Research on Debris as Resources Applied In-situ for Wild Creeks after Typhoon Morakot

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ABSTRACT

In recent years, especially after typhoon Morakot, extreme torrential rain has resulted in large amounts of landslides. The debris that accumulated downslope blocks the drainage way and easily induces debris flow. The large amount of debris transported to wild creeks downstream may caused elevated riverbeds and channel siltation. All nearby villages and utilities are under this threat. The cleanout work of aggregated debris is of great priority after a disaster.

The cleanout of the debris can help the natural drainage system to recover its capability, and the recovered material can be effectively reused. Low-lying lands that were eroded in the past can be filled and protection measures can be applied, so as to raise the level of safety.

Feasible methods to improve the engineering properties of the material can be applied for the purpose of ground modification. A certain percentage of cement can be added to the debris in situ to form a new material, which can then be applied in many situations, such as improving the durability of road beds, protecting river banks from erosion, and promoting foundation properties, etc.

Every wild creek cleanout plan should include the amount of material that needs to be removed, the area where it is to be applied, and the engineering procedures required to adjust its properties. The cleanout work for wild creeks can help prevent future flooding and debris flow problems. This important remedial work that should be performed whenever needed or every year before the rainy season, and it should also be arranged as a part of the routine maintenance work carried out by the watershed's management. Instead of using sabo dams, cleanout work for blocked wild creeks is a new treatment of the debris problem. Standard procedures for cleanout plans, including the above-mentioned details, should be set as soon as possible.

KEYWORDS: Wildcreek, Debris Flow, Earth Resources

1. INTRODUCTION

After typhoons and torrential rain, wild creeks are often filled with debris due to upstream erosion. If nothing is done to remedy this situation, it will become a source of debris flow when the next period of heavy rain occurs. The transported debris often has a serious impact on the environment. However, regarding the practice of trafficking the debris, if the quality is poor, no manufacturer will be willing to purchase it.

The public often thinks that the Government implements cleanup plans poorly. Faced with this difficult situation, the implementation will of organizations can get lower and lower, causing a vicious cycle in which everyone is a victim.

Wild creek cleanouts tend to be urgent matters that must be completed before the next typhoon or period of torrential rain. Otherwise, the lack of dredging will result in the silting of the riverbed or overflowing from the sides. During cleanup, if the construction steps can be simplified, the efficiency of construction can be enhanced, and the construction period can be shortened, this will be a great help for wild creek cleanout work. In addition, the recovered material can be effectively reused in-situ. It can be used for filling in low-lying land, constructing slopes, and riverbank protection. This is an effective way to solve the above-mentioned problems.

2. In-situ reuse

The methods of adding cement for the in-situ use of debris, according to the characteristics of the production process, are shown in Figure 2-1.

It can be regarded as cement concrete, using debris as the source of the concrete aggregate in accordance with the graded concrete material standards and the requirements for cement mixing methods, such as the accuracy of the scales in the ready-mix plant and the performance of the batching machine.

Another use of the material is for ground improvement, in which the aggregate requirements and the mixing requirements are not strict as those for cement concrete. Bulldozers are often used to compact the concrete after it is poured. The main mechanisms of cement to stabilize soil are the Pozzolanic reaction and the hardening effect. In other words, the calcium ion of the lime contained in the cement and the silicate and aluminum acid salt of the minerals in the soil generate a cemented reaction to form CSH and CAH; such colloids can help to promote the bonding of particles and the filling of the pores of the soil to considerably promote strength and reduce water permeability. Moreover, it is generally believed that the changes of the engineering properties of cement are mainly caused by the hardening of the cement. When the cement hardening occurs, the cement particles and the surrounding soil particles will bind to form discontinuous strong and hard aggregate around the soil particles. The aggregates can be regarded as the fillings of the pores in the soil (Chen, 2008).

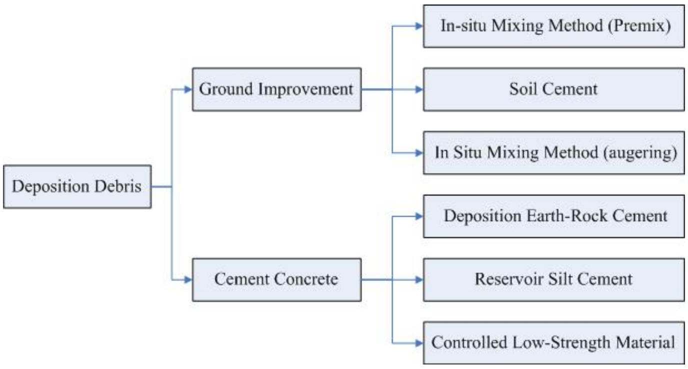

Figure 2-1 Classification of the in-situ reuses of adding cement to debris

Table 1 Comparison of engineering methods of debris use

Type	Special Aggregate Limitations	Remarks
Deposition debris cement (made in-situ)	1. Use in-situ deposited debris. 2. The coarse aggregate's maximum particle size is 50mm. 3. Should be used with cerement sand (in compliance with CNS 1240 regulations).	1. Deposition debris from different regions with different characteristics should be added individually in terms of a mixing ratio. 2. The in-situ hire of self-propelled in-situ mixing machinery. 3. No economic benefits unless the project is above a certain level.
In Situ Mixing method (ISM)	1. Use in-situ deposited debris. 2. The coarse aggregate's maximum particle size is 300mm.	1. Japanese patented engineering method; special mixing machinery. 2. The in-situ establishment of cement silos, cement paste mixing tubs, and cement paste

			delivery pumps. 3. Mixing ratio is designed according to the earthwork types and purposes.
Soil cement		1. Use in-situ deposited debris. 2. The coarse aggregate's maximum particle size is recommended to not be above 75mm. 3. At least 55% of the particles can pass a 4.75mm (No.4) sieve.	1. Following the soil cement regulations in Chapter 02715 of the Public Works Construction Program Standards. 2. The in-situ use of the optimal water content model to control the engineering quality. 3. After the in-situ cement distribution, use the mixing machine for repeated blending and mixing until the cement and the pounded and smashed soil are fully and evenly mixed.
Reservoir silt cement		1. Use reservoir silt to replace part of the fine aggregates. 2. According to the requirements of Cement Basic Material and General Requirements on Construction in Chapter 03050 of Public Works Construction Program Standards.	1. Following the reservoir silt cement regulations in Chapter 03801 of the Public Works Construction Program Standards. 2. Conduct trial mixing according to the silt characteristics and recommended mixing ratios before construction. 3. Suitable for pure cement or low strength steel reinforced cement for secondarily important structures.
CLSM	In-situ excavation of earth and stone	1. The in-situ excavated earth and stone should be delivered for mixing by the construction unit. 2. According to the classifications of ASTM D2487, the content of peat soil as well as organic soil of high plasticity and low plasticity should be lower than 10%. 3. The material particle size should be no more than 50mm, and the usage of coarse particles larger than a No.4 testing sieve of 4.75mm should be no more than 400 kg/m^3.	1. Following CLSM in Chapter 03377 of the Public Works Construction Program Standards. 2. Made in the ready-mix cement plant and transported by ready-mix cement vehicles. 3. The materials should comply with the requirements in Chapter 02320 of the Public Works Construction Program Standards.
	Cement aggregate	1. The cement aggregate should comply with the provisions of CNS 1240. 2. The aggregate particle size should be no more than 50mm, and the usage of coarse particles larger than a No.4 testing sieve of 4.75mm should be no more than 400 kg/m^3.	

Source: Public Works Construction Program Standards; Deposited Debris In-situ Use-Research and Pilot Engineering (Chen, 2008); ISM Engineering Research Institute Website

2.1 Soil Cement

According to the definition of soil cement in Chapter 02715 of the Public Works Construction Program Standards, soil cement is made in the following process: first according to the design descriptions, pound and smash the soil; then, spread cement on the soil and blend by in-situ mixing or other mixing methods; finally, make compact the mixture using rolling pressure. The standards suggest that the aggregate particle size should be no more than 75mm, and that at least 55% of the particles should be able to pass through a 4.75mm sieve. Such soil cement is suitable for road bases and bottom layers.

2.2 CLSM (Controlled low-strength material)

CLSM has the properties of self-fulfillment and high flow, similar to high performance cement, and it therefore does not require rolling or vibration for compaction. CLSM is suitable for the backing of underground pipelines by replacing traditional earth and stone backfilling. According to the CLSM provisions in Chapter 03377 of the Public Works Construction Program Standards, CLSM can be produced by the in-situ excavation of earthworks and recycled materials, in addition to using clean aggregates for general cement in the ready-mix plant. At present, most of the ready-mix plants in the market use clean aggregates that have controllable quality but also have relatively higher prices. However, in-situ excavated earthworks are an acceptable replacement for aggregate. Despite their lower prices (60-80% of clean aggregates, according to the Public Works Engineering Price Database, 2011, and Construction Material Prices, Issue 81), the in-situ excavated earth and soil still have to be delivered to the ready-mix plant by the construction unit, resulting in higher costs.

2.3 Deposition earth-rock cement

According to Chen (2008), the deposited stone material sized above 5cm can be separated using a mechanical hand with a hopper (known as large filling materials, a self-propelled pounding machine can be used to grind them into stone materials with a particle size below 5cm). Adding cement to the smaller filling materials (with a particle size below 5cm) will comply with the cement aggregate provisions of CNS (to adjust the proportions of improper earth and stone contents). In-situ self-propelled mixing machines and other machinery can be used to produce deposition earth-rock cement with a design strength of 210 kg/cm2 and a slump degree of 12.5cm ± 4.5cm. According to the cost estimation and in consideration of the material, machinery and testing fees, this process has no economic benefits, unless the usage is over a certain level.

2.4 In situ mixing method

The in situ mixing method, which uses cement to solidify in-site stone and soil, was developed in 1992 in Japan. On the construction site, cement, water and a mixing agent are mixed according to a mixing ratio into a cement slurry. This is delivered to a mixing machine installed at the front of an excavator and is directly mixed with earth and stones that have a particle size below 300mm, which is then excavated in-situ and selected to produce a base or structural body similar to cement of a certain strength. The equipment configuration is as shown in Figure 2-3 (Japan, ISM Engineering Method Research Institute Website, 2011).

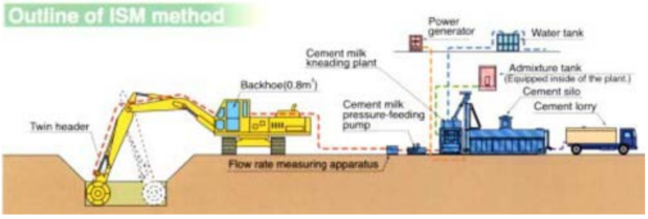

Figure 2-3 ISM engineering method in-situ equipment configuration

(Source: ISM Engineering Research Institute Website)

2.5 Reservoir silt cement

After a typhoon or torrential rain, the earth and stones carried by floods often cause reservoir silting. This reduces the effective capacity of the reservoir and poses a threat to the safety of the reservoir. The excavation of dry silt during the dry season for effective reuse is a good countermeasure to this threat. According to the definition of reservoir silt cement in Chapter 03081 of the Public Works Construction Program Standards, reservoir silt can replace some of the fine aggregate to make pure cement or low strength steel reinforced cement for secondary structures. The recommended ratio design strengths are of two types: 175 kg/cm2 and 210 kg/cm2.

3. Silt Mixing Test

The in-situ mixing engineering method uses in-situ de-silting materials for mixing improvement, coupled with the protection measures required for construction, to achieve results that are in line with the required characteristics.

For example, cement stabilized soil uses soil mixing additives to improve its stability, strength, permeability, and durability. The in-situ materials will have higher strengths and durability due to the compaction of the cement into the mixing additives, as the pore sizes have been reduced. The cement solidification effect reduces the material expansion and modifies the material permeability. Good mixing effects will affect the finished products. Using cement to improve the in-situ soil characteristics can effectively take advantage of the in-situ earth-rock resources to help the de-silting operations of the upstream water collection area.

The earth and rock produced in de-silting operations in various places may have great differences due to the source and the selection effects of the transportation process. Therefore, the engineering properties of the earth and rock should be tested and summarized to facilitate the planning of follow-up applications.

3.1 Ratio Test

Due to factors such as material resources, river bed vertical slope changes, debris flow scales and scour-and-fill levels, the ratio of silt gradation variability is large. To understand the engineering properties of debris cement mixing projects in various areas, this study selected ten de-silting sites across Taiwan that had been affected by Typhoon Morakot in 2009. Using a fixed ratio of W/C=0.55, the common cement ratios of 1:2:4, 1:3:6 and 1:4:8 used in traditional construction were simulated to discuss the applicability of the in-situ mixing engineering method for different ratios and engineering sites. The sample sites of the in-situ use of debris are shown in Table 3-1, and the indoor testing process is shown in Figure 3-1.

Table 3-1 Sampling sites of in-situ silt use

No.	Site Name	Coordination System TW67	
		X coordinate	Y coordinate
1	Shanli, Hualien	281,495	2,592,350
2	Daniao, Taitung	239,781	2,477,006
3	Hewang, Nantou	263,149	2,657,374
4	Shehsing Bridge, Alishan River, Chiayi	221,499	2,605,753
5	Shahe River, Miaoli	234,478	2,718,976
6	Sinle Bridge, Chianshih, Hsinchu	275,397	2,735,857
7	Qietungliao, Toubiankeng, Taichung	225,325	2,669,574
8	Dabang, Chiayi	221,932	2,594,352
9	Main stream of Houjue River, Tainan	207,308	2,562,835
10	Yameikeng, Houjue River tributary, Tainan	207,392	2,562,424

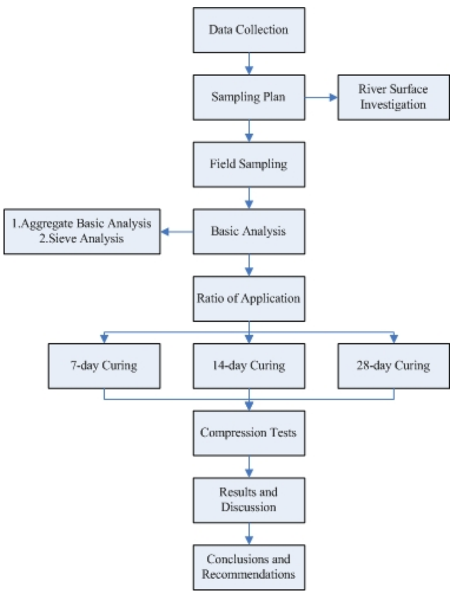

Figure 3-1 Ratio test process

3.2 Test of basic properties of the in-situ samples

This study first investigated the river channel siltation status and took random samples from the representative sites in-situ. According to the earth and rock proportions of the silt from the mountain rivers, the content of the coarse aggregates with a particle size above 4.75mm was of a very high percentage, accounting for roughly 50%~80%. In other words, it reached at least Class G of the USCS classification.

This study also investigated the surface particle size of the aggregates in the upper and lower reaches of the sampling sites. Approximately 60kg of aggregates for each group of ratio tests were taken back to the laboratory for drying. The aggregates were divided into coarse and fine ones for the test of basic properties in individual regions and for mixing tests. The testing results of the basic properties of the aggregates are shown in Table 3-2.

Table 3-2 In-situ aggregate basic testing results of the sampling sites

Testing Iter / Sampling Site	Water Content (%)	F.M	Density	Saturated Water Content (%)	Surface Water Content (%)	Maximum particle size (cm)
Shanli, Hualien	2.86	2.60	2.25	14.35	0.82	40
Daniao, Taitung	5.12	2.40	2.10	17.56	0.84	39.6
Hewang, Nantou	1.78	2.60	2.35	13.57	0.80	69.5
Shehsing Bridge, Alishan River, Chiayi	2.86	2.80	2.65	14.01	0.85	69
Shahe River, Miaoli	1.98	2.60	2.60	14.02	0.83	36
Sinle Bridge, Chianshih, Hsinchu	2.01	2.80	2.45	15.31	0.81	74
Qietungliao, Toubiankeng, Taichung	8.24	2.40	2.07	13.66	0.88	39.6
Dabang, Chiayi	5.24	2.60	2.55	15.70	0.87	52.4
Main stream of Houjue River, Tainan	5.10	2.60	2.31	15.14	0.87	52
Yameikeng, Houjue River tributary, Tainan	4.24	2.60	2.43	15.02	0.85	48.7

3.3 Compression test

In this experiment, according to different ratios and sampling sites, this study used cylindrical specimens sized 15 cm × 30 cm for 7-day, 14-day and 28-day compression tests. The resistance strength is shown in Figures 3-2~3-4.

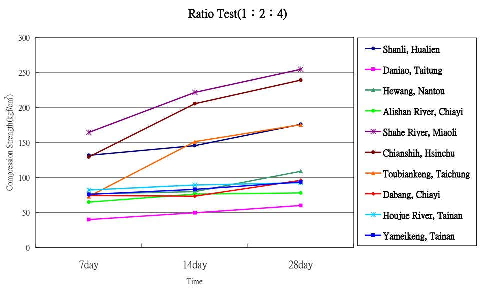

Figure 3-2 Compression test of the sampling sites using a ratio of (1:2:4)

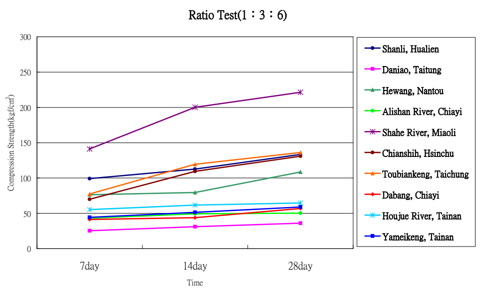

Figure 3-3 Compression test of the sampling sites using a ratio of (1:3:6)

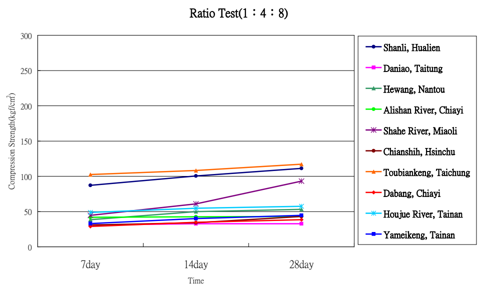

Figure 3-4 Compression test of the sampling sites using a ratio of (1:4:8)

First, the effects of different testing sites were discussed to determine the mixing ratios and the optimal cement mixing ratios for different regions. The analysis results suggested that, using 70 kgf/cm2 (half of the general cement standard of 140 kgf/cm2) as the expected standard, at a ratio of 1:2:4, two thirds of the total testing areas could pass the standard.

Regarding the 28-day compression strength, in case of a ratio of 1:2:4, nine testing regions, including Shanli, Hewang, Shehsing Bridge, Shahe River, Chianshih, Qietungliao, Dabang, Houjue River, and Yameikeng, could meet the set standard of 70kgf/cm2. The testing results of the Daniao area was also close to the standard. In case of a 1:3:6 ratio, six testing areas, including Shanli, Hewang, Shahe River, Chianshih, Qietungliao, Houjue River and Yameikeng, could meet the set standard. In the case of a 1:4:8 ratio, three testing areas, including Shanli, Shahe River and Qietungliao, could meet the set standard. Using the cement compression strength standards of ACI, seven testing areas could meet the standard of 70kgf/cm2: Hewang, Shehsing Bridge, Shahe River, Chianshih, Qietungliao, Dabang, and Houjue River.

Table3-3 Compression strength of the sampling sites using different ratios (Unit: kgf/cm2)

Testing Area	1:2:4	1:3:6	1:4:8
Shanli, Hualien	176	133	111
Daniao, Taitung	60	36	33
Hewang, Nantou	109	71	53
Shehsing Bridge, Alishan River, Chiayi	78	50	43
Shahe River, Miaoli	254	221	93
Sinle Bridge, Chianshih, Hsinchu	239	131	43
Qietungliao, Toubiankeng, Taichung	175	136	117
Dabang, Chiayi	96	57	38
Main stream of Houjue River, Tainan	92	65	57
Yameikeng, Houjue River tributary, Tainan	93	59	45

4. In-situ Mixing Method

The purpose of this study was to find the optimal balance between engineering economic benefits, and energy savings and carbon reduction. Therefore, this study selected the common ratios for construction engineering to design the engineering ratios in various testing areas. This could speed up the promotion of in-situ mixing as well as facilitate engineering personnel in using the in-situ mixing of cement.

According to the literature, after blending the in-situ cement and soil evenly by the in-situ mixing method or by other methods, and after full compaction, the soil will classified as GW, GP, GM, or GC. The recommended usage of cement for in-situ mixing is around 3%~9%, as shown in Table 4-1, and the compression strength is roughly 66 kgf/cm2 (6.5MN/mm2), as shown in Table 4-2.

Therefore, the in-situ mixing method can be defined as a method for soil improvement. The principle of improvement is similar to that of soil cement, namely, mix the in-situ excavated earth and stone with the cement for ready use. The aggregates are not separated in-situ. By adding water into the aggregates and mixing evenly, the produced material can be directly used in backfilling as a composite material for erosion resistance, with improved structural safety and in-situ strength. With the in-situ mixing method, the cement content can be as high as 7%~8%. To simplify the construction procedure, if the in-situ earth and rock belong to Class G of the USCS classification, the weight ratio of the cement and silt is recommended to be 1:12 (the cement usage is 7.7%). In other words, each cubic meter of in-situ mixing material will use 165 kg of cement. In addition, the silt debris is a composite material made up of mud, earth, sand and stone, which may have different water absorption rates. The water content of the in-situ earth may also be different due to the depth of excavation or the distance from the river channel. In practice, water usage should be gradually added in-situ until all the materials have been evenly mixed.

In consideration of the minimum economic costs, the minimum amount of cement was used. With a ratio of 1:4:8, the lowest strength was at least 33kgf/cm2. In order to reduce project costs and use the least amount of cement required to maintain a certain level of strength and a higher level of compression strength, this study implemented in-situ mixing in Hewang and Hongxian using a ratio of 1:3:6.

Table 4-1 Typical cement requirements for various soil types

[after Anon 1990, State of the art report on Soil-cement, ACI 87(4)]

Unified soil classification	Typical range of cement requirement,* (% by wt)	Typical cement content for moisture-density test (AMST D 558),+ (% by wt)	Typical cement contents for durability tests (ASTM D 559 and D 506), ☆ (% by wt)
GW, GP, GM, SW, SP, SM	3-5	5	3-5-7
GM, GP, SM, SP	5-8	6	4-6-8
GM, GC, SM, SC	5-9	7	5-7-9
SP	7-11	9	7-9-11
CL, ML	7-12	10	8-10-12
ML, MH, CH	8-13	10	8-10-12
CL, CH	9-15	12	10-12-14
MH, CH	10-16	13	11-13-15

*** Does not include organic or poorly reacting soils. Also, additional cement may be required for severe exposure conditions such as slope protection.**

+ ASTMD558(1992) Standard Test Method for Moisture-Density Relations of Soil-Cement Mixtures, American Society for testing Materials, Philadelphia.

☆ ASTMD559(1982) Standard Methods for Wetting and Drying Tests of Compacted Soil-cement Methods for Freezing and Thawing Tests of Compacted Soil-Cement Mixtures, American Society for Testing Materials, Philadelphia.

Source:F.G.Bell (1993), “Engineering Treatment of Soils”, E & FN SPON, an imprint of Chapman & Hall, London

Table 4-2 Typical average properties of soil-cement and soil-lime mixtures[after Ingles and Metcalf, 1972]

Typical ment* properties of soil-cement+						
Soil type (Unified classification)	Compressive strength (MN/m^2)	Young' s Modulus, E (MN/m^2)	CBR	Permeability (m/s)	shrinkage	Comments
GW, GP, GM, GC, SW	6.5	2×10^4	>600	Decreases ($\cong 2\times10^{-7}$)	Negligible	Too strong; liable to wide spaced cracks ☆
SM, SC	2.5	1×10^4	600	Decreases	Small	Good material
SP, ML, CL	1.2	5×10^3	200	Decreases ($\cong 1\times10^{-9}$)	Low	Fair material
ML, CL, MH, VH	0.6	2.5×10^3	<100	Increases	Moderate	Poor material
CH, OL, OH, Pt	<0.6	1×10^3	<50	Increases ($\cong 1\times 20^{-11}$)	High	Difficult to mix; needs excessive cement

* Variations of approximately 50% around the mean may be expected.
+ Values shown are at 10% cement content
☆ Good material if less cement is used
Source：F.G.Bell (1993), “Engineering Treatment of Soils”, E & FN SPON, an imprint of Chapman & Hall, London

4.1 Indoor mixing simulation test

According to the above silt mixing test results, the lowest strength using a ratio of 1:4:8 (equivalent to a cement usage of 7.7%) was up to 33kgf/cm2. This study used a 1:12 cement to silt (coarse and fine aggregate mixture) ratio to conduct a simulation test.

To support the Hewang River de-silting project, this study took samples from the Hewang River in Ren-ai Township, Nantou County, and conducted an indoor test using a 1:12 cement to silt ratio. The water usage referred to the general settings of cement preparation: the water/cement ratios were set at W/C=1.82 and W/C=1.98 for a slump of 15 cm and 20 cm, respectively. The mixing ratio referred to CNS 1174 by removing rocks sized at or above 37.5mm to make cylindrical specimens that were 15 cm in diameter and 30 cm in height. The strength testing results are shown in Figure 4-1. For a slump of 15cm and 20cm, the strength of the 28-day cement was 39kgf/cm2 and 36kgf/cm2, respectively, which was lower than the lowest strength found at a mixing ratio of 1:4:8, as mentioned in the previous section. This could have been caused by the relatively higher W/C ratio of the simulation test in the laboratory.

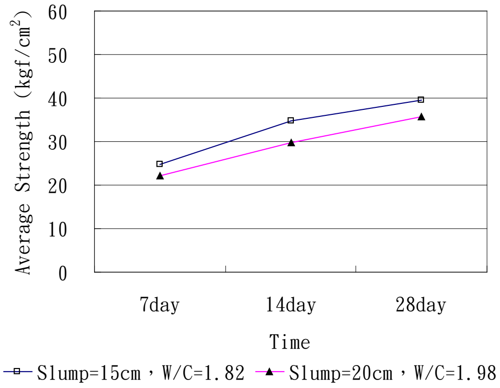

Figure 4-1 Indoor Strength Testing Results

4.2 Application of in-situ mixing method

The Hewang area in Nantou was hit by three typhoons in 2008: Kalmaegi, Sinlaku, and Jangmi, all of which caused a large amount of earth and sand to flow into the river channel. The floods damaged the riverside lands and buildings, and the debris accumulated in the channel of Hewang River, resulting in an insufficient cross section of the river channel. The slopes collapsed under the impact of the river floods, and a number of roads were damaged. Reconstruction was badly needed, and thus, the de-silting project of Hewang River and a nameless bridge commenced.

During the de-silting project, the silt materials obtained in-situ were modified according to their properties. Coupled with the planned protection measures, the in-situ mixing method was promoted. Hence, along Hewang River, the mixing for ground improvement engineering method was applied in various places to achieve the designed purpose. In Nantou County's Hewang River and Honghsiang Tribe, troughs were excavated along the river channel. The troughs were filled with the in-situ mixture, which formed an underground improvement structure between the river channel and the objects under protection, as shown in Figure 4-2. In normal times without flooding, the river channel will run left and right due to landforms, rainfall and other factors. The river water will gradually erode and remove the fine aggregates, leaving the coarse aggregate with its pseudo stability to temporarily support the soil. Once too much sand and stone have been carried away, or when the river water's scouring force becomes greater, the structure will be damaged and there will be in soil erosion. If the eroded area has gabions or stone deposits on the top, the bottom will become depleted, ultimately damaging the gabions and the slope. On the contrary, the mixing land improvement engineering method will improve the level of resistance to the scouring of river water. However, the erosion resistance capability must be higher than that of the uncompressed silt. When the river channel is close to the improved structure, this method can prevent or at least delay the earth and stone from being eroded or scoured.

Application of the mixing land improvement engineering method along Hewang River:

1. Riverbank at the toe of the collapsed slope

2. Riverbank at the toe of the slope in the area of earth and rock backfilling

3. Attack riverbank

4. Riverbank at the toe of the slope of the agricultural land base

5. Riverbank at the toe of the slope below the agricultural land

Figure 4-2 The mixing land improvement engineering method improvement structure, showing the objects to be protected

4.3 Compression results of the mixing land improvement engineering method

Regarding the de-silting project in Hewang River and Honghsiang Tribe of Nantou County, according to the in-situ characteristics and protection requirements, this study applied the mixing ground improvement engineering method using the ratio from CNS 1174 by removing pebbles sized at and above 37.5mm to make cylindrical specimens with a diameter of 15 cm and a height of 30 cm. The land improvement compression strength of 28 kgf/cm2 was about 20% that of general concrete (140 kgf/cm2), which provided resistance to lateral erosion, improved structural safety and in-situ strength considerations to protect objects, as shown in Figures 4-3~4-4. The compression strength testing results of the cylindrical specimens in Hewang and Honghsiang are shown in Figure 4-4. The results indicated that the standard of 28 kgf/cm2 had been met in both cases.

Figure 4-3 Hewang mixing land improvement engineering method used to protect against collapsed land

Figure 4-4 Honghsiang mixing land improvement engineering method used to protect against collapsed land

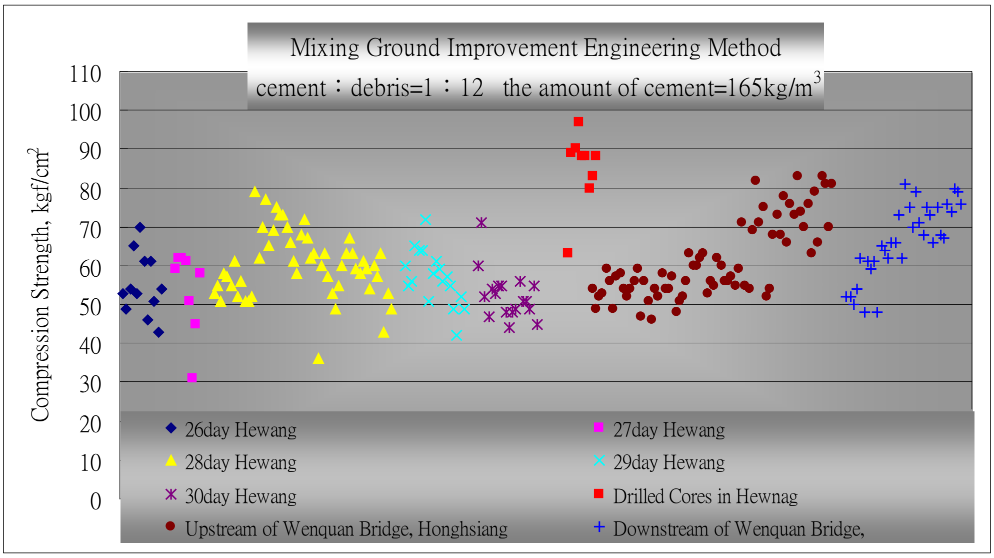

Figure 4-4 Hewang and Honghsiang in-situ mixture's compression strength

5. Conclusion

In recent years, continuous typhoons and bouts of torrential rain have caused slope landslides to silt river channels, causing serious floods. The de-silting of rivers and rivers should be done immediately and without delay. With limited budgets and time constraints, it is recommended to dig deep troughs to de-silt river channels at a minimum cost in the shortest time. The excavated silt can be reused. According to the in-situ restoration and protection requirements, with the help of the in-situ mixing engineering method, riverbank land improvements can be carried out. This engineering method is fast, easy to apply and has a low cost, making it economically effective and environmentally conscious, as it can save energy and reduce carbon emissions.

The mixing land improvement engineering method is a method that requires a more even mixing, as compared with soil cement. The product can be used directly in backfilling to provide resistance to lateral erosion and scouring, improved structural safety and in-situ strength. As far as the compression strength of the in-situ engineering method is concerned, it was found to be 70 kgf/cm2, or 50% of that for general concrete (140 kgf/cm2); for land improvement, it was 28 kgf/cm2, or 20% of the standard for general concrete.

Protection factors should be taken into consideration during the de-silting process, including the filling of low-lying land and the in-situ mixing land improvement method, in order to make most effective use of silt resources during reconstruction planning.

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