



A Review on the Seismic Impact of Reinforced Concrete Frames with and without Base Isolation under Varied Soil Conditions Utilizing Soil-Structure Interaction Effects

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ABSTRACT—

Seismic events present a considerable risk to reinforced concrete (RC) edifices, especially in areas marked by intense seismic activity and diverse soil conditions. The seismic behavior of structures is affected not solely by their design and the nature of the earthquake but also by the interplay between the soil and the foundation, known as soil–structure interaction (SSI). Base isolation is a proficient seismic defense method that diminishes the transfer of earthquake-generated stresses from the ground to the superstructure by incorporating flexible isolation mechanisms between the foundation and the structure. The current research seeks to examine the seismic behavior of reinforced concrete frameworks both with and without base isolation across various soil conditions, taking into account the implications of soil-structure interaction. Analytical models of reinforced concrete frames will be constructed and assessed utilizing appropriate structural analysis software. The research will analyze several soil profiles, including hard, medium, and soft soil, to assess their impact on the dynamic properties and seismic behavior of the structures. Both fixed-base and soil-interaction models will be examined, with and without base isolation, to conduct a comparative evaluation of their performance under seismic loading. The primary reaction metrics will encompass natural time period, base shear, storey displacement, inter-storey drift, acceleration response, and overall structural integrity. The study will concentrate on comprehending the effects of soil pliability and base isolation on the allocation of seismic pressures and the deformation traits of reinforced concrete frames. The findings are anticipated to reveal the comparative effectiveness of base isolation in enhancing seismic performance under various soil conditions and to ascertain the impact of soil-structure interaction on the behavior of both isolated and traditional structures. The results could aid in the creation of more secure and cost-effective earthquake-resistant structural systems by elucidating the synergistic impacts of base isolation and soil-structure interaction during seismic occurrences.

Keywords – Base Isolation System, Soil Structure Interaction, Lead Rubber Bearing, Friction Sliding Isolator, Seismic Analysis, Etabs.

1. Introduction -

In the seismic design of building structures, it is typically presumed that the soil is unflexible, a notion that holds true only when the foundation rests on solid rock or when the soil exhibits considerable stiffness. In all other instances, the soil surface interaction (SSI) comprises two separate effects – kinematic and inertial interaction, which is intricate. Soil-structure interaction (SSI) denotes the phenomenon where the soil's reaction affects the structure's response, and conversely, the structure's reaction impacts the soil's movement (Kramer, 1996). The structures are regarded as detached with a stationary foundation for the purpose of facilitating easier computations. Nevertheless, the structures are not constructed in seclusion in actuality. The seismic behaviour of structures, particularly when in proximity, does not function autonomously; given that their foundations rest on the same substrate, their responses influence one another. Moreover, contrary to the assumption that Soil-Foundation-Structure Interaction (SFSI) prolongs the natural time period of a structure and is advantageous during design, research indicates that this extension can result in resonance. Furthermore, SSI can cause the ductility to rise dramatically when the natural period of the structure increases. Permanent soil deformation and failure may worsen the structure's seismic reactivity.

Due to the recent surge in population, there has been a marked increase in the demand for multi-story buildings. However, as the number of stories increases, particularly in relation to seismic events, the safety of the structure must be taken into consideration [1-4]. Seismic forces are unpredictable and can cause significant damage when they occur, so understanding how structures behave and react during an earthquake is crucial. Devastation in terms of life, money, and structural failure is immense in the aftermath of an earthquake. Historical evidence from earthquakes shows that traditional buildings often crumbled or suffered damage when the ground shook. Modern cities are characterized by skyscrapers because to the rising demand for office and residential space caused by the fast expansion of both populations and businesses. Furthermore, structures must be erected inside earthquake zones. thus, seismic energy dissipation devices and base isolation are appropriate strategies that must be incorporated into the design of our building structure to withstand seismic forces. The world over, seismic control strategies are embraced. It can be utilized for retrofitting reasons to enhance the structure's flexibility.

The main rationale for building at a higher level is to safely transfer the main gravity load. Gravity loads can be either dead or live. Furthermore, the building must be able to resist the lateral loads imposed by wind, blasting, and earthquakes, all of which vary according to the types of terrain. Sway moments and high stresses caused by the lateral load reduce the structure's stability. Therefore, under these situations, stiffness is comparable to strength when it comes to resisting lateral loads. In order to enhance the seismic performance of structures, there are multiple methods for providing a lateral load resisting system, such as bracing, base isolation, and dampers. A passive vibration control system, base isolations harness the motion of the structure to provide control force without the need for external power sources. Advantages of this approach include ensuring security in the face of massive earthquakes while keeping the structure essentially flexible.

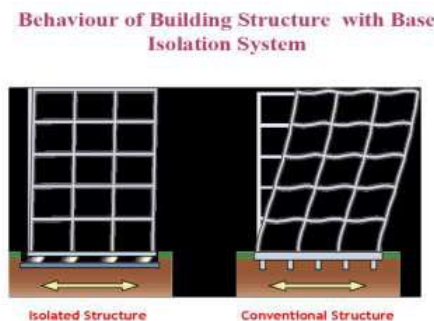
1.1 Soil Structure Interaction -

Soil-structure interaction (SSI) refers to the relationship between the ground and a construction erected on it. It is fundamentally a reciprocal exchange of stress, in which the dynamics of the ground-structure system are affected by the nature of both the substrate and the edifice. This is particularly relevant to regions with seismic activity. Different configurations of soil and structure can either enhance or reduce movement and ensuing damage. A structure situated on rigid terrain as opposed to pliable soil is likely to incur more significant damage. A secondary interaction impact related to the mechanical characteristics of soil is the subsidence of foundations, exacerbated by a seismic occurrence. This occurrence is referred to as soil liquefaction.

The majority of civil engineering constructions incorporate a structural component that directly interacts with the ground. When external pressures like earthquakes influence these systems, the structure displacements and ground displacements are interdependent. The phenomenon where the soil's response affects the movement of the structure and vice versa is referred to as soil-structure interaction (SSI).

1.2 Base Isolation System –

Base isolation of edifices is among the most sought-after methods for safeguarding them against seismic pressures. The essential principles of earthquake engineering can be characterized as the process of isolating or decoupling the structure from its foundation. This phenomenon minimizes inter-storey drift and optimizes displacement in the floors of base-isolated structural systems, hence ensuring minimal damage to facilities and safeguarding life and property. The notion of base isolation has been proposed throughout the past few decades, with technology now accessible, and the understanding of base isolation systems being utilized, refined, and therefore well-established. Seismic isolation technologies demonstrate greater efficacy in high stiffness, low-rise structures due to their capacity to transform the building's properties from rigid to flexible. The progressive rise in the quantity of structures requiring isolation underscores the growing acceptance of base isolation systems as a validated technique for mitigating seismic hazards. Notably, base isolation functions as a passive control mechanism; it operates without the necessity for external forces or energy to initiate its action.



2. OBJECTIVES OF THE STUDY

Prior research unequivocally demonstrates the efficacy and significance of Base Isolation in contemporary architecture. It significantly contributes to diminishing the seismic response of structures while also effectively reducing inter-storey drifts, overturning moments, base shear, axial forces, and more, all at a favourable cost. The SSI effect elucidates the true behaviour of the substructure, offering a first insight into the foundation's stability. The necessity for this research stems from the significance of comprehending the performance of base isolation across various soil conditions when soil-structure interaction is taken into account. The research may discern variations in seismic parameters, including base shear, storey displacement, inter-storey drift, natural time period, acceleration, and foundation reaction, by contrasting RC frames equipped with base isolation against those without.

The results of this study will assist in evaluating the appropriateness and efficacy of base separation systems across various soil types. The research could offer valuable insights for designing earthquake-resistant structures, choosing suitable foundations and isolation systems, and enhancing structural safety and functionality in seismically vulnerable areas.

3. Literature Review –

Numerous investigations have been carried out on the static and dynamic assessment and design of such structures, considering various soil influences and base isolation techniques. The research also indicates the challenges that emerge in the seismic design of tall structures when such circumstances

happen. A limited selection of data from earlier research has been examined here, including the employed technique and resultant results. Numerous studies have been conducted on the implementation of base isolation systems in multi-storey buildings.

Novak and Henderson (1989) examined the influence of soil rigidity on the seismic behavior of reinforced concrete structures using shear walls. Innovative Infrastructure Solutions, DOI: <https://doi.org/10.1007/s41062-016-0004-0> - investigated the modular characteristics of base-isolated structures and posited that the influence of soil-structure interaction should not be disregarded when the adaptability of soil and isolators is comparable.

Kelly (1991) - "Seismic soil-structure interaction: new evidence and emerging issues," 3rd Conference on Geotechnical Earthquake Engineering and Soil Dynamics, Seattle, USA - conducted an investigative assessment regarding base-isolated nuclear facilities situated on vulnerable sites, concluding that the design of the isolators must be considered for substantial displacement demands.

Spyrakos and Vlassis (2002) - Influence of Soil Structure Interaction on the Seismic Behavior of Framed Structures. The International Research Journal of Engineering and Technology, 08(3):317-323, examined the effects of SSI on the response of base-confined spans through a parametric study. They deduced rational expressions to illustrate the significance of SSI characteristics in influencing the response of the disengaged system.

Tsai and colleagues (2004) - Equivalent linear model for current soil-structure systems. The International Journal of Structural Stability and Dynamics, 1450099, DOI: <https://doi.org/10.1142/S0219455414500990>, developed a spatial area technique to investigate the efficacy of isolators in reducing the energy absorbed in an FPS-isolated system during seismic activity. Radiation damping and setup flexibility were seen as essential for the accuracy of response predictions and the integrity of the isolated system.

Juan C. Ramallo and colleagues (2008) conducted system identification of a base-isolated structure utilizing seismic response data. The authors of this work have examined the impact of employing controlled semi-active dampers, including magneto-rheological fluid dampers, within a base isolation system. A model of a base-isolated structure with two degrees of freedom is employed. The primary idea is to detach a structure from the ground, particularly within the frequency spectrum that most influences the building. The objective is to minimize inter-storey drifts and floor accelerations to mitigate damage to the structure and its contents economically. This study examines the enhancements that can be realized by substituting additional linear viscous damping systems in base isolation with semi-active dampers. A linear, two-degree-of-freedom (2DOF), lumped mass model of a base-isolated structure serves as the experimental framework for this research. The system model employed in this examination is a single degree-of-freedom model characterized by mass, fundamental modal frequency, and damping ratio. This research employs passive linear viscous dampers, active dampers, and semi-active dampers. Generalized semi-active and magneto-rheological fluid dampers were employed in the earthquake protection system. Researchers have determined that the semi-active damper achieved results comparable to those of the fully active damper. The semi-active damper resulted in reduced peak base drifts when contrasted with the ideal passive linear damper. This research indicates that semi-active dampers, including magneto-rheological fluid dampers, exhibit considerable potential for base isolation applications with markedly lower power demands than active systems.

J. C. Ramallo¹ and colleagues (2008) determined the hysteretic model of rubber bearings via sequential nonlinear least-squares estimation. The article in Earthquake Engineering, 9: 375–383, (2008) introduces a novel base isolation technique that demonstrates its efficacy in safeguarding structures from severe earthquakes while maintaining performance during more common, mild seismic occurrences. This groundbreaking idea incorporates a base isolation system using semi-active or adjustable passive dampers to alleviate seismic responses. In this approach, the structure is represented as a single degree-of-freedom system that embodies the underlying mode. Upon the incorporation of the isolation layer, the enhanced model constitutes a system with two degrees of freedom. Experimental tests have demonstrated that the linear characteristics of low-damping rubber bearings can persist at shear strains exceeding 100%. Lead-rubber bearings serve as the standard for evaluating clever damping solutions. The rubber insulation in both systems is the same. The diverse ground stimuli are employed for modal excitation. A set of controllers that reduces baseline drift and absolute accelerations (in comparison to the LRB) is developed for an adjustable smart damper. The base isolation system, consisting of low-damping elastomeric bearings and adjustable semi-active dampers, demonstrated enhanced efficacy relative to several passive base isolation configurations utilizing lead-rubber bearings.

Radmila B. Salic et al. (2008) in their paper "Performance of sliding resilient-friction base-Isolation system," published in ASCE's Journal of Structural Engineering, vol. 11, Issue No. 7, pp. 56-69, illustrate the impact of dynamic responses on a seven-story residential structure subjected to seismic ground motions. The mode shapes, natural frequencies, and damping ratios of the current fixed-base structure are derived using ARTAMIS (Ambient Response Testing and Modal Identification Software). The fixed base model illustrates the dynamic characteristics of the structure, whereas the seismic isolated model depicts the dynamic behavior of the structure utilizing a lead rubber bearing seismic isolation system. Dynamic evaluation of both models has been conducted using ETABS (Nonlinear version 9.0.4). The finite element model was selected to meet the requirements of this investigation. The dynamic reactions of fixed base and seismic isolation models have been computed for four varieties of actual earthquake time histories with varying frequency attributes, the values of which are established through comprehensive site response investigation. The authors have demonstrated that an increase in the natural period of a structure enhances its flexibility. In a seismic isolation model, the base shear force is significantly diminished. The augmented adaptability of the system resulted in a rise in overall displacements attributable to the elasticity of the current isolation. The execution of the isolation system led to a decrease in inter-story drifts. Examination of the seismic isolation model has demonstrated a substantial decrease in narrative accelerations.

B.R. Jayalekshmi, Katta. Venkataramana, R. Shivashankar, (2009) "Seismic reaction of multi-story reinforced concrete structures. Frames exhibiting the impacts of soil-structure interaction." NITK Research Bulletin Volume. Sixteen. Volume 1, June 2009, pages 14 to 18 - Analyzed the seismic behavior of space frames with unconnected equilibrium on stratified soil. This study examines the seismic response of multi-story reinforced

concrete structures with isolated foundations situated on shallow layered soil. Various degrees of stiffness in layered soil, ranging from extremely soft to hard, are taken into account. The analysis of construction subjected to code setup using ANSYS programming. The influence of soil layering on fundamental frequency and base shear is presented. The influence of SSI amplifies the seismic base shear.

Mr. Magade S B and Prof. Patankar J P (2009) examined the impact of soil-structure interaction on the dynamic characteristics of building frames in their article "Assessing lateral period of building frames incorporating soil flexibility," published in the Journal of Sound and Vibration, 269 (2009), pp. 795-821. In this study, the structural model is anchored at its foundation for the purpose of evaluation. The overall evolution of the soil medium affects the structure's degree of distortion. This reduces the overall robustness of the basic structure, which constitutes the typical framework. The response of the structure is modified by the partial rigidity of the foundation due to soil flexibility. The main objective of this study is to focus on the influence of soil structure interaction on infill and exposed frames with shear walls, evaluated under various soil conditions using the STAAD-PRO 2008 software package. The evaluation considers the displacement, base shear, and regular recurrence, which are compared against various soil profiles.

H. Matinmanesh and M. Sales Asheghababi (2011) conduct a critical examination of idealization and modeling about the interaction within the soil-foundation-structure system in their article, "A critical review on idealization and modeling for interaction among soil-foundation structure system," published in Computers and Structures 80 (2011), pages 1579-1594, focusing on seismic analysis of structures situated on sandy soil. This research examines a 2D plane strain finite element method (FEM) analysis of seismic soil-structure interaction (SSI) using three ground motion recordings throughout low, moderate, and high seismic activities, focusing on recurrence, amplification, velocity response, and stress generation associated with earthquakes of varying soil and structural heights. The influence of SSI in sandy soils amplifies seismic waves on the SSI.

Vivek Garg and M.S. Hora, (2014) "An analysis of the interaction dynamics between structural foundations and soil systems.", International Journal of Engineering Research and Applications, Vol. Volume 2, Issue 6, November - December 2014, pages 639-644 analyzed the audit interaction behavior of the structure-foundation-soil system. This review presents the structure and soil through a limited component method and conventional non-linear analysis, with the elements in the structural framework anticipated to rest on the non-yielding support. The behavior of the construction due to static and seismic stacking is analyzed by finite element analysis. The present evaluation aims to examine the influence of SSI on the structural frameworks. The variations in stacking patterns, total and differential settlements in non-linear analysis are examined.

Ayman Ismail (2015) "Influence of Soil Structure Interaction on Seismic Loads of Framed Structures"; International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2015 ISSN 2229-5518 focused on the impact of soil pliability on the seismic behavior of three-dimensional frames. This study examines the influence of soil rigidity on the seismic performance of rigid structural frameworks situated on isolated foundations. The flexibility of the soil causes the lateral standard duration of the main structure to diminish in concurrent rigidity. The analysis has been conducted with Sap2000. The influence of soil-structure interaction on the parallel regular period, akin to that of a pontoon foundation, is presented alongside distinct equilibrium.

Minal Ashok Somwanshi (2015) Investigates the Impact of Soil-Structure Interaction on the Seismic Behavior of Base-Isolated High-Rise Structures, International Journal of Structural and Civil Engineering Research Vol. A study on the Seismic Analysis of Fixed Based and Base Isolated Building Structures was conducted by 4, No. 3, (2015) et al. The study focuses on the modeling and examination of a 13-storey rigid jointed planar structure under two scenarios. The initial scenario involves a fixed basis, while the subsequent scenario features a base isolation system. The E-TABS program is utilized for modeling and analyzing the ground motion recordings of the Bhuj earthquake. The highest vertical reaction is derived from analysis conducted in E-TABS software. The design of lead rubber bearings is conducted manually, utilizing the vertical reaction and the overall mass of the structure. Time-history analysis is conducted to assess floor reactions, accelerations, and displacements in response to ground motion. This document aims to illustrate the efficiency of an isolation system by assessing its performance for the structure concerning maximum shear force, maximum bending moment, base shear, storey drift, and reductions in storey displacement. Analytical findings indicate that the base separation method is crucial for diminishing the seismic response of both symmetric and asymmetric structures when contrasted with fixed base constructions, hence mitigating damage during intense ground shaking.

Chinju Joseph and Nirmal George - The Influence of Soil-Structure Interaction on Frames with Varied Base Conditions, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Published by www.ijert.org, NCRACE-2015 Conference Proceedings - Traditional modeling of frame structures typically neglects soil-structure interaction. This results in variations in the structural reaction. However, the interplay between the structure, foundation, and the underlying soil significantly modifies the actual performance of the structure compared to an analysis based solely on the structure. The pliability of the soil substrate beneath the foundation diminishes the overall rigidity of the building structures, leading to an extension of the system's natural period. Soil-Structure Interaction (SSI) encompasses various phenomena related to the behavior of structures influenced by the pliability of foundational soils, as well as the behavior of soils affected by the existence of structures. Analytical and numerical approaches for dynamic analysis generally overlook the soil-structure interaction (SSI) effects inherent in the interconnected structure-foundation-soil system. The influence of SSI impacts is acknowledged to be considerable, particularly in scenarios with substantial structures and soft soil environments. This study examines the influence of soil-structure interaction on the dynamic performance of buildings through analysis: 1. A naked structure 2. A frame that is isolated from the base 3. A symmetrical structure with inadequately designed foundations

Donato Cancellara et al. (2016) conducted an investigation on the dynamic nonlinear analysis of several base isolation systems for a multi-storey reinforced concrete building with an irregular design, published in ELSEVIER, Soil Dynamics and Earthquake Engineering 66, pp. 167-177. Two base isolation methods were examined, and their seismic performance was contrasted with that of a multi-storey reinforced concrete structure. A

comparative examination is conducted to assess the performance of a base-isolated irregular structure during seismic occurrences. Two base isolation methods have been evaluated: the High Damping Rubber Bearing (HDRB) functioning in conjunction with a Friction Slider (FS) and the Lead Rubber Bearing (LRB) operating alongside a Friction Slider (FS). A dynamic nonlinear assessment is conducted for the three-dimensional base-isolated framework. A comparison analysis is performed on the behavior of the structure isolated by the two examined base isolation systems alongside the behavior of the conventional fixed base structure.

Dr. Manjunath N Hegde (2016) conducted a seismic evaluation of multi-story structures situated on both level and inclined terrains throughout various seismic zones, with and without base isolation, published in *I-manager's Journal on Structural Engineering*, Vol. This study investigates the outcomes for structures with a fixed basis, rubber base isolators, and dampers alongside shear walls. An irregular plan structure of seven floors (G+7) is selected for examination. For seismic zone IV, utilizing type II (medium) soil with ETABS Software. The analysis is conducted using both the equivalent static approach and the response spectrum method. Comparative analysis of outcomes such as time duration, displacement, storey drift, and base shear is conducted between a building equipped with a base isolator and shear wall and a fixed base structure. A structure equipped with a base isolator experiences greater movement than one with fixed supports or shear walls. In contrast to fixed base structures, base shear is minimized in base isolated buildings, resulting in superior seismic performance for buildings equipped with base isolators.

D. K. Jain and M.S. Hora (2017) Seismic design resources for structures considering soil-flexibility impact, J. Asian Architecture. Build., 5(2), 2017, 341-348 concentrated on an examination of the interplay between space frame, shear wall, and soil systems to analyze foundation forces during seismic stacking. This study examines the soil construction analysis of G+5 reinforced concrete shear wall multi-story structures founded on isolated column footings. The model analysis is finalized with the application of ANSYS software. Concerning the Is code 1893-2000, the seismic deposit mixture is considered. The influence of SSI investigation on shear dividers, both present and absent, regarding the footings for differential soil settlement. The SSI collectively influences the forces and durations in relation to the differential settlement. In a substantial segment of the foundation, the bowing moments are diminished.

Athanasios et al. (2018) conducted a non-linear analysis of a g + 4 multistory building utilizing the time history method with Newmark's linear and average acceleration approach, published in the International Journal of Engineering Sciences & Research Technology, ISSN: 2277-9655, (2018), focusing on the response simulation of hybrid base isolation systems during seismic events. The foundational isolation system comprises high-damping rubber bearings and low-friction sliding bearings. Two distinct models are utilized for the numerical modeling of the high damping rubber bearing element, specifically a bilinear and a tri-linear system, both operating in conjunction with a linear viscous damper. A sequence of numerical simulations is conducted to examine the performance of the analyzed hybrid base isolation system under various excitation and site conditions.

Fabio De Angelis and colleagues (2018) conducted system identification of a base-isolated structure utilizing seismic response data. The Journal of Structural Engineering - ASCE, 2016, 131: 268–275 performed an investigation on nonlinear dynamic analysis for reinforced concrete structures utilizing hybrid base isolation systems amid bi-directional ground vibrations. The study examined three distinct hybrid base isolation technologies to safeguard reinforced concrete edifices against bidirectional ground movements. The three hybrid base isolation methods examined include Elastomeric Spring Dampers functioning in conjunction with Friction Sliders, Lead Rubber Bearings working alongside Friction Sliders, and High Damping Rubber Bearings operating in parallel with Friction Sliders. A comparative examination is conducted on the three base-isolated composite structures by documenting the base acceleration, base shear, base displacements, inter-storey drifts, and the maximum values of the base shear. A comparative evaluation is ultimately provided between the base-isolated structure utilizing the three examined base isolation technologies and the fixed base structure.

Mistry Hemal A.1, Patel Nirav S.2 - The Influence of Soil-Structure Interaction on the Seismic Resilience of Multi-Story Reinforced Concrete Buildings with and without Shear Walls, International Journal for Research in Applied Science & Engineering Technology (IJRASET) Volume 6 Issue VI, June 2018 –

Although structures are founded on soil, many designers overlook the implications of soil-structure interaction and its impact on the structure during seismic events. Recent research indicates that Soil Structure Interaction (SSI) can adversely affect the seismic performance of structures, and overlooking SSI in evaluations may result in overly conservative designs. Notwithstanding this, the traditional design methodology typically presumes rigidity at the foundation's base, overlooking the foundation's flexibility, the soil mass's compressibility, and the subsequent impact of foundation settlement on the redistribution of bending moments and shear force requirements. The impacts of SSI are examined for a standard multi-story structure situated on a raft base. Two analytical approaches are employed for assessing seismic demands of special moment-resisting frame structures: equivalent static load (ESL) and response spectrum (RS) methodologies, utilizing ETABS Ultimate 2016 software in accordance with IS 1893:2002 "Criteria for Earthquake Resistant Design of Structures. Numerical outcomes derived from soil-structure interaction model parameters are juxtaposed with those associated with fixed-base support situations. The maximum responses of natural time period, roof displacement, story drift, and foundation shear are examined.

N Murali Krishna et al. (2019) examined the nonlinear time history analysis of structures equipped with seismic control systems in their study titled "Seismic Response Control of R.C.C. Structure using Base Isolation," published in the International Journal of Research in Engineering Science and Technology, vol. 2, no. 1.

Asymmetric edifices have been used for the analysis to regulate the seismic behavior of the framework. The research focused on nonlinear time history analysis, taking into account the influence of shear walls and base isolation systems. The RCC moment-resisting frame undergoes nonlinear time history analysis (NLTHA). The lateral drift, base shear, torsional moment, and story displacement of the structure were analyzed. The findings reveal that the base isolation had a substantial impact on the storey drift, storey shear, storey displacement, and torsional moment of low-rise asymmetric structures, while the shear wall significantly influenced the same responses in high-rise asymmetric buildings.

M. A. Aden¹, Alyaa A. Al-Attar², F. Hejazi^{3,*}, M. Dalili¹, and Nima Ostovar¹ - Impact of soil-structure interaction on base-isolated edifices IOP Conf. Series: Earth and Environmental Science 357 (2019) 012031 IOP Publishing doi:10.1088/1755-1315/357/1/012031 –

Ensuring structural integrity and seismic resilience of edifices in the face of earthquakes has posed significant challenges for structural engineers. Numerous investigations have focused on the advancement of seismic isolators to enhance the seismic performance of civil engineering constructions. This research examines the evaluation of building frameworks using SAP2000, taking into account soil-structure interaction and base isolation impacts in El Centro. Four distinct models are examined, comprising a fixed base structure, a base-isolated structure, a frame supported by springs simulating the soil, and a structure featuring both base isolation and springs. The seismic outcomes are examined concerning displacement, shear force, axial force, moment, and drift of the columns and beams. The interaction between soil and structure was noted to afford the structure a degree of flexibility by augmenting its displacements and inducing variations in internal forces inside the system. Consequently, integrating base isolation with an analysis of soil-structure interaction enhances the accuracy of structural reaction predictions.

Dr. S. Amaresh Babu, 2 Ahmed Zubedi conducted a study on soil-structure interaction and base isolation systems for the seismic performance of structures situated on various soil types, published in IJEDR 2019 | Volume 7, Issue 4 | ISSN: 2321-9939 –

The traditional methodology for seismic-resistant design involves integrating sufficient strength, rigidity, and inelastic deformation capacity into the building framework to endure induced inertia forces. This was based on the assumption that during intense ground motion, when inertia forces above their designated seismic thresholds, the structure will absorb this surplus energy via deformations at specified sites distributed throughout the structural framework. It was noted that, despite the inclusion of elements engineered for ductility, the constructions did not consistently function as intended. It became apparent that a design only reliant on the notion of integrating ductility as a protection against seismic impacts requires thorough examination. Engineers devised a novel concept of implementing a pliable interface between the foundational ground and the edifice, thus isolating the structure from the energetic elements of seismic ground vibrations. This approach is referred to as the Base Isolation method. This dissertation seeks to assess the importance of employing Base Isolation as a means to endure seismic pressures. This dissertation seeks to demonstrate the significance of accounting for soil-structure interaction instead of treating the structure as a fixed basis. The analysis primarily focuses on structures exhibiting soil-structure interaction effects vs base-isolated structures. The evaluation is conducted utilizing the software SAP2000 version 18. The analytical approach employed is Fast Nonlinear Analysis (FNA). Eighteen models are examined, encompassing both symmetric and asymmetric configurations, categorized as fixed base models, models accounting for soil-structure interaction, and models incorporating base isolation (lead rubber bearing). These models are presumed to be situated on three types of soil: limestone, rigid clay, and loose sand. All the models consist of G+13 levels. The findings indicate that the impact of soil structure interaction is more pronounced for structures situated on medium and soft soils than for those on hard soils, as minimal variation is observed in the responses of structures with and without soil structure interaction effects on hard substrates. A base isolation system is most appropriate for edifices situated on firm soil. The base shear, floor displacements, and torsional effects are significantly diminished.

Arcan Yanik and Yalcincan Ulus - Consideration of Soil-Structure Interaction for Base Isolated Structures Subjected to Earthquake Excitation, Buildings 2023, 13, 915. This research is to analytically apply base isolation with soil-structure interaction (SSI) on a model structure and to devise a straightforward method for incorporating these combined effects into the mass, damping, and stiffness matrices of the structure. A spectrum analysis is additionally conducted with regard to base-isolated structures and SSI. Dynamic simulations are conducted throughout the research. In these simulations, three shear frame constructions with varying characteristics are examined. The robust seismic activities chosen for these evaluations consist of eighteen distinct occurrences featuring both far-fault and near-fault elements. Furthermore, four distinct combinations of base and soil structure scenarios are considered. These four analytical scenarios consist of a standard framework with a stable foundation and a seismically isolated structure, either incorporating or excluding the SSI. The numerical findings indicated that the inclusion of SSI may diminish the efficacy of the base isolation system, particularly in softer soil environments.

Hakan Öztürk 1,* , Erkan Çelebi 1, and Cemalettin Kaya 2 - An Experimental Investigation into the Seismic Performance Assessment of a Multi-Story Steel Structure Utilizing Rolling-Type Seismic Base Isolation, Buildings2024, 14(10), 3268; https://doi.org/10.3390/buildings14103268 –

Essential infrastructures like hospitals, high-precision manufacturing plants, telecommunications hubs, and fire stations must retain operational capacity even amidst significant seismic events. In this regard, seismic isolation technology functions as an essential design approach for maintaining their operability. Seismic isolators, referred to as earthquake isolation systems, function to mitigate the impact of earthquakes on structures by detaching them from the underlying ground. By minimizing the transmission of acceleration and force to the superstructure, both the structure and the equipment within it are safeguarded from earthquake damage. This experimental research intends to perform vibration assessments on a miniature multi-story steel structure including a uniquely engineered rolling-type seismic base isolation mechanism. The correlation between the test model and the prototype was established using frequency simulation. The evaluations will be conducted on a shake table utilizing six distinct earthquake accelerations to analyze the model's dynamic response. The main objective is to assess the isolation efficacy of the rolling-type seismic base isolator subjected to seismic forces, concentrating on capturing the vibrations at the summit of the test structure. The isolator situated at the foundation of the structure has notably diminished the maximum acceleration and displacement metrics of the floor movement. In the context of the most extreme earthquake simulation conducted on the shake table, the acceleration experienced at the apex of the building equipped with an isolator was observed to diminish by around 50% in comparison to the scenario without isolation.

Ke Yang, Pengrong Cai, Zixuan Zhang, Qinglin Hou, Ruige Zheng, Bin Hao, and Bo Wang examine the influence of soil–structure interaction (SSI) on the seismic behavior of reinforced concrete frame–shear wall edifices subjected to distant long-period ground motions in their paper

published in *Buildings* 2024, 14(12), 3796; <https://doi.org/10.3390/buildings14123796>. Elastic-plastic time-history assessments were conducted with ABAQUS. The influence of ground motion characteristics, soil composition, and structure frequency on seismic response is examined and statistically assessed. Based on this foundation, the impact mechanism of SSI on the seismic response to distant long-period ground motions is examined and elucidated using a ground motion spectrum analysis. The findings indicate that accounting for the SSI effect results in an augmentation of the displacement response and a reduction in the shear response. The SSI coefficient for the base shear is uniformly below 1, varying between 0.5 and 1. The SSI effect is more significant during far-field long-period ground motions compared to typical ground motions. The existing code's reduction of shear force may not be relevant to structural design when accounting for the SSI effect during distant long-period earth vibrations. The amplification of displacement response due to the SSI effect on loess soil (Site 2) is more pronounced than on sand soil (Site 1). The SSI effect has the potential to diminish the structural frequency, particularly in buildings with fewer stories situated on softer terrain. The "bimodal trait" of the acceleration response spectrum for distant long-period ground motions could result in shear force enhancement when soil-structure interaction is taken into account.

Ragi KRISHNAN¹, Vidhya Lakshmi SIVAKUMAR THE INFLUENCE OF SOIL-STRUCTURE INTERACTION (SSI) ON THE STRUCTURAL INTEGRITY AND SUSTAINABILITY OF REINFORCED CONCRETE STRUCTURES CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS CEER 2024; 34 (1): 0116-0136 DOI: 10.59440/ceer/184254 - The concept of SSI pertains to the response of the earth or soil beneath a structure erected upon it. The characteristics of the structure and the properties of the soil influence the tensions present between them, thus affecting the movement of both the structure and the underlying soil. The matter is significant, especially in seismic zones. The relationship between soil and structure is a highly captivating element in either exacerbating or mitigating structural deterioration or displacement. Structures positioned on pliable earth rather than firm soil will undergo heightened static settlement and diminished seismic damage. The engineer must consider that soil liquefaction issues arise on soft ground within earthquake zones. The dynamic response of a dual framework consisting of a reinforced concrete wall and frame to soil-structure interaction has not been adequately researched and is rarely acknowledged in engineering applications. The seismic behavior of structures including SSI effects remains uncertain, and there are persistent misunderstandings surrounding the concept of SSI, particularly in relation to reinforced concrete wall-frame dual systems. The examination of the soil under the foundations profoundly influences the frequency response and dynamic characteristics of the structure. Consequently, this study will examine the comprehensive importance of SSI in terms of structural and sustainability dimensions.

Fadhil A. Jasim*, Nabeel A. Jasim, Abdullah A. Al-Hussein - Evaluation of Soil-Structure Interaction Impacts on the Seismic Performance of Buildings with Isolators and Mass Dampers Mathematical Modeling of Engineering Problems Vol. This research investigates the influence of Soil-Structure Interaction (SSI) on the behavior of seismic-isolated structures. Investigations are conducted on reinforced concrete office structures of varying elevations. The High Damping Rubber Bearing (HDRB), Lead Rubber Bearing (LRB), and Double Sliding Pendulum (DSP) isolators are employed to separate the building's foundation. Additionally, a Tuned Mass Damper (TMD) is employed atop structures to enhance their reactivity. Soft, medium, and hard soils are represented by direct and substructure methodologies. Conversely, the impact of foundation type on the structural reaction of structures is analyzed. The findings reveal that incorporating SSI in soft soil decreases the base shear of a six-story structure by 30%, while elevating the displacement of the top story from 128 mm to 182 mm. Base isolators demonstrate superior efficacy in diminishing base shear (41-66%) compared to TMD (10-25%). Elementary equations are proposed to determine the basic period in relation to building height. The soil stratum adjacent to the foundation, approximately 75% of the building's elevation, predominantly influences the structure's reaction. Consequently, soil exploration may be limited to a maximum depth of 75% of the structure's height. Ultimately, it has been determined that employing pile foundations in soft soil modifies the building's response to mimic that of hard soil conditions.

Pranoy Debnath, Tanmoy Das, and Deepankar Choudhury examine how soil-structure interaction and ground motion factors affect the seismic vulnerability of reinforced concrete buildings in their study published in *Scientific Reports* (2026) 16:9400. The seismic performance of reinforced concrete structures is significantly affected by soil-structure interaction, which is contingent upon soil characteristics, foundation pliability, and the nature of seismic input. This research examines the seismic behavior and susceptibility of a five-story reinforced concrete frame building by explicitly factoring in soil-structure interaction during seismic events. A three-dimensional computational model is created in PLAXIS3D to replicate the interaction between the structure and the underlying thick sand and soft clay substrates. The impact of SSI on lateral movements, interstory shifts, and seismic vulnerability is assessed. The Mohr-Coulomb (MC) model is utilized for clay soils, but the Hardening Soil model with small-strain stiffness (HSS) is applied to sandy soils, with findings demonstrating that the HSS model more precisely reflects the seismic behavior of sandy deposits. The analysis of the soil profiles and structural arrangements suggests that soil-structure interaction (SSI) could result in heightened lateral displacements and interstory drifts, especially when soft clay soils and flexible foundation conditions are present. Fragility curves are created to measure structural susceptibility to both near-fault and far-field seismic activities. The results indicate that the synergistic impact of SSI and near-fault seismic traits elevates the likelihood of surpassing damage thresholds at reduced peak ground acceleration (PGA) levels for the analyzed system. These findings underscore that the impact of SSI on seismic response varies by scenario and stress the necessity of integrating site-specific soil characteristics and authentic soil-structure interaction modeling in performance-oriented seismic design and risk evaluation.

Manisana Rajkumar, Sunil Singh Mayengbam - Incorporation of soil-structure interaction influences in the design of base-isolated reinforced concrete frame buildings, *Structural Engineering and Mechanics* Volume 98, Issue 3, May 10, 2026, pages 309-335. This research examines the influence of soil-structure interaction on the design and evaluation of a base-isolated reinforced concrete frame structure. The initial design of the structure utilizes the direct-displacement base design methodology to provide minimal inter-story drift, aligning with the fully functional performance spectrum. The lead rubber bearing functions as a separator for the sequestered structure. The design forces and moments are ascertained by modeling the single-degree-of-freedom, base-isolated structure, while accounting for the effects of soil-structure interaction. The foundation is designed to maintain eccentricity and safety factors within permissible limits. The lateral deformation components are deemed to encompass displacements caused by the

isolator, the superstructure, and the foundation's tilting and oscillation in relation to the soil. The distinction between the fundamental period with and without soil-structure interaction is also examined. The methodology is validated by time-history assessments of diverse soil profiles and base-isolated architectural designs.

4. Conclusion –

The conceptualization of soil support through springs is a rough estimation. This does not demonstrate the adaptability with great accuracy. Consequently, it produces results of diminished accuracy. The realistic idealization of supporting soil can be achieved by FEM. Incorporating variability in soil characteristics, stratified soil, and boundary conditions is feasible. This will yield more accurate data than the spring model. The research additionally indicates that there exists a disparity in the outcomes of both. The spring model fails to accurately represent the values.

The disparity between the spring model and the finite element method model is minimal for soils of medium hardness. The disparity is significant for soft soils. Consequently, Spring models can be utilized for rigid soil, while FEM models are suitable for pliable soil. The Finite Element Method has demonstrated significant utility in examining the impact of SSL. To simplify practical applications, the Winkler hypothesis should be utilized to account for soil-structure interaction rather than assuming a fixed foundation.

The aforementioned literature on base isolation systems indicates that employing base isolation significantly diminishes the structural response to seismic forces. Base isolation is a highly promising technology designed to safeguard various structures, including buildings, bridges, airport terminals, and nuclear power plants, against seismic disturbances.

The primary feature of base isolation systems enables the superstructure to exhibit stiff movement, hence diminishing the relative story displacement and story drift of structural elements, which in turn reduces the internal forces in beams and columns.

As a result of diminished lateral forces on the floors, the accelerations of the levels are lessened. This leads to a decrease in inertial forces. The overturning moment and shear forces in base-isolated structures are similarly diminished. Based on the aforementioned points, it may be inferred that the efficacy of isolated structures is notable in regions susceptible to earthquakes.

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