CSIR–Central Building Research Institute, Roorkee

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CSIR–Central Building Research Institute, Roorkee has been vested with the responsibility of generating, cultivating and promoting building science and technology in the service of the country. Since its inception in 1947, the Institute has been assisting the building construction and building material industries in finding timely, appropriate and economical solutions to the problems of building materials, health monitoring and rehabilitation of structures, disaster mitigation, fire safety, energy efficient rural and urban housing. The Institute is committed to serve the people through R&D in the development process and implementation of innovative housing programmes.

Keywords: Building materials, bio-concrete, fire research, intelligent building, structural health monitoring.

THE CSIR–Central Building Research Institute (CSIR–CBRI), Roorkee, was established in 1947 as a Building Research Unit at the University of Roorkee, presently IIT Roorkee. The Unit became an institute and was named as the Central Building Research Institute in 1950 with J. N. Mukherjee as its first Director. The foundation stone of the building for the institute was laid on 10 February 1951.

Present research focus

CSIR–CBRI has played a pivotal role in the area of building science and technology. A glimpse of some of the scientific activities that are ongoing in the Institute is given below.

Engineering of landslide disaster mitigation

In India, human and economic losses due to landslides are enormous and are growing as development expands in the hilly regions under the pressure of the increasing population. The examples include the 2013 flood and landslide disasters in Uttarakhand, and the losses due to a recent landslide at Malin village, Maharashtra. To minimize such disasters, an integrated study to develop a real-time landslide early warning system and control measure has been initiated in CSIR–CBRI.

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Rainfall threshold for landslide occurrences

A local rainfall threshold model for landslide occurrences along the national highway corridor of about 80 km stretch around Chamoli–Joshimath region has been established based on 128 landslide events for the monsoon period during 2008–2012 (Figure 1). Rainfall intensity–duration threshold has revealed that for rainfall events of shorter duration (i.e. 24 h) with a rainfall intensity of 1.06 mm h^{-1}, the risk of landslide occurrence in this part of the terrain is expected to be high during monsoon period.

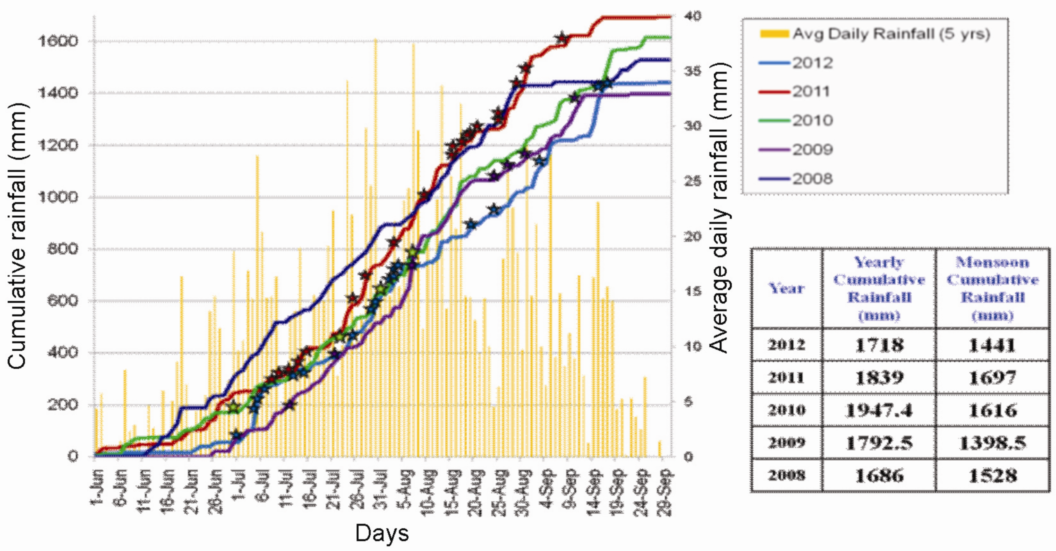
Landslide instrumentation for real-time early warning

CSIR–CBRI is in the process of developing landslide early warning system based on real-time monitoring through field instrumentation. A real-time landslide monitoring system has been installed at an active landslide site at 9 km ahead of Pipalkoti on the Chamoli–Joshimath National Highway (NH-58) in Uttarakhand (Figure 2). The system includes 16 inclinometer sensors, four piezometric sensors and three wire-line extensometer sensors along with an automatic weather station (AWS). The real-time data from all these sensors are being collected at CSIR–CBRI. After analysing landslide movement and rainfall data for a period of at least one year, it may be possible to fix a rainfall threshold for landslide early warning and generate a real-time alarm to be transmitted to the disaster management authorities of the state.

Geo-investigation for control measures

A comprehensive geological and geotechnical study of the same landslide area has been carried out. The results of stability analysis have revealed that in dry condition a shallow part of the slope is unstable, while under saturated condition a significant portion of the slope becomes unstable having a slip surface depth of about 10–12 m (Figure 3).

A composite scheme of control measures, which primarily includes soil nailing for soil reinforcement of uphill slope, gabion wall to strengthen downhill slope and surface drainage along with bio-measures has been framed to minimize the landslide activities. The analysis and design of these measures are underway.



Year	Yearly Cumulative Rainfall (mm)	Monsoon Cumulative Rainfall (mm)
2012	1718	1441
2011	1839	1697
2010	1947.4	1616
2009	1792.5	1398.5
2008	1686	1528

Figure 1. Cumulative rainfall and landslide occurrences during monsoon period from 2008 to 2012.

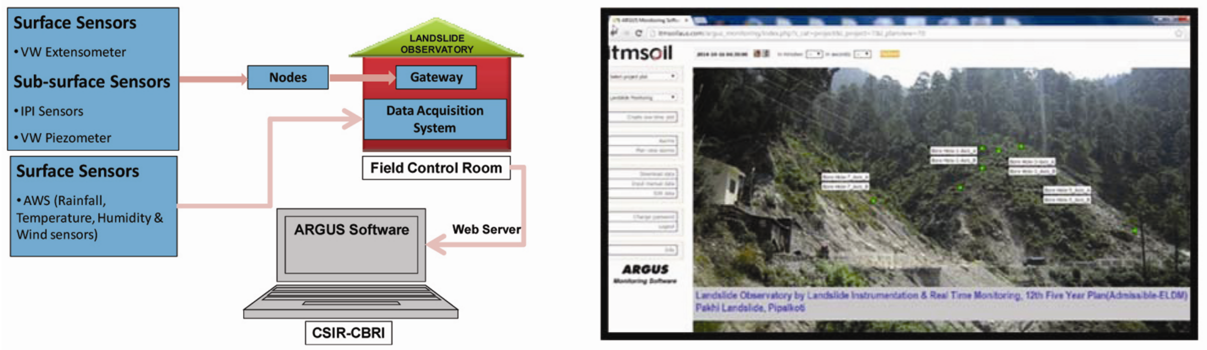


Figure 2. Wireless instrumentation for landslide early warning.

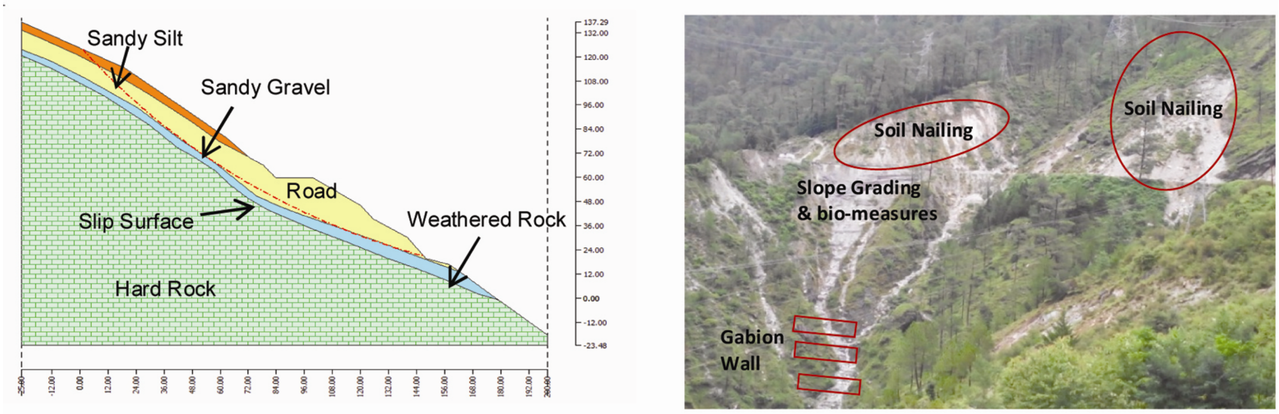


Figure 3. Slope stability analysis and scheme of control measure.

Seismic micro-zonation studies of Srinagar City, Uttarakhand

The aim of seismic micro-zonation is to estimate the locations and relative severity of future seismic events in an area so that the potential hazard can be assessed and the effects can be mitigated or avoided. The seismic micro-zonation study of Srinagar city, Uttarakhand which falls in seismic zone IV, is important for future developmental activities in the city. The study has been initiated

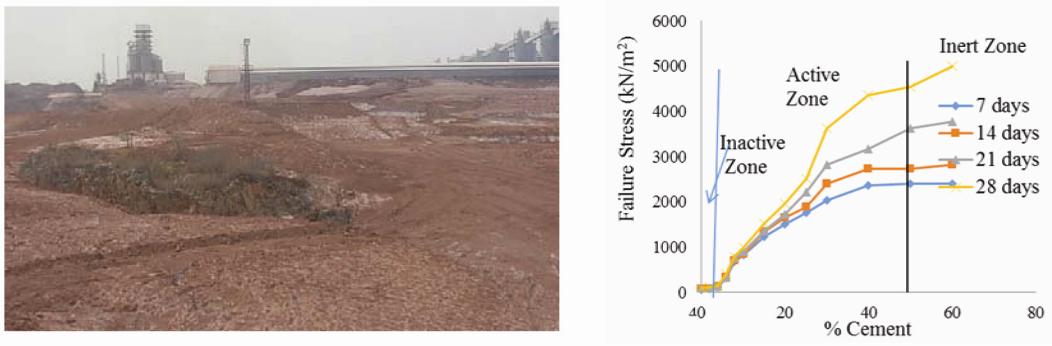


Figure 4. Red mud pond at Renukut and failure stress of stabilized red mud versus percentage of cement.

with the establishment of a strong motion network in the city. The subsurface geological study has been carried out through geophysical survey using engineering seismographs.

Earth pressure and associated problems under seismic condition

Proper design of earth-retaining structures, shallow foundations and ground anchors under seismic condition is essential for earthquake-prone areas. A new methodology has been developed to consider the seismic forces in a more realistic manner than the available theories. In this approach, the soil is assumed to behave as a viscoelastic material overlying a rigid stratum and subjected to harmonic horizontal acceleration. In the present methodology, the amplification of seismic acceleration depends on the soil properties and can be evaluated. The methodology can be applied for a variety of stability problems such as stability of retaining walls, bearing capacity of shallow foundations and pullout capacity of shallow anchors under seismic condition.

Utilization of industrial waste for civil construction

Red mud, which is generated at 1.0–1.6 tonne/tonne of alumina, is a major solid waste from aluminium industry. Unfortunately red mud all over the world has not found any use so far and is usually stored in a red mud pond. The Institute is currently studying the mechanical and environmental suitability of red mud as resource geomaterial for civil constructions. To improve the mechanical suitability, i.e. strength and compressibility characteristics of red mud, cement has been used as a stabilizer. Strength and compressibility characteristics of the stabilized red mud have been studied for different rest periods (Figure 4).

The study has shown that the cement stabilization of red mud improves its strength and compressibility characteristics. Leaching test results also reveal the environmental suitability of the stabilized red mud as civil construction material.

Fire engineering research

International interaction

Under the Indo-US R&D Network project sponsored by Indo-US Science & Technology Forum (IUSSTF) on ‘Fire centre for advancing research and education in structural fire engineering’, exchange visits of faculty and scientists were carried out. The teams focused on exchanging and sharing research expertise, experimental facilities and generate test data for improving fire safety aspects on built environment in India and USA. In this project the partnering institutions are CSIR–CBRI, Roorkee; Indian Institute of Technology, New Delhi; Michigan State University, USA; Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, USA and Building and Fire Research Laboratory (BFRL), National Institute of Standards and Technology (NIST), Maryland, USA. All these organizations are working with an objective to strengthen the available expertise, and enhance research capabilities in the area of structural fire engineering.

R&D

Studies have been carried out to develop numerical models to predict the fire behaviour of beams. Further experimental studies have been carried out and the test data generated on fire performance of reinforced concrete (RC) beams. To study the fire performance of RC beams under loading conditions, experiments were carried out using a well-designed set-up. The experimental set-up consists of a floor furnace to produce the requisite fire exposure conditions and a reaction frame for applying loads, to which generally a structural member is exposed during a fire in practice.

A number of beam specimens were cast and tested under simultaneous actions of loading and fire exposure. A few samples of the tested specimens are shown in Figure 5.

Technology

Uninterrupted spread of fire in buildings is one of the major issues responsible for increasing the quantum of direct and indirect fire losses. Door openings by necessity breach compartment walls allowing failure of integrity and insulation, thus causing the fire to spread uninterrupted. It is therefore essential to restrict the spread of fire to achieve the required degree of containment. Failure to do so may cause considerable loss of life and property.

A fire door with a specific fire-resistance rating is used as part of the passive fire protection system to reduce the spread of fire from one compartment to another and to enable safe egress from a occupancy (Figure 6). CSIR–CBRI has developed a fire-resistant door and transferred the technology to M/s GMP Technical Solutions, Solan, H.P.

Infrastructure

In the area of structural fire engineering, the infrastructure facilities were upgraded to carry out the experimental studies, especially on beams and slabs under loading conditions, to meet the future requirement of structural fire safety. Further experimental studies were carried out on the fire behaviour of RC beams under loaded conditions. Existing facility on fire resistance evaluation was upgraded to study the fire behaviour of structural elements under hydrocarbon fuel fires. A project to study the behaviour of protected steel column under high-temperature loading (hydrocarbon fire) was successfully completed on the developed set-up (Figure 7).

Figure 5. Tested specimens.

Figure 6. Testing of fire door in the furnace.

Technical aid to industry

The work carried out on fire resistance evaluation of building elements and safety and security equipment helped in improving the fire safety level in different projects of national repute through promotion of tested quality products. Also, the set-up and facilities on fire resistance evaluation of building elements helped the industry to indigenously test their passive fire protection systems. It resulted in improvement and development of indigenous systems/products, savings of foreign exchange and time.

Building materials

Wood Without Trees

Development of diversified composite materials as wood substitutes is being considered as an attractive solution to conserve forest resources. The existing wood substitute materials such as reconstituted panel products and other materials cannot meet the increasing demand of wood, without fresh efforts. The Indian import of industrial round wood is ~4.1 million m^3 annually and is expected to triple in the next decade. To meet wood scarcity, the utilization of renewable raw materials such as agro-residues, leaves and stalks of forest plants and natural

Figure 7. Fire testing of structural specimens.

fibres has been widely recognized in making ligno-cellulosic panel products for building industry.

Realizing a desire to develop materials/products from renewable resources, rice husk is used as an alternative to wood fibres in producing plastic composites under melt blend processing. The selection of rice husk is made over other agricultural residues because of its large availability (~20 million tonnes/annum) and adequate heat stability due to high silica content (~20% by weight). Various bottlenecks related to this material such as poor compatibility with non-polar thermoplastics, thermal instability, hygroscopicity and difficulty of mixing in conventional equipment, etc. have been overcome. As a result, manufacturing knowhow has been developed for making solid and hollow profiles. The salient features of the profiles are: wood-like surface appearance, carpenter-friendly, biologically durable and recyclable, and also meet the requirements of National Building Code, 2005 when tested according to IS: 1708. The main applications include: door/window frames, sheets, decking, fencing, furniture, lumber and other moulded items. The products (Figure 8) are now commercially available under the brand name ‘Wood Without Trees’.

Pine needle composite boards

Pine needle is a renewable natural resource material produced annually in large quantities in the Western part of the Himalayas (Indian forests: ~2.7 million tonnes/annum). Because of its inefficient utilization, every year forest fire causes substantial damage to the flora and fauna of the area. A systematic study was carried out at a pilot plant level on the production of pine needle composite boards/panels (Figure 9) using isocyanate adhesive. Various material and processing parameters such as adhesive content, type of treatment, pressing time, mould temperature, etc. related to the production of pine needle boards were optimized. The developed panels are characterized for their physico-mechanical properties, dimensional stability under wet condition, reaction to fire characteristics, thermo-acoustic properties and biological attack. The developed composite board satisfies the requirements of IS: 3087-2005/EN 312-2003. It can be painted and laminated.

Geopolymeric concrete products

Geopolymers have increasing interest as an alternative to ordinary Portland cement for concrete due to limited reserves of limestone, limited manufacturing growth and increasing carbon taxes. The additional motivation for exploring this alternative is attributed to its high early compressive strength, low drying shrinkage, good fire resistance and durability in aggressive environment compared to Portland cement concrete.

A study was initiated on the development of geopolymer-based construction materials using fly ash as an alumino-silicate resource material. Geopolymer paste is optimized as a function of activator concentration and its dose, liquid/solid ratio, curing time and temperature, and durability in sulphate and acid environments. The optimized paste is utilized for making various kinds of mix proportions suited to end use. Several items such as acid-resistant bricks, concrete, insulation concrete, self-compacting concrete, solid and hollow blocks, foam and reinforced beams have been produced. The properties of these products (Figure 10) have demonstrated satisfactory performance according to the existing standard specifications for cement-based materials.

Development of value-added products utilizing Kota stone waste

Stone has been commonly used for various purposes like flooring, cladding, etc. since ancient times. Stone industry generates both solid and stone slurry waste. The solid waste results from the rejects at the mine sites or at the

Figure 8. Wood Without Trees – various kinds of profiles.

Figure 9. Pine needle boards.

Figure 10. Geopolymeric products.

processing units, whereas stone slurry is a semi-liquid substance consisting of particles originating from the sawing and polishing processes and water used to cool and lubricate the sawing and polishing machines.

Kota and Jhalawar districts of Rajasthan have been subsisted with about 100 million tonnes (MT) of splitable type of decorative grade flooring limestone, known as Kota stone. It is also deposited in Ajmer, Sawai-Madhopur, Rajsamand, Udaipur and Banswara. The year-wise production of Kota stone is increasing. The average yield of acceptable quality of Kota stone per hectare land area is about 1 lakh MT and with the current trend of yearly production level, 55–60 ha land is brought under stone mining each year.

Every year about 2.50–3.00 lakh MT of stone polish is discharged into local convenient places, which poses major environmental and ecological problems besides occupying a large area of land for its storage or disposal. Looking to such huge quantity of waste as minerals or resources, there is a tremendous scope for setting up secondary industries for recycling and using such solid wastes in construction materials. Keeping this in mind the engineering properties of Kota stone waste has been studied and this waste has been utilized as replacement for fine and coarse aggregate of size ≤ 4.75 mm (F.M. 2.5) to develop flooring tiles meeting the specifications of IS:1237 and light weight blocks according to IS:2185 (iv).

It has been found that the utilization of high volumes of Kota stone slurry waste (bulk specific gravity 2.73 and fineness 275 m^2/kg) in lightweight concrete leads to higher strength than that of normal lightweight blocks without Kota stone waste. The work has been done to produce lightweight foamed concrete with a given design targeted density of 800 and 1000 kg/m^3 according to IS code that can be classified for non-structural applications. The decreased density reduces the self-weight, foundation size and construction costs. Non-structural lightweight foamed concrete is generally used to reduce dead weight of structure as well as to reduce the risk of earthquake damages to a structure because the earthquake forces that will influence the civil engineering structures are proportional to the mass of those structures.

Cathodic protection of steel reinforced concrete structures

Steel reinforced concrete is widely used in the construction of structures. However, corrosion-induced deterioration of steel in concrete poses a challenge to durability of these structures all over the globe. Although highly alkaline concrete provides protection from corrosion with formation of a passive layer on the surface of reinforcing steel, the passive layer deteriorates with time due to penetration of chloride ions and neutralization of alkalinity caused by carbonation. This depletion of the passive layer leads to formation of electrochemical cells and corrosion of steel.

Various measures are adopted to control the corrosion of steel in concrete, such as protective coatings, use of inhibitors and cathodic protection. A study was undertaken at CSIR-CBRI to compare effectiveness of these measures. The results showed that cathodic protection (CP) is the most effective technique for corrosion control of steel in reinforced concrete in comparison to the conventional protection measures like coatings and inhibitors. This technique involves application of electric current to force electrons to move towards the steel rebar thereby steel behaves as a cathode and thus reduces corrosion. There are two types of cathodic protection – sacrificial cathodic protection and impressed current cathodic protection (ICCP). Impressed current cathodic protection requires a power supply or rectifier and permanent anode to protect the metal or structure by making it a cathode. A low-voltage direct current is driven from the anode through the concrete to the surface of the steel. In galvanic system, more reactive metal (anode) with respect to steel bar gets consumed to protect the rebar.

Anode is the most important component in a cathodic protection system from the function and cost point of view. The major role of an anode is to provide uniform distribution of current to the reinforcing steel through the electrolyte. Therefore, selection of an anode is one of the most important criteria for successful protection of reinforced steel by cathodic protection. One of the objectives of the current R&D work on CP is to develop a low-cost conductive cementitious anode using various conductive fillers such as carbon fibre, graphite powder, pyrolytic carbon black and coke breeze. The systems using these anodes have comparatively low resistivity for an ICCP system and are effective for better current distribution over large area of reinforced structure. The results obtained so far are encouraging and further studies are in progress.

Multifunctional coating systems for protection of concrete structures

Conventional coating systems are used for the decoration as well as protection of structures. These types of systems are based on acrylics, epoxies, polyurethanes, alkyds, etc. As the development in coatings progressed with the time, the requirement and demands also changed drastically. Now the demand is for advanced coating systems for specific end-user applications. As demand is shifting towards energy-efficient buildings, intelligent systems, green buildings and smart intelligent housings, there is a strong need for research and development of multifunctional coating systems, e.g. corrosion-resistant, water-proof, energy-efficient, etc. The work in multifunctional coating systems is being carried out under the 12th Five Year Plan using nanotechnology. This can significantly improve and enhance the performance of protective coatings. The objective of the ongoing work is to develop multifunctional coating system/s for the protection of concrete structures.

Nano-engineered approach for sustainable and durable concrete

CSIR–CBRI has recently initiated efforts on the applications of 'nanotechnology in construction'. Efforts are being made to enhance the performance of cement and polymer-based materials using nanomaterials.

Nanotechnology is gaining widespread attention and is being applied in many fields to formulate materials with novel functions due to their unique physical and chemical properties. The applications of nano materials in construction may significantly improve the essential properties of building materials such as strength, durability, bond strength, corrosion resistance, abrasion resistance and novel collateral functions such as energy-saving, self-healing, anti-fogging, etc. In fact, a roadmap has been developed with regard to the use of existing construction materials such as concrete, bitumen, and plastic using nanotechnological features vis-à-vis their use in the buildings of the future.

Nano-engineering encompasses the techniques of manipulating the chemical structure at the nanometre scale to develop a new generation of materials with superior performance. The enabling nature of nanotechnology implies that it can provide traditional construction materials with new functionalities, including new eco-innovative solutions. A wide range of commercially available products worldwide illustrates that much is beginning to happen in this area. Table 1 shows a few types of common nanoparticles expected to dominate in construction materials. Applications of nanotechnology have been described for cement, wet mortar and concrete, paints and coatings, insulation materials, glass and infrastructural materials. More advanced 'smart' developments have been reported, including building materials containing nano-sensors and nano-particulate self-repairing materials. Some of the applications of nanotechnology have already reached the market and many are still under development. Diverse applications of nanomaterials in construction industry are shown in Table 1, which clearly indicate the huge potential of nanotechnology in the construction sector.

Spherical silica nanoparticles with controllable size have been synthesized using organic and inorganic silica precursors as starting material by sol–gel method. Further, these silica nanoparticles were supplemented to cement for studying the strength-imparting behaviour of the calcium silicate hydrate (CSH) gel. Using sol–gel process the size and shape of silica nanoparticles may be controlled by additives such as electrolytes, surfactants and organic acids. The size of the silica nanoparticles was controlled using non-ionic surfactants. The SEM photomicrographs revealed that silica nanoparticles are spherical, dispersed and approximately 50 nm in size (Figure 11). X-ray diffraction profile further revealed the amorphous nature of the synthesized particles. The ^{29}Si MAS NMR spectra of silica nanoparticles show the T and Q sites. The signals at approximately –113.0 and –103.0 ppm arise from the Si species Q^4 ($Si(OSi)_4$) and Q^3 ($Si(OH)(OSi)_3$) respectively. A low-intensity peak at –94.20 ppm arises from chemical shift correlation and relaxation data to germinal-hydroxyl silanol sites (Figure 11).

Further, to investigate the comparative mineralogical and morphological attributes of CSH gel, these silica nanoparticles were added to cementitious system. Cement is the mixture of tricalcium silicate, dicalicum silicate,

Table 1. Selected nanomaterials applications in the construction industry

Construction material	Nanomaterials	Expectations
Cement/concrete	Carbon nanotubes, SiO_2, Fe_2O_3, TiO_2	Reinforcement, crack hindrance, strength and durability
Steel	Copper nanoparticles	Weld ability, corrosion resistance
Window	TiO_2, SiO_2	Self-cleaning, anti-fogging, UV and heat blockings
Coatings/painting	TiO_2, Silver nanoparticles	Anti-fouling, biocidal activity

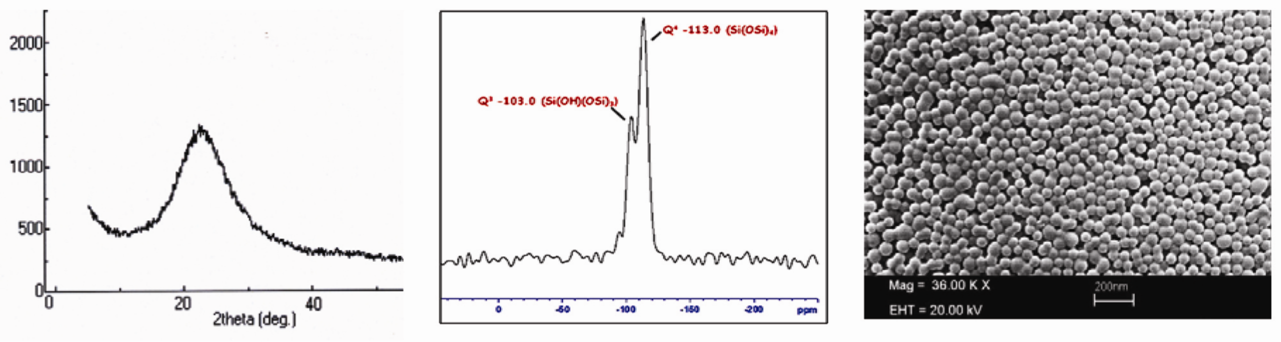


Figure 11. XRD, 29Si (Mass Absorption Spectroscopy) NMR and SEM of silica nanoparticles.

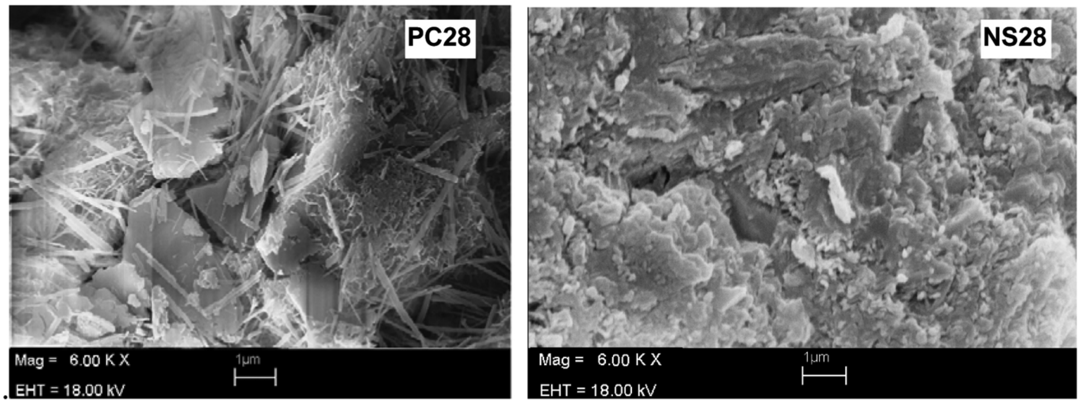


Figure 12. SEM photomicrographs of plain cement paste (PC28) and nano silica-incorporated cement paste (NS28) at 28 days of hydration.

Table 2. CH content (%) in cement paste

	CH content (%) at			
	1 day	3 days	7 days	28 days
Plain cement paste	4.1	7.4	12.3	20.0
Cement + nano silica (5%)	0.4	3.3	4.9	8.2

triclacium aliminate and tetracalcium aluminoferrite. The main strength-imparting phase in the cement matrix is the CSH gel, which is approximately 50% of the total quantity produced during the hydration process. Through recent advancement in microscopy, it has recently been established that the CSH gel is a granular structure of a few nanometre in size. Addition of silica nanoparticles up to 5.0% improved compressive strength of cement paste and the setting time of fresh cement paste was decreased by increasing the content of silica nanoparticles. Addition of silica nanoparticles into cement paste improves the microstructure of the paste and calcium leaching is significantly reduced as silica nanoparticles react with calcium hydroxide (CH), thereby forming a secondary CSH gel. It was further established that, CH content in silica nanoparticles-incorporated cement paste reduced 90% at day 1 and up to 59% at 28 days (Table 2). Results of SEM studies show the comparative micro-structural behaviour of controlled cement paste with the addition of silica nanoparticles, indicating a denser structure and significant reduction in CH content (Figure 12). The compressive strength of cement paste containing 5% silica nanoparticles is 64% higher at day 1 and 35% at 28 days than that of control cement paste (Figure 13). Therefore, it can be concluded that the microstructure of cement can be tuned with the help of nanoparticles, thus producing more durable and sustainable concrete.

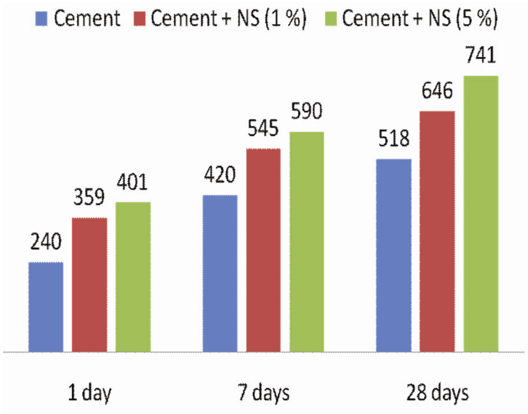


Figure 13. Compressive strength (kg/cm^2) of plain cement and nano silica-incorporated paste at 1, 7 and 28 days.

Environmental science and technology

Fluorogypsum, a cardinal waste material of the hydrofluoric acid industry, is produced to an extent of about 4.0 MT annually, which poses the problem of disposal, pollution and health hazards. However, this anhydrite form of gypsum contains impurities of free acid and fluoride that interfere with its setting properties. Therefore, to activate its hydration behaviour, it is ground with chemical activators to a fineness of 90% passing through a 90 µm IS sieve. This cement-free binder attains a compressive strength of 32 MPa (28 days) with a setting time of 95 min and water absorption 4.5%. This binder is found suitable for use in flooring tiles, light-weight blocks, masonry and plastering works, pre-fabricated panels, etc. The technology of formulation of fluorogypsum cement for use in plastering has been transferred to M/s Navin Fluorine International Ltd, Mumbai.

Recycled aggregates were used to develop concrete with different percentage replacement of natural aggregate. Performance of concrete had been evaluated in terms of mechanical and durability properties and compared with natural aggregate concrete. Microstructural study of interfacial transition zone of recycled concrete was made through SEM and petrographic analysis. Paver blocks of various strengths were made with various percentages of recycled and natural aggregates along with the incorporation of recycled fine aggregate. Novel treatment processes such as thermochemical treatment method have been adopted for both recycled coarse and fine aggregate to improve its properties and its influence on the mechanical performance of concrete. Currently, the use of recycled aggregate in structural performance is being focused upon and work is underway.

Development of bio-concrete as self-healing material for sustainable structures

In this study initially isolation, screening and characterization of ureolytic, alkaliphilic, endospore-forming calcifying bacteria from alkaline soil and other materials was carried out. Followed by the study of growth characteristics (pH, temperature) of the selected isolate(s), preparation of seed culture, standardization and screening of the media were accomplished. The study of all the possible forms in which bacteria can be incorporated into mortar and concrete specimens was identified. Finally, the cell concentration, to be incorporated in concrete, was optimized to achieve maximum calcite precipitation. To study the effect of self-healing by bacteria, the standardization of methods for crack generation was carried out. Characterization and quantification of carbonate and microbial deposits was accomplished through XRD and study of microstructure of bacteria was performed using SEM. Furthermore, bacterial viability assay after regular intervals of time was done using transmission electron microscope (TEM).

An integrated adsorption–solidification/stabilization process for fixing and immobilizing the toxic heavy metals has been developed for irreversible fixation of these metal ions. In this study, treatment of heavy metals containing industrial wastewater has been carried out using fly ash. Results show that the fly ash can be used as an effective metal adsorbent. This altered sludge has been used for preparation of building components. Feasibility of using this product as a secondary construction material was also assessed. Finally, the metal leach ability from the fixed products was studied.

According to the Ministry of Health and Family Welfare, Government of India, the country has 17 million persons living with chronic obstructive pulmonary disease (COPD), a number that is estimated to rise to 22 million by 2016. Annually, IAP accounts for between 1.5 and 2 million deaths globally. In India, work is being done in the institutes like IITs and some universities. Understanding the dynamics of fine particulate matter indoors is a crucial step in establishing the exposure parameters for health assessment as well as energy consumption of buildings. To achieve these objectives, we are carrying out experimental and modelling studies for quantifying resuspension rates under the influence of human activities and ventilation conditions.

Protection of buildings from termites is also an important area of research at CSIR-CBRI. In buildings, damage caused by termites is not confined to timber only as generally believed, but it also spreads to most of the cellulosic materials. Some species of termite have been known to attack non-cellulosic materials also, such as thin sheets of soft metal (lead or copper) asphalt, plaster, mortars, creosote, rubber and plastic, etc. Wooden objects kept in museums are susceptible to attack. Archival materials and some other works of art of composite origin, such as murals, panel paintings, canvas paintings are also liable to attack by termites. The routes of entry of termites into buildings are usually wall cavities, joints or cracks in concrete or directly out of soil by way of

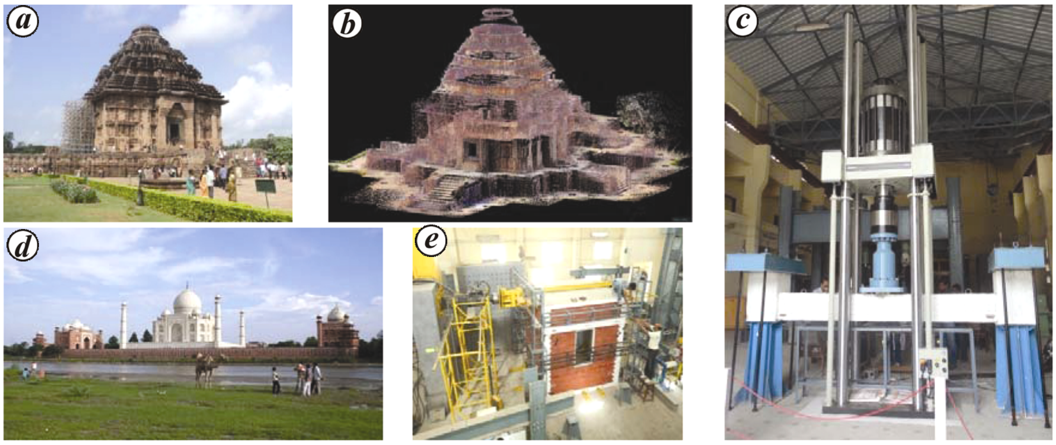


Figure 14. ***a***, Sun temple, Konark; ***b***, laser scanned view of the Sun temple; ***c***, 300 UTM; ***d***, Taj Mahal; ***e***, testing of confined masonry buildings in the laboratory.

protective earthen tunnels. R&D work has been carried out for the development of anti-termite barrier for buildings using industrial waste. The barrier is non-pesticidal, environment-friendly and long-lasting.

Structural engineering

The Structural Engineering group is equipped with state-of-the-art facilities to cater to the needs of emerging engineering challenges in building research. At present, the thrust areas of the group include conservation of world heritage buildings, structural health monitoring, development of prefabricated building components, low-velocity impact studies, building dynamics, and development of new-generation concrete.

Conservation of important heritage monuments like the Taj Mahal and Sun Temple involved use of modern techniques like 3D laser scanning, endoscopy, ground penetration radar studies and damage mapping (Figure 14). The research work in structural health monitoring relates to damage identification in the structural components of buildings using wireless sensors.

The development of prefabricated beam-column joint modules is an initiative to prevent the inferior construction issues associated with the joints of multi-storey buildings. This will lead to faster and safe construction with enhanced capability to resist earthquake loads. Low-velocity impact studies are being carried out on RC structural elements to assess their performance under high strain rate of loading. This will ultimately help analyse and prepare guidelines for structural design of components subjected to impacts like rockfall, blast loading, etc.

To address this issue of the construction sector in the country, the group is actively involved in the development of a new generation of concrete-like hybrid fibre reinforced concrete, pervious concrete. The performance of masonry buildings at the time of an earthquake is still a major problem. The ongoing R&D activities on confined masonry construction are a promising solution towards earthquake-resistant masonry buildings.

Keeping in view the changes in living standards, one of the new areas of research taken up by the group is 'intelligent building systems'. This includes development and integration of intelligent features into a dwelling unit like intelligent HVAC and lighting controls, glass facade cleaning robotic system, smart home controller using mobile or web connectivity, automatic floor cleaning robot, security features of fingerprint, face recognition and Iris along with centralized network monitoring system.

The group is also being recognized at the national level for work on damage survey, categorization and recommendations for repair, seismic strengthening and retrofitting of earthquake-affected and other deteriorated buildings. Retrofitting strategies like RCC jacketing, FRP wrapping, and micro-concreting have been successfully implemented in many projects of national importance. The group is actively involved in various committees at the national level and also in drafting standards for the Bureau of Indian Standards.