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Determination of Strength Properties of Cement Concrete Utilizing Recycled Concrete Aggregates and Thickness Design of Rigid Pavement for Low Volume Road

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Abstract:- Recycled concrete aggregate refers to aggregate obtained from demolished concrete. It can be utilized for cement concrete production to meet rising need of huge quantities of aggregates and reduced problem of disposal of demolished concrete simultaneously. Low volume road carries average daily traffic less than 450 commercial vehicle per day.

In laboratory, properties of recycled concrete aggregate was studied and it was mixed with coarse crushed aggregate in different proportions i.e. 100%, 80%, 60%, 40%, 20%, 0% by weight to produce concrete with addition of plasticizer and microsilica. The concrete was casted and cured to perform compressive strength, split tensile strength and flexural strength tests for 7 days and 28 days concrete. Design of thickness of cement concrete pavement was done according to Guideline for Design and construction of cement concrete pavements for low volume road IRC:SP:62-2014 & Design and construction of rigid pavement for low volume roads prepared by Institute of Professional Training and Management Nepal. Cost estimation was done for construction of cement concrete pavement according to Department of Roads norms for Road and Bridge Work.

Result showed that M30 grade concrete for low volume road can be produced with coarse recycled concrete aggregate. The compressive strength, split tensile strength, and flexural strength of concrete gets reduced with addition of recycled concrete aggregate upto 6.7%, 6.25% & 8.99% respectively as compared to crushed aggregate concrete. Design thickness of plain jointed cement concrete pavement for low volume road was developed for different value of subgrade CBR 4, 5, 6, 7, 8, 9, 10, 15, 20, 50 traffic volume 50 CVPD, 150 CVPD, 300 CVPD & 450 CVPD, Hilly/Terai region underlying granular sub-base or cementitious sub-base. Cost estimation calculation for M30 grade concrete with crushed aggregate, recycled concrete aggregate and their combination showed upto 8.5% cost saving per cubic meter concrete if recycled aggregate concrete is used.

Keywords*: Recycled Concrete Aggregate, Rigid Pavement, Low Volume Road, Thickness Design, Cost Estimation*

1. Introduction

Recycled aggregate is defined as aggregate resulting from the processing of inorganic material previously used in construction. Recycled aggregate concrete is an alternative to using natural aggregate in concrete. Roads carrying an average daily traffic exceeding 450 Commercial Vehicle Per Day (CVPD) with laden weight exceeding 30KN are categorized major roads and roads carrying average daily traffic less than 450 CVPD are low volume roads [1,2].

While upgrading rural roads in case of weak sub-grade or poor drainage system and extremely overloaded vehicular movement rigid pavement construction is required. Huge quantities of demolished cement concrete waste is generated worldwide. Its disposal is a problem. Crushed stone aggregates are widely used for concrete production. On the other hand, increase in demand of aggregates for cement concrete production leads increased quarrying of natural aggregated and depletion of natural resources. These two problems can be solved by recycling demolished concrete into aggregates for utilizing cement concrete production.

Cement concrete pavement has been widely used on minor roads of cities and rural roads in Nepal carrying low volume of traffic [3]. Cement concrete pavement is preferred over flexible pavement due to its longer life, less maintenance requirement, more environment friendly construction with local materials and cheaper life cycle cost compared to flexible pavement [4]. This study attempts to design thickness of rigid pavement for low volume road and develop design thickness table with the help of IRC:SP:62-2014 'Guidelines for design and construction of cement concrete pavement for low volume roads and Design and Construction of Rigid Pavement for Low Volume Roads prepared by IPTM considering different traffic volume, subgrade CBR, joint spacing and underlying sub-base requirement.

2. Objectives

The objective of the study is to determine the strength properties of cement concrete for rigid pavement utilizing recycled aggregates and design thickness for low volume road.

3. Methods

The material required for the sample preparation for this research included cement, sand, demolished concrete, aggregate, water, and admixtures. Ordinary Portland Cement (Shivam OPC grade 43) from the local market was used. Coarse aggregate was collected from Dukuchhap, Lalitpur. Fine aggregate was collected from Melamchi Crusher. For recycled concrete aggregate, sample was collected from demolished cement concrete road while laying pipeline in Mahalaxmi Municipality-4, Lalitpur. Recycled concrete aggregate was manually prepared by crushing demolished concrete using a hammer. Recycled aggregate was separated manually. Properties of recycled concrete aggregate was checked according to Standard Specification for Road & Bridge Work (SSRBW). Gradation of recycled concrete aggregate followed as per gradation requirement of coarse aggregate mentioned in SSRBW. ESTEEMA 2001 (PD-122) was used as plasticizer. AGRM Microsilica grade 92D was used as mineral admixture. Laboratory tests were conducted in the laboratory in Everest Laboratory, Balkumari & laboratory of Infrastructure Development Office, Lalitpur. Tests were done to determine properties of aggregate and concrete.

Preparation of Sample

Recommended characteristic 28 days compressive strength is at least 30MPa for low volume road rigid pavement [1,4]. Trial mix design for M30 grade concrete was done utilizing crushed aggregate. Same mix design was used for recycled aggregate concrete as well. Laboratory test was done for primary data collection. Aggregates samples collected were tested at laboratory for primary data.The value of modulus of elasticity (E) is taken 30000 MPa, the value of poisson's ratio (μ) is taken 0.15 and the coefficient of thermal expansion (α) is taken 10^{-5} per ^{o}C for concrete [1].

Data Analysis

Values obtained from laboratory tests were analyzed to determine properties of aggregate and concrete. Thickness design of cement concrete pavement for low volume road was done according to guidelines.

Properties of aggregates were tested in laboratory. Different compositions 0%, 20%, 40%, 60%, 80% & 100% by weight of recycled coarse aggregate with crushed aggregate were mixed for M30 grade cement concrete production at 0.4 water cement ratio with super plasticizer for workability along with mircosilica as per trial mix design.

Thickness design of cement concrete pavement for low volume road

Guideline for Design and construction of cement concrete pavements for low volume road IRC:SP:62-2014 & Design and construction of rigid pavement for low volume roads prepared by IPTM was followed for the design of low volume road rigid pavement design.

Jointed plain cement concrete pavement is designed underlying either granular sub-base or cementitious sub-base. For traffic up to 50 CVPD, sub-base of 75mm water bound macadam over 100 mm granular sub-base is considered. For traffic from 50 CVPD to 150 CVPD sub-base of 75mm water bound macadam over 100mm granular sub-base is considered. For traffic greater than 150 CVPD to 450 CVPD, 150mm thick water bound macadam is laid over 100mm granular sub-base. Again, if cementitious sub-base is underlying cement concrete pavement, then for traffic upto 150 CVPD, 150mm thick cementitious sub-base can be used. For traffic greater than 150 CVPD to 450 CVPD, 200mm thick cementitious sub-base is considered [1].

CBR values of 4, 5, 6, 7, 8, 9, 10, 15, 20 & 50 were selected. The corresponding values of the modulus of subgrade reaction for CBR values were used for calculating stresses. The joint spacing recommended by guideline is 2.5m to 4m. So, joint spacing of 2.5m, 3m, 3.5m and 4m was selected for thickness design. For calculating curling stress temperature differential values varies according to hilly or terai region as well as thickness of concrete slab. That's why cement concrete pavement thickness design was done for hilly and terai region [4].

Cost Estimation

Cost estimate for designed cement concrete pavement was prepared with approved district rate of Lalitpur/Kathmandu district for fiscal year 2024/25 according to norms approved by Department of Road for Road and Bridges. Rate of recycled concrete aggregate was prepared by interviewing representative from Kantipur Crusher at Tikabhairav and rate analysis according to Department of Road norms.

4. Results

Properties of aggregate and concrete

Concrete mix was prepared according to mix design for crushed aggregate, recycled concrete aggregate and its different proportion of coarse aggregate i.e. 100% crushed aggregate only (100C), 80% crushed 20% recycled concrete aggregate (80C/20R), 60% crushed 40% RCA(60C/40R), 40% crushed aggregate 60% RCA (40C/60R), 20% crushed 80% RCA (20C/80R) and 100% RCA only(100R). Laboratory test result of aggregate and concrete showed in Table 1.

Table 1: Summary of the Physical Properties of Aggregate and Concrete

Sample	100C	80C/20R	60C/40R	40C/60R	20C/80R	100R
Water Absorption	1.33%	1.35%	1.38%	1.38%	1.42%	1.43%
Specific Gravity Test	2.69	2.68	2.68	2.67	2.66	2.66
AIV	27.98%	28.1%	28.8%	29.5%	29.8%	29.96%
LAA	31.33%	32.1%	33.2%	33.8%	33.9%	34.21%
Compressive Strength at 28 days	42.55 MPa	41.56 MPa	40.52 MPa	40.12 MPa	39.77 MPa	39.7 MPa
Split Tensile Strength at 28 days	3.04 MPa	2.96 MPa	2.94 MPa	2.93 MPa	2.9 MPa	2.85 MPa
Flexural Strength at 28 days	8.68 MPa	8.46 MPa	8.34 MPa	7.95 MPa	7.92 MPa	7.90 MPa

Water absorption, AIV and LAA value of recycled concrete aggregate is less than crushed aggregate due to mortar attached to the recycled concrete aggregate [5]. The result indicated that recycled concrete aggregate meets the required properties of aggregate.

Compressive strength & Split tensile strength of recycled aggregate concrete reduced compared to crushed aggregate concrete due to cement mortar attached on the surface of the recycled concrete aggregate [5]. Flexural strength of recycled aggregate concrete is reduced compared to crushed aggregate concrete because of weakness in bonding strength, linking the aggregate fraction and cement paste contributed due to cement mortar attached on the surface of the recycled concrete aggregate [6]. Target strength according to mix design was 38.25 MPa. All sample result complied the target strength. So M30 grade concrete can be produced with 100% recycled concrete aggregate. Cement concrete pavement is designed with 28 days flexural strength value of 3.83 MPa and 90 days flexural strength of concrete 4.22 MPa [1]. So, all sample complied the requirement of flexural strength of concrete for cement concrete pavement. Thus, it can be concluded that recycled aggregate concrete can be used as cement concrete pavement utilizing all combination of crushed aggregate and recycled aggregate.

Thickness Design of Cement Concrete Pavement for Low Volume Road

The minimum thickness in mm of jointed plain concrete pavement for low volume road for different value of traffic, CBR of subgrade, Joint spacing and region underlying granular sub-base are calculated and presented in following tables 2-9:

Table 2: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 2.5m underlying granular subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	153	153	156	156	203	202	205	204
	5	150	150	154	155	202	201	204	203
	6	150	150	154	155	202	201	203	203
	7	150	150	153	155	201	201	203	203
	8	150	150	153	155	201	201	203	203
	9	150	150	153	154	201	201	203	203
	10	150	150	153	154	201	201	203	203
	15	150	150	152	153	200	201	202	202
	20	150	150	151	153	200	201	201	202
	50	150	150	150	150	198	202	200	204

Table 3: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 3.0m underlying granular subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	153	153	161	163	211	212	213	213
	5	150	150	160	162	211	212	213	214
	6	150	150	160	162	211	212	213	214
	7	150	150	160	162	211	212	212	214
	8	150	150	160	162	211	212	212	214
	9	150	150	159	162	211	212	212	214
	10	150	150	159	162	211	212	212	214

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
	15	150	150	158	162	211	213	212	215
	20	150	150	158	162	211	214	212	215
	50	150	150	152	158	213	219	215	221

Table 4: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 3.5m underlying granular subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	153	153	167	170	220	222	222	224
	5	150	150	166	170	221	223	222	225
	6	150	150	166	170	221	224	222	225
	7	150	150	165	170	221	224	223	226
	8	150	150	165	170	221	224	223	226
	9	150	150	165	170	221	225	223	226
	10	150	150	165	170	221	225	223	226
	15	150	150	164	169	222	226	224	228
	20	150	150	163	168	223	227	225	229
	50	150	150	155	164	227	235	229	238

Table 5: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 4.0m underlying granular subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	153	153	172	177	230	234	232	235
	5	150	150	171	176	231	235	233	237
	6	150	150	171	176	232	236	234	238
	7	150	150	170	176	232	237	234	239
	8	150	150	170	176	233	237	234	239
	9	150	150	170	176	233	237	235	239
	10	150	150	170	176	233	238	235	239
	15	150	150	168	175	235	240	237	242
	20	150	150	167	174	236	242	238	245
	50	150	150	157	167	241	251	243	253

Table 5: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 2.5m underlying cementitious sub-base

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	150	150	152	154	201	201	202	202
	5	150	150	151	153	200	201	201	202
	6	150	150	150	153	200	201	201	202
	7	150	150	150	152	199	201	201	202

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
	8	150	150	150	152	199	201	201	202
	9	150	150	150	152	199	201	201	202
	10	150	150	150	152	199	201	201	202
	15	150	150	150	152	199	201	200	203
	20	150	150	150	151	199	201	200	203
	50	150	150	150	150	199	205	201	207

Table 6: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 3.0m underlying cementitious subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	150	150	159	161	211	213	212	214
	5	150	150	158	161	211	214	212	215
	6	150	150	157	161	211	214	213	216
	7	150	150	157	161	211	214	213	216
	8	150	150	157	161	211	214	213	216
	9	150	150	156	161	211	215	213	216
	10	150	150	156	161	211	215	213	216
	15	150	150	155	160	212	216	213	218
	20	150	150	154	159	212	217	214	219
	50	150	150	150	153	214	224	216	226

Table 7: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 3.5m underlying cementitious subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	150	150	164	169	222	226	224	228
	5	150	150	163	168	223	228	225	229
	6	150	150	163	168	223	228	225	230
	7	150	150	162	168	224	229	226	231
	8	150	150	162	168	224	229	226	231
	9	150	150	162	168	224	229	226	231
	10	150	150	162	168	224	230	226	231
	15	150	150	159	166	226	232	228	234
	20	150	150	158	165	226	234	228	237
	50	150	150	150	155	229	241	232	244

Table 8: Minimum design thickness in mm of jointed plain concrete pavement with joint spacing 4.0m underlying cementitious subbase

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
CBR	4	150	150	169	176	234	240	236	241

Traffic (CVPD)		50		150		300		450	
Region		Hilly	Terai	Hilly	Terai	Hilly	Terai	Hilly	Terai
	5	150	150	167	174	236	242	238	244
	6	150	150	167	174	236	243	238	245
	7	150	150	166	173	236	244	239	246
	8	150	150	166	173	236	244	239	246
	9	150	150	166	173	237	244	239	246
	10	150	150	165	173	237	244	239	247
	15	150	150	162	171	238	247	240	249
	20	150	150	161	170	239	248	241	250
	50	150	150	150	155	240	255	244	258

Cost Estimation of Cement Concrete Pavement for Low Volume Road

Cost estimate was done for One cubic meter of M30 grade cement concrete production utilizing crushed aggregate concrete and recycled aggregate concrete according to norms for road and bridge works published by Department of Road and district rate for Lalitpur. For Recycle aggregate concrete, cost estimate was done considering demolished concrete waste transporting from Imadol, Mahalaxmi Municipality 4, Lalitpur to Kantipur crusher at Tikabhairav for production of recycled concrete aggregate. Cost of production of recycled concrete aggregate was calculated considering transportation cost of demolished concrete aggregate, production cost according to interview with personnel of Kantipur crusher, Tikabhairav, Lalitpur and DoR norms. Summary of cost comparison for different proportions of crushed aggregate and recycled concrete aggregate is shown in figure 1:

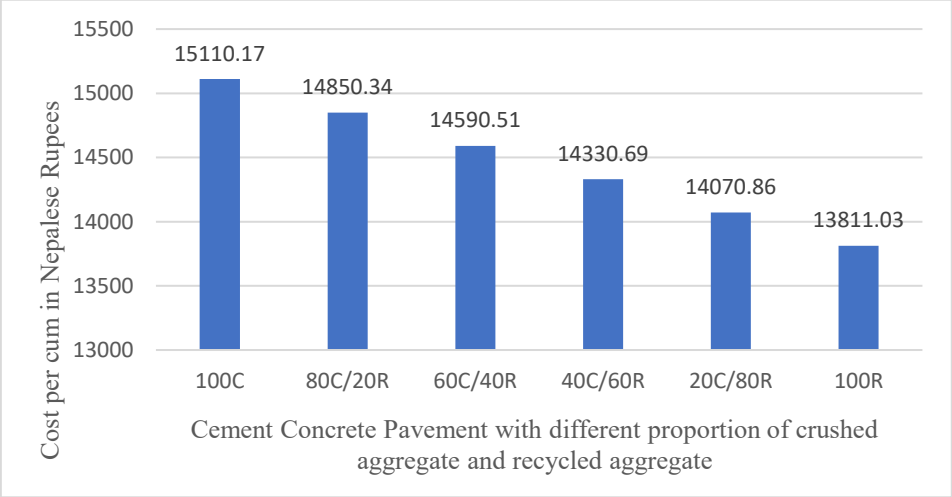

Figure 1: Cost Comparison of Jointed Plain Cement Concrete Pavement per cum in Nepalese Rupees

The cost of concrete production reduces with increase in recycled concrete aggregate proportion due to lower cost of recycled concrete aggregate compared to crushed aggregate.

5. Result & Discussion

Strength properties of recycled aggregate concrete complied with the SSRBW requirement for M30 grade concrete production for low volume road. It was found that increase in replacement ratio of crushed aggregate by recycled concrete aggregate reduced compressive strength, split tensile strength & flexural strength value of concrete. Reduction in the compressive strength, split tensile strength & flexural strength value was upto 6.7%, 6.2% &

8.9% respectively at 100% replacement of crushed aggregate by recycled concrete aggregate due to cement mortar attached with recycled concrete aggregate.

Minimum design thickness of plain jointed cement concrete pavement for low volume road was developed for different value of CBR (4, 5, 6, 7, 8, 9, 10, 15, 20, 50), traffic (50 CVPD, 150 CVPD, 300 CVPD & 450 CVPD), Hilly/Terai region underlying granular subbase or cementations subbase.

Cost estimation calculation for M30 grade concrete with different proportion of crushed aggregate and recycled concrete aggregate showed 8.5% cost saving per cubic meter concrete if 100% coarse recycled aggregate concrete is used compared to 100% crused aggregate concrete.

According to this study and its results, recommendations are recycled concrete aggregate can be used for production of M30 grade cement concrete pavement for low volume road provided aggregate comply with properties requirement as per Standard Specification for Road and Bridge Work published by Department of Road. Thickness of cement concrete pavement for low volume road can be selected from thickness table according to traffic volume, subgrade CBR, sub-base type and region for project. Cost estimate for cement concrete pavement varies according to proportion of crushed aggregate and recycled concrete aggregate. Greater proportion of recycled concrete aggregate results cheaper concrete. 100% recycled aggregate concrete is recommended for jointed plain concrete pavement for low volume road due to its lower cost. However, crushed aggregate concrete or combination of crushed aggregate and recycled concrete aggregate may also be used for concrete production, depending on the availability of aggregate type.

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