Applying In Situ Debris-cement Mixtures to the Ground Improvement of Bank in Wild Creeks

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ABSTRACT: This paper explores a new method of in situ debris-cement mixtures for laboratory experiments in order for the reuse of dredging debris for the ground improvement of bank in wild creeks. The paper undertook laboratory testing to determine the optimum ratios of water, cement and in situ debris by weight which can be suitable for the field work and compressive strength of ground improvement in wild creeks. Taking into account an economical and efficient mixing method of recycling debris in wild creeks, the optimal cement-aggregate ratio is 1:12, slump test is 15 ± 3.8 cm, sand content is less than 50%, and unit weight of test specimen is greater than 2.07 t/m^3 as compressive strength of the admixture can be as high as 400 psi, which is suitable for erosion control and bank protection of ground improvement in wild creeks.
Keywords: Debris-cement Mixtures, ground improvement, wild-creek remediation.

1. INTRODUCTION

This paper presents a new method of in situ debris-cement mixtures (ISDCM) for the reuse of desilting debris in wild creeks so that it can be used for the ground improvement of the creek bank. In recent years, large amounts of landslides in the watershed occurred in Taiwan after extreme torrential rain, which caused debris blockage on the drainage way or debris flow. In order to solve the problem, dredging debris of rivers or creeks is a method of remediation (Kantoush, & Sumi, 2010; Kondolf et al., 2014; Knighton, 2014). However, debris disposal of creeks is a difficult subject for the environmental management and rehabilitation work in alpine watersheds. In term of the processes on the dredging work in wild creeks, debris could be used as useful resources by improving its engineering properties with cement for the ground improvement in the field.

By comparison of engineering methods of the ground improvement, the first kind of methods is a concept of soil cement which is used as a stabilizing material for soil in the construction of highways or earth dams (Bell, 1993; Das, 2014). The standard process of soil cement is that the aggregate particle size should be no more than 75 mm and the least 55% of the particles should be able to pass through a 4.75 mm sieve (American Concrete Institute (ACI), 1990). Secondly, Controlled low-strength material (CLSM) is a self-compacted, cementitious material used primarily as backfills, structural fills, pavement bases, erosion control, etc. (ACI, 1999). CLSM can be produced by mixing clean aggregates, in-situ excavation or recycled materials which be delivered to a ready-mixed plant (Adaska, 1997; Gabr, & Bowders, 2000; Chang & and Chen, 2006). Finally, an in situ mixing method was developed in Japan, which uses in-site soil, sand and gravel with cement to fill the foundations and wings of Sabo dam, groundsill, riverbed girdle, front apron and so on (Watanabe, et al., 1999; ACTEC & ISM method Association Office, 2017).

About all, some methods are not suitable for alpine field sites in the research, for example CLSM and in situ mixing method both need a big mixing machine for production and transport of admixtures but it cannot be installed in wild creeks of alpine sites easily and economically. Thus, the paper integrates these concepts to innovate a method of on-site excavation, in-situ mixing and real-time fill, namely ISDCM, for the remediation work and dredging of wild creeks, which can solve the problem of debris disposal in wild creeks and make them become the materials of ground improvement for the protection of bank and embankment of creeks.

In the paper, there are 7 case study areas where the characteristics of the debris are significant various in the field. After field investigation and debris sampling are carried out, some laboratory experiments were undertaken in the research, such as water-cement ratio, cement-aggregate ratio, sand content, slump test and unit weight, as well as compressive strength tests. Finally, the optimum mixing ratio of water, cement and in-situ debris of test specimens can be determined by laboratory experiments so as to be suitable for field work and reach desired strength of ground improvement in wild creeks.

2. METHOD

There are four processes of laboratory tests for the ISDCM method to determine the optimum mixing ratios of cement, water, and aggregate, which affects the workability, strength and cost of admixtures. Firstly, tests of particle-size characteristics for field sampling are carried out so as to understand the condition of in-situ debris in case study areas. According to ASTM D2487 (2011), the standard of the Unified Soil Classification System (USCS) provides a useful first step in any field or laboratory investigation for geotechnical engineering purposes which classifies soils from any geographic location into categories representing the results of prescribed laboratory tests so that the particle-size characteristics and other engineering properties can be determined. The paper uses the standard to analyse fine and coarse aggregates and to classify gravel and sand with No.4 sieve in seven different field samplings. The sand content and soil classification of every field site is shown in Table 1. The results of article-size distribution curves for field sites are plotted in Figure 1.

Table 1 Soil classification of field sites

Site Code	County	Region	Sand Content (%)	Symbol of Soil classification
A	Nantou	Hewang River	25.2	GW
B	Kaohsiung	Taoyuan District	34.7	GP
C	Kaohsiung	Namasia District	17.6	GW
D	Nantou	Chichi weir	46.0	GP
E	Pingtung	Laiyi Township	34.0	GW
F	Taitung	Dazhu River	28.5	GW
G	Taitung	Taimali Township	60.7	SP

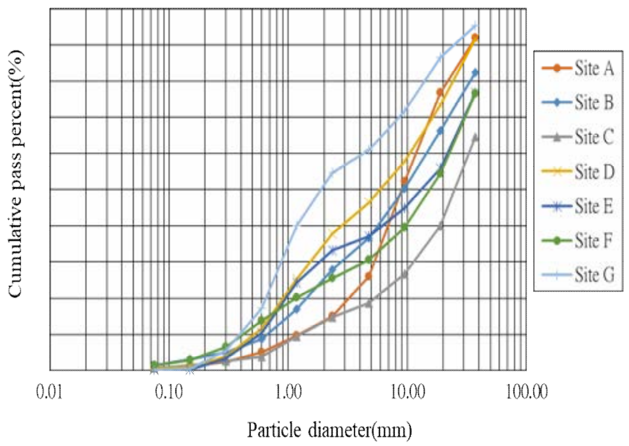

Figure 1 Soil particle-size distribution curves of field sites

Secondly, the paper explores the influence of water-cement ratio and sand content on the compressive strength of in-situ admixture. The ratio of water and cement by weight, namely workability, can be regarded as the slump of a specimen test. Although workability is better if the slump is larger, the strength and durability could reduce (Su & Miao, 2003). Meanwhile, the strength of admixtures is affected by in-situ sand content as well as the amount of cement (Tomomatsu, 1998; Watanabe,1999; Katayama, 2008). Thus, this study used three sand-aggregate ratios of 30%, 50% and 70% by weight in the upstream of Jiji Weir to undertake tests of compressive strength, corresponding to three water-cement ratios of 0.75, 1.25 and 1.75, respectively. There are 27 test specimens of which cement-aggregate ratios are the same as 1:12 and curing ages are 28 days in the experiments in order to determine the optimum ratios of sand to aggregate and water to cement for the ISDCM method. In terms of the ratio of cement to aggregate 1:12, According to Bell (1993), the author suggests that the amount of cement requirement for the soil types of GM, GP, SM, or SP is 5%~8% by weight on the soil improvement of soil-cement method. As a result, if the in-situ soil or debris belongs to Class G of the USCS classification, the ratio of cement to aggregate 1:12 (the cement usage is 7.7%) by weight is recommended.

Third step of the study methods is concerned about the ratio of cement to aggregate for the ISDCM method. Generally, the concrete mixing ratios are taken into account cement, fine and coarse aggregates that are commonly applied the ratios of 1:2:4, 1:3:6 and 1:4:8 to construction sites or soil improvement (Bell, 1993; Das, 2016). However, the research used five cement-aggregate ratios of 1:8, 1:9, 1:10, 1:11 and 1:12 by weight in seven case study areas, respectively, to undertake tests of compressive strength. The water-cement ratio of these test specimens is 1.25 and curing ages are 28 days in the experiments. After tests, the optimum cement-aggregate ratio for the ground improvement of ISDCM method can be determined.

Finally, the paper establishes a desired compressive strength for the ground improvement of the bank in wild creeks by using ISDCM method practicably and economically. In terms of the compressive strength for the ground improvement, According to Bell (1993), the author points out that while the amount of cement is 5%~8% by weight used for the soil improvement of soil-cement method, their values of compression strength are approximately 6.5MN/mm^2 (66 kgf/cm^2) and 1.2 MN/mm^2 (12 kgf/cm^2) for soil types of 'GW, GP, GM, GC, SW' and 'SP, ML, CL', respectively. Based on CLSM method, compressive strengths for the ground improvement of pavement bases and erosion control of can be estimated to range from 400 to 1200 psi (28 to 84 kg/cm^2) (ACI, 2005; Siddique, 2009; Yan et l., 2014). With regards to strength tests of ISM method, it uses in-situ dredging debris efficiently for the foundation of construct and the ground improvement by mixing cement; the design strengths are between 18 to 24 N/mm^2 and between 5 to 10 N/mm^2 for foundation structure and ground improvement, respectively (Watanabe, et al., 1999). Above all, design strengths of ISDCM method can be determined by all tests in the research corresponding to the optimum slump (water-cement ratio), sand content and cement-aggregate ratio.

3. RESULT AND DISCUSSION

In terms of sand content, water-cement ratio and slump tests, the strength tests of sand contents include three ratios (30%, 40% and 50%), corresponding to three water-cement ratios, namely 0.75, 1.25, 1.75, respectively. The results of compression strengths, sand contents and water-cement ratios related to slump tests are shown in Table 2. Figure 2 illustrates the relationships of compression strengths, sand contents and water-cement ratios, which shows the strength is strongest as water-cement ratio is 1.25 in tests. However, the testing shows the results of slump tests are different although the water-cement ratio is the same. That is because the sand contents of test specimens are different in the laboratory, which is similar to the cases in the field. The sand content of each case study area is different (see Table 1) and the water amount control of water-cement ratio by weight is difficult in alpine wild creeks so the paper suggests that optimum water-cement ratio of ISDEM method can be controlled to approximately 1.25 by slump test in the field, at 15 cm roughly.

Table 2 Results of sand content and water-cement ratio tests

Region Code		Unit weight	Compressive strength	Sand content	Water-cement ratio	Slump
Chichi weir	J1	2.10	21	50	0.75	10.2
	J2	2.13	37	40		10.5
	J3	2.17	59	30		10.4
	J4	2.37	99	50	1.25	15.0
	J5	2.36	77	40		15.5
	J6	2.34	63	30		15.8
	J7	2.32	42	50	1.75	18.5
	J8	2.31	33	40		18.3
	J9	2.27	29	30		18.0

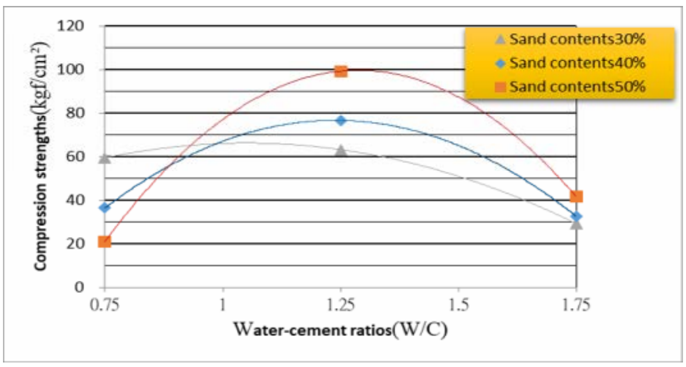

Figure 2 Relationships of compression strengths, sand contents and water-cement ratios

With regards to the tests of cement-aggregate ratios by weight, the results of 28-day compression strengths in mixing ratio 1:12 are shown in Table 3. Then, using all results of compression strengths from cement-aggregate ratios 1:8 to 1:12, the relationships of compressive strengths, sand contents and cement- aggragate ratios for the test specimens of in-situ debris in field sites are shown in Figure 3 where x axial is the sand content of each site, y axial is the compression strength of each test specimen in different cement-aggregate ratios. The results illustrate that compression strengths and cement-aggregate ratios are positive correlations which means the more cement contents, the stronger compressive strength of test specimens are. As can be see in Figure 3, the compressive strenght dramatically drops when sand content is approximately 60% and the soil class of the USCS classification is 'SP'. It means that if sand contents are greater than 60% and soil class is poorer than 'SP' in field sites, there will be in need of increasing cememt amount to cement-aggregate ratio of 1:8 or 1:9, for desired strength of ISDCM method.

Table 3 Results of the strength tests of cement- aggregate ratio 1:12 for the test specimens of in-situ debris in field sites

Site Code	County	Region	Compressive strength (kgf/cm²)	Sand content (%)	Unit weight
A	Nantou	Hewang River	44.1	25.2	2.10
B	Kaohsiung	Taoyuan District	64.5	34.7	2.25
C	Kaohsiung	Namasia District	74.9	17.6	2.29
D	Nantou	Chichi weir	64.6	46.0	2.21
E	Pingtung	Laiyi Township	31.4	34.0	2.10
F	Taitung	Dazhu River	41.3	28.5	2.16
G	Taitung	Taimali Township	16.9	60.7	2.09

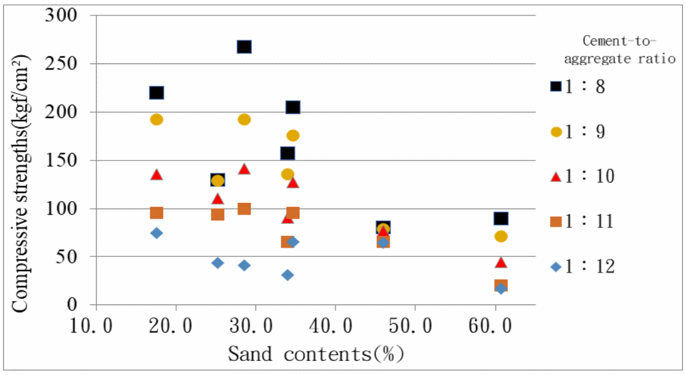

Figure 3 Relationships of compressive strengths, sand contents and cement- aggragate ratios for each test region

Furthermore, using other data of Table 3, the relationship between unit weight and compressive strength of each test specimen can be plotted, corresponding to different cement-aggregate ratios; then the maximum envelope curve of an equation (y=486.67x-977.9) is built up, where y means unit weight and x means compressive strength, as shown in Figure 4. As a result, the desired strength of an in-situ admixture in the field can be determined by the equation as known unit weight of the admixture.

Above all, the design strengths of the ISDCM method can be determined as two types by the results of laboratory tests and the standards of CLSM method. One is type I that the design strength is up to 84 kgf/cm^2 (1200 psi); the other is type II that the design strength is between 28 kgf/cm2 (400 psi) to 84 kgf/cm^2 (1200 psi). The design strengths of type I and II are in line of the permanent structural fill and erosion control, respectively, for the ground improvement by CLSM suggestion (ACI, 2005; Yan et al., 2014). The compression strengths of two types are plotted in the Figure 4 that shows almost all test specimens of 1:12 cement to aggregate belong to type II and all test specimens of 1:9 cement to aggregate are over the strength of type II except some test specimens of sand content roughly or over 50%. As a result, the design strengths of two type is suitable for the aim of creek remediation and erosion control of ISDCM ground improvement. It is economically and practicably considerable for the ground improvement that the admixtures of a ratio of 1:12 cement to aggregate, slump test of 15 ± 3.8 cm and sand content less than 50% can be designed to achieve 28-day compressive strength as high as 28 kgf/cm^2 (400 psi) as a standard of ISDCM method.

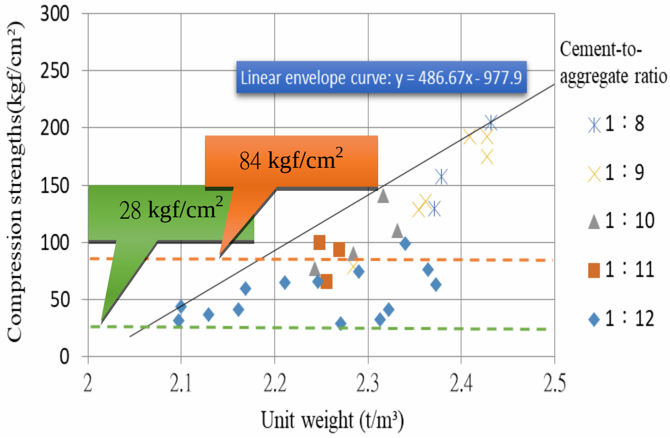

Figure 4 Relationship between unit weight and compressive strength of each test specimen

Finally, the paper divides the ground improvement of ISDCM method into two types and establishes their optimum ratios of related materials, compressive strengths and engineering properties, as shown in Table 4. In terms of type I, the design strength is up to 84 kgf /cm^2 (1200 psi) which is suitable for the permanent structural fill of embankments, berms or dams in wild creeks. The optimal design is a ratio of 1:9 cement to aggregate , slump test of 15 ± 3.8 cm (corresponding to a water-cement ratio of 1.25), sand content of 20% to 40% and unit weight of greater than 2.15 t/m^2. With regards to type II, the design strength is between 28 kgf /cm^2 (400 psi) to 84 kgf /cm^2 (1200 psi) which is used for erosion control or bank protection in wild creeks. The optimal design is a ratio of 1:12 cement to aggregate, slump test of 15 ± 3.8 cm and sand content of less than 50% and unit weight of greater than 2.07 t/m^2.

Table 4 Design strength and engineering properoties for the ground improvement of ISDCM in wild creeks

Type	Aim	Compressive strength	Cement-to-aggregate ratio by weight	Slump test	Sand content	Unit weight
I	Permanent structural fill	Up to 84 kgf /cm^2 (1200 psi)	1:9	15 ± 3.8 cm	20% to 40%	Greater than 2.15 t/m^3
II	Erosion control or bank protection	28 kgf /cm^2 (400 psi) to 84 kgf /cm^2 (1200 psi)	1:12	15 ± 3.8 cm	less than 50%	Greater than 2.07 t/m^3

4. CONCLUSION

The paper presents a new method of ISDCM for the ground improvement of band protection and erosion control in wild creeks. In terms of the cement-aggregate ratio of laboratory experiments, using ratios of 1:8, 1:9, 1:10, 1:11 and 1:12, respectively, there are significant correlations between the cement contents and compressive strength as well as the unit weight of test specimens. The optimal ratios of ISDCM for up to 84 kgf/cm^2 (1200 psi) of 28-

day test specimens which is in line of the permanent structural fill designed by CLSM are a ratio of 1:9 cement to aggregate, a water-cement ratio of 1.25. Meanwhile, it is economically considerable for the aim of river erosion control and bank protection of ISDCM ground improvement that the admixtures of a ratio of 1:12 cement to aggregate can be designed to achieve 28-day compressive strength as high as 28 kgf/cm^2 (400 psi) of CLSM standards; however, it is not suitable for soil class 'SP' of the USCS classification because there is a significant drop in the strength of the soil. The paper suggests that if the in-situ soil or debris belongs to Class S of the USCS classification or sand content greater than 50%, the cement-aggregate ratio of ISDCM should be increased to 1:9 or more for the desired strength of the method.

Overall, two types of ISDCM designed standards are: 1) type I is the compressive strength of up to 84 kgf /cm^2 (1200 psi) which is suitable for the permanent structural fill of embankments, berms or dams in wild creeks. The optimal design is a ratio of 1:9 cement to aggregate , slump test of 15 ± 3.8 cm (corresponding to a water-cement ratio of 1.25), sand content of 20% to 40% and unit weight of greater than 2.15 t/m^3. 2) Type II is the compressive strength between 28 kgf /cm2 (400 psi) to 84 kgf /cm2 (1200 psi) is used for erosion control or bank protection in wild creeks. The optimal design is a ratio of 1:12 cement to aggregate, slump test of 15 ± 3.8 cm and sand content of less than 50% and unit weight of higher than 2.07 t/m^3. In conclusion, type II of ISDM is an economical, efficient and useful method of recycling debris and ground improvement in wild creeks. In the future, the method could be applied to filed experiments in order to understand the practices of the optimal relative ratio of ISDM.

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