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Comparison and Effects of Compaction Methods on Gradation and Strength of Natural Unbound Materials

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Abstract: This paper, evaluates the effects of the conventional laboratory compaction methods on gradation, plasticity, shrinkage and strength of natural unbound materials. Three different trial sections were constructed accompanied with field and laboratory tests to study and evaluate the most suitable compaction methods that simulate field compaction. The materials used in this investigation are colluvial deposits originally conglomerates belonging to Nubian Sandstone Formation. Experimental testing programs comprising two different activities were conducted, firstly: routine tests, Los Angeles abrasion, and CBR and secondly three field trial sections were constructed using field compaction equipment. The test results have shown that impact hammer resulted in more breakage of coarse particles and finer products compared to the other two methods. The measured strength after impact compaction was very high whereas the measured strength was low for the gyratory compaction method. The three field tests have shown that the gyratory compaction method simulated better field conditions. The impact compaction normally used for the estimation of the CBR of earthen pavement materials and highly overestimates the strength of these natural unbound materials.

Keywords: *Natural gravel, gradation, compaction method, trial section, strength*

1. INTRODUCTION

Natural gravelly unbound materials are commonly used in highway and airport pavements as base, sub-base and filling materials in Khartoum state. These materials are formations originally conglomerates belonging to the Nubian Sandstone Formation. The natural materials are used as base and sub-base and they do not usually satisfy AASHTO and Transport Research Laboratory of United Kingdom (TRL) gradation and strength requirements for base course materials. They are often mixed with crushed stones to satisfy the gradation, strength and any requirements for base course materials. The strength is usually assessed using the soaked California Bearing Ratio (CBR) test.

Impact compaction method is usually used to prepare samples for CBR test. Many researchers reported inadequacy of impact compaction when compared with the field compaction results for different types of field compaction equipment [2], [3]. The inadequacy will probably depend on the nature and properties of the tested materials. The effects of impact compaction compared to other laboratory compaction methods on the unbound materials properties from Khartoum state have not been studied.

The main objective of this study program is to investigate and compare the effects of different laboratory compaction methods, namely impact, vibratory and gyratory compaction on the gradation, plasticity, shrinkage and strength of natural unbound aggregates obtained from open quarries of Khartoum state and to find out the compaction method which better simulates field compaction conditions

2. LITERATURE REVIEW

Four compaction effort types or mechanisms are usually used in the laboratory for compacting soils and asphaltic materials; these are: vibration, impact, kneading and pressure [1]. The impact compaction and static press are poor in simulating field conditions. However, the impact method is the most widely used in the laboratory since it is applied in Proctor compaction, CBR and Marshall tests.

Proctor compaction is the most popular world–wide laboratory test method for the evaluation of pavement materials for its ease and simplicity. However, it does not simulate well the compaction done in the field and it causes post compaction particle–size variations leading to different behaviour compared to the field post-compaction behaviour [2]. Inge Hoff *et al.*[3] reported that the impact hammer (Proctor) does not offer good simulation of the compaction process in the field when heavy compaction roller is combined with some sort of vibration or oscillation.

Seed *et al*. [4] recommended the use of two compaction methods for the preparation of unbound materials test specimens; kneading or impact. The laboratory compaction equipment which gives good simulation of the kneading action is the gyratory compactor. The gyratory compaction equipment was earlier developed for compacting hot asphalt mixtures, Texas Department of Transport (Tx DOT) has standardized and validated the use of the gyratory equipment for compacting unbound granular materials [9] and found that material degradation and orientation reduced to minimal and closely matched field compaction.

Commercial vibration equipment are available and being used to prepare laboratory samples, mainly sandy soils and unbound materials. Ping *et al* [5] investigated and reported that gyratory compaction has a stronger resemblance to field compaction than the impact does. Browne [6] remarked that compaction in the field is typically obtained from a combination of kneading, vibration and static pressures. According to Browne, soil degradation is expected during both laboratory and field compaction and it is likely that degradation that occurs as a result of the gyratory compaction is more representative of field degradation than degradation caused by Proctor tests". In addition, gyratory compaction is a feasible method of laboratory soil compaction with granular soils.

Sample preparation in the laboratory is essential when testing materials of low cohesion. In addition to the type of compaction mechanism utilized during sample preparation, the size of the test specimen is another critical factor. Dondi *et al*. [7] found that the gyratory compactor with a pressure of 600 kPa and 130 revolutions as being ideal to ensure a density level comparable with the Proctor one. Hicks and Monismith [1] reported that the significance of changes in density decreased as the fines content of the granular material increased. Adu-Osei [8] noted that one of the main disadvantages of impact compaction method is that aggregate orientation and distribution is different from what is achieved in the field. According to [8] vibratory compaction is successful for compacting unbound materials to predetermined densities because material degradation is reduced compared to the impact method.

3. MATERIALS AND METHODS

Khartoum, the capital of Sudan, has been experiencing huge growth during the last decade. A number of open quarries containing different types of natural gravelly soils are mined for selected fill, sub-base and base course materials. These gravelly materials are originally conglomerate formations belonging to the Nubian Sandstone Formation. They are also used as base materials when blended with crushed stone or natural coarse wadi sand.

Four materials were obtained from three different sources namely Huttab (Huttab1, Huttab2), Kadaro and Alhashaba. The sources are located within a radius of 50 km or greater from the city center. These materials were basically selected to represent three different ranges of gradations, (coarse, medium and fine) with different fines contents. The measured strength (CBR), plasticity, Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and abrasion value are shown in Table 1 whereas the gradation plots for the three natural unbound materials compared to Transport Research Laboratory (TRL) GB3 base gradation are presented in Fig. 1. The material samples represent different gradation levels, Huttab2 sample was selected as relatively coarse gravel, Huttab1 as medium size gravel whereas Kadaro and Alhashaba natural gravels were selected as fine.

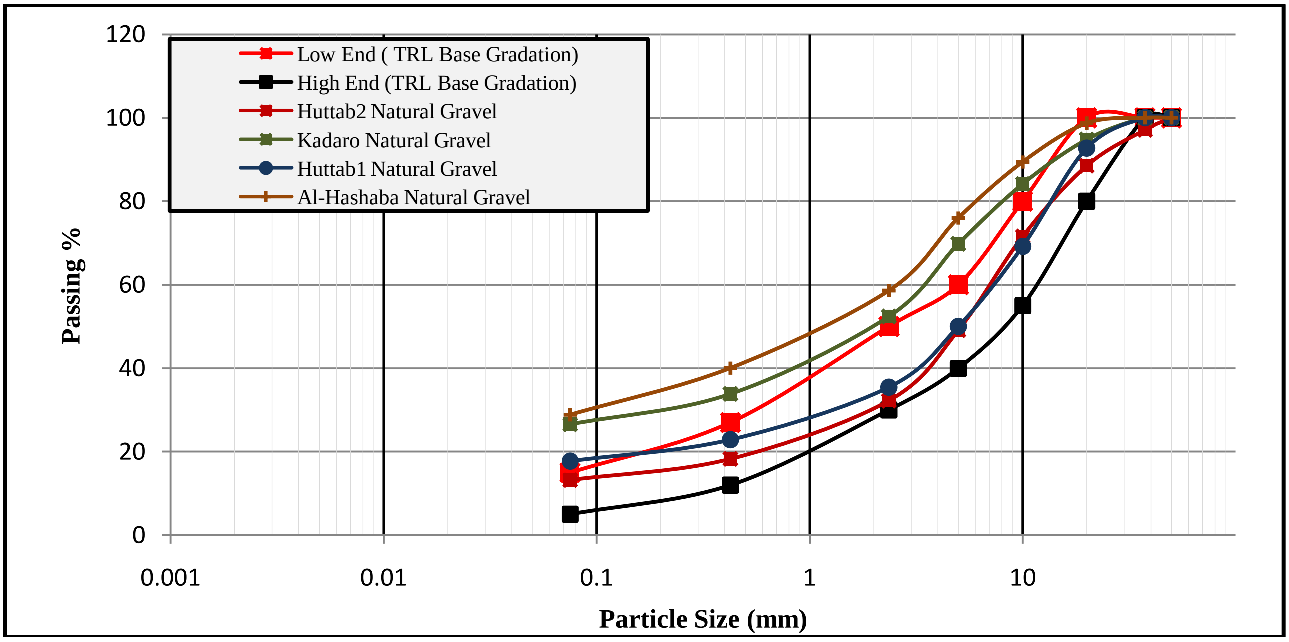

Fig.1. Grain Size Distribution for the Four Studied Materials

Table 1: Laboratory tests results for the four studied materials

Natural material	OMC%	MDD (kN/m2)	CBR (%)	Fine Content %	PI (%)	Abrasion Value (%)
Huttab1	7.12	21.5	38	18	16	36
Huttab2	5.7	22.8	52	13.27	22	42.64
Kadaro	5.8	20.5	15	27	20	Not Performed
Al-Hashaba	7.5	21.4	32	27.46	13	44.9

Table 2: The engineering properties for the four natural gravels before and after compaction methods

Type of Material	Compaction Method	%age Passing (Sieve Size in mm)					CBR%	Bulk Density (kN/m^2)	Dry Density (kN/m^2)	PI%	LS%
		# 10	#5	# 2.36	# 0.425	# 0.075					
Huttb1	Uncompact	72.42	50.02	35.07	22.85	17.72	-	22.45	21.18	20	10
	Impact	72.28	52.16	34.43	19.47	14.11	38	20.73	19.8	18	7.9
	Vibratory	76.67	52.33	34.87	19.63	14.03	10	22.9	21.84	19	8.5
	Gyratory	74.85	52.62	36.86	22.29	17.05	16	22.55	21.26	20	10
Kadaro	Uncompact	87.1	69.8	52.38	33.83	26.18	-	21.69	20.5	19.5	10
	Impact	86.29	68.88	51.03	30.25	21.43	15	22.82	21.569	18.3	10.71
	Vibratory	84.04	66.51	49.12	29.62	20.69	12	20.65	19.52	19	9.3
	Gyratory	89	72	50	31.7	23.78	5	21.085	20.65	19.5	10
Huttab2	Uncompact	78.07	49.12	32.25	18.26	13.27	-	23.405	22.8	22	12.86
	Impact	77.9	55.76	39.16	23.43	14.14	52	23.79	22.57	21	6.43
	Vibratory	74.71	51.8	33.5	21.02	12.914	14	23.264	22.076	22	9
	Gyratory	75.3	51.3	32.3	20.9	12.81	7	22.803	21.64	22	10
Al-Hashaba	Uncompact	90.29	72.65	56.1	37.77	27.46	-	22.95	21.37	13	6.43
	Impact	91.2	77.31	61.21	41.11	29.68	32	22.98	21.37	11	4
	Vibratory	90.41	75.72	59.42	39.72	28.5	31	22.71	21.12	12	5.5
	Gyratory	88.9	72.28	57.08	38.98	28.03	8	23.243	21.62	13	6

The test program in this investigation comprised two activities; Activity I was carried out in the laboratory on samples from the four sources whereas Activity II was a field study applied on three of the samples.

Activity I– Laboratory Testing Program

The four natural unbound gravelly materials (Kadaro, Huttab1, Huttab2 and Al-Hashaba) were used in this activity.

The material from Kadaro is commonly used as selected fill whereas the other three are used as sub-base material. Large quantity from each of the four representative sources samples was supplied in plastic bags to the laboratory. The program was designed to investigate the effect of the different laboratory compaction methods, namely impact, gyratory and vibratory compactionon gradation, plasticity, shrinkage and strength of the four unbound materials.

The testing program included firstly; performing sieve analysis, Atterberg limits and Modified Compaction tests on the four raw samples. Then the materials were watered at their OMC's, batched and compacted in five layers using the impact (Modified Proctor), vibratory and gyratory compaction methods. The test equipment used for compaction comprised Modified impact hammer, the standard vibratory compactor used for sample preparation of resilient modulus test (150 mm diameter) and the laboratory gyratory testing machine. The target density was the "Modified Proctor" maximum dry density. Soaked CBR test was performed on the compacted specimens. Secondly; post sieve analysis, Atterberg limits and Linear shrinkage tests were carried out on the same compacted specimens stated above for the three compaction methods. The initial gradations for the four natural gravels (before compaction) and grain size distribution data after compaction are displayed in Fig.1 and Table 2 whereas the soaked CBR values, plasticity index, linear shrinkage before and after laboratory compaction are arranged in Table 2.

Activity II- Trial Sections

Activity II comprised three different constructed trial sections (TS 1, TS 2 and TS 3), TS 1 was constructed adjacent to Khartoum airport runway shoulder, and TS 2 was at the new extension of Nile Avenue in Khartoum whereas TS 3 was at Um-Bedda ring road in Omdurman. The objective of this activity was to compare the pre and post compaction gradations and index properties to point out the laboratory compaction method which closely simulates field compaction. The sample from Kadaro was used in TS 1, i.e. at Khartoum Airport. The natural gravel for TS 2 was supplied from Huttab2 and it was used as sub-base material in the project. As for TS 3 the natural unbound gravel was transported from Alhashaba quarry for use as sub-base material. The activity was subdivided into field and laboratory programs.

Trial Section TS 1: the field program constituted a section of 7.5 m width and 30 m length, constructed close to Khartoum airport runway shoulders where the sub-grade support soil is predominantly clay (CBR=3%). The sub-grade was scarified, watered and compacted to 95% compaction degree. Two layers of compacted fill, each 150 mm thick were constructed after proper watering of the material to attain the OMC. The field compaction was carried out using 15 ton smooth roller compactor and 20 ton pneumatic roller. A compaction degree of 100% was achieved.

Trial Section TS 2: selected sub-base layer was constructed in a portion of the new Nile avenue of 7.0 m wide and 60 m long over a 20 cm compacted gravel. About 20 cm layer of sub-base of gravel from Huttab2 was laid after being watered at OMC using 20 ton smooth-drummed vibratory roller through 6 passes. The tested field density reported an average value of 99% compaction degree.

Trial Section TS 3: selected subbase layer was constructed in a section 10 m wide and 60 m long in Um-Bedda ring-road. 20 cm layer of Alhashaba fine gravel was laid after being watered at optimum water content using 20 ton smooth- drummed vibratory roller for 8 passes. The average reported compaction degreeis 98%.

Material samples for the Trial Sections were tested before and after field compaction for their gradation, Atterberg limits, linear shrinkage and CBR. Summary of the tests results, the engineering properties for TS 1, TS 2 and TS 3 are given in Table 3 whereas Figs 2-4 show the gradation plots for materials used in TS 1, TS 2 and TS 3 respectively.

4. RESULTS AND DISCUSSION

Activity 1

The prime objective of this activity is to compare the effects of the three laboratory compaction methods on the gradation, plasticity, shrinkage and strength of unbound granular materials from the four different sources.

Table 1 shows the engineering properties for the four natural unbound gravels. Grain size distribution results for the four natural gravels, compared with the two ends of TRL GB3 base gradation are shown in Fig. 1. It is observed that Huttab2 gradation fitted well within the TRL GB3 base gradation ends whereas Huttab1, Kadaro and Al-Hashaba shifted towards the finer side.

To study the impact of the different compaction methods on the gradation of the four natural materials, the accumulated percentage retained on 5 mm sieve (gravel size), and accumulated particles that passed 5 mm sieve and retained on 0.075 mm sieve (sand size) as well as the percentage passing 0.075 mm sieve (fine size) were computed and presented inTable 4 for the natural materials and the compacted specimens after different compaction methods. The table reflects the changes in particle size caused by each compaction method compared to the natural material for different sizes and enables differentiating their products into gravel, sand and fines zones.

For a more detailed evaluation and comparison, additional exercise was performed using the resulted ratios for the total coarse particles retained by weight on 2.36 mm sieve to the total weight of the dry sample (Table 5) aiming at observing the decrease of these ratios caused by the three compaction methods when compared to that measured before, after laboratory compaction and after construction. Table 6 presents the percentage retained by weight on 0.075 mm sieve (gravel and sand sizes) to the total weight of the dry material for the four natural gravelly samples in the investigation before and after compaction. The effect of the compaction methods will be evaluated separately for each material.

Table 3: The engineering properties for the three natural gravels before and after compaction

Type of Material	Compaction Method	Percentage Passing (Sieve Size in mm)					Bulk Density (kN/m^2)	Dry Density (kN/m^2)	PI%	LS%
		# 10	# 5	# 2.36	# 0.425	# 0.075				
Kadaro	After Construction	91.03	74.42	53.7	33.61	25.38	20.705	21.569	14	6.43
	Impact	86.29	68.88	51.03	30.25	21.43	22.82	21.569	18.3	10.71
	Vibratory	84.04	66.51	49.12	29.62	20.69	20.65	19.52	19	9.3
	Gyratory	89	72	50	31.7	23.78	21.085	20.65	19.5	10
Huttab2	After Construction	74.554	47.689	32.36	22.35	16.65	22.91	22.12	21	10
	Impact	77.9	55.76	39.16	23.43	14.14	23.79	22.57	21	6.43
	Vibratory	74.71	51.8	33.5	21.02	12.914	23.264	22.076	22	9
	Gyratory	75.3	51.3	32.3	20.9	12.81	22.803	21.64	22	10
Al-Hashaba	After Construction	88.96	72.05	56.45	35.31	26.1	22.91	21.156	13	6.43
	Impact	91.2	77.31	61.21	41.11	29.68	22.98	21.37	11	4
	Vibratory	90.41	75.72	59.42	39.72	28.5	22.71	21.12	12	5.5
	Gyratory	88.9	72.28	57.08	38.98	28.03	23.243	21.62	13	6

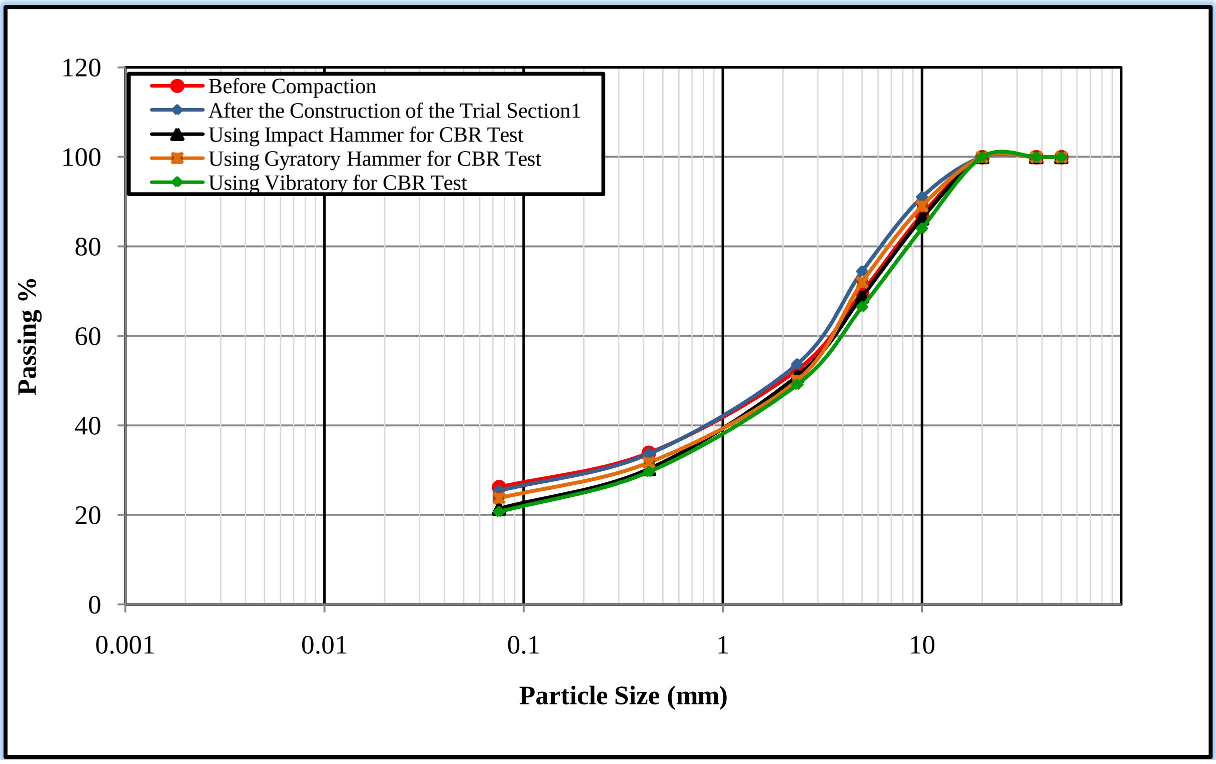

Fig.2. Grain size distribution for Kadaro natural unbound used in trial section1 before/after construction and for the three compaction methods.

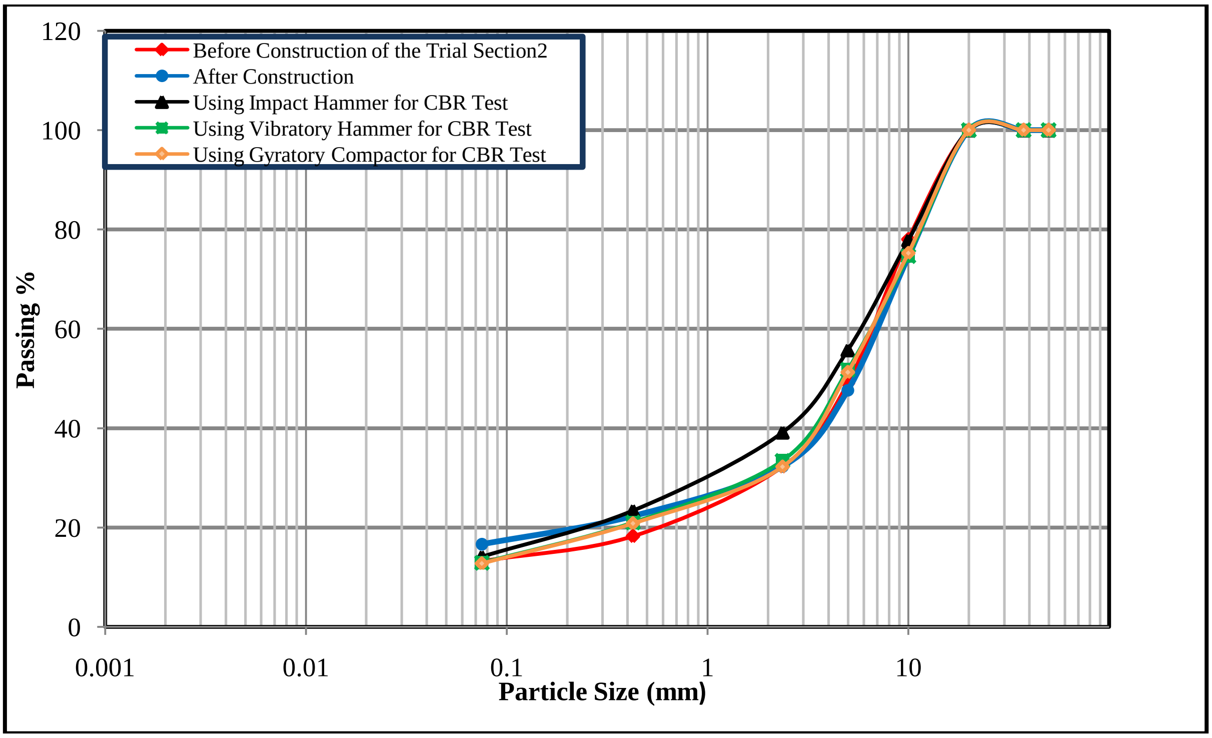

Fig.3. Grain size distribution for Huttab2 natural unbound used in the trial section 2 before/after construction and for the three compaction methods.

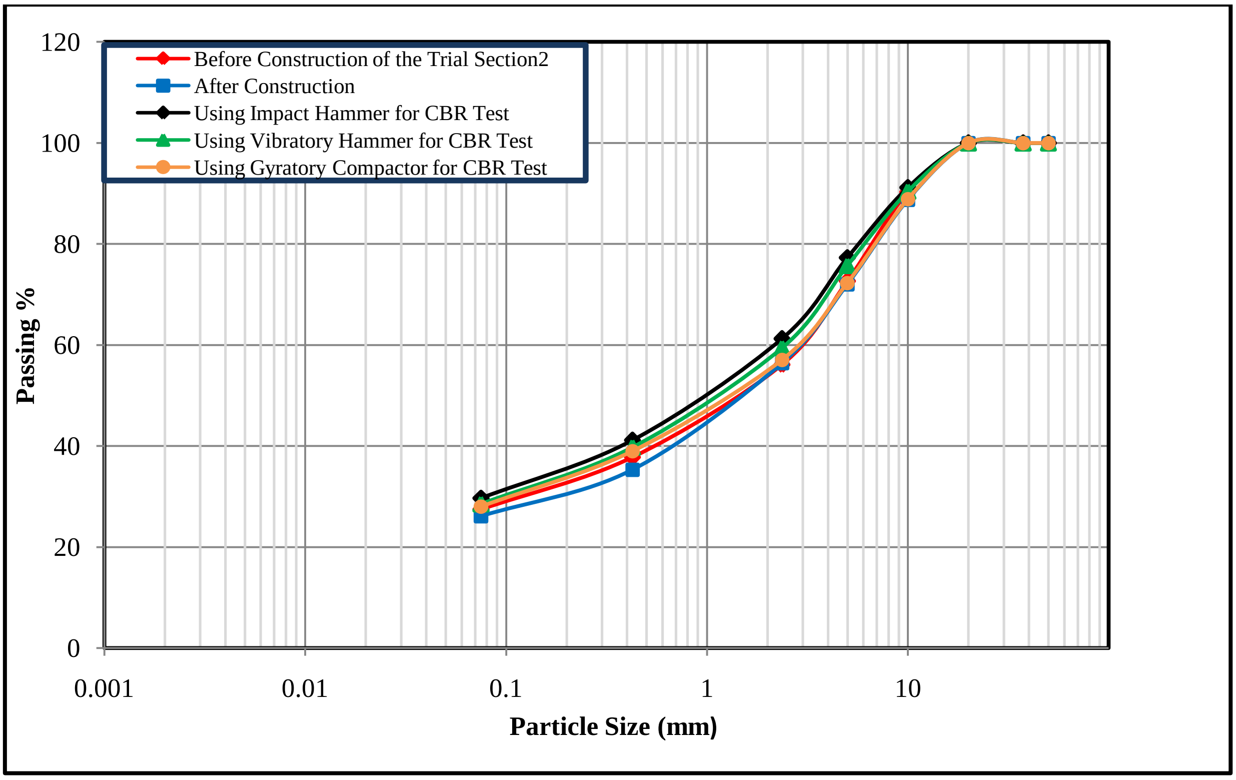

Fig.4. Grain size distribution for Al-Hashaba natural unbound used in the trial section 3 before/after construction and for the three compaction methods.

Table 4: Measured percentage retained by weight for the four natural unbound materials (retained on 5.0, 0,075 mm sieve and pan)

Natural Material	PercentageRetained	Soil Zone(Size)	Before Construction	After Construction	Impact Method	Vibratory Method	Gyratory Method
Huttab1	% Rt. On 5.0mm	Gravel	49.98	-	47.84	45.58	47.4
	% Rt. On 0.075mm	Sand	32.3	-	38.05	36.62	35.57
	% Rt. On Pan	Fines	17.72	-	14.12	17.81	17.06
Kadaro	% Rt. On 5.0mm	Gravel	30.2	25.6	31.1	33.49	28
	% Rt. On 0.075mm	Sand	43.7	49.05	47.44	45.82	48.47
	% Rt. On Pan	Fines	26.2	25.38	21.42	20.69	23.52
Huttab2	% Rt. On 5.0mm	Gravel	50.88	52.31	44.24	48.2	48.74
	% Rt. On 0.075mm	Sand	35.85	31.03	41.61	38.89	38.45
	% Rt. On Pan	Fines	13.27	16.66	14.15	12.92	12.81
Al-Hashaba	% Rt. On 5.0mm	Gravel	27.4	27.94	22.68	24.28	27.71
	% Rt. On 0.075mm	Sand	45.2	46.4	47.6	47.22	44.24
	% Rt. On Pan	Fines	27.4	26.05	29.68	28.5	28

Table 5: Resulted ratios for total retained weight of coarse particles on 2.36 mm sieve to the total weight of the dry sample (before, after laboratory compaction, and after compaction)

Type of Material	Before Compaction	After Construction	After Impact Hammer	After Vibratory	After Gyratory	Application
Huttab1	0.645	-	0.656	0.623	0.631	Laboratory only
Huttab2	0.677	0.676	0.61	0.665	0.677	Trial Section1
Kadaro	0.476	0.463	0.49	0.509	0.53	Trial Section2
Al-Hashaba	0.439	0.435	0.388	0.406	0.43	Trial Section3

Table 6: Total retained percentage on 0.075 mm sieve for the coarse particles (gravel &sand) to the total weight of the dry sample

Type of unbound material	Before Construction (un-compacted)	After Construction	After Impact Hammer	After Vibratory Hammer	After Gyratory Compactor
Huttab1	82.38%	---	85.89%	85.746%	82.95%
Huttab2	86.73%	83.345%	85.85%	87.09%	87.2%
Kadaro	73.82%	74.62%	78.57%	80.25%	76.48%
Al-Hashaba	72.61%	74.6%	70.2%	71.48	72.04%

Huttab1: Fig. 5 shows that the gradation curve after gyratory compaction coincides well with Huttab1 gradation curve before compaction. The gradation after vibratory compaction showed slight diversion in 10 mm sieve size that could be attributed to the breakdown of coarse particles caused by the high vibration pulses induced by the hammer plate when pressing the projected coarse particles when levelling the top of each layer of the specimen.The impact hammer gradation is slightly shifted towards the coarser side.

Table 4 reads the computed percentage of the retained weights on 5 mm, and 0.075 mm sieves and that passing 0.075 mm for Huttab1 before and after the three compaction methods. It is observed that the sample after vibratory compaction computed a decrease of 4.4% in the retained weight lower than that measured by the un-compacted sample due to the break-down of the coarse particles during levelling as stated above whereas the remaining two compacted samples (impact & gyratory methods) exhibited slight breakage in gravel size and gave a decrease of 2.4% in the retained weight compared to that measured by the un-compacted material.

For sand size (5.0-0.075 mm) it can be noted that the gyrated sample measured the closest percentage retained by weight to the un-compact while the impact method resulted in the highest difference (an increase of 5.75% of retained by weight). This is attributed to the break-down of coarse particles.

Fines zone is denoted by the percentage passing 0.075 mm sieve. It is interesting to note that the gyrated and vibrated samples gave the same percentage of retained by weight that was experienced by the un-compact material.

Table 5 results displayed that Huttab1 gyrated sample obtained the closest ratio to the un-compact materials compared with the two other methods whereas Table 6 shows that the gyrated sample obtained the same percentage retained as compared with the un-compacted (82%). The impact hammer method attained the highest CBR value (38%) compared to the gyratory and vibratory methods (more than twice). The high strength that resulted from the impact method could be attributed to the breakage of coarse particles upon sample preparation process which consequently improved the gradation after compaction. It can be summarized that the gyratory compaction method experienced less effect in breaking Huttab1 unbound gravel compared to the vibratory and impact ones.

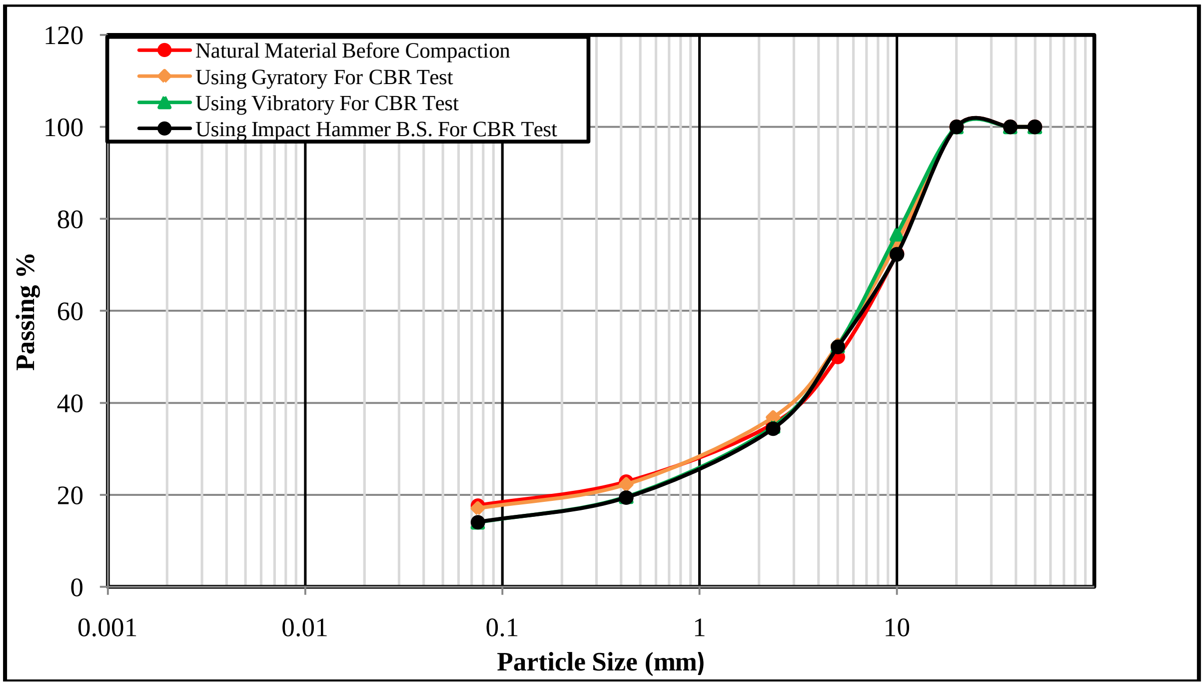

Fig.5. Grain size distribution for Huttab1material before and after CBR test for the three compaction methods

Kadaro: The gradation results are plotted in Fig. 2 and tabulated in Table 2. It can be noted that the gradation plot measured by the gyratory method exhibits slight convergence in the coarse zone and remarkable in the fine zone to the reported gradation before compaction.

Table 4 presents the percentage retained by weight on 5.0 mm, 0.075 mm sieves and pan for Kadaro. The results showed that in the gravel area only the gyrated sample measured less percentage than un-compacted sample whereas the other two compaction methods samples measured greater than the un-compacted sample.This could be reasoned by the high amount of fines which physically provide soft media surrounding the coarse particles reducing the compaction pulses (no tangible breakage). In the sand area (passing 5.0 mm and retained on 0.075mm sieves) the three compaction samples reported slightly higher percentage compared to the un-compacted samples. In the fines zone the gyrated samples measured close to that obtained by the un-compacted material.

Table 5 showed that the three compacted samples obtained higher values of percentage retained by weight on 2.36 mm sieve than that resulted by the un-compacted sample. Table 6 indicated that Kadaro gyrated sample measured the closest percentage. The laboratory compaction results show insignificant change in plasticity index, linear shrinkage and fines content after gyratory compaction method whereas the impact and the vibratory compaction methods gave slight change in plasticity index and linear shrinkage and decrease in fines content.

The measured CBR “by impact compaction” for the natural material is 15%. The vibratory compactor sample measured CBR value equals 12% whereas the gyratory compaction sample gave a CBR of only 3%. The CBR tests were repeated for confirmation and very slight difference was noticed. Given the fact that the samples were compacted at the same OMC and MDD (Table1), the high CBR value measured for the impact and vibratory samples is attributed to the breakage of coarse particles upon sample preparation process consequently improved the gradation after compaction.

As general, from Table 6, it can be noted that the gyrated Kadaro sample closely represents the un-compacted material compared with the other compaction methods.

Huttab2: The gradation results are plotted in Fig. 3 and tabulated in Table 2 gradation results are summarized in Table 2. The gradation after gyratory compaction method plotted the closest curve to before compaction gradation plot. The gradation after vibratory compaction fitted to some extend well with before compaction but it experienced slight increase in passing percentage 2.36 mm sieve that could be attributed to the break-down of few coarse particles as reasoned in Huttab1. The impact hammer gradation is slightly shifted towards the finer side with an average increase of 3.9 in percentage passing compared to before compaction curve.
Table 4 gives the measured percentage retained by weight on 5.0, 0.075 mm sieves and pan for Huttab2. The results show that in the gravel area the gyrated sample gives the closest percentage to the un-compacted material while the impact sample determined the largest difference with a decrease of 6.64% due to the breakage of coarse particles. In sand area (passing 5.0 mm and retained on 0.075mm sieves) the gyrated sample gave the closest percentage of the retained value to un-compact sample whereas the impact method sample did the opposite. In the fines zone the gyrated and vibrated samples measured close to that obtained by the un-compacted material.

Table 5 shows that the gyrated sample measured the same ratio value of the percentage retained by weight on sieve 2.36 mm compared to the un-compacted sample (0.677) whereas the impact one computed smaller ratio (0.61) due to the break-down of coarse particles. Table 6 also shows that the gyrated sample reported almost the same ratio compared to the un-compacted sample whereas it was different for the impact method as a result of breakage of the coarse particles.

The impact hammer method attained the highest CBR value (52%) compared to the vibratory and gyratory methods which measured 14% and 7% respectively (more than three times). The high strength that resulted from the impact method could be attributed to the breakage of coarse particles upon sample preparation process by adding the broken fragments into the sample consequently improved the gradation after compaction.

The laboratory compaction results show almost insignificant change in plasticity index, linear shrinkage and fines content after gyratory compaction method whereas the impact and the vibratory compaction methods gave slight change in plasticity index and linear shrinkage, and increase in fines content only after impact method.

As general, based on the gradation results, it is apparent that the impact hammer method had high influence on degradation of Huttab2 gravel whereas the gyratory exhibited low effect.

Al-Hashaba: The gradation test results are shown in Table 2 and Fig. 4. Table 4 gives the measured percentage retained by weight on 5.0, 0.075 mm sieves and pan for Al-Hashaba. The results showed that in the gravel area the gyrated sample gave the closest percentage to the un-compacted material while the impact sample determined the largest difference with a decrease of 4.72% due to the breakage of coarse particles. For the sand size, the gyrated sample gave the closest percentage of the retained value to the un-compacted sample whereas the impact sample gave the opposite. In the fines zone the gyrated sample was closer to the un-compacted material.

Table 5 shows that Al-Hashaba gyrated sample measured almost the same ratio of the percentage retained by weight on sieve 2.36 mm compared to the un-compacted sample whereas the impact one gave the smallest ratio, due to the break-down of coarse particles. The computed ratio by gyrated sample of the percentage retained on 0.075 mm sieve (Table 6) is the same as that for the un-compacted sample whereas the impact percentage retained was different due to the breakage of the coarse particles.

The impact hammer method measured the highest CBR value (32%) compared to the vibratory and gyratory methods which gave 31% and 8% respectively. The high strength that resulted from the impact method could be attributed to the breakage of coarse particles upon sample preparation process. The laboratory compaction results show almost insignificant change in plasticity index, linear shrinkage and fines content for the gyrated sample whereas the impact and the vibratory compaction methods showed slight change in plasticity index and linear shrinkage, and tangible increase in fines content for the impact method. As general, based on the gradation results of Al-Hashaba the impact hammer method caused degradation of Al-Hashaba gravel whereas the gyratory compaction had very low effect.

Activity II: Trial Sections

The pilot objective of this activity is to compare the effects of different laboratory compaction methods, namely impact, vibratory and gyratory compaction on the physical properties, and strength of natural unbound aggregates that used in the construction of the three trial sections and to find out the compaction method which better simulates field compaction conditions. The same evaluation trends that were used in activity I are applied in activity II.

Trial Section TS 1

Fig. 2 and Table 2 give the laboratory test results for Kadaro material before and after laboratory and field compaction. It is important to observe that Kadaro material has high fines content. The laboratory compaction results show almost insignificant change in plasticity index, linear shrinkage and fines content after gyratory compaction method whereas the impact and the vibratory compaction methods gave slight change in plasticity index and linear shrinkage and decrease in fines content. The plasticity index decreased or improved after field compaction. This improvement may be attributed to the break-down and trimming of the natural material during motor grading and compaction.

Table 4 shows the measured percentage retained by weight on 5.0, 0.075 mm sieves and pan for Kadaro. The results showed that in the gravel band the three compaction methods measured greater amounts compared to the after construction material. In the sand band the three compaction samples reported less amounts compared to the after construction sample but the gyrated sample gave the closest percentage of the retained value to the un-compacted sample. The impact method measured close to the after construction sample. In the fines band the gyrated samples measured the closest percentage to that obtained after construction.

Table 5 shows that the three compacted samples obtained slightly higher percentage values (retained on 2.36 mm sieve) than what resulted before and after construction. Table 6 indicates that Kadaro gyrated sample measured the closest percentage (retained on 0.075 mm sieve) to that reported by the after construction sample.

As general and from Table 6 it can be noted that the gyrated Kadaro sample resembles better the field compaction compared to the other methods. It is concluded from the above that none of the three compaction techniques closely simulated the field compaction for this particular material, however, from the overall measured results the gyratory compaction method was the closest to the field conditions. The field compaction caused breakage of the coarse aggregates resulting in the observed degradation and the substantial reduction in plasticity.

Trial Section TS 2

The second trial section as stated above was executed from Huttab2 natural unbound gravel. Fig. 3 shows the resulted gradation plots for Huttan2 material before, after laboratory compaction and after construction whereas Table 3 presents the engineering properties for Huttab2 natural after the construction as well as after the three compaction methods. The resulted plasticity index and the shrinkage limit values for the executed section are the same values that obtained when using the gyratory compaction method; this could emphasize the suitability of the named method for simulating the field conditions when compared with the two other ones.

Table 4 gives the measured percentage retained by weight on 5.0, 0.075 mm sieves and pan for Huttab2. The results showed that in the gravel band the gyrated sample gave the closest % to the after construction material while the impact sample demonstrated the largest difference with a difference drop of 8% due to the breakage of coarse particles. In the sand band, the gyrated sample gave the closest percentage of the retained value to the after construction sample whereas the impact method gave the opposite. In the fines zone the three compaction samples measured slightly less than that reported by the after construction material. Table 5 shows that Huttab2 gyrated sample computed the same ratio which is obtained by the after construction sample whereas the impact one measured the smaller ratio (0.61) due to the break-down of coarse particles. Table 6 also demonstrated that the gyrated and vibrated samples measured close to what was reported after construction. In general, based on the gradation results of Huttab2 it is apparent that the impact hammer method had high influence on degradation of Huttab2 gravel whereas the gyratory had the lowest.

Trial Section TS3

The third trial section as stated above was constructed from Al-Hashaba natural unbound gravel. Fig. 4 shows the resulted gradation plots for Huttan2 material before, after laboratory compaction and after construction whereas Table1gives the resulted plasticity index and the linear shrinkage values for the executed section which are the same computed values that were obtained by the gyratory compaction method. Table 4 gives the measured percentage retained by weight on 5.0, 0.075 mm sieves and pan. The results showed that in the gravel band the gyrated sample gave the same percentage to the after construction material while the impact sample demonstrated the largest difference with a decrease of 5.26% due to the breakage of coarse particles. In the sand band the gyrated samples gave the closest percentage of the retained value compared to the after construction samples while the impact method showed the opposite. In the fines band the gyrated sample also measured the closest percentage to what was obtained after construction. Table 5 and Table 6 results support the above findings.

Finally from the laboratory and field investigations reported in this paper it can be noticed that the gyratory compaction method better simulates the field conditions when compared to the vibratory and impact methods with the impact method showing the greatest variation from the field conditions.

5. CONCLUSIONS

This paper evaluated the effect of different compaction methods on the gradation, strength and physical properties of unbound gravelly soil materials obtained from quarries in the vicinity of Khartoum. The materials in this investigation are colluvial deposits originally conglomerates belonging to Nubian Sandstone Formation. Four materials were selected and sampled to cover different gradations (coarse, medium and fine gradations). The fine gradation was represented by two gravelly materials (from Kadaro and Al-Hashaba) and the medium gradation material from Huttab1whereas the semi-coarse material was obtained from Huttab2. The four unbound materials were tested in their natural state and were subjected to three compaction methods in the laboratory namely; impact, vibratory and gyratory compaction.The gradation, plasticity and linear shrinkage were measured before and after compaction. The strength was assessed by the CBR test for Huttab1, Huttab2, Kadaro and Al-Hashaba samples.

Three trial sections were constructed in three different sites; the objective was to find out the effect of field compaction on the gradation and engineering properties of the tested material and the laboratory test method which better simulates field conditions. The important findings of the field and laboratory test campaigns could be summarized in the following points:

- The impact compaction generally resulted in breakage of the coarse aggregates and increase in fines content for the four natural materials. The effect on gradation was lesser for the fine material.
- The vibratory compaction caused minor changes to the gradation of the materials stated above whereas the impact method caused major changes. The effect of the gyratory compaction method on gradation was minor for the four materials compared to the two other compaction methods.
- The impact compaction caused decrease in plasticity index and linear shrinkage of the four materials. The effect of the vibratory compaction method on the mentioned properties was less noticed when compared to impact method. No remarkable effect was observed on plasticity index and linear shrinkage by gyratory method.

The impact compaction resulted in high strength (CBR) values for all the natural materials compared to the other two compaction methods. This could be attributed to the better particles' interlocking that was enhanced by the produced broken pieces when the impact hammer was used. The gyratory compaction reported the lowest strength values for Huttab2, Kadaro and Al-Hashaba natural gravels. Very low CBR strength value was reported for gyratory compacted fine material from Kadaro. It is evident from this study that the three laboratory compaction methods give different strength values for the unbound materials tested.

Generally the trial sections tests showed that the gyratory compaction method gave close simulation of the field compaction, and therefore the strength values from the gyrated samples could be regarded as representative of the field conditions. Consequently, the strength values given by the impact compaction, which is used as a standard compaction method for the CBR test in the laboratory, could lead to great over-estimation of the strength of field compacted samples for the same placement conditions, i.e. density and water content.

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