# Use of Rubber and Soil Mixture as a Base Isolation Technique for Developing Countries : A Review

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**Abstract**

**Seismic Isolation technique has been in a developing phase for more than a century. For developing countries like Nepal, this technique ought to be viewed on the basis of its significance in terms of reducing Earthquake vibrations, while contiguously taking cost-effectiveness as an indispensable factor. To account for this, Rubber Soil Mixture (RSM) has been proposed as a suitable isolation mechanism. Furthermore, using rubber in this technique helps in significantly reducing the environmental effect caused by stockpiling of waste tire scraps. Addition of rubber on soil to form RSM mixture in the foundation layer shows that the mixture influences geotechnical properties of the soil, thereby, reducing the effect of ground excitation to the superstructure. Moreover, the structural responses in terms of base shear, base moment, inter-story drift, and acceleration gets reduced ensuring safety of the structure.**

**Keywords: Geotechnical property, rubber-soil mixture (RSM), seismic isolation, structural response, waste scrap tires**

## I. INTRODUCTION

Nepal, being in a seismically active zone has encountered many large-scale earthquakes in the past and it is inevitable that it might face similar kinds of seismic hazards. So, in order to counteract the colossal loss of properties and lives, there is a need to address these problems. Considering the damages done by earthquake to structural components, seismic isolation system has been pragmatically implemented to decouple the ground motions from structural vibrations.

In the past decades, there has been extensive use of recycled rubber and rubber-sand mixtures with its special application as light fills for embankments, slopes, and retaining walls. Recent study depicts use of RSM mixture as a suitable foundation material. From the perspective of environmental safety, along with reduction in overall cost, rubber soil mixture has been proposed as a viable technique to considerably reduce the horizontal and vertical components of earthquake motions.

Hauksson and Gross [7] discussed that damage to the structure is mainly caused by the soft, near-surface ground conditions. So, RSM could not be a viable option in case of nonlinear soil. On the other hand, research done byTrifunac and Todorovska [24] considers soft soil as a natural damper, which absorbs the seismic waves and precludes the damage on the superstructure. Moreover, addition of rubber on the soil further adds to the absorption potential of soft soil. Along with this, there were concerns for environmental implications of the rubber in RSM mixture, but side by side tests done on laboratory and on the field Liu, Mead, and Stacer [12]shows that recycled shredded tires are not hazardous.

Evidently, rubber soil mixture is a cost-effective base isolation system and numerous researches have been

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done in order to evaluate the geotechnical properties of RSM, which can alter the soil and structural response.

## II. LITERATURE REVIEW

Nanda, Dutta, Khan, and Majumder[16] proposed rubber soil mixture as a suitable seismic isolation method for developing countries. They performed numerical simulations of buildings on rubber sand mixture with 75% rubber mixed in sand in ABAQUS environment and concluded that RSM mixture is effective in reducing ground acceleration by 50% on an average and the system was much effective for low rise buildings and greater depth of rubber soil layer.

Chiaro, Palermo, Granello, & Banasiak [4] investigated property of gravel and granulated tire rubber(GTR) mixtures, especially shear strength for use in seismic isolation. They conducted direct shear test with change in rubber percentage by mass from 10% to 50% which showed change in property in shear strength and volumetric response of mixtures from strain softening/dilative to strain hardening/contractive.They also pointed out that the transition from gravel matrix to binary matrix occurs at GTR 20% and binary matrix to rubber matrix occurs at GTR 35%. Finally, friction angles at failures for all mixtures being greater than $39^{o}$ showstheeffectivenessof the system for foundation applications.

Pistolas, Anastasiadis, & Pitilakis [18] presented dynamic properties of the granular rubber mixture, mainly focusing on shear modulus, as well as damping ratios for small strain range from the obtained results from cyclic tri-axial test and resonant column test. Cyclic tri-axial tests were done when rubber content was greater than 40% and confining pressure was greater than 25 MPa where deformability of materials makes resonant column testing non-feasible. They obtained the result that small-strain shear modulus decreased with increase in rubber mixture and also, the modulus gets more affected in the case with mean grain size, $D_{50r}/D_{50s}$ less than 1 for rubber inclusion. With addition of rubber as well as decrease in confining pressure, there was increase in damping ratio for low shear strain.

Pistolas, Anastasiadis, and Pitilakis [19] analyzed dynamic properties, especially G- γ-D curves for wider strain range from $10^{-4}$ to $5*10^{-2}$ for Resonant Column and $10^{-2}$ to 2% for cyclic triaxial tests. With increase in mean grain ratio,$D_{50r}/D_{50s,}$ higher rubber content is required to obtain rubber-like behavior and also, the $G/G_0–\gamma–D/D_0$ degradation curves showed more linearity with increasing rubber content in the mixture. Mixtures which went under low shear strain($\gamma < 10^{-2}$ %)were seen to have higher damping ratio, but further increase in shear strain shows lower damping ratio until inversion occurs approximately at $\gamma > 0.5\%$.

Tsang, Sheikh, and Lam [25] proposed RSM for developing countries as a suitable isolation method particularly and performed a series of numerical simulations on QUAD4M finite element modelling software to evaluate effectiveness of the proposed method. They found out that not only shaking along horizontal direction gets reduced by 60-70%, but vertical shaking also gets reduced by 80-90%. They also proved their point on effectiveness of RSM by counter-acting the criticisms and issues, namely, nonlinear site response, soil resonance effects, liquefaction, ground settlement, and environmental effects.

Pitilakis, Karapetrou, and Tsagdi [20] investigated the seismic performance of moment resisting RC structure with rubber-sand mixtures(RSM) as a foundation layer. They assessed effectiveness of RSM through use of Opensees finite element platform in which thickness of RSM layer and building's height were taken as variables. The beneficial effects of the RSM are mainly in lower shear modulus and less related to the shear strain dependent damping characteristics of the mixture. The fundamental time period was observed to increase with RSM layer for all the models but for medium to high-rise buildings it was seen to have more beneficial effect with average decrease in base shear, bending moment, and inter-story drift even up to 30-40%. The stresses were observed to be more uniformly distributed under the foundation with RSM layer and also tensile stresses were limited. This was the reason for stress concentration and shear failures of the soil.

Kim and Santamarina [10] investigated the small-strain and zero-lateral strain responses of the rubber sand mixture with Dr/Ds=10 using oedometer cells with bender elements to gather datasets and numerical simulations to analyze. They observed sand skeleton to control response of the proposed mixture when volume fraction of rubber particles was less than 0.3 and rubber skeleton to prevail the response when volume ratio was greater than 0.6. Mixture with volume fraction less than 0.3 indicates increase in local small strain shear modulus resulting in earlier wave arrival.

Yadav, Hussain, Tiwari, and Garg [29] examined the load-deformation behavior of rubber fiber reinforced cemented clayey soil using split tensile strength and unconfined compressive strength with cement content

3% and 6%,and rubber content varying from 0% to 10%. Addition of rubber upto 2.5% to clayey soil showed minute improvement in compressive and tensile strength but when rubber was mixed with cemented clayey soil, there was decrease in compressive and tensile strength. However, with increment in rubber content, the toughness of cemented clayey soilincreased.

Tsiavos et al. [27] presented experimental investigation on the feasibility of rubber-sand layer for low-cost seismic isolation and also mechanical characteristics of a potential failure mechanism. Direct shear test was performed for quantification of the angle of friction of mixtures and quasi-static friction of RSM, whereas, dynamic shaking table was used to evaluate the dynamics of rigid sliding block and kinetic friction of sliding interfaces against sand rubber layer. They observed that the mixture with mean grain size ratio equal to 2 acts as an attractive engineering solution, which was found to be more effective in minimization of static friction coefficient against timber sliding interface than mixtures with other mean grain size ratio. Sliding is not activated for small intensity motions and so, the superstructure is to be designed to resist seismic forces. However, for higher intensities of 0.4 (PGA>0.4g), there was reduction in seismic response and the associated structural damages founded on the RSM layer because of the sliding in rubber-soil and timber formwork interface.

Tafti, and Emadi [23] focused on the impact of rubber content on the mechanical properties of clayey soil and found that addition of tire fibers upto 1.5% leads to improvement in tensile strength and beyond that value of 1.5%, there was decrement in the tensile strength of the mixture.

Fu, Coop, and Li [5] discussed the work by combining shredded rubbers with Completely Decomposed Granites (CDG) and more standard quartz Leighton Buzzard Sand (LBS), encompassing normal standard lines and state boundary lines so as to make detailed investigation of a critical state framework and investigating behavior of small strain. This paper experimented on two base soils CDG and LBS mixed with various compositions of rubber fibers and rubber granules using oedometer and triaxial tests. As LBS samples were stiffer than the CDG samples with a rubber content of 30%, the particle type affected stress-strain and small stress behavior. While comparing between rubber fibers (RF) and Rubber Granules (RG), rubber fibers had more reinforcing quality for the soil when added in large quantities.

Jastrzębska [9] discussed cohesion values and angle of friction for pure red clay (RC) specimens mixing with shredded rubbers of 5%, 10%, and 25% masses for pure powder (P) and Granulate (G). Moreover, the cohesion properties were also taken into consideration after considering pre-mentioned samples. Unconsolidated and undrained (UU) triaxial tests was implied on the European standard in order to avoid the impact of swelling. For this procedure, prior to shearing, the specimens were not saturated. Moreover, various forms of specimen like clay and clay rubber mixture, pure rubber powder or granulate and each of them were applied to the apparatus. While adding 5% of powder or granulate, internal friction did not change significantly, that is, 1% whereas, it increased with increase in rubber in the mixture. In fact, it was observed that internal friction was greater when rubber was added to the clay. With greater inclusion of rubber in the mixture, there less electromagnetic forces formed between the clay particles, thus, reducing value of cohesion. For Kaolinite clay and Kaolinite rubber clay-crumb rubber mixtures, UU triaxial tests had given same result for the internal angle of friction. In the analysis of shear strength results, swelling pressure was reduced in the rubber clay mixture, thus, increasing the chances for axial failure as compared to pure clay. In the mean-time, the stress was maximum at the failure for pure clay than for the rubber clay mixture.

Sellaf, Trouzine, Hamhami, and Asroun[22] conducted different tests like direct shear, loading unloading, modified proctor, CBR, and Atterberg limit analysis on soils as well as their mixtures on scrap tire rubber in different ratios (10%, 20%, 25%, and 50%) to evaluate the significance of RSM. With inclusion of scrap tires, liquid limit and plasticity index decreased and the decrease was significant for plastic soils. Also, the optimum moisture content and specific weight values decreased with increase in proportion of scrap tires. For shear strength, when the internal angle vacillates, cohesion decreases with increase in scrap tires. For increase in scrap tire numbers, the compression and recompression indexes also had been found to increase gradually. The impact of water was prominently found out to be negative for proctor soil as the CBR value for W= 3% was greater than W=5%. Thus, the pressure needed was higher for the former than the latter.

Gong et al. [6] used discrete element modeling to track microstructural quantities like contact normal orientation, coordination number, particle displacement, particle sliding, and rolling during shearing. A triaxial test using particle flow code 3D (PFC3D) was conducted for 3D discrete model to comprehend intrinsic micro mechanisms of RSM. In order to confirm the mechanical behavior, DEM simulation was used. With increase in percentages of rubber, the rubber particles formed into a participation of a chain dominated by sand-sand contacts. Thus, the behavior of RSM was dependent on sand matrix. Including rubber in the mixture certainly limited the development of strain localization band. Stable weak contact network was formed because of the presence of high frictional rubber particles as it prevents the particle from sliding. As a result, the rotational rate decreased because it resisted the particle rearrangement and microstructure rearrangement. Additionally, contact normal anisotropy decreased along the loading direction due to the addition of rubber particles.

Hazarika, Otani, and Kikuchi [8]addressed two novel Japanese experiences for tire-derived recycled products in ground improvement application and used non-destructive technique to evaluate the deformation mechanisms. From shake table tests, it was confirmed that tire chips act both as reinforcing materials or as cushion aids in reducing the dynamic load on the structure and could also reduce permanent displacement of structures during earthquake. Also, if a suitable proportion of tire chips or cushions are selected, then the mixture does not undergo liquefaction. In fact, the liquefaction decreases as a result of compression and reinforcing nature being implied on the backfill soil. From deformation behavior observed through X-Ray/ CT scanning, the shear stress obtained under direct shearing was small and increased consistently for tire chips and also, dilatancy effect was miniscule as compared to sand. While shear deformation is observed less in tire chips, compressive deformation was the foremost failure which is being depicted by drained triaxial testing. Moreover, the generated shear strain was less than the observed shear strain of sand which ultimately helps to decrease strain localization and also change in volume shifts from dilative to compressive. So, this type of behavior acts as a reinforcing agent to prevent soil liquefaction in sandy soils.

Promputthangkoon and Hyde [21] evaluated compressibility of liquefaction potential of rubber composite soils to obtain how rubber soil composites will affect the compressibility of land fill materials, limit the proportion of land fill materials through experimental study, and use susceptibility to liquefaction for seismic zones. Oedometer cell and cyclic triaxial testing system were used to achieve the significance of this research. Compressibility was same for pure sand and sand mixed with 5% tire chips. For 10% of tire chips added, compressibility increased prominently and finally, when it increased to 20%, the compressibility increases significantly and it may be intolerable. For pure sand mixture of 2.5% rubber, liquefaction occurred at 2 or 3 cycles and while increasing the rubber content greater than 2.5%, liquefaction then occurred at only 1 or 2 cycles and this phenomenon was conspicuously marked for 15% rubber content. Also for pure sand, the hysteresis curve showed sharp increase in deviator stress at constant peak strain. However, when tire chips were added, there was a more gradual response. While comparing cyclic strength curves, the gradient was steeper for sand mixed with tire chips than that for the sand. Overall, the mixtures showed no sign of increasing liquefaction strength except for the 99:1 mixture at 10 and 15 cycles. However, only one size of tire chips was tested and further study considered other factors such as size, shape, and materials properties as required.

Lele, Truong, Lee, and Lee [11] investigated the characteristics of RSM to understand small strain behavior from stress deformation through variations in size ratios and determine the constrained modulus at an intermediate strain level and small strain shear modulus, axial strain stress response at large strain level. Irrespective of their size ratio, $D_{rubber}/D_{sand}$, for rigid soft mixture, increment in volume of sand results in the increment of stiffness. However, the small and middle strain moduli did not increase linearly with an increase in sand volume. In a mixture, small particles in a rigid particle played an important role in the change of porosity despite the vertical effective stress because it controlled minimum porosity. Also, while attaining minimum porosity, the effect of sand fraction decreased with increase in vertical effective stress as the voids between sand particles were filled up with rubber tires. With increase in sand fraction with size ratio greater than or equal to 1, small strain shear modulus increased for all specimens except for size fraction 0.2 and 0, in which small strain modulus remained constant for any size ratio.

Mashiria, Vinoda, Sheikh, and Tsang [14] studied three zones *viz.,* sand, sand-rubber and rubber, and triaxial tests were conducted on sand tire chips. Zone 1 had the mixture of sand as matrix-materials, Zone 2 of sand and tire chips as skeleton of the mixture. In this zone, it was observed that dilatancy got reduced and on the other hand, shear strength began to improve. In zone 3, rubber formed the skeleton and showed similar level of sand strength although dilatancy and initial tangent modulus reduced significantly. Meanwhile, the optimum sand tire chips of 35% includes 35% tire chips by mass, and 65% of sand. This reduced significant amount of dilatancy but increased shear strength of pure sand. Also, shear strength increased when it was found that relative density and confining pressure had increased. Meanwhile, with increase in confining pressure, dilatancy was found to decrease, but it increased with the increase in initial relative density.

Tsanga, and Pitilakis [26] focused on the dynamic analysis of the GSI system for ordinary structures and the building was analyzed on a Soil Shallow FoundationStructure (SSFS) model. In the process, linear equivalent method was used for the non-linearity of subsurface materials which surrounds the foundation. The efficiency was determined through the analysis done on five story building with RSM at the foundation. Four input motions with distinctive frequency contents were applied on the structure. Base moment, inter story drift, accelerations had been reduced in the order of 50-60%. With an application of Geotechnical Seismic Isolation(GSI) system on the structure, it was found that RSM stiffness was lowered and also due to lower modulus of RSM, rocking modulus was reduced. With this type of seismic isolation, damage associated to superstructure can be minimized and thus, there will be reduction in the seismic demand. Thus, GSI system mainly aims to redistribute the seismic demand on the whole SSFS system.

Mavronicola, Komodromos, and Charmpis [15] presented the usage of a rubber soil mixture to reduce seismic loads as a seismic isolation system. They performed numerical simulations and parametric studies using finite element method through the SAP2000 software under linear elastic analysis. They incorporated the energy dissipation mechanism as rubber soil mixture damping ratio. A set of six earthquake accelerograms were used to conduct simulations and for performing the parametric analysis, different values of damping ratios and elastic modulus were used. They made the study of the structure simulated by the program on the dynamic response which showed that peak absolute top floor acceleration decreased by 25-40%. Also, the computed results indicate that the reduction of the peak absolute top floor accelerations was influenced by the increase of stiffness hardening ratio. They concluded that increase in layer thickness of lower rubber content as the intervention layer results in the maximum reduction in the peak absolute top floor acceleration. However, the study falls short of presenting the effect of utilizing such rubber soil mixtures in the building response in the vertical direction.

Abbaspour, Aflaki, & Nejad [1]studied the reuse of Waste Tire Textile Fibers (WTTF) in order to reinforce soil instead of burying or burning them. The mixture with the ratio ($\rho$) of WTTF of two types of USGS soil class (SW-SC and CL) were taken as 0.5%, 1%, 2%, 3%, and 4% by weight. Compaction test resulted in optimum moisture content to rise, maximum dry density to decrease, and greater change in clay type soil, whereas the ductility increased significantly after $\rho$= 3%and 4%. California Bearing Ratio Test in addition of WTTF upto $\rho$=2% resulted in the decrease in CBR. However, the WTTF augmentation led both solids towards perfect ductility and hardening. They conducted the microscopic study using optical microscope image in order to better identify the interaction between WTTF and soil grains where they found that a lubricant layer was responsible for the material to reduce its strength in case of mix between clay and WTTF. However, in the sand type SF mix, in absence of lubricant layer, it resulted in increase of friction and cohesion due to the attraction caused by hygroscopic water. Even though more studies are required in order to study the effect of these WTTF on other specific parameters like permeability, compressibility, etc.. This paper is able to demonstrate the efficiency of using WTTF as reinforcement to granular soils.

Vinod, Sheikh, and Mashiri [28] presented the cyclic behavior of scrap-tire chip mixtures to evaluate their liquefaction and dynamic properties. They conducted the strain controlled cyclic triaxial laboratory experiment of the scrap-tire chip mixtures, of poorly graded sand and pieces of scrap tires with nominal dimension according to ASTM D, tire chips prepared by the use of dry deposition method (Ishihara, 1996). Their study of the cyclic behavior demonstrated that the maximum shear stress decreased with the inclusion of tire chips. When the deviator stress reached zero and liquefaction potential decreased on the addition of tire chips, liquefaction was observed.Damping ratio and shear modulus both decreased with the increase in number of cycles. However, when the shear strain amplitude increased, shear modulus decreased while damping ratio increased.

Madhusudhan, Boominathan, and Banerjee [13] presented the results of experiments on sand-rubber tire shred mixtures. They conducted a series of consolidated undrained static and cyclic triaxial tests on sand and fine size tire shred rubber mixtures. They used cyclic testing to carry out various axial strains for the amplitude range of 0.1-2%, under 1Hertz of constant frequency and loading cycles of 100 to all the specimens. They found that the static strength decreased for the increase in the rubber content. Shear modulus showed inverse relation with the increase in shear strain amplitude as well as increase in rubber content. They found decreasing damping ratio for increase in rubber content but opposite for the increase in amplitude of shear strain. They concluded the mixture with 10% rubber content by weight was suitable to be used for seismic base isolation for low rise buildings. In addition, the ductile nature of the mixture was because of the introduction of rubber.

AbdelRazek, El-Sherbiny, and Lotfi [3] investigated the rubber content effect of sand-granulated rubber mixtures along with the saturation conditions and confining pressure. Also, investigation was done for different rubber sizes taking into account their mechanical properties. A poorly graded siliceous sand (coarse-to-medium) as host sand granulated rubber obtained from the stripped and shredded tires were mixed to get a sand-granulated rubber mixture [2].Incorporating Wykeham Farrance triaxial device, consolidated drained triaxial tests were performed by adopting three confining stresses 50, 100 and 200kpa. Compressibility tests were executed and recorded every day for seven days in order to investigate creep behavior of RSM. They found the advantages of the ductile behavior of RSM layers of seismic isolation under the foundation of structures. Also, for the experimented rubber tires, when rubber content increased, frictional angle, and shear strength decreased. They concluded that the increased rubber content decreased unit weight of the mixture. As the behavior of the mixture changed from brittle to ductile failure, they concluded the mixture could be effective for use as seismic isolation layers under the structure's foundation.

Abdelhaleem, El-Sherbiny, and Al-Ashaal[2] presented the effect of the usage of RSM layer within replacement soil during an earthquake on the ground surface. Parametric studies were based on 2D finite element analysis, modelling the seismic effect and site response of multilayered soil profile in QUAKE/W to evaluate the site response. Three earthquake ground motions named San Francisco, Lytel Creek, and Mammoth Lake earthquake with different frequencies content and comparable magnitude were used in the model. The analysis with RSM resulted in the increase in site natural period which caused spectral acceleration to damp at low periods amplification of spectral acceleration at higher periods in contrast to baseline case. Deeper layer of RSM resulted into more effective damping and lower response spectrum at ground surface for a wide range of periods. However, further investigation is required to confirm the obtained results through physical modeling of earthquake, incorporating the sol-structure interaction, creeps, and settlement effects. However, they concluded that RSM is more effective at the bottom to effectively damp the spectral acceleration of ground surface than a thick layer of RSM, for the same depth of excavation.

Nikitas, Bhattacharya, Hyodo, Konja, and Mitoulis [17] presented a new low-cost mitigation technique against liquefaction from a series of shake table tests. They used scrap tires as small pieces by shredding them around 2.5 mm wide and placed underneath the foundation in sandbags. Two models of identical scaled slab foundation, one with the tire chips cushion underneath and the other without the cushion were modeled on a single box single shaking table possible to simulate in all six degrees of freedoms. Cushion was made of tire chips with Redhill 110 sand in 4 layers thickness which was made saturated by pouring water from the top. The experiment clearly demonstrated that the liquefaction process was altered by the addition of tire due to the reduction in the pore pressure rising close to the surface, allowing the structure to float on top of the water surface.

## III. CONCLUSION

While reviewing all the research, effectiveness of rubber-soil mixture is conspicuously observed as a suitable form of seismic isolation in the context of developing countries. Furthermore, the environmental effect of waste rubber tire can also be addressed with its proper utilization, but to achieve the effectiveness of RSM as a foundation material, the rubber content in the mixture should be in a certain proportion.

The rubber soil mixture which is characterized by low stiffness and high damping affects the fundamental time period of the structure and thus, reduces acceleration demand. Also, increase in frictional angles of the mixture shows the effectiveness of RSM mixture as a tool for foundational application. The beneficial effects of the RSM are mainly in their lower shear modulus and are less related to the shear strain dependent damping characteristics of the mixture. Shear modulus showed inverse relation with the increase in amplitude of shear strain as well as increase in rubber content. On an average, structural response like base shear, bending moment, and inter-story drift was reduced with the addition of rubber in the foundation layer in the order of 50-60%. In the meantime, shaking along horizontal direction and vertical direction gets reduced by 60-70% and 80-90% respectively.

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