



Performance Analysis of a Random Rubble Stone Masonry Building with Different Configurations of Seismic Bands

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Abstract

The traditional construction technique of masonry building with rubble stone has become obsolete due to the lack of scientific study of its performance analysis. Seismic bands are one such great technique to strengthen masonry buildings, the application of which is yet to be investigated in-depth. The objective of this study is to evaluate the requirement of reinforced concrete seismic bands on random rubble stone masonry buildings due to seismic activity. The paper also deals with the effect of the roof diaphragm on the lateral load response of stone masonry buildings. In this study, a single-story school building constructed with random rubble stone and cement mortar is considered for analysis. Numerical modelling of the stone masonry building is carried out to perform the parametric analysis of the building due to seismic bands and diaphragms. The Finite element modelling is performed by adopting the macro-modelling-based approach implemented in Abaqus software. A non-linear pushover analysis is performed by uniformly applying the body force to obtain the global force-deformation responses of the building models. Finite element analysis illustrates that continuous horizontal bands at the roof and lintel level of the stone masonry building, result in a note-worthy increment of 95% in the base shear capacity. Furthermore, it is found that with successive addition of horizontal bands the improvement in the base shear capacity of the building models is insignificant, with comparable capacity to a building with a rigid diaphragm. The obtained results highlight the importance of horizontal bands in ensuring the box-action even without diaphragm or with negligible contribution of the diaphragm, thus providing the desirable seismic performance.

Keywords: Random rubble stone masonry, Seismic band, Flexible and rigid diaphragm

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 6



Experimental Study on Radius-Cut RBS-CFT Connections with Bidirectional Bolts under Cyclic Loadings

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Abstract

This paper presents experimental investigation on evaluation of performance of radius cut steel reduced beam section (RBS) and on its role in improving overall behaviour of RBS-CFT connections subjected to cyclic load. The radius-cut RBS was designed as per steps proposed by Engelharth et.al. Behavior of radius cut RBS and concrete filled tube (CFT) connections with bidirectional bolts were examined. An experimental study was performed to find the performance of radius cut RBS under cyclic loading. It exhibited stable hysteretic behavior, and the RBS-CFT connection is found to be semi-rigid in nature. The strain data showed that the panel zone remained elastic always during the test. It reached a rotational capacity of 0.04 radians without any damage in the joint panel region, and thereby meets the seismic provisions of the AISC 2010 for a special composite moment-resisting frame.

Keywords: RBS, Semi-rigid joints, Bidirectional bolts, CFT



Probabilistic Arias Intensity Maps of Uttarakhand State (India)

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Abstract

Uttarakhand, an Indian state in the western Himalayan region, is highly seismically active and falls under zone IV (severe) and V (very severe) as per the seismic code of India. The region is home to some highly significant hydropower and infrastructure projects which are either operational or in the planning phase in the region. Therefore, it is vital to determine the area to be impacted by the high seismicity of this region. As Arias Intensity is a very efficient measure to quantify the strength of ground motion, none of the prior studies tried to map the Arias Intensity distribution throughout Uttarakhand. Therefore, in the present study, Arias Intensity is mapped for the Uttarakhand state by the Cornell–McGuire approach. A thorough earthquake inventory was created, considering all earthquake occurrences within a 300 km radius of the research area, incorporating events of magnitude (M_w) > 4 from 1900 to 2020. The inventory was declustered and homogenized into a commonly used moment magnitude scale. Ten distinct seismogenic area source zones were established in the study area. Seismic recurrence parameters for all sources were computed using the earthquake inventory and tectonic framework. The hazard evaluation at the bedrock level was conducted using a logic tree framework that included regional and global attenuation models. The findings were presented in terms of Arias Intensity hazard maps for 475 and 2475 years return period. It was observed that Arias Intensity values vary from 0.15 to 2.13 m/s for 475 year return period and 0.21 to 6.23 m/s for the 2475 year return period. Approximately 80 % of the study area was found to be vulnerable to co-seismic hazards. The ground motion intensity estimated in this study will assist in the effective planning of major infrastructure projects and earthquake-induced landslide hazard assessment.

Keywords: Arias intensity, PGA, Uttarakhand, PSHA, Logic tree, Attenuation model



Investigation on Influence of Embedment Depth of Shallow Foundation on Seismic Response of Building Considering Soil - Structure Interaction

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Abstract

Embedment depth of foundation plays significant role on the seismic response of the superstructures. The present study investigates the effect of embedment depth of shallow foundation on the seismic response of building through the scaled down test. A scaled-down model of five storey and shallow foundations of different embedment depth (75, 150, 300, and 600 mm) has been used in the present study. All the model tests are conducted through shake table testing in laminar shear box. The model is subjected to scaled down earthquake motions. The seismic response of the building has been estimated and expressed in terms of amplification ratio, maximum lateral displacement, interstorey drift, and rocking of the foundation. The test results indicate that the change in embedment depth of the foundation has a significant effect on lateral displacement, interstorey drift and rocking of the foundation. It is found that lateral displacement, interstorey drift and rocking of the foundation for the maximum embedment depth (600 mm) is reduced by 70%, 74%, and 41%, respectively, when compared with smallest embedment depth of foundation (75 mm).

Keywords: Shake table, Model, Shallow foundation, Earthquake, Seismic amplification



Design Methodology for Cold-Formed Steel Wall Framed Buildings under Lateral Loadings

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Abstract

Being light in weight, fast to construct, non-combustible, durable, recyclable etc. Cold-Formed-Steel (CFS) Wall Panels fabricated with lipped C-sections and sheathing boards are widely utilized in low & mid-rise buildings, often as structural element with lateral/seismic loads. Design guidelines for CFS buildings are not well developed for different sheathing boards against axial (gravity) and lateral loads, which hampers the adoption and application of the CFS wall-framed construction technology on the field at a large scale. In CFS shear wall panels (CFSSWP) with lateral eccentric load, end studs of the assembled frame will be under tension or compression as the assembly in whole try to show resilience against the load applied. Therefore, CFS end studs' axial strength (generally compression) is pivotal for estimating lateral strength of a CFSSWP. In the present study, modified approach for assessing the lateral strength of CFSSWP is validated with existing experimental studies given by Rogers (2004) and compared with approximate method proposed by Lei Xu (2006). Direct strength method (DSM) based on AISI S100-16 is engaged here for evaluating axial capacity of CFS wall. According to this methodology Local (P_{cri}), Distortional (P_{crd}) and Global (P_{cre}) Elastic buckling loads obtained will be utilized to get the actual buckling loads as per procedure detailed by Vieira & Schafer 2013 [7] and Sonkar et. al. 2020 [3]. Further, a modified approach for assessing the lateral capacity of CFSSWP is also proposed and validated. The modified approach considers broad range of parameters that might affect the resilience (stiffness) and capacity of CFSSWP, namely: material configuration, geometric configuration of studs (framing members), Assembly configuration of CFSSWP, and details such as size and spacing of the sheathing to frame fastening assembly. The adopted methods provide a ready tool for practitioners and designers for assessing the axial and lateral strength of CFSSWP for designing a CFS wall framed building. The estimated results agree well with the experimental results with a standard deviation of 4-5%.

Keywords: Cold-Formed-Steel (CFS), Lateral strength, Axial capacity, Direct strength method, CUFSM



Bayesian Model Updating in Time Domain by an Iterated Model Reduction Technique

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Abstract

The present study deals with time-domain structural model parameters identification. Specifically, an iterative model reduction algorithm is proposed to solve the transformation parameter such that no prior choices of response parameters are required. The time responses obtained from the reduced-order model and the responses at the measured degrees of freedom (DOF) are utilized to estimate the likelihood functions. The reduced-order model is subsequently implemented for updating unknown model parameters using Markov Chain Monte Carlo (MCMC) algorithm through a Metropolis–Hastings (MH) sampling scheme. The proposed methodology is elucidated numerically for an eight-storey shear building model to update its stiffness parameters considering different real-time earthquake data and noisy responses as evidence. The capability of the proposed model reduction technique coupled with the Bayesian updating algorithm is compared with the results obtained from existing model reduction approach. The numerical study focuses on the effect of reduced number of measurements for various measurement configurations in estimating the variation of errors in determining the structural model parameters. Subsequently, its effects on reducing the uncertainty of updated parameters are investigated.

Keywords: Time domain, Model updating, Markov chain Monte Carlo, Model reduction, Incomplete data



Structural Behaviour of Precast Concrete Sandwich Panel: A Review

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Abstract

Precast concrete sandwich wall (PCSW) panel consists of two concrete wythes separated by an insulation material and bonded together with the shear connectors which helps the walls to behave in a composite manner. This paper reviews the considerable number of studies related to the structural performance of precast concrete sandwich panels subjected to the in-plane and out-of-plane loads. This review highlights various important parameters such as shear connectors, concrete compressive strength and sandwich material that influence the structural response of these wall panels. The shear connectors have a crucial role in the transfer of shear forces through-out the concrete wythes. Different types of shear connectors made with steel, glass or carbon fibres in various geometric configurations have been used in PCSW systems. Similarly, different materials such as expanded polystyrene (EPS), extruded polystyrene (XPS), and polyurethane are used as an insulating layer. The insulation used in between the wythes resist thermal conductance. This paper will discuss the effect of slenderness ratio, aspect ratio etc. on the behaviour of the PCSW panel. It highlights the gap areas and scope for future research for the wider application of PCSW systems in civil infra-structure.

Keywords: Precast concrete sandwich panel, Shear connectors, Structural performance



Evaluation Of Dynamic Properties Of MICP Treated Ennore Sand through Bender Element Test

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Abstract

Bio-geotechnical method for mitigation of liquefaction of saturated cohesionless soils is one of the emerging methods owing to its lesser carbon-intensive, economic and environmental friendly propositions. Among the various bio-geotechnical methods, *Microbially Induced Calcite Precipitation* (MICP) technique is one of the popular choice of ground improvement for its easy implementation. In this study, poorly graded standard Ennore sand is treated with MICP technique through the urease producing bacteria for improving its behaviour against liquefaction. The morphological and chemical composition of the bio-cemented sand are investigated through *Scanning Electron Microscope* (SEM) and *X-Ray Diffraction* (XRD) tests respectively. Bender element testing has been carried out to investigate the improvement in low-strain stiffness indicated by shear wave velocity of bio-cemented sand. Results indicate significant enhancement in the stiffness of the bio-cemented sand. Therefore, the study may be helpful for the practicing re-searchers and engineers in understanding the efficacy of MICP treatment for dynamic/cyclic behaviour of Ennore sand.

Keywords: Standard Ennore sand, MICP treatment, Bender element test



Seismic Site Characterization and Ground Response Analysis of Railway Line on Eastern Dedicated Freight Corridor

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Abstract

Response of local soil during seismic events influences the response of the motion of the structure. Therefore, it is important to consider the local site characteristics while designing the structure for seismic design. In the present work, seismic site characterization and ground response analysis (GRA) have been performed for the proposed railway line between New Karchana Station - New Bhaupur (Kanpur) railway station, India. Total of 27 borehole data has been collected from the site. Further, seismic site characterization has been performed by adopting US National Earthquake Hazard Reduction Program (NEHRP) guidelines. A power method of nonlinear regression analysis has been used to propose an empirical correlation between SPT blow count (SPT-N) and shear wave velocity (V_s) for the study site to estimate the V_s profile. All the borehole location has been characterized as class D as per 30 m average V_s and SPT-N. In addition, a 1D equivalent linear approach has been used for the seismic GRA for six borehole locations by using *DEEPSOIL v7.0* software. Total 3 ground motions have been considered for GRA. Significant amplification has been observed at the site. Maximum displacement at the surface layer, Fourier amplification ratio, amplification factor, amplified PGA at surface level, effective stress, and maximum stress ratio have been also estimated for all the locations. Average response spectra have been estimated for the site. With the help of the above findings, liquefaction studies, seismic hazards analysis, and existing structures could be retrofitted with seismic protection.

Keywords: Correlation, Seismic site characterization, Ground response analysis



Statistical Analysis of Completeness Period and Seismicity Parameters of Earthquake Catalogue for Sree Padmanabhaswami Temple, Thiruvananthapuram District, Kerala

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Abstract

In the present study, seismicity data analysis of SreePadmanabhaswami Temple, Thiruvananthapuram District, Kerala, India has been performed. The area is having a radius of 500 km with SreePadmanabhaswami Temple (8.48°N Latitude and 76.94°E Longitude) as the centre. Earthquake catalogue from 1822-2021 has been compiled and homogenized using regional empirical relationships recommended by Kolathayar and Sitharam (2012). Data on earthquakes were declustered using Uhrhammer's (1986) method to exclude foreshocks and aftershocks within a time and space window, and then statistical analysis was done to ensure data completeness. Using the Gutenberg-Richter (1944) relationship, the seismic parameters are 1.234 and 0.532, respectively. The M_{max} value calculated using Kijko's MATLAB algorithm found to be 6.08 ± 0.26 .

Keywords: Gutenberg-Richter, Statistical analysis, Foreshocks, Seismicity



Earthquake Induced Damage Assessment of Coal Mine Overburden Dump Slope using Extended Finite Element Method Coupled with Voronoi Tessellation Scheme

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Abstract

Seismotectonic activity in the coal mining areas is a threat to the stability of overburden (OB) dump slopes. The consequent dump failures cause the loss of innocent lives, hamper the mining infrastructure and disturb the mining activities. Thus, there is an undesirable delay in the production of coal. The challenges in obtaining the material properties of the OB dump and the heterogeneous nature of its particles forbid the assessment of earthquake induced damage in an appropriate manner. The present study utilizes multi-channel analysis of surface waves (MASW) test based material properties of an OB dump slope situated at an Indian opencast coal mine located in Jam-bad. The representation of heterogeneity in size and shape of the dump particles was done by coupling extended finite element method (XFEM) with Voronoi tessellation scheme through RS2 software. The earthquakes, Coyote (1979) and Kobe (1995) were used to perform the dynamic analysis of a coal mine OB dump consisting of two benches. Finally, the effect of peak ground acceleration (PGA) on amplification ratio and permanent deformation at different key locations of the OB dump was investigated after ten seconds of the cease of the input seismic motion. In the absence of guide-lines regarding the threshold of damage due to seismic forces on the coal mine OB dump, this work would prove beneficial for the mining authorities in the preparation of guidelines for ensuring the safety of coal mine OB dumps in earthquake prone areas.

Keywords: Coal mine overburden dump slope, Extended finite element method (XFEM), Voronoi tessellation scheme, Amplification ratio, Permanent deformation



Deep Tuned Sloshing Damper with Multiple Horizontal Baffles for Structural Vibration Control

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Abstract

In most of the real-life installations of tuned sloshing dampers (TSDs), small containers with shallow liquid depth ($d/B \leq 0.1$, where d = liquid depth and B = container dimension along excitation direction) have been used as higher d/B or B leads to reduced inherent damping of the TSD. A shallow-TSD system normally consists of a large number of small damper units to fulfill the requisite mass ratio. This may create maintenance issues and difficulty in using the damper liquid, generally water, during emergencies such as firefighting. Although one, or a few deep-TSDs ($d/B > 0.5$) with higher B , could cater to the required mass ratio, such TSDs have insignificant inherent damping. This leads to the inclusion of energy dissipating devices such as nets, and baffles in deep-TSDs. This article focuses on enhancing the energy dissipation in a deep-TSD by using multiple horizontal baffles to present deep-TSDs as a practical alternative to shallow-TSD systems. The deep-TSD with multiple horizontal baffles is represented through an equivalent mechanical model. The structure is modeled as a single-degree-of-freedom system. The equations of motion of the structure-damper system are developed. The performance of the deep-TSD with horizontal baffles is evaluated through a numerical study by considering an example structure-damper system under seismic excitations. The results indicate that the performance of the deep-TSD is significantly improved due to the installation of the horizontal baffles. Further, the effectiveness of the deep-TSD with multiple horizontal baffles is found to be comparable to that of a shallow-TSD system having an identical mass ratio.

Keywords: Deep tuned sloshing damper, Multiple horizontal baffles, Earthquake excitation, Structural vibration control



Effects of Open Stories on Expected Seismic Losses in Hilly Buildings

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Abstract

Due to the lack of adequate flat land in the hilly region, it is often opted to construct buildings on the slope. Further, to accommodate the need for large covered open spaces (e.g., parking, shops etc.), open stories are provided in the hilly buildings at levels based on the location of the approach road. In this study, an attempt is made to determine the variation in the expected seismic losses due to the presence of open story in reinforced concrete (RC) hilly buildings. For this, two basic types of hilly buildings with different story ratios are considered. Bi-directional non-linear dynamic analyses are performed under 22 ground motions. The expected repair cost is estimated considering the repair of four drift-sensitive building components. The component-wise and floor-wise deaggregation of the expected repair costs due to the considered components are studied. It is observed that the unreinforced masonry wall contributes to the majority of the expected seismic repair cost in all the considered hilly buildings. Moreover, the presence of open stories just above the uppermost foundation level is observed to be the most critical in terms of estimated seismic losses to structural components.

Keywords: Hilly buildings, Open story, Seismic loss estimation



Experimental Investigation of Direct and Mitigated Pounding in Base-Isolated Frames with Adjacent Rigid Walls

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Abstract

Base-isolated structures pounding with surrounding walls have been observed due to large displacement at isolation level and insufficient gap between the structure and surrounding walls during many major earthquakes. Due to pounding at the isolation level, the response at the structure's top slab is also affected. Hence, an experimental investigation into direct pounding (DP) and mitigated pounding (MP) at the isolation level of a base-isolated frame structure is necessary. So far, many researchers have experimented with point contact pounding, but no experiments with surface contact pounding have been conducted. An experimental study on two base-isolated frame models of different lengths, surrounded by rigid walls in the longitudinal direction, was carried out for earthquake excitation on a shake table. The isolated slab cross-section and wall surface are free for pounding interaction during excitation, which is realistic in the field. The pounding responses at the isolation level and frame slab level are acquired and analysed. These experiments are repeated with mitigation material (rubber pad) in the gap between the isolated slab and the wall to study MP responses. Results show that the magnitude of acceleration responses decreases at the isolation level and frame slab level due to pounding. Despite the reduction in the open gap, the mitigation technique significantly reduced base shear forces compared to DP. The effect of pounding is observed more in the lengthier model as compared to the shorter one.

Keywords: Pounding, Base-isolation, Pounding mitigation, Frame structure, Shake table testing



Preliminary Studies on Developing a Physics-Based Smoothed Particle Hydrodynamics Model for Landslides

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Abstract

Landslides triggered by earthquakes pose a major threat worldwide, in terms of economic loss and casualties. In order to effectively mitigate this hazard, it is requisite to carry out Quantitative Risk Assessment (QRA) of landslides wherein the probability of landslide occurrence and the post-failure scenario both can be studied in detail. Several researches carried out in different parts of the world revealed that all landslides are the outcome of more than one triggering factor and in order to precisely estimate the probability of landslide occurrence in an area, it is important to study the effects of all these contributing factors. Moreover, the devastating effects of any landslide can be attributed to its post-failure phase which involves large deformations and due to the complex nature of these deformations, it is difficult to model them using slope stability methods like the Limit Equilibrium or the Finite Element Method (FEM). The presented work aims at studying the behavior of land-slides triggered by seismic action and exploring the applicability of the mesh-free computational method, Smoothed Particle Hydrodynamics (SPH) in predicting the size of landslides, in terms of volume and run-out distance. To achieve the said objectives, slopes in vulnerable areas shall be analyzed using SPH; a threshold value for sliding mass volume and runout distance shall be chosen based on some prominent works to decide on the stability of a given slope. Hence, the objective of getting an insight into the entire process of landslides, right from the initiation phase to the final consequences, shall be achieved. This particular article includes a preliminary study carried out to assess the applicability of our initial model and to gauge its performance when applied to the real life scenario. For that purpose, the famous Daguangbao landslide triggered by the 2008 Wenchuan earthquake has been modelled and the results have been found to be in good agreement with the field data.

Keywords: SPH, Landslides, Volume, Runout distance, Earthquake



Whither EBFs Instead of CBFs for EQRD?

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Abstract

Earthquake cause major non-structural, if not structural, damage in buildings. This damage increases with increase in inter-storey drift ratio (ISD). Bracings increase the lateral stiffness and thereby reduce ISD. In this study, a review of existing literature on Eccentric Braced Frames (EBFs) is presented, particularly focusing on literature showing EBFs superior to Concentric Braced Frames (CBFs). Here the issues in EBFs such as rather limited energy dissipation through ductile behavior of links, large floor deflections, adverse effect on beam adjacent to the link element, and the damages to Non-Structural Elements (NSEs) due to large ISD are clearly discussed. To evaluate the performance of the structure, two steel chevron (inverted V) braced frames (one for CBFs and another for EBFs with active link of 0.4m) have been developed in SAP 2000 and designed using IS 800 2007. The systems have been evaluated based upon two parameters – (a) ISD and (b) energy dissipation. Non-Linear Time history Analyses (NLTHA) have been performed to evaluate the performance of the above systems. On these basis, CBFs are found to be superior over EBFs for resisting lateral load.

Keywords: Earthquake resistance, Inter-storey drift, Energy dissipation, Serviceability



Influence of Source Offset on the Resolution of Dispersion Image

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Abstract

A non-invasive method called Multichannel analysis of surface waves (MASW), which has been used for geotechnical site characterization since the late 1990s, has become very prevalent. In field surveys, things like the quality of the input source and the geophone parameters (resolution, spacing, orientation layout) can have a big impact on the dispersion curve. This paper will look at how the distance between the source and the first geophone receiver (offset) affects the resolution of dispersion images in the MASW method. An experimentation site was chosen within the NIT Jamshedpur campus. According to borehole data, the location (22°46'37.2"N, 86°08'38.5"E) has a stiff silty clay soil (up to a depth of 5 m) followed by a dense to very dense weathered mica schist. A 10 kg sledgehammer was used to strike the striker plate, which generated surface waves that were recorded by 24 geophones (of 4.5 Hz frequency) arranged in a linear array pattern. Wave fields were recorded using a sampling frequency of 1000 Hz and a varying offset distance (1 m, 2 m, 4 m, 6 m, 8 m, 10 m, and 12 m) with 1 m geophone spacing and five stacking. Based on the results obtained, an optimum offset was determined as 8 m for 1000 Hz sampling frequency and 1 m geo-phone spacing, producing a high signal-to-noise ratio of 92%, resulting in an appropriate resolution of the dispersion image.

Keywords: Offset distance, Dispersion images, Active MASW, Geophones



Co-Seismic Deformation of Iran, 2021 Earthquake using DInSAR Technique

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Abstract

In the present study, the co-seismic deformation of an earthquake of Mw 6.4 magnitude (maximum intensity between VII-IX) occurred NNW side of the Bandar Abbas in Iran on 14th November 2021 at 12:08:38 (UTC) was estimated. The epicenter of the event was 27.73° N, 56.068° E with a focal depth of 10km. The epicentral region was near the southern margin of the collision zone of the Eurasian plate and the Arabian plate. Co-seismic de-formation of the earthquake was estimated using the differential InSAR (DInSAR) technique, which is carried out using microwave SAR data pairs from both ascending and descending pass of the Sentinel-1A satellite. LOS ground deformation for the Iran earthquake that occurred on 14th November 2021 is estimated using GMTSAR open software. SRTM DEM of 30 m is used in the processing of the SAR data. The preliminary results indicate that the earthquake deformation field has thrust fault characteristics. In ascending pass, subsidence of about -200 mm SSE side of the fault, i.e., away from the line of sight (LOS) of satellite and uplift of about 300 mm NNW side of the fault, i.e., towards the line of sight of the satellite. In descending pass, subsidence of about -135 mm SSE side of the fault and uplift of about 348 mm NNW side of the fault.

Keywords: Sentinel-1A, DInSAR, Co-seismic deformation, Thrust fault, Microwave SAR data



Dynamic Response Characteristics of RC Buildings with Irregularities

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Abstract

In today's world, it is observed that many modern structures contain structural irregularities such as irregularities in mass, stiffness, or structural form. Buildings with stories in the range of 7 to 15 are prevalent; these buildings often have structural irregularities for different purposes such as economy, aesthetics, space consideration, and such other. The performance of any building under the action of dynamic forces primarily depends on its configuration. [5] Former studies suggest that buildings with irregularities behave very differently as compared to the buildings with regular configurations. [4] One of the main reasons for RC building failure recognized from precedent earthquakes is structural irregularities in plan (horizontal irregularity) and elevation (vertical irregularity).

In the present research work, a seismically-excited 12-story building with different configurations and irregularities is analyzed using ETABS software. For study of horizontal irregularities, different plan configurations such as L-shape, C-shape, I-shape and plus shape are analyzed. The dynamic analysis is performed using response spectrum method and time history analysis, considering time histories of five Indian earthquakes, which occurred in zone V. The building parameters studied are story displacement, story drift, base shear, time period and modal frequencies. The results by both methods are presented. The performance of a regular rectangular shaped building is compared with that of the buildings of horizontal and vertical irregularities, to study the influence of horizontal and vertical irregularities.

The research work provides insight into the behavior of irregular structures under dynamic loading. It is found that the floor plan of the buildings has a significant impact on their seismic behaviour. Compared to regular shaped buildings more displacement, story drift and story shears are detected in buildings with severe plan and vertical geometric irregularities. In the vertical irregularity analysis, the vertical set-backs cause a sudden decrease in stiffness. Also, in buildings with soft stories due to parking or refugee areas, the stiffness decreases causing an increase in story drift and displacement. Most critical irregularity has been identified from the different irregularities considered for the study. The study will assist in identifying the suitable configurations, from seismic considerations.

Keywords: ETABS, Dynamic analysis, Response spectrum, Irregularities



Seismic Fragility Assessment of Aging Highway Bridge Considering Climate Change Effects

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Abstract

Highway bridges play an important role in sustained economic growth and societal development of any country. The behavior of reinforced concrete bridges may be adversely affected by climate change due to global warming. Along with continuous exposure to unfavorable weather conditions, bridges are also susceptible to intermittent damaging earthquakes. A case-study bridge located in high seismic region is selected, and a detailed finite element model of the bridge is developed by taking into account the time-dependent corrosion deterioration effects and nonlinear behavior. The corrosion deterioration model takes into account the climate change effects to estimate the lifetime corrosion of the reinforced concrete bridge. A set of ground motions that represents regional seismic hazard are used to conduct nonlinear time history analyses. Seismic fragility curves are developed at various time-instants along the service life, taking into account aging and climate change effects. The results show that the failure probability of a deteriorated bridge increases when compared to its pristine or as built condition, indicating the significance of taking into account the climate change effects when assessing seismic vulnerability.

Keywords: Reinforced concrete highway bridge, Climate change, Time-dependent corrosion Deterioration, Seismic fragility



Optimization of Single-Track PSC I-Girder for Metro Viaduct

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Abstract

Metro is becoming a popular mode of urban transportation in the rapidly developing modern world (India). There are two major components in a metro viaduct, substructure and superstructure. Various types of girders used in superstructure are U-Girder, Box Girder, I-Girder, etc. I-Girder is the focus of research in this paper. Design engineers involved in metro projects have used either codal provisions or previously laid down thumb rules for the design of I-Girder. Designs as per these standards give satisfactory results but optimizing the design to obtain an economical section needs further investigation. Optimization of I-Girder is a challenging task due to complexity and correlation among the variables. A large number of variables play an important role in the design of I-Girder such as span, depth of I-Girder, cross-section, grade of concrete, number of I-Girders, Pre/Post tensioning, number of strands, etc. This paper focuses on the computation of optimum cost for different spans and span to depth ratio for I-Girder under the influence of dynamic loading. FEM software Midas Civil is used for the analysis. Computation of results and graphical presentation is performed using MS Excel. Results presented in this study may provide a cost-effective guideline for the design solution of an I-Girder metro viaduct superstructure.

Keywords: Cost optimization, Pre-stressed I-girder, Dynamic analysis



Numerical Investigation of Steel Sheathed Cold Formed Steel Shear Wall Under Cyclic Loading Using Abaqus

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Abstract

Cold formed steel (CFS) is a general name for steel products that are treated at near room temperatures using cold-working methods. Wood, Gypsum board or OSB (Oriented Standard Board) sheathed shear walls, Strap braced walls, and steel sheathed shear walls are the most common CFS lateral framing systems used. There is limited research available on the seismic response of CFS shear walls. It is required to record and assess its lateral behavior at both the sub-system/member and system levels. The current study focuses on its behavior at system level subject to Monotonic and Cyclic Push. Commercially available Finite Element (FE) software, ABAQUS, is employed for numerical analysis of steel sheathed CFS shear wall. Structural members such as studs, tracks and sheathing are modeled using the shell elements. The effect of inelastic behavior of the screw connections modeled using Coupling constraint, MPC beam connector elements and SPRING2 elements on the overall numerical analysis has been compared. It has been observed that the Coupling Constraints underestimates the lateral strength vis-à-vis other modeling techniques. The lateral strength of the Steel sheathed CFS panel has also been compared for varying solution technique, screw spacing and material nonlinearity modelling techniques for CFS.

Keywords: Steel sheathed shear wall, Cold formed steel, Connection modeling, Loading protocols, ABAQUS



Structural Behaviour Assessment of Existing Reinforced Concrete Buildings under Earthquakes

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Abstract

The reinforced concrete (RC) buildings are a common sight in any urban environment and are often treated as a safe habitat. However, these myths have proved futile during devastating earthquakes (Bhuj (2001), Manipur (2016), Nepal (2015), Sikkim (2011) etc.,) which has exposed the weakness of engineered buildings in facing the eventuality. In view of this, seismic codes have undergone revisions with time to provide a safe and functional RC building design under earthquake forces. However, given the research updates resulting in revisions of seismic codes, there is a need to evaluate the performance of existing RC buildings ensuring conformity of latest code regulations. It has been reported that most of the existing RC buildings were constructed with or without seismic provisions and are proved to be vulnerable during a disastrous earthquake event. Hence, due to the necessity and importance of transforming these vulnerable building stocks into safe functional buildings, seismic structural assessment of RC buildings is a necessity. Therefore, RC multistoried building existing in Warangal city, Telangana State is considered as case study to visualize the structural behavior under earthquake forces. The nonlinear static analysis is performed on the structural model of the existing Multistoreyed RC building to evaluate its inelastic behavior. The outcome of this analysis envisages the structural capacity and its performance under design earthquake forces in terms of response parameters i.e., absolute horizontal displacement, inter storey drift (IDR) and ductility. Further, suitable repair/strengthening measures necessary for the building structure to remain functional at the chosen performance objective during its serviceable lifetime can be proposed. Moreover, the structural assessment of modified / strengthened structural model conforming to the latest IS (Indian Standard) codal provisions for the chosen performance objective, portray its structural behaviour and non-linear capacity achieved under design seismic load. It can be observed from the results, that existing old RC building possess limited or no ductility and modified /strengthened RC building structure has improved capacity and ductility. This approach of ensuring the functionality of the RC building configuration for the chosen performance objective needs to be extended for all existing RC buildings in any urban environment to arrive at safe functional and resilient habitat for the mankind.

Keywords: Nonlinear static analysis, Strengthening measures, Inelastic behaviour



Effect Of Saturated Porous Soil Medium on Seismic Wave Propagation

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Abstract

The seismic response of a structure depends on many factors such as earthquake fault properties, local site conditions like local topography, soil stratigraphy, soil saturation, and structure material. For structures like dams that are located near a large water body, to simulate a realistic site response, the effect of pore water on seismic wave propagation must be coupled with the local site conditions. The present study aims to investigate the effect of a fluid-saturated porous medium on seismic wave propagation at a fundamental level. The MASTODON/MOOSE software developed by Idaho National Laboratory is used for numerical analysis. A three-field coupled model (u-p-w) is implemented in a finite element framework to analyze the problem and verified using analytical results. Models of the 1D soil column and 2D idealized dam geometry in saturated and dry conditions subjected to vertically propagating Ricker SV wave are simulated. To isolate the impact of pore-water, the estimated response for each case is compared against similar scenarios with the dry condition. The results from this study give an insight into seismic wave propagation in saturated porous medium and will facilitate different structures' economical and optimal design and liquefaction studies.

Keywords: Wave propagation, Saturated porous medium, Dynamic response



Three Dimensional Crustal Velocity Structure of Tehri, Garhwal Himalaya

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Abstract

We estimated a three-dimensional (3D) structure of crustal velocity of Tehri, Garhwal Himalaya using seismic data of local earthquake events collected from January 2008 to December 2015 by a seismological network of 12 re-mote stations. The network is spread over an area of nearly 100 km × 80 km around Tehri dam. The study area between 29°50'N to 31°50'N latitude and 77°50'E to 80°E longitude, falls in the Garhwal Himalayan region of the central seismic gap between Main Central Thrust (MCT) and Main boundary Thrust (MBT). Inversions were performed simultaneously for P- and S-wave velocity anomalies and source coordinates. Dataset for tomographic inversions consists of 3543 local earthquake events with 29451 P- and 28692 S-wave picks. Results of inversion include P- and S-wave velocity anomalies and revised locations of earthquake sources. Tomograms of P- and S-wave velocity anomalies point to strong lateral heterogeneities in the region of investigation. Several zones of low velocity are depicted in the Lesser Himalayan region of the study area which indicates the presence of fluid filled structures in the region. Our velocity model shows that the Uttarkashi earthquake of 1991 is located at the transition zone of a high and a low velocity anomaly. Tomographic inversions could well resolve the investigated area up to a depth of 20 km.

Keywords: Tomography, Local earthquake data, Three-dimensional velocity model, Crustal velocity structure, Travel time inversion, Garhwal Himalaya



Formulation of Response Reduction Factor for Wall Type-Bridge Piers

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Abstract

The response reduction factor also known as R-factor is one of the most significant parameters in the force-based analysis to reduce the maximum considered seismic force by a level that is reliable with the implied ductile capacity of the structure under consideration. Currently, there is a notable difference in the values of response reduction factor for wall-type bridge piers as mentioned in the Indian standard codes as compared with the internationally referred code such as AASHTO, EN1998. The primary goal of this investigation is to formulate the response reduction factor for typical reinforced concrete (RC) wall type bridge piers located in a highly seismic zone in India by pushover analysis and to show how much conventional or non-conventional value is followed in the Indian standard codes and to formulate the most probable value of R-factor for wall type bridge piers, that are needed to be considered in the design. The nonlinear behavior, sequence, and mechanism of plastic hinge formation are carried out in the structural analysis program SAP2000.

Keywords: Pushover analysis, Response reduction factor, Wall type pier, SAP 2000



Experimental Investigation for Quantifying Damage Considering Soil-Structure Interaction Effect on a Small-Scale Model

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Abstract

Vibration-based damage detection techniques have gained popularity in structural health monitoring due to their non-destructive nature. Most of the experimental studies on buildings are developed considering fixed-base models without considering the underneath soil effect. The scope of the present study is to develop a realistic scenario of soil-structure interaction (SSI) through a small-scale model. The main objective is to determine structural damage based on the modal parameters by considering flexible base of the structure. For the experimental study, a 6-storey mild steel moment-resisting frame with single-bay on both sides has been designed. The length of the soil mass has been considered such that it imitates free-field response. By similitude laws, a geometric scale factor of 1:60 has been applied to finalize the small-scale model. An equivalent shear beam (ESB) container of aluminum and rubber layers has been developed to replicate soil dynamic response with minimum possible error. Fixed-base and flexible-base experiments have been performed for both the damaged and undamaged cases using APS400 long-stroke shaker. Results showed that structural damage can be localized as well as quantified with efficacy. The novelty of the study lies in modelling the effect of the semi-infinite soil layer under realistic base excitation by operating on a scaled-down model. The study also signifies the influence of SSI in determining structural damage.

Keywords: Damage identification, Soil-structure interaction, Small-scale model



A Comparative Study of the Performances of FPS and LRB Isolators installed in Building

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Abstract

The study investigates the seismic behavior of a ten-story base-isolated building frame with a Friction pendulum system (FPS) and Lead rubber bearing (LRB) as base isolators. A non-linear time history analysis is carried out to obtain various demand parameters like base shear, maximum inter-storey drift, peak top storey displacement, top absolute acceleration, residual displacement of the isolator, number of plastic hinges (NP), plastic rotation for three selected earthquakes. The earthquake time histories typically represent the far field (FF), near field earthquakes (NF) with two effects (forward directivity and fling step). The time histories are scaled at different PGA levels such as 0.2g, 0.4g, 0.6g, 0.8g. To investigate the response behaviour of building frame at low, moderate, and high PGA levels. For comparing the engineering demand parameters between the FPS and LRB isolated building frames the properties of the isolator are so selected that their backbone curves are comparable to a great extent. The non-linear time history analysis (NTHA) is carried out by commercial software SAP 2000. The result of the study shows that the performance of the base-isolated (BI) building frame in resisting seismic forces is greatly alleviated as compared to the fixed base (FB) frame at the considered PGA levels. Further, the overall performance of the BI building frame with the FPS system is better as compared to the performance of the BI building frame with LRB.

Keywords: Base isolation system, Sliding isolator, Elastomeric isolator, Non-linear time history analysis



Seismic Risk Assessment of Base-Isolated Liquid Storage Tanks with Friction-Pendulum System using Vector-Valued Intensity Measures

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Abstract

In the context of performance-based earthquake engineering (PBEE), seismic risk assessment of structures is performed considering various uncertainties in the input excitation and the structural system. Generally, the seismic risk is expressed in terms of the mean annual rate of exceeding a specified limit state for an assumed performance measure. Herein, seismic risk assessment of cylindrical liquid storage tanks with broad and slender configurations is evaluated when base-isolated with a friction pendulum system (FPS) considering different friction coefficients (μ). Efficiency analysis is performed to obtain suitable vector-valued intensity measures (vIMs) that ensure minimum deviation in seismic risk assessment. Fragility analysis is performed using stripe analysis, considering a defined damage state, in terms of the peak base shear ($V_{b,p}$) which is related to the elastic buckling of the tank wall, for a range of friction coefficients of the FPS. The annual joint probability of occurrence of the intensity measures (IMs) at the selected site is evaluated using vector-valued probabilistic seismic hazard analysis (VPSHA) and it is convoluted with the fragility functions for obtaining the seismic risk. The results are expressed in terms of the mean annual rate of exceedance of the base shear demand ($V_{b,d}$), λ_{EDP} , for the considered tanks at the selected site. It is observed that there is a sudden drop in the computed λ_{EDP} , which strongly depends on the friction coefficient.

Keywords: Base-isolated liquid storage tanks, Friction pendulum system, Vector-valued intensity measures, Seismic-risk assessment



Seismic Vibration Control of Jacket Platform with the aid of Tuned Liquid Dampers

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Abstract

For the offshore platform located in an active fault zone, earthquakes are a significant additional burden to the wave load. When mining and producing resources from the ocean, jacket platforms are frequently exposed to a variety of environmental stresses, including waves, strong winds, earthquakes, tsunamis, etc. Jacket platforms are more susceptible to seismic loads because of their inflexible design. The goal of the current investigation is to determine how well Tuned Liquid Dampers (TLD) manage the earthquake-induced responses of jacket platforms. A linear time history analysis is performed in SAP2000, with and without TLDs. The TLD behavior has been simulated using a simplified lumped mass model. The efficiency of TLD was evaluated for three different seismic excitations in order to determine its durability. For the purpose of examining the impact of various factors on the functionality of the TLD, the effectiveness of TLDs is explored for variable depth ratio, mass ratio, and structural damping. The general conclusions of the numerical investigation show that TLD has the ability to regulate the jacket deck vibrations under seismic excitation.

Keywords: Jacket platform, Tuned liquid damper, Seismic load



Effect of Stiffness and Strength of URM Infill Walls on Seismic Demands and Response of RC Buildings with Open Ground Storey

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Abstract

In urban reinforced concrete buildings, ground storeys are usually left open to facilitate parking. The earlier and common practice of designing frame members in the open storeys using a scale factor increases member sizes and thereby improves its stiffness and strength. But, this improvement needs to be seen relative to the stiffness and strength of the masonry infill panels in the upper storeys; performance of improved (with increased member sizes and reinforcement) members in open ground storey buildings is largely dependent on the type of masonry infill panels, namely, soft and weak masonry or stiff and strong masonry, present in the storeys above. The effect of type of masonry infills on seismic response of buildings with open ground storey, designed for different seismic demands, is discussed in this paper. Nonlinear static analysis investigations are presented on formation of undesirable storey collapse mechanism in such open ground storey buildings with stiff and strong masonry infills in upper floors. On the other hand, over-designing the open ground storey frame members leads to storey mechanism in the first storey, when infills are soft and weak. Therefore, it is recommended that any solution for improving earthquake behaviour of buildings with open ground storey should also consider stiffness and strength of masonry infills in adjacent storeys. In addition, this study suggests that design of columns for shear demand with increase in drift demand cannot be overlooked, especially in buildings located in high seismic regions. Thus, it is recommended that special confining reinforcements be provided throughout the height of column, as against the current practice of providing special confining reinforcement over a distance $2d$ from both ends alone, where d is the effective depth of the section, to avoid possible shear failure in columns before flexural yielding.

Keywords: Open storey, Masonry infills, Shear demand, Nonlinear static analysis



Estimation of Shear Strain Magnitude due to Impact Z Section Sheet Pile Driving

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Abstract

The rapid growth of infrastructure development in metropolitan cities is increasing in tandem with human evolution. The vibration associated with various construction activities is one of the primary issues that have evolved during infrastructure development in metropolitan cities. The construction-induced vibrations mainly occur due to pile driving, blasting, dynamic compaction, and the operation of heavy machinery on site. The dynamic behavior of the soil medium primarily depends on the magnitude of the shear strain developed in the soil media while the pile penetrates. The development of the magnitude of shear strain due to construction-induced vibration is essential to understand the soil's stiffness characteristics during pile driving. The magnitude of shear strain induced in the soil medium depends on the vibration amplitude with frequency-dependent wave velocity. A field study has been carried out to determine the ground motion parameters during impact sheet pile driving. The ground motion parameter has been obtained in terms of peak particle velocity (mm/s) with varying radial distances of 5 m to 20 m from the alignment of the sheet pile driving. The 750 kg drop hammer has been used to drive the Z section sheet pile up to a depth of 12 m from ground level. The present research work mainly focuses on estimating the shear strain magnitude induced along or very near the ground surface. The current approach relies on the wave propagation method to estimate the shear strain amplitude during Z section sheet pile driving. The values of maximum shear strain induced near the soil surface are 4.1 %, 3.65 %, 3.18 %, and 1.54 % at radial distances of 5 m, 10 m, 15 m, and 20 m, respectively during the driving of the Z section sheet pile.

Keywords: Shear strain magnitude, Impact hammer, Z section sheet pile driving, Construction induced vibration, Peak particle velocity

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 71



Numerical Modelling of Infill Panel_ Review and Application

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Abstract

Infill panels have shown far-fetched effects on the global response of infilled framed structures during seismic actions. Regardless of this, the infill panels are, in general, considered non-structural elements due to complex analysis. However, in the past few decades, researchers have developed several numerical models that attempt to depict the actual behaviour of the infilled frames. In this article, a state-of-the-art review of the numerical models for infill panels is presented with emphasis on the macro model where the infill panel is modelled as an equivalent strut. In addition, the nonlinear analysis of infilled framed structure is carried out to discuss the application of one of the simplest yet efficient multi-strut models.

Keywords: Infill panel, Nonlinear analysis, Multi-strut model



Influence of Biaxial Interaction in Bouc-Wen Hysteresis Model used for Modeling High Damping Rubber Bearing under Bi-Directional Excitation

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Abstract

The uniaxial Bouc-Wen hysteresis model is well established for simulating the bearing behavior in unidirectional excitations. However, the real scenario is quite different as seismic control devices like high damping rubber bearing exhibits the influence of the orthogonal excitations. In the current work, the feasibility of modelling the high damping rubber bearing (HDRB) using biaxial Bouc-Wen model is established. Further, the comparison of uniaxial Bouc-Wen and biaxial Bouc-Wen model is made for HDRB through responses and the correlation coefficients. The effect of bi-directional coupling compared with the uniaxial model is investigated for ten real earthquake input excitations. Further, the results validate the suitability of the biaxial Bouc-Wen model for simulating the interaction effects among HDRB. The changes in the correlation coefficients are significant when interaction is considered. Moreover, it was found that there is under estimation of peak displacement if interaction effects are ignored.

Keywords: Bouc Wen model, Biaxial Bouc Wen model, High damping rubber bearing, Interaction effects



Correlation between Cone Tip Resistance and Shear Wave Velocity at Quaternary Alluvium

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Abstract

Several correlations were envisaged in the literature to find out shear wave velocity (V_s) using cone penetration test (CPT) data, but still, a considerable discrepancy is found when CPT correlations are compared for the studied site. A comparison study is conducted with the previously given correlations which also shows the requirement of developing a new correlation for the site. Empirical correlations have been derived in this study from measured field data at 5 sites in the IIT Patna Campus for the estimation of shear wave velocity using CPT data. The shear stress-related parameter, i.e., shear wave velocity is defined in terms of various parameters obtained from the CPT. Various parameters such as cone tip resistance (q_c), soil behaviour Index (IC), effective stress (σ'_0), and depth (z) are correlated with V_s because some factors are interrelated, like the soil layer's ageing, effective confining stress, etc. Regression analysis is carried out to correlate V_s with q_c , I_C , σ'_0 and z . Empirical correlations are developed for a site and validated with the rest of the other locations in the campus area. This research will help to predict the subsurface material properties by reducing the overall time and cost of an investigation. By using this correlation, important soil parameters used in design can be obtained more accurately with only CPT data.

Keywords: Shear wave velocity, CPT, Correlation, Penetration tests, Quaternary alluvium



Response Reduction Factor of Open Ground Storey Reinforced Concrete Buildings with and without Haunch.

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Abstract

The key feature of open ground storey (OGS) reinforced concrete (RC) framed building is to facilitate parking by keeping the ground storey open, without the use of infill walls. However, in the past, such framed structures have been found to perform poorly during seismic events. For instance, during the Bhuj earthquake in 2001, open ground storey type buildings were found to have failed the most. In open ground storey buildings subjected to earthquake loading collapse mechanisms are generally initiated due to higher flexible (soft)-storey behavior of ground storey than the storey above. Furthermore, the inability of the ground storey to not withstand horizontal motions during the earthquake drives this failure process. Therefore, the aim of this work is to propose a novel solution for open ground storey problems so that its seismic vulnerability can be reduced. In this study, a unique shape of column i.e., haunched shape column has been proposed which will provide good strength, stiffness as well as a good solution to open ground storey buildings problems without hampering the parking space in urban housing perspective. The open ground storey RC buildings having 3, 4, 5, and 6-storeys with and without haunches has been modelled and analyzed by adaptive pushover method in Seismostruct software. The analyses are carried out for open ground storey RC building models with and without haunches. It has been observed that the response reduction factor, overstrength factor and peak base shear of open ground storey RC buildings with haunches are significantly higher as compared to the buildings without haunches. It is also noted that the evaluated response reduction factors for open ground storey RC building with haunch are higher than the recommended value by BIS code.

Keywords: Open ground storey, Soft-storey, Adaptive pushover analysis, Pushover analysis, Response reduction factor, Overstrength factor, Ductility, Ductility reduction factor, Peak base shear



Recovery-Based Seismic Resilience Assessment of IS Code-Conforming RC Buildings

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Abstract

Earthquake-induced damage to various structural and non-structural building components results in direct and indirect losses and hinders achieving desired performance objectives such as immediate occupancy after the event. Modern code-compliant buildings prove adequate to meet collapse-prevention and life-safety performance requirements and reduce the risk of casualty. However, the buildings may experience long downtime and disruption. The conventional approaches traditionally focus on structural damage and loss immediately following an earthquake and do not consider post-event parameters to quantify recovery. The present study considers resilience by including repair time and cost under the performance-based earthquake engineering framework. The study also takes into account the collapse potential and damage beyond repairability. The study also examines likelihood of unsafe placard. The implementation of the framework is demonstrated on three archetypical special moment-resisting reinforced concrete (RC) frame buildings. It considers component-level fragility and consequence functions for structural and non-structural components. Monte Carlo simulations are used to account for uncertainties in structural response, damage, repair costs and repair time. The empirical and lognormal-fit performance curves for repair cost ratio and repair time are developed, and the range, mean, median, and 90th percentile values are reported. The contribution of structural and non-structural damage to different performance indicators has been investigated. The results indicate that the buildings in high seismic areas in India are likely to suffer extensive damage, resulting in unacceptably high economic loss and downtime, and thus trigger the need to revisit the current design provisions, and promote recovery-based design approaches.

Keywords: Seismic performance assessment, Repair cost, Repair time, Unsafe placards, Recovery-based design, Performance-based engineering



Simulation of Interaction Properties in Confined Masonry Walls at Wall-to-Tie-Column Interface

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Abstract

The confined masonry (CM) structure consists of load bearing walls strengthened with nominally reinforced concrete tie-elements at the perimeter and other key locations. The confined masonry system has evolved based on its satisfactory performance in past earthquakes and can be considered as one of the most suitable alternatives to seismically vulnerable unreinforced masonry systems due to its similar construction practice and economic feasibility. Thus, various numerical studies using finite element (FE) analysis have been performed on CM walls for a better understanding of their response under in-plane and out-of-plane loads. For reliable FE analysis, it is important to simulate the interaction behavior at the wall-to-tie-column interface in CM walls. The current method of defining the wall-to-tie column interaction for FE analysis is to consider both masonry wall and tie-column as monolith. However, this simplified assumption results in stiffer response of the CM wall. Thus, in the present study, the wall-to-tie-column interaction properties were evaluated using experimental and analytical investigation. Initially, tension and shear bond tests were conducted on sub-assemblages consisting of masonry and concrete. The tensile and shear bond properties obtained from the experiments were used to calibrate the cohesive and friction interaction properties for FE analysis. Using the iterative procedure for fine-tuning the interaction properties, a reasonable match was achieved between the experimental and numerical simulations. Finally, the interaction properties such as bond stiffness, damage initiation, and evaluation criteria were proposed for simulating the wall-to-tie-column interaction in CM walls.

Keywords: Confined masonry, Interaction properties, In-plane load response, Cohesive and friction properties, Numerical modelling



Parametric Finite Element Analysis of Confined Masonry Walls Strengthened with Fabric Reinforced Cementitious Matrix

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Abstract

Confined masonry (CM) construction is popularly practiced in many countries as it generally performs better than unreinforced masonry and non-ductile RC infill masonry under seismic loads. However, the confined masonry buildings have also experienced damage during past earthquakes. Poor seismic performance is generally seen due to construction errors, design flaws or material deficiencies in the building design and construction process. To overcome these deficiencies, there is a need to strengthen the confined masonry structures. Thus, this paper focuses on developing a numerical model to study the in-plane seismic behavior of CM walls strengthened using Fabric Reinforced Cementitious Matrix (FRCM). Based on previous experiments and literature studies, a three dimensional (3D) finite element macro-modelling technique was developed using the commercial software package ABAQUS for solid CM walls and infill-RC wall strengthened with glass FRCM.

The strength and stiffness degradation of masonry, cementitious matrix and concrete was defined using Concrete Damaged Plasticity (CDP), which is a damaged plasticity-based continuum constitutive model. The masonry panel, RC tie-frame, strengthening composite and reinforcements were discretely modelled. The calibrated FE model showed close prediction of numerical results with the past experiments. Thus, the proposed model was used to conduct the parametric FE study on CM walls strengthened with FRCM. Three different aspect ratios for solid CM walls, masonry strengths and different type of FRCM composites were considered for this parametric study. In addition, the effect of one side and two-sided strengthening was taken into consideration. The results of parametric study provide understanding on influence of various parameters on the lateral load response of CM walls strengthened with FRCM.

Keywords: Finite element modelling, FRCM strengthening, Confined masonry



Site Specific Response Spectrum Analysis of Various Wall-frame Composite Tall Buildings

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Abstract

Consideration of site-specific response spectrum for seismic analysis helps in creating efficient structures. The present study examines the influence of site-specific response spectra and time histories derived based on the Bhuj earthquake on the composite tall buildings with a wall-frame lateral load resisting system. The research considered 24, 44, and 64-story composite tall buildings with plan dimensions of 48 m × 48 m and located at three distinct sites in Ahmedabad. ProSHAKE software is used to develop site-specific response spectra and time histories. The software ETABS is utilised to perform site-specific response spectrum and acceleration time history analysis, in addition to conventional response spectrum analysis of wall-frame buildings in accordance with IS 1893 (Part 1): 2016. Various shear wall locations are explored to meet the criteria of relevant Indian standards. This paper compares the analysis and design outcomes for tall buildings' strength and serviceability criteria such as the time period, base shear, story displacement, inter-story drift ratio, and design forces, as determined by site-specific response spectrum and time history, in addition to response spectrum analysis as specified in IS 1893 (Part 1): 2016. The results of these analyses indicate that site-specific response spectra influence both the serviceability requirements for tall buildings and the design of structural elements in 24- and 44-story tall buildings. Additionally, it is established that buildings with shear walls at the centre of core faces performed better in terms of meeting the strength and serviceability criteria for tall buildings.

Keywords: Site-specific response spectrum, Time history analysis, Tall building, Composite Structure



A Comparative Study of Computational Modelling Frameworks for Structural Assessment of Reinforced Concrete Beam

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Abstract

Computational models play an important role in assessing the structural response of reinforced concrete (RC) buildings under seismic excitation. The computational modelling frameworks available for RC structures are i) macro-element modelling, ii) high fidelity 3D finite element modelling, and iii) multi-scale modelling with the adoption of sub-structure technique. Macro-element models are computationally least demanding but require extensive calibration for simulating the inelastic responses of RC members and connections with complex details. Further, 3D finite element models require minimal calibration for modelling complex RC members and connections but are computationally challenging. In contrast, the multi-scale computational framework adopts 3D finite element modelling at complex detail regions and macro-elements for the rest of the structure to provide a balance between computational efficiency and calibration complexity. This paper presents the simulation of an RC beam under linear and nonlinear analysis along with the analytical or experimental validation to assess the efficacy of abovementioned computational frameworks for modelling the elastic and inelastic responses of RC structures. Considering experimental results as the benchmark while predicting the inelastic response; capacity curve, estimated toughness and the computation time were used to compare the reliability and computational efficiency of abovementioned modelling frameworks. The findings show that all three computational frameworks can predict the elastic response of an RC beam close to analytical results. However, the 3D finite element and multi-scale models gave better prediction of the inelastic response of the RC beam in comparison to macro element model. The computation time taken by the three modelling techniques was maximum for the 3D finite element, intermediate for the multi-scale and minimum for the macro element model. Hence, obtained results validates the computational efficacy of multi-scale model while predicting the inelastic response of a structure accurately.

Keywords: Finite element model, Macro element model, Multi-scale model, Toughness, Computational efficiency.



Experimental Investigation on Small-Scale MR Damper With Frequency Variation for Seismic Resistant Structure

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Abstract

The magneto-rheological (MR) damper is one of the most sophisticated applications in the field of semi-active control devices. Its popularity is growing on a daily basis as a result of its numerous benefits and diverse applications. When the viscosity of the MR damper's internal MR fluid is changed, the force delivered by the MR damper changes. Most MR damper modeling and simulation have been completed without much experimental study, which has been accomplished by taking fundamental factors into account. The performance of a small-scale MR damper designed and manufactured was tested experimentally using an MTS Servo Hydraulic 311.31 system. To accurately characterize the MR damper behavior, it was tested experimentally for two different displacements at different excitation frequencies. The forces developed by the MR damper, as well as the relationship between governing frequency, velocity, displacement, and maximum energy dissipation by the MR damper, have been studied and presented in this paper based on experimental findings.

Keywords: MR damper, MR fluid, Displacement, Frequency, MTS Suite



A Comparative Study of Seismic Performance of RC Frame-Wall Structures Designed as Per Various Inter-National Codes

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Abstract

The structures now are rapidly growing vertically instead of horizontally and for taller buildings, consideration of lateral load is extremely important. Earthquakes are one of the most disastrous forces, which has caused immense loss of life and property in past decades. Seismic design of building has been undergoing a major revolution in recent years, with importance changing from strength to performance. The present study focuses on comparison of seismic performance of RC frame-wall building designed as per three national seismic design codes viz. Indian Code (IS 1893 Part I-2016), American Code (ASCE 7-10), and European Code (EN 1998-1 2004, Eurocode 8). Illustrative problems of 15, 18, 22, and 26 storey frames are analyzed and designed for Indian, American and European design provisions, considering both seismic and gravity loads. Performance evaluation of frames are done using nonlinear static pushover analysis and non linear time history analysis (NLTHA) using SeismoStruct software for set of 6 spectrum compatible artificial ground motions and a strong and weak ground motion of past earthquakes of India, America and Europe. It is observed from results of NLTHA that drift limit in terms of interstorey drift ratio has not exceeded the drift limit of 2%. Hence, buildings showed satisfactory performance when evaluated by a set of artificial as well as natural ground motions.

Keywords: Performance evaluation, International codes, RC frame-wall structures, Non-linear time history analysis, Static pushover analysis



Seismic Design of Periphery RC Beams in Buildings With Large Plan Aspect Ratio

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Abstract

Seismic behavior of buildings with large plan aspect ratio is affected by the in-plane flexibility of the floor diaphragms. Generally, reinforced concrete (RC) monolithic slab–beam system with plan aspect ratio less than or equal to 3 is considered to provide rigid diaphragm action. This helps in distribution of lateral load to the individual lateral load resisting systems in proportion to their stiffness. According to Indian Standard, a diaphragm is considered to be flexible if it deforms such that the maximum in-plane displacement is more than 1.2 times the average displacement of its ends. This study presents quantitatively additional reinforcement requirement in the periphery beams of buildings, arising due to in-plane flexibility of floor diaphragms with large plan aspect ratios. For the purpose, buildings with various plan aspect ratios are studied including the influence of different configuration of RC structural walls and URM brick infill. It is observed that 5% to about 240% more longitudinal reinforcement is required in the periphery beams to resist the additional tensile forces induced in them due to in-plane flexibility of the floor diaphragms.

Keywords: In-plane bending, Diaphragm, Axial tension, P-M interaction, Shear design



Ground Motion Predictive Equations And Its Applicability In North-Eastern Indian Region: A Critical Ap- Praisal

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Abstract

The level of ground shaking, to which earthquake-resistant structures are subjected, is estimated using Ground Motion Prediction Equation (GMPE) in terms of ground motion parameters. More than 1000 GMPEs worldwide and more than 50 GMPEs for India are available to estimate ground motion parameters like PGA, PGV, PGD, spectral acceleration, etc. However, the selection of a GMPE for seismic hazard analysis, out of available ground motion models becomes a critical task for seismic hazard analysis. In the present study, the GMPEs were selected for the Northeast region of India according to qualitative analysis and then ranked to those GMPEs for their suitability using the quantitative information-theoretic approach, based on the estimation of the Log-Likelihood value. Further, the ranking of models for discrete ranges of distance was estimated considering respective weights for the Northeast region. Based on the variable performance of models, for the different range of data, it has been observed that NDMA (2010) and Bajaj and Anbazhagan (2019) are the best-suited model for the study area. However, the weighted ground motion models have shown the efficiency and robustness in the process of selecting and ranking GMPEs for diverse applications, particularly for the Northeast Indian region, which has witnessed some devastating earthquakes in past and is vulnerable as per seismic hazard analysis.

Keywords: Ground motion, GMPE, PGA, LLH



Damping Characteristics of Next-Gen Masonry Infilled RC Panels: Experimental Investigations

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Abstract

Current construction practices adopt next-gen masonry infilled Reinforced Concrete panels with Autoclaved Aerated Concrete (AAC) Block and Fly Ash Brick (FAB) replacing conventional Red Clay brick as masonry infill. Present paper aims to evaluate damping coefficient for RC panel infilled with various types of masonry materials. Scaled test specimens of RC panels infilled with FAB and AAC Block, cast non-integrally, have been prepared. Masonry infills are expected to alter the dynamic response of the RC panel due to varied damping characteristics of an individual element under dynamic loading. Pseudo-static or Pseudo-dynamic test are mostly performed to estimate equivalent viscous damping coefficient of infilled RC panel. However, damping estimation can be done through free vibration test for lightly damped linear systems. Experimental programme has been developed comprising of masonry prism and masonry infilled RC panel test specimens with relevant instrumentation to perform free vibration tests at Heavy Structures Laboratory (HSL). The programme has been extended further to investigate the variation of damping coefficient with ensuing damage in infill/RC elements due to pseudo-static testing with increasing force controlled loading protocol through hydraulic jack on infilled RC panel test specimens. Free vibration test has been performed before each cycle of loading protocol of pseudo-static testing by imparting initial velocity on test specimens. Free vibration test on masonry prisms revealed that inherent viscous damping coefficient of AAC block prisms for in-plane direction yields average 32% higher value than FAB block prisms. For RC infilled test specimens, the damping coefficient was found to increase with the progression of damage in infills and RC panels under pseudo-static testing. AAC block infilled RC panels yielded average damping coefficient values ~ 20% higher as compared to FAB infilled RC panels.

Keywords: Free vibration test, AAC masonry prism, Damping coefficient, Infilled RC panels, Pseudo-static test, Infilled RC panel



A Fragility Analysis of Retrofitted RC Bridge Damaged Under Severe Earthquake

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Abstract

Historic and old RC bridges are more vulnerable in an event of an earthquake either due to lack of ductility or lack of the practice of incorporating seismic guidelines in earlier design codes. Thus, these structures require structural strengthening. To assess the effectiveness of a chosen retrofitting technique, a study is carried out using RC jacketing on columns of bridge using the seismic fragility analysis under earthquake events. The study is implemented separately on isolated columns and columns of a box-girder bridge. Performance levels are compared in terms of fragility for minor damage state to the collapse damage state. Varying performance under slight and extensive damage states is observed. RC jacketing is observed to be effectively contributing to enhancing the performance under collapsed damage state based on assessed fragility curve using non-linear time history analysis. This study is useful to decide the efficacy of a particular method to rehabilitate seismically damaged bridges.

Keywords: Bridge pier, Seismic hazard, Jacketing, Rehabilitation, Fragility



Probabilistic Mapping of Ground Displacement Hazard for Allah Bund Fault

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Abstract

The seismic hazard is most commonly described in terms of various parameters defining the intensity ground shaking. Other parameters like liquefaction potential, landslides, ground subsidence, tsunami etc. have been also used. However, permanent ground displacement due to surface rupture along a fault is also an important parameter to be used for characterization of seismic hazard and it occurs only on the fault unlike other hazards. This can cause tremendous damages especially to lifeline structures such as highway bridges, tunnels, buried pipelines (oil and gas pipelines), etc. if they lie across a fault. This study emphasizes the need of estimation of ground displacement using the Probabilistic Seismic Hazard Analysis (PSHA) method. Various examples resulting in the damages due to permanent ground displacement followed by the earthquakes displaying vertical displacements has been presented. Necessary modifications in the commonly used Probabilistic Seismic Hazard Analysis (PSHA) approach have been described for its application to permanent ground displacement which in turn can be helpful to mitigate the risk on buried lifeline system.

Keywords: Probabilistic, Ground displacement hazard, Lifelines



Vibration Characteristics of Gravity Dams for Varying Reservoir and Tailwater Heights, and Interaction Effects

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Abstract

Vibration characteristics i.e., natural frequency and mode shape of structure or structural component are essential parameters in its earthquake resistant design. Modal analysis helps to calculate natural frequencies and mode shapes of the structure in free vibration. The present paper investigates the modal analysis of the gravity dams for varying reservoir and tailwater heights and interaction effects. For modal analysis, two gravity dams (e.g., Koyna and Outardes-3 gravity dams) are chosen. The Lanczos algorithm is used in Abaqus to find out dams un-damped natural frequencies and mode shapes. Various reservoir and tailwater heights are considered for the gravity dams. In addition, the effect of dam-foundation-reservoir and dam-reservoir interaction are considered for the modal analysis of the gravity dam. In finite element meshing, a 4 node plane strain elements are utilized for modeling purpose of both the dam and foundation domains; whereas, a 4 node acoustic elements are used to model the reservoir domain. The effect of reservoir surface waves is not considered in the numerical study. In modal analysis, lower reservoir water level causes more horizontal crest deformation; however, the consideration of higher reservoir and tail water levels of the dam makes it more flexible; and thus reduces the system's natural frequencies. As compared to dam-reservoir interaction, dam-foundation-reservoir interaction causes lower natural frequency for the system.

Keywords: Gravity dam, Reservoir and tailwater heights, Dam-foundation-reservoir interaction, Dam-reservoir interaction, Modal analysis



Risk-Targeted Seismic Design of Critical Buildings Using Force-Based Method

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Abstract

Critical buildings such as hospitals, communication facilities, and

emergency operations centers play vital roles during the response to extreme seismic events. Recent research shows that the inability to ensure continued functionality of such buildings in the aftermath of an earthquake severely impacts the post-disaster response and recovery. Importance factors have been used in the prescriptive force-based design standards to increase the seismic design forces and thereby provide higher safety for such buildings. These importance factors are based on judgment and the associated enhancement of the performance of buildings is not quantified. The present paper describes a generalized risk-targeted importance factor formulation meeting pre-specified seismic risk target levels that is suitable for use with prescriptive force-based design standards. The framework extends the performance-based seismic design methodology to calibrate the risk-targeted importance factors. The framework also accounts for the uncertainty in seismic demand, structural capacity, and inter-building variation within a specific typology. Sensitivity studies for parameter selection are also presented. The methodology is applied to special RC moment frame archetype buildings located in two metropolises in high and very high seismic regions of India (Delhi in Zone IV and Guwahati in Zone V). The paper shows that regular RC moment frame building typology conforming to Indian Standards has an additional risk margin of 25–30% for important buildings (importance factor 1.2) and 65–85% for critical buildings (importance factor of 1.5). The study underlines the need to consider both the seismic hazard and the structural response for the design of critical buildings requiring enhanced performance.

Keywords: Important buildings, Risk-targeted Seismic design, Performance-based seismic design, Disaster risk reduction, Force-based Design, Importance factor



Comparative Performance Analysis of Post Tensioned Hybrid Concrete Shear Wall with Openings Under Monotonic and Cyclic Loading

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Abstract

Damage is more likely to occur with substantial residual lateral displacements and wide residual cracks in traditional RC shear wall structures. There has been a growing body of experimental research on self-centering structural systems in the recent past that can sustain severe earthquake motions with minimal residual damages. In the present study, to address the short-comings of traditional shear walls, post-tensioned (PT) tendons are utilized along with external energy dissipating reinforcement (EDR) in the form of mild steel bars to facilitate higher energy dissipation. This proposed system is expected to make it easier to repair the wall after an earthquake and to keep it ready for the next seismic shock. A numerical study has been carried out to fully understand the behaviour of the proposed hybrid shear wall. Effect of various parameters like post-tensioning force, aspect ratio and tendon profile has been taken into account. To study the performance of this resilient shear wall system further, openings has been provided and the shear wall has been analyzed for both monotonic and cyclic loading. The results of the study depict that aspect ratio plays an important role. It was observed that, the specimens with a lower aspect ratio (2-3), the yielding of EDR began early. The aspect ratio of 2.4-3.4 was found to exhibit desirable features and can be used in practice. Literatures suggest that effective prestressing force can improve a structure's resistance to lateral deformations. From the analysis, it was observed that to achieve the desired seismic performance and increase the lateral load carrying capacity, a minimum prestressing force of 0.4 times the ultimate stress in PT tendon (f_{pu}) is required. A comparison between rectangular, square, circular and diamond opening with respect to its performance to full wall without opening under monotonic and cyclic loading has been performed. A suitable configuration is suggested based on the obtained results such as base shear, ultimate and yield stiffness and ductility.

Keywords: Resilient systems, Shear wall, Post-tensioned tendons, Energy dissipating reinforcements, Rocking behaviour



Influence of Site-City Interaction on the Response of Buildings on Trapezoidal Basin

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Abstract

The paper presents the response of cluster of buildings located on soft sediment in double resonance situation. In order to comprehend the influence of Site-city interaction on the response of the buildings, two symmetrical models- Cluster 1 (9 buildings) and Cluster 2 (25 buildings) situated on trapezoidal shaped basin are simulated using Finite Difference algorithm. The analysis of FDM simulation for 3D SCI reveals a reduction in spectral amplitude at natural frequency of building which increases with the number of buildings. The reduction of spectral amplitude is of the order of 65% in the case of cluster 2 with 25 buildings as compared to standalone building located at the centre of closed 3D trapezoidal basin. The S-wave response of buildings shows much larger value of spectral amplitude (approx. 180) for standalone building for 3D analysis in comparison with that of 2D analysis for SH and SV-wave and also there is larger reduction of SAF (Spectral Amplification Factor) at fundamental frequency with the splitting of bandwidth for both Cluster 1 and Cluster 2. These findings call for the urgent need of 3D Site-City Interaction studies in urban environment in development of the seismic resilient and sustainable city.

Keywords: Site-city interaction, Basin effects, S-wave response

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 117



Study of Liquefaction Potential at Jaigarh Port Using Standard Penetration Test Data and Consequences: A Case Study

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Abstract

Indian ports are rapidly expanding their infrastructures all along the coastlines. Many of the important ports are located in seismically active zones. The paper presents the study of liquefaction Potential and analysis is carried out for Jaigarh Port at Ratnagiri, Maharashtra. The focus is mainly on determination of liquefiable layers in the region of multi-layered soil stratigraphy. The SPT data shows that the ground is composed of loose sand with silt underlain by basalt rock (-15 m from Natural Ground Level or NGL). The water table at shallow depth and loose sand in the reclaimed fills make the area susceptible to liquefaction hazards. The IS 1893 Part 1: 2016 is used to figure out the ground safety factor (FOS) against liquefaction for the Port. The soil tests and subsequent quantitative analysis suggest potential liquefaction of loose upper layers.

Keywords: Liquefaction, SPT, Reclaimed fill



Seismic Assessment of Deep Tunnel in Near Fault Ground Motion

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Abstract

Underground tunnels are an essential part of transportation and utility networks, and their vulnerability to earthquakes has significant socio-economic impacts. Tunnels have suffered substantial damage in past earthquakes, including the 2008 Wenchuan (China) earthquake, the 1995 Kobe (Japan) earthquake, the 2004 Niigata (Japan) earthquake, and the 1999 Chi-Chi (Taiwan) earthquake. Past studies on the 2D plane strain analysis of tunnel cross-sections subjected to vertically propagating seismic waves provide essential insights on the racking and ovaling of the tunnel cross-section during an earthquake. However, during the recent 2008 Wenchuan (China) earthquake, tunnels located near earthquake faults suffered damage not just to the cross-section but also in the longitudinal direction, which previous 2D studies cannot explain. The primary reason for the failure of the 2D studies in these near-fault scenarios is because the wave field near the fault is much more complex than a simple vertically propagating seismic wave. Therefore, a 2D plane strain approximation of the problem considering only the tunnel cross-section subjected to a uniform vertically propagating seismic loading in the out-of-plane direction is no longer valid in this case. The present study aims at understanding the coupled longitudinal and transverse response of underground tunnels subjected to obliquely incident (with respect to tunnel axis) seismic waves. The wave fields are generated through earthquake fault rupture simulations using earthquake faults with different dip angles. The numerical simulation of the soil-tunnel system is conducted using the open-source finite element software called MASTODON, developed by Idaho National Laboratory. Four different earthquake fault rupture scenarios for 2D and 3D are considered for this study. Analysis results reveal that the seismic responses of the tunnels increase with the increase in dip angle up to a fault dip of 45°. Additionally, the results showed that the 3D model needs to be considered for more general earthquake scenarios to capture both in-plane and out-of-plane responses (bending and cross-sectional changes) of the tunnel structure during the seismic loading.

Keywords: Underground tunnels, Seismic analysis, Soil-structure interaction, Seismic wave propagation, Longitudinal seismic response



Comparison of Base Isolation and Concentric Braced Frame Systems For EQRD - A Case Study

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Abstract

Swift and effective measures are needed to sustain economic growth and the general welfare of earthquake-struck countries. The economic consequence of earthquakes may occur both before and after the seismic event itself. Base isolators, bracings, and shear walls are three major systems to meet the demand for earthquake-resistant structures. The base-isolated system isolates the structure from the horizontal component of the ground motion by placing an element having lower horizontal stiffness between the structure and the foundation. The study has been broadly classified into two parts. In 1st part, an economic comparison is made between the fixed base braced steel building and the base-isolated steel building. Both buildings have been designed for MCE (Maximum Considered Earthquake). From this study, fixed base braced system is found to be more economical than base-isolated system under MCE conditions. In the 2nd part, non-linear time history analysis (NLTHA) has been performed to evaluate the dynamic characteristics of ground motion on the base isolation system. It is observed that the base-isolation system is most efficiently used for those structures that are in resonance with ground motion.

Keywords: Base-isolated system, Braced frame system, Cost effectiveness, Non-linear time history analysis



Effect of Reinforced Soil Interaction with Other Components on Static and Dynamic Performance of MSE Wall

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Abstract

Mechanically stabilized earth (MSE) walls are reputed for demonstrating improved static and seismic performance over conventional retaining walls. The stabilization of the earth is generally done by placing reinforcing elements such as metal strips, geosynthetic layers or micro-piles in different layers of the backfill soil. There is no scarcity of literature on numerical analysis of MSE walls for both static and dynamic loading. However, the present state of the research lacks a comprehensive analysis of the combined effect of the various contributing factors on the performance of the wall. The reinforced fill interacts with other components, namely the wall, retained fill, reinforcement and foundation. Under operational conditions all these interactions occur simultaneously and therefore also have a combined effect. For dynamic analysis additional factors have to be accounted for such as seismic wave passage effect on the wall and backfill, acceleration and displacement amplification through the backfill. The present study aims to develop a finite element model that can effectively analyze the effect of these factors on the wall performance under static and dynamic loading. The performance of the wall is assessed by the lateral displacement and strain levels in the reinforcement layers at the end of construction and during a seismic event.

Keywords: Finite-element analysis, Mechanically stabilized earth (MSE) walls, Seismic motions, Geogrid reinforcement, Soil-geogrid interface

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 123



Numerical Solution For 1-D Consolidation Of Partially Saturated Soil Under Cyclic Loading

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Abstract

The distribution of consolidating load in a partially saturated soil is directly related to the dispersion of pore-water and pore-air pressures within the soil matrix. This paper presents a numerical solution to 1-D consolidation equation proposed by Fredlund and Hasan's for two layered partially saturated soil subjected to various cyclic loadings. It is assumed that during consolidation process rate of volume change and coefficient of permeability remain constant. Particularly, an implicit finite-difference method is used to find numerical solution. A computer program is developed and based on the developed formulation the response of pore-air, pore-fluid and soil-mass along with degree of consolidation for pore-air and pore-water is presented. Validation for analytical method is also presented for constant loading using numerical techniques.

Keywords: Partially saturated soil, Finite-difference method, 1-D consolidation, Numerical solution, Cyclic loading



Cost-Effective Strengthening Methodology For RCC Buildings by Jacketing Against Failure Due to Earthquake: A Study

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Abstract

Modern infrastructure management against failure due to unaccounted forces like earthquake forces is a great need in the society due to high cost and structural strengthening can help them last longer and be more resilient to earthquake. In general, structures are severely affected by earthquake loads. Strengthening by Jacketing technique can be effective in protecting reinforced concrete structures while simultaneously prolonging their life. Literature survey reveals a good number of studies have been performed in the past but effective strengthening methodology for RCC buildings by jacketing against failure due to earthquake is not available in Indian perspective. The purpose of this study is to compare on jacketing procedures such as concrete jacketing, steel jacketing, and Carbon fiber-reinforced polymer (CFRP) jacketing, combinations of different jacketing methods through numerical investigation using Finite Element Analysis (FEA) software i.e., ABAQUS due to real type earthquake ground motion. It was discovered that concrete jacketing is a viable alternative for use in low rise buildings, as it decreases 11.83% of deflection globally. The optimal combination of concrete jacketing at ground floor columns and CFRP at joints reduces global deflection by 28.69% when compared to the reference structures. It was observed that concrete jacketing is the most cost-effective option for low-rise buildings, accounting for only 6.55% of the overall building cost when only material costs are considered. The cost of combining concrete and CFRP is also lower, accounting for only 19.83% of the total cost.

Keywords: Strengthening, Concrete jacketing, Steel jacketing, FRP jacketing, FEA, Earthquake, RCC building



Seismic Response Analysis of Concrete Gravity Dam using Response Spectrum Analysis and Response History Analysis

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Abstract

The seismic analysis of concrete gravity dams has been a topic of considerable research in the earthquake literature. Because of the computational difficulty in performing a complete analysis of realistic dams considering different types of interactions, many simpler methods are adapted to assess the seismic performance of the concrete gravity dams. In this paper, the 2D analysis of the dry dam is performed using three types of analysis, namely response spectrum analysis (RSA), Base sliding method, and Response history analysis (RHA). Two slices are considered for the 2D analysis, one across the spillway section and the other across the highest non-overflow section. The seismic performances of these two slices are evaluated by these three types of analysis and compared. The example problem considers the Koyna dam subjected to the Koyna earthquake ground motion and its response spectrum. The performance evaluation is met with respect to three response quantities: displacement at the crest, peak maximum principal stress, and the maximum principal stress induced at the neck of the downstream where the slope changes. The results of the study show that (i) responses obtained by these three analyses significantly vary, (ii) both RSA and the base method underestimate the response by about 20-30%, (iii) the difference in response depends on the slices considered, and (iv) RSA appears to be not suitable for the design of the dam for earthquake analysis.

Keywords: Concrete gravity dam, Seismic performance, Comparison of RSA and RHA



Seismic Analysis of Vertical Asymmetric RC Building

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Abstract

Urbanization is demanding multi-storied buildings to accommodate a large amount of population in a limited space. To accommodate the need of the occupants, soft-storey and green-roof buildings are becoming common. The parking demands are leading to the soft storey and green roofs or recreational roofs are leading to mass asymmetric buildings. Green roofs are becoming familiar for roof gardening so that sustainability can be maintained. Recreational roofs like swimming pools, and rooftop stadiums are also leading to mass asymmetric structures. These modern requirements are making the building vertically asymmetric by stiffness and mass. The multi-storied buildings with stiffness and mass asymmetry are vulnerable to external loads and critical under seismic vibrations. A dynamic analysis of vertically asymmetric RC structures under seismic loading is performed by developing a MATLAB program. The mathematical models of the structures are developed based on a single super-element (SE) model on each floor. The effects of lateral load-resisting (column and core) elements in a particular floor are equated with a single super element. Each SE model has displacements in longitudinal and transverse directions and rotation about the vertical axis as the degrees of freedom at each node. The natural periods are estimated for a plan asymmetric building with different eccentricities and found that the natural period is increasing with the increase in eccentricity. A unidirectional and bidirectional time-history analysis under seismic load is performed for vertical mass and stiffness asymmetric buildings. The Bhuj earthquake (2001) data is considered for the study. The analytical results shows, that the soft-storey building is relatively more sensitive to external vibration when compared with mass asymmetric building. Hence it is recommended to design and construct the buildings by avoiding soft storey at bottom floor.

Keywords: Free vibration analysis, Mode shape, Dynamic analysis, Vertical asymmetric building, Soft-storey building



Effect of Earthquake Directivity on Behaviour of PSC I-Girder Bridge

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Abstract

Ground motions near to a fault are unlike from those which are detected further far from seismic sources. In near fault zone, ground motions at a specific site depend upon rupture mechanism and slip direction relative to site and by an everlasting ground displacement which results from tectonic movement. Depending on rupture mechanism and slip direction, ground motions in the near fault can show the dynamic consequences of “forward directivity”, “neutral directivity”, and “backward directivity”. Ground motions close to the surface rupture may incorporate a significant everlasting static displacement called as fling-step. Pulse type motions have been recognised as critical in the design of structures in near fault zone. Time histories which contain pulse like effect are needed when conducting dynamic time-history analysis for structures located near possible active faults. In this paper, an investigation is shown regarding the effect of the directivity pulses inherent in near-fault ground motions on behaviour of PSC I-Girder Bridge. To understand the earthquake directivity effect on the structures and to obtain a set of ground motions with dispersed directivity. A finite element model of PSC I-Girder Bridge is prepared, and the seismic investigations of the considered bridge structure is carried out for acquiring its response for earthquake directivity effect.

Keywords: Near-fault ground motion, Forward directivity, Fling-step, PSC I-girder bridge



Risk Targeted Seismic Hazard Assessment in Uttarakhand Himalayas

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Abstract

Earthquake is a natural calamity which has troubled the human civilization since ages. With the passage of time, the knowledge of seismic forces intensified and in the present scenario a lot is known about the earthquake resistant design of structures. The first step of design is the determination of demand. There are several philosophies which help in determining the demand forces on the structures. One of them, is the site specific probabilistic seismic hazard assessment, which is discussed in this study.

The probabilistic seismic hazard assessment (PSHA) for the two Indian states in the Himalayan region is estimated in this study. Three seismic source models are taken into consideration while calculating the hazard. The hazard estimation is done using one areal source models and two smoothed seismicity models.

After the hazard estimation, the collapse risks maps are developed using the standard fragility curves, for the study region. In the next step, the iterative calculation of the hazard values is done, to achieve the targeted value of collapse risk of 1% in 50 years.

From the developed risk targeted hazard values, the risk for the building designed for the current Indian standards is calculated at different locations, assuming the fragility curve to be same for different locations. It is found that the code design building results different seismic risk at different locations. Therefore, another building is designed using the risk targeted hazard at the chosen site. Fragility analysis of the building is carried out to obtain the risk of collapse in its life-time. A discussion on the obtained results is also presented in this study.

Keywords: PSHA, Fragility, Collapse risk, Risk targeted hazard



13th August 2021 Chenab River Coalescent Disaster: A Geo- Informatics Based Investigation

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Abstract

A huge landslide blocked the flow of the Chenab River near Nalda village in Himachal Pradesh's Lahaul-Spiti district on the morning of 13th August 2021, which led to the flooding of several villages (Nalda, Jsrath, Tarang, etc.) in Udaipur subdivision. The slope on the left bank of the Chenab River failed which brought huge soil and debris blocking the Chenab River, near Leh Baring village which lies upstream of Nalda Village Bridge and opposite to Junde village creating a huge water reservoir that later started overflowing, posing a major threat to downstream villages. This caused damage to houses located downstream which were submerged, animals were also washed away, and a large part of agricultural land was also inundated. This event was observed and studied using high-resolution satellite images from Google Earth. The Spatiotemporal images from Google Earth were used to observe the scars developed from several landslides in the past along the river, which evidently show the early signatures of slope failure. To analyse the stability of the hill slope, factor of safety of the hill was evaluated using SLOPE/W GeoStudio software. Considering the vulnerability of the Chenab valley, where several hydroelectric power projects are planned on Chenab River and its tributaries, it is important to consider the effect of highly fragile terrain conditions while planning any such project. The paper also emphasizes monitoring of such vulnerable areas based on high-resolution time series satellite images which are available on regular basis to avoid the loss of human lives in the future.

Keywords: Spatio-temporal images, Factor of safety, GeoStudio



Numerical Simulation of Special Moment Resisting Frame with Reduced Beam Section Under Cyclic Load

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Abstract

In this paper, seismic performance of steel Special Moment Resisting Frame (SMRF) with Reduced Beam Section (RBS) was evaluated. In this study, radius-cut RBS was considered for facilitating the formation of plastic hinge in the desired location in the beam because of its excellent performance during past experiments. Two 5 storied sample steel SMRFs, with and without RBS were designed as per IS 800. NPB and WPB sections from IS 12778 were used for the beam and column of the connection respectively. Beam and column of the frame was connected through welded connection. Each of the beam-column subassemblies was modelled using finite element software ABAQUS (Version 6.14-1). Moment-Rotation curves were then extracted after applying quasi-static cyclic load at beam tip as per AISC. This Moment-Rotation curves for each connection were then used to define plastic hinge properties in software SAP2000 (Version 22.0.0). First mode pushover analyses were then carried out for both conventional frame and frame with RBS. The yielding at the location of RBS was observed earlier than the yielding of beam at corresponding location in the conventional frame. Some reduction in strength was also observed in SMRF with RBS. Formation of plastic hinges observed to spread in all the stories in SMRF with RBS. Whereas in conventional SMRF, plastic hinge was concentrated in lower stories. Thus, SMRF with RBS satisfied strong column weak beam criterion and thereby ensured higher ductility and energy dissipation.

Keywords: SMRF, RBS, Beam-column connections, Finite element analysis, Pushover analysis



Seismic Stability Analysis of Saturated Slope Reinforced with Pervious Anti-Slide Piles Subjected to Repeated Shaking Using Shaking Table Tests

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Abstract

Occurrence of sudden cloudbursts found common in slopes of Uttarakhand region, especially during monsoon seasons. This led to a sudden increment in water content within the slope, causing a variation in slope saturation. In case, when these partially saturated slopes are subjected to dynamic events, the consequences are highly unexpected and can cause serious threat to the adjacent infra-structures located nearby. To improve the stability of slope, various slope improvement measures such as providing drainage, use of slope reinforcement, installation of anti-slide piles etc. are adopted in the field. However, very limited studies were available on the combined effect of drainage and slope reinforcement techniques. Also, detailed studies regarding the influence of these combined effects in partially saturated slope under dynamic loading are not available. Considering this, an attempt has been made to evaluate the influence of pervious anti-slide pile for slope reinforcement and drainage is proposed in this study. For understanding dynamic improvement characteristics, repeated shaking tests were performed to evaluate the efficiency of this control measure during multiple shaking events. The selection of repeated loading events simulates the occurrences of repeated shaking events as reported in several case studies in past. For experimental testing, debris soil collected from the Uttarakhand region was used. A 1:1 slope having dimensions of 600 mm × 600 mm slope with 200 mm bed depth and 750 mm width was prepared with 45% Saturation and 16 kN/m³ density equivalents to in-situ field density as observed in similar site in Narendra Nagar, Uttarakhand. The slope was subjected to repeated incremental shaking of loading intensity 0.1g, 0.2g and 0.3g with 5 Hz frequency. To simulate slope-structure interaction, a scaled-down G+3 storey building structure was installed at 200 mm distance from the crest portion of the slope. Parameters such as pore pressure response, acceleration response, slope and structure displacement under repeated shaking loading has been evaluated. For assessing the slope and structural response, 2-Digital Image Correlation technique was used. Based on the obtained test results, the seismic stability of the reinforced slope was assessed and presented.

Keywords: Slope stability, Partially saturated slope, Pervious anti-slide piles, 2D DIC



Seismic Protection of Reinforced Concrete Structure Using Combined Passive Vibration Controlling Device

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Abstract

Current earthquake resistant philosophy leads to damage of structure during moderate seismic event results into loss of life and economy. Whereas, important structure like hospital, bridges, water-tank, dams, power transmission towers etc. should be workable after such catastrophic event. It is accepted that, the vibration controlling instrument mainly isolation devices are highly effective during seismic event. Therefore, current work consists of seismic analysis and design of G+4 R.C. structure with and without isolation system. The seismic performance of the structure is evaluated by using time history analysis (THA). For THA four scaled historical devastating ground motion records are considered namely 1940 EL Centro imperial valley, 1989 Loma prieta, 1994 Northridge and 1995 Kobe earthquake. From the THA result it is observed that use of isolation system is highly effective in reducing base shear, storey drift and overturning moment of the structure with a cost of high displacement in isolators. A comparative study considering combination of base isolated system is also done and response of structure to combined base isolation system were recorded. From the result it is observed that use of combined devices is highly effective.

Keywords: Isolation system, LRB, FPS, Time history analysis



Probabilistic Seismic Vulnerability Assessment of RC Frame Building Considering Time-Dependent Deterioration

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Abstract

The Earthquake though infrequent events, causes enormous structural, monetary, and human losses. To plan risk mitigation strategies, it is crucial to estimate the seismic vulnerability associated with the structural elements of building stock. In addition to intermittent seismic risk during their service life, reinforced concrete (RC) buildings are continuously exposed to multiple environmental stressors. In RC structures, corrosion deterioration can cause significant reduction in the reinforcing steel area along with several secondary effects including loss of core and cover concrete strength, reduction of yield or ultimate strength and ductility of steel reinforcement, and loss of bond strength, among others. Therefore, for realistic vulnerability assessment of aged building stock, it is crucial to consider the time-dependent effects of deterioration. There are very few such studies pertaining to the old stock buildings in India, hence the present study considers an older non-ductile RC frame to assess its seismic vulnerability under joint aging and seismic threats. A finite-element model of the frame is developed by considering the nonlinear behavior of different components and time-dependent aging effects. Nonlinear time-history analysis is carried out using a suite of ground motion representative of the seismic hazard. The fragility curves are obtained for both as-built conditions and at different times along the service life of the building. Results have shown an increase up to 44% in the failure probability of deteriorated RC frame when compared to its pristine or as-built condition, highlighting the need for due consideration of aging effect in seismic vulnerability assessment.

Keywords: Time dependent corrosion, Seismic vulnerability, Fragility analysis



Investigations on Rubber-Sand Mixture Reinforced with Geogrid as a Low-Cost Geotechnical Seismic Base Isolation Technique

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Abstract

Nowadays, several structural base isolation techniques, such as dampers or elastomeric bearings, are commonly used to isolate structures from earthquake vibrations. However, the installation and maintenance costs of these energy-absorbing materials are quite expensive. Thus, studies are conducted on decoupling the structure from the base using a Geotechnical Seismic isolation (GSI) system, which can safeguard the structure from earthquake-induced vibrations. GSI system consists of soil mixed with high damping materials like shredded tires provides an efficient and economical option. However, the compressive nature of the rubber sand mixture (RSM) layer restricts its wide usage. The excessive strains in the RSM layer can be controlled by introducing geogrid. This paper presents the use of RSM reinforced with geogrid to provide a seismic isolation layer below the building foundation. Numerical analysis was done for a residential building using the finite element software PLAXIS 3D. Various parametric studies were conducted to find the minimum thickness of the RSM layer, the location of geogrid, and the number of geogrid layers to control the transmission of seismic vibrations. The effectiveness of the GSI was determined by comparing the parameter like peak spectral acceleration (PSA), and settlement of the system for various earthquake input motion with and without a rubber sand mixture layer. The results showed that the introduction of an RSM layer of thickness 0.05 - 0.15 times the width of the foundation can reduce the PSA up to 30-55%, and the addition of geogrid as a reinforcing material can reduce the seismic induced vertical settlement up to 68% which will ultimately lead to the broad applicability of RSM layer as a low-cost seismic base isolator.

Keywords: Geotechnical seismic isolation, Rubber sand mixture, Geogrid, Peak spectral acceleration, PLAXIS 3D



Analysis of Flexural Vibrations and Control of a Periodic Rail-Track System

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Abstract

Vibrations generated from the passage of trains including that from metros often get transmitted to the adjacent structures including buildings. This problem is particularly serious in cities wherein the resulting vibrations can either cause structural issues or can lead to serious discomfort for the occupants. Also, wheel-rail interaction often produces unwanted noise which can affect the inhabitants of the buildings near to these tracks. Understanding the propagation behavior of vibrations in the rail and thereby to the adjacent structures is essential in order to efficiently control them. Thus, the propagation behavior of flexural wave in a typical rail is analyzed in the context of Floquet-Bloch theorem for periodic structures. The ensuing dispersion relations are validated using finite element models. Subsequently, two-degrees-of-freedom resonators are coupled with rail to tune the stop band characteristics. The targeted frequency ranges in the considered pass band are very efficiently controlled using these resonators. Further, the efficacy of this control strategy is assessed using a random Gaussian white noise loading in the time domain and comparing the resulting vibration transmission characteristics from the original rail with that of the rail embedded with the proposed resonators. This study helps to realize the propagation characteristics of flexural waves in rails and the design of passive control mechanisms to reduce the transmission of the resulting vibrations.

Keywords: Periodic rail-track system, Vertical flexural wave, Dispersion relation, Passive control, Two-degree-of-freedom resonator



Assessment of Double Resonance from Microtremor Observations for Jammu Region in India

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Abstract

The Jammu region (JR) in the union territory of India is located in the northwestern Himalayas, affected by moderate to large magnitude earthquakes. To assess the possibility of double resonance effects (DRE) during significant earthquake events, this study examines the influence of Reinforced Concrete (RC) building vibrations in the JR in the context of local seismic response investigations. Using microtremor, a single station seismic ambient noise investigation was conducted at 242 locations to assess the predominant frequency (f_p) and H/V spectra for subsurface soil. During the field survey, building data is collected, and an empirical relationship between building height and vibration period is developed. The findings show that the fundamental frequency (f_f) of 17.35% of structures overlaps with the predominant frequency (f_p) of the site locations in the study area where microtremor testing was done. The vulnerability map divides the city into three discrete zones with high, medium, and low resonance levels, allowing for better hazard mitigation and town planning.

Keywords: H/V spectra, Double resonance, Predominant frequency, Jammu, Himalayas



Influence of Epistemic Uncertainty on the Seismic Vulnerability of Indian Code-Compliant RC Frame Building

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Abstract

The study's primary goal is to examine the presence of epistemic uncertainty in the RC frame when subjected to lateral force. The seismic response of the RC frame and the impact of uncertainties, namely material ($\gamma_c, f_c, & f_y$) and geometrical (D_b & b_c) nonlinearity, on the structural elements are determined using nonlinear static analysis. A fragility curve for a 4-storey RC frame structure designed using the most recent IS 1893 for seismic zone-V was created using a simulation-based method. The traditional deterministic technique was also utilised to compare the effect of the structure's lateral response uncertainty. The classifications for the various damage levels, including slight, moderate, severe, and complete, were established. The random variables are the strength properties of the concrete (f_{ck}) and steel (f_y) materials, the depth of the beam (D_b), the width of the column (b_c), and the weight density of concrete (γ_c). The Monte Carlo technique is used to determine the structural randomness of the RC frames. The gathered data demonstrated a significant increase in the fragility uncertainty and structural responsiveness compared to the deterministic technique. A fundamental conclusion of this study is the critical relevance of tackling issues about the building's fragility and predicted damage state from a stochastic perspective.

Keywords: RC frame, Epistemic uncertainty, Seismic vulnerability, Pushover analysis



Spatial Distribution of the Gutenberg-Richter Parameters and Fractal Dimension and Their Correlations in Northeast India and its Vicinity

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Abstract

The study aims to estimate the Gutenberg-Richter parameters (a and b) and fractal dimension (D_c) using the maximum likelihood estimation (MLE) method in 18 shallow (≤ 70 km) and 5 intermediate (> 70 km) depth seismic zones in northeast India and its vicinity. Scaling relations have been developed among the estimated hazard parameters. A unified and comprehensive earthquake catalogue spanning the period from 1897 to 2016 is used for the purpose. The regions associated with the low b -value and high D_c -value have been considered the utmost potential regions for the incidence of big events in the examined area. The b -values in the examined region vary from 0.59 to 1.31 in shallow zones and from 0.88 to 0.98 in intermediate zones. Similarly, the D_c -values vary from 1.81 to 2.65 in shallow zones and 2.22 to 2.71 in intermediate zones. The low b -values (less than 0.9) and the high D_c -values (greater than 2.0) are related to shallow zones 3 (Arunachal Himalaya), 6 (Eastern Himalayan syntaxis), 13 (Burmese region), 17 (south of Shillong Plateau), and all intermediate zones in Indo-Burmese regions. This makes these zones the most vulnerable to high earthquake hazards. The associations between D_c and b , and D_c and a/b illustrate a positive and negative correlation, respectively. The spatial variations of these parameters can be used as important parameters of earthquake hazard levels in the region.

Keywords: b -value, Fractal dimension, Earthquake hazard, Northeast India



Seismic Evaluation of RC Frame Designed by Forced Based Design and Direct Displacement Based Design

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Abstract

Force based Design (FBD) and Direct Displacement Based Design (DDBD) methods are used in this paper for seismic design of RC moment resisting frame. FBD requires designing the structure for a given load and checking for displacement; however, the damage is directly related to displacement. For assessment of structure during the earthquake for damage control state accepted that FBD has limitations. Performance Based Seismic Design (PBSD) methods were found to be a more reliable approach for elastic and inelastic behaviour of structural and non-structural elements and are effective in overcoming FBD limitations.

In the present study, DDBD and FBD methods are utilized to study RC moment resisting frame of 8 stories, which is regular in terms of height and bay width with conforming to IS code. Furthermore, the capacity design principle is used for DDBD to make sure to pre-determine failure patterns. After obtaining the internal design force of structural elements IS 456 - 2000 and IS 13920-1993 are used to design and detail the structural member.

Performance evaluation of frames is carried out by nonlinear static pushover analysis and nonlinear dynamic time history analysis. Comparison is done for Base shear Vs. Displacement and failure pattern is studied. Further, based on pushover analysis response modification factor, R is investigated.

The Results obtained shows performance satisfaction when evaluated by nonlinear static analysis (Pushover). Response modification factor, R, calculated for DDBD and FBD frames, and the values obtained for both approaches are greater than the IS 1893 specified value (R=5.0) which indicate the ductility effect account for both methods.

Keywords: Force based design (FBD), Performance based seismic design (PBSD), Direct displacement based design (DDBD)



Passive Vibration Control of Bridges: A State-of-the-art Review

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Abstract

Bridges are the most crucial components of infrastructural systems and are susceptible to severe damage when subjected to environmental and man-made hazards. In recent years, vibration control has emerged as an important technique for reducing structural damage. The present paper provides a systematic review of the various vibrational control techniques reported in the literature for response reduction in bridges. The review is carried out under the different categories of passive control strategies and methods are compared, broadly highlighting their advantages and drawbacks. From the review, it is observed that the general trend is progressing towards different combinations of passive systems over the conventional passive systems, as they possess the advantageous versatility of different passive systems. It is also found that the non-linear technique of passive vibration control has a superiority over the linear vibration control technique.

Keywords: Bridges, Vibration control, Passive control, Combination of passive systems, Non-linear technique



Seismic Hazard Analysis Considering the Effect of the Shape, Size and EQ Distribution of Seismic Sources for Different Locations in Sikkim, NE India

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Abstract

For a seismically active region, ensuring the safety of the structures against future Earthquakes (EQs) is very important. This seismic safety is mainly ensured by designing the structures to withstand the probable EQ hazard that may occur in the future. This future probable EQ hazard level can be estimated by performing seismic hazard analysis (SHA) for the region. The two types of SHA, deterministic (DSHA) and probabilistic (PSHA), strongly depend on the presence of seismic sources near the region, its past EQ history, and the site condition of the region. In the present work, DSHA and PSHA are used to obtain the seismic hazard level (SHL) of different locations in Sikkim, NE India. This is to be noted here that some faults near Sikkim are not linear, and different segments of some faults show different seismic activity rates. The effect of these types of shapes is considered for the present SHA. As SHA depends on the type of seismic sources, two types of seismic sources (linear and areal), with multiple source models (SMs) are considered. These SMs are based on geotectonics and EQ distribution. For DSHA, highest SHL is obtained when SM with large areal sources is considered. However, for PSHA, hybrid SM, which contains both linear and areal sources, gives the highest SHL. In DSHA and PSHA, significantly lower SHL is obtained when linear SM is considered. Thus, SHL obtained from more than one SM should be examined before reaching a judgement about SHL of a specific region.

Keywords: Seismic hazard, Seismicity parameters, GMPE, NE India



A Comparative Study on Application of Machine Learning Algorithms in Ground Motion Prediction Equations

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Abstract

Ground Motion Prediction Equations (GMPEs) play an important role in the field of Earthquake Engineering and Seismic Hazard Analysis. With the advancements in the area of Artificial Intelligence (AI) and Machine Learning (ML), it becomes critical to have a comparative study on the new methods of obtaining ground motion parameters for a region. Traditional GMPEs developed using parametric regression assume a fixed functional form, and in doing so, it becomes challenging to draw the complex and non-linear characteristics of the data completely. Adopting non-parametric regression methods, which are independent of predefined equations, helps us to overcome these limitations. This paper investigates a comparative study of some common machine learning algorithms to forecast Peak Ground Acceleration (PGA) associated with Ground motion data of NGA West. The prediction model considers non-parametric types of regression and tries to manifest the advantages of these models over conventional GMPEs, derived using parametric regression. The present work explores algorithms like Decision Trees, Random Forests, Support Vector Regression and Weighted Average Ensemble Method (WAEM). Also, the performance of the developed models is compared with that of conventional methods. In this study, the earthquake magnitude, rupture distance, average shear wave velocity, and the type of faulting mechanism are used as predictor variables. The algorithms are trained using a database of 13555 ground motions, with magnitude ranging from 3.0 to 7.9 recorded over the rupture distance range of 0-500 km. Finally, an efficient model is identified using evaluation metrics like Mean Squared Error (MSE), R-Squared value, and Standard Deviation.

Keywords: Machine learning, GMPEs, Support vector regression, Decision trees, Random forest



State of the Art Review on Performance Based Retrofitting of Structures

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Abstract

Performance-based design (PBSD) procedure, allows for selecting the desired performance objectives for a structure subjected to seismic events based on the functionality or importance of the structure. The PBSD methodology significantly improves the building performance required for varying seismic demands. This approach reduces the seismic damage to infrastructures at the Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) levels. Based on FEMA P-58, the performance-based seismic design involves steps such as selecting appropriate performance objectives, selecting seismic force-resisting systems, determining appropriate stiffness/strength of structural members, and finally verifying design adequacy. Performance-Based Seismic Retrofitting of Structures (PBSR) is highly relevant in the present scenario of seismic hazards. This paper reviews the current state of performance-based retrofitting from national/international literature and code provisions. The configuration, structural characteristics, and seismic deficiencies of the structures, which has significant importance, are evaluated from the literature. The appropriate performance parameters are analysed based on the seismic tests carried out in the literature.

Keywords: Retrofitting, Performance objectives, Shake table testing



Performance Evaluation of Saturated Slope Subjected to Repeated Shaking Events Using 1-G Shaking Table Experiments

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Abstract

The rainfall in the state of Uttarakhand has a dynamic version. The erratic cloudbursts with unpredictability in rainfall intensity usually cause sudden variation in slope saturation especially during monsoon seasons. This led to frequent rainfall-induced slope failures in past years. Additionally, the region is also categorized under seismic zone IV and V as per the Indian seismic zonation map. When unforeseeable seismic events may associate with these partially saturated slopes, the sudden slope failures can endanger human lives and can affect major infrastructures in these regions. The observed re-peated shaking events such as the Japan earthquake (Tohoku) (2011), Nepal earthquake (2015), etc., highlighted the possibility of multiple shaking events and its influence on the infrastructures. Considering the above, this study aims to evaluate the behaviour of the partially saturated slope subjected to repeated dynamic loading conditions. Using 1-g shaking table experiments, the dynamic response of slope was evaluated. For experimental studies, de-bris material collected from the lower Himalayan region in Uttarakhand was used for model slope preparation for simulating field behaviour. For experimental testing, slope having 45° slope angle with 60% density was prepared using 10% water content for achieving 40% partial saturated conditions. The model slope was then subjected to repeated incremental dynamic loading conditions of 0.1g, 0.2g, 0.3g, and 0.4g acceleration intensity respectively. To compare the influence of repeated shaking on the slope and its interaction with the adjacent structures; a scaled-down model structure was installed at a 250 mm distance from the crest portion of the slope. The influence of acceleration response, pore pressure generation, soil settlement and structure displacement were evaluated and compared. In addition to above instrumentation scheme, a 2-D digital image correlation system was additionally used for slope and structural displacement. An attempt also made to model the experiments using FLAC 3D software for estimating the failure conditions. Based on the obtained test results, parameters influencing the stability of partially saturated slope subjected to repeated acceleration loading events have been evaluated and its influence on the adjacent structure is presented.

Keywords: Partially saturated slope, 2-D Digital image correlation, Slope-failure, Repeated dynamic Events, FLAC3D



Numerical Study on One-Dimensional Aperiodic Foundations for Seismic Isolation of Structures

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Abstract

The concept of frequency band gaps in the wave propagation physics of crystalline solids has suggested the possibility of attenuating and filtering seismic waves with the provision of a periodic foundation. One-dimensional periodic foundations are basically an ordered arrangement of material layers of constant thickness repeated in a particular sequence. The periodicity of these foundations prevents the destructive seismic waves from reaching the superstructure. Despite numerous benefits of these foundations over conventional earthquake-resistant design techniques, past research has highlighted the limitation with the starting frequency and range of frequency band gaps over which these can be effective for seismic applications. The periodic foundation intended for seismic application needs to have a low starting frequency and wide frequency bandgap (typically between 0 Hz and -20 Hz). However, it has been observed the reduction in the starting frequency is accompanied by a reduction in the bandgap as well. This paper proposes the idea of using an aperiodic, instead of the periodic, arrangement of material layers in such foundations that can result in wider attenuation frequency ranges including a better lower starting frequency closest to earthquake ground motion. The aperiodicity refers to the irregularity induced due to the varying thicknesses of alternate rigid and softer layers arranged in the foundation. The idea is to take advantage of Anderson's theory of localization in disordered systems. A detailed comparative study has been carried out on periodic and aperiodic foundations and the possibility of reliable outcomes for the application in seismic isolation has been discussed.

Keywords: Aperiodic foundations, Anderson's theory, Phononic crystals



Study of Anomalous Behaviour of Atmospheric Parameters as an Earthquake Precursors for Himalayan Region Earthquakes

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Abstract

This research work concentrates on how the atmospheric parameters act as a precursor of earthquakes occurred in the Himalayan region. In the past decade, several literature results suggest there is a link between the observation of atmospheric phenomenon and the earthquake occurrence. In this study we have chooses to analyse the outgoing longwave radiation (OLR) and relative humidity (RH) scenario prior to the occurrence of earthquakes. Eight notable earthquakes ($M \geq 5.0$) are selected that happened in the Himalayan region, along the Main Central Thrust (MCT). The Himalayas are emphasized by one of the world's largest continental megathrusts, which causes the occurrence of massive seismic events that produce significant destruction. The atmospheric parameters like OLR and RH data sets were derived from satellite observation and variations were identified using the Z-factor method. The temporal analysis of the atmospheric parameters was done for six months before the occurrence of the earthquake. An abnormal deviation was observed in OLR and RH before the occurrence of the earthquake. From the observation, all the anomalies present in the atmospheric parameters were observed ten days prior to the occurrence of the earthquake except for two events, which shows the heterogeneous nature of the earthquake process. For all earthquakes, the RH value dropped predominantly before observing the anomaly rise of the OLR. Similarly, the pattern of these atmospheric parameters indicates sudden drops of RH value followed by the sudden rise in the OLR, which is proposed by the LAIC model. Thus, the authors concluded that atmospheric parameters like OLR and RH are the important short-term earthquake precursor to forecast the earthquakes.

Keywords: Outgoing longwave radiation (OLR), Relative humidity (RH), Earthquake, Earthquake precursors



Probabilistic Seismic Hazard Assessment of North East India

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Abstract

Probabilistic Seismic Hazard Assessment of the North-East Indian region is carried out considering three models of seismic source, i.e., areal sources, line sources, and smoothed gridded seismicity model. Between 87°- 98° E and 20°- 30° N, earthquake catalogs and various tectonic features are collected from multiple sources which produce a seismotectonic map. Based on seismicity, tectonic provinces, and fault rupture mechanism, the study region is divided into six area source zones. Thirty-two identified fault sources are modelled as linear source models; the gridded seismicity model is modelled as a point source model. For each source model, seismicity parameters are calculated by considering only the completed earthquake catalog. Four Next-generation (NGA) Ground Motion Models are applied to estimate the hazard at the reference rock condition. The logic tree framework is implemented in the source models and GMPEs to account for the epistemic uncertainties. Peak ground acceleration (PGA) and spectral acceleration (S_a) are estimated at different cities of Northeastern states for a 2% and 10% probability of exceedance in 50 years. The hazard curves and uniform hazard spectra are also presented.

Keywords: PSHA, Logic tree, OpenQuake



Experimental Investigation of Seismic Response of Hybrid Shear Wall with External Energy Dissipating Reinforcement

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Abstract

A conventional shear wall has negligible reusability capacity if it gets severely damaged during any strong earthquake. This forms a major drawback for many civil installations, which are prone to frequent seismic activities. Often, a post-tensioned (PT) shear wall having self-centering capacity is used as one of the effective ways of resisting such large lateral shear forces, however it has limited energy dissipation capability. Therefore, in situations having a higher force and limited drift demand, PT shear walls with internal Energy Dissipating Reinforcements (EDRs) is that, once they get damaged, they cannot be replaced. Hence to solve this problem use of external energy dissipating reinforcement has been introduced due to its merit of easy replacement. A new configuration of external energy dissipating device has been introduced in this study, where notch plates are used as external energy dissipating devices. The suitability and functionality of such External Energy Dissipating Notched Bars (EDNB) have been checked experimentally and reported.

Keywords: Post-tensioned shear wall, External energy dissipating notched bars (EDNB), Self-centering



Fluid-Soil-Structure Interaction of Offshore Wind Turbine: An Analytical Approach for Natural Frequency Estimation

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Abstract

With the increasing demand for renewable harvested energy, the size of the turbine blade keeps on increasing which makes the turbine tower much taller and slender. Owing to the advantage of stable wind velocity and space availability, the offshore wind turbines have become prevalent. Wind turbine tower undergoes various dynamic loading in regular operation such as rotor excitation (1P), vibration due to passing of blade (3P), in addition to wind, storm, wave (in case of offshore) and earthquake. Thus, estimation of natural frequency of a wind turbine is of utmost importance to avoid any frequency matching with the regular excitation, 1P and 3P. In this paper, a transfer matrix-based analytical methodology has been proposed to estimate the natural time period of an offshore wind turbine with a mono-pile foundation. Fluid-structure interaction has been incorporated within the study by using hydrodynamic mass throughout the length of transition piece and mono-pile and soil-structure interaction has been considered by providing linear elastic p-y springs throughout the length of monopile. A complete parametric study has been considered which shows the dependency of natural frequency on the various geometric and material properties of both tower and monopile and the material properties of soil. The natural frequency was found to be significantly affected by soil properties, which shows the importance of soil-structure interaction in the design of offshore structures.

Keywords: Wind turbine, Natural frequency, Transfer matrix



Lateral Capacity of Concrete Bridge Piers with Steel Rebar Reinforcement and Glass Fibre Reinforced Polymer Rebar Reinforcement

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Abstract

Corrosion remains a challenge for maintenance of important infrastructure like bridges and researchers are involved in looking for alternative materials for replacement of steel reinforcement. Studies are reported in literature on fabrication and characterisation of engineering properties of Glass Fibre Reinforced Polymer (GFRP) rebars. Non-degradable property of GFRP rebars against alkaline and corrosive environment is the major desirable characteristics for infrastructure located at severe corrosive sites like offshore. Studies are reported in literature on the use of GFRP rebars for bridge decks. In the present study, three-span continuous steel girder composite bridge consisting of two bents with two piers each with a concrete deck slab has been considered. Two types of reinforcements are considered for bridge piers viz., steel rebar reinforcement and GFRP rebar reinforcement. Stress strain and other engineering properties of GFRP rebars are adopted from literature. Lateral capacity of bridge bents is evaluated through pushover analyses. Base shear capacity of bridge piers with GFRP reinforcement is observed to be similar to the base shear capacity of bridge pier with steel reinforcement however, ductility is observed to be very less for bridge pier with GFRP reinforcement. Hence it will be desirable to use GFRP rebars and steel rebars in combination in order to achieve desirable inelastic behaviour of bridge piers for highly corrosive sites located at high seismic prone zones.

Keywords: Bridge piers, GFRP reinforcement, Lateral capacity



Seismic Performance Assessment of Reinforced Concrete Moment Resisting Frame Designed by Force Based Design Method and the Performance Based Plastic Design Method

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Abstract

Performance Based Plastic Design (PBPD) method is an advance method of seismic analysis since it includes preselected target drift and inelastic behavior of structure during a seismic event. In this study a 4, 8 and 12 storied RC-MRF have been analyzed and designed by Force Based Design (FBD) which is also known as codal method of design and by Performance Based Plastic Design (PBPD) method. A comparison is prepared in terms of seismic performance of the study building. The design guidelines and parameters are adopted as per IS code. A Non-linear static pushover analysis is the tool utilized to assess the seismic performance of study frames in terms of base shear displacement curve and drifts for specified limits. The result indicates that the base shear value for all PBPD frames at performance point is almost 2.2 times higher than the analytical solution. Similarly, all PBPD frames are within drift ratio limit of 0.02 while FBD frames surpassed the permissible drift ratio limit of 0.004 from which it can be said that PBPD frames have better seismic performance than FBD frames.

Keywords: RC-MRF, Force Based Design (FBD), Performance Based Plastic Design (PBPD), Performance level, Pushover analysis



Influence of Existing Tunnel - Surface Structure Interaction under Repeated Dynamic Loading Conditions.

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Abstract

According to past studies, subsurface spaces induce variation in ground response during an earthquake incidence and directly impacts the surface structures' seismic behaviour. Though, these subsurface structures (tunnels) are less susceptible to deformation than superstructures; its interaction with the surface structures during dynamic loading needs to be assessed carefully. Especially when these tunnels are located in partially saturated sand deposits, the interaction between soil-tunnel-structure is more complicated. The generation of pore water pressures, acceleration response during dynamic conditions may induce soil deformation and create deformations in the tunnel and superstructure system. Recently, repeated shaking events (i.e., continuous foreshock/aftershock associated events during earthquake incidence) posing a serious threat to the safety of significant infra-structures (Christ church earthquake 2011, Japan earthquake 2011, etc.) Hence, it is crucial to consider the response of surface structures with an existing tunnel under multi-seismic events where the studies were very limited. Considering the above, this study aims to understand the dynamic interaction behaviour between the surface structure with a shallow tunnel under repeated dynamic loading conditions. The experimental studies were conducted on a 1-g uniaxial shaking table with ground having 25% saturation replicating partially saturated conditions. A scaled-down structural member fixed on a pile foundation was used for simulating surface structure. Similarly, a scaled-down square tunnel of dimension 280×280×750 mm embedded at 420 mm depth was used for simulating shallow tunnel system. The tunnel-structure embedded ground was then subjected to repeated incremental sinusoidal acceleration loading of 0.1g, 0.2g, 0.3g, 0.4g and 0.5g with 5 Hz frequency. The effects of acceleration response, structural displacement, soil displacement, and pore water pressure were compared and analysed. The tunnel and structural displacement during testing were monitored and estimated using 2-D digital image correlation. The parameters influencing tunnel-soil-surface structure interaction under repeated seismic loading conditions were analysed and presented. The results show that, the irrespective of improved soil reinforcement induced by the pile foundation, occurrence of repeated shaking with longer duration affects the performance of the surface structure and its interaction with the tunnel embedded ground.

Keywords: Tunnel-soil-surface structure interaction, Partially saturated sand, 2-D Digital image correlation, 1-g Shaking table, Repeated seismic events



1D Velocity Model For NW India in and Around Delhi

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Abstract

We derive a 1D crustal velocity model based on P- and S-wave residual time arrivals at the national seismological network maintained by National Centre for Seismology (NCS) for NW India around Delhi between latitude range 22°N to 33°N and longitude range 73°E to 80°E, which separates inter-plate area in the north and intraplate area in the south. Available models are mostly from regional studies having low crustal resolution. We use 413 earthquakes in all, which are chosen based on the maximum number of stations, minimum azimuthal gap, and root mean square travel time. We use VELEST code to invert the 1-D velocity model, hypocenter locations, and station delays. The Indo-Gangetic (IG11) model is used as a starting model and in this model, we further created 500 initial models by adding random perturbation +/- 10%. We also evaluate the effect of different Moho depths (i.e., 38, 43, and 48 km). We selected the preferred model based on how the models con-merge and on the travel time residuals. The minimum residual travel time of P and S-arrivals indicated crustal thickness as 43 km. Further, this model can be used for seismicity and 3-D seismic tomographic studies of the area.

Keywords: Earthquake location, 1-D crustal velocity model



Anomalous Deviations in Atmospheric Parameters as Pre-Earthquake Signals: A Case Study on Sumatra Region Earthquakes($M \geq 6.0$)

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Abstract

One of the most demanding disciplines in geoscience is earthquake forecasting, which is widely debated due to its heterogenetic nature. Several strategies for forecasting the destructive earthquake events have been developed in recent decades. This work focuses on exploring and understanding of the precursory signals which is associated with the occurrence of earthquakes. The earthquake precursors are identified by anomalous deviation in Out-going Longwave Radiation (OLR) and Relative Humidity (RH) before Strong magnitude earthquakes. This work concentrates to study the correlation of anomalous variations in atmospheric parameters such as relative humidity and OLR flux index associated with the earthquakes through Lithosphere-Atmosphere-Ionosphere coupling (LAIC) model. The retrospective analysis of temporal variations is done on the daily datasets of RH and OLR is carried out for eight earthquakes with magnitude ≥ 6.0 occurred during 1991–2021 within 75km radius of December 26, 2004. The exploratory data analysis is carried out based on the investigation of earthquake activity in the study region taken from United States Geological Survey (USGS), anomalous Outgoing longwave radiation (OLR) flux index, Anomalous Relative humidity index for the period of six months. According to our preliminary findings, the relationship among the anomalous drop of relative humidity and anomalous in-crease in OLR flux index anomalies with the occurrence of earthquakes were observed near epicentral region as proposed by the LAIC model. This anomalous behavior was observed 3 days to 3 months prior to the occurrence of earthquakes. Hence, the authors inferred that there exists a possible link between the abnormal deviations in atmospheric parameters and the occurrence of earthquakes. Further incorporation of various precursors along with OLR and RH studies can help us to develop an effective tool for forecasting the earthquake on a short-term basis.

Keywords: Earthquake precursors, Outgoing longwave radiation, Relative humidity, Earthquake forecasting



Similitude Characteristics Between Small-Scale Model and Full-Scale Piles under Dynamic Excitations

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Abstract

In this study, it is intended to use a flexural rigidity-based scaling law proposed by Wood (2004) to predict the dynamic frequency-amplitude responses of the full-scale piles from small scale model pile responses. To obtain this objective, axial harmonic tests on hollow steel single and 2×2 pile group having a diameter of 0.114 m and pile length of 3 m are performed in the field for different magnitudes of dynamic forces (0.868 and 1.944 Nm). The frequency versus amplitude responses obtained from the test show a single peak at resonance within the range of the dynamic test (0-50 Hz) for both types of pile foundation. The responses also exhibit nonlinear characteristics by virtue of reducing the resonant frequency with the increase of dynamic forces. The single pile responses also indicate lower resonant frequency and higher amplitude values as compared to the pile group responses. Using these experimental responses, the responses of the full-scale piles are calculated by assuming the scaling factors of 6, 8, and 10 to consider the full-scale pile lengths of 18 m, 24 m, and 30 m respectively, without changing the aspect ratio of the piles. It is found from the full-scale pile responses that the resonant frequency values are decreased about 4 to 6 times and the resonant amplitudes are increased about 15 to 32 times as compared to the small-scale piles. However, the basic characteristics of soil-pile responses of the small-scale model and full-scale piles are observed to be similar for both the single pile and 2×2 -pile group.

Keywords: Model pile, Axial harmonic tests, Full-scale pile, Dynamic responses, Scaling law



Inelastic Seismic Behaviour of RC Buildings with floating Columns Considering Soil Structure Interaction

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Abstract

In recent times, the construction of buildings with irregularities is increased in the comeliness point of view and also to acquire more space at parking areas for movement. However, from the post-earthquake investigations, it is noticed that the construction of such irregular buildings is vulnerable to seismic forces although the soil-structure interaction (SSI) is not accounted for in the design process. In this study, the nonlinear seismic behavior of multi-storey buildings with and without floating columns considering structure interaction is investigated. Nonlinear time history analysis was conducted on buildings with floating columns resting on medium soil strata. Impedance functions such as stiffness and damping coefficients were computed and assigned at the base of the building to account for the effects of SSI. Incremental dynamic analysis was performed using SAP2000 and the inelastic response of the building was quantified. Seismic fragility curves are plotted and the probabilities of damages are estimated. The comparison of probabilities of damages between the buildings with and without floating columns considering soil-structure interaction effects is studied and presented.

Keywords: Floating columns, Soil structure interaction (SSI), Incremental dynamic analysis, Fragility curve



Numerical Simulations and Validation of a Rocking Foundation Model for Seismic Loading

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Abstract

The objective of this study is to develop a numerical model for rocking shallow foundations supporting shear wall and bridge pier structures and to validate the numerical model using centrifuge experimental results. OpenSees finite element framework was used to build the numerical model, where a Contact Interface Model (CIM) was used to model the rocking behaviour of soil-foundation system and the structural components were modelled using elastic beam-column elements. The numerical model was first developed using soil properties obtained from theoretical and empirical relationships and validated using the cyclic moment-rotation results of foundations obtained from centrifuge experiments. The numerical model was then used to calculate seismic energy dissipation in soil during rocking, peak rotation of foundation during shaking, and tipping-over stability ratio of rocking systems for the same base accelerations of earthquake motions used in centrifuge experiments. Numerical model predictions for seismic energy dissipation of rocking foundations as a function of Arias intensity of the earthquake motion and peak rotation of rocking foundation as a function of peak ground acceleration of the earthquake motion compare reasonably well with the corresponding experimental results (with mean absolute percentage errors of 0.5 to 0.6). For 24 out of 26 centrifuge experiments considered, the tipping over stability ratio obtained from both the numerical simulations and experimental results vary between 0.85 and 1.0, demonstrating (i) the excellent stability of rocking systems against tipping over failure and (ii) the numerical model's ability to capture the tipping over stability of rocking systems.

Keywords: Rocking foundation, Contact interface model, Seismic energy dissipation, Peak rotation, Tipping-over stability



Influence of Ground Motion Characteristics on the Seismic Vulnerability of Bridges

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Abstract

This study focuses on understanding and quantifying the differences in vulnerability of highway bridges when subjected to near-field pulse-like ground motions and long duration records as compared to widely available far-field ground motions that are short-duration. For this purpose, a case-study highway bridge located in the Himalayan region is selected. Suites of near-field pulse-like and long duration ground motions are selected that are spectrally equivalent to recorded far-field short-duration ground motions widely adopted for the design and assessment of bridges. A detailed FE model of the bridge is developed, and a set of non-linear time-history analyses are performed for each ground motion suite at numerous scaled intensity levels to develop seismic fragility curves. Results reveal that there is a 33% difference in the median fragility estimates of complete damage state between short and long duration record sets, and a 25% difference between long duration and pulse-like record sets. The findings highlight the inclusion of ground motion duration and velocity pulse-like effects for the design and construction of highway bridges.

Keywords: Bridges, Near-field pulse-like ground motions, Long-duration ground motions, Seismic fragility curves



Experimental Studies on Tunnel-soil Interaction in Partially Saturated Ground Subjected to Repeated Shaking Events Using 1-G Shaking Table Experiments

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Abstract

Underground structures are increasingly used worldwide mainly for transportation and utility services and has become a major component in infrastructure development. Although underground structures are considered safer than above ground structures due to its confinement characteristics, past earthquake events such as Kobe earthquake (1995), Wenchuan earthquake (2008) etc. revealed that tunnels are equally vulnerable under dynamic events. Based on Tohoku, Japan Earthquake (2011), Nepal Earthquake (2015) repeated shaking events (i.e., fore-shocks and aftershock occurrences during earthquake) also contributed equally in inducing failures in infrastructures. In India, major portion of tunnel projects were carried out in Northern parts i.e., Indo-Gangetic plains which contains significant portion of silty sand deposits. In case of dynamic events, the changes in soil saturation in these deposits due to variation in ground water table conditions may results in pore pressure generation and can affect the structural stability of the tunnel system. Considering the above aspects, the present study aims to assess the dynamic behavior of shallow tunnels embedded in partially saturated silty sand bed under repeated shaking events. For this purpose, 1-g shaking table experimental study was conducted on scaled down square tunnel embedded in partially saturated sand bed having 60% relative density with 25% saturation. Incremental repeated shaking events of 0.1g and 0.2g was applied sequentially and tunnel-soil interaction behavior was evaluated in terms of acceleration response, developed pore water pressure, pore water pressure ratio, dynamic earth pressure and displacement of soil respectively. The displacement of tunnel and strain developed during dynamic events, were evaluated using 2-D digital image correlation technique. Based on the obtained test results, the factors influencing the dynamic behavior of tunnels in partially saturated ground under repeated incremental shaking events were evaluated and presented.

Keywords: Tunnel soil interaction, Soil saturation, Repeated shaking events, 2- Digital image correlation technique, Liquefaction



Non-linear Dynamic Behaviour of the Multi-arch Gallery Masonry Bridge of Kalka Shimla Mountain Railway

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Abstract

The Indian railway network is amongst the oldest railway networks in the world. Some of the bridges in the Indian railway that were constructed under British rule are still operational. Although these bridges have crossed their service life span, their present-day serviceability is questionable, especially those located in high seismic zones. The performance of such heritage bridges in the occurrence of any seismic activity is poor due to inadequate seismic resistance. Consequently, the seismic vulnerability assessment of these heritage bridges is necessary to understand the most vulnerable structural elements and performance of the bridges for different seismic loading. This research study presents the seismic vulnerability assessment of Bridge No. 493 of Kalka Shimla Mountain Railway (A UNESCO recognized World Heritage). For this purpose, an experimental campaign adopting Ambient Vibration Testing (AVT) and Operational Modal Analysis (OMA) was performed on the bridge to estimate the dynamic characteristics (mode shape, frequency). Further, a three-dimensional numerical model of the bridge was developed in ABAQUS finite element software. The initial numerical model was updated by modifying the material properties to match the behaviour results from AVT and OMA. Then, the nonlinear dynamic behaviour of the bridge was simulated with the updated model using the synthetic time history in agreement with different hazard scenarios (Zone IV seismicity with return period of 95 years, 475 years, 2475 years). Lastly, the results of the performance of the bridge for different seismic hazard scenarios are discussed. The numerical simulation showed that the bridge is heavily damaged by the seismic loading having a return period of 2475 years and the primary failure mechanism is the shear failure of the bridge's piers.

Keywords: Ambient vibration testing, Operational modal analysis, Seismic analysis, Heritage, Bridge



Spatial Distribution of Stress Orientation by Inversion of Focal Mechanism Solutions Using MSATSI: A Case Study Across Japan Trench

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Abstract

Estimation of stress field orientations is a necessary aspect for recognition of crustal mechanics as well as the physics behind occurrence of earthquakes. A case study employing the new MATLAB software package SATSI (Spatial and Temporal Stress Inversion) for stress inversion utilizing the focal mechanism data is presented here to produce stress orientation models in North East (NE) Japan. In this work, the study region is divided into 49 small sub-regions so that the stress tensors and focal mechanisms can independently fit in each sub-region. Determination of any stress variation is strongly needed by the data while eliminating the artifacts due to overfitting of noisy or nonuniquely fitting data. To resolve it, a damped inversion procedure was applied which inverted the stresses in all sub-regions, while at the same time reducing the difference in stress between adjacent sub-regions. Earthquake focal mechanisms have been used to determine the stress patterns at depths capable of generating earthquakes in NE Japan since 1960-2021. In this work, 0D, 1D and 2D stress inversion using the MSATSI (MATLAB package for Spatial and Temporal Stress Inversion) routine was performed and examined the spatial variation of stress orientations over NE Japan along the Japan Trench and put forward recent knowledge about the stress pattern. From the obtained 2D inversion results, a spatially varying stress regime is observed in the crust which demonstrates normal faulting on the subducting Pacific plate which changes to reverse faulting on the Okhotsk Plate through an intermediate state of oblique faulting.

Keywords: MSATSI, Stress inversion, Focal mechanism solution



Experimental Verification of Improved SSI-COV Method for Health Monitoring of Base-Excited RC Structures

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Abstract

Condition assessment of civil infrastructures using operational modal analysis (OMA) has gained immense popularity in the recent past. OMA, being a non-destructive technique, can be directly employed utilizing structural vibration, i.e., measurements due to ambient excitation. It is versatile and fairly accurate for the frequency range generally encountered in structural engineering. A more improved version of this tool, i.e., covariance-driven Stochastic Subspace Identification (SSI-COV), has emerged as a popular signal processing tool for modal identification of structures owing to its minimal input requirements and simultaneous multi-mode identification ability. The SSI-COV compiles the multiple channel data before the identification step to obtain one set of global modal parameters, taking advantage of different ambient excitation characteristics of measurements. However, to achieve best results, characteristics of excitation acting on the structural system and response signals quality should meet certain requirements, which sometimes are difficult to satisfy. In this study, experimental verification is conducted using an improvised variant of the SSI-COV technique based on agglomerative hierarchical clustering for modal identification of a full-scale reinforced concrete framed building in the IIT Guwahati campus subjected to multi-component earthquake excitations. The results obtained are compared with the structure's theoretical model to validate the proposed method's performance.

Keywords: Stochastic subspace identification, Structural health monitoring, Agglomerative hierarchical clustering



Comparative Study of Fibre-Based Frame Elements to Analyse Shear-critical RC Frames

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Abstract

Failures due to inadequate shear critical section design have been observed during many seismic excitations. The commonly used one-dimensional distributed-plasticity fibre frame element usually neglects the shear deformation. Although many researchers have tried to develop a shear-flexure model for beam, a simple and realistic shear critical model is yet under the process of development. Its implementation poses many difficulties, which lead to erroneous predictions. The paper discusses some of the issues in implementing a force-based fibre frame element within a shear beam theory. In the present study, a comparison between two commonly used approaches to consider shear in fibre frame elements is presented. The first approach uses an independent shear force-strain relation at the section level, which is the equivalent of considering a shear spring along the member. The second approach considers normal and shear stress coupling at the fibre level using a rotating smeared-crack constitutive relation for concrete material. The effectiveness of both the approach is assessed by simulating the response of two column specimens failed in flexure-shear and shear mode from the literature. The columns are also modelled using the common force-based fibre element based on the Euler-Bernoulli beam theory for comparison purposes. The result indicates that both approach gives a better prediction than the conventional element. However, the first approach is highly dependent on the adopted shear relation. Whereas the second approach, although complex, can simulate the overall experimental behaviour more closely than the commonly used element.

Keywords: Fibre based frame element, RC, Shear failure



Seismic Landslide Hazard Assessment of Mandi Town, Himachal Pradesh

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Abstract

This study performs slope displacement-based probabilistic seismic landslide hazard assessment for Mandi town. Here, the slope angles of the concerned region are obtained from the digital elevation map (DEM), and the material properties are obtained from lithological information and literature. The critical acceleration of the slopes is estimated by combining the obtained slope angle and material properties. In this work, hazard assessment is performed considering the arid and fully saturated condition of the soil mass of the slopes. The PGA values are estimated for 100, 475 and 2475 years return periods by performing probabilistic seismic hazard analysis of the study region. Further, the PGA values and the slope displacement prediction equation are used to estimate Newmark's sliding displacement. Finally, the hazard map in terms of the probability of slope displacement (SD) value exceeding the threshold values of 5cm is presented. The developed seismic landslide hazard map highlights the areas that may experience co-seismic landslides in the future. The probability of occurrence of co-seismic landslides gets as high as 93.4% for saturated soil and 86.3 % for arid soil for a return period of 2475 years. This hazard map will help local authorities and planners with tools for assessing the seismic landslide risk associated with land use and taking necessary measures to minimize the damages.

Keywords: Co-seismic landslide, Seismic landslide hazard, Newmark sliding displacement, Mandi



A Parametric Study of Seismic Behavior of Concrete Gravity Dam using Abaqus

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Abstract

The Seismic analysis of a concrete gravity dam is a complex problem due to the mutual interaction between reservoir water, rock foundation, and concrete dam. To design earthquake-resistant dams, it is essential to have accurate and reliable analysis procedures to predict the dam response. In this study, seismic analysis of the concrete gravity dam using the finite element model via ABAQUS has been investigated for the Koyna earthquake (1967). A 2-D Finite Element Model of the dam was constructed to simulate a dam-reservoir system. The reservoir water domain is represented as an incompressible and non-viscous fluid continuum having a finite length in the upstream direction. The foundation of the dam is assumed as rigid. Both the mass concrete and foundation are assumed to have homogenous, isotropic, linearly elastic properties. Seismic dam responses are expressed in terms of dam deformations, dam stresses, spectral displacements, mode shapes, natural frequency, and response time history. Spectral results confirm that there is a significant effect of the natural period on the seismic behaviour of the dam. Considering the dam-reservoir-foundation interaction, the maximum principal stress, minimum principal stress, top board displacements, natural frequencies, and mode shapes are analyzed and the results are discussed by comparing results obtained from the proposed FEM model in the literature.

Keywords: Concrete gravity dams, Seismic analysis, Dam-reservoir system, Finite element model



Influence of Bearing Plate on Stiffened Cleat Angle J-Bolt Precast Beam Column Connections Under Cyclic Loading

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Abstract

Generally dry connections are adopted in precast beam column connections because it can easily be demounted. Precast beam column dry connections uses either corbel or steel components like billet, cleat angle, stiffeners. Previous study on dry connections with corbel indicates that the load carrying capacity is not same in both the positive and negative directions because of heavy damage to the concrete corbel. Hence an attempt has been made to study the influence of steel bearing plate on stiffened cleat angle J-Bolt precast beam column connection. This study describes the experimental investigation of precast beam to column J-Bolt connections with beam stiffened at the top using cleat angle with single and double stiffeners and at the bottom with steel bearing plate under reverse cyclic loading. Two beams to column precast specimens and a monolithic specimen of one-third scale were tested under displacement controlled cyclic loading. The first precast connection consists of a J-Bolt with cleat angle stiffened with a single stiffener and bearing plate (JC-SSB) whereas and the second connection consists of J-bolt with cleat angle stiffened with double stiffeners and bearing plate (JC-DSB). The parameters studied were load carrying capacity of the connection, load displacement hysteresis, ductility and energy dissipation. The monolithic specimen performed better when compared to the precast specimen (PC-SSB) in terms of strength and energy dissipation. The precast specimen (JC-DSB) exhibited comparable behaviour in terms of strength and better performance in terms of ductility and energy dissipation when compared to the monolithic specimen (ML).

Keywords: Cyclic loading, Precast concrete, Beam-column, Dry connection

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 222



Assessment of Liquefaction Potential of Allahabad, India: A Future Smart City

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Abstract

In the present work, seismic hazard assessment is performed for Allahabad city in terms of LPI (Liquefaction Potential Index) for a hypothetical earthquake along the Allahabad fault of magnitude Mw 6.7 for different surface Peak Ground Acceleration (PGA) levels (0.06 g, 0.1 g, 0.15 g and 0.2g). Factor of Safety against liquefaction (FS) has been estimated using modified Semi-empirical process from Idriss and Boulanger (2006) for all depths of 116 boreholes across Allahabad. Estimated FS values are used for computing LPI (deterministic) values. Liquefaction potential hazard contour maps are shown in terms of spatial distribution of FS and LPI indices. It is observed that a large part of Allahabad is safe against FS for lower PGA values (0.06 g and 0.1 g) but has a potential to liquefy under high intensity shaking of 0.15 g and 0.2 g PGA at depth 15 m or more. In terms of LPI, most places have 'Low' to 'Very low' liquefaction severity (i.e. LPI<5) for (0.06 and 0.1) g. It gets modified to 'High' (i.e. LPI *b/w* 5 to 15) for (0.15 and 0.2) g at Naini, Jhalwa, Sangam area, near Railway station and Jhunsi region.

Keywords: Liquefaction, Cyclic stress ratio, Peak ground acceleration, Lateral spreading, LPI



Infill Wall Effect on Seismic Analysis of Reinforced Concrete Buildings

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Abstract

Infill walls are used to fill the gap between the structural elements in a framed structure. It protects the structure from external environment and also act as partition wall to create separate rooms according to the requirements. Different types of infills are used to create masonry wall like red clay brick, fly ash brick and AAC blocks. In seismic analysis the infill wall contribution is ignored as it is considered as non-structural element. But in recent years, much research has been conducted by many researchers to study the behaviour of the unreinforced masonry during seismic event. Here, the study is to find the infill wall effect on seismic analysis and design. In our study, Bare frame model (BFM), hybrid frame model (HFM) and infilled frame model (IFM) are taken to perform the seismic analysis. Equivalent diagonal strut method is used to include the unreinforced masonry infill wall effect in seismic analysis using codal provisions of IS1893:2016. In this method, the wall is converted as a diagonal strut which only takes compressive force when the structure is subjected to some lateral forces such as seismic load. We performed few experiments on red clay brick masonry to obtain the data required for designing the diagonal strut dimension. Both static and dynamic analysis (response spectrum method) are performed using ETABS software. G+4, G+9, and G+14 models are designed to study the infill wall contribution in earthquake analysis by varying the elevation of the structure. Storey drift, storey displacement, member forces and time period are taken as the parameters. After performing both the analysis, this is observed that the infill wall significantly affect the member forces and stiffness of the structure during seismic event. So, the practicing engineers must include infill wall effect while designing real structures.

Keywords: Diagonal strut method, Hybrid frame, Infilled frame, Bare frame, Storey drift, Storey displacement, Response spectrum method



Simplified Computational Model for Post-tensioned Shear Walls

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Abstract

The shear walls fitted with the prestressed tendons that remain in an elastic state are termed, “Post-tensioned (PT) shear walls”. These walls have the benefit of self-centering and reusability over conventional shear walls. These walls when fitted with energy dissipators increase the energy dissipation capacity of the walls and save them from any structural damage. Various analytical, experimental, and numerical studies have been undertaken in the past to study the behaviour and performance of the isolated PT shear walls. Though several computational models exist to study the behaviour and performance of these walls, the existing models are computationally expensive. Therefore, this study aims at developing a simplified computational model in SAP2000 that can be computationally inexpensive. The developed simplified model is compared with an ABAQUS model developed for a PT shear wall used in a past experimental study. The results show that the model satisfactorily matched the base shear versus drift behaviour as well as the model took very less time relative to the ABAQUS model. Also, the model developed in SAP2000 has the potential to be integrated into a building frame as SAP2000 is one of the most used software for building design and analysis. These factors make the developed simplified computational model computationally inexpensive and have the potential to be used as a preferred choice of the computational model.

Keywords: Post-tensioned, Computational model, Numerical study



Understanding the Effect of Localized Impacts in Seismic Response of Electrical Cabinets and Control Panels

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Abstract

The safety-related electrical equipment used in important structures must be seismically qualified. The seismic demands on electrical equipment are governed by the dynamic response of electrical cabinets and buildings. The seismic demand on the electrical equipment is represented by in-cabinet response spectrum (ICRS). A cabinet may exhibit several small gaps at the cabinet base, between its door and the main structural frame, or between two cabinets located next to each other. Such gaps can result in localized impacts which can induce high frequency vibrations inside the cabinet leading to functional failures of electrical equipment. In this paper, we conduct a fundamental study using a single degree of freedom system with a gap to study the effect of such localized impacts. It is shown that such localized impacts lead to high frequency spectral amplitudes in the ICRS which are otherwise not present in an ICRS generated using a linear analysis. Moreover, the secondary peaks tend to occur in a periodic pattern. To understand and explain this behavior, a single degree of freedom (SDOF) system with gap is subjected to harmonic ground displacement of various amplitudes and excitation frequency. The major difference between behavior of nonlinear and linear systems is the transient behavior. The response of nonlinear model is governed by its transient response which is reinitiated each time the gap closes. Furthermore, the impact on SDOF acts as an impulse load which explains the occurrence of high frequency peaks and valleys in the ICRS.

Keywords: Equipment response, High-frequency accelerations, Geometric nonlinearity, Localized impact

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 243



Geotechnical Seismic Base Isolation Using Rubber Sand Mixtures - Review

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Abstract

Automobile industry has achieved an exponential increase in the sales of vehicles during the past decades. Consequently, the problem with the disposal of vehicle tires has become a potential threat especially among the developing countries. Geotechnical research community has resolved the problem by employing the tire shreds for vibration isolation applications, retaining wall construction, as a sound barrier, cushioning foams etc. Current work discussed the previous studies related to the historical background, engineering properties, mechanical behaviour, dynamic characteristics and numerical modeling of rubber sand mixtures. This review paper will provide the researchers a general insight towards the factors influencing the static and dynamic properties of rubber sand mixtures, advantages, disadvantages, contradictory results and the areas which require future studies.

Keywords: Automobile industry, Tire shreds, Vibration isolation, Dynamic properties, Rubber sand mixtures, Contradictory



Seismic Evaluation of Assam Type Building Using Abaqus®

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Abstract

Assam-type housing is a building typology that was promoted by the British PWD after the 1897 Assam Earthquake, in which a light-weight construction was made possible by suitable use of locally accessible resources such as timber, bamboo, ikra (a reed which is locally accessible), etc. for the superstructure, while modern masonry confined with RCC posts were used till sill level. This low-cost, green and sustainable housing typology is slowly replaced by costly, environmentally degrading, unsustainable RCC frame structures.

In this study, an attempt is made to promote this green, cost-effective and safe housing typology by showing its efficacy analytically against seismic excitation using appropriate finite element modeling. Modeling is done using state-of-the-art Finite Element Analysis software ABAQUS®, which could capture the intricate joinery details of different materials such as timber, bamboo and ikra, interfacing with modern minimal elements such as masonry and concrete/RCC. Dynamic characteristics are evaluated using modal analysis so as to test the efficacy of the model. Seismic evaluation is performed using response spectrum method of IS 1893(Part 1): 2016. It has been observed that the model is safe against the seismic excitation for this region.

Keywords: Assam type building, Finite element modelling, ABAQUS®, Modal analysis, Response spectrum analysis



Seismic Evaluation of Eccentric Brace Frame Designed by Force Based Design and Performance Based Plastic Design Methods

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Abstract

Eccentric Brace Frames (EBF) is a combination of moment Resisting Frames (MRF) and Concentric Braced Frames (CBF). It combines the stiffness and strength of a concentric braced frame with the energy-dissipating capacity and inelastic behavior of a moment frame. The current seismic codes used for the design of EBF are based on the Force Based Design (FBD) method where, the substantial ductility and inelastic deformation capacity of the EBF cannot be completely used since the inelasticity is implicitly compensated by the response reduction factor 'R'. The drawbacks of the FBD method are overcome by using the Performance Based Plastic Design (PBPD) method. The PBPD method is based on an energy balance equation that considers the system's inelastic behavior by predefining the target drift and pre-selected yield mechanisms. By explicitly accounting for the system's inelastic behaviour in the design formulation, this method tends to be more reasonable and takes into consideration damage unpredictability, which is unusual in medium- to high-intensity earthquakes. In the present study a 10- storey D-Braced Eccentric Brace Frame is studied and designed using FBD method and PBPD method, and evaluation of seismic is been carried out through Non-linear Static Pushover Analysis (NSPA) and Non-linear Dynamic Time History Analysis (NDTHA). According to the study, the PBPD method for EBF is substantially more effective than the FBD method in attaining a specific inelastic displacement for a given set of seismic hazards.

Keywords: Eccentric brace frames (EBF), Performance based plastic design (PBPD), Force based design (FBD), Non-linear dynamic time history analysis

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 253



Seismic Response of Idealized Three Storey Frame Equipped with Magnetorheological-shape Memory Alloy hybrid Damper

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Abstract

The requirement of more spaces for residential and business offices and advancement in construction technology attracts civil engineers and contractors to build high-rise and asymmetrical buildings worldwide. Such buildings are more vulnerable during seismic and wind loadings. The present study is focused on vibration mitigation of 3-storey buildings using a Magnetorheological (MR)-shape memory alloy (SMA) hybrid damper. The seismic response of an idealized three-storey frame equipped with an MR-SMA damper is investigated using numerical analysis. To perform the analysis of the idealized building, the Simulink tool is used for the constitutive modeling of SMA and MR dampers along with the state space equation. To check the effectiveness of the proposed damper, a displacement response of a controlled frame with MR-SMA damper is compared with an uncontrolled frame. Further, the results show that the MR-SMA damper is capable of reducing the displacement of the structure significantly.

Keywords: Shape memory alloy, Magnetorheological fluid, Earthquake, Buildings



Development of Soil Amplification Factors Using 1D and 2D Ground Response Analysis

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Abstract

1D ground response analysis is quite popularly used for determining soil amplification numerically. 1D GRA works well for layered soil material with infinitely extending boundaries. However, in case of irregular ground, complex site stratigraphy, river basin, etc. 2D analysis or even 3D analysis is preferable where soil properties in all the corresponding direction is incorporated and thus depicts the real behaviour when it is subjected to an earthquake motion. In the present study, an attempt has been made to determine soil amplification using the 1D, and 2D GRA. The analysis is carried out on numerous multilayer real soil profiles taken from author's past work. As a first step, 1D EL GRA is conducted for 8 real sites from India, using the DEEPSOIL software. Spectrum compatible time histories matched with the Type I spectra of Indian code, corresponding to Effective Peak Ground Acceleration (EPGA) of 0.36 g are used. Deconvoluted motion of earthquakes are applied at the bottom of strata/ preferably on bedrock, and the response throughout the thickness of the strata is recorded in order to get the soil amplification profile. Later, using commercially available FEM software, ABAQUS 1D and 2D analysis is done where the layered soil medium is modelled using continuum approach. The results from 1D and 2D are compared together in terms of response spectra and amplification factors. This study brought forth the comparison of GRA results using discrete and continuum approach in 1D and 2D analysis.

Keywords: Soil amplification, Seismic response, Ground response analysis, 1D, 2D



Suitability of Foam Concrete and Confined Masonry for Retaining Walls Application in Seismically Active Regions: A Review

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Abstract

The self-weight of retaining wall and the supported backfill play a vital role in its stability, particularly in weak soil conditions. Further, the seismic activity and moisture content in this soil condition aggravates the instability of retaining wall leading to its failure. Hence, the self-weight and seismic resistance of retaining walls is of utmost importance along with pore water pressure dissipation. It is to be noted that any structure's seismic behaviour is primarily influenced by its mass, strength, and stiffness, as well as by all other factors that may have an impact on those characteristics. This paper presents a detailed review on the seismic performance and energy absorption characteristics of foam concrete, which contribute to the stability of retaining walls through optimization in self-weight along with pore water pressure dissipation. Later, the limitations of using foam concrete in various types of retaining walls is discussed. Though masonry retaining walls is a potential solution, reinforced concrete confining elements along with foam concrete interlocking blocks could be more effective in enhancing their ductility, integrity, stability and strength against in-plane and out-of-plane seismic excitation. Further, few researchers have shown that confinement of wall with reinforced concrete tie-columns improve lateral resistance and deformation capacity of an unreinforced masonry wall by more than 1.5 times and five times respectively. This is in addition to a six to seven times enhancement in the energy dissipation capacity. This way, the stability of retaining walls could be enhanced by the use of foam concrete, interlocking blocks and confined masonry technologies. It should be highlighted here that though the combination of these technologies has a lot of potential in the aforementioned application, very limited research exists in the literature on use of foam concrete and confined masonry for retaining wall applications. In this light, the present work also presents an in-depth review on dynamic properties of foam concrete, enumerating the seismic resistance mechanism.

Keywords: Foam concrete, Confined masonry, Interlocking blocks, Retaining wall



Role of Hydrodynamic Forces on the Seismic Response of a Dam

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Abstract

The static and seismic response of dams is always a serious concern in the design and construction phases of these massive manmade structures. The gravitational stability of these structures is continually challenged by various forces acting on the dam structure, including the upstream water. But the role of hydrodynamic forces on the seismic response of dams is not been much studied in the past. Moreover, the hydrodynamic forces vary with the depth and shape of a dam, leading to an underestimation of its effect on the seismic response of a dam. This paper studies the seismic response of a concrete gravity dam using finite element analysis, considering the hydrodynamic effects. The hydrodynamic impact on the dam structure is simulated using two methods, the inertial mass concept and water as a structure. Three natural seismic motions, Koyna, Kobe and Chi-Chi, are used to study the influence of seismic motions on the hydrodynamic effects on the dam. The study shows that the hydrodynamic forces contribute to stresses on the dam structure in seismic activity, and the hydrodynamic forces acting on the dam are proportional to the shaking intensity. Moreover, the study also reveals the underestimation of hydrodynamic forces in the inertial mass approach with the help of modelling water as a continuum.

Keywords: Concrete dams, Seismic response, Hydrodynamic forces, Inertial mass concept, Finite element modelling



2020 Tuipuiral Earthquake Review

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Abstract

Tuipuiral is located in the eastern end of Mizoram in Champhai District sharing its international border with Myanmar. The region is frequented by many microearthquakes along with some of the noticeable disastrous earthquakes in the past in this area. An earthquake of Magnitude Mw 5.6 was reported on the 22nd June 2020 at 10:46:25 IST at 23.8867 latitude and 93.1256 longitude at a depth of about 12 km followed by another earthquake of Mw 5.6 on 22 June 2020 at 04:10:52 IST at similar focal depth. This resulted in sporadic damages around Champhai District, Mizoram. The tremors were felt strongly in the capital city Aizawl. The earthquake was followed by a number of aftershocks as well. The present paper is a report on the damage observed around the area. It was observed that, though the earthquake may be placed under minor-moderate earthquake, yet the damage observed were much greater than expected. The paper highlights macro seismic effects of the earthquake through field observations, assessing the damage pattern of buildings and wrong construction practices occurring in the area along with its remedial measures. The relatively more damage observed is attributed to the vulnerable construction practices and poor quality workmanship.

Keywords: Tuipuiral, Earthquakes, Construction practices



Evaluation and Prediction of Tensile Strength of Steel Fiber Concrete

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Abstract

The random orientation of steel fibers in steel fiber concrete (SFC) improves crack bridging, significantly enhances ductility and tensile strength of concrete. Several studies have shown an improvement in these mechanical properties of SFC. Unlike in plain concrete, the SFC exhibit high toughness. As a result of which, they try to yield even before being pulled out from the concrete matrix before complete failure. Over the two decades, extensive research has been carried out in this field and certain empirical relations were developed to understand and evaluate the tensile behavior of SFC through direct and indirect tensile test methods. However, existing equations may not be able to account for a wider range of input datasets considering various fiber contents and also validating the tensile strength through direct tensile test. Considering this issue, the current research focuses on carrying out an experimental study on notched beams tested under three-point loading. A total of 54 beams were cast with fiber contents varying from 0% to 2% (varied at an interval of 0.25%). Based on these experimental results and data from the literature, 457 data points were obtained, and an empirical relationship has been proposed for the tensile strength of SFC.

Keywords: Steel fiber concrete, Tensile strength, Volume fraction



Experimental Investigations on Pervious Concrete Piles in Saturated Ground Under Repeated Shaking Conditions

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Abstract

Abstract: Soil liquefaction has a significant influence in inducing structural failures during seismic events. Further, the recent repeated seismic events such as Christchurch earthquake (2010-2011), Tohoku earthquake (2011) raised alarm over the possibility of reliquefaction occurrence in saturated grounds. To alleviate liquefaction effects, various ground improvements methods were being used continuously for improving the seismic resistance of saturated ground. Among those ground improvement techniques, use of stone column and sand compaction piles are the most commonly used ground reinforcement techniques. The improvement in load-carrying capacity and drainage characteristics highly benefit the seismic improvement in saturated ground. However, the performance of these conventional ground treatment systems also depends upon the confinement provided by the surrounding soils and its assessment under repeated shaking events also not available/limited. Considering this, use of pervious concrete pile (PCP) as an alternative to conventional stone column technique is attempted in this study. Considering the sustainability approach, the pervious concrete pile was prepared with construction and demolition waste. Further, the efficiency of pervious concrete pile in mitigating the liquefaction and reliquefaction potential is also attempted in this study. For experimental studies, saturated ground having 40% relative density was prepared with and without pervious concrete pile treatment technique. Both, the unreinforced and pervious concrete pile reinforced ground was then subjected to repeated incremental acceleration of 0.1g, 0.2g, 0.3g and 0.4g with 5 Hz frequency to evaluate the seismic resistance of the prepared ground with and without improvement system. The variation in generation of excess pore water pressures ratio and settlement of untreated and pervious concrete pile treated ground was compared and observations on the obtained results were presented.

Keywords: Pervious concrete pile, Reliquefaction, Excess pore water pressure ratio



Small-strain Shear Stiffness and Strain-dependent Dynamic Properties of Gravel-rubber Mixtures

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Abstract

The purpose of this study was to investigate the small-strain shear stiffness and strain-dependent dynamic properties (i.e., shear modulus degradation curve) of mixtures of gravel and recycled granulated tire rubber for use in geotechnical applications, including geotechnical seismic isolation foundation systems for buildings. Therefore, bender element and small-strain cyclic triaxial tests were carried out on dried specimens of pure gravel and gravel-rubber mixtures with 10%, 25%, and 40% rubber content by volume. In this paper, the small-strain shear stiffness (G_{\max}) characteristics as well as shear modulus (G) vs. shear strain (γ) amplitude curves are presented, and the effects of stress level and rubber content are discussed. Hence, an analytical hyperbolic model for estimating G as a function of the rubber content, stress level and shear strain amplitude is proposed for gravel-rubber mixtures (GRMs).

Keywords: Gravel-tire rubber, Bender element, Shear modulus, Damping ratio, Small strain, Cyclic triaxial tests

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 280



Parametric Study on the Self-centering Buckling-restrained Braces Based on Post-tensioned Composite Cables

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Abstract

A self-centering buckling-restrained brace (SC-BRB) has excellent potential to reduce the residual drifts of a structure while utilizing the seismic energy dissipation capacity of the steel BRB core. The present study uses post-tensioned carbon fiber composite cables (CFCCs), which provide the necessary restoring force and additional post-yield stiffness to minimize residual deformation. The carbon fiber composite cables have limited post-tensioning (PT) force loss under cyclic tensile loading, thus ensuring a sufficient restoring mechanism until its failure strain level. A numerical model has been developed using OpenSees to study the hysteretic response of the brace subjected to the loading protocol as per the American Institute of Steel Construction (AISC) 2016 Seismic Provision manual. The effect of the different core areas, cable area, and initial PT force for a particular brace force demand on the residual deformation and hysteretic energy dissipation potential has been extensively studied using the numerical model. The optimum range of values of energy dissipation ratio (β_{ed}) and post-yield stiffness ratio (α) has been proposed in the study for designing the SC-BRBs.

Keywords: Buckling-restrained braces, Seismic analysis, Self-centering, Carbon fiber composite cable



Effect of Semi Active Tuned Mass Damper on Seismic Response of Structure with Soil Structure Interaction

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Abstract

The seismic response of a five- storey building with soil structure interaction (SSI) utilising semi-active tuned mass damper (SATMD) is obtained. A magneto- rheological (MR) damper with friction type damping scheme is used alongside a tuned mass damper to constitute a semi active tuned mass damper. To study the effect of SSI, the seismic response of the building with a fixed base is compared with that of the building resting on soft soil. The soft soil is considered to have a shear wave velocity of 100 m/s. The optimum damper parameters of SATMD considering four different ground motions are obtained and these parameters are utilised to show the superiority of SATMD with friction type damping scheme in terms of efficiency and robustness. It was observed that the SATMD could significantly decrease the response of the building subjected to ground motions, but the reduction varied widely with the ground motion considered.

Keywords: Soil structure interaction, Semi active tuned mass damper, Seismic response



Seismic Response of Multistorey Building with Varying Stiffness Modifiers

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Abstract

Due to rapid urbanization, many high-rise buildings are constructed and safety is the primary concern for engineers and researchers if the high-rise building is situated in a higher seismic zone. The cracks can be developed in the structural members for ultimate load condition. To consider crack section of structural elements for seismic load condition, the stiffness modifiers are considered to reduce the seismic demand on the structures. The concept of stiffness modifiers is mentioned in IS 1893 (Part 1)-2016 code stating that to consider effective moment of inertia which is 35% of the gross moment of inertia for beams and 70% of the gross moment of inertia for columns in clause no. 6.4.3.1 of IS1893-2016. As the code specified, the value can be modified in the next revision depending on the suggestions and submission of papers on proposed values. On account of this, a detailed analytical and numerical study is carried out to observe the impact of stiffness modifiers on building subjected to seismic force. The present paper aims towards the comparative analysis of multistorey building with different heights subjected to seismic force are investigated by considering different stiffness modifier values. The building is analyzed in all seismic Zones with soil type-III. Analysis has been carried out by the response spectrum method using finite element-based software. Different response parameters such as story displacement, story drift, and story shear have been determined. From the examination, it is observed that the model considering the optimal value of moment of inertia (I_2) is showing lower story drift and story displacement resulting in higher seismic holding capacity than with the model considering other moment of inertias.

Keywords: Stiffness modifiers, Response spectrum method, Story drift, Story displacement, Multistorey building



Numerical Evaluation of the Seismic Performance of GSI Foundation Systems for Buildings Using Gravel-rubber Mixtures

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Abstract

Geotechnical seismic isolation (GSI) using gravel-rubber mixtures (GRMs), as an energy dissipative horizontal layer, is a promising foundation technology to enhance the seismic resilience of low-rise residential buildings. This paper presents preliminary results of a numerical study carried out to evaluate the seismic performance of a selected GSI-GRM system and compare it to that of a standard non-isolated foundation system placed on a compacted gravel layer (i.e., without rubber). To this scope, a 3-dimensional FE model is created in OpenSees and calibrated using experimental data. In the model, a 12m × 6m × 50cm concrete raft foundation is placed on a 60cm-thick layer of GRM (having volumetric rubber content (VRC) of 40%) or gravel (VRC = 0) resting on a 20m-thick medium-dense dry sand deposit. No structures were placed on the foundation. The model was subjected to a ramped sinusoidal input base acceleration ($a_b = 0.1 - 0.5 \text{ g}$) at different frequency levels ($f = 1 - 8 \text{ Hz}$). The accelerations at the base ($a_{GIS,base}$) and top ($a_{GIS,top}$) of the GRM/gravel layer are compared and it is found that, the effectiveness of GSI-GRM systems significantly increased with increasing a_b and f . The best seismic performance is attained at $f = 8 \text{ Hz}$, where the acceleration reaching the GSI top ($a_{GIS,top}$) is reduced up to 60% as compared to that of the non-isolated gravel foundation.

Keywords: Geotechnical seismic isolation, Gravel-rubber mixtures, Numerical model, Seismic performance



A Critical Review on Soil Reliquefaction Resistance Using Physical Modelling Experiments

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Abstract

Liquefaction and associated ground deformations are one of the major causes of the devastating damage to the foundations and structures during earthquakes. Past research works focused on understanding the liquefaction mechanism and behavior subjected to the initial/independent seismic loading events. Henceforth, research related to understanding the reliquefaction mechanism and resistance of sand deposits was limited. The instance of historical earthquakes witnessed occurrence of reliquefaction, soil liquefied more than once when subjected to successive earthquakes (e.g., the main shock associated with foreshocks and aftershocks). The recent historic earthquakes (2010 – 2011 Canterbury earthquakes series, 2011 Tohoku, 2016 Kumamoto, and 2019 Vancouver among many) illustrated the destructive nature of the reliquefaction phenomenon. Multiple liquefaction was spotted during these repeated earthquakes/earthquake swarms, despite the earthquake magnitude being less than the previous shaking. Some of the field observations reported an increase in reliquefaction resistance due to the previous liquefaction occurrences and the beneficial effect of preshaking. In contrary to this, some studies reported a significant reduction in the resistance to reliquefaction. The present study critically reviews the complex nature of reliquefaction characteristics in increasing/decreasing the resistance of sand deposits to future liquefaction events. Physical modelling experiments have been used for simulating the liquefaction and reliquefaction phenomenon and in understanding the factors influencing the reliquefaction resistance. Factors such as method of sample preparation, initial relative density, input motion characteristics (acceleration amplitude, dynamic frequency and shaking duration), effect of preshaking on reliquefaction resistance was critically reviewed. It is concluded that all the above-mentioned parameters are critical in influencing the reliquefaction resistance to a certain extent. This study will be useful in understanding the reliquefaction mechanism and factors influencing liquefaction resistance when sand deposits subjected to repeated shaking events. This review will be highly useful in achieving the efficient design of ground improvement system to mitigate reliquefaction and associated deformations.

Keywords: Reliquefaction, Physical modelling experiments, Preshaking, Ground improvement system



Effectiveness of Seismic Isolation of Highway Bridge on Design of Well Foundation

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Abstract

During earthquake events, the respite and restoration works are completed conceivably when bridges are protected from failures. Nevertheless, as their structural redundancy is low, bridges are severely damaged and may lead to catastrophic failures during earthquakes. Just by increasing the tolerable stress level of bridge components is not effective. It is uneconomic, unless the spread of earthquake-induced forces and energy into the bridge structure is controlled. This can be achieved by decoupling the bridge superstructure from the substructure, by interposing seismic isolators at the level of bridge bearings. In India, river bridges located in seismically active regions have very large size of well foundations. As per the conventional design, the well diameter can be as large as 12 m, in some cases. Principally in case of long span bridges, such as those on river Brahmaputra in Assam, the cost of foundations becomes enormous. Seismic isolators, provided in place of conventional bridge bearings dissipate the kinetic energy, thereby reducing deformations of the piers and the deck. Lead rubber bearings (LRB), also known as New Zealand (NZ) bearings are the most common type of seismic isolators, installed in different structures, worldwide. In the present research work, a study is conducted to investigate the effect of NZ bearings on design of well foundations, considering a case study bridge [4], in which, time history analysis of the bridge considering Kobe (1995) earthquake excitation is carried out with and without installation of NZ isolators. Kobe earthquake is among the most damaging seismic events ever occurred universally. The response of the bridge with the LRB is compared with the uncontrolled response. The response parameters considered are pier shear force and pier base moment. Well foundations are designed for non-isolated and isolated bridge. The specific objective of the study is to evaluate effectiveness of seismic isolation on economizing the size of well foundation. It is revealed that there is a significant reduction in the well diameter and thickness of steining, which can decrease the cost of foundation. This will lead to saving in the overall cost of the project, in particular where the number of well foundations is large.

Keywords: Bridge structure, Seismic isolation, Lead rubber bearings, Well foundation, Seismic design



Seismic Pounding Mitigation of Two Adjacent Reinforced Concrete Buildings with Bracing System

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Abstract

Insufficient or no separation gap between adjacent buildings leads to seismic pounding during the earthquake. The seismic pounding is defined as the collision of the adjacent buildings amid the earthquakes. This type of seismic induced pounding between closely spaced buildings accumulates the damages, as well as hampers the structural safety under earthquake loads. This paper aims at studying the proper required mitigation techniques to prevent seismic induced pounding between the adjacent reinforced concrete (RC) buildings by equivalent static force method (ESFM), response spectrum method (RSM) and non-linear dynamic time history method (NLTHM). The variation of seismic responses like base shear, time period, shear force, bending moment, storey drift and storey displacement with different equal area steel sections of the bracing and its arrangements is investigated and finally, the best suitable bracing is concluded. Thereupon, its effectiveness in mitigating seismic pounding between two adjacent Reinforced Concrete buildings is studied by comparing the required separation with and without bracing.

Keywords: Seismic pounding, Two adjacent RC buildings, Steel bracing, Earthquake



Seismic Risk Assessment of a Himalayan Town: A Case Study of Queen of Hills, Mussoorie, Uttarakhand, India

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Abstract

The Himalayan region in north India is characterized by both mild-to-steep hill slopes as well as high seismicity. The presence of topographic features significantly alters the earthquake ground-motion characteristics in terms of both the amplitude and frequency content. In addition, the building configurations observed in these regions are also significantly different than those usually observed in the plain areas. As a result, hilly regions pose significantly higher seismic risk compared to their plain terrain counterparts with comparable seismicity. In the present study, probabilistic seismic risk assessment is conducted for a typical Himalayan town of Mussoorie, in the state of Uttarakhand, India. Firstly, the topographic amplification effects are estimated corresponding to various hill geometries using finite element simulations and amplified seismic hazard maps are developed. The building stock inventory for the town is prepared using a combination of satellite imagery and random sample ground surveys. The available building fragility and vulnerability functions from the Global Earthquake Model along with the developed hazard and exposure models are integrated into OpenQuake to obtain seismic risk maps for Mussoorie, with and without considering the topographic amplification effects. It is shown that the topographic amplification effects alone can increase seismic losses upto ~200%, thereby highlighting a need to include them in seismic design of structures.

Keywords: Seismic hazard, Topographic amplification effects, Seismic vulnerability, Seismic risk



Inclusion of Fatigue Checks in Current IS Codes for Monopole and Stack Structures

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Abstract

This paper covers the Fatigue design of Monopoles, spun towers, and steel stacks. Steel stacks/ Spun towers are amongst high vertical, flexible, and wind resisting structures. They help to resist cyclones, wind turbulence and dynamic forces during earthquakes. Mostly, the cyclic stresses due to wind forces are governing in tall steel stack structures. The authors provide methodology of fatigue design for cyclic loadings in these structures. NBC and IS codes fail to provide systematic methodology for fatigue design. This study is carried out to understand the performance of a fatigue resistant design of steel structures by presenting a case study. Due to cyclic loadings, weld connections also need to be checked as per IS 1024.

The paper is subdivided into two parts, former part consists of an introduction to the topic under consideration and explains in brief the methodology that will be adopted for fatigue design. And the later part consists of a case study. As part of a case study, it has been decided to analyse and design a 5m monopole, spun towers of 15m and 20m and to evaluate their feasibility with respect to installation through National Cyclone Risk Mitigation Project which are under construction at Altinho, Panaji Goa from Structural safety point of view.

Monopole/ Steel stacks are subjected to dynamic wind pressures, as a result, joints will be subjected to Fatigue stresses. Hence, it is advisable to check the welded joints for these cyclic stresses. Residual stresses due to installation of bolts or welds are usually not required to be considered in statically loaded structures, but connections in cyclically loaded structures shall be designed considering fatigue as specified by this author. Fatigue assessment is required especially for steel structures supporting lifting or rolling loads, members subjected to repeated stress cycles from vibrating machinery, wind induced oscillations of many cycles in life, and members subjected to crowd induced oscillations of a large number of cycles in life etc.

Furthermore, Modelling and analysis of monopole of 5m and spun towers of 15m and 20m will be carried out using STAAD Pro and ETABS, MIDAS and their corresponding fatigue checks considering the above provisions.

Keywords: National cyclone risk mitigation project, ETABS, STAAD, MIDAS



Behavior of Monopiles for Offshore Wind Turbines in Clayey Soil for Gulf of Khambhat Region

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Abstract

The FOWIND consortium performed various feasibility studies to establish initial pathways for assessing the development of offshore wind power in Gujarat and Tamil Nadu, India. It paved the way for the researchers to investigate further the viability of various Offshore Wind Turbines (OWTs) elements. A 200 MW project titled FOWPI (First offshore Windfarm project in India) is planned in Zone-B off the coast of Pipavav port in Gujarat to demonstrate the risk issues involved before the large-scale implementation of offshore wind farms. This paper presents the development of a three-dimensional finite element model to simulate the monopile foundation of OWTs subjected to monotonic loading for the soil conditions of the Gulf of Khambhat. Soil properties are considered for the clayey soil obtained from the geotechnical investigation done for the LIDAR platform established at the site. Feasibility studies under FOWIND suggested three rating turbines of 4 MW, 6 MW, and 10 MW. Therefore, the current study considered the structural dimensions and material properties of monopiles for these three turbines. Response of all three monopiles has been evaluated for the service-ability limit. Further, p-y curves are developed for the monopile of each turbine, which is then compared with the conventional and recently developed p-y methods.

Keywords: Monopile, Offshore wind turbine, Monotonic loading, Finite element modelling



Probabilistic Seismic Hazard Assessment for Assam, North-East India

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Abstract

In this study, Probabilistic seismic hazard assessment (PSHA) is performed for Assam, North-East (NE) India. NE India being bounded by latitude 200-300 N and longitude 870-980 E, is considered as one of the most earthquake-prone areas in the world. As per seismic zoning map of India (IS 1893 (2016), Part 1), most of the states in NE region have been placed in seismic zone V, which has the highest zone factor in the country. Among the eight north-eastern states, Assam serves as the gateway to the other seven states. As this region lies on one of the most vigorous tectonic plates in the world, it has experienced several devastating earth-quakes in the past. The most devastating earthquakes include 1869 Cachar Earthquake ($M_w=7.5$), 1897 Assam-Shillong Earthquake ($M_w=8.1$) and 1950 Assam Earthquake ($M_w=8.7$). Considering the seismicity of this region, seismic hazard assessment plays a significant role to assess the seismic risk for the future. The NE India region is broadly divided into four seismogenic sources, and further sub-divided into eleven seismogenic sources based on the tectonic features and seismicity characteristics. For the study of hazard assessment, a unified moment magnitude catalogue has been used, where the events are assembled from various databases (ISC, IMD, USGS-NEIC). The catalogue has been declustered and the seismicity parameters are calculated for each source zone. The hazard maps have been presented at the bedrock level, in terms of peak ground acceleration (PGA) and spectral acceleration (Sa) values. The PGA values vary in between 0.16-0.57 g, while the Sa values are obtained in the range of 0.12-0.77 g. These hazard maps are expected to give insight to the local site-specific seismic hazard variation for the Assam region and would be useful for the preparedness of risk and disaster mitigation measures.

Keywords: PSHA, NE India, Assam, PGA, Hazard map



Linear Spring Constants of Soil for Pile Groups for the Nuclear Power Plants

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Abstract

The nuclear power plants are very massive and stiff structures. For such structure when founded on soft layered soil mass, the soil-structure interaction (SSI) has significant influence to the seismic response. Most of the existing nuclear power plants in India are constructed on rock which may not have the requirement of seismic soil-structure interaction analysis but some of the upcoming nuclear power plants will be founded on the alluvial soil necessitating to consider SSI. The pile foundation will be appropriate for nuclear power plants and high-rise buildings in the soft soil conditions and subjected to earthquake loading because of its effectiveness in load distribution to soil. In this research, simplified linear spring constants of soil are proposed to simulate the behavior of pile group foundation. These springs shall take care of pile-soil-pile interaction i.e. group effect. The pile group is modeled as an embedded beam element with the finite element discretization. In order to verify the validity of the proposed linear spring constants, computed response (in terms of Bending Moment, Shear Force and Deflection) is compared with the published results, where the soil is modelled as a continuum using the Finite Element Method. The good agreement achieved shows that the proposed method provides a simple and useful tool for engineering design of pile groups.

Keywords: Bending, deflection, Finite element method, Nuclear power plants, Pile group, Spring constant



Three-dimensional Slope Stability Under Bidirectional Pseudo-static Seismic Load

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Abstract

In general, two-dimensional slope stability methods assume the slope material as homogeneous, isotropic, and horizontally distributed, which is rarely true in reality. When the slope has complex geometry (sharp ridges, corners, cut and fill slopes, unplanned excavations, etc.), heterogeneous distribution of materials (along with depth and in out of plane direction), and complex loading conditions (seepage and seismic loading), a three-dimensional analysis for slope stability is preferred. In this article, a numerical study was conducted to assess the stability of the 3D slope under bi-directional seismic loads using the simplified pseudo-static method. The strength reduction technique is employed in a finite element framework to obtain the failure surface and factor of safety (FoS). A parametric study was performed considering four generic slopes having different complex three-dimensional geometries with similar cross-sections, soil properties, and boundary conditions to understand the variation in failure surface and FoS. The FoS obtained from the present study is plotted against the horizontal seismic coefficient applied in both lateral directions. As evident, the FoS is found to be decreasing rapidly with increasing horizontal seismic coefficients.

Keywords: 3D slope stability, Strength reduction method, Bi-directional seismic load



Parametric Study of Base Isolation System for Nuclear Power Plant

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Abstract

Base isolation systems are widely used to protect various types of structures like buildings, bridges, viaducts, industrial plants and are considered one of the most promising technologies to protect nuclear reactors from violent earthquakes. Satisfactory and safe performance of nuclear structures under seismic occurrence is necessary for Nuclear Power Plant (NPP) to avoid radioactive leakage from Nuclear Reactor Building (NRB). The parametric study presented illustrates how changing a design parameter of the isolation system influences the seismic response of the NPP and also provides guidance on isolation parameters that lead to improved response. The earlier study illustrates that the finite element (FE) model has the same behaviour as of Lumped Mass Stick Model (LMSM) model. Thus, NPP structure analysis is done by LMSM for ease of seismic analysis. The governing equations of motions are formulated and solved in a state-space form using MATLAB/SIMULINK. Further, the study has been carried out of the parameters such as displacements, acceleration, base shear and hysteresis loop of the fixed and isolated NPP structure concerning horizontal earthquake excitation. The various isolation systems considered are Laminated-rubber bearing, Lead-rubber bearing, Pure friction bearing, Friction pendulum system, and Resilient-friction base isolator.

Keywords: Parametric study, Base isolation system, Earthquake, Nuclear power plant, Lumped mass stick model



Strength of Masonry Infill RC Frame Influenced by Weak and Strong Type RC Frames

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Abstract

Masonry is most commonly used as an infill material in RC buildings. It considerably increases RC buildings' lateral strength and stiffness if appropriately connected with the RC frame members. It has been observed from past earthquakes that if the infill walls are severely damaged, then it may put the life of persons inside the building in danger. So, it is crucial to determine the effect of infill walls on the behavior of RC buildings. The present study investigates the effect of varying percentages of steel reinforcement of beams and columns on the strength and damage pattern of the RC frame with and without infill. The RC frame is modelled in the Abaqus using the continuum modelling approach, and the masonry is modelled using a simplified micro-modelling method also known as discrete element modelling. It has been found that reinforcement percentage significantly affects the strength and damage pattern of the RC frame.

Keywords: RC frame, CDP, Infill masonry, Discrete element model



A Novel Damage Indicator Evolved from Poincare Map for Detection and Localization of Seismic Damage in Structures with Nonlinear Breathing Crack

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Abstract

The proposed damage indices are formulated with an intention to utilize the computational advantages of time-domain analysis as well as to minimize the time-dependent fluctuations. To demonstrate efficiency of these damage indicators, a vibration analysis with harmonic excitation is performed on a structure considering nonlinear behavior of crack. The complexity in analyzing the state of a system under nonlinear vibration has been addressed by the graphical Poincaré map-based method. The difference in the estimated value of Poincaré index derived from the state variables of the system is considered as the fault signature. The novelty of this work lies in the combination of distribution of three state variables in phase space. Seismic damage is simulated considering failure of all bracings of a specific floor in the event of an earthquake and the same is incorporated in the experimental model with damaged bracing at the corresponding story. To achieve contact nonlinearity, damaged bracing is modeled with opening-closing mechanism. The present method evaluated in this work facilitates in minimizing the false identification of damage in time-domain by lowering time-dependent fluctuations.

Keywords: Structural health monitoring, Forced vibration, Poincaré map, Breathing mechanism, Damage localization



Drained and Undrained Response of Fully Saturated Specimen in Resonant Column Tests Subjected to Large Number of Torsional Vibrations

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Abstract

In this paper, the drained and undrained responses of the saturated sand specimens have been investigated when subjected to small strain torsional excitation cycles using the resonant column apparatus. The sand specimens were reconstituted at an identical relative density of 40%. The fully saturated sand samples were then subjected to different effective isotropic consolidation stresses of 65, 100, and 150 kPa. For each test, thousands of vibration cycles were applied to the specimen by keeping the amplitude of cyclic driving torque constant. The response of the specimen was evaluated in both drained and undrained conditions. Beyond threshold strain, the undrained response of the saturated specimen demonstrated a considerable increase in porewater pressure and decrease in shear modulus; whereas axial strain increased substantially in case of vibrations applied to the specimen in drained conditions. This type of study would be beneficial to determine deformational characteristics of fully saturated sand stratum beneath various vibratory machines which impart small strain and high-frequency vibrations.

Keywords: Resonant column test, Vibration cycles, Porewater pressure



Strengthening of Reinforced Concrete Beams for Shear Using Concrete Jackets

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Abstract

Existing reinforced concrete multi-storeyed buildings may be deficient to resist the effect due to earthquake. Of the possible failure modes of beams, shear failure of short span beams is brittle. Although under lateral loads they behave similar to the coupling beams in buildings with shear walls, they are not designed as such. The present study deals with strengthening of such shear-critical beams, by concrete jacketing. The study is investigating the improvement of the capacity and behaviour of short span beams retrofitted by concrete jacketing, specifically for shear. The paper includes a review of prior studies on strengthening of beams using jacketing techniques employing conventional concrete, self-compacting concrete, ferrocement concrete and fiber-reinforced polymers. Results of a numerical analysis are presented to demonstrate the effect of lateral loads on short beams in a typical mid-rise framed building. The effect of jacketing on the shear strength of short beams is demonstrated by testing two specimens under monotonic loading. It is concluded that the use of inclined stirrups is efficient in increasing the shear strength substantially.

Keywords: Concrete jacket, Coupling beam, Reinforced concrete building, Seismic retrofit, Shear strength, Short beam



Structural Performance of Hill Buildings During Earthquakes

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Abstract

The dynamic behaviour of reinforced concrete (RC) buildings in hilly areas varies from building stocks on flat terrains. Due to the inherent mass, stiffness, and structural irregularity, buildings on slopes experience amplified torsional forces under seismic excitations. Some typical structural configurations of buildings in hill cities were identified. Dynamic analyses were carried out on the analytical models simulating the hill building configurations. These models were then subjected to seismic excitations along and across slope directions. The dynamic characteristics and seismic responses of these hill buildings were recorded. The findings of the analysis are presented and discussed in terms of the fundamental period of vibration, storey drift, maximum top storey displacements, base shear and are finally compared within the considered configurations of hilly buildings. Analysis results reveal that the shorter columns on the uphill side being stiffer attract a higher amount of shear force, eventually leading to the collapse. Thus, short column effect is one of the critical patterns of structural response observed amongst buildings on slopes. This study concludes that the buildings on hills possess lower seismic capacity and are more prone to damage during seismic events than regular symmetric buildings on flat terrain. Some insights and suggestive measures to help reduce the failure of building stocks in hilly areas are also discussed.

Keywords: Random hill slopes, Earthquakes, Irregularity, Ground slope, Short column effect



Development of Application Software for Lateral and Vertical Load Carrying Capacity of Piles

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Abstract

Pile foundation is one of the preferred deep foundation for construction of structures either in coastal region or seismically active regions. In the present study, an attempt has been made to develop an application software for determining the lateral and vertical load carrying capacity of pile as per the provisions of IS 2911. This software is developed using Python Programming language and would be helpful for the preliminary design of pile foundation. Libraries such as NumPy, Matplotlib, Pandas, xlwt, etc. were used for backend work, whereas Tkinter and Treeview libraries were used for front end i.e. Graphical User Interface (GUI) work. This software provides you with a comparative study of how the load carrying capacity of pile changes with respect to change in soil profile (density, water table depth) and pile design (length and diameter) in tabular form. This tabular data can be directly exported to MS-Excel for further desired calculation. With the ongoing development enhancement and modification in the software, deflection of pile, slope, bending moment and soil reaction in graphical form with respect to length of pile can be viewed. This is a first step to make designing of pile foundation an easy task, less time consuming and also to make pile foundation more cost efficient. This software can also be used by teachers, professors, engineering professionals for a quick review, check and for optimal designing of pile foundation. This would be made available in public domain for updating and improvement to the source code.

Keywords: Pile foundation, IS 2911, Python



A Strategy for Multi-hazard Response Analysis of Structures Using Real-time Hybrid Simulation

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Abstract

This paper focuses on the development of a real-time hybrid simulation (RTHS) framework for multi-hazard response analysis of structures. The RTHS controls for the transfer system are designed using a strategy based on impedance matching. The major advantage of this strategy is that it decouples the control design from the physical subsystem, which may exhibit arbitrary complex behaviour. The proposed strategy can be adapted to incorporate different type of hazard scenarios, occurring individually or in sequence. Although applicable more generally, the strategy is demonstrated for the response analysis of two-storey structure subjected to base- and force-excitations. The physical subsystem consists of the bottom storey. The effect of the remaining structure, which forms the virtual sub-system, is realized with the help of a transfer system (electromagnetic shaker) placed at the top of the physical subsystem. The earthquake loading is applied using a shake table, while the effect of wind loading is accounted in the computer model. The responses obtained from RTHS are found to match well with that of the full structure. The proposed strategy can be effectively used for the response analysis of structures subjected to dynamic loads due to various hazards like wind, earthquake, tsunami or fire.

Keywords: Multi-hazard, Impedance matching, Controller design



Effect of Optimum Control Input in Seismically Excited Structure Considering Modal Control Spillover

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Abstract

In this work, the adverse effects of the modal control spillover are investigated for a multi-degree-of-freedom (MDOF) system under seismic excitation. The spillover occurs primarily due to the non-ideal optimal control force applied to the structure. In the study, the optimum control force is designed in accordance to the linear quadratic Gaussian control algorithm in the independent modal space. A closed form expression is developed in the frequency domain in the form of transfer function for assessing the amplification in responses due to the presence of spillover. Based on the formulation, a numerical investigation is carried out for a ten-story frame structure subjected to three ground excitations within the range of modal natural frequencies of the structural system. The optimum modal control force is designed by minimizing the displacement of the system considering a single input location. The performances of the structure under the designed control action are assessed in terms of the floor displacement and the horizontal floor acceleration. A huge amplification of the absolute maximum horizontal floor acceleration is observed for the structure under the control action as compared to the uncontrolled structure. The performance is found to be satisfactory in case of the floor displacement however, a response degradation in terms of the absolute maximum horizontal floor acceleration is observed for all the floor levels due to the spillover phenomena.

Keywords: Control spillover, Transfer function, Linear quadratic control



Effect of Randomness of Slip and Source Time Function on Pseudo-dynamically Simulated Ground Motion Characteristics

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Abstract

This paper presents the effects of randomization of slip and the parameters of source time function on the pseudo-dynamically simulated ground motion characteristics. In the case of numerical simulations, the radiation of seismic energy from the rupture plane as per Brune's model as well as to avoid the coherency effects is a challenging job for the simulators. The randomization of slip, rise-time, and peak-time of the source time function and the rupture arrival time, as well as the incorporation of fault-roughness and damage-zone, play important roles in seismic energy release from the rupture plane as well as in the reduction of coherency effects on the high-frequency seismic radiations. Inversion of earthquake data or statistical analysis of dynamic rupture simulations is used to estimate the slip distribution. The statistical approach assumes that the earthquake slip follows a random distribution on the fault plane. The simulation of pseudo-dynamic ground motion has been carried out using a fourth-order accurate staggered-grid time-domain 3D finite-difference method. The ground motions are simulated taking ten different slip patterns for a hypothetical strike-slip Mw 6.0 earthquake. In addition, for each slip pattern, a stochastic perturbation in the parameters of the source time function is introduced. The simulated results have been analyzed based upon some important parameters such as arias intensity, peak ground acceleration, peak ground velocity, and peak ground displacement. Considerable variation in the computed values for the aforesaid parameters is obtained with the change of slip patterns and parameters of the STF. A good match of the computed average pseudo-spectral acceleration (PSA) using the simulated ground motion with that obtained using NGA-West2 GMPEs is obtained in the frequency range 0.1–5.0 Hz and at an epicentral distance of 11 km.

Keywords: Pseudo dynamic rupture, Finite difference method, 3D ground motion simulation



Quantification of Ridge-weathering Effects on the Simulated Ground Motion Characteristics Across 2D and 3D Topography Models

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Abstract

This paper quantifies the impact of ridge-weathering on the simulation of ground motion across 2D and 3D topographical models. The models are excited with plane wave-fronts of Gabor-wavelet. The seismic responses of a 3D ellipsoidal ridge topography having shape ratio 1.0 and one of its cross-section (2D model) are simulated for different thickness and velocity of weathered layer. The SH- and SV-waves responses of a 2D cross-section of 3D topography are computed to understand the effect of dimensionality on the amplification pattern. The analysis of simulated responses reveals very large spectral amplifications and ASA in the case of 3D topography as compared to 2D. An increase of weathering effect on ground motion is inferred with an increase of weathering-thickness and a decrease of weathering-velocity. A considerable variation of topography amplification with elevation is obtained. Finally, it is concluded that the shape of ridge-topography, rheological parameters of the weathering layer should be taken in to account for the quantification of topographical effects on the ground motion characteristics.

Keywords: 3D topography effect, Finite difference method, Azimuth effect, Weathering effect

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 332



Comparative Performance Evaluation of Conventional and Base Isolated Building Including Life Cycle and Cost Analysis

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Abstract

Comparative performance evaluation of conventional RC frame building and Base isolated building has been carried out including life cycle and cost analysis. The conventional building, base isolated building and isolation bearing will design as per relevant standard. The effectiveness of a base isolation system are designed as per bilinear characteristic offered by the isolator. The lead rubber bearing (NZ type) is used as an isolator. It has high flexibility and energy absorbing capacity, so that during an earthquake, when the ground in horizontal direction vibrates strongly only a small fraction of lateral forces are transferred in the super structure. The performance will be evaluated by non-linear time history analysis under earthquake ground motions and pushover analysis. Further, life cycle analysis will be done from fragility curves developed and cost comparison will be carried out to study economic impact of base-isolated buildings.

Keywords: Base isolation, Pushover analysis, Seismic vulnerability analysis, Cost analysis



Seismic Re-evaluation of Cable Bridge Using Modal Pushover Analysis

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Abstract

In case of revision in the expected seismic hazard at site or revision in safety classification of the structure, seismic re-evaluation of the structure needs to be performed. Seismic performance expected for revised seismic level needs to be compared with post-seismic functionality of the structure. In past, Cable Bridge of Nuclear Power Plant (NPP) was designed for spectrum corresponding to SSE (Safe Shutdown Earthquake) level ground motion developed based on deterministic approach available at that time. Subsequently the spectrum was revised following the probabilistic approach and uniform hazard spectrum has been developed for arriving revised SSE spectra. It was decided to re-evaluate the structure for revised SSE spectra. In the present study, Seismic Re-evaluation of Cable Bridge of a NPP has been performed using Modal Pushover Analysis technique. This paper contains structural description, detailed methodology followed, analysis results and conclusion of the study. Structural behaviour of the Cable Bridge has been checked for SSE condition using modal push over analysis methodology presented by Chopra and Goel. (2002). A three-dimensional mathematical model of Cable Bridge has been developed in SAP2000. In the mathematical model, beams and columns are modelled as frame elements with plastic hinge properties defined as per Federal Emergency Management Agency, FEMA356. Capacity Curves of the structure are obtained by performing pushover analysis for significant modes of vibration in each direction. Capacity curves obtained are compared with demand spectra (corresponding to SSE condition) to obtain performance points. Seismic responses of structure at performance points for different modes of vibration are combined to obtain response of the structure under SSE condition. In order to ensure the safety and functionality of the Cable Bridge, response of the structure under SSE condition is checked with respect to required performance objective as per FEMA356. In the present study, it is concluded that the Cable Bridge is safe under revised SSE level ground motion and desired post-earthquake performance has been demonstrated.

Keywords: Modal push over analysis, Cable bridge, Safe shutdown earthquake, Plastic hinge



Developing a Comprehensive Historical Tsunami Database for the Indian Ocean

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Abstract

The Indian Ocean is one of the most active Tsunamigenic zones on the earth. The destructive Tsunami of 26th December, 2004 and 28th September, 2018 are standing testimonies of the tsunami city in the region. The occurrence of two strong Tsunami in consecutive decades is a driving force behind the compilation of a comprehensive historical catalog for the region. Unlike the other tsunamigenic regions of the earth, there exist no historical Tsunami catalog in a concretized form for the Indian Ocean. The importance of this study is that it gives impetus towards developing a probabilistic Tsunami hazard analysis methodology for long-term risk reduction against Tsunami. For this study, the Geographic area between 45°S -27°N and 24°E -120°E has been considered as the extent of the Indian Ocean. All the significant Tsunami events from 416 AD Till 2021 have been collected from various online catalogs globally. A few regional catalogues have also been referred to. All magnitudes of tsunamigenic earthquakes are homogenized into moment magnitude scale (M_w) using global correlation equations. Statistical regression tools like standard linear regression (SLR), Inverse standard linear regression (ISR) and Orthogonal standard regression (OSR) are used to developed correlation between Tsunami magnitude (M_t) and Earthquake magnitude (M_w). The missing data on Tsunami intensity of several events is calculated on the Soloviev scale using already existing relations. An updated catalogue for tsunami events of the Indian Ocean is hence developed which fills several missing values in the already existing catalogue. The catalogue so compiled is presented on a webpage.

Keywords: Tsunami catalog, Magnitude homogenization, Tsunami intensity, Tsunami magnitude



Seismically Induced Landslide Hazard Analyses for a Road Corridor in the Lower Himalayas

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Abstract

Seismically induced landslide hazard assessment for important road networks in the hilly regions constitute a significant component of planning and management of road infrastructures. Such multi-hazard assessment, though complicated, carries even more significance for seismically active mountains like the Himalayas. However, traditional Landslide Hazard Zonation (LHZ) practice generally lacks in incorporating seismic factors. An endeavor has been made in the present study to carry out seismically induced LHZ mapping for 85 km stretches of Kalka-Shimla highway (NH 5) in the lower Himalayan belt under a scenario earthquake condition. Eight different landslide preparatory factors viz. lithology, slope angle, aspect, elevation profile, distance from fault, distance from drainage, distance from road, and land-use-land-cover patterns are integrated with the landslide triggering seismic factors in a Geographical Information System (GIS). The seismic factor is included in terms of Peak Ground Acceleration (PGA) parameters generated for a 10% exceedance probability in 50 years using Probabilistic Seismic Hazard Assessment (PSHA). The study develops a heuristic model of landslide hazard assessment coalescing semi-quantitative and bi-variate frameworks to generate the seismically induced LHZ map. The prepared LHZ map demarcates more than 40% of the study area as the zones of high to very high landslide hazard under the scenario earthquake. The prediction accuracy of the proposed method is estimated as 80% for the study. Based on the findings, the study recommends that the seismic element be taken into consideration for a more realistic evaluation of the current landslide threats in seismically active mountain ranges like the Himalayas.

Keywords: Seismically induced landslide hazard zonation, Earthquakes, Probabilistic seismic hazard assessment, Analytical hierarchy process (AHP), Frequency ratio (FR) method



Assessment Of Proxy-Based V_{s30} Estimation in Roorkee, Uttarakhand

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Abstract

A well-liked measure for site characterization and classification is the averaged seismic shear-wave velocity with time for the top 30 meters below the surface, abbreviated $V_{s,30}$. It is associated with material property and thus has a strong influence on ground motions. $V_{s,30}$ is an important aspect of earthquake site effects and a crucial element for Ground Response Analyses (GRA) and localized site-specific effects. To examine shear wave velocity (V_s), Standard Penetration Test and Cone Penetration Test are a few in-situ field tests in practice. Additionally, there are surface wave techniques like Continuous Surface Wave Systems, Multi-channel Analysis of Surface Waves test and Spectral Analysis of Surface Waves test (SASW), etc. that provide a non-intrusive, non-invasive, economical, and expedient way to conduct site investigations. Complex geomorphology, geology, and lack of in-situ measurements emphasize establishing a more suitable approach for $V_{s,30}$ based site-classification. To deal with such issues, various proxy-based techniques have been proposed, such as topography slope, surface geology, and terrain-based approach. Among the three proxy-based approaches, the topography slope method is gaining importance for preparing site condition maps for seismic damage assessments. The goal of the current study is to carry out an MASW test at various locations, enumerate the shear wave velocity profile at each location, and compare those results to those from the proxy-based $V_{s,30}$ estimation. Both MASW and Proxy based $V_{s,30}$ estimations have emerged as an important tools. This paper presents important aspects of both techniques and their reliability for future site investigations and effectiveness in geotechnical seismic site characterization.

Keywords: V_{s30} , MASW, Slope-proxy, Site characterization



Challenges in Seismic Qualification of Substation Equipment

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Abstract

Earthquake shock waves cause vigorous ground shaking. These waves are three dimensional in nature. Earthquake records have revealed that electrical equipment are vulnerable to seismic forces, this lead to an increased focus on the earthquake performance evaluation of substation equipment. Ensuring functionality of equipment during and after seismic event is the major challenge in seismic qualification of electrical equipment. Substation equipment are unique in nature when compared to civil structures. In addition to conventional approach of computing stress, strain and deflection, evaluating functional capability of substation equipment is paramount. Interconnection of substation equipment and mounting methodology shall also be engineered based on site specific seismic loading. High voltage substation equipment like instrument transformer, surge arrester, trans-former bushings are highly vulnerable to earthquake. Seismic qualification ensures reliability of equipment in the event of earthquake, resulting in uninterrupted power supply. Uninterrupted and secure power supply is the most important requirement for rescue operation after earthquakes. Codal recommendations, challenges in seismic qualification of substation equipment and seismic qualification of equipment by shake table test are discussed in this paper.

Keywords: Seismic qualification, Damping, Natural frequency, Substation equipment



Ground Motion Prediction Equation for NW Himalaya and Its Surrounding Region

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Abstract

An attenuation relationship, also known as ground motion prediction equation (GMPE) has been developed for Northwest Himalaya and its neighboring region using the strong motion data recorded by National Center for Seismology Network. In the present study, we have used the 40 records of 18 earthquakes from the 2010 to 2020 having magnitudes ($5.0 < M_w < 5.6$) that occurred in the region. To develop the new attenuation relationship, we have used the maximum peak ground acceleration (PGA) of two horizontal components. Two-step stratified based regression approach is followed. The newly developed relationship is:

$$\text{Log}_{10} \text{PGA}(\text{gal}) = 0.36512 + 0.55599 * M - 0.957736 \text{Log}_{10} (\text{HD} + e^{1.27581 * M})$$

Where PGA is peak ground acceleration in gal, M is the magnitude, and HD is hypocentral distance. The standard error is of the order of 0.0093. The established GMPE is proposed to be useful for seismic hazard estimation, ground motion simulation, site specific studies, and other engineering applications.

Keywords: Attenuation relationship, Regression, GMPE, Amplitude



Identification of Strong Motion Generation Area of the 2019 Hualien Earthquake

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Abstract

Strong motion generation areas are the extended areas with large uniform slip velocity within the entire rupture plane. The high frequency ground motion due to these areas need to be studied to model the contribution of stress released with respect to the entire rupture plane. In this paper, the high frequency ground motion due to strong motion generation area (SMGA) within the rupture plane responsible for Hualien earthquake has been studied. The Eastern coast of Taiwan was hit by a strong earthquake of M_w (6.2) on 18 April 2019. This earthquake was recorded at 107 stations of Central Weather Bureau across Taiwan. The epicentral distance of stations recording this earthquake varies from 5 to 242 km. In the present work, 10 near-field stations have been analyzed to study the source characteristics of this earthquake. The records from these near-field stations shows the presence of two prominent phases in the horizontal components. These prominent phases have been termed as SMGA and are the source of high frequency radiations (Miyake et al. 2003). The SH component obtained by the horizontal components has been numerically integrated to find the size of SMGAs. The displacement record obtained clearly shows the presence of two SMGAs. The seismic moment (M_o) related to these SMGAs are $(3.60 \pm 0.82) \times 10^{17}$ Nm and, $(4.55 \pm 0.7) \times 10^{17}$ Nm respectively.

Keywords: 2019 Hualien Earthquake, Strong motion generation area, Source parameters



Effect of Corrosion of RC Pier on Seismic Performance of Bridges

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Abstract

Effects of corrosion on reinforced concrete bridges have drawn more attention in recent years. Corrosion of RC structural members causes deterioration of strength and ductility, which subsequently affects the service life of the RC bridges. It has been observed by many researchers that the most crucial parameter for deterioration of RC member capacity is corrosion of reinforcing steel bars. The amount of corrosion in reinforcing steel bar of RC elements depend on type of exposure, duration of exposure, concrete quality and durability parameters. In present study, the state of corrosion has been classified as non-corrosion, slight, moderate and severe corrosion of reinforcing steel bar. Assessment of the strength degradation of bridge piers at various stages of service life has been carried out considering the effect of area loss of steel cross-section due to pitting corrosion and reduction in steel yield strength. Change in seismic performance of the bridge pier at given stage of the service life has been assessed using nonlinear static analysis. From the results, it has been observed that the pitting corrosion reduces the bending moment capacity and corresponding curvatures of RC piers. Ultimately, the different levels of pitting corrosion can be related to the reduction of base shear capacity which significantly affects the bridge service life for the anticipated seismic forces.

Keywords: RC pier, Bridges, Corrosion, Seismic performance, Nonlinear analysis



Role of SH Wave in the Mapping of Shallow Subsurface

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Abstract

SH waves are directly related to soil matrix which makes SH wave refraction/reflection methods effective in site investigation. This paper presents the generation of purely SH wave by using a specially designed SH wave source, this generator plate is made of aluminum metals and the wave is generated by giving impact on the generator plate in the horizontal direction, and it has nails on its base which keeps it fixed to the ground so that only horizontal motion is recorded. Since the SH wave propagates in a plane transverse to the ray path, this SH wave generator is kept fixed in a direction perpendicular to the geophone spread. The seismic waves have been recorded using geophones with a natural frequency of 10 Hz and 4.5 Hz. The propagation of SH waves in shallow subsurface can be modeled by the finite difference (FD) method based on a staggered algorithm. The developed software for FD modeling of the medium has been tested for SH wave propagation in a purely elastic medium in terms of numerical stability, dispersion, and boundary conditions. The obtained near-surface properties have been used as an input in the FD method to simulate SH waves and to compare with the real data records acquired in the region surrounding North Almora Thrust (NAT).

Keywords: Finite difference modeling, MASW, Ground motion simulation



Numerical Analysis of a Rigid Wall Retaining Soil Reinforced With C&D Waste

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Abstract

The enormous population growth brings some environmental concerns due to the need for exploitation of natural resources, and the implementation of recycling programmes is a fundamental element for achieving sustainable development. Natural well-graded readily draining granular materials such as sand are commonly employed as filling materials for various geotechnical structures. But, because of the shortage of perfect granular materials, the researchers were forced to look into other options. However, because granular material is in high demand, unlawful sand dredging from riverbeds is becoming more popular. The construction sector generates a huge amount of construction and demolition waste (CDW) in India and other areas of the world, which is created by operations such as demolition, excavation, site preparation, and other activities. The paper highlights the possibility of using CDW as a sustainable reinforced backfill material for retaining walls. The geotechnical properties of CDW, soil and mixture of both were determined and observed that it meets the requirements of backfill material for retaining walls. Further, the numerical studies were conducted to study the static and dynamic behaviour of retaining walls with an optimum dosage of CDW in soil for backfill, using a finite element (FE) analysis GEO5 software. The paper emphasises the potential application of CDW as a sustainable reinforced backfill material for retaining walls in dynamic condition.

Keywords: Construction & demolition waste, Numerical analysis, Retaining wall, GEO5 software

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 357



Damage Identification of Bridge Under Vehicle Induced Vibration Using Empirical Mode Decomposition

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Abstract

It has become essential to create a mechanism for accurate and trustworthy structure health monitoring. An effective tool for identifying global damage is provided by time-frequency algorithms. This paper proposes an instantaneous phase angle based damage indicator. The empirical mode decomposition (EMD) has been exploited for determining the instantaneous parameters. Using EMD, the signal is decomposed into its mono components. The damage index has been derived from the correlation of the extracted Intrinsic Mode Functions (IMFs) of healthy and damaged structures. To show that the suggested approach is effective, a numerical case study employing the bridge's Finite Element Model under vehicle-induced vibration has been considered. The result shows that the proposed method effectively detects and locates the damage under vehicle-induced vibration loads.

Keywords: Time frequency methods, Empirical mode decomposition, Damage identification



Understanding the Torsional Response of Unbonded Fiber Reinforced Elastomeric Isolators: A Finite Element Study

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Abstract

Conventional steel reinforced elastomeric isolators (SREI) have been widely used to improve the seismic performance of buildings; however, they are not economical for low-rise residential buildings in developing countries like India. Hence, Unbonded Fiber Reinforced Elastomeric Isolators (UFREI) have been developed as a cost-effective alternative to conventional isolators. Although studies have been conducted to understand the seismic behaviour of UFREIs, limited research related to their torsional behaviour was reported in the literature. Therefore, the primary aim of this study is to understand the torsional response of UFREIs by conducting finite element simulations on experimentally validated numerical models, using ABAQUS software. The rotational hysteresis behaviour of UFREI with respect to the torsional moment and rotation is obtained and a detailed comparison of torsional stiffness with the increasing rotation is presented. These results are used to develop a two-storeyed base isolated RC framed building model in SAP 2000 software. The global torsional response of the building model is studied by conducting linear time history analyses using bi-directional ground motions. A comparative analysis of the behaviour of the structure isolated by UFREI and the corresponding behaviour of the traditional fixed base structure are presented to understand how the rotational response of UFREI influences the performance of building under earthquakes in both horizontal directions. The results show that the torsional behaviour of isolator has negligible effect on the torsional response of the building under bi-directional ground motions.

Keywords: Unbonded fiber reinforced elastomeric isolators, Finite element simulations, Linear time history analyses, Bi-directional ground motions



Seismic Life Cycle Cost Analysis of Indian RC Building Considering Hazard Uncertainty

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Abstract

Seismic life cycle cost analysis (SLCCA) is a reliable approach to assess the economic implications of the structure over the lifetime of the structure in terms of present-day value for lifetime investment planning, especially when located in moderate to high seismic zones. The state-of-the-art methodology of SLCCA incorporates three essential components: a) seismic hazard curves representing expected seismic intensity at the site, b) seismic fragility curves describing the likelihood of a structure being damaged beyond an explicit damage level and c) cost related to damage levels. The expected seismic intensity at the site can vary significantly due to various sources of uncertainty such as earthquake source and site characteristics, ground motion prediction equations, etc. For engineering applications, the mean hazard curve is typically used. However, the possible values of hazard can be significantly higher than the mean estimates. As seismic hazard assessment is the furthestmost component of the SLCCA framework, the seismic hazard uncertainty propagates through subsequent components, and seismic life cycle cost (SLCC) may vary substantially. Presently, limited literature exists that calculates the SLCC in the Indian context and quantifies and propagates different sources of uncertainty. This study aims to assess the influence of hazard curve uncertainty on SLCC using a case study example of reinforced concrete (RC) building located in cities with different seismic zones (Chennai, Mumbai, Delhi, Bhuj). For that purpose, a Monte Carlo simulation-based approach is used. Results reveal the criticality of incorporating uncertainty as opposed to a deterministic approach.

Keywords: Fragility, Hazard, Indian building, Reinforced concrete, Seismic life cycle, Uncertainty



Seismic Analysis of Railway Track

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Abstract

In the past earthquakes, there are quite a few instances wherein, railway tracks got damaged. There are also instances when train (coach) got derailed either in stationary or running conditions like in the Tangshan Earthquake of July 1976, when 9 trains were overturned and derailed (Esmaili and Noghabi 2013). There are many studies on dynamic response of railway tracks to moving loads, however, there are very few studies on seismic response of railway tracks. Particularly, the lateral seismic response of ballasted track is not properly understood (Sogabe et al. 2013). In the present study, seismic response in lateral direction (perpendicular to the track length) is studied. First, a simple beam on an elastic foundation with lateral springs is analysed. Then, rails and sleepers are explicitly modelled, and the ballast and subgrade are represented using vertical and lateral springs. Seismic response is obtained using a Finite Element (FE) model. In the FE model, track stiffness is suitably quantified in vertical and horizontal directions. Three models in increasing order of refinement in representation of the sleepers, sub-ballast, subgrade, etc. are modelled. First, an earthquake in lateral direction is applied over the entire length of the FE model. Then, the earthquake is applied over a selected length in the central portion of the FE model. Seismic responses (displacement) from all three models are compared and they are found to be in good agreement. Further, it is noted that if base excitation is applied over a limited length in the central region, the maximum displacement at the central node remains unaltered. However, along the track length, the seismic response decreases rapidly beyond the region of the earthquake. This study can help in suggesting means to control seismic response of railway tracks.

Keywords: Railway track, Seismic response, Track damage, Train derailment



A Variational Mode Decomposition Approach for Modal Identification of Structures

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Abstract

Modal Identification describes the behaviour of the structure under dynamic loading conditions such as earthquake, wind etc. A newly developed variational mode decomposition (VMD) method identifies the modal parameter of structures based on dynamic responses. The VMD algorithm decomposes the acceleration response from the structure under the earthquake excitation into a series of a finite number of the mono-components. The decaying amplitude of the extracted modal responses is then utilized to find the natural frequencies by using a Fast Fourier Transform. Finally, the mode shape in the modal space for each decomposed modes in the structure is recognized from the obtained modal response data. This paper presents the applicability of the variational mode decomposition for modal identification purposes and its comparison with the earlier developed Hilbert Spectral Analysis (HSA) and Empirical Mode Decomposition (EMD) method. To demonstrate the efficiency of VMD algorithm, two case studies were considered. First, modal parameters of a numerical model of a three-story shear-beam type building are computed using VMD technique followed by an experimental study on multi-storey building model. The results demonstrate that the proposed VMD approach can be easily identified the modal parameter of building with better accuracy.

Keywords: Variational mode decomposition, Empirical mode decomposition, Modal identification



Seismic Risk Assessment of Nagpur City Using Google Maps

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Abstract

According to past studies, rapid urbanization of Indian cities lead to densely populated regions which increases exposure & ultimately the risk for seismic hazard. Risk management is very important to reduce the consequences of forthcoming earthquake. So, seismic risk assessment of cities is essential to estimate the expected life loss, injuries, property loss and to recommend future course of action to reduce the losses. Basically, the methods of risk assessment require building inventory data and seismic hazard as input. Collection of building inventory data (Exposure) for any city is most challenging task as it requires extensive field surveys. In present study, a methodology of developing building inventory data is proposed using the satellite images, street views and user uploaded images in google map. Using ArcGIS, socioeconomic clustering has been carried out for Nagpur city. Further, the accuracy of the methodology has been verified using ground truthing of randomly selected clusters. Vulnerability for Nagpur building typologies is carried out using SeisVARA spectrum tool. Using HAZUS methodology, the risk of various clusters of Nagpur city has been assessed. 2011 census data has been used to find risk of Nagpur wards. The estimated risk based on analytical vulnerability assessment under MCE (Maximum Considered Earthquake) level hazard has been mapped on Nagpur Municipal Corporation (NMC) map and results are compared with Dehradun city. The proposed methodology can be further implemented using AI-ML tool.

Keywords: Exposure, Seismic hazard, Seismic Risk, ArcGIS, AI-ML tool



Time Series Analyses of Bhatwari Landslide Triggered by 1991 Uttarkashi Earthquake

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Abstract

Uttarkashi earthquake (1991) triggered many landslides in the lower Garhwal Himalayas, primarily affecting Uttarkashi and surrounding areas. Few of the slides are still active in this zone, and it is advisable to investigate the entire zone against instabilities to avoid further calamities. The present study investigated one such landslide – Bhatwari landslide (Uttarkashi, India). Forensic analysis of a landslide site has been performed to ascertain the possibility of landslide activity over a period of time. Several factors have been considered while performing the stability analysis, such as the effect of fluctuating water table in the static and pseudo-static condition, the impact of the 2013 Kedarnath flood, and the potential of failure and permanent displacement if an earthquake similar to Uttarkashi, 1991 ever strikes again. It was found that the landslide is still active after being triggered by the 1991 Uttarkashi earthquake, with factor of safety (FoS) values degrading with the passage of years. It was verified that the slope failure also occurred post the 2013 Kedarnath flash flood event based on the sudden-drawdown analysis results. The present study suggests that the slope may collapse during heavy rainfalls. The FoS was found less than unity under saturated conditions. The possibility of failure also exists against an earth-quake of similar magnitude that of Uttarkashi, 1991 based on obtained potential Newmark displacement values.

Keywords: Uttarkashi earthquake 1991, Slope stability analysis, Sudden drawdown, Newmark displacement



Importance of Multiple Geophysical Tests for Effective Subsurface Profiling

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Abstract

The dynamic properties of subsoil such as Shear modulus (G), S-wave velocity (V_s), P-wave velocity (V_p) and Poisson's ratio (ν) help us to understand the response of a site under dynamic and seismic loading. These properties are determined using geophysical and laboratory testing methods. Geophysical methods can be Invasive methods which use a borehole to conduct tests such as Standard Penetration Test (SPT), Crosshole (CH), Downhole (DH), Dilatometer (DT) and Seismic Cone Penetration (SCPT), or Non-invasive methods which consist of surface tests that do not require a borehole, like Multichannel analysis of Surface Waves (MASW), Seismic Refraction, Microtremor HVSr (MHVSR) and Electrical Resistivity Survey (ERT). Often because of the ambiguity associated with the profiles obtained from surface methods, a need to compare them with borehole-based methods arises. In this study MASW, MHVSR, DH and CH tests are performed at the same location in Chennai, Tamil Nadu to estimate V_s profile up to the depth of 40 m. These test results are then correlated with the borelog obtained during SPT. It is observed that V_s profiles obtained from different geophysical tests are not similar and vary in their prediction of soil stiffness and bedrock depth. The V_s profiles obtained from CH, DH and MASW, are similar up to the depth of 18, beyond which the CH and DH results show an increase in V_s . Interestingly, 18 m is the depth where weathered rock occurs in the borelog. However, the MASW V_s profile does not capture the velocity contrast. The MHVSR method shows a fundamental frequency of 3.0 Hz which also agrees with the fundamental frequency obtained from the MASW method. However, MASW is not able to differentiate between soft and hard rock present in this area and underpredicts the bedrock depth. The difference might be because of the more global spread of the MASW test, whereas CH and DH tests are localized around the borehole.

Keywords: Site characterization, MASW, Downhole, Crosshole, HVSr



Geo-factor Inference Modelling with Empirical Susceptibility Weights Approach for GIS-based Seismic Hazard Mapping of Thiruvananthapuram City

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Abstract

Appropriate assessment of various site parameters influencing the spatial distribution of seismic hazard was investigated to critically identify the susceptible spots in the study area, Thiruvananthapuram city, a low to moderately active seismic zone in southern Peninsular India (PI). The Geo-Factor Inference (GFI) model developed in this study, evaluates respective contribution level of local geo-factors to estimate the Peak Ground Acceleration (PGA), representing regional seismic hazard. Considering the complexity and limitations in the widely accepted Analytic Hierarchy Process (AHP), mostly used in seismic studies, a simplified Empirical Susceptibility Weights Approach (ESWA) was proposed to assess the attribute weights for GFI model. The ESWA weights were mathematically calibrated by Rank-Order Centroid (ROC) tool and subsequently, compared with AHP weights to deduce variations in scale ranges. ESWA values from GFI were finally assigned to respective geo-factor thematic layers for weighted over-lay analysis in Geographical Information Systems (GIS) platform. The solution from GFI model, integrated with GIS-approach provides distinctive distribution of susceptibility levels ranging from very low to high in the seismic hazard mapping of the city.

Keywords: Seismic hazard, Geo-factor inference (GFI), Empirical susceptibility weights approach (ESWA), Rank-order centroid (ROC), AHP



Optimum Parameters for Tuned Inerter Damper

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Abstract

In this work, optimum parameters of the Tuned Inerter Damper (TID) are obtained using Equal Eigenvalue (EEV) criterion. Performance of this TID is compared with that of other optimum TID available in the literature. EEV criteria is loading independent whereas, other criteria available in the literature, are loading dependent. TID uses an inerter, a mechanical device with two terminals that appears to have a mass amplification effect. TID performance is first assessed for harmonic loading. Frequency Response Function (FRF) from both the TID is compared. Robustness, i.e., sensitivity to mistuning is also assessed and it is found that TID with EEV parameters is more robust. Under seismic excitation, both the TID are found to give similar reduction in response.

Keywords: Tuned inerter damper, Equal eigenvalue criterion, Frequency response function



Nonlinear Seismic Analysis of Nuclear Containment with Soil-structure Interaction: Study on Stresses and Damage Criteria

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Abstract

One of the most popular sources of clean energy, nuclear power plants are very critical structures as any failure in them is associated with huge ecological and economic losses, hence this necessitates investigating the response when subjected to dynamic loading. In this study, a nuclear containment structure is modelled and analyzed under unidirectional equivalent sine-sweep earthquake data considering soil-structure interaction using five different types of underlying media. Tension and compression damage is evaluated in the structure by considering non-linear material properties of concrete. The maximum stress in the vertical direction is achieved in the critical elements at the junction of the cylindrical wall of the containment and the raft foundation, normal to the application of earthquake excitation, for fixed base and also over rock media. Significant tensile damage is also observed in the critical elements in the aforementioned cases. When stratified soil is used with rock at the top and stiff soil at the bottom, the acceleration response of the structure is lower than that of homogeneous stiff soil underneath. Whereas, when stratified soil with stiff soil at the top and rock at the bottom is used, the acceleration response is much more than that of homogeneous stiff soil but less than that of homogeneous rock. The above observation is in line with the response of a composite spring in series subjected to lateral excitation. The stress response of the critical elements of the structure also follows a similar pattern.

Keywords: Nuclear containment, Nonlinear analysis, Soil-structure interaction, Stratified soil, Damaged plasticity model



Assessment of Seismic Slope Stability through Incremental Dynamic Analysis

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Abstract

Analysis of seismic slope stability is important to predict the failure of natural or artificial slopes under earthquake-induced shaking. The severity of damage to a slope depends on several factors like variability in ground motions, geometry of the slope and the dynamic soil properties of the slope and foundation material and their associated uncertainties. So, probabilistic analysis of slope presents a more practical way for seismic vulnerability assessment considering different sources of uncertainties. Seismic fragility analysis is a probabilistic way for seismic risk assessment that describes the probability of exceedance of different prescribed limit states at different seismic intensity levels. A fragility function indicates the probability of collapse or the probability of exceedance of some other limit state of interest which is estimated using statistical procedures. In this study, incremental dynamic analysis (IDA) based seismic fragility assessment is performed to evaluate the seismic performance of a slope. To quantify the performance and seismic demand of slope, different vulnerability states of the slope are selected, and the probability of exceeding these selected vulnerability states for different seismic intensity is determined from the obtained fragility function parameters. The study clearly exhibits the importance of seismic fragility curves to assess the performance of a slope under seismic conditions.

Keywords: Seismic slope stability, Incremental dynamic analysis, Vulnerability states, Seismic fragility assessment



Seismic Response of RC Buildings with Shear Wall Incorporating Soil-structure Interaction

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Abstract

The present paper investigates the seismic response of the Reinforced Concrete (RC) building with a shear wall incorporating soil-structure interaction. The study is mainly concentrated on in situ clayey soil conditions considering soft, medium, and hard clayey soil. The purpose of this study is to analyze G+10 story RC buildings with and without soil-structure interaction. Effect of SSI is accounted through point spring element and fixed support condition. Analysis has been done on all the building models as per IS1893:2016. For a comparative study, G+10 story RC buildings with a fixed base is also considered. The responses of some parameters like story drift, story displacement, story shear, time period, and base shear are obtained to understand the different conditions of the soil on the structure for comparative study. The study has used the tools ETABS 17 for modeling and analysis and SAFE 16 for foundation design. From the obtained results, it is observed that without considering soil-structure interaction, the response of structures is overestimated and also, it is recommended that for the safety of a building SSI should be considered.

Keywords: Soil-structure interaction, Shear wall, ETABS, Seismic analysis



GNU-Octave Tool for Probabilistic Seismic Hazard Assessment

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Abstract

Earthquake-resistant design of structures is aimed at withstanding a certain level of ground shaking with repairable damage and avoid structural collapse in more severe shaking. The design ground motion for a particular region is defined by estimated seismic hazard which may be presented in various formats. The uncertainties in seismic source characterization, lower and upper bound magnitudes, earthquake recurrence laws and ground motion prediction equations play an essential role in developing the seismic hazard curves. This study provides a simple and effective way for estimating seismic hazard curves using the GNU-Octave platform while accounting for all uncertainties. GNU-Octave is a free and open-source numerical computing platform. For the implementation, three regions from seismic zone IV (namely, Delhi, Patna and Darjeeling) and zone V (namely, Guwahati and Mandi) are selected as per the IS-1893. The earthquake catalogues are collected from various sources, mainly from the United States Geological Survey (USGS). Before using them to estimate the seismicity using the Gutenberg-Richter (G-R) recurrence relationship, these raw catalogue entries need to undergo some treatment (specifically, homogenization, declustering, and completeness check). Because of its simpler format and limited number of parameters, the ground motion prediction equation by Boore and Atkinson is utilised for ground motion intensity measure (IM). The seismicity of the Darjeeling region, which is categorised in zone IV of IS-1893, is found to be miscalculated based on the hazard curves for these locations, putting the structure in this region at greater risk.

Keywords: Seismic hazard, Structural design, GNU-Octave, Seismicity



Comparative Analysis of Base Isolation and Fixed Base Irregular Structures

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Abstract

It is very crucial to protect important structures such as hospitals, historical buildings, heritage monuments, etc., against the ground motion to safeguard people and structures. There are many ways to increase the structural stiffness, but only a handful of techniques are available such as dampers and base isolators which can increase the damping of the structure. A mid-rise building is considered in this paper to compare the effectiveness of base isolation. A comparative study of the effectiveness of base isolation using Rubber Bearing with a fixed base structure is carried out by considering a hospital building that is situated in seismic zone V. Further, the analysis is carried out by both linear and non-linear time history analysis. Parameters such as base shear, time period, storey displacement and storey drift are compared to understand the effectiveness of Rubber Bearing isolators. The main objective of this paper is to understand the principle behind base isolation and to study the effect of increasing damping in the structure. Moreover, an attempt is made to study the percentage reduction of displacement of the structure with Rubber Bearing isolators to a fixed base. This paper concludes that parameters such as base shear, storey drift and acceleration of the structure were a lot lesser in base isolation model compared to the fixed base model. The application of base isolation in structures enhances seismic protection thus offering better safety and durability.

Keywords: Non-linear time history analysis, Base isolator, Rubber bearing, Seismic analysis

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 397



Seismic Safety of Post Installed Anchors

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Abstract

In India, the hazard profile indicates around 59% of the country is susceptible to moderate and major earthquakes while 10.9% of the land is prone to severe earthquake. To minimize the disaster due to earthquake, the civil bodies have updated the seismic standards which are now more stringent and have led to adoption of earthquake resistant design and detailing of structures in the last few years. However, the standards are still silent on the design of post installed anchors which form an integral part of the overall load transfer mechanism. The failure of these post installed anchor connections in the event of an earthquake, either due to improper selection, non-compliance to design standards or inadequate detailing against seismic condition, are cause of major safety concern. The endeavour of this paper is to highlight the salient points regarding performance assessment and design of post installed anchors under seismic loading to ensure overall safety of the connection.

Keywords: Post installed anchor, Seismic, Performance assessment, Design, Seismic performance category



Site Amplification Study Using Strong Motion Data Recorded at Various Stations in India from Far-field Earthquakes

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Abstract

Given the importance of site effects, the site response characteristics in the present work are evaluated at different locations of India using recorded data of three earthquakes that occurred in different parts of the country. The used earthquakes include the 2015 Afghanistan earthquake (M_w 7.5); 2016 Hindukush earthquake (M_w 6.7) and 2016 Manipur earthquake of (M_w 6.7). The results are presented in form of peak ground acceleration (PGA), peak ground velocity (PGV), amplification, and predominant frequency. For both Afghanistan and Hindukush earthquakes, the highest and lowest PGA values are observed at SMLA and HYB stations, respectively. For the Manipur earthquake, the highest PGA value of the order of 103 cm/s^2 was observed at the SHL station. In the case of the Afghanistan earthquake, the PGV values did not show much variation, as observed in the Manipur earthquake. The local soil effects at horizontal components of ground motion are strongly amplified compared to the vertical components. It is found that three sites, namely SMLA, SHL, and KOHMA are amplified in the frequency range 8-10 Hz, exhibiting less amplification and may be treated as rock sites, or stiff-soil sites. The other sites, namely, BHPL, HYB, JORHT, and LEKHA show amplification at a lower frequency range of 0.1-2.9 Hz with amplification a little higher than the previous three sites. The shift of peak amplification from higher to lower frequency range indicates that these sites lie in soft soil regions. The estimated predominant frequency and amplification values in the present work may be very important for the valuation of seismic hazard assessment of the region of study. The site amplification characteristics play an important role in altering the ground motions recorded at different locations and because of this, the damage may vary widely.

Keywords: Site amplification, Seismic hazard assessment, H/V Ratio



ROSERS - A Deep Learning Framework for Earthquake Early Warning and its Interpretation

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Abstract

Earthquake early warning (EEW) systems are swiftly evolving from standalone physics-inferred methods (requiring computationally expensive inversions in real-time) to data-driven strategies for efficient earthquake hazard mitigation in real-time. Besides being speedy in prediction, data-driven approaches such as artificial neural networks usually require minimal assumptions in the training and execution processes. This study discusses and attempts to interpret the data driven EEW framework: ROSERS (Real-Time On-Site Estimation of Response Spectra) proposed by Fayaz and Galasso (2022). ROSERS aims to utilize the early non-damaging p -waves and the recording site characteristics to predict the acceleration response spectrum ($S_a(T)$) of the anticipated on-site ground motion waveform. The framework's efficacy is analyzed using an extensive database of ground motions, and it is observed that ROSERS leads to exceptional prediction power when implemented in a real-time backdrop. To provide a better interpretation of the framework, this study utilizes the concepts of explainable artificial intelligence (i.e., Shapley additive explanation, SHAP) to obtain insights into the decision-making process of the trained neural networks. Particularly, the cause-effect relationship of the computed latent variables and $S_a(T)$ is explored. The analyses showcase that the two latent variables of the framework complement each other in capturing stiff short-period and flexible long-period $S_a(T)$ thereby leading to excellent reconstruction power.

Keywords: Variational autoencoders, Neural networks, Earthquake early warning, Explainable artificial intelligence, Model-agnostic interpretability



Seismic Performance of Different Typologies of Stone Masonry Houses in India

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Abstract

World over, stone has been extensively used as a building construction material due to its local availability and high durability. The scenario for the construction of buildings in India is no more different than compared to other parts of the world. According to the 2011 Census of India, 43.48 million houses (~14% of the total number of houses) have stone as the predominant wall material. Owing to the fact of non-engineered construction, wide variations in terms of stone masonry construction can be seen in the Indian subcontinent, particularly in the Himalayan belt. In this study, a field survey is conducted to identify the seismic resistant features in traditional building practices which make use of stone for construction, e.g., Thathara construction, Dry-stone construction, Koti Banal construction, etc. The percentage of these types of structures is decreasing due to an increase in urbanization, increasing housing demands, non-availability of traditional construction materials and skilled artesian for building new structures as well as costly repair and retrofitting techniques for damaged and existing structures. Thus, there is a dire need to safeguard these structures as if this trend continues, these buildings will become things of the past. In this paper, a review of structural configuration, roofing systems, foundation type and potential failure modes of these construction typologies are studied, and the effect of different retrofitting techniques that exist in the construction type on their expected seismic performance is discussed.

Keywords: Stone masonry, Typologies, Construction features, Seismic behaviour



Seismic Retrofitting of Existing Stone Masonry Houses: An Overview

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Abstract

Recurrent earthquakes in the past two decades have taken thousands of lives (e.g., the Kashmir earthquake killed some 80,000 people) and destroyed millions of homes and other buildings. This colossal loss of lives was not because of the earthquake but because people were inside buildings (e.g., stone masonry structures) that were highly vulnerable. Had these buildings been retrofitted with a small fraction of the cost of reconstruction, the death count would have been much smaller. The past earthquakes have brought out many weaknesses in masonry design and construction practices as these structures behaved unsatisfactorily and sustained major damage. Hence, the safety and retrofitting of existing stone masonry houses are very important. Considerable research work has been directed towards evolving suitable methods of earthquake resistance in stone masonry houses, but despite the availability of such methods, masonry buildings have been damaged in the event of earthquakes, because of the following reasons: (i) lack of awareness, formal training and technical knowledge in earthquake-resistant construction; (ii) lack of concern about seismic safety because of the in-frequent occurrence of earthquakes; (iii) people lack financial resources to meet the earthquake-resistant requirement; and (iv) despite the availability of provisions and recommendations of earthquake-resistant measures to be applied on stone masonry buildings in the form of various codes, these are rarely being implemented in actual practice. Therefore, in the present study, an overview is presented about how the retrofitting of existing stone masonry houses using different techniques can be implemented to reduce their seismic vulnerability and loss of life.

Keywords: Existing construction, Stone masonry, Retrofitting techniques, Strengthening of structural elements



Variation in Ionosphere due to 2005 Kashmir Earthquake- Implication from GPS Observation

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Abstract

In 2005, a major earthquake (Mw 7.6) struck the Kashmir region in the morning hour (03:50:40 UTC) of 8th October, and it was felt significantly up to far located cities of north-central India. The earthquake occurred in Pakistan, nearly 10 Km from east of Balakot and 19 km from northeast of Muzaffarabad. The epicenter of an earthquake is 34.493°N, 73.629°E. This earthquake has occurred due to the shallow reverse faulting between the Indian and Eurasian plates in the Indus Kohistan Seismic Zone (IKSZ) of the Northwest Himalaya. For the analysis of the Co-seismic Ionospheric Disturbances (CID) due to the 2005 earthquake, we have used cGPS data from 9 stations, namely, Soloman Islands (SOL1), Kazarman (KAZA), Naval station Newport (NPRI), Talas (TALA), Kumtor-2 (KMTR), NADI, Munsiyari (MUNS), BHTW and PAN2, which were geographically located within 1000 km of the epicenter. A prominent anomalous co-seismic CID was observed at three cGPS stations, viz., NADI, PAN2 and SOL1, which are located in the distance range of about 350 – 500 Km from the epicenter. However, other cGPS stations located beyond 500 km have not shown such anomalous changes. The Co-seismic ionospheric disturbances have been observed approximately 20 - 25 minutes after the occurrence of an earthquake. The similar time delay in co-seismic changes at NADI, PAN2 and SOL1 may be attributed to near identical distances of the stations from the epicenter, which can be studied extensively as one of the potential earthquake precursors.

Keywords: Co-seismic ionospheric disturbances (CID), Total electron content (TEC), Earthquake precursors



Nonlinear Static and Dynamic Behaviour of RC Wall-frames Using Fiber Inelasticity in Structural Elements

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Abstract

Wall-Frames, the recommended structural system for lifeline buildings is expected to have satisfactory and desirable seismic performance, especially if located in high seismic regions. In this work, fiber modeling approach is used to model inelasticity in walls and moment frames in a 6 storey-3-bay 2D wall-frame system. Displacement-controlled nonlinear static pushover analyses results from commercial software PERFORM3D suggest, the fiber type inelasticity in numerical models help predict nonlinear static behavior of study wall-frames reasonably well, compared to behavior of wall-frames with lumped inelasticity. In particular, increasing wall plan-aspect ratio enhances earthquake resistant virtues of wall-frames, namely stiffness, strength, and ductility. Further, early yielding is observed in stiffer wall-frames and reasonable ductility achieved in all study wall-frames. Alongside, limit states of structural damages are also monitored to grade the damages and in turn the seismic performance of wall-frames. In addition, results obtained from nonlinear static analyses are confirmed by performing nonlinear time history analyses of study wall-frames, towards quantifying the critical earthquake resistant virtues — results and investigations from the study is a precursor towards recommending design measures to ensure post-earthquake functionality of lifeline buildings.

Keywords: Fiber modeling, Nonlinear static analysis, Limit states, Structural damages



Dynamic Characterisation and Ground Response Analysis of Clay Soil Profiles

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Abstract

The analysis of foundation vibrations and geotechnical earthquake engineering problems in Civil engineering requires the characterization of dynamic soil properties. Hence the dynamic soil properties play a significant role in the determination of the stiffness of the soil against various dynamic loadings. The soil properties associated with dynamic loading are shear modulus (G), damping ratio (D) and Poisson's ratio (μ). Many problems related to dynamic loadings, such as earthquakes and vibrations from traffic, are dominated by wave propagation effects where only low-level strains are induced in the soil. In the past, only a few studies have discussed the low strain dynamic properties of clay soil. In this paper, Bender element testing has been conducted to induce the shear wave velocity in the clay soil by varying the test parameters. The parameters varied in the test program are the degree of consolidation, effective confining pressures, density, cohesion and plasticity of clay soil. The study proved that the tested parameters of clay soil significantly affect shear wave velocity and the maximum shear modulus of clay soil. With the obtained dynamic parameters of shear wave velocity and modulus, ground response analysis has been performed using the Proshake GRA programme to assess the amplification of motion towards the soil foundation level.

Keywords: Clay, Bender element, Dynamic shear modulus, GRA



Early Warning System: An Efficient Earthquake Disaster Mitigation Tool

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Abstract

The earthquake risk mitigation goals are achieved by applying a number of approaches to reduce the vulnerability of the built environment. The most widely known long-term risk mitigation approaches are earthquake-resistant design and construction, reviewing building use regulations and codes, and retrofitting of the existing vulnerable infrastructure. Construction experts, earthquake and civil engineers must emphasize on structural and non-structural elements to avoid potential damages and human loss. Accurate predictions of earthquakes would effectively reduce the damage caused by earthquakes. Unfortunately, seismic stress buildup inside the earth's crust and its release starting from the nucleation to the end of the rupture, is a complex phenomenon. Therefore, making accurate predictions of earthquakes is quite tricky. Revolution in digital seismology, telecommunication, and high-performance computing has provided strong support for risk mitigation measures in the last four decades. The recent advancement in real-time processing and transmission of seismic data has enabled the evolution of a real-time risk mitigation system like an earthquake early warning system (EWS). The EWS is a real-time system for earthquake risk reduction.

Keywords: Earthquake, Early warning system, Lead-time, Risk mitigation



Effectiveness of Friction Pendulum System in Controlling Structural and Non-structural Responses of Short-period Reinforced-concrete Buildings at Near-fault Sites

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Abstract

The present study investigates the structural and non-structural responses of a four-story reinforced-concrete building with and without friction pendulum isolation system. The non-linear time history analyses are conducted using the design level and maximum considered earthquake ground motions with velocity pulses. Two different subsets of earthquake ground motions: one with pulse periods in the vicinity of the structural periods and the other with pulse periods sufficiently away from the structural periods, are considered. The structural and non-structural engineering demand parameters, i.e., maximum inter-story drift ratio, peak floor acceleration, and floor response spectra, are estimated and compared for the fixed base and base-isolated buildings. The effectiveness of the isolation system is demonstrated with respect to reduction in both the structural and non-structural responses. It is shown that base isolation may not necessarily be equally helpful in reducing the non-structural response of all components and secondary systems.

Keywords: RC frame buildings, Friction pendulum bearing, Structural response, Non-structural response



Application of Regression Techniques for Preparing a Homogenous Earthquake Catalog - An Overview

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Abstract

Standard Least-Squares Regression (SLR) and General Orthogonal Regression (GOR) address different questions and make different assumptions about measurement errors in one or both of the variables. SLR minimizes the sum of squares of the vertical deviations and provides estimation of the dependent variable (Y). It assumes that the independent variable (X) is an observed value which is known without error, and only the dependent variable (Y) suffers from measurement error.

GOR, on the other hand, yields a linear relationship ($Y_t = \beta_0 + \beta_1 X_t$) between the dependent (Y_t) and the independent (X_t) variables based on observed data (X, Y) having measurement errors in both the variables involved. Therefore, it is mathematically incorrect to use observed value X in place of X_t in the equation $Y_t = \beta_0 + \beta_1 X_t$ and thus, if done so (as in the conventional GOR method), this procedure will produce biased estimates.

The present study is an overview of different methodologies used for preparing a homogeneous earthquake catalog for different seismic environments. The error variance ratio (η) used in GOR has not been addressed in seismological literature and this overview will address this critical issue as well. This study will also suggest a guideline for the use of regression methods for preparing a homogeneous earthquake database which is an important input to obtain improved seismic hazard assessment.

Keywords: Regression analysis, Orthogonal regression, Homogenous earthquake catalog, b-value



Effect of Vibration Induced by Dynamic Tests on an Adjacent Building - Finite Element Investigations

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Abstract

Structures often experience vibrations generated by different sources that propagate through the soil mass. These vibrations might adversely affect the occupants immediately and building upon long exposure. These vibrations should be quantified and limited to the permissible values recommended by the relevant standards. Pile driving during the construction process is one such source of vibration. Depending on the driving technique, the vibration is either transient or continuous. This paper presents experimental and numerical studies on vibrations induced in a nearby building from the dynamic load tests (similar to continuous source of vibration) on pile groups. Vibrations generated during the dynamic pile load tests were quantified at the source and different floor levels of an adjacent building in the form of acceleration and velocity-time histories. 2D Finite Element (FE) integrated model of the building with foundation, pile group with pile cap, and supporting soil mass has been developed in commercially available FE package ABAQUS. The integrated 2D FE models have been analyzed for the combined effect of gravity and dynamic loading. The response obtained through the experiment is also compared with 2D FE analyses of the integrated building-pile group-soil system. The estimated vibration responses in terms of peak ground acceleration (PGA) and peak ground velocity (PGV) are compared with the specified maximum permissible limits recommended in the relevant standards and codes of practice.

Keywords: Dynamic pile tests, Vibration measurement, Field experiment, 2D Finite element analyses, Building vibration



A Cluster-based Seismic Risk Assessment: Economic Loss Using GIS for Jaipur Sub-urban Area

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Abstract

Economic risk is an integral part of seismic risk assessment, which is eventually required in seismic risk mitigation, response planning, and better resource allocation for adaptation and mitigation. Geospatial techniques like remote sensing-based image clustering and Geographical Information systems (GIS) can be used for seismic risk assessment at city level.

In this paper, a GIS-based framework is proposed to assess the seismic risk of a part of the city in terms of economic loss using homogeneous clusters of different built-forms, which are proxies to different building typologies. A random sampling strategy is adopted for geo-tagged proportionate building surveys as a function of homogenous built form clusters and built-up density for Jaipur Sub-urban Area. An extensive survey was conducted using GNSS receiver to collect the geo-tagged information of different building typologies and the GIS database was created in real-time. Further, an analysis is carried out using HAZUS methodology for the estimation of seismic risk in terms of economic loss spatially, which can also help policymakers in planning and mitigation.

Keywords: Geographic information system, Economic loss, Seismic hazard, Earthquake, Damage



Modelling of Empirical Accelerograms of 1999 Chamoli Earthquake (Himalaya) Using a Modified Hybrid Approach

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Abstract

In the present study, the empirical accelerograms of the 1999 Chamoli earthquake (M_s 6.6) have been modelled using a modified hybrid approach. The earthquake occurred in the Central Seismic Region of the Himalayan region and was recorded at the seismic network installed and maintained by the Department of Earthquake Engineering, IIT – Roorkee. The modified hybrid technique (Yadav, 2019) has been used to model the empirical accelerograms of the 1999 Chamoli earthquake at 9 recording sites. The epicentral distance of various observing stations lies in a range of 10 – 110 km. The empirical accelerograms of the earthquakes are available at the sampling rate of 50 Hz. The hybrid technique includes the generation of envelope functions by summing the envelope functions of the randomly distributed subevents on the fault plane. In the present modified hybrid technique, the site response high-frequency decay parameter i.e., kappa factor (κ) has also been evaluated and incorporated in to the existing technique. The site response functions have been estimated using the HVSR technique. The high-frequency decay parameter ' κ ' has been estimated to be in the range of 0.04 – 0.07. The simulated accelerograms have been compared with those of recorded ones in terms of Peak Ground Acceleration (PGA), duration, Response, and Fourier spectra. The modelled value of PGA is 347 cm/s^2 estimated at Gopeshwar is found to be close to the observed one (352 cm/s^2). The essential parameters of simulated accelerograms, including PGA values, duration, Response, and Fourier spectra, are well-matched with those of the recorded accelerograms for most sites.

Keywords: Seismic hazard, Simulation, Earthquake, Kappa, Site response function



Effect of High-stress Triaxiality on Yield and Ultimate Tensile Strength of E250 Structural Steel

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Abstract

The study focuses on evaluating the effect of the high-stress triaxiality on the tensile strength at yield and ultimate stage of commonly used structural steel, E250. Three circumferentially notched specimens with varying radii of curvature are selected to cover a specified range of stress triaxialities. The selected specimens are extracted from a 25 mm thick structural steel plate of E250 grade. The extracted specimens are subjected to uniaxial tensile tests for evaluating the engineering stress-strain curves, using which the mechanical strength at yield and ultimate stage of all the specimens are determined. The yield and ultimate tensile strength of specimens with notches are compared to those of specimen without notches, and the percentage increase in tensile strength is reported. The tensile strength noted at both stages is observed to linearly increase with increasing stress triaxialities of study specimens. The results obtained through experiments and sophisticated finite element models are used to propose equations in terms of stress triaxiality employed in predicting the increased tensile strength of E250 structural steel at yield and ultimate stage.

Keywords: Stress triaxiality, Lode angle, Fracture initiation, Steel fuse element



A Promising Alternative for Low Rise Buildings in Seismic Regions: EPS Core Sandwich Panel Structural System

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Abstract

In the present study, use of Expanded Polystyrene (EPS) Core Sandwich Panel Structural System in seismic regions has been explored through experimental and analytical studies both. The mechanical properties of the chosen Reinforced Concrete Sandwich Panels (RCSP) system are determined experimentally, and detailed seismic safety evaluation of a proposed low rise 4-storey RCSP, Expanded Polystyrene (EPS) core sandwich panel building is been performed using finite element method (FEM). The specimens are tested in displacement control mode, and displacements (strains) measurement are done with Digital Image Correlation (DIC). The mode of failure, propagation of cracks, ultimate axial load carrying capacity, in-plane shear strength, and out-of-plane flexural capacity are studied. The experimental results are also compared with analytical values. The analytically calculated capacities are matching with experimental results.

A FE (finite element) model of a 4-storey RCSP building using layered shell elements has been developed in SAP2000. The axial force, bending moment, and shear force acting on the critical sections in the ground storey piers under all the considered load combinations are compared with the capacity of piers. The results of the analysis conclude that the design of the building is adequate to withstand the gravity and seismic forces of Zone V and EPS Core sandwich panel structural system is a promising alternative for low rise buildings in seismic regions.

Keywords: Composite structures, Expanded polystyrene (EPS) core, Reinforced concrete sandwich panels (RCSP), Seismic safety



Fatigue Life Evaluation of Corroded Steel Truss Bridge Girder

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Abstract

Truss bridges are one of the most typical configurations used for the medium to long-span steel bridges. Under railway loading, such bridges are subjected to reversal of loads, leading to fatigue damage. Fatigue life is affected by corrosion, as corrosion reduces the net section available for resistance and also affects the regions of connections and bearing locations. Pitting corrosion in small areas leads to formation of small pits, which on application of fatigue load develop as cracks. Due to the reduced cross sections, the pits cause stress accumulation, and behave like stress raisers. Together with the stress concentrations, the residual stresses form the datum for stress reversals, during loading cycles of vehicles. These actions compound up to result in the enhancement of initial cracks (due residual stresses and material reshaping). The damaging effect of corrosion and fatigue are interwoven, and superposing independent results will lead to erroneous overestimations. Therefore, to determine the structure's service life, a time-based coupled assessment of corrosion and fatigue is required. In order to relate to real-world scenario, the deterioration of the bridge needs to be observed under the effect of incremental train speed. Hence, in this study, a numerical model of a truss bridge span using currently available codes is developed. The cross girder and stringer, which experience high levels of fatigue stresses and corrosion, are numerically assessed for their residual life due to increasing train speed and daily carriage volume.

Keywords: Fatigue, Corrosion, Truss, Bridges, Residual stress



A State-of-the-art Review on Metallic Dampers based on Different Yielding Mechanism

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Abstract

Conventional seismic design approach primarily relies on the strength and ductility of the structure. The structure remains elastic under low magnitude earthquakes; however, during high magnitude earthquakes, the structure undergoes large inelastic deformation to dissipate the energy and rely on the ductility of the structure. Thus allow the formation of hinges at the predefined locations in primary lateral load resisting members, which may lead to the collapse of the structures. For the last few decades, structural response control devices such as dampers have been extensively used to alleviate these damages. These devices have become more prevalent due to their ability to mitigate the structural response caused by wind and seismic load. Response control devices can be broadly divided into three parts 1) Active, 2) Passive, and 3) Semi-active. Active and semi-active devices depend on the external power supply and require skilled labor for installation and replacement. Passive devices are easy to install and replace, and no external power supply is needed to operate them during dynamic loading. Among all passive devices, metallic yield dampers are widely recognized and accepted owing to their easy installation, workability, resistance to ambient temperature, cost-effectiveness, and stable hysteretic behavior. Metallic yield dampers dissipate energy by inelastic deformation of the metals. The present article focuses on the state-of-the-art literature review, including development, yielding mechanism, comparative performance, and modeling of metallic yield dampers based on previous studies.

Keywords: Metallic dampers, Ductility, Hysteresis, Yielding mechanism, Energy dissipation



Seismic Strengthening of Precast Beam Column Connection Using Stainless Steel Wire Mesh (SSWM)

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Abstract

In this study, Stainless Steel Wire Mesh (SSWM) is explored for a strengthening of precast beam column connection. Experiments are conducted to study the behaviour of SSWM strengthened precast beam column specimens under monotonic vertical loading applied at the end of the beam. Wet precast beam column connection is considered for the study. Connection is provided at the intersection of beam and column within column portion. U-shaped reinforcement bars projecting from the beam are inserted into column gap at the intersection and subsequently empty gap is filled with cast-in-place micro concrete. Total of two reduced (1/3rd) scale precast test specimen with and without SSWM strengthening are tested. Strengthening is carried out by wrapping SSWM around beam and column surfaces near the junction. Epoxy based adhesive SIKADUR 30 LP with resin to hardener ratio of 3:1 is used for bonding SSWM with concrete surface. The performance of test specimens is evaluated in terms of ultimate load carrying capacity, deflection behaviour of specimens, crack formation and failure propagation. Strain is measured at selected locations on reinforcement bars, on concrete surface as well as on SSWM. From the experimental results, it is evident that strengthening using SSWM is effectively enhances load carrying capacity and ductility of precast wet connection. Ultimate load carrying capacity and deflection corresponding to ultimate load of strengthened precast specimen is increased by 41.43% and 33.12%, respectively, as compared to control specimen. Failure pattern clearly indicates that SSWM effectively provide confinement to the concrete and reduces crushing of concrete.

Keywords: Precast wet connection, Strengthening of beam column junction, Stainless steel wire mesh



Importance of Epistemic Uncertainty on Seismic Analysis of RC Wall-frame Buildings

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Abstract

During the seismic vulnerability assessment of structures, uncertainties can be considered from two sources, namely (a) aleatory characteristics and (b) epistemic characteristics. However, response variability is primarily attributed to the aleatory uncertainties, and the propagation of epistemic uncertainties through the analysis is generally not considered. In the present study, the influence of the epistemic uncertainties on the seismic response performance of a reinforced concrete wall-frame building is evaluated separately, and then compared with those obtained using aleatory uncertainties only. The variability in seismic demand is considered using a suite of ground motion records. A total of 11 ordinary strong motion records are selected using the magnitude-distance categorization, which ensures consideration of a wide range of earthquake scenarios. The uncertainty related to structural capacity is accounted for by considering 20 different structural models generated using Latin Hypercube sampling technique with different realizations of six input random variables. Considering the computational expense of incremental dynamic analysis, the variability in several response parameters is studied using single stripe nonlinear response analyses at a seismic intensity level indicating near collapse state of the selected wall-frame building. Consistent with earlier findings, it is noted that the impact of the epistemic uncertainties on seismic response variability is lesser as compared to those due to aleatory uncertainties. However, completely ignoring the contribution of epistemic uncertainties in response variability may not be prudent for a comprehensive seismic fragility estimate of wall-frame buildings. Thus, all sources of uncertainty need to be considered to ensure a reliable performance-based assessment of wall-frame buildings.

Keywords: Shear wall, Wall-frame building, Epistemic, Aleatory, Uncertainty, Seismic fragility, Incremental dynamic Analysis, OpenSees



Seismic Evaluation and Retrofitting of Reinforced Concrete Building Using Multiple Combination of FRP Wraps

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Abstract

Seismic retrofitting of vulnerable structures is critical for reducing risk. Seismic retrofitting is the upgradation of existing structures to make them more resilient to future seismic events. Among various seismic retrofitting techniques, the FRP wrapping have been proved to be very promising with respect to the ease and effectiveness. This study explores the effectiveness of multiple combination of different types of fiber reinforced polymers laminates (FRP) viz. basalt fiber reinforced polymer (BFRP), carbon fiber reinforced polymer (CFRP), and glass fiber reinforced polymer (GFRP). The effectiveness of different combinations of FRPs have been assessed by comparing the capacity curve for the retrofitted building. Further, the assessment of cost efficiency vis-à-vis their effectiveness in the level of increase in seismic protection. From above study it can be concluded that these innovative materials are good in strength and they have impressive ductile property. Combinations of these innovative materials is efficient in retrofitting the existing RC buildings as well they are economical for application.

Keywords: Retrofitting, Carbon fiber reinforced polymer, Glass fiber reinforced polymer, Basalt fiber reinforced polymer



Development and Implementation of a Regional Earthquake Early Warning System in Northern India

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Abstract

The Himalayan region has experienced many devastating earthquakes, due to the collision of the Indian Plate with the Eurasian plate. The movement of the Indian Plate is continuous but for a long time, this region has not released the accumulated energy. This accumulated energy makes this region more vulnerable to major to great earthquakes in near future. The urbanization and initialization in this region have magnified the effect of earthquakes by many folds. Earthquake Early Warning (EEW) systems are being used to mitigate the effects of earthquakes in many countries, by sending alerts of upcoming damaging waves to the users. The development of an EEW system in Uttarakhand was started in 2014 as a pilot project after validating its feasibility, which is now operational for the public. The operation EEW system includes (i) a central processing server at Roorkee; (ii) a warning server at Google cloud platform; (iii) around 160 sensors in Kumaun and Garhwal region of Uttarakhand; (iv) 80 public sirens at schools, hospitals, district emergency centers, etc. and (v) a smartphone for the public. This paper elaborates on the different components and architecture of the implemented EEW system. Further, this paper also includes information about the tasks carried out to aware the public about earthquakes safety tips and the EEW system to utilize its potential at the user end.

Keywords: Earthquake early warning system, Warning dissemination system, Disaster risk reduction, EEW smartphone app



Seismic Behaviour of Regular and Vertically Irregular Reinforced Concrete Building for 3D and MDOF Model

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Abstract

Buildings behaviour in seismic forces is dependent on the structural configuration of the building. Regular buildings have more stable and predicted behaviour than the irregular one. Irregular configuration in plan or in elevation is one of the major causes of failure of building during earthquakes. Vertical irregularity is mainly due to strength, stiffness and mass irregularities, are the main cause of failure of the building during the earthquake. Damages mainly due to vertical irregularities were seen in the Bhuj Earthquake in 2001. This irregularity is more vulnerable and also less attempted by the researcher. To find out the most vulnerable condition of vertical irregularity during the earthquake is the main focus of the paper. 3D and MDOF medium rise RC building models are analyzed using SAP 2000 NL and compared for finding the results reliability of both the models. The results are analyzed by considering seismic parameters such as fundamental time period, frequencies, base shear and displacement of irregular buildings compared with a regular building. The 3D model is more difficult to analyze than the MDOF model but results obtained by the 3D model are similar and realistic to the real structure than the results obtained by the MDOF model. Displacements in 3D models are observed more than the displacement in MDOF models. Eigenvalue results variation of the first mode in 3D and MDOF models is under 5%. Overall base shear results are observed more in case of MDOF model as compared to 3D model. Model 2 i.e. double height storey at middle floor is more flexible in case of 3D system and model 4 i.e. floating columns structure is more flexible in case of MDOF system.

Keywords: Seismic behaviour, Vertical irregularity, 3D and MDOF model



ML-based Surrogate Model for RC Bridge Pier Collapse Fragility Prediction

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Abstract

Fragility analysis is a powerful tool in performance-based earthquake engineering framework that facilitates in decision making and helps in communication between the stakeholders and design professionals. However, the fragility analysis requires performing a number of nonlinear dynamic analysis, which is computationally expensive and hinders design optimization. Therefore, surrogate models are developed to reduce the computational cost. In this paper, a computationally efficient machine learning based surrogate model framework is proposed for seismic fragility prediction of RC bridge piers. The framework utilizes Gaussian Process Regression to generate surrogate models that can predict the mean and standard deviation of the fragility functions as function of the influential material parameters. Despite using 100 samples for training, the surrogate model is mostly successful in predicting the fragility function parameters with error less than 20%.

Keywords: Bridge, Performance based earthquake engineering (PBEE), Fragility curves, Surrogate model, Gaussian process regression

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 465



Seismic Consideration of a RC Frame Building from the Sustainability Aspect

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Abstract

In terms of earthquake engineering buildings need to be functional and resilient at post-earthquake events. During earthquake events, the performance of the building degrades. It is required to evaluate the actual performance of the buildings in terms of ductility and strength at different intensity of earthquakes so that the appropriate repair and strengthening can be done to improve the future performance. In the present study, a 5 storey RC building has been considered and the performance of the buildings has been determined with variation of the material properties as referred in various country codes all over the world. For the study purpose, the building has been analyzed for different levels of earthquake ground motion with return period of 475 years, 950 years, 2475 years and 4950 years. It has been observed that the ductility and performance of the building have been influenced by variation of engineering properties of materials. In terms of design consideration from the sustainable point of view, a balance between the reduction of force and achievement of ductility can be made based on the current study.

Keywords: Building, Earthquake, Ductility, Performance, Sustainability



Effectiveness of DDBD Procedure for RC Frame Buildings

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Abstract

The main cause of damage to structural members during a seismic event is relative displacements and thus damage to the structure can be controlled by controlling the same. The Direct Displacement-Based Design (DDBD) procedure estimates the required stiffness of the structure by approximately correlating the inelastic displacement of the actual structure and its equivalent linear Single-Degree-of-Freedom (SDOF) structure for an anticipated seismic hazard level. The framework of the prevailing DDBD is primarily for regular buildings however, actual buildings possess some irregularity. Further, various national codes like IS 1893(1):2016, EC-8 and ASCE-7 also allows some limited irregularity in the building. The presence of irregularity in the building alters its dynamic behaviour which also depends on the type and location of irregularity. Amongst all types of irregularities, the mass and stiffness irregularity are very common in buildings. Therefore, the present study attempts to check the efficacy of the prevailing DDBD procedure in designing RC frame buildings with IS 1893(1):2016 code-compliant mass and stiffness irregularity. Three, six and nine-storey buildings representing low, medium and high-rise buildings have been considered in the study. A comparative assessment of the nonlinear seismic performance of regular buildings and the corresponding irregular buildings have been performed. It has been observed that variation in dynamic characteristics and base shear distribution is higher in building with nominal mass irregularity compared to building with nominal stiffness irregularity. From the non-linear analysis, it has been observed that building with nominal mass irregularity designed by the DDBD procedure has altered performance than the regular building.

Keywords: Direct displacement-based design, IS 1893(1):2016, Mass irregularity, Stiffness irregularity, RC frame buildings, Non-linear analysis

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 475



A Critical Review of Existing Building Regulations and Bye-laws in Hilly Regions Of India

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Abstract

In this article, an attempt has been made to understand and review the existing Building Regulations and Bye-laws available in the hilly region of India, primarily focusing on the structural configurations and construction provisions, like the number of stories and building height in seismically active hilly areas. This article also examines and compares the customization of individual-specific regulations, framed after considering guidance from Model Building Bye-Laws- 2016. A comprehensive summary is presented herein, including most of the available Bye-Laws containing the construction and architectural regulations in hilly regions, which will help classify different building typologies along with their associated constraints.

Keywords: Bye-laws, Seismicity, Hilly regions, Topography, Building regulation



Structural Performance of Retrofitting Strategies for Dry Stone Masonry Arch Structures

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Abstract

Stone Masonry has been one of the most used construction types in India since ancient times, where most of these structures are constructed using locally available stones or commonly available sandstone, basalt, granite and other stones. These age-old stone structures have suffered damage over a period of time, and these structures have not been appropriately maintained. Often these structures require strengthening and repairment strategies for local and global performance re-establishment and sometimes enhancement. Before deciding on these strengthening strategies, studying the basic strength characteristics, material and structural compatibility, and breathing characteristics of the repair material is essential. These strategies also vary due to structural and architectural demands for a particular structure. Together with the inherent uncertainties in material and structural level, high inertial forces proportional to the high mass of the structure make these unreinforced masonry buildings vulnerable to earthquakes and other static and dynamic loadings. This paper compares state-of-the-art commonly prevalent retrofitting strategies used to strengthen stone arches. The study is also focused on some of the recent development in this field. The issues with respect to the analysis of dry jointed arches and the applicability of different repair strategies have been discussed in detail. The study also points out some of the common limitations and shortcomings of different strategies. The behaviour of various retrofitting strategies for stone masonry arch structures has been demonstrated and compared in the presented study.

Keywords: Heritage, Stone masonry, Arches, Un-reinforced Structures, Retrofitting



Seismic Behaviour of Dry Stack Stone Masonry - A Numerical Study

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Abstract

Most of the studies on structural masonry are focused on the units that are bonded together with mortar, i.e., wet jointed. However, dry stack masonry also constitutes a good amount of building stocks in ancient Indian Structures, especially in the case of stone. These historical dry stack masonry structures, such as plinths, walls, arches, vaults, and domes, were generally constructed as compression-only structures. However, these structures pose a high risk of damage due to huge inertial force during an earthquake. The failure modes of these structures during a seismic event depend on the structural configuration and intensity of the earthquake. The jointing arrangement of these structural stone masonry units also plays a vital role in their load transfer mechanism and dissipation of any lateral forces. The present study is focused on the seismic behavior of the dry stack structures having different joinery arrangements. A numerical study has been carried out on a FEM-based numerical platform to simulate the seismic behavior of stone masonry. The arrangement of stone units has also been varied to obtain the improved response of different dry stack masonry structures. The response of several structural arrangements has been compared with different intensity earthquake forces. The study presents the effect of structural configuration and joinery on the overall structural performance of the dry jointed stone structure through a numerical investigation.

Keywords: Heritage structures, Dry jointed, Un-reinforced masonry, Load transfer



Liquefaction Susceptibility of Bottom Ash Under Cyclic Loading

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Abstract

The present study mainly focuses on defining the consolidated-undrained behaviour of bottom ash under cyclic loading conditions. An appropriate evaluation of liquefaction potential is the key to accurate dynamic response analysis. A series of strain-controlled consolidated undrained cyclic triaxial tests were conducted on bottom ash samples at a loose state until the occurrence of initial liquefaction. Undrained cyclic loading behaviour is studied for an effective confining pressure of 100kPa at different cyclic axial strains (0.30%, 0.50%, 0.75%, 1%, and 1.25%). The loading frequency is kept constant at 1Hz. Exponential decay of deviator stress is observed with an increasing number of cycles for initial liquefaction, which can be attributed to the deformation of the sample. After initiation of liquefaction, the deviator stress tends to decline toward zero. The pore pressure response and effective stress path of bottom ash indicate the high liquefaction susceptibility of bottom ash at high cyclic axial strain, i.e. liquefaction susceptibility increases with the cyclic axial strain of bottom ash samples. The stress-strain response pointed out the degradation of shear stiffness with an increasing number of loading cycles. In all cases, the bottom ash can hold some deviator stress during the beginning of the cyclic loading. However, for the time being, its holding capacity decreases to zero due to the sudden accumulation of excess pore water pressure, which creates initial liquefaction in ash samples.

Keywords: BA, Liquefaction, Pore pressure response, Shear stiffness



Soil-structure Interaction Effect on a Multi-storied Building with Pile Foundation Considering Linear Approach

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Abstract

Soil-Structure Interaction (SSI) has important effects on the seismic response of structures as it modifies both deformations and inertial forces. In this paper, an attempt to study the seismic response behaviour of a 3D multi-storied RC-framed building considering the effect of soil-structure interaction is done using the finite element method based program LUSAS 15.2. The ground response spectra as given in IS: 1893-2002 are converted into simulated time history data, by using the TARSCTH code. The obtained synthetic time history response is given as an input to DEEPSOIL V 6.1 and the deconvolution analysis is performed to obtain the appropriate input motion at a particular depth. Furthermore, the obtained input motion is used in the present numerical model and a study of fundamental frequency for different soil conditions has been carried out and it is found that SSI significantly affects the behaviour of buildings resting on the soil. Considering the effect of pile foundation embedded up to 12m depth, two different soil domains (soil up to 12m and 60m depth) are analyzed. For both models (soil to a depth of 12m and 60m), it is noticed that soft soil models exhibit greater displacement values than medium and hard soil models. This indicates that the interaction is maximum in soft soil. Also, for hard and soft soil models, an effort has been made to replace the soil strata with equivalent spring stiffness. This shows convergence for hard soil, but there is a difference for the soft soil models.

Keywords: Soil-structure interaction, Deconvolution, Equivalent soil-spring



Heterogeneous Fusion of Sensor Data for Response Recovery During Earthquakes

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Abstract

In this study, a methodology is developed for the fusion of strain and absolute acceleration data by using weighted least squares for response recovery. For recovery of responses, modal displacement coordinates, a quantity termed the pseudo-modal acceleration coordinates, and the ground acceleration is estimated in the framework of classical estimation. This methodology is developed explicitly for application during earthquake events. It must be noted that the scheme requires a finite element model of the structure and explicitly considers the varying level of noise in different sensors. By fusing data from a sparse array of strain and acceleration sensors, the responses like displacements, strains, and accelerations at locations without instruments are recovered. The recovered strain data help assess the damage that the structure might have sustained during an earthquake. These recovered strains are especially beneficial for steel structures as they can keep track of fatigue. The methodology is verified on the numerical model of a real-life water-carrying steel bridge in Jhansi, India, subjected to earthquake excitation. It is observed that the scheme could successfully recover strains, relative accelerations, and relative displacement locations without sensors.

Keywords: Strain analysis, Sensor fusion, Classical estimation, Response recovery



Seismic Response Control of Elevated Liquid Storage Tank Using Negative Stiffness and Inerter Based Dampers

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Abstract

The effect of novel negative stiffness and inerter based damper (NSID) for seismic response control of elevated liquid storage tanks is investigated. Liquid storage tanks form important structures that must stay in working condition during earthquakes. Herein, NSID is employed as a supplemental damper to elevated liquid storage tanks. The tank's continuous liquid mass is represented as two lumped masses: sloshing mass and rigid mass. The tank wall and liquid mass specifications are used to compute the stiffness constant related to these lumped masses. Time history analysis is carried out under real earthquake records to investigate the performance of NSIDs as supplemental dampers. The differential equations of motion are written in state-space form. The NSID parameters are subjected to a parametric analysis, and the best parameters are identified. Response quantities like base shear, liquid sloshing displacements and rigid mass accelerations are controlled efficiently using the NSIDs.

Keywords: Negative stiffness inerter damper, Seismic response, Liquid storage tanks, Supplemental dampers



In-plane Behavior of Un-reinforced Brick Masonry Walls Retrofitted with Partially Confined Reinforced-concrete Bands: Shake Table Experiments

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Abstract

Un-reinforced brick masonry structures are popular in many countries. In India, un-reinforced brick masonry constitutes the majority of the total building stock, which is quite common in urban and rural areas due to cost constraints. In seismically active places, failure of such structures, frequently not designed and built according to best engineering practice, can be catastrophic. Hence, strengthening of these structures has become extremely important. In this study, the efficiency of partial-confinement using reinforced-concrete bands on the in-plane behavior of un-reinforced brick masonry walls was investigated using shake table tests. For this purpose, several half-scale clay brick masonry walls were constructed. Many of these wall specimens were retrofitted with horizontal and vertical reinforced-concrete bands by cutting grooves on the wall surface to simulate partial confinement. These wall specimens, with and without reinforced-concrete bands, were then tested on a unidirectional shaking table at IIT Kanpur. A series of ground motions, scaled to simulate different intensity levels, were then applied in the in-plane direction of the wall specimens. It was observed from these tests that while the un-reinforced wall specimens showed a tendency to significant damage, the partially confined wall specimens maintained structural integrity. Further, the proper connection of reinforced-concrete bands with the wall, roof slab, and base slab was found to delay the failure, thus improving the structural performance.

Keywords: Un-reinforced masonry, Reinforced-concrete bands, Partial-confinement, Shake-table test



Experimental Investigation on Flexural Behavior of Precast Beam-beam Connections Using Mechanical Connectors

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Abstract

The present study discusses two distinct forms of novel connections to join precast concrete beam elements using couplers and U-bolts. Monotonic testing (Three-point bending) was conducted to investigate the flexural behaviour as well as feasibility and reliability of proposed connections. The couplers and U-bolts have been placed at the centre of the connection region which connects the beam elements. The overall performance of the connection was varied with respect to location of couplers and U-bolts. Also, the shear key and high-performance materials were used in the connection region to enhance its flexural performance. The key parameters obtained from bending test such as load-deflection behaviour, stiffness degradation, energy dissipation capacity, failure pattern illustrates the satisfactory performance of the proposed connections. The test's failure pattern shows that the coupler-enabled specimens exhibited flexural ductile failure and were successful in efficiently transferring stresses. Due to a lack of adhesion between the old concrete and the new HPFRCC mix, the U-bolts enabled specimen experienced interface failure. In order to prevent interface failure, surface treatment must be done between structural elements utilizing various adhesives. In comparison to coupler-enabled specimens, the U-bolts specimen performed better in terms of energy dissipation and load carrying capacity.

Keywords: Precast structural elements, Hybrid rebar coupler, U-bolts, Shear key, High performance materials

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 499



Connection Design Between Steel Brace and RC Frame Using Post-installed Anchors

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Abstract

While retrofitting, existing reinforced concrete (RC) frames using steel braces, it is important to detail every aspect of the frame-brace system carefully. Amongst these aspects, connection design between the frame and brace plays a crucial role as it is governed by force transfer between the brace and RC frame. Post-installed chemical anchors are a good choice for simple, direct, and economically feasible solutions. But this requires critical design; otherwise, the frame-brace system may fail to give the expected performance. This paper describes the design procedure for brace connections, including gusset plate and post-installed anchors.

Keywords: Gusset plate, Post-installed anchors, Retrofitting, Reinforced concrete, Steel brace

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 504



Failure Mechanism of Energy Dissipating Hysteretic Infill System: An Assessment

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Abstract

The sudden post-peak strength reduction and the resultant brittle failure of the brick infill is the primary reason for the failure of infilled RC frame buildings during large earthquakes. The infills that enhance strength and stiffness develop a strut diagonally that alters the lateral performance of the RC frames under lateral loading. The formation of the strut mechanism leads to a sudden shear failure of the non-ductile members of the frame. A novel infill system that does not develop a diagonal strut mechanism but enhances the strength and stiffness of the frame is discussed here. These infills that are developed from slotted concrete blocks and the energy dissipating hysteretic link elements exhibit an improved post-peak behavior and energy dissipation capabilities.

Keywords: Energy dissipating hysteretic infill, Full-scale cyclic testing, Infilled RC frames



Parameter Study on ADAS Metallic Damper

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Abstract

Protection of structures to frequently occurring earthquake has been an active area of research due to devastating effects of an earthquake. Energy dissipating devices undergoing inelastic deformation have been developed and implemented successfully for protection of various type of structures. The present paper aims to perform numerical study of hysteretic behavior of laboratory based scaled model of ADAS type metallic damper under increasing cyclic loading. A parametric study is conducted for ADAS type metallic damper in terms of thickness and number of plates under predefined yield load/ displacement. Nonlinear Chaboche model is considered for defining metal plate behavior in the post-yield region. FE model of ADAS type metallic damper is developed and is subjected to increasing cyclic loading. It has been found that ADAS type metallic damper has good energy dissipation capability. Equivalent viscous ratio, ζ , for the damper is of the order of 47% following yielding of the X-shaped steel plate. Parametric study in term of thickness and numbers of plates for ADAS type metallic damper shows marginal improvement in energy dissipation capacity.

Keywords: ADAS Metallic damper, Energy dissipation devices, cyclic loading, FE analysis



Numerical Study on Post-earthquake Fire Behavior of Hollow Tubular Sections Filled with Concrete Under Non-uniform Heating

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Abstract

Following an earthquake, a building's capacity to withstand fire greatly diminishes, while the probability of fire breaking out also significantly increases. It is known that fire in the aftermath of an earthquake can severely damage buildings, but the topic has not been explored extensively. In this numerical study, using ABAQUS, a tool for finite element-based analysis, the effect of post-earthquake fire on the behavior of concrete-filled steel tube (CFST) columns is investigated. The numerical modelling procedure included earthquake analysis, heat transfer analysis, and structural analysis steps. To mimic seismic behavior, a cyclic analysis was performed first, and its output, measured in the form of residual deformations, was then fed into a nonlinear thermal stress analysis performed in a subsequent step. The available literature on large-scale testing of CFST columns under cyclic and thermal loading conditions was used to first verify the accuracy of the simulated numerical model. This was done in order to ensure that the model was accurate. Following that, the validated FE model was utilized to predict the behavior of the CFST column when subjected to multilevel loading scenarios such as fire followed by an earthquake. According to the findings, the column with residual deformation exhibited a lower degree of resistance to fire than the column that had not been damaged.

Keywords: Finite element analysis, Structural fire behavior, Steel-concrete composite columns



Effect of URM Infills on Seismic Behaviour of RC Frame Building: Part-1

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Abstract

The reliability of multi-storey buildings against natural calamities like earthquakes becomes more critical because of high occupancy. Unreinforced masonry walls (URM) in reinforced concrete (RC) frames are most commonly practised and usually considered as non-structural element and their effect on the behaviour of building against the seismic loading is generally ignored. The different modelling techniques of URM infill walls have been explored by researchers. In the present study, the seismic performance of a six-storey (G+5) RC frame building with and without consideration of URM infill has been estimated and compared using non-linear pushover analysis. The building has been modelled as bare frame (BF) as well as frame with infills, which has been modelled as equivalent compression only strut. Different configurations of equivalent strut have been considered for numerical modelling of URM infill walls, i.e., Eccentrically Braced Infilled Frame (EBIF), Concentrically Braced Infilled Frame (CBIF) and both Eccentrically and Concentrically Braced Infilled Frame (ECBIF). Infills have been modelled as multi-linear plastic tie links with a pre-defined force-displacement relationship. It has been observed that URM infills and their modelling configuration considerably affect the seismic performance of RC framed buildings. As evident from the results, it increases the lateral stiffness and decreases the fundamental period of vibration. Also, variation in strength, stiffness and effect of infill walls and its modelling techniques on capacity curve parameters has been compared.

Keywords: Infilled RC frame building, Unreinforced masonry walls, Braced infilled frame, Modelling of URM infill walls



Mechanical Properties of Friction Damper Using Different Layer of Interface

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Abstract

The energy dissipation capacity of structural elements plays a vital role in a structure's seismic resistance and ductility. Natural Damping of Reinforced concrete structure is insufficient to discharge higher energy during a seismic event. This necessitates the use of a secondary source such as dampers or isolators to release the input energy without causing major structural damage. This article is mainly focused on the mechanical properties of the frictional damper. In a friction damper, the coefficient of friction between the damper plate enhances the resistance and energy dissipation. This study focuses on the influence of rubber-based interface material on the cyclic behaviour of damper. This frictional damper consists of steel plates with a dry friction compound, which creates friction between the components. The purpose of this device is to enhance the local performance of the beam-column joint. Different torque has been used to understand the friction coefficient and energy dissipation capacity of the damper. Friction dampers work by slipping friction plates at a predetermined force, forcing the surface to slide, and producing friction, therefore dissipate energy. Several critical metrics are evaluated, including hysteresis behaviour, energy dissipation, damping ratio and coefficient of friction. The test result shows that at different torque level interface material plays a crucial role in damping capacity and resistance to the applied force.

Keywords: Passive device, Rubber-based material, Energy dissipation, Coefficient of friction, Damping ratio, Torque level



Mechanical Properties of Hybrid Friction-viscoelastic Damping

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Abstract

Viscoelastic dampers (VEDs) are one of the most common passive control devices used in new and retrofit building projects which reduce the structure responses and dissipate seismic energy during an earthquake. This study is about the idea of passive damping devices for solving challenging problems across failure of RC beam-column joints. Passive damping devices aid to dissipate input energy and consequently limit the damage. In this study, a new type of hybrid friction-viscoelastic damping device using steel plates with rubberized cork interface material is proposed to study the damping properties of damper under cyclic loading in order to determine the damping coefficient and energy dissipation. Seismic dampers permit the structure to resist severe input energy and reduce harmful deflections, forces, and accelerations to structures and occupants. Dampers cannot bear static loading. Each type of damper has its features and simultaneous usage of different dampers helps compensation of demerits. Mechanical property analysis of the components of damping devices is to be focussed on stiffness ratio, damping coefficient, and multiple response history which ensures the dissipation of energy of seismic waves moving through a building structure to heat. Many studies have been conducted using different type of dampers on structural elements and tested under cyclic loading.

Keywords: Friction-viscoelastic damping device, hysteresis curve, rubberized cork



Cyclic Performance Evaluation of Interlinked Coupler-box Confinement as a Local Retrofitting Technique

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Abstract

An innovative coupler-box confinement technique is proposed to interconnect the longitudinal reinforcing bars of columns at their potential plastic hinge locations. Displacement-controlled reverse cyclic tests are conducted on columns with the recommended coupler-box assemblies and the conventional stirrup-bound couplers. Efficiency of the proposed confinement technique is evaluated by comparing the hysteresis behaviour, performance index parameters of energy dissipation and ductility, along with the damage pattern and failure analysis in tested columns. The experimental test results validate the competency of proposed coupler-box confinement in enhancing the hysteretic performance of column with improved energy dissipation and ductility. The column with conventional stirrup-bound coupler experiences failure at a lower lateral drift of 3 %, whereas the column with suggested coupler-box confinement fails at 6 % drift which is higher than the collapse prevention drift level of 4 %, as recommended by FEMA codal guidelines. This experimental study manifests the use of coupler-box assembly as a probable futuristic approach in seismic retrofitting of severely damaged reinforced concrete frame buildings, where the buckling failure of longitudinal rebars at the plastic hinge location of columns is inevitable.

Keywords: Rebar coupler sleeve, Coupler-box assembly, Interlinking, Seismic retrofitting, energy dissipation



Geotechnical Characterisation of Natural Sub-base and Subgrade Material for Pavements

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Abstract

This study shows experimental results of evaluating shear strength parameters for natural debris material for use in pavements, including coarse aggregate. A proper geotechnical characterization is required to assess the strength and durability of this material for utilization in engineering projects. Most of the past studies have mainly focused on evaluating strength parameters for fine aggregate (sand size). The present work addresses the geotechnical characterization of pavement material, including the coarse aggregate (gravel size). For this purpose, a large-scale direct shear (LSDS) apparatus with a 300×300×150 mm size shear box was used to determine the shear strength on a pre-defined failure plane for material characterization. The direct shear tests were performed following the grain size analysis for gradation of the material and compaction tests for relative density. This study can be further extended to other areas such as geotechnical characterization of mine tailings for the stability of mines, uses of debris material as structural and geotechnical fill, and modeling and simulation of natural debris material to gain a more thorough understanding of the mechanism of landslides, etc.

Keywords: Strength parameters, Gravel fraction, Large scale direct shear test, Shear strength, subgrade, Sub-base



Seismic Margin Assessment of Elevated RCC Water Tank Supported on RCC Circular Shaft

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Abstract

Many elevated water tanks suffered damage to their staging (support structure) in the Mw 7.7 Bhuj earthquake of January 26th, 2001. The reinforced cement concrete (RCC) circular shaft-type support for elevated tanks lacks redundancy, damping and additional strength typically present in building framing systems and, therefore, require scrutiny of their designs. The elevated water tanks are inverted pendulum-type structures which resist lateral forces by the flexural strength and stiffness of their circular hollow shaft type staging. The section close to the ground is subjected to the maximum flexural demand. Any damage to the staging at this critical section should be considered alarming as it can seriously undermine its lateral load-carrying capacity. Hence, it is essential to study nonlinear behaviour of such critical structure against lateral load. This paper addresses the analytical work on seismic margin assessment of elevated RCC water tank supported on shaft type staging. A Pushover analysis is performed on an elevated water tank of 16-meter height and 65 m³ capacity. This elevated water tank is supported on the circular RCC shaft. In this study, different practical approaches utilizing frame and shell elements for modelling the RCC elevated water tank (EWT) are used and compared. In framed based model, moment curvature relationship for hollow circular shaft is evaluated for hinge characteristics. In shell element-based model, stress strain curves for the layer of concrete and rebar are defined as layered shell element in SAP2000. Kent and park model for concrete and bilinear model for rebar's are used in both approaches. After pushover analysis, performance point is evaluated using capacity and demand curve as per ATC40 procedure and seismic margin is obtained. The seismic margin of EWT is evaluated for the various cases such as reinforcement disposition on the both faces, reinforcement present only on outer face and for the cut out located at X face of the shaft in presence of both face of reinforcement.

Keywords: Pushover analysis, Nonlinear shell element, Seismic margin, Elevated water tank, Shaft support, Reinforced cement concrete

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 530



Microseismic Analysis Using Event Count and Potency Displacement for Stability Evaluation of an Underground Cavern

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Abstract

The long-term stability of an underground hydroelectric powerhouse cavern, which depends on the rock-mass deformation rate, is paramount for tunnel engineers. The underground powerhouse cavern of the Tala Hydroelectric Project (THP), Bhutan had faced several strata instabilities issues during its construction and even post-construction. So, a Micro-Seismic Monitoring System, which is continuous real time monitoring, was installed at this underground powerhouse cavern to assess the rock-mass strata status. Seismic source parameters event count and potency displacement revealed the zone of maximum inelastic damage zone in both the major tunnels, namely machine hall and transformer hall, while Gutenberg-Richter relationship forecasted the maximum magnitude in and around the powerhouse cavern. This helped to augment timely support measures to enhance the life of this underground structure.

Keywords: Micro seismic monitoring, Underground cavern, Hydropower, THP and seismic potency



Performance Based Seismic Design of Structures by Considering Local Site Effects

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Abstract

The magnitude of earthquakes occurring over the years have proven to be a major threat to the sustainability of new structures as well as preservation of old historic structures. Structures such as hospitals need to be in working conditions even after an earthquake. Due to this, developing countries are emphasizing the need for Earthquake Risk Assessment (ERA) in order to prepare a structure from the incoming forces of an earthquake. Past history has evidence of severe damage during earthquake due to amplification of ground motion to the places which has been far from the epicenter. In view of such events, the two components of ERA, namely, Ground response analysis (GRA) and Performance Based Seismic Design (PBSD), were developed. GRA is primarily concerned with predicting overall regional earthquake response without much highlighting the behaviour at specific locations while PBSD gives a realistic analysis of the structural response when subjected to a generalized earthquake ground motion. PBSD procedure confirms that the structure has obtained desired performance levels based on FEMA guidelines. This paper focuses on some of the research work of GRA and PBSD concepts. A procedure to include GRA effects in seismic assessment performance of structures is presented. In this study, GRA is carried out for a specific site in Vasco (latitudes of 15°3982'N and longitude of 74°8113'E), a central city in the state of Goa. Seismic Performance is conducted for (G+8) RC frame building. Structure is designed as per IS 456:2000 and IS 1893 (Part 1):2016 criteria. Response spectrum analysis is used for seismic investigation. Response spectrum curves are generated using DEEPSOIL V7 software. The structure is subjected to multiple design performance criteria like the maximum lateral displacement of the RC frame, storey drift, base shear, support reactions and moments. Analysis was carried out using ETABS 20 software. The RC frame building is found to exhibit fully operational level of performance for different ground motions. The proposed structural design is conservatively sufficient in satisfying the required performance levels.

Keywords: ETABS, DEEPSOIL, GRA, PBSD



Response of a Nuclear Containment with Soil Underneath Under Earthquake Excitation

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Abstract

It aims to study the response of a Nuclear Containment Plant under earthquake excitation resting on stiff soil, hard soil and rock and its behaviour is compared to fix base condition. The NCP is about 67 m high, with an outer diameter of 42 m and a wall thickness of 1.2 m (Cervera ¹). Thus, the overall weight of the structure is very large. To ensure safety against seismic force, there is a need to study the details of seismic analysis.

Linear and Nonlinear behaviour of the model under earthquake loading is being analysed when the reinforced concrete (RC) is modelled both for compression damage and tension strain hardening using Concrete Damage Plasticity Model (ABAQUS). The results obtained is validated with the results presented by Guo-Qiang Liu [3]. The fundamental time period obtained for the structure lying under different types of soil are determined and it is observed that the fundamental time period for a structure lying over rock is almost equal to fixed base which gradually decreases as the soil properties varies. As referred by Guo-Qiang Liu the sine sweep equivalent to El-Centro earthquake [8] is considered for analysis.

The soil is modelled both for finite and infinite domains. It is observed that for a limited soil domain the displacement response is larger than the case where infinite domain is included particularly for lesser stiff soil than rock. With inclusion of infinite element, it is concluded that the displacement response of NC is the least for Stiff Soil whereas for rock it is maximum.

Keywords: SSI, Nuclear containment plant, Finite and infinite soil element, Linear and non-linear analysis, Stress



Influence of Building Occupancy on Seismic Life Cycle Cost

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Abstract

Past studies show that seismic hazard related losses have negative implications on the economy of the nation and society. Seismic loss estimation methodology based on next generation “Performance Based Earthquake Engineering (PBEE)” is used for evaluating seismic losses. Repair and replacement costs, casualties, injuries, and repair time are the various performance metrics used to quantify seismic hazard related losses. Seismic hazard related losses will also depend on the type of occupancy such as commercial, residential, hospital, educational, hospitality, research, and warehouse as the non-structural components of the building will vary as per the occupancy type. In this study, seismic hazard related losses are compared for structural steel buildings considering different occupancy types. Buildings with the same plan and elevation are designed, with the site location adopted as Los Angeles, California, USA. State of art modeling technique is used for non-linear modeling of the steel buildings and non-linear time history analysis is used for their structural analysis. The case study buildings are perimeter special moment-resisting frame buildings. This study will help us determine the influence of occupancy type on different seismic hazard related loss performance metrics.

Keywords: Steel buildings, PBEE, Seismic life cycle cost, Building occupancy



Seismic Response of Reinforced Concrete Frames Resting on Hill Slopes

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Abstract

The Constructions done in the hilly regions are more vulnerable seismically in contrast with the structures built in flat terrains. The structures constructed in hilly regions are usually irregular, these structures are irregular both in mass and stiffness. Constructions done on the sloping ground is different from usual structures since they are asymmetrical in both horizontal and vertical directions. Columns of the bottommost story have a varying height because of slanted ground and are torsionally coupled, henceforth draw in a lot of shear forces, and without proper detailing building constructed on sloping ground is susceptible to moderate to heavy damage. In this analysis, the seismic response of three different building configurations i.e., Regular, Stepback, Stepback-Setback is evaluated. Seismic analysis using the linear static and dynamic methods was carried out using the structural analysis application ETABS 2017. Studying several building designs on a hillside includes bare frames, soft stories, concrete blockwork infill, soft stories with shear walls at corners, and frames with composite columns at the bottom story. For the various structures on the sloping ground, typical parameters such as Base Shear, Forces in the lowest floor columns, story drift, maximum top story displacement, time period, the B.M in columns at each floor, and story shear in structure will be identified and studied. Finally, several slope structure designs would be discussed in terms of their appropriateness.

Keywords: Stepback, Stepback-setback building, ETABS 2017, the slope of the ground, Linear Static method, Seismic analysis, Shear wall, Composite column, Response spectrum analysis



Unbonded Fiber-reinforced Elastomeric Isolators Coupled with Negative Stiffness-based Dampers

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Abstract

The efficiency of unbonded fiber-reinforced elastomeric isolators (UFREI) in mitigating the seismic hazard due to near fault earthquakes on a benchmark structure is investigated. Since near fault ground motions often contain high amplitude and long period pulses, thus isolated structures are prone to high isolator displacements under such ground motions. Therefore, supplementary damping devices are installed alongside the non-linear UFREI isolation system in the benchmark structures to mitigate this excessive displacement demand on isolators under near fault ground motions. Negative stiffness dampers (NSD) are a relatively new kind of energy dissipation device based on a compressed spring and a viscous damper. It produces significant damping forces even with very low damping coefficients, and it has been seen to be particularly helpful in mitigating the seismic hazards due to long period near-fault ground motions.

The behaviour of the benchmark structures isolated using UFREI coupled with NSD is then further investigated under a wide range of ground motions, including both far-fault and near fault earthquakes. A significant improvement is observed in the UFREI isolated structure's response under both types of ground motions (especially under near-fault ground motions) with the inclusion of the NSD as a supplementary damping device.

Keywords: Unbonded fiber reinforced elastomeric isolators, Negative stiffness damper, Near fault earthquakes, Supplementary damping device

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 555



Numerical Studies of a Laminar Soil Box for Seismic SSI Effects of Nuclear Facilities

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Abstract

Model tests are required to study the soil structure interaction effect for nuclear facilities subjected to seismic load. One of the methodology adopted is to perform experiments on a shaking table in 1g gravity field using a soil laminar shear box to reduce the spurious boundary effects. In the present work, a detailed pretest numerical simulation of a soil laminar shear box of size 1.5m × 1.1m (in plan) × 1.2m (in height) which is fabricated in house is presented. The first part of the numerical work is focused on one dimensional pretest site response finite element analyses to predict the soil amplification and the expected base shear during the dynamic excitation. The pay load capacity of the actuators required for the tests will also be obtained from the analysis. The second part of the study includes more advanced 2D finite element nonlinear analyses to evaluate the effect of wall friction on rocking motion of the soil and boundary effects of the laminar box.

Keywords: Laminar box, DEEPSOIL, Nonlinear analysis



Characteristics of Strong Ground Motions for Delhi National Capital Region (NCR) Using Small to Moderate Size Earthquakes

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Abstract

The characteristics of strong ground motions such as spectral acceleration and their behaviour on the structural design code are rigorously studied using small to moderate earthquakes occurred in the Delhi NCR region and recorded at local seismic network installed by IIT, Roorkee under the sponsorship of the Ministry of Earth Sciences. Seven earthquakes with magnitude range 3.3 to 4.9 occurred at depths of 5 to 22 km have been used in the present study. Total 159 earthquake waveforms from 27 seismic stations are processed for this purpose. The observed peak ground acceleration (PGA) associated with 5th March 2012 (M 4.9) lies in range of 2.4 to 30.8 cm/sec² and the peak ground velocity (PGV) lies in between 0.07 to 0.88 cm/sec. The maximum PGA (30.8 cm/sec²) is observed at Jaffarpur station and minimum PGA (2.6 cm/sec²) is observed at ridge observatory of New Delhi. The maximum horizontal spectral amplification occurred at 0.054 s in Holocene age formation, 0.109 s in Pleistocene age formation and 0.068 s in Proterozoic age formation. The maximum vertical spectral amplification is at 0.045 s in Holocene age formation, 0.084 s in Pleistocene age formation and 0.060 s in Proterozoic age formation. The normalized acceleration response spectra for Holocene, middle to late Pleistocene and Proterozoic age group is overestimated when compared with that of the Bureau of Indian standard code particularly in short period range whereas it is underestimated for the longer periods associated with the available data. The present analysis is beneficial for the seismic hazard studies in the Delhi NCR and may be utilized to improve the design code by characterizing the strong motion scenarios in the region.

Keywords: Strong ground motion, Amplification, Normalized response spectra



Fragility Curves for Structures Using Energy Criterion

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Abstract

The adaptation of structures to various regulations for the disaster, and therefore its developing risk and management, is the major problem of resilient and sustainable infrastructure. Generally, the drift based damage index has been used to compute the number of lives lost and the amount of money lost for structures damaged by disasters such as earthquakes, explosions, and other natural disasters. In our research, we demonstrate that the energy based damage index is superior for the buildings under consideration when subjected to various earthquake ground motions. For more precise loss estimation for those disasters, the energy based damage index is more suited than the drift based damage index. The energy concept is the approach of the future since it tackles the performance of a structure at both the global and local levels when subjected to varied dynamic loading. For the same reason, energy based fragility assessment is seen to be more useful because higher values indicate a greater likelihood of exceeding the threshold. In the field of damage assessment, drift based fragility curves are widely used to quantify damage under a variety of failure criteria. Well-designed three story and six story steel building structures have been modelled and analysed for various earthquake ground motions. Incremental dynamic analysis estimates drift and energy components. Output data, such as drift and energy, are looked at for their mean and standard deviation, then compared to each other. Fragility curves were created based on the mean and standard deviation data. Finally, observations and conclusions were made that, energy based fragility assessment are more effective for identification and quantification of performance of a structure under varying earthquake ground motions.

Keywords: Fragility curves, Incremental dynamic analysis, Nonlinear time history analysis, RAM PERFORM 3D, Performance levels



Numerical Derivation of Pressure-impulse Diagrams for a Fixed-end RC Beam Subjected to Blast Loads

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Abstract

This paper presents numerically derived Pressure Impulse (P-I) diagrams for a fixed end reinforced concrete (RC) beam subjected to blast loads. To capture the nonlinearities associated with the load deflection (resistance) function of the beam, a numerical approach was used to derive these diagrams. Several dynamic analyses were conducted to generate the P-I combinations resulting in an identical response limit (iso-damage). The first set of analyses was performed using a three dimensional finite element model implemented using general purpose software ABAQUS. Another set of analyses was conducted using a single degree of freedom (SDOF) elastic perfectly plastic idealization of the beam. These diagrams were generated for two response limits corresponding to the adequacy of flexural action being maintained in the beam. Results show good agreement between the P-I diagrams derived using the two distinct sets of analyses in the quasi-static loading regime. However, the diagrams deviate significantly in the dynamic and impulsive loading regimes based on the type of modeling approach used. Furthermore, stiffness degradation contours from finite element simulations reveal that shear dominant modes of failure can occur prior to the deflection limit being attained in the RC beam.

Keywords: RC beams, Blast loads, P-I diagrams, Damage pattern



Detection of Liquefaction Phenomenon from the 2015 Nuweiba Earthquake Using Remote Sensing Data

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Abstract

Egypt is a country situated in the northeastern part of the African continent. It has great historical importance, making this country's economy depend on tourism. Egypt faced significant earthquakes throughout history. One of the major earthquakes occurred in 1995, with a magnitude of 7.8. It left its marks on Nuweiba city, located at the banks of the gulf of Aqaba, in the form of liquefaction. This disaster called for much economic loss in the country. Hence, it is essential to know that the area is still undergoing liquefaction. The estimation of liquefaction related damages is possible using conventional field investigation approaches. However, conducting field research is difficult due to several factors, including cost, tool limitations, and accessibility issues. In this study, an attempt is made to detect water content changes which is a manifestation of soil liquefaction, using the 2015 Nuweiba earthquake of moment magnitude 5.5 in the vicinity of the epicenter. Band ratios and a statistical technique have been used to analyse pre- and post-earthquake optical satellite imageries to identify changes in water content. The algorithm has shown a change throughout the area of the study. Moreover, all the techniques produce a similar pattern for the immediate vicinity of Nuweiba city, proving the need for detailed geotechnical discussion.

Keywords: Liquefaction, Nuweiba Earthquake, Remote Sensing



Seismic Evaluation of Building Having Steel-concrete Composite Columns and RC Beams

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Abstract

In the recent times, the use steel-concrete composite structures in construction industry is growing due to ease of construction and also speedy construction offered by these kind of structures. In spite of this, India lacks the availability of a detailed dedicated design code of practice for construction of steel-concrete composite structures. IS 11384 gives certain guidelines but is not a detailed code of practice. In this paper, we aim to study performance of a steel-concrete composite building structure designed as per the Indian standards as well as the European standards to assess the effectiveness of the Indian codes of practice when compared with the European standards. To achieve this aim, a regular rectangular plan is selected. This building is then designed using both Indian and European standards. For that purpose, same gravity loads are considered. In case of lateral loads, IS 1893 and Eurocode 8 are used. Based on these forces obtained, sections sizes are decided for the buildings. For the Indian building, M30 grade of concrete and Fe345 grade of steel is used. The materials and assumptions in case of building to be designed by European standards are kept of similar nature to have comparable results. These buildings with the obtained section sizes are then modeled using a finite element modeling software. Non-Linear Time History Analysis is used for the assessment of these structures in the event of an earthquake. In this process, time histories of 11 earthquakes are used to perform this analysis so as to have a detailed comparison between the responses from both the structures under different earthquake loads. Various factors like, story displacements, story drifts, story shear, etc. are considered for comparison. As it was expected, the differences were observed in the obtained values for both the structures and those differences were tabulated in form of tables and graphs and thus a general conclusion was drawn based on these results.

Keywords: Composite structure, Ductility, Finite element modeling, Non-linear time history analysis, Eurocode 8, IS 11384

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 601



Chaos Game Representation of Indian Plate Seismicity

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Abstract

Chaos Game Representation (CGR) based on Iterated Function Systems is one of the modest techniques to create fractal structures but can unveil characteristic structures and hidden correlations effectually. This method has been applied currently to unveil the characteristic structure in DNA and also in the field of nonlinear time series data. In this paper, we propose a novel way to represent earthquake sequences using CGR. This representation showed that a characteristic correlation exists between events occurring at different parts of a plate boundary, which are otherwise difficult to explore. The method of CGR is used here to unveil this characteristic for the Indian plate and show that there exists a correlation between earthquakes occurring at different parts of a plate.

Keywords: Chaos game representation, Iterated function systems, Datadriven IFS, Indian plate, Correlation between earthquakes, Sequential occurrence of earthquakes



Estimation of Site Amplification Factor and Predominant Frequency in and Around Panchkula City, Haryana, India

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Abstract

In this study, we used the Horizontal to Vertical Spectral Ratio (HVSr) technique to estimate the site amplification factor and the fundamental/predominant frequency at some of the sites in the Panchkula city of Haryana state of India. This technique gained popularity when Nakamura (1989) estimated the site amplification factor by considering the Horizontal to Vertical spectral ratio of microtremor noise data. This method helps in the seismic microzonation of an area with very less seismicity. It has been found that the site amplification factor and the fundamental frequencies at 19 sites in the city vary in the range of 1.9-3.1 and 0.4-1.0 Hz, respectively depending upon the local geological conditions. The sites associated with the riverside show more site amplifications (>2.8), while sites away from the river show lesser amplifications (< 2.1). Similarly, we observed that some sites show higher predominant frequencies (>0.85), while some sites show less predominant frequencies (<0.5). It has been also observed that some sites show clear H/V peaks, while some sites show broad peaks suggesting poor impedance contrast between bedrock and soil. The variation of site amplification factor and predominant frequency in the study region exhibits variable geological conditions and site characteristics. This study is highly useful for civil engineers in designing and constructing high-rise buildings in this region.

Keywords: Site amplification, Predominant frequency, Microzonation, Horizontal to vertical spectral ratio



A Fast Staggered Grid Finite Difference Modelling of Rayleigh Wave

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Abstract

Staggered grid finite difference methods are extensively used for elastic wavefield modelling of Rayleigh waves due to their stability and easy implementation. However, the technique requires a very high spatial grid resolution in the presence of low velocity layers near the surface. The fine grid increases the computational cost and causes oversampling for relatively longer wavelengths at deeper depths. To overcome these challenges, we propose a vertically non-uniform staggered grid finite difference approach that significantly reduces the computational cost without sacrificing accuracy. The non-uniform discretization strategy is based on the Rayleigh wave dispersion relation, where the penetration depth is assumed to be roughly one and a half of a wavelength. Using the above assumption, an exponential relationship between grid size and grid number is established. After applying the systematic discretization, the finite difference coefficients are calculated at respective main and staggered grid positions. The proposed modelling method is applied to different synthetic models. The accuracy of the proposed approach has been demonstrated by comparing the vertical and horizontal responses and dispersion images. The proposed approach produces identical dispersion images using only 1/3rd to 1/4th of the computation time compared to the uniform grid approach.

Keywords: Staggered grid finite difference, Synthetic seismogram, Non-uniform grid, Rayleigh wave



Experimental Investigation of VFPI and FPS Under Harmonic Loading

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Abstract

Previous analytical studies have shown that Variable Frequency Pendulum Isolator (VFPI) system can effectively mitigate the resonance issue that is likely to occur in a standard Friction Pendulum System (FPS) because of its variable isolation frequency. However, experimental research on the performance of VFPI is limited compared to analytical research; hence, designers are discouraged of using VFPI for practical design as compared to FPS. Therefore, in this research work, the experimental performance of rigid mass isolated by VFPI and FPS has been investigated on the shake table and, the hysteresis curves of both systems plotted from the experimental data have been validated with the analytical. This research work also compares the experimental behavior of the VFPI and FPS under harmonic ground motion. The results show that the VFPI successfully mitigates the response phenomenon, which is clearly observed in the case of FPS at the design isolation frequency ($T_b = 1.5$ sec). Under low excitation frequency ground motion (< 1.0 Hz), the VFPI system efficiently decreases the absolute acceleration response of the rigid mass than the FPS system, although the VFPI system may exhibit larger sliding displacement than the FPS system. Under excitation frequencies larger than 1 Hz, the performance of the rigid mass isolated by VFPI and FPS is approximately similar.

Keywords: Base isolation, Variable frequency isolators, Variable frequency pendulum isolator (VFPI), Friction pendulum system (FPS), Harmonic loading



A Review of Seismic Safety Measures for the Construction of New Stone Masonry Houses

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Abstract

Stone masonry walls have inherent weaknesses against the lateral forces of an earthquake. These weaknesses result in inadequate performance during earthquakes. Mistakes are commonly committed in the construction of stone walls, especially in the random rubble type masonry. These mistakes further erode strength. When shaken, poorly constructed walls having inadequate interlocking between the inside and the outside faces (wythes), the faces begin to separate, resulting in rapid weakening of the wall and leading to the collapse of one or both wythes. In the presence of excessive openings, the wall becomes weak against the tearing action caused by the earthquake forces that are parallel to the length of the wall. This results in diagonal cracking of varying severity in the walls. Further, due to poor connection between the walls and the floor/roof, it results in failure of the floor diaphragm and affects the overall stability of the structure. Hence, while choosing to construct a building with stone masonry, the owner must make sure that the measures required to counter these weaknesses are taken during the construction so that in the event of a potentially destructive earthquake, the structure can withstand its impact without suffering much damage. Therefore, in the present study, an overview is presented for different failure modes of stone masonry houses, seismic safety provisions for the new construction considering the regulations for the wall, floor/roof construction, and the provision of horizontal and vertical reinforcement to ensure good seismic performance against the future earthquakes.

Keywords: New construction, Stone masonry, Failure modes, Seismic safety provisions, Wall and floor/roof



Use of GIS for Hypsometric Analysis for Determining Erosion Proneness of Mandakini Watershed, Lesser Himalaya, Uttarakhand, North India

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Abstract

An attempt has been made for the assessment of erosion proneness which is quite essential in tectonically active, highly fragile and environmentally sensitive hilly regions. The assessment will not only help in knowing erosion proneness but also supports in adopting the best practices for integrated watershed management. The hypsometric analysis was performed to know the geological stages of the development of erosional landscapes that reveal the health or condition of a watershed. The hypsometric integral was estimated from the graphical representation of the measured contour height and enclosed area, and using the empirical formula. The study was carried out to assess erosion susceptible areas of the Mandakini River watershed, which forms a tributary of the Alaknanda River catchment of Lesser Himalaya, Uttarakhand. Six sub-watersheds were delineated from the Mandakini Watershed for performing the hypsometric analysis using contours generated from the DEM in a GIS environment. The hypsometric integral values were quantified by the elevation-relief method for all the sub-watersheds and are ranging between 0.46 (B3) and 0.50 (B4). Further, it was found out that almost all the sub-watersheds are comparatively matured and erosional processes are in the course of stabilization. The study reveals that the sub-watershed primarily B1 of the Mandakini Watershed are susceptible to erosion. Moreover, the past Earthquakes occurred near by area can also lead to the instability of the zones. Therefore, suitable remedial measures such as structural and non-structural methods may be adopted to mitigate soil erosion and also in enhancing sustainable conservation and management practices.

Keywords: Hypsometric analysis, Lesser Himalaya, Erosion proneness, Mandakini watershed, GIS



Effect of URM Infills on Seismic Behaviour of RC Frame Building: Part-2

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Abstract

This paper is the second part of the study conducted on a six storey (G+5) RC frame building to understand the effect of URM infill walls and its modelling techniques on the behaviour of RC frame buildings under the application of seismic forces. As mentioned in the first part of this study, the building has been modelled as bare frame (BF) and frame with infills modelled as equivalent compression only struts using three different configurations, i.e., EBIF, CBIF and ECBIF. Also, non-linear seismic analysis methods have been briefly discussed, along with their advantages and limitations. However, due to high seismic forces, non-linear static (pushover) and non-linear dynamic (time history) analysis procedures have been adopted in this work to evaluate the seismic performance of the building. While on one hand, infills help in lateral load resistance and increase the stiffness and strength of the structure. On the other hand, the diagonal strut behaviour of infills causes large shear forces at the end region columns where the strut action is taking place. Therefore, the effect of infills and their different modelling techniques and the response of different seismic analysis procedures have been estimated and compared, in terms of Inter Storey Drift ratios (ISD), storey displacements and column shear forces, to obtain more accurate behaviour. It has been observed that URM infills and their modelling configuration considerably affect the dynamic behaviour, distribution of plastic hinges and consequently alter the seismic performance of buildings.

Keywords: Infilled RC frame building, Unreinforced masonry walls, Braced infill frame, Non-linear pushover analysis, Non-linear time history analysis



Understanding the Structure and Tectonic Configuration of Bengal Basin for Earthquake Magnitude Prediction

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Abstract

The Bengal Basin is a living model of an active and complex geological entity consisting of dynamic deltaic depositional complex, heterogenous and multidimensional tectonic deformational settings from three tectonic plates. The earthquake risk of the basin is not rationally anticipated due to the absence of adequate seismic and geodetic data, subsurface geological maps, insufficient representative, and instrumental data acquisition system. For a geo-metrical array and vector mapping of tectonic deformation, intensive data search is done from published sources. An investigation on crustal configuration using available seismic data; velocity images, travel time tomography along number of profiles is done. Based on these studies, the basin is classified into five geotechnical domains. An attempt is made to understand the scenario of sediment input, tectonic and gravitational stress distribution, and their pattern of deformation vectors for earthquake magnitude prediction. The crustal study indicates that the basin is severely fragmented, and topography of the sedimentary sequences are shaped and stressed by various sizes of graben and horsts. The basin received enormous volume of sediments, which resulted in deposition of very thick clastic sediments. A seismic zoning map is prepared using the five major geotechnical domains with maximum possible magnitude of earthquakes to be occurred. The 1918 Srimangal event of $M_w \approx 7.5$ is the largest recorded earthquake and no seismogenic structure has been found to cause great earthquakes in Bangladesh.

Keywords: Bengal Basin, Tectonics, Seismicity, Earthquake

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 633



Numerical Analysis of Steel Beam Column Connection Assembled with Replaceable Fuse Under Cyclic Loading

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Abstract

This work follows the latest development trend in resilient structures by arresting inelastic damage in a small replaceable link at a predetermined location. Towards this, here innovative beam fuse has been proposed with circular, triangle, square, and elliptic openings. These openings are also provided with a stiffening plate of 5 mm thickness to reduce the stress concentration effects inside the opening edge. Comparative analysis has been carried out for four beam column sub assemblages in ABAQUS FEM software. In this modeling, the bolted end plate has been omitted as the focus is only on the connection's pure fuse behavior. SAC loading protocol has been adopted to evaluate the cyclic behavior of the connections. Strength degradation, ductility, and energy dissipation have been studied. All the fuse connections show excellent ductility under the cyclic loading. For all the fuses based on rupture, index cracking may occur between the web plate and the stiffening plate of the fuse. Here fuse with a circular opening shows the highest amount of energy dissipation.

Keywords: Replaceable fuse, Energy dissipation capacity, Stiffening plate, Resilient structures, FEM, Cyclic



Seismic Response of Coupled Structure, Equipment and Piping System with and without Base Isolation - An Experiment

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Abstract

Generally, when structures are subjected to an Earthquake, the response gets amplified from ground to higher floor levels. This is a function of ground motion frequency amplitude characteristics, frequency and damping characteristics of structure. To make the response of structure independent of its frequency and damping, seismic base isolation techniques are adopted. It makes the structure isolated from ground motion and results in low seismic responses such as accelerations and forces. However, there will be large displacement with respect to the ground. This concept will also help to reduce seismic demand on floor mounted equipment and piping systems. Eventually helps the utility to standardize the seismic design of Structure and floor mounted Equipment and Systems. In addition, the data generated will be useful for the designer to validate the design. Tests were performed on coupled structure equipment (vessel) and piping systems. This paper presents details of experiments carried out, observations made on structure, vessel and piping responses.

Keywords: Attenuation, Regression, GMPE, Amplitude

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 637



Blast Resistance Capacity of Seismically Designed Building Frames

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Abstract

A seismically designed building may be subjected to blast loading in its life span due to a sudden terrorist attack or an accidental explosion. As blast loading is associated with inherent uncertainty, most buildings are not designed for blast loading, but they are routinely designed for earthquake demand. By upgrading the seismic design, the blast resistance capacity of a building can also be improved. The paper investigates the blast resistance capacity of a 6 storey reinforced concrete (RC) building frames designed for peak ground acceleration (PGA) levels of 0.6g, 0.4g, and 0.2g. The building frames are subjected to blast loading caused by the explosion of 500kg of TNT(trinitrotoluene) at small to medium standoff distances. Nonlinear time history of analysis (NTHA) of the frames for blast loading is performed in SAP 2000. Responses of the frames are obtained in terms of peak top floor displacement, maximum inter-storey drift, and number of plastic hinges formed. NTHA results of the building frames are compared to evaluate the relative performances of the three different seismically designed buildings under blast loading.

Keywords: Blast load, RC building, Nonlinear analysis



Calibration of UBC3D-PLM Constitutive Model to Simulate the Dynamic Response of Earthen Embankment Resting on Liquefiable Soil

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Abstract

The objective of the current work is to create a numerical model to assess the dynamic behaviour of earthen embankments built on liquefiable soil. The PLAXIS 2D program, which is based on the finite element approach, was used to create the model. The foundation soil, which is the primary focus of this study, has been modelled using UBC3D-PLM constitutive model while the earth embankment material has been simulated considering the Mohr Coulomb constitutive model. To calibrate the crucial model parameters, a series of calibration studies have been conducted. The well calibrated model parameters are later has been implemented for simulating a well-documented centrifuge study. The difference in experimental and numerical model has been highlighted. Study reveals that excess pore water pressure near the embankment toe is the main concern of instability of earthen embankment which results in excessive embankment crest settlement. However, soil below embankment crest never reaches initial liquefaction condition and undergoes dilation, which shows the capability of the UBC3D-PLM constitutive model in capturing the shear induced dilation behaviour. A well comparative study of experimental and numerical analysis can provide us deeper insights on this aspect and which can also highlight key features in order to provide counter-mechanism against liquefaction induced settlement of earthen embankment. Study showed a good agreement in evaluating the effect of liquefaction on the response of earthen embankment.

Keywords: Earthen embankment, Embankment crest settlement, Excess pore water pressure, Numerical modeling



Comparative Study on Seismic Performance of RC Frame with Different Types of Steel Bracing System

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Abstract

The steel bracing technique has proven the most efficient system to resist lateral load in earthquake resistant design. It offers excellent energy dissipation capacity in case of earthquake induced ground motion. This technique for new building construction or as a retrofitting method is used to strengthen the earthquake damaged structure or to enhance the strength of old and capacity deficient structures. In the present study, an analytical study is carried out to show how the bracing system affects the structural performance of buildings in high seismic regions. The objective is to determine the effectiveness of the different bracing systems, namely X, Chevron, V, and diagonal shapes, in increasing the lateral load capacity and decreasing the overall displacement of the RC frame. The non-linear static analysis is carried out using ETABS 2020 software to evaluate the different bracing systems. The results are presented in terms of base shear, drift ratio, lateral displacement, and stiffness.

Keywords: Steel bracing, RC frame, Lateral strength, Seismic design



Modified Framework of Selection of Input Ground Motion for Fragility Analysis of the Structure

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Abstract

In this present study, an updated ground motion selection methodology is proposed for the evaluation of seismic performance of mid-rise reinforced concrete building with multi stripe analysis (MSA) based probabilistic seismic hazard analysis (PSHA). The structures are model in finite element software FEA NX. The nonlinear behavior of beams and columns are represented by Modified Takeda model. The seismic fragility function of a three storied instrumented test building is generated for different performance levels of maximum storey drift under a series of input ground motions (IGM). IGM are obtained from the uniform seismic hazard response spectrum (UHRS) compatible synthetic time histories. In this procedure, the frequency contents of the input motion during the scaling of high intensity earthquakes are conserved. The site specific UHRS are developed from probabilistic seismic hazard analysis (PSHA) and 1st mode spectral acceleration is considered as an intensity measure for the building. The fragility curve generated for the building is also compared for two different methods, such as, the presently proposed method and the existing method of generation of input motion by simple scaling of particular spectrum compatible time history. The proposed method provided a conservative result for all the performance levels.

Keywords: Ground motion selection, Fragility analysis, PSHA, Multiple stripe analysis



Dynamic Behaviour of Railway-bridges: A Review of Code Provisions for Passengers' Comfort and Operational Safety

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Abstract

Railway has a larger number of advantages over other modes of transportation, such as cost efficiency, environmental friendliness, larger capacity, etc., which has led to rapid growth in high-speed and semi high speed railways during the last decade. Bridges are subjected to much higher impact due to high-speed train load, magnified several times in the vicinity of resonance. Indian bridge rule takes into account the dynamic effects with the help of the coefficient of dynamic augment (CDA) and is limited up to the speed of 160 km/h only. As speed increases beyond 160 km/h, chances of resonance are going to increase, nothing about which is mentioned in the Indian code. A comparative study of the Euro code, UIC guidelines, and Indian bridge rule is carried out to investigate the effects of resonance on passengers' comfort and running safety of trains at higher speeds on bridges designed as per Indian bridge rule. FEM model of a standard Research Designs and Standards Organisations (RDSO) bridge in MIDAS, as per UIC and Euro code guidelines, and Vandebharat train loading is considered in this study. Model verification with the theoretical solution of Chopra (2007) is presented. It is concluded that the design of bridges considering CDA is insufficient for high-speed trains, as it is not able to capture magnifications due to resonance.

Keywords: Dynamic analysis, High-speed trains, Railway bridge, Indian bridge rule



Exploring an Alternate Perspective of the Importance Factor for Seismic Design of Structures

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Abstract

Contingent to the risk to human life in the event of failure structural systems are designed with an additional factor, commonly known as the importance factor (CI 7.2.3) [1]. In other words, importance factor is aimed to augment the design seismic hazard to reduce the probability of failure of a structure contingent on the associated risk to human life. Most standards recommend a factor (such as 1.5, 1.2 and 1.0 by Indian standard) based on the importance of a structure. The important question arises here is, given the varying level of epistemic uncertainty contingent on the fundamental period and regional seismicity, are we maintaining the underlying objective of uniform mean annual rate of exceedance while using a constant importance factor (such as that specified by most seismic standards)? This study offers an alternate perspective of increasing the design seismic hazard while maintaining the same underlying principle in an effort to comprehend the underlying problem. The ratio of fractile to weighted mean- hazard is envisioned in this study as an alternate perspective of the importance factor used in seismic design, which appears to be dependent of the regional seismicity and fundamental period (but not on the soil sites). Besides, PSHA of the North-East Indian region is carried out using the logic tree approach and the results of few cities are presented here for the purpose of comparative illustrations. Finally, the importance factor is given by a linear function of the time period with contour maps of location dependent constants.

Keywords: Importance factor, Weighted mean and fractile seismic hazard, Logic tree, Contour map

17th Symposium on Earthquake Engineering
November 14-17, 2022
IIT Roorkee, India
Paper No. 650



Simplified Damping Modification Factor for Vertical Response Spectra

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Abstract

Damping modification factor of vertical response spectra (DMFV) for 1%, 2%, 8% and 10% damping levels with that at 5% of the critical is explored for a period range of 0 ~ 4.0sec. The dependence of DMFV on seismological parameters (magnitude, epicentral distance and soil type) is studied and is shown to be weak and insignificant for practical purposes. Simplified relation for computing DMFV as a function of the period is proposed irrespective of any seismological parameters.

Keywords: Vertical earthquake shaking, Damping modification factor



Machine Learning Based Seismic Drift Response Estimation of Buckling-restrained Braced Frames

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Abstract

Machine learning (ML) approach has the potential to predict the seismic structural responses that are aleatoric in nature. A well-trained data set using a suitable ML algorithm is essential for this goal. One 8-storey buckling-restrained braced frame (BRBF) was selected and designed as per applicable code provisions. The chosen BRBF was incorporated in OpenSees numerical frame work with pertinent nonlinearities. For the nonlinear time response history analyses, a suitable number of ground motion records were adopted and the structural responses were assessed in terms of drift responses. These drift responses were classified in to different damage states (DS) based on their magnitude and severity. The related regression fits for drift vs seismic intensity measure (IM) and the resulting fragility curves were developed to understand the vulnerability of the system. Using the obtained data ML algorithms such as K-Nearest Neighbour (KNN), Decision Tree (DT), Random Forest (RF), AdaBoost (AB), XGBoost (XGB), Light Gradient Boost (LGB) and CatBoost (CB) were utilized and the corresponding confusion matrixes were generated to obtain the best prediction model. It is found that the RF approach gave the highest accuracy among all the algorithms used.

Keywords: Buckling-restrained braced frames, Non-linear time response analyses, Drift response, Machine learning



December 01, 2020, Haridwar, Earthquake: Fault Plane Solution and Tectonic Implications

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Abstract

On December 01, 2020, a small-sized earthquake ($M_L=4.0$) occurred 25km northwest of Haridwar after a gap of about 45years. The location of the earthquake falls on Main Frontal Thrust (MFT) about 105km southwest of the 1991 Uttarkashi earthquake ($M_w=6.8$). The earthquake was sourced in the Crust-Mantle boundary (40.6 km). Data from the local broadband seismic network around the Tehri region have been used for the study of the source mechanism. The fault-plane solution of this event, suggests that deformation occurred by strike-slip faulting with a significant reverse component. The trend/plunge of the major and minor principal axes P/T are $201^\circ/10^\circ$ and $296^\circ/24^\circ$ respectively. This paper is based on the determination of the focal mechanism through the Moment Tensor Inversion Solution of waveforms derived from the records of the local event, employing ISOLA software. The Moment Tensor solution is considered a stable and more robust method to quantify the fault orientation of faults that slipped due to an earthquake and the method yields more accurate results than any other standard approach. A numerical technique, developed based on forward modeling, is used for the inversion of the observed waveforms for the components of the moment tensors and the earthquake source-time function (STF(t)). We used f_{min} of 0.15Hz and f_{max} of 0.55Hz to perform the waveform inversion of the earthquake.

Keywords: Moment tensor analysis, Source parameter, Focal plane solution, Seismicity



Local Seismicity around Tehri Dam, Garhwal Himalaya

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Abstract

Tehri dam with a height of 260.5 m is the highest earth and rock fill dam in India. It is situated on the confluence of the Bhagirathi and the Bhilangana rivers in the Garhwal Himalaya and located in the highly strained region of the north-western Himalaya. The region around Tehri dam lies in zone IV & V as per the seismic zoning map of India where the 1991 Uttarkashi earth-quake $M_b \sim 6.6$ and the 1999 Chamoli earthquake $M_b \sim 6.4$ have occurred.

The local seismicity in the environs of Tehri dam is being monitored for last more than two and half decades. For this purpose, a local seismological network was deployed by the Department of Earthquake Engineering in September 1993 under the scheme of Department of Science and Technology (DST). The network has been upgraded time to time. Presently, 18-stations of state-of-the-art seismological network is being operated around Tehri dam reservoir area. The spatial variation of local seismicity follows the trend of surface trace of MCT in the Garhwal Lesser Himalaya. The focal depth distribution of seismic events along and across the strike direction of the regional tectonic features reveal the confinement of activity within 10 to 15 km.

In the present paper, attributes of local seismicity for more than two and half decades have been presented for Tehri dam. In addition, the changes in seismicity due to dam reservoir as a part of Reservoir Induced Seismicity (RIS) has been studied and no correlation of seismicity activity with the dam reservoir filling has been observed even after about seventeen years filling/drawdown of dam reservoir.

Keywords: Microearthquake, Seismicity, MBT, MCT