PERFORMANCE OF RECYCLED CRUSHED CONCRETE FOR PAVEMENT MATERIALS

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Abstract: The reclaimed crushed concrete debris obtained in the metropolitan city of Taejon, S. Korea is tested for ensuring that the material can be used as a substitute for pavement material. Standard compaction, CBR and cyclic triaxial compression tests were performed for this purpose. The gradation of the specimens obtained was modified to meet the specification of Korea Road Institute as SB1 and subgrade soil categories. A series of exploratory tests were performed to assess the effectiveness of using the recycled concrete debris as subbase materials and subgrade soil that can be judged based on engineering properties. The values suggested by the agency were compared with those from this study. It is found that, for a

given gradation, the recycled concrete can be used as the substitute for crushed rock to be used as subbase materials effectively.

Keyword: recycled concrete, pavement materials, compaction, CBR, cyclic triaxial test

1.INTRODUCTION

It is anticipated that dramatic increases occur in S. Korea in the proportion of road building devoted to rebuilding existing pavements. Consequently, the decline in available high quality new crushed rock debris for pavement demands for the economic reuse of demolished infrastructures in urban areas. It makes economic sense to seek alternative means of disposal of concrete from construction and demolition operation. Portland cement concrete can be reclaimed during demolition operations. Therefore, the reclaimed concrete can be crushed into granular materials that may be used as a substitute for new pavement materials. However, users of the reclaimed concrete aggregate should take precautions to ensure that the material is suitable for the intended application.

In this study, performance of subbase material and subgrade soil made with recycled crushed concrete is tested and investigated with compaction test (e-type), laboratory CBR test and tri-axial compression test. Specifically, the samples made with the recycled crushed concrete were tested under repeated load (cyclic) tri-axial test condition.

Statistical correlations will be established between CBR and resilient modulus from following further tests. Further intensive investigation is being performed at present time using the APT (Accelerated Pavement Tester) of Korea Highway Corporation to monitor the small-scale experimental pavements constructed at a site of the KHC.

2. SPECIMEN PREPARATION AND EQUIPMENT SETUP

2.1 Material Origin and Engineering Index

The engineering properties [liquid limit (LL), plasticity index(PI), maximum dry density(MDD), optimum moisture content(OMC), specific gravity(GS), abrasion ratio, and CBR] for the recycled crushed concrete materials used in this study were evaluated. The summary of test results is presented in Table 1. Required specification for the subbase materials is compared with the test results in Table 2. Some index properties including LL, PI, CBR, and abrasion ratio were satisfied. However, water absorption ratio and specific gravity were not satisfied. The test methods used to determine these engineering properties are shown in Table 3.

The AASHTO designation T180-90D (KSF-2312) was used to determine the MDD and OMC. Table 1 shows that the maximum dry density (MDD) values of the recycled concrete were much lower than those of the natural materials, typically 22.5 kN/m^3 in S. Korea. As reported by Coffman et al. (1964) and Hicks (1970), the usual values of the MDD of the subbase material were ranging from 21.3 to 22.7 kN/m^3. It is considered that these lower values of the MDD are due to lower value of specific gravity of the recycled concrete and higher values of water absorption ratio.

Table 1. Summary of Index Properties

Test No.	Material	LL (%)	PI (%)	MDD (kN/m^3)	OMC (%)
1	Recycled	N.P.	N.P.	18.05	12.1
2	Recycled	N.P	N.P	18.1	12.0
Specification Required	Natural	<25	<6	N/A	N/A

Table 2. Comparison of Index Properties with Specification

	Lab. CBR	LA abrasion	% Passing No.200 Sieve	Specific Gravity	Water absorption ratio
Specification	30<	<50	<10	2.5<	<3.0
Recycled*	88.0	40.8	3.1	2.3	6.2

* average value

Table 3. Test Methods used in Determination of Index Properties

Specification	LL	PI	MDD	OMC	CBR
AASHTO	T89-50	T90-87	T180-90D	T180-90D	T193-81
KSF	2303	2304	2312	2312	2320

2.2 Sieve Analysis and Gradation Adopted

After collecting the recycled crushed concrete from the crushing batch, the samples were first open dried for one week and then a sieve analysis was performed. The crushing batch provides two types (type A and type B) of the crushed concrete. The maximum size of the type A samples was 4.75mm. The maximum size of the type B samples was approximately 40.0 mm. Therefore gradation of both types did not meet the Korea Road Institute's specifications at first due to mechanical crushing operation. To meet the KRI's specification of gradation and to ensure the same gradation for all the samples in this study, a gradation curve was selected for specimen preparation by sieving and regrouping the materials again. The selected gradation curves used in this study and the gradation required by the KRI are compared in Table 4 and Fig. 1.

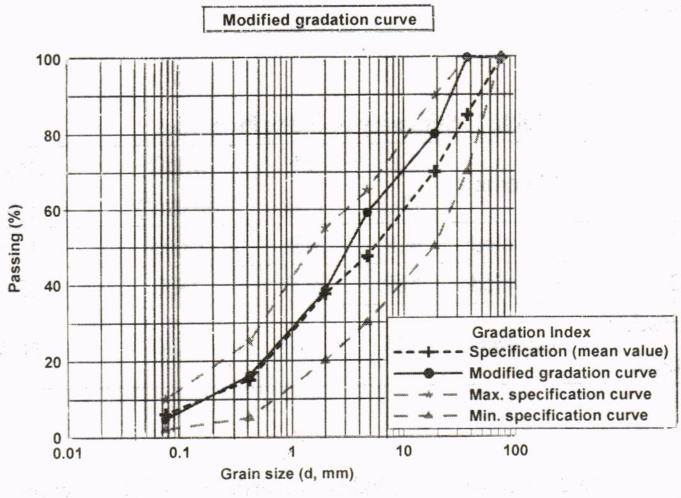

Figure 1. Modified Grain Size Distribution of Recycled Concrete Compared to SB1 Specification

Table 4. Gradations required by the Korea Road Institute and Those used in this study

	Percent Passing					
	KRI-Specification		This study			
	SB-1	SB-2	Gradation1	Gradation2	Gradation3	Mean Gradation
75.0mm	100	-				
53.0mm	-	100				
37.5mm	70-100	80-100				
19.0mm	50-90	55-100	100	100	100	100
4.75mm	30-65	30-70	97.4	98	97.7	97.7
2.00mm	20-55	20-55	74.4	70.6	68.5	71.17
425μm	5-25	5-30	31.4	25.7	26.0	27.7
75μm	2-10	2-10	5.2	2.1	2.1	3.1

2.3 Triaxial Specimen Preparation

The specimens prepared were 72.0mm in diameter and 150.0 mm in height, giving a height to diameter ratio of 2. The compaction method developed consisted of a trial-and-error adjustment in the weight of aggregate per layer, the number of compacted layers, the falling height of the rammer, and the weight of the rammer to produce specimens at a specified density. A specimen was prepared in 5 layers of approximately 580 g of aggregate per sample utilizing 988g of rammer weight and 20cm of falling height of the rammer when the moisture content kept 11 %.

The compacted samples provide approximately 17.9 kN/m^3 of maximum dry density. The energy level (55,986 ft•lb/ft) specified by the AASHTO designation T180-90D (1990) of the compaction method to prepare the soil samples for Mr testing causes the breakage of particles too much in the samples. Thus a decreased energy level (about 50% of original level) is considered for preparing the samples in proper condition. This is to prevent breakage of particles in the samples during compaction even though vibratory compaction method is suggested by AASHTO designation T294-92I and T292-91I for this purpose. Usually, it is a well-known fact that changes in MDD does not significantly affect the Mr values as compared to changes caused by stress level and moisture content. A compaction tool including a small rammer and a split mold was designed to obtain proper energy transfer effect as far as possible. A vacuum pump was used to provide the required suction to stretch the membrane around the wall of the mold so as to aid in the compaction of the specimen.

2.4 Experimental Setup for Cyclic Triaxial Testing

The load frame, triaxial cell, pressure gauge, load cell, and the overall setup used are shown in Fig. 2. A 5 kN capacity load cell mounted outside the triaxial chamber and attached to the loading piston was used to monitor the deviatoric stress. A data-acquisition system was used to monitor and to record the signals transmitted by the transducer. Cyclic triaxial test system as used for Mr test was applied to this study. The applied loading sequence and the number of loading cycles are summarized in Table 5. The conventional static triaxial test was modified to adapt the testing procedure AASHTO T292-91I and T294-92I by providing number of cycles of loading to the samples. This modification is to check whether simple testing procedure can provide the same resilient effect to the samples compared to the Mr testing procedure suggested by the AASHTO T294-92I and T292-91I. During testing, the vertical deformations from LVDT's were monitored and recorded at each cycle.

Air actuator was used to provide axial cyclic loading with air pressures giving confining pressures. Total loading and unloading time of 60 seconds (1 cycle) was selected to provide 0.02%/min. of loading rate to the samples between the end and beginning of consecutive load repetitions. This loading time is comparatively slow comparing to that of AASHTO testing procedure.

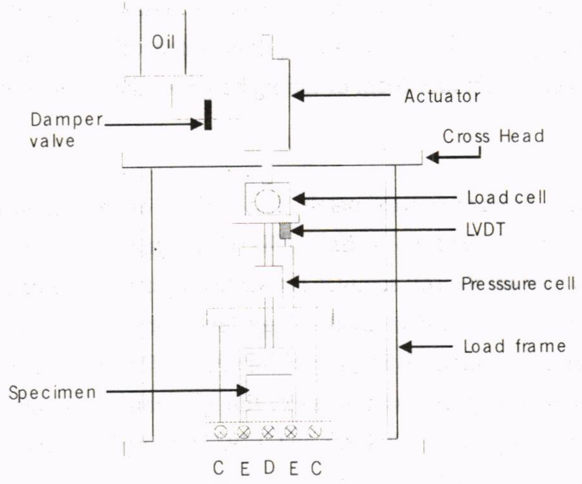

Figure 2. Setup for Triaxial test

Table 5. Loading Sequence for Modified Mr Test of Subbase with Static Triaxial Apparatus

Confining Stress (σ_3) (kPa)	Loading Pressure (kPa)	Unloading Pressure (kPa)	No. of Cycles
104.0	13.8 → 117.0	117.0 → 13.8	1- 3
21.0	13.8 → 75.8	75.8 → 13.8	1- 3
35.0	13.8 → 117.0	117.0 → 13.8	1- 3
69.0	13.8 → 220.0	220.0 → 13.8	1- 3
138.0	13.8 →289.6	289.6 → 13.8	1- 3
Seating Pressure		13.8 kPa	

3. MODIFIED TRIAXIAL TESTS FOR OBTAING Mr

Design of pavement thickness depends on a proper characterization of the stress-strain relation of the pavement materials. The resilient modulus (Mr) is defined as the deviatoric stress σ_d divided by the resilient (recoverable) strain ε_r as the following equation:

$$M_r = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

Even though the procedure for the determination of Mr has not yet been standardized, guidelines (T292-91I and T294-92I) are suggested by AASHTO. For this study a different testing procedure was adapted as mentioned previously. Even though different testing procedures may provide possibilities of different Mr values, there have been on-going arguments that unique modulus of pavement materials should be obtained regardless of the testing procedures. Therefore, in this study a different testing procedure was adapted to investigate resilient characteristics of the recycled concrete debris. The used testing procedure is modified static triaxial test, giving cyclic effect. The adapted testing procedures use lower bulk stress ($\theta=\sigma_1+\sigma_2+\sigma_3$) than the ASSHTO T294-92I and T292-91I as shown in Table 5. These modifications in the magnitude of load and load cycles are due to the lower stresses found in the field than anticipated (Jackson, 1989; Ho, 1989). Thus in this study, the variation of Mr values due to different testing procedures were not investigated.

A series of confining pressures was introduced for this study as shown in Table 5, since resilient characteristics of pavement materials can be influenced significantly by confining pressures. The test results for the subbase made with recycled concrete are shown in Fig. 3 – 8. Young's modulus values equivalent to Mr are calculated from the slopes of the unloading-reloading stress paths in these figures and are shown in Fig. 9.

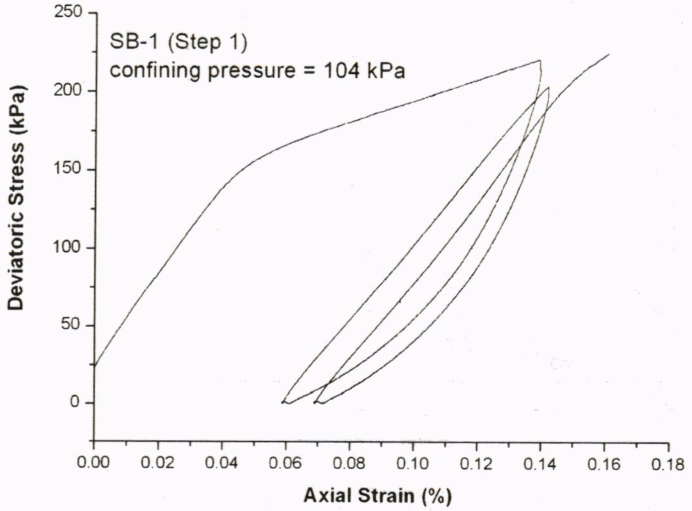

Figure 3. Results of Cyclic Triaxial Tests: σ_3 = 104 kPa

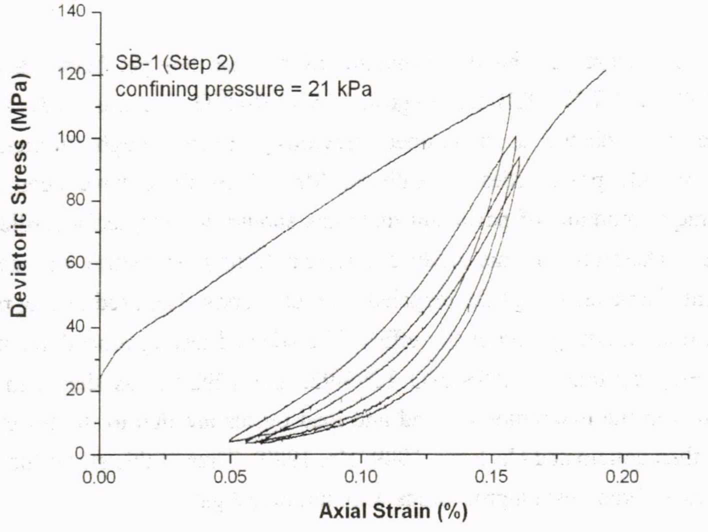

Figure 4. Results of Cyclic Triaxial Tests: σ_3 = 21 kPa

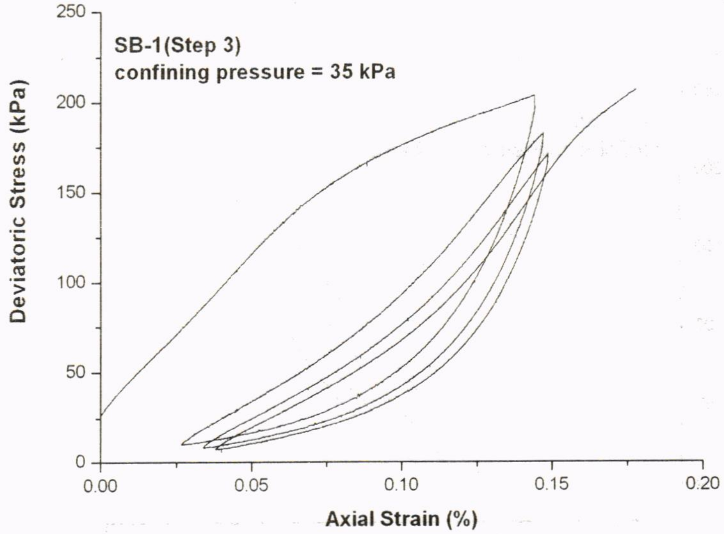

Figure 5. Results of Cyclic Triaxial Tests: σ_3 = 35 kPa

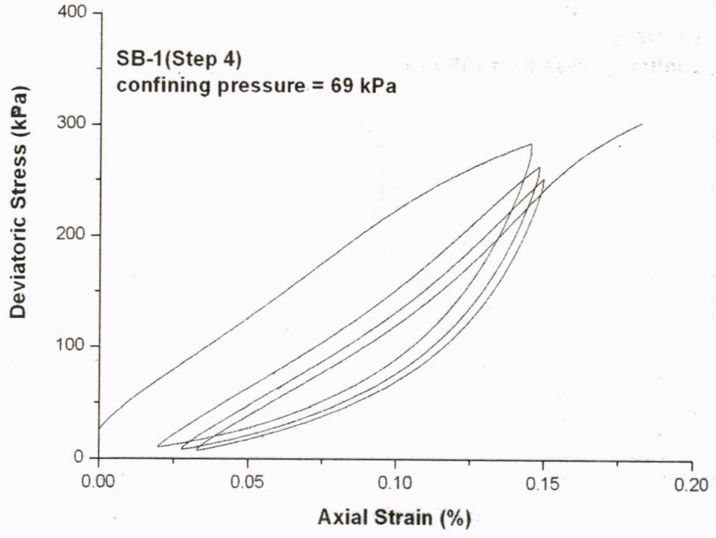

Figure 6. Results of Cyclic Triaxial Tests: σ_3 = 69 kPa

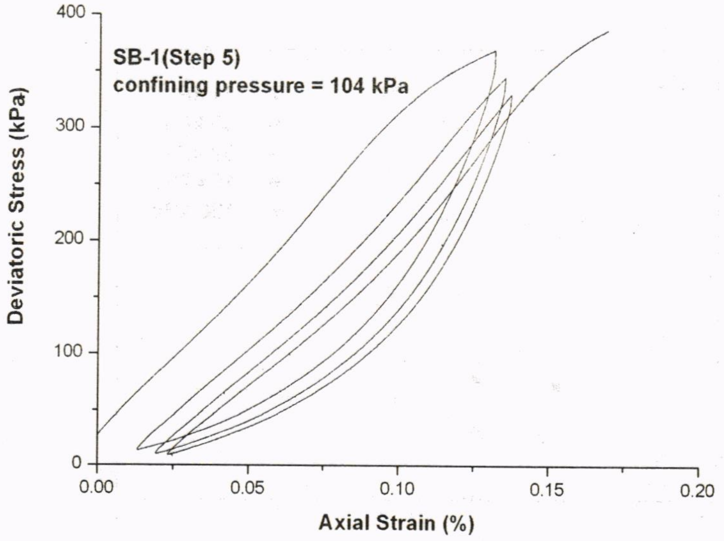

Figure 7. Results of Cyclic Triaxial Tests: σ_3 = 104 kPa

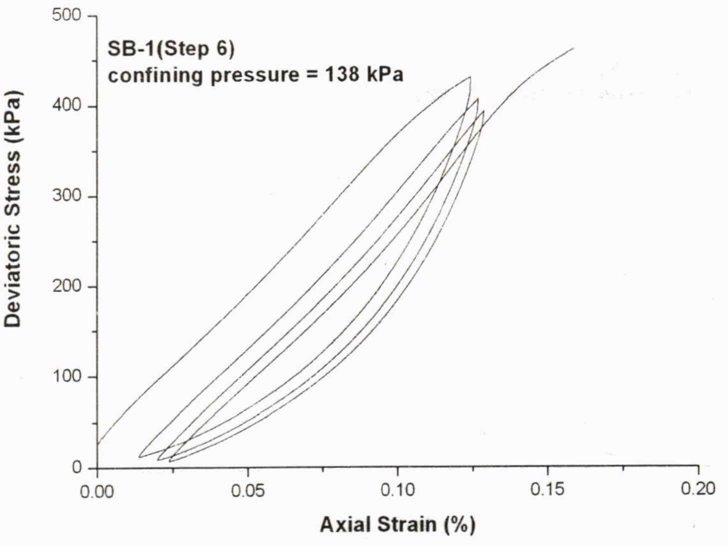

Figure 8. Results of Cyclic Triaxial Tests: σ_3 = 138 kPa

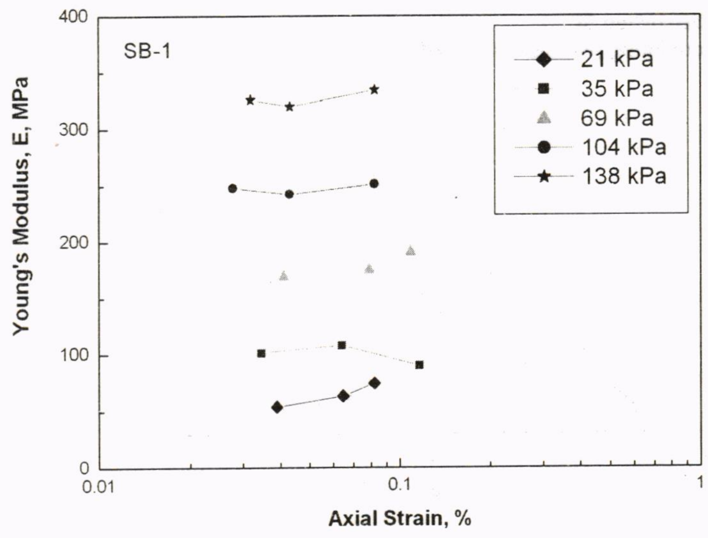

Figure 9. Computed Young's Modulus from the Results of Cyclic Triaxial Tests

The Mr values for subbase materials can be represented as the following equation in which the regression constants k_1 and k_2 should be specified as the following equation.

$$M_r = k_1 \theta^{k_2} \tag{2}$$

where θ = bulk stress. The obtained regression constants k_1 and k_2 for the recycled concrete materials were represented in Table 6 and in Fig. 10. The obtained k_1 and k_2 values are in the range of usual k_1 and k_2 values of subbase aggregate. Typical values of k_1 and k_2 for the natural crushed aggregates are in the range of 180 to 500 and 0.3 to 0.7, respectively.

Table 6. Summary of k_1 and k_2 for Recycled Concrete Aggregate

k_1 (kPa)	k_2 (kPa)
474.1	0.87

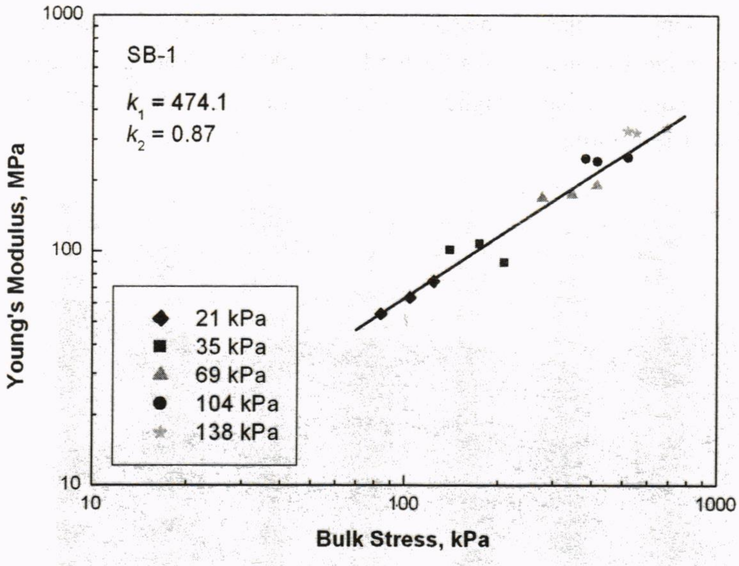

Figure 10. Computed k_1 and k_2 values from the Results of Modified Mr Test with Triaxial Test Apparatus

It was reported that Mr values are independent upon source of aggregates unless the gradations are different. However, there exists a different point of view so that the source of aggregate has some effect on the Mr values (Zaman et al., 1994). The obtained Mr value for the recycled concrete is dependent on stress level also.

4. ACCELERATED PAVEMENT TESTING

The test is also being performed at this time using the APT (Accelerated Pavement Tester) of Korea Highway Corporation to monitor the small-scaled experimental pavements constructed at a site of KHC. The KHC-APT is a pavement testing facility, with two cart systems traveled along the track guidance (Fig. 11). It can be operated by 10 km/hr, and the load weight of each cart system is about 4tons. Track of the APT is composed of two 6m long test sections, which are 1m deep. A photograph for plan and section schematic of the APT can be seen from Fig. 12 which also shows compaction method for lean concrete.

Two types of lean concrete materials were used to test recycled concrete aggregate (RCA) as a substitute for lean concrete materials: a) 100% RCA, b) 100% virgin aggregate (Fig. 13). Table 7 summarizes lean concrete mix design for 100 % virgin aggregate and 100% RCA. As shown in Fig. 13, each soil pressuremeter was embedded into subgrade, 50mm beneath the lean concrete to monitor strains (or pressures) of the top portions of subgrade. Figure 14 shows soil pressure measurement results for the first 1,000 APT loading passages. It seems that RCA test section produces higher soil pressures. This study will undertake a comprehensive APT tests further.

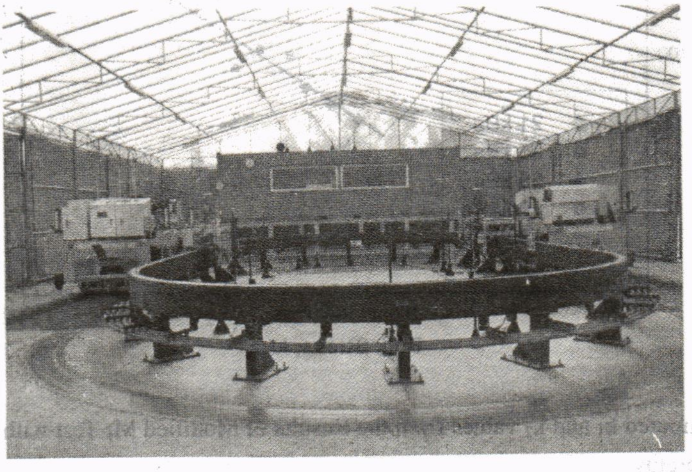

Figure 11. Front view of the small-scaled APT Facility

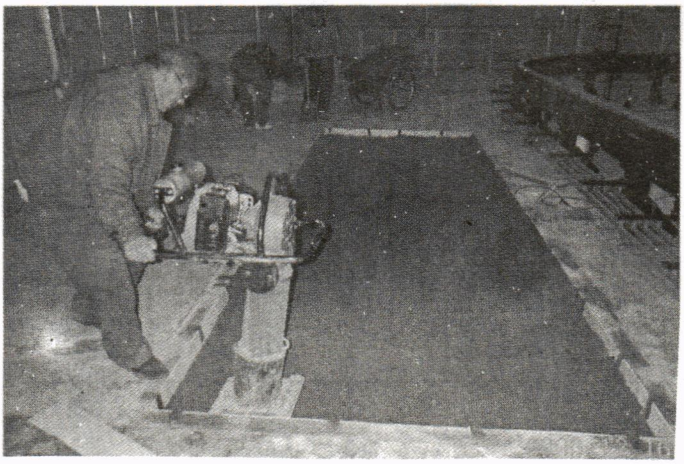

Figure 12. Compaction for Lean Concrete

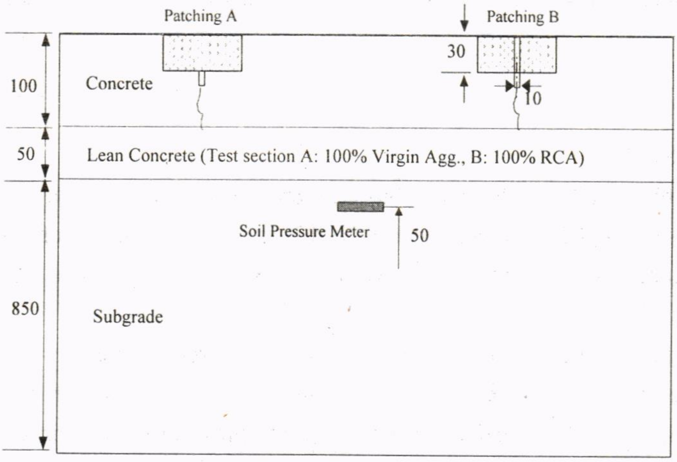

Figure. 13 Section Schematic of the Test Section

Table 7. Lean Concrete Mix Design

Agg. Type	Maximum Size (mm)	Water (kg/m^3)	Cement (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)
Virgin Agg.	40	68	158	885	1312
RCA	25	56.4	107	405	715

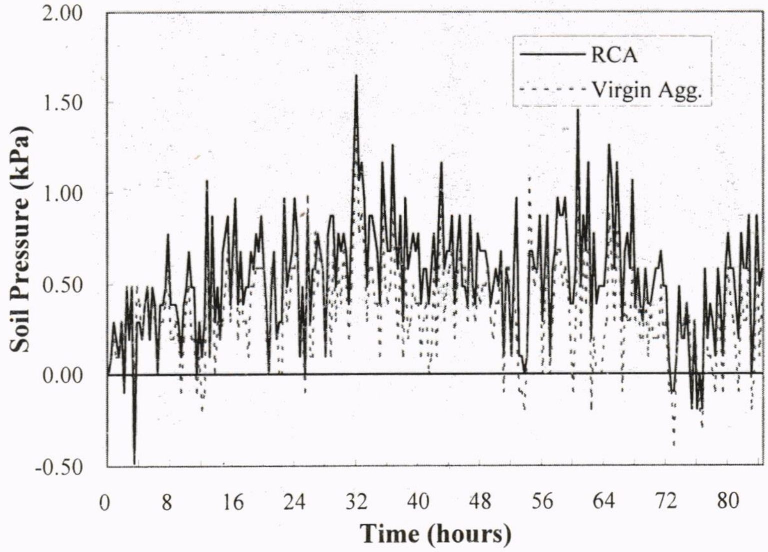

Figure. 14 Soil Pressure Measurement During First 1000 APT Passages

5. CONCLUSIONS

Recycled aggregate is the material that has been previously used in construction and has been crushed and separated from contaminants. In this study, effectiveness of using the recycled aggregate as road pavement material is investigated by performing several laboratory tests.

The reclaimed crushed concrete debris obtained in the metropolitan city of Taejon, S. Korea is tested for ensuring that the material can be used as a substitute for pavement material. Standard compaction, CBR and modified cyclic compression tests using the classical static triaxial apparatus were performed for this purpose. The gradation of the specimens obtained was modified to meet the specification of Korea Road Institute as SB1 category. A series of exploratory tests were performed to assess the effectiveness of using the recycled concrete debris as subbase materials that can be judged based on engineering properties.

From cyclic triaxial tests with modified testing procedure, constants k_1 and k_2 could be obtained that can be used to establish an equation of Mr for recycled concrete aggregate. The obtained k_1 and k_2 values are in the range of usual k_1 and k_2 values of subbase aggregate. In order to obtain Mr value for the subbase with recycled concrete materials, five levels of confining stress at each Mr (cyclic) test were conducted. It is necessary to perform further more tests for constructing a common equation.

The values suggested by the agency were compared with those from this study. It is found that, for a given gradation, the recycled concrete can be used as the substitute for crushed rock to be used as subbase materials effectively. Statistical correlations will be established between CBR and resilient modulus from further research. Further intensive investigation is being performed at present time using the APT (Accelerated Pavement Tester) of Korea Highway Corporation to monitor the small-scale experimental pavements constructed at a site of the KHC.

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