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ANALYSIS OF MECHANICALLY STABILIZED EARTH WALL, REINFORCED EARTH STRUCTURE

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ABSTRACT

There is an increasing interest on environmental concern all around the world. Waste management or storage of wastes takes attention of civil engineers to design environment friendly structures. Developing world increased mobility of people all around world and transportation of goods. Tires are used on vehicles which are used transportation of goods and people. When tires come to end of their life cycle, storage of them becomes huge problem. They are cut into small pieces to use in civil engineering applications such as production of asphalt concrete, concrete. Another usage area of scrap tire is a fill material in geotechnical engineering structures, such as retaining walls and embankment. In this study, tire chips are mixed with sand and clay and their mixtures at a range of 10%, 20% and 30% by weight in order to produce lightweight backfill. In order to determine strength parameters of mixed soils, direct shear tests are performed. Results of direct shear test is modelled on finite element code. Reinforced earth walls are designed using federal highway administration (FHWA) method using direct shear test results for sand, clay, sand tire crumb mixture and clay tire crumb mixture backfills. Designed walls are constructed at laboratory and tested with a loading plate. Another aspect of design of reinforced earth structures consist of effect of foundation layers, because design codes do not consider foundation layers' effect into consideration. Finite element analysis is conducted for different foundation layer properties for reinforced earth wall with different backfills. Results of this study showed that, tire crumbs can be considered as a backfill material and performance of reinforced earth wall depends on properties of foundation soils.

KEYWORDS

Sand, clay, tire crumb, reinforced earth wall, geosynthetic, foundation, direct shear test

ABSTRAKT

Na celém světě roste zájem o životní prostředí. Stavební inženýři navrhují konstrukce, které jsou šetrné k životnímu prostředí s využitím druhotného materiálu z odpadového hospodářství. Z důvodu rychlého rozvoje technologií dochází ke zvýšení přepravy zboží a mobility lidí na celém světě. Pneumatiky, které se využívají v automobilovém průmyslu se stávají na konci své životnosti velkým problémem. Při nevhodné formě likvidace mají nepříznivý dopad na přírodu a životní prostředí. V současné době jsou dnes při recyklaci pneumatiky ve stavebnictví využity v podobě pryžového granulátu, který se přidává jako příměs do asfaltových směsí. Další využití je možné definovat v oblasti lehkých zásypů geotechnických konstrukcí při výstavbě opěrných zdí a zemních násypových těles. Ve své práci se zabývám využitím pryžového granulátu, který je v kombinaci s pískem a jílem míchán v poměrech 10%, 20% a 30%, pro vytvoření lehkého zásypu. Pro stanovení nutných parametrů smykové pevnosti vytvořeného lehkého zásypu byly provedeny a vyhodnoceny krabicové smykové zkoušky a stanoveny základní fyzikálně mechanické vlastnosti testovaného materiálu. Získané výsledky přímého měření smykové pevnosti byly porovnány s modely vytvořenými metodou konečných prvků. Pro návrh zemních konstrukcí byly využity předpisy (FHWA), které definují užití pryžového granulátu se zeminou pro oblasti vyztužených zemních těles v návaznosti na parametrech smykové pevnosti zeminy. V laboratoři Výukového a výzkumného centra v dopravě (VVCD), Dopravní fakulty Jana Pernera byly testovány fyzikální modely navržených zemních těles, kde pro zatěžování a stanovení modulu přetvárnosti byla využita metoda statické zatěžovací zkoušky. Pro rozdílné hodnoty poměru vyztužení granulátu a zeminy byly výsledky získané z fyzikálních modelů analyzovány a porovnány s výsledky modelů vytvořených pomocí metody konečných prvků. Dosažené výsledky svědčí o tom, že lze pryžový granulát mísený se zeminou využít při stavbě vyztužených zemních konstrukcí v oblasti dopravního i pozemního stavitelství.

Klíčová slova

Písek, jíl, drť pneumatik, vyztužená zemní stěna, geosyntetika, zakládání, přímý smykový test

TABLE OF CONTENT

1 INTRODUCTION

Reinforcement of concrete by steel rods has been well known by civil engineers. Therefore, strengthening structures with other materials is not a new idea for civil engineers. This idea was adopted to geotechnical engineering by French engineers nearly five decades ago. Their idea was simple enough, could we strengthen the soil by using steel rods like in concrete structures. They performed some experiments and showed that the idea of reinforcing the soil could be applied in the design step of geotechnical structures. Since that time, a lot of research has been done to understand behaviour of reinforced earth structures. Reinforced earth could be used under the foundations where bearing capacity of the soil is under desired value. Another application of reinforcing soil is retaining walls. Reinforced earth walls can be used to retain railway and road embankments, bridge abutments. They are also used to retain contaminated wastes in valleys under some special conditions. Reinforced earth walls are constructed by inserting reinforcement material into backfill soil, placing facing elements (example: concrete blocks, steel facings, wooden facings), adding another backfill soil again. Construction of reinforced soil can be considered as staged construction because, first of all levelling pad is laid through foundation soil and then backfill soil must be placed, compacted, after that, reinforcement rods must be placed. This process continues until the desired height of the wall is reached. Since the day that reinforced earth walls are introduced, they are widely used in practical engineering. It is easier to construct reinforced earth wall than conventional retaining wall. Reinforced earth walls also have economical advantage than conventional retaining walls because it is cheaper to construct. Another advantage of reinforced earth wall is their aesthetic appearance. Reinforced earth walls are considered as flexible walls because they tolerate lateral and vertical deformation more than conventional retaining walls. They provide faster construction speed than traditional retaining walls.

1.1 Aim of Thesis

This thesis concerns about following topics

(i) Mixing sand and clay on different ratios to find out change in shear strength parameters under low vertical stress.

(ii) Finite elemenet modelling of conducted direct shear tests.

(iii) Adding tyre crumbs into soil mixtures to determine new shear strength parameters.

(iv) Construction of scaled reinforced earth walls at laboratory with sand and clay backfills and sand-tire crumb mixtures, clay tire crumb mixtures in order to clarify effect of tire crumb into performance of reinforced earth walls.

(v) Finite element modelling of the small scale reinforced earth walls tested at laboratory.

(vi) Finite element analysis of reinforced earth wall in order to determine the effect of foundation layers' properties into performance of reinforced earth walls.

2 BACKGROUND

Behaviour of reinforced earth wall is highly dependent on properties of reinforced backfill. Therefore, all design codes define some restrictions on properties of reinforced backfill. Therefore, effect of backfill is discussed by various articles at the literature [11, 16, 41, 27, 29, 31, 44, 58 and 64].

M. Riccio et al. [11] found that cohesion tends to increase reinforcement strains. M. Pinho-Lopes [16] et al. conducted flume tests over reinforced earth wall with fine backfill. Results are compared with traditional walls which are used at region. Traditional walls are found to be more suitable than reinforced earth wall. Guangqing Yang et al. [41] measured behaviour of 12m height reinforced earth wall with sand backfill from 0 to 6 meter and clay backfill from 6 meter to 12 meters. Highest foundation pressure is measure at the middle. Reinforcements in sand backfill showed two peaks in case of maximum strains. Huabei Liu [27] investigated short term and long term behaviour of reinforced earth wall with four different sands. It is seen that, stiffness of reinforced soil, lateral earth pressure behind the wall are affected from type of backfill. Huabei Liu et al. [29] studied long term behaviour of reinforced earth wall with marginal soil by modelling 8-meter height wall on Abaqus. They concluded that, keeping soil creep rate constant, increasing reinforcement creep yields increased wall deformation. Abdelkader Abdelouhab [31] analysed reinforced earth wall with different backfills with finite element method. It is found out that as cohesion of backfill increases, lower displacement of wall is observed. Abdolhosein Haddad and Gholamali Shafabakhsh [44] investigated possible failure reason of a failed reinforced earth wall is investigated. It is found out that, backfill used during construction has a considerable fine content. High fine content yielded low permeability and low factor of safety against pull-out capacity. D. M. Carlos and Margarida Pinho-Lopes [58] conducted external stability analysis for a reinforced earth walls with sand and sand-fine particle mixtures with two different design methods. Results provided that, in case of short term behaviour walls might have a problem regarding sliding. Robert M. Koerner and George R. Koerner [64] suggested several solutions for a reinforced earth walls with a fine backfill regarding low drainage systems.

Several studies can be found in literature which are considered effect of foundation to behaviour of mechanically stabilized earth wall [24, 26, 34, 38, 43, 48]. Jian-Feng Chen et al. [24] studied behaviour of reinforced earth wall constructed over soft soil. Foundation layers consisted of preliminary fill, silty clay, mucky silty clay, clay and silty clay. Prefabricated vertical drains are installed till silty clay layer. Researchers concluded that, construction duration should be prolonged in order to construct more stable wall. This is due to dissipation of pore water pressure. Weaker sub-soil requires extension of reinforcement layers can be stated as another outcome of this study. Dev Leshchinsky et al. [26] studied difference between theoretical and actual failure of reinforced earth wall due to bearing capacity. It is concluded that, failure mechanism is different than failure mechanism assumed by Meyerhoff's method which is used in some design codes. I. P. Damians et al. [34] modelled a reinforced earth wall with respect to different foundation stiffnesses. Foundations are modelled by changing only stiffness. It is stated that as the stiffness of foundation and reinforcement stiffness are reduced, facing deformations increase. It is also stated that, if reinforcement with lower stiffness is used over the low stiff foundation soil, higher stresses are observed over reinforcement. Graeme D. Skinner and R. Kerry Rowe [38] studied design of reinforced earth wall on a one layer yielding foundation. Researchers concluded that, horizontal and vertical deformations of wall are increased after consolidation. Jian-Feng Xue et al. [43] investigated failure of reinforced earth wall constructed on soft clay foundation. They concluded that, prefabricated vertical drains are damaged during construction and excess pore water pressures can not be dissipated properly which caused failure of wall. A. Sengupta [48] investigated reasons of failure of failed reinforced earth wall constructed over multi-layered foundation soil. Researcher found the failure reason as underestimated unit weight of backfill and overestimation of bearing capacity of foundation soil. This yielded to high amount of consolidation which caused failure.

In order to design more reliable reinforced earth walls, researchers have been looking for several methods. Reinforcing backfill is one of those methods. Some of those studies can be found in the literature [10, 15, 18, 20, 22]. Taesoon Parka and Siew Ann Tanb [10] investigated behaviour of reinforced earth wall with sandy silt and polypropylene fibers. The mixture ratio of polypropylene and soil is chosen as 0.2%. Researchers concluded that, best results are obtained by reinforcing sand with geogrid and polypropylene. Sutapa Hazra Æ Nihar Ranjan Patra [15] studied counterfort retaining wall using sand-fly ash mixture as backfill and geogrid as reinforcement. They concluded that wall with sand-fly ash mixture with geogrid as backfill produced more stable results. S. Bali Reddy and A. Muradi Krishna used recycled tyre chips mixed with sand. The wall performed better when 30% tyre chip is added to sand. Guangqing Yang et al. studied the behaviour of lime treated cohesive soil backfilled soil. Researchers concluded that, lateral earth pressure decreased with time due to increasing strenght of lime treated sand and horizontal deformation of wall face. Sompote Youwai and Dennes T. Bergado studied behaviour of reinforced earth wall with a backfill which consists of tire chips using finite difference method. Researchers concluded that, lateral movement of wall and tensile force in reinforcement increased as the ratio of chip tire increased.

It can be seen from the literature that, effect of reinforced backfill is generally evaluated using clay backfill and measuring or computing displacements. However, behaviour of reinforced wall covers more extensive range such as change of maximum forces on geotextile, horizontal displacements and settlements. In this work, different backfills are created by mixing sand and clay. Mechanical properties of backfills are determined in laboratory and used in finite element analysis in order fully evaluate behaviour of reinforced earth walls with different backfill regarding, horizontal displacements of wall face and retained soil, settlements and forces acting on reinforcements.

Another important aspect which determines behaviour of reinforced earth wall is condition of foundation beneath it. However, very little study is available on the literature for this phenomena. The related studies related to effect of foundation is generally case studies which are conducted after failure of reinforced earth wall. In order to prevent from failures, change of horizontal displacements of wall face, retained soil, settlement of wall and forces acting on reinforcement evaluated with respect to foundation conditions in this study.

There is a contradiction in the literature in case of using tyre chips to obtain light weight backfill. It is also unclear to effect of tyre crumbs which have smaller grains to behaviour of reinforced earth wall. In order to clarify its effects reinforced earth walls constructed at laboratory with various tyre crumb contents. Effect of tyre crumbs to clay backfill is also evaluated at the laboratory.

3 METHODS AND METHODOLOGY

Backfills are created by mixing sand and clay. In each mixture, clay content is increased by 10%. Grain size distribution of sand and clay is determined. Maximum dry unit weights and optimum water content are evaluated. Direct shear tests are conducted to determine shear strength parameters of mixtures. Direct shear tests are conducted under 9.81 kPa, 19.62 kPa, 40.81 kPa and 58.86 kPa. After that, direct shear tests are modelled on Abaqus. Then, tyre crumb is added to each mixture to determine effect of tyre crumbs. Tyre crumb is also added 10% of mixture and increased by 10% for increment of tyre crumbs in mixtures. Maximum dry unit weights of all mixture with tyre crumbs are also determined. Direct shear tests are also conducted for soil-tyre crumb mixtures. Then small-scale reinforced earth walls are constructed at laboratory and tested in order to study effect of tyre crumbs to performance of reinforced earth walls. Finite element analyses are conducted in order to determine effect of backfill and foundation. Tested soils' properties in laboratory are used during finite element analysis.

3.1 Experimental Setup

Standard proctor tests are conducted in order to determine maximum dry unit weight and optimum water content. Standard proctor test is chosen, because it is required during construction of reinforced earth walls construction by some codes.

Direct shear tests conducted at rate of 0.25 mm/min when sand content is above 50% of the mixture. When sand content in the mixture is below 50%, shear rate is decreased to 0.065 mm/min in order not to produce excess pore water pressure inside samples during shear test. Mixtures with tyre crumbs are also tested at same shear rates.

Small scale reinforced earth walls are constructed in Research and Educational Center (VVCD) at transport structures laboratory. Walls are constructed inside a steel frame which is placed inside the laboratory. This steel frame is given on Figure 3.1 below.

Figure 3.1. Steel Frame Used during Construction and Testing

Constructed walls tested with a loading plate which has a 300 mm diameter. Loading plate is placed 2 cm behind the wall face so that, entire load in applied to reinforced backfill. Loading is applied step by step. Initial load step is chosen as 0.06 MPa and increased 0.06 MPa at each increment. Increment is applied when settlement of loading plate is stabilized.

Deformation of wall face is measured at three different points, while settlement of loading plate is measured from load application point. Loading system can be seen from Figure 3.2 below.

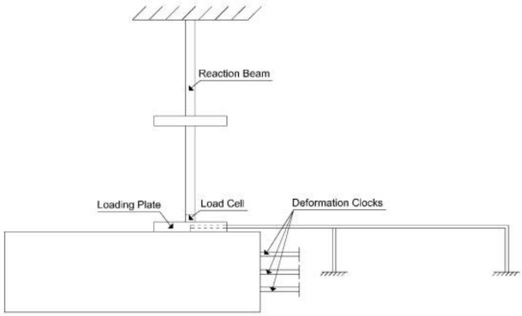


Figure 3.2. Schema of loading system

3.2 Analytical Design of Reinforced Earth Walls

Analytical design of reinforced earth wall is conducted for two different chapter of this study. In the first chapter, analytical design for laboratory. Wall height is chosen as 45 cm and length of reinforcement chosen as 0.7H to comply with minimum requirement of FHWA [70]method. In the second chapter, reinforced earth wall is designed with height of 6 meter and reinforcement length is chosen as 1H.

Analytical designs of the walls are done according to Federal Highway Administration (FHWA) design code. External analysis is conducted initially, and safety of walls are determined for overturning and sliding. After external design is completed internal design is conducted. Forces on reinforcement and pull – out capacity are determined for each reinforcement layers.

3.3 Finite Element Modelling

Abaqus and Plaxis finite element codes are used in this study. Abaqus is used to model direct shear tests. Geometry and mesh structures are given on Figure 3.3. Mohr-Coulomb material model is used during analysis. Mohr – Coulomb material model properties are given on Table 3.1 below.

Small scale walls without tyre crumb content are modelled on Plaxis. Plane-Strain modelling technique is applied. Mohr-Coulomb material model is used during analysis. Geometry and mesh structure of Plaxis model for small scale wall is given on Figure 3.4. Material parameters for small – scale wall is provided on Table 3.2 below.

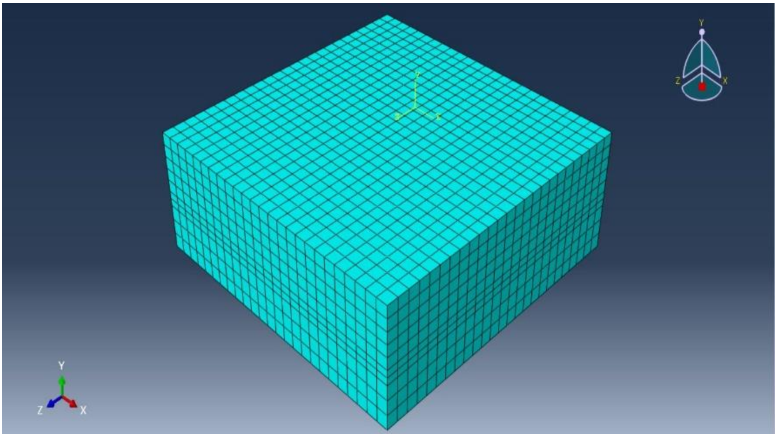


Figure 3.3. Geometry and mesh of finite element model for direct shear test

Table 3.1. Mohr – Coulomb Material Model Parameters for Finite Element Analysis for Abaqus

							9,81 kPa	**19,2 kPa**	**40,81 kPa**	**58,86 kPa**
	γ_{sat} (kN/m^3)	γ_{unsat} (kN/m^3)	**Φ (º)**	**C (kPa)**	**φ (º)**	**ν**	**G** (MPa)	**G** (MPa)	**G** (MPa)	**G** (MPa)
100% Sand	19,50	1,74	47,38	0,456	17,38	0,3	4.04	7.20	13.5	14.41
80% Sand + 20% Clay	22,31	2,07	42,35	11,61	12,35	0,3	4.74	6.58	11.88	13.22
60% Sand + 40% Clay	22,10	2,05	41,19	24,01	11,19	0,3	7.76	11.04	13.77	24.08
40% Sand + 60% Clay	22,53	2,06	38,84	25,84	8,84	0,3	10.44	12.58	11.36	18.84
20% Sand + 80% Clay	22,10	2,00	36,51	34,36	6,51	0,3	13.30	15.59	22.5	22.93
100% Clay	20,80	1,85	32,44	37,66	2,44	0,3	15.73	17.77	21.05	25.39

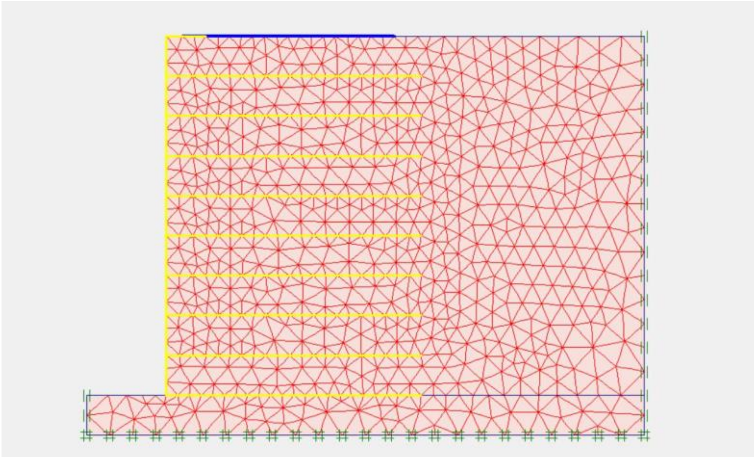
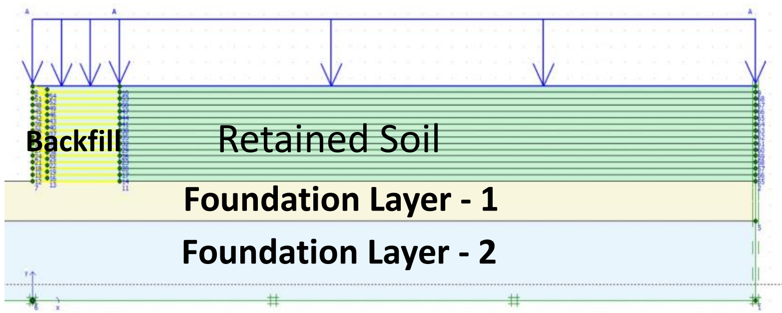


Figure 3.4. Geometry and Mesh Structure of Wall

Table 3.2 Material Parameters for Soil's Used During Analysis

Soil Type	γ (kN/m^3)	E (kPa)	ν	φ	c (kPa)	ψ
Sand	17.4	64020	0.3	47.4	1	17.4
Clay	18.5	85670	0.3	32.4	37.7	2.4

As it is told earlier, finite element analysis was conducted in order to determine effect of foundation layers. Created finite element model is given on Figure 3.5 below.



Material properties used to model reinforced backfill, retained backfill, and foundation layers are provided in Table 3.3, Table 3.4 and Table 3.5 respectively.

Table 3.3. Material Parameters of Reinforced Backfill

	Reinforced Backfill			
	φ	γ (kN/m^3)	c (kPa)	E (GPa)
100% Sand	47.4	17.4	0.5	64.02
80% Sand + 20% Clay	42.4	20.7	11.6	55.72
60% Sand + 40% Clay	41.2	20.5	24	90.22
40% Sand + 60% Clay	38.8	20.6	25.8	59.48
20% Sand + 80% Clay	36.5	20.0	34.4	85.54
Clay	32.4	18.5	37.7	85.67

Table 3.4. Material Parameters of Retained Backfill

Retained Backfill			
φ	γ (kN/m^3)	c (kPa)	E (GPa)
20	15	1	15
30	17	20	50

Foundation Soil 1					Foundation Soil 2				
φ°	γ (kN/m^3)	c (kPa)	E (GPa)	D (m)	φ°	γ (kN/m^3)	c (kPa)	E (GPa)	D (m)
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0

20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	2.5	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	5.0
20	15	1	15	5.0	20	18	35	60	2.5
20	15	1	15	5.0	20	18	35	60	2.5
20	15	1	15	5.0	20	18	35	60	2.5
20	15	1	15	5.0	20	18	35	60	2.5
20	15	1	15	5.0	20	18	35	60	2.5
20	15	1	15	5.0	20	18	35	60	2.5

35	17	20	55	2.5	20	18	35	60	5.0
35	17	20	55	2.5	20	18	35	60	5.0
35	17	20	55	2.5	20	18	35	60	5.0
35	17	20	55	2.5	20	18	35	60	5.0
35	17	20	55	2.5	20	18	35	60	5.0
35	17	20	55	2.5	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	5.0
35	17	20	55	5.0	20	18	35	60	2.5
35	17	20	55	5.0	20	18	35	60	2.5
35	17	20	55	5.0	20	18	35	60	2.5
35	17	20	55	5.0	20	18	35	60	2.5
35	17	20	55	5.0	20	18	35	60	2.5
35	17	20	55	5.0	20	18	35	60	2.5
35	17	20	55	5.0	20	16	1	15	2.5
35	17	20	55	5.0	20	16	1	15	2.5
35	17	20	55	5.0	20	16	1	15	2.5
35	17	20	55	5.0	20	16	1	15	2.5

35	17	20	55	5.0	20	16	1	15	2.5
35	17	20	55	5.0	20	16	1	15	2.5
35	17	20	55	5.0	20	16	1	15	5.0
35	17	20	55	5.0	20	16	1	15	5.0
35	17	20	55	5.0	20	16	1	15	5.0
35	17	20	55	5.0	20	16	1	15	5.0
35	17	20	55	5.0	20	16	1	15	5.0
35	17	20	55	5.0	20	16	1	15	5.0
20	15	1	15	2.5	20	16	1	15	2.5
20	15	1	15	2.5	20	16	1	15	2.5
20	15	1	15	2.5	20	16	1	15	2.5
20	15	1	15	2.5	20	16	1	15	2.5
20	15	1	15	2.5	20	16	1	15	2.5
20	15	1	15	2.5	20	16	1	15	2.5
20	15	1	15	2.5	20	16	1	15	5.0
20	15	1	15	2.5	20	16	1	15	5.0
20	15	1	15	2.5	20	16	1	15	5.0
20	15	1	15	2.5	20	16	1	15	5.0
20	15	1	15	2.5	20	16	1	15	5.0
20	15	1	15	2.5	20	16	1	15	5.0
20	15	1	15	5.0	20	16	1	15	2.5
20	15	1	15	5.0	20	16	1	15	2.5

20	15	1	15	5.0	20	16	1	15	2.5
20	15	1	15	5.0	20	16	1	15	2.5
20	15	1	15	5.0	20	16	1	15	2.5
20	15	1	15	5.0	20	16	1	15	2.5
20	15	1	15	5.0	20	16	1	15	5.0
20	15	1	15	5.0	20	16	1	15	5.0
20	15	1	15	5.0	20	16	1	15	5.0
20	15	1	15	5.0	20	16	1	15	5.0
20	15	1	15	5.0	20	16	1	15	5.0
20	15	1	15	5.0	20	16	1	15	5.0

4 RESULTS

4.1 Determination of Soil Properties

As it is told before, sand, clay and their mixtures and tyre crumbs are used in this study. The grain size distribution of sand and tyre crumbs are given on Figure 4.1.

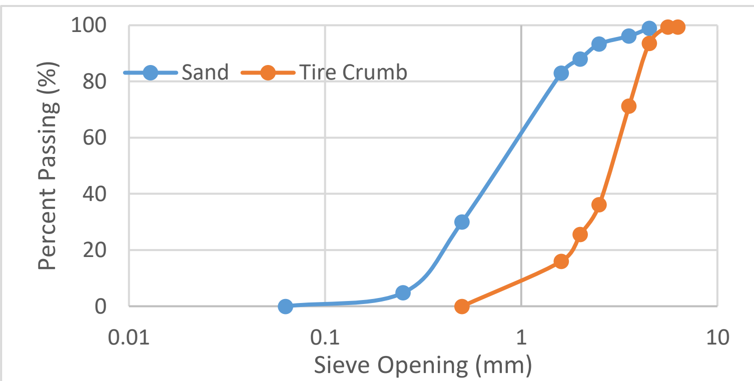


Figure 4.1. Grain Size Distribution of Sand and Tyre Crumb

Specific gravity of sand is given as 2.9. Coefficient of uniformity and coefficient of gradation is calculated as 3.3 and 0.84 respectively. Sand is classified as poorly graded (SP) sand according to unified classification system.

Hydrometer analysis results of clay is provided on Figure 4.2 below.

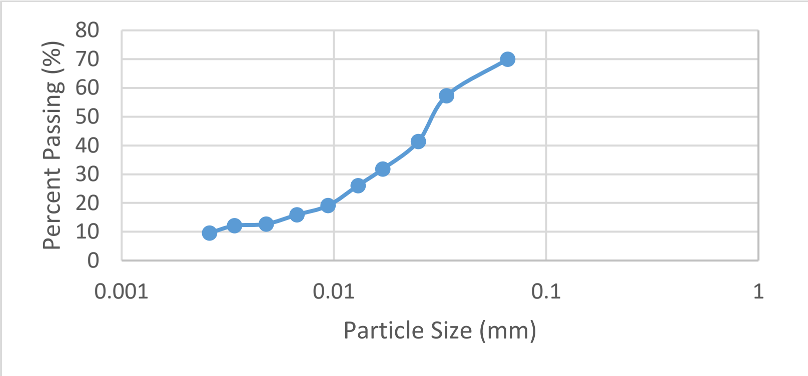


Figure 4.2. Grain Size Distribution of Clay

Specific gravity of clay is found as 2.69. Plastic limit and liquid limit is found as 20.18% and 35.86%. Clay is classified as CL according to unified classification system.

Maximum dry unit weight and corresponding optimum water content of sand clay and its mixtures are provided below.

Table 4.1. Maximum Dry Unit Weight and Optimum Water Content of Samples

Mixture	Maximum Dry Unit Weight (g/cm^3)	Optimum Water Content (%)
100% Sand	1,74	11,5
90% Sand + 10% Clay	1,80	9,5
80% Sand + 20% Clay	2,07	8,0
70% Sand + 30% Clay	2,13	6,8
60% Sand + 40% Clay	2,05	8,0
50% Sand + 50% Clay	2,12	8,6
40% Sand + 60% Clay	2,06	9,1
30% Sand + 70% Clay	2,02	10,0
20% Sand + 80% Clay	2,00	11,0
10% Sand + 90% Clay	1,99	10,0
100% Clay	1,85	12,5

When these mixtures are mixed with tyre crumbs with different ratios, maximum dry unit weights change as follows on Table 4.2. It should be noted here that; water content is kept same to find out unit weight change.

Table 4.2 Unit Weight of Soil Tyre Crumb Mixtures

Tyre Chip Content				
Mixture	**10%**	**20%**	**30%**	**40%**
100% Sand	1,55	1,47	1,22	1,20
90% Sand + 10% Clay	1,75	1,56	1,33	1,27
80% Sand + 20% Clay	1,84	1,62	1,42	1,40
70% Sand + 30% Clay	1,91	1,69	1,46	1,42
60% Sand + 40% Clay	1,78	1,72	1,50	1,44
50% Sand + 50% Clay	1,90	1,69	1,50	1,42
40% Sand + 60% Clay	1,91	1,70	1,59	1,45
30% Sand + 70% Clay	1,85	1,74	1,58	1,44
20% Sand + 80% Clay	1,65	1,67	1,55	1,43
10% Sand + 90% Clay	1,79	1,64	1,52	1,40
100% Clay	1,79	1,64	1,50	1,39

Direct shear tests are conducted to these samples. Results showed that, as the sand content decreases, angle of friction decreases, and cohesion increases. When tyre crumbs are added to mixture, angle of friction slightly decreases for 10% tyre crumb content. Addition of 20% tyre crumb content into soil mixtures, the highest values of angle of friction is measured. Adding 30% tyre crumb caused reduction in angle of friction. All tyre crumb inclusions caused increase on cohesion only for pure sand and 90% sand. In other soil mixtures, addition of tyre crumb reduced cohesion. Measured values of angle of friction and cohesion is given on Table 4.3.

Table 4.3 Measured angle of friction and cohesions from direct shear tests

	0 % Tyre Chip		10% Tyre Chip		20% Tyre Chip		30% Tyre Chip	
	ϕ	c (kPa)	ϕ	c (kPa)	Φ	c (kPa)	ϕ	c (kPa)
100% Sand	47,38	0,46	45,39	7,39	47,74	5,86	41,16	6,64
90% Sand + 10% Clay	44,19	3,07	43,84	13,36	46,23	9,73	41,01	7,09
80% Sand + 20% Clay	42,35	11,61	42,17	17,46	46,02	11,56	39,89	8,88
70% Sand + 30% Clay	41,36	21,51	41,04	21,93	44,80	12,50	38,35	11,61
60% Sand + 40% Clay	41,19	24,01	40,70	23,09	43,30	17,11	38,06	17,86
50% Sand + 50% Clay	41,04	26,68	39,86	24,63	42,08	20,26	37,09	19,88
40% Sand + 60% Clay	38,84	25,84	37,78	25,74	41,72	20,63	36,69	20,02
30% Sand + 70% Clay	38,05	26,10	37,45	25,66	41,14	22,58	36,27	23,52
20% Sand + 80% Clay	36,51	34,36	35,61	25,76	40,62	22,64	36,07	26,56
10% Sand + 90% Clay	36,37	37,48	35,54	25,76	38,62	23,69	35,41	26,71
100% Clay	32,44	37,66	33,37	30,19	37,47	28,14	34,60	28,63

When direct shear tests of pure soils are modelled with Abaqus, less than 10% error is computed with respect to shear strength of soils. The measured and computed results are given on Table 4.4.

Table 4.4 Maximum Shear Stress Values from Experiment and Finite Element Model and Difference

Content	Confining Pressure	Experiment	Abaqus	Difference (%)
100% Sand	**9,81 kPa**	11,0	10,8	1.82
	19,62 kPa	22,7	24,8	9.25
	40,81 kPa	43,1	44,9	4.18
	58,86 kPa	65,3	64,9	0.61
80% Sand + 20% Clay	**9,81 kPa**	19,2	17,7	7.81
	19,62 kPa	30,4	27,4	9.87
	40,81 kPa	50,5	46,8	7.33
	58,86 kPa	64,0	63,3	1.09
60% Sand + 40% Clay	**9,81 kPa**	34,7	34,8	0.29
	19,62 kPa	40,3	41,0	1.74
	40,81 kPa	55,9	59,5	6.44
	58,86 kPa	78,1	80,2	2.69
40% Sand + 60% Clay	**9,81 kPa**	31,6	32,6	3.16
	19,62 kPa	43,2	42,1	2.55
	40,81 kPa	61,1	60,1	1.64
	58,86 kPa	71,4	72,7	1.82
20% Sand + 80% Clay	**9,81 kPa**	40,7	39,1	3.93
	19,62 kPa	49,1	45,9	6.52
	40,81 kPa	66,6	74,1	11.26

	58,86 kPa	76,6	73,7	3.76
100% Clay	**9,81 kPa**	44,6	45,3	1.57
	19,62 kPa	50,4	49,7	1.39
	40,81 kPa	61,1	61,2	0.16
	58,86 kPa	76,6	79,5	3.79

When angle of friction and cohesion values are calculated from finite element analysis, less than 10% error occurred between results. Those values are provided on Table 4.5 below.

Table 4.5 Shear Strength Parameters from Experiment and Finite Element Model and Difference

	Experiment		**Abaqus**		**Difference (%)**	
Content	**φ (º)**	**c (kPa)**	**φ (º)**	**c (kPa)**	**φ (º)**	**c (kPa)**
100% Sand	47.4	0.46	48.2	0	1.7	100,00
80% Sand + 20% Clay	42.4	11.61	43.0	8.80	1.5	24.20
60% Sand + 40% Clay	41.2	24.01	43.0	23.90	4.4	0.46
40% Sand + 60% Clay	38.9	25.84	39.4	25.40	1.5	1.69
20% Sand + 80% Clay	36.1	34.36	37.5	32.60	3.9	5.12
100% Clay	32.4	37.66	34.5	36.80	6.4	2.28

4.2 Results from Small Scale Wall Tests

When small scale walls are tested at the laboratory, it is seen that the lowest settlements of loading plate measure for pure sand, while the highest settlements are measured for sand 20% tyre crumb mixtures. Change of settlement with respect to load and tyre crumb content is given on Figure 4.3 below.

When measured horizontal displacements are compared with each other, it is seen that, lower or almost equal horizontal displacements are measured for sand and 10% tyre crumb mixtures up to 0.42 MPa. Then measured horizontal displacements gets higher than pure sand. This behaviour is given on Figure 4.4 for.

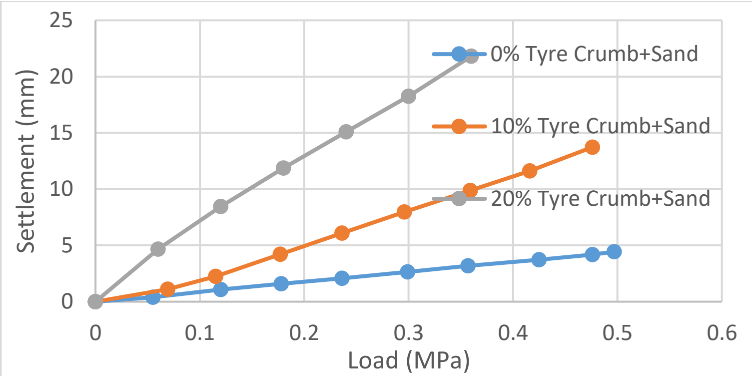


Figure 4.3 Settlement of Loading Plate for sand and tyre crumb mixtures

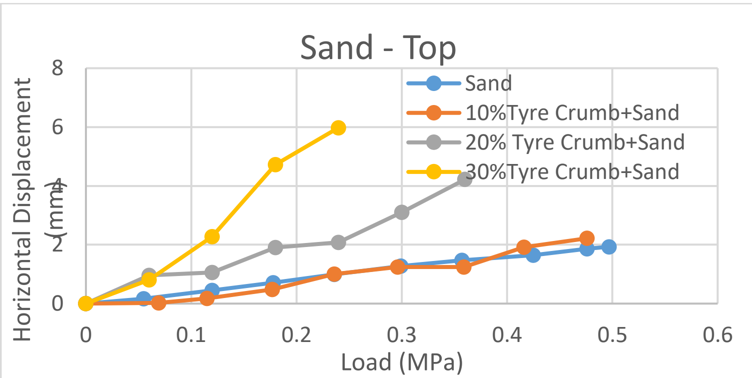


Figure 4.4 Measured horizontal displacements for sand and tyre crumb mixtures at top measurement point

When behaviour of small-scale walls investigated, the lowest settlement is measured for pure clay. The change settlement with respect to tyre crumb content and load is given on Figure 4.5.

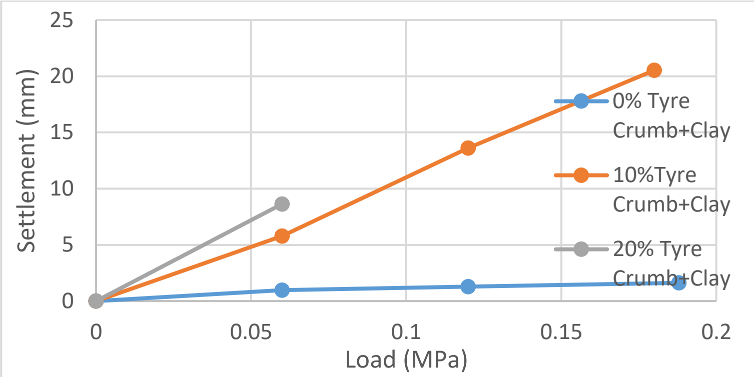


Figure 4.5 Settlement of Loading Plate for clay and tyre crumb mixtures

When horizontal displacements are compared with respect to different clay-tyre crumb mixtures, it is seen that the lowest horizontal displacements computed for a wall with a pure clay backfill. Figure 4.6 shows measured horizontal displacement on top of wall for clay backfills and tyre crumb mixtures.

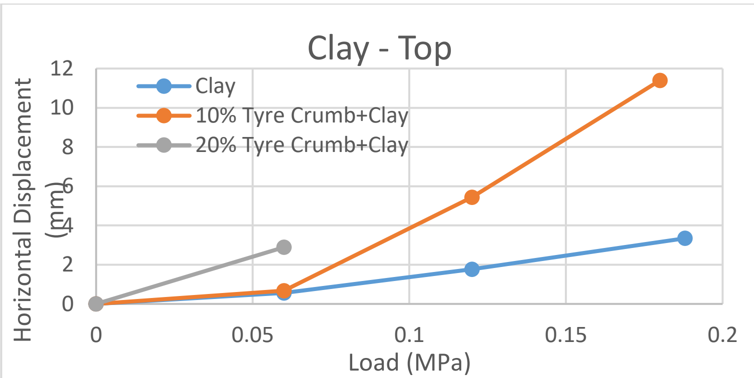


Figure 4.6 Measured horizontal displacements for clay and tyre crumb mixtures at top measurement point

4.3 Finite Element Model of Small-Scale Walls

When tested walls are modelled in finite element software Plaxis, it is seen that walls with sand backfill approximates to real results better than walls with clay backfill. Measured and computed settlement values of loading plate are given on Figure 4.7 for sand backfill.

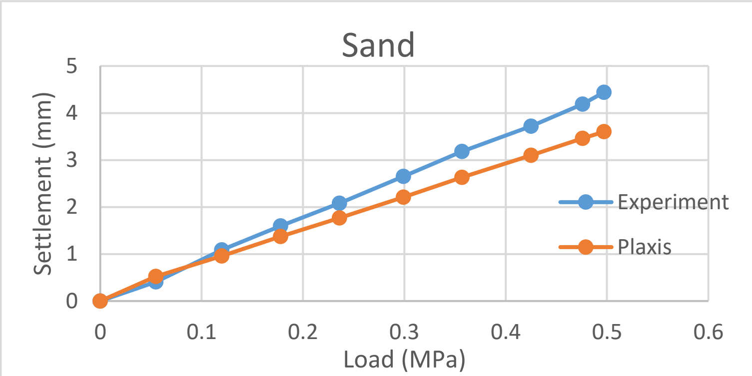


Figure 4.7 Measured and computed settlement of loading plate for sand backfill.

The measured and computed settlement of loading for clay backfill is given on Table 4.6 below.

Table 4.6. Measure and computed settlement values of loading plate for clay backfill

Load (MPa)	Test Settlement (mm)	Plaxis Settlement (mm)
0	0	0
0.06	0.97	0.36
0.12	1.28	0.63
0.188	1.62	0.99

4.4 Effect of Backfill Foundation Soil to Behaviour of Reinforced Earth Wall

The lowest horizontal displacements are computed for sand backfill while the highest displacements are computed for 80% sand + 20% clay backfill. The change of horizontal displacement at reinforced earth wall face is given on Figure 4.8.

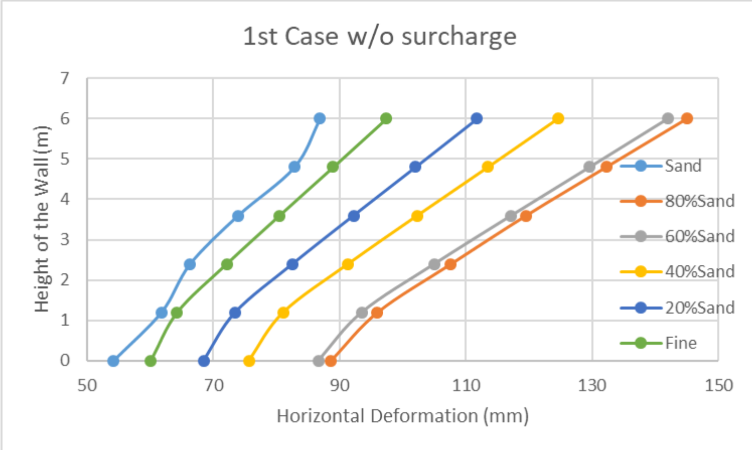


Figure 4.8 Computed horizontal displacements on wall face for different type of backfills.

If the settlement of reinforced earth wall with different backfills are considered, the highest settlements are computed for 80% Sand-20% clay backfill. Figure 4.9 shows change of computed displacements for different backfill.

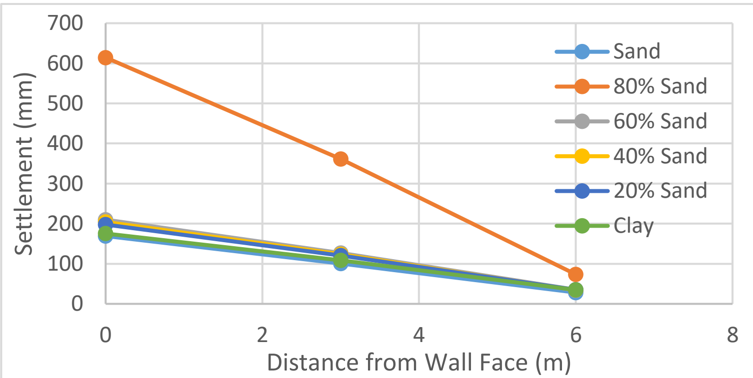


Figure 4.9 Computed settlement values for different type of backfill

Computed forces on reinforcements is shown on Figure 4.10. According to figure 4.10, the highest forces are computed for sand backfill except for the last layer. The highest force is computed for 80% sand – 20% clay mixture at last layer. The highest resultant force is computed for sand backfill.

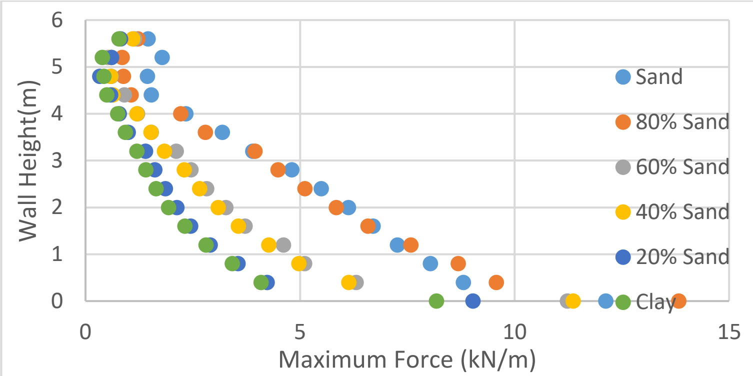


Figure 4.10 Computed maximum forces on geosynthetic layers

When the effect of foundation conditions to horizontal displacement of wall face is investigated, it is seen that, horizontal displacements are highly dependent on foundation conditions. Computed horizontal displacements for different foundation conditions are given on Table 4.7 below.

Table 4.7 Computed horizontal displacements with respect different foundation conditions

H (m)	1st Case	2nd Case	3rd Case	4st Case	5th Case	6th Case	7th Case	8th Case	9th Case	10th Case	11th Case	12th Case	13th Case
6.0	86.92	33.92	96.73	92.10	8.61	7.60	8.52	6.35	2.89	97.40	106.35	97.25	111.65
4.8	82.86	32.79	90.46	85.86	8.80	8.01	8.72	7.04	4.26	90.64	98.35	90.34	103.60
3.6	73.94	30.73	83.59	78.89	8.41	7.87	8.36	7.18	5.13	83.16	89.63	82.73	94.98
2.4	66.34	27.56	75.64	70.93	7.33	7.05	7.30	6.70	5.36	74.64	79.92	74.16	85.37
1.2	61.81	23.28	66.36	62.22	5.47	5.56	5.47	5.47	4.50	65.19	69.32	64.85	74.73
0	54.23	22.42	61.78	60.02	2.38	2.49	2.41	2.84	2.83	60.34	63.59	62.01	68.19

When the computed settlements are investigated with respect to different foundation conditions, it is seen that the magnitude and pattern of the settlements change with respect to foundation conditions. Those changes are given on Figure 4.11 below for sand backfill.

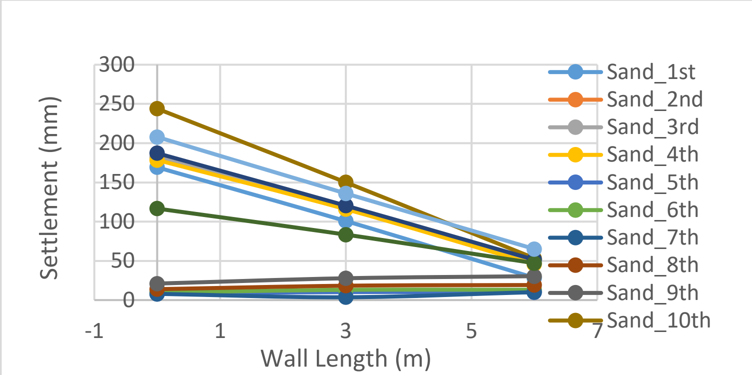


Figure 4.11 Computed settlements with respect to different foundation conditions for sand backfill

If the forces computed at different geosynthetic layers are investigated, it is seen that, computed forces on each geosynthetic layers are highly dependent on foundation conditions. Computed forces are given on Table 4.10 below for sand backfill.

Z (m)	1st Case	2nd Case	3rd Case	4th Case	5th Case	6th Case	7th Case	8th Case	9th Case	10th Case	11th Case	12th Case	13th Case
0	4.79	1.69	5.10	4.76	0.75	0.73	0.74	0.75	0.72	5.08	4.58	3.31	5.14
0.4	2.64	2.30	1.66	2.12	1.07	1.02	1.06	1.07	1.02	2.47	2.33	2.33	1.70
0.8	2.39	2.95	1.83	2.18	1.38	1.32	1.37	1.38	1.32	2.50	2.16	1.98	1.78
1.2	2.62	3.55	2.19	2.42	1.69	1.62	1.68	1.68	1.60	2.70	2.45	2.34	2.17
1.6	2.98	4.11	2.86	2.84	1.98	1.90	1.97	2.01	1.88	3.02	2.89	2.81	2.87
2.0	3.61	4.56	3.78	3.68	2.27	2.20	2.26	2.27	2.18	3.91	3.85	3.58	4.00
2.4	4.55	5.03	4.90	4.75	2.50	2.45	2.49	2.51	2.45	4.63	4.90	4.71	4.94
2.8	5.70	5.50	5.80	5.63	2.65	2.62	2.63	2.65	2.64	5.63	5.78	5.60	5.80
3.2	6.50	5.95	6.57	6.40	2.68	2.67	2.66	2.65	2.64	6.39	6.48	6.26	6.61
3.6	7.16	6.39	7.29	7.02	2.81	2.67	2.81	2.77	2.68	6.96	7.21	7.00	7.27
4.0	7.78	6.84	7.94	7.66	3.09	2.93	3.08	2.96	2.91	7.59	7.82	7.53	7.88
4.4	8.51	7.40	8.64	8.61	3.26	3.03	3.25	3.28	3.02	8.40	8.53	8.17	8.55
4.8	9.67	7.90	9.51	9.84	3.15	3.14	3.13	3.17	3.13	9.39	9.63	9.20	9.45
5.2	11.11	8.41	10.56	11.37	3.14	3.76	3.20	3.28	3.85	10.80	10.95	10.37	10.44

5.6	18.62	11.06	17.34	26.34	0.25	0.22	0.26	0.18	0.22	17.58	16.21	22.47	16.76
Resultant	98.63	83.64	95.97	105.63	32.69	32.28	32.59	32.62	32.25	97.06	95.77	97.66	95.36

5 CONCLUSION

Behaviour of reinforced earth wall is investigated under following conditions in this study.

- Addition of tyre crumbs in different ratios to sand and clay backfill in order to measure change of behaviour of reinforced earth walls.
- Effect of different backfill materials to behaviour of reinforced earth structures
- Effect of different foundation conditions to behaviour of reinforced earth structures.

According to results of this study, it is seen that, in case of sand backfill, lower horizontal displacements are observed for 10% tyre crumb inclusion. It should be noted that, settlement measured for this tyre crumb content is slightly higher than pure sand case. In case of clay backfill, addition of tyre crumbs resulted higher displacement and settlement than pure clay backfill case.

It seen that, behaviour of reinforced earth wall is highly dependent on used backfill soil. Different backfill soils react to surcharge load differently which may yield change of behaviour of reinforced earth wall.

Computed horizontal displacements, settlements and geosynthetic forces are highly dependent on foundation conditions. It should be also noted that, thickness of soil layer also affects computed deformations.

Following contributions to literature are made by the results of this study.

- Tyre crumbs can be used as a backfill material with sand up to 10% tyre crumb content. Several researchers found contradicting results about usage of tyre chips in reinforced earth wall, however, experimental part of study proved that, tyre crumbs can be used.
- Effect of backfill materials are generally considered by working conditions of reinforced earth wall. This study proved that, not only working conditions, but also change of working conditions of reinforced

earth wall should be considered during design of reinforced earth walls, especially for the walls which contains clay particles.

- Foundation conditions are important property of the design stage. Changing foundation conditions may yield to totally different behaviour of the wall. Amount of change is revealed by this study.

The outcome of this study can be used for a further research in the following areas.

- Investigation of decreasing settlement of loading plate when tyre crumbs are used with sand backfill.
- Implementing a coefficient to analytical design of reinforced earth walls in order to account foundation conditions. It is clear that, checking for a bearing capacity of foundation is not enough to design a reinforced earth wall.

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