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Effect of Rubber Scrap Tire Pads on the Behavior of Partially Connected Pile Raft Foundation System Subjected to Dynamic Loading

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ABSTRACT

A partially tied piled foundation raft where both horizontal and vertical movements will be tamed. Interfacing RSTP changes are in structural dynamics and the way the forces are distributed. Nevertheless, the overall seismic behavior of this type of foundation in medium dry sand soil links to the pile raft foundation system with partial structural connection has not been studied adequately. To fill this gap we experimentally tested ten pile and group pile layouts in the laboratory in order to explore the interaction of the cushion layer with piles at different spacing. These tests concern the displacement mechanism of the raft foundation and the stressing change of the RSTP layers that occur during earthquakes. The results showed that using RSTP layers helps to minimize the variations in displacement between patterns with connected piles and those with disconnected piles when subjected to shaking loads. The pattern 1DR6cm showed a high settlement reduction ratio compared with 1DR2cm. Pattern 2C2D appeared less reduction in the vertical displacement. More significant displacements and rotating behavior anticipate lateral shaking due to reduce the number of connected piles for pattern 1C4D compare with pattern 4C1D. The pattern 3C6DHR2cm decreased the vertical displacement by 48.4% using one layer of RSTP. Using three layers of RSTP contributes to reducing the displacement by 36.4%. The number of the piles in a connection condition with the piled raft and the cushion thickness belongings on the strain deformation values.

Keywords: Partial connected pile raft, Rubber scrap tire pads (RSTP), Dry sandy soil, Shaking table loading.

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تاثير الوسائد المطاطية المعاد تدويرها كطبقة وسادة لمنظومة الركائز المتصلة جزئيا مع الأساس الحصيري المعرض للأحمال الديناميكية

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الخلاصة

تقنية أسس الركائز المتصلة جزئيا والتي تتضمن وجود طبقات من الوسائد المطاطية المعاد تدويرها هي تقنية وضعت لغرض مقاومة الازاحات الافقية والعمودية. كذلك تعمل هذه الوسائد على تحسين الأداء الديناميكي الانشائي للمنشئات وتعمل على نقل احمال عالية الى أسس الركائز اسفلها. على اية حال، التصرف الزلزالي لمنظومة أسس الركائز المتصلة جزئيا مع وجود الوسائد المطاطية المعاد تدويرها في التربة الرملية الجافة الاعتيادية لم يتم دراسته بالشكل الكافي. في هذه الدراسة. الفحوصات المختبرية تتضمن 10 فحوصات لركائز مفردة ولمجموعة من الركائز لغرض تقييم تصرف استقرارية طبقة الوسائد المطاطية تحت تأثير الهزات الأرضية مع الاخذ بنظر الاعتبار دراسة تأثير الازاحات العمودية والتغاير الذي ممكن ان يحدث في الوسائد المطاطية تحت تأثير الهزات الأرضية. تأثير عدد وتوزيع الركائز ضمن المجموعة كان له دور كبير في التقليل من تأثير الازاحات والتشوهات التي تحدث خلال الهزات الأرضية. حيث تم ملاحظة ان النمط 1DR6cm اظهر مقاومة عالية للازاحات العمودية مقارنة بالنمط 1DR2cm. النمط 2C2D اظهر إزاحة عمودية اقل. تم ملاحظة وجود إزاحة إضافية وتدوير لأساس الركائز للنمط 1C4D مقارنة بالنمط 4C1D كون ان عدد الركائز المتصلة كليا في منتصف الركيزة فقط مقارنة بعدد الركائز المتصلة كليا للنمط الاخر. النمط 3C6DHR2cm قلل من مقدار الازاحة العمودية بمقدار % 48.4 عند استخدام طبقة واحدة من الوسائد المطاطية المعاد تدويرها. استخدام ثلاث طبقات قلل الازاحة بمقدار % 36.4. التغاير بمقدار قيم التشوهات في الاتجاه العمودي من اتجاه الاهتزاز تتأثر بعدد الركائز المتصلة وسمك طبقة الوسادة المستخدمة.

الكلمات المفتاحية: الركائز المتصلة جزئيا، الوسائد المطاطية المعاد تدويرها، تربة رملية جافة، حمل المنضدة الاهتزازية.

1. INTRODUCTION

Several studies have exposed the seismic responses induced by the Iraqi Meteorological Organization and Seismology Report **(IMOS, 2017)** in which earthquakes are more intense than those previously recorded. Iraq country has a noticeable escalation in both severity and magnitude. For the newly constructed projects, the contrivance earthquake-impervious design measures to explore alternative solutions. To get the conventual foundation design, it can mitigate the potential seismic hazards using new techniques to reduce this effect. The superstructure loads are protected through the use of a group of piles forming a piled raft, which is a composite foundation consisting of three components: the raft, piles, and soil. Unlike conventional foundations, where either a raft or pile group assumes the responsibility of carrying and ensuring a specific safety factor, the design philosophy of piled rafts differs significantly **(Poulos, 1994)**.

A suitable type of foundation can transfer the superstructure loads to the deep depths when the soil strength is not in sufficient condition to resist the applied loads **(Poulos, 1994; Poorooshasb et al., 1996).**

The primary objective of a piled raft design is to minimize settlement to an acceptable level. This is achieved by incorporating a group of piles that efficiently transmit loads between the piles and the raft. The aim is to create an economically viable design compared to conventional pile foundations by carefully selecting the required number of piles and appropriately distributing the conducted loads between the raft and piles **(Ha et al., 2019).**

However, it is essential to acknowledge that connecting the piles structurally to the raft's head can chief to differential failure. This, in turn, may result in the formation of cracks, imposition of high stresses, and generate significant bending moments in the raft foundation. Thus, it becomes crucial to carefully assess the structural implications and adopt appropriate measures to ensure the piled raft's stability and integrity. One of the requirements that needs deep studies is the complexity of the structural connection between the piles head and the raft foundation. Many factors can affect this behavior such as the magnitude of the seismic applied load, the distribution of the loads on the pile head connection, and the nature of the pile surrounding soil **(Peiris, 2014; Hussein and Albusoda, 2021; Al-Jeznawi et al., 2022; and Khalaf and Al-hadidi, 2023).**

The investigation of the vertical forces transferred from the raft to the head of the piles necessitates a granular cushion arrangement that closely aligns with the actual boundary conditions of the piled raft foundation. So, when evaluating piled raft foundations, it is a common practice to assume a seamless and uninterrupted interface between the raft and the fundamental soil, as illustrated in **Fig. 1**. Additionally, the connection linking the raft and the piles is typically conceptualized as a sliding ball joint. It is worth noting that the presence of a limited number of piles within a pile raft system can potentially lead to noteworthy outcomes such as bending moments, cracks, and concentrated axial stresses at the pile tips. An alternative scenario emerges, these effects can have an important impact.

However, in areas prone to seismic activity. In parts where the piles are linked to the raft, substantial shear forces and failure moments can arise at the pile tips due to lateral dynamic loading. Under these conditions, the potential for structural failure within the foundation develops more pronounced than the likelihood of soil-related failure **(Al-mosawe et al., 2013).** At the same time, designing the piled raft including part of the piles in connected condition and the other parts of piles in dis-connected condition could reduce the structural failure design compared with a fully connected piled raft foundation for this determination, the piled raft foundation can develop to resist the seismic loading. The name of this suggested type of piled raft foundation is a partially connected piled raft system.

When the ratio of the length to the diameter of the pile rises, the bending moment and displacement decrease. More reduction in the settlement of the pile with more length of the pile compared with more increase in the diameter of the piles. Anchoring or fixing the piles reduces the settlement. **(Ali and Rahman, 2017; Deendayal and Nigitha, 2017; Mashallah et al., 2021).** The concept of Geotechnical Seismic Isolation presented by **(Tsang, 2009; Karatzia and Mylonakis, 2017; Hernández et al., 2020; Gatto et al., 2021; Somma et al., 2022**), represents a promising seismic mitigation strategy capable of effectively tackling the aforementioned challenges and objectives. GSI embodies a novel class of seismic isolation methodologies, encompassing the dynamic interplay between the structural framework and either unaltered or engineered earth materials. Significantly, GSI's design revolves around the alteration of foundation soils, obviating the necessity for adjustments to the structural layout.

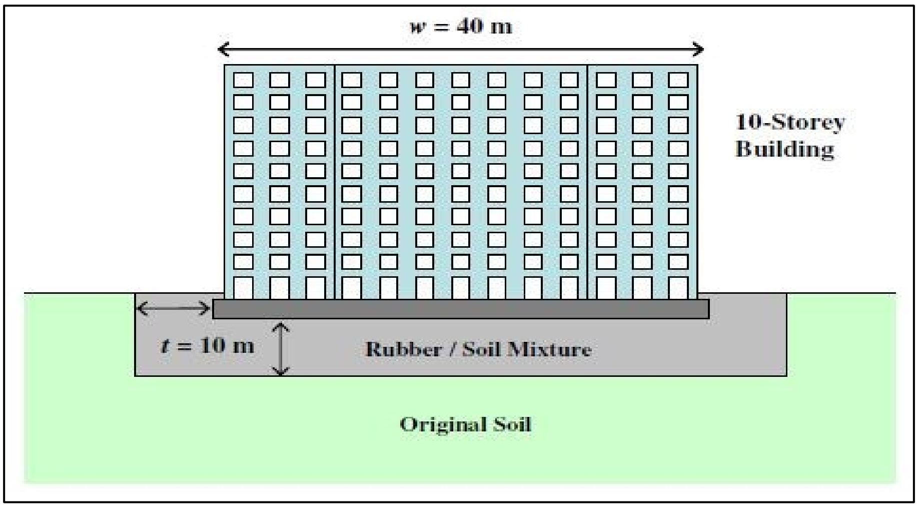

Figure 1. Schematic of the studied problem by using the rubber/soil mixture under the raft foundation of the building **(Tsang, 2008)**.

Both of **(Tsang, 2008; Tsang, 2009)** presented a method that was next level in the twist of the base of the building-soil net in dealing with the prevailing of the earthquake. This method not only lowers the vertical and horizontal ground vibrations but also deals with the global issue of rapidly growing amounts of discarded tires. A mix of numerical simulations, parametric studies, and other assessments were conducted to determine the performance and strength of the method that was hypothesized as a solution. The vertical and horizontal accelerations decreased by 90% and 70% respectively. The liquefaction effect of sandy soil, soil resonance effects, ground settlement, site response, and environmental effects were proposed in this study. Using the rubber of the recycled scrap tiles played an important role in reducing the horizontal, and vertical motions of the soil below the building foundations and the amplitude of the vibration with the frequency as shown in **Fig. 2**.

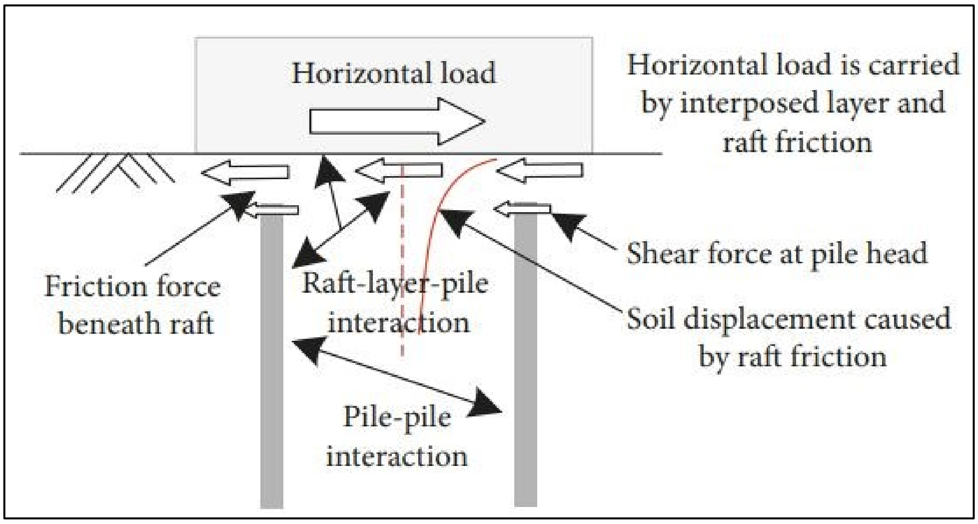

Figure 2. The horizontal forces transmitted from the raft to the head of piles **(Zhu et al., 2018).**

The benefit of using the rubber pads (Scrap Tire) offers decreasing in the elongation of the periods, filtering the high modes of the vibration to the orthogonal mode. This will reduce the effect of the transmitted waves on the structure (Turer, 2008; Turer, 2012). The manufactured pattern of the rubber pads is elastomeric bearings that resist rotational and horizontal displacement due to vibration loads. At the same time, the weak point of these pads is to lose their ability to resist the permanent shear forces **(EN 1337-3, 2005)**.
There were various applications involving the use of the pad materials above the pile heads as a cushioned layer. One such application involved the development of a novel piled raft foundation is proposed, featuring a 1-meter-thick soil cushion, designed to safeguard buildings from fault rupture.The idea of connected piled raft is to reduce the minimize the vertical settlement and distribute the loads between the raft and the piles for economic design **(Katzenbach et al., 1999; Wong et al., 2000; Al-mosawe et al., 2013; Al-Salakh and Albusoda, 2020)**. Nonetheless, significant bending moments can arise when a substantial number of piles are interconnected with the raft, potentially leading to the formation of cracks in the raft and elevated axial stress concentration at the pile heads. To report this challenge associated with interconnected piles, an alternative method has been envisaged. This approach involves employing isolated piles, provided that a cushioning layer is inserted between the raft and the piles. Consequently, the potential for structural failure in the raft foundation surpasses that attributed to soil-bearing capacity issues **(Reul and Randolph, 2003; Jebur et al., 2020; Karkush et al., 2022).**
To understand the behavior of the displacement pile supported raft type of foundations **(Ko et al., 2019)** carried out dynamic centrifugation experiments. A series of dynamic centrifuge tests was carried out at the 50g using actual earthquake records, supplied by Hachinohe and Ofunato. The centrifuge model was developed through the creation of a prototype bridge scaled for use in our experiment. For duplicating the flexural stiffness of dummy PHC (prestressed high-strength) and steel-pipe piles studs were made of aluminum and stainless steel in a (3×3) configuration. Inaccurate piled raft and DPR (disconnected piled raft) were also replicated in the model box with the same materials and details as in the pile**.**
The investigation purpose is to observe the load-bearing capacity of varied patterns of pile groups, in a single and multiple manner, to evaluate the degree of change in maximum and minimum lateral seismic displacement, and vertical displacement for piled-raft foundations in dry sandy soil. The aim of the improvement is one of the principal objectives in the provision of economical bases to the structures exposed to high lateral and longitudinal seismic loads by means of incorporating rubber pad layers. On the other hand, comparisons in the maximum pile moment of piles and between the pile heads and the raft foundation by means of acceleration along the soil section and deflection along the pad centerline are also a focus of this study.

2. EXPERIMENTAL SETUP

The experimental setup is fabricated and shown in **Fig. 3**

2.1 Testing Shaking Container and Raining System

To replicate earthquake-induced vibrations and loads within a laboratory setting, various techniques are available. Among these methods, the utilization of a shaking table stands out. A shaking table serves as a crucial piece of laboratory apparatus designed to mimic the dynamic loading experienced during seismic events, accurately reproducing their effects **(Hanash et al., 2020; Hussein et al., 2021; Alzabeebee and Keawsawasvong, 2023).**

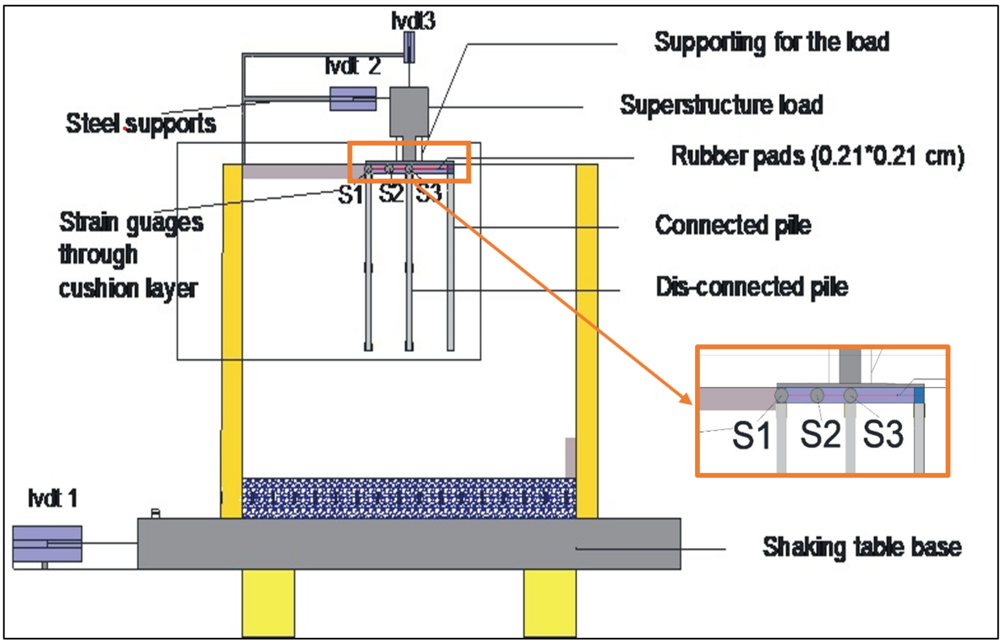

Figure 3. Schematic diagram of the experimental model.

The shaking table is one of the easiest techniques and inexpensive loading types. The type of waves can be periodic, random, sinusoidal, etc. The shaking table was designed and manufactured with the following specifications:

- The dimensions of the shaking plate were 1x1 m and 1 ton loading capacity manufactured from a high-quality steel plate of thickness 10 mm.
- The steel frame which supported by a steel real with 4 rollers moving in one direction smoothly by using ball bearing support.
- To ensure the rigidity of the steel frame, vibration or sliding of the shaking, and eliminate any motion during the controlled shaking, all the parts of the plate were fixed on steel frame C section ST52 of size 130 mm depth and 70 mm fixed on the concrete pad not less than 250 mm thickness by 8 fixed nodes.

In the present study, the method used in raining sand was by employing a steel hopper 450 mm high with bottom-adjusted manual valves to control the sand raining on the sample. A funnel, which is attached to the hopper through the plastic connecting piece, is a device that ensures that sand gets evenly distributed, as shown in **Figs. 4 and 5**. The sieve with a 4.75 mm opening size was placed at the piping side of the hopper. The hopper was hung by a pulley-powered system that regulated the downpour height. **Fig. 4** is the graph that keeps naming the dry densities and shows where the vertical displacement is at given particular values.

2.2 Shaking Loading Base

The available frequency range, spanning from 0 to 20 Hz, had a significant impact on the type and behavior of motion. In addition to the AC drive system mentioned above, our setup included time governors and protective devices (as depicted in **Fig. 6**), enabling us to select shaking durations while ensuring that safety measures were in place for any emergencies. **Fig. 7** provides a detailed explanation of the physical components of the shaking table model.

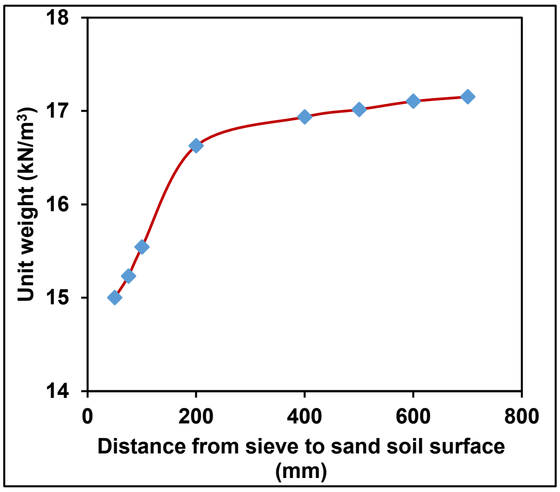

Figure 4. The relationship between the height of falling and the dry density of sand.

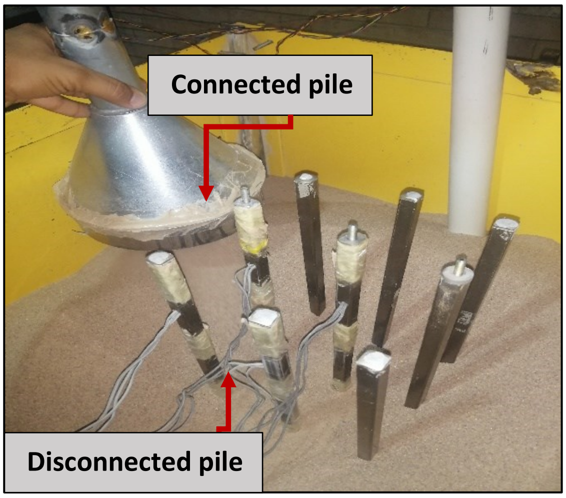

Figure 5. Curtain miner raining hopper.

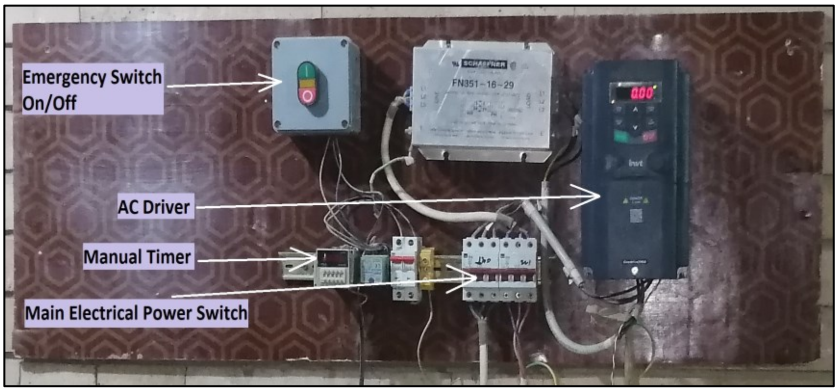

Figure 6. The electrical board details of the model.

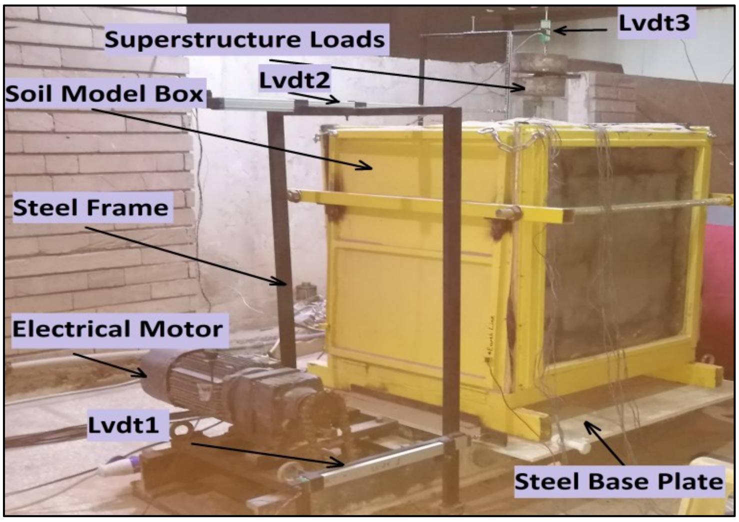

Figure 7. Shaking table and soil box with complete setup.

2.3 Soil, Connected and Disconnected Piles and Piled Raft

In the present study, the bed soil utilized in the model was dry sand sourced from Al-Najaf City, Iraq. The test results, along with standard specifications, are summarized in **Table 1**. Analysis of the grain size distribution revealed that the sand primarily comprises fine grains. According to the Unified Soil Classification System (USCS), this sand is categorized as poorly graded

Table 1. Laboratory tests for model and cushion sand soil.

Property		Value (Cushion soil)	Value (Model soil)
Internal friction angle (Ø) (Direct shear test), **(ASTM D3080, 2011)**		35.4	29
Max dry unit weight (kN/m^3), **(ASTM D4253, 2017)**		18.65	17.20
Min Dry unit weight (kN/m^3), **(ASTM D4254, 2017)**		14.45	13.89
Dry unit weight (kN/m^3) (at Dr =50%)		16.28	15.36
D_{60}	(mm) **(ASTM D422, 2019)**	1.18	0.5
D_{30}		0.44	0.65
D_{10}		0.13	0.76
Coefficient of uniformity (Cu)		9.07	1.52
Coefficient of curvature (Cc)		1.26	1.11
Specific gravity GS, **(ASTM D854, 2014)**		2.68	2.64

while the soil in the cushion layer is categorized as well-graded sand soil (SW). The pile model employed in this study is constructed using Aluminum alloy, featuring a hollow square cross-section with outside dimensions of 14 mm and a wall thickness of 1.5 mm. To simulate the disconnected pile, an embedded pile length of 350 mm was utilized, while for the connected pile, the embedded pile length was 370 mm. In the case of connected piled raft model tests, each pile was fixed with the raft using a 10 mm diameter bolt, 30 mm in length, fastened with a nut at the top head of the pile. Additionally, the piles' ends were sealed with square aluminium pieces, measuring 14 mm on each side and having a thickness of 2 mm. As for the raft, it was fashioned from a square steel plate with side dimensions of 210×210 mm and a thickness of 10 mm. The material properties of soil, raft, and piles, including the Poisson's ratio and modulus of elasticity, are presented in **Table 2.**

Table 2. Mechanical assets for soil, pile, and raft foundation.

Property Name	Soil	Pile	Raft
Poisson's, v	0.31	0.28	0.31
Elasticity Modulus, E (MPa)	21.3	4.8x10^4	2.3x10^5

2.4 Rubber Scrap Tire Pads (RSTP)

This research focuses on the development of Rubber Scrap Tire Pads (RSTP) as cost-effective seismic base isolation pads. The study involves experimental investigations using discarded automobile tire pads (STP) to create the RSTP specimens.

The mechanical and dynamic properties of these specimens, manufactured from various crushed tires, are evaluated through a series of experiments. Axial compression tests and large displacement static shear tests, including free vibration beam tests, are conducted to analyze the performance of RSTP in different scenarios. **Table 3** clarifies the physical and mechanical properties of the main material for the RSTP. The overall benefits associated with employing (RSTP) encompass several aspects, including the use of cost-effective, low-tech padding, reduction in weight, convenient handling, the ability to shear stiffness by adjusting the layer count, and environmentally positive outcomes due to the recycling of discarded tires.

Table 3. The properties of the RSTP

Item Name	Standard and the accepted range	Value
Sp Gravity (g/cm^3)	**(ASTM D297, 2018)**	0.98
Heating loss %	**(ASTM D1509, 2016)**	0.95
Sieve analysis %	**(ASTM D5603, 2019)**	Passing sieve No.6 by 90%
Fiber content %		0.43
Steel content %		0.087

The main role of using the RSTP as a cushion layer between the top of the piles and the below surface of the raft foundation is to resist the vertical loads that are transferred from the buildings. Two recognized items for the RSTP, are the ability to resist vertical heavy loads and low horizontal stiffness. This will prevent vertical rocking displacement. The raft and structure horizontal displacement can be reduced by making some of the piles in a connected condition while another number of piles in a disconnected case. The thickness of the RTSP is selected depending on the specification standard **(BS EN, 1337-3, 2005)** for the compression test. **Fig. 8.** shows the diagram details of the compression test to calculate the compression modulus using the following equation:

$$E_c = \frac{d\sigma}{d\varepsilon} \tag{1}$$

The compression modulus is calculated depending on two strain values 0.1 and 0.15 to get the Ec. Also, it can be observed by visual examination like surface defects and irregular bulges. **Fig. 9 and Table 4** display the compression test results for the RSTP.

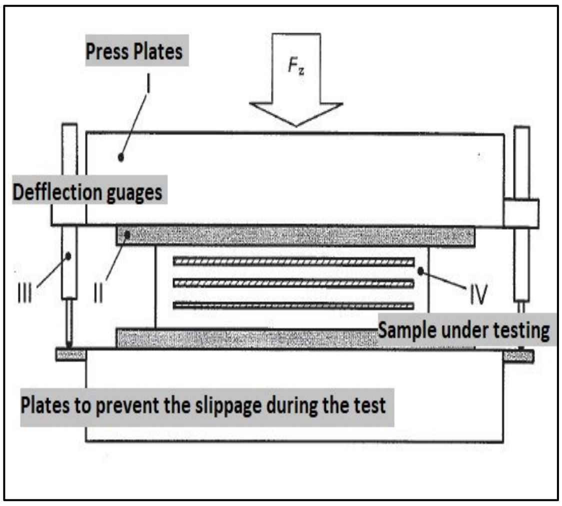

Figure 8. Schematic diagram of the compression test device

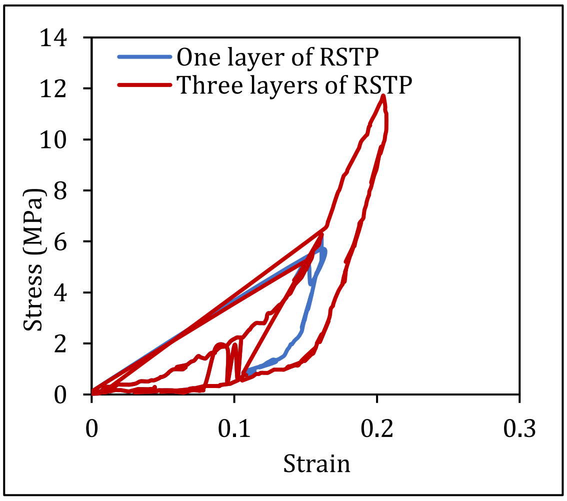

Figure 9. Results of the compression test for one and three layers of RSTP

Table 4. Compression test results for RSTP1 and RSTP3.

Type	Dimensions of the RSTP	No. of layers	Strength (MPa)			
			Strain	0.1	0.15	0.2
RSTP1	210 x 210 x 20 (mm)	1	2.23		4.91	-----
RSTP3	210 x 210 x 60 (mm)	3	-----		5.2	11.32

3. SAND BED PREPARATION AND TESTING PROCEDURE

A method of applied in the tube sample is the single hose raining technique. Raining box with control systems for adjustment of the quantity and angle of sand flowing horizontally or vertically is the part of the equipment. The aluminum material offered in local area is what is used in constructing the sand distribution system. These sieves are equipped with hooks and chains that enables them to move up and down, thus controls the displacement movement of the height. The sand raining velocity is controlled by modifying the drop height, keeping fall velocity constant at a certain level by rising the sand raining at the same rate as the sand layer's height in the box increases. The flight pile method was adopted for emulation of the pile behaviour which was done in order to prevent damage to the strain gauge which was set on the outer side of the pile shaft. After that, the raft base was put on piles and robotically affixed with steelhead nets. To overcome the formation of weird texture and the inclined surface of the pile model on the raft surface, steel mesh was used. The assembly of the raft model in the center of the sand pot and the loading platform coincide with each other.

The laboratory work involved the use of several sensors, as listed below:

- Nine strain gauges were positioned on the surface of the piles.
- Two LVDTs are used to measure the model horizontal displacement and the raft foundation.
- One LVDT was employed to measure the vertical settlement of the piled raft foundation.
- Five accelerometers were utilized, with three placed along the soil depth, one within the rubber pad layer, and one on the surface of the raft foundation.
- Additionally, three strain gauges were distributed on the surface of the midline of the rubber pad layer in a perpendicular direction to the shaking direction.

When the required quantity of piles is benchmarked across the various patterns of choice, these Rubber Scrap Tire Pads (RSTP) are subsequently set on the top of the piles. For the case where contiguous piles are found, the RSTP has holes that make the connected pile to provide support to the raft foundation from below. The real-life RSTP is modeled by a 3D model of which the beginning state (before installation) and the current state (after installation) are represented by **Fig. 8**. Accelerometers (Acc) were strategically placed: First acc with Acc 1 on raft foundation base, second acc on the cushion layer with Acc 2, third acc the depth of 20cm with Acc 4 and the last acc the depth of 30cm with Acc 5.

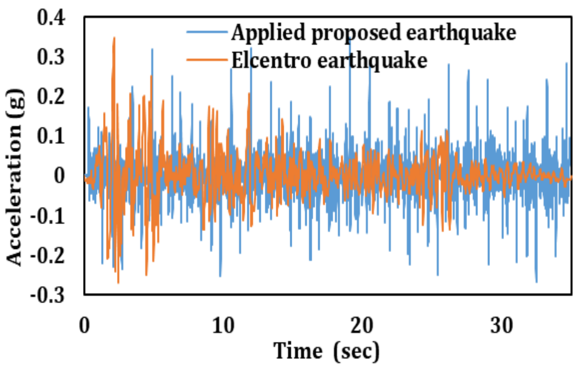

Figure 10. Comparison of the El-Centro earthquake data with the applied acceleration on the base of the model.

An earthquake acceleration history from **Fig. 10** shows that the software has been used for simulating the earthquake motion which is Lab view**. Fig.11** displays the sequences of the RSTP1 and RSTP3 installation during the shaking model test.

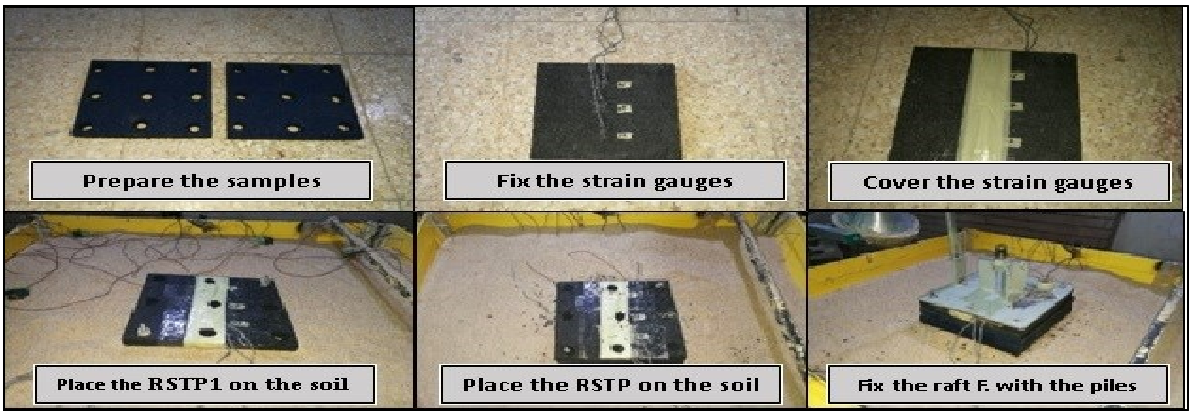

Figure 11. The sequence of the RSTP 1 and 3 installation during shaking table

3 RESULTS AND DISCUSSIONS

In this section, 10 model tests have been clarified to show the role of the rubber pad as a cushion layer. Engineering benefits from using this layer to absorb the shaking loads that transform from the raft foundation above the cushion layer in both directions (horizontal and vertical directions). Rubber pads can accommodate seismic movements. They allow for some degree of lateral displacement between the top of the piles and the surface of the raft foundation. Ground shaking due to the earthquake can cause excessive settlement and stress. The flexibility of the rubber pads can reduce these effects by vibration isolation, accommodating the horizontal and vertical displacement. **Table 5** summarizes the dry experimental details for rubber pad reinforced cushioned layer for different patterns of the pile group.

Table 5. Summary of the dry experimental test's details for RSTP1 and RSTP3 cushioned layer.

Test No.	Symbol	Details	No. of the dis-connected and connected piles	Cushion thickness	Max vertical displacement failure ratio (δrf)	Load at Static (St) (kg.)
1	1D	CR2cm	1 pile Disconnected	Cushion 2cm	0.55D	2.41
2		CR6cm		Cushion 6cm	0.50D	
3	2C2D 1st P	2C2D1stPR2cm	2 piles Connected	Cushion 2cm	0.26D	9.64
4		2C2D1stPR6cm	2 piles Disconnected	Cushion 6cm	0.37D	
5	1C4D	1C4DR2cm	1 pile Connected	Cushion 2cm	0.56D	12.05
6		1C4DR6cm	4 piles Disconnected	Cushion 6cm	0.20D	
7	3C6DH	3C6DHR2cm	3 piles Connected	Cushion 2cm	0.27D	21.69
8		3C6DHR6cm	6 piles Disconnected	Cushion 6cm	0.27D	
9	6C3DV	6C3DVR2cm	6 piles Connected	Cushion 2cm	0.21D	21.69
10	6C3DH	6C3DHR6cm	3 piles Disconnected	Cushion 6cm	0.77D	

3.1 Variation of the Vertical Displacement with the Shaking Time

Fig. 12 explains the variation of the vertical displacement time for one rubber pad reinforced and non-reinforced disconnected piled-raft.

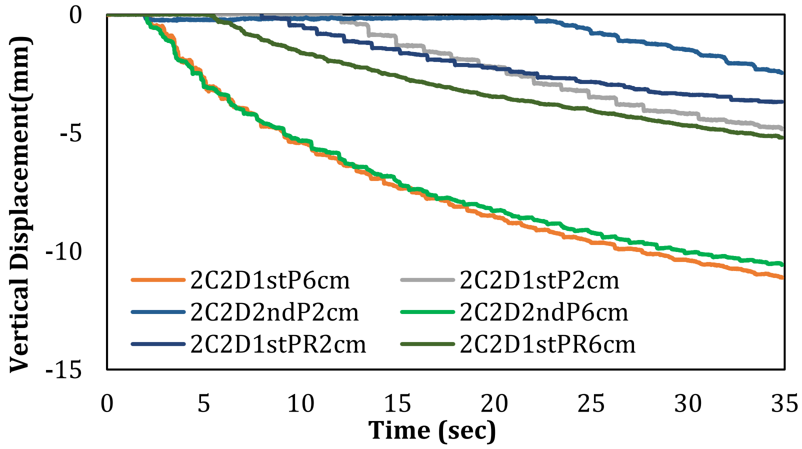

Figure 12. Variation of the vertical settlement- time in the pile-raft system for the 1D patterns (with and without RSTP
).

The results show that using the rubber pads can reduce the settlement ratios for 1DC2cm and 1DC6cm by 47.9% and 53% using 1DR2cm and 1DR6cm respectively. This is due to the engineering role of the rubber pads as (shaking isolation layer) to reduce the shaking effect of the piled raft foundation system. As it is drawn in **Fig. 13**. the pattern 2C2D appears less reduction in the vertical displacement. This is due to using two connected piles compared with two disconnected piles. In the same, using the RSTP to resist the vibration through the shaking loads. The reduction ratio increases to 23.6% for the pattern 2C2C1stPR2cm and 53.23% for the pattern 2C2C1stPR6cm.

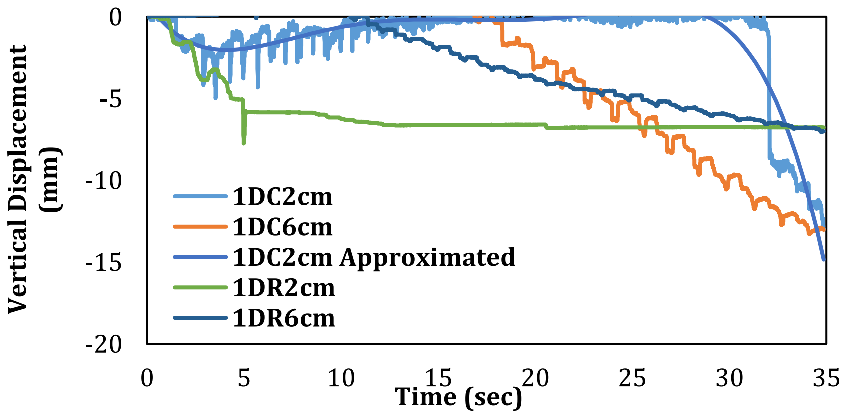

Figure 13. Variation of the vertical settlement- time in the pile-raft system for the 2C2D patterns (with and without RSTP).

Fig. 14 illustrates the vertical response of the partially disconnected piled raft system for patterns 1C4D and 4C1D throughout the earthquake. More significant displacements and rotating behaviour are observed during lateral shaking due to the reduced number of connected piles in pattern 1C4D compared to pattern 4C1D. This phenomenon is due to the increased separation provided by the rubber layer between the piles and the raft model. The results indicate that employing a rubber pad with a thickness of 2cm results in vertical displacement that is 20% less than that of the normal patterns (without rubber pads). This reduction is further enhanced for rubber pads with a thickness of 6cm, yielding a reduction ratio of 39%.

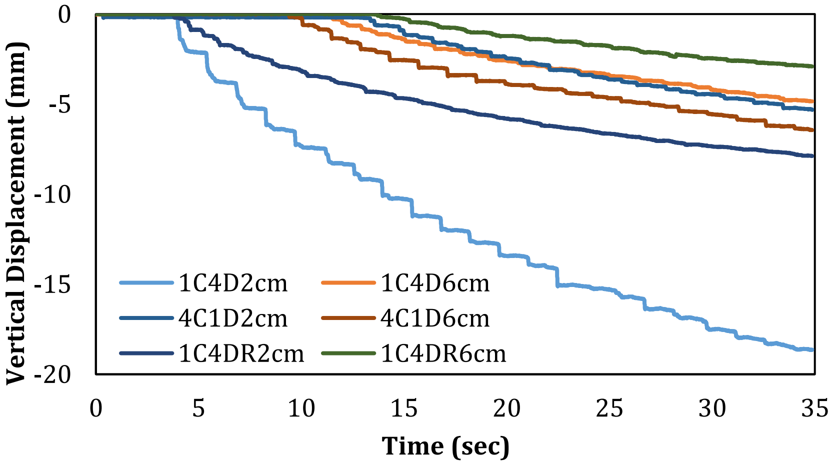

Figure 14. Variation of the vertical settlement- time in the pile-raft system for the 1C4D and 4C1D patterns (with and without RSTP).

Fig. 15 compares the patterns of using nine piles. These piles are distributed in three patterns with different cushion thicknesses. These patterns are 3C6DH, 6C3DH, and 6C3DV. The pattern 3C6DHR2cm decreased the vertical displacement by 48.4%. Using three layers of RSTP contributes to reducing the displacement by 36.4%. The separation between the RSTP layers can play a significant role in the same direction of the shaking (H).

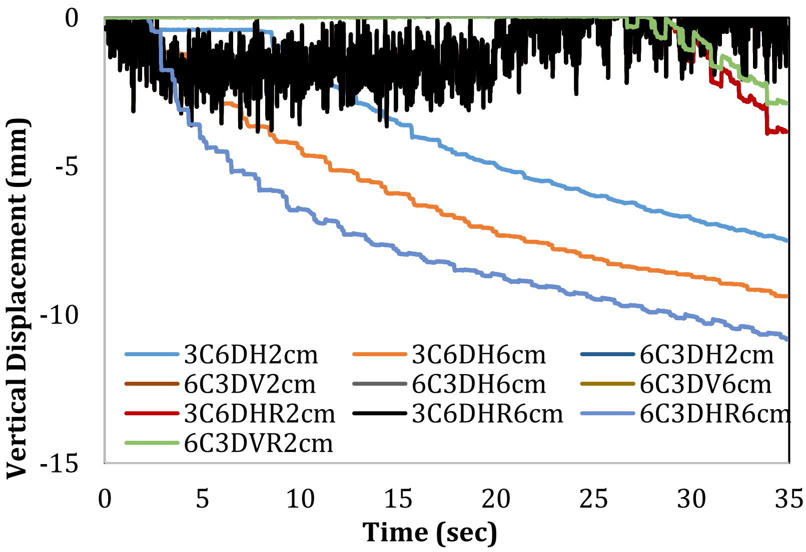

Figure 15. Variation of the vertical settlement- time in the pile-raft system for the 3C6DH, 6C3DH, and 6C3DV patterns (with and without RSTP).

The pattern 6C3DH proves the true of increasing the number of the co-nnected piles compare with the number of dis-connected piles in the same direction of the shaking effect. The reduction ratio was 14.13% using three layers of RSTP (the thickness of the cushion layer is 6cm). The pattern 6C3DVR2cm shows a high ratio of the reduction in the vertical displacement compared with the pattern 3C6DHR2cm. The ratio is 52%. This is due to the number of disconnected piles compared with the number of connected piles. **Fig.16** summarizes all the maximum values of the used patterns.

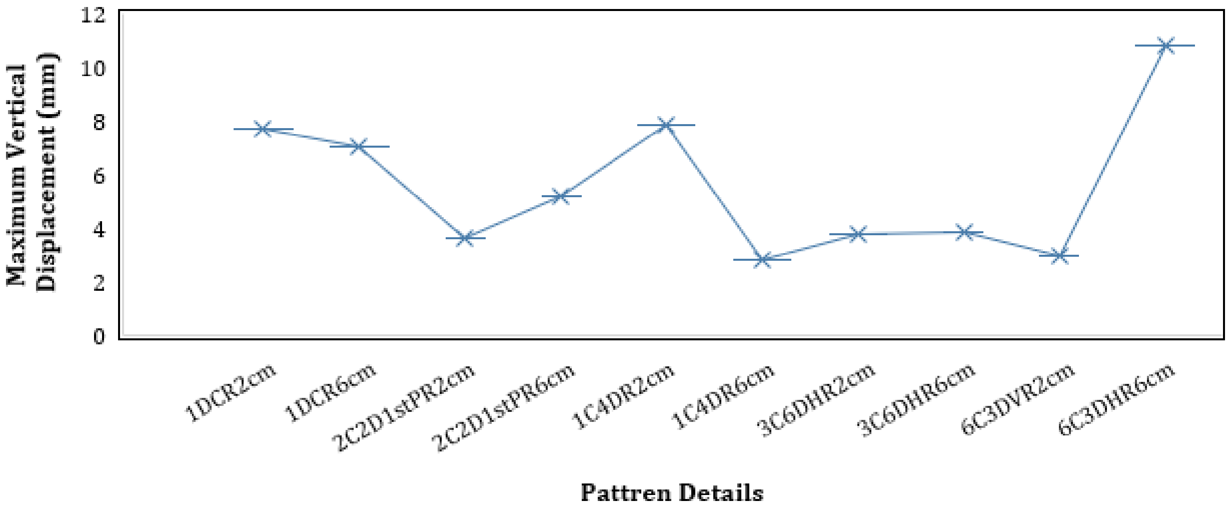

Figure 16. Variation of maximum vertical displacement for tested models (RSTP tests).

From this figure, it can be confirmed that the highest value for the vertical displacement is for the patterns 1C4DR2cm and 6C3DHR6cm. The lowest value of the vertical displacement is for the patterns 1C4DR6cm, 3C6DHR2cm, 3C6DHR6cm, and 6C3DVR2cm. Plate 6 captures the horizontal and vertical movements of the RSTP layers during the shaking loading effect, especially for the patterns with the RSTP3.

3.2 Variation of the Strain Values in the Midline of the RSTP

In this section, the variation of the strain reading with longitudinal distance through the center line of the rubber pad with the perpendicular direction of the variation is studied. The values of the strains are measured depending on three pieces of strain gauges. These strains are fixed in a perpendicular direction of the shaking direction as shown in **Fig. 17**. **Fig. 18** clarified the 1D pattern that the rubber pad of 2cm thickness shows less variation compared with that of 6cm thickness.

Using three separated rubber pad layers appears to variation with the ratio 24.8% at the edge side of the rubber pad layer. This variation is increased by the ratio of 74.05% at the mid-point of the rubber pad. This is due to the pile pattern being a dis-connected pile at the mid-point of the raft foundation.

For pattern 2C2D, by increasing the number of connected piles compared with disconnected piles, the rubber pad layer of 6cm can reduce the variation of the strain readings, using connected piles can put the rubber pad in a confining situation, as illustrated in **Fig. 19**.

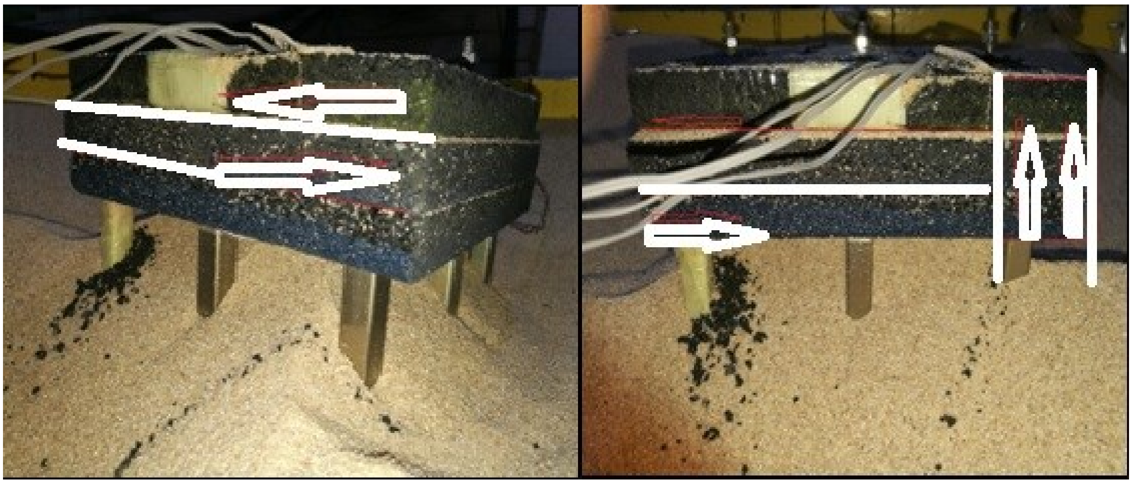

Figure 17. The deformation behavior of the rubber pads layers (thickness is 6cm) after the shaking loading effect.

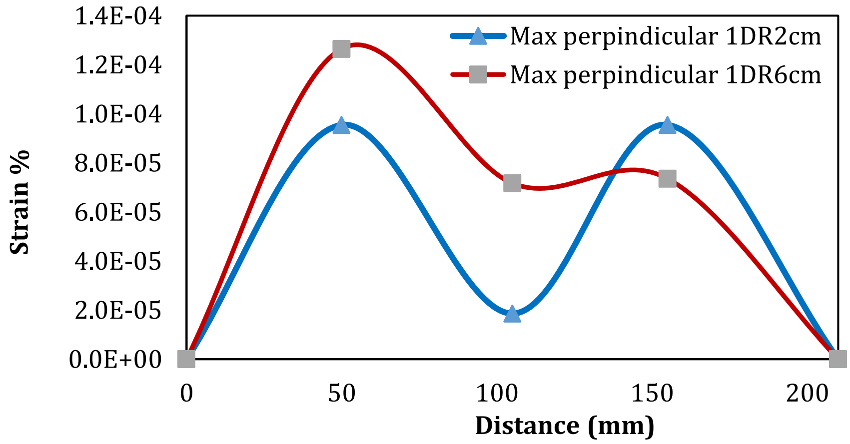

Figure 18. Strain distribution of the cross-section in the reinforced RSTP layer of the pattern 1D.

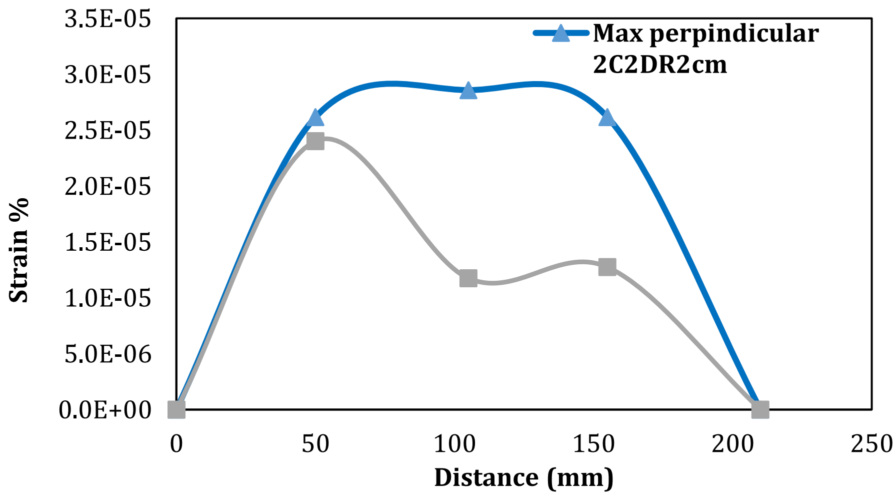

Figure 19. Strain distribution of the cross section in the reinforced RSTP layer of the pattern 2C2D.

Making the pile in the center of the piled raft foundation can reduce the variation of the stain reading. The connected pile fixes the mid part of the raft foundation by making the cushion layer a reinforced layer with connected piles. This is confirmed using the two patterns 1C4DR2cm and 1C4DR6cm as it is shown in **Fig. 20.**

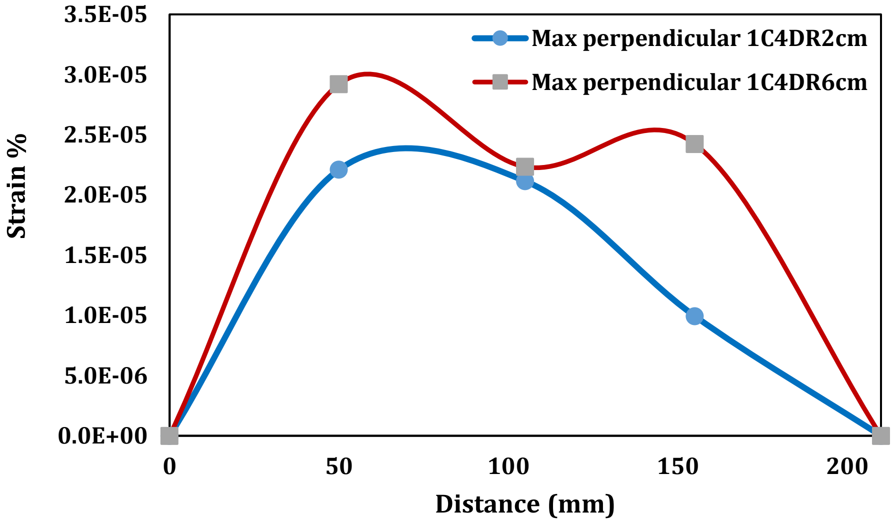

Figure 20. Strain distribution of the cross section in the reinforced RSTP layer of the pattern 1C4D.

Fig. 21 demonstrates the behavior of the strains in the midline of the RSTP of the pattern 3C6DH. Here, the variation in the midline is reduced due to using three connected piles. One of these piles is in the mid-center point of the piled raft foundation. Also, this variation is minimized due to the balance of the vibration through the shaking loading effect.

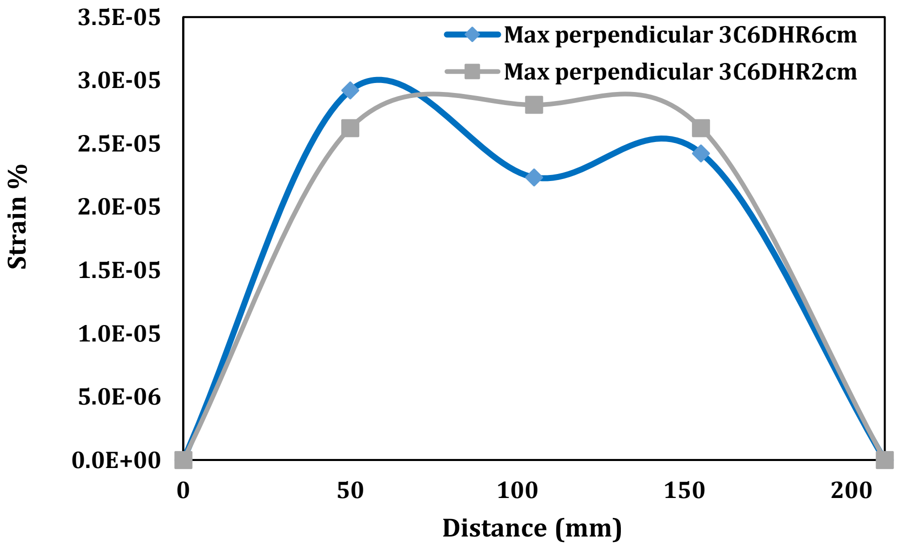

Figure 21. Strain distribution of the cross section in the reinforced RSTP layer of the pattern 3C6DH.

4. CONCLUSIONS

In this work, a partially cushioned pile raft foundation with layers of rubber scrap tire pads (RSTP) in dry sand soil was proposed for seismic protection for the foundation under superstructure loads using shaking table experimental tests. Model tests were conducted to assess the behavior as well as the stability of the cushion layer under the effects of vertical displacement and strain value variations of the RSTP in the raft foundation. Based on the discussed results, the following conclusions can be drawn:

1. Utilizing layers of Rubber Scrap Tire Pads (RSTP) decreases the vertical displacement differential in patterns featuring multiple connected piles under the influence of shaking loads. This phenomenon arises from the behavior and quantity of connected piles as opposed to dis-connected piles.
2. Pattern 1DR6cm shows a higher settlement reduction ratio compared with 1DR2cm. This is attributed to the engineering role of the rubber pads (RSTP) as a shaking isolation layer to reduce the shaking effect of the piled raft foundation system.
3. Pattern 2C2D shows less reduction in vertical displacement. This is due to using two connected piles compared with two disconnected piles. Similarly, using the RSTP to resist the vibration through the shaking loads. The reduction ratio increases to 23.6% for pattern 2C2C1stPR2cm and 53.23% for pattern 2C2C1stPR6cm.
4. More significant displacements and rotating behavior are anticipated upon lateral shaking due to the reduced number of connected piles for pattern 1C4D compared with pattern 4C1D.
5. Pattern 3C6DHR2cm decreased the vertical displacement by 48.4%. Using three layers of RSTP contributes to reducing the displacement by 36.4%.
6. Pattern 6C3DVR2cm shows a higher ratio of reduction in vertical displacement compared with pattern 3C6DHR2cm.
7. For pattern 1D, it is observed that the rubber pad (RSTP) with a thickness of 2cm shows less variation compared with a thickness of rubber of 6cm. The supporting of the edges and sides of the rubber pad (RSTP) can provide enough support against the shaking loads.
8. Pattern 2C2DR6cm proves a high reduction in the variation of the strain values compared with the 2C2DR2cm pattern.
9. Fixing the pile in the center location of the piled raft foundation, as it is formed in patterns 1C4DR2cm and 1C4DR6cm, can reduce the variation of the strain reading when other piles are found surrounding this pile.
10. The strain values in the mid-line of the RSTP of pattern 3C6DH were reduced due to using three connected piles in the same line with six supported disconnected piles.

These conclusions highlight the effectiveness and impact of various configurations and parameters on the behavior and stability of the proposed cushioned pile raft foundation system under seismic conditions.

NOMENCLATURE

Symbole	Description	Symbole	Description
RSTP	Rubber Scrap Tire Pads	E_c	Rubber pad elasticity modulus
t	time, s	Sp	Spescific of gravity (g/cm^3)
v	Poisson's ratio	D_{60}	Particle diameter equal to 60%
E	Elasticity modulus, (MPa)	D_{30}	Particle diameter equal to 30%
		D_{10}	Particle diameter equal to 10%

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Credit Authorship Contribution Statement

Karrar Ali Jawad is responsible for collecting data, executing the experimental simulation, analyzing and interpreting the writing, and reviewing and editing the manuscript. Ala Dawod Salman supervised, reviewed, and edited the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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