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Engineering Properties of Aggregates for Railway Ballast, Rapati Nadi, Central Nepal Sub-Himalaya

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ABSTRACT

Nepal has proposed various railway projects, such as the East-West Railway, Kathmandu Metro Railway, and Raxaul-Kathmandu Railway. Good ballasts are always sought in the projects to diminish maintenance cost. Sediments from the Rapati Nadi (River) in central Nepal are among probable sources of ballasts as those sediments are rich in quartzite clasts. To meet the ballast requirements for railway projects, the study assessed the physical, mechanical and durability properties of alluvial deposit aggregates.

The compositional analysis yielded maximum percentage of quartzite followed by sandstone and others. The aggregates yielded uniformity in gradation. Flakiness and Elongation Indices of the tested samples ranged from 11.18 to 24.10% and from 13.07 to 42.77%, respectively. Specific gravity exceeded 2.4. Aggregate Impact Value, Aggregate Crushing Value and Los Angeles Value of the tested samples were respectively 4.4-13.2%, 10.20-17.67% and 15.75-34.25%. Similarly, the point load strength index ranged from 3.69 to 6.57 MPa, and the Sodium Sulphate Soundness Values ranged from 0.96 to 2.06%. All the test results satisfied the conditions based on IS specification in the context of aggregate shape, crushing strength, impact strength, and durability against abrasion. When the results of different indices and values are rated based on their higher, intermediate and lower ranges, all the samples fall in the range of the high rating. Thus it shows suitability of aggregates of the Rapati Nadi and sediment aggregates deposited between Basantapur and Bastipur seem better compared to other locations.

Keyword: Aggregate. Geotechnical properties, Railway Ballast, Engineering properties, Los Angeles Abrasion Value

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INTRODUCTION

Railway transportation is one of the fastest medium in land traffic system. The railway track consists of steel rails installed on sleeper set in ballast. Ballast is the selected natural gravel or crushed and graded material, composed of medium to coarse gravel-sized aggregates (10-60 mm), with a small percentage of cobble-sized particles (Chrismer 1985; Esveld 2001; Indraratna 2006). It is placed upon the railroad for the purpose of providing drainage, to resist the growth of vegetation and distribute the track loading to the subgrade (Robnett et al. 1975; Selig and Watters 1994; Mishra et al. 2013). The ballast layer is the important parts of the railway track, which supports the sleeper against vertical, lateral and longitudinal displacement (Indraratna 2006). The thickness of the railway ballast layer is 250-300 mm (Esveld 2001). Therefore, railway ballast is one of the most important components in a railway track. Fulfillment of quality requirements should be made for getting good ballasts to diminish maintenance cost. Rock type, particles size, surface texture, shape indices, specific gravity, water absorption, strength, durability against abrasion and weathering are the main properties which determine the quality of railway ballasts (Chrismer 1985; Esveld 2001; Indraratna et.al. 1998, 2000, 2003b, 2006).

In general, fine- to medium-grained igneous rocks i.e., granite, basalt, gabbro are the most preferable compared to either sedimentary or metamorphic rocks. Few well cemented sandstones and calcareous siltstones, and massive quartzites are preferable than the rocks such as slate, phyllite, schist and gneiss (Raymond 2006).

The gravelly materials of the Rapati Nadi (River) section (Fig. 1) dominantly compose of sub-rounded, rough to smooth textured quartzites, and are appropriate for the concrete and road aggregate based on Nepal standard (Maharjan and Tamrakar 2007). Currently, different railway projects are being proposed in Nepal. Among them are the East-West Railway, the Raxaul-Kathmandu Railway, the Kathmandu Metrorail, the Kerung-Kathmandu Railway, etc. (Thapa 2018; Chitrakar, 2021), which

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will requires huge amount of railway ballasts. Therefore, the main aims of the present study are (i) to determine various engineering properties of gravelly sediments from the Rapati Nadi, and (ii) to assess for suitability of aggregates for the railway ballasts by comparing the test results with the specification of the Indian Standard.

LOCATION AND PHYSIOGRAPHY

The study area is located along the Rapati Nadi stretch between Bastipur and Basantapur, Makawanpur, Central Nepal. Geologically the area lies under the Sub-Himalayan Zone. The study area consists of hilly terrain with rugged elevated topography, resulting different landforms. In study area, the minimum elevation of the Rapati Nadi is 310 m and maximum elevation is 400 m but the area covers altitude that ranges from 310 m at Basantapur to 940 m at Sanobhawar. The major tributaries of the Rapati Nadi in study area are seasonal streams, Chakari Khola, Makari Khola, Thado Khola, Masine Khola, Twanra Khola, Darai Khola, Bhotu Khola, Badh Khola and Chanura Khola. All these streams flow south from the Rapati Nadi and flow northward from their origin.

GEOLOGICAL SETTING

The Department of Mines and Geology published five geological maps in Nepal Himalaya (Fig. 2). In them, the Lesser Himalayan rocks are classified into the Surkhet Group, Midland Group Kathmandu Group and the Himal Group. The Midland Group is subdivided into the Pokhara or Dailekh Subgroup, Lakharpata Subgroup, and the unconformably overlying Gondwana Subgroup. The Kathmandu Group also subdivided into Phulchoki Subgroup and Bhimphedi Subgroup (DMG 1991). From the Lesser Himalayan Zone, the rocks of Lakharpata Subgroup and Bhimphedi Subgroup falls in Rapati watershed.

The Lakharpata Subgroup begins with the Galyang Formation and is followed upwards, respectively, by the Sangram Formation, Syangja Formation and the Lakharpata Formation. The rocks of Galyang

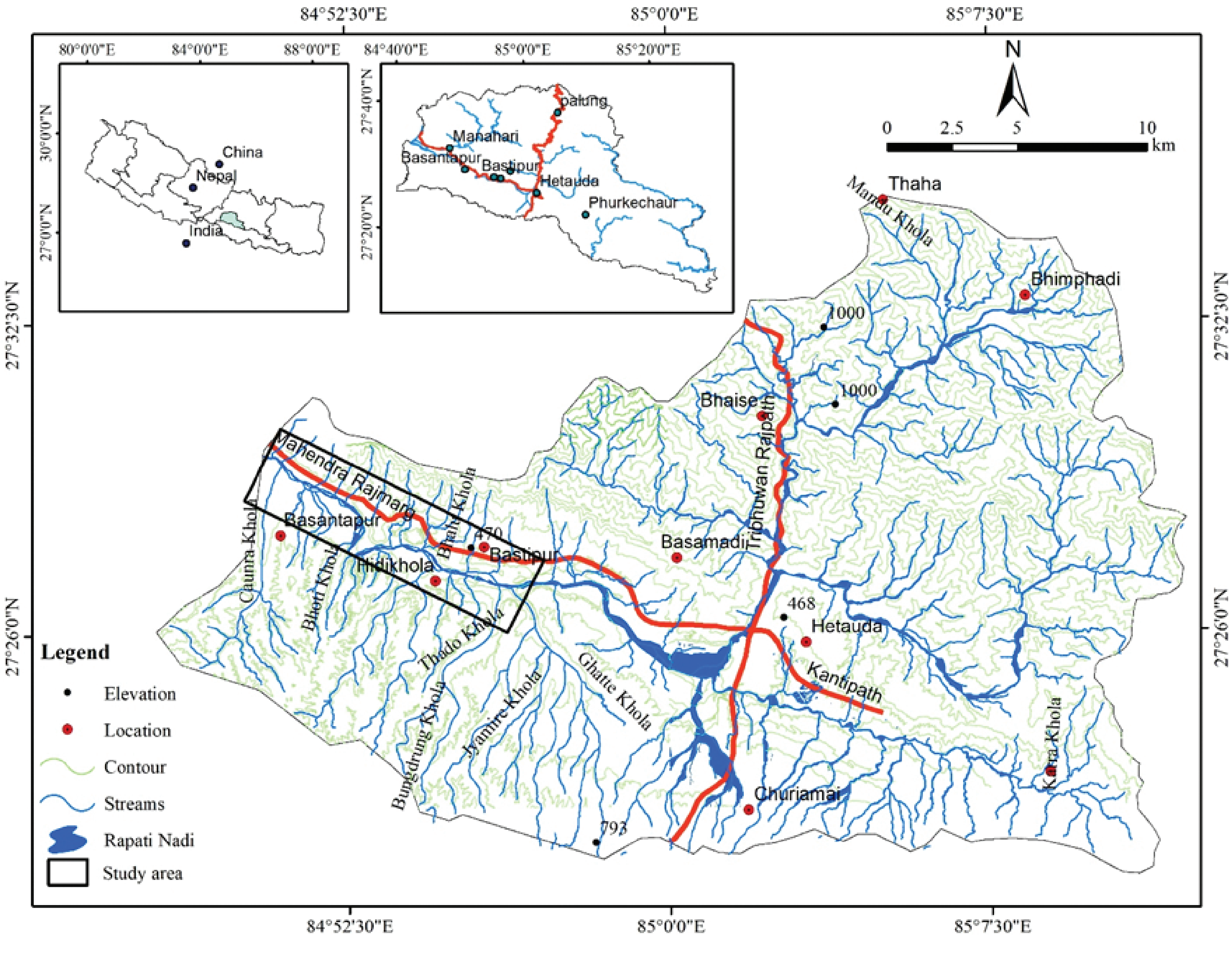

Fig. 1: Drainage map of the portion of the Rapati Nadi Basin

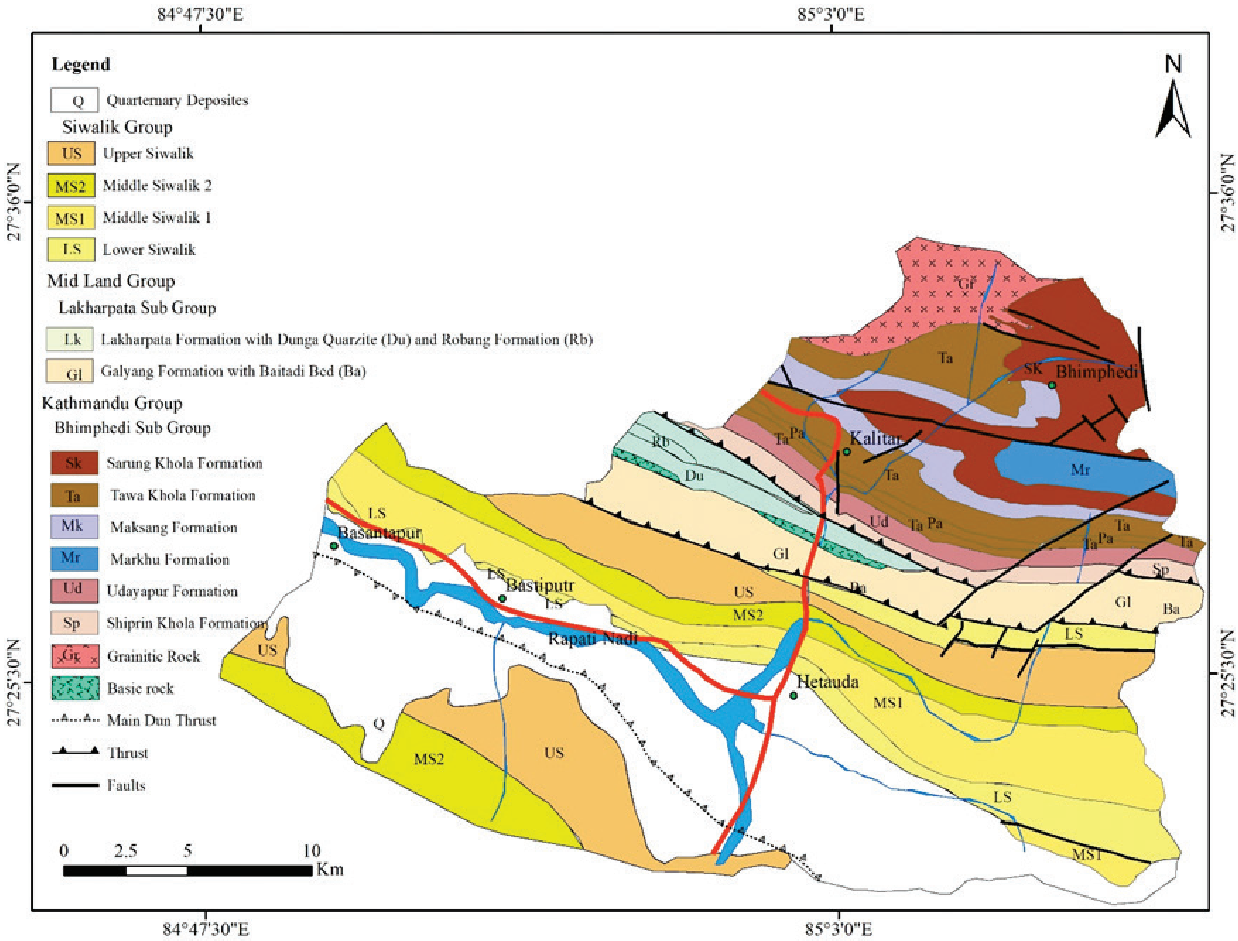

Fig. 2: Regional Geological map of the Rapati Watershed around study area (After Department of Mines and Geology 1993)

Formation and Lakharpata Formation lies under the Lakharpata Subgroup in the study area. Also, Bhimphedi Subgroup represent metamorphic succession composed of schist, phyllite, quartzite and marble.The Bhimphedi Subgroup begins with the Markhu Formation and is followed upwards, respectively, by the Sarung Formation, Maksang Formation, Tawa Khola Formation, Udayapur Formation and the Shiprin Formation in the Rapati Watershed.

The Siwaliks are regarded as tectonically the most dynamic zone of the Himalayas (Kizaki 1994). The Siwalik Group is a thick sedimentary sequence, which extends throughout the east-west of the southern Himalayan Belt that represents the youngest belt. The Siwalik Group is bounded by the Main Boundary Thrust (MBT) in the North and the Himalayan Frontal Thrust (HFT) in the South, and is separated from the Lesser Himalaya in the North and the Indo Gangetic Plain in the South.

The Siwalik Zone can be divided into two belts separated by the Main Dun Thrust (MDT) and these belts are termed as north belt and south belt (Schelling et al. 1998). The study area lies in the north belt of the Siwalik and the river flows across the rocks of the Lower Siwalik Subgroup. The Siwalik group is mostly divided into Lower Siwalik, Middle Siwalik and Upper Siwalik subgroups on the basis of lithology and grain size (Auden 1935). In 1964 Ganser also classified the same three group on the basis of previous studies of the Siwalik Group with same lithology.

The Siwalik Group, composed of fluvial sedimentary rocks like mudstone, sandstones and conglomerate, (Tamrakar 2002) shows a coarsening upward succession, and is divided into the Lower Siwalik Subgroup, the Middle Siwalik Subgroup and the Upper Siwalik Subgroup.

The Quaternary deposits consist of cobble to gravel clasts from the Lesser Himalayan Group and the Siwalik Group and have mostly clasts of quartzite and sandstone with few granite, gneiss, limestone and phyllite in matrix of sand, silt and clay according to their size limit in various deposits. The sediments are deposit by the north-flowing southern tributaries of the Rapati Nadi. The terrace deposit consists of flood deposit that constitutes clasts, which are mostly rounded to sub-rounded with few angular to flaky, having dominance of smooth texture. The deposits are mostly ill sorted.

METHODOLOGY

An engineering geological map of the study area was prepared based upon the geological classification, soil classification and its thickness, terrace classification, geomorphologic and physiographic features and engineering infra-structures. The base of the map was derived from the topographical map and the field investigations.

Samples were collected from 12 different locations at a distance of about 1 km apart from each point. The sampling points were established mostly in the river bar deposits and the terrace deposits (Fig. 3) digging the pits, so that the samples can be extracted in a larger volume and cost-effective manner. For the quality assessment of the samples different tests were done using the Indian Standards.

Fig.3: Sampling of the aggregate through terrace (a) and pit (b).

GRADATION ANALYSIS

The sieve analysis of coarse aggregate was conducted according to standard gradation test IS: 2386: (Part I)-1963. The data of sieve analyses were used to prepare graphs in the field to analyze the appropriate size of the ballast.

Fig.4: Sieved sample for the test in field (a) and apparatus of Indian Standard thickness gauge and length gauge (b).

The Indian standard railway ballast specification is 90-100% of ballast passing through 63 mm, 40-60% passing through 40 mm and 0-2% passing through 20 mm. The total percentage of sample passing through 63 mm and retained on 19.5 mm is listed in the result.

ELONGATION INDEX

Elongation index (EI) of an aggregate is the percentage by weight of particles whose greatest dimension i.e. length is greater than 1.8times of the mean size of the sieve.This test was conducted following the IS: 2386: (part I)-1963. More than 200 pieces of sample were prepared for elongation index. Elongation index was estimated using the following relation:

$$EI = \frac{\Sigma W_2}{\Sigma W_1} \times 1001 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, $W_1 =$ weight of total sample taken for the test, $W_2 =$ weight of total sample retained in the length gauge.

FLAKINESS INDEX

The flakiness index (FI) of aggregate is the percent by weight of particles whose least dimension i.e. thickness is less than three-fifth times of their mean dimension. So, aggregate particles are classified as flaky when they have a thickness of less than 0.6 of their mean sieve size. More than 200 pieces of sample were prepared for testing Flakiness Index, following the IS: 2386: (Part I)-1963. Flakiness Index is estimated as:

$$FI = \frac{\Sigma W_2}{\Sigma W_1} \times 100\% \quad \ldots \quad (2)$$

Where, $W_{1} =$ weight of total sample taken for the test, $W_{2} =$ weight of total sample passing in the Thickness Gauge.

The particle shape was determined by the percent of elongation and flakiness of particles contained in it.

SPECIFIC GRAVITY, DENSITY AND WATER ABSORPTION TESTS

For coarse aggregate, specific gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Absorption is the increase in aggregate mass due to the soaked water in the permeable pores of the material. Hence, the water absorption increases with increased connected pores in the material. These properties were determined according to the IS: 2386: (Part III)-1963.

For coarse aggregate, 2 kg of sample retained on 10 mm sieve was saturated and weighed in water (mass B) (Fig. 5a). Then the saturated surface dried (SSD) mass was obtained (mass A). Finally, it was oven dried for 24 hours at 100-105ºC, and then cooled and weighed (mass C). The following equations were used to compute specific gravity, density and water absorption:

$$\text{Specific gravity (oven dried)} = \frac{C}{A-B} \ldots\ldots\ldots\ldots \quad (3)$$

$$\text{Apparent specificgravity} = \frac{C}{C-B} \ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$\text{Water absorption (\% dry mass)} = \frac{A-C}{C} \times 100 \ldots \quad (5)$$

AGGREGATE IMPACT VALUE TEST (AIV)

Aggregate impact value test was conducted following IS: 2386: (Part IV)-1963. About 500 g of aggregate sample between 9.5 and 12.5 mm was tested in the apparatus (Fig. 5b). The sample after test was removed from the holder and was sieved on 2.36 mm sieve. Then the aggregate impact value (AIV) was obtained as IS: 2386: (Part IV)-1963:

$$\text{Aggregate impact value (AIV)} = \frac{W_2}{W_1} \times 100\% \ \ldots..(6)$$

Where W_1 is the total weight of dried sample and W_2 is the total weight of crushing aggregate passing through 2.36 mm sieve.

AGGREGATE CRUSHING TEST (ACV)

Aggregate crushing value test on coarse aggregate give a relative measure of the resistance of an aggregate crushing under gradually applied compressive load. About 3 kg of a test sample between 9.5 and 12.5 mm was filled in the holder by tamping (IS: 2386: (part IV)-1963). The sample was loaded in compression machine applying load in such a way that it took 10 min. to reach 400 KN (Fig. 5b). The crushed sample was removed and sieved on 2.36 mm sieve. Then the Aggregate Crushing Value (ACV) was obtained as:

$$\text{Aggregate Crushing value (ACV)} = \frac{W_2}{W_1} \times 100\% \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where,

W_1 is the total weight of dried sample and W_2 is the total weight of crushed aggregate passing through 2.36 mm sieve.

Fig. 5: Sample saturated and weighed in water (mass B) and SSD weight (mass A) for specific gravity (a) and Aggregate impact value test and aggregate crushing value test apparatus (b).

POINT LOAD TEST

The point load strength index is often used to provide a quick assessment of uniaxial, tensile and compressive strength of rock and can easily be determined in field or laboratory on rock lumps and core samples. Point load test was done for irregular lump of aggregates following IS 8764-1998. The point load strength index is given as:

$$Is = \frac{P}{{D_e}^2} \quad \ldots\ldots\ldots\ldots (8)$$

Where, P is the failure load in KN and D_e is the specimen equivalent diameter in m.

For diametral test D_e = D (core diameter)

$${D_e}^2 = \frac{4A}{\pi} \quad \ldots\ldots\ldots\ldots (9)$$

Where A is the minimum cross-sectional area of plane through the platen contacts point

Here, Cross section area (A) = W × D and $W = \frac{W_1+W_2}{2}$ .... (10)

W_1 is the upper surface width and W_2 is the lower surface width of lump specimen in mm and D is the distance between platens in mm. The size of specimen affects the value of I_s which increases as De increases. To consider the size effect, it has been common to convert the measured that corresponding to D_{50} mm that is standard index $I_{s(50)}$ in MPa:

$$I_{s\,(50)} = \frac{P*1000}{(D*W)^{0.75}\sqrt{D^*}} \quad \ldots\ldots\ldots\ldots (11)$$

Where, D^* = Standard size of lump = 50 mm

Los Angeles Abrasion Test

The abrasion test was carried out in Los Angeles Abrasion (LAA) machine governed by Indian standard IS: 2386: (Part IV)-1963. To conduct the test, about 5 kg of the 25-40 mm, together with 5 kg of 40-50 mm test samples and 12 steel charges were placed into a Los Angeles testing device that was revolved for 1000 rotations. The IS specified reporting matrix for LAA testing was material loss finer than the 1.70 mm sieve relative to the original weight of a sample. Then, LAA was calculated using the following equation:

$$LAA = \frac{W-R}{W} \times 100\ \% \quad \ldots\ldots\ldots (12)$$

Where,

W is the total dry weight of the LAA sample and R is the total weight of sample retained on 1.70 mm sieve.

Sodium Sulphate Soundness Test

The sodium sulphate soundness test was carried out on the aggregate samples to determine the durability of aggregate against physical weathering and carried out as of Indian Standard IS 2386: (Part V)-1963.The five-cycle test was conducted and the sodium sulphate soundness value was calculated using the following expression:

Sodium Sulphate Soundness value (SSSV) = $\frac{W_1 - W_2}{W_1} \times 100$ .... (13)

Where, W1 is Initial weight of samples and W2 is the weight retained on 8 mm sieve after five cycles.

RESULTS

DESCRIPTION OF SAMPLES

Engineering geological map of the study area at the stretch of 12 km section of Bastipur-Basantapur along the Rapati Nadi was prepared. The area consists of the Lower Siwalik Subgroup and the Quaternary Deposit. The Lower Siwalik Subgroup consists of gray to light gray, thick to thinly bedded, fine-grained, slightly weathered sandstone and fine-grained, gray, slightly weathered mudstone. The Quaternary deposit consists of well graded gravel, cobble with rounded to angular clasts and few matrixes of sand and clay (Table 1). About 82% of the sample is of smooth texture while 18% of the sample is of rough texture. Since the test is carried out in alluvial deposit samples, most samples are of smooth texture. Similarly, during the clast counting, 78% of sample is of rounded shape, 13% of sample is elongated and 9% are flaky in shape.

The major composition of cobble gravel is of quartzite, sandstone, granite, and the minor compositions is phyllite, schist, marble, slate, gneiss and limestone (Table 1). About 80% of the aggregate are metamorphic while 16% are sedimentary and 4% are igneous. In all locations, the major composition of the sample is quartzite and sandstone. They reach about 90% of the modal composition in each location, of which quartzite is about 75% in each case. The cobbles gravels are derived mainly from the Lesser Himalayan Zone and the Upper Siwalik Zone, and few are derived from the Middle and the Lower Siwalik Zones. The samples are polymictic in composition although quartzite clasts are dominant.

Assessment on availability of desirable sized aggregates, i.e. 19.5-63 mm (based on IS) in 12 locations were made. It is found that 19.5-63-mm aggregates range from 26.71 to 48.52%. The aggregates retained on 63 mm vary from 8.3 to 31.17%. Therefore, the >63-mm aggregates can be crushed to use for ballast.

SHAPE INDICES

The Flakiness index (FI) of the test sample range from 11.18% to 24.10% and the elongated index (EI) range from 13.07% to 42.77% The flakiness index should be less than 25% and elongated index should be less than 45% for good aggregates (BS812 Part 105.1). Hence, the whole sample is acceptable because the entire samples are within the specified limits.

PHYSICAL PROPERTIES

The apparent specific gravity of test samples ranges from 2.43 to 2.73 and SSD specific gravity ranges 2.41 to 2.64 respectively. Similarly, the range of dry bulk specific gravity of test sample is 2.38 to 2.58. The water absorption value (WAV) of the test sample ranges from 0.48 to 2.26% (Table 2).

MECHANICAL PROPERTIES

Point load strength index ranges from 3.69 MPa (sample L8) to 6.57 MPa (sample L12). Aggregate Impact Value (AIV) of the test samples varies between 4.4% (sample L1) and 13.2% (sample L12). Similarly, aggregate crushing value (ACV) of the test sample varies from 10.20% (sample L6) to 17.67% (sample L12).

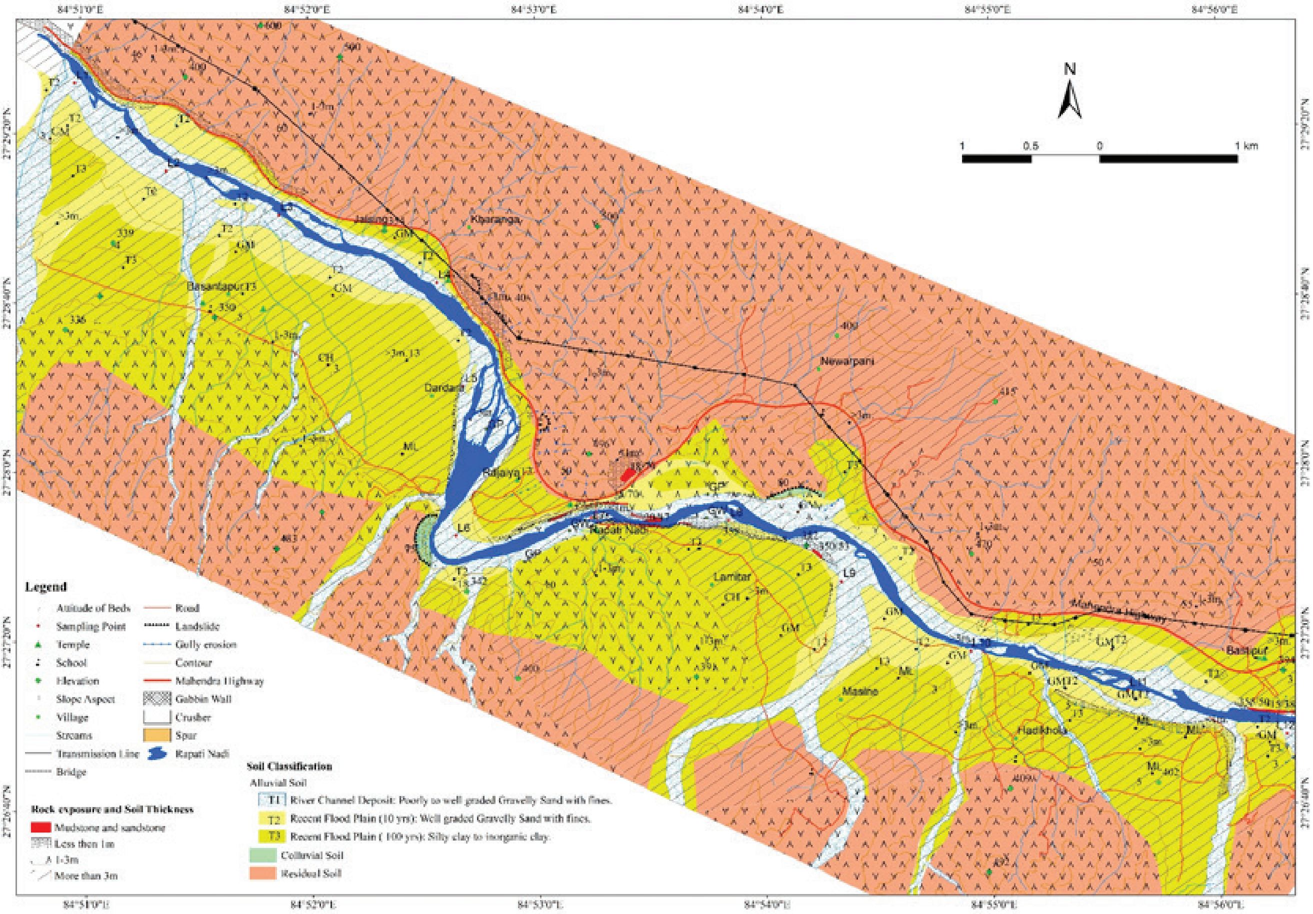

Fig. 4: Engineering geological map of the study area.

Table 1: Detailed location, description and composition of twelve samples.

Sample points	Longitude / Latitude	Location	Description	Composition (%)
L1	84°51’33.529”E 27°28’38.702”N	On the left side bar of the Rapati Nadi, 10m ahead from the confluence of the Rapati Nadi and the ChanuraKhola.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 91 Sandstone: 7 Others: 2

Sample points	Longitude / Latitude	Location	Description	Composition (%)
L2	84°51’21.459”E 27°29’14.651”N	On the left side bar of the Rapati Nadi, midway between the Chanura Khola and the Sukara Khola	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 68 Sandstone: 22 Others: 9
L3	84°51’48.959”E 27°28’47.619”N	At the mid channel bar of the Rapati Nadi, and 40m. upstream of Jaising-Basantapur suspension bridge	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 72 Sandstone: 23 Others: 5
L4	84°52’32.329”E 27°28’47.348”N	On the right side bar of the Rapati Nadi, under the Kharanga village’s temple.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 76 Sandstone: 19 Others: 5
L5	84°53’25.145”E 27°28’23.374”N	On the left side bar of the Rapati Nadi and about 150 m downstream of Rajaiya-Dardara suspension bridge	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 67 Sandstone: 25 Others: 8
L6	84°52’37.85”E 27°27’43.918”N	On the right side bar of the Rapati Nadi and at the confluence of the Rapati Nadi and the Bhotu Khola.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 70 Sandstone: 17 Others: 13
L7	84°53’14.037”E 27°27’50.136”N	At mid cannel bar of the Rapati Nadi under the Rajaiya-Lamitar Road Bridge.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 67 Sandstone: 16 Others: 17
L8	84°53’49.764”E 27°26’59.405”N	At the left terrace of the Rapati Nadi and about 800m upstream of Rajaiya-Lamitar moterable bridge.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 77 Sandstone: 20 Others: 3
L9	84°54’17.745”E 27°27’33.608”N	On the left side bar of the Rapati Nadi and at the confluence of the Rapati Nadi and the Masine Khola.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 73 Sandstone: 21 Others: 6
L10	84°54’53.763”E 27°27’19.404”N	On left side bar of the Rapati Nadi and confluence of the Rapati Nadi and Hadi Khola.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 69 Sandstone: 19 Others: 12
L11	84°55’36.997”E 27°27’4.076”N	At the left side terrace of the RapatiNadi in front of the Darimtar village.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 79 Sandstone: 16 Others: 5
L12	84°56’20.299”E 27°26’57.339”N	On the left side bar of the Rapati Nadi and at the confluence of the Rapati Nadi and the Pantale Khola.	Well graded gravel, cobble gravel with rounded to angular clast and few matrix of sand and very low clay.	Quartzite: 79 Sandstone: 16 Others: 5

Table 2: Summarized lab test results of samples from twelve locations.

Test/ Location	Suitable aggregate % through gradation	FI (%)	EI (%)	WAV (%)	PLSI (Mpa)	AIV (%)	ACV (%)	LAAV (%)	SSSV (%)
L1	33.15	19.91	16.44	1.94	4.55	4.40	15.20	24.05	1.06
L2	45.82	12.22	13.07	0.73	6.00	7.60	13.30	20.10	1.59
L3	32.13	22.92	42.77	0.48	5.83	8.80	14.57	23.75	1.25
L4	42.65	24.10	22.05	1.75	4.02	4.80	14.70	27.30	1.42
L5	33.53	18.45	27.34	1.96	5.76	6.20	17.57	29.75	1.40
L6	48.51	12.36	24.75	1.91	4.17	8.80	10.20	15.75	1.06
L7	46.27	20.65	22.99	0.48	4.47	6.20	15.40	24.25	1.18
L8	45.33	22.37	29.21	1.75	3.69	11.80	15.83	22.95	0.84
L9	34.03	12.95	31.74	2.05	4.66	7.40	15.13	29.45	0.74
L10	39.76	11.18	28.95	2.16	4.91	5.60	17.20	28.15	1.70
L11	26.71	14.20	23.90	1.74	4.56	9.80	17.27	29.85	0.94
L12	46.35	17.68	30.50	2.26	6.57	13.20	17.67	34.25	0.82

DURABILITY

Abrasion test of the sample was done using Los Angeles Abrasion value test (LAAV). The result indicates that LAAV varies between 15.75 (sample L6) and 34.25% (sample L12). According to Indian Railway Standard, the LAA value should be less than 30% for the railway ballast for BG (Broad Gauge), MG (Metre Gauge) and NG (Narrow Gauge) (planned/Sanctioned for conversion) and less than 35% for NG and MG (other than those Planned for conversion) railway ballast. Hence, eleven test samples agree with standards for BG, MG and NG, and one test sample for NG and MG railway ballast.

The Sodium Sulphate Soundness Value (SSSV) ranges from 0.96 (sample L8) to 2.06% (sample L10). The overall SSSV is low most probably because of very good interlocking among quartz mineral in the quartzite. According to DOR, aggregate is chemically sound if SSSV is less than 12%. Hence all the tested aggregates are durable and are resistant to disintegration and decomposition by weathering due to diurnal variation of temperature.

DISCUSSION

Among the 12 different, each location has variation in test results. The difference in the values in the tests is due to the variation in types of rock material derived from various sources in the catchment from different streams. The variation in the gradation value is due to the deposition and mixing of the sediments by the different lateral contributory streams. The maximum samples are smooth in texture as the samples tested are alluvial deposit and also they result in difference of FI and EI. The higher and lower value of specific gravity is due to the rock types of particles present in the samples tested, i.e. quartzites have higher values than the sandstones have. The higher the values, more the compaction of grains and are favorable for the railway ballast. The WAV ranges due to the presence of secondary pores in the tested sample. WAV of the tested samples lies within 2.5%. Higher the value of WAV possessed by the samples, lower the strength and durability, and therefore suitability of aggregates. According to the Indian Standard specification of railway ballast, the maximum water absorption in any case should not be more than 2.5% for railway ballast. Hence in any case the whole test samples are useful and suitable for railway ballast.

The PLSI, ACV and AIV give strength against loading, crushing and impact. PLSI of the aggregate samples exhibits that samples performed well under loading as rocks are very strong. ACV and AIV of samples lie below 20% as specified by Indian standard (Table 3). Hence the entire test samples are appropriate for railway ballast with respect to AIV.

LAAV and SSSV give the resistant to abrasion and weathering, which depend upon the nature of samples. Majority of the tested samples possessed LAAV of less than 30 and SSSV of less than 5%, therefore indicating their suitability for ballasts as the indices meet the specified value of Indian standard and other standards (Table 3).

Table 3: Comparison of Indian Standard with American, European and Australian Standards of railway ballast

Tests	Gradation	FI	EI	WAV	AIV %	ACV %	LAAV	SSSV
IS Standard	65 mm-20 mm	Less than 25%	Less than 45%	Less than 1% in any case max 2.5%	20% to max 30%	20% to max 30%	30%, for NG & MG 35% max	--
Remarks	Acceptable							--
American Standard, ASTM D4791		Max 5% (ASTM D4791)	Max 5% (ASTM D4791 3:1)	1-2% (ASTM-C127)	--	--	Max 30% (ASTM-C535- C131)	Max 5% (ASTM-C88: 5 cycles)
Remarks		Not Acceptable		Acceptable except L8, L9 & L12			Acceptable except L12	Acceptable
European Standard		Max 15-35% (EN 933-3 1997)	3:1, Max 4-12% (EN 933-3) Length> 100mm <6%	Max 1% (EN1097-6)	4%<AIV <22% (EN 1097-2)	--	Max 12 to 24% (EN 1097-2)	
Remarks		Acceptable	Not Acceptable	Acceptable			Not Acceptable except L2, L6 and L8	

Tests	Gradation	FI	EI	WAV	AIV %	ACV %	LAAV	SSSV
Australian Standard		Max 30% (AS1141.14)	2:1 ratio Max 30% 3:1 possible Alt.	--	--	Max 25-40% based on class of track (AS 1141.21)	Max 25-40% Based on class of track (AS 1141.22)	--
Remarks		Acceptable				Acceptable		

Comparison of test result with American, European and Australian Standard

The test result of the sample is compared to the American Standard, European Standard and Australian Standard as shown in Table 3.

Based on ASTM Standards, since FI and EI of the tested samples show exceedence of 5%, they are to in acceptable limits. Similarly, in terms of the WAV which should be 1-2%, all the samples except for three samples (L8, L9 and L1) are acceptable. All samples except L12 is acceptable as the LAAV value is less than 30%. Finally, the SSSV is less than 5% and therefore all the samples fall in the acceptable limit.

Based on European Standard, the maximum limit of FI value is 35% and hence the whole sample is acceptable for railway ballast with respect to Flakiness Index but in case of Elongated Index value, the maximum limit is 12% and hence the samples do not lie in the acceptable limit. The AIV is less than 13.2%, which meets the condition less than 22%. Regarding LAAV, majority of samples do not meet the specified limit, and hence are not acceptable except samples L2, L6 and L8.

Based on Australian Standard, the maximum limit of FI and EI value is 30% and hence all of the studied samples are acceptable for railway ballast expect the sample of location L12 in context of EI value. Similarly, the maximum limit of ACV (AS 1141.21) and LAAV (AS 1141.22) is 40%, which is satisfied by all the samples from 12 locations and hence are acceptable for the railway ballast.

Evaluation among the samples from twelve locations

The test results summarized in Table 2 is rated from 1 to 3, the maximum rating being given to the least figures of values or indices as indicated in Table 4. Seven test properties are considered for rating assignment to find out whether the samples fall in to low (rating 7-12), medium (rating 12-17) or high rating (rating 17-21). Doing rating, all the samples fall in to high rating. This indicates that the studied samples perform well considering workability,

Table 4: Rating and ranking of test results of samples

Sample Number	FI (%)	EI (%)	WAV (%)	AIV (%)	ACV (%)	LAAV (%)	SSSV (%)	Total Rating		Ranking by Rating
L1	2	3	2	3	3	3	3	19	High	2
L2	2	3	3	3	3	3	3	20	High	1
L3	2	2	3	3	3	3	3	19	High	2
L4	2	3	2	3	3	2	3	18	High	3
L5	2	2	2	3	3	2	3	17	High	4
L6	2	3	2	3	3	3	3	19	High	2
L7	2	3	3	3	3	3	3	20	High	1
L8	2	2	2	3	3	3	3	18	High	3
L9	2	2	2	3	3	2	3	17	High	4
L10	2	2	2	3	3	2	3	17	High	4
L11	2	3	2	3	3	2	3	18	High	3
L12	2	2	2	3	3	2	3	17	High	4

Rating: FI: <10 = 3, 10-25 = 2, >25 = 1; EI: <25 = 3, 25-45 = 2, >45 = 1; WAV: <1% = 3, 1-2.5% = 2, >2.5% = 1; AIV: <20% = 3, 20-30% = 2, >30% = 1; ACV: <20% = 3, 20-30% = 2, >30% = 1; LAAV: <25% = 3, 25-35% = 2, >35% = 1; SSSV: <5% = 3, 5-10% = 2, >10% = 1 strength against impact and crushing and durability against abrasion and freeze and thaw weathering.

The ranking among the samples after they are rated, gives L2 (Basantapur area) and L7 (Rajaiya area) samples are the best, and the upstream samples L9, L10, L12 (Masine-Bastipur area) and L5 performed comparably less among the samples. Therefore, the sediments of the Rapati Nadi located between Basantapur and Bastipur seems promising as they are better ranked.

CONCLUSIONS

The major composition of clasts of the Rapati Nadi includes quartzite, sandstone, granite, phyllite, schist and minor compositions are marble, slate, quartz veins, gneiss and limestone. Among them quartzite is dominant in all sample points.

The test results show that the samples exhibit uniform gradation. About 44% of the samples can be used without any treatment. The Flakiness and Elongated Indices of the test samples range from 11.18% to 24.10% and 13.07% to 42.77%, respectively. The strength of samples, determined using PLSI, ACV and AIV, ranges respectively from 3.69 to 6.57 MPa, 10.20 to 17.67%, and 4.4%to 13.2%. Similarly, WAV, LAAV and SSSV of the test samples range from 0.477 to 2.256%, 15.75% to 34.25 and 0.96 to 2.06%, respectively. These strength and durability indices fall within the acceptable range of Indian Standard and other standards. Thus, studied samples are suitable for railway ballasts based upon the results of various analysis.

When the results of different indices and values are rated based on their higher, intermediate and lower ranges, all the samples fall in the range of the high rating range, demonstrating the suitability of aggregates of the Rapati Nadi stretch between Basantapur and Bastipur area. Among the aggregates, those located downstream at the Basantapur area come to lie in the higher rank compared to those of the upstream at the Masine-Bastipur area.

For optimal quality, all the materials should be washed to remove clay, and crushed to increase the friction angle among the particles. Additionally, boulders in the locations can be crushed into achieve the desirable size of the ballast to enhance productivity.

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