Vol. 04 | November 2023

SEISMIC ACADEMY

Seismic ACADEMY

JOURNAL

EARTHQUAKES

- Case Studies
- Events
- Seismic Splendour

Seismic Academy Journal

An Initiative by HILTI
Building Benchmarks for Industry and Academia

A CE&CR Production
unmatched coverage

SEISMIC ACADEMY

A forum for professionals, academicians, authorities and industry experts to interact and disseminate knowledge on various aspects of earthquake engineering with different stakeholders, with an intent to increase awareness and develop their expertise on the subject.

OUR VISION

To make seismic academy as one source of information and use it for promotion of all seismic initiatives in our country.

OUR ADVISORY BOARD

A CE&CR PRODUCTION

IN THIS ISSUE - Total No. of Pages: 28 (Including Cover)

For further information, contact -
Shounak Mitra, Head - Codes & Approvals (Fastening), Hilti India Pvt. Ltd.
M: 9899732127 | E: support@theseismicacademy.com

SEISMIC ACADEMY

FROM THE DESK OF ADVISORY BOARD

A country's economic growth is intricately linked to industrial demand and societal needs. Armed with technological advancements and innovative products, industries strive to balance societal requirements and market trends. These two factors coalesce in the infrastructure sector, where safety from earthquake events is one of the mandates. Thus, there is always a thrust to develop and introduce new seismic technology that is safer, economical, and durable.

The Seismic Academy understands that building a safer environment against seismic events depends on increasing societal awareness and establishing structured industry regulations. In the Indian context, seismic events are sporadic yet highly intense. The irregularity of earthquakes creates challenges with regard to public awareness, regulatory seriousness, and compliance issues. Hence, seismic safety needs to be tailored to suit the needs of different sections of society.

For example, industry contractors must understand and strictly abide by the differing safety regulations when building malls, railway stations, hospitals, and schools compared to constructing residential spaces. Lack of understanding affects regulatory compliance, leading to inefficient constructions that could be hazardous. Therefore, there is a need to mandate compliance, prioritise structures that require special safety regulations, and provide avenues to test innovations.

The Seismic Academy tackles these technological obstacles and compliance issues by creating pipelines to solve sector-wise problems using holistic approaches. Towards this, comprehensive resource repositories have been established, which have helped develop domain expertise. These efforts have provided an impetus to industrial innovations, reflected in the appearance of novel products in the market.

These unique multi-prong approaches taken by the Seismic Academy nurture R&D innovations, build core expertise, introduce revolutionary technology to the markets, and boost their widespread use. Through these strong foundational initiatives, the Academy creates a safer environment against seismic events with due consideration to the country's economic growth.

Dr. Amit Prashant
Professor of Civil Engg.
& Dean of Research & Devt.
IIT Gandhinagar

"These unique multi-prong approaches taken by the Seismic Academy nurture R&D innovations, build core expertise, introduce revolutionary technology to the markets and boost their widespread use."

TABLE OF CONTENTS

SEISMIC ACADEMY

Annual Conference 2023

SEISMIC RESILIENT INFRASTRUCTURE IN HEALTHCARE FACILITIES

The Second Annual Conference under the aegis of the Seismic Academy was organized on 31st August 2023 at India Habitat Center, Delhi.

To view the session videos and the event gallery please visit - https://theseismicacademy.com/event-detail/seismic-resilient-infrastructure-in-health-care-facilities---annual-conference-2023

EVENT DETAILS -

- **Venue - India Habitat Centre, New Delhi**
- **Date - 31st August '23**

ANNUAL CONFERENCE 2023

31ST AUGUST '23, NEW DELHI

Seismic Academy continued its saga with the second Annual Conference was organized on 31st August 2023 at India Habitat Center, Delhi. The theme for the conference was "Seismic Resilient Infrastructure in Healthcare Facilities".

More than 85 participants from standardisation bodies, practising engineers, academicians, and researchers working in the field of earthquake engineering and healthcare facilities were present at the conference, representing a variety of participants from across the nation disciplines, alike.

Our esteemed Advisory Board graced the conference and added their esteemed insights to the discussion. Senior practising consultants, academicians representation from government agencies like MCD, PWD, and CPWD, professionals from organisations like IAStructE, architects from the School of Planning & Architecture, representatives from Indian Institute of Health Management Research, Bureau of India Standards, National Institute of Disaster Management, Coalition for Disaster Resilient Infrastructure, Indian Society for Technical Education and engineering team from Life Insurance Corporation were among the participants.

The day started with a welcome address by Mr. Ashish Mittal, Vice President - Engineering, Hilti India Pvt. Ltd. who summarized the initiative and the progress in terms of the different activities which was made over the last year.

Er. Vinay Gupta, Managing Director, Tandon Consultants Pvt. Ltd. and Advisory Board Member, Seismic Academy shared his insight and perspective from the Advisory Board and how the academy can be an enabler to create precise content for reference by engineers.

Dr. Ajay Chourasia, Head – Structural Engineering, CSIR-CBRI and Advisory Board Member, Seismic Academy emphasized on the importance of seismic resilient infrastructure in healthcare facilities and highlighted on the need to secure building non-structural elements in the event of earthquake to retain hospital functionality without disruption and at the same time ensure safe evacuation of patients.

Mrs. Sangeeta Wij, Managing Partner, SD Engineering Consultants and Advisory Board design guidelines and recommendation laid down by the National Disaster Management Authority specific to healthcare facilities.

Mr. Amandeep Garg, Managing Director, Creative Design Consultants & Engineers Pvt. Ltd. spoke on the structural audit requirement and Dr. Pratima Rani Bose, Associate Director, DDF Consultants Pvt. Ltd. highlighted different case studies on hospital retrofit works carried out and learning from them.

Mr. Alok Bhowmick, Managing Director, B&S Engineering Consultants Pvt. Ltd. and Advisory Board Member, Seismic Academy shared his insights and some recommendation to the industry.

Dr. S.M. Ali, Director General, Solar Energy Society of India and Advisory Board Member, Seismic Academy gave valuable insight as to how the capacity building activities can be taken up more actively to build a competent future engineering fraternity.

The day also had 2 engaging panel discussions. The esteemed panelists included the likes of Dr. Abhay Gupta, Director, Skeleton Consultants; Dr. Vasant Matsagar, Dogra Chair Professor, Indian Institute of Technology Delhi and Advisory Board Member, Seismic Academy; Dr. Chandan Ghosh, Head Resilient Infrastructure Division, National Institute of Disaster Management, Government of India; Mrs. Madhurima Madhav, Joint Director - Civil Engineering, Bureau of India Standards and Dr. Amit Prashant, Professor, Indian Institute of Technology Gandhinagar and Advisory Board Member, Seismic Academy along with the speakers.

Like-minded stakeholders had a great opportunity to communicate, learn from one another, share ideas, and spread more information about the subject throughout the session. They also shared their expectation and willingness to associate and contribute in a more meaningful manner to the initiative. The day was brimming with learning and knowledge exchange.

The event was managed by Revered Media, a unit of CE&CR.

"The conference was well managed, organised and covered holisticly all related topics. The seismic academy initiative is good forum for knowledge & experience sharing. It provides a good platform for various stakeholders to experiment and explore new ideas and initiatives."

- Mr. Ankit Sahay

"I personally found the seismic academy and the conference really a very helpful. One of the most enjoyable and informative conferences/seminar I have ever attended. Thanks to the organisers & very special thanks to the great speakers."

- Er Dushyant Kumar

"I had an amazing experience at the Seismic Academy Annual Conference. The atmosphere was electric! It was an enlightening and enriching experience. I was inspired by the knowledge shared by the incredible speakers. It gave me a fantastic opportunity to network and connect with professionals in the industry. The organization and execution of the Conference were flawless. Hats off to the team for their hard work! I was blown away by the quality of presentations at the Seismic Academy Annual Conference. It exceeded my expectations. It was truly awe-inspiring. I appreciate the thoughtfulness and attention to detail put into every aspect of the Seismic Academy Annual Conference. It made for a seamless and enjoyable experience."

- Mr. Vishal Bhatia

"A great initiative to start Seismic Academy chapter in India. Though I have been attending the webinars by Seismic Academy, this has been my first time in the conference and had a very satisfying learning experience from the different experts. I belong to Uttarakhand which is highly prone to seismic activity. Apart from the seeking knowledge of the experts in this field, my personal interest was also a big reason for me. The conference has been a very enlightening experience and look forward to further webinars and conferences."

- Mr. Ravindra Shah

"It was an incredibly enlightening and well-organised event that left me with a wealth of valuable insights.

What truly made this conference exceptional were the insightful presentations and discussions. The speakers not only possessed a deep understanding of the subject matter but also had a remarkable ability to convey complex concepts in an accessible manner. Their expertise and real-world experiences provided valuable perspectives on the challenges and solutions in ensuring seismic resilience in healthcare facilities.

The panel discussions opened the floor for interactions amongst professionals, researchers, and practitioners who share a passion for ensuring the safety and resilience of healthcare infrastructure. These interactions opened up avenues for potential collaborations and knowledge sharing that I look forward to exploring in the future.

I left the conference feeling inspired and armed with a deeper understanding of the critical importance of seismic resilience in healthcare facilities."

- Ms. Sanika Upasani

"The conference was an eye opener when it comes to resilient and safe designing, especially for healthcare infrastructure, which is supposed to be the 'last building standing' in all disasters. To have professionals together as a community, working rigorously towards providing safety to the citizens and hospitals, is an important source of security and certainty for the communities and the country."

- Ms. Sumedha Dua

EARTHQUAKE VULNERABILITY IN AND AROUND INDIA IN THE RECENT PAST

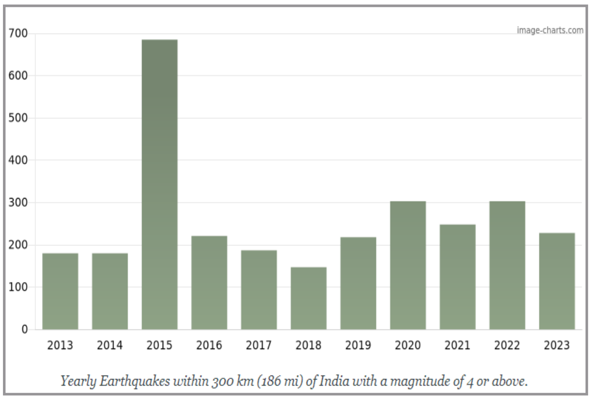
India is positioned on the boundary of the Indian and Eurasian tectonic plates, making it susceptible to earthquakes. The Himalayan region, in particular, is a seismic hotspot due to the ongoing collision between these plates. The convergence of these plates generates immense tectonic stress, periodically released in the form of earthquakes.

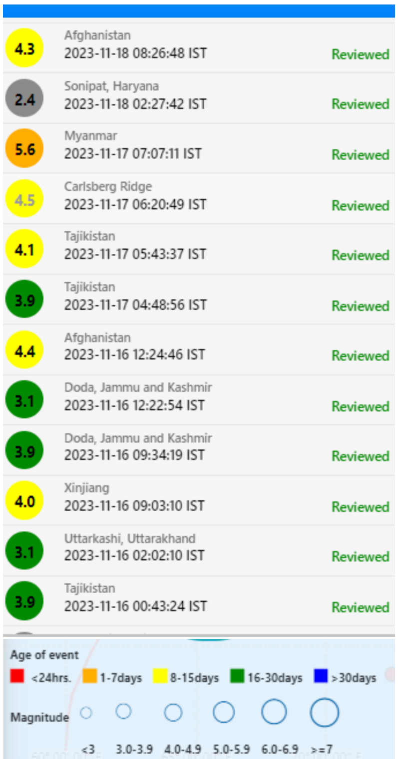
Over the past decade, India has experienced a staggering total of 2748 earthquakes with a magnitude of four or above within a 300 km radius. This comes down to a yearly average of 274 earthquakes per year, or 22 per month.

In 2015, a large number of earthquakes occurred near India. That year, 685 earthquakes of magnitude 4 or higher were detected within 300 kilometres of India. The most powerful had a magnitude of 7.8. Since the epicenter of this devastating earthquakes was in Nepal, the impact was strongly felt in northern India.

The table below depicts the distribution of all earthquakes that occurred within 300 kilometres of India in the previous ten years.

MAGNITUDE	EARTHQUAKES	PERCENTAGE
MAG. 4	2514	91.65%
MAG. 5	217	7.91%
MAG. 6	10	0.36%
MAG. 7	2	0.07%
MAG. 8	0	0.0%
MAG. 9	0	0.0%
MAG. 10	0	0.0%





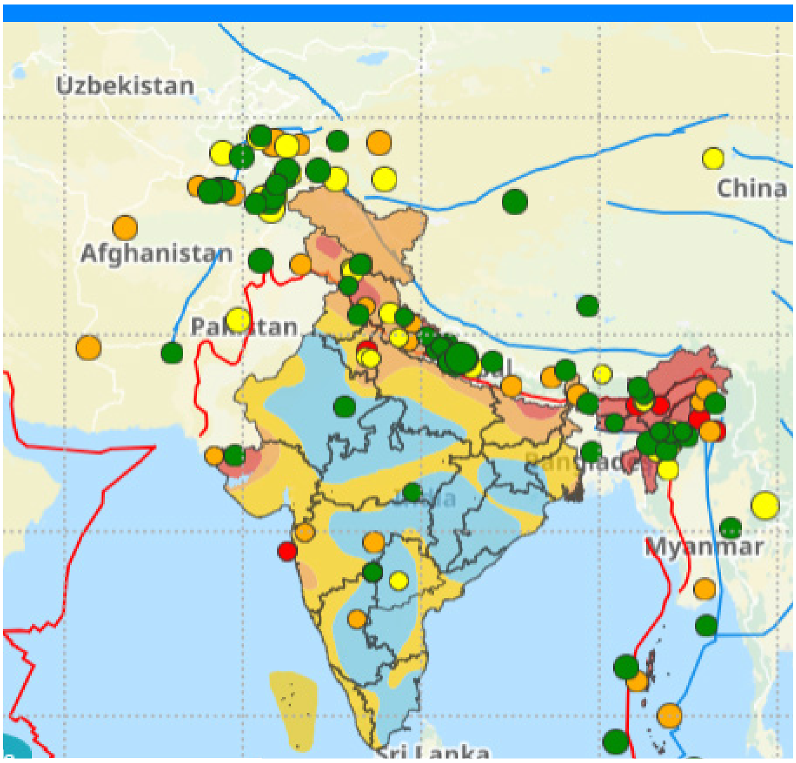


Image Source: https://riseq.seismo.gov.in/riseq/earthquake

2 EARTHQUAKES RAVAGE AFGHANISTAN WITH DEATH TOLL CROSSING 2000 AND FLATTENING HUNDREDS OF HOMES

Four large earthquakes measuring **magnitude 6.3** and their aftershocks struck Herat Province in western Afghanistan. The first two earthquakes struck near Herat on 7th October '23, followed by numerous aftershocks. Two more magnitude 6.3 earthquakes struck the same area on 11th & 15th October '23. These earthquakes were linked to thrust faulting. The complex and active tectonic interactions between the Arabian, Eurasian, and Indian plates are responsible for Afghanistan's seismicity.

The first event, with a magnitude of 6.3, took place at 11:11 AFT. An afterschok with a magnitude 5.5 occured exactly eight minutes later. At 11:42 AFT, another event struck with a magnitude 6.3, followed by a magnitude 5.9 aftershock. On 11th October '23, a third earthquake occurred with a magnitude of 6.3 in the same area, followed by another of the same magnitude on 15th October '23.


Image Source: https://thehill.com/

According to assessments, the earthquakes destroyed over 21,500 homes, mostly in Herat, Injil, and Zindajan districts, affecting approximately 154,000 people.

FARIDABAD HIT BY 3.1 MAGNITUDE EARTHQUAKE , CAUSING TREMORS ACROSS DELHI-NCR

On 15th October '23, Delhi-NCR was affected by earthquake as reported by the National Center for Seismology (NCS).

A **3.1 magnitude earthquake** occurred in Faridabad, Haryana, at a depth of 10 kilometers.

According to the NCS, the epicentre of the earthquake was 9 km east of Faridabad.

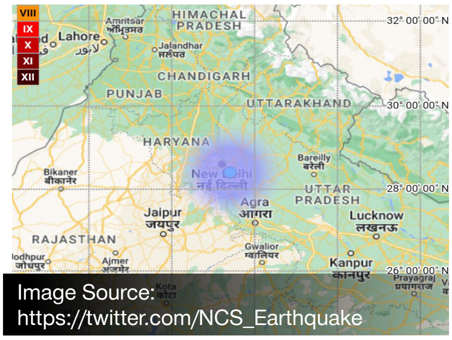


Image Source: https://twitter.com/NCS_Earthquake


Image Source: https://www.hindustantimes.com/

EARTHQUAKE STRIKES ANDAMAN AND NICOBAR ISLANDS, MULTIPLE TREMORS REPORTED

A **magnitude 5.1** earthquake occurred in the Andaman Sea off the southeast coast of the Andaman Islands on 1st November '23. The epicenter was about 89 km south-southeast of Port Blair.

This is subsequent to the 4.3 and 5.8 magnitude earthquakes struck the Andaman and Nicobar Islands magnitude earthquake on 3rd August and 29th July '23 respectively.

EARTHQUAKES RATTLE MEGHALAYA AND NEPAL WITHIN A SPAN OF 24 HOURS

An earthquake of **magnitude 5.2** jolted North Garo Hills in Meghalaya on 2nd October '23**.** The earthquake's epicentre was located around 3 km from Resubelpara, the district headquarters. The jolt was also felt in nearby states like Assam, and northern part of West Bengal and Sikkim. This follows the two earthquakes of magnitudes 4.4 which hit Assam over the past 2 months at Cachar district and West Karbi Anglong district.

Meanwhile, within an hour time, two major earthquakes rocked western Nepal on 3rd October '23, with strong tremors felt in parts of north India including Delhi-NCR. The quakes of **magnitude 6.2 and 4.6** struck in the afternoon and triggered a landslide near its epicenter. Two aftershocks of magnitude 3.6 and 3.1 followed the main shock.

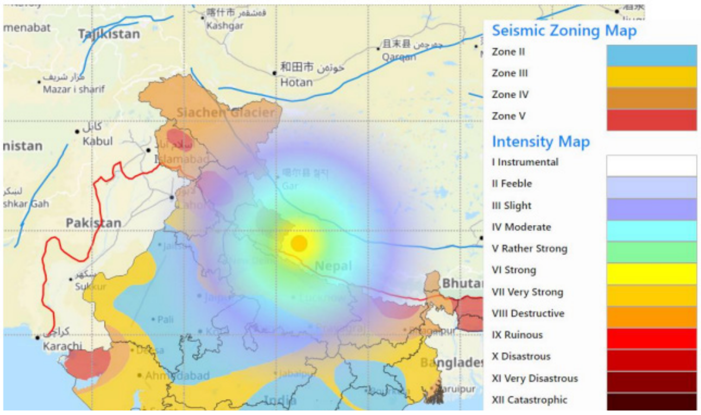


Image Source: https://seismo.gov.in/sites/default/files/pressrelease/Earthquake_report_revised_03_10_2023.pdf

The quakes reportedly blocked a major highway in Nepal. One person was person was injured by a falling object while some houses collapsed in Chainpur town. At least five people have been admitted at the District Hospital Bajhang after the earthquakes.

A building of the district police office in Bajhang was damaged and several houses developed cracks, according to the local administration office. While the tremors were felt strongly in India, there were no immediate reports of damage. Nepal lies in one of the most active tectonic zones (seismic zone IV and V) of the world, making the country extremely vulnerable to earthquakes.

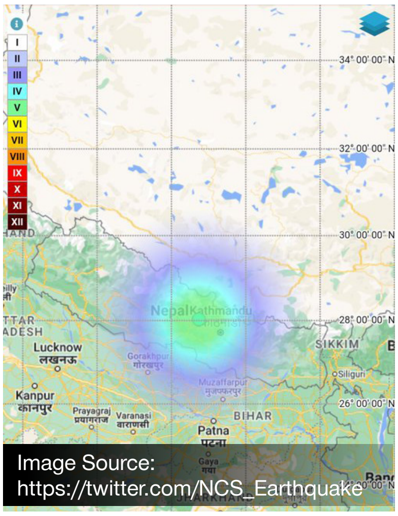


Image Source: https://twitter.com/NCS_Earthquake

EARTHQUAKE STRIKES NEPAL TWICE IN A DAY

Two consecutive earthquakes rattled Nepal on 22nd October '23, with the second one measuring 4.3 on the Richter scale, as reported by the National Center for Seismology.

The earthquake, occurred at 5:18 pm, with its epicenter.
It struck at a depth of 5 kilometers beneath the ground within Nepal. The earlier earthquake, measuring 5.3 on the Richter scale, jolted Nepal at 7:24 am the same day.

The country is located on the ridge of where the Tibetan plate and Indian tectonic plate meet and advance two meters closer to one another every century. The pressure so generated gets released in the form of earthquakes.

This follows the 4.8 magnitude earthquake in Nepal's Sudurpaschim province a week before. It's worth noting that in 2015, Nepal suffered a devastating earthquake with a magnitude of 7.8, which resulted in the loss of around 9,000 lives.

NEPAL STRUCK BY EARTHQUAKE, LEAVING 128 DEAD AND MANY INJURED

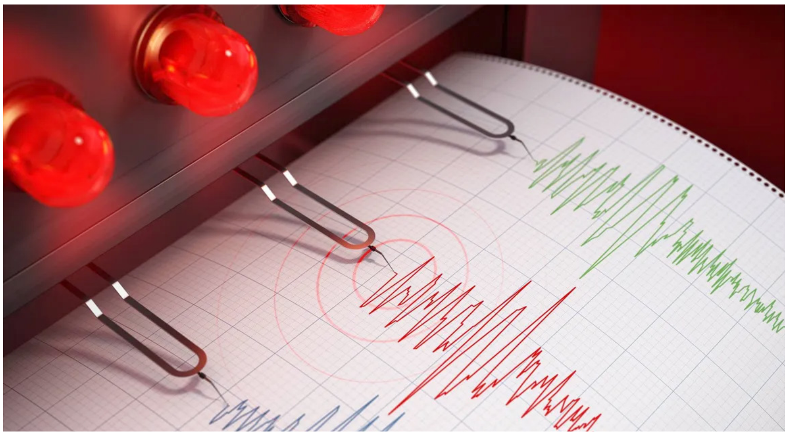
On 3rd November '23, a 6.4 magnitude earthquake struck in the Jajarkot and Rukum Districts in Nepal causing extensive damage. Reportedly, nearly 153 people have lost their lives and nearly 338 people have been injured. Over 4,000 homes were damaged in the hardest hit districts. About 10,000 people have been forced to leave their homes after the earthquake, with many families losing everything in the ruins of their homes.


Image Source: https://www.instagram.com/p/CzNSGEpx-SoR/?img_index=1

Hospitals have been struggling to cope with the number of injured people and more than 300 schools have been destroyed. As the country was grappling with the aftermath of this earthquake, the land was hit by another tremor of magnitude 5.6 on 6th November 2023.

Nations must recognise that high precision in earthquake prediction is a critical scientific challenge in the ongoing pursuit of earthquake preparedness. As seismic events shape the landscape, leveraging artificial intelligence (AI) becomes increasingly important, providing a powerful tool for analysing vast datasets and identifying patterns, ultimately improving our understanding and response capabilities in the face of inescapable seismic challenges.

ARTIFICIAL INTELLIGENCE PREDICTS EARTHQUAKES WITH A 70% ACCURACY RATE ONE WEEK BEFORE THEY OCCUR.



Some artificial intelligence models are now used to predict earthquakes with a high degree of certainty by examining geological features and previous seismic data. These models estimate the probability of earthquakes occurring in specific areas over a given time period. These forecasts, however, are frequently too general to account for precise predictions.

It is critical to understand that earthquake prediction is a difficult task because earthquakes are caused by the movement of tectonic plates deep within the Earth's crust, a process that involves a number of variables and uncertainties. Even though artificial intelligence can aid in the analysis of earthquake-related data and the improvement of early warning systems, accurately predicting the exact timing, location, and magnitude of an earthquake remains a difficult task.

This could soon change. Researchers at The University of Texas (UT) at Austin tested an AI algorithm that predicted 70% of earthquakes a week in advance. The trials, which lasted seven months in China, raised hopes that a reliable AI system for predicting earthquakes would soon be available.

The AI system had the ability to predict the location and strength of 14 earthquakes within about 200 miles of where they in fact occurred. Only eight false warnings were flagged by the system, and one earthquake was missed.

As a next step, the AI will be tested in Texas using the bureau's TexNet data, which includes information from over 300 seismic stations and more than six years of continuous records.

References

- https://earthquakelist.org/india/#major-latest-earthquakes
- https://crisis24.garda.com/alerts/2023/11/india-a-magnitude-51-offshore-earthquake-occurs-near-the-andaman-islands-at-around-1821-nov-1
- https://economictimes.indiatimes.com/news/india/earthquake-of-magnitude-4-3-jolts-andaman-and-nicobar-islands/articleshow/102370587.cms
- https://en.wikipedia.org/wiki/2023_Herat_earthquakes
- https://reliefweb.int/disaster/eq-2023-000184-afg
- https://indianexpress.com/article/cities/delhi/tremors-felt-across-delhi-ncr-after-3-1-magnitude-earthquake-hits-faridabad-8984118/
- https://www.livemint.com/news/world/earthquake-today-4-3-magnitude-quake-struck-nepal-today-evening-11697977141594.html
- https://www.reuters.com/business/environment/nepal-hit-by-64-earthquake-felt-new-delhi-2023-11-03/
- https://interestingengineering.com/innovation/ai-predicts-70-of-earthquakes-a-week-before-they-occur

STRUCTURAL ASSESSMENT AND STRENGTHENING OF BRIDGE NO. 5/5 AT UMNGI RIVER (UMPUNG) ON BALAT BAGLI ROAD, MEGHALAYA, INDIA

Er. Ayush Agarwal
Structural Consultant
Cadmetric Consulting

Er. Lambha Deilang Suchiang
Secretary (Roads)
PWD Meghalaya (Retired)

Dr. Jayanta Pathak
Professor & HOD
Civil Engineering
Assam Engineering College

Er. Khangenbom Prasenjit Singha
Structural Rehabilitation Expert &
Proprietor
NT Industries

INTRODUCTION

Bridges are the lifeline of any region and aging and degradation of transportation infrastructure pose significant safety concerns, with increase in the vehicular traffic on such bridges, for which, they were not designed. The structural health assessment of such old bridges are very important and involves a process starting form a visual inspection to detailed non-destructive test programme without affecting the flow of the traffic during such exercises. The bridges in the state of Meghalaya are mostly in deep valley connecting otherwise inaccessible mountains and hills and assesment and monotroing of such high bridges are challenging for the engineering departments. The bridge No. 5/5 at Umngi River (Umpung) on Balat Bagli Road is one such bridge, which was built about 60 years before by the Public Works Department of the undivided Assam. The bridge is 150 m long in total with 4 spans of 37.5 m each resting on tall piers of average 1.75 m diameter, sitting on well foundations as shown in Fig. 1 and 2. The pier above the well TOC is about 8.4 m up to the pier head as shown in Fig. 2.

It is important to carry out a detailed assessment of this old bridge to understand the status of the bridge in terms of its resilience to increased traffic loading and overall adequacy and integrity of the structural components viz. piers, girders etc against prescribed seismic loading. A detailed inspection and assessment programme was planned and executed to understand the structural health and integrity of the bridge structure and prepare necessary advisory for retrofitting the structure with feasible economics.

Figure 1:
Total length 150 Meter with 4 Spans of 37.5 meter each

Figure 2: Pier heights are 8.4 meter each

USE OF DRONE FOR RAPID VISUAL SCREENING (RVS)

The application of drones have been seen in various areas now a days and remotely controlled drone (Figure 3) was used in extensive initial inspection to access difficult areas, locations and surfaces to accomplish the initial Rapid Visual Screening (RVS) of the bridge. The visuals were streaming from the drone camera to a hand-held station / data logger and the necessary assessment photographs were captured and stored for subsequent detailed studies. It was thereby possible to access and visually inspect locations, which were otherwise not assessable physically.

Figure 3: Drone Survey at the site for RVS with remote access

Figure 4: Drone accessing difficult locations for RVS - Pier Top

Figure 5: Suspended platform for physical access and NDT at site

NON-DESTRUCTIVE TESTING PROGRAMME FOR HEALTH ASSESSMENT

A detailed Non-Destructive Testing (NDT) programme was planned to assess the structural health of the bridge components. The quality checking of the concrete is of utmost interest for assessing overall structural integrity and adequacy of the bridges. The main purpose of the testing is to determine the quality of the concrete on all the piers and girders and to determine the possibility of retrofitting of the same in view of enhanced safety for traffic movement. The NDT carried out are briefly described below.

Ultra Sonic Pulse Velocity (USPV) Test: Ultrasonic Pulse travel faster in denser material and each material has its typical ultrasonic pulse velocities viz. Steel, Concrete etc. Using benchmarks over a period of time and conducting extensive laboratory and in-situ tests, ultrasonic pulse velocity is correlated with quality of concrete.

A customized suspended gondola (Figure 5) was specially fabricated for the NDT jobs in the bridge. The suspended gondolas were prepared with wheel and pulley based Jib - crane to safely suspend them from the deck of the bridge and move the system along the length of the bridge without disturbing the traffic flow during the entire testing programme.

DETAILED STRUCTURAL ASSESSMENT OF THE BRIDGE GIRDERS

To carry out a detailed structural assessment of the bridge girders, a 3-D computational model (Figure 7) is developed, and appropriate dead and imposed loads are applied to the model. The vehicular is defined as IRC Class A Loading and applied as a moving load to

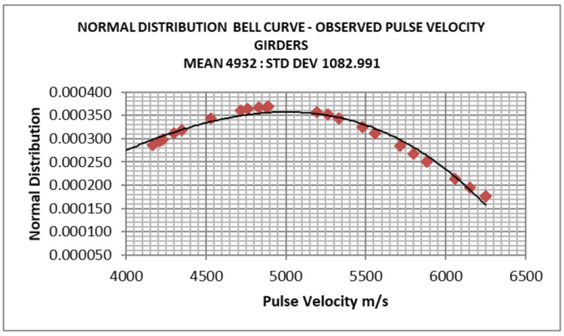


Figure 6:
Normal Distribution of the observed USPV data in the girders of the bridge. The quality of concrete in all the girders were found to be of excellent quality as per NDT data.

assess the maximum demand forces at different sections along the span of the girder.

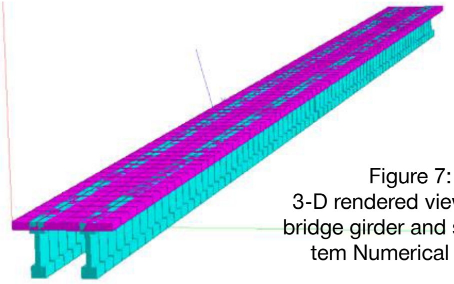


Figure 7: 3-D rendered view of the bridge girder and slab system Numerical Mode

demand is greater than the capacity of the girder. Strengthening of girders using Carbon Fibre Reinforced Polymer (CFRP) Laminates is thus explored.

- For girder sections near support, it is observed that the shear demand is greater than the capacity of the girder. Strengthening of girders using Carbon Fibre Reinforced Polymer (CFRP) Wraps is thus explored.

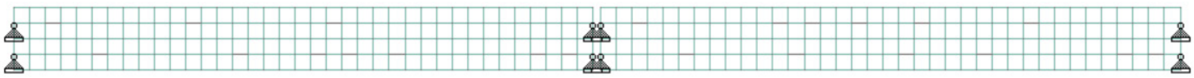


Figure 8: Plan view of the bridge girder and slab system Numerical Model

CAPACITY ANALYSIS OF THE PRE-STRESSED GIRDER

To estimate the bending strength of the pre-stressed girder, a moment-curvature analysis is performed for girder sections at 6 different locations along the span of the bridge. The maximum moment capacity is then plotted along the length of the girder to obtain the capacity curve, which is then compared with moment demand curve as shown in Figure 9. Similarly, the shear demand and capacity for the girder is calculated and compared as shown in Figure 10.

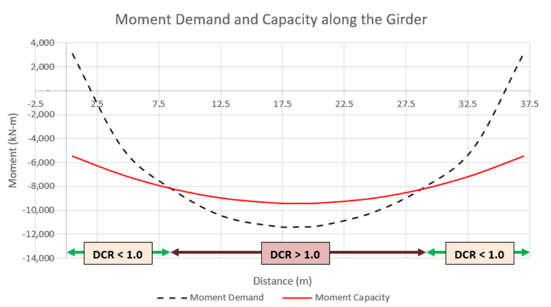


Figure 9: Comparing Moment Demand vs Capacity along the span of the girder

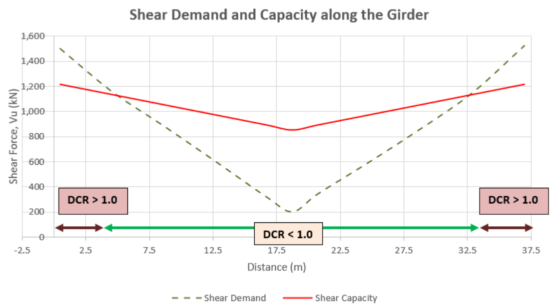


Figure 10: Comparing Shear Demand vs Capacity along the span of the girder

ANALYSIS RESULT

- For girder sections near and around mid-span, it is observed that the moment

STRENGTHENING BY CARBON FIBRE REINFORCED POLYMER (CFRP) LAMINATES

Carbon Fibre Reinforced Polymer (CFRP) Laminates are be used to increase the ultimate moment capacity of the girders. Figure 11 below compares the increase in moment capacity of the girder strengthened with one and two layers of CFRP laminates.

From Figure 11, it is advised to provide 2 layers of CFRP Laminates along the mid 12-meter span of each girder, and 1 layer of laminate for an additional 6 meters on each side. Figure 12 shows the resultant moment capacity of the girder (after strengthening) and compares with the demand moment.

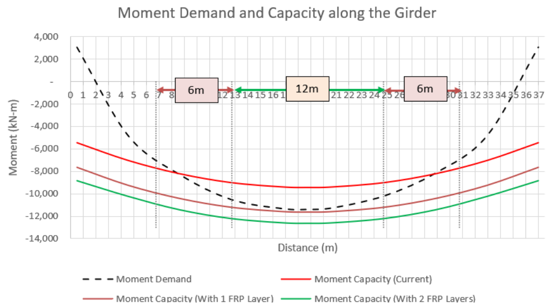


Figure 11: Comparing Moment Demand vs Capacity along the span of the girder (before and after strengthening)

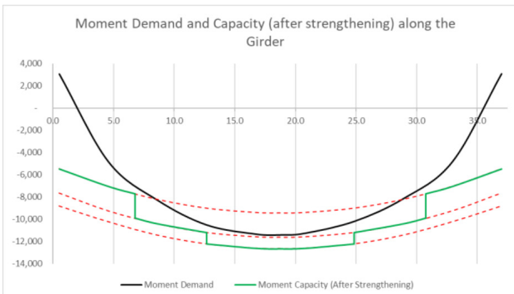


Figure 12: Comparing Moment Demand vs Capacity along the span of the girder (before and after strengthening)

CHECK FOR SHEAR STRENGTH (GIRDER STRENGTHENED WITH CFRP WRAPS)

Carbon Fibre Reinforced Polymer (CFRP) wraps are be used to increase the shear capacity of the girders. Figure 13 shows the increase in shear capacity of the girder strengthened with CFRP wrap. It is advised to provide 1 layer of CFRP wrap along both sides of the girder for a distance of 5 meters from the support.

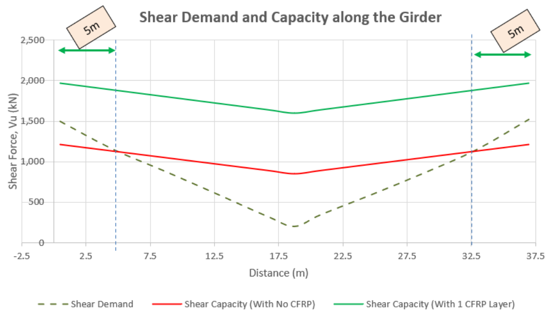


Figure 13: Comparing Shear Demand vs Capacity along the span of the girder (both with and without CFRP)

Seismic Demand	Peak Ground Acceleration (PGA)	Target Performance Level
Design Basis Earth-quake (DBE)	0.18g	IO (Immediate Occupancy)
Maximum Considered Earthquake (MCE)	0.36g	LS (Life Safety)

At Design Basis Earthquake (DBE): The Pier should perform within Immediate Occupancy (IO) Acceptability Criteria, i.e., after the earthquake, the pier should remain safe for continued operation, and essentially retain its pre-earthquake strength and stiffness.

At Maximum Considered Earthquake (MCE): Pier hinge should perform within Life Safety (LS) Acceptability Criteria, i.e., after the earthquake, the pier may be damaged, but would still have sufficient margin of safety against onset of partial or total collapse.

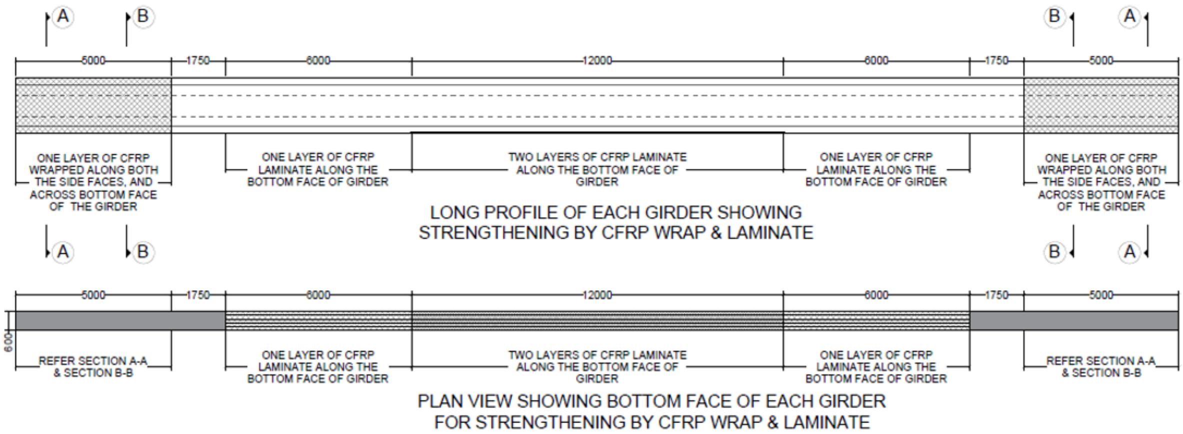


Figure 14: Strengthening of Bridge Girder using Carbon Fibre Reinforced Polymer (CFRP) Laminates and Wraps

DETAILED STRUCTURAL ASSESSMENT OF BRIDGE PIER

In order to carry out a detailed structural assessment of the bridge pier, a 2-D model with lumped non-linear hinge properties is developed, and appropriate dead and imposed loads are applied to the model. Then, a Static Pushover Analysis is performed to obtain the capacity curve of the pier, and check its performance at Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) levels. The non-linear hinge defined for static pushover analysis is based on guidelines as per ASCE41-17 Table 10-9.

PERFORMANCE OBJECTIVE

The performance objective of the pier is set as follows:

STATIC PUSHOVER CURVE

Figure 15 shows the Static Pushover Curve (Capacity Curve) for the bridge pier. The target displacement (demand) for DBE & MCE levels are calculated following guidelines as per ASCE41-13. Hinge status at target displacement is then compared with acceptability criteria for IO (Immediate Occupancy), LS (Life Safety) & CP (Collapse Prevention) in order to predict the performance level of the pier. Pier Hinge Status for Target Displacements at DBE and MCE are checked against acceptability criteria for IO & LS performance levels.

STRENGTHENING OF PIER BY REINFORCED CONCRETE JACKETING

Based on the results of Static Pushover Analysis, it is observed that the pier fails to achieve its performance objectives. Thus, Strengthening by Reinforced Concrete Jacketing (RCJ) is recommended to improve the performance of the pier. Reinforced Concrete Jacketing improves column flexural strength and ductility. For strengthening of the pier, a 200mm thick reinforced concrete jacket (as shown in Fig. 49) is added around the existing pier.

Seismic Demand	Target Performance Level	Target Displacement	Hinge Status	Remarks
DBE	IO	46mm	IO-LS	Target performance not achieved. Strengthening of Pier is recommended.
MCE	LS	93mm	> CP	Target performance not achieved. Strengthening of Pier is recommended.

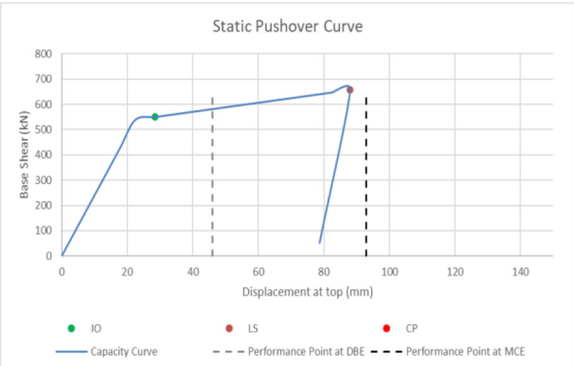


Figure 15: Static Pushover Curve for the Bridge Pier

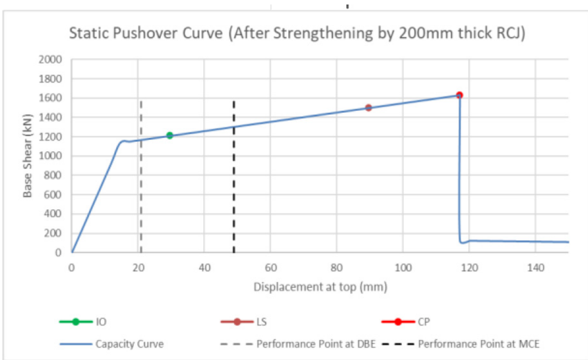


Figure 17: Static Pushover Curve of the Bridge Pier Strengthened with Reinforced Concrete Jacket

STATIC PUSHOVER CURVE (AFTER STRENGTHENING BY 200MM THICK RCJ

Figure 17 shows the Static Pushover Curve (Capacity Curve) for the bridge pier strengthened with 200mm thick reinforced concrete jacket. It is observed that after strengthening by Reinforced Concrete Jacket (RCJ), the pier successfully meets its performance objectives.

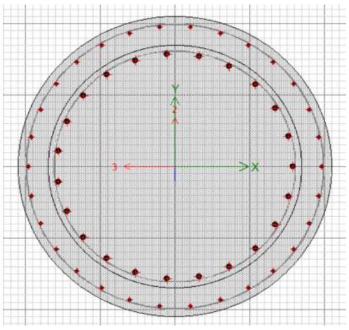


Figure 16:
Cross section of RC jacketed pier as defined in computational model

Seismic Demand	Target Performance Level	Target Displacement	Hinge Status	Remarks
DBE	IO	15mm	<IO	Target performance achieved. Strengthening of Pier is successful.
MCE	LS	34mm	IO – LS	Target performance achieved. Strengthening of Pier is successful.

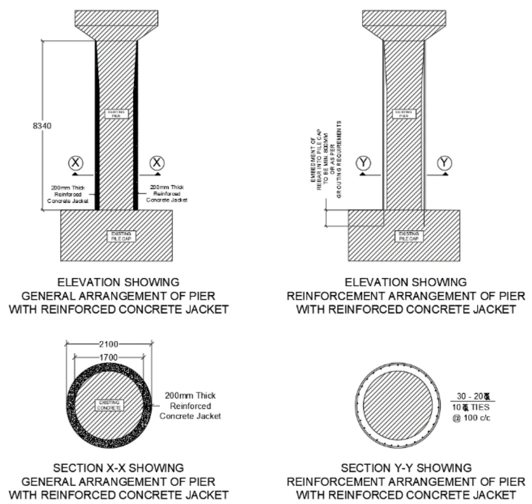


Figure 18: Strengthening of Bridge Pier by Reinforced Concrete Jacketing

Thus, Strengthening by Reinforced Concrete Jacketing (RCJ) is found to be effective in improving (and achieving) the performance of the pier.

CONCLUSION

The article presented the effort undertaken by the department of the PWD (Roads), Meghalaya to carryout inspection, assessment and retrofit the old bridges in the state. A brief of the effort undertaken with special reference to the Bridge No. 5/5 at Umngi River (Umpung) on Balat Bagli Road. The assessment work included capacity analysis and static pushover analysis followed by retrofitting design and implementation plan.

REPAIR AND REHABILITATION OF ADMIN BLOCK IN SCHOOL BUILDING

Mr. Rohit Yadav
Founder & Mentor, Texel Consulting Engineers Pvt Ltd

INTRODUCTION

Repair and rehabilitation are essential processes in maintaining and restoring structures and infrastructure. These terms are often used in addressing structural deficiencies, wear and tear, or damage to ensure the assets' continued functionality, safety, and longevity. Generally, repair is a corrective measure applied to rectify localized problems, such as cracks, leaks, or corrosion, whereas rehabilitation is a more comprehensive process that aims to enhance or restore the overall performance and capacity of a structure that has experienced significant deterioration. Rehabilitation has some environmental impact, but this impact is significantly less than the extensive demolition and rebuilding process for the structures that have been allowed to deteriorate without rehabilitation. Sometimes, rehabilitation is the only option due to functionality and economic aspects. A widespread misconception in this sector is the belief that rehabilitation serves as a means to conceal structural deterioration.

This case study comprises the details of the repair and rehabilitation of the admin building in a school situated in the central part of Rajasthan. It is a two-story building constructed about 35 years back, and the ground floor roof has deteriorated significantly, as shown in Fig. 1. Texel Consulting Engineers Pvt Ltd was appointed for the engineering part of this rehabilitation project. Engineers from the company conducted a site visit and encountered challenges such as the absence of drawings, a lack of information regarding the structural components, time constraints, and the need for minimal demolition. Upon visual inspection, the structure appeared to be a frame structure, as illustrated in Figure 2. However, upon closer examination, it was revealed that the columns in the elevation were constructed using stone masonry for aesthetic reasons.

Fig.1 – Deteriorated ground floor roof slab

Fig.2 – Exterior view of the building

CONDITIONAL ASSESSMENT AND SOLUTION

A conditional assessment of an existing structure involves evaluating its condition based on specific criteria or conditions. This assessment aims to determine the structural integrity, safety, and performance of the structure under various circumstances. The conditional assessment process comprises specific steps that vary depending on the problem statement. In this project, we adhered to the procedures outlined in Fig. 3 to assess the current structural strength.

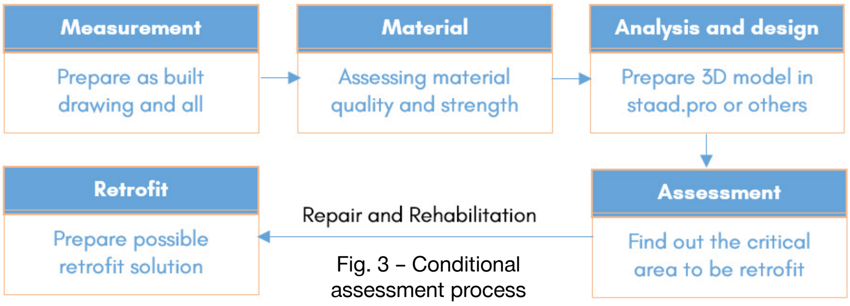


Fig. 3 – Conditional assessment process

In line with the procedure above, engineers conducted comprehensive measurements of the entire building, including masonry wall dimensions and beam-slab details. Non-destructive testing (NDT) methods, such as rebound hammer and ultrasonic pulse velocity (UPV), were employed to evaluate the concrete quality. Additionally, core samples were extracted to assess the closest compressive strength, as depicted in Fig. 4. Visual assessment of slab reinforcement was carried out in exposed areas, including measurement of reduced diameters using a vernier caliper. For areas where the reinforcement was not exposed, an instrument called HILTI Ps-200 was utilized to gather reinforcement information, as shown in Fig. 5.


Fig.4 – Extracted core and prepared sample

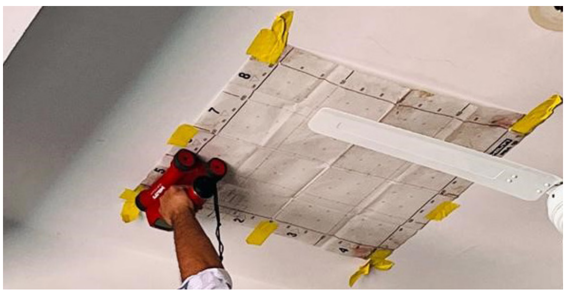


Fig.5 – Mapping by HILTI PS-200

Following the measurements and material assessment, the structural analysis revealed that the load-bearing masonry walls remained adequate and relatively undegraded. However, the beams and slabs experienced a loss of strength of approximately 30%. At this point, two processes are to be considered: first, repairing the deteriorated portions to prevent further degradation, and second, restoring the lost strength through a retrofitting technique known as rehabilitation. In the repair process, the following steps were followed.

1. **Chipping and removing loose concrete:** Loose and carbonated concrete on the surface of the existing beams and slabs was carefully chipped away using a chisel and hammer until sound concrete was exposed. Laitance, oil, and other impurities on the concrete surface were removed through grinding or sandblasting. The exposed reinforcement surfaces were also descaled using a brush to eliminate rust scales.
2. **Corrosion treatment:** An alkaline rust-converting primer was applied after removing all the rust scales from the corroded steel bars. This primer is alkaline and transforms hematite and magnetite compounds into stable compounds. Following the application of the primer, two coats of anti-corrosive epoxy coating were applied to protect the bars from future corrosion.
3. **Making up the lost section with polymer-modified mortar (PMM):** Before applying the PMM, a concrete bonding agent was used on the exposed concrete surface to ensure a strong bond between the concrete surface and PMM. A mixture comprising 50 kg of cement, 150 kg of sand, 2.5 to 5 kg of polymer latex, and 15-20 liters of water was prepared and applied to the surface after the bonding agent had reached a tacky consistency.

Following the repair process, the core aspect of the project revolved around selecting an appropriate retrofitting technique. While several techniques were available, each came with its own set of constraints. Strengthening through FRP laminates was deemed unfeasible due to inverted beams and limitations on minimal demolition. Breaking the floor above the roof was not an option.

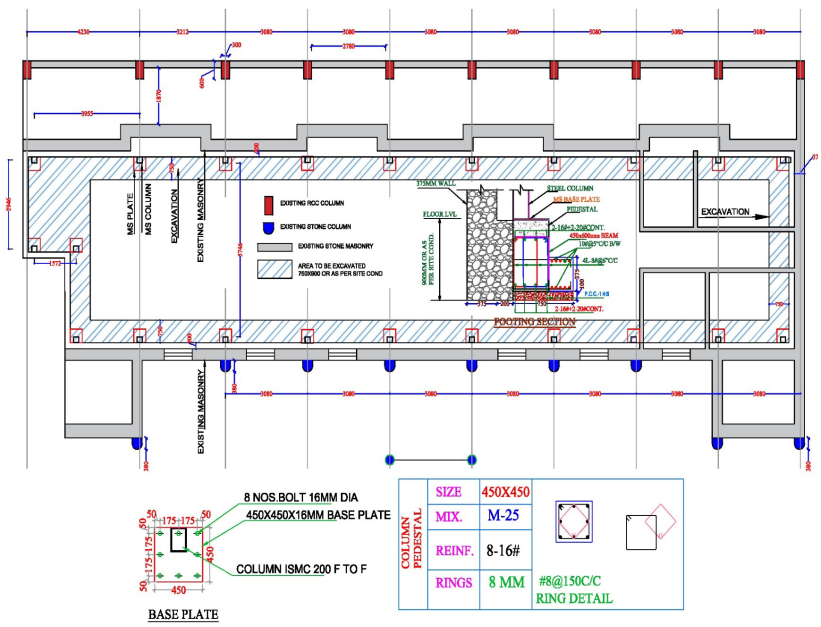


Fig.6 – Foundation layout to erect the steel column to support steel beams

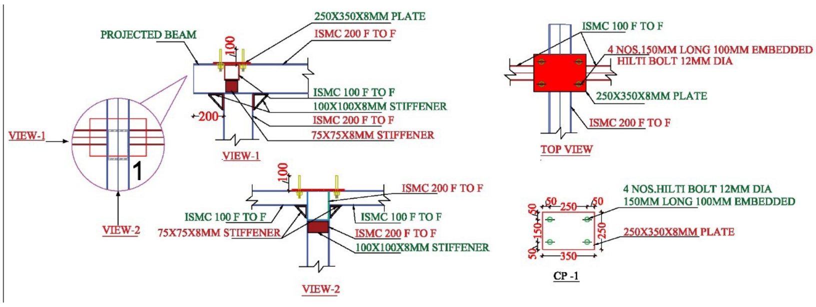


Fig.7 – Connection details (weld and chemical anchoring)

Additionally, the initial consideration of adding a steel beam under the existing beam was dismissed as it posed the risk of creating or transferring concentrated loads or moments to the masonry wall. Subsequently, the decision was made to divide the slab into smaller sections using transverse members positioned between the two beams. This approach eliminated the need for additional strengthening. The transverse members were securely embedded into the slabs through chemical anchoring as shown in Fig. 7. Steel beams were provided to support the concrete beams from below. However, as mentioned previously, these steel beams could not be directly connected to the masonry walls. Therefore, steel columns were erected beneath these beams, as illustrated in Fig. 8, and these columns were further supported by the continuous foundation, as depicted in Fig. 6.

Fig.8 – Structural Steel frame

Fig.9 – Finished after strengthening

CONCLUSION AND SUMMARY

In the process of repair and rehabilitation, the initial step involved addressing the problem statement, which led to a conditional assessment of the material's current condition. This assessment revealed the need for strengthening to increase the load-carrying capacity by approximately 30%. Subsequently, a structural model was selected, with the design focusing on a steel moment-resisting frame structure capable of handling about 40% of the total loads with an additional 10% safety margin.

In terms of execution, the foundation beneath the columns presented some challenges. However, a continuous footing design was adopted to overcome these challenges. On-site welding and chemical anchoring were employed for the execution of the work. The deteriorated sections underwent suitable repair techniques, and the entire structural system was clad and included a false ceiling.

Remarkably, the administration block was made functional within just 45-60 days, all achieved without significant demolition.

Training Program on

URBAN RISK MITIGATION – FOCUS ON SEISMIC & FIRE SAFETY

Held on 8th – 10th August '23

Organised by

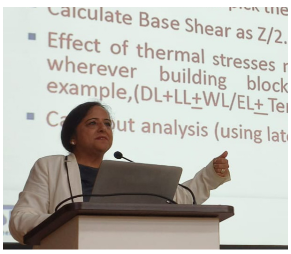
In Collaboration with

Officials and representatives from various government agencies, including the Departments of PWD, DMRC, Municipal Corporations, Development Authorities, Town Planning Departments, Skill & Entrepreneurship University, Irrigation & Flood Control Department, DDMA, Mines & Geology, Faculty from different institutes (BITS Pilani, Manipal Institute of Technology, etc.), practising engineers from Jaipur, Delhi, and other cities attended the workshop.

The workshop had clear direction setting in the inaugural session by Shri Rajendra Ratnoo (IAS), Executive Director, National Institute of Disaster Management, Shri Narendra Singh Bundela (IPS), Inspector General, National Disaster Response Force, Dr. Shailesh Agrawal, Executive Director, Building Materials and Technology Promotion Council, Mr. Arun Kumar S, Director & Head - Civil Engineering Dept., Bureau of Indian Standard, Dr. Chandan Ghosh, Head - Resilient Infrastructure Division, National Institute of Disaster Management, Dr. Garima Aggarwal, Senior Consultant, National Institute of Disaster Management and Mr. Shounak Mitra, Head-Codes and Approval, Hilti India Pvt. Ltd.

Mr. Jitendra Kumar Chaudhary, Assistant Director (Civil Engg.), Bureau of Indian Standard, started the workshop with an expert presentation on the creation of earthquake resistant standards in India and also touched on the revision of IS 1893.

Mrs. Sangeeta Wij, Managing Partner, SD Engineering Consultants, stressed the need of design requirements for critical life line buildings like as hospitals, citing previous earthquakes, human fatalities, and infrastructure loss. She also referred all practising engineers to the NDMA Guideline for Hospital Safety.



Shri Mohsen Shahedi, Deputy Inspector General, National Disaster Response Force shared perspectives of disaster management

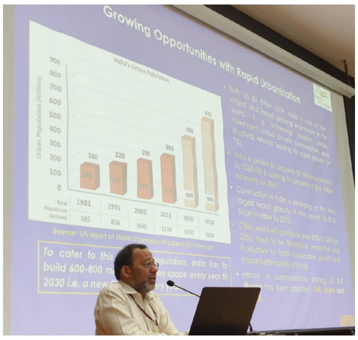
team for earthquake hazard, including challenges, learnings & recommendations. He shared their experience from the recent Turkey Earthquake.

Mr. Shounak Mitra, Head - Codes & Approval, Hilti India Pvt. Ltd. highlighted on the seismic safety of non-structural elements. In his presentation, he referred to Hilti's recent full-scale testing with IIT Roorkee and offered his insights and learning for the benefit of all.

Dr. Naveet Kaur, Senior Scientist-Bridge Engineering & Structures, CSIR-Centre Road Research Institute explained the importance of sensors technology in health monitoring of structures, focusing on case studies from bridges.

Day 2 started with Dr. Shailesh Agrawal, Executive Director, Building Materials and Technology Promotion Council deliberating on the development of advanced construction technologies to facilitate faster completion of construction, focusing on mass housing projects. He took reference of multiple projects across the country which has already been executed under the aegis of BMTPC and also lined up for future.

The session was followed by dedicated session by Mr. Vinay Gupta, Managing Director, Tandon Consultants Pvt. Ltd. & Dr. Pratima Bose, Associate Director, DDF Consultants Pvt. Ltd. on the different retrofitting techniques, with the help of exclusive case studies. While Mr. Gupta focused on bridges and other infrastructure, Dr. Bose highlighted on hospital project retrofitting in Uttarakhand.



This was followed by a session by Dr. Amit Bose, Director – DDF Consultants Pvt. Ltd. who shared his views on mainstreaming DRR into urban planning.

The final session of the day featured a demonstration by Shounak Mitra on how to ensure appropriate implementation of any retrofitting work as well as educate and emphasise the need of good installation practises.

Day 3 was more focused on ensuring safety against fire where Mr. R C Sharma, Former Director, Delhi Fire Services, Mr. Rajesh Choudhary, Associate Director, Bureau of Indian Standard and Mr. Shounak Mitra covered different aspects of National Building Code – Fire & Life Safety, different standards, learning from case studies, active fire protection and compartmentation measures, in line with the different codes and standards in India.

BRIDGING THE GAP BETWEEN ACADEMIA AND INDUSTRY THROUGH COMBINATION OF CLASSROOM AND HANDS-ON EXPERIENCE ON SEISMIC SAFETY !!!

To know more, click - https://theseismicacademy.com/workshops

Workshop on:

Revision of IS 1893 Parts-1 & 2 and IS 16700:

METHODOLOGICAL CHANGES IN SEISMIC DESIGN OF BUILDINGS

Held on 24th – 25th November'23

By Prof. (Dr). Yogendra Singh – IIT Roorkee

Organised by - EFC in association with VJTI - Structural Eng. Dept.

Sponsored by -

This workshop focused on the methodological changes in the codes (IS: 1893, IS:13920, and IS:16700) which are either in the process of revision or have been revised. Major changes in approach of hazard estimation, estimation of period of vibration, ductile detailing provisions, and provisions related to torsion were discussed.

Speaker - Prof. (Dr.) Yogendra Singh, Department of Earthquake Engineering, IIT, Roorkee
Worshop Convener: Mr. Jayant Kulkarni
Moderators: Mr. Anand Kulkarni, Mr. Arvind Parulekar, Mr. R. D. Deshpande
To know more, click - https://theseismicacademy.com/workshops

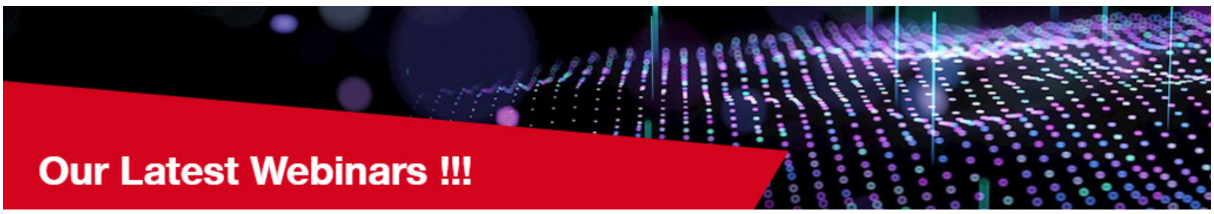
Workshop on:

CAPACITY BUILDING

Along with many other workshops

Held at - Assam Engineering College

Conducted By Mr. Shounak Mitra, Head – Codes & Approval (Fastening), Hilti India Pvt. Ltd.



SERIES OF THEMATIC WEBINARS PRESENTED BY EMINENT EXPERTS FROM THE INDUSTRY AND ACADEMIA HIGHLIGHTING VARIOUS ASPECTS OF EARTHQUAKE ENGINEERING !!!

To know more, click - https://theseismicacademy.com/webinars

TAIPEI 101 IS AN ICONIC EARTHQUAKE WITHSTANDING HUMAN MARVEL

Formerly known as the Taipei Financial Center, Taipei 101 is an office building in Taipei, Taiwan, standing 508 m tall. When it was completed in 2004, it dethroned the Petronas Twin Towers in Kuala Lumpur Malaysia, 452 m as the tallest building in the world.

Designed by C.Y. Lee & Partners, a local architectural firm and structural consultants from Thornton-Tomasetti Engineers, New York City and Evergreen Consulting Engineers; Taipei 101 is an iconic structure, engineered to withstand strong earthquake tremors as well as powerful typhoons that wreak havoc in Taiwan. It is designed to be resilient against gale winds of 134 mph and the strongest earthquake with an estimated return period of 2,500 years. This performance is mainly attributed to the 660 tonne steel pendulum that serves as a tuned mass damper.

Construction of Taipei 101 began in 1999. The structure was topped out in 2003, and work was completed in 2004. The largest section of the building, between the base and the spire, consists of eight blocks or groupings of eight stories. The building also has a distinctively Chinese character in its resemblance to a stalk of bamboo or an elongated pagoda.

In comparison to a straight shaft, the ninth module, which is the top of the main shaft and supports an architectural spire, has a 25-story base fashioned like a truncated pyramid, which increases lateral stiffness and overturning resistance. Medallions modelled by ancient Chinese coins illustrate the change from the lower pyramid to the upper modules. There are also exterior curtain panels slope 5 & 7 degrees, resembling a shoot of bamboo, and tying back to the mega-columns. The facade is able to withstand an impact of up to 7 tonnes and the Saw-toothed corners greatly reduce crosswind oscillation.

> **“It is designed to be resilient against gale winds of 134 mph and the strongest earthquake with an estimated return period of 2500 years.”**

The structural system is core plus outrigger, with 16 steel columns in the core and 8 steel "supercolumns" at the perimeter. All columns are filled with concrete up to floor 62. Massive steel outrigger trusses link the core and perimeter columns every eighth floor. The building's most noteworthy structural element is the tuned mass damper, which can be viewed from the indoor public observatory. Suspended between the 92nd and 87th floors at the building's centre, under conditions of seismic stress, the sway of the damper tends to counteract any sway of the building, thereby rendering stability and eliminating any vibration that can jeopardize the stay. This negates up to 40% oscillation.

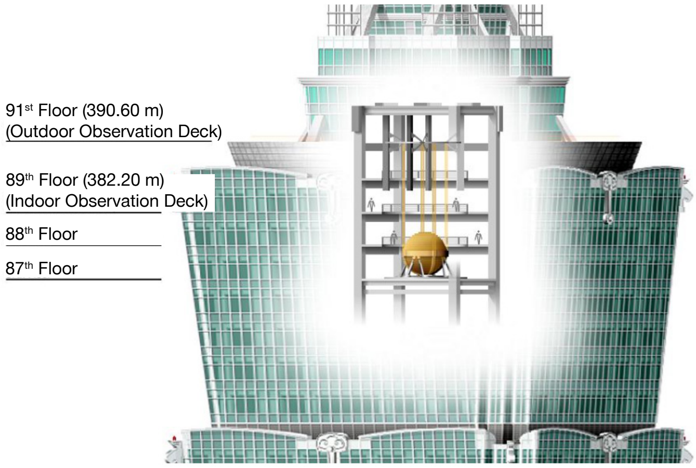
Called the "wind damper" or "tuned mass damper", a massive golden ball is suspended beneath the observatory deck of Taipei 101. The wind damper is made up of three major components: an oscillating mass (for inertial force), a spring (for elastic restoring force), and a visco-damper (for energy dissipation). At such a height, the Taipei 101 is a massive skyscraper, and is therefore susceptible to oscillation caused by earthquakes or strong winds. If the shaking is too violent, office workers and tourists inside the building may experience dizziness and discomfort. According to Evergreen Consulting Engineering which supervised the structural design of Taipei 101, when oscillation caused by wind exceeds 5cm/sec^2, people within the skyscraper will experience discomfort.

However, due to its great height, the vibration experienced by the higher office levels is already 6.2 cm/sec^2 in normal weather. The figure shoots up to 7.4cm/sec^2 when there's a typhoon. Both numbers are greater than the recommended 5cm/sec^2. Therefore, Taipei 101 needs a wind damper to reduce the vibration caused by high winds.

While wind is an ever-present environmental condition, Taiwan's geology also directs that earthquake resistance must be considered. A structural system stiff enough to limit wind drift does not automatically have the overload behavior desired for seismic ductility. But frames specifically designed for seismic ductility can be too flexible for wind conditions. The solution here was to design for stiffness and then check for seismic ductility and seismic strength. For example, where braces are 'opened' (work points do not coincide), in a seismic-controlled design they might be treated as ductile Eccentric Braced Frames with beam sections selected to meet specific proportions that force web shear to control over beam flexure. But such members would introduce undesirable flexibility for wind conditions.

Instead, the open 'link' portion of the beam is strengthened by side plates to maintain stiffness and ensure the link is not controlling strength across the eccentric links. At the same time, where flexure was inherent in the design and large rotations were anticipated during seismic events, such as the deep beams crossing core corridors to link braced bays, ductility was provided by a Reduced Beam Section or 'dogbone' detail using proportions developed at the local university. In addition, a dual system was applied: steel moment frames along each sloping face of the building work in parallel with the braced core and outriggers. In addition, full moment connections between braced core beams and columns provide an alternative load path in the event of brace member overload.

The steel damper weighs 660 metric tons and has a diameter of 5.4 m. It is suspended with numerous tension rods with hydraulic pumps that secure the base. Currently, the wind damper in Taipei 101 is the second largest in the world. It was made by welding together 41 layers of steel boards, each 125 mm thick.

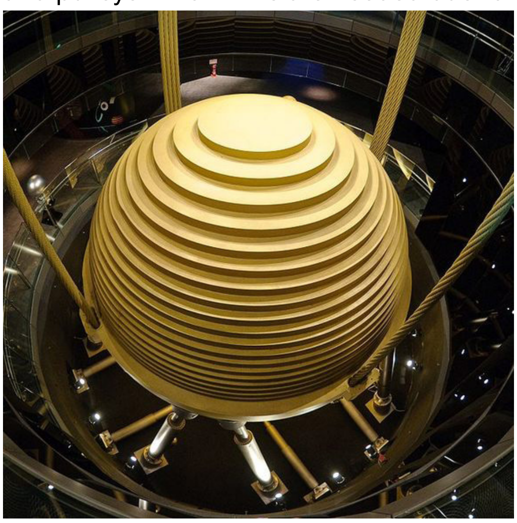


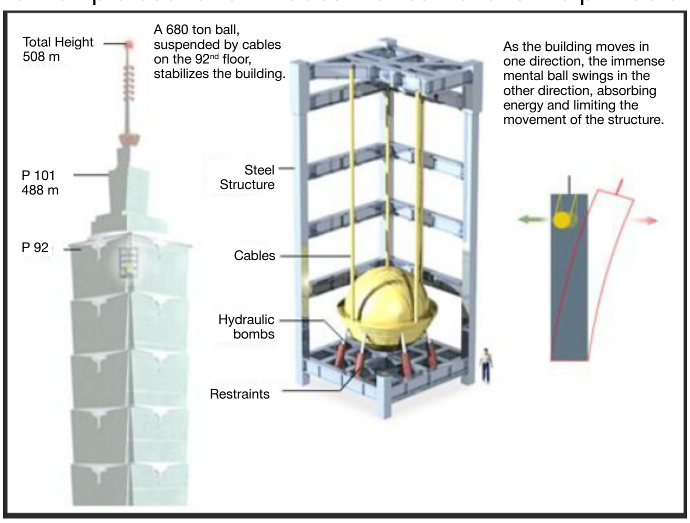
The sheer size and weight of the wind damper made it difficult to move to the construction site, and it was simply impossible for cranes to lift it up to between the 87th and 92nd floors, where it was to be installed. Workers had to send the damper up in smaller pieces, then weld the whole thing together on the spot.

In July of 2013, when Typhoon Soulik made landfall, wind speed in the Taipei area reached Force 14 on the Beaufort scale. At 4:10 in the morning, the wind damper in Taipei 101 experienced an oscillation of 70 centimeters in both directions, the greatest since the building was completed.

On April 18th, 2019, an earthquake measuring 6.1 on the Richter scale struck Xiulin Township in Hualien. At 1:01 in the afternoon, the wind damper in Taipei 101 swung 20 cm in both directions, a record-breaking oscillation that's caused by an earthquake. This ingenious protection mechanism prevented people inside the skyscraper from harm or discomfort.

The pinnacle presented further engineering difficulties. The pinnacle is vulnerable to crosswind excitation due to its uniform cylindrical shape and location on top of a building. With many more cycles at lower stresses accumulating at low wind speeds, three mode forms were found to have the ability to produce substantial stress ranges during storms. Due to these circumstances, fatigue life was a crucial design factor for the steel-trussed pinnacle spine. There were two strategies for reducing fatigue. First, local supplemental dampening was applied to lessen dynamic response. In addition to the building's primary TMD, Motioneering, of Guelph, Ontario, designed two ingenious compact TMDs to be placed within the uppermost 8 m of the pinnacle. Each has a 4.5 Mg (5 ton) steel mass that can slide on rollers horizontally along two axes, like a bridge crane traversing the width and length of a factory bay. The TMDs are "tuned" with vertical precompressed spring sets tied to the masses through flexible cables and pulleys. Two TMDs are needed due to the multiple oscillation modes that can excite the pinnacle.





The second fatigue life technique involved identifying the areas that were most susceptible to fatigue and lowering their cyclic stress ranges. Using Goodman's Simplification to treat variable stress cycles as uniform cycles, thousands of high-stress cycles and many more lower-stress cycles were processed and combined using the Modified Miners Rule, a form of weighted average, to establish an equivalent 2 million cycle uniform stress range for further study. Welded splices of the vertical pinnacle trusswork chords were identified as highly stressed by overturning moments, and sensitive to fatigue at one-sided penetration welds. To reduce the stress ranges, steel plate 'ears' on the chords that were originally intended to receive only temporary erection bolts were redesigned to receive permanent connections with plates connected by slip-critical high-strength bolts. By sharing the chord force, these plates reduce stresses in the welded splices and reduce their cyclic stress ranges.

The Taipei 101 site required a well-planned foundation system in light of the findings of the soil study, which showed that the building site comprises soft soil in the form of clay that is abutted vertically with colluvial soil and has a low load bearing potential. Additionally, at a depth of 40 to 60 m, there is a layer of soft rock called sandstone beneath this layer, necessitating the usage of a solid foundation. The site has a matt foundation with bored piles to distribute the weight of the superstructure. The location's water table is 2 m below the surface and the tower's 21-m-deep basement presses upward on the foundation of the building.

Slurry walls 47 m deep and 1.2 m thick were built to support the foundation and excavation below ground. 380 1.5 m diameter piles and 167 piles placed beneath the platform make up the tower's foundation. To carry the weight of the columns and walls, the piles were covered with 3 to 4.7 m concrete raft slabs.

Notably, during the construction of the Taipei 101, in May 2002, a 6.8-magnitude earthquake rocked Taipei, which brought down two construction cranes, killing five people. The building, however, was not damaged. Taipei 101 is an ingenious marvel, breaking the seismic barriers and showcasing the world the prowess on the engineering capacity.

Structure	Eight eight-story modules standing atop a tapering base, satisfying demands of esthetics, real estate economics, construction, occupant comfort in mild-to-moderate winds, and structural safety in typhoons and earthquakes.
Foundation	The site has a matt foundation with bored piles to distribute the load of the superstructure. The tower has a 21 m deep basement with the water table at the site 2 m below the ground level.
Architect (s)	C.Y. Lee and C.P. Wang
Structural Engineer	Evergreen Consulting Engineering and Thornton Tomasetti
Height	508.2 m
Floors	101 Above Ground, 5 Underground
Construction Period	1999-2004
Cost	$1.9 Bn USD

REFERENCES

1. https://tomorrow.city/a/taipei-101-earthquakes#:~:text=Particularly%20because%20of%20its%20structure,is%20uncommon%20in%20tall%20buildings.
2. https://english.cw.com.tw/article/article.action?id=2374
3. http://faculty.arch.tamu.edu/anichols/courses/applied-architectural-structures/projects-631/Files/Case%20Study_%20Taipei%20101%20Presentation.pdf
4. https://global.ctbuh.org/resources/papers/download/1650-structural-design-of-taipei-101-the-worlds-tallest-building.pdf

Vol. 04
November 2023

SEISMIC ACADEMY

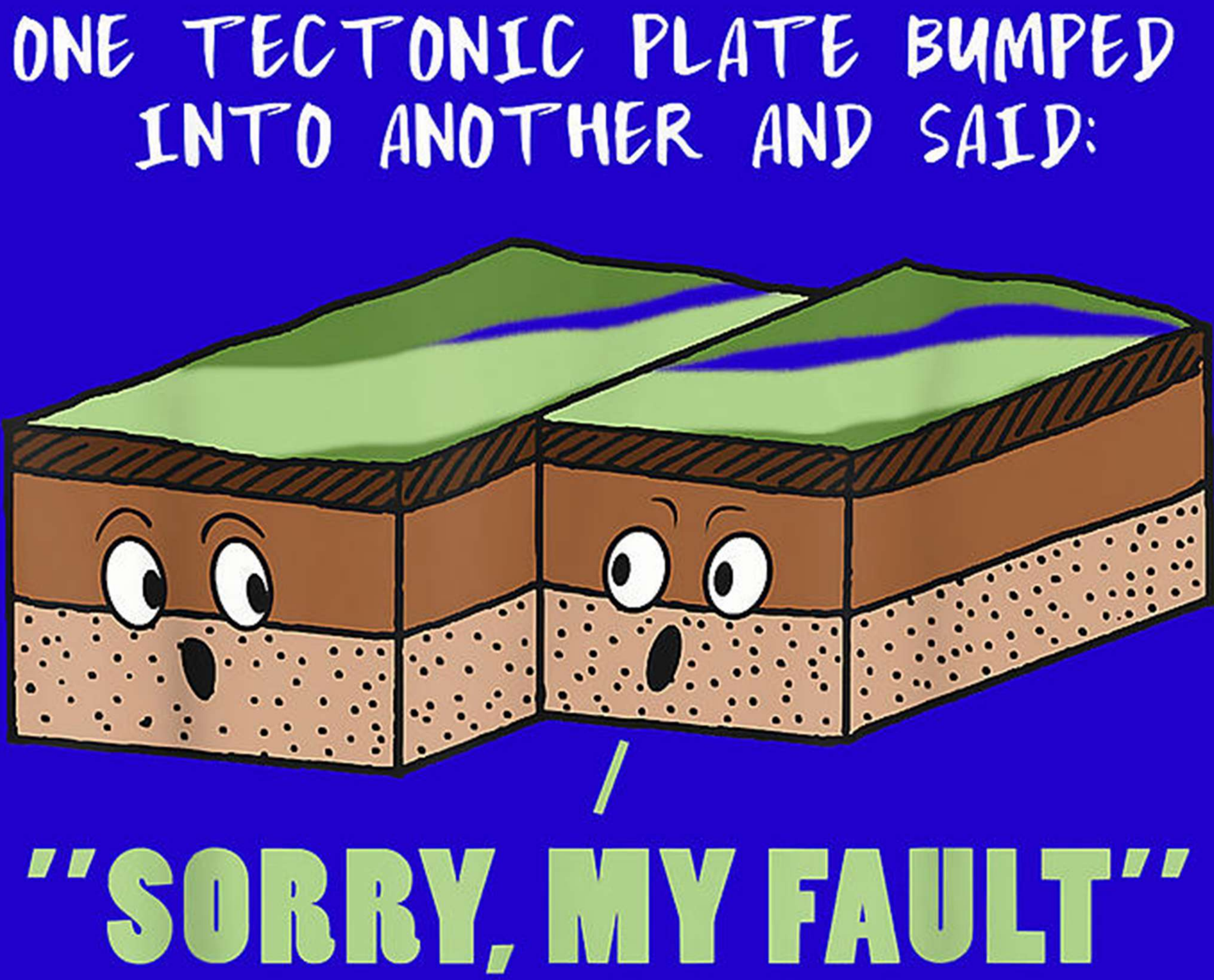


Image source: https://fineartamerica.com/

FOR MORE DETAILS ON THIS INITIATIVE, PLEASE VISIT OUR WEBSITE

https://theseismicacademy.com