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Recent developments in utilizing waste tires to reduce seismic earth pressures and liquefaction potential

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Abstract: In recent time's great development is being made in utilizing waste materials viz. Tire wastes in ground improvement especially in earthquake mitigation. Utilizing rubber tires in earthquake mitigation is an effective way of dealing with growing waste of tires and costly earthquake protection systems. Its properties like being lightweight and durability make it a very good reinforcing material and its easily available and cheap being a waste product. In recent years' research is carried out in studying the static and dynamic properties of soil mixed with tire wastes. This review paper summarizes several research works based on the use of tire chips for seismic resistance of soil.The studies revealed that recycled tire chips are efficient in reducing the dynamic earth pressure and absorbing the earthquake vibration because of its relatively high damping ratio and low stiffness values. Liquefaction of saturated sands is one of the most important topics in geotechnical engineering. Scrap derived recycle materials (such as tire chips and tire shreds) are some kinds of reinforcing materials, which can be used to reduce the pore water pressure of soils thus reducing its liquefaction potential.

The emerging geo material leads not only to the reduction of the seismic load, but also the seismically induced permanent displacement of the structure. Due to their potential economic and environmental benefits that can enhance the structural performances during earthquakes, tire derived recycled material can be used as reinforcing materials.

Keywords: *Dynamic Earth Pressure, Dynamic Properties, Liquefaction, Shredded Tires, Tire Derived Aggregates, Recycled Material, Tire Chips*

Introduction:

Growing emphasis on cost, environmentand structural performance, has led to an increasing attention to research on alternative reinforcing materials. Scrap tire derived recycle materials (such as tire chips and tire shreds) are such alternative materials, which have applications similar to those found in other conventional geo-synthetics. Scrap tire disposal has been a critical environmental problem in many urban cities due to the huge increase in the numbers of vehicles. The number of scrap tires may further increase due to rapid economic growth in some developing countries such as China and India where the demand for vehicles has been increasing significantly. It is estimated that 13.70 million tons of tires (The United States 4.7 million tons, European Union (EU) 3.6 million tons, and the rest of the world 5.9 million tons) are removed every year. In India, the average waste tire rubber generation has been reported to be of the order of 118 million kilograms annually (Genan, 2014) [64]. The properties of scrap tire open up new possibilities in geotechnical engineering applications. Features, at first sight limiting the use, have been discovered to create new uses. Working with scrap tire as a construction material is multi-disciplinary since it covers both technical and environmental aspects. ASTM D 6270-08 defines tire chips and tire shreds as pieces of scrap tires having basic geometric dimension of 12 to 50 mm and 50 to 305 mm, respectively. It also defines granulated rubber as particulate rubber composed of mainly non-spherical particles having dimensions from smaller than 425 µm to 12 mm. Granulated rubber is also commonly known as rubber crumbs.

Some of the current uses of scrap tires include generation of tire-derived fuel (TDF), ground rubber application (new rubber products, playground and other sports surfacing and rubber-modified asphalt, etc.), and civil engineering application. Significant research efforts have been devoted in recent years to explore the use of scrap tires in civil engineering application, as reuse or re-cycling of scrap tires is the preferred option from a waste management perspective. The use of scrap tires (alone or with soils) in civil engineering application includes: soil reinforcement in road construction; ground erosion control; slope stabilization; vibration isolation; non-structural sound barrier fills; light-weight materials for backfilling of retaining structures; aggregates in leach beds of landfills; additive materials to asphalt; and low-strength but ductile concrete.

Literature Review:

Use of recycled tires for civil engineering application has been investigated mainly for reducing the stockpiles of scrap tires and using them in environmentally sustainable ways. Since the early 1990s, studies have been conducted to investigate the engineering properties of scrap tires (mainly tire chips and tire shreds) and soil mixtures to study its use in different civil engineering applications. Different tests were carried out on soil and soil-tire chips mixture to study the effect of the addition of waste rubber tire chips. Heimdahl and Druscher (1999) [30] studied the engineering properties of waste tire chips. Cecich, et al. (1996) [10] and Foose, et al. (1996) [20], investigated the feasibility of using shredded tires as a lightweight backfill material for retaining wall and in reinforcing sand. Tatlisoz et al. (1998) [55] studied the mechanical properties of soil-tire chips mixtures relevant to geosynthetic-reinforced earthworks. A comprehensive collection of papers on recent researches and applications worldwide can be found in Hazarika and Yasuhara (2007) [25] that includes the state of art reports by Edil (2007) [15], Humphrey (2007) [32] and Yasuhara (2007) [63]. Furthermore, a standard has been provided on the use of old tires for engineering works through the ASTM standards (ASTM 2008). [6]

Waste tires are used for reinforcing soft soil in road construction (Bosscher et al. 1997 [8]; Nightingale and Green 1997 [47]; Heimdahl and Druscher 1999) [30], to control ground erosion (Poh and Broms 1995) [51], for stabilizing slopes (Poh and Broms 1995 [51]; O'Shaughnessy and Garga 2000 [22], Fukutake et al. 2003) [21], as lightweight material for backfilling in retaining structures (Bosscher et al. 1997 [8];; Tatlisoz et al. 1998 [55];Lee et al. 1999 [43]; Garga and O'Shaughnessy 2000 [22]; O'Shaughnessy and Garga 2000a [48]), as aggregates in leach beds of landfills (Hall 1991; Ahmed and Lovell 1993 [3]; as an additive material to asphalt (Foose et al. 1996 [20]; Heimdahl and Druscher 1999) [30], as limiting for freezing depth (Humphrey et al. 1997), [33] as a source for creating heat (Lee et al. 1999) [43], as a fuel supplement in coal-fired boilers (Ahmed and Lovell 1992 [2]; Park et al. 1993), for vibration isolation (Eldin and Senouci 1993) [17], as cushioning foams (Bader 1992; Ahmed and Lovell 1992 [2]). Various Dynamic properties of soil are also studied by various researchers like Hardin and Black (1968) [23], Wu et. al. (1997) [60], Feng and Sutter (2000) [19], Jeremicetal.(2000) [37], Hong (2000) [31], Edincliler et al. (2004) [16], Pamukcu and Akbuluta(2006) [4,50],Kim and Santamarina (2008) [40], Lee et al. (2008; 2009; 2010) [41], Senetakis et al. (2012) [5,54], Nakahei et .al (2012) [46]Kaneko et al. (2013)[38] are among few researchers who studied various dynamic properties of soils viz. Dynamic moduli such as Young's modulus E, shear modulus G, and bulk modulus K. Poisson's ratio. Dynamic elastic constants, such as coefficient of elastic uniform compression, the coefficientof elastic uniform shear, the coefficient of elastic non-uniform compression and coefficient of elastic non-uniform shear, Damping ratio, liquefaction parameters, such as cyclic stress ratio, cyclic deformation and pore pressure response. The studies concluded that addition of tire wastes as reinforcement greatly improves various dynamic properties of soil. Reinforced Sand tire mixture can be used as a backfill in earth retaining structures to improve seismic resistance and also to reduce liquefaction potential of soils. Comprehensive literature review for the two properties viz. Dynamic earth pressure and liquefaction are discussed in following sections.

1 Dynamic Earth Pressure:

In the seismic zones, the retaining walls are subjected to dynamic earth pressure, the magnitude of which is more than the static earth pressure due to ground motion. Since a dynamic load is repetitive in nature, there is a need to determine the displacement of the wall due to earthquakes and their damage potential. This becomes essential if the frequency of the dynamic load is likely to be close to the natural frequency of the wall-backfill-foundation-base soil system. This essentially consists in writing down the equation of motion of the system under free and forced vibrations. This requires the information on the distribution of backfill soil mass and base soil mass participating in vibrations. Duncan and Seed (1986) [12] and Duncan et al. (1992) [13], studied the effects of wall movement to the earth pressure on the retaining wall. If the wall moves out from the backfill, the earth pressure reduces. On the other hand, if the wall moves into the backfill, the earth pressure increases. When a cushion material, i.e. recycled tire chips, which has low stiffness compared to the backfill soils, is installed between the culvert wall and backfill, the dynamic earth pressure due to the vibratory roller can be reduced similarly. That is, the force generated by the dynamic loading is first transferred to the cushion. The cushion is then deformed due to the force resulting in the reduction of earth pressure acting on the concrete culvert without wall movement. Tweedie et al. (1998) [58] conducted experiments on 4.88m retaining walls using tire-derived aggregates (TDA) and sand respectively and found that the lateral pressure of TDA is 35% less than that of the sand. Humphrey et al. (1998) [34] investigated the bridge abutments using TDA backfills and reported a 50% reduction of lateral pressure. Jeremic et al. (2000; 2004)[36,37] showed the possible reduction of dynamic loads on abutments walls or abutment walls and supporting pile group system. This benefit can be achieved if tire shreds are placed appropriately, in horizontal layers of appropriate thickness and with the appropriate placement of those layers. The placement of layers of tire shreds can significantly influence the dynamic behavior of the bridge abutment and consequently the forces in the wall. The numerical analysis and field experiments carried out by Lee and Roh (2007) [53]to study the effects of the cushion materials on the stress variation with soil depth in the backfill areas also showed that recycled tire chips as cushion material between the culvert wall and backfill soil, with low elastic modulus, lower stiffness and high damping ratio can effectively reduce the dynamic earth pressure induced by the compaction loading because of the effects of wall movement as well as improve the characteristics of compacted soils. According to the numerical analysis results, the peak horizontal earth pressures induced by the dynamic compaction were developed at a depth of 0.7 m below from the ground surface regardless of the fill heights. The peak horizontal earth pressures decreased as the fill height increased. However, when a cushion material was applied to the culvert wall, the peak horizontal earth pressure was not significantly changed with fill height. The tire board was able to reduce the dynamic earth pressure up to 70%. Likewise, Lee and Roh (2007) [53] examined the use of recycled tire chips and expanded polystyrene boards as methods to reduce the dynamic earth pressure exerted by compaction efforts in the backfills of concrete culverts. From the results of their numerical simulations and field tests, they concluded that due to the relatively high damping ratio and low stiffness of recycled rubber tires, recycled rubber tires are more efficient in reducing the dynamic earth pressure from compaction in comparison to expanded polystyrene. From the studies of Hazarika et al. (2007; 2008) [24,26,27,28,29], it can be observed that, as compared to conventional backfill, use of tire chips cushion yields a significant reduction of the seismic earth pressure acting on the caisson at each depth. While the caisson without any protective cushion experiences high fluctuation of the earth pressure with a predominant peak, the earth pressure on the cushion-protected caisson stabilizes soon. The reduction in the earth pressure at common peak ground acceleration was 75, 25, and 66% at the top, middle, and the bottom of the caisson, respectively. This implies that the seismic performance of the caisson improves with the use of the sandwiched cushion. This innovative cost-effective disaster mitigation technique developed using tire chips, the emerging geomaterial, leads not only to the reduction of the seismic load, but also the seismically induced permanent displacement of the structure. The technique developed also could prevent the bumpiness of the backfill after an earthquake, thus maintaining the performance of infrastructural facilities after strong earthquakes. Xu et al. (2009) [62] also proposed the use of scrap tires as a cushion around buildings in order to absorb the vibrating energy exerted during an earthquake. He conducted numerical simulations to determine the effectiveness of such uses for scrap tires. Xiao et al. (2012) [18,61] pointed out the advantages of TDA backfill over sand, that include less lateral displacement, less vertical settlement, less acceleration, apparent acceleration attenuation toward the top of the wall and less static and dynamic stresses in the TDA backfill. Abdelhaleem et. al. (2013) [1] concluded that the effect of using RSM (Rubber sand Mixture) layer is dependent on the site natural period and the frequency content of the ground motion while the effective configuration of the RSM layer is subject naturalperiodoftheintendedstructure.PlacingalayerofRSMresultedinincreasingthesitenatural period causing damping of spectral accelerations at low periods and amplification of spectral accelerations at higher periods compared to the baseline case. The deeper the RSM layer, the larger the shift in site natural period resulting in more effective damping and lower response spectrum at ground surface for a wider range of periods. Thus, the higher the natural period of the structure, the deeper the sand / rubber lay ernbeded to achieve damping. For the same excavation depth, using a thin layer of RSM at the bottom of the excavation is more effective in damping the spectral accelerations at the ground surface than using a thick layer of RSM. Meles et. al. (2015) [45] made nonlinear elastic material models for TDA (Tire derived aggregates) produced from PLTT (passenger and light truck tire) and OTR (off-the-road) based on previous large-scale, one-dimensional compression tests for TDA up to 300 mm in size. Based on the results from the FE analysis and data measured in the field during construction of the full-scale field experiment, the following conclusions can be made:

- Compressibility is the governing parameter in the design of structural fill using TDA. The compressibility of TDA can be determined from large-scale, one-dimensional laboratory compression tests performed on compacted samples.
- The incremental tangent constrained modulus for TDA derived from the large-scale, one-dimensional compression test increases as vertical stress increases. The functional relation can be represented by a second-degree polynomial function.
- The computed settlements of an embankment using the FE (Finite Element) analysis agree reasonably well with field measurements. Thus, the material model proposed for PLTT and OTR in this study can be used to calculate deformation in geotechnical TDA applications, such as highway embankment fill material and backfill behind retaining walls.

Takano et. al. (2015) [11] conducted series of direct shear tests for not only tire chips but also sand. X-ray CT scanning was conducted to investigate the material behavior in the shear box. Based on the results it was concluded that shear stress of the tire chips and mixed sand with tire chips under direct shearing are small and increased monotonically compared with that of sand. There is no peak stress observed for the samples containing tire chips. There is a less dilatancy effect with the tire chips and mixed sand with tire chips compared to sand so that it may be effective for the use of backfill materials. The tire chips can reduce the propagation of shear strain which could be considered to be local shear bands so that tire chip could have a potential property for reducing soil failure. The particle with high contact force develops along the shearing from top right to bottom left this tendency has decreased as the tire chip mixing rate increases.

2 Liquefaction:

Liquefaction is a state primarily in saturated cohesion less soil wherein the effective shear strength is reduced to negligible value for all engineering purpose due to pore pressure caused by vibrations during an earthquake when they approach the total confining pressure. In this condition, the soil tends to behave like a fluid mass. Saturated loose sands, silty sands, non-plastic silts, marine clays, other sensitive clays and some gravel are susceptible to liquefaction in an earthquake. The two most important factors accounting for the occurrence of liquefaction include

- The cohesiveness and density of the soil deposit
- The level of shaking.

Liquefaction of sand may develop at any zone of a deposit, where the necessary combination of in-situ density, surcharge conditions and vibration characteristics occur. Such a zone may be at the surface or at some depth below the ground surface, depending only on the state of sand and the induced motion. An important feature of the phenomenon of liquefaction is the fact that, its onset in one zone of deposit may lead to liquefaction of other zones, which would have remained stable otherwise. Many failures of earth structures, slopes and foundations on saturated sands have been attributed in the literature to liquefaction of the sands.

Edil and Bosscher (1994) [14] showed that the density of a rubber sand mixture can be reduced from 17.4 kN/m^3 (of pure sand) to 9.5 kN/m^3 as rubber content varies from 0-75%, this may lead to a decrease in the shear strength and potentially enhance the possibility of liquefaction occurrence. However, there is evidence to show that the shear strength of loose sand becomes greater than that of dense sand with an addition of more than 10% tire chips (Edil and Bosscher, 1994) [9,14]. The use of waste tire shreds as backfill material to increase the permeability that resists under compaction and high gravity loads in a soil mass could result in a decrease of directional strength (Heimdahl, 1999) [30]. Various studies of the engineering properties of rubber soil mixtures have also demonstrated a significant increase in the cohesion intercept (commonly referred to as the c–value) (Masadet al., 1996) [44]. Moreover, rubber normally has higher frictional angles (commonly referred to as the phi value) than normal soils (Edil and Bosscher, 1994) [14] and the cohesion value increases with the percentage of shred content in the mix (Fooseet al., 1996 [20]). Liquefaction mitigation by mixing tire chips with sand has beena topic of interest in recent years. By making use of the granular and highly permeable nature of tire chips, was used as vertical drains, as an agent for reducing liquefaction-induced deformation (Yashara et al. 2004). Sand and tirechips were mixed at various ratios by volume and performed undrained cyclicand monotonic triaxial shear tests (Hyodo et al. 2007 [35,39]; Okamoto et al. 2008) [49]. Based on the results, the effect of tire chips in controlling the generation of the excess pore-water pressure induced by cyclic and monotonic shearing was confirmed, with the effect being more remarkable as the tire chips content in the mixture was increased.

Preliminary studies by Promputthangkoon and Hyde (2007) [52] have shown that the addition of small quantity of tire chips reduces the cyclic shear strength of rubber soil mixtures. In addition, randomly mixing tire chips can reinforce sand, resulting in greater shear strength than that of pure sand at its densest state. That implies densification can reduce the void ratio and thus increase the density in order to minimize liquefaction. The tire board may be able to reduce the ground water table in the backfill area because of its high permeability coefficient (Lee et al. 2006) [42]. The results of the test series conducted by Hyodoet. al. (2007) [35, 39] have confirmed that excess pore water pressure does not generate inside tire chips, and hence, liquefaction does not occur. Therefore, such material has enormous potential in mitigating liquefaction when used them as drainage materials.

Hazarika et al. (2006; 2007; 2008) [24,25,27,28,29] have also confirmed that the highly granular tire chips layer prevents any development of excess pore water pressure, except for the little increase in the form of dynamic water pressure. The unprotected caisson backfill shows a significant development of the excess pore-water pressure twice that of the cushion protected caisson, and thus may experience liquefaction-induced failure. The cushion protected caisson backfill, on the other hand, does not experience an appreciable increase of the pore water pressure, and thus is not likely to undergo liquefaction. In the case of backfill improved by the technique, the built up pore water pressure dissipates within a very short interval (2.5 seconds), preventing any chance for the backfill to liquefy. Granular and highly permeable tire chips give the pore water pressure a chance to dissipate and consequently, there is a less chance of the increase of pore water pressure near the caisson. TheCompressibility of the tire chips also plays its role here. The presence of highly compressible tire chips cushion can control the shear yielding of the sand particles, and thus increasing the cyclic mobility of the backfill soil. Consequently, there is less chance of increase of pore water pressure near the cushion. Beyond the influence zone, which may vary depending on the cushion thickness and the relative density of the backfill, of the tire chips cushion, there is a likelihood of liquefaction unless some protective measures against liquefaction are taken. The type of strong motion wave can have an influence on the liquefaction behavior of the backfill soils. Concerning the intensity of ground shaking, it is noted that the damping effects of rubber soil mixtures reduces the probability of liquefaction occurrence (Tsang, 2008; 2009) [56,57], by lowering both the peak and root-mean-square ground accelerations Kaneko et al. (2013) [38] investigated the seismic response characteristics of tire chips, tire chip-sand mixtures, and alternating layers of tire chips and sands using online seismic response tests. His findings showed that the presence of tire chips reduced the accumulation of excess pore water pressure in the layer, preventing the occurrence of liquefaction. In addition, when tire chips are installed as layers beneath the sand, liquefaction is not generated in the upper sandy layer because the amplitudes of the seismic waves are attenuated. Finally, the effectiveness of tire chips mixed with sand increased as the mix ratio was increased. When they were installed as pure layers, tire chips were more effective when placed at a deeper location or when the layer was thicker. Bahadori and Manafi (2013) [7] concluded that tire chips can control the pore water pressure of the mixture during earthquake and increase liquefaction resistance. Unreinforced sand showed are duction in stiffness during earthquake due to rapid buildup of excess pore water pressure and no sign of loss in stiffness was observed in reinforced sand with tire chips, maximum shear modulus of reinforced soil increased with increasing tire chips content in mixture due to decreasing excess pore water generation. Also, mean damping ratio is increased with increment of tire chips in sand tire mixture.

Conclusions drawnand suggestions for further research- It’s a consensus among researchers that due to properties of recycled tire wastes such as high damping ratio and low stiffness, they are very effective in reducing the dynamic earth pressure. The addition of tire wastes not only reduces the dynamic pressures and forces in retaining walls but also leads to effective use of waste materials which otherwise will lead to a serious environmental problem.

Due to the high permeability of tire shreds excess pore pressure built up is prevented. As liquefaction is related to built up of excess pore pressures in saturated sands, the probability of liquefaction gets reduced. Waste tire chips can be used as free draining material to act as anti-liquefaction measure, however design methodology needs to developed. Further assessment is required to study adverse effect of tire chips on stiffness. As the world today is dealing with growing problems of disposal of various types of wastes. This novel technique of using tire wastes in earthquake protection systems is both a boon to civil engineering and environmentin near future.

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