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Research Article

Evaluation of Techniques for the Improvement of Subgrade Soils in Flood and Rainfall Inundation Affected Areas

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Abstract: Highways are amongst the most costly resources contributing directly to the growth of any country's economy. Subgrade soils as component of highways deteriorate normally from numerous factors resulting into flushing or excessive settlements of embankment involving huge maintenance costs. In this research, an attempt has been made to evaluate suitable technique for stabilization of commonly available subgrade soils of Pakistan based on cost effectiveness and ease in construction. The soils identified as A-3(0) by American Association of State Highway and Transportation Officials (AASHTO) criteria has been stabilized with conventional additives i.e. cement and bitumen in this research. The optimum content of each additive for stabilization based on their relative effectiveness was used. Trials were also made to economize the cost of stabilization from both conventional additives by controlled replacing of them with waste polythene and polyester fibers. The construction methodology for stabilization using waste fibers was also proposed. Cement was observed to be the most effective stabilizer with respect to strength and durability for A-3(0) soils. Bitumen was found effective but uneconomical for A-3(0) soils. Waste polythene and polyester wastes (organic materials) have potential to economize the cost of stabilization with cement and bitumen for A-3(0) soils. However, long term degradation of these organic materials in soil stabilized mixtures needs further exploration.

Keywords: Subgrade soils, stabilization, cement, bitumen, polythene, polyester

1. INTRODUCTION

Highways are the road passages which are constructed to facilitate communities in cities, districts, villages, etc. for domestic, professional and trading purposes. As the world is becoming the global village the highways are also extending beyond the borders of the countries. Motorways and expressways are the key types of highways. The highway networks of most of the countries are administered by government controlled authorities. In Pakistan the national network of highways are administered by National Highway Authority (NHA). The provincial highways of Pakistan are administered by provincial highway section of Communication and Work Department.

Highways and roads network as communication means are the backbone of the future development prospects of any country. Pakistan being an underdeveloped country has been lagging in the sufficient provisions of these communication means. However, it should be recognized that highways and road network will act as catalyst in future development of any country. Due to high initial construction cost the new highway projects mostly remained among descending preferences of authorities in developing countries. Fig. 1 shows existing and planned highways network in Pakistan. The Grand Trunk Road (N-5) is the longest highway of the country and most of the other highways of Pakistan are extending from it. M-2 was the first motorway section that was constructed in Pakistan followed by M-1 and M-3. Currently work on M-4 is under progress and M-5 to M-9 is in pipeline.

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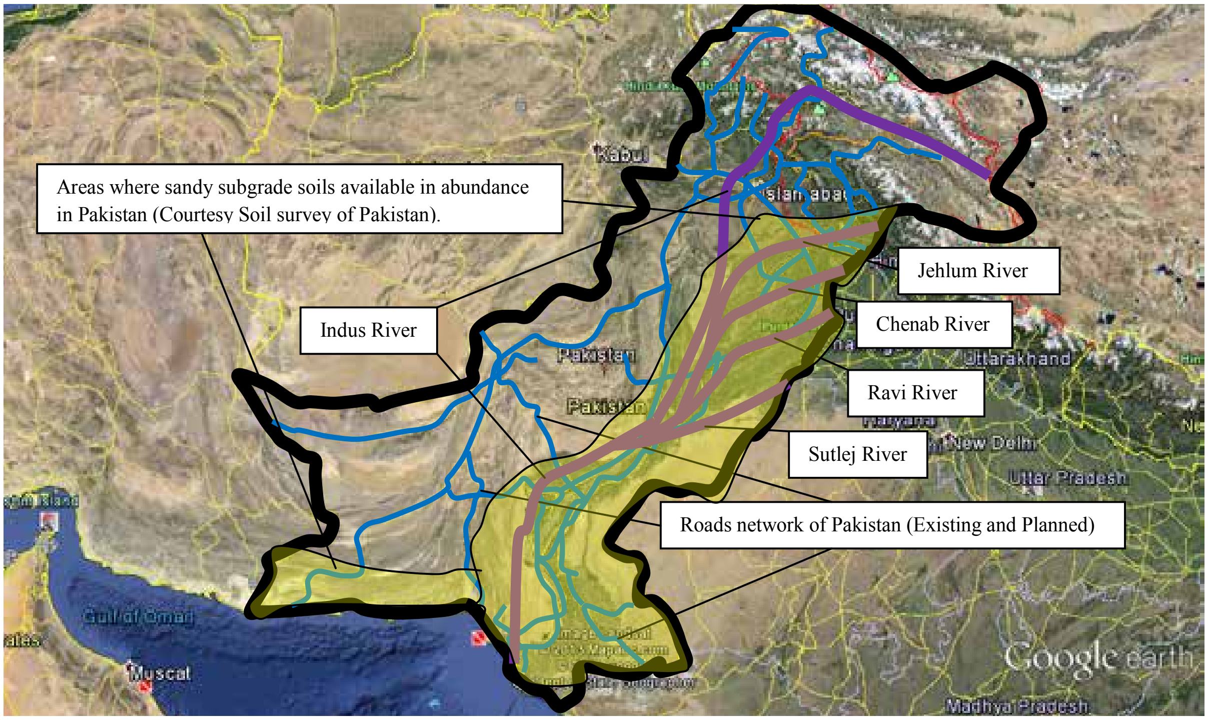

Fig. 1. Orientation of major rivers and highways of Pakistan (Courtesy: Google Earth, US Dept. of State Geographer, 2015).

Table 1. Details and characteristics of different highway components used in Pakistan.

Description	Composition	Sources of Materials*	Typical Thickness Used (mm)[8]**
Asphaltic wearing course	Asphalt	NRL, ARL	38-50
	Aggregates	Margallah, Sargodha, Ubhanshah	
Asphaltic base course	Asphalt	NRL, ARL	75-125
	Aggregates	Margallah, Sargodha, Ubhanshah	
Base course	Aggregates	Margallah, Sargodha, Ubhanshah	125-250
Subbase course	Aggregates	Margallah, Sargodha, Ubhanshah	250-350
Subgrade	Aggregates	-	Variable depending upon terrain and requirement of cut or fill.

NRL = National Refinery Limited - Karachi, ARL = Attock Refinery Limited - Attock,
*Approved by National Highway Authority (NHA)
** Depends on axle load, traffic type & frequency. Based on California Bearing Ratio (CBR) Test [8] Guidelines

Most of the highways shown in Fig. 1 are crossing or passing parallel to the route of water passages like rivers and canals. Due to monsoon rains the rise in water levels of five major rivers of Pakistan i.e. Ravi, Chenab, Jehlum, Sutlej, Indus along with 58,000 km length of canal system are the sources of floods in Pakistan which causes normally deterioration to subgrade layers of roads and highways.

The main components of highways are shown in Fig. 2. The thicknesses of each component depend on loading requirement of the highway and strength of materials [1]. Table 1 presents a summary of guidelines about the characteristics of these components in Pakistan.

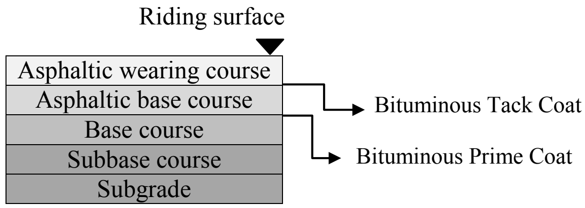

Fig. 2. Components of highways.

Subgrade as aggregate is a common soil material. During construction of new highways the soils along the routes are utilized as subgrade subjected to fulfillment of design strength [2, 3]. If the soils are weak in strength than improvement of the soils is carried out to enhance its durability against water infiltration and environmental changes [4]. Depending on the type of soil and scale of improvement various additives like cement, lime, bitumen and fly ash are used to improve the strength of subgrade soils [4, 5, 6]. By addition of these additives not only strength is improved but the durability of the material is also enhanced [7].

The subgrade materials used in roads and highways of Pakistan are normally not stabilized. Due to environmental changes and water infiltration in unstabilized soils used in roads and highways at different parts of Pakistan these subgrade materials had been damaged. That cause lot of maintenance cost incurrence each year by different provincial and federal road maintenance agencies. Pakistan has lot of prospects for the construction of new highways in coming years. Keeping consideration in view, this research has been initiated with aim to study the best possible additive for improving the strength of commonly available subgrade soil of Pakistan in respect of cost as well as ease of construction to enhance its durability against environmental and water associated degradation.

2. MATERIALS AND METHODS

The objectives of this research were achieved by adopting following methodology:

The identification of locations, where potential subgrade material used in roads and highways is available in abundance. For that purpose the database, literature and survey records of Soil Survey of Pakistan have been consulted. In addition, literature from geotechnical investigation reports and Geological Survey of Pakistan was also studied.

Collection of disturbed and representative identified alluvial sandy soil samples. Determination of engineering properties of soil by performing laboratory tests, i.e., sieve analysis, specific gravity, description and identification of soil, shear strength by direct shear, standard and modified proctor compaction. To enhance the confidence three replications of each test were carried out. The soils were stabilized by cement and bitumen. For determination of the strength of stabilized soil unconfined compression test [8, 9, 10] was employed on three representative samples with three replications. The cement used was ordinary port land type (OPC) manufactured by Mapple Leaf confirming to quality requirements [10]. The cement stabilized reconstituted samples were cured as per guidelines [10] of curing for 7, 14 and 28 days.

The subgrade soils were stabilized by locally available medium curing (MC) and rapid curing (RC) bitumen [11, 12]. Three samples each with three replicates were evaluated. Kerosene oil was used as solvent to cut back both MC and RC during preparation of bitumen samples. For estimation of preliminary quantity of MC and RC following equation was used [13]:

$$p = 100\,[(0.02\,a + 0.07\,b + 0.15\,c + 0.20\,d\,)/(100 - S)] \qquad (1)$$

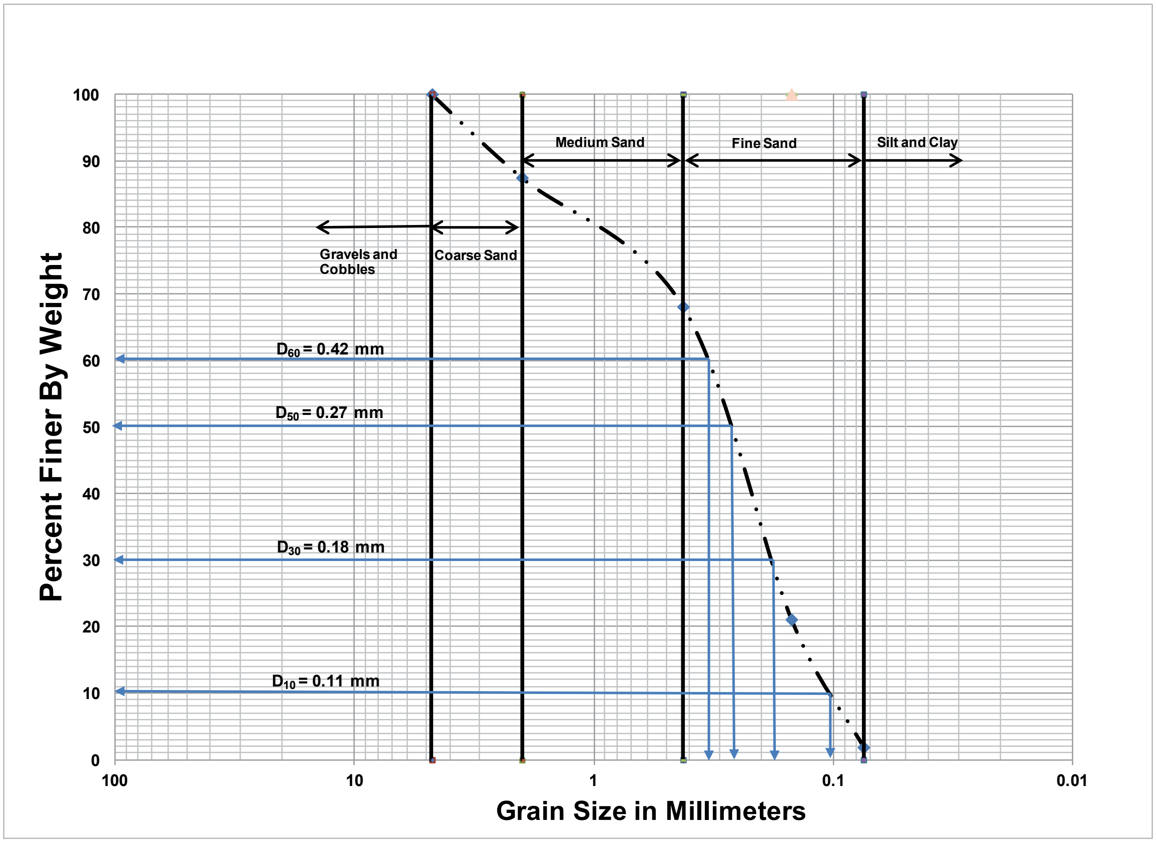

Fig. 3. Grainsize analysis of the soil sample.

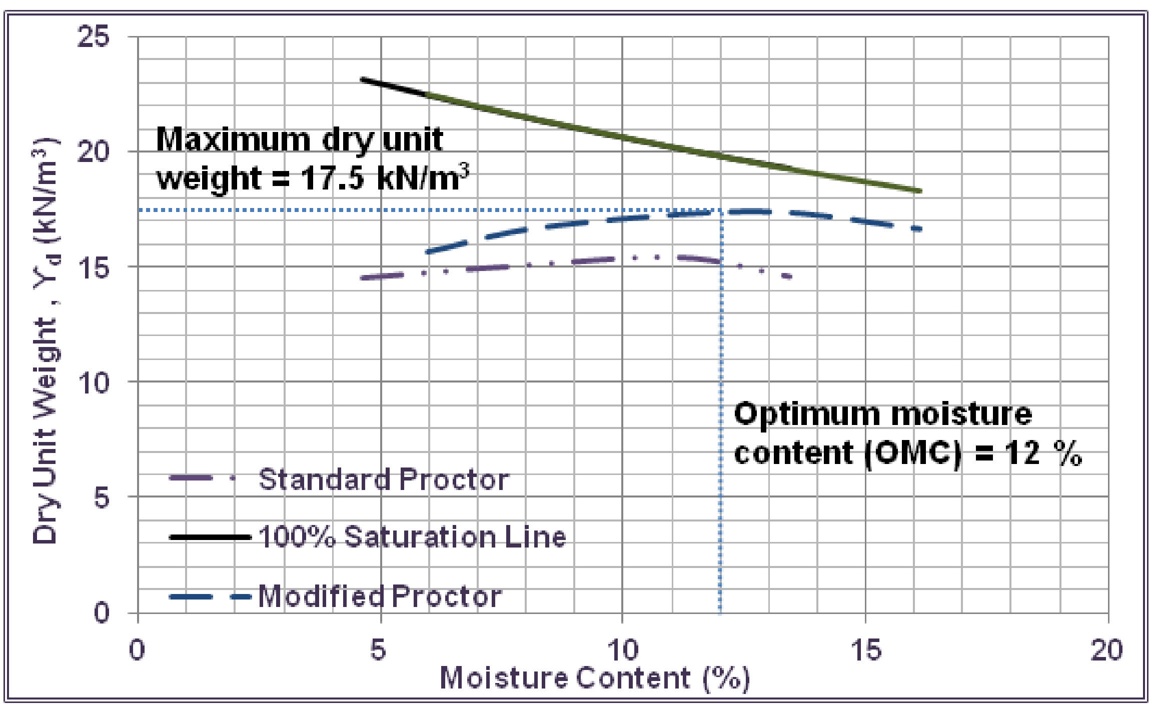

Fig. 4. Compaction test curve of the A-3 soil by modified and standard proctor test methods.

Table 2. Geotechnical properties of the investigated soil sample

Soil Parameters	Laboratory Tests/ Empirical Methods	Results	Test Methodology
Coefficient of Concavity, $C_c = (D_{30})^2 / (D_{60}\ D_{10})$	Grain size analysis	0.70	ASTM D422[15]
Coefficient of Uniformity, $C_u = D_{60} / D_{10}$	Grain size analysis	3.82	ASTM D422[15]
Plasticity Index	Atterberg limits	Non Plastic	ASTM D4318[16]
Specific gravity	Specific gravity	2.66	ASTM D854[17]
Group Index	Grain size analysis and Atterberg limits	0	ASTM D422[15] & ASTM D4318[16]
Drained friction angle (ϕ')	Direct shear	33.1^0	ASTM D3080[18]
Maximum dry density	Modified proctor	17.50 kN/m^3	ASTM D698[19]
Optimum moisture content	Modified proctor	12.0 %	ASTM D698[19]
California bearing ratio (CBR)	Soaked CBR Test	17.0 %	ASTM D1883[8]
Resilient Modulus (MPa)	Empirical Method	48	NCHRP[20]

where

p = MC / RC bitumen by weight of dry aggregate;
a = Aggregate percentage retained on No. 50 sieve;
b = Aggregate percentage passing No. 50 sieve and retained on No. 100 sieve;
c = Aggregate percentage passing No. 100 and retained on No. 200 sieve;
d = Aggregate percentage passing No. 200;
S = percent solvent

The polythene and polyester materials can also be used to stabilize subgrade soils [14]. According to environment protection agency (EPA) of Pakistan, both of these materials are available in abundance in Pakistan as waste material whose safe disposal to environment is costly and time consuming. Therefore, as the part of this research; an evaluation has been made to study the stabilization of subgrade soils using polythene and polyester waste materials. Polythene and polyester fiber samples taken from waste plastic bags and waste packing materials were shredded in form of threads. Three samples of soil were prepared against three percentages of both polythene and polyester fibers to evaluate its improvement through stabilization. Three replications were performed to enhance precision and accuracy.

3. RESULTS AND DISCUSSION

In provinces of Punjab and Sindh alluvial soils were found in abundance (Fig. 1) especially along the deltas and bunds of rivers (Ravi, Chenab, Jehlum, Sutlej, Indus), canals, streams etc. These soils are loose at its deposition location; however, as a material it does have potential to act as a useful subgrade against environmental changes and rainfall indentation. According to soil survey of Pakistan, in most locations its depth of deposition is even extending beyond 50 m. Samples of soils were taken from three locations in the forthcoming routes of the motorways (M-4, M-5 and M-6) to be constructed consulting the database of Soil Survey of Pakistan. All three samples were found similar in physical appearance with fraction of variation in grains contents. The typical grain size analysis curve of the soil used for research is shown in Fig. 3. The moisture density relation curve of the soil by standard and

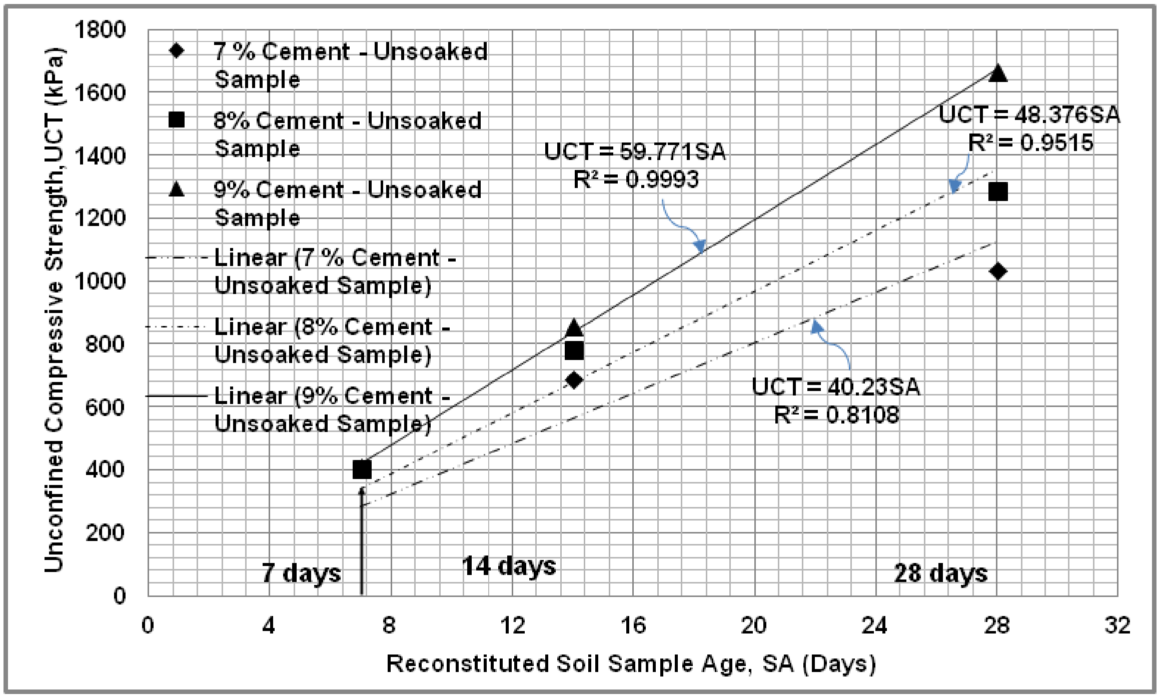

Fig. 5. Variation in cement stabilized soil unconfined compressive strength with curing age.

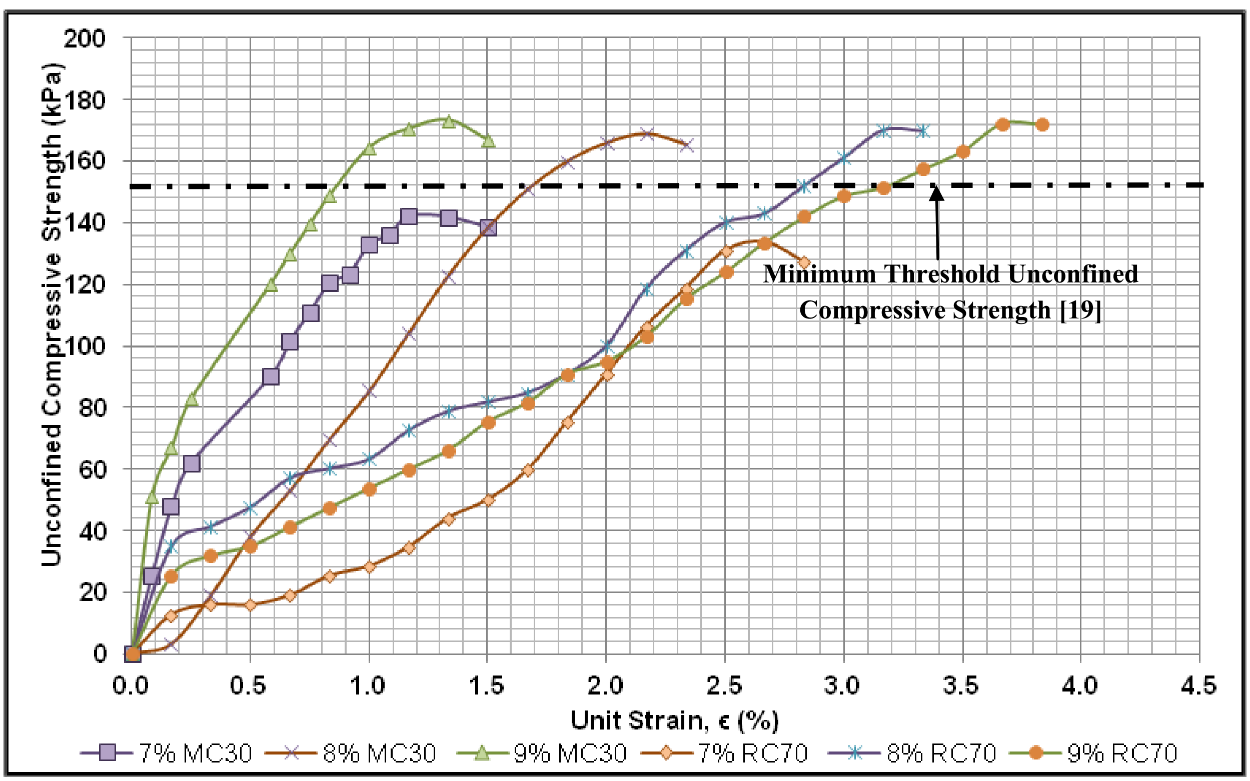

Fig. 6. Variation in soil unconfined compressive strength with bitumen type and content.

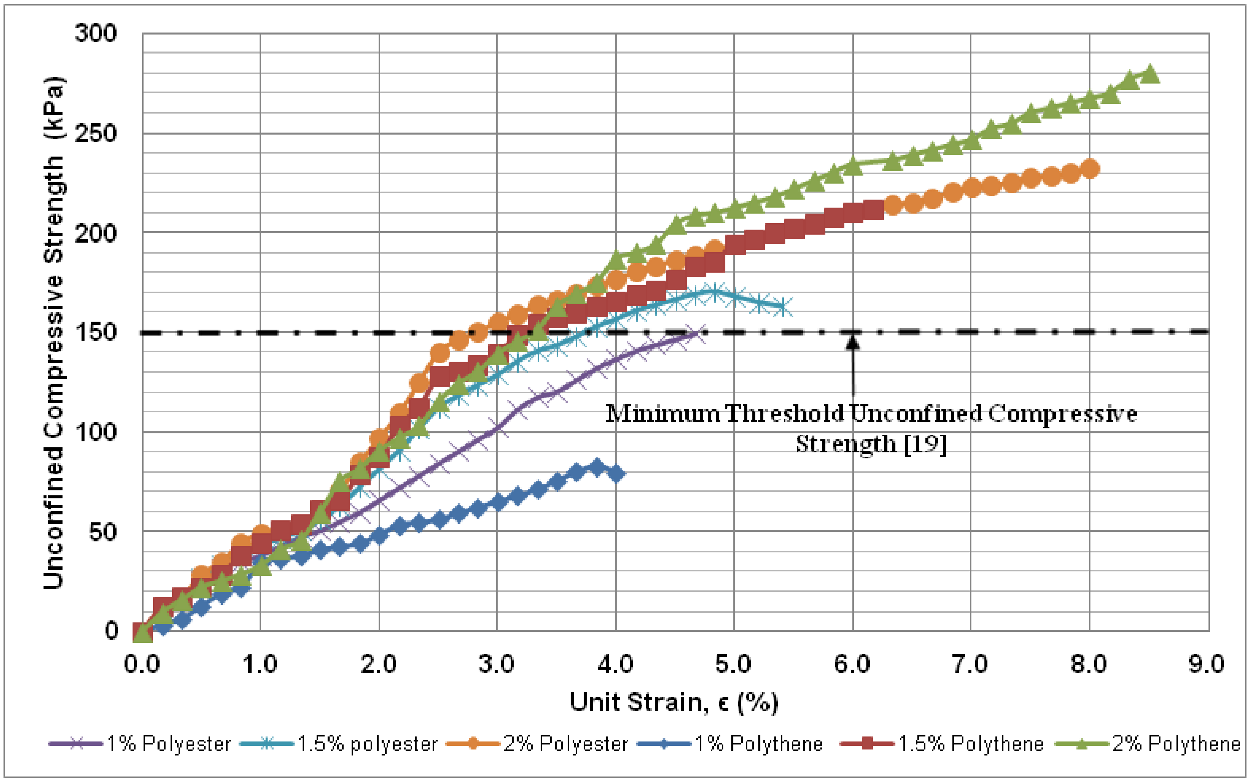

Fig. 7. Variation in soil unconfined compressive strength with fibers type and content.

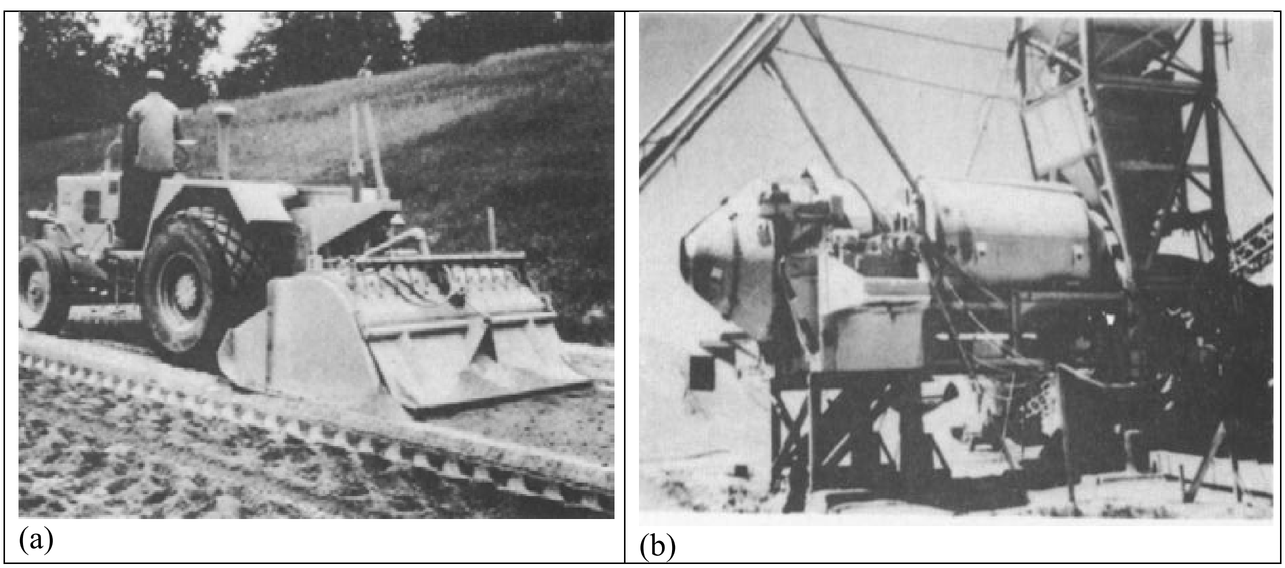

Fig. 8. Methods for cement stabilization at construction site (a) direct mixing (b) mix plant (Photos courtesy of US Army Technical Manual [13]).

modified proctor tests is shown on Fig. 4. A summary of geotechnical parameters of soil deduced from the analysis of different laboratory tests are summarized in Table 2.

The soil sample is classified as “SP – Poorly Graded Fine Sand” based on the unified soil classification system [21]. Soil is classified as A-3(0) using AASHTO soil classification system [22]. A-3 soils can be rated as excellent to good subgrade material in areas not affected by excessive environmental changes, water of flood and rainfall inundation [23]. Further, A-3 material is preferred to be used as subgrade by designers in the areas having dry moisture deficit climate, deep water table, good external drainage and no permeability inversion [24]. However, in case of using A-3 soil material as subgrade without stabilization in environmental variant conditions and water inundation areas its performance is capricious [25]. Therefore, A-3 soil materials when used in areas having inversion of permeability due to floods or rains than it need to be stabilized by additives. Cement and bitumen are most suitable additives for improving the strength and durability properties of A-3 subgrade soils [26]. Generally, soils are stabilized for highways subgrade to achieve unconfined compressive strength (UCS) of 150 kPa more than the UCS of soils originally anticipated without the use of additive [26].

For stabilization of A-3 soil, an initial estimated cement content of 7, 8 and 9 % was employed [10]. The samples for unconfined compression test was reconstituted at density and moisture determined from modified proctor test (Table 2). Fig. 5 shows the unconfined compressive strength variation with age of curing in stabilized samples. It is eminent from Fig. 5 that the soil unconfined compressive strength with stabilization additive increased drastically and reached to an average value of more than 1200 kPa against curing time of 28 days. The strength values observed in cement stabilized subgrade samples of the samples are comparable with strength values of the same soils reported in literature [27].

Fig. 6 shows test results of A3 soil sample stabilized using MC30 and RC70 cut back bitumen samples. The 30 and 60 represented the minimum kinematic viscosity of the cutback determined using Saybolt Furol Viscometer [28]. 7 to 9 % bitumen content by weight of dry aggregates was obtained by keeping kerosene oil from 25 to 40 % and using equation 1 [13]. The A3 soil stabilized with MC30 and RC70 were remolded at density determined from modified proctor test. On the same density the A3 soil stabilized with 7 % MC30 and RC70 showed strength less than threshold of desired unconfined compressive strength. However, both 8 and 9 % MC30 and RC70 samples showed reasonable strength above threshold level. The soil samples stabilized with MC30 showed lesser distinctive plastic phase than samples stabilized with RC70 during unconfined compressive strength. However, both MC30 and RC70 samples showed distinctive elastic phase.

In recent years, the use of different non-traditional additives like waste fiber materials for the stabilization of soils is an area of interest around the globe. The random size polythene and polyester fibers can be used effectively for stabilization of sandy soils [29]. Polythene bags and polyester packing material from a local waste lot was collected. Both materials were manually shredded in random sizes approximately with diameter range between 0.1 to 0.2 mm and length ranges from 22-26 mm. 1 – 2 % polythene and polyester fibers were added by weight of dry soil during remolding of samples at modified proctor density and optimum moisture content [30]. Fig. 7 shows results of unconfined compressive strength of soils stabilized using polyester and polythene fibers. It is eminent that both fibers enhance the strength of the A3 soil drastically, hence both has strong potential to be used as alternate stabilization material for A3 type soils. However, amount of polyester and polythene should be

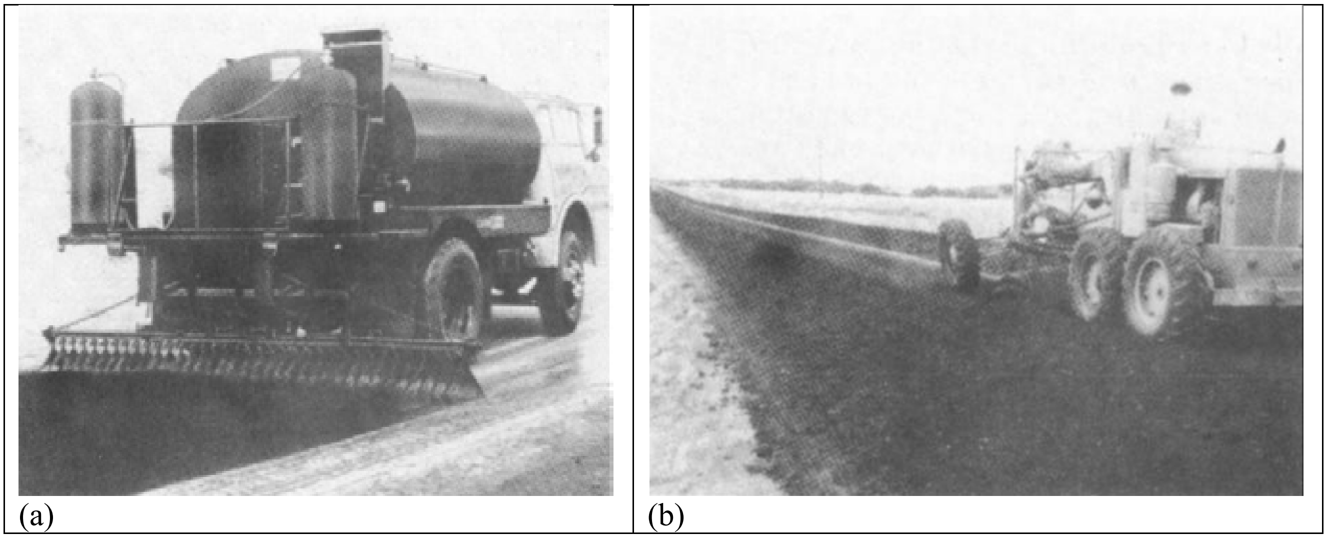

Fig. 9. Steps for bitumen stabilization at construction site (a) Bitumen spreading (b) Bitumen mixing with soil (Photos courtesy of US Army Technical Manual [13]).

Fig. 10. Proposed steps for polythene/polyester fibers stabilization at construction site: (a) Fibers shredding; (b) Fibers spreading; (c) Fibers mixing with soils (Photos courtesy of Google Images, http://www.google.com).

greater than 1.5 % to achieve the minimum threshold unconfined compressive strength under soaked conditions.

Cement stabilization at the construction site is usually carried out either by direct mixing method or by mix plant method (Fig. 8). Bitumen stabilization at the site is carried out by direct mixing method (Fig. 9). More laboratory experimentation literature is available about the stabilization of subgrade soils using polythene and polyester fibers. However, to date insignificant literature is available about its construction methodology. In this research brief cost effective construction methodology of polythene / polyester fibers stabilized soils is described. Waste plotythene/polyester can be shredded in desired dimensions using automatic shredders (Fig. 10 a). The shredded materials are than spread using hydraulic jack trolley system (Fig. 10 b). The fibers are than thoroughly mixed with subgrade soil using motor graders (Fig. 10 c). To evaluate the cost effectiveness of these three stabilization methods, an analysis of rates for their construction has been established. Fig. 11 shows the comparison of rates between different stabilization methods using database of five districts of Pakistan having sufficient A3 soils deposits in it and around its surrounding. A3 unstabilized soils rates database has been taken from latest

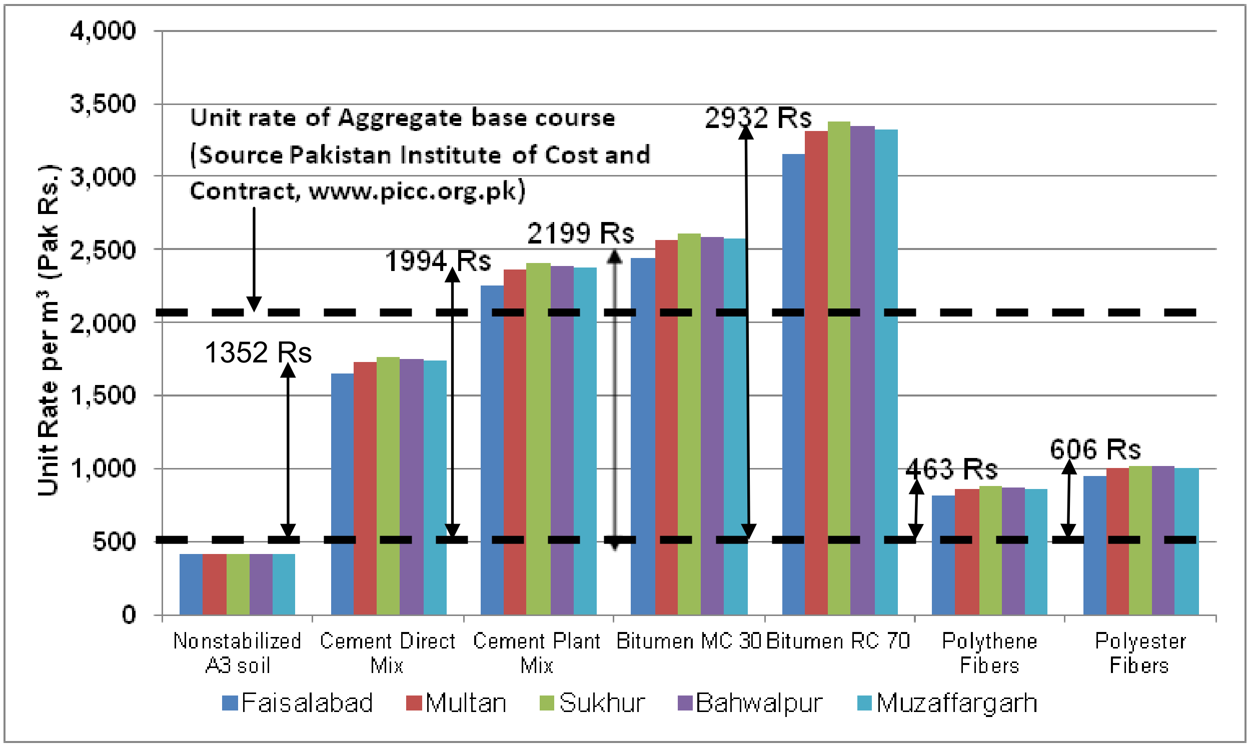

Fig. 11. Cost comparison of different stabilization methods in five major districts of Pakistan.

composite items rates for different districts of Pakistan published by Pakistan Institute of Cost and Contracts for August 2013. In analysis of cement direct mix rate cost of material (cement for 8 % optimum, A3 soil, and water), machinery (spreader, compactor, water tanker and grader) and labor cost of field activities has been used. For cement plant mix rate analysis the cost of material (cement for 8 % optimum, A3 soil, and water), cost of machinery (cement plant, transit mixer, pump/hydraulic dump, compactor, water tanker and motor grader) along with allied field labor has been employed. The analysis of rates for bitumen stabilization soils has been carried out by using cost of materials (kerosene, MC-30/RC-70, A3 soil and water), cost of machinery (sprayer/spreader, grader, water tanker, and compactor) and relevant field labor. The rates for waste fibers stabilized soils has been analyzed by considering cost of materials (polythene, polyester, A3 soil, water), cost of machinery (shredder, spreader, compactor and water tanker) and associated labor. It is eminent from Fig. 11 that both waste materials showed minimum unit cost in comparison to other stabilization additives i.e. cement, bitumen. Extraordinary rise in petroleum products (kerosene and bitumen) in recent years around the globe makes bitumen stabilization relatively uneconomical (Unit cost even more than aggregate base course). The cost of plant mix cement stabilization is also high. The option of cement stabilization using direct mix method is seems to be relatively more comparable option in term of economy as well as strength with other stabilization options. Insignificant change has been observed in the composite unit rates of different individual stabilization methods in five major districts of Pakistan.

4. CONCLUSIONS

Pakistan has number of important highways/road projects whose design and construction is in pipeline now like M4 (Faisalabad Multan Motorway Section), M5 (Multan Rajanpur Motorway Section), M6 (Rajanpur to Ratodero

Section), M7 (Ratodero to Liyari Section), M8 (Ratodero to Gawadar Section), M9 (Hyderabad Karachi Section). Most of passages of these projects have been significantly affected by the floods and rain inundation in recent years. Further, the surroundings of most of these projects have significant deposits of A3 soil materials that can be used after stabilization as subgrade in its construction. This research is going to give a comprehensive elaboration of different stabilization methods of A3 soils to be used for prospective projects in Pakistan based on strength characteristics, methodology of construction and economy. Following specific conclusions can be drawn from above findings:

1. The cement stabilized A3 soils has merit over other stabilizations in strength therefore it can be used with confidence as subgrade on new highways effected by environmental variations and water inundation areas subjected to any kind of traffic loading (light, medium or high).
2. The A3 soils stabilized with bitumen MC30 and RC70 are less cost effective than cement stabilization. The strength of bitumen stabilization is in lower threshold and cement stabilization is in higher threshold of design ranges. Therefore, bitumen stabilized soils should be preferred as subgrade on new roads effected due to environmental variations and water subjected to relatively light to medium traffic loading. Further, to maintain quality control and environmental protection of bitumen stabilization during field operations is also complex. Hence, its use for highways subjected to relatively heavy traffic loading is restricted.
3. A3 soils stabilized with waste polythene and polyester fibers do have reasonable potential to act as alternate of bitumen stabilization in term of strength. However, creep studies of these organic materials in the mix under traffic loading are needed to be investigated.
4. A3 subgrade soils stabilized by cement, bitumen or polythene/polyester fibers have its application horizon in both technologies of roads construction (surface treatment and plant pemix) in Pakistan.
5. Polythene bags and polyester packing are two most abundantly found waste materials in Pakistan. The treatments of these materials are costly to make it environment friendly. By using these materials for the soil stabilization can be a good mode of its disposal for the protection of environment.

Based on the findings of this laboratory-based research it is recommended to construct trial sections of the subgrade in the field and directly evaluate stabilization characteristics under different loading and inundation conditions. This will give further confidence to the findings of this research.

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