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RESEARCH PAPER

Swell and Shrinkage Percentages for Various Soil Types and their Prediction from Intrinsic Soil Properties

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ABSTRACT:

Earthwork construction involves excavation, hauling, placing and compaction of soil, gravel, and other materials that exist on the soil surface. The soil volume varies depending whether the soil is bank, loose or compacted material. Therefore, the final generated volume of earthwork should be adjusted for volume changes during the above states by applying shrinkage and swell-correction percentages. Estimating these correction factors by engineering expertise or selecting predetermined tables without extensive knowledge of the local soils has proven to be costly and may be misleading. Accordingly, the current study was initiated to develop the database of swell/ shrinkage percentages for various soil materials and link them to other soil properties. Standard procedures were applied for determining soil density at different states along with the physical, chemical and geotechnical properties for soils obtained from 39 surveyed projects within and on the outskirts of Erbil city. The obtained data were subjected to different statistical analysis and the results indicated that the swell percentage ranged from 36.10 -55.7% for clays, 18.40 – 69.20% for silts and 11.90 – 54.5% for gravels. Shrinkage percentage ranged from 9.20 – 16.5% for clays, 4.40 – 20.20% for silts and 0.80 - 23.5% for gravel. Overall, within each group, the swell percent was superior to the shrinkage percent. Additionally, the swell percent was characterized by having a higher coefficient of variation compared to that of shrinkage percent. The in situ soil density and clay content have emerged to be the most effective soil properties for predicting swell percent. On the other hand, the influential variables for predicting shrinkage percent were in situ soil density and the maximum dry density. The mean absolute error of prediction of swell and shrinkage percentages were 6.79 and 1.17 respectively, indicating that shrinkage percent can be predicted more accurately compared with swell percent.

KEY WORDS: Soil volume change; Swelling/shrinkage percentages; Bank site; Soil geotechnical properties.
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1. INTRODUCTION :

Earthwork construction involves excavation, hauling, placing and compaction of soil, gravel and other materials that exist on the soil surface (Cole and Harbin, 2006).

There are many unknowns and assumptions required in estimating the earthwork construction and these make this task is at a great risk (Anupriya, 2018).The earthwork projects having two types of constrains, viz., quantitative (cut or fill volumes, swell shrinkage factors, traveling distance/time and unit cost) and qualitative (access to/on site, road condition etc.) (Li and Lu, 2019).

When soil materials are excavated, it undergoes a change in volume and density. As

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material is loosened, air voids increase and gives rise to a decrease soil density. This increase over the original undisturbed volume is termed swell (Uhlik III, 1984). On the other hand, as the soil is compacted in embankment areas it usually occupies less volume than it did in its bank state. The decrease in volume is known as shrinkage. Shrinkage factor is a parameter that represents soil volume changes from the bank state to the compacted state, while swell factor is a parameter represents soil volume change from bank state to the loose state (White et al., 2010).

Soil shrink factors also affect to overall quantity estimation, which depend on the soil type (Burch, 1997). Increase in swelling factor, increases the volume of the embankment and consequently gives rise to an increase in the demand on fuel and energy (Alzoubi et al., 2017). This factor is always greater than 1 depending on the feature of the excavated floor (Sağlam and Bettemir, 2018). By taking swell, compaction and productivity factors into calculations, the total volume of hauling, back filling and other earthworks can be estimated (Najafi and Gokhale, 2005).

It may be misleading to calculate cut-fill volumes without considering the amount of swelling and/or shrinkage (Göktepe et al., 2008). When estimating the amount of cut and fill, the potential for soil shrinkage and swelling must be taken in account; otherwise, volume calculations to and from the site will not be balanced.

Further, Akiije (2013) has shown that where a shrinkage factor of a given soil is known, it could be used in the computation of fill and cut volumes to amend the required net soil materials while calculating mass haul diagram ordinate.

The determination of the soil properties affecting earthwork optimization, such as swelling/shrinkage factor, is highly ambiguous due to the complex behavior of soils (Göktepe et al., 2008). Therefore, for most of the highway designs, swelling/shrinkage factors are selected from predetermined tables according to specific soil types being considered.

Bannister et al. (1998) gave typical swell and shrinkage factors for certain materials. Garber and Hoel (2010) claimed that shrinkage used are generally between 1.10 and 1.25 for high fills and between 1.20 and 1.25 for low fills in order to determine the required quantity of fill material. Chopra et al. (1999) revealed that adopting factors without extensive knowledge of the local soils has proven to be costly. Usually, these factors are estimated by local engineering expertise or general values presented in handbooks or texts (Martínez et al., 2014), but when working with large soil movements, the values of these parameters have great impacts on planning of activities and associated costs. Thus, their determination will be interesting.

Burch (1997) revealed that understanding these factors for different soil groups and the factors affecting these parameters are significant for accurately predicting quantities and subsequently costs. The swell/shrinkage factors are influenced by the material type (clay, silt, sand, gravel, etc.), in situ moisture content of the material (dry damp, or wet), final moisture content and density of the material and the type of equipment used for excavation and compaction (Helton, 1992).

Shamo (2013) developed a multivariate model to predict the shrinkage factor and observed that 99.9% of variation in this parameter was attributed to variation in clay content, bulk and densities of the borrow material, and the dry and bulk densities of embankment.

In view of the above facts, the current study was initiated to develop the database for shrink/swell percentages for different soil materials and link them to soil physical and geotechnical properties.

2. MATERIALS AND METHODS

2.1. Site Selection and Sample Preparation

Thirty-nine projects were surveyed and selected within and on the outskirts of Erbil city Figure 1 The work also includes obtaining and transporting suitable fill material from off-site when suitable on-site material is not available. A representative sample was taken from each site and has been reduced to the proper size by quartering method. Each sample was thoroughly mixed, air dried and kept in polyethylene bags until use. The soil from each project site was subjected to a battery of tests (geotechnical, physical and chemical) using standard methods.

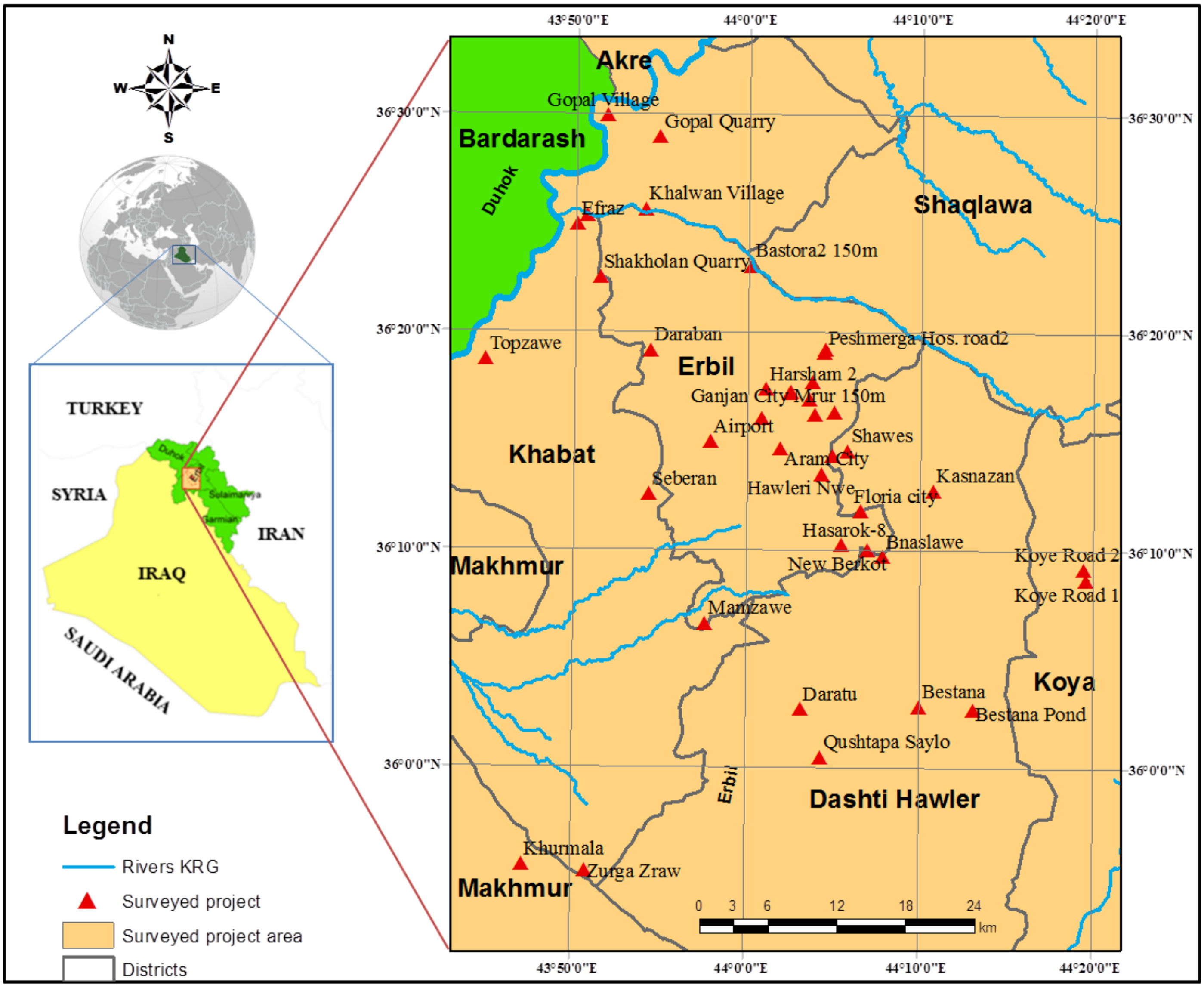

Figure 1: Location map showing the surveyed projects sites

2.2. Measurement of Soil Density at Different States

The bank (in situ) site density was determined for each site in 7 replications using core or sand cone method, depending on soil type and soil condition according to Blake and Hartge (1986) and ASTM (D1556-07, 2007). A unit volume box with a volume of exactly 0.31 cubic meter was also used to determine the soil density under loose conditions. On the other hand, the sand cone method was used for measuring soil density in the compacted state according to ASTM (D1556-07, 2007). The soil density measurement at any of the three states was accompanied by soil moisture determination by gravimetric method.

2.3. Calculation of Shrink/ Swell percentages

The shrinkage percentages was expressed in terms of dry unit weight of two states of soil as follows (Burch, 1997)

$$SF = \left(1 - \frac{\rho_B}{\rho_C}\right) \times 100 \qquad [1]$$

Where
SF = Shrinkage percentages
ρ_B = Density of bank material
ρ_C = Density of compacted material

The swelling (bulkage) was expressed in terms of dry unit weights at loose and in-place states:

$$BF = \left(\frac{\rho_B}{\rho_E} - 1\right) \times 100 \qquad [2]$$

Where:

BF = Bulkage percentages (Swell percentages)

ρ_B = Density of bank material

ρ_E = density of excavated material (in loose state)

2.4. Soil Physical, Chemical and geotechnical Analysis

Sufficient quantity of soil materials were taken according to procedure of granular materials ASTM (C136-06, 2006) and (D6913, 2009) for conducting sieve analysis using a nest of sieves(3, 2.5, 2, 1.5, 1, 0.75, 0.5 inches) along with sieve No.4, 8, 10, 40, 50 and 200.

The compaction characteristics of the soils were determined using modified effort in accordance to ASTM (D1557-12, 2012) and (D2216, 2005).

In addition, the California Bearing Ratio (CBR) was used for evaluating subgrade strength as an aid to the design of pavements. The soil samples were compacted at optimum moisture content using 56, 25, 10 blows per layer (if the C.B.R. for soil at 95% of MDD is required) according to ASTM (D1883-16, 2016) method C in which materials coarser than 19mm sieve compensated by material 0.75 inch (19mm) sieve and retained on No. 4 (4.75mm) sieve. The mold into which the soil was placed has a diameter of 152 mm and a depth of 177 mm.

Atterberg limits were determined in accordance with ASTM (D4318, 2010) after passing the soil materials through the No. 40 (0.425mm) sieve.

Particle size distribution for materials passing through a 2-mm sieve was also determined using hydrometer analysis in accordance with ASTM procedure (D422–63, 2007). Test procedure of ASTM (C127, 2015), (D854-14, 2014) and ASTM (C128, 2012). (Specific Gravity and Absorption of Coarse Aggregate) and (Specific Gravity and Absorption of Fine Aggregate) were followed to determine Specific Gravity of the soil samples.

The pH of the soil extract solution was measured by HANNA pH-meter, Model microprocessor pH meter using the procedure of Jackson (1958). Electrical conductivity of the soil extract solution was measured using EC-meter model BC3020 TRANS and adjusted to 25 °C to give an indication of the total dissolved ions in the solution (Hesse, 1971). The calcium carbonate equivalent which involves the dissolution of carbonate in excess of HCl (1N), followed by back titration with (0.5N) NaOH as described in Rowell (2014). Organic matter was determined by the modified (Walkley and Black) method as described by Jackson (1958).

2.5. Data Analysis

Pearson’s correlation was used to determine the degree of correlation between the dependent variables (Shrinkage and bulkage percentages) and input variables using SPSS program IBM Ver.23. Additionally, linear and non-linear least square techniques were employed to estimate the shrinkage and swell factors from other soil properties using Microsoft Excel 2013 and SPSS.

3. RESULTS AND DISCUSSION

3.1. General Aspects of the Database

Table 1 and 2 an exhibit physical, geotechnical and chemical properties of the investigated sites (projects) along with the classification of the obtained materials according to Unified and AASHTO classification systems. Close examination of Table 1 indicates that soil materials cover fine grained and coarse grained materials with different proportions of fines.

Table 3 exhibits the summary of some statistical parameters of swell and shrinkage percentages belonging to different soil groups. The swell percent ranged from as low as 11.9% for Daratu project to as high as 69.2% for the Harsham 2 project (Table 2). As a whole the swell percent tends to decrease with an increase in gravel content. This result supports the findings of FHWA (2007). According to these findings, the swell percent of common materials ranging from mud to hard rocks varied from as low as 5% for uniformly graded gravel to as high as 79% for shale. The low soil water content in the field may be responsible for the relatively the high swell percent of the investigated soil materials.

Table 1 Some geotechnical properties of the soil materials of the surveyed projects

No.	Locations	Atterberg's Limits			Specific gravity	Absorption	Proctor test		C.B.R (%)	According to USCS system				
		Liquid Limit	Plastic Limit	Plastic Index			MDD (Mg m^{-3})	OMC (%)		Gravel (%)	Sand (%)	Fine (%) < 0.075mm	Silt (%)	Clay (%)
1	Shawes	34	23	11	2.638	0.6	2.277	5	110	69	15	16	7	9
2	Future City	43	28	15	2.717	NA	1.731	15.1	4	1	20	79	30	49
3	Hawleri Nwe	40	28	12	2.609	1.2	2.164	6.6	32.7	47	23	30	12	18
4	Floria city	N.L.L	N.P.L.	N.P.I.	2.621	0.7	2.315	4.9	163.8	65	28	7	4	3
5	Kasnazan	21	N.P.L.	N.P.I.	2.654	0.7	2.369	4.1	196.3	68	27	5	3	2
6	Hasarok-8	31	23	8	2.702	NA	1.907	12	7	9	24	67	41	26
7	New Berkot	28	21	7	2.61	1.3	2.239	6.8	39.4	31	24	45	31	14
8	Bnaslawe	N.L.L	N.P.L.	N.P.I.	2.612	0.9	2.328	4.7	180.7	71	25	4	2	2
9	Koye Road 1	37	29	8	2.543	2	2.238	6.1	113	75	19	6	3	3
10	Koye Road 2	46	35	11	2.525	1.5	1.918	13	15.3	11	22	67	41	26
11	Daratu	45	31	14	2.606	1.2	2.154	7	29.5	62	17	21	14	7
12	Bestana	41	30	11	2.622	0.9	2.274	6.1	95.8	68	13	19	10	9
13	Bestana Pond	38	27	11	2.708	NA	1.782	18.3	7.7	5	12	83	48	35
14	Qushtapa Saylo	32	23	9	2.712	NA	1.775	14.7	8.2	2	10	88	52	36
15	Mamzawe	43	26	17	2.705	NA	1.792	16.2	5.5	2	14	84	39	45
16	Zurga Zraw	22	N.P.L.	N.P.I.	2.599	1.4	2.27	5.8	60.4	72	23	5	2	3
17	Khurmala	24	20	4	2.537	1.6	2.203	6.4	52.1	70	21	9	6	4
18	Seberan	46	31	15	2.601	1.1	2.221	6.1	62.2	49	30	21	10	11
19	Airport	40	25	15	2.703	NA	1.88	14.8	9.2	2	14	84	40	44
20	Daraban	42	26	16	2.711	NA	1.797	15.9	3.3	1	11	88	40	48
21	Topzawe	26	16	10	2.66	0.6	2.317	5.2	144.7	77	17	6	4	2
22	Shakholan Quarry	29	20	9	2.616	1	2.267	5.7	85.6	60	26	14	9	5

Table 1 Continued

No.	Locations	Atterberg's Limits			Specific gravity	Absorption	Proctor test		C.B.R (%)	According to USCS system				
		Liquid Limit	Plastic Limit	Plastic Index			MDD (Mg m^{-3})	OMC (%)		Gravel (%)	Sand (%)	Fine (%) < 0.075mm	Silt (%)	Clay (%)
23	Efraz	26	20	6	2.612	0.7	2.315	5.1	157.2	68	23	9	6	3
24	Gopal Quarry	30	20	10	2.636	0.6	2.304	4.3	134.6	66	28	6	1	5
25	Gopal Village	40	23	17	2.699	NA	1.899	13.4	2.3	8	21	71	30	41
26	Bastora 1	N.L.L	N.P.L.	N.P.I.	2.68	0.3	2.388	3.3	136.8	64	32	4	1	3
27	Khalwan Village	N.L.L	N.P.L.	N.P.I.	2.67	0.2	2.408	3.4	213.5	76	20	4	2	2
28	Bastora2 150m	29	21	8	2.652	1.1	2.328	4.6	121.9	73	18	9	5	4
29	Peshmerga Hosp. road 1	36	25	11	2.714	NA	1.748	18.5	4.9	1	19	80	37	43
30	Peshmerga Hosp. road 2	37	26	11	2.551	1.7	2.078	8.7	12.2	30	17	53	23	30
31	Kalakan Village	49	36	13	2.518	2.2	2.079	8.6	41.2	63	15	22	13	9
32	Mamostayan City	41	29	12	2.713	NA	1.713	17.6	3.3	1	19	80	32	49
33	Kurdistan City	34	24	10	2.547	1.7	2.057	9.3	22.6	40	26	34	15	19
34	Perzin Village	37	24	13	2.613	1.6	2.11	8.7	20.7	63	17	20	11	9
35	Ganjan City	26	19	7	2.663	0.4	2.265	6.2	75.4	56	21	23	10	13
36	Mrur 150m	41	30	11	2.719	NA	1.671	18.5	2.6	0	16	84	36	48
37	Harsham 2	42	31	11	2.723	NA	1.643	18.6	2.2	0	15	85	35	50
38	Libanon Village	35	24	11	2.712	NA	1.796	15.6	3.2	1	17	82	36	46
39	Aram City	42	27	15	2.581	1	2.187	6.9	43.9	63	19	18	9	9
Minimum		24	16	4	2.518	0.2	1.643	3.3	2.2	0	10	4	1	2
Maximum		49	36	17	2.72	2.2	2.408	18.6	213.5	77	32	88	52	50
Average		32.1	21.5	9.3	2.641	1.08	2.082	9.5	62.18	40.8	19.9	39.3	19.3	20.0

N.L.L: Non or without Liquid limit; N.P.L: Non or without Plastic limit and N.P.I: Non or without Plasticity index.

Table 2 Some geotechnical and chemical properties of the soil materials of the surveyed projects

No.	Locations	In situ (Mg m^{-3})	Loose (Mg m^{-3})	Embankment (Mg.m^{-3})	pH	EC (µS cm^{-1})	$CaCO_3$ (%)	O.M (%)	According to USDA			Swell (%)	Shrinkage (%)	C_u	C_c	Unified system	AASHTO system
									Clay (%)	Silt (%)	Sand (%)						
1	Shawes	1.726	1.405	2.189	7.3	549	33.5	0.096	32	20	48	22.8	21.2	5300	120.75	GC	A-2-6
2	Future City	1.574	0.975	1.675	7.26	341	33	0.186	51	27	22	61.4	6	NA	NA	ML	A-7-6
3	Hawleri Nwe	1.837	1.189	2.052	7.55	275	42	0.114	37	29	34	54.5	10.5	7250	1.21	GM	A-2-6
4	Floria city	2.115	1.613	2.203	7.48	259	31.5	0.087	9	12	79	31.1	4	291	10	GP-GC	A-1-a
5	Kasnazan	2.175	1.665	2.281	7.46	202	31.5	0.078	10	10	80	30.6	4.6	30	4.12	GP-GM	**A-1-a**
6	Hasarok-8	1.578	1.165	1.794	7.34	567	32	0.159	29	35	36	35.5	12	NA	NA	ML	A-4
7	New Berkot	1.719	1.495	2.027	7.37	491	32	0.132	22	27	51	15	15.2	333	0.19	GC	A-4
8	Bnaslawe	2.128	1.655	2.305	7.66	117.2	37	0.078	7	11	82	28.6	7.7	63	3.71	GP	A-1-a
9	Koye Road 1	1.838	1.545	2.108	7.58	164.6	35	0.15	14	17	69	19	12.8	60	6.29	GP-GM	A-2-4
10	Koye Road 2	1.451	1.226	1.819	7.51	271	35.5	0.15	31	29	40	18.4	20.2	NA	NA	ML	A-7-5
11	Daratu	1.597	1.427	2.024	7.51	276	29	0.132	23	20	57	11.9	21.1	2986	93.28	GM	A-2-7
12	Bestana	1.819	1.488	2.117	7.38	231	36	0.132	35	21	44	22.2	14.1	7500	533.33	GM	A-2-7
13	Bestana Pond	1.405	1.172	1.708	7.25	418	28	0.168	39	38	23	19.9	17.7	NA	NA	ML	A-6
14	Qushtapa Saylo	1.551	1.140	1.709	7.47	431	32.5	0.168	38	28	34	36.1	9.2	NA	NA	CL	A-4
15	Mamzawe	1.537	0.987	1.72	7.45	618	32.5	0.186	47	36	17	55.7	10.6	NA	NA	CL	A-7-6
16	Zurga Zraw	2.167	1.632	2.222	7.54	158.3	29.5	0.096	12	15	73	32.8	2.5	122	5.58	GP-GM	A-1-a
17	Khurmala	1.878	1.596	2.127	7.46	200	27.5	0.123	14	21	65	17.7	11.7	159	6.36	GP-GC	A-1-a
18	Seberan	1.779	1.465	2.136	7.47	493	32.5	0.132	28	19	53	21.4	16.7	4706	36.03	GM	A-2-7
19	Airport	1.597	1.092	1.805	7.5	418	35.5	0.15	46	33	21	46.2	11.5	NA	NA	CL	A-6
20	Daraban	1.617	1.203	1.691	7.52	345	35	0.168	49	30	21	34.4	4.4	NA	NA	ML	A-7-6
21	Topzawe	2.172	1.678	2.217	7.72	152.4	26.5	0.132	11	13	75	29.4	2	67	5.44	GP-GC	A-2-4
22	Shakholan Quarry	2.143	1.629	2.183	7.63	168	31	0.105	14	14	72	31.6	1.8	1059	5.11	GC	A-2-4

Table 2 Continued

No.	Locations	In situ (Mg m^{-3})	Loose (Mg m^{-3})	Embankment (Mg m^{-3})	pH	EC (µS cm^{-1})	$CaCO_3$ (%)	O.M (%)	According to USDA			Swell (%)	Shrinkage (%)	C_u	C_c	Unified system	AASHTO system
									Clay (%)	Silt (%)	Sand (%)						
23	Efraz	2.145	1.636	2.19	7.62	168.6	35.5	0.096	11	14	75	31.1	2.1	481	7.39	GP-GC	A-1-a
24	Gopal Quarry	2.103	1.528	2.214	7.66	185.5	22	0.078	21	10	69	37.6	5	45	2.35	GW-GC	A-2-4
25	Gopal Village	1.5	1.098	1.79	7.29	254	26.3	0.159	47	21	32	36.6	16.2			CL	A-6
26	Bastora 1	2.286	1.786	2.304	7.83	150.8	23	0.06	10	4	86	28	0.8	83	2.55	GW	A-1-a
27	Khalwan Village	2.301	1.926	2.326	7.7	192.5	24.5	0.069	8	8	84	19.5	1.1	65	6.15	GP-GM	A-1-a
28	Bastora2 150m	2.171	1.679	2.215	7.68	163.1	23.8	0.069	22	15	63	29.3	2	267	20.17	GP-GC	A-2-4
29	Peshmerga Hosp. road1	1.516	0.915	1.664	7.41	260	35	0.195	44	29	27	65.7	8.9	NA	NA	ML	A-6
30	Peshmerga Hosp. road2	1.646	1.158	1.909	7.56	345	40.5	0.141	48	28	24	42.1	13.8	NA	NA	GM	A-6
31	Kalakan Village	1.468	1.192	1.919	7.52	227	45.3	0.168	32	39	29	23.2	23.5	4643	139.08	GM	A-2-7
32	Mamostayan City	1.511	0.952	1.615	7.47	301	31.5	0.186	50	32	18	58.7	6.4	NA	NA	ML	A-7-6
33	Kurdistan City	1.618	1.102	1.89	7.51	294	32.5	0.15	39	30	31	46.8	14.4	NA	NA	GM	A-2-4
34	Perzin Village	1.677	1.354	2.034	7.55	279	42	0.132	31	33	36	23.9	17.6	3556	40.14	GC	A-2-6
35	Ganjan City	1.698	1.286	2.141	7.45	340	35.5	0.114	34	19	47	32	20.7	NA	NA	GC	A-2-4
36	Near Mrur 150m	1.505	0.894	1.591	7.46	299	31.5	0.177	49	30	21	68.3	5.4	NA	NA	ML	A-7-5
37	Harsham 2	1.418	0.838	1.603	7.5	296	32.3	0.204	52	27	21	69.2	11.5	NA	NA	ML	A-7-5
38	Libanon Village	1.446	0.962	1.732	7.49	289	29	0.159	49	25	26	50.3	16.5	NA	NA	CL	A-6
39	Aram City	1.684	1.389	2.04	7.59	255	44	0.123	28	37	35	21.2	17.5	4000	31.60	GM	A-2-7
Minimum		1.4	0.838	1.591	7.25	117.2	22	0.06	7	4	17	11.9	0.8				
Maximum		2.3	1.926	2.326	7.83	618	45.3	0.204	52	39	86	69.2	23.5				
Average		1.8	1.337	1.982	7.5	293.9	32.6	0.133	30.1	23.2	46.7	34.9	10.8				

Table 3 Some Statistical parameters of swelling and shrinkage percentages of the investigated materials during the current study

Soil group	Classification symbol	Parameter	Number of projects	Range	Minimum	Maximum	Mean		Std. deviation	Coefficient of variation	Skewness	Kurtosis
							Statistic	Std. error				
Silt of low plasticity	ML	Shrinkage%	9	15.80	4.40	20.20	10.28	1.87	5.61	54.56	0.85	-0.49
		Swelling %	9	50.80	18.40	69.20	47.94	6.95	20.84	43.47	-0.44	1.40
Clay of low plasticity	CL	Shrinkage%	5	7.30	9.20	16.50	12.80	1.50	3.34	26.13	0.34	-2.85
		Swelling %	5	19.60	36.10	55.70	44.98	3.83	8.57	19.05	0.06	-2.17
Silty gravel	GM	Shrinkage%	8	13.00	10.50	23.50	16.45	1.49	4.22	25.65	0.51	-0.26
		Swelling %	8	42.60	11.90	54.50	30.41	5.37	15.18	49.92	0.61	-1.25
Clayey gravel	GC	Shrinkage%	5	19.40	1.80	21.20	15.30	3.55	7.93	51.83	-1.74	3.16
		Swelling %	5	17.00	15.00	32.00	25.06	3.15	7.05	28.12	-0.50	-0.69
Poorly graded gravel with silt	GP-GM	Shrinkage%	4	11.70	1.10	12.80	5.25	2.62	5.23	99.71	1.57	2.49
		Swelling %	4	13.80	19.00	32.80	25.48	3.62	7.25	28.45	0.08	-5.52
Poorly graded gravel with clay	GP-GC	Shrinkage%	5	9.70	2.00	11.70	4.36	1.87	4.19	96.10	2.02	4.12
		Swelling %	5	13.40	17.70	31.10	27.72	2.54	5.67	20.45	-2.10	4.53
Well graded gravel	GW	Shrinkage%	1				0.80					
		Swelling %	1				28.00					
Poorly graded gravel with clay	GP	Shrinkage%	1				7.7					
		Swelling %	1				28.6					
Well graded gravel with clay	GW-GC	Shrinkage%	1				5					
		Swelling %	1				37.6					

On the other hand, the shrinkage percent varied from a minimum of 0.80 % for Bastora 1 project to a maximum of 23.5 % for Kalakan project. The remaining values were ranged between these values. These observations are in tune with the findings of Nunnally (2011), who observed that the shrinkage percentages for sand and gravel, common earth and clay were 12, 10 and 20%. It is commendable to mention that comparison between the results of the current study to those found in literature is not any easy task. This is due to the fact that different procedures and formulas have been used for determining swell and shrinkage factors (White et al., 2010). As a result the values should be back-calculated using the formulas used in the current study.

Similarly, the shrinkage percent tended to decrease with gravel content. Overall, within each group, the swell percent was superior to the shrinkage percent. Additionally, the swell percent was characterized by having a higher coefficient of variation compared to that of shrinkage percent. By contrast, White et al. (2010), observed that the shrinkage factor varied more than the swell percentages as the shrinkage values are likely influenced by the percent of compaction achieved in the field

It is also evident from Table 3 that the swell percentage ranged from 36.10-55.7% for clays, 18.40-69.20% for silts and 11.90-54.5% for gravels. Shrinkage percentage ranged from 9.20-16.5% for clays, 4.40-20.20% for silts and 0.80-23.5% for gravels. These results are in concordance with the findings of Crooks (2013), who reported that the swell percentage ranged from 30-50 % for clays, 5-40% for gravels. They also indicated that shrinkage percentage ranged from 10-18% for clays, and 5-22% for gravels.

The soil materials of the surveyed projects were categorized into different classes and the results are presented in Figure 2. It is evident from this Figure that the silt of low plasticity has the highest percentage (frequency) and followed by the silty gravel class the second highest. On the other hand, each of poorly graded gravel (GP), well graded gravel and well graded gravel with clayey gravel offered the least percentage (2.56%). Furthermore, no soil material fell in the class of well graded gravel with silty gravel

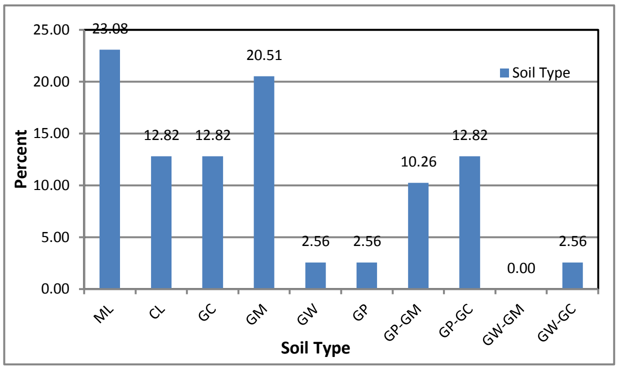

Figure 2: Percent of Projects within soil material groups: ML = Silt of low plasticity; CL = Clay of low plasticity; GC = Clayey gravel; GM = Poorly graded gravel with silt; GW = Well graded gravel; GP = Poorly graded gravel with clay; GP-GM = Poorly graded gravel with silt; GP-GC = Poorly graded gravel with clay; GW-GM= Well graded gravel with silt, and GW-GC = Well graded gravel with clay.

Based on swell and shrinkage percentages, the soils were categorized into different classes and the results are presented in Figure 3 and 4. It is apparent from Figure 3 that the swell class of 30-40 offered the highest frequency followed by the swell class of 20-30. Conversely the swell class of 40-50 offered the least frequency. It was also observed that the shrinkage of 0.0-2.5 offered the highest frequency and followed by the shrinkage class of 10.0-12.5 the second highest. Unlike these classes, the shrinkage of class of 22.5-25.0 offered the least frequency (Figure 4).

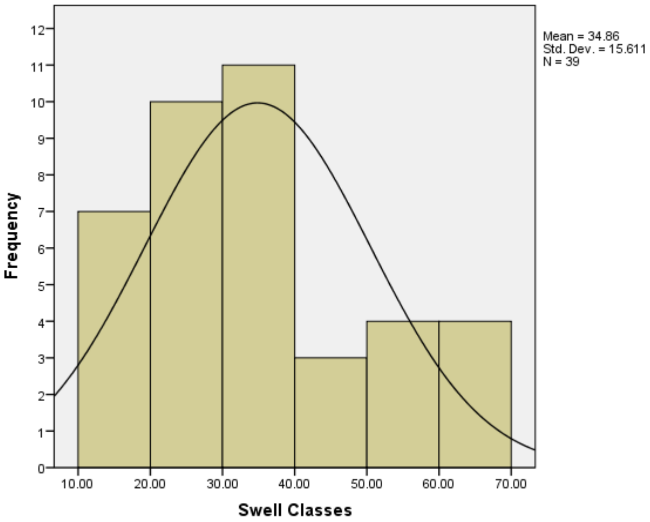

Figure 3: Frequency of soil groups within swell classes

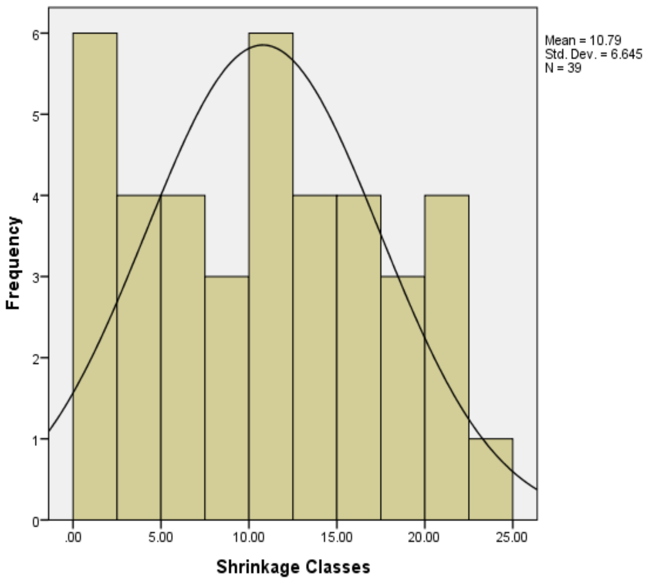

Figure 4: Frequency of soil groups within shrinkage classes

A box-whisker plot was also constructed by drawing a box between the upper and lower quartiles (Figure 5). The upper and lower quartiles were used to calculate the interquartile range, from which the inner and outer fences were created. No value of both swell and shrinkage percentages fell beyond the inner and outer fences on both sides, indicating the neither mild nor extreme outlier exists within the swell and shrinkage data.

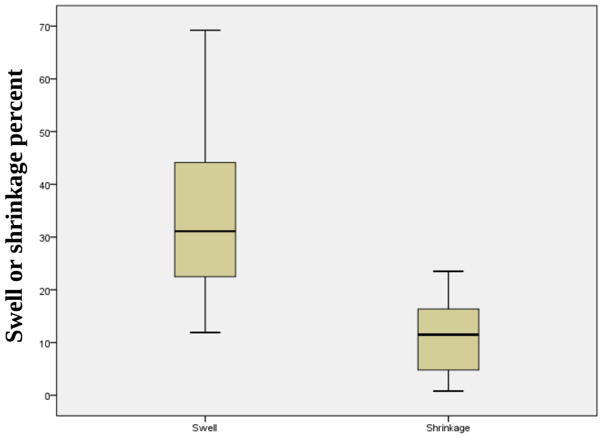

Figure 5: Represention of swell and shrinkage percentages data by Box - Whisker plot.

The Kolomogorv-Smirnov test was conducted to test for the normality of swell and shrinkage percentages. The K-S statistics for these two variables were 0.148 and 0.110 respectively. Both of these values were less than the critical D (0.035, 39) =0.21, indicating these data did not differ significantly from that which is normally distributed.

Prior to model building for predicting swell and shrinkage percentages, Pearson correlation analyses was conducted as a guide or simple sensitivity analysis to identify the influential factors affecting the overall response variables. Table 4 displays the correlation matrix for the study variables. As it can be seen in this Table, among the study input variables, the in situ soil density was negatively and very high significantly ($P \leq 0.01$) correlated with shrinkage percent, followed by CBR. It can be also noticed from Table 4 that both soil density in the loose state and specific gravity were negatively and high significantly ($P \leq 0.05$) correlated with shrinkage factors. Unlike these input variables, the remaining input variables were not significantly correlated with shrinkage factor. In addition, it was noticed the soil density at the loose state offered the strongest correlation with swell factor ($r = -0.720$) followed by maximum dry density ($r = -0.666$). Similarly, most of the remaining input variables were very high significantly ($P \leq 0.01$) correlated with the swell percent. It is commendable to mention the intercorrelation between the input variable were also displayed as a guide to avoid multicollineartly problem during model calibration.

3.2. Model Calibration

A trial was made to predict swell percent and shrinkage percentages separately from other soil attributes using linear multiple regression. The all possible cases algorithm was followed to specify which predictor variables were to be included in the regression equations. The variables which did not give rise to a considerable improvement in the accuracy of prediction were deleted.

It was discerned that among the developed models, Models 1and 2 offered the best performance for predicting the swell and shrinkage percentages respectively (Not shown here). According to our findings, the in situ soil density and clay content have emerged to be the most effective soil properties for predicting swell percent. On the other hand, the influential variables for predicting shrinkage percent were in situ soil density and the maximum dry density obtained from the laboratory tests.

Table 4 Correlation matrix showing the relationship among some selected input and response variables

Variables	Variables													
	In situ density (Mg m^{-3})	Loose density (Mg m^{-3})	Embankment density (Mg m^{-3})	Specific gravity	MDD (Mg m^{-3})	OMC (%)	CBR (%)	Gravel (%)	Sand (%)	Fine (%) < 0.075 mm	Silt (%)	Clay (%)	Swell (%)	Shrinkage (%)
1. In situ density (Mg m^{-3})	1	0.901**	0.883**	-0.209	0.843**	-0.813**	0.886**	0.779**	0.560**	-0.811**	-0.801**	-0.773**	-0.357*	-0.675**
2. Loose density (Mg m^{-3})	0.901**	1	0.938**	-0.406*	0.923**	-0.892**	0.860**	0.869**	0.473**	-0.880**	-0.798**	-0.903**	-0.720**	-0.379*
3. Embankment density (Mg m^{-3})	0.883**	0.938**	1	-0.480**	0.987**	-0.970**	0.866**	0.939**	0.549**	-0.956**	-0.909**	-0.945**	-0.632**	-0.252
4. Specific gravity	-0.209	-0.406*	-0.480**	1	-0.543**	0.587**	-0.217	-0.603**	-0.296	0.605**	0.529**	0.638**	0.566**	-0.327*
5. MDD (Mg m^{-3})	0.843**	0.923**	0.987**	-0.543**	1	-0.986**	0.834**	0.942**	0.540**	-0.958**	-0.901**	-0.955**	-0.666**	-0.191
6. OMC (%)	-0.813**	-0.892**	-0.970**	0.587**	-0.986**	1	-0.791**	-0.940**	-0.553**	0.958**	0.906**	0.951**	0.653**	0.157
7. CBR (%)	0.886**	0.860**	0.866**	-0.217	0.834**	-0.791**	1	0.788**	0.463**	-0.803**	-0.785**	-0.775**	-0.435**	-0.465**
8. Gravel (%)	0.779**	0.869**	0.939**	-0.603**	0.942**	-0.940**	0.788**	1	0.400*	-0.989**	-0.952**	-0.965**	-0.639**	-0.138
9. Sand (%)	0.560**	0.473**	0.549**	-0.296	0.540**	-0.553**	0.463**	0.400*	1	-0.533**	-0.534**	-0.500**	-0.146	-0.287
10. Fine (%) < 0.075 mm	-0.811**	-0.880**	-0.956**	0.605**	-0.958**	0.958**	-0.803**	-0.989**	-0.533**	1	0.966**	0.973**	0.614**	0.174
11. Silt (%)	-0.801**	-0.798**	-0.909**	0.529**	-0.901**	0.906**	-0.785**	-0.952**	-0.534**	0.966**	1	0.880**	0.443**	0.237
12. Clay (%)	-0.773**	-0.903**	-0.945**	0.638**	-0.955**	0.951**	-0.775**	-0.965**	-0.500**	0.973**	0.880**	1	0.730**	0.108
13 Swell (%)	-0.357*	-0.720**	-0.632**	0.566**	-0.666**	0.653**	-0.435**	-0.639**	-0.146	0.614**	0.443**	0.730**	1	-0.268
14. Shrinkage (%)	-0.675**	-0.379*	-0.252	-0.327*	-0.191	0.157	-0.465**	-0.138	-0.287	0.174	0.237	0.108	-0.268	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

To investigate the degree of agreement between the observed and predicted values, the predicted values from each of M1 and M2 were plotted versus the observed values of the swell and shrinkage percentages in relation to line 1:1 (Figure. 6 and 7). As it can be seen from Figure 6 that there is considerable scattering over the whole range of swell percent. The variation in in situ soil density and clay content in Model 1 explained about 64% variation in swell percent. In contrast, there is a limited scattering over the whole range of shrinkage percent (Figure 7). Furthermore, the results indicated that more than 95% of variation in shrinkage percent can be attributed to variations in in situ soil density and maximum dry density. In a similar study by Shamo (2013), it was observed that the bulk bank density, the dry bank density, the dry embankment density and the dry embankment density accounted for 99.5% of variation in shrinkage factor.

Additionally, the plot of residuals of predicted swell from M1 indicated that the employed data were normally distributed (Figure 8). The same conclusion was drawn as the residual of the predicted shrinkage percent values were plotted versus the observed values (Figure 9).

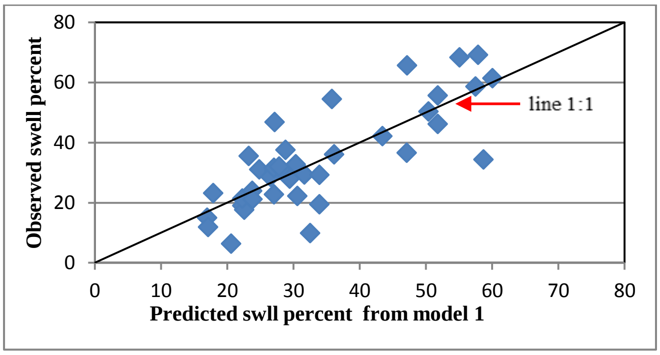

Figure 6: Plot of observe shrinkage percent predicted shrinkage percent from model 1

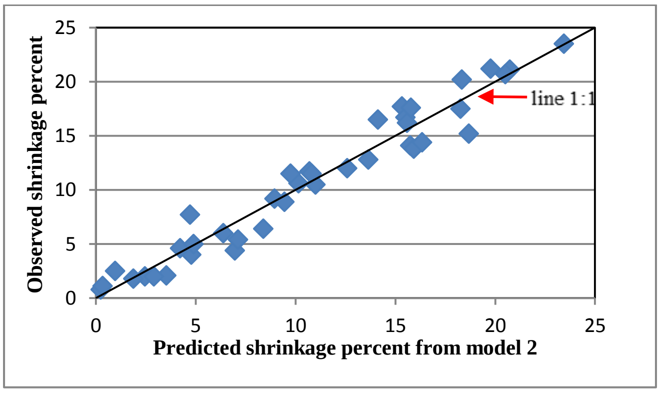

Figure 7: Plot of observed shrinkage factor versus predicted values from model 2

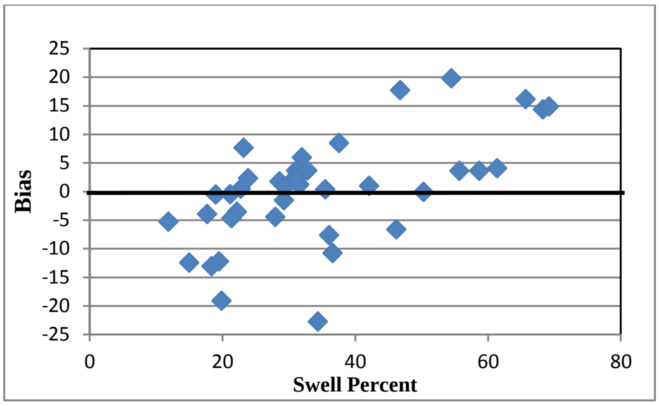

Figure 8: Plot of bias versus observed swell percent

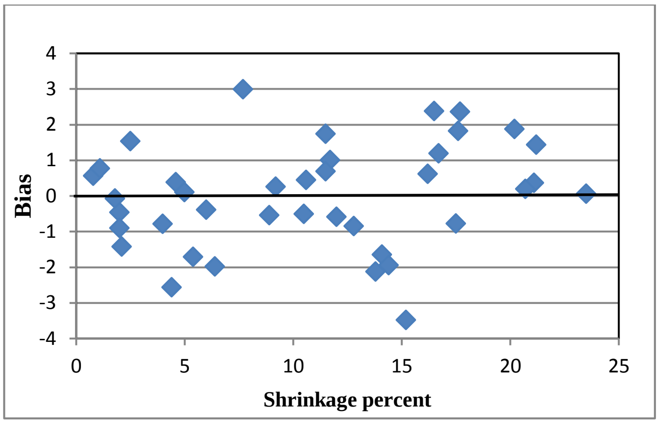

Figure 9: Plot bias versus observed shrinkage percent

3.3. Evaluation of the Models Performance

To further confirm the results, a host of performance indicators pertinent with Models 1 and 2 were calculated and depicted in Table 5. It is worth to note that there was a steady increase in R2 with increase in number of regressors beyond 2 (not shown here to save space), but this was not observed for adjusted coefficient of determination (R^2adj). The mean absolute error of prediction of swell and shrinkage percentages were 6.79 and 1.17 respectively, indicating that shrinkage percent can be predicted more accurately compared with swell percent.

Close inspection of Table 5 and judging from mean biased error (MBE) and coefficient of residual mass (CRM) indicated that Models 1 very slightly underestimated the overall swell percent, while model 2 neither overestimated nor underestimated the shrinkage percent.

Judging from mean absolute percentage error (MAPE), Models 1 and 2 enlisted in Table 5 fell within the” forecast potentially reasonable “ and ” forecast potentially good “ respectively (Lewis, 1997).

Table 5 The proposed models for predicting swell and shrinkage percentages of the soil materials along with some selected performance indicators for their evaluation.

Model	Constant	Input variables coefficients			Performance indicators							
		ρ_{bank} Mg m^{-3}	MDD Mg m^{-3}	Clay %	R2	R^{2}adj	MBE	MAE	MAPE	RMSE	CRM	CV
Model 1	-35.28	28.50		0.98	0.64	0.62	0.15	6.79	22.42	9.23	0.00	28.06
Model 2	9.88	-42.04	36.21		0.95	0.95	0.00	1.17	18.77	1.45	0.00	13.42

The MAPE classes for the study percentages are: 20% < MAPE < 30% and MAPE< 20% respectively.

It was also noticed from Table 5 that the root mean square error for the shrinkage percent was substantial lower than that of the swell percent (1.45 versus 9.23).

Smaller root mean square error (RMSE), Mean absolute error (MAE) and MAPE values from a given approach indicate the closeness of the modeled values to the observed ones. The mean absolute percentage error (MAPE) is one of the most widely used measures of forecast accuracy, due to its advantages of scale-independency and interpretability. However, MAPE has the significant disadvantage that it produces infinite or undefined values for zero or close-to-zero actual values (Kim and Kim, 2016).

Based on the classification scheme proposed by Wilding (1985) the coefficient of variability of the predicted and observed shrinkage percentages (CV) for model 2 is low (CV <15%). Model 1 exhibited higher value for CV (28.06%), which fell in the moderate class (15% < CV < 30%).

The higher the CV, the greater the dispersion in the variable. The lower the CV, the smaller the residuals relative to the predicted values and is suggestive of a good model fit.

It is noteworthy to mention that apart to the fact that adding additional variables to the proposed models did not give rise to significant improvement of prediction of swell and shrinkage percentages, insertion of some variables created the problem of multicollinearity. For instance, addition of gravel as a third input variable to model I created the problem of instability of the model coefficients because this variable is closely related with clay content (r =0.973). Furthermore, it is impractical to add the soil density of the embankment as an additional input variable to Model 1 and 2 because we intend to predict the swell and shrinkage percentages before implementing the projects. In the light of the above results is recommended to perform cost analysis to determine the acceptable percentages of swell and shrinkage percentages.

4. CONCLUSIONS

The results of the current study indicated that the swell percentages of the soil materials of the surveyed projects are characterized by having a wider range compared with shrinkage percentages. There is also the possibility of predicting of these factors with reasonable accuracy in general and the shrinkage percentages in particular.

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