Integrated Perspectives in Civil Engineering: Geotechnical, Structural, Water Resources, and Environmental Aspects

Swami Vivekananda University
Kolkata 700 121
India

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Contact us: deptce@svu.ac.in

Preface

“Integrated Perspectives in Civil Engineering: Geotechnical, Structural, Water Resources and Environmental Aspects”- is a comprehensive exploration of cutting-edge innovations, from the structural aspects required to minimize the damage due to earthquake to waste management and development of sustainable smart cities. This book is designed to provide readers with a comprehensive understanding of the latest breakthroughs.

In the first chapter, a pioneering investigation into the utilization of laterite soil as a cost-effective and sustainable alternative for ash pond liners. With growing environmental concerns surrounding conventional liners, this study aims to assess the efficacy of laterite soil in adsorption processes. The chapter meticulously outlines the materials and methods employed, detailing the preparation of the adsorbent and adsorbate. Key experimental components include batch adsorption studies, adsorption isotherm experiments, vertical column tests, and the implementation of the HYDRUS-1D model. Through a comprehensive analysis, the chapter establishes the effectiveness of laterite soil in adsorption processes and its potential as a sustainable liner material. The concluding section summarizes the findings, emphasizing the cost-effectiveness and sustainability of laterite soil as an ash pond liner. Additionally, the chapter outlines future research prospects, suggesting avenues for further exploration in this promising field. The inclusion of references provides a scholarly foundation for the methodologies and insights presented in this pioneering study.

The second chapter of the book addresses the escalating issue of heavy metal contamination in the industrial zones near Durgapur. Beginning with a comprehensive introduction highlighting the significance of the problem, the chapter delves into the materials and methods employed for the study. The methodology section details the research approach, providing insights into the collection and analysis of data. Moving forward, the chapter presents the key findings in the "Results and Discussion" section. It specifically explores heavy metal concentrations in the industrial areas, shedding light on the extent of contamination. Moreover, the chapter conducts a critical assessment of heavy metal contamination, offering a nuanced discussion on the implications of the observed concentrations. By presenting a detailed examination of the data, this chapter contributes valuable information to the understanding of environmental challenges in industrial regions, laying the groundwork for potential mitigation strategies.

The Chapter 3, titled "Wind-Induced Vibration on Bridge Deck," provides a comprehensive exploration of the intricate dynamics associated with wind-induced vibrations on bridge decks.

The introduction sets the stage by delving into types of drag, offering a historical overview, and presenting the current scenario of wind-induced vibrations. This foundation underscores the significance of the research. The research methodology section serves as the heart of the chapter, where a systematic approach is detailed. A thorough literature review is conducted, followed by meticulous field measurements, wind tunnel testing, Computational Fluid Dynamics (CFD) simulations, and the application of Tuned Mass Dampers (TMD). Each method contributes uniquely to the understanding of the complex interplay between wind forces and the structural response of bridge decks. The subsequent summary distills the chapter's essential findings and methodologies, providing a quick reference for readers seeking a concise overview. The conclusions section synthesizes the insights gained, drawing implications from the research findings and potentially suggesting avenues for future exploration in comprehending and mitigating wind-induced vibrations on bridge decks. The chapter concludes with a list of references, acknowledging the scholarly foundation that supports the methodologies and insights presented in the study.

In Chapter 4, titled "Seismic Performance of Box-girder Bridge with Different Piers using CSiBridge Software," the investigation begins with a comprehensive introduction, laying the groundwork for a detailed examination. The research significance is underscored, emphasizing the critical importance of understanding the seismic performance of box-girder bridges with varied piers. The analytical modeling section follows, providing insight into the methodology employed. This includes details on bridge component data, pushover analysis, and time history analysis (THA). The subsequent presentation of results and discussion delves into the findings of pushover analysis, nonlinear dynamic time history analysis, and a comparative assessment of both results. The chapter then draws conclusions based on the insights gained from the seismic performance analysis. Finally, the chapter concludes with a list of references, acknowledging the sources that form the scholarly foundation for the analytical methodologies and findings presented in the study.

In Chapter 5, the exploration begins with an introduction emphasizing the critical need for sustainable solutions in waste management. The chapter delves into the global perspective on the valorization of Iron Ore Tailing (IOT), offering insights into the circular economy approach to maximize the utility of tailing waste. A comprehensive examination of the disposal and environmental impacts of IOT follows, providing a holistic understanding of the ecological footprint of mining activities. The chemical compositions of tailing waste are meticulously analyzed, contributing to the comprehension of its characteristics. The chapter explores the main policy guidelines, standards, or rules governing the management of IOT waste, offering a regulatory framework for responsible waste management practices. It introduces zero waste concepts through circular economy policy in the context of tailing waste valorization, highlighting innovative strategies to minimize waste. The chapter addresses difficulties or bottlenecks preventing bulk usage of tailing, providing insights into challenges that need to be addressed for widespread adoption. It further discusses good practices in the mining industry and sustainable management of tailing waste, showcasing exemplary approaches. The chapter concludes with a forward-looking perspective, presenting the way forward, and offers concluding remarks, summarizing the key findings and emphasizing the significance of sustainable tailing waste management in the broader context of resource conservation and climate change mitigation.

In Chapter 6, titled "Enhancing the Efficient Utilization of Reclaimed Asphalt Pavement (RAP) in Granular Sub Base for Road Construction: A Recent Trend," the exploration begins with a comprehensive introduction. This section provides an overview of the Indian road network, its growth, and future projections, offering historical context and presenting the present scenario. The chapter delves into studies on recycling, setting the stage for a detailed discussion on the research methodology. The recycling of pavement is a central focus, and the methodology encompasses laboratory tests on materials, including coarse aggregates and alternative materials. Additionally, the chapter explores the stabilization techniques employed in enhancing the efficient utilization of Reclaimed Asphalt Pavement (RAP) in the granular sub base for road construction. A succinct summary distills the key findings and methodologies presented in the chapter, providing a quick reference for readers. The chapter concludes with a section on conclusions, summarizing the insights gained from the research, and a list of references, acknowledging the scholarly foundation that underpins the methodologies and findings presented in the study.

In Chapter 7, the application of the Response Spectrum Meth-od across seismic zones in India, ranging from low to critical seismic regions has been described. In the realm of civil engineering, constructing buildings of varying heights necessitates a paramount focus on ensuring structural safety, serviceability, and durability. With the growing significance of seismic events in modern times, safeguarding structures against potential damage caused by seismic excitations becomes a critical concern. The extent of seismic damage inflicted upon structures hinges on several factors, including building height, seismic zone classification, seismic resistance techniques, and soil characteristics. The relationship between earthquake effects and structure height is particularly noteworthy, as seismic waves can alter ground motion, thereby influencing structural integrity.

This study delves into the performance of structures of diverse heights situated in different seismic zones. It places specific emphasis on the Response Spectrum Method, a seismic resistance technique known for enhancing structural behavior when confronted with lateral forces during seismic events. By analyzing the effectiveness of this method across varying structural heights in different seismic zones, this research contributes to a deeper understanding of seismic resilience in the context of Indian construction practices.

The Chapter 8 explores the inexorable trajectory of Smart City development as an essential facet of the future. It underscores the imperatives of energy conservation, eco-friendly urban environments, and climate change mitigation as driving forces behind the necessity of Smart Cities. Investigating global smart city market projects, the study delves into the intersections of digital and green concepts in smart city infrastructures. Examining the repercussions on the job market, the document focuses on Smart Buildings, Infrastructure, and Transportation. A detailed analysis of a Smart City encompasses efficient data management, environmental considerations, transportation dynamics, town planning, skill development, and population demographics. The chapter further scrutinizes the role of Artificial Intelligence and Machine Learning in Smart Cities, elucidating their advantages, disadvantages, and diverse learning paradigms. Insights into dataset intricacies, guidelines, model training, and applications in Civil Engineering are provided. With a concise yet comprehensive approach, this document offers a holistic understanding of Smart City development, serving as a valuable resource for researchers, practitioners, and policymakers navigating the dynamic landscape of intelligent and sustainable urban futures.

This book aims to bridge the gap between technology enthusiasts, researchers, and practitioners by providing a comprehensive overview of these diverse topics. Each chapter is written by experts in their respective fields, offering valuable insights and up-to-date information. We hope that this book will serve as a valuable resource for those seeking to explore the frontiers of emerging technologies and their applications in our ever-evolving world.

Thank you for embarking on this journey with us, and we hope you find this book bothinformative and inspiring.

(Dr. Abir Sarkar) 05-12-23

Assistant Professor, Swami Vivekananda University,

Kolkata, West Bengal, India

Acknowledgement

I am writing to convey my sincere appreciation for the invaluable support and encouragement extended by Swami Vivekananda University, Kolkata, India, in the development of the book titled "Integrated Perspectives in Civil Engineering: Geotechnical, Structural, Water Resources, and Environmental Aspects." The university's unwavering commitment to advancing education and research has been instrumental in shaping the content and direction of this publication. We are profoundly grateful for the collaborative spirit and resources provided by Swami Vivekananda University, Kolkata, which have enabled us to explore and disseminate the latest innovations and technologies across various fields. It is our hope that this book proves to be a valuable resource for this esteemed institution and the broader academic community, reflecting our shared dedication to knowledge, progress, and the pursuit of excellence.

With sincere appreciation,

(Dr. Abir Sarkar) 05-12-23

Assistant Professor, Swami Vivekananda University,

Kolkata, West Bengal, India

List of Authors

Dr. Abir Sarkar, Assistant Professor, Swami Vivekananda University, Kolkata, 700121, India

Dr. Bishnu Pada Bose, Professor, Swami Vivekananda University, Kolkata, 700121, India

Dr. Ashes Banerjee, Assistant Professor, Swami Vivekananda University, Kolkata,700121, India

Dr. Nilanjan Tarafder, Assistant Professor, Swami Vivekananda University, Kolkata, 700121,

India

Mr. Avishek Adhikary, Assistant Professor, Swami Vivekananda University, Kolkata, 700121,

India

Mr. Sunil Priyadarshi, Assistant Professor, Swami Vivekananda University, Kolkata, 700121,India

Mr. Samir Kumar, Assistant Professor, Swami Vivekananda University, Kolkata, 700121, India

Mrs. Debanjali Adhikary, Assistant Professor, Swami Vivekananda University, Kolkata, 700121,India

Ms. Sarnali Sarkar, Assistant Professor, Swami Vivekananda University, Kolkata,700121, India

Contents

Chapter 1

Laterite Soil: A potential cost-effective and sustainable ash pond liner

Authors:

Email addresses:

1. avisheka@svu.ac.in (Avishek Adhikary), Swami Vivekananda University, Kolkata-700121, West Bengal, India.
2. debanjalia@svu.ac.in (Debanjali Adhikary), Swami Vivekananda University, Kolkata-700121 West Bengal, India.

1.1.INTRODUCTION

Surface water and groundwater pollution, whether caused by artificial or natural sources, has been a primary source of worry for society and communities. When activities are connected to the discharge of effluents containing high concentrations of heavy metals in the soluble form to the environment from the electroplating industry (Ma et al. 1994), metallurgical, chemical, pharmaceutical, mining, and other industries (Ernst, 1995; Li and Li, 2001), metals typically cause groundwater pollution. Heavy metals, such as lead (Pb2+), cadmium (Cd2+), zinc (Zn2+), nickel (Ni2+), and chromium (Cr6+), are one of the contaminant groups that are commonly found in various types of waste and landfill leachates. These contaminants are toxic to human health, the biosphere, and the ecosystem (Shackelford, 1990; Yong and Phadungchewit, 1993). According to reports, occupational exposure to lead and nickel can cause a number of ailments, including neurological disorders, kidney and liver damage, asthma, and carcinogenic effects (Marko-witz, 2000; You, 1995). As a result, removing Pb2+ and Ni2+ ions from aqueous solutions is considered necessary for maintaining water quality. However, a variety of treatment methods, such as chemical precipitation (J.W. Paterson 1975), ion exchange (S.E. Jorgensen 1979), and reverse osmosis (H. Ozaki et al. 2002), have been used to remove heavy metals from industrial waste. Forecasting how heavy metals will migrate through the subsurface aquifer and where they will end up depends on the porous media's sorption and transport capabilities. Numerous variables, such as hydraulic conductivity, tortuosity adsorption capacity, and pH, impact how heavy metals travel through subsurface soil (Sharma and Reddy, 2004; Vaishya et al., 2008; Mesquita and Vieira, 2002). The soil should have a low hydraulic conductivity (1.010-7cm/s), according to Güler and Avci (1993), to stop contaminants from moving through the subsurface soil. To study the sorption of two or more metals onto soils, batch sorption experiments have typically been carried out (A. Putthividhya 2008).S. Chotpantarat (2008) found that the maximum sorption affinity of Pb2+ was under both binary and multi-metal systems employing batch tests for the competitive sorption of four heavy metals onto soils. Column experiments have been carried out to explain the transport-related data of heavy metals in porous media. However, the majority of this research focuses on a single metal under different flow conditions. SS Baral (2009). The sorption of heavy metals in multi-metal systems has been discussed in many studies. For instance, S. Chotpantarat et al. (2011) showed that the retardation factor of Pb was more significant than those of Ni, Zn, and Mn in non-equilibrium conditions using columns experiment with laterite soils to test Pb, Mn, Ni, and Zn sorption. According to V. Vinodhini et al. (2010), the presence of co-ions reduced the breakthrough and exhaustion times for a soil column. In a polluted soil environment, T. Sherene (2010) investigated the factors that affect the mobility and transport of various heavy metals. Some issues with multi-metal systems are unknown, like the potential rivalry between heavy metals for sorption sites, mass transfer, and non-equilibrium sorption on soils. The HYDRUS-1D model was chosen for this study's evaluation of the subsurface soil's attenuative capability for delaying the transfer of heavy metals to groundwater.

Cement, chemical, pharmaceutical, iron and steel, thermal power plants, coke ovens, and other industries in West Bengal's Durgapur leak effluent into neighbouring land, which could one day be a significant source of heavy metal contamination. This study aimed to determine how well lateritic soil can prevent linked heavy metals from migrating. Soil column experiments were carried out to comprehend the sorption and transport of heavy metals in the lateritic soils. The HYDRUS-ID model was then used to model the breakthrough curves (BTC) (Simuek et al. 2008).

1.2. MATERIALS AND METHOD

1.2.1 Preparation of adsorbent :

By auger boring, the laterite soils were extracted from the area surrounding Durgapur, West Bengal, at a depth of 0.5 metres. According to the recommendations provided by the Bureau of Indian Standards (IS 2720, 1985), the physiochemical characteristics of the obtained soil samples were assessed in the Soil Mechanics and Foundation Engineering Laboratory of the National Institute of Technology, Durgapur, West Bengal, India.

1.2.2 Preparation of adsorbate:

Lead (II) Sulphate (Pb(SO4) and nickel (II) sulphate hexahydrate NiSO4.6H2O were the compounds utilized. Daily preparation of the stock solution of 1000 mg/l of heavy metal ions involved dissolving the aforementioned salts in a 1-L volumetric flask of ultrapure millipore water and diluting it to the proper concentration. All tests employ analytical and lab reagent grades of chemicals (Merck).

1.2.3 BATCH ADSORPTION STUDY

Using lead and nickel solution as the adsorbate, batch tests were carried out in the lab to examine the adsorption phenomena of the in situ soil. A series of conical flasks with a 100-mL capacity were filled with a starting solution with a concentration between 5 and 10 mg/L and a soil adsorbent dosage between 5 and 30 g/L. As a buffer solution, 1 N HCl and 1 N NaOH were used to keep the pH of the solutions at 8. Afterwards, the conical flasks were agitated at 150 rpm in an orbital rotary shaker. After the treated solutions were filtered via filter paper (Whatman 42 grade), the flasks were removed sequentially from the shaker at various specified time intervals (15 minutes, 30 minutes, 1 hour, 2 hours, and 3 hours). The AAS (Perkin Elmer) system assessed the filtrate's residual concentrations. The percentage of these heavy metals adsorbed by the soil was calculated using

$$Percentage\ of\ removal\ of\ heavy\ metals = \frac{Ci - Ce}{Ci} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{eq (1)}$$

Where,
Ci and Ce are the initial and equilibrium concentrations in milligrams per litre, respectively.

1.2.4 ADSORPTION ISOTHERM EXPERIMENTS

The adsorption isotherm study can assess an adsorbent's adsorptive capacity for removing contaminants from wastewater. The kinetic equilibrium experimental data are typically examined for fitting with the linear, Langmuir, and Freundlich isotherm models. The adsorption isotherm tests were conducted by keeping a constant dosage of adsorbent with changing starting concentrations of heavy metals ranging between 5 and 10 mg/L at a consistent solution pH level of 8 maintained for each set of experiments as previously stated. The equilibrium heavy metals adsorption capacity, Q (mg/kg), was calculated by Eq.

$$Q = \frac{(Co - Ce)}{M \times V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq (2)}$$

Where V is the volume of solution in millilitres, M is the mass of adsorbent (soil) in grams, Co is the initial concentration of coupled heavy metals, and Ce is the equilibrium concentration. Linear and nonlinear like Langmuir and (Freundlich) isotherm models in equations (3),(4), and (5) have been applied to derive the isotherm constants.

Linear isotherm model $$Qe = KdCe \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq(3)}$$

Langmuir isotherm model

$$Qe = \frac{QmaxbCe}{1 + bCe} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq(4)}$$

The Freundlich model

$$qe = KfCe^{\frac{1}{n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq(5)}$$

Where K_d is the Linear isotherm constant, Qmax is the maximum adsorption capacity (mg/Kg), b= Constant related to the free energy of adsorption in Langmuir isotherm(L/mg). K_f is the Freundlich isotherm constant (L/kg), and 1/n is adsorption intensity.

1.2.5 VERTICAL COLUMN TEST

Using a wooden mallet, the oven-dried soil samples were broken down. The vertical column of the Perspex sheet was used to collect the dirt that had been screened through 600 m sieves and retained on the 425 m sieve. The column measured 2.5 cm in diameter and 10 cm in height. Lateritic soil was compacted in three layers using the wooden tamping rod of the column to consolidate the soil and remove air bubbles after being packed into columns of 3 cm and 4 cm depth, respectively. Glass beads were put at the top and bottom of the soil column for even flow distribution. The synthetic solution of coupled heavy metals was made to run through the column in downflow mode at a constant flow rate of 5 ml/h and had a concentration of 10 mg/L with a pH of 8. A constant hydraulic head of 5 cm was maintained over the top of the soil beds throughout the experimental column model to imitate field conditions. The soil beds were initially drenched with twice-distilled water for two days. The residual concentrations were monitored in an Atomic Adsorption spectrophotometer, as mentioned before in the batch experiment, and the effluent sample solution was collected through the sampling port at specified time intervals from the bottom of the column. The experiment should be terminated when the effluent metal concentration surpasses the influent metal concentration by 90%. The relative concentration (Ce/C0) in the effluents vs. time elapsed in days, where Ce and Co are effluent and influent metals concentration in milligrams per litre, was used to plot the breakthrough curves (BTC).

1.2.6 HYDRUS-1D model description

Binary metal solution migration investigations in soil media were conducted using the HYDRUS-1D model. In a steady or transient regime for a known metric system and at different time steps, HYDRUS-1D models one-dimensional solute transport in incompressible, porous, variably saturated media (Simunek et al. 2008). Using the Freundlich isotherm model constant, the HYDRUS-1D model numerically resolves the following forms of advection-dispersion equations for reactive solute transport in saturated homogeneous and isotropic porous media under steady-state circumstances.

$$\frac{\partial(\theta C)}{\partial t} = \frac{\partial}{\partial x}\left[\theta D_x(\theta, q)\frac{\partial C}{\partial x}\right] - \frac{\partial(qC)}{\partial x} - \frac{\rho_d}{\theta}\frac{\partial\left(K_F \theta C^{\frac{1}{n}}\right)}{\partial t} \text{……eq (6)}$$

The following boundary conditions are considered for solving the above partial differential equation,

$$C(0,t)=C_0; \quad t\geq 0 \text{……………………………………..eq(7)}$$

$$C(x,0)=0; \quad x\geq 0 \text{……………………………………eq(8)}$$

$$\partial C/\partial x=0; \quad x=\infty \text{…………………………………eq(9)}$$

Where C is the solution phase solute concentration (mg/L), θ is the saturated water content (cm^3/cm^3), q is the water flux (cm/h), D is the dispersion co-efficient(cm^2/h), t is the time in hours, ρ_d is the dry density of soil, x is the distance in the direction of flow (cm), and K_f is the Freundlich isotherm constant (L/kg) and 1/n defined as adsorption intensity.

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1.3. RESULT AND DISCUSSION

The physicochemical properties of the soil are shown in Table 1 below.

Table 1: Physicochemical properties of soil

Depth below GL(m)	**Grain size distribution Sand(%) Silt(%) Clay(%)**	**NMC (%)**	**LL (%)**	**PL (%)**	**G**	**Ks(cm/sec)**	**pH**	**pHzpc**	**OC (%)**	γd **(g/cc)**	**BET m^2/g**
.5	49 39 12	12.61	26	13.12	2.69	3.74×10^{-8}	6.5	7.2	1.12	1.93	23.50

According to IS 1498-1970, the soil can be categorized as well-graded soil since the coefficient of uniformity is less than 5 and the coefficient of curvature is between 1 and 3. This means that the soil has uniform grain-size particles. The pH of the soil is 6.5, which is mildly acidic. It was discovered that the saturated hydraulic conductivity was (Ks=3.7410-8cm/s).In places where industrial wastewater is released to the land, this soil can be considered a tremendous primary lining material for waste containment (Güler and Avci (1993). The pHzpc of the soil indicates that the samples' surfaces behave negatively at pH values greater than pHzpc and positively at pH values equal to or lower than pHzpc. Therefore, when the pH values are greater than 7.2, heavy metal adsorption by the soil occurs. The soil's specific surface area (SSA) was discovered to be 23.502 m2/g. Because more adsorption sites are available for the adsorbate, the bigger SSA can be very beneficial to sorption (Liang et al. 2010).

1.3.1 Batch adsorption study

Fig 1 and Fig 2 shows the laboratory batch test result for the removal of Pb^{2+} and Ni^{2+} coupled heavy metals, respectively, with different contact time (15, 30, 60, 120, 180) min against different initial heavy metals concentrations (.5, 1, 5, and 10 mg/L) using adsorption dose of 20 g/L at a pH solution of 8. From Figs. 1 and 2, it can be seen that for higher starting concentrations of 10 mg/l, maximum adsorption of 98% and 96% for Pb and Ni, respectively, occurs after 120 min. The difference between the bulk concentration of the solute in the solution and that at the surface of the solid is more significant at 10 mg/l than the lower one when all other parameters are constant, indicating a higher driving force for mass transfer.

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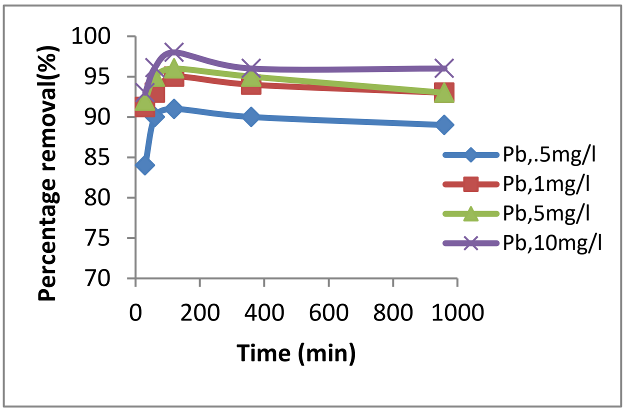


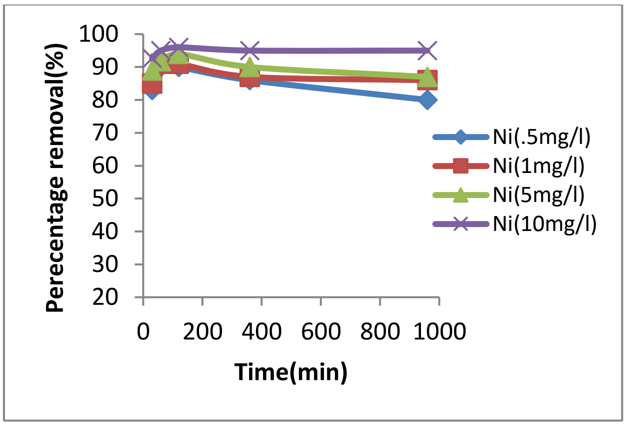
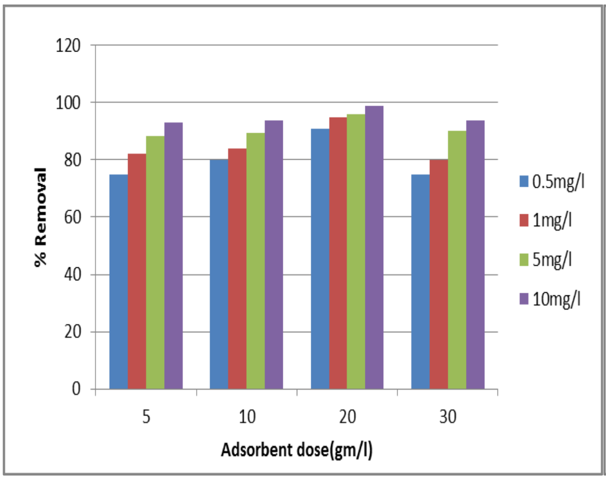


Figure 1: Percentage removal for 20 gm/l **Figure 2:** percentage removal for 20 gm/l

Figures 3 and 4 below illustrate how varied adsorbent doses affected the removal of Pb^{2+} and Ni^{2+} linked heavy metals over 120 min of equilibrium time in response to various initial concentrations (.5, 1, 5, and 10) mg/L while keeping a pH of 8 in the solution. According to the results of the laboratory batch tests, the removal of Pb2+ and Ni2+ associated heavy metals rises with increasing adsorption dosage up to 20 g/L and then slightly falls off after that. The adsorbent surface area tends to rise with increased adsorbent dosage in a solution, resulting in more metals being adsorbed on the adsorbent surface. Due to the overlapping of active sites after achieving limiting equilibrium, the surface area may decrease, reducing the adsorption of metals (Tahir 2005).



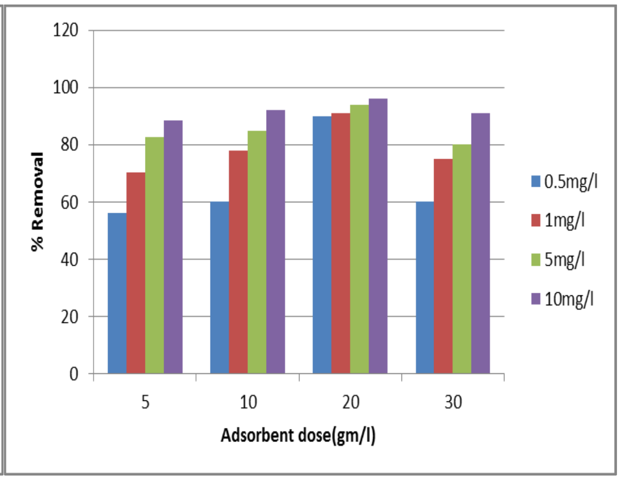


Fig 3: Effect of adsorbent dose on Pb^{2+} removal **Fig 4:**Effect of adsorbent dose on Ni^{2+} removal

The adsorption capacities of laterite soil were observed at 1857.2mg/kg and 1766 mg/kg for Pb^{2+} and Ni^{2+} contaminants, respectively, for optimum adsorbent dosage with an initial concentration of 10 mg/l at pH 8. Thus, laterite soil’s observed higher adsorption capacity can be used as liner material for waste containment structures. The larger SSA can be the reason for the sorption of coupled heavy metals.

1.3.2 Adsorption isotherm study

Adsorption isotherm models can be used to forecast the type of adsorption that the adsorbate will undergo on the adsorbent. The Langmuir and Freundlich equations can be used to define adsorption isotherm in general. The results of individual analyses of equilibrium data using the linear and nonlinear Langmuir and Freundlich adsorption isotherm models are presented in Table 2. It has been discovered that the Freundlich adsorption isotherm model best fits equilibrium data. A greater R2 value and a lower error value indicate the best fit of the model with the experimental data. In the current investigation, the Freundlich isotherm model fit the test results better (R= 0.99, RMSE=.06) than the Langmuir isotherm model (R= 0.95, RMSE =.04). In the Freundlich isotherm model, 1/n is somewhat higher than 1 (1.75). A normal adsorption is indicated if the value of 1/n is less than one. On the other hand, cooperative adsorption is indicated when 1/n is more than one (S. Mohan 1997). The table demonstrates that the Freundlich isotherm is the best-fitting model for characterizing the adsorption phenomena by soil, especially when considering the soil surface's heterogeneity.

Table 2: Isotherm parameters

Model Use for Pb	**Isotherm Constant**	**R^2**	**RMSE**	**Model Use for Ni**	**Isotherm Constant**	**R^2**	**RMSE**
Linear	K_d=2087 l/kg	0.86	287	Linear	K_d= 1258 l/kg	0.83	256
Langmuir	Qmax=434.7mg/kg b=1.27 l/mg	0.95	0.001	Langmuir	Q_{max}=250mg/kg b= 0.93	0.91	0.007
Freundlich	1/n=1.5 K_f=30.8L/kg	0.99	0.06	Freundlich	1/n=1.9 K_f=21.7 mg/kg	0.98	0.05

1.3.3 COLUMN EXPERIMENT RESULT

The figure below shows the multi-metal BTCs data of the column experiment, expressed as the ratio of effluent and influent concentrations (i.e., Ce/C0) versus the elapsed time in days for different bed heights of 3 cm and 4cm.

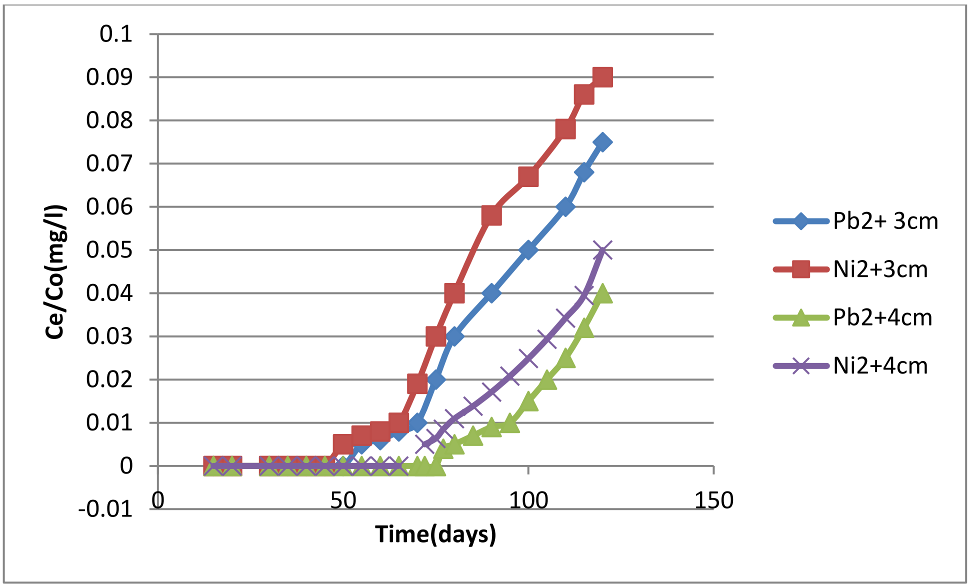


Figure 5: Experimental relative concentration of respective heavy metal as a function of time in vertical column test of bed height 3 cm and 4 cm

The breakthrough curves' forms and gradients are altered with the rise in bed depth from 3 cm to 4 cm. As the breakthrough time approached, it was discovered that the metal ion concentration in the effluent increased. Figure 5 shows that when the column with a low bed depth of 3 cm was utilized for the experiment, the first solute breakthrough times for the metal ions Pb(II) and Ni(II) were 70 days and 66 days, respectively. As shown in Figure 5, the initial solute breakout time was discovered to increase from 70 days to 94 days for Pb2+ and from 66 days to 89 days for Ni2+ metal ions upon raising the bed depth from 3 cm to 4 cm. This observation might be explained by taking into account the fact that with short bed depth, the metal ions do not have enough time to diffuse into the entire adsorbent mass, which is why the column attained the breakthrough time earlier. However, the longer the solution stays in the column due to the increased bed depth of the column, the deeper the metal ions can diffuse into the adsorbent. Therefore, a deeper bed depth column resulted in greater breakthrough time values. However, due to a lack of time during the project period, the experiment was unable to be carried out till the point of exhaustion. Thus, using the mathematical model HYDRUS-1D, the exhaustion times for the individual heavy metals were displayed. The results of the HYDRUS-1D model were compared to the actual values. For the soil bed heights (3 cm and 4 cm), the curve predicted by the HYDRUS-1D model appears closely related to the experimental heavy metals BTCs.

The HYDRUS-1D model predicted heavy metal BTCs in vertical column tests for varied soil bed heights (3 cm and 4cm), as shown in Figures 6 and 7. Using assumed dispersivity, tortuosity factors, and calculated nonlinear Freundlich isotherm parameters from batch adsorption investigations, the HYDRUS-1D model for heavy metal BTCs was created. Compared to Figure 7, where the BTCs got flatter as bed heights increased, it can be seen that Figure 6's curve is significantly steeper, indicating that the bed exhausts after 1000 days and that this amount of time is insufficient to achieve the exhaustion point. Thus, it amplified that the soil has good adsorption potential. It showed that in situ lateritic soil has excellent resistance to impede the migration of heavy metal contaminants via the subsurface to reach aquifers.

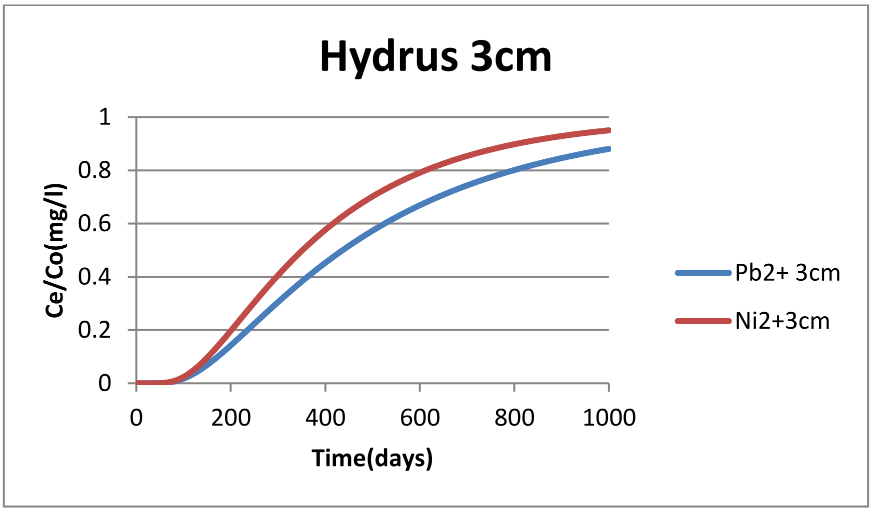


Figure 6:.HYDRUS-1D predicted a breakthrough curve for a soil bed height of 3 cm

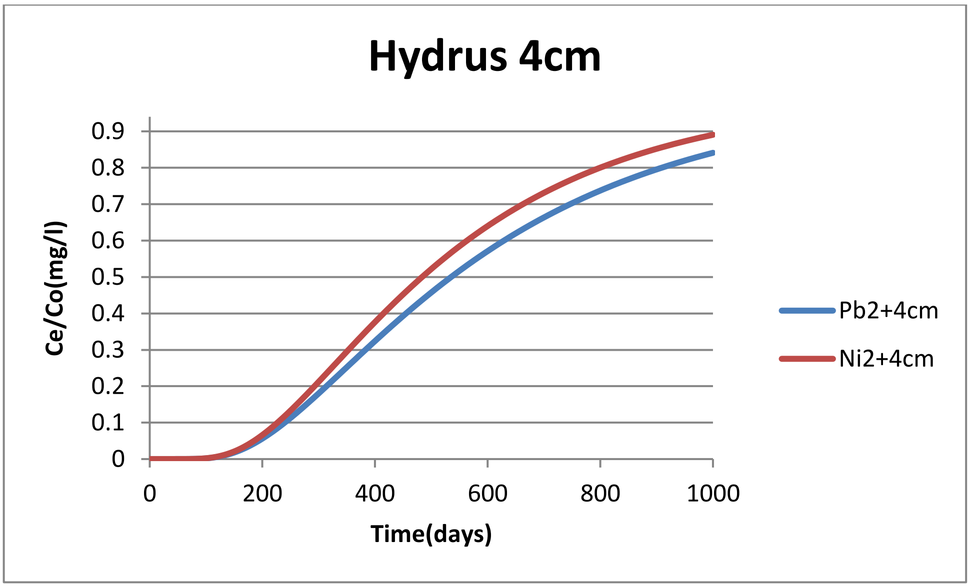


Figure 7: HYDRUS-1D predicted breakthrough curve for a soil bed height of 4 cm

1.4.CONCLUSION

In the present study, an effort has been made to examine the effectiveness of locally accessible laterite soil in reducing the subsurface movement of two heavy metals (Pb and Ni). Laboratory scale batch and vertical column experiments were conducted to evaluate the Pb and Ni adsorption capacity and their migratory behaviour through the soil. The test findings showed that a pH of 8 and an initial concentration of 10 mg/l of adsorbates resulted in a maximum removal of 98% and 96% for Pb and Ni, respectively, at the equilibrium reaction time of 2 hours. For Pb and Ni pollutants, the adsorption capacities of laterite soil were measured at 1857.2 mg/kg and 1766 mg/kg, respectively. The experimental data matches the nonlinear Freundlich isotherm model more satisfactorily. A laboratory column investigation utilizing two different column heights (3 cm and 4 cm) revealed that as bed height was increased, both the initial solute breakthrough time and the fatigue time grew. The HYDRUS-1D model was employed to mimic heavy metal's movement through the soil. The test findings show that the soil has good adsorption potential. This leads to the conclusion that heavy metal removal can be accomplished using lateritic soil. The lateritic soil can be used as the principal landfill liner in waste containment systems. The HYDRUS 1D software package's mathematical modelling accurately simulates the BTCs for both contaminants, making it useful for calculating soil liner thickness.

Future Scope

This study holds promise in the low-cost, sustainable, and effective liner design for effectively attenuating heavy metals and other contaminants and preventing them from contaminating precious groundwater. The significant advantage of this study is its practical applicability. However, this study was only on a laboratory scale and needs to be upscaled to demonstration or prototype in the future before actual application in the field, including other complex phenomena that can be challenging. Hence, further studies, including multi-metal and metal-organic combinations, are required to understand those complexities. Yet, the promising results show a glimpse of hope for this method's success in appropriately arresting toxic and hazardous components to prevent them from reaching groundwater.

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Chapter 2

Heavy Metal Contamination Levels in Industrial Areas Near Durgapur: A rising concern

Authors:

Email addresses:
1. debanjalia@svu.ac.in (Debanjali Adhikary), Swami Vivekananda University, Kolkata-700121 West Bengal, India.
2. avisheka@svu.ac.in (Avishek Adhikary), Swami Vivekananda University, Kolkata-700121, West Bengal, India.

2.1.INTRODUCTION

The rising levels of soil pollution are a crucial source of worry today [1]. This could be due to soils' peculiar characteristics, such as their poor structure, unpredictable layering, and high concentrations of trace elements [2]. In addition, soils are the receivers' of significant amounts of heavy metals from various sources, including industrial wastes and effluents. The Durgapur industrial city in West Bengal, India, which is around 160 km from Kolkata and is part of the Burdwan District, is one of the industrialized cities. In this case, pollution harms the lithosphere, hydrosphere, and atmosphere. The sole focus of this essay is atmospheric pollution. Numerous activities carried out by these companies result in enormous amounts of air pollutants, liquid effluents, and solid trash. Because these wastes and effluents contain many harmful chemicals and certain heavy metals as well, they may result in soil pollution if they are disposed of in an untreated manner. Because they are not degradable like organic matter and persist in the soil once they are ingested, heavy metal contamination of soil is one of the main areas of concern among these pollutants, which has been the focus of this study. The goal of the current study is to assess the level of heavy metal contamination in Durgapur, specifically concerning Cadmium (Cd), Mercury (Hg), Zinc (Zn), Lead (Pb), and Nickel (Ni).

Detailed objectives of this study include:

- Evaluation of the levels of heavy metal concentrations, their spatial distribution, and comparison to the USEPA 2002 soil quality guideline in Durgapur's soil samples.
- Application of cutting-edge statistical methods like correlation matrices to study the linkages between sources of high levels of heavy metals in the soil and the complicated dynamics of pollutants.
- Various pollution indices [3] are chosen to quantify the level of heavy metal contamination.

2.2.MATERIALS & METHODS

Table 1 shows 48 topsoil samples (0–20 cm) were taken from 16 distinct Durgapur locations. Three soil samples were taken from each area, separated by 40 to 60 metres. Most of Durgapur's regions were considered while choosing the research sites so that a more precise assessment of the area's soil pollution could be made. The samples were procured in virgin plastic bags. The resulting soil samples were air-dried for 48 hours. To create a uniform sample, the samples were later lightly ground with the aid of a mortar. After that, each sample was evenly combined and sieved. Then, a 250 ml beaker containing 1 g of soil was filled with 10 ml (1:1) HNO_3, heated for 5 minutes, and allowed to cool for 5 minutes before being filled with 5 ml of conc. HNO_3 was re-added and heated for 5 minutes (if strong brown fumes arise, keep adding HNO_3 until no more brown smells escape). Then, 3 ml of 30% H_2O_2 and 2 ml of distilled water were added. The amount was then decreased to 5 ml. The solution was then cooled, water was added, and Whatman No. 41 filter paper was used to get the final volume of 100 ml. Using distilled water, reagent blanking was done simultaneously. Then, using an Atomic Absorption Spectrophotometer (AAS), the heavy metals (Cd, Hg, Zn, Pb, and Ni) were analyzed in accordance with the guidelines provided in APHA (1995), Standard procedures for the assessment of water and wastewater, 21stEdison; American Public Health Association, Washington, DC.

Table 1: Regions of sample collection with latitude & longitude

Sample Regions	Latitude	Longitude
PCBL	23°30'15.88" N	87°18'48.30" E
ASP	23°31'41.46" N	87°16'9.46" E
DSP	23°33'39.84" N	87°15'6.24" E
DCL	23°30'23.53" N	87°17'8.76" E
G.I.	23°29’23.95”N	87°20’5.70”E
DCW	23°33’43.40 "N	87°13'59.90"E
BEN	23°33'24.71"N	87°16'36.64"E
B.Z.	23°34'3.57"N	87°18'59.48"E
CC	23°32'26.45"N	87°18'14.75"E
BID	23°31'55.72"N	87°19'35.25"E
KALNG	23°31'52.05"N	87°21'44.81"E
DCOC	23°29'56.26"N	87°17'56.86"E
SGB	23°29'43.23"N	87°20'7.00"E
ANG	23°30'53.20"N	87°16'4.98"E
SUKP	23°29'13.74"N	87°19'26.53"E
FULJ	23°32'9.84"N	87°20'22.21"E

Note: PCBL: Philips Carbon Black Ltd**.**, **ASP:** Alloy Steels Plant**, DSP:** Durgapur Steel Plant**, DCL:** Durgapur Chemicals Ltd.**, G.I.:** Graphite India**, DCW:** Durgapur Cement Works**, BEN:** Benachity**, BZ:** B-Zone**, CC:** City Centre**, BID:** Bidhannagar**, KALNG:** Kalinagar**, DCOC:** Durgapur Coke Oven Colony**, SGB:** Sagarbhanga**, ANG:** Angadpur**, SUKP:** Sukanta Pally**, FULJ:** Fuljhore**.**

Different regions' soil samples contained high levels of heavy metals, and various indices were used to measure the pollution caused by heavy metals. Additionally, the heavy metal concentration was compared with the accepted standards for soil quality from the USEPA in 2002 and the CCME in 2007.

2.3. RESULTS AND DISCUSSION

2.3.1 Heavy Metal Concentrations

Table 2 displays the total metal concentration discovered in the soil samples for each sampling site. Each region provided three samples, and the average value of the three samples—which provides a more reliable and accurate depiction of the concentration of heavy metals—was determined. In Table III, these average values are listed. According to the table, the concentration of metals ranged over the following boundaries: Cd: 1.03 to 2.20 mg/kg, Pb: 4.85 to 26.19 mg/kg, Hg: 0.01 to 0.11 mg/kg, Zn: 6.67 to 529.66 mg/kg, and Ni: 4.04 to 22.96 mg/kg. The sampling site's mean heavy metal content was: This enables them to be arranged in decreasing order of heavy metal content as Zn > Pb > Ni > Cd > Hg. Cd: 1.61 mg/kg, Pb: 12.68 mg/kg, Hg: 0.07 mg/kg, Zn: 71.43 mg/kg, and Ni: 10.59 mg/kg.

Table 2: Concentration of Heavy Metals in soil samples (mg/kg) (dry weight basis)

Sample Regions	Cd	Pb	Hg	Zn	Ni
PCB	1.89	14.2	0.06	30.05	4.18
ASP	1.92	17.2	0.08	34.79	7.64
DSP	1.94	13	0.09	50.19	4.04
DC	2.2	26.19	0.11	**529.66**	21.59
GI	1.75	17.2	0.05	62.75	12.72
DCW	1.84	21.4	0.04	78.53	7.26
BEN	1.55	18.2	0.06	80.68	7.4
BZ	1.03	4.98	0.07	14.73	15.28
CC	1.67	7.4	0.09	23.61	5.34
BID	1.91	4.85	0.05	13.16	10.52
KALNG	1.43	9.8	0.08	28.02	7.9
DCOC	1.75	14.8	0.09	58.35	7.34
SGB	1.33	7.2	0.05	50.60	12.76
ANG	1.25	5.6	0.08	43.07	22.96
SUKP	1.19	14.4	0.05	38.00	14.26
MEAN	**1.608**	**12.676**	**0.065**	**71.428**	**10.593**
MAX	**2.2**	**26.19**	**0.11**	**529.66**	**22.96**
MIN	**1.03**	**4.85**	**0.01**	**6.67**	**4.04**
SD	**0.351**	**6.408**	**0.025**	**124.148**	**5.676**

Table 3 below shows the Pearson correlation coefficient matrix for the heavy metals identified in the soil samples from Durgapur. Cadmium and Lead (0.64), Cadmium and Mercury (0.50), Lead and Zinc (0.66), and Zinc and Nickel (0.50) all showed a substantial association in the data, which can be interpreted as coming from the same or similar sources.

Table 3: Correlation matrix between heavy metals in soil samples

	Cd	**Pb**	**Hg**	**Zn**	**Ni**
Cd	1				
Pb	**0.64**	1			
Hg	**0.50**	0.28	1		
Zn	0.49	**0.66**	0.46	1	
Ni	-0.24	0.00	-0.03	**0.50**	1

2.3.2 Assessment of Heavy Metal Contamination

(i) Assessment of Heavy Metal according to USEPA, 2002 and CCME, 2007 Guidelines :

The heavy metal contaminations in the soil were assessed by comparing it with the soil quality guideline proposed by USEPA 2002 & CCME 2007. These standards are shown in **Table 4** below.

Table 4: USEPA 2002 & CCME 2007 Guidelines for soil [mg/kg (dry weight)]

	US EPA Guidelines 2002			
METAL	Not Polluted	Moderately Polluted	Highly Polluted	**CCME Guidelines, 2007**
Pb	<40	40 – 60	>60	70
Cd	….	….	>6	1.4
Zn	>90	90 – 200	>200	200
Ni	_	_	_	50
Hg	_	_	_	6.6

The current investigation shows that only some locations are contaminated by Pb, Hg, and Ni. Only the area next to Durgapur Chemicals has significant Zn pollution. Pollution from Zn is absent from all other areas. All the sites for Cd are polluted except for B.Z., SGB, ANG, SUK, and FULJ.

(ii) Assessment according To Geo-Accumulation Index(I_{geo})

The geo-accumulation index is a commonly used metric to assess the soil's level of heavy metal contamination. Muller [4] suggested comparing the current concentration of a heavy metal with the pre-industrial levels of a heavy metal to estimate the metal pollution in the soil or sediments. The formula for the Geo-accumulation index is as follows:

$$I_{geo} = \log_2 [C_n/1.5B_n]$$

Where C_n is the element concentration, and B_n is the geochemical background value (in this study, B_n is considered the world surface rock average given by Martin and Meybeck **[5]**.

A factor of 1.5 is included in the above equation to justify the possible variation in the background data due to the lithogenic effect. Based on Muller's classification, the soil or sediments can be classified into seven pollution levels, shown in **Table 5**.

Table 5: MULLER'S Classification for Geo-accumulation.

I_{geo} Value	Class	Soil or Sediment Quality
≤0	0	Unpolluted
0-1	**1**	Unpolluted to Moderately Polluted
1-2	**2**	Moderately Polluted
2-3	**3**	Moderately to Highly Polluted
3-4	**4**	Highly Polluted
4-5	**5**	Highly Polluted to Extremely Polluted
>6	**6**	Extremely Polluted

The geo-accumulation index (Igeo) scale consists of seven grades (0 - 6) ranging from unpolluted to highly polluted (shown in Table 6).

Table 6: Igeo for Different Samples

Sample Site	Lead	Mercury	Nickel	Cadmium	Zinc
PCB	-0.757	-0.137	-4.136	2.655	-2.664
ASP	-0.480	0.277	-3.266	2.678	-2.453
DSP	-0.884	0.447	-4.185	2.693	-1.924
DC	0.125	0.736	-1.767	2.874	1.475

GI	-0.480	-0.400	-2.530	2.544	-1.602
DCW	-0.165	-0.722	-3.339	2.616	-1.278
BEN	-0.399	-0.137	-3.321	2.369	-1.241
BZ	-2.272	0.599	-2.272	1.779	-3.698
CC	-1.698	0.446	-3.795	2.476	0.275
BID	-2.307	-0.401	-2.805	2.67	-3.816
KALNG	-1.293	0.277	-3.224	2.252	-2.766
DCOC	-0.698	0.446	-3.336	2.544	-1.708
SGB	-1.736	-0.401	-2.531	2.148	-1.915
ANG	-2.101	0.277	-1.68	2.058	-2.152
SUKP	-0.736	-0.722	-2.363	1.987	-2.329
FULJ	-1.91	0.084	-3.158	1.847	-4.836

(iii) Assessment Based on Contamination Factor, Pollution Load Index And Degree of Contamination

The contamination factor and degree of contamination are used to determine the contamination level of the soil, and these are used in the present study. According to D. C. Thomilson, D. J.Wilson, C. R. Harris, and D. W. Jeffrey[4], the contamination factor can be calculated as below:

Contamination factor (CF) = $C_{metal}/C_{background}$

C_{metal}: Concentration of the metal in the sample

$C_{background}$: Background concentration of metal (pre-industrialization concentration).

In the present study, the world surface rock average proposed by Martin and Meybeck5 is considered background concentration.

(iv) Pollution Load Index(PLI)

The term PLI represents the number of times by which the metal content in the sample soil exceeds the background concentration value of the metal. It gives a summative signal about the overall level of heavy metal toxicity in a particular sample or region **[6]**. The pollution load index for a specific sample can be calculated as below:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \times \ldots \times CF_n)^{1/n}$$

PLI < 1 indicates no pollution

PLI > 1 indicates pollution

The sum of all the contamination criteria for a site is the degree of contamination. The contamination level of each sample location is determined from the contamination factor table by adding up the contamination factors for each heavy metal for each sample location separately. The outcome demonstrates significant heavy metal contamination near PCB, ASP, DSP, DC, DCW, and DCOC. The other areas (shown in Table 7) have moderate heavy metal pollution.

Degree of contamination = Summation of contamination factor of each heavy metal for a location.

Table 7: Terminologies used to describe the contamination factor.

C.F.	Cd	Degree of contamination
CF<1	Cd<6	Low
1<CF<3	6≤Cd<12	Moderate
3<CF<6	12≤Cd<24	Considerable
CF>6	Cd≥24	Very high

The contamination factors, pollution load indices, and the degrees of contamination are tabulated in **Table 8** below.

Table 8: Contamination factors, Pollution Load indices (PLI) and Degree of Contamination

Sample Location	**Contamination factors**					**PLI**	**Degree of contamination***
	Pb	**Hg**	**Cd**	**Ni**	**Zn**		
PCB	0.89	1.35	9.45	0.09	0.24	0.75	12.02
ASP	1.08	1.80	9.6	0.16	0.27	0.96	12.91
DSP	0.81	2.02	9.7	0.08	0.40	0.87	13.01
DC	1.64	2.47	11	0.44	4.17	2.41	19.72
GI	1.	1.	8.	0.	0.	1.	11.7

	08	12	75	26	49	06	
DCW	1.34	0.90	9.2	0.15	0.62	1.01	12.21
BEN	1.14	1.35	7.75	0.15	0.64	1.03	11.03
BZ	0.31	0.22	5.15	0.31	0.12	0.42	6.11
CC	0.46	2.02	8.35	0.11	0.19	0.70	11.13
BID	0.30	1.12	9.55	0.21	0.10	0.58	11.28
KALNG	0.61	1.80	7.15	0.16	0.22	0.77	9.94
DCOC	0.93	2.02	8.75	0.15	0.46	1.03	12.31
SGB	0.45	1.12	6.65	0.26	0.40	0.81	8.88
ANG	0.	1.	6.	0.	0.	0.	9.21

	35	80	25	47	34	91	
SUKP	0.9	0.90	5.95	0.29	0.30	0.84	8.34
FULJ	0.4	1.57	5.40	0.17	0.05	0.49	7.59

*by Tomlinson et al. (1980).

From Table VIII, it can be inferred that:

- All the locations have a very high degree of contamination for cadmium.
- There is a moderate degree of contamination for Lead, ASP, DC, G.I., DCW, and BEN. The rest of the locations have a low degree of contamination.
- Mercury, DCW, B.Z., and SUKP have a low degree of contamination. The rest of the locations are moderately polluted with mercury.
- For Nickel, all the locations have low contamination.
- For Zinc, only D.C. has a considerable amount of pollution. The rest all have low pollution.

2.4.CONCLUSION

According to the analysis of surface soil samples taken from 16 industrial areas of Durgapur City, the areas are polluted with Zinc, Lead, cadmium, Nickel, and chromium in the following decreasing order: Zn > Pb > Ni > Cd > Hg. The statistical correlation study revealed that the source inputs for the pairs of cadmium and Lead, cadmium and mercury, Lead and Zinc, and Zinc and Nickel may be identical or comparable. In most regions, there is a sizable source of cadmium pollution, per USEPA soil quality criteria from 2002. According to USEPA 2002, the research region has little to no pollution for the other heavy metals. Zinc pollution in the areas close to M/s. Exit of Durgapur Chemicals Ltd. By leaching, the high concentration of Zinc in the area around it has the potential to pollute nearby soil and groundwater. All of the study area's regions have very low mercury pollution levels. Still, since mercury is extremely hazardous even at very low concentrations, it may build up in the soil and pose a concern to the environment and human health.

To repair contaminated land, a variety of in-situ procedures may be used, including electrokinetic extraction of pollutants from surface or nearby land [11], solidification/stabilization of contaminated soil using additives [10], bioremediation and phytoremediation [12], etc. However, it is wise to carefully analyze their economic viability before choosing any of the aforementioned strategies to clean up polluted soil.

Future Scope

This study points out the risks of heavy metal contamination in and around the industrial city of Durgapur. While, this study provides the insights on the potential contamination problem, the are still in-depth studies required for the effective attenuation of those metals to prevent them from reaching groundwater table. Also, this study incorporates only inorganic heavy metals, which is only a fraction of total contaminating toxic chemicals present in the environment. Hence, the incorporation of organic chemicals is also a key feature for a complete study regarding this aspect.

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Chapter 3

Wind Induced Vibration on Bridge Deck

Author: - Samir *Kumar, (**Email: -samirk@svu.ac.in**) Assistant Professor, Civil Engineering Department, SVU, Kolkata, India Pin-170121*

3.1. INTRODUCTION

Wind-induced vibrations on bridge decks represent a multifaceted challenge at the intersection of fluid dynamics and structural engineering. As the wind interacts with the intricate geometry of a bridge, it imparts dynamic forces that can lead to oscillations and vibrations. These aerodynamic forces, including lift and drag, create a complex dance between the wind and the bridge structure. Vortex shedding, a phenomenon where vortices form as the wind flows around obstacles, adds another layer to this intricate interplay, inducing periodic forces. The natural frequency of the bridge becomes a critical parameter, as resonance—where wind forces align with the structure's inherent vibrational frequency—can lead to amplified vibrations. Structural dynamics, encompassing mass, stiffness, and damping properties, influence how a bridge responds to wind-induced forces. These vibrations manifest in various modes, such as vertical, torsional, and lateral movements. Understanding the impact on both the structural integrity and user comfort is paramount, leading engineers to deploy sophisticated mitigation strategies, including tuned mass dampers and aerodynamic modifications. In the ever-evolving landscape of bridge engineering, advancements in technology, from wind tunnel testing to computational fluid dynamics, play a pivotal role in comprehending and addressing the intricate challenges posed by wind-induced vibrations on bridge decks.

Wind-induced vibrations on bridge decks can pose challenges to the structural integrity and user comfort of a bridge. As wind flows around a bridge, it imparts forces on the structure that can lead to oscillations and vibrations. The dynamic interaction between the wind and the bridge can result in a range of responses, from subtle vibrations to more pronounced movements.

Aerodynamic Forces: Wind exerts pressure on the surfaces of the bridge, creating aerodynamic forces such as lift and drag. These forces vary with wind speed, direction, and the geometric characteristics of the bridge. Aerodynamic forces are the forces exerted on an object as it moves through air or another fluid medium. These forces are a result of the interaction between the object and the air molecules surrounding it. In the context of bridge engineering and wind-induced vibrations, understanding aerodynamic forces is crucial for assessing the effects of wind on the structure. The primary aerodynamic forces are lift and drag.

Lift: Lift is the aerodynamic force perpendicular to the direction of the airflow. It acts in a direction opposite to gravity and is responsible for the upward force that allows aircraft to become airborne and contributes to the dynamic behavior of structures like bridges.

Generation of Lift: Lift is generated by differences in air pressure above and below an object. As air flows over the surface of the object, it follows the shape of the object. According to Bernoulli's principle, the pressure decreases where the airflow is faster, creating lift.

Drag: Drag is the aerodynamic force parallel to the direction of the airflow. It acts in the opposite direction to the object's motion and is a resistance force that opposes the motion through the fluid medium.

Types of Drag:

Form Drag: Arises due to the shape of the object and the pressure differences created as air flows around it.

Skin Friction Drag: Results from the friction between the surface of the object and the moving air.

Induced Drag: Occurs as a consequence of lift production. It is associated with the creation of vortices at the wingtips or other protruding features.
Factors Influencing Aerodynamic Forces:
Shape of the Object: The geometry of the object strongly influences the generation of lift and drag. Streamlined shapes are designed to minimize drag and enhance lift, especially in applications like aircraft and vehicles.
Angle of Attack: The angle between the oncoming airflow and the chord line of the object affects the lift and drag forces. Changes in the angle of attack can significantly impact aerodynamic performance.
Surface Roughness: The smoothness or roughness of the object's surface affects skin friction drag. Rough surfaces generally experience higher drag forces.
Velocity of the Airflow: The speed of the air relative to the object influences the magnitude of aerodynamic forces. Faster airspeed generally leads to increased lift and drag.
Effect on Bridges:
In the context of bridges, aerodynamic forces can induce vibrations and dynamic responses. Vortex shedding, a phenomenon where vortices are formed and shed into the downstream flow, can lead to periodic forces on the structure, contributing to wind-induced vibrations.
For long-span bridges, the interaction of wind with the structural elements, such as towers, cables, and the bridge deck, becomes a critical consideration in design to ensure stability and safety.
Understanding aerodynamic forces is essential for designing structures that can withstand the effects of wind while minimizing undesirable vibrations and ensuring the safety and functionality of the bridge. Engineers use wind tunnel testing, computational fluid dynamics (CFD), and analytical methods to model and predict these forces during the design and assessment of bridge structures.
Vortex Shedding: Vortex shedding occurs when the wind flow separates and forms vortices as it encounters irregularities or features on the bridge. This phenomenon can induce periodic forces, contributing to the vibrations.
Resonance and Natural Frequency: The natural frequency of the bridge structure plays a crucial role. If the wind-induced forces coincide with the natural frequency of the bridge, resonance can occur, amplifying the vibrations.
Structural Dynamics: The dynamic behaviour of the bridge under wind loading is influenced by its mass, stiffness, and damping characteristics. Understanding these properties is essential for predicting and mitigating wind-induced vibrations.
Vibration Modes: Different vibration modes may be excited by the wind, including vertical, torsional, and lateral vibrations. The mode shapes and frequencies depend on the bridge's geometry and material properties.
Impact on Occupants and Structure:
Wind-induced vibrations can affect the comfort and safety of bridge occupants. Excessive vibrations may lead to discomfort, and in extreme cases, structural damage. Balancing structural performance with user experience is a key consideration in bridge design.
Mitigation Strategies:
Engineers employ various strategies to mitigate wind-induced vibrations. These include the use of tuned mass dampers, aerodynamic modifications, and adjustments to the bridge's geometry or material properties.
Design Standards and Guidelines: Design standards provide guidelines for assessing and addressing wind-induced vibrations. Engineers follow these standards to ensure that bridges meet safety and performance criteria in windy conditions.
Technological Advances: Advances in technology, such as wind tunnel testing, computational fluid dynamics (CFD), and structural health monitoring, have enhanced the understanding and management of wind-induced vibrations on bridge decks.
Research and Innovation:

Ongoing research and innovation in bridge engineering focus on developing new methods and materials to improve the resilience of bridges to wind-induced vibrations, ensuring the longevity and safety of these critical infrastructure elements.

In conclusion, understanding and managing wind-induced vibrations on bridge decks are essential aspects of bridge design and maintenance. Engineers employ a combination of analytical methods, simulations, and practical measures to ensure that bridges remain structurally sound and comfortable for users under varying wind conditions.

History at a Glance

The history of wind-induced vibrations on structures is closely tied to the evolution of structural engineering and the recognition of the impact of dynamic wind forces on buildings and bridges. Over the years, researchers and engineers have developed a deeper understanding of the complex interaction between wind and structures. Here's a brief overview of the historical aspects:

Early Observations and Experiences (Pre-20th Century):

Early structures, especially tall and slender ones, have likely experienced the effects of wind-induced vibrations for centuries. However, systematic studies and understanding were limited during this period.

Early 20th Century:

With the rise of taller and more innovative structures, such as early skyscrapers, engineers began to recognize the need to account for wind effects. Wind tunnel testing emerged as a valuable tool for studying aerodynamics, and researchers started investigating the impact of wind on building and bridge structures.

1940s-1950s:

The mid-20th century saw increased interest in the dynamic behavior of structures under wind loading. Research efforts, often driven by the aerospace industry, contributed to the development of analytical methods to assess the effects of wind-induced vibrations.

1960s-1970s:

Advances in technology, including the use of computers for numerical simulations, allowed for more sophisticated analyses of wind effects on structures. Engineers started incorporating dynamic analysis into structural design, considering the natural frequencies and damping characteristics of buildings and bridges.

1980s-1990s:

This period marked a significant leap in the understanding of wind-induced vibrations. Researchers and engineers began to focus on mitigating wind effects, introducing concepts like tuned mass dampers—a technology designed to counteract wind-induced oscillations. Wind engineering standards and guidelines also started to incorporate more detailed provisions for assessing and mitigating wind effects on structures.

21st Century:

The 21st century witnessed further advancements in wind engineering. Computational Fluid Dynamics (CFD) simulations became more prevalent, enabling detailed modeling of wind flows around structures. The integration of sensors and monitoring systems into structures allowed for real-time assessments of structural health, helping identify and address potential wind-induced vibration issues promptly.

Ongoing Research and Innovation:

Today, ongoing research continues to refine our understanding of wind-induced vibrations. Engineers are exploring new materials, advanced monitoring techniques, and innovative mitigation strategies. The field is also adapting to the challenges posed by increasingly complex and sustainable architectural designs.

Present Scenario:

The present scenario regarding wind-induced vibrations on bridge decks.

I. Research and Development:

Ongoing research focuses on improving our understanding of wind-induced vibrations and developing innovative solutions. This includes advancements in computational methods, wind tunnel testing, and field studies to enhance the accuracy of predictions and assessments.

II. Design Standards and Guidelines:

Design standards continue to be crucial in ensuring the safety and reliability of bridges. These standards are regularly updated to incorporate the latest knowledge and methodologies for assessing and mitigating wind-induced vibrations.

III. Advanced Modelling Techniques:

Engineers increasingly use advanced modelling techniques, such as Computational Fluid Dynamics (CFD), to simulate and analyse wind flows around bridge structures. These simulations help in predicting the aerodynamic forces that induce vibrations.

IV. Structural Health Monitoring (SHM):

Structural Health Monitoring systems are employed to continuously assess the condition of bridges. These systems use sensors to measure structural responses, enabling real-time monitoring of vibrations. SHM plays a vital role in identifying potential issues early and informing maintenance decisions.

V. Mitigation Strategies:

Mitigation strategies for wind-induced vibrations include both traditional and innovative approaches. Tuned mass dampers, tuned liquid column dampers, and aerodynamic modifications are among the techniques used to reduce vibrations and enhance the overall performance of the bridge.

VI. Sustainability Considerations:

Modern bridge designs often integrate sustainability considerations. Engineers strive to balance the need for mitigating wind-induced vibrations with environmental and economic factors, ensuring that solutions are both effective and sustainable in the long term.

VII. Technological Integration:

Technology plays a significant role in addressing wind-induced vibrations. Advances in sensor technology, data analytics, and communication systems contribute to more efficient monitoring and management of bridge structures.

VIII. Climate Change Adaptation:

Considerations related to climate change and its potential impact on wind patterns are increasingly factored into the design and assessment of bridges. Engineers may need to account for changing wind profiles when planning for the long-term resilience of bridge structures.

IX. Public Safety and Awareness:

Public safety remains a top priority. Awareness campaigns and public education initiatives help inform bridge users about the normalcy of certain vibrations and the safety measures in place. Clear communication is crucial to address concerns and ensure public confidence in bridge infrastructure.

Studies on Wind-induced Vibration

Numerous studies have been conducted on wind-induced vibrations on bridge decks, reflecting the importance of understanding and mitigating the effects of wind on bridge structures. Here are a few key studies that delve into this subject:

I. Title: "Wind-Induced Vibrations of a Long-Span Bridge: Field Measurements, Model Validation, and Fatigue Assessment"

Authors: Y. M. Wu, H. T. Bu, and J. Y. Zhu

Published: Journal of Structural Engineering, ASCE, 2019
Abstract: This study presents field measurements of wind-induced vibrations on a long-span bridge. The research includes validation of numerical models with the field data and an assessment of the fatigue life of critical components. The findings contribute to understanding the dynamic behavior of long-span bridges under wind loading.

II. Title: "Aerodynamic Damping and Flutter Analysis of a Suspension Bridge Deck"
Authors: H. Q. Li and Y. Q. Ni
Published: Journal of Bridge Engineering, ASCE, 2017
Abstract: The study focuses on the aerodynamic damping of a suspension bridge deck and analyzes its impact on flutter instability. The research employs computational methods to investigate the complex aerodynamic forces and their effects on the dynamic behavior of the bridge.

III. Title: "Wind-Induced Vibration Analysis of a Cable-Stayed Bridge Based on the Full-Scale Monitoring"
Authors: Y. X. Yang, J. H. Xie, and W. Q. Sun
Published: Advances in Structural Engineering, 2018
Abstract: This study presents a comprehensive analysis of wind-induced vibrations on a cable-stayed bridge using full-scale monitoring data. The research provides insights into the dynamic response of cable-stayed bridges under different wind conditions.

IV. Title: "Aeroelastic Analysis of Long-Span Bridges Under Turbulent Wind: A State-of-the-Art Review"
Authors: J. L. Cao, L. M. Cao, and Y. Q. Ni
Published: Journal of Wind Engineering and Industrial Aerodynamics, 2018
Abstract: The study reviews the state-of-the-art in aeroelastic analysis of long-span bridges subjected to turbulent wind. It covers methodologies for modeling turbulent wind effects and discusses the challenges and advancements in understanding and mitigating wind-induced vibrations.

V. Title: "Influence of Vehicle Aerodynamic Interaction on the Flutter Stability of Long-Span Bridges"
Authors: X. L. Li, Y. Q. Ni, and J. H. Xie
Published: Engineering Structures, 2017
Abstract: This study investigates the influence of vehicle aerodynamic interaction on the flutter stability of long-span bridges. The research combines computational simulations with wind tunnel testing to assess the impact of moving vehicles on the aeroelastic behavior of the bridge.

These studies showcase the diverse approaches to studying wind-induced vibrations on bridge decks, including field measurements, numerical simulations, and wind tunnel testing. Researchers aim to improve our understanding of the complex interaction between bridges and wind, leading to more accurate predictions and effective mitigation strategies.

3.2. Research Methodology

Research on wind-induced vibrations typically involves a combination of experimental and analytical methodologies. Researchers aim to understand the complex interactions between the wind and structures, especially for bridges where wind-induced vibrations can have significant implications for both structural integrity and user comfort. Below is an outline of the research methodology commonly employed in studying wind-induced vibrations:

1. **Literature Review:**
    - Before initiating new research, a comprehensive literature review is conducted to understand the existing body of knowledge. This includes reviewing published studies, journal articles, conference papers, and relevant books to identify gaps in understanding and areas that need further investigation.
2. **Field Measurements:**
    - Field measurements involve installing sensors and data acquisition systems on existing bridges to collect real-world data on wind-induced vibrations. Instruments such as accelerometers, anemometers, and strain gauges are strategically placed on the bridge structure to capture dynamic responses under varying wind conditions.
3. **Wind Tunnel Testing:**
    - Wind tunnel testing is a crucial experimental method for simulating wind effects on scaled models of bridge structures. Physical models of the bridge, often made to scale, are subjected to simulated wind flows in a controlled environment. This method allows researchers to observe and measure the aerodynamic forces and structural responses.
4. **Computational Fluid Dynamics (CFD) Simulations:**
    - CFD involves creating virtual models of the bridge and its surroundings to simulate airflow patterns and aerodynamic forces. CFD simulations provide insights into the complex fluid-structure interactions, helping researchers understand how different design parameters and wind conditions affect the structure's response.
5. **Dynamic Analysis:**
    - Dynamic analysis involves using mathematical models to simulate the behavior of the bridge under wind loading. Finite Element Analysis (FEA) and other numerical methods are employed to predict natural frequencies, mode shapes, and responses to wind-induced forces. Dynamic analysis helps identify critical areas prone to vibrations and assesses the potential for resonance.
6. **Tuned Mass Dampers (TMD):**
    - TMDs are devices designed to counteract the effects of wind-induced vibrations. Research may involve the design, implementation, and testing of TMDs to mitigate vibrations. This includes studying the optimal characteristics of TMDs for specific bridge configurations.
7. **Material Testing:**

- In some cases, researchers may conduct material testing to understand how different materials respond to dynamic loading. This can include laboratory tests on the fatigue properties of bridge materials under simulated wind-induced vibrations.

8. **Structural Health Monitoring (SHM):**

   - SHM involves the continuous monitoring of the bridge's structural condition using sensors. This ongoing data collection helps researchers understand the long-term effects of wind-induced vibrations, identify trends, and assess the structural health of the bridge over time.

9. **Validation Studies:**

   - Validation studies compare the results obtained from experiments and simulations with observed field data. This step ensures that the models and methods used in the research accurately represent the real-world behavior of bridges under wind loading.

10. **Mitigation Strategies:**

    - Research often includes the investigation of various mitigation strategies, such as aerodynamic modifications, structural enhancements, or the use of dampers. Evaluating the effectiveness of these strategies helps in proposing practical solutions for minimizing wind-induced vibrations.

By combining these methodologies, researchers can gain a comprehensive understanding of wind-induced vibrations on bridge structures and develop strategies to enhance their design, safety, and performance.

3.2.1 Literature Review

The literature review process begins with clearly defining the research question or objective. This helps to focus the review and ensures that the researcher identifies relevant literature that directly addresses the research goals.

Develop Search Criteria: Researchers establish specific criteria for selecting literature sources. This may include keywords, publication dates, specific journals or conferences, and relevant subject areas. The criteria help streamline the search process and ensure the inclusion of the most pertinent literature.

Search Databases and Libraries: Researchers utilize academic databases (e.g., PubMed, IEEE Xplore, ScienceDirect) and library resources to systematically search for literature. The chosen databases should align with the subject matter of the research. Searches may involve combinations of keywords, Boolean operators, and filters.

Retrieve and Organize Literature: Once the initial search is conducted, researchers retrieve relevant articles, conference papers, books, and other scholarly materials. The collected literature is then organized systematically. Tools like citation management software (e.g., EndNote, Zotero) can assist in efficiently managing and categorizing references.

Evaluate and Select Sources: Each retrieved source undergoes a thorough evaluation to determine its relevance and credibility. Criteria for evaluation may include the author's credentials, publication venue, methodology, and the significance of the findings. The goal is to select high-quality sources that contribute to the understanding of the research topic.

Analyze and Synthesize Findings: Researchers analyze the selected literature, extracting key findings, methodologies, and theoretical frameworks. The goal is to synthesize the information to identify patterns, trends, and gaps in the existing knowledge. This process helps in developing a conceptual framework for the new research.
Identify Gaps and Contradictions: Through the synthesis of findings, researchers identify gaps in the existing body of knowledge. These gaps may include areas where research is lacking, contradictions in findings, or opportunities for further exploration. Recognizing these gaps informs the rationale for the new research.
Revise and Refine: The literature review undergoes multiple rounds of revision and refinement. Feedback from mentors, peers, or advisors may be sought to ensure clarity, coherence, and accuracy. The goal is to present a comprehensive and well-supported review that sets the stage for the new research.
Continuous Updating: Throughout the research process, researchers continue to monitor the literature for new publications and developments related to the topic. This continuous updating ensures that the research remains current and incorporates the latest findings in the field. A well-executed literature review is foundational to the research process, providing a solid understanding of existing knowledge, guiding the development of research questions, and contributing to the construction of a theoretical framework for the study

3.2.2. Field Measurements:

I. **Instrumentation Selection:** Before field measurements can commence, the researchers must carefully select the appropriate instrumentation. Common instruments for studying wind-induced vibrations include accelerometers, anemometers, and strain gauges. Accelerometers measure accelerations, anemometers measure wind speed, and strain gauges measure deformation or strain in the bridge structure.

II. **Sensor Placement:** Once the instruments are selected, they are strategically placed on the bridge structure. The placement is critical and is often determined based on the bridge's geometry, structural components, and expected areas of interest. Sensors may be installed on different parts of the bridge, such as the deck, towers, cables, and other critical structural elements.

III. **Accelerometers:** Accelerometers are attached to the bridge to measure the accelerations experienced by the structure. They can be placed on various locations, including the deck, towers, or other structural members. These sensors record vibrations in multiple directions, providing a comprehensive understanding of the dynamic response.

IV. **Anemometers:** Anemometers are deployed to measure wind speed and direction. These instruments help correlate the recorded vibrations with the intensity and direction of the wind. Anemometers are often positioned at different heights to capture variations in wind profiles.

V. **Strain Gauges:** Strain gauges are applied to structural elements to measure the deformation or strain. Placing strain gauges on critical parts of the bridge allows researchers to assess how different components respond to wind-induced forces. Strain measurements are crucial for understanding the structural health and integrity of the bridge.

VI. **Data Acquisition Systems:** Sensors are connected to data acquisition systems, which collect and record the data. These systems often include analog-to-digital converters that convert sensor signals into digital data. The collected data is then stored for further analysis.

VII. **Remote Monitoring Systems:** In some cases, remote monitoring systems are employed, enabling real-time data collection and monitoring. These systems allow researchers to access data remotely, making it possible to respond quickly to changing conditions or unexpected events.

VIII. **Calibration:** Before deployment, sensors need to be calibrated to ensure accuracy and reliability. Calibration involves verifying that the instruments provide accurate measurements in comparison to known standards. This step is essential for producing trustworthy data.

IX. **Data Analysis:** After the field measurements are complete, researchers analyze the collected data. This analysis involves studying patterns, frequencies, and amplitudes of vibrations under different wind conditions. Researchers may also correlate the data with meteorological information to understand the relationship between wind characteristics and structural response.

X. **Interpretation and Reporting:** The final step involves interpreting the results and reporting findings. Researchers draw conclusions about the bridge's dynamic behavior under wind loading, identify any critical issues or vulnerabilities, and suggest potential mitigation measures if needed.

3.2.3. Wind Tunnel Testing:

Wind tunnel testing begins with a clearly defined objective. Researchers outline what specific aspects of the bridge's aerodynamic performance they aim to investigate. This may include studying vortex shedding, determining critical wind speeds, or evaluating the effectiveness of mitigation measures. A scaled model of the bridge is designed and constructed to replicate the essential features of the actual structure. The scale is determined based on the size of the wind tunnel and the desired level of detail. The model should accurately represent the geometry, materials, and key structural elements of the real bridge. Researchers choose an appropriate wind tunnel for the testing. The selection considers factors such as the size of the model, the required wind speed range, and the level of turbulence needed for realistic simulation. Wind tunnels come in various sizes, from small, low-speed tunnels to large, high-speed tunnels. Wind tunnel tests aim to simulate the atmospheric boundary layer, which is the layer of air closest to the ground. To achieve this, researchers implement techniques to simulate the boundary layer in the wind tunnel, ensuring that the airflow over the model closely resembles the conditions the bridge would experience in the field. Various instruments are installed on the bridge model to measure aerodynamic forces, pressures, and structural responses. These instruments may include pressure taps, strain gauges, and accelerometers strategically placed on the model. The goal is to capture detailed data on the bridge's performance under simulated wind conditions. The wind tunnel generates controlled airflow around the bridge model. Researchers can adjust the wind speed, direction, and turbulence levels to replicate different wind conditions. This simulation allows for a systematic exploration of the bridge's response to various wind scenarios. During the wind tunnel test, data is continuously collected from the instruments installed on the bridge model. This data includes aerodynamic forces, pressure distributions, and structural responses. High-speed cameras may also be used to visually capture the flow patterns around the model. The collected data is analysed to extract meaningful insights into the bridge's aerodynamic behaviour. Researchers study the aerodynamic forces, identify critical wind speeds, assess the occurrence of vortex shedding, and evaluate any adverse effects on the structural integrity. Based on the initial results, researchers may refine the model or testing parameters and conduct additional tests. This iterative process helps improve the accuracy of the results and ensures that the wind tunnel testing provides a comprehensive understanding of the bridge's behaviour. The final step involves reporting the findings of the wind tunnel testing. Researchers discuss the implications of the results, validate theoretical models if applicable, and provide recommendations for design modifications or mitigations to address any identified issues.

Wind tunnel testing is a powerful tool in bridge engineering, providing valuable insights into the aerodynamic forces and structural responses under different wind conditions. It helps bridge designers optimize their structures for safety and performance in real-world environments

3.2.4. Computational Fluid Dynamics (CFD) Simulations:

CFD simulations begin with clearly defining the problem at hand. Researchers establish the goals of the simulation, including the specific aspects of aerodynamic behaviour they want to investigate. This may involve studying flow patterns, pressure distributions, or the impact of wind on different structural components. A detailed virtual model of the bridge and its surroundings is created using specialized software. The geometry of the bridge, including its structural components, is accurately represented in the virtual domain. This step involves capturing intricate details to ensure the simulation's accuracy.

The geometry is divided into a mesh of small elements to facilitate numerical calculations. Mesh generation is a crucial step, and the density and quality of the mesh impact the accuracy of the simulation. Fine meshes are often used in areas where complex flow phenomena are expected. Researchers specify the properties of the fluid (air) in the simulation, including density, viscosity, and temperature. Boundary conditions are also defined to simulate the interaction between the air and the bridge. This includes specifying wind speeds, directions, and turbulence levels.

CFD simulations are based on solving the Navier-Stokes equations, which describe the motion of fluid. Additional equations, such as those for turbulence modelling, may be incorporated to capture complex flow phenomena. These equations are solved numerically for each element in the mesh. Advanced numerical algorithms are employed to solve the governing equations iteratively. These algorithms calculate the flow field, pressure distributions, and other relevant parameters across the entire computational domain. The simulation progresses through multiple time steps to capture dynamic behaviour.

After the simulation is completed, post-processing is conducted to extract meaningful insights. Visualization tools are used to create graphical representations of the results, such as contour plots showing pressure distributions, streamline patterns, and velocity profiles. These visualizations aid in the interpretation of the complex fluid-structure interactions.

To ensure the accuracy and reliability of the CFD simulation, results are often compared to experimental data from wind tunnel tests or field measurements. This validation step helps confirm that the virtual model accurately represents the physical behaviour of the bridge under wind loading. CFD simulations enable researchers to conduct parametric studies, exploring how different design parameters and wind conditions impact the aerodynamic performance of the bridge. This may involve varying the bridge's geometry, adding aerodynamic features, or changing wind speeds to assess their effects. Insights gained from CFD simulations contribute to the optimization of bridge design. Engineers can use simulation results to refine structural elements, improve aerodynamic efficiency, and enhance the overall performance of the bridge under varying wind scenarios.

3.2.5. Tuned Mass Dampers (TMD):

Before implementing TMDs, it's crucial to have a clear understanding of the wind-induced vibrations affecting the bridge. This involves studying the dynamic response of the bridge under various wind conditions, identifying critical frequencies, and assessing the potential impact on structural integrity and user comfort. A Tuned Mass Damper (TMD) is a mechanical device designed to reduce vibrations in a structure by introducing a secondary mass that is tuned to a

specific frequency of the structure. TMDs are particularly effective in mitigating resonant vibrations induced by external forces, such as wind. Researchers conduct dynamic analysis to determine the natural frequencies and mode shapes of the bridge. Understanding the dynamic characteristics is crucial for designing TMDs that can effectively counteract vibrations at specific frequencies.
The design process involves determining the optimal characteristics of the TMD, including the mass, damping ratio, and stiffness. These parameters are selected based on the identified frequencies of the bridge's natural modes. The goal is to tune the TMD to resonate in opposition to the undesired bridge vibrations.
Researchers decide on the locations where TMDs will be installed on the bridge structure. Strategic placement is essential to maximize the effectiveness of the damping system. Common locations include the bridge deck, towers, or other structural elements prone to wind-induced vibrations.
Numerical simulations are often employed to model the interaction between the bridge and the TMDs. Finite Element Analysis (FEA) or other analytical methods can be used to predict the response of the coupled system under different wind conditions. Simulation helps refine the TMD design before physical implementation.
In some cases, researchers may conduct laboratory testing to validate the performance of the TMD. This can involve testing scaled models of the bridge with integrated TMDs under controlled conditions. The results of laboratory tests provide insights into the practical effectiveness of the damping system. Once the design is finalized and validated, TMDs are implemented on the actual bridge structure. The installation process must be carefully planned to ensure that the TMDs are securely attached and do not adversely affect the overall structural integrity.
After implementation, the performance of the TMDs is continuously monitored. This may involve the use of sensors to measure vibrations and assess the effectiveness of the damping system. If needed, adjustments to the TMD parameters can be made to optimize performance. The final step involves evaluating the overall effectiveness of the TMDs in mitigating wind-induced vibrations. Researchers assess whether the implemented system aligns with the design objectives and makes any necessary adjustments for optimization.
Tuned Mass Dampers play a crucial role in enhancing the resilience of bridges against wind-induced vibrations, contributing to both the safety of the structure and the comfort of bridge users. The design and implementation process involves a combination of theoretical modeling, simulation, and practical testing to ensure the efficacy of the damping system.

3.3 Summary

Wind-induced vibrations on bridges are a dynamic phenomenon that arises from the intricate interaction between wind forces and the structural components of a bridge. As wind flows around a bridge, it imparts forces on the structure, leading to a range of responses from subtle oscillations to more pronounced movements. The causes of wind-induced vibrations are multifaceted, involving the generation of aerodynamic forces, vortex shedding, and resonant vibrations. The complex fluid-structure interaction between the wind and the bridge can result in both vertical and lateral movements, posing challenges to the structural integrity and user comfort of the bridge.
Understanding the potential impact of wind-induced vibrations on the structural integrity of a bridge is paramount. Prolonged exposure to vibrations, especially at resonant frequencies, can induce fatigue and damage in structural elements, potentially compromising the long-term durability of the bridge.
Dynamic analysis techniques play a crucial role in comprehending the response of a bridge to wind-induced vibrations. This involves identifying natural frequencies, mode shapes, and assessing the potential for resonance, enabling engineers to design bridges that are less susceptible to undesirable dynamic effects.
To mitigate the effects of wind-induced vibrations, various strategies are employed. One approach involves incorporating aerodynamic modifications into the bridge design to alter the way the structure interacts with the wind. Structural enhancements, such as modifying the shape of the bridge elements,

can also be implemented to reduce the impact of wind forces. Additionally, damping systems, such as Tuned Mass Dampers (TMDs), are utilized. TMDs are designed to counteract vibrations by introducing a secondary mass tuned to specific frequencies. Research in this area involves the intricate design, implementation, and testing of TMDs, considering the optimal characteristics for specific bridge configurations to ensure effective vibration control.

Experimental methods play a crucial role in gaining real-world insights into wind-induced vibrations. Field measurements involve installing sensors on existing bridges to collect data on dynamic responses under varying wind conditions. Wind tunnel testing, using scaled models, allows researchers to simulate wind effects in a controlled environment. These experimental methods provide valuable data that helps bridge engineers refine their understanding of actual bridge behavior, validate theoretical models, and develop effective mitigation strategies.

In tandem with experimental methods, computational modeling, specifically Computational Fluid Dynamics (CFD) simulations, offers a virtual testing ground. CFD simulations create virtual models of bridges and simulate airflow patterns and aerodynamic forces. These simulations provide insights into the complex fluid-structure interactions, helping researchers understand how different design parameters and wind conditions affect the bridge's response. This computational approach enhances the efficiency of bridge design by allowing engineers to explore a wide range of scenarios and optimize structures for safety and performance.

3.4. Conclusions

In conclusion, wind-induced vibrations on structures, particularly bridges, pose challenges that demand careful consideration in the field of structural engineering. The dynamic interaction between the wind and the structure can lead to oscillations and movements that, if not properly addressed, may impact structural integrity and user comfort. Through extensive research, experimentation, and analysis, several key conclusions can be drawn regarding wind-induced vibrations:

Dynamic Interaction Complexity: Wind-induced vibrations result from the complex interaction between the wind and the intricate geometry of the structure. The dynamic behaviour of bridges under wind loading is influenced by factors such as wind speed, direction, structural design, and the surrounding environment. Understanding this complexity is crucial for accurate predictions and effective mitigation.

Structural Vulnerabilities: Wind-induced vibrations can reveal vulnerabilities in the structural design and materials of bridges. Prolonged exposure to wind forces, especially at resonant frequencies, may lead to structural fatigue and damage. Identifying potential weaknesses is essential for implementing design modifications to enhance the resilience of structures.

Mitigation Strategies are Essential: The development and implementation of mitigation strategies are paramount in addressing the challenges posed by wind-induced vibrations. From aerodynamic modifications and structural enhancements to the use of damping devices like Tuned Mass Dampers (TMDs), these strategies play a crucial role in minimizing the impact of wind forces on structures.

Importance of Field Measurements and Testing: Field measurements and testing, including wind tunnel experiments, provide invaluable real-world data on the dynamic response of bridges to wind. This empirical evidence is essential for validating theoretical models, refining design approaches, and gaining a deeper understanding of the actual behaviour of structures under varying wind conditions.

Role of Computational Modelling: Computational Fluid Dynamics (CFD) simulations contribute significantly to the understanding of wind-induced vibrations. These simulations allow for virtual testing of structures under different wind scenarios, aiding in the optimization of designs and the exploration of various mitigation strategies.

Tuned Mass Dampers as Effective Solutions: Tuned Mass Dampers (TMDs) emerge as effective solutions for mitigating wind-induced vibrations. Research in this area focuses on designing TMDs with optimal characteristics tailored to specific bridge configurations. These devices counteract vibrations by introducing secondary masses tuned to resonate in opposition to undesired structural movements.

Continuous Monitoring and Maintenance: Structural health monitoring and continuous data collection are essential for identifying changes in the dynamic behaviour of a bridge over time. Regular inspections and maintenance activities help ensure the long-term durability and safety of the structure, particularly in regions prone to strong and variable winds.

In summary, the study of wind-induced vibrations on bridges is a multidisciplinary endeavour that involves a combination of experimental methods, computational modelling, and engineering innovation. The conclusions drawn from this research contribute to the development of safer and more resilient structures capable of withstanding the dynamic forces imposed by wind, ultimately ensuring the safety and well-being of the public utilizing these vital infrastructures.

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Chapter 4

Seismic Performance of Box-girder Bridge with Different Piers using CSiBridge Software

Authors:
Email: nilanjantf@gmail.com (Dr. Nilanjan Tarafder), Swami Vivekananda University, Kolkata-700121, West Bengal, India

4.1. Introduction

The purpose of bridge construction is to provide passage over obstacles. The first ever bridges made by humans were of wooden logs or planks. Some rural part of our country witnesses the bridge made by bamboos and wooden logs. The Romans built arch bridges and aqueducts. The Romans also practiced cement that replaced the strength of natural stone. The design of a bridge vary according to its function, availability of materials, terrain over which it is constructed and anchored. Bridge is an important structure which is a gateway for the transportation of man and materials from one place to another. During major hazards like earthquake, floods, wars etc. bridge should perform well so that the rescue and rehabilitation process can be carried out more effectively. Hence it is necessary to check the vulnerability of the bridge whether it is strong enough to withstand such calamities or not. Seismic analysis is a subset of structural analysis to find out the response of structures under any earthquake excitation. For earthquake analysis, it is necessary to come to a conclusion whether the structure is safe under ground motion or retrofitting should be performed in order to withstand safely. Hence the past earthquake data is necessary to carry out the present analysis. Data are mainly available in two forms: probabilistic and deterministic. Deterministic data are used for design purpose while probabilistic data are mainly used for seismic risk assessment like damage of a structure under dynamic vibration subjected to the particular ground motion. The data are available in the form of acceleration, displacement, velocity etc. with respect to the time period.

Some membrane equations was used with plane frame analysis to approximate the actual finite element model of concrete box girder bridge. This method gives the prestressing and reinforcing proportional to the transverse bending and stirrups proportional to the longitudinal torsion and shear in a single celled precast segmental concrete box girder [1]. A study was done on the PSC box girder subjected to live load to generate influence lines and surfaces shows that the multi cell PSC box girder has an efficient means to resist the forces coming to it. They are mostly used for the light weight transportation system and the light weight rail system like a metro rails in compared to the RCC which is used for the heavy loads. The design parameters like displacement, bending moments and shear force can be controlled effectively by using intermediate web of varying thickness. Low span/depth ratio allows to decrease the dead weight of the structure and it’s bending moment. PSC girders are more economical as compared to RCC girders as the reduced section can be obtained [2]. Time history analysis of a truss bridge shows that almost all the stresses and the loads were affected under the load case of occurrences of an earthquake. Displacements are fluctuated and reaches its peak value and then decreases slowly, finally becoming stable. Displacement and rotations are varied with the variation in damping ratios. The minimum damping ratio gives the maximum structural responses but the damping ratios are not directly proportional to the structural responses [3]. The shorter span cable stayed bridges have maximum frequency as compared to higher spans. Hence it can be said that the shorter span bridges are stiffer than the bridge having long spans. Medium span bridges are preferred since the vibration and deflections are within the limits [4]. Ductility failure and wall bending were more common in longitudinal direction while the transverse direction showed the bearing failure. Over the entire length of the bridge, the hinges were distributed. The exterior piers were observed to be weak as the hinge formation were early in longitudinal push over analysis [5]. A study on rectangular pier with circular edges subjected to axial compression showed that the pier under strain hardening region shows increased capacity, behaving in ductile manner. With the increase in axial load the capacity of a pier increases accordingly to the aspect ratio. The pier that failed in brittle manner was found to be slender. The circumferential steel protects and confines the concrete core while the concrete core prevents the inward buckling of the steel tubes [6]. An experiment was performed to access the performance based design approach in order to achieve objectives to see the failure pattern. The displacement time history greatly influences the failure and deformation pattern of any reinforced concrete frame structure when subjected to seismic forces. Larger crack width ranging from 0.01 inches to 0.02 inches should be filled using epoxy immediately to prevent any further damage. Fatigue failure in bridges is the main concern and the failure of concrete with respect to fatigue should be replaced completely. Fatigue in longitudinal bars and core should be partially or completely removed [7].

From the literature it was found that studies on PSC girders were done with respect to live loads, time history loads and pushover loads. Also research on the effect of span length was carried out. Ductility failure, displacement and rotational behaviours, axial compression behaviour were studied in various research papers. But no research has been done yet to understand the shape effect of piers of a bridge. In this paper, a bridge structure was studied choosing a location in India, i.e, Silchar. Silchar is situated in the earthquake zone V and the area is having soil type IV. This is a very weak combination for building any structure. The bridge was studied with single pier and double pier of different shapes and detailed comparison was described in the paper. No research work has been done yet which considered different shapes of piers in their studies. Therefore no data is available to consider from, which can confirm that which type of pier is better for earthquake resisting purpose. We have done the required study to understand the behaviours of the pier with respect to earthquake in addition with maximum traffic load condition. In this respect both the pushover and time history analysis was performed to analyse the structure under seismic activity [8]. Displacement capacity and base shear capacity for each of the bridges were found out and the capacity limit was prescribed. Time history as per multiple ground motion data showed the exact behaviour of the bridges and performance for each one was defined during a real earthquake event. Design capacity ratio also confirmed the safety level of each bridge in addition with a comparison of performance between the two bridges [9].

4.2. Research Significance

In the present study, performance comparison of bridge was conducted under two structural conditions. One condition considers a bridge with single circular pier having a diameter of 4.5 m. Whereas another structural condition considered the bridge with double elliptical pier acting together having dimensions of 4.5 m and 0.75 m as major and minor axes respectively. The performance of the bridge under static and dynamic lateral force or as we can say earthquake lateral force was obtained based on the different shape of piers was used. This type of work was never carried out before and research in this direction revealed in depth knowledge about the performance and durability of the bridge. So in this project the seismic performance of a pre stressed box girder bridge was checked using single circular pier and two elliptical piers at the same station. By using elliptical piers scouring depth is reduced and hence the durability of bridge was increased comparatively than using one circular pier.

4.3. Analytical Modelling

Both the bridges were modelled in SAP 2000 for the analysis. Steps used in modelling were- defining the material properties, section properties, bridge span discretization, assigning piers and bent to the bridges, bearings, restraints etc. and defining various parametric variations for the bridge deck like depth, top slab thickness, bottom slab thickness, web thickness etc. For the double elliptical piers, section designers were used to model the section and finally finite element model were updated to bridge object for generating the full bridge model.

4.3.1. Bridge Component Data

The deck section of the proposed bridge was box girder type and M40 grade of concrete was used the grade of construction. The geometry of the deck section varies as shown in the table 1 and it considers the dimension of deck section of the abutment section at two ends. The thickness of the deck section throughout its length was not constant, rather it was following a parametric variation. The parametric variation of three parameters i.e. height of girder, thickness of soffit and web thickness for three spans were defined. A detailed cross section of the box girder deck section is shown in the figure 1. The bridge is equipped with two abutments having bottom girder support. These abutments on the starting and end station were assigned keeping the foundation spring properties as fixed. Details of the abutment properties are shown in table 2. Bent cap also known as pier cap is a RCC member of 8 m in length, produced in transverse direction of the bridge with 4.5 m width and 2.25m depth. The superimposed and wheel load of the bridge was transferred to the pier through the bent cap section. Detailed properties are mentioned in table no. 3. Double elliptical pier section was designed with section designer as the cross section property is not available in the default section list. For assigning the pier at the center of pier cap it is placed at 4 m distance from the edge of the cap section. M35 grade of concrete was used for pier section. The detailed property of the pier section is shown in table 4. Bearing for pier and abutments of a bridge is necessary to assign in order to transfer the loads from decks to the pier and abutments. The bearing elevation is an action point of bearings and details are shown in table 5.

Table 1. Deck Section at 60 m away from the Pier

Component	Width (m)	Height (m)	No.s
Top Slab	12	0.26	1
Haunch(inner)	1.2	0.35	2
Haunch(outer)	2	0.35	2
web	0.35	1.9650	2
Soffit Slab	6	0.2750	1
Bottom Haunch	0.6	0.15	2

Table 2. Abutments Properties

Abutment	Girder support	Sub Type	FS Prop
BABT1	Bottom	Spring	Fixed
BABT2	Bottom	Spring	Fixed

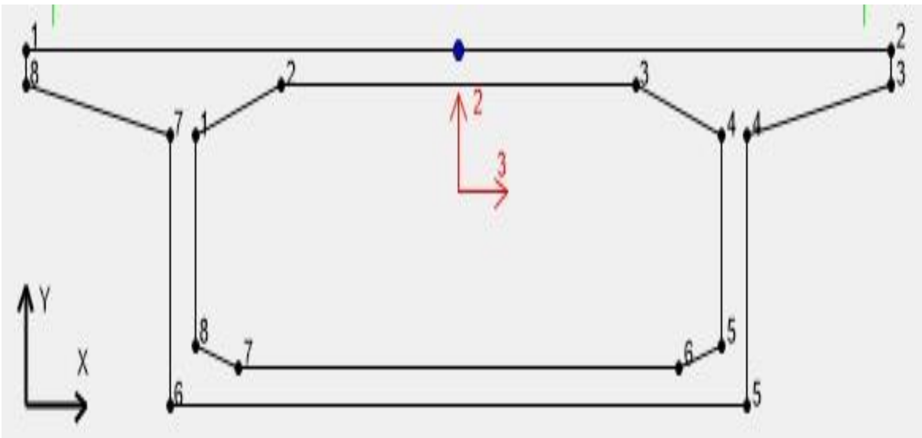

Fig. 1. Cross section view of a Single Box Girder

Table 3. Bent cap properties

Bent	Beam Length	Beam Section	Type	Girder Support	Number of Pier
BENT1	8.0 m	Pier cap	Single	Bottom	1

Table 4. Pier property

Bent	Column No.	Section	Distance (m)	Height (m)	Angle	Pier Support	R1 Release	R2 Release	R3 Release
BENT1	1	Pier	4.0	9.5	0.00	Fixed	Fixed	Fixed	Fixed

Table 5. Bridge Bearings Properties

Bridge Object	Span Name	Station (m)	Type	Bearing	Bearing Property	Bearing Elevation (m)	Bearing Angle
BOBJ1	Start Abutment	0	Abutment	1	BBRG_A	-7.7	0
BOBJ1	Start Abutment	0	Abutment	2	BBRG_A	-7.7	0
BOBJ1	Span1	65	Bent	1	BBRG_B	-7.7	0
BOBJ1	Span1	65	Bent	2	BBRG_B	-7.7	0
BOBJ1	Span2	188	Bent	1	BBRG_B	-7.7	0
BOBJ1	Span2	188	Bent	2	BBRG_B	-7.7	0
BOBJ1	Span To End Abutment	253	Abutment	1	BBRG_A	-7.7	0
BOBJ1	Span To End Abutment	253	Abutment	2	BBRG_A	-1.83	0

4.3.2. Pushover analysis

The response spectrum function used was IS-1893:2002 design spectrum function for earthquake zone V and stiff soil which represents Silchar. Seismic design request is generated using AASHTO LRFD 2002 design code for bridges selecting seismic design category D which is pushover analysis and previously defined response spectrum as a function [10]. At first dead load of entire structure was applied and several iterations were performed to calculate crack section properties. Based on these crack section properties response spectrum analysis was performed and lastly pushover analysis was performed. The response spectra for seismic zone V and proposed area soil type, is shown in the figure 2.

4.3.3. Time History Analysis (THA)

Time history analysis was performed on the bridge structure to study the behaviour of the bridge under real-time earthquakes. Non-linear dynamic time history analysis (NLDTHA) was done using following four earthquake datas- i) Indo-Burma (Baigao) earthquake – 0.36g, ii) Silchar earthquake - 0.36g, iii) Dawki earthquake – 0.36g, iv) Cherapunji earthquake – 0.36g. Figure 3 shows all of the four earthquake ground motion spectra which were occurred recently. As we can see from the figure, Dawki earthquake is having the highest peak acceleration amongst all but Indo-Burma earthquake occurred for the longest duration of time which was much more severe than all.

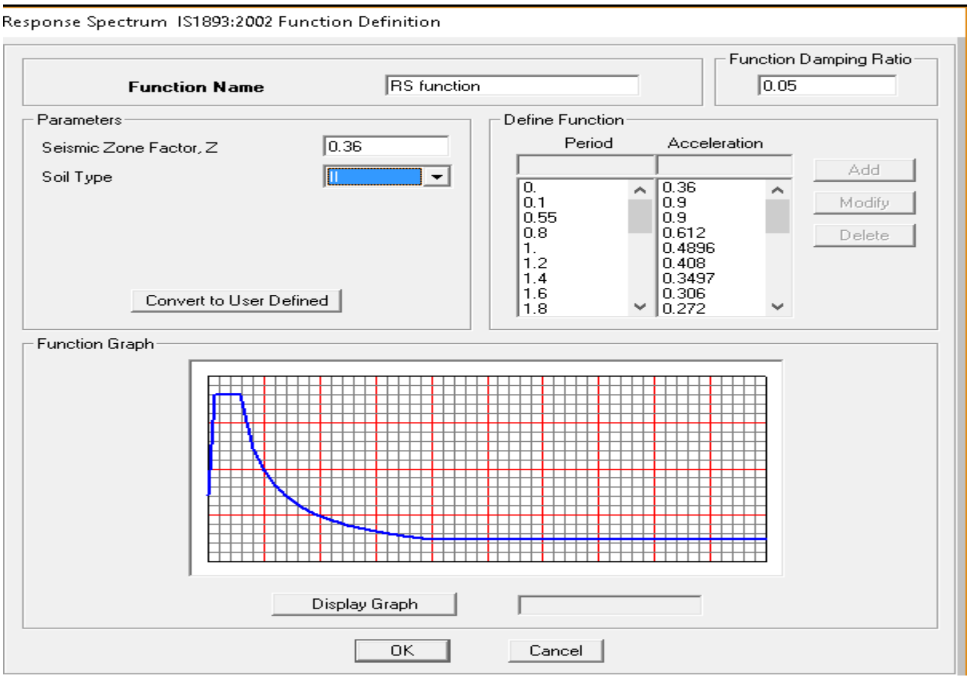

Fig. 2. Response Spectrum function used in Pushover Analysis

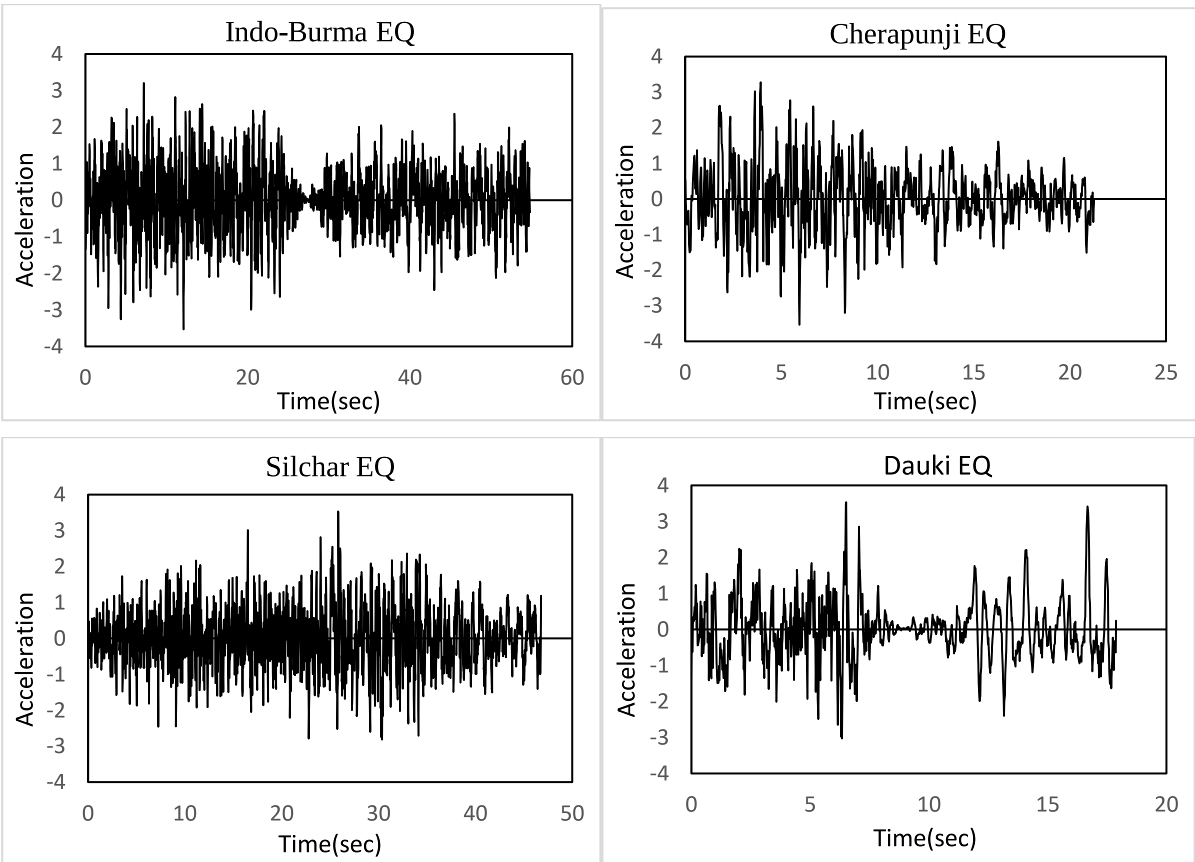

Fig. 3. Time History Function for Earthquake Ground Motion

4.4. Results and Discussion

4.4.1 Pushover Analysis Results

Capacity Curve: The graphical presentation is a visual evaluation of how the structure will perform when subjected to seismic ground motions. The capacity of the structure was represented by a force –displacement curve obtained by nonlinear static (pushover) analysis. In this method first a distribution for the lateral loads on the frame was assumed and increased monotonically. Due to this, the structural element yields chronologically and the structure experiences a loss in stiffness. Figure 4 shows the capacity curves for the bridges in longitudinal direction. Bridge with double elliptical pier can resist up to 40% more base shear force than the bridge with single circular pier. Also bridge with double pier was able to withstand a displacement up to 103 mm under all loads before it completely collapse which was 43% higher than the displacement capacity of bridge with single pier. Even for the case of yielding area, bridge with double pier showed 0.5 mm of more displacement safety than that of the bridge with single circular pier in longitudinal direction.

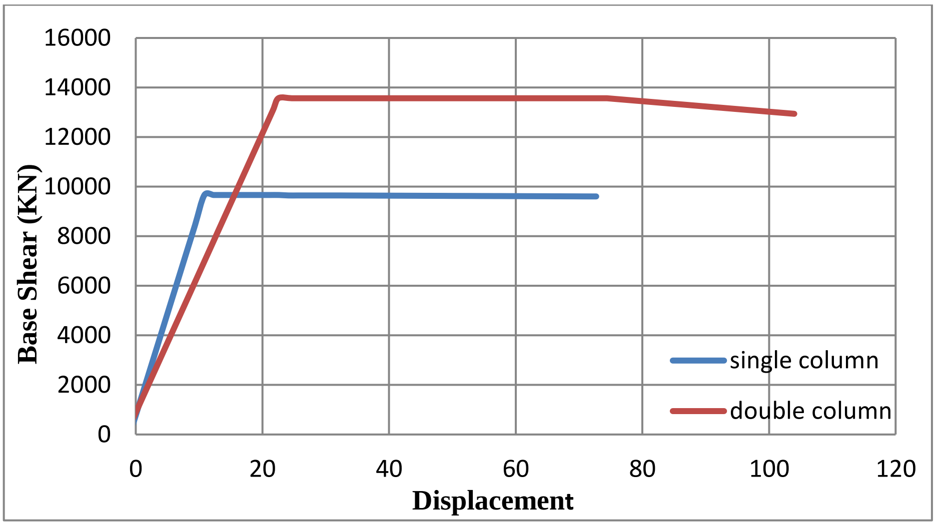

Fig. 4. Comparison of pushover curve in longitudinal direction

Figure 5 shows the capacity curves for the bridges in transverse direction. The only advantage of bridge with double elliptical pier was its ability to resist up to 30% more base shear force than the bridge with single circular pier. But as far as the yielding of the material is concerned, bridge with single pier obtained higher yielding are than the other bridge which leads to more time available for the users to move to the safety before complete collapse of the bridge. Single pier bridge was able to provide 16 mm displacement after starting of yielding whereas other bridge provided only 5 mm of displacement. Moreover bridge with single pier was able to take a displacement of 97.9 mm which was 34.6% higher than that of bridge with double pier.

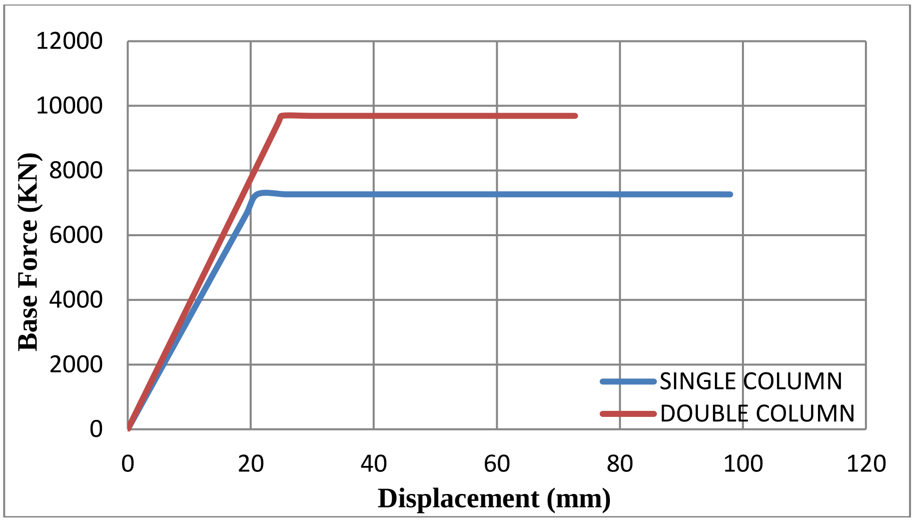

Fig. 5. Comparison of pushover curve in transverse direction

Demand/Capacity (D/C) Ratio: It is an important aspect to check the seismic vulnerability of bridges when subjected to a seismic event. When the demand to capacity ratio comes out to be less than 1, structure is considered safe but if the ratio was found to be more than 1 then the structure requires retrofitting. Table 6 explained the design/capacity ratio for the structure in both the directions with single pier as well as double pier. The bridge was having 3 spans, hence at two stations 65 and 188, there was two pier sections. For single pier bridge, piers from both the pier stations were having a D/C ratio of 0.612 in transverse direction and in longitudinal direction the ratios were 0.602 and 0.624 for the stations 65 and 188 respectively. For double pier bridge, piers were having a D/C ratio of 0.327 and 0.362 in longitudinal direction for stations 65 and 188 respectively. In transverse direction the ratios were 0.849 and 0.842 respectively. It is clear that although both of the single and double pier bridges were having the d/c ratio as less than 1 which means safety of structure is confirmed, the ratios for double pier bridge was nearly half of that for single pier bridge. Double pier bridge was proved to be safe by twice as per the safety level for single pier bridge.

Table 6. Comparison of Demand Capacity Ratio

Type of pier	Station (m)	Direction	Demand (m)	Capacity (m)	D/C Ratio
Single circular pier	65	Transverse	0.059897	0.097934	0.612
		Longitudinal	0.043740	0.072718	0.602
	188	Transverse	0.059898	0.097934	0.612
		Longitudinal	0.043741	0.070110	0.624
Double elliptical pier	65	Transverse	0.061247	0.072066	0.849
		Longitudinal	0.033963	0.103995	0.327
	188	Transverse	0.061247	0.072716	0.842
		Longitudinal	0.033965	0.093715	0.362

4.4.2. Nonlinear dynamic time history analysis result

Indo-Burma earthquake: Figure 6 shows displacement response of the structure under the Indo-Burma earthquake which was active for 55 sec. For 1.5 sec time both the bridges were not affected by the earthquake, but after that they experienced displacements. In longitudinal direction, double column displaced up to a length of 50 mm where single column displaced up to a length of 55 mm. Bridge with double column proved to be 9% better during Indo-Burma earthquake in longitudinal direction. Figure 7 described the response of the bridges in transverse direction under Indo-Burma earthquake and a comparison of displacement capacity was explained in the plot. In this direction also bridge with double pier proved to be a better option than bridge with single pier as the displacement occurred in the piers during the prescribed earthquake was 6% more in single pier bridge.

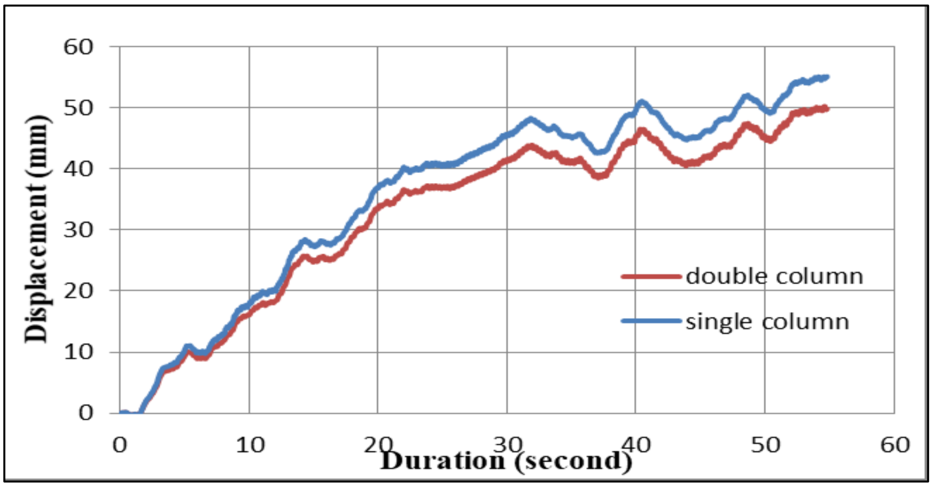

Fig. 6. Displacement response for Indo–Burma earthquake in longitudinal direction

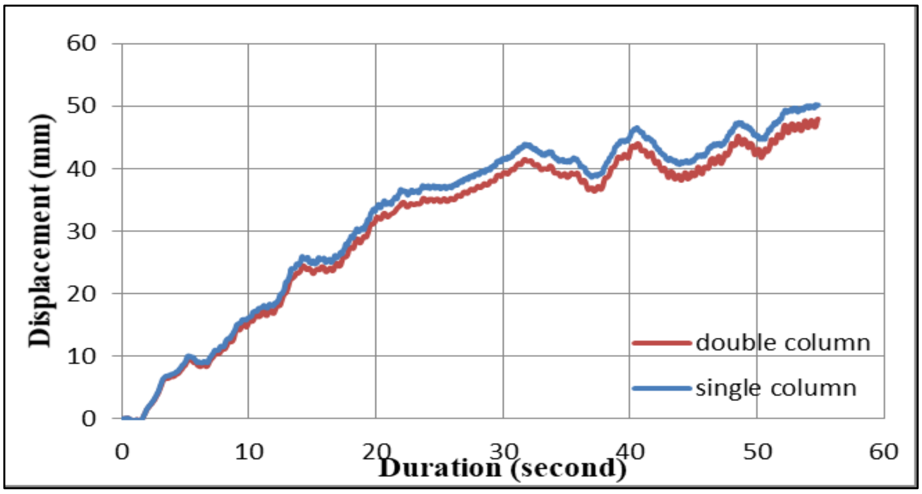

Fig. 7. Displacement response for Indo–Burma earthquake in transverse direction

Silchar earthquake: Figure 8 shows displacement response of the structure under the Silchar earthquake which was active for 47 sec. For 0.2 sec time both the bridges were not affected by the earthquake, but after that they experienced some displacements. In longitudinal direction, double column displaced up to a length of 43 mm where single column displaced up to a length of 48 mm. Bridge with double column proved to be

10.4% better during Silchar earthquake in longitudinal direction. Figure 9 described the response of the bridges in transverse direction under Silchar earthquake and a comparison of displacement capacity was explained in the plot. In this direction also bridge with double pier proved to be a better option than bridge with single pier as the displacement occurred in the piers during the prescribed earthquake was 12.7% more in single pier bridge.

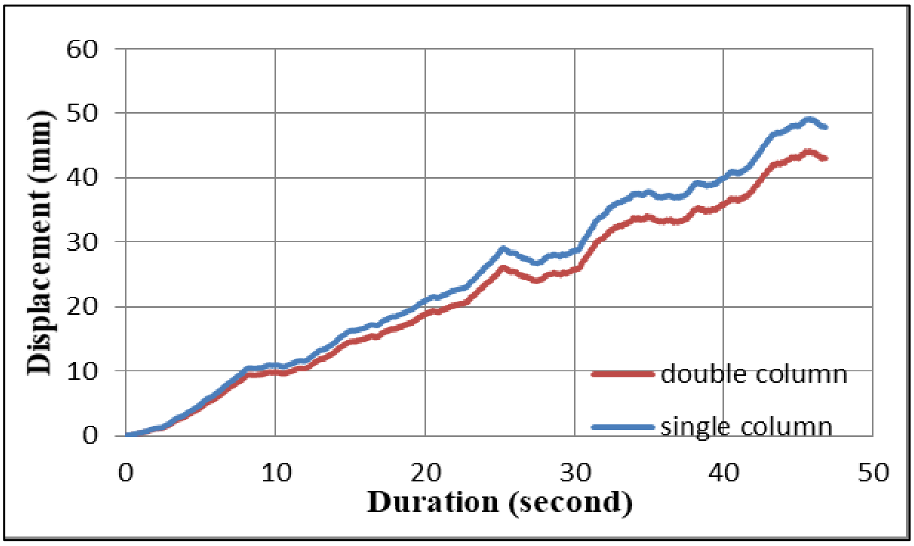

Fig. 8. Displacement response for Silchar earthquake in longitudinal direction

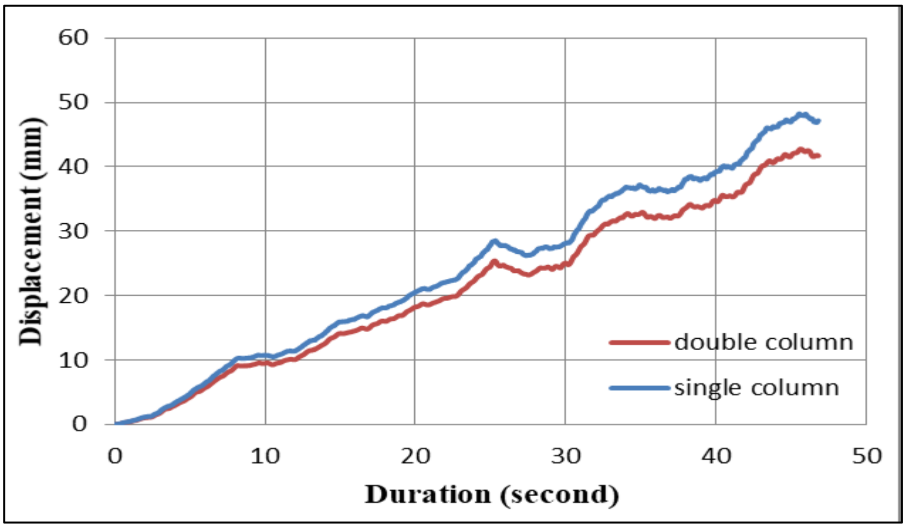

Fig. 9. Displacement response for Silchar earthquake in longitudinal direction

Dawki earthquake: Figure 10 shows displacement response of the structure under the Dawki earthquake which was active for 18 sec. For 0.2 sec time both the bridges were not affected by the earthquake, but after that they experienced some displacements. In longitudinal direction, double column displaced up to a length of 20 mm where single column displaced up to a length of 24.16 mm. Bridge with double column proved to be 17.2% better during Dawki earthquake in longitudinal direction. Figure 11 described the response of the bridges in transverse direction under Dawki earthquake and a comparison of displacement capacity was explained in the plot. In this direction also bridge with double pier proved to be a better option than bridge with single pier as the displacement occurred in the piers during the prescribed earthquake was 23.5% more in single pier bridge.

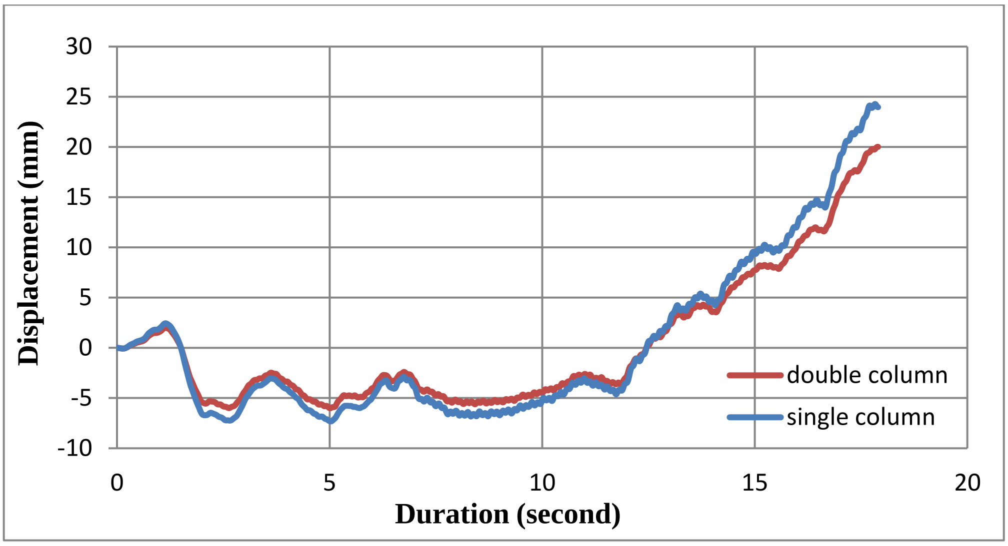

Fig. 10. Displacement response for Dawki earthquake in longitudinal direction

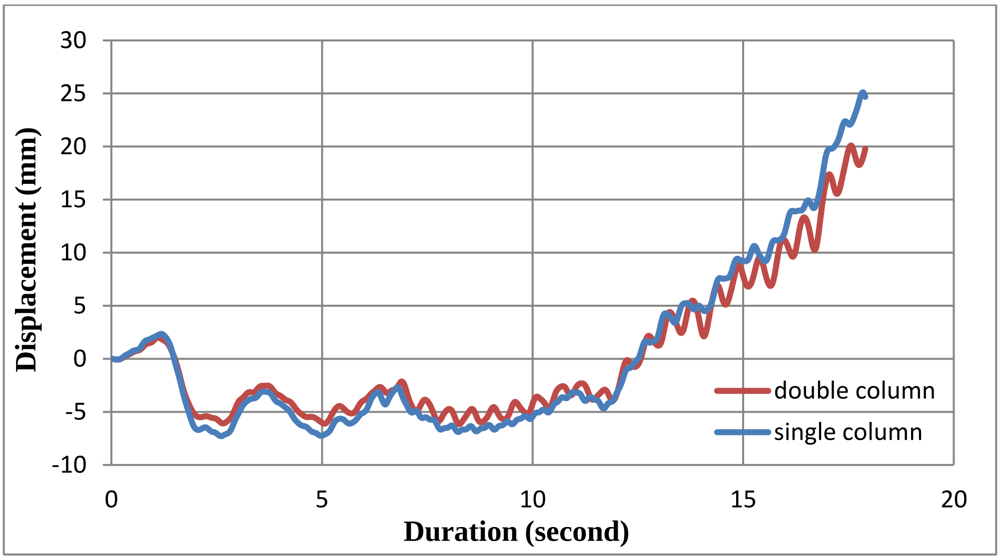

Fig. 11. Displacement response for Dawki earthquake in transverse direction

Cherapunji earthquake: Figure 12 shows displacement response of the structure under the Cherapunji earthquake which was active for 21.3 sec. From the beginning of the seismic activity, bridges were affected by the earthquake and experienced some displacements. In longitudinal direction, double column displaced up to a length of 55.4 mm where single column displaced up to a length of 60.7 mm. Bridge with double column proved to be 8.7% better during Cherapunji earthquake in longitudinal direction. Figure 13 described the response of the bridges in transverse direction under Cherapunji earthquake and a comparison of displacement capacity was explained in the plot. In this direction also bridge with double pier proved to be a better option than bridge with single pier as the displacement occurred in the piers during the prescribed earthquake was 9.95% more in single pier bridge.

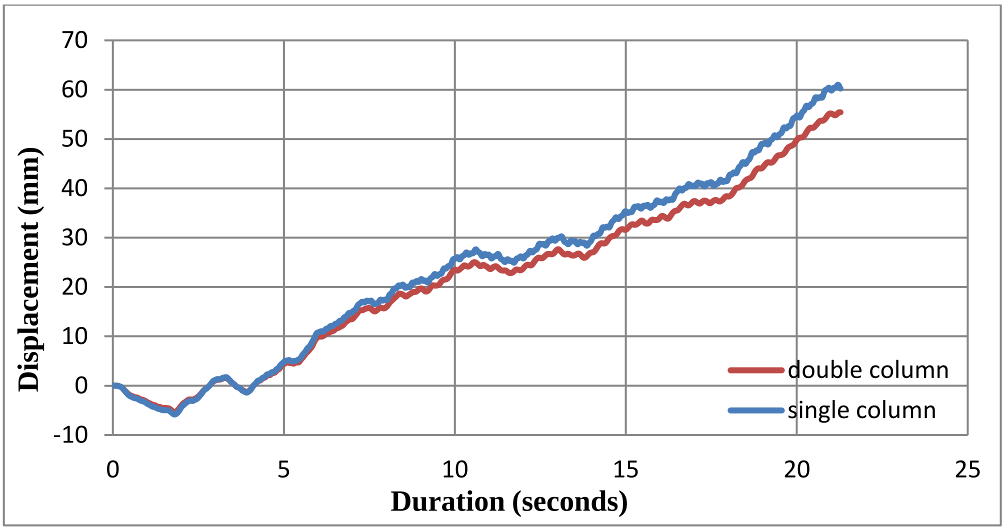

Fig. 12. Displacement response for Cherapunji earthquake in longitudinal direction

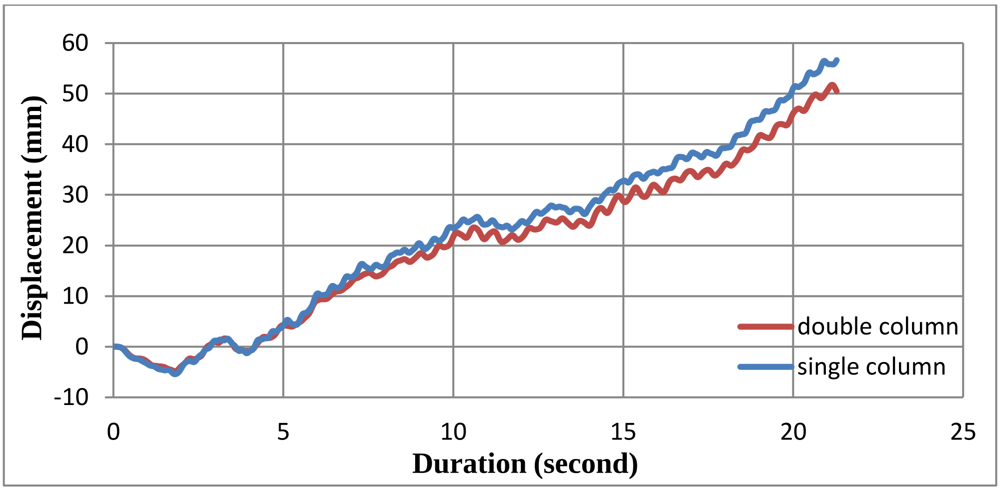

Fig. 13. Displacement response for Cherapunji earthquake in transverse direction

4.4.3. Comparison of pushover and time history analysis results

For comparing time history analysis (THA) and pushover analysis (PA) results, lateral load capacity and displacement capacity parameters were considered from each of the analysis. Time history result of Indo-Burma earthquake was taken into consideration as it was the most severe earthquake amongst all. Figure 14 explained a comparison of the base shear force capacities between time history and pushover analysis for the bridges in both longitudinal and transverse direction. Results from these two analysis for both the bridges proved that base shear force experienced by the structure under earthquake loading was always higher in case of time history analysis.

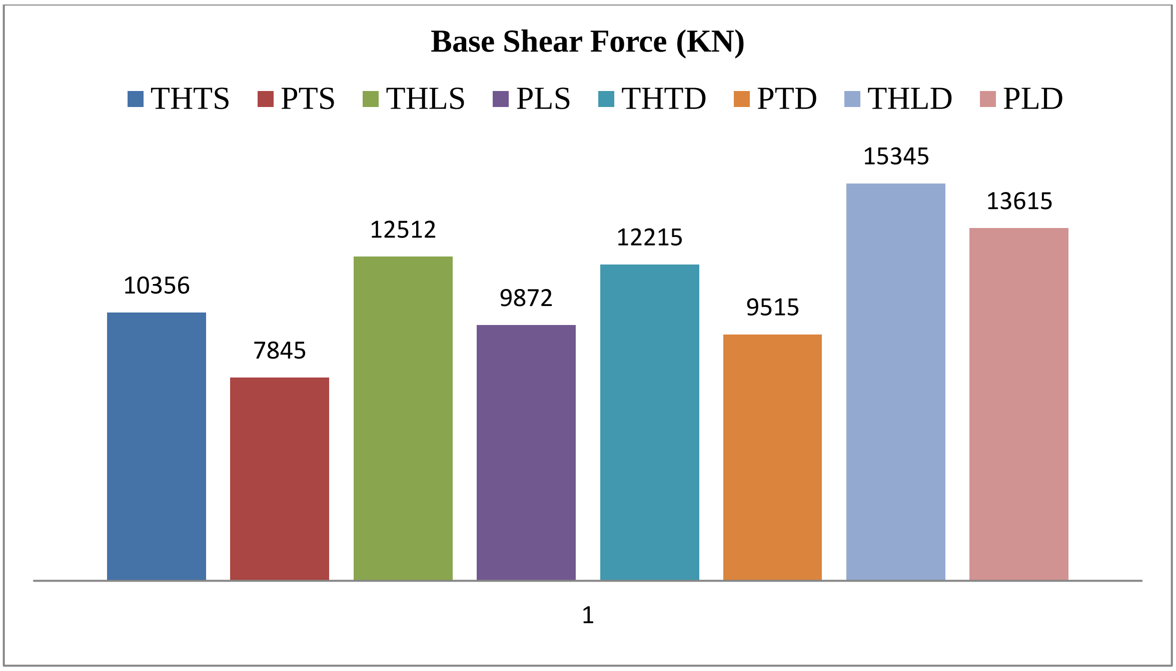

Fig. 14. Base force comparison of single and double pier bridge with pushover and time history analysis results in transverse and longitudinal direction

*Here, TH = Time History, P = Pushover, T = Transverse direction, L = Longitudinal direction, S = Single pier, D = Double pier

The reason behind this, in time history analysis real ground motion data were used but in pushover analysis prescribed codal data was used and real ground motion data were of higher magnitude with more occurrence period than the codal data. Both the bridges fully withstood the earthquake loads and base shear force generated from both type of analysis were shown in the figure 14. In longitudinal direction double pier bridge was able to withstand 37.9% more base shear force than single pier for PA whereas the percentage was 22.6% for THA. In transverse direction, double pier bridge withstood 21.3% more base shear force than single pier for PA whereas the percentage was 17.9% for THA.

Whereas figure 15 shows the comparison of displacement capacities between time history and pushover analysis for the bridges in both longitudinal and transverse direction. Displacement occurred in the pier sections was less for double pier bridge in comparison with the single pier bridge. Longitudinal and transverse in both the direction, displacement due to the earthquake load was less for double pier because the formed displacement was distributed in both elliptical piers. Single pier bridge displaced more by 7.8% in longitudinal direction for THA but the displacement was more for double pier bridge by 29.1% for PA in the same direction. For PA single pier performed better but when coming to the real life experience (THA), double pier gave better performance. In transverse direction, both for PA and THA single pier displaced more than double pier bridge by the percentages of 34.7% and 6.4% respectively.

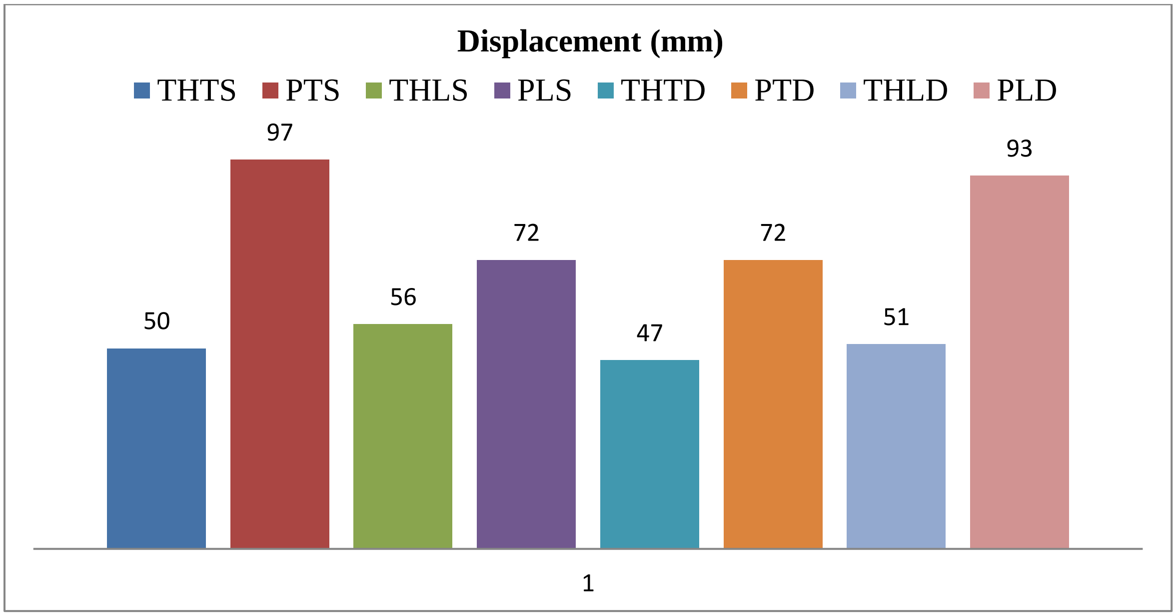

Fig. 15. Displacement comparison of single and double pier bridge with pushover and time history analysis results in transverse and longitudinal direction

*Here, TH = Time History, P = Pushover, T = Transverse direction, L = Longitudinal direction, S = Single pier, D = Double pier

4.5. Conclusion

To consider the effect of earthquake force in designing it was necessary to carry out time history analysis to calculate base shear which is governing force for the lateral input forces. The results clearly show that shape effect of pier is very important in case of the construction of a bridge. Till now no research paper was available to be used for real construction work, but this paper will surely help in huge amount in that matter. Time history analysis overestimated base force so it is recommended to use output results from time history. Pushover analysis is recommended for the existing bridges to check its vulnerability against the ground motion and to check whether retrofitting is required or not. Using double elliptical pier the seismic performance of the bridge was increased and also its durability was increased.

- From the capacity curve it was concluded that bridge with double elliptical pier can resist up to 40% more base shear force than the bridge with single circular pier in longitudinal direction. In transverse direction the percentage was a little less as 30% but it was still a big difference while comparing between two types of pier.
- Displacement capacity in the longitudinal direction of bridge was found to be 43% higher for bridge with double pier than that of bridge with single pier. But in transverse direction single pier bridge was found to be 34.6% more effective in case of displacement capacity of bridge. In transverse direction double elliptical piers were acting individually whereas in single pier a circular column section of higher diameter was used, which increased the performance for the bridge with single circular pier.
- The design capacity (D/C) ratio in longitudinal direction was 1.7 times more for single pier bridge in comparison with double pier bridge. Bridge with double pier was 42% more safe than bridge with single

pier in this direction for an earthquake event. In transverse direction also double pier bridge performed better and provided 86% more safety than single pier bridge.

- Base shear force can be taken by the double pier bridge was always greater than single pier bridge whether it is pushover analysis or time history analysis. In longitudinal and transverse direction bridge with double pier was able to withstand 37.9% and 21.3% more base shear in pushover analysis procedure respectively. Also they were able to withstand 22.6% and 17.9% more base shear in longitudinal and transverse directions as well in comparison with single pier bridge in time history analysis.
- The displacement generated in double piers were smaller than that of single piers even though the base shear counteracted by the double piers were higher than that of the single piers. In longitudinal and transverse direction double piers displaced 7.8% and 6.4% less than the displacement occurred in the single pier bridge.

It can be concluded that bridge with double pier was not only able to withstand more base shear, it also displaced less than that of single pier bridge which gives more performance for double pier bridge. Design capacity ratio also confirmed that bridge with double pier was safer than the bridge with single pier. Capacity curves supported the capacity performance of the double pier bridge, which was better than the bridge with single pier.

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Chapter 5

Valorization of iron ore tailing (IOT) waste through the circular economy concept: A sustainable solution towards mitigation of resource crisis and climate change

Dr Bishnu Pada Bose
Professor, Department of Civil Engineering, School of Engineering, Swami Vivekananda University, Kolkata, India
Mail Id: bosebishnu@gmail.com

5.1. Introduction

The global population is growing significantly faster than at any time in history. Subsequently, minerals and metals consumption is growing faster than the population, as more demand is placed in the market for minerals and as the worldwide standard of living changes and improves; at the same time, processing of mining and minerals ore poses a tremendous negative impact on the environment and sustainability (Kesler, 2007; Tuokuu et al., 2019; Manhart et al., 2019). Worldwide, mine tailings are the solid waste generated after separating valuable fractions from the uneconomic fraction of various minerals ore. Generally, tailing is the fine particles of crushed rocks and a mixture of low-value mineral residues. The estimated global tailing production was 14 billion tonnes in 2010 (Adiansyah et al., 2015), and the worldwide production rate of mine tailing has been assessed as a range between 5 and 7 billion tonnes per year (Edraki et al., 2014; Schoenberger, 2016). Based on the evidence in the literature and records with regulatory officials, there are estimated to be more than 3500 appreciable tailings dams worldwide (Davies and Martin, 2000; Clarkson and Williams, 2020). Because of such a large volume of tailings waste produced and the nature of the chemical composition involved, the storage, handling, and maintenance of mine tailings is a significant environmental and ecological problem. It puts pressure on the biosphere and biodiversity. Among the important consequences of a large amount of tailing waste are the failure and disasters of the tailing dam. During 1971-2009, worldwide 237 cases of serious tailings dam failure were reported (Adiansyah et al., 2015), such as the tailings dam failures in Brazil in 2019, the Cadia mine in Australia in 2018, and elsewhere, the Mount Polley mine in Canada in 2014, Philex Padcal in the Philippines in 2012 (Owen et al., 2020; Do Carmo et al., 2017; Lyu et al., 2019; Clarkson and Williams, 2020).

Tailing dam failure incurs substantial environmental, economic, human, and animal losses, declining sustainability in mining industries. Utilizing tailing as an alternative to virgin resources through recycling would be a sustainable solution to eliminate all associated hazards and impacts of tailing storage and maintenance. To eradicate the associated adverse effects of tailing dams, including storage and maintenance, R&D experts are striving and working on it, and technology has already been developed for the recycling of tailing in different applications. At present, tailing has been utilized in many aspects, not per the proportion of the production level of tailing, so surplus tailing remains a burden for the environment and the biosphere. Based on the report of UNEA, with the global demand for sand and gravel standing at 40 to 50 billion tons per year, a new report by UN Environment reveals that aggregate extraction in rivers has led to pollution, flooding, lowering of water aquifers, and worsening drought occurrence (UN et al., 7th May 2019). Research has proven that mine tailing can be used as a virgin resource like sand, aggregates, and many natural resources, so utilization of mine tailing as an alternative to natural resources can replenish the depletion of natural resources and save the environment, ecology reduce the burden from the biosphere and increase sustainability as a whole (Wells & Collins, 2011; Gupta et al., 2017; Ivannikov et al., 2019; Paiva et al., 2019).

5.2. Global perspective towards valorization of IOT

Materials like minerals and metals are essential for developing and functioning modern civilization and economy. Mining activities provide significant economic opportunities throughout the globe. However, the entire process of mining industries creates challenges and risks for the well-being of all living species, climate change, and the environment (Xu et al., 2019). A key challenge is to manage mining in a way that contributes to economic enhancement, societal development, and overall sustainability, and at the same time, it should not endanger the sustainability of the planet Earth (Lambert, 2001; Zhironkin et al., 2018; Monteirobet et al., 2019).

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Since 1984, mining activities and mineral production rising continuously at 17.7 BMT as compared to 9.6 BMT was 1984, a 45% increase during the span of 1984-2018 (World Mining Data 2020), presented in **Figure 1**

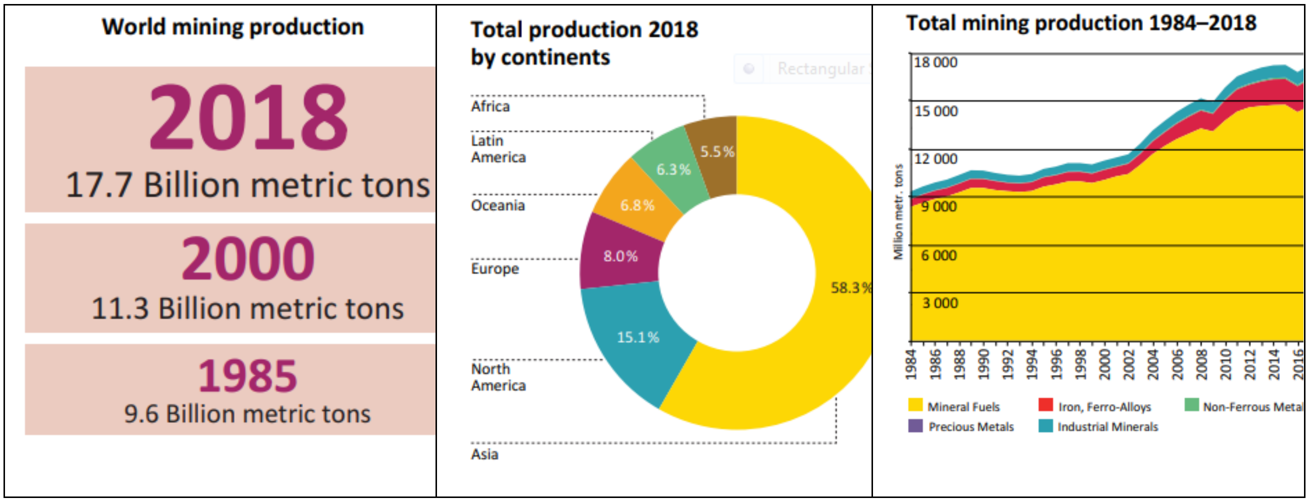

Figure 1 Global mining production (1984-2018) (Source: World Mining Data 2020)

Due to the growing demand and the unprecedented rate of mining and mineral processing over the last few decades, the generation of mine waste, viz. iron ore tailing (IOT), etc., is increasing much faster, causing enormous environmental degradation, damaging biodiversity, and a substantial economic loss. The mining and mineral process generates a large volume of residues which mainly includes waste rock, tailings, and slag, as shown in **Figure 2,** that must be scientifically and strategically managed to combine with the demand for societal and environmental sustainability, economic efficiency, including resource optimization (Durucan et al., 2006; Gou et al., 2019).

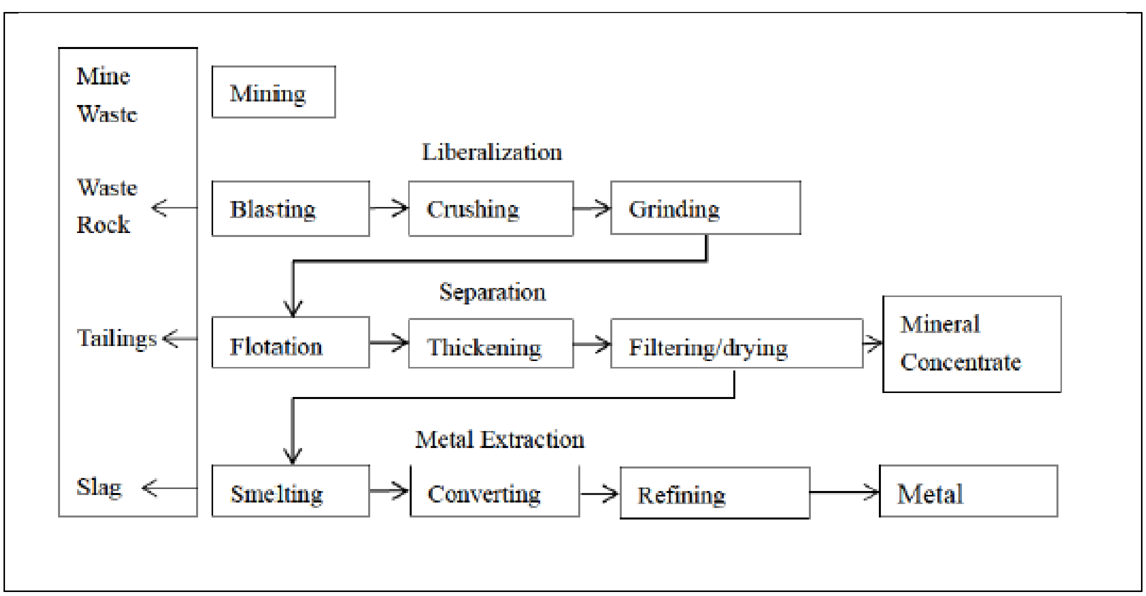

Figure 2 Waste generation during mining, mineral, and metallurgical processes, (Source: Gou et al., 2019).

Out of the various waste generated from mineral processing, IOT is one of the highly risk-oriented wastes in the mining industries in respect of storage and maintenance of tailing dams; the annual production rate ranges between 5 and 7 billion tonnes per year (Edraki et al., 2014; Schoenberger, 2016). Due to the catastrophic failure of a tailing dam at Brumadinho, Brazil, 259 people have been confirmed dead, and 11 remain missing; this was a remarkable human and environmental tragedy regarding tailing dam failure. On 5th August 2020, the initiative of ICMM and UNEP launched “The Global Industry Standard on Tailings Management” with the ultimate aim of preventing catastrophic failure, the safety of tailing storage facilities, zero harm for humans and living species, and protecting the environment (https://globaltailingsreview.org/).

From the perspective of sustainability in natural resources, future strategies of mining industries and ore processing may compound the risk and challenges for managing tailing waste, as ore grade of lower economic value increases the ratio of tailing waste produced for a given unit of the mineral resource, and emphasize the priority and need for the mining industry to adopt new approaches (Ali et al., 2017). New innovative strategies and technologies to reduce risk in managing tailing storage facilities, such as thickened tailings, dry stacking, and paste backfill, have significantly reduced the risk and increased the sustainability in mining industries as well as meet the future challenges to sustainable development (Franks et al., 2011; Adiansyah et al., 2015; Schoenberger, 2016). Many literatures emphasizes and proposes to implement an adequately strict policy, regulation in the regime and proper enforcement are the keys to avoiding and eliminating the hazards of tailings dam collapses (Schoenberger et al., 2016). Despite storage and maintenance for the accelerating volume of tailings produced annually, there should be more emphasis on research for the comprehensive utilization of tailings for a broader range of applications. Recycling and valorizing tailing waste can replenish the depletion of natural resources, reduce the volume of tailing dams, increase the land area, and increase the sustainability of mining industries and natural resources.

5.3. Circular economy approach towards valorization of tailing waste

Discharging waste, such as tailing from mining industries, causes severe environmental degradation, including air, water, and soil pollution (Dudka and Adriano, 1997). The impact of tailing waste also damages ecology and biodiversity and badly affects the flora, fauna, and other inhabitant (Sun et al., 2018). Storage and maintenance of the tailing dam also incur enormous economic and social costs. Recycling and utilizing tailing through the scientific process and appropriate technology is challenging and requires considerable revenue. To eliminate the associated hazards from the tailing waste, including severe catastrophic failure of the tailing dam, valorization of tailing waste is one of the best options. Since the last few decades, stakeholders are taken initiatives to recycle tailing waste for different applications; however, most of the mining industry manages their tailing waste with the linear economy model (Kinnunen and Kaksonen, 2019). The application of the circular economy can boost up the valorization of tailing waste and increase sustainability in mining industries (Golev et al., 2016). The transformation toward a circular economy needs to identify the barriers and future possibilities and address the issues to accelerate the business opportunities for recycling and utilization of tailing waste (Zhao et al., 2012; Kinnunen and Kaksonen, 2019 ; Tayebi-Khorami et al., 2019). According to Bechtel et al. (2013), the reluctance to think is one of the significant factors and barriers to transformation towards a circular economy for the valorization of tailing waste. Typically there is a mixed factor, which may be favorable or hinder the adoption of the circular economy concept in the context of mining industries presented in **Figure 3** (de Jesus and Mendonça, 2018; Kinnunen and Kaksonen, 2019).

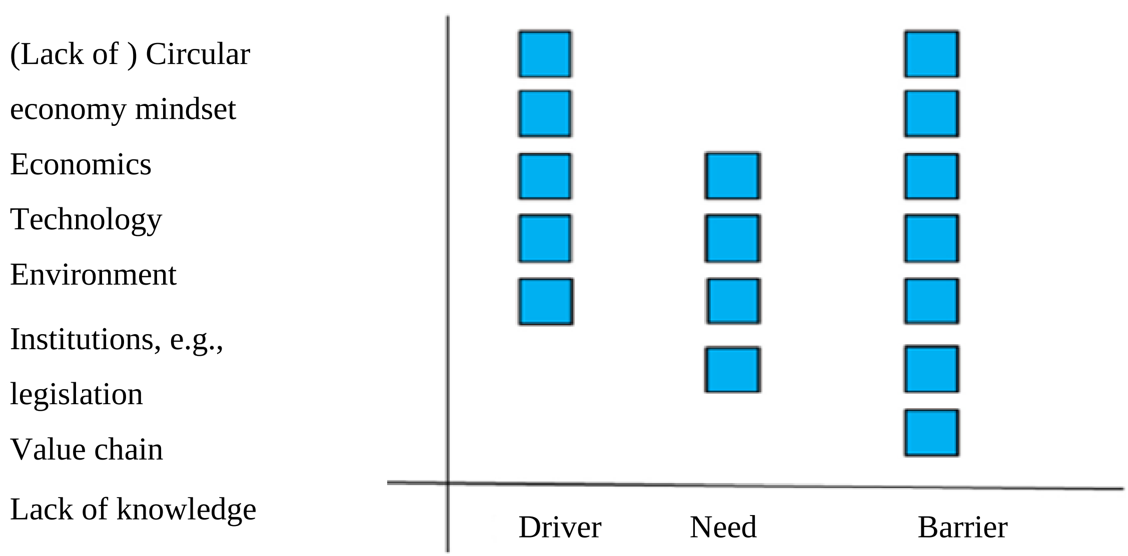

Figure 3 Complementarity and mutual inclusiveness of the categories of drivers, needs, and barriers. (Source: de Jesus and Mendonça, 2018; Kinnunen and Kaksonen, 2019).

Most of developing countries, waste recycling is considered to improve global sustainability, and they overcome many barriers concerning circular economy, such as integrated solid waste management, environmental policies, public awareness, and favorable investment policies. In contrast, the same has become a significant issue in economically weak countries (Ferronato et al., 2019).

Knowledge gaps on potential utilization of tailing and business opportunities for valorization are the primary Bottleneck; in most cases, the lack of initiatives among the stakeholders makes valorization of tailing challenging. Online platforms and exchange facilities for knowledge sharing, resource availability, and a data bank for “tailing generation, storage, and utilization" business and investment opportunities can accelerate the valorization of tailing (Kinnunen and Kaksonen, 2019; Almeida et al., 2020). The circular economy strategy is gaining interest as an effective way to achieve a low-carbon footprint through waste recycling and industrial symbiosis. The concept of the term 'circular economy' would be the most suitable approach for recycling and utilization of every bit of tailing waste which now remains treated as unwanted waste in most cases, as closing the gap of resource utilization and increasing sustainability is one of the concepts of the circular economy model (Zhu et al., 2019; Singh et al., 2020). Despite having the potential for tailing valorization, viable both economically and technically, there still needs to be more knowledge and information available with the mining companies. A database of tailing resource status such as generators, processors, recycling facilities, and market opportunities can enhance the recycling of tailing waste and close the gap in the circular economy. To accelerate the implementation of the circular economy concept in mining industries needs to form a firm policy, regulation, and initiative by the stake holders and national authorities. Through the circular economy model, recycling and utilization of tailing can be boost up, reducing the volume of the tailing waste, increasing the land area, reducing the burden of the biosphere, and can be possible to eliminate the repeated catastrophic failure of tailing dam as well (Singh et al., 2020)

5.4. The disposal and environmental impacts of IOT

Despite technological development and advances in mineral extraction and processing, mining industries still need help to store and maintain tailing waste. Increasing stringent policy and regulations, strategy on environmental protection, and social demands is the primary key to adopting clean technology in mining industries, especially in the tailing disposal method. Because of different agenda on global sustainability and resource optimization, tailings storage facilities (TSFs) come under scrutiny; generators and operators are looking at alternative tailings management technology and strategies. Integrated tailings management is the best option for tailing disposal and storage facilities.

Traditional tailing disposal method has led to heavy metal contaminated sites with serious impact on the ecosystems and risk to human health, including severe catastrophic failures of tailing dam.

Instead of the conventional tailing disposal method, thickened tailing disposal technology results in less environmental impact than most other systems used in the mining industry today for the best way to manage tailing materials (Ozkan et al., 2002; Hatje et al., 2017). The initial investment and operating costs for “thickened tailing disposal” systems are slightly higher, and the system can be implemented in any given topography. The most damaging aspect of tailing waste disposal is seepage into the surrounding land, and the environment creates leachate. It pollutes the entire surrounding area leading to soil and water pollution. In the conventional method of tailing disposal, seepage can only be prevented partially, but the thickened tailing disposal system creates less contamination than traditional methods. It maximizes evaporation, optimizes runoff, and eliminates dusting, including air pollution. The significant advantage of "Thickened tailing disposal” systems over the conventional tailing disposal method (Mudd and Boger, 2013) is presented in **Table 1**.

Table 1 The significant advantage of "Thickened tailing disposal” systems over the conventional tailing disposal method (Mudd and Boger, 2013)

Sl No	The significant advantage of "Thickened tailing disposal” systems over the conventional tailing disposal method
1.	Reclaim water, process reagents, and energy,
2.	Maximize the density of tailings.
3.	Minimize tailings storage facility footprints,
4.	Render tailings suitable for mine backfill,
5.	Reduce the potential for acid drainage (by removing water available for leaching, decreasing permeability, and oxygen diffusion), and minimizing (or eliminating) risks.

5.5. Chemical compositions of tailing waste

Several studies have determined the chemical composition of iron ore tailing waste in different locations; a few of them are presented in **Table 2**

Table 2

Chemical compositions of the tailing from different locations.

Chemical composition (%)	Wu et al., 2020	Osinubi et al., 2015	Perumal et al., 2019	Perumal et al., 2019	Perumal et al., 2019
SiO_2	57.20	45.64	32.99	72.52	78.44
Al_2O_3	9.11	3.36	7.09	16.43	12.57
CaO	11.30	0.607	12.92	0.05	0.30
MgO		0.393	17.27	0.82	0.14
Fe_2O_3	3.03	47.7	7.99	1.90	0.51
TiO_2	0.34	0.24			
SO_3					
P_2O_5	9.86				
Na_2O	0.11	0.405	0.71	0.08	4.44
MnO		0.067			
K_2O	2.11	0.607	5.53	3.05	2.80

5.6. Main policy guidelines, standards, or rules governing the management of iron ore tailing (IOT) waste

When designing specific policies to promote the recycling process, it is essential to understand all potential bottlenecks, needs, barriers, and inefficiencies in such processes and how such bottlenecks, obstacles, and inefficiencies can be overcome through public policy intervention. Recycling is an important economic sector for employment, turnover, and investment. The recycling policy pertaining to IOT waste utilization shall guide and establish an appropriate legislative, administrative, and institutional framework (Bose et al., 2021; Bose et al., 2022: Bose, 2022; Bose & Dhar, 2022).

5.7 Zero waste concepts through circular economy policy in the context of tailing waste valorization

The mineral processing unit generates a large volume of tailing waste annually. The tailing materials can be converted into value-added products with less effort and energy. The circular model of tailing materials can compensate for all resources, energy, and GHG through a circular economy process, clear policy framework, and regulation that can increase the tailing utilizations rate. The following Bottlenecks needs to be considered while forming the policy, framework, and regulations for enhancing the utilization facilities of tailing materials presented in **Table 3**.

Table 3 Bottlenecks needs to be considered while forming the policy, framework, and regulations for enhancing the utilization facilities of tailing materials (Bose et al., 2021; Bose et al., 2022: Bose, 2022; Bose & Dhar, 2022).

- Lack of initiative by governments and private agencies for processing tailing materials to valuable resources
- Lack of proper policy framework and amendment of existing policies of the new policy to deal with tailing materials
- Bridging the gap between industry and government.
- Government should make a policy regarding sustainability context for tailing recycling and utilization.
- To make realizing that tailing material is wealth.
- Policy formation for circular economy instead linear economy
- Understanding of hazardous and non-hazardous waste for common people and organizations
- Lack of adequate and attractive scheme for the entrepreneur who can open up a startup for recycling processing plant for utilizations of tailing waste.
- Introduce code and standards for the products developed by recycling tailing waste.
- A dedicated data bank hub is necessary for the accountability of natural resources in the country, such as analysis of demand and supply in construction, the infrastructure sector, and other areas.
- Policy correlation within tailing recycling and utilization, sustainable development, and mitigation of climate change

5.8. Difficulty or Bottleneck preventing bulk usage of tailing

Among the different literature, bottleneck were categorized under new value chains, technological, environmental, institutional, economic, and knowledge bottlenecks (Cezarino et al., 2021). The specific needs and barriers must be addressed appropriately to speed up the transformation from a linear economy to a circular economy towards managing bulk usage of tailing waste.

Major bottlenecks towards managing bulk usage of the iron ore tailing (IOT) waste has presented in **Table 4** (Bose et al., 2021; Bose et al., 2022).

Table 4 Major bottlenecks towards managing bulk usage of the tailing waste

- Knowledge gaps on the potential utilization of tailing and business opportunities for tailing valorization.
- Unfavorable market forces, lack of investment opportunities for value chain establishment
- The presence of an informal market
- Lack of proper infrastructure facilities for processing bulk amounts of tailing waste
- Consumer forces and commodity prices
- Lack of infrastructure for collection, storage, and processing of tailing waste
- Unfavorable market forces affecting the recycling process
- Lack of legal and policy initiatives for the recycling process
- Lack of political support for recycling, low level of awareness of environmental, economics and sustainability aspects
- Most of the cases, recycling is not considered a priority in government programs and budgets,
- Lack of support for collection systems to ensure that the demand for recycling is met.
- Legislation is not enforced, and policy decisions must be consistent with legislation.
- Development or revision of legal instruments
- Adoption of supportive policies
- Measures to raise awareness among politicians, the private sector, small enterprises and civil society
- Strengthening enforcement through global and regional networks and partnerships
- Strengthening of cross-border cooperation
- Different national regulatory requirements for the management of recyclable materials
- Engagement through global or regional trade agreements
- Possible approaches to support capacity building and funding
- Legal, policy, and governance challenges at the international, national, and sub-national levels
- Disposal capacity and process
- Most of the cases, there is no strict law or regulations for preventing landfilling by tailing waste.
- Critical barrier on transporting tailing to a different location in respect of cost, safety, environmental issues, etc.
- Lack of government initiative in respect of promoting mission zero waste (tailing)
- Delay in necessary approval and responses from the official pertaining to dealing with tailing waste
- Lack of policy frameworks, especially in the context of managing tailing waste.

- Transparency of information systems.
- Introduce code and standards on the secondary product from tailing materials so users can use the products.

5.9. Good Practices in the mining industry and sustainable management of tailing waste

Good practices that can be followed for sustainable management of tailing waste, prerequisites towards managing the bulk amount of iron ore tailing waste, presented in **Table 5** (Bose et al., 2021; Bose et al., 2022: Bose, 2022; Bose & Dhar, 2022)

Table 5 Prerequisites for managing the bulk amount of tailing waste

Sl No	Good practices and prerequisites for managing the bulk amount of iron ore tailing waste
1.	Sufficient storage and disposal capacity for tailing waste generated annually
2.	Characterization and analysis of chemical and physical properties of tailing waste
3.	Proper and plane-wise investment
4.	Startup facilities and funding scheme
5.	Exclusive policy, regulation, and guidelines in the context of managing the bulk amount of tailing waste
6.	Transparency of information systems among the stakeholders and Industry partners
7.	Initiatives to introduce code and standards on the products developed from tailing (cement, concrete, brick, etc.)
8.	Tariff and non-tariff barriers to using tailing waste
9.	Building networks and partnerships to promote a harmonized approach to recycling and utilization of tailing
10.	Development of internationally accepted criteria for recyclability of tailing waste
11.	Technical capacity building and funding

5.10 Way Forward

Worldwide, a vast amount of tailing waste has been discharged, and billions of tons of tailing remain in the tailing dams. There is an opportunity to extract exceptional residual mineral values from the stored tailing in the dam, which could minimize the risk of tailing dam failure and eliminate associated environmental issues while generating additional economic values. Through recycling, miming companies can set the strategy to transform huge amounts of tailings waste from a liability into wealth. With a strong commitment towards a more sustainable vision in mining industries, mining companies around the globe are looking for more sustainable solutions and strategies for reducing tailings materials generated during mineral processing activities. From the circular economy perspective, there is strong business potential for recycling tailing materials. Still, the identified factors, hinder, and barriers are the main issues that must address early to accelerate the transformation. Recycling and reusing tailing waste through the circular economy model is a viable and sustainable solution that helps minimize risk in terms of tailing dam failures, related environmental issues, and resource optimization and delivers a valued return on investment by the mining companies and stakeholders.

5.11. Concluding Remarks

The transformation from a linear economy to a circular economy needs significant initiatives and changes in policy and regulation and filling the knowledge gap of the factors that affect the existing process for mineral resource consumption and valorization of tailing waste. The valorization of tailings waste in the mining industries is still significantly lower. Still, the commitment towards sustainability goal, in the future, the mission "zero waste" would be the main focus to all concerns. Mining companies need more knowledge about the valorization process of tailing waste. To make a transformational change to managing tailing waste through the circular economy concept, all the factors and barriers needs to be address appropriately, which will make the most feasible and sustainable business model towards the valorization of tailing waste and will succeed in the mission of "Zero waste."

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Chapter 6

Enhancing the Efficient Utilization of Reclaimed Asphalt Pavement (RAP) in Granular Sub Base for Road Construction: - A Recent trends

Author:- *Sunil Priyadarshi,(**Email:-sunilp@svu.ac.in**) Assistant Professor, Civil Engineering Department, SVU, Kolkata, India Pin-170121*

6.1. INTRODUCTION

6.1.1. Indian Road Network, its Growth & Future:

Road transport is considered to be one of the cost effective and preferred modes of transport for both freight and passengers because of its flexibility and accessibility. As compared to railways or airways, the road transport provides maximum service to the users and it serves as the feeder system for railways and airways. Apart from these basic advantages, presently the road transportation has become a backbone of a country's economy because of the industrial developments and economic benefits associated with a development project Reclaimed Asphalt Pavement (RAP) abundant waste available due to resurfacing and up gradation of the existing roads like Major District Roads, State highway, and National Highways(N.H).Since the quantities available is more which makes Highway and Transportation Engineers to find solution to reuse the RAP materials and thereby consuming the waste and conserving the natural resources. It is obtained either by milling or by a full depth recovery method. It may highly useful materials when crushed and screened properly. Use of RAP aggregate is not very common in India and other developing countries. In addition to financial investments, another input to the road development project is the raw material. Expecting future road developments in the country, Indian Roads Congress's special publication 'Road Development Plan VISION: 2021' states a requirement of 3500 million cubic meters of aggregates. These investments will keep on rising as the modernization of road network and demand for travel continues to increase in India. So, a need of today in India is to implement a developed methodology for construction & maintenance of roads to minimize the investments & bring down the requirement of raw materials. In order to reduce the usage of fresh aggregate, recycled aggregate can be used as a replacement materials. RAP aggregate used in the present study is obtained from the debris of dismantled roads. In order to reduce the usage of fresh aggregate, RAP aggregate can be used as replacement materials.RAP has been called the most recycled material in the world. It is most commonly used as an aggregate substitute in bituminous mix, granular sub-base, base aggregate and embankment or fills material. The material reviewed useful for this research process has various resources It is an open alternative for implementation on Indian roads to save the construction costs as well as sustain sources of raw materials. Roads Construction is quite cost intensive. Construction and maintenance of roads and highways involve millions of tonnes of aggregate. Considering the scarcity of fresh aggregate, replacement of part of the fresh aggregate with recycled aggregate is considered in the present study. Because the Government wants to conserve budgets in every possible situation and presently the whole world is giving special attention to the environment by focusing on the 'Green Technology. Hence, it can be concluded that recycling of pavements is an efficient solution for construction and maintenance of roads which offers enormous benefits like cost savings, preservation of environment and virgin materials.

6.1.2 History at a Glance

Recycling of bituminous pavements is a developed methodology used in various countries for rehabilitation of pavements. The concept was originated in 1915 but it became popular in1970's when there was an abrupt increase in the price of bituminous. The inflation necessitated development of a technology to reduce construction costs and recycling was studied and implement since then. The performance of these high RAP mixtures was found comparable to that of conventional mixes. A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they can be safely transmitted on to the soil subgrade. One of the major objectives of well designed and constructed pavement is to keep elastic deformation of the pavement in the permissible limits there by pavement can sustain a large number of repeated applications of load during the design life.

6.1.3 Present Scenario:

Reclaimed Asphalt Pavement (RAP) is a new emerging technique in India. The concept of reusing pavement materials will not only be beneficial for the government but also the contractors may increase their efficiency. Although not much research has been done on RAP in India but RAP is being widely used in the United States and many other countries. Best practices related to RAP sampling, testing, and material characterization are progressing to aid both contractors and departments of transportation in mix design and quality control. Low-temperature testing, rutting susceptibility assessment, cracking resistance, moisture susceptibility, and mixture stiffness should be assessed based on regional requirements. The bituminous industry needs to continue to assess which performance tests will provide the best correlation to field performance. An effort has been made in this study to find out the optimal percentage of RAP that should be used in sub base course. Reclaimed Asphalt Pavement(RAP) is a material which is obtained during the reprocessed, reconstruction or rehabilitation of roads which can be used as a replacement for fine aggregates and coarse aggregates. The material which was recycled has more resistance to scuffing and shearing, which in turn increase the rutting resistance. Scarcity of aggregates and crude oil results in increase in the cost of asphalt binder and aggregates spurred a new interest in the reuse of RAP. Recycling solve the problem of construction waste in transportation engineering projects. Strength parameters either of same or better quality are produced by RAP when compare to virgin aggregates. Reusing of RAP reduces the consumption of fuel and reduces damages to other materials due to the transportation of minerals from quarry sites.

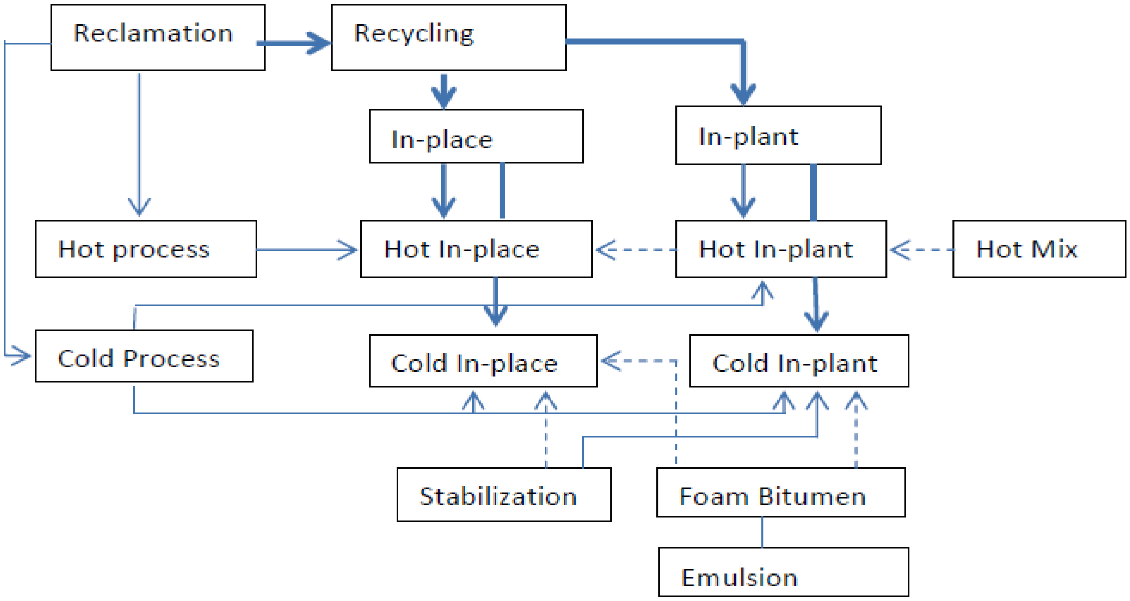

Fig: flow process of Reclamation

6.2. Studies on Recycling

The performance of the recycled mixes was compared with the control mixes through the testing for resilient modulus. The resilient modulus was found out after conducting the accelerated aging procedure through alternate freezing and thawing cycles ensuring that the mixes would be subjected to worst moisture conditions. Mc- bee et al (1988**)** conducted a "Detailed evaluation study on the recycled mixes**"** The study was a combination of field and laboratory evaluation Suggested that the use of rejuvenator in recycled bitumen mix would decrease the potential rutting and also increase the life of recycled pavement. Kandhal P.S. et. al.(1995**)** They performed "A laboratory study of recovered binder and a detailed evaluation on the recycled mixes in Georgia**"**. in which the blending process of reclaimed asphalt pavement (RAP) with virgin mixture was analyzed through controlled experiments. Screened RAP was blended with virgin (new) coarse aggregate at different percentages. A blended mixture containing 20% of screened RAP was subjected to staged extraction and recovery. The result from this experiment indicated that only a small portion of aged bituminous in RAP actually participated in the remixing process. Thomas.W.Kennedy, **- "**Effect of reclaimed asphalt pavement on binder properties using the SUPERPAVE system**"** This study was set out to establish guidelines for the use of RAP in bituminous mixes using SUPERPAVE binder specifications. This study concludes that the stiffness of the binder is higher at higher percentages of RAP binder. The rate of change of stiffness is either constant from 0–100% RAP binder or increases with lower temperatures. The rate of change of stiffness is either constant from 0–100% RAP or increases at higher percentages of RAP in the blend. West R. et. al. (2009) Has conducted an accelerated field performance testing at National Center for Asphalt Technology (NCAT) test track. The study investigated field as well as **"** laboratory performance parameters of recycled pavements**"**. Field analysis was carried out using the measurements for rutting, roughness, texture change and cracking. The loading on the track was accomplished through five trucks pulling heavily loaded triple trailers. The laboratory investigation included advanced tests such as asphalt pavement analyzer (APA) rutting tests, dynamic modulus, bending beam fatigue and energy ratio. the conclusions from this study are The recycled pavement sections performed well on the test track under heavy loading. Valdes G. et. al. (2010) carried out "A study on recycled asphalt mixes containing higher RAP percentages". The study was carried out for rehabilitation of a highway section. Two semi dense mixtures of 12mm and 20mm maximum aggregate size containing 40% and 60% of RAP respectively were made and their properties were compared with the control mixtures prepared using two grades of bitumen viz. penetration grade 60/70 .finally conclusions of the study are, The results of impact test were satisfactory for laboratory prepared recycled mixes and comparable to that of virgin mixes.RAP content of 60% can be effectively incorporated in recycled mixes provided a proper handling and mix design practice is carried out. The analysis of stiffness modulus and indirect tensile strength test indicated that, the performance of recycled mixes is comparable to that of virgin mixes. Eric J. McGarrah-(2010) “Evaluation of current practices of Reclaimed asphalt pavement/virgin aggregate as base course material” This report analyzes existing studies that have examined the properties and performances of 100% RAP mixtures as well as RAP/virgin aggregsate blends. Various findings of this study are described. Although 50% RAP is a common maximum percentage, but this does not mean it is the best percentage, so it should be limited to 25%. RAP is a highly inconsistent material, producing RAP with a constant gradation will limit this variability and will likely ensure more consistent performance results. Montepara, et.all (2012) “Effect of payment performance of a sub base layer composed by natural aggregate and RAP” Reclaimed Asphalt pavement(RAP) recycling in pavement engineering can be actually carried out by means of hot recycling and cold recycling. An additional option arises from mixing with natural aggregates to build the sub base layer. in this study shows the first results of research activity undertaken on a test track specifically constructed with the aim to analyze the effect on pavement performance of a sub base layer mixture with 50% of natural aggregates and 50%of RAP. This paper concluded that habitant to improve the economic condition, transportation and employment opportunity and also help create jobs through labour based construction and maintenance. Khushbu.M.vyas, shruti (2013) “ Technical viability of using reclaimed asphalt pavement in Ahmadabad BRTS Corridor for Base Course” Major findings from the laboratory investigation were The RAP aggregates did not meet the required gradation as per MoRTH. we observed that the large size of aggregates were deficient in RAP mix due to the action of crushing & aging. So, to meet the required gradation numbers of trials are made with natural aggregate and by adding 60% of RAP mix, 30% of 40mm size of aggregates & 10 of % stone dust, we can achieve gradation of aggregates. Aggregate Impact Value was 14.89%, The Combined Flakiness & Elongation index was 27.64% which is less than the 30 % maximum permissible limits as per MoRTH for WMM. Hence the material is satisfied. The specific gravity of aggregates was lying from 2.8 to 3.0 and the water absorption of aggregates ranges from 0.3 to 2.0 % which was between specifying limit so material is satisfied. From the study analysis it was found that recycled aggregates confirmed to the standards specified in MoRTH specification, and can be used as base course.

Sharma Jitender, Singla Sandeep (2014).“Study of Recycled Concrete Aggregates” This paper describes the introduction and production of recycled concrete aggregates and its variousApplications in the construction industry. And also, properties of recycled aggregates and its comparison with the natural aggregates are mentioned. Finally concluded that we may use in like Aggregate base course, or the untreated aggregates used as foundation for roadway pavement, is the underlying layer we may which forms a structural foundation for paving.Singh Veresh P., Mishra Vivek , Harry N.N. and Bind Y.K.. (2014) “Utilization of Recycled Highway Aggregate by Replacing it with Natural Aggregate” Recycled aggregates comprise crushed, graded inorganic particles processed from the materials that have been used in the highway roads. The aim of the present investigation is to determine and compare the maximum dry density, optimum moisture content and California Bearing Ratio (CBR) of Granular Sub Base(GSB) and Wet Mix Macadam (WMM) by using different percentages of recycled aggregates. This investigation was carried out using modified proctor CBR for total of 5 batches of mixes prepared in which 0, 10, 20, 30, 40 and 50% replacement of fresh aggregate by recycled aggregate at optimum moisture contents was carried out. The maximum dry density of recycled aggregate matrix up to 30% replacement level is about 0.01 g/cc more than the referral mix by natural aggregate. The CBR of recycled aggregate matrix up to 30% replacement level is about 1% less than the referral mix by natural aggregate. This reduction in strength may be due to lesser the strength of recycled aggregate as compared with the fresh aggregate. Rao et. al(2014) “Utilization of RAP (Reclaimed Asphalt Pavement) Material Obtained By Milling Process” in this practical study shows the definite impact on replacement of virgin material for various road constructions. The CBR values increasing to 2, 3.8 and 6.8 % respectively by 20, 40 and 60 % RAP mixing in black cotton soil surely work for improved sub-grade. Also the study shows the saving of 25 % virgin material for GSB grade – II and 35 % for WMM by utilizing RAP. We may use the RAP material as GSB (Granular Sub Base) after analyzing and adding the missing sieve size material. Sreedhar. (2014) Cost Analysis of Low Volume Rural Roads using Rap Materials as G.S.B." Reclaimed Asphalt Pavement (R.A.P.) is the most and abundant Industrial waste available due to expansion and up gradation of the existing asphalt roads like Major District roads(M.D.R),State highway(S.H) and National Highways(N.H).Since the quantities available is more which makes Highway and Transportation Engineers to find solution to reuse the RAP materials and thereby consuming the Industrial waste and conserving the natural resources. Reusing of RAP materials in the G.S.B. will also saves the construction cost by 25-30%. Various techniques have been devised for finding the characterization of the RAP materials by conducting lab tests for Aggregates as well as for the Bitumen. Cost analysis is done for a stretch of 5 KM and saving of 35% is achieved.Singh Jaspreet et.al (2015)] , "A Review paper on Reclaimed Asphalt Pavement (RAP)", RAP is a new technology with the help of which bituminous pavement can be it involve the usage of old bituminous pavement materials. Also it ensures supports sustainable development and optimization of resources. We can adopted 20% to 50% of RAP in different layer of flexible pavement.Using RAP does not only help in minimizing the cost of project but also ensure proper utilization of resource. From this study it can be concluded that using RAP is advantageous as RAP mixes can yield result equal or even higher than virgin mixes. Over all from this study it was concluded that RAP 30% showed results similar to that of virgin bituminous mix and best performance amongst other RAP %. Also if 30% of RAP mixes are used in project, the 21% of cost will be reduced.

6.3.Research Methodology

The following gives the step by step process of various activities. 1. RAP samples are collected from the ongoing projects or stocks. 3-4 type of samples from one or more site shall be taken. 2. Properties of RAP shall be ascertained: e.g. grading, aggregate impact value, residual bitumen etc. 3. Sample with different proportion of aggregate for various grading of GSB shall be prepared. 4. Sample shall be tested to verify conform to grading. 5. CBR value of some sample shall be ascertained. 6. Suitable/ optimum percentage of RAP shall be ascertained. 7. Effect of residual binder if any, shall also be evaluated.

6.3.1 Recycling of Pavement

Recycling of pavement is the process in which the existing pavement materials are reclaimed and re-used after reprocessing for either (a) resurfacing, or (b) repaving, or (c) reconstruction of pavement depending upon the condition of the existing pavement, the nature of the reclaimed materials, the method of reprocessing, and the treatment that the pavement requires

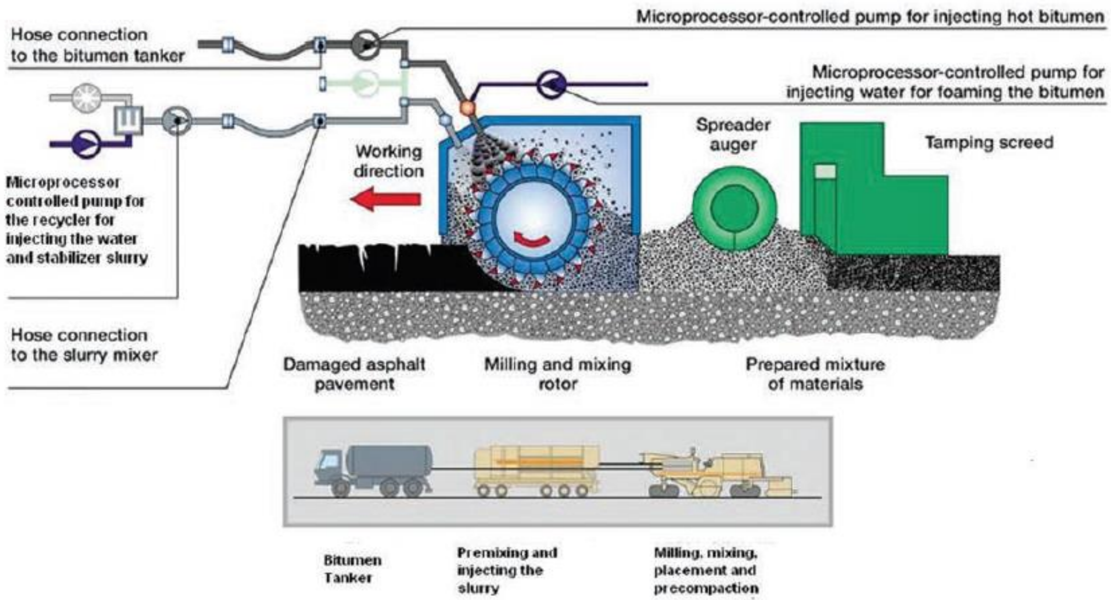

Fig: milling process

6.3.2 Laboratory Tests:

It is very common to conduct the series of tests on the aggregates before using them in any road construction. Many properties of aggregates are needed in designing the pavement mixes. In 28 present study the pavement mix considered for study is granular sub base. The GSB is prepared using the 20 mm fresh aggregates and recycled aggregates to evaluate the usability of recycled aggregates in pavement construction. It is helpful in deciding whether the recycled aggregates are acceptable for use in GSB construction. The details of tests on aggregates are as follows: i) Bitumen Content Test (ASTM 2172) ii) Aggregate Impact Value (IS: 5640) iii) Sieve Analysis of Coarse and Fine Aggregate (IS: 2386Pt 1) iv) Moisture Content (IS: 2720 Pt II)s v) Specific Gravity Test – for all the aggregates of GSB vi) Standard Proctor Compaction Test (IS 2720 Pt VIII) vii) California Bearing Ratio Test (IS 2720 Pt V)

6.3.3. Materials:

It is required to determine the materials and their sources opted for this study. The materials include RAP material, Coarse aggregates, Bitumen (VG 30). 4.1 RAP material The material which was obtained during the reconstruction and rehabilitation of roads is called Reclaimed Asphalt Pavement. RAP material which was collected for this study has undergone several laboratory tests after crushing into nominal size aggregates in order to determine its suitability in the construction of flexible pavements and to determine the physical properties like toughness, strength, hardness, quality, durability, shape and size.

Fig:- Existing road and RAP Materials

6.3.4. Coarse aggregates

The Coarse aggregates (Virgin aggregates) of distinct sizes like 20mm,12mm, 10mm, 4.75mm, 2.36

mm were taken and different tests were conducted to determine the properties like toughness, strength, hardness, quality, durability, shape and size and to compare the results of RAP as well as Virgin aggregates. 4.3 Bitumen Bitumen used for this study is VG- 30. It is the viscosity grade which is most suitable in the construction of flexible pavements as it has more durability and more resistance to sustain in the different temperature conditions.

6.3.5. Alternative Materials

As discussed above, not all economically available materials are suitable for the pavement layers, particularly the more important structural subbase and base. In such cases, the need for improving these materials arises. Material improvement can be achieved in several ways, the most appropriate being mechanical or chemical stabilization. It is important to differentiate between modification and stabilization. The former improves the material properties without any marked cementation (i.e., the material remains in a granular state), whilst the latter causes cementation and the development of tensile strength.

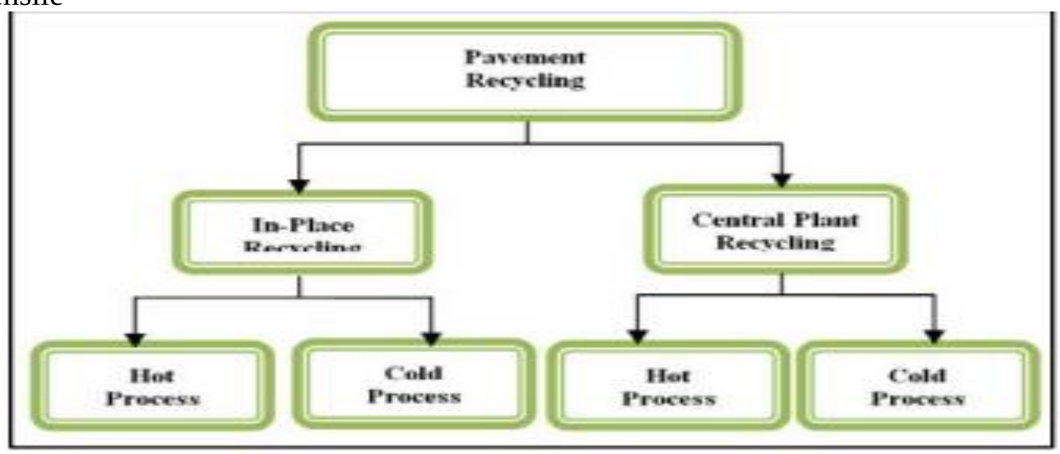

Fig: pavement recycling process

6.3.6. Stabilization:-

Mechanical stabilization Mechanical stabilization is a standard construction practice that includes blending of different materials, removal or break-down of oversize material and, obviously, densification. Modern equipment such as bucket-crushers and screeners which attach to conventional excavators allow on site breaking down and screening of materials. Chemical stabilization Chemical stabilization involves adding a product to the material such that bonding between individual particles within the material may occur. This could involve direct bonding (such as with bitumen) or the creation of new bonding products as is the case with lime or cement. The bonding products (cement, lime, bitumen) are well established and not covered in this presentation but is discussed elsewhere at this conference. There are also numerous modern proprietary soil improvers on the market. Each of these has a particular mechanism of "reaction" and needs to be tested on the proposed material to be treated to ensure that the required material properties are achieved (usually an end-product specification" in terms of strength or stiffness. In addition, there are numerous materials/chemicals that are combined with cement, lime or bitumen that are being increasingly used for soil improvement. These include nano-polymers in bitumen, which in particular is showing significant success (Jordaan and Steyn, 2021)

6.4. Summary

4.1Advantages of Using Recycled Road Aggregate :

As explained above the need for Recycled Road Aggregate (RRA) has been justified, following are some other important factors which further justify the need for using Recycled Road Aggregate (RRA).

- Sustainable development
- Optimizing the use of natural recourses
- Reducing environmental impact
- Increase in restrictions on the dumping of reusable materials
- Reduction in material cost, energy cost and total job cost
- Less emission of carbon due to less crushing
- Save time: - There is no waiting for material availability

4.2 Limitations Using Recycled Road Aggregate :

Following are some other important factors which are not justify the need for using RRA.

- Less quality (e.g. compressive strength reduces by 10-30%).
- Duration of procurement of materials may affect life cycle of project.
- Land, special equipment machineries are required (more cost).
- Very high water absorption (up to 6%).
- It has higher drying shrinkage & creep.

6.5. Conclusions

Following conclusion is drawn from the present study:.

- Percentage of RAP used varies from project to project and condition of RAP materials. It has been successfully upto70% used in the construction of the road projects.
- Preparing a Granular mix with 100% use of RAP is not advisable.
- It was observed that the large size of aggregates were deficient in RAP mix due to the action of crushing and aging.
- Aggregate impact value and CBR value of RAP in different literature was found to be significantly lower than the maximum permissible value as per MoRTH and hence satisfactory from strength criteria.
- The use of recycled aggregate in road construction in GSB will not only result in achieving economy in the road projects, but also minimizes mining pollution.
- Different percentages of RAP have been used in different projects; there is no optimal percentage of RAP that should be used for Granular mixes..
- Recycling aggregate from the demolition projects can save the cost of transporting the material to the land fill, and the cost of disposal.

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Chapter 7

Dynamic seismic analysis of multi-storied buildings having different heights for all seismic zones in India

Author:-

*Ms. Rejina Yasmin, (**Email:- rejinayasmin3@gmail.com**), Research Scholar, Department of Civil Engineering, Swami Vivekananda University, Kolkata 700121, INDIA*

*Dr. Abir Sarkar,(**Email:-abirs@svu.ac.in**) Assistant Professor, Civil Engineering Department, SVU, Kolkata, India Pin-700121*

7.1. Introduction

Throughout history, earthquakes have claimed countless lives and inflicted extensive property damage. The sheer force of seismic waves has the potential to induce ground motion leading to building collapses, landslides, tsunamis, and volcanic activities. A stark reminder of this vulnerability is the recent 6.4 magnitude earthquake that struck Assam, India, on April 28, 2023, resulting in two fatalities, and at least 12 injuries, with buildings collapsing at the epicenter. This region falls within the highly seismic Hazard Zone V. These incidents underscore the paramount importance of implementing earthquake-resistant design principles in structures to mitigate casualties and damage. Structural engineers have tirelessly endeavored to reduce lateral loads and enhance structural rigidity through mechanisms such as "moment resisting frames." These frames aim to bolster a building's seismic resistance, particularly during major earthquakes. However, the effectiveness of these techniques varies with factors such as building height, seismic zone classification, and the inherent soil characteristics of the location. India's seismic zoning map classifies the country into four seismic zones (Zone II, III, IV, and V), with Zone V experiencing the highest level of seismicity. These zones are outlined in the Indian standard code IS:1893, part-1, 2016. This study encompasses all seismic zones to provide insights into structural performance under varying seismic excitations.

This research focuses on the performance of structures of differing heights across all seismic zones, with a specific emphasis on the utilization of the Response Spectrum Method. Understanding the interaction between building height and seismic zones in India is crucial in advancing our knowledge of structural resilience. The numerical analysis in this study is conducted using SAP2000 software, known for its capabilities in structural analysis. A multi-storey building is analyzed, considering critical lateral load conditions, and designed as a Special Moment Resisting Frame (SMRF) to enhance performance. AutoCAD software is employed for floor plan creation. Response Reduction Factor, R, as per IS 1893, part-1, 2016, guides the structural design. The study evaluates storey displacement, base shear, and base moment to gauge structural response.

The primary aim of this study is to conduct seismic analysis on G+5, G+10, G+15, and G+20 storey residential buildings across all seismic zones in India using SAP2000, v24 software. The objectives encompass dynamic analysis of buildings with varying heights, improving seismic resistance compared to conventional construction, adherence to IS 1893-2016 part-I criteria, ensuring safety, stability, and serviceability during earthquakes, creating awareness of seismic effects, and demonstrating improved building response under dynamic loading conditions. This research aims to enhance our understanding of the seismic behavior of buildings of different heights in various seismic zones, ultimately contributing to safer and more resilient structural design practices.

7.2. Literature review

The literature review concentrated on seismic forces and their influence on the quality of life, as explored by researchers who have analyzed seismic forces across different earthquake zones. These authors also elucidated the investigations carried out to mitigate or manage seismic effects. Below, we delve into these research papers to acquire insights into seismic responses and gain an understanding of seismic analysis from previous studies.

Dr. Nagesh, Yash Dehankar (May, 2022): The paper involves the comparative study of Seismic analysis of different heights building on different types of soil using Base Isolation technique (for G+10, G+15, G+20, G+25). The comparative study focuses on the behavior of different height of structure, Earthquake Zone, and type of Soil with Base Isolation techniques (Codes are: IS456:2000; IS1893:2016 and IS 13920:1993). Friction Isolator, Triple pendulum Isolator, Lead Rubber bearing Isolator is used in Base Isolation techniques. There has Friction Isolator which has better results than other base Isolator. In case of soft soil Frictional Isolator is better but in case of other types of soil frictional Isolator and Triple pendulum Isolator shows the same result. For the analysis of Base Isolation technique has been used and modeling of structures has done by ETABS.

In June 2022, Shaik Akhil Ahamad and K.V. Pratap conducted a dynamic analysis of a G+20 multi-storied building using shear walls located in various positions within different seismic zones. They employed the ETABS software for this investigation, focusing on the comparative behavior of braced frame buildings through dynamic analysis (according to IS 13920:1993 and IS: 875-1987 standards). The study utilized the Response Spectrum Method.

The findings revealed that incorporating a braced system in the structure is advantageous for resisting seismic waves, as it effectively reduces displacement, axial forces, and bending moments in columns. Across all seismic zones in India, the study observed higher maximum displacement values in seismic zone V. It was also noted that introducing uniform stiffness in the structure can further mitigate displacement. In the case of soft soil, structures featuring symmetrically placed shear walls demonstrated superior performance compared to those without shear walls. Vinay Danam (Oct, 2015): The paper has done lateral load analysis of multistoried RCC building (G+10) by considering 4 models. In the first model is without providing any shear wall, in the second model has coupled type with openings and the third model has a rectangle type shear wall at four corners, and the fourth model corner core type shear wall system has done by SAP2000 software. This study mainly focused on seismic forces, lateral displacement and shear wall system. In this paper G+10 storey building analyzed with different types of shear walls. Maximum earthquake intensity area (Zone IV, Zone V) where four corners and centroid shear wall can reduce the deflection of the building. Also, it can reduce the shear force and bending moment of the building. It is observed that in Zone III, rectangular type shear wall and in Zone II coupled type shear wall is more suitable.

In September 2013, A.E. Hassaballa, Fathelrahman M. Adam, and M.A. Ismaeil used STAAD PRO software to analyze a G+25 storey reinforced concrete building's seismic response via the Response Spectrum Method. Their study aimed to assess displacements, stresses, and seismic hazards. The results showed excellent column and beam deflection performance. Exterior columns had a greater seismic impact than interior ones, and ground floor columns experienced compression stresses 1.2 to 2 times higher than tensile stresses. Beams exhibited nearly equal maximum tension and compression values during seismic analysis.

Mr. Murat Saatcioglu and JagMohan Humar (23 April 2003): They studied dynamic analysis of (G+5, G+10, G+15) building for earthquake resistance design by SAP2000 software. This analysis is done by linear dynamic method. The paper provides an overview of dynamic analysis, elastic analysis, fundamental period, seismic design, structural analysis and structural design. The comparative study focuses on the behavior of braced frame building with the help of dynamic analysis (IS 13920:1993, IS: 875-1987). The result gives better if we provide Braced system in the structure to reduce displacement, axial force and bending moment in columns.

E. Pavan Kumar, A. Naresh, M. Nagajyothi, and M. Rajasekhar (November, 2014) conducted earthquake analysis on a G+15 multi-storied residential building using the Response Spectrum Method. Their study compared the seismic behavior of Ordinary Moment Resisting Frames (OMRF) and Special Moment Resisting Frames (SMRF) through STAAD.PRO V8i software.

Vinay Mantha and S.S.Sanghai (June, 2016) conducted a study comparing seismic and non-seismic analysis of a G+17 storey building using SAP2000. They employed the Equivalent Static Method with the goal of minimizing structural damage during seismic events in a cost-effective manner. The study focused on analyzing maximum shear forces and bending moments, revealing significantly increased values in seismic analysis compared to non-seismic analysis.

Dr. Sachin Balkrishna Mulay, Dr. Jyotiprakash G. Nayak, and Mr. Rahul Tarachand Pardeshi (Dec, 2022) conducted research on the analysis and design of shear walls and storey drift in a high-rise building under seismic excitations. They utilized I-shaped shear walls and employed the Response Spectrum Method via ETABS software. The objective was to determine the optimal location for shear walls to enhance resistance against lateral forces in seismic zone IV. The study compared two building conditions: one with shear walls, which effectively resisted lateral forces, and another without shear walls, which failed to provide sufficient lateral force resistance.

K. Supreem, N. Ragunath, S. Madhu (Oct, 2022): In the research, there has seismic analysis of G+15 storey building has done by using Response Spectrum Analysis method by using SAP2000 software. The

comparative study is focused on the response spectrum method and Time period method for seismic analysis. In Time period method results more. In time period method results show that to check the Time period of structure, should be 2.7 sec for regular structure.
K.Ramakrishna Reddy, DR. S. Vijaya Mohan Rao (Nov, 2016): The paper involves the comparative study of Seismic analysis of different heights of building using Time History method (for G+15, G+20, G+25). The comparative study focuses on the behavior of different height of structure, Earthquake Zone, and type of Soil. The response spectrum method has been used for this study. Response spectrum method has been used for this study. To resist seismic wave it is better if we provide Shear wall in the structure to reduce displacement, axial force, and bending moment in columns. In all the seismic zones of India, maximum displacement values are found to be higher in seismic zone v. It is better if we provide uniform stiffness in the structure to reduce displacement. In case of soft soil, the structure with shear walls placed symmetrically will give better results as compared to the structure without shear walls.
Dr. B. Anil, N.V.S.S.Raju (July, 2012): The paper involves the comparative study of response spectrum analysis for (G+5, G+10, G+15, G+20) storied building. Comparative study on the displacement of different height building under different soil condition is done. The comparative study focuses on the behavior of different height of structure, Earthquake Zone, and type of Soil. Response spectrum analysis and Time history analysis method has been used for this study. To resist seismic wave it is better if we provide Shear wall in the structure to reduce displacement, axial force, and bending moment in columns. Maximum displacement is found in the soil of Sathupally than Eluru and Guntur. In response spectrum analysis, it is better if we provide shear wall and also if we provide shear wall symmetrically.
Dheeraj Bothra, Yashish Rathi (Feb, 2022): The paper is about the seismic analysis of high-rise building with vertical irregularities. In this research, there have (G+30, G+30 with vertical irregularity) multi-storied building is analyzed by using ETABS software. In this paper behavior, seismic response, time period, storey drift, shear force, and axial force is compared with normal building and building with vertical irregularities.
Mohsin Aakib Shamim Akhtar (Feb, 2022): The paper involves dynamic seismic analysis of multi-storey buildings in seismic zone V by using STAAD.PRO software. In this research, behavior, seismic response, time period, storey drift, shear force, and axial force is compared with normal building and building with double cross type bracing.
Kassem Trabolsi (Nov, 2020): The paper is about the study of the effect of soil structure interaction of a high rise building on a raft foundation by using SAP2000 software. The objective of the study is to observe the effect of soil structure interaction on the response of high-rise buildings with raft foundations. In this paper building on different types of soil with seismic excitation has been observed.

7.3. Methodology

The study focuses on the seismic analysis of a multi-storied building with varying heights. However, seismic analysis encompasses different approaches. The Equivalent Static Method proves adequate for smaller building structures in terms of seismic resistance analysis. For taller structures, it necessitates consideration of more than two modes and the calculation of mass weights for each mode to withstand lateral seismic loads. This method is unsuitable for analyzing high-rise structures. Conversely, seismic analysis requires specific location considerations. The Time History Method encounters challenges in obtaining seismic records for every location within a seismic zone area.
In contrast, the Pushover Method faces limitations in accounting for variations in dynamic properties and nonlinear responses caused by changes in stiffness and strength during load cycles. Consequently, the Response Spectrum Method is employed to address these challenges. This method enables the analysis of displacement and member forces within the structure and can calculate maximum displacement values and member forces for each mode of earthquake shaking using a design spectrum.

7.4. Problem Statement

The SAP2000 software is used for developing 3D modeling and analysis. The lateral loads that are applied on the different heights of buildings are based on the Indian standard codes. The study is performed for different seismic zones in India as per IS 1893:2016 (part 1).

Modeling

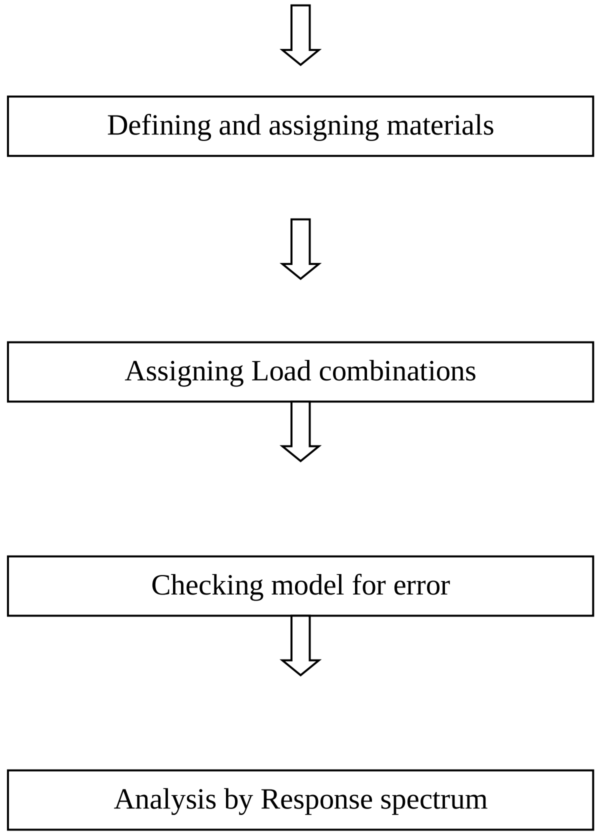

Fig. 1. Flow chart of methodologies

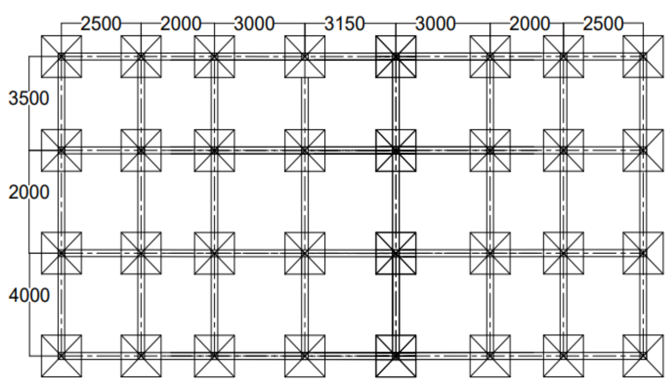

Fig. 2. Column & beam positions

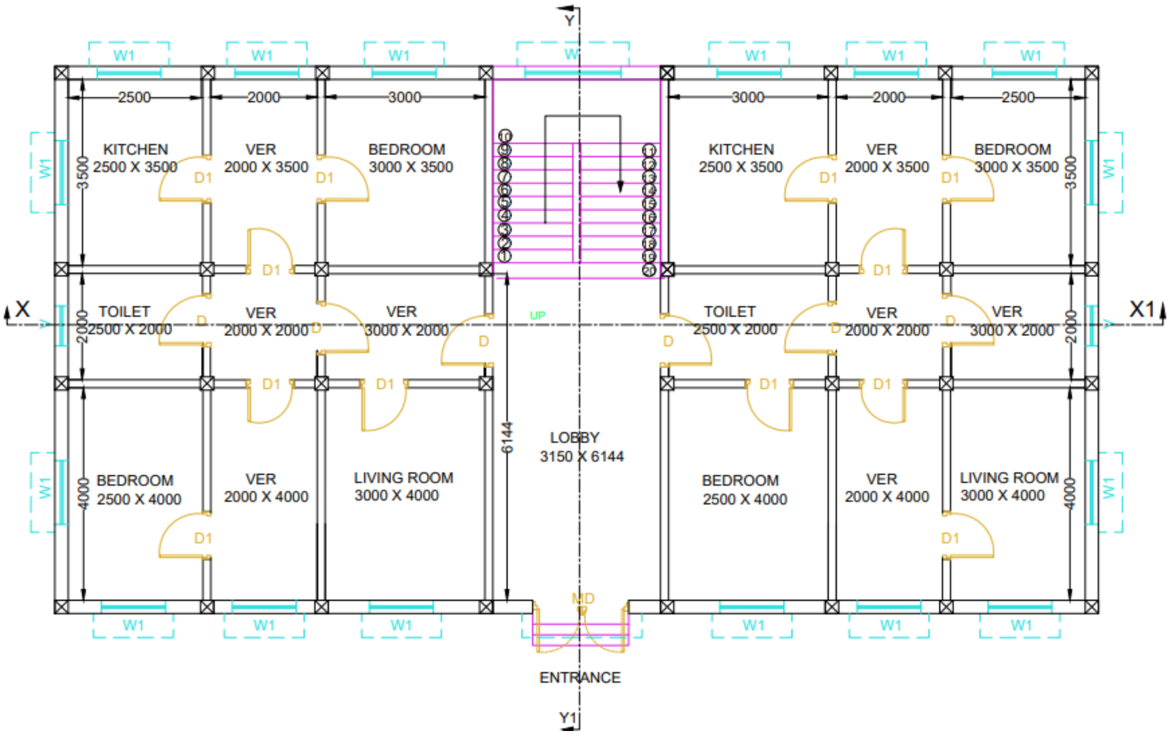

Fig. 3. Plan of Multi-storid building

Table-2:

Building Specification

Component	Value
Structure	SMRF
Number of model	16
Each Storey height	G+5,G+10,G+15,G+20
Type of building	Residential
Seismic Zone	Zone II, III, IV, V (As per IS 1893:2016(part1))

Table-3: Material properties

Component	Value
Grade of concrete	M25, M30
Grade of steel	Fe500
Density of reinforced concrete	25 KN/m2
Density of steel	78.5 KN/m2

Table-4: Member properties

Component	Value
Beam size	300mm X 250mm
column size	Rectangular column: 350mm X 300mm Square column: 300mm X 300mm
Slab thickness	150mm

Table-5: Seismic properties

Component	Value
Live loads	2KN/m2, 3KN/m2, 1.5 KN/m2 and 0.75 KN/m2 (as per IS 875(part2))
Zone factor(Z)	0.10, 0.16, 0.24, 0.36 (as per IS: 1893:2016; table-3(part-1, cl-6.4.2))
Importance factor(I)	1

	(as per IS:1893(part-1):2016,table-8)
Response reduction factor	5 (as per IS:1893(part-1):2016,table-9)
Soil type	II (medium soil) (as per IS:1893(part-1):2016,table-4)
Damping factor	0.05 (as per IS: 1893:2016; (part-1, cl-7.2.4))

The 3D model of the plan

- Model 1: G+5 storey RC SMRF building in Seismic zone II
- Model 2: G+5 storey RC SMRF building in Seismic zone III
- Model 3: G+5 storey RC SMRF building in Seismic zone IV
- Model 4: G+5 storey RC SMRF building in Seismic zone V
- Model 5: G+10 storey RC SMRF building in Seismic zone II
- Model 6: G+10 storey RC SMRF building in Seismic zone III
- Model 7: G+10 storey RC SMRF building in Seismic zone IV
- Model 8: G+10 storey RC SMRF building in Seismic zone V
- Model 9: G+15 storey RC SMRF building in Seismic zone II
- Model 10: G+15 storey RC SMRF building in Seismic zone III
- Model 11: G+15 storey RC SMRF building in Seismic zone IV
- Model 12: G+15 storey RC SMRF building in Seismic zone V
- Model 13: G+20 storey RC SMRF building in Seismic zone II
- Model 14: G+20 storey RC SMRF building in Seismic zone III
- Model 15: G+20 storey RC SMRF building in Seismic zone IV
- Model 16: G+20 storey RC SMRF building in Seismic zone V

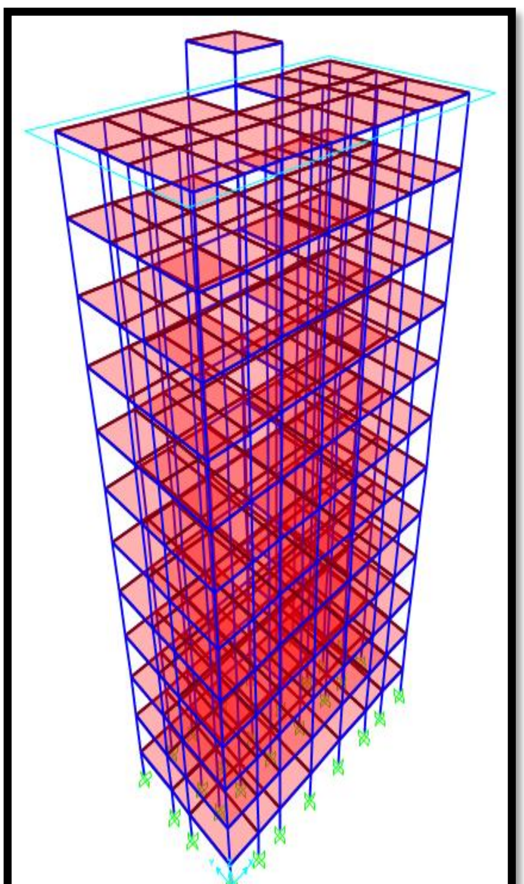

Fig. 4. 3D model for G+10 storey

To find out the performance of the different heights of the RCC building, the comparative study about storey displacement, frequency, time period, base shear and moment with the help of linear analysis by SAP2000 software. Four different heights of models were studied for medium soil in low seismic zone to critical seismic zone.

7.5. Response spectrum analysis

Conducting a response spectrum analysis aims to ascertain the seismic forces' distribution across each floor of a multi-story residential building and its various lateral load-resisting components.

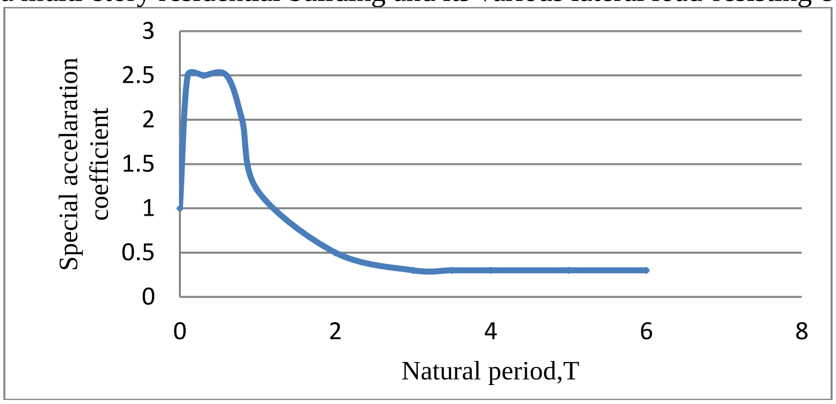

Fig. 5. Design acceleration coefficient (Sa/g) vs. Time period (T) for Medium soil (Source: IS: 1893, 2016 (part-1, Fig.2))

The SAAP2000 software utilizes the following bellow procedure to generate the lateral seismic loads to the building.

1] Creating grid points and generating the structure

2] Defining and assigning of properties

3] Assigning of supports

4] Defining approximate fundamental natural period Ta of oscillation in second,

$Ta=0.075h^{0.75}$ (As per IS: 1893 (part-1):2016; cl-7.6.2)

For G+5 storey building, $Ta= 0.075 \text{ X } 22^{0.75} = 0.76$ cycle/sec

For G+10 storey building, $Ta= 0.075 \text{ X } 37^{0.75} = 1.13$ cycle/sec

For G+15 storey building, $Ta= 0.075 \text{ X } 52^{0.75} = 1.45$ cycle/sec

For G+20 storey building, $Ta= 0.075 \text{ X } 67^{0.75} = 1.76$ cycle/sec

5] Defining load pattern and load combination

This analysis has been done by horizontal X and Y to resist lateral seismic forces. Out of all the load combinations analyzed, the following seismic load combinations are given below,

1.2(DL+LL±RSX)

1.2(DL+LL±RSY)

1.5(DL±RSX)

1.5(DL±RSY)

0.9DL±1.5RSX

0.9DL±1.5RSY

6] Assigning of dead loads

For Slab load

Floor load= Slab thickness X concrete density

= 0.15 X 25 = 3.75 Kn/m2

For floor finish load = 1 Kn/m2

For wall load

External wall load= wall thickness X unit weight of brick X (total height – beam depth)

= 0.25 X 20 X (3.1-0.3)

= 14 KN/m

Internal wall load= wall thickness X unit weight of brick X (total height – beam depth)

= 0.15 X 20 X (3.1-0.3)

= 8.4 KN/m

Parapet wall load= wall thickness X unit weight of brick X height of parapet wall

= 0.125 X 20 X 1.2

= 3 KN/m

7] Assigning of live loads

The live loads or imposed loads to be taken in the residential buildings have been given in IS 875 (part-2) -1987. The live loads which are used in this analysis, are: 2KN/m2 (for rooms and floors), 3KN/m2 (for the staircase), 1.5 KN/m2 (for the accessible roof) and 0.75 KN/m2 (for the non-accessible roof).

8] Assigning of seismic loads

9] Assigning of load combinations

10] Analysis of G+5, G+10, G+15, G+20 storey buildings.

7.6. Results and Discussion

Data obtained from the Saap2000 software has been compiled in various formats, including tables and figures. These visual representations facilitated the comparison of results across different building heights within various seismic zones in India. The figures and tables below illustrate the analysis of maximum displacement, base shear, base moment, fundamental time period, and frequency, all of which were examined to assess the lateral stability of the building.

Joint Displacements

Table-6: Maximum displacement obtained from SAP2000

Seismic Zones	Building Height	RSX (mm)	RSY (mm)
Zone-II	G+5	8.2	8.8
	G+10	14.3	19.2
	G+15	15.2	20.5
	G+20	40.6	54.0
Zone-III	G+5	13.1	14.1
	G+10	23.0	30.0
	G+15	24.3	32.8
	G+20	65.1	86.5
Zone-IV	G+5	19.7	21.2
	G+10	36.4	49.2
	G+15	54.0	73.0
	G+20	97.6	129.0
Zone-V	G+5	29.5	31.8
	G+10	51.8	69.3
	G+15	78.0	97.0
	G+20	146.0	194.0

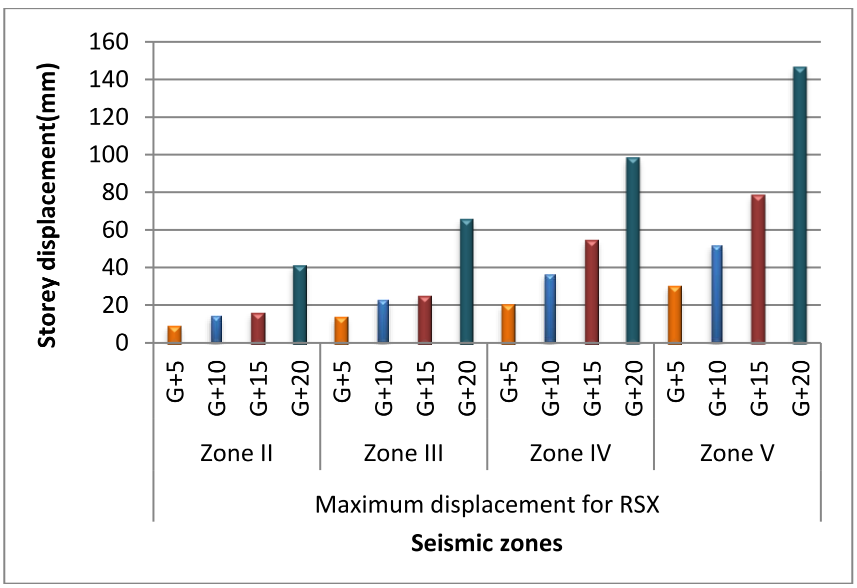

Fig. 6. Comparison of Maximum displacement of different building heights vs. seismic zones along X direction

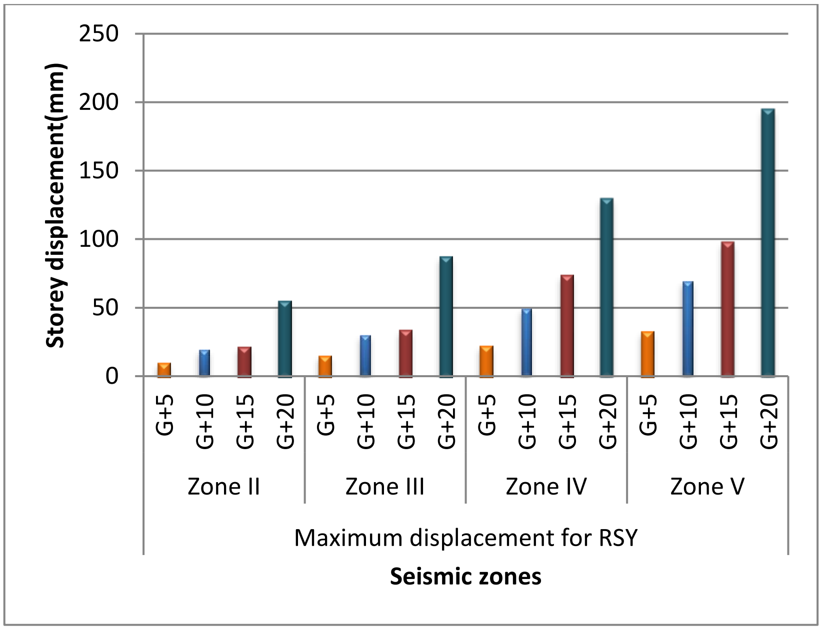

Fig. 7. Comparison of Maximum displacement of different building height vs. seismic zones along Y direction

Base Reactions

Table-7: Maximum base shear obtained from SAP2000

Seismic Zones	Building Height	RSX (KN)	RSY (KN)
Zone-II	G+5	131	131
	G+10	215	370
	G+15	271	425
	G+20	280	597
Zone-III	G+5	202	203
	G+10	345	351
	G+15	434	477
	G+20	460	629
Zone-IV	G+5	485	468
	G+10	518	580
	G+15	621	629
	G+20	637	670
Zone-V	G+5	728	728
	G+10	777	780
	G+15	978	998
	G+20	1015	1021

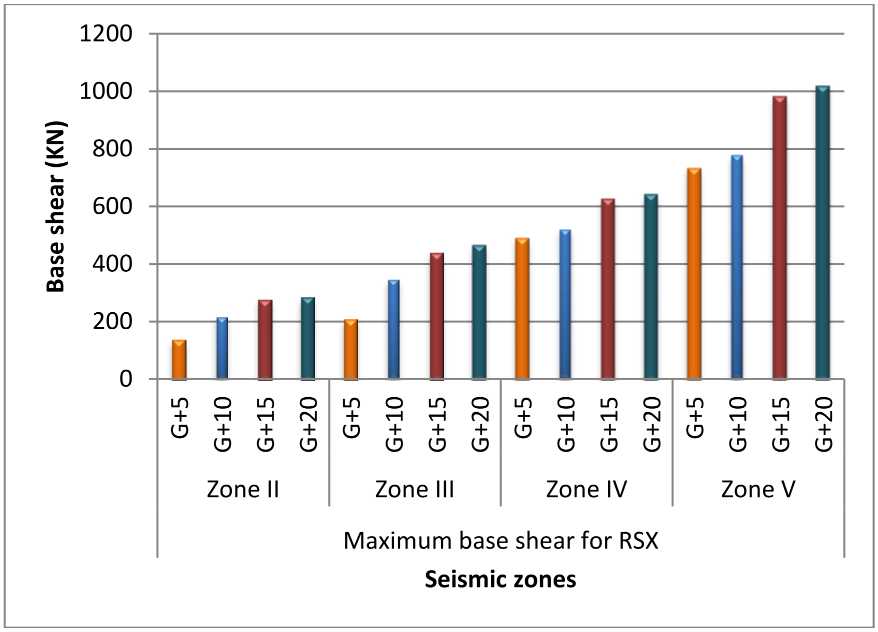

Fig. 8. Comparison of Maximum base shear of different building height vs. seismic zones along X direction

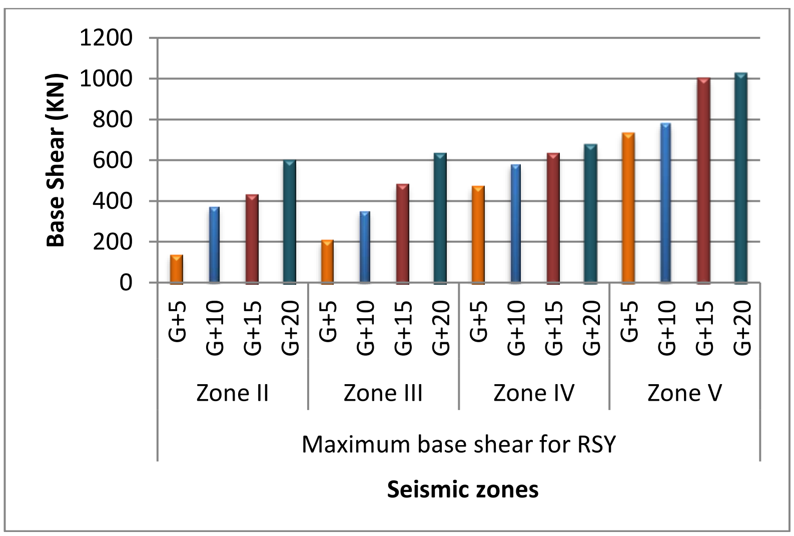

Fig. 9. Comparison of Maximum base shear of different building height vs. seismic zones along Y direction

Table-8: Maximum base moment obtained from SAP2000

Seismic Zones	Building Height	RSX (KN.m)	RSY (KN.m)
Zone-II	G+5	82	82
	G+10	102	108
	G+15	118	118
	G+20	159	163
Zone-III	G+5	105	109
	G+10	180	183
	G+15	181	181
	G+20	225	270
Zone-IV	G+5	157	197
	G+10	210	225
	G+15	225	225
	G+20	251	290
Zone-V	G+5	210	210
	G+10	246	267

	G+15	259	305
	G+20	301	324

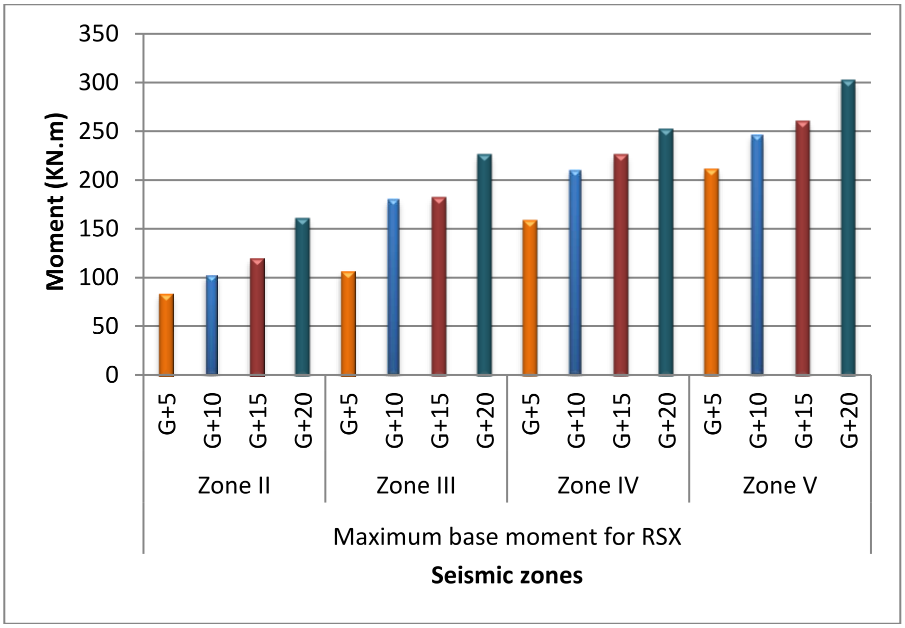

Fig. 10. Comparison of Maximum base moment of different building heights vs. seismic zones along X direction

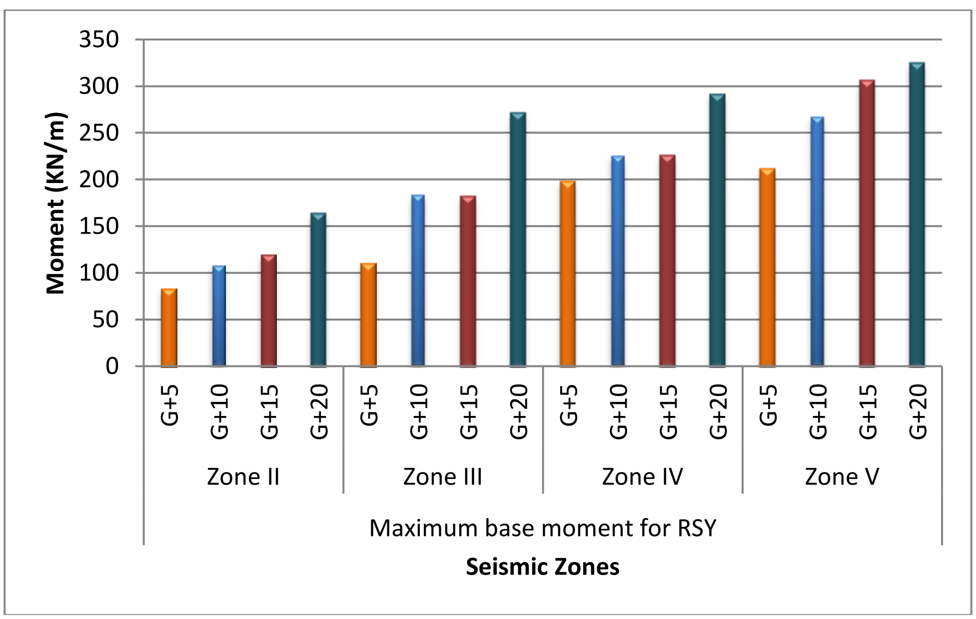

Fig. 11. Comparison of Maximum base moment of different building height vs. seismic zones along Y direction

Periods and Frequencies

Table-9: Time period & Frequencies are obtained from SAP2000

Seismic Zones	Building Height	Time Period (Sec)	Frequency (Cycle/sec)
Zone-II	G+5	1.67	0.59
	G+10	3.3	0.30
	G+15	3.3	0.30
	G+20	6.12	0.16
Zone-III	G+5	1.68	0.60
	G+10	3.3	0.30
	G+15	3.2	0.30

	G+20	6.12	0.16
Zone-IV	G+5	1.67	0.59
	G+10	3.3	0.30
	G+15	3.4	0.30
	G+20	6.12	0.16
Zone-V	G+5	1.69	0.59
	G+10	3.3	0.30
	G+15	3.3	0.30
	G+20	6.13	0.16

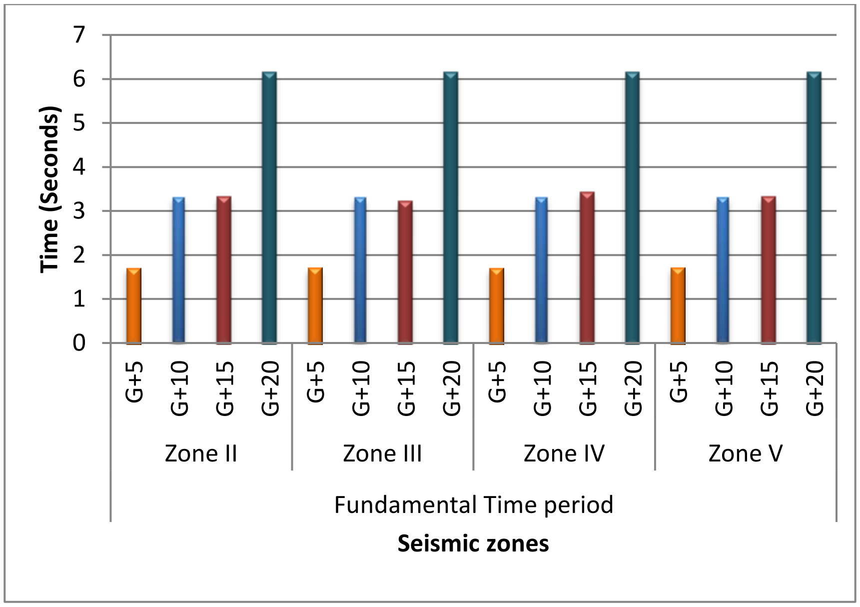

Fig. 12. Comparison of fundamental time period of different building height vs. seismic zones

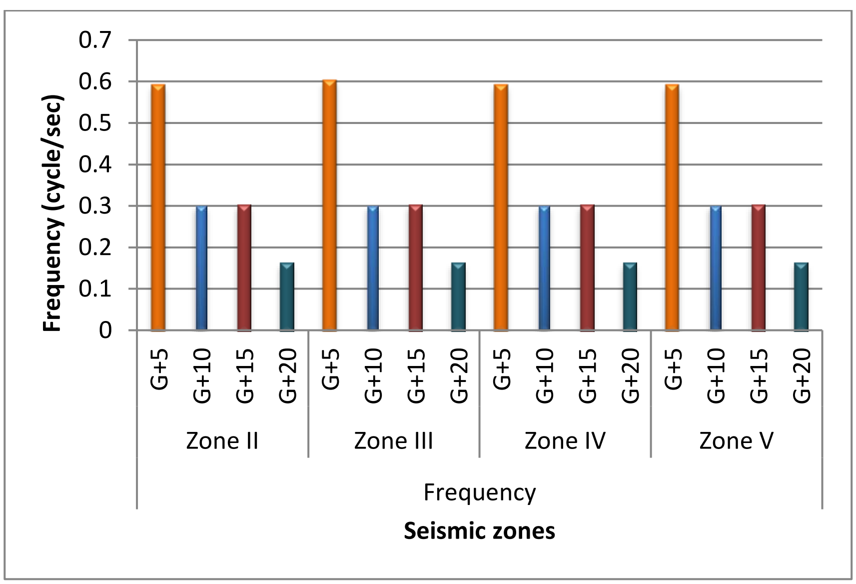

Fig. 13. Comparison of frequencies of different building height vs. seismic zones

7.7. Discussion

The analysis of various building heights, including G+5, G+10, G+15, and G+20 storey buildings, revealed distinct maximum storey displacements. In the X direction, the G+5 storey building exhibited a maximum displacement of 29.5mm, increasing to 51.8mm for the G+10 storey building, 78mm for the G+15 storey building, and 146mm for the G+20 storey building. In the Y direction, the corresponding values were 31.8mm, 69.3mm, 97mm, and 194mm. These results indicate

that, as per the analysis, the maximum storey displacement values increase with the height of the building in response to varying seismic zones.
According to IS:1893, 2016 (part-1), the maximum allowable displacement at the top floor of buildings should not exceed 0.004h, which translates to 88mm for G+5 storey, 148mm for G+10 storey, 208mm for G+15 storey, and 268mm for G+20 storey buildings. However, the case study revealed lower displacement values: 31.8mm for G+5 storey, 69.3mm for G+10 storey, 97mm for G+15 storey, and 194mm for G+20 storey. Therefore, the analysis results indicate that the displacements are within acceptable limits compared to the maximum allowable displacement values.
The maximum base shear values for different building heights also vary with seismic zones. In the X direction, the G+5 storey building experienced a maximum base shear of 728KN, which increased to 777KN for the G+10 storey building, 978KN for the G+15 storey building, and 1015KN for the G+20 storey building. In the Y direction, the corresponding values were 728KN, 780KN, 998KN, and 1021KN. These findings suggest that the maximum base shear increases with the height of the building in response to different seismic zones.
Similarly, the maximum base moment values for different building heights vary in response to seismic zones. In the X direction, the G+5 storey building exhibited a maximum base moment of 210KN.m, which increased to 246KN.m for the G+10 storey building, 259KN.m for the G+15 storey building, and 301KN.m for the G+20 storey building. In the Y direction, the corresponding values were 210KN.m, 267KN.m, 305KN.m, and 324KN.m. The analysis indicates that, as per the results, the maximum base moments increase with the height of the building in different seismic zones.
The study also examined the maximum base shear, base moment, and displacement for a G+20 multi-storey building across global X and Y directions.
The fundamental time period for different building heights was determined. For G+5 storey, it was 1.68 Sec, for G+10 storey, 3.3 Sec, for G+15 storey, 3.4 Sec, and for G+20 storey, 6.12 Sec. notably, these values remained relatively consistent across different seismic zones.
Regarding the frequency of oscillation, the G+5 storey building exhibited a frequency of 0.60 cycle/sec, while the G+10 storey and G+15 storey buildings had a frequency of 0.3 cycle/sec. The G+20 storey building had a slightly lower frequency of 0.16 cycle/sec. These frequencies were comparable across various seismic zones for each building height.

7.8. Conclusion

In conclusion, the findings of this study, conducted using the response spectrum method on multi-story residential buildings of varying heights (G+5, G+10, G+15, and G+20 storeys), yield several significant insights:
1. Seismic analysis is imperative for ensuring the structural integrity of buildings. The investigation showed that, with increasing building height, the maximum storey displacement, base shear, and moment values also increase in response to varying seismic zones.
2. Notably, the largest storey displacement, base shear, and moment values were observed in G+20 storey buildings in seismic zone V, compared to zones II, III, and IV. This suggests that the structure's uniform stiffness can help mitigate displacement, base shear, and moment, enhancing overall performance.
3. The study examined the resonance effect by comparing the approximate time period (Ta) of oscillation, as per IS 1893:2016 (Part-1), with the analysis results. The results indicated that multi-storied residential buildings are safe from resonance effects.
4. Furthermore, it was observed that, for buildings of the same height, the frequency and time period values remained consistent across different seismic zones.
5. The study also revealed an inverse relationship between frequency and time period, with frequency decreasing as building height increases. This insight is crucial for understanding the behaviour of high-rise buildings.
In light of these findings, it is recommended that seismic analysis is essential for buildings above G+10 storeys to ensure their performance against seismic forces. The analysis results have provided valuable comparisons across different structure heights in low to high seismic zones in India. The methodology employed in this study offers opportunities for further research. Future investigations could compare results obtained in soft and rocky soil within different seismic zones or explore soil-structure interactions to enhance our understanding of seismic responses.

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Chapter 8

Recent Advances in Civil Engineering: Smart Cities and Artificial Intelligence

Author:- *Dr. Ashes Banerjee,(**Email:-ashesb@svu.ac.in**) Assistant Professor, Civil Engineering Department, SVU, Kolkata, India Pin-700121*

8.1. Introduction to Smart City Development as an unavoidable future:

A city is deemed "smart" when it can gather and analyse large amounts of data from many businesses, ranging from urban planning to trash collection [1]. A sophisticated network of linked sensors, equipment, and software should be developed and maintained in a smart city (Fig.1). A smart city is a technologically advanced metropolitan region that collects data using various electronic technologies, voice activation methods, and sensors. The information obtained from that data is utilised to effectively manage assets, resources, and services; in turn, that data is used to enhance operations across the city. Smart cities are described as such by their governments' use of technology as well as how they monitor, evaluate, plan, and administer the city.

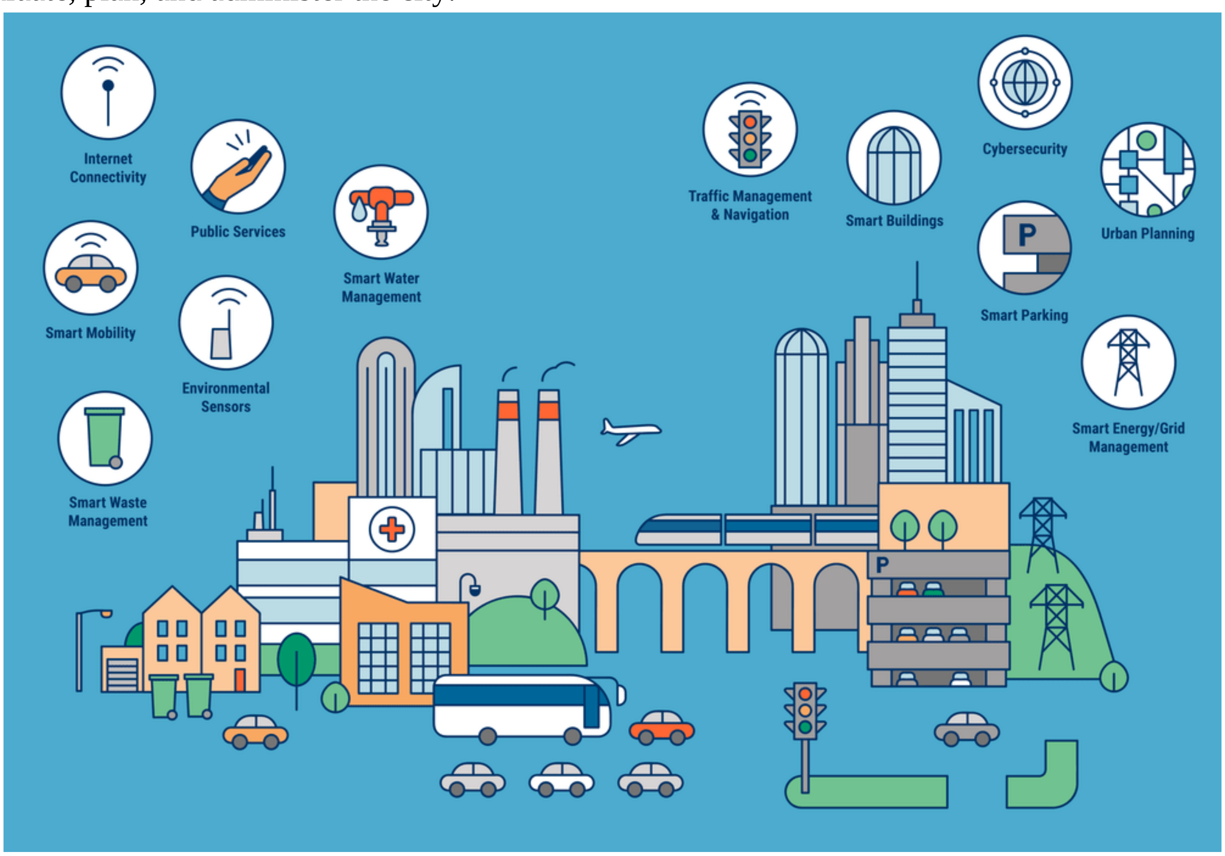


Fig.1 Components of a Smart City [2]

Smart cities are aided by a variety of technologies, including:

a. Information and Communication Technology (ICT)
b. Internet of Things (IoT) network
c. Geographical information systems (GIS)

Each collaborates to gather and interpret vast quantities of data that may be utilized to enhance municipal components and systems. For example, the ICT framework is made up of many equipment and sensors that are all linked to the IoT network and can rapidly communicate data. Sensors, for example, may be used to monitor traffic in a specific region. Cloud-based IoT applications may then receive, analyze, and manage real-time traffic data. This data may also be utilized for city's ever-changing demands throughout time, as well as to optimize for safety. Smart cities may also use GIS for city planning and mapping, as well as for better city development. Consequently, cities can better handle challenges for various usage to inadequate trash management.

Necessity of Smart Cities:

Cities house 54 percent of the world's population, which is predicted to climb to 66 percent by 2050 [2]. This predicted population expansion makes it crucial to ensure the sustainability of the resource. Citizens and local officials may collaborate to create projects and employ smart technology to maintain resources in the increasing urban environment in smart cities. A smart city should offer citizens with a good quality of life while simultaneously producing economic development. This entails providing people with a bundled set of services while reducing infrastructure expenses. This is becoming more crucial in light of projected urban population expansion, which will need more effective use of data and assets. These services and apps will enable these enhancements, resulting in a better condition of life for inhabitants. Smart city enhancements can add value to existing infrastructure by introducing new income sources and operational efficiencies that help governments and residents save money.

Co

Saving energy:

Sustained energy supply is one of the biggest challenges of the present century due to overexploitation of the fossil fuel. The cities are responsible for much of the energy demands. Therefore, cities may deploy a broad variety of IoT technologies to reduce the energy demand.

Impact of climate change [6]

Smart street lighting may save energy by remaining low while no vehicles or people are present and then lighting up when sensors detect someone approaching. Chicago has developed a proposal to convert 270,000 streetlights with LED lighting integrated with sophisticated automation by 2021 [5]. These saves estimated $10 million in energy expenditures each year. According to Navigant Research, 73 million linked streetlights are scheduled to be implemented globally by 2026.

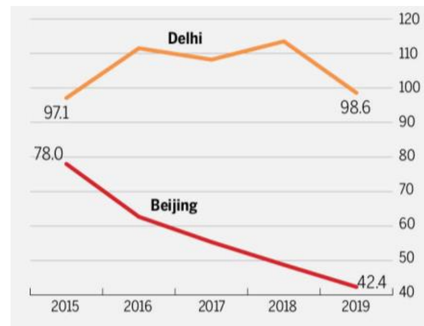
Creating eco-friendly Cities:

Typically, the different systems inside a structure, such as illumination, surveillance cameras, temperature regulation, ventilation, and fire protection, perform their functions independently. Smart buildings, on the other hand, link all of these systems via an IoT network, enabling them to speak with one another and collaborate to make the whole thing as effective as possible via constant modifications. Devices can determine when a room or office is empty and provide less lighting and temperature controlling resources to that region. This reduces the overall energy usage of the building. Comfy, for example, which was bought by Siemens in June 2018, has developed limited occupant-facing controls that may be utilised with current HVAC systems. For building inhabitants to regulate temperature and lighting, the business instals sensors and IoT devices.

Smart streetlights in Bhopal [4]

Climate Change:

Companies are also working to increase energy consumption in homes and offices and optimize the electrical infrastructure. Energy Worx, for example, is being sponsored by ENGIE and is building an electricity data analysis application that consumes and analyses smart metre and IoT data to create insights about consumption habits, allowing utility firms to improve bidding and pricing choices. These measures are critical for lowering a city's carbon footprint since structures contribute up to 70% of overall energy usage inside a metropolis and 30% of worldwide greenhouse gas emissions. Further the use of automated public transport system and smart traffic network can reduce the number of vehicle owners in the city reducing the use of fossil fuel. The use of electric vehicle in the city can further reduce the carbon footprint and help in slowing down the adverse impact of climate change. These cities offer further environmental advantages, such as smaller geographical footprints, but they also have some negative impacts, including the use of fossil fuels to power them. However, smart technologies could help alleviate these negative effects, such as through the implementation of an electric transport system to reduce emissions. Electric vehicles could also help to regulate the frequency of the electric grid while not in use. Such sustainable transport options should also see a reduction in the number of cars in urban areas as autonomous vehicles are expected to reduce the need for car ownership amongst the population. Creating such sustainable solutions could deliver environmental and societal benefits.



Air quality comparison Beijing vs Delhi [10]

Digital & Green concepts in smart city infrastructures- projects in global smart city market:

As the number of cities, factories, and people increases, so do the pressures on the environment. Several digital and green concepts are inherent to a smart city such as:

a. Applications like building automation systems, changing prices for electricity, and some mobility apps could help cut emissions by 10 to 15% [7]. Advanced metering and digital feedback messages can be used to track how much water people use. This can encourage people to save water and cut consumption by 15% in cities where people use a lot of water at home [8].
b. In many parts of the developing world, pipes that leak are the main cause of water waste. When sensors and analytics are used, these losses can be cut by up to 25%. Applications like digital tracking and "pay as you throw" can cut the amount of solid waste per person by 10 to 20%. Overall, cities can save 25 to 80 litres of water per person per day and 30 to 130 kg. of non-recycled solid waste per person per year [8].
c. Air quality sensors don't automatically fix the problems that cause pollution, but they can find the sources and help figure out what to do next. Beijing cut the amount of dangerous air pollution by about 20% in less than a year by keeping a close eye on the sources of pollution and regulating traffic and building work accordingly [9]. Sharing real-time information about the quality of the air with the public through smartphone apps lets people take steps to protect themselves. Depending on the level of pollution, this can reduce bad health effects by 3 to 15%.
d. The city of London is pushing towards the “zero emission goal”. One of the main aspect of this initiative is to encourage the population using cycles or electric vehicles which are completely green.

8.2. Smart cities and job market:

It can be understood from the discussion presented above that the world is gradually shifting towards the smart cities. Since the construction and running of a smart city completely depends on the technology, therefore, the different engineering branches is going to have important role to play in the future. However, arguably Civil Engineering has to take the lead and manage majority of these aspects. A civil engineer can play a major role in smart city projects in.

Smart Building:

The most important concentration of any construction is building. Improvement is being done as per the necessities over the time. The features like lightning, ventilation, heating, air conditioning, and security can be selected separately. The future of building can be predicted in functional integrated and dynamic way. The vision is successfully implemented only when the energy is minimized, boot support to electrical grid and accessing the impacts in the environment. The serviceability of the building is considered on the basis of good sanitation, thermal comfortableness, good quality of air, security system etc. With minimum possible expenditures. Smart buildings use ICT to optimize the performance of total building.

Smart Infrastructure:

Infrastructure is the term used for the underlying physical and organizational structures and facilities that support city systems and keep a city functioning. It includes roads, buildings, electricity grids and communication networks. In many countries the building of infrastructure is a centralized, governmental activity that aims to solve one issue at a time, such as a network for water supply. Future infrastructure designs will gain the additional remit of anticipating long term, global phenomena. City infrastructures will need to withstand pressures such as extra stress on the electricity grid resulting from more homes having solar panels and increasing incidents of extreme weather resulting from climate change such as tornadoes and storm surges.

Smart Transportation:

It advocates more efficient transportation systems and promotes new social attitudes towards vehicle usage, ensuring that citizens have access to local and public transportation, and that ICT again is integrated to increase efficiency. Smart cities seek to increase how efficiently people, goods, and vehicles are transported in an urban environment.

The activities of specific branches of civil Engineering can be illustrated as follows:

a. **Structural Engineering:** A smart city asked for optimization in terms of space. This calls in for optimum structures consuming lesser space and accommodating more people. Also, smart cities ask for increasing accessibility to the disabled, elderly, etc.
b. **Transportation Engineering Expert:** Cities are vulnerable to overcrowding and hence efficient traffic management as well as construction of good and long-lasting roads is necessary.
c. **Water Resources Engineering:** As they say - 'The next world war will happen over access of water', water management becomes a top priority task. Also governments are planning for interlinking of rivers to reduce flooding and promote cost effective water supplies to drought affected localities. All these call for expert hydrologists and water resources experts.
d. **Geotechnical Engineers:** Some concepts of smart cities call in for earthquake resistant structures and metro railways. Geotechnical Engineers would be the first ones to be called in for such projects.
e. **Environmental Engineers:** Smart cities need to incorporate sustainability along with development. Each and every project will demand environmental impact assessment and clearance.

f. **Building Technology and Construction Management:** They would work shoulder to shoulder with structural engineers and would also be responsible for planning of the city.

London: Capital of England [11]

8.3. Study of a smart city:

There are several smart cities around the globe such as London, Barcelona, Sydney, Las Vegas, Seoul etc. All these cities are great example for understanding the functionalities of a smart city. However, in this chapter we will focus on the city of London. London is the biggest city in England and its capital. South-east England is made up of 607 square miles and is near the River Thames. The core city of London, also called the "Square Mile," is the center of London's history. In the 20th and 21st centuries, it set fashion trends all over the world.

8.3.1. Efficient Data collection and management System:

London datastore [12]

London became a global pioneer in 2010 when the London Data Store was launched and made the city-data free. Data handling is as crucial to London as roads, railways, and electricity systems. Mission 2 of Smarter London Together aims to "strike a new bargain for city data" to foster data partnerships and enhance data sharing for Londoners. It pledged a city-wide cyber security strategy to assist public services, companies, and residents cope with online dangers. Since 2018, it's been working on programmes and activities to attain these aims. The City Data Analytics initiative provides additional tools to speed up data exchange and collaboration on projects and exercises using external and internal data. Currently there are around 6000 available dataset which are used for infrastructure management, town planning, transport planning, environmental and ecological monitoring etc. The efficiency of the data collection and management system was evident during the Covid-19 pandemic. The Greater London Authority (GLA) developed an API which ensured the consistency of the data. It also developed an integrated interactive platform for the caseload and hospitalization and discharge.

8.3.2. Environment & energy:

Ultra-low emission zones [13]

In 2020, new data from City Hall showed that London's air quality had gotten better since 2016. The authority claimed the success was achieved through initiatives such as Ultra low emission zones (ULEZ). These are the zones where the polluting vehicles has to pay a fee for driving. It showed that the number of Londoners living in areas with high NO2 levels dropped by 94% and that the number of public elementary and high schools in those areas dropped by 97%. The authority is considering creating several new ULEZ, which are expected to reduce the carbon emission to significant level. The city is on its way to enhance the efficiency of public transport system and increase the use of electric vehicles to achieve the goals such as “zero emission streets”, zero carbon city by 2030.

The network of air quality sensors in London is another important part of the clean air strategy. In addition to that there is an efficient data collection and management system that provides rea-time information to the residents of the city about the quality of the air.

8.3.3. Transportation:

The city of London has committed themselves to develop an emission free efficient transport system. This is believed to reduce the waiting time also help to reduce the air pollutio n. The authority is working towards converting 80% of the trips by walks or cycle by 2041. The residents are provided 781 docking stations and around 14,000 bikes, which can be used around the city for transportation purposes.

Launch of UK India Startup Corridor [16]

Hire a Santander Cycle to ride around London [14]

Further the city is investing heavily to enhance the efficiency of public transport network such as rail, tube and bus with a vision of converting the transport system "zero emission" by 2050. In the future, London may have self-driving electric cars, water taxis, and even air taxis. But in the short term, to get the right mix, London will have to make sure that public transportation and greener ways to get around are appealing enough that people feel safe enough to leave their cars at home.

8.3.4. Town Planning:

The city of London is often known by the high-rise buildings. However, the does not only focus on the skyline of the city. The municipal development authority of the city is also planning to construct buildings that are sustainable and use less energy. The plan's main goals are to make sure that new homes are a good size and have better fire safety, to improve air quality by making sure that Londoners have access to open and green spaces, to build up local community infrastructure like schools and hospitals, and to help high streets and town centres across the capital thrive by helping them change and include a mix of retail, leisure, and workspaces. The plan asks for developing green infrastructure plans that look for ways to work together with other sectors. If a green infrastructure plan is to work, it needs to be planned, designed, and managed. This includes green and blue spaces, street trees, green roofs, and natural or semi-natural drainage features. The city's urban forest is made up of about 8.4 million trees and takes up about 21% of the city's land area. By 2050, the mayor plans this number to be 10% higher than it is now. In London's green belt, 83 hectares are being turned into two new wooded areas that will be open to the public. At the same time, the Woodland Trust has bought more land to make Hainault Forest bigger. London has been known for its parks for a long time, and in 2019 it became the first National Park City in the world. London's population is expected to grow by 70,000 every year and reach 10.8 million people in 2041. The London Plan aims to meet a long-term goal of making 50% of new homes affordable.

London urban forest plan [15]

8.3.5. Skill development and Employment ecosystem:

London's efforts to become a smart city have benefited for a long time from being able to draw on a large tech and skills ecosystem that includes universities, research institutions, living labs, testbeds, and both private and public sector organizations.

People say that the 2008 financial crash gave birth to a thriving start-up community. This community grew out of the area of London called Silicon Roundabout, which is also known as The Old Street Roundabout. Tech Nation, a network for entrepreneurs that is backed by the government, says that this original cluster has grown into a grid of more than 35,000 businesses all over the country. Figures from the UK government show that London is still the leader in technology around the world. Between January and June 2020, London-based tech companies had already raised £3.2 billion, which is more than Paris, Stockholm, Berlin, and Tel Aviv put together, though most deals would have been done before the Covid-19 health crisis. It also shows that London is ahead of the rest of Europe in the race for Fintech unicorns. Fintech is the most popular way to raise money in the capital, making up almost 40% of it.

Along with new businesses, more than a third of the biggest tech companies in Europe are based in London. All of this makes for a strong digital and tech ecosystem, but it needs the right skills and talent to work.

8.3.6. Population statistics and Demographics:

London is Britain's most populous city. Its population is currently under 9 million but is expected to reach 10.8 million in 2041, an annual growth of 70,000. Its median age is 35.6 compared to 40 in the rest of the UK. More than half of the inner city's population is in their 20s and 40s, according to Trust for London. People go to London early in their professions but leave to e stablish families or as they age. Only 9.5% of London's population is over 65, but 13.9% in central London. 37% of the people who live in London were born somewhere else. This has made London one of the most racially and culturally diverse cities in the world. Nearly 80% of the people in the city speak English, but more than 300 other languages are also spoken, such as Polish (1.5%) and Bengali (1.3 per cent). Nearly 45 percent of the people who live in London are white-British, and 14.9% are white from other countries. 18.5 percent of the people who live in London are Asian, 13.3 percent are black, and 5% are a mix of the two.

The country has the most billionaires in the world, but income and wealth are not all the same. The Poverty Profile from Trust for London shows that after housing costs, 28% of Londoners are poor. There are 56,000 families in temporary housing in London, which is 30% more than there were five years ago. More than three-quarters of poor kids come from working families, which is 8% more than it was five years ago. London has committed to rebuild better and more justly, and the mayor has a nine-mission recovery plan. Digital access for everyone, a safety net to help prevent or escape poverty, and better communities are among its goals.

Ethnic diversity of London [17]

8.4. Artificial intelligence:

Artificial intelligence is the ability of machines, especially computer systems, to mimic human intellectual capabilities [18].

Examples of specialized AI applications include expert systems, natural language processing, voice recognition, and machine vision (Fig.2).

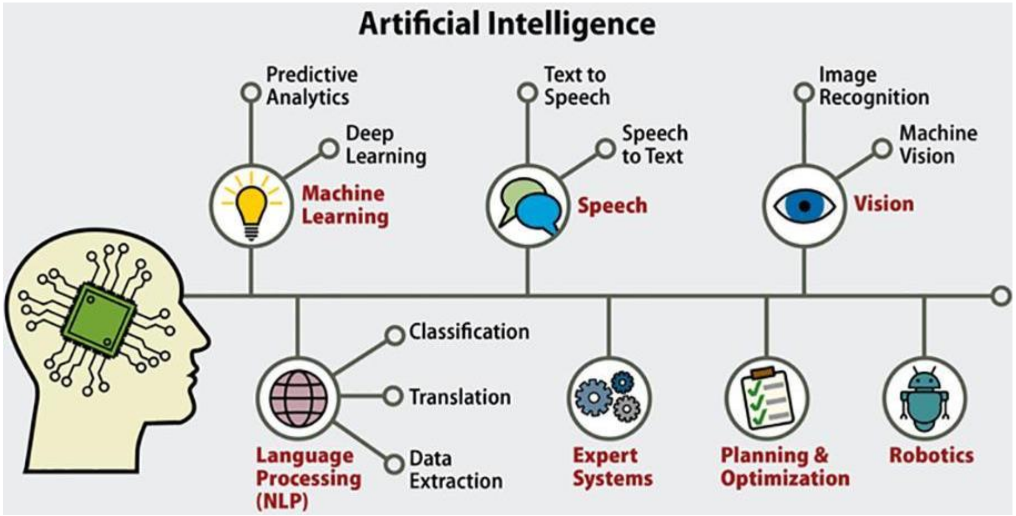


Fig.2 Components of Artificial intelligence [19]

A single AI component, such as machine learning, is often used to represent AI. AI requires a foundation of specialized hardware and software for the development and training of machine learning algorithms. Although there isn't a single programming language that is solely related to AI, a few are, including Matlab, Python, R, Java, and others.

AI systems usually consume a large amount of labelled training data, evaluate it, look for correlations or trends, and then use these patterns to predict future states. Just as a chatbot that is shown examples of text conversations may learn to generate realistic dialogues with humans, an image recognition system would learn how to detect and characterize items in images by examining millions of cases.

8.5. Machine Learning:

Machine learning can be broadly defined as making machines (computers) mimic human behavior. It can be considered as a subset of Artificial Intelligence (Fig.3). This would essentially mean that the computers will learn from a real-life dataset. These models are then expected to adopt and predict for additional or new dataset. Some tasks where we seek to machines to learn include

- Classification Tasks: Divide and group objects
- Regression (prediction) tasks: Predict the response of a variable using other variables or forecast values into future times.
- Create Association Rules: Use logical statements and programme using IF-THEN rules

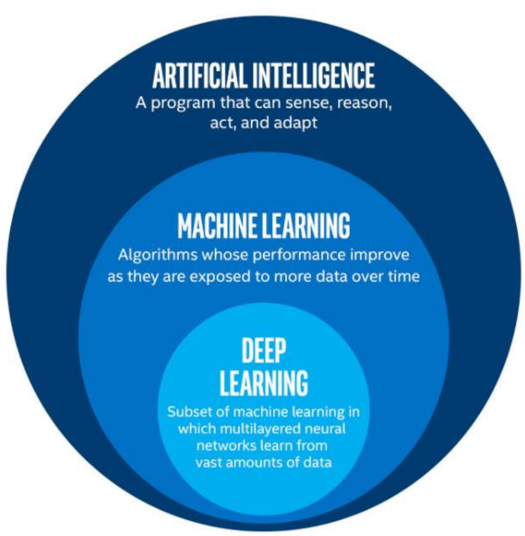


Fig.3: Relation between Artificial Intelligence and Machine Learning [20]

The application of machine learning in various fields of research has skyrocketed in last few decades as presented in Fig. 4. As it can be seen there is a growing trend since 2014. The previous growth till 1990's can be best characterized by theoretical development in the field. The recent interest can be credited to the following factors:

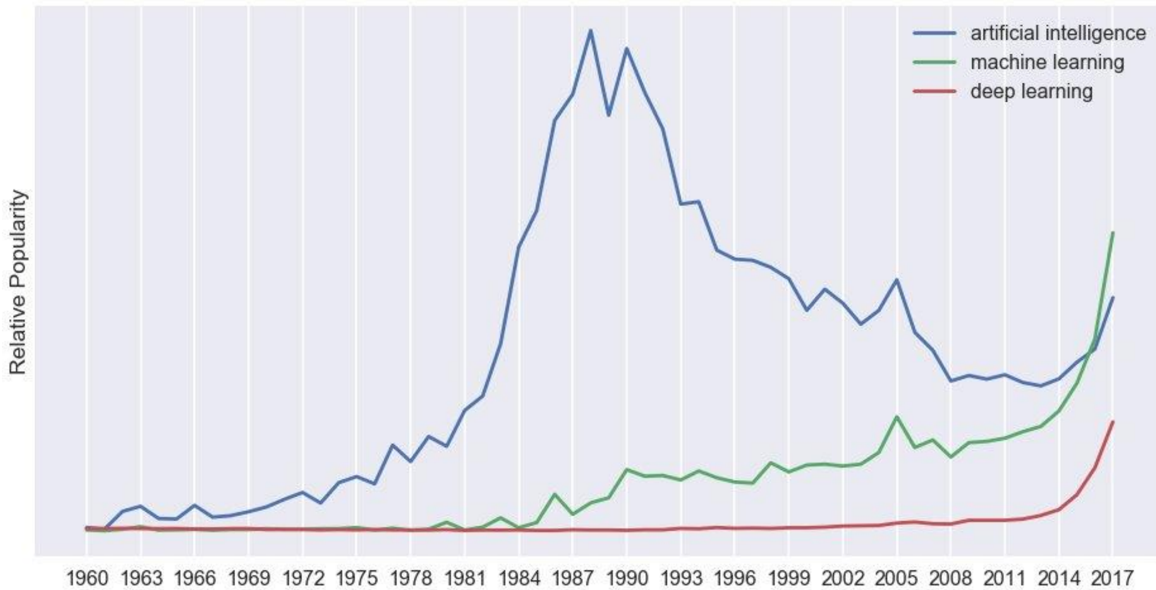


Fig 4(a) Relative popularity of AI, ML, and deep learning 1960 to 2017 [21]

Fig 4(b) development of Windows operating system over the years [39]

• Large volumes of data are becoming accessible worldwide
• Computational sources have become cheap
• Computation can be carried out in parallel
• It is easier to implement machine learning algorithms
• Software availability

Machine learning can map highly nonlinear phenomena

• Therefore, it can capture the dynamics associated with natural systems
• Very useful in water resources and environmental fields

8.5.1. Role of Artificial Intelligence and Machine Learning:

I definitely fall into the camp of thinking of AI as augmenting human capability and capacity."

– Satya Nadella, CEO of Microsoft

Any intelligent work may benefit from using current AI-based technology, and their list of uses is constantly expanding (Fig. 5). Let's quickly review a few of them.

Fig.5 Application of Artificial Intelligence in different fields [22]

Healthcare:

Artificial intelligence has shown to be a life-saving assistance in healthcare. For instance, the AI system in a wristwatch monitors vital activities to identify cardiac issues and even informs emergency personnel. Furthermore, AI has aided in increasing the speed and precision of medication development.

Financial Services:

For the last three decades, artificial intelligence has helped financial services. AI can help with accounting, stock forecasting, and even fraud detection in the banking industry. Large corporations utilise AI to handle and audit transactions while adhering to tight compliance standards.

Retail Sector:

By controlling inventories, AI algorithms in the retail industry can address supply-chain issues. AI can assist estimate demand and improve customer experience in addition to forecasting future global trends in the garment industry via real-time data analysis.

Automobile Industry:

The vehicle sector is a good illustration of how AI may be used. The current research topic is autonomous or self-driving cars, in which every automaker is spending extensively. Several automakers have already included AI functions like as voice control, lane switching, collision detection, and enhanced driver safety.

Engineering:

One of the biggest applications of AI lies in the engineering sector. Various branches of engineering including the "core branches" such as Civil, Mechanical and Electrical engineering are increasingly utilizing machine learning for solving their problems.

Disaster mitigation:

In recent few decades, attempts are being made by the researchers to use the information technology clubbed with artificial intelligence for the prediction of natural hazards and explore the possible mitigation techniques.

8.5.2. Advantages and Dis-advantages:

Advantages:

- Effective at activities requiring attention to detail.
- Shorter processing times for data-intensive tasks
- Reliable outcomes.

Dis-Advantages:

- Costly; demands a high level of technical knowledge;
- Limited availability of skilled workers to create AI tools;
- Only is aware of what has been shown
- Inability to translate generalisations from one activity to another.

Artificial intelligence (AI) technologies like deep learning and artificial neural networks are rapidly developing, mostly because AI can process enormous volumes of data far more quickly and correctly than a human can.

While the enormous amount of data generated every day would drown an investigator, AI technologies that are using machine learning can swiftly transform that data into useful knowledge. The cost of processing the vast quantities of data is now the main drawback of employing AI.

8.5.3. Supervise, Unsupervised and Semi-supervised learning:

Machine Learning models can be categorized in several ways. Broadly they can be classified as

Unsupervised Learning

The goal of unsupervised learning is primarily to cluster the data into a set of groups or seek associations within the data. Clustering is often carried out on a multivariate d ataset. The number of groups (clusters) need to be known a-priori. In most techniques this is specified. One of the most widely clustering technique is known as K-means clustering.

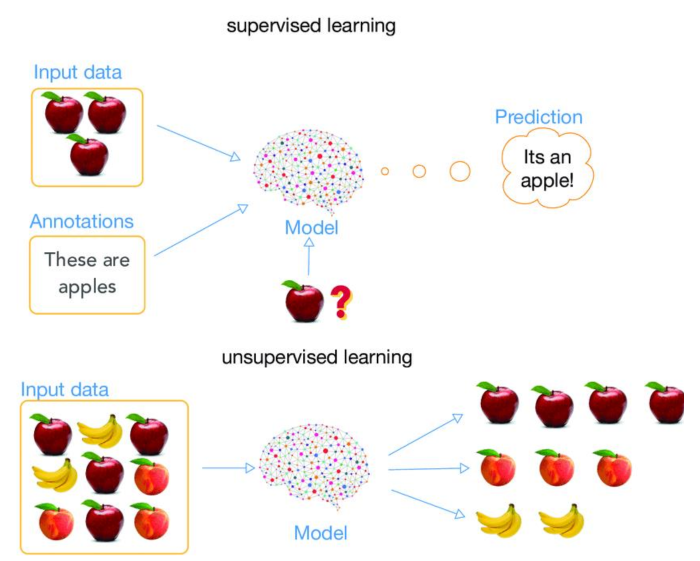
Creation of association rules is another unsupervised learning method. The goal is for the algorithm to seek to map the relationship between Y (output) and X (input)

Supervised Learning:

The supervised learning essentially indicates learning from a training dataset. Therefore, in supervised learning approach, the user has to show examples to the algorithm to facilitate the learning process. Supervised learning is commonly used for 2 classes of problems:

• **Classification:** Used for dataset with discrete variables

• **Regression:** Used for dataset with continuous variables. In regression, supervised learning is used when the data are labeled (i.e., have an output)



Supervised and unsupervised learning [23]

Semi-Supervised learning:

Useful when some data are labeled but a large amount of data is not labeled. These models can be useful in conditions when it is easy to collect inputs but hard to collect outputs. In semi supervised models we can use unsupervised learning to cluster input data (step 1) and then Make predictions for each cluster (step 2). Then we can use the inputs and outputs from step 1 and 2 to create a supervised learning model

These models can also be classified as "black-box" or White (Grey)-box models

• **Blackbox models:** The learning/mechanisms by which the ML learns and processes data is unknown

• **While(grey) box models:** The learning is more transparent

8.5.4. Dataset:

The machine learning models are essentially data driven models. Therefore, they use data for training itself and gathering valuable information. The dataset used for the training can be of various types such as

- Discrete data such as Binary and multiple classifications dataset.

Or

- Ordered data such as Count data or Continuous data.

The ML models can also work with unstructured datasets for example: Text Mining has some profound applications in environmental and water fields through looking at news media, social media to gage public perceptions

8.5.5. Guidelines- Inputs Output and Technique:

The output is a function of the objectives of the study. For example, if we are interested to predict flood characteristics? Peak flow, flood duration, total flood volume can be used as output based on the availability of the data.

A candidate set of inputs can be ascertained based on the following:

1. Based on the theoretical understanding of the subject.
2. The parameters for which data is available.
3. In case data for some of these parameters are not available, good surrogates for some parameters can also be used.
4. The parameters used in the model should be independent, as much as possible.
5. In case there are too many variables, we can use a data reduction technique such as Principal Component Analysis (PCA).

Machine Learning model [24]

8.5.6. Model Training and Hyperparameter Tuning:

Three cognitive abilities—learning, reasoning, and self-correction—are the main concerns in AI programming.

Learning: The goal of this branch of AI programming is to acquire data and create the rules required to convert it into knowledge that can be used to decision-making. The steps, usually referred to as algorithms, provide computer hardware specific instructions on how to carry out a certain action.

Reasoning: This area of AI programming is concerned with selecting the best algorithm to achieve a particular result.

Self-correction: This feature helps to continuously improve algorithms and make sure they deliver the most precise results. The self-correction is done through a process called hyperparameter tuning. Hyperparameters can be described as the coefficients of the specific model, whose values are determined by the algorithm through the following steps:

1. Backward selection: Start with a full model and remove variables as necessary
2. Forward selection: Start with an empty model and add parameters as necessary

The accuracy of the model can be evaluated based on the performance accuracy or the model and complexity of the model. Akaike Information Criterion (AIC) is one such metric that is widely used to evaluate different models. Model with lowest AIC or AICc is generally considered the best model.

8.5.7. Challenges & Limitations:

Though the machine learning algorithms are being widely used by people from every field of study, they do have some severe limitations. It is important to understand these limitations before using them to solve any problem.

a. The relationship between the input and output is not fully known or understood. Therefore, the justifying the input selection to use in the model is quite unclear.
b. Since the architecture of most of the models and functional relationship between a given input and output are not properly understood, the selection of algorithm/technique is difficult.
c. The selection of functions used during the training is quite unclear. These are essentially parameter estimation or optimization models. There are many choices, therefore assessment of the quality of the model is difficult because in many cases the model has not seen the test Data.
d. Finally, since it is a data driven approach, therefore data is the main driving factor behind the accuracy of these models. However, it is difficult to operate when there is not enough data to build and independently test the model.

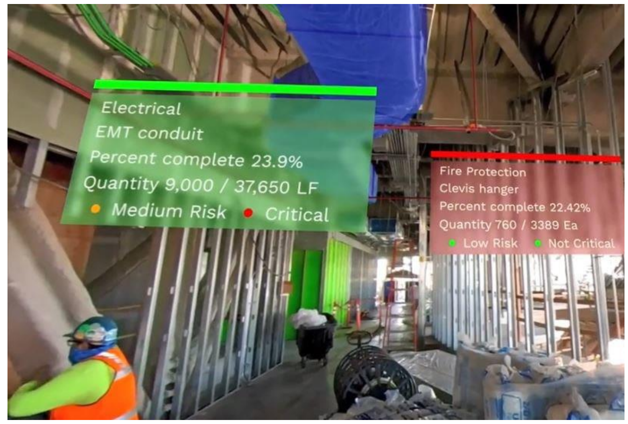
The following guidelines may be used for addressing these issues:

- The user should never choose a single algorithm (say ANN). Instead always try to use more than one algorithm for addressing one problem.
- The user should always make an attempt to justify the selection of a specific algorithm. The user may use the performance in the previous studies in the same area for different conditions or previous studies outside the same area but with similar situations.
- Always include current state of the practice (e.g., linear regression, logistic regression) as part of the comparison. If a ML model does as good or worse then a simple regression than there is no need to do ML.
- The user should compare and contrast what a particular technique provides in terms of superior forecasts and understanding of the physics. In case, only prediction is sufficient, the user can proceed with a black box model. However, these models are not suitable for acquiring insights on inner workings and mechanisms underlying the data.

8.5.8. Uses of Machine Learning in Civil Engineering

Deep learning technologies have been used successfully in a number of sectors for several decades, particularly in civil engineering. Indeed, with the rise of complex structures including high rises, machine learning algorithms took center stage in the industry a long time ago. We are witnessing more AI application and development in the construction industry than ever before, including the use of machine learning algorithms, big data, that have impacted productivity performance. AI has been employed by practicing engineers and contractors to solve a variety of problems. Artificial intelligence in civil engineering, has evolved to the point where efficiencies are incorporated directly into building processes. AI is also employed in the early phases of many projects to enhance design, risk management, and efficiency.

Construction and Structural Engineering:



Doxl-AI based construction progress monitoring [26]

It is crucial to note that companies who have already started to use AI in building operations are 50% more lucrative. More significantly, AI has also a broad variety of civil engineering applications. Professionals can make better judgments and provide better services in an era where machines can analyze rather than merely do.

AI for Improved Building Designs:

We can all agree that the bounds of engineering and manufacturing have been pushed to the maximum by the iconic skyscrapers of various shapes and sizes that dot architectural landscapes of metropolitan areas throughout the globe.

Before beginning construction, civil engineers may more easily generate and design more accurate 3D models using Artificial intelligence systems such as Building Information Modelling (BIM). The use of AI-based design exploration has allowed engineers to better designs using data from simulations, models, and past projects. By introducing artificial intelligence in the process, civil engineers may create blueprints for buildings, floor plans, and more. They may also implement the required adjustments globally.

Risk Mitigation [27]


Building Information Modelling [25]

Efficient Cost and Time management:

Although it is incredibly difficult to finish a project precisely within the anticipated cost, using AI in construction helps an engineer to have a clear picture of cost estimates and results from previous projects, enabling them to build superior planning and budgeting. Using learning algorithms that employ features from completed projects, civil engineers may anticipate cost overruns and visualize realistic timelines for ongoing projects.

Doxel, an AI-based startup, uses deep learning algorithms and drones on the site to recognize products, evaluate construction quality, and measure materials used, to mention a few examples. The collected data is used to provide quick guidance and feedback to all customers on actual costs and time spent vs the desired budget and timetable.

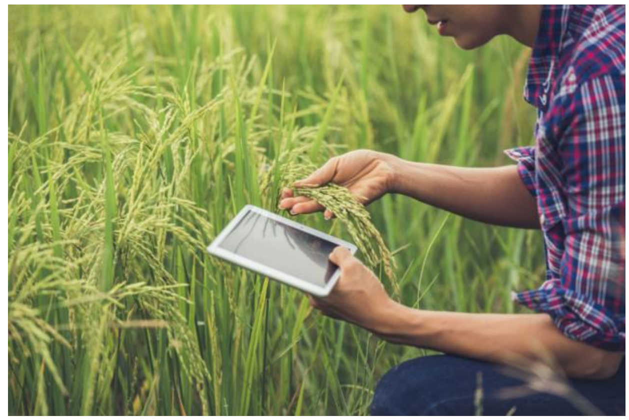
Risk Mitigation:

A variety of possible safety dangers exist throughout the building process, some of which may result in real accidents. AI enables more accurate data collecting from real-world context models, which may assist civil engineers in recognising potential dangers throughout the building process.

AI algorithms can evaluate construction site data to provide relevant insights. This finally permits the design and use of suitable building technology, which assists an engineer in adopting beneficial risk management methods.Indus.ai is a fantastic illustration of how such technology might be used. This San Francisco-based tech firm installed AI-assisted cameras around construction sites to deliver real-time imagery while gathering and analysing data to provide construction managers with information on things like material movement and worker deployment in different sections of the site. This interface also enables civil engineers to identify potential hazards and make more informed judgments about worker safety.

Facility Management

Based on pre-existing blueprint and design information from past projects, AI based models can advise engineers on the optimum techniques of on-site building. AI can also be utilised in administrative roles, such as helping staff to book vacations and sick days, tracking building material deliveries, and identifying delays.



Can AI solve water wastage? [28]

Because of the large amount of data collected, AI can be used to automatically spot understaffed construction regions that may require additional people. Thereby, it can be used to switch staff and machineries between sites.

Application of Machine Learning in Water Resources:

Artificial intelligence is upending businesses with its many capabilities, which include enhancing human intellect and processing massive amounts of data. There have been conversations and publications on how to create sustainable AI that works effectively while also saving the environment. AI has also shown promise in the water resources and management sector. Water is an essential need for survival, yet it has long been polluted and scarce. Climate change is a fact that may exacerbate water stress in many areas, and rising water pollution will result in a massive water catastrophe that we are not yet prepared to cope with. According to a UNICEF and WHO study, one in every three people worldwide has not had access to clean drinking water. If we do not tackle the issues, it will worse in the following years.

AI in water management may seem to be a great surprise, but it has the potential to revolutionize the way we handle and manage the freshwater resources around us.

The reasons for enhanced popularity of AI and ML in water resources can be as follows:

- Collection of data is easier than fully describing the theory
- Highly nonlinear processes so ML models offer advantages
- Machine learning in environmental fields is still not as highly prevalent
- Collection of data is difficult at the field scale
- Phenomenon poorly understood
- Considerable amounts of data are still not in the public domain
- Secondary use of data is difficult.

Let's explore how AI affects the worldwide water sector. Machine learning is seeing extensive use in water resources and hydrology.

Managing Water Wastage:

According to an India Today article, around half of water transported through pipe piped water in India is wasted due to leakage. There are large scale wastage We waste a lot of water due to leaks, broken pipes, and other causes, and AI and IoT may help decrease this loss. Implementing artificial intelligence for monitoring such loss and to cut off anytime there is a leak may help reduce water waste. AI can anticipate leakage in storage tanks and assist in their repair proactively. IoT-connected devices may interact more effectively and integrate diverse systems throughout a city or location.

Digital Water:

With data analytics, regression models, and algorithms, AI can make water management simpler. These innovative technologies aid in the development of effective water network systems. AI may be used to construct water plants and determine the state of water supplies. Hydrologists and governmental organizations may utilise artificial intelligence to develop a highly effective water system that can design optimal structures for water management and adapt to changing circumstances. These technologies will be cost-effective and long-lasting, allowing all water management solutions to be optimised and possible problems predicted.

Smart Irrigation:

Agriculture is the most water-intensive industry, and many regions rely heavily on groundwater for irrigation. Smart Irrigation will employ AI algorithms to reduce water use while also optimising water resources to avoid waste. AI systems can monitor groundwater levels and predict agricultural demands in order to balance water use by directing sprinkler systems.


‘KisanRaja’ Smart Irrigation Device [29]

More advanced accuracy AI systems can anticipate weather, climate, and humidity, enabling for enhanced agricultural management. Using AI sensors, intelligent farms can eliminate leaks and analyse the soil to identify the state of crops and their water demands.

Disaster mitigation and risk assessment:

In recent years, development of early warning systems has become increasingly important for geohazards risk mitigation (Fig.6). In this view, identifying the relationship between triggering/causative factors and geohazard incidences is the main interest. The need for early warning system has sparked the development of mathematical models capable of relating geohazard occurrences with triggering factors. The models aim to identify triggering conditions from the data collection and analysis which are updated regularly to incorporate the dynamic nature of the geohazards. In the literature, the most common approaches for such forecasting are empirical in nature or physics based. The physics-based approaches can be applied only over small regions as site-specific conditions have to be incorporated. While at large regional scale, the most viable methodology is the use of models based on empirical or statistical methods as it becomes practically impossible to use physics-based models for large areas. The models generate empirical correlations between the primary cause and the effect.

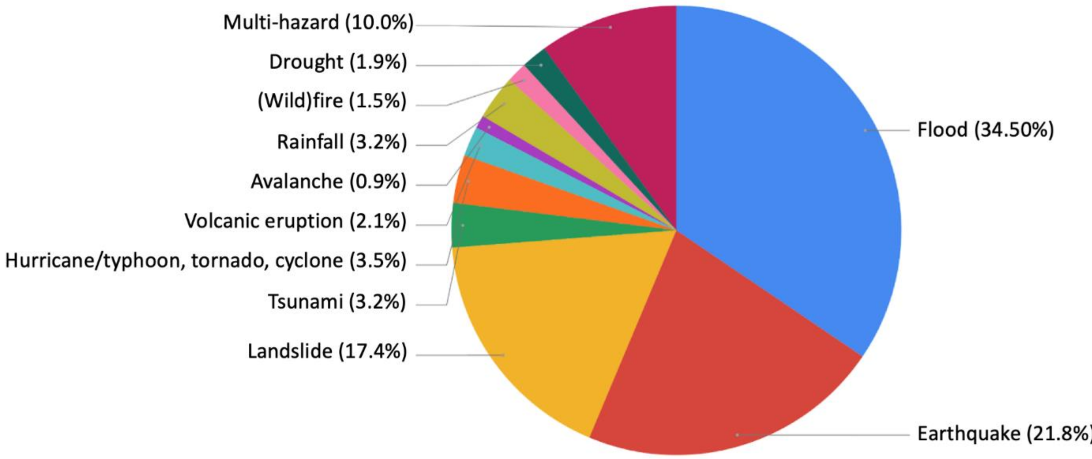


Fig. 6: Application of AI to the detection and forecasting of natural hazards and disasters [30]

Landslide Detection:

The deep learning models have been used recently for classification of satellite imageries and for object detection applications. Deep learning techniques has been used for landslide detection in the Nepal Himalayas. It is also used for detection of landslides in Shenzhen, China with a landslide detection accuracy of 67%. Deep learning models have been recently used for mass movement detection and their application is limited to identification of geohazard susceptible regions.

Landslides detection [31]

Cyclone and Flood Susceptibility Modelling:

For urban and coastal flooding, action may include clearing trash screens in urban areas, calling in additional staff to respond to incidents, activating community response mechanis ms, and installing property-level protection.

As flooding occurs, the reactive actions such as rescuing people and vehicles from inundated areas or activating pumps dominate. Different decision-makers have different requirements from a flood forecasting system. The actions they take may require different lead times to activate, and they may be willing to act at different levels of probability based on their acceptance of “acting in vain”. There are two essential current advances in the field which needs to be discussed. First, is the development of an impact-based forecasting which has allowed to concentrate on regions with the maximum probable effects. This permits proficient resource management in spite of significant uncertainties associated with spatial distribution of rainfall. Second, there has been a rising recognition of the necessity for probabilistic predictions for flood forecasting. Researches have attempted to recognize the precise requirements of the decision-makers at the local level for flood forecasting in the United Kingdom. Some efforts have also been made to develop a probabilistic flood forecasting system using Quantitative Precipitation Forecast coupled with location uncertainty.

Assam flood [32]

Further, the forecasting systems were also extended for the assessment of flood impact on socio-economic conditions. The machine learning approaches have now been increasingly employed for the prediction of flash floods. However, these approaches are mostly data driven and therefore require a wide range of data for successful training and prediction. The scarcity of continuing streamflow data can create some severe obstructions for the use of data-driven approaches.

Self driving vehicles [34]

Earthquake Prediction:

Methods based on artificial intelligence for earthquake prediction can be divided into non-supervised and supervised learning frameworks. In non-supervised learning framework, some methods based on clustering techniques or association rules have been applied to predict earthquake magnitudes in areas with high seismic activity in Chile, Portugal, and Spain. A neuro-fuzzy inference system was used to predicate earthquakes in Iran.

Bhuj earthquake- Gujrat, India, 2001 [33]

The supervised learning framework, namely regression or classification techniques, has been preferred by the majority of researchers to forecast earthquakes in recent years. Researchers proposed a probabilistic neural network to predict earthquakes in a specific zone, using eight kinds of earthquake indicators to train the model, and obtained good results for earthquakes with magnitudes ranging from 4.0 to 6.0 on Richter scale.

Subsequently, they used RNN to predict the time and location of earthquakes with magnitudes equal to or greater than 6.0. Besides this, a multilayer perception neural network has been used to predict earthquakes. An ANN based on earthquake predictors has been proposed to the prediction of earthquakes of medium-large magnitude for the city of Tokyo.

Transportation Engineering:

Over the previous few hundred years, the transportation sector has been through several transformations and revolutions, and we are now at a point when important advancements are being made using AI and ML.

AI is capturing the attention of transportation executives all around the globe, whether via self-driving vehicles for increased dependability, highway situation monitoring for increased protection, or congestion analysis for increased efficiency.

AI and ML in transport may also aid in the development of "smart cities," such as Glasgow, where the system analyses vehicle stay durations, parking infractions, and traffic density patterns.

Self-driving Vehicles:

The notion of self-driving cars is not novel. It was first presented by General Motors in 1939. However, it is only now, in the era of AI transportation, that corporations can combine computer vision methods such as object detection to construct intelligent systems, allowing a car to drive itself. While a self-driving vehicle may seem difficult, the theory underlying its AI is really rather simple: the algorithm is given massive amounts of relevant data before being taught to recognize certain objects and then conduct the appropriate measures. Tesla, along with Uber Waymo, and Motional, has been developing driverless cars for many years, always keeping ahead of the competition.

Traffic Detection (and Traffic Signs):

An AI-based system may be used to recognize lights (green, amber, and red) using computer vision models trained in a variety of settings such as low light, bad weather, and occlusions.
As a result, a self-driving vehicle’s camera initially detect a traffic signal before analyzing and processing the image—and, if the signal is red, the car applies the brakes. Researchers developed a new method for light identification that combines image categorization using feature recognition to identify the colour types of using Remote sensing and map information and cameras to recognize traffic lights at varied ranges.

Pedestrian Detection:

Because pedestrians may be very unexpected in the setting of road traffic, detecting them is a critical topic in Computer Vision and Image Processing. They're so unexpected that they're one of the most serious challenges to self-driving vehicle success. Various kinds of features, such as motion sensors, surface attributes, pattern aspects, have been employed to identify pedestrians. Some techniques have also included a methodology that captures data on a subject's current behaviour. This is intended to send data to the autonomous car about what the pedestrian expects to do next.

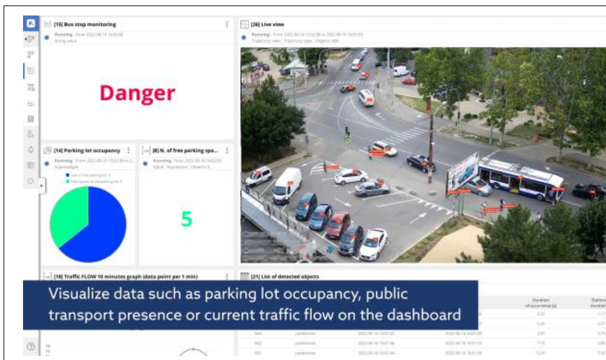
Computer Vision-Powered Parking Management [36]

Traffic Flow Analysis:

Traffic has an influence on a country's economy, both positively and negatively, and it also has an impact on road safety. Congestion in traffic wastes m oney and time, generates stress for people contribute to climate change.
Traffic has an influence on a country's economy, both positively and negatively, and it also has an impact on road safety. Congestion in traffic wastes money and time, generates stress for people contribute to climate change. A country's economy may expand more quickly with increased traffic flow, and road users' safety improves immensely. With this in mind, it's no wonder that AI is already leading the way for improved traffic flow monitoring through ml algorithms and computer vision. AI can assist in reducing congestion and eliminating choke spots that jam the roads.
Drone, sensor and camera aided traffic flow monitoring and estimate are now feasible, thanks to advances in computer vision.

Computer Vision-Powered Parking Management:

The parking place problem is extremely common in today's culture. Of course, finding a parking place isn't hilarious. It may be very irritating (as well as harmful to the environment), and cities around the world all over the globe are struggling to solve the parking lot issue. Sensors are placed throughout the parking lot to detect any vacant spots. The sensor can determine the distance to a vehicle's underbody whenever it is placed



AI based Traffic analysis [35]

in a spot.
However, because a sensor cannot read license plates, cameras, parking meters, and computer vision must be used. T-Cameras that employ computer vision to locate places without meters are thus mounted. detect parked cars and track the time duration of parking using automated number-plate recognition technology.
Data may then be used by computer vision to update the database of all vacant and available spaces in real time. Drivers may then use mobile to see a map of all available parking places. This saves a lot of time and is particularly handy in congested parking lots like airports.

Geotechnical Engineering:

Foundation settlement [37]

The uses of AI in geotechnical engineering mostly comprises of knowledge-based intelligent machines and methodologies. Many areas of geotechnical engineering, including as rock and soil parameters, interrelation between parameters, estimation of settlement and bearing capacity, behavior of pavements, slope stability assessments, are predicted using AI systems.

Site characterization:

The primary goal of site investigation is to predict in situ soil parameters anywhere at a site based on the available experiments. The machine learning models can be feed with the site exploration data from various experiments. Based on these datasets the model can be further used for the prediction.

Soil properties and behavior:

The use of ANNs in predicting soil characteristics and behaviour is becoming more common. There are several researches works that proves the viability of utilizing neural networks to capture nonlinear relationships between numerous factors in complicated civil engineering systems. Neural Network models utilized to simulate two issues requiring engineering correlations between several soil properties, for both typically consolidated and over-consolidated sands. Laboratory data can be utilised to properly train and evaluate the neural network model. Further the ANNs have been used for the modelling of the stress strain relationship for various soils.

Settlement of foundations:

In last few decades the ANNs are being widely used for the prediction of settlement of foundation under various types of soil and loading conditions. Various soil properties, load and foundation dimensions cam be used as input and the settlement can be used as output in these types of model. These models provide quite accurate prediction across varied soil types and loading parameters.

Rock slope instability:

Let's take a deeper look at the application of Machine learning and artificial intelligence to rock slope stability. In many transportation situations, rock slope instability on streets and highways may result in unsafe circumstances. It is critical to identify the potential for rock slope collapse for governmental and non - governmental usage so that it may be adequately controlled. Using AI algorithms to create slope failure potential maps is a quick, practical, and cost-effective solution. AI systems may first be used to estimate slope collapse potential based on slope conditions such as geology, topography, meteorology, and environment, human domain expertise, and the ambiguity of evaluations. GIS datasets are utilised as a foundation for AI assessment to anticipate slope instability. To begin the procedure, the GIS data is loaded with information. The AI system then proceeds to model the complicated issue utilising the known connection between the variables in the model to compute slope failure potential and generate failure potential maps.

The failure risk maps created employing Artificial intelligence systems also improve slope management by emphasizing follow-up efforts to alleviate the situation, such as leading more extensive investigations and defining appropriate techniques to monitor and implement an early-warning system.

Rock slope failure [38]

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