it is carcinogenic,” says Sivakumar Babu.

“When these heavy metals are in the soil, they enter the crops and then the food chain,” explains Kalyani. The goal, therefore, is to convert the metals into forms that are less available to plants, either using compounds that bind to and stabilise them, or precipitate them out of the contaminated soil. Some nanoparticles they are testing in the lab, for example, can convert the more toxic form of chromium (hexavalent) into a less toxic form (trivalent). “Soil chemistry is quite complex. Every metal reacts differently to the same remediation method,” Kalyani says.

Sivakumar Babu’s lab is also interested in landslides, a recurring disaster in several parts of Karnataka which receive heavy rainfall. The reason why civic authorities are unable to effectively prevent and manage landslides is due to a lack of understanding of soil behaviour, he says. His lab has been exploring the use of various geosynthetics like geotextiles and geogrids, which can hold the topsoil in place and reduce the impact of landslides.

“We can also use sensors to track and predict what could be the soil movement during landslides, and forewarn people,” Sivakumar Babu says. “[But] at the same time, the response from government agencies is not very effective. They say, ‘Let the problem come, we will solve it later.’”

Raghuveer echoes this sentiment. Most of the government or private contractors he consults for call him only for “forensic” analyses, to try and figure out what went wrong after a building or structure has collapsed. He highlights the example of a major research facility that was recently built by a governmental agency, which began developing water leakage in the basement due to lapses in soil investigations and design of the foundation. Many “settled” buildings across Karnataka and slope failures due to rainfall – such as one that his PhD student Vibha S and former MTech student Mohit Jadav are currently investigating in Chikkamagaluru district – could have been avoided by proper site investigation, analysis and design, he says.

“Unfortunately, people pay a lot of attention to the elevation of the building. They will pay the architect a lot of money and ask them to make it look nice, but they will not be willing to pay a geotechnical engineer to do the site investigation. But once it goes out of control, they will come to us,” he says, with a chuckle.

“Our accomplishments are not visible outside, but they are very important,” Raghuveer says. “Everyone says you need a strong foundation. That strong foundation is built by geotechnical engineers.”

Flooding in Tatanagar, Bengaluru following heavier than normal rains

Photo courtesy: Wikimedia commons/Shyamal

Dealing with Disasters

- Rohini Subrahmanyam

Researchers at CiE have extensively worked on understanding and tackling natural hazards

KS Jagadish recalls being one of the earliest students to start a PhD in structural dynamics – the study of structures under forces that vary over time.

“Civil engineers never bothered about dynamics; they were always very static in their thinking,” he says. He went on to become a faculty member in structural engineering at the Department of Civil Engineering (CiE), IISc. “It was the vision of KTS Iyengar to start structural dynamics, and I happily got into it.”

Jagadish first joined the Institute back in 1961 for a Master of Science by Research (MSc (Engg)) degree before starting his PhD under Iyengar in 1963, one of the early leaders in structural engineering at the Civil and Hydraulic engineering section of the Department of Power Engineering, which later became CiE. Jagadish, immediately drawn to structural engineering, helped set up a structural dynamics lab. Under the guidance of Iyengar, he went on to work with R Narayana Iyengar (RN Iyengar) – a young postgraduate research student at the time – on vibrations in bridges, and together they initiated research in the structural dynamics domain in the department.

A major aspect of studying structural dynamics is understanding earthquakes. Over the years, CiE faculty have also worked towards understanding and mitigating multiple deadly disasters, including floods, droughts, and landslides.

The faculty's research on various types of natural disasters has even led to the development of new courses, which include "Natural hazards and their mitigation" offered to undergraduate students and "Disaster Management for Dams" and "Hydrologic Safety Evaluation of Dams" to graduate students at the Institute.

"Natural hazards are not in the control of human beings; nature has its own way of doing things," says KS Nanjunda Rao, Chief Research Scientist in CiE. "Preparation is very important to face these natural hazards, whether [it is an] earthquake, a flood, or a drought. So, the Department of Civil Engineering has significantly contributed to addressing [many issues] in all these areas."

Engineering for earthquakes

Back in the 1960s, Jagadish first began by building a shaking table.

A shaking or shake table can simulate ground vibrations, which is why engineers use it to study earthquakes. At the time, IIT Madras had a table that could create vertical vibrations, but Jagadish was keen on building one with horizontal vibrations as well. "Fortunately, we had a very good mechanic, Mr Krishna, and he was able to [help] develop the vibration table," he recalls.

Photo courtesy: KS Nanjunda Rao

KS Nanjunda Rao built a large shock table to test earthquake resistance of buildings

Many years later, between 2006 and 2008, Nanjunda Rao worked on developing a large, 3-metre-by-3-metre shock table. A shock table is cheaper and simpler to use than a shake table; it is also used to make structures move and test their earthquake resistant capabilities. As compared to modern shake tables which cost Rs 25 to 30 crore for setting up the test facility, a shock table of similar size can be fabricated and installed in less than Rs 15 lakhs, according to Rao.

RN Iyengar, who later became a faculty member, worked on collecting data on earthquakes and modelling them when he joined in 1963. “Natural phenomena [like earthquakes] are uncertain; we don't know when they occur. So, if there are uncertain phenomena, how [can they] be modelled mathematically, how [can they] be analysed? That was the problem that I was working on,” he explains. “The civil engineer must make sure the structure doesn't collapse, whatever may be the kind of ground motion, whatever may be the magnitude, wherever it may occur.”

People studying earthquakes in the department at the time had to change one major misconception that earthquakes never happened in South India, where the Institute was located. Earthquakes were common in the Himalayan region and the education curriculum imposed by the British insisted that Southern India was very stable because of the Deccan plateau.

“Earthquakes were researched only in the north, in Roorkee. People thought that South India was free of earthquakes,” says RN Iyengar. “When I started working on this, people asked: ‘Why do you want to work on earthquakes?’” He struggled to come up with a good reason even to then director Satish Dhawan who posed the same question.

Then, the Koyna earthquake of 1967, which happened near the Koyna dam in Maharashtra, shook people’s views. “I did not know whether to feel happy or not that there was an earthquake in the south,” says RN Iyengar, with a laugh.

RN Iyengar also provided solutions for rehabilitating habitats in Uttarakhand after disasters like the 1999 Chamoli earthquake, one of the strongest earthquakes to hit the foothills of the Himalayas in almost a century. He also studied the seismicity of Delhi, which was struck by a massive 6.5 magnitude earthquake in 1720.

From nuclear reactors to heritage buildings, many structures need to be designed to withstand earthquakes and tremors, he emphasises. “You have to forecast what kind of earthquake may occur in the next 5,000 [or] 10,000 years, and whether a particular structure will withstand that or not.”

Along with building earthquake-resistant structures, it falls on the civil engineers to ensure the soil on which the structure is being built is stable. In 1997, TG Sitharam, Chair of All India Council for Technical Education (AICTE) and Professor (on lien) at CiE, began work on earthquake engineering from a geotechnical perspective in the department.

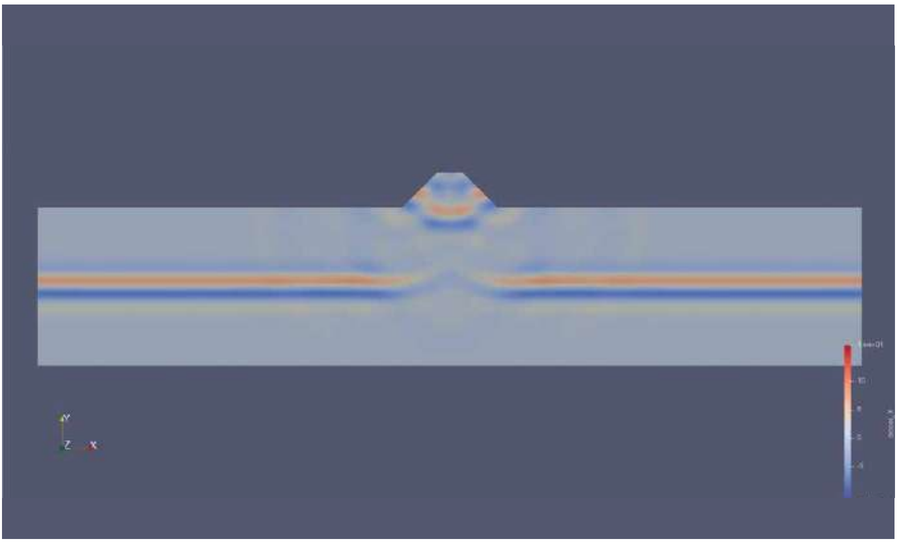
Sometimes the stress from an earthquake can shake up loose or wet soil – also called cohesionless soil – in a way that it almost turns to liquid, in a process called soil liquefaction. Sitharam worked on cyclic triaxial tests to check for liquefaction, a method in which engineers put a cylinder of water-saturated soil in a chamber that can apply pressure on all sides in a cyclic way – essentially shaking the soil sample hard to check if it turns to slush. Based on how the soil responds, they can assess whether the soil under some building, bridge, or dam is safe against an earthquake.

Sitharam also worked on the seismic microzonation of Bengaluru, which is to identify sub-regions of the city that may be susceptible to earthquakes. For this, he and his students have conducted seismic hazard analysis studies at multiple sites and looked at how the soils local to those sites will respond to earthquakes.

Work on geotechnical earthquake engineering continues today in CiE. Swetha Veeraraghavan, Assistant Professor in CiE, currently studies the seismic safety of structures like dams, bridges, and nuclear reactors in earthquake-prone regions.

Say one wants to build a new structure like a tunnel or a bridge at a specific location close to a fault line prone to earthquakes. Some properties, like the type of soil in the region, can't be changed. But other factors, like how the waves of energy from the earthquake will interact with and affect the structure can be estimated and modelled computationally, based on data from previous earthquakes in the area.

Image courtesy: Swetha Veeraraghavan



Modelling graphic showing an earthquake wave travelling through the dam embankment and getting trapped within the trapezoidal geometry of the dam, causing that part to have higher ground motion for a longer duration

“What type of interaction can actually be beneficial to the structure and which ones are going to completely damage it? That's what we're trying to understand from our studies,” she explains.

“Earthquake vibrations last for a few tens of seconds. But the lifetime of a civil structure like a building, bridge or dam is 50-100 years; for nuclear power plants, about 1,000 years,” says Nanjunda Rao.

It is hard to predict what magnitude of earthquake the structure might face during its lifetime, if at all. Thus, engineers have to design structures keeping these uncertainties in mind, making the task of designing them non-trivial. They have to design buildings not just to withstand more common, low-magnitude earthquakes, but also the less common – but more destructive – higher magnitude earthquakes.

“The central theme of earthquake resistant design is saving lives,” says Nanjunda Rao. “Saving lives is more important than saving the structure.”

Photo courtesy: KS Nanjunda Rao

Behaviour of masonry building models with and without near surface containment reinforcement, subjected to horizontal base motion on the shock table

Rao has worked on earthquake resistant design of unreinforced masonry structures which are made up of brick and mortar and lack steel reinforcements. Both during the 1993 Latur earthquake in Maharashtra and the 2001 Bhuj earthquake in Gujarat, it was the unreinforced masonry structures that collapsed and killed a lot of people.

The idea was to introduce ductility into these structures – the ability to withstand large deformations caused by the vibrating ground in an earthquake without fracturing and falling apart. He worked on a method called near surface containment reinforcement, which involves introducing steel bars vertically close to the surface of the structures in order to strengthen them against seismic events. He also worked on a method called confined masonry, in which the masonry walls are strengthened by providing reinforced concrete bands in both horizontal and vertical directions. Lab models showed that such reinforced buildings showed ductile behaviour and could withstand earthquake-like vibrations without collapsing.

BK Raghuprasad, a former CiE faculty member worked on contingency measures to help citizens after the unfortunate occurrence of an earthquake, or other disasters like typhoons and even wars. He worked on light-weight houses to shelter people, designing them in a way that they should not weigh more than 10 kg. For this, he used aluminium.

"Aluminium reflects almost 95% of the heat. If you have aluminium roofing, it is much cooler beneath," he says. He experimented and verified that under a reinforced concrete roof, on a midsummer very hot day, the temperature inside even with a fan is about 35°C. But under the small aluminum roof he set up inside the department, the temperature inside was almost the same without a fan. "It expels the same kind of heat," he explains.

Although courses on earthquake engineering were being taught in CiE, the subject wasn't very well-known across the country. It was only after the 2001 Bhuj earthquake that it became an important part of the civil engineering curriculum. "Earlier, when structural engineers were designing structures – unless it is very important infrastructure which has to be designed for earthquakes – earthquake as a load was not considered at all, even in the structural engineering fraternity," Rao says. "That was one of the reasons for so many fatalities in these two [Latur and Bhuj] earthquakes."

Authorities realised that to prevent losing lives, the structures being built needed to behave better, and they decided to focus on capacity building across the country to solve this issue. The Ministry of Human Resource Development, New Delhi (now the Ministry of Education) started an initiative called the National Programme on Earthquake Engineering Education (NPEEE) which ran from April 2003 to March 2007. Faculty at CiE and different IITs across India were asked to teach engineering college teachers the basics of structural dynamics, earthquake engineering, and earthquake-resistant design.

"Disaster mitigation is a very important area that has to be done by civil engineers," insists RN Iyengar. "[It is] not simply enough to build, they have to protect [what they build]."

Fielding floods

Unlike earthquakes, devastating floods are a more common occurrence in Indian cities. "Cities like Bengaluru, Delhi, Chennai, Mumbai, and Hyderabad have been experiencing floods year after year, especially in the last 10-15 years," says Pradeep P Mujumdar, former Professor at CiE.

Two factors contribute to floods in cities, according to Mujumdar. One is how city authorities manage their land use. With rapidly expanding construction in the cities, essential urban infrastructure for safeguarding against floods has become especially strained.

“Even if we want to increase the drainage patterns, there is no land available,” says Mujumdar. “By constructing roads, pavements, buildings, and so on we are increasing the impervious area, which means that if the rain falls there, it has no way to go down [to the soil]. It has to only run on the surface.”

The other factor could be an increase in the rainfall level itself, exacerbated by climate change. The urban heat island effect could also be contributing to heavy rains, according to Mujumdar.

“When we put all these concentrated constructions in one place, we are creating an island which captures the heat. For example, the building material, cooling systems, vehicular traffic – all of these will increase the temperatures in the city,” he explains. “Because of this heat island, it is known that rainfall intensities will increase.”

Image courtesy: Nruthya Kishore

HEC-RAS simulated 2D-flood inundation for the event 4-6 September 2022 in and around HSR Layout of Koramangala Challaghatta Valley overlayed on Google Hybrid

He recalls a massive flooding event that happened in the ONGC residential complex in Panvel, Mumbai, in the late 1980s. The engineers had to suspend their offshore drilling for three days, and there was widespread economic loss. Hydrology specialists like Mujumdar were called on to provide innovative solutions at the time. “You may have to pump [water] out. And you may have to store it in the campus somewhere, creating lakes,” he explains.

Even in cities like Bengaluru, managing lakes to control floods is important. “There are several lakes that can be operated in an integrated manner, so that you have a cushion for storage,” he adds.

To solve issues of urban flooding, Mujumdar and his group have worked on a digital twin of Bengaluru – to reproduce, using computational models, what happens to the city during rains. Using past rain and floods data that they obtained in collaboration with organisations like Bruhat Bengaluru Mahanagara Palike (BBMP) and Karnataka State Natural Disaster Monitoring Centre (KSNDMC), they created a digital platform complete with buildings, road and drainage networks, lakes and other water bodies, and open areas. Then, they developed hydrologic models, to first calculate how much flooding a given area experienced or how much time it took to clear away once the rain stopped, for a past flooding event. As an example, they built hydrologic models to show how the city responded to floods on 4 and 5 September 2022. They then calibrated and validated their models based on exactly what happened, to use for future predictions. They also plan to scale this up and apply it to other cities like Pune, Chennai, and Guwahati.

“Once the model is prepared, you can play around with it as a tool,” Mujumdar says. “Digitally, you can remove the buildings and then show how it will affect [floods]; these [are for] long-term actions. [Even] for short term relief measures, when the rainfall is happening, they should know how [the flood] is evolving at which location. So, these digital twins will come in handy.” They also developed a very high-resolution rainfall forecasting model called Weather Research and Forecasting (WRF) model that can forecast rainfall at 3 km and 1 km spatial resolution with a lead time of 6-30 hours. The WRF model is coupled with the flood model to forecast flood depth and inundation for Bengaluru.

Photo courtesy: Wikimedia Commons/Dil Shad Roshan

A home at Companypady flooded during 2018 Kerala floods

“Being a Bengaluru citizen, you know that there is a huge spatial distribution of the rainfall,” he adds. “If it is raining here in IISc, it may not be raining about 10 kilometres away. It is important to capture this high spatial variation of the rainfall in forecasting.”

The team has also recommended the building of perforated pavements. Mall basements, parking lots, roads, pathways – all these structures can be perforated in a way that rainfall can percolate through and fill groundwater reserves, thereby preventing flooding.

Mujumdar and colleagues also worked on river floods, which operate on a different scale as compared to urban ones. “River floods have a larger area of reach; they also cause havoc in agricultural lands and villages,” he explains. For example, in the 2018 Kerala floods, multiple days of heavy rainfall lashed many cities, causing rivers to overflow, washing away entire villages and taking many lives.

A unique issue posed by river floods is the risk of dams overflowing. Heavy rainfall can cause reservoirs to fill up, so unless some water is released by opening the dam gates, the reservoirs can overflow or burst open. For the first time in history, the massive floods in 2018 forced the Kerala government to open the gates of 35 dams to release water, with the Idukki dam having all five of its gates opened. But the doubt that lingered amongst Kerala residents, which Mujumdar and others from IISc were asked to step in and resolve, was whether the gates were opened at an already precarious moment in the flooding. If the downstream areas are already flooded, then heavy discharge coming from the reservoirs as well could have further exacerbated the already devastating flooding.

For a project assigned to them by the Controller and Auditor General of the central government, Mujumdar and his group had to go to the area and study how the dams were operated – whether they were opened by keeping the forecast in mind and in a way as to prevent rather than further aggravate the floods.

The answer they found was more nuanced than a mistake as straightforward as opening the dams at the wrong time. “What we found was that they have operated according to the rule curves,” Mujumdar explains. “But the rule curves themselves were slightly old, so they had not accounted for the recent increases in the rainfall and how to incorporate the forecast.”

Rule curves are guidelines that specify how much water should be released when water is at specific levels in the reservoir, taking into account the flow of water coming into the reservoir. But with changing rainfall patterns, these rule curves need to be constantly updated. If the new 12-hour rain forecasts had been incorporated, then the dams should technically have been opened much earlier, before the rains had already inundated many areas downstream of the dams. Hence, even though the guidelines were followed, opening the dams may have led to excessive flooding.

“We could not exactly blame the reservoir authority. But we suggested improvements to best operate [the dams] when you know that the downstream is already flooded,” Mujumdar explains. “They did the best [they could] at the wrong time – they should have done the best much earlier.”

He mentions how digital twins of the reservoirs would be very useful in this situation, to assess the kind of rainfall coming in and how likely the floods were to increase if gates were opened. “For more of a smooth reaction, rather than an impulsive reaction,” he says. “If you do an impulsive reaction, when the [downstream villages] are already flooded, you are putting additional water and therefore the flooding will get aggravated.”

He also explains how while operating one reservoir, all the others should also be looked at in an integrated fashion, to get a sense of the downstream impact.
Mujumdar and his students also worked on floods in Uttarakhand, using remote sensing and geographic information system (GIS) tools, and hydrologic models to reconstruct the floods and using digital twin-like platforms to forecast future flood events.

In a 2024 *Scientific Reports* study, Mujumdar and his student describe how multiple factors, apart from heavy rains, can affect floods. Some of these factors include groundwater levels, reservoir operations, or storm surges from nearby oceans in coastal regions. Excess water drainage into the sea – due to heavy rains – can cause sea levels to rise and flow back into cities, thus increasing flooding.

“I think naively, we just imagine that heavy rainfall leads to floods, and we think about drainage systems a little bit. But there are lots of other [factors],” he notes.

VV Srinivas, Professor at CiE, has also contributed several new approaches for the stochastic modeling of riverine, or river-related flood events, to overcome long-standing challenges. When Amaravati emerged as the newly founded capital city of the current Andhra Pradesh state, the state government called upon him to provide expert suggestions in committees constituted to study the riverine flood and stormwater management issues.

In recent decades, incidents of dam failure have increased – leading to loss of life and adversely affecting the economy and environment. The Government of India initiated the Dam Rehabilitation and Improvement Project (DRIP) aimed at enhancing the safety and operational performance of existing dams in India. As part of this initiative, the Government of Karnataka called in multiple CiE faculty, including Srinivas, Sekhar, and Nanjunda Rao, as specialists to provide solutions to dam-related issues through the Karnataka State Committee on Dam Safety (SCDS). “CiE research has contributed new approaches for the estimation of probable maximum precipitation and the consequent floods at dams, and to analyse the risk associated with the breach of several ageing dams in the country under climate change scenarios," says Srinivas.

While storm events cause floods, low rainfall triggers various types of droughts. Srinivas and Nagesh Kumar, also a professor in the department, focused on characterising conventional and flash droughts in Indian river basins and elsewhere, in the present and changing climate conditions. They also worked on developing new and effective drought indices, which can tell us how dry a place is over time as compared to how it is normally. They also focused on the analysis of compound extremes, which are combinations of multiple interacting hazards – thus having more severe consequences than individual hazards.

Stabilising slopes

Heavy rains and earthquakes can cause enough damage on their own, but they can also trigger another kind of natural disaster – landslides.

"You have natural soil or rock formations in hilly areas. Above these, you have a highly weathered, disintegrated rock or soil, which is prone to slips when there is some rainfall or earthquakes as a disturbing force," explains GL Sivakumar Babu, Professor at CiE. His team has been working on landslides in rough terrains like the Himalayas and the Western Ghats for more than 35 years.

Photo courtesy: Sivakumar Babu

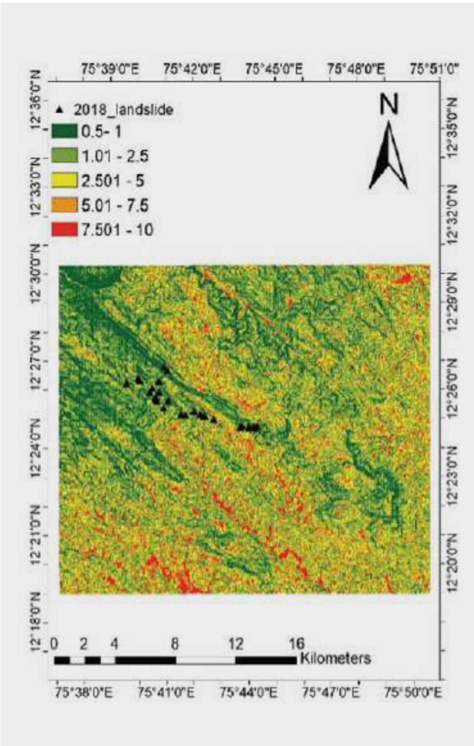
Landslide in Malin village in Pune district, Maharashtra in 2014, resulting in the washout of the village and death of about 150 persons

Human activities like building roads on hilly and mountainous terrain have also exacerbated the landslide problem, according to Sivakumar Babu. Cutting a stable rock/soil formation to carve out a road and then failing to stabilise the cut-out section properly can make the soil and debris much looser, more disintegrated, and prone to slips.

Comprehensive geological, geophysical studies of the geology – the type of soil, rock, or formation – in such regions are also lacking, according to Sivakumar Babu. Seepage points are areas where the water enters and exits the soil on the hills, and if they are not accounted for during construction, the soil can erode. Heavy rains can also cause the soil to slip and flow along with the flowing water, so the drainage patterns need to be systematically analysed. Once such properties of the soil are better understood with the help of geological surveys, remedial measures – like slope stabilisation – can be undertaken.

Apart from conducting such surveys, Sivakumar Babu and others have worked on taking and analysing soil samples from landslide-prone areas. They estimate soil cohesion or how intact it is, and the friction angle of the soil on a slope, which tells us about the soil's resistance to shear stress or deformations. They also take samples from the failure surface – the mass of soil that collapses and falls down during the landslide. Once they get a sense of the type of debris in the sample, and what caused the failure, they can estimate the kind of reinforcements needed to stabilise that slope going forward.

Image courtesy: Sivakumar Babu



Mapping of landslides along a highway due to rainfall in 2018

Most kinds of soil already have some resistance – determined by their shear strength – and may not fail immediately. "If the shear strength is not available, we have to provide it based on systematic analysis of causative factors such as rainfall and earthquakes," adds Sivakumar Babu.

Reinforcements can even come in simple forms for shallow failures that don't cut very deep into the slopes as they slip out. Planting grass or putting 2 metre-high rods with some netting and stitching the whole area together can prevent failures, Sivakumar Babu says.

Trees with their deep, vertical roots also form good reinforcements. “We call it root reinforcement,” he explains. “That's why in some places where there is no vegetation, you have slides.” The team tries to promote vegetation that grows about 2-3 metres deep into the soil to prevent surface runoff and withstand the speed of running water.

Predicting rainfall patterns correctly can also help prevent damage from huge landslides. Climate change has increased the frequency of high intensity rains, something that many houses in hilly areas are unprepared for. “Maybe they would have constructed all the houses 30 years back, but the rain comes back after 30 years and it damages the whole thing,” Sivakumar Babu notes. “If you're able to predict that this is going to be happening in the next month or after 3-4 days, [then] you can evacuate people and raise the alarm.” But better predictions also require proper prior data collection, something that is lacking according to Sivakumar.

Many areas in Karnataka suffer landslides regularly, like Coorg, Hassan, Mangalore, and so on. But systematic collection, handling, and analysis of landslide and soil data is missing. Engineers get transferred every three years and are not able to maintain records for long periods, like 20 or 30 years, Sivakumar says. Instead, they mostly make site visits and collect data for individual events, which is not enough, as the landslides could either return in a year or in five years.

“In terms of money lost, the number of lives lost, damage to our crops, damage to highways, and damage to all the other infrastructure that we have, the cost [of landslides] is so much every year,” Sivakumar says. “You can avoid all of that if you do regular, systematic studies, which is completely missing.”

Sivakumar believes that stabilising solutions already exist for dealing with landslides, so it’s less of a research problem and more of a cautionary tale that exposes flaws in our management systems. “I'll be happy not to do research on landslides,” he says. “Solutions are known, and if we continue to do research on a known problem, it’s not okay.” He emphasises on how systematic data collection can help prepare for future events rather than reacting to individual disasters.

This is true not just for landslides, but for most natural hazards that ravage our country. “Prevention is better than cure, right?” Sivakumar asks. “My personal opinion is that in most of the systems in India that we're trying to do research on, there are problems that are created. If you're serious enough, [those] problems will not happen in the first place.”

Photo courtesy: Wikimedia commons/aokomoriuta (青子守歌))

A Saga of Water Research

- Ananthapathmanabhan, with inputs from faculty and students at CiE

Researchers at CiE have worked on a diversity of water-related issues

The story of the Department of Civil Engineering's (CiE) research on water-related issues is a fascinating journey of water research – from fundamental hydraulics studies to very exhaustive hydrological studies towards water resources at several scales. The research spanned across the local, basin, and country levels, addressing the challenges of food security, water security, energy security, and environmental concerns.

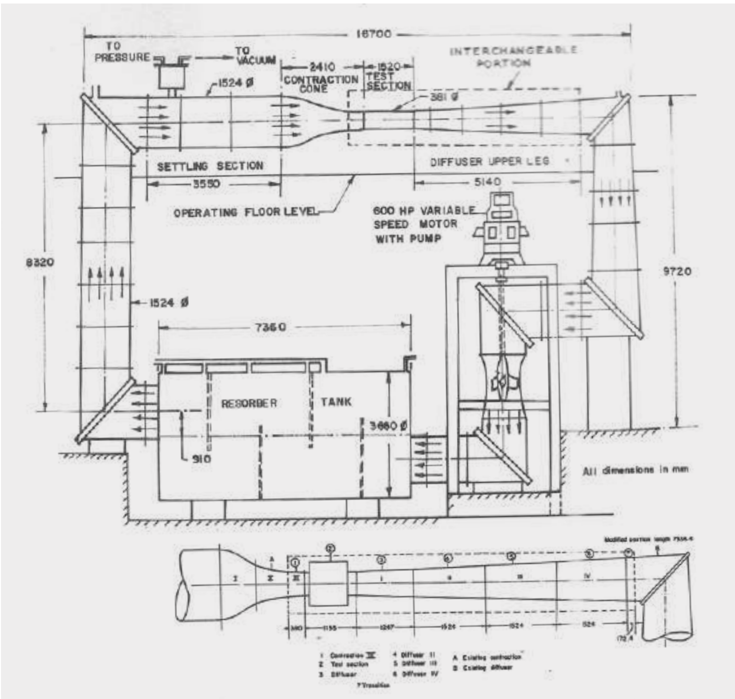
A handful of years after independence, India was still going through her 'tryst with destiny'. During the 1950s, there were several challenges that the nation struggled with, including irrigation and agriculture. Among the several nation-building projects was setting up ways to efficiently use water from the rivers. Thus, CiE at IISc was roped in to assist with national river valley developments. "Just after independence, a lot of projects happened, on river valleys, hydropower, energy, water conservation, building of dams, and building of water supply systems," says Mohan Kumar, former Professor at CiE.

Hydraulic jump on Naramata-gawa river, Japan

The department's contribution to nation-building was timely. From understanding the scope of water resources to building infrastructure to transport water, the department was at the forefront of addressing challenges in critical areas. Later, when the nation faced the challenge of transporting water to places far away from water bodies, research and development were aimed at understanding groundwater. The department's role was critical in developing the nation's water infrastructure.

Early efforts at CiE involved studies on hydraulic systems, open channel flows, and hydraulic machines. The hydraulics lab was used for several cavitation studies, which examined flow past different objects and the effect of cavitation on various materials. Such research was paramount for the Central Board of Irrigation and Power (CBIP). A high-speed closed-jet water tunnel facility was designed, fabricated, and established under the guidance of NS Govinda Rao. "There was only one such lab in India on cavitation," says Sekhar M, Professor at CiE.

Image courtesy: Vijay Arakeri/Current Science



Schematic of the water tunnel circuit and the interchangeable portion

Early experimental research included studies on the hydraulic jump, which were later extended to supercritical self-aerated channel flows. For these experiments, a tilting flume was constructed in the hydraulics lab. This period saw significant contributions that earned international recognition, such as the

PhD work by former faculty member T Gangadharaiah on characteristics of self-aerated flows. His thesis received the Lorenz G Straub award for meritorious thesis in hydraulic engineering from the University of Minnesota, USA, in 1970.

Activities were subsequently expanded to add several research projects in open channel hydraulics, including flow measurement, end depth hydraulics, flow division at channel junctions, self-aerated flow, scour at bridge piers, and hydraulics of alluvial bed. Flow measurement, particularly on weirs – structures to control water flow – provided substantial inputs to the Technical Committee of the International Organisation for Standardisation (ISO), and the department actively participated in activities related to national standardisation. A generalised theory of proportional weirs was developed, leading to weirs for special applications. Extensive experimental work on weirs was also conducted.

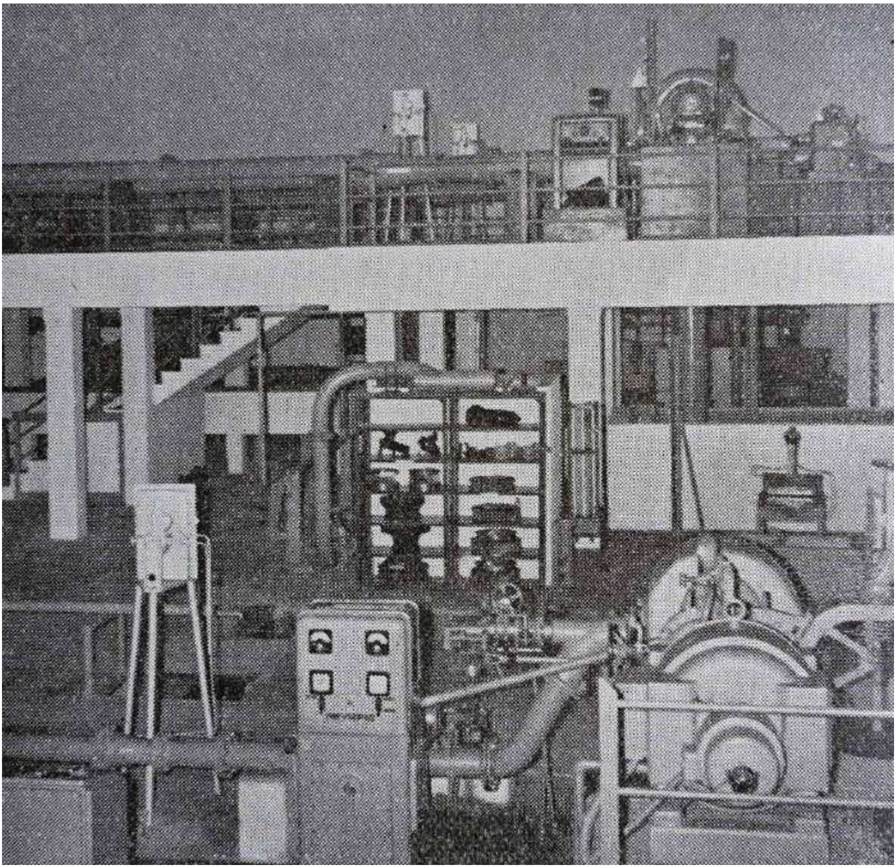


Photo courtesy: IISc golden jubilee souvenir, 1959

Testing equipment for hydraulic turbines

Beneath the soil

In the late 1960s and early 70s, research evolved from pure hydraulics to understanding water resources systems management, particularly in the catchment areas that fed water into rivers, a conundrum that the country faced at the time. The aim was to learn how the catchments respond to rainfall and what causes floods. Work began with flood analysis and moved into catchment runoff modelling to the soil – to analyse the infiltration of water from the main surface water resources to the soil, especially during the rainy season.

Early work was centred around hydraulic structures like dams, but as systems grew more complicated, the emphasis turned towards optimising the use of water. “The key question became: ‘Now that we have dams and stored water, how do we manage it effectively?’" says Sekhar.

But by the mid-1970s, large-scale agriculture changed the demands on irrigation. This kickstarted a collaboration between groundwater agencies and the department to model aquifer hydraulics. Unlike canal systems, which rely on gravity and serve limited areas, groundwater access enabled irrigation in upland regions beyond river valleys. The shift marked a change from surface water management to integrated groundwater governance, balancing irrigation needs with sustainability.

By the 1980s, groundwater pumping came into vogue, enabling irrigation in areas that are far from water bodies. This shift expanded agriculture beyond river-fed zones through tubewells and borewells, transforming India's farming landscape.

Gradually shifting from hydraulic machines and fluid mechanics, the department focused on water resources and hydrology in line with perceived national interests. A new area involved applying systems techniques for water resources management to utilise resources at the basin level effectively. This was used to allocate resources for water supply, irrigation, hydropower, accounting for flood control, and the techniques were successfully applied to major river valley projects, including the Upper Krishna and Narmada basins. A common thread in all these studies is the development and use of mathematical and statistical techniques, which was new to the country at the time.

Achanta Ramakrishna Rao, a former professor in CiE, known fondly as ARK sir by his students, made exceptional contributions to the field of sediment transport in alluvial channels. His work spans a wide range of topics, from the dynamics of riverbeds and flow variability in natural and engineered channels to the effects of sediment size and flow variability on sediment movement. During his PhD, ARK Rao developed the binary law of velocity distribution, which combines all three layers of the velocity zone in an alluvial channel. He was also instrumental in building a large tilting flume which was used to study sediment transport at various scales, especially at the bed. His other interest was on aeration of waste waters through mini scale experiments at the lab. When research areas were changing rapidly and moving more towards computer modeling etc, he firmly believed in and stood as a colossal figure in the area of experimental hydraulics throughout his career.

Using space technologies to manage crops

Satellite remote sensing, image processing and geographic information system (GIS) offer a wide range of options for crop acreage estimation, condition assessment, irrigation scheduling and yield estimation during the crop season. "This vital information from space technologies will play a key role in sustainable agriculture management and decide on Export-Import (EXIM) policy of food grains in India well in advance", says Nagesh Kumar, professor at CiE.

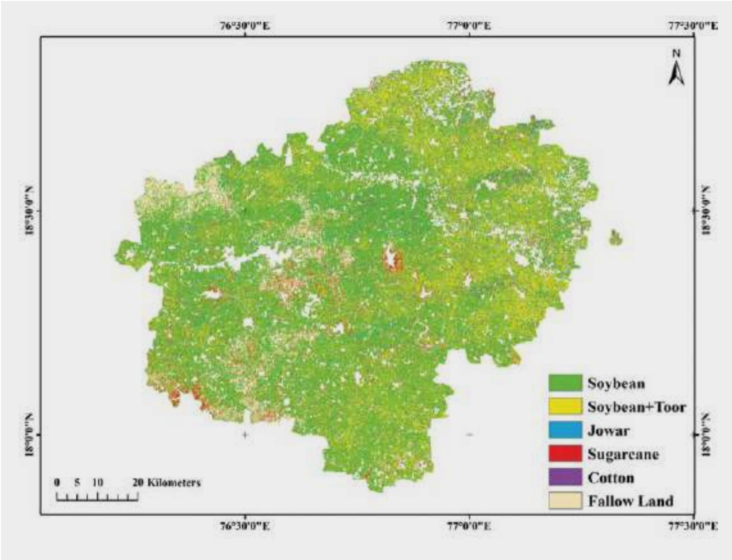
CiE has done such assessments for many river basins in Karnataka, such as Bhadra, Tunga, Malaprabha, Cauvery basins and many other major river basins in India, including Krishna, Godavari, Mahanadi, Narmada and more.

"Use of hyperspectral remote sensing and high spatial resolution images along with AI and ML-based image processing techniques is helping to address the problems unique to Indian agricultural management, such as small farm holdings, heterogeneous cropping patterns, and more," says Nagesh Kumar.

Photo courtesy: Mohan Kumar

Side view of 1:12 scale model of 1 x 500 MW cooling water sump for the thermal power plant

Image courtesy: Nagesh Kumar



Crop map obtained for Latur District, Maharashtra as on September 20, 2019, using multi-temporal microwave satellite data and AI based image processing

From rivers to taps

Image courtesy: Mohan Kumar

Arrangements of piers for equal water distributions to pumps

In the 1970s, Bengaluru's first Cauvery water supply project faced a critical challenge: Power failures caused pressure surges in large pipelines. Under the guidance of faculty member K Sridharan, former Professor at CiE, the department pioneered computer simulations to predict these extremely high/low pressures during pump trips. Their work enabled the design of surge protection systems, ensuring pipeline safety beyond standard pumping pressures. This innovation was vital for stabilising water transmission infrastructure against sudden power disruptions.

The department designed a protection system through computer simulations. "We cannot wait for the system to be constructed, record the pressures, and then provide the details. So, before construction, we must simulate on the computer and then design the surge protection," says Raghuveer Rao, Principal Research Scientist at CiE.

Modelling flow

Within water resources and hydrology, studies focused on understanding and modelling different components of the hydrologic cycle for practical assessment and utilisation. To properly assess catchment yield, research in surface water hydrology concentrated on the rainfall-runoff process from small watersheds to river basins, including evapo-transpiration, infiltration, and irrigation return flow. Modified evapo-transpiration formulae were developed specifically for the state of Karnataka. A model for forecasting water availability in administrative geographical units was also designed.

Through modelling and field data analysis, the focus was also on understanding groundwater systems in porous and fractured rock formations. The department pioneered in the development of the first regional groundwater model in a complex hard rock area in India, for the Vedavathi River Basin in Karnataka and Andhra Pradesh. Computer model studies were conducted on the Vedavathi basin to identify groundwater potential. The department made a significant contribution to the work of the Ground Water Resource Estimation Committee (1997), formed by the Ministry of Water Resources.

“Research activities were also going on [related to water distribution systems], such as how to control water flow. [For example], what will happen to quality as [water] moves through pipelines?” says Mohan Kumar.

A big part of this work was understanding how to use different sources of water – groundwater, surface water, and so on – optimally based on the capacity, terrain, and accessibility through computer modelling. Imagine a dam as a resource. To supply water for different purposes, a systems engineer might rely on dynamic decision-making aided by computer models to adjust the water supply based on demand. “We developed the first computer model in the whole country,” says Mohan Kumar.

Contribution to National Projects

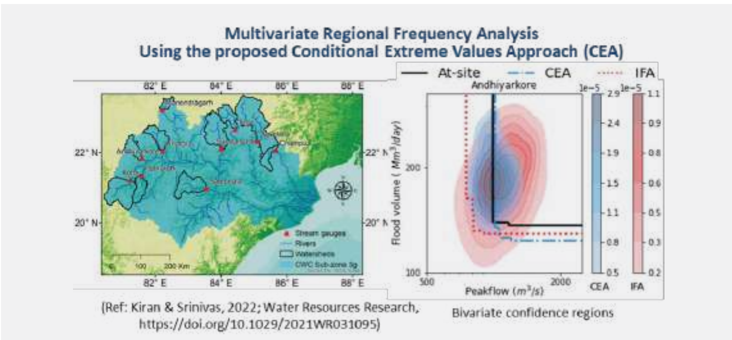
With the expertise developed over the years in several areas of water research, the department has taken up the role as an expert in advising Government/quasi Government and private agencies on their water related projects, with some of them being very technically challenging. Over the years, a very large number of projects have been handled under this.

Making hydrological predictions in river basins with limited or no records

Prediction and simulation of hydro-meteorological variables, streamflows, and environmental extreme events (e.g., rainstorms, floods, droughts) are vital to planning, design, and risk assessment of civil engineering infrastructure, which is meant for water control, conveyance, and management. The task of prediction becomes a challenge for sparsely gauged and ungauged locations – areas where we don't have enough data (or any) tools to measure and track how much water is flowing – and in areas where there is evidence of climate change.

"For use in these contexts, we contributed new approaches," says Srinivas, professor at CiE. The approaches include those for regionalisation of watersheds, hydrometeorological variables (HMVs), facilitating regional analysis of climate, and design of hydrometric monitoring networks. Further, Srinivas and his team worked on developing new regional frequency analysis methodologies in conventional/fuzzy frameworks, for risk analysis of extremes (thunderstorms/floods/droughts) at data-sparse locations. He also contributed towards downscaling General Circulation Model (GCM) simulations to local-scale HMVs, simulating flows in river basins, and tracking low-pressure systems for risk mitigation.

Image courtesy: VV Srinivas



Proposed CEA outperformed the conventional Index Flood Approach (IFA) in predicting flood volume and peak flow at ungauged sites [Example: Andhiyarkore, Mahanadi River basin]

Capacity Building

With the natural tendency of sharing knowledge through teaching, the department has extended their services to many Government/quasi-Government and agencies in training their engineers and scientists to appraise them of the latest developments in the areas of instrumentation, modelling, and so on. As a follow up of this, there is a new mechanism created for engineers in service to upgrade their academic knowledge and skills through post-graduate degree programmes.

Finding the balance

The department's efforts also led to the establishment of the Indo-French Cell for Water Sciences (IFCWS) at IISc in the early 2000s as a pioneering interdisciplinary collaboration between Indian and French scientists. It focused on studying the "critical zone" – the dynamic interface between vegetation and groundwater that sustains ecosystems and human needs. Initiated during Cauvery water supply challenges and growing groundwater sustainability concerns, this partnership addressed India's water management crises through long-term observational science. French scientists brought their expertise in geophysics, geochemistry, and hydrology, complementing IISc's civil engineering focus, thus creating a multidisciplinary framework to analyse water, energy, and biogeochemical cycles in stressed environments.

The Kabini River Basin experimentation site, established by the Cell in Karnataka, was selected as India's first Critical Zone Observatory (CZO), mirroring global efforts like the US CZO network. This site is a laboratory to study how human activities like agriculture and chemical use interact with natural processes like recharge, erosion, and pollutant degradation.

Over 25 years, IFCWS has also facilitated joint research on sustainable water use, emphasising "more crop per drop" strategies to balance agricultural productivity with dwindling groundwater reserves. Projects have ranged from pipeline surge protection to advanced aquifer modelling and farmer-centric water efficiency tools. The cell's legacy lies in its interdisciplinary approach, integrating field data, instrumentation, and cross-border knowledge to inform policy. French scientists embedded at IISc have collaborated on instrumentation and data analysis, while Indian researchers have contributed localised insights.

Today, IFCWS continues to address emerging challenges like climate resilience and equitable water distribution, reflecting its founding vision: to harmonise human demands with the critical zone's ecological limits through science and innovation.

Banashankari circle, Banashankari, Bengaluru (2024)

Photo courtesy: Wikimedia commons/Gpkp

Planning Better Cities

- Abinaya Kalyanasundaram, Sandeep Menon, and Ranjini Raghunath

How civil researchers are tackling Bengaluru's urban challenges

In 2018, the Bengaluru Metro Rail Corporation Limited (BMRCL) had a quandary on its hands. The engineers noticed that a railing was cut near Trinity Station. They also noticed that the entire section between the two pillars looked deformed, which was what caused the railing to break.

What could have caused such a major failure? They checked the foundation, but it seemed in order. Not knowing what to do, they called JM Chandra Kishen, Professor at the Department of Civil Engineering (CiE), IISc. "From what they described, I could just feel that there must be something wrong with the concrete beams. I told them to go below that beam near the station and see if the wooden shutters [used during construction to pour concrete into] are still there," says Chandra.

And lo and behold, he was right. There were wooden shutters still left behind on one of the beams. When they removed the shutter, to everyone's horror, they found that the concrete hadn't been compacted properly all the way to the bottom. "The beam is supposed to be about two metres deep. But almost 30 cm of the beam had been left incomplete, with no concrete. Had they removed the shutter after construction itself, they could have noticed this and repaired it," says Chandra. But now it was too late.

Finding a solution now, with the metro line in full operation, was not going to be easy. To make matters worse, one of the bearings had also gotten crushed because the incomplete beam couldn't support the structure; it was tilted. "We told them that the whole structure must be lifted and the bearings replaced. But if you are not careful, the concrete will crack at many places," Chandra explains.

His team set to work over the next week. Working during the night, when the metro operations could be stopped, they deployed almost 66 sensors throughout the structure to monitor the lifting and replacement. "We had a large monitor, and the procedure was done carefully, step by step, so that the concrete doesn't exceed a certain limit of tensile strength. We lifted the viaduct, including the crossbeam that had developed gaps in the concrete, before reinforcing the damaged part's structure," he explains. Since the structure was bent, they made special bearings of different sizes and fixed them. The team then monitored the structure for the next three months to ensure that there were no complications. "That was a very well-calculated and executed correction," says Chandra.

Such out-of-the-box problem-solving is not new to him. Over the past 30 years, he has been working with various government agencies, assisting them in monitoring the health of structures and in various other capacities. Like him, several other researchers from CiE have been helping the city tackle some of the challenges arising from rapid urbanisation. In addition to studies and policy recommendations, many have actively worked on solutions for civic issues such as infrastructure collapse, traffic congestion, public transit improvements, and more.

Understanding traffic

Bengaluru was once known for its plentiful green spaces, pleasant weather, and booming IT industry. But now it has become notorious for its traffic jams. As the city's population exploded to almost 14 million (as of 2025), public transit systems have been struggling to keep up, resulting in increased dependence on private vehicles, which in turn is leading to more congestion.

CiE researchers have been working with the Karnataka state government to address some of these mounting challenges. "We are working on several projects with the authorities, including Metro master planning, feeder routes, and schedules for last-mile connectivity," says Ashish Verma, Professor and convenor of the IISc Sustainable Transportation Lab (IST lab) of the Department of Civil Engineering. He established the lab in 2009 to focus on sustainable transportation planning and policy to support resilient, livable communities.

The IST lab has partnered with the Bengaluru Metropolitan Transport Corporation (BMTC) to rationalise bus routes and services, and improve the reliability and safety of public transport operations. “My lab’s core focus is a systems approach, especially since we are also looking at positively impacting the sustainable development goals (SDGs) when solving problems of transportation,” says Ashish. “We look at a network-level solution and the links between mobility and multiple aspects, such as land use, air quality, public health, and quality of life. It is a complex interlinked system.”

In 2018, the lab developed a city-scale travel demand model for the whole Bengaluru Metropolitan Region (BMR), as part of an Indo-Norwegian project called CLIMATRANS. They used this model to suggest bundled policy interventions to reduce congestion and emissions. “We presented a range of scenarios to account for the emissions generated not just by transportation, but also accounted for electricity production,” explains Ashish. They considered four scenarios: two extremes – one assuming 100% non-renewable energy and the other 100% renewable – and two intermediate scenarios with 50-50 and 70-30 renewable-to-non-renewable energy mixes. “The idea was to show that if we push towards 100% renewable energy, what is the extent of benefit and reduction in emissions that can be achieved, besides solving the transport issues,” he explains. A comprehensive report published by them is now being referred to extensively by the Karnataka government and different transit agencies.

The lab has also developed basic models of the “heterogenous, disordered” traffic of Indian roads, where there is a chaotic jumble of buses, cars, and two-wheelers that don’t stick to lanes but squeeze into whatever gaps they can find. In 2018, they published a modified version of a well-established signal delay model by introducing a new queuing behaviour that takes into account this gap-filling attitude. Using this, they were able to propose more effective timings for three separate intersections in Bengaluru.

The team has also been working on improving last-mile connectivity and public transport infrastructure to help ease the city’s traffic woes. Their research shows that the city needs 80% of its daily commute to be via public transport. But expecting people to change their behaviour – switch from private vehicles – without improving footpaths and roads or offering better last-mile connectivity, is not easy, Ashish points out.

Interdisciplinary centre for transportation research

In the late 2000s, the Karnataka State Government approached IISc to establish a dedicated centre that would foster a multidisciplinary and sustainable approach to transportation research. With initial funding from the government, the Centre for Infrastructure, Sustainable Transportation and Urban Planning (CiSTUP) was established in 2009, with CiE researchers taking the lead to set it up. "At that time, we had a lot of mobility issues in the city of Bengaluru," says TG Sitharam, a former professor at CiE and the first Chair of CiSTUP. "We worked on many projects with the Department of Urban Land Transport (DULT), the BMTC, and others. We also created an MTech programme in transportation." Since its inception, faculty members from CiE have been Chairs of CiSTUP, starting with TG Sitharam (2009-2014), JM Chandra Kishen (2014-2017), and now Abdul Rawoof Pinjari.

Image courtesy: Tarun Rambha

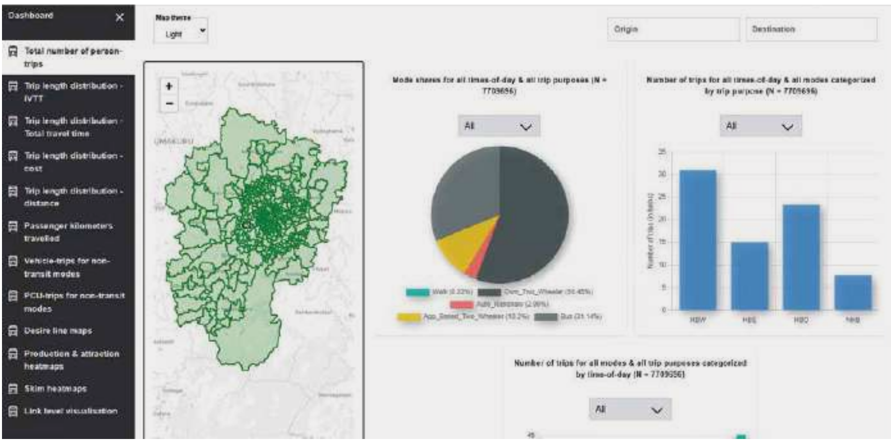
Screenshot of the app to monitor and manage bus spacing in real time

CiSTUP focuses on research, education, and technology development around multimodal transportation science, sustainable transportation systems and urban planning, and infrastructure systems related to transportation.

"Many of the projects we're focusing on right now are around urban mobility," says Abdul. One example is bus bunching. "In cities like Bengaluru with over 6,000 buses, it's common for buses to bunch together instead of being evenly spaced out, due to traffic congestion," explains Abdul. To address this, Tarun Rambha, Associate Professor at CiSTUP, led a project to develop a tool and app to monitor and manage bus spacing in real time. Another project looked at understanding the factors that influence public transit ridership. The team found that one of the most critical factors was the uncertainty in travel time. "If a trip takes 30 minutes one day and 50 the next, that uncertainty makes it difficult for travellers to plan their schedule," explains Abdul.

Reducing bus bunching is one way to reduce this uncertainty. Another is bus priority lanes. In 2019, a pilot bus lane was tested along a stretch of Outer Ring Road. Working with Rajesh Sundaresan, Professor from the Department of Electrical Communication Engineering (ECE), the team measured travel times before and after the introduction of the priority lane. “We saw a discernible reduction in uncertainty, and we also saw how this reduction in uncertainty led to an increase in ridership using models,” says Abdul.

CiSTUP is also working on improving first- and last-mile connectivity in public transit systems. They have embarked on an ambitious project of building city-scale travel demand models to estimate and forecast the spatial, temporal and modal distribution of traffic. “If we can forecast for various scenarios – how much travel happens from where to where, at what times in the day, and by what mode of transport – then we can use these models to ask ‘what if’ questions. Such as: if the bus frequency to Mantri mall station is increased from 2 per hour to 10 per hour, from locations X, Y and Z, what is going to be the increase in ridership in the Metro and the reduction in congestion?” says Abdul. Their model also takes into account the diverse means of transport available in India – commute apps such as Uber and Ola, auto rickshaws, bikes, and more. “If this multimodal travel is made seamless, then more people would opt for public transit,” he says. They plan to make these models open source so that they can be used for other cities as well.



Screenshot of the city-scale travel demand model for Bengaluru

Image courtesy: Anil Koushik NP

The infrastructure doctor

CiE researchers like Chandra Kishen have also significantly contributed to maintaining and repairing existing infrastructure.

He and his team were first approached by the Indian Railways in 2007 to test several ageing bridges across the country – some over 120 years old – as to whether they can handle heavier freight loads. The successful completion of that project spurned a new area of research on structural health monitoring. They are developing better tools to monitor the health of structures. "We are working on a non-contact, no-sensor tool to measure structural displacements using optical methods – you take images and use those to do digital imaging correlations to determine displacement," he explains. So far, they have been successful in the lab and are looking to test it out in the field.

In recent years, Chandra Kishen has also been part of a National Highways Authority of India (NHAI) committee to work on repairs of the Goraguntepalya bridge on Tumkur Road, a very high-density junction which had been abruptly closed after maintenance crews discovered broken internal cables due to corrosion. "The bridge was just 13 years old or so; such damage shouldn't have happened so soon in its life span," he says. He recommended against the state government's plan for demolition – which would take about 7-10 years and cost Rs 400 crore – and instead proposed strengthening and retrofitting the bridge with new cables featuring four layers of corrosion protection: galvanisation of each wire, grease or wax coating during braiding, overall epoxy coating for the braided cables, and finally cement encapsulation. Additional support cables are also being installed in each span to handle the load. "Over the past two years, 80 of the 120 spans have been completed, all at a cost of just Rs 40 crore. The remaining work is expected to finish within six months," he says.

Chandra Kishen has also been working closely with the BMRCL ever since the Trinity station incident. When a metro pillar collapsed earlier in 2023 on Outer Ring Road in Bengaluru, tragically killing two people, it was his lab that was roped in to analyse the damage and cause. "It's a very challenging

People enjoying their walk on Church Street during the time it was pedestrianised project for the metro, constructing in these high-density corridors. I gave them new guidelines on how it should be done in two stages, to avoid future mishaps," he shares.

He also suggested the adoption of a precast and prestressed construction technique, from his prior experience on a similar aqueduct project to bring water to the city from the Western Ghats. Unlike the method that was being used by the metro, where segments were stitched at height using launching girders and taking nearly 20 days per span, this technique involves casting and stressing entire 30-metre-long segments on the ground, then lifting and placing them with cranes in just a few hours. "This is much faster and has better quality control," he says. The method is now being used in the metro construction from Silk Board to KR Puram and onward to the airport.

A space for the public

Cities should ideally offer vibrant public spaces designed for people – places that are accessible, walkable, and inclusive. However, in Bengaluru, many public areas remain unfriendly to pedestrians. To explore how that might be changed, Ashish's lab embarked on an interesting experiment in November 2020, partnering with UK and Indian government agencies. They picked one of Bengaluru's iconic streets – Church Street – and decided to restrict it to pedestrians on the weekends, for a period of four months.

Photo courtesy: Ashish Verma

One of the most famous streets in the city, it attracts a huge footfall, is easily accessible via public transport and has become more pedestrian-friendly with renovations such as expanded sidewalks. The findings from the project were significant. During the test period, footfall in the metro station increased by more than 100%. Restaurants and gift shops also saw an increase in footfall. Street vendors enjoyed unprecedented sales. There was a 25% improvement in air quality, a reduction in noise pollution, and an 11-15% increase in a shift to public transport, walking, and cycling, according to Hemanthini Allirani, a PhD student who worked on the project.

Two years after the test, the social activities that picked up pace during the test period – live music, street shows, and artists selling paintings, jewellery, crafts, and other trinkets – continue to this day.

Photo courtesy: Ashish Verma

Ashish Verma (centre) speaks at a public meeting organised by the Bengaluru Bus Prayanikara Vedike (BBPV), where testimonies of bus commuters were heard

“Pedestrians are reclaiming the street by themselves. It has induced a positive behaviour change. These kinds of spaces become vibrant social places and help social wellbeing,” Ashish remarks. Such has been the success of the project that the authorities are mulling over the idea of expanding this project to other parts of the city.

Ashish feels that just doing such research is not enough. He believes that scientists should also be active participants in social discourse, attending town halls and citizen discussions. He has attended and spoken at several such spaces; for example, he lent his voice against a proposed flyover on Sankey Road a few years ago, which he believes, according to research, will not help solve the problem of traffic congestion in the area.

“Mobility is an area where we do research and come up with solutions, [but] we do not have the power and privilege to implement it,” explains Ashish. “You can empower common people. A research lab like ours can go and educate [people] so that they are empowered to ask the right questions to their elected representatives. It is a way to translate your research for the betterment of society.”

Being Engineers at a Science Institute

- Debraj Ghosh and Tejas Murthy

CiE has always struck a balance between participating in engineering of large infrastructure to fundamental theories, simulations and experiments that push the boundaries of science

As engineers at a science institute, we often encounter curiosity about why, despite being expected to design large infrastructure like bridges, we concern ourselves with nanoscale tolerances or invest considerable time on thermodynamics of small systems. The essence of engineering research blends pragmatism in problem selection with universal computational, experimental, and theoretical tools. Over the last 75 years, the Department of Civil Engineering (CiE) has consistently contributed to fundamental research across mechanics of solids, fluids, geosystems, and transportation systems.

Advancements in computational capabilities and experimental methods have allowed the department's research to span diverse length and time scales.

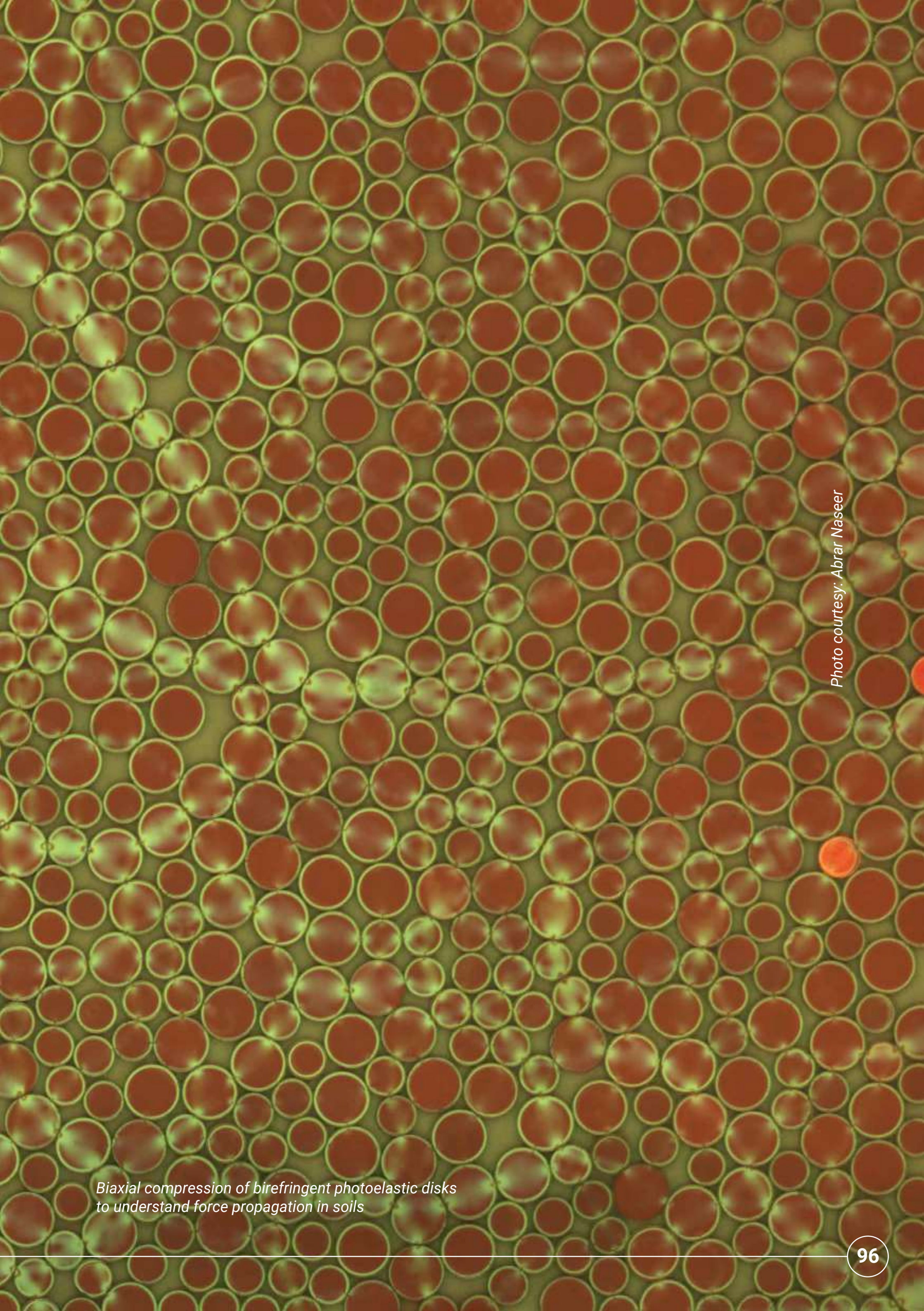


Photo courtesy: Abrar Naseer

Biaxial compression of birefringent photoelastic disks to understand force propagation in soils

Debasish Roy's group, prominent over two decades, employs Cosserat theories and finite element analysis to model extreme phenomena such as missile strikes and tsunamis. Debasish's recent focus involves reframing inelastic mechanics and thermodynamics of solids using probability measures rather than traditional material points, significantly enhancing state-of-the-art materials modelling. His interesting research journey from chaos theory to stochastic differential equations to materials modelling has contributed to shape the evolution of this area. His pioneering work led to the establishment of the Centre of Excellence in Advanced Mechanics of Materials, supported by ISRO.

Jyant Kumar's team integrates finite element analysis with advanced optimisation algorithms for estimating upper and lower bounds of collapse load and integrating complex constitutive models in geotechnical engineering. Their solutions impact foundations, anchors, retaining walls, and tunnels, advancing soil mechanics and foundation engineering rigour in India. Jyant has mentored many PhD graduates, who now uphold this emphasis on theoretical rigour in geomechanics as faculty.

High-performance computing has been a cornerstone of departmental research. Debraj Ghosh's group has conducted high-fidelity simulations ranging from dam-break scenarios to atomistic studies of nanotubes and polymer nanocomposites. Narayan Sundaram's team similarly employs computational methods to analyse solid-solid interactions at structural to microstructural scales, covering adhesion, machining, indentation, and triboplasticity, pioneering simulations on architected metallic solids. Their research has produced some first-in-class high-fidelity computer simulations. In an illustrious career spanning over three decades, CS Manohar was at the forefront of research in applications of probability theory in reliability analysis and structural health monitoring. This theme is now being continued by Debraj Ghosh and P Anbazhagan.

Experimental mechanics has always been integral to the department's research, from photoelasticity to advanced synchrotron tomography. Tejas Murthy's team focuses on micromechanics of geomaterials using tomography and

Photo courtesy: Tejas Murthy

From left to right: Tarun Rambha, Debraj Ghosh, Abdul Pinjari, and Narayan Sundaram

Photo courtesy: Debraj Ghosh

Group photo of some current and former CiE faculty members

photoelastimetry, interpreting results through plasticity theory and statistical mechanics. These studies reveal how inter-particle interactions manifest themselves at the engineering scale. Madhavi Latha's research on friction between geopolymer and soil particles explores unprecedented scales in geosystems. Anbazhagan's team extends micromechanical studies to rail ballasts and recycled tire-soil mixtures.

Concrete research remains central due to its ubiquitous usage. Chandra Kishen's group investigates fatigue-induced fracture in quasi-brittle materials using irreversible thermodynamics, providing deep insights into microcrack evolution crucial for structural longevity assessment. Infrastructure materials research, by Ananth Ramaswamy, Chandra Kishen, Vidya Sagar R, and recently Keshav Bharadwaj Ravi, integrates modelling with cutting-edge experiments to decode the fundamental physics and chemistry of reinforced concrete, pushing the boundaries of our understanding. Vidya Sagar's group complements this through research into corrosion and experimental fracture mechanics. Working from fundamental science of materials, Venkatarama Reddy and Nanjunda Rao have brought in a new perspective of low carbon alternatives for reinforced concrete and masonry.

Building on the department's rich legacy in hydraulics, groundwater modelling, and catchment-scale water management, recently, Debsunder Dutta has embarked on expanding this foundation to regional and global scale ecohydrological studies using satellite imaging, heralding in a new era of ecohydrology research. This emerging direction holds immense promise for transforming agricultural management, ecosystem restoration, and climate adaptation. It continues the department's tradition of nation-building – now with satellites as tools, and the biosphere as the laboratory.

The ICED programme has brought together 10 groups working towards retrofitting and rehabilitation of large infrastructure. This collaborative programme provides an excellent opportunity to build on our focus on strong fundamentals to tackle problems of national importance, especially large dams, serendipitously taking us back to our roots 75 years later.

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