INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

SAFETY CENTRE

Annual Report

(March 2015 – March 2016)

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Indian Institute of Technology Gandhinagar

Mission and Vision

The Safety Centre's vision is to be the preeminent national leader in the creation and dissemination of knowledge for a Safer India. We will achieve this vision through excellence in research and by promoting safety in the public and private spheres. The Safety Center advances these objectives with activities to:

- Discover: Research projects, consultancies and project implementation. Promoting awareness and undertaking public advocacy around safety.
- Teach: Introducing industrial safety courses in IIT Gandhinagar's graduate and undergraduate curriculum.
- Outreach: Safety conferences and seminars to enable safety professionals from around the world to network and explore the state of the art and new safety technologies; as well as training programs for safety professionals.
- Practice: Training staff and students on safe working practices in all aspects of IIT Gandhinagar's operations such as labs and event organization.

The Safety Centre is focused on conducting cutting-edge research with the aim of improving research and practice in the area of

- Earthquake Engineering
- Fire Safety
- Chemical Process Safety
- Road Safety

The following summarizes the key developments in these themes over this year.

1. Research in Fire Safety

- **Overall objectives and motivation**

  Fire is a hazard that is present everywhere and can quickly become a disaster if proper safety measures are not employed. It has been consistently rated in the top 10 risks by the India Risk Survey carried out by FICCI. The objective of fire research at IIT Gandhinagar is to assess risk and enhance safety of building systems against fire.

- **Summary of completed work**
  - Characterization of in-plane and out-of-plane behavior of masonry infill panels: A large proportion of construction in India utilizes RCC framed structures with masonry infills. In case of compartmentalized fires, the masonry infills can be subjected to one-sided fire leading to a steep thermal gradient across its thickness which can reduce its in-plane initial stiffness and induce unwanted out-of-plane loads. The objective of this study was to characterize the behavior of infill systems under such conditions. The portal frame and infill system considered for this study is as shown in Figure 1. Table 1 shows various quantities of interest for a 60 minute exposure to various types of fires (ISO 834, ISO external fire, parametric Eurocode fires). Key observations are: enhancement in out-of-plane displacement, and smaller reduction in lateral load-carrying capacity and initial stiffness in presence of infill.

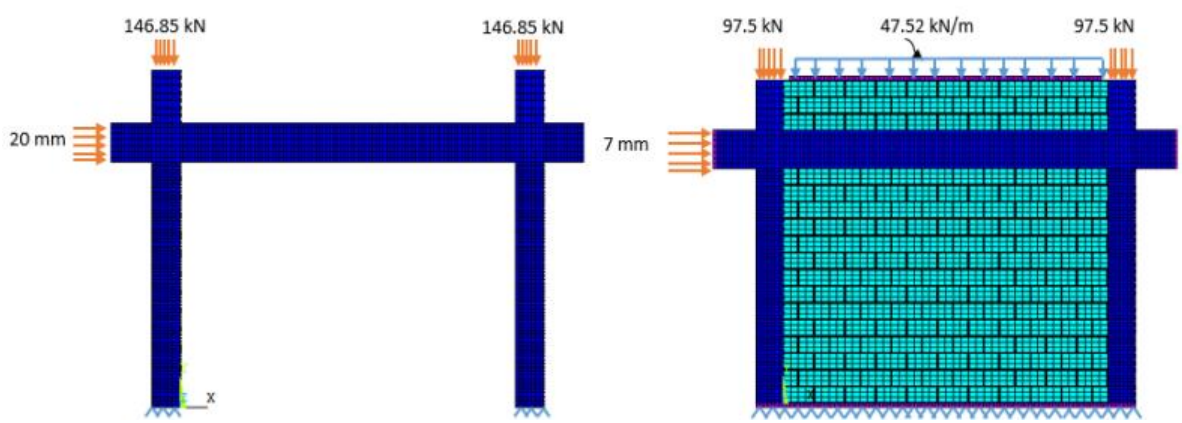


Figure : Portal frame and infill system

Table 1: Quantification of effect of infill in performance of portal frame subjected to fire

Quantity	Portal frame	Frame with infill
Out-of-plane displacement (mm)	55	70
Reduction in lateral load carrying capacity (%)	45	23
Reduction in initial stiffness (%)	46	30

- Development of design fire curves for Indian buildings: The first step in moving from a prescriptive design methodology to a performance-based design (when designing against fire) is to develop the design fire curves for a structural system that indicates the fire loads expected by the structural elements. While such curves are available in the form of parametric fires in American and European codes, there are two major caveats in their usage in Indian scenario: (a) they are derived from data collected in USA and European countries, and (b) they are mostly based on data collected between 1970s to 1990s. Data collection efforts in the Indian context have been very limited and there have been no effort towards development of design fire curves till date. The objective of this study was to collect fire load data from office buildings along with their geometric configurations, develop design fire curves, and compare these curves with standard ISO fire curve. The necessity of comparison with the ISO curves arises due to the fact that the fire ratings specified by the Indian codes assume exposure to the standard fire. Figure 2 shows the developed design fire curves. A comparison with the standard fire curve reveals that the design curves are more severe in terms of initial heating rate and have the potential to render the fire ratings derived from standard fire unsafe.

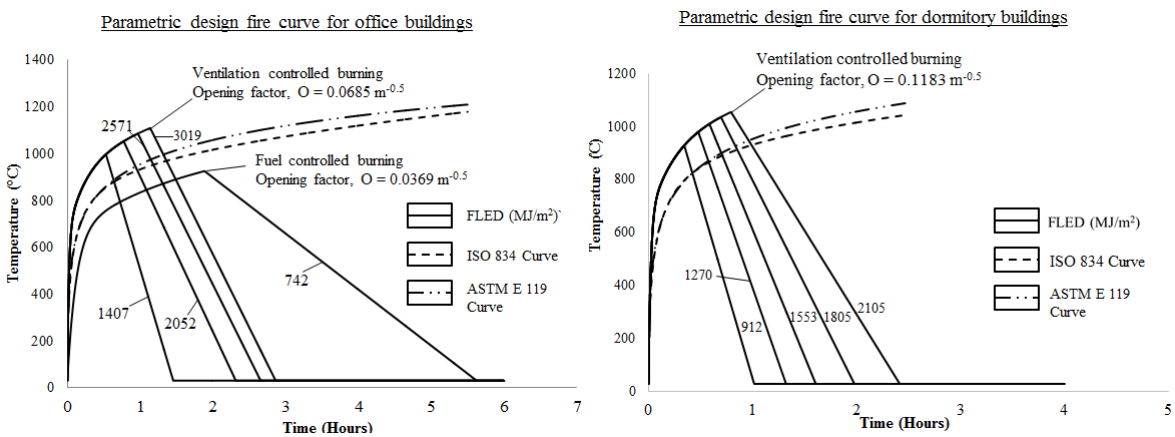


Figure : Design fire curves for office and dormitory buildings

- <u>Development of efficient methods for structural fire analysis of RCC framed buildings</u>: Any performance-based design procedure requires analysis of the structural system for various fire scenarios including progressive collapse analysis to ascertain the worst possible conditions. Analysis of entire structural systems can be computationally very demanding thereby limiting the number of scenarios that can be analyzed. The objective of this work is to develop computationally efficient analysis methods that can facilitate such progressive collapse analysis. Presently, the developed method, based on matrix analysis method, can consider 2D planar structures, and is capable of considering large deformations and temperature-dependent material nonlinearity. The developed method has been verified and validated using available experimental data. Analysis of the portal frame (without infill) shown in Figure 1 using this methodology takes about 3.5 minutes of computation time compared to 17 hours of the same analysis performed using a full finite element method (in ANSYS).

- **Plans for the next year**
  - <u>Meso-scale modeling of RCC elements</u>: This will consider separate material models for rebar, aggregates, and mortar to study the interaction of these three constituents of concrete when subjected to fire.
  - <u>Non-destructive characterization of residual strength of mortar</u>: The aim is to develop correlation curves for estimating post-fire residual strength using non-destructive testing mechanisms.

- Progressive collapse analysis of RCC buildings: The matrix analysis frame work will be extended to 3D and subsequently, scenario-based progressive-collapse analysis will be performed.

- **Electrical Fire : UL Safety Science Challenge 2014**

  Under UL Safety Science Challenge 2014, students are working on Electrical Fire problem and its understanding. Phase 1 of the project included literature review of the causes of electrically induced fires and case studies of some major fires caused by electrical means. Mr Desikan, Director, Operation of UL South Asia announced the winning teams on April 23, 2015. Total eight students selected as winners of UL Challenge 2014. During phase 2 the team worked at IITGN on design of experiments and analysis to study the causes of electrical fires in low voltage applications in greater depth. **The major lab scale experiments include – impact of harmonics current in electrical generated sparks, harmonics assessment and thermal analysis of commonly used ballasts, study of sparking at 5 A sockets, and sequence currents in neutral conductor. Many experimental samples were generated to draw technical implications of each study.** The work done in phase 2 was extended using the lab facilities at Underwriters Laboratories in Chicago.

  Except Dipen Somani who is part of the eight membered winning team, all seven students Suraj Kumar Bhosale, Mayank Khewaria, Akshay Verma, Amit Yadav, Surya Kumar Mane, Pratham Goel, Kapil Pathak visited UL, Chicago and National Renewable Energy Laboratories, Colorado, (NREL) Denver lab. The team is currently working on a technical paper based on their work and on a design project on safe electrical receptacles.

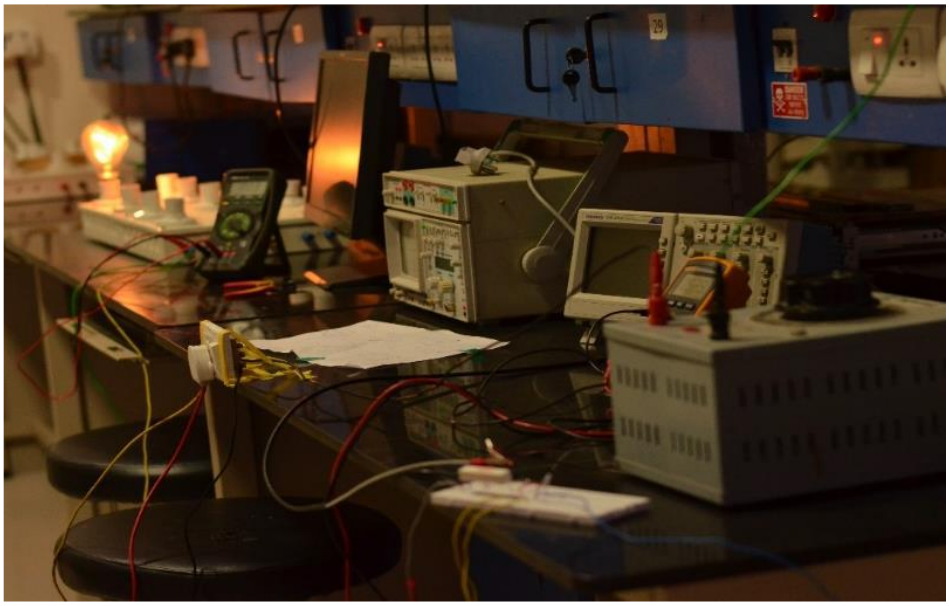


Figure: Experimental setup @ Henry Merrill Safety Lab, IITGN

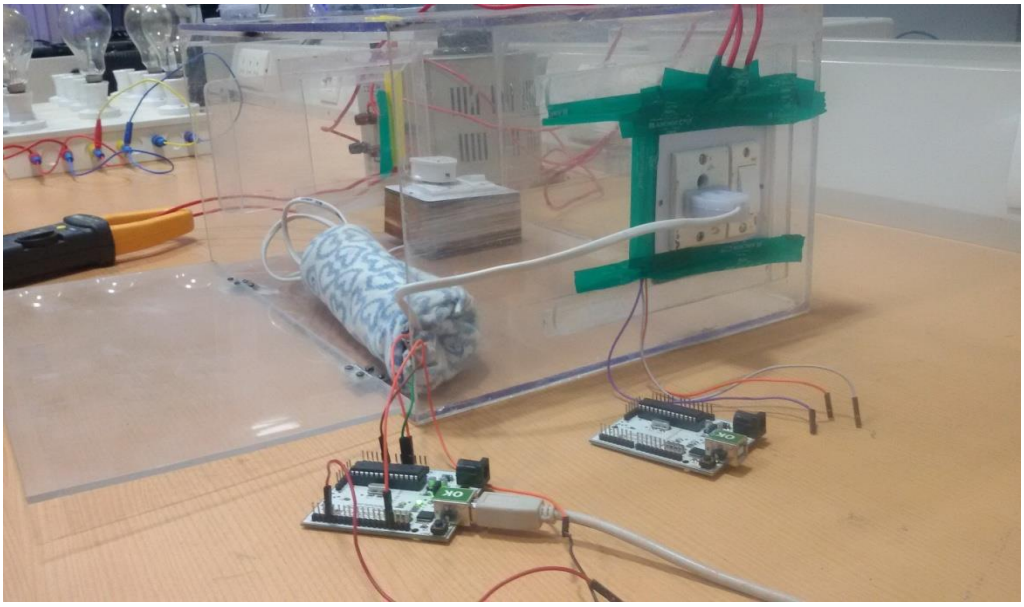


Figure: Experimental setup of excessive insulation @ Henry Merrill Safety Lab, IITGN

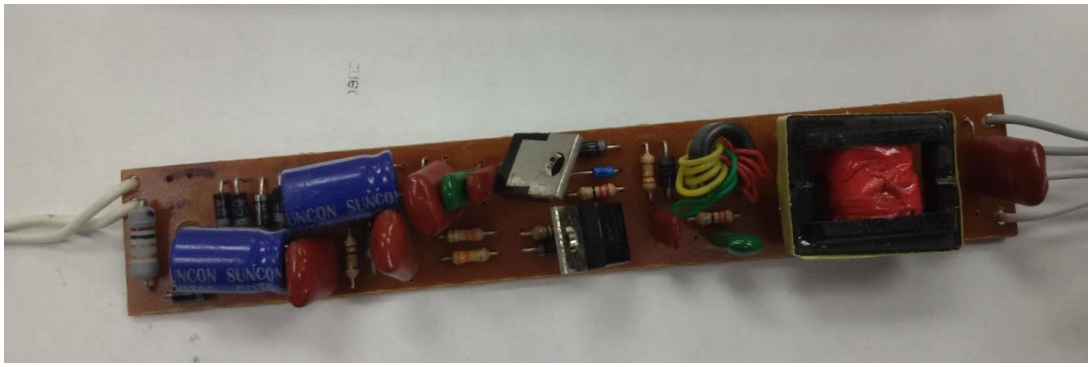


Figure: Ballast under test with its outer cover removed

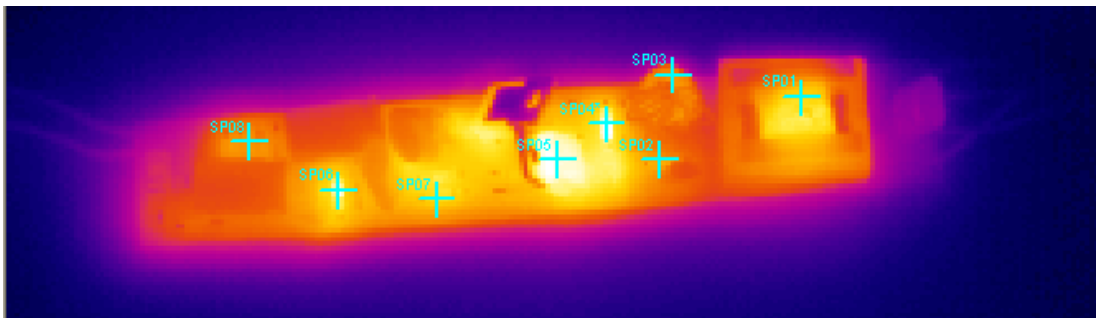


Figure: Ballast under IR image camera to know temperature distribution @UL, Chicago

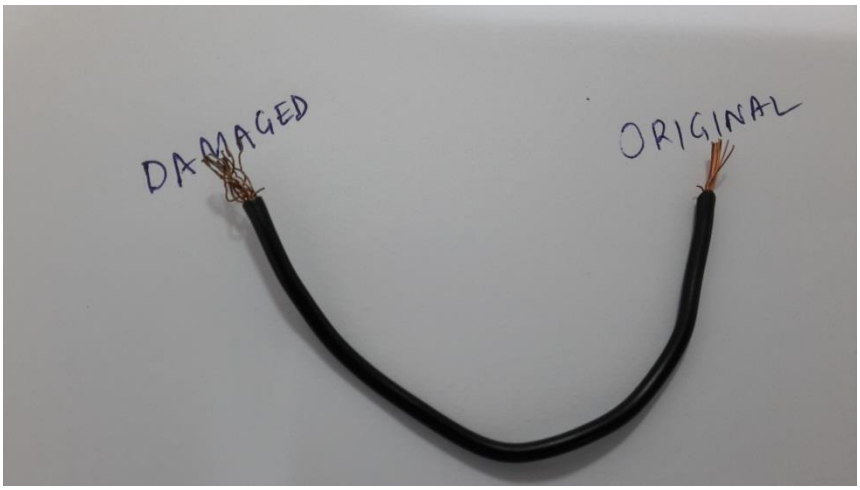


Figure: Damaged and undamaged Cu wire after multiple sparking

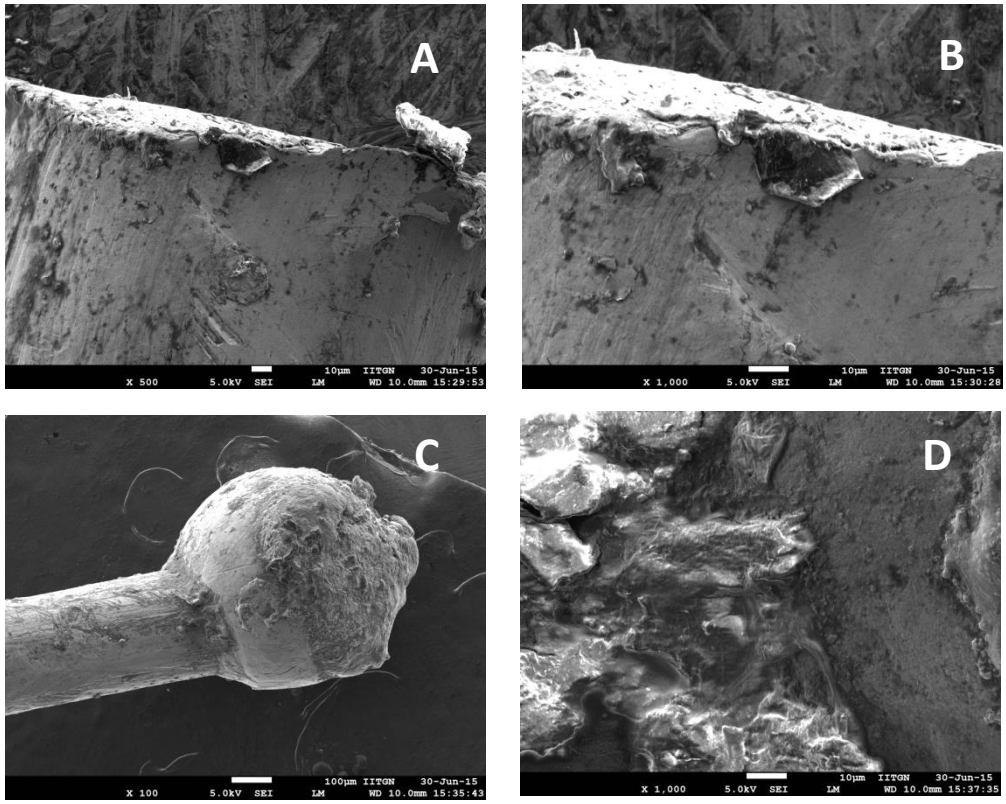


Figure: SEM of original (undamaged – A, B) and damaged (C, D) Cu wire before and after multiple sparking. Melt formation observed on the Cu wire (C and D) after multiple sparking.

- **Development of FireApp for Goa Fire Service**

Fire Safe Goa– An Android App to report Fire and Educate people during Emergencies 'Fire Safe Goa' - an android based application is developed by Gaurav Sharma and Ashish Gupta under the guidance of Prof. Rajagopalan Srinivasan and Prof. Chinmay Ghoroi to aid fire services for Goa was officially launched by the Goa Chief Minister on 14 April 2015, the National Fire Service Day. This project was supported by Underwriters Laboratories and does much more than for reporting. In addition to helping fire services in reaching the accident spot faster through the short and less congested route, it also offers useful information on how to act, the type of fire extinguisher for specific fire type etc, to those trapped in handling situation until help arrives. The app uses satellite information to communicate the precise location of the accident and type of fire. The news was appeared in many National daily newspapers.

Figure: Photo from DNA (National Newspaper)

Figure: The initial version of FireSafeGoa app was uploaded in the Goa Fire Service website and Safety Centre website

2. Research in Chemical Process Safety

Goal and Motivation:

Our goal in this research program is to develop novel sensing and measurement techniques for quantifying, modeling, and predicting cognitive behaviors of control room operators during various scenarios.

Accidents in process plants often lead to large losses. In the last two decades both governments and industry around the world have made numerous interventions to improve process safety. Consequently, nowadays process plants regularly use highly reliable equipment with modern automation and control strategies along with numerous

layers of protection. Despite these measures, the spate of accidents has not been stemmed – by one measure, 25% of the accidents that led to largest losses in the hydrocarbon industry over a period of 40 years have happened in the last 5 years. Analyses of various incidents indicate human errors as a primary cause for more than 70% of accidents in the recent past. Unlike equipment where incipient failures can be inferred from readily available sensors, human failures are considered entirely stochastic and not amenable to prognosis. *Our research seeks to build on recent development in cognitive engineering and address human error in a proactive fashion*. Most accidents arising from human error originate at the cognitive level due to missteps in orientation, diagnosis and execution steps. We therefore seek to develop sensors such as eye trackers, EEG headsets and others that can serve as reliable indicators of various cognitive tasks performed by the operator, especially during process abnormalities.

Key results:

Result 1: Distinct Eye gaze patterns are evident

We have experimentally determined the eye gaze patterns that manifest themselves while a control room operator is using a Human Machine Interface (HMI) to control a process. In our experiments, graduate students played the role of control room operators. From their eye gaze data, a strong correlation is evident between Area of Interest (AOI) based measures and the orientation, diagnosis, and execution steps while rejecting a process disturbance. It was observed that while the trend pane in the HMI was the most dominant AOI during the entire course of the task, the dominance and relevance of the trend pane does vary among phases. During the initial orientation steps, the primary tag is the most used while trend information is ranked higher during later phases that correspond to diagnosis and execution. Similarly, transitions between the primary slider and trend pane ranked highest during the execution phase. These insights provide a new approach to tackling human error in a proactive fashion.

Result 2: Distinct differences between successful and unsuccessful operators visible

We have also sought to understand some key characteristics of maloperation when an operator is controlling a chemical process. Our experiments studied the simple task of open-loop disturbance rejection in a simulated ethanol process. Junior year undergraduate students played the role of a control room operator and were assigned various tasks where

the operator's active intervention is essential to continue normal process operation. The cognitive behaviors of the operators were measured by an eye tracker. Although 91% of the tasks could be successfully controlled by the operators, patterns in the eye gaze behavior indicated that not all successful operations were alike; nearly 12% of the successful operators (called as Group II) closely resembled operators who had failed to control the process (Group III). Both Group II and Group III were characterized by relatively lower attention on the primary variables, which indicates a lower understanding of the underlying process dynamics. Our experiments also confirmed quantitatively that the use of trend information is important especially in the orientation phase of situation assessment.

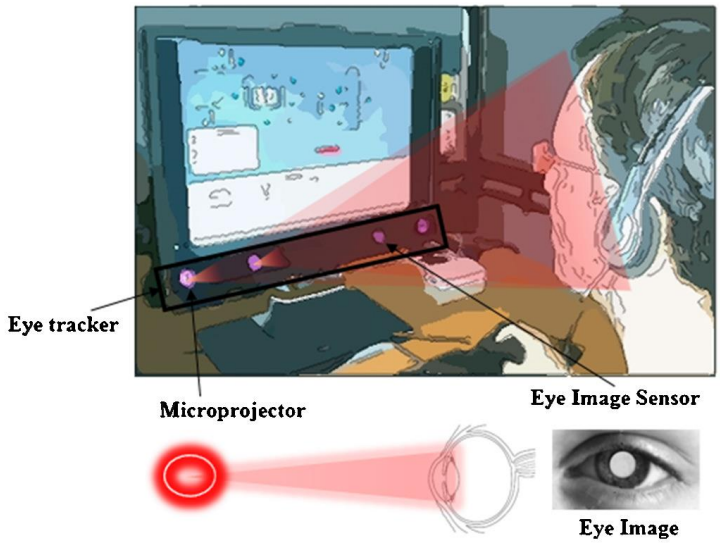


Figure: Eye tracker setup for process control and human error studies

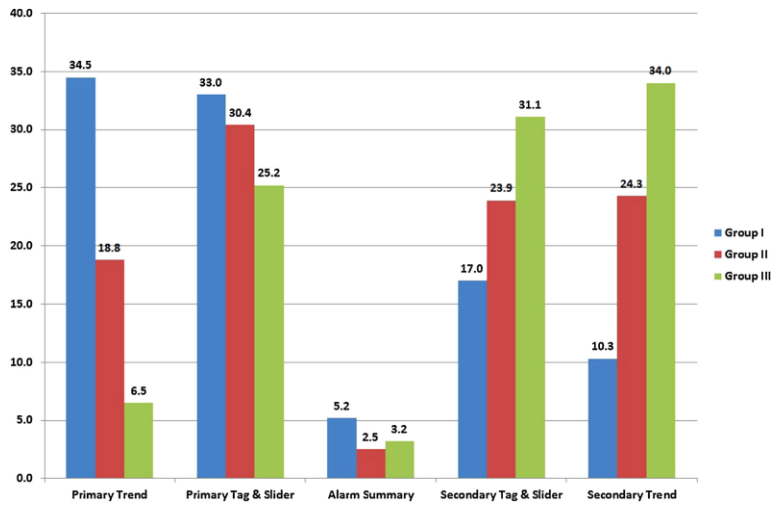


Figure: Significant differences in eye gaze patterns can be seen bertween Group 1 subjects who easily complete the task and Group III subjects who fail. Group II subjects succeed in their task but have many characterisics similar to Group III.

Result 3: Real-time assessment of mental load is possible using pupillometry

We utilized pupillometry data from an eye tracker to understand the cognitive behavior of operators. Experimental studies conducted on 44 participants reveal that pupil size variation can provide reliable indication of the mental workload perceived by the operator. The developed methodology only utilizes pupil size measurements and therefore can provide real-time measurements of cognitive state of the operator. Experimental studies clearly identified participants with low mental workload (successful tasks with use of single slider), moderate workload (successful tasks with use of multiple sliders), and high workload (unsuccessful tasks). The proposed approach has the potential to be used for real-time tool performance assessment of plant operators.

Plans for future work:

Our current research builds on the above three directions and seeks to apply them in two distinct directions:

1. Develop new metrics such as entropy that enables eye gaze behavior to be quantified. Once quantified it can be included with other sensor measurements in a multivariate fashion

2. Design new methods for training: Human error can be obviated if shortcomings in operators' knowledge can be identified and customized training provided. We seek to develop cognitively informed methods for this purpose.

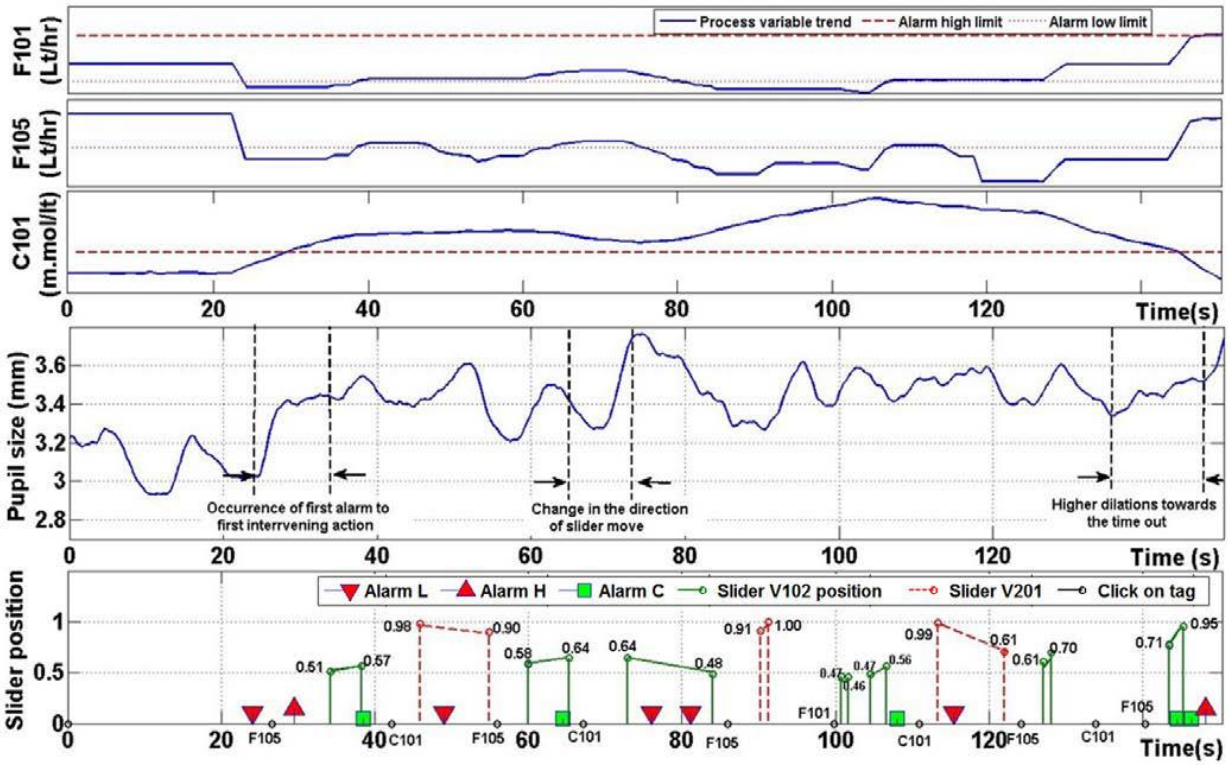


Figure : Context dependent variations reflecting the cognitive state of the subject can be observed in pupil dilation during the course of a control task

Animation of Jaipur IOCL Terminal Fire

IIT GAndhinagar's Safety Centre animated the Jaipur Terminal Fire of October 29, 2009. Two undergraduate student Suman Kumari and Nikhil Tank has developed the animated video of the fire event under the guidance of Prof. Shanmuganathan Raman, Prof. Raj and Prof. Chinmay. In the evening of 29 October, 2009 a fire broke out at IOCL terminal, at Sitapura industrial area in Jaipur. About 50,000 kl of fuel had been wasted in this accident. It was a huge disaster in terms of life and property, around 12 people were killed and more than 150 were injured and fire continued for 11 days. The animation shows the probable sequence of events as per the MB Lal committee's accident investigation report. Similar case studies are available in US Chemical Safety Board. But in the Indian context, this is the first of its kind.

Figure: Animation of Jaipur IOCL Terminal Fire

3. Research on Road Safety:

Safety Centre conducted a one day workshop on Road Safety (Padayatricks) on Feb 5, 2015. Several eminent people like Vikas Sahay (Joint Commissioner of Police, Ahmedabad City), Amit Sheth (CEO, Mind's Eye Design Pvt. Ltd), Gauri Wagenaar (Danaeconsultancy), Arjit Soni, Director (MYBYK), Anuj Malhotra (Executive Director, Centre For Green Mobility), Kiran Sethi (The Riverside School, Founder – aProCh), Priyanka Prasad (Coordinator – aProCh), Kirti Zala (The Riverside School, Coordinator – aProCh), Neena Mehta (The Riverside School, Coordinator – aProCh) along with IITGN faculty and students participated in the workshop. The event was centered around the 'Pedestrian in the City'. Prof. Manuel Joao Ramos, Vice-director of the Centre of International Studies, ISCTE-IUL, Lisbon, Visiting Professor at IIT Gandhinagar, and Co-editor of the recent book, 'The Walker and The City' introduced the book at the event. Prof. Ramos is actively involved with Global Alliance of NGOs for Road Safety and is vice-president of European Federation of Road Traffic Victims and is its representative to UN Road Safety Collaboration.

After the day long discussion, Prof. Dinesh Korjen (IITGN) was planned a study the seemingly chaotic happenings on our roads. Two complex intersections in Ahmedabad were taken up for observation viz. Ellis Bridge junction and Juna Wadaj circle.

Ellis Bridge junction is a junction of 10 roads and has traffic police intervening in a couple of points during peak hours. Juna Wadaj circle connects 6 main roads and other smaller lanes. This place is regulated during peak hours, at three points.

Video footage of traffic flow at both places were obtained during free flow times, as well as, when traffic was regulated by policemen.

Some observations:

– Traffic signals were disregarded if there were no policemen manning the intersections.

– Pedestrians were at risk if they used Zebra crossings during traffic as vehicles would not stop even if pedestrians were on it.

– At the intersections, the two wheelers usually park on the zebra crossing while waiting for the signal to turn green.

– During non-peak hours conflicts would form and disperse by themselves.

– Regulation was required only during high density of traffic and when flow of vehicles in one direction dominated.

– Stoppage time was higher for everybody during regulated conditions.

– The geometry of a conflict is mostly a perpendicular block/ obstacle by vehicles moving from one's right and / or left.

– During a stoppage to allow one directional flow by stopping other directional flows, vehicles lined up behind each other, increasing the stoppage time for everybody.

– Right of way is presently a power play between the drivers who make eye contact and negotiate for crossing first.

– Motorists are good at gauging conditions on the road and adjusting their speed and direction to move as fast as possible.

– Generally, the desire is to keep moving. One is willing to slow down if it is possible to continue moving. Stopping completely (as at signals) in order to move again, one does reluctantly – which should explain the innumerable cases of 'jumping the signal'.

The most important question was that if self- regulation could work during intermittent traffic flow in non- peak hours, how we could replicate these conditions during peak hours so that the flow could be smooth without external regulation.

A geometric analysis of the conditions indicates that blocks are caused by vehicles moving in a perpendicular direction and are cleared when such vehicles pass. Usually the motorists adjust their speed and direction in order to navigate this with minimum stoppage. We could

go one step further and not let a block form at all! If a specific distance could be maintained between vehicles moving in a direction, all the different directional flows could happen seamlessly without anybody having to stop at all!

The challenge is how can we make this happen? Our current thinking is that we could provide every vehicle with a simple signalling device that helps you move with minimum stoppage by telling you when it is okay to move (green), when it is necessary to slow down (amber?) and when it is time to stop (red) by studying the speed and direction of vehicles in front, by one's side and the one's moving in perpendicular directions.

We understand that many complexities would be involved in implementation.

- How to populate the devices to every vehicle on the road?
- What is the incentive for one to follow the signals from this device?
- What if it breaks down?
- What if some vehicles do not follow the device's instructions at all?
- Will it work if there is a deadlock or jam?
- etc. etc.

4. Research in Earthquake Safety

- **Seismic Safety Assessment of Non-structural components**

  Buildings are usually equipped with Non-structural Components (NSCs) and cost of which remains in the range of 65-85% of the total building's cost. A large variety of NSCs are acceleration sensitive and hence, their safety assessment involves an estimate of the likelihood floor response in terms of peak absolute acceleration (and peak velocity). Performance assessment of buildings against an anticipated seismic hazard involves a displacement-based approach, for example, the pushover analysis (such as modal pushover), which does not provide any information on the likelihood of these dynamic responses. Incremental Dynamic Analysis (IDA) can be considered as a viable approach, in such cases, which however is computationally expensive and hence, is rarely practiced in a routine job. Consequently, safety assessment of NSCs is ignored unless the building is categorized as 'important' and IDA is adopted. **A procedure is developed in this study that enables modification of the pushover (MPA) results to predict the peak dynamic responses.** Steps involved in this procedure cannot be strictly derivable from the first principle, as implied by the name, but the resulting responses always match the theoretical results within the elastic regime. A number of illustrations are included to verify the close proximity of the prediction of proposed method against the rigorous and computationally expensive IDA. In summary, the framework offers a simple and offhand tool to assess the likelihood safety of acceleration sensitive NSCs, at least at the stage of preliminary assessment.

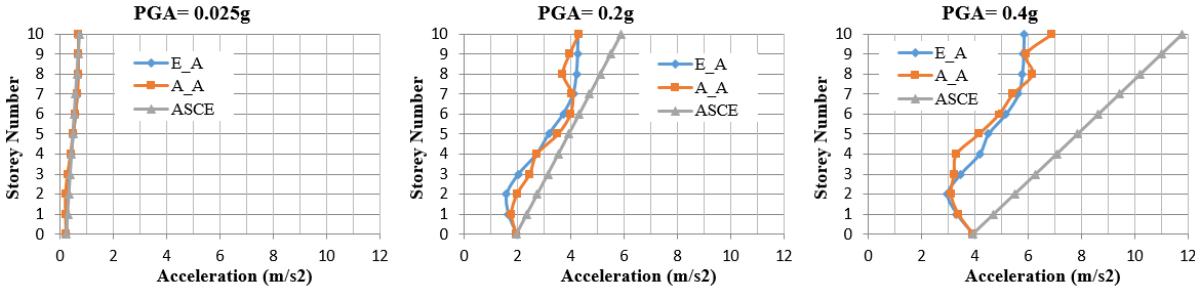


Figure : Peak absolute floor acceleration in ground motion-1 (based on MPA) —Building - B1

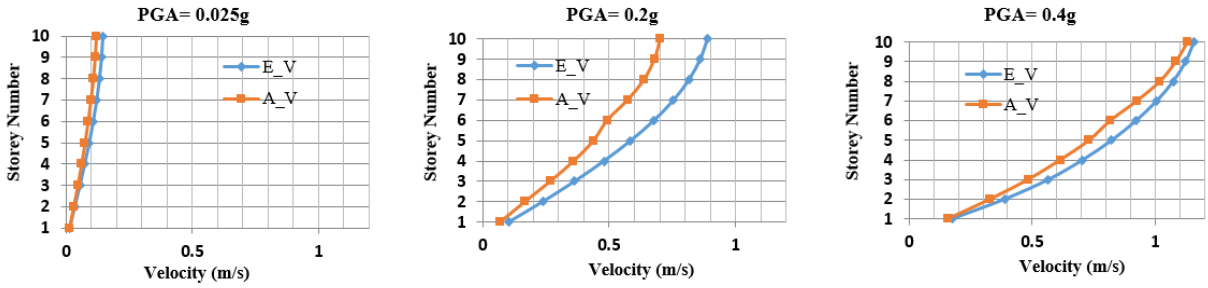
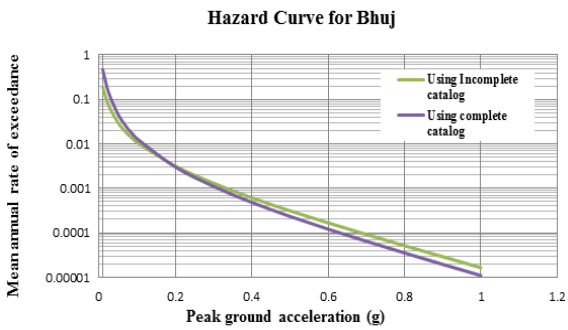


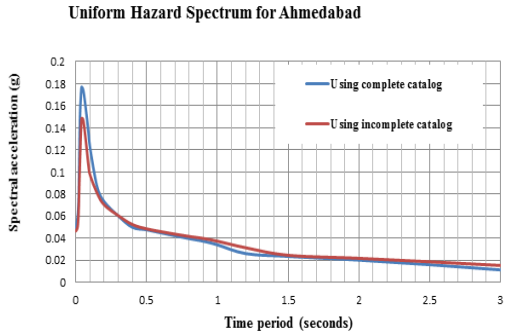
Figure : Peak floor velocity in ground motion-1 (based on MPA) —Building - B1

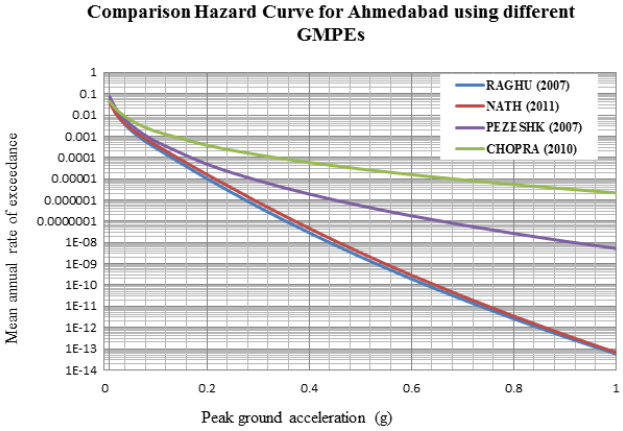
- **Seismic Hazard Analysis of Gujarat with a Focus on Ground Motion Characterization**

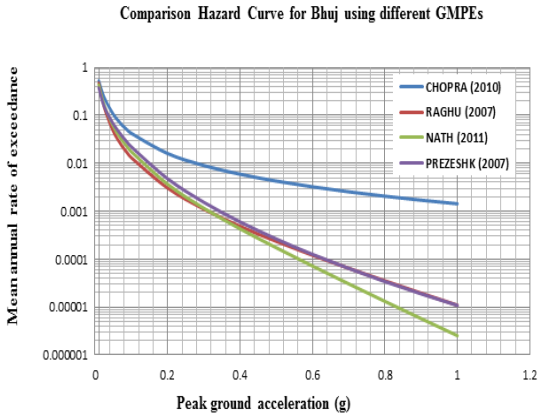
An effort is initiated to revisit the seismic hazard analysis of Gujarat with an emphasis to ground motion characterization. The state is divided into three source zones, namely, Kachchh (1819 – 2014), Saurastra (1872 – 2014) and Mainland (1821 – 2014). Length of the catalogue is shown within the braces. Attenuation relations relevant to the tectonic setting are chosen: i) Atkinson and Boore (2006); ii) Pezeshk et al (2007); iii) Toro et al (1997); iv) Raghukanth and Iyenger (2007); v) Nath et al (2011) and vi) Chopra (2010). Most of the seismic catalogues are biased against small shocks because of the seismograph station density. This bias is more severe in earlier recording periods and can lead to wrong estimation of the seismicity parameters. Apparently, the catalogue needs to be checked and corrected for completeness before it can be used for seismic hazard assessment. The correction, however, is likely to disregard a number of the recoded small events, which seems not appropriate. One of the objectives here is to study the effect of completeness correction on hazard curve and uniform hazard spectra (UHS). Other objectives of this study include incorporating the time-dependent seismicity model in general probabilistic seismic hazard framework, assessing maximum magnitude for each fault from the catalogue and study of the deaggregation (with epsilon) in a few selected cities including Bhuj and Ahmedabad.

Region	**Before Completeness Correction**		**After Completeness Correction**	
	a	**b**	**a**	**b**
Kachch	0.33	0.55	0.98	0.75
Saurastra	0.12	0.43	0.51	0.72
Mainland Gujarat	0.14	0.57	0.43	0.91









- **Other Works in Progress**
    - Estimating natural properties through full scaled testing of confined masonry buildings.
    - A new modal pushover analysis to account for the bidirectional horizontal and torsional ground motions.

4 Visitors @ IITGN Safety Centre

- Mr. Suresh Sugavanam (Managing Director for UL South Asia) visited IITGN on January 12, 2015.

Figure: Prof. Naran Pindoriya explaining the roof-top plant to Suresh Sugavanam.

- Mr. Desikan Srinivasa (Director, Operation of UL South Asia) visited IITGN and announced the winning teams of UL Safety Science Challenge 2014 on April 23, 2015. Total eight students were selected as winners of UL Challenge 2014.

Figure: Mr Desikan Srinivasa in UL Safety Science Challenge 2014 presentation

- R.A.Venkitachalam (VP, Public Safety, Underwriters Laboratories) on June 18, 2015 for review of UL-IITGN joint research.
- Mr. G Vishwanathan (Former DGM, IPCL) visted on July 1, 2015 for Safety Centre review.
- Dr. Pravinray D. Gandhi (Corporate Fellow, Commercial and Industrial R&D) and R.A.Venkitachalam visited IITGN on October 14, 2015 to announce the UL Safety Science Challenge 2015 and overview of other student project.

Figure: Interaction with UL alumni and discussion on water purification prototype @ IITGN Palaj campus

- Dr. A P Tiwari (Outstanding Scientist, Director Reactor Control Division, Bhabha Atomic Research Centre, Reactor Control Division) visited IITGN for Safety Centre Review meeting on March 09, 2016.
- Prof. Bozidar Stojadinovic, Chair of Structural Dynamics and Earthquake Engineering, Department of Civil, Environmental and Geomatic Engineering, Swiss Federal Institute of Technology (ETH) Zurich, Switzerland. Prof. Stojadinovic delivered an lecture on “Modeling Community (Seismic) Resilience” on January 7, 2016 at IITGN
- Dr. J. Thomas Chapin (UL Corporate Fellow and Vice President, Research Underwriters Laboratories Inc.) and R.A.Venkitachalam (VP, Public Safety, Underwriters Laboratories) visited IITGN on February 26, 2015. Dr. Chapin delivered a seminar on "The Boeing Dreamliner 787 and the Lithium ion battery incident" to IITGN community. Also both the guests have met several faculty members and students. Students have showcased their work on electrical safety at Henry Merrill Safety Lab@ IITGN.

5 Workshop/Symposium/ Short course

- DST-Royal Society Scientific Seminar on Water, Food and Energy nexus arranged by Prof. Rajagopalan Srinivasan, March 02-04, 2015
- 1st Indo-Chinese Young Engineering Leaders Conclave (ICON –1), Technical Session on Safety: Culture and Technology, 7-9 October 2015.
- Short course on Geotechnical Investigation for Structural Engineering, October 15-17, 2015 by Prof. V.S. Raju, (Distinguished Honorary Professor, IIT Gandhinagar,

Former Director, IIT Delhi, and Dean IIT Madras) along with Prof. Ajanta Sachan (IITGN) and Prof. Amit Prashant (IITGN)

6 Publications

Monograph published under series 'Campus on Sabarmati' by Prof. S. K. Jain and coauthors

This publication is the first in a series describing the development of IIT Gandhinagar's campus on the bank of river Sabarmati in Gandhinagar. The campus development provided numerous opportunities for innovation and the series is meant to document these. The focus of this first document is on the use of confined masonry for the housing. Confined masonry construction has a proven record of good seismic performance, is economical, and does not require very large engineering effort in design and construction. This publication describes the use of confined masonry construction technology for thirty-plus housing buildings (student hostels and faculty and staff apartments). It is hoped that this monograph will help sensitize and educate building professionals in India and elsewhere about the excellent features of confined masonry.

Editorials in the Bridge and Structural Engineer

Jain, Sudhir K., "Seismic safety challenge in India", The Bridge and Structural Engineer, vol. 45, no. 1, Mar. 2015.

Edited special issue of Journal of Loss Prevention in the Process Industries

Prof. Rajagopalan Srinivasan and Chinmay Ghoroi edited a special edition of Journal of Loss Prevention in the Process Industries (Elsevier journal). The special issue contains the selected papers from the International Conference on Safety, 2014 – Commemorating the 30th anniversary of the Bhopal gas disaster. Based on feedback from the program committee, session chairs, and other delegates a small number of the over 50 process safety related papers presented in the ICS 2014 conference were invited to submit an extended version of their paper. The special issue is in the process of publication.

Journal Papers

1. Kumar P. and Gaurav, S.. Numerical modeling of structural frames with infills subjected to thermal exposure: State-of-the-art review. *Journal of Structural Fire Engineering*, 2016. (in review).
2. Basu, D. and Giri, S.. "Accidental eccentricity in multistory buildings due to torsional ground motion." *Bulletin of Earthquake Engineering*, Vol. 13 (12): 3779-3808.
3. Basu, D. and Whittaker, A. S. (2015). "Efficient Generation of Statistically Consistent Demand Vectors for Seismic Performance Assessment", *Journal ING-IABSE*, Special Issue on Earthquake Engineering, March-2015.
4. Basu, D., Whittaker, A. S. and Constantinou, M. C. "Characterizing rotational components of earthquake ground motion using a surface distribution method and response of sample structures." *Engineering Structures*, Vol. 99: 685-707, 2015.
5. Bhavsar, P., Srinivasan, B., and Srinivasan, R.,. Pupillometry Based Real-time Monitoring of Operator's Mental Workload to Prevent Human Error during Process Operations, *Industrial & Engineering Chemistry Research*, 2016 (In Press).
6. Kodappully, M., B. Srinivasan, and R. Srinivasan, Towards Predicting Human Error: Eye Gaze Analysis for Identification of Cognitive Steps Performed by Control Room Operators, *Journal of Loss Prevention in the Process Industries*, 2016 (In Press).
7. Sharma C., P. Bhavsar, B. Srinivasan, and R. Srinivasan, Eye Gaze Movement Studies of Control Room Operators: A Novel Approach to Improve Process Safety, *Computers & Chemical Engineering*, 85, 43-57, 2016.
8. Jain, Sudhir K.; Brzev, Svetlana and Rai, Durgesh C., "Use of confined masonry for improved seismic safety of buildings in India", The Bridge and Structural Engineer, vol. 45, no. 1, pp. 29-39, Mar. 2015.

Conference Presentations

1. R. Srinivasan, Cognitive Engineering: Eliciting the Building Blocks of Human Error during Decision Making, 3rd International Conference on Cognition, Brain and Computation, Gandhinagar, India, Dec 5 -7, 2015.
2. K. Madhu, B. Srinivasan and R. Srinivasan, Event Driven Multivariate Analysis of Eye Gaze Data for Behavior Analysis in Process Operations, AIChE Annual Meeting, Salt Lake City, UT, Nov 7—13, 2015, Paper #243i
3. P. Bhavsar, B. Srinivasan and R. Srinivasan, Performance Monitoring of Control Room

Operators through Eye Gaze Analysis, AIChE Annual Meeting, Salt Lake City, UT, Nov 7—13, 2015, Paper #703h

4. P. Bhavsar, S. Parmar, B. Srinivasan and R. Srinivasan, Attention Aware Systems in Process Control Rooms through Real-Time Pupillometry, AIChE Annual Meeting, Salt Lake City, UT, Nov 7—13, 2015, Paper #721d
5. P. Bhavsar, S. Parmar, K. Madhu, B. Srinivasan and R. Srinivasan, Cognitive Engineering: Towards Preventing Human Error during Process Operations by Real-Time Monitoring of the Plant Operator, 12th International Symposium on Process Systems Engineering and 25th European Symposium on Computer Aided Process Engineering , Copenhagen, Denmark, May 31- Jun 4, 2015.
6. P. Kumar and Gaurav. Thermo-mechanical modeling of reinforced concrete masonry infill panels exposed to fire. In EMI/PMC 2016, USA, May 2016.
7. Gaurav. Structural Fire Engineering at IIT Gandhinagar. In International Workshop on Fire Research, IIT Madras, Chennai, February 2016.
8. P.R Prakash and Gaurav, Development of a Matrix Method Based Framework for the Thermo-Mechanical Analysis of RCC Frames, in Response of Structures under extreme loading: Proceedings of PROTECT-2015, pp. 972–980, 2015.
9. Basu, D. and Reddy, P. R. (2015). “Design of a New Passive Energy Dissipation System”, 5th Tongji-UBC Symposium on Earthquake Engineering, May 4-8, 2015 Tongji University Shanghai, China.
10. Rodda, G. R. and Basu, D. (2015). “Development of a Window Based Approach for Simplified Estimation of Rotational Ground Motion”, 5th Tongji-UBC Symposium on Earthquake Engineering, May 4-8, 2015 Tongji University Shanghai, China.
11. Jain, S.K., Brzev, S., Basu, D., Rai, D.C. and Mitra, K. (2016). “Confined Masonry Construction for Improved Seismic Safety of Buildings in India.”, International Seminar on Emerging Building Materials and Construction Technologies, BMTPC.
12. Jain, Sudhir K.; Brzev, Svetlana and Rai, Durgesh C., “Use of confined masonry for improved seismic safety of buildings in India”, The Bridge and Structural Engineer, vol. 45, no. 1, pp. 29-39, Mar. 2015.
13. Jain, Sudhir K. and Brzev, Svetlana, “Promoting sustainable and earthquake safe building construction practices in India”, Canadian Civil Engineer, Spring 2015, pp. 29-32, 2015.
14. Kumar, Manish; Rai, Durgesh. C. and Jain, Sudhir. K., “Ductility reduction factors for masonry-Infilled reinforced concrete frames”, Earthquake Spectra,, DOI: 10.1193/110512EQS322M, vol. 31, no. 1, pp. 339-365, Feb. 2015.

7 Other important activities

- IITGN has extended the appointment Dr. Pravinray D.Gandhi as Institute Guest Professor at IITGN for two more years till June 2018.
- Safety Centre supported summer scholarship to 8 undergraduate students to carry out their summer research on electrical fire project @IITGN.
- Prof. Rajagopaalan Srinivasan presented on Chemical transportation safety in UL 7th Fire Safety Council meeting 7 to 8 October, 2015 in Delhi.

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- Supported student poster presentation: Priyanka Bansal, Rajagopalan Srinivasan, "Harmonizing Process Safety Standards using text miining techniques" in 2nd CCPS Global Summit on Process Safety, Kuala Lumpur, Malaysia, 3 - 5 November, 2015
- M.Tech thesis submitted by Kunal Ghaisas (2015) "DISPLACEMENT BASED DESIGN FRAMEWORK FOR CONFINED MASONRY SYSTEM USING STRUT AND TIE MODEL" under the guidance of Prof. Dhiman Basu.

Abstract

The confined masonry construction has become increasingly popular in earthquake prone areas due to its satisfactory performance in withstanding the past seismic events and low construction cost. Computation and design member force resultants involves numerical modelling. Since FEM is computationally expensive, simplified approach like Wide Column Model (WCM) is widely accepted in routine seismic design. However it has its own limitations such as, inability to capture the stress concentration around the joints and openings. In such cases Strut and Tie Method (STM) serves as a viable alternative. A case study is presented identifying the lacunae of the current STM when applied to confined masonry system. One of the challenge is the inherent indeterminacy. An approximate approach is proposed to resolve the issue. Further Performance Based Earthquake Engineering has been accepted all over the world. However little has been reported to date in context with the design of confined masonry system. A design framework is proposed in this thesis, with numerical modelling for performance assessment. Example problem is included and compared with the experimental results reported in literature. Overall, the proposed

framework shows a great promise of developing performance based design of confined masonry system.