April- June 2022 Vol. 6, No. 2

e-STRUCT

e-Newsletter of CSIR-Structural Engineering Research Centre

CSIR-SERC
ENGINEERING SUSTAINABLE STRUCTURES

In this issue

From the Director's Desk

e-Struct, the quarterly newsletter showcases the scientific activities and myriad events that are part of day-to-day life on the CSIR-SERC campus. I am very happy to present Vol. 6, No. 2, 2022 issue of e-STRUCT. This edition of newsletter showcases the varied skills of the CSIR-SERC community, highlighting our R&D pursuits, achievements, skill development initiatives and other significant events & endeavors during April-June 2022. I hope you enjoy reading the online versions of past newsletters.

CSIR-SERC's work on structural integrity assessment of Reactor Pressure Vessels in order to ensure safety of the vessel under PTS condition is showcased in this edition of e-struct. Reactor Pressure Vessel (RPV) of a Pressurised Water Reactor (PWR) is subjected to severe thermal shock under events like Loss of Coolant Accident (LOCA). Twelve major projects have been undertaken through sponsorship or in collaboration with public / private / Government organizations. During this quarter, MoU was signed with East Central Railway, Mahendrughat, Patna for a research project on Analytical Investigations, Instrumentation and Dynamic Response Measurements on Typical Spans of Rail cum Road Bridge over River Ganga and a contract agreement with M/s. InDriya Power Limited, Mumbai for the project 220 kV Suspension and Angle Type Concrete Transmission Towers including Foundation, Phase 1: Preliminary Design Validation Phase 2: Final Design Validation. Eleven major projects were also undertaken during this period.

During the period, the 88th Management Council meeting and the 64th Research Council (RC) meeting was held in April. CSIR-SERC organized two online advanced courses as a part of CSIR Integrated Skill Initiative for the benefit of the student and research community. Celebrations were held for the 131st Birth Anniversary of Babasaheb Dr. B.R. Ambedkar, National Technology, CSIR Foundation Day and International Yoga Day. Our campus was graced by Dr. Jitendra Singh, Hon'ble Minister of State for the Ministry of Science and Technology and Vice President, CSIR and Shri R. Madhan, Director, Indo-German Science and Technology Centre (IGSTC). This has indeed been an eventful quarter and as always we look forward to more exciting opportunities in future. Exciting times ahead!

With best wishes

25.10.2022 Dr. N. Anandavalli

Visit of Dr. Jitendra Singh, Hon'ble Minister of State for the Ministry of Science and Technology and Vice President, CSIR, New Delhi

Research highlights

Fracture behaviour of reactor pressure vessel steel under pressurised thermal shock

Reactor Pressure Vessel (RPV) of a Pressurised Water Reactor (PWR) is subjected to severe thermal shock under events like Loss of Coolant Accident (LOCA). During such an event the RPV is subjected to Pressurised Thermal Shock (PTS). Severe thermal transient in combination with internal pressure in the vessel can cause crack formation or in some cases complete collapse of the RPV. Structural integrity assessment of RPV becomes important in order to ensure safety of the vessel under PTS condition. First stage of the integrity assessment of RPV involves computation of temperature field in the RPV primary circuit during the thermal shock. Once the input parameters like transient duration, inflow velocity and pressure in the pipes are determined, the PTS event can be simulated. The thermal-hydraulic analysis helps in determining the response of the RPV primary circuit, i.e., spatial and temporal variation of temperature of the coolant. The results of thermal-hydraulic analysis will then be used to evaluate the thermal and mechanical stress field in an RPV. Final step in the integrity assessment is the evaluation of fracture parameters, i.e., Stress Intensity Factor (SIF), J-integral & Crack Mouth Opening Displacement (CMOD) for the applied loading conditions. Fracture analysis is performed for different postulated crack geometries at different time of the transient. Fracture parameters are then compared with fracture toughness of the RPV material to evaluate the crack initiation. Numerical investigations were carried out to simulate thermal shock in a standard Compact Tension [C(T)] specimen using commercially available FE software. The numeral analysis consisted of three stages: (a) thermal-hydraulic analysis, (b) thermo-mechanical analysis and (c) fracture analysis. Material properties of the C(T) specimen conforms to 20MnMoNi55 steel used a RPV in Indian Pressurised Heavy Water Reactors (PHWRs). Mechanical loading on the specimen was applied to the specimen in the form of static displacement throughout the transient period. Stress field near the crack tip is obtained by performing coupled thermo-mechanical analysis. Fracture analysis was then performed under thermal shock using contour integral technique. Elastic-plastic fracture parameter, J-integral was evaluated at the crack tip during the thermal transient for different values of applied displacement. Stress intensity factor (SIF) values were then obtained from J-integral and compared with the fracture toughness of the material. It was observed that at higher values of applied displacement, the SIF value reached fracture toughness of the material indicating occurrence of fracture during the thermal shock event.

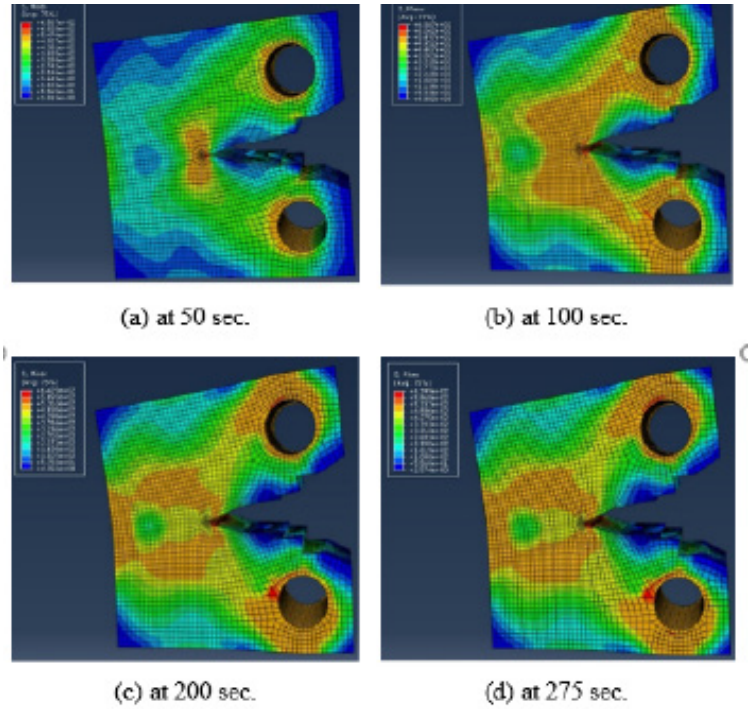
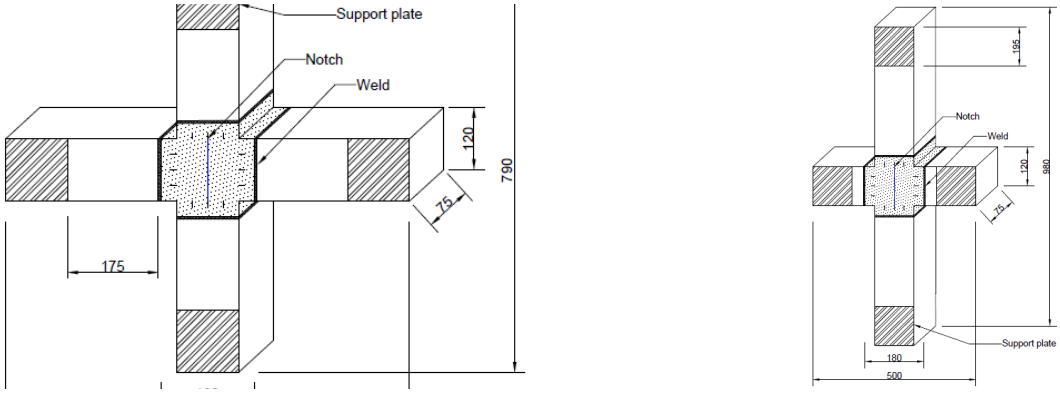


Fig.1: Stress contours at different instances of time

Fig.2: Set- up for tension tests on RPV steel

Figure 1 shows stress contours at different instances of time, viz., 50 sec, 100 sec, 200 sec, and 275 sec. Fracture studies were carried out on cruciform specimens fabricated from 20MnMoNi55 steel; the arms made of steel conforming to ASTM SA 516 Gr. 70. Mechanical properties of 20MnMoNi55 steel were evaluated by carrying out tension tests at different temperatures varying from -75 °C to 300 °C. Figure 2 shows set-up for tension tests. In order to study the effect of stress biaxiality, specimens were designed with two different stress ratios namely 1:1 and 2:1. The biaxial stress ratio indicates ratio of stress produced in the arm perpendicular to the notch to the ratio of stress produced in the arm parallel to the notch. Figure 3 shows details of cruciform specimens with different biaxiality ratios. Semi-elliptical notch of crack ratio (notch depth to specimen thickness, a/W) of 0.2-0.25 has been machined in the specimens in order to ensure a shallow crack profile. Specimens were fatigue pre-cracked under sinusoidal cyclic loading with maximum cyclic load equal to 10% of plastic collapse/ limit load of the specimen. The plastic collapse load of cruciform specimens were computed using different numerical techniques. Alternate Current Potential Difference (ACPD) technique was employed for measuring crack growth in the depth direction of the notch. ACPD uses steel pins of 1 mm diameter which were spot welded at a distance of 20 mm along the notch to compute the potential drop. A close up view of ACPD instrumentation along the notch is shown in Fig. 4. Fracture tests on the cruciform specimens were carried out using a ± 2000 kN servo-hydraulic actuator. Two cruciform specimens CR11-A and CR21-A were subjected to quasi-static monotonic loading under displacement control at room temperature and two cruciform specimens CR11-B and CR21-B were subjected to thermal transient loading prior to fracture test. The cruciform specimens CR11-B and CR21-B were heated to a temperature of 300 using an induction coil heater on all four arms of the specimens. The specimens took 35 and 40 min respectively to reach the target temperature of 300 . . Figure 5 shows a close-up view of cruciform specimen attached with heating coils and wrapped with glass wool. After the specimens reached the target temperature, the central core of the specimens was cooled down by spraying coolant (water) until it reached room temperature (30). The temperature during the whole process of thermal shock was measured using 4 numbers of thermo-couples spot welded at the core region of the cruciform specimens. Figure 6 shows set-up for fracture test



(a) Biaxiality ratio = 1:1 (b) Biaxiality ratio = 2:1

Fig. 3 Cruciform specimens with different biaxiality ratios

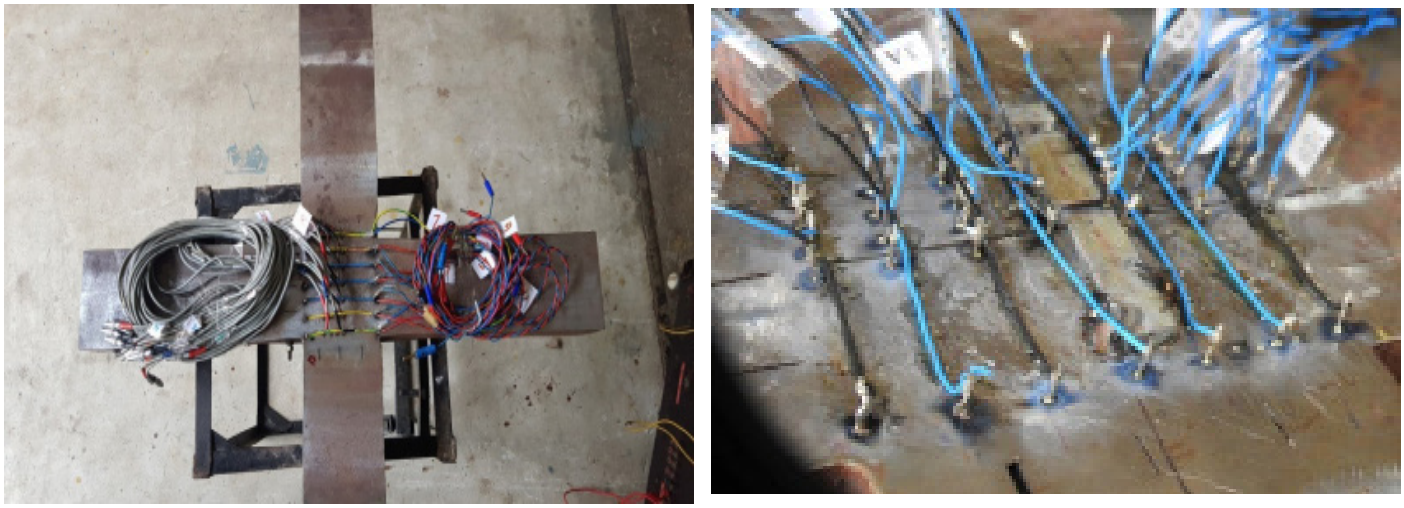


Fig. 4 ACPD instrumentation along the notch for crack growth

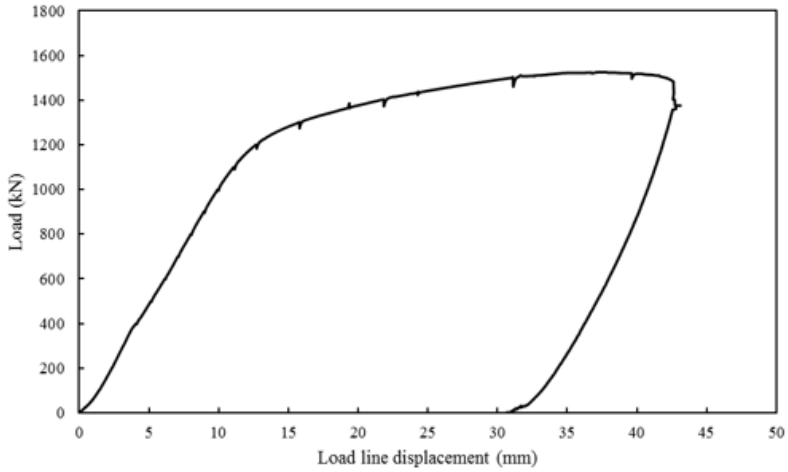
Fig. 5 Cruciform specimen attached with heating coils and wrapped with glass wool measurement

Fig. 6 Set-up fracture test measurement

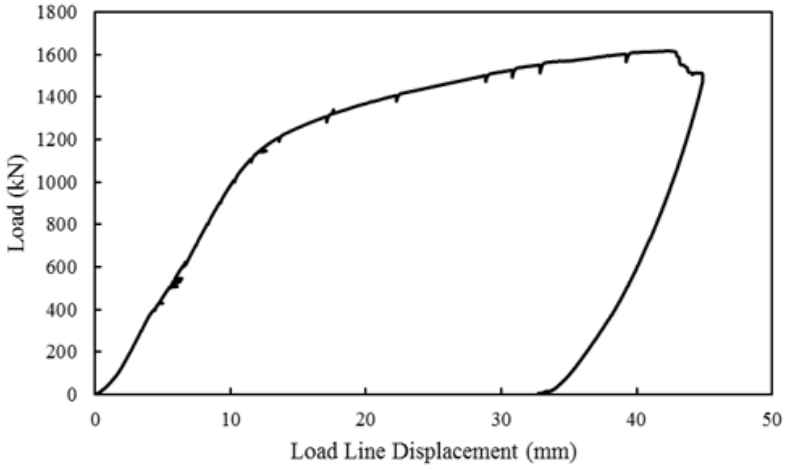
Fig. 7 Close-up view of fracture test set-up

on cruciform specimen. Figure 7 shows close-up view of test set-up. Figure 8 shows load vs. load-line displacement plots obtained from fracture tests on cruciform specimens. Figure 9 shows notch portion of cruciform specimens after fracture tests. All the four cruciform specimens except CR21-A failed by gross plastic collapse. It was observed from the results of fracture tests on specimens CR11-A and CR11-B that the thermal shock/transient on the cruciform specimen CR11-B prior to application of bending load reduced the ductility of the specimen and increased the maximum load by ~100 kN. Similarly, maximum crack mouth opening displacement (CMOD) reduced by 57% in specimen CR11-B compared with that of specimen CR21-B. On comparison of CMOD and fracture energy of specimens CR11-B and CR21-B, it can be concluded that the specimen with equi-biaxial stress ratio is highly constrained.

In order to understand the effect of biaxial bending on the fracture behaviour of components subjected to thermal shock, finite element studies were also carried out on cruciform specimens containing shallow flaw with different biaxiality ratios (1:1, 2:1 and 1:0) and fracture parameters such as *J*-integral and CMOD were evaluated. Material properties of cruciform specimens confirm to Indian RPV steel 20MnMoNi55. Thermal stresses were produced in the specimen by inducing thermal shock on one face of the cruciform specimen. Heat transfer analysis was performed using commercial FEA software to obtain the spatial and temporal distribution of temperature across the specimen during the thermal transient. From the heat transfer analysis, it was observed that the specimen takes about 900 seconds to cool down to room temperature. Stresses were evaluated by sequentially coupled thermo-mechanical analysis. To quantify the effect of thermal shock on the fracture behaviour, the specimens are also analysed under isothermal loading condition at 300 °C. Crack propagation in the specimens was simulated through XFEM approach. Elastic Plastic Fracture Mechanics approach was employed to evaluate the non-linear fracture behaviour. A 2-D rectangular crack of length (2c) of 20 mm and depth (a) of 5 mm is embedded into the central portion of the cruciform specimen on the surface cooled by water. The applied load was increased monotonically until the combined stress developed in the specimens reached 80% of the maximum stress withstood by the specimens. Fracture parameters namely J-integral and Crack Mouth Opening Displacement (CMOD) were obtained from the fracture analysis. It was observed that the J-integral values were significantly larger for specimens subjected to thermal shock than those under isothermal conditions. However, for specimens subjected to uniaxial bending stress, higher energy release rate was observed in specimens under isothermal loading. Maximum value of J-integral obtained for the specimen with biaxiality ratio of 1:1 is twice as that observed for the specimen with biaxiality ratio of 2:1. Comparison of J-integral with its critical value showed that crack growth could be expected in specimen with biaxiality ratio of 1:1 during thermal shock.



(a) CR11-A



(b) CR11-B

Fig. 8 Load vs. load-line displacement plots

Fig. 9 Cruciform specimens after fracture tests

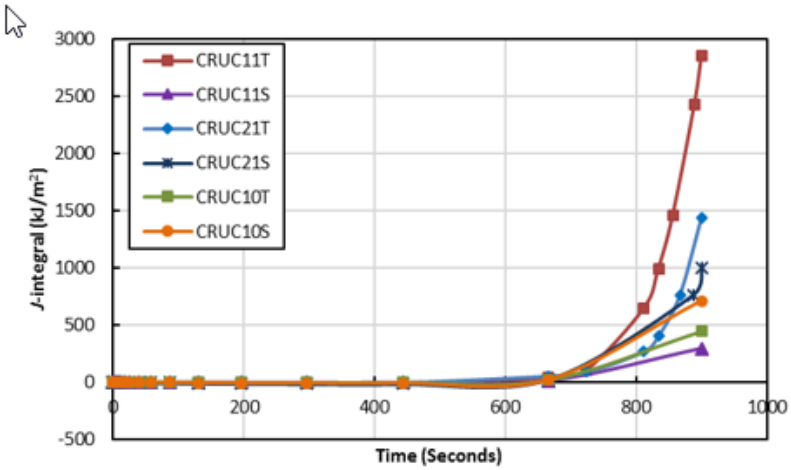


Fig. 10 J-integral with time for cruciform specimens under thermal shock and isothermal conditions

Major Publications

- **Nuclear Engineering and Design, 2020**
- **Nuclear Engineering and Technology, 2021**

Major Projects Undertaken

- Condition assessment of lump ore stacker and reclaimer - NMDC Donimalai
- Condition assessment of concrete at EL 115.5 of RB 3 & 4 - Kakrapar Atomic Power Station, Surat
- Detailed NDT inspection on all the accessible beams and connections in steel framing of FM vault at RB-3KAPS - NPCIL Kakrapar
- Perfomance evaluation of composite segments, DRDO - Pune
- Wind tunnel investigations to study the aerodynamic behavior of the proposed 150m tall RC chimney - for Singareni TPP Stage - 1 (2x600 MW), M/s. PES Engineers Private Limited - Hyderabad
- Investigations on structural adequacy of the selected super-structure spans of BR No-11 in HJP-BCA section of Sonepur Division M/s. Ircon International Limited - Patna
- Wind tunnel investigations on aeroelastic models of 125m tall RC chimneys - for 2x800 MW Yeramarus Thermal Power Station - M/s. Shapoorji Pallonji and company private limited - Mumbai
- Assessment of performance of super structure through instrumentation in two major bridges 166 (1 span) and 169 (2 span) between Dahanu road and Vangaon stations - Western Railway, Maharashtra.
- Condition assessment of identified RC plant structures of NMDC Ltd., Donimalai - NMDC, Hyderabad
- Condition assessment & structural stability of identified steel structures of OCSL plant, Donimalai based on NDT studies - NMDC, Hyderabad
- Analytical investigation, instrumentation and dynamic response measurements on typical spans of rail cum road bridge (Br No.7, J.P. Settu) over river Ganga at Patna and formulate necessary retrofitting measures - Bihar
- Structural assessment of railway bridges in ETMIKTYM-CGV section of TVC Division of Southern Railway - Ernakulam, Kerala

Technology transfers / MoUs

- Memorandum of Understanding (MoU) between CSIR-SERC and East Central Railway, Mahendrughat, Patna, for the project "Analytical Investigations, Instrumentation and Dynamic Response Measurements on Typical Spans of Rail cum Road Bridge over River Ganga" was signed on 24th May 2022.
- Contract Agreement with M/s. InDriya Power Limited, Mumbai, Maharashtra, for the project titled "220 kV Suspension and Angle Type Concrete Transmission Towers including Foundation, Phase 1: Preliminary Design Validation Phase 2: Final Design Validation" was signed on 02 June 2022

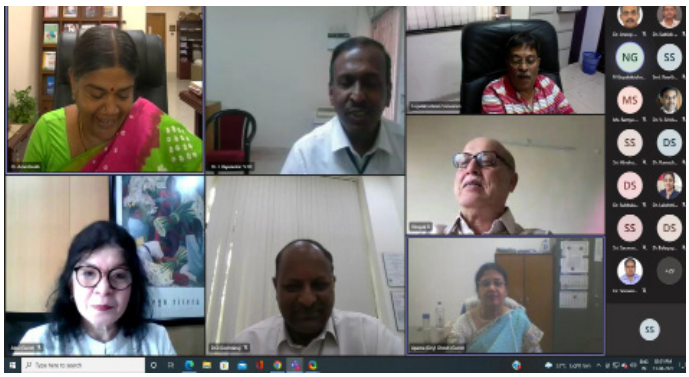
Capacity development

Courses organized as a part of CSIR Integrated Skill Initiative

- Advanced Course on "Smart Materials and Intelligent System Designs (SMISD-2022)" was held during 05-06 May 2022.
- Advanced Course on "Fatigue and Fracture Behaviour of Steel and Concrete Structures and Components (FFBSCSC-2022)" was held during 19-20 May 2022

Events

- Management Council (MC) Meeting 88th MC Meeting was held on 4th April 2022.
- Research Council (RC) Meeting 64th RC Meeting was held on 13th and 18th April 2022



In-House Training/Health Camp

CSIR-SERC & CMC organized Onsite Basic Life Support (First Aid) Training Session for staff members in association with M/s. Gleneagles Global Health City, Chennai, at CSIR-SERC Campus on 19 April 2022

Celebration of 131st Birth Anniversary of Babasaheb Dr B.R. Ambedkar

Swachhata Pakhwada 2022 was observed in CSIR-SERC and CMC from 01.05.2022 to 15.05.2022. As a part of Cleanliness Programme, the Swachhata Shapath Pledge was taken on 2nd May 2022.

Events

- The National Technology Day was celebrated with great enthusiasm on 11 May 2022, by CSIR-SERC and CMC through MS Teams. The function was presided over by Dr. N. Anandavalli, Director, CSIR-SERC and Coordinating Director, CMC. Dr. G. Aghila, Director, National Institute of Technology, Tiruchirapalli, was the Chief Guest of the function.

- In connection with the observance of International Day of Yoga, CSIR-SERC and CMC jointly organized yoga activities with great enthusiasm in CSIR Campus from 26 May 2022 to 21 June 2022. The sessions were handled by Mrs. Vasanthi Ahok and Mr. Arjun Ashok, Yoga Teachers from Art of Living International Foundation. With active participation from SERC and CMC, the yoga series concluded with the International Yoga Day on 21.06.2021.

- CSIR-SERC, celebrated its 58th Foundation Day on 10 June 2022 with great enthusiasm. The function was presided over by Dr. (Mrs.) N. Anandavalli, Director, CSIR-SERC and Coordinating Director, CMC. Shri R.N. Ravi, Hon'ble Governor of Tamil Nadu was the Chief Guest. Prof. C. V. R. Murty, Professor, Department of Civil Engineering, Indian Institute of Technology Madras was the Guest of Honor.

Distinguished visitors

- Dr. Jitendra Singh, Hon'ble Minister of State for the Ministry of Science and Technology and Vice President, CSIR, visited CSIR-SERC on 19 May 2022. He was accompanied by Shri Mahendra Kumar Gupta, Joint Secretary, CSIR Headquarters; Dr. Kannan Srinivasan, Director, CSIR-CSMCRI; Prof. A.B. Mandal, Former Director, CSIR-CLRI and Prof. Santosh Kapuria, Former Director, CSIR-SERC

- Shri R. Madhan, Director, Indo-German Science and Technology Centre (IGSTC), visited CSIR-SERC on 25 May 2022 in connection with the Indo-German collaborative project titled "Modular Lightweight Wastewater Treatment units made with TRC for Rural and Periurban Dwellings (CleanWater)". He had discussion with the young scientists of CSIR-SERC and visited major Infra-structure facilities of CSIR-SERC

Invited talk

- Dr. M. Saravanan, Senior Scientist, delivered an invited lecture titled "Seismic Resilient Steel Structure" organised by Amrita Vishwa Vidyapeetham, Coimbatore on 17 June 2022

Industrial visit

- 25 students (B.E.Civil Engineering) and 2 faculty from the Mar Baselios College of Engineering and Technology, Thiruvanthapuram, Kerala visited on 14th June 2022

Honours, awards & recognitions

- **Dr. N. Anandavalli**, Director, CSIR-SERC was the Chief Guest of the Inaugural Programme of "National Program for Orientation of Science Teachers" held on 16.04.2022 at Rajalakshmi Institute of Technology, Chennai
- **Mr. M. Saravanan**, Senior Scientist, chaired a session titled "*Assessment and Retrofitting: 2*" during the "10th International Conference on Behaviour of Steel Structure in Seismic Areas" organized by Polytehnica Universitatae of Timisoara, Romania, during 25-27 May 2022.
- **Dr. N. Anandavalli**, Director, CSIR-SERC, has been nominated as a Member of Syndicate of Madras University by the Governor of Tamilnadu for a period of three years from 28.05.2022 to 27.05.2022
- **Dr. N. Anandavalli**, Director, CSIR-SERC, has been nominated as a Member of Programme Advisory Committee (PAC) on Technology Development Programme under the Technology Development & Transfer Division of DST.
- **Dr. N. Anandavalli**, Director, CSIR-SERC, has been nominated as Member of International Cooperation (IC) Advisory Committee for the ISTAD activities.
- **Dr. N. Anandavalli**, Director, CSIR-SERC has been nominated as Member of Board of Governor of Engineering Council of India (ECI) for the term 2022-2024
- **Dr. N. Anandavalli**, Director, CSIR-SERC has been nominated as a Member of the Governing Body of CSIR Society up-to 01.03.2023
- **Dr. K. Sathish Kumar**, Chief Scientist, (Civil 87 - alumni) has been honoured as "EMINENT ENGINEER" in ACCE(I) Foundation cum Awards Day 2022 at Hyderabad on 24 June 2022
- **Dr. C.K. Madheswaran**, Chief Scientist, Mr. J. Prakashvel, Senior Technical Officer and Dr. K. Sathish Kumar, Chief Scientist, have been honoured as contributors of outstanding merit and the winners of ICJ Best Paper Awards

Paper Publications

- **SCI Journals - 10**
- **Reputed Indian Journals - 2**