A study on seismic response of buildings on coir mat reinforced sand bed

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Abstract. The present study examines the efficacy of coir mat as a seismic isolation material for reducing the earthquake energy transferred and, so to reduce the dynamic response of the building. A three-dimensional finite element simulation of field-scale models of G+2 and G+3 buildings resting on raft foundation in a sand bed, with and without the seismic isolation mechanism has been carried out by time history analysis with El Centro (1940) input motion. Seismic responses such as roof acceleration, roof deflection, bending moment and shear force of G+2 and G+3 buildings are studied. Variation in the base shear ratio which is defined as the ratio of seismic base shear to the total weight of the building is also analyzed by incorporating the three-dimensional soil-structure interaction effect. The results from the analysis inferred that the reinforcement of the coir mat as a seismic isolation medium limits the transmission of earthquake energy to the superstructure.

1. Introduction
Earthquake is one of the most critical kinds of hazards that damage buildings all over the world. Either building should be designed to mitigate the severity of earthquakes or such destructive effects have to be reduced by using seismic isolators to provide safe living conditions. A seismic isolation system can be either structural or soil isolation. Structural isolation is defined as the mechanism in which earthquake damaging effects on the structure and its building contents can be reduced by the provision of a sliding or flexible mechanism between the foundation and structure, to separate the lateral motions of the structure from the lateral motions of the ground. But in soil isolation, material reinforced in soil absorbs the earthquake energy before it reaches the structure. There are so many methods of seismic isolation available from the previous studies. Provision of smooth synthetic liners below the foundation or within the soil at a distance below footing to dissipate seismic energy through sliding are studied [1] and providing a rubber-sand mix layer (RSM) around and at bottom of the foundation of the structures to act as a cushion. For countries where adequate resources, as well as technology, are not well developed for reducing the severity of the earthquake, economical seismic isolation techniques can be beneficial.

Initially investigated the advantage of using a geosynthetic reinforced isolation system to reduce seismic response during a ground motion [2]. For using this concept shear strength characteristics at interfaces of geomembrane and geotextile should be studied [3]. Under the various combination of shake table motion frequencies, normal stresses and table acceleration, dynamic shear strength property of nonwoven geotextile and geomembrane materials were investigated [4]. Later shaking table tests were conducted at the interface of geomembrane and soil interface and geomembrane–
geotextile interface [4]. Dynamic friction coefficients at the interfaces are also investigated. The idea of cost-effective earthquake mitigation methods using natural materials such as sand was explored [5].

Much attention is now focused to replace plastic reinforcement materials with natural materials [3]. In comparison to polymeric plastic reinforcement materials, natural materials are environmentally safe, cost-effective and readily available. Research in the application of coir as a material for soil reinforcement began in the 1990s. The inclusion of fibre in cohesionless soils increases the resistance to liquefaction [5]. According to the stress-strain pattern for coconut fibers, coconut fiber is the most ductile fiber in the natural fibers, as some researchers have noted. Coconut fibers are 4-6 times more stainable than other fibers. They are used in the fields of slope stabilization in railway embankment, for the protection of waterways, reinforcement of rural unpaved roads, a sub-basis layer on highways, land reclamation, and filtration in road drains, etc. [6]. The influence of the reinforcement material form on the response of coir geotextile strengthened sands with triaxial compression experiment was investigated [7]. An improvement in the peak axial strain and deviatoric stress at the failure by the inclusion of coir material in the soil was observed. In comparison to the discrete and planar forms, coir geocell performs better due to its three-dimensional structure.

The durability of the coir material is a matter of concern. Researchers [8] indicated that the longevity of the fibre is enough to be used as a soil reinforcement material, by the durability analysis on coir. The durability of the coir fibre can be improved by coating the fibers with bitumen and phenol [9]. Chemical treatment is the main technique to enhance durability and mechanical properties, especially for natural fibres. Coconut fibre has been chemically treated with silane, alkali, and silane-alkalized coconut fibre for various concentrations [10]. In a previous study [1], coir fibre reinforcement in the matrix of polyethylene (PE) and polypropylene (PP) polymer material was analyzed. In a sieve shaker, the raw coir fibre was treated chemically with the basic sodium bicarbonate and chromium sulphate before it is reinforced in the polymer matrix. Compared to the raw coir fibre reinforced polymer composites, better properties were obtained by the chemical treatment of coir fibre. Raw coir was treated with a benzene diazonium salt in separate media such as alkali, acidic, and neutral media [11]. The hydrophilic groups in the coir fibre cellulose were changed to hydrophobic groups when it is chemically treated.

From the review of the literature in this field, it is noted that the soil isolation efficiency of the coir is not yet addressed. The finite element program based numerical modeling of the soil isolation-structure system was carried out. Linear behavior of building, raft foundation, and soil was assumed in the analysis. The time history analysis of the soil isolation-structure system incorporating soil flexibility was performed for dynamic loading. Corresponding to the scaled acceleration data of the El Centro (1940) earthquake recorded at Imperial Valley.

2. Proposed scheme of geotechnical isolation

Obtaining a high-quality alternative geo-material in geotechnical engineering is a challenging and essential work. Application of coir mat is the geo-material used for the isolation technique is proposed in this study. Incoming seismic vibration energy is completely transferred by the ground motions to the above structure, while the foundation of conventional structures directly rests on the non-isolated soil medium. This is because of the large friction at the soil-foundation interface. In this study, two sets of G+2 and G+3, three-dimensional building models were considered to estimate the seismic response variation at top of the building for the conventional conditions of soil and with the isolation mechanism. The soil considered for the model was medium sand with a shear wave velocity of 107 m/s in accordance with the FEMA 273 classification [12].

Buildings considered were single-bay RCC frames having a bay length of 4m and storey height of 3m. For both the buildings, beams, and columns were provided with cross-sections of 300x300mm. The live load on floors and floor finishing load were taken as 3kN/m² and 1kN/m² respectively, apart from the self-weight of the structural mass. Soil stratum of size 55mx55m with a depth of 25m and raft of size 5mx5mx0.5m were considered. The coir mat of thickness 20mm was placed below the raft
foundation (Figure 1a). The schematic diagram of the soil isolation-structure model considered for the study is shown in Figure 1b.

3. Numerical Modeling

The three-dimensional finite element model of the structural system was created in ANSYS software. SOLID 185 element was used to discretize the soil stratum, which is an 8 node first-order linear brick reduced integration element. In contact analysis, this element is good for convergence. SOLID 185 element was also used to mesh the raft foundation as that of soil. BEAM188 element was used to model the building frames, which is a 2-noded beam element with a linear behavior. Since the coir mat subject to bending under the loads, it is modeled with SOLSH190, a 3D finite strain 190 elements having very low stiffness for bending. The coir mat was modeled directly below the raft foundation.

The linear elastic behavior was assumed for the integrated building-foundation-soil system. The most fundamental and important material model used for the soil and structural mechanics analysis is the linear elastic model. The vast majority of numerical simulations considering the linear elastic models use isotropic materials. For many very brittle materials, the linear elastic model describes the full stress-strain response up to the point of fracture of the materials, given the stresses are small enough. Mainly three dependent material parameters like Young's modulus, Poisson's ratio and shear modulus are needed to represent such materials.

Reinforcement material properties are arrived at based on the previous studies on the engineering properties of the coir materials [13,14,15]. The engineering properties of coir mat, soil and concrete are shown in Table 1.

![Figure 1](image)

**Figure 1.** a) Coir mat b) Schematic illustration of soil isolation-structure system.
Soil stratum with infinite boundaries plays an essential role in the seismic response. Hence non-reflecting boundaries should be provided to eliminate the problem with waves reflecting from the boundaries into the model. Viscous boundaries were provided at the lateral boundaries to serve the purpose. The base of the soil stratum was constrained against all the movements in the horizontal as well as vertical directions to represent the rock surface at the base. To incorporate the frictional resistance between the sand and coir mat, the frictional behavior was modeled with contact and target elements. A dynamic friction coefficient of 0.5 was assigned at the interface of sand and coir mat. The minimum value of the coefficient of friction at the soil-coir mat interface was used [16,17]. The rough interaction option available in ANSYS was used to define the soil-foundation interface of the conventional and isolated systems. Formulation of rough friction means an infinite frictional coefficient which can prevent all kind of relative sliding motions between two different surfaces which are in contact [13]. Finite element models of the soil-foundation-structure system modeled in ANSYS is shown in Figure 2.

Table 1. Material properties of soil

| Material Properties       | Coir mat | Sand | Concrete |
|---------------------------|----------|------|----------|
| Density (kN/m³)           | 15       | 18.40| 25       |
| Modulus of elasticity (MN/m²) | 4100    | 55   | 25000    |
| Poisson’s ratio           | 0.3      | 0.3  | 0.15     |

Figure 2. Finite element models of a) isometric view of G+2 building b) cross-sectional view of G+3 building.

4. Seismic Analysis
The accelerogram recorded corresponding to El Centro Earthquake data on 18th May 1940 at Irrigation Project Imperial Valley, was scaled down to a PGA of 0.3g and used as the input ground excitation on the soil surface. Figure 3 represents the input time history. The efficacy of the soil isolation technique with coir mat placed below the raft foundation was investigated numerically using this accelerogram. The seismic response of G+2 and G+3 RCC framed buildings under the effect of seismic ground motion was compared among the conventional and isolated cases. Absolute maximum acceleration response in the roof mass is the main response structural quantity to assess the
performance of the isolation system since the shear force and bending moment exerted at the base of the building is proportional to this.

![Image of acceleration vs. time graph]

**Figure 3.** Time history of input ground acceleration.

### Table 2. Comparison of roof responses for with and without soil isolation mechanism

| Building | Roof acceleration (m/s²) | Reduction in roof acceleration | Roof deflection (mm) | Reduction in roof deflection |
|----------|--------------------------|-------------------------------|----------------------|----------------------------|
|          | Conventional model       | Isolated model                |                      |                            |
| G+2      | 27.3                     | 17.8                          | 35%                  | 17.8                       | 11.4 | 36% |
| G+3      | 20.7                     | 16.2                          | 22%                  | 18.7                       | 13.1 | 30.5% |

![Image of roof acceleration and deflection graphs]

**a)**

**b)**
Figure 4. a) Roof acceleration in the G+2 building b) Roof deflection in the G+2 building c) Roof acceleration in the G+3 building d) Roof deflection in the G+3 building for conventional and isolated soil-structure system.

Figure 5. Variation in the base shear ratio considering the fixed base and the three-dimensional SSI system.

5. Results and discussions
The study investigates the efficacy of natural fibre mat, the coir mat as a seismic isolation material by evaluating the seismic response in three-dimensional finite element models of G+2 and G+3 RC building-foundation soil system with and without soil isolation. The maximum absolute acceleration and deflection responses under seismic loading were evaluated at the roof of buildings. Figure 4 represents the time history plot for seismic responses observed for the building models, for the conventional (model without soil isolation) and isolated (model with soil isolation) conditions which clearly depicts the reduction in seismic energy transferred to the structure in an isolated case.

The effect of using coir mat as isolation material on the seismic response of both the G+2 and G+3 buildings under the ground motion is shown in Table 2. In comparison with the conventional model, a reduction of approximately 35% and 36% for maximum roof acceleration and roof deflection responses are obtained. It is also noted that the percentage reduction of roof responses in the soil-
structure system of G+2 building is more as compared to the G+3 building. The present isolation technique provides more efficient isolation as compared to the earlier reported research with both geotextile and UHMWPE (Nanda et al 2017) and also emphasizes that a single layer of coir mat as isolation reduces the seismic responses of building significantly.

The variation in the base shear ratio (base shear divided by the weight of building) obtained by considering the fixed base case and also incorporating the three-dimensional soil-structure interaction (SSI) effect is compared (Figure 5). It is found that the seismic base shear is more when the SSI effects are taken into consideration than the fixed base condition. The base shear ratio is also evaluated for the conventional and isolated soil-structure system. G+2 and G+3 buildings show almost 30% and 45% reduction in the base shear ratio in the isolated SSI system as compared to the conventional SSI system.

Shear forces and bending moments in the exterior column of the ground floor of buildings resting on soil reinforced with coir mat under the ground motions are analyzed. Absolute maximum response of shear force and bending moment in G+2 and G+3 RC framed buildings under input motion is compared among the conventional and isolated cases and represented in Figure 6a and Figure 6b. It is observed that bending moment and shear force are significantly reduced by the provision of coir mat in the soil below the raft foundation. In general, this reduction in seismic response is seen higher in G+3 buildings compared to G+2 buildings. G+2 and G+3 buildings show almost 29.5% and 45% reduction in the bending moment in the isolated soil case as compared to the conventional soil case. In comparison with the unreinforced soil base, a percentage reduction of about 30% and 44.5% in the shear force is observed in G+2 and G+3 buildings by the inclusion of coir mat in the soil.

6. Conclusions
The current numerical investigation explores the seismic-soil-isolation effect of the coir mat, which is when placed as an isolation material under the foundation. The effectiveness of the coir mat reinforced soil isolation method is demonstrated with parametric studies by conducting the transient analysis of three-dimensional finite element models of the SSI system in ANSYS. The following are the conclusions arrived from the study:

Figure 6. a) Bending moment and b) shear force in the outer column of the ground floor in the G+2 and G+3 building.
• The coir mat provision in isolated soil-structure system could reduce the maximum acceleration and deflection at the roof of building by an average of 35% and 36% respectively as compared to the conventional system.
• The maximum attenuation in acceleration at the roof of buildings is observed for the G+2 building than the G+3 building.
• The base shear in buildings with the fixed base assumption is lesser as compared to a flexible base building (incorporating SSI). It is therefore mandatory to consider the influence of soil-structure interaction on the buildings to obtain more accurate building responses.
• Coir mat reinforced soil base causes 30% and 45% reduction of base shear in G+2 and G+3 buildings respectively as compared to conventional soil base.
• The maximum attenuation in the bending moment and shear force is observed for the G+3 building than the G+2 building. By the inclusion of coir mat in soil, 29.5% and 45% reduction of bending moment, as well as 30% and 44.5% reduction of shear force, are observed in G+2 and G+3 buildings respectively compared to the unreinforced soil base.
• Seismic isolation with coir mat is proposed as a simple and alternative technique to reduce earthquake severity on buildings than the available traditional geotechnical isolation methods.

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