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# Evaluation of gravel for concrete and road aggregates, Rapti River, Central Nepal Sub-Himalaya

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## ABSTRACT

Several local mining sites of sand and gravel have been operating for decades in the Rapti River. River gravels are consumed in Hetauda, Narayanghad and areas in India near the border between Nepal and India. Until now little known about consumers concerning about quality of gravel. The present study was carried out to evaluate quality of river gravel to know its suitability for aggregate (raw material for concrete and road). The samples of river gravel were analysed for petrographic, physical, mechanical and chemical properties. Samples were categorised as quartzite group, carbonate group and granite group according to British Standard Institution (BSI). Among these, samples of quartzite group were found dominant. Image analysis of gravel showed that clasts were well graded. The majority of the samples had rounded, high sphericity and oblate triaxial clasts. The surface texture of clasts was rough to smooth. In terms of shape, workability of gravel was satisfactory. Gravel samples possessed low water absorption value (0.69 to 1.12%) and low effective porosity. Dry density of samples ranged from 2460 to 2680 kg/m$^3$. Aggregate impact values of samples (14.2 to 16.1%) showed good soundness. Los Angeles abrasion test also showed consistent hardness of each of the samples as uniformity factor did not exceed 0.2. Magnesium sulphate values ranged between 4.46% and 7.29% suggesting good resistance against chemical weathering and frosting. Comparing with the existing Nepal Standard, British Standard and American Standard of Testing Material, the studied samples were suitable for concrete and road aggregates.

## INTRODUCTION

The Rapti River is known for carrying large amount of sediments from the Lesser and the Sub-Himalayas. The river sediments are chiefly gravel with few sand and mud. Gravel (coarse aggregates greater than 4.75 mm) can be easily collected from the river area after deposition during each flood season. Hence, the river is perennial source of coarse aggregates. The use of coarse aggregate from the Rapti River as construction material has been extensive because of high demand in major cities like Hetauda and Narayanghad. Gravel is also exported to nearby border towns in India. About 3.4 million m$^3$ of boulders, gravel and sand are reported to be present for the depth of one meter in the major rivers of the Central Development Region (Duvadi et al. 2006). From this region the construction material of worth Rs. 53 million has been exported to India in the year 2000/2001 (DMG 2004). Therefore, the sediments of the Rapti River are of economic importance of the Central Development Region. Although coarse aggregates have been used for concrete and filling material for road embankment in the area, there is little concern about quality. Therefore, authors obtained samples from the river elements (side and mid bars) and analysed to evaluate quality of coarse aggregate.

## STUDY AREA

The study area lies in Hetauda Dun Valley, Central Nepal (Fig. 1). The Rapti River flows northeast to southwest and contributes the Narayani River. It is a meandering river in the upper stretch and becomes braided in the middle to downstream stretches. It includes different bar deposits containing huge amount of gravel and minor sand. The East-West Highway

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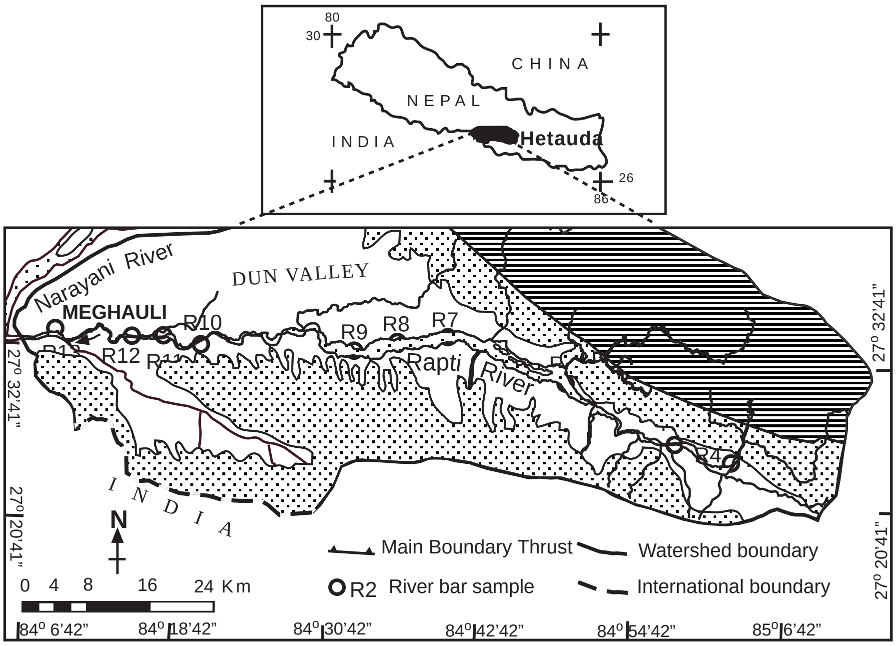

Fig. 1 Location map of study area showing sampling points of river sediment

runs along the right bank of the river which is the main access of the study area. Gravel roads and foot trails link the river from the highway.

## Material and method

Altogether 12 samples from bar deposit (surface) of the river were taken for analysis (Fig. 1). Sampling was made following the method of Howard (1993). About 10 kg of each sample was collected. The photographs of the sampling spots were obtained and image analyser was used for photo sieving. The gravel samples were utilised in determining composition, texture, aggregate impact value, abrasion value and chemical durability.

The samples were washed to remove surface coating of organic material and clay, if any present for easy identification of clast type. Then, the samples were grouped into categories after BSI (1975). About 100 clasts of each sample were measured for their three mutually perpendicular axes; longest (a), intermediate (b) and shortest (c) axes to determine shapes of clasts (Fig. 2). The physical properties such as water absorption and dry density were determined after ISRM (1979). Aggregate Impact Test and Los Angeles Abrasion Test were made to obtain mechanical soundness and hardness of samples. To obtain soundness of aggregates against frosting and chemical weathering, Sodium Sulphate Soundness Test was made based on ASTM (1978 and 1989).

## RESULTS

### Composition and texture

The major constituents of gravel samples were quartzite, sandstone, granite gneiss and limestone. Among them, quartzite is the dominant constituent in all the samples (Table 1). The clasts of amphibolite, schist, phyllite, slate, quartz and feldspar were commonly found in all the samples. The samples were categorised as quartzite group, carbonate group, schist group and granite group (BSI 1975) (Table 1).

Surface texture defines the periphery of aggregates whether it is smooth, rough, honeycombed, granular and crystalline (BSI 1989). From the observation, quartzite clasts had smooth surface texture whereas granite, sandstone, carbonate, gneiss, schist, phyllite and slate clasts had rough surface texture. Therefore, the samples had mixed type of surface texture which should provide sufficient bonding with cement.

The clast shape was quantified in terms of elongation ratio (q = b/a) and flatness ratio (p = c/b) (Table 2). The shape factor (F = p/q) ranged from 0.82 to 1.03 showing nearly equant shape of clasts. The plots of elongation and flatness ratios on the modified Zingg's (1935) shape classification diagram after Lees (1964) showed that the clasts were oblate

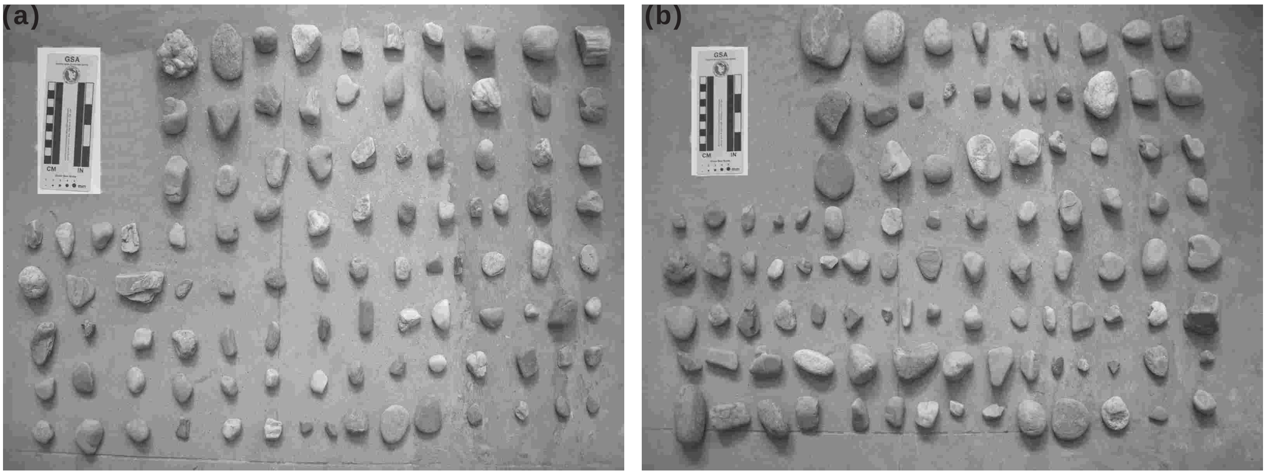

Fig. 2 Clasts used for measuring the longest, the intermediate and the shortest axes to determine shape of clasts in samples; (a) sample R5 and (b) sample R7

triaxial (Fig. 3).

Sphericity ($\Psi$) was calculated using the expression of Aschenbrenner (1956) as:

$$\Psi = \{12.8\ (p^2q)^{0.3}\}/\{1+p\ (1+q) + 6\ (1+ p^2\ (1+q^2))^{0.5}\} \qquad (1)$$

Sphericity ranged from 0.84 to 0.91 (Table 2), therefore the clasts possessed high sphericity (Fig.3).

Roundness of clasts was calculated after Janoo (1998) as:

$$R = 4\pi A/P^2 \qquad (2)$$

where, A is area and P is perimeter of a clast. The average roundness (R) varied between 0.81 and 0.86 (Table 2) and were subrounded to rounded.

The river gravel had dominantly rounded, prolate triaxial and high sphericity clasts. These shape attributes suggest that the gravel when it will be used

Table 1: Composition of gravel of the Rapti River

| | Samples | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Composition (%) | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | R10 | R11 | R12 | R13 |
| Sandstone | 9 | 6 | 6 | 12 | 12 | 10 | 13 | 15 | 15 | 17 | 9 | 13 |
| Limestone, dolomite and marble | 25 | 22 | 26 | 28 | 11 | 6 | 2 | 4 | 12 | 7 | 8 | 6 |
| Quartzite | 28 | 21 | 29 | 42 | 50 | 55 | 60 | 66 | 48 | 62 | 62 | 44 |
| Slate and phyllite | 12 | 20 | 15 | 2 | 6 | 2 | 2 | 0 | 2 | 1 | 0 | 0 |
| Schist | 15 | 11 | 6 | 3 | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 3 |
| Gneiss | 5 | 11 | 6 | 2 | 2 | 2 | 4 | 1 | 4 | 1 | 1 | 7 |
| Granite and pegmatite | 2 | 5 | 5 | 4 | 10 | 15 | 18 | 9 | 15 | 10 | 18 | 25 |
| Amphibolite | 2 | 3 | 4 | 0 | 2 | 3 | 1 | 1 | 1 | 2 | 0 | 1 |
| Vein quartz | 2 | 1 | 2 | 6 | 5 | 5 | 0 | 3 | 1 | 0 | 1 | 0 |
| Feldspar | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Undifferentiated grains | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| *Compositional group | QG-SG-CG | SG-QG-CG | QG-CG | QG-CG | QG | QG-GG | QG-GG | QG | QG-GG | QG | QG-GG | QG-GG |

*(BSI 1975): QG = Quartzite group; SG = Schist group; CG = Carbonate group; GG = Granite group

Table 2: Results of form, sphericity, roundness and size of clasts of the gravel samples

| Samples | Elongation ratio<br>q | Flatness ratio<br>p | Shape factor<br>SF | Sphericity<br>Ψ | Roundness<br>R | Median grain size<br>$d_{50}$ (mm) |
|---|---|---|---|---|---|---|
| R2 | 0.7 | 0.58 | 0.82 | 0.85 | 0.86* | 34.3 |
| R3 | 0.7 | 0.57 | 0.82 | 0.84 | 0.84* | 34.3 |
| R4 | 0.68 | 0.62 | 0.91 | 0.86 | 0.81[a] | 13.9 |
| R5 | 0.72 | 0.64 | 0.89 | 0.88 | 0.82* | 15.5 |
| R6 | 0.71 | 0.66 | 0.94 | 0.88 | 0.83* | 21.1 |
| R7 | 0.73 | 0.63 | 0.86 | 0.88 | 0.85* | 15.5 |
| R8 | 0.72 | 0.69 | 0.96 | 0.89 | 0.83* | 23.4 |
| R9 | 0.74 | 0.76 | 1.03 | 0.91 | 0.85* | 19.7 |
| R10 | 0.72 | 0.66 | 0.92 | 0.88 | 0.86* | 39.4 |
| R11 | 0.71 | 0.63 | 0.88 | 0.87 | 0.82* | 22.6 |
| R12 | 0.74 | 0.66 | 0.88 | 0.89 | 0.84* | 21.9 |
| R13 | 0.74 | 0.67 | 0.9 | 0.89 | 0.84* | 59.7 |

[a] subrounded; * rounded; interpretation of roundness after Folk's roundness ( $\rho$): $\rho = 10.83 \log (R) + 6.18$

as aggregate will provide good workability with cement. In fact the shape of coarse aggregates affects workability and mobility of concrete (Lees 1963). Workability decreases if the majority of clasts are disc and rod shaped (Neville 1996). If the clasts are angular, they can decrease workability by 10% (Kaplan 1958). Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Angular and rod shaped particles require more water to produce workable concrete than rounded and compact particles in aggregate. In this case cement should also be increased to maintain the water-cement ratio.

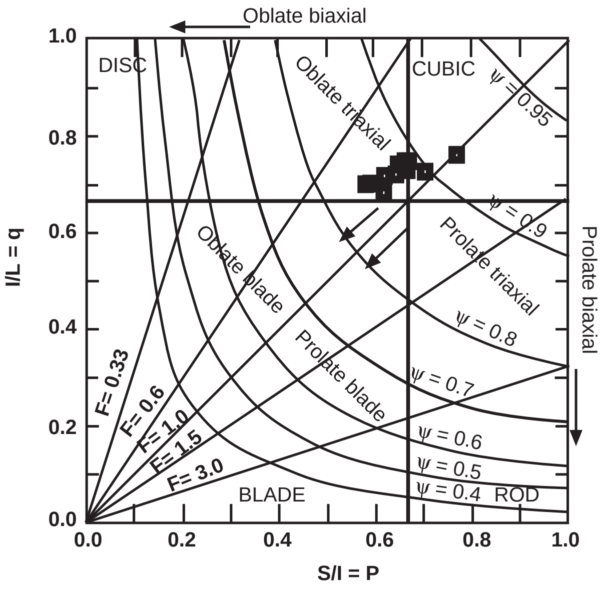

Fig. 3 Shape of clasts on modified Zingg's diagram after Lees (1964); the parameters are after Aschenbrenner (1959)

The average median grain size varied from 59.71 to 13.93 mm (Table 2). The river gravel had well graded clasts. The grading curves of the samples were compared with that of the coarse aggregate, 40 mm of NS (1994) as shown in Table 3 and Fig. 4. The gradation lines of the samples do not lie within the gradation zone and are coarser compared with the standard grading. The river gravel may therefore be crushed and screened to obtain appropriate grading before using as coarse aggregate.

## Water absorption and dry density

Water absorption ranged from 0.69 to 1.12% (Table 4). It is less than 3% indicating very low effective porosity of clasts (BSI 1987). The aggregates having clasts with low effective porosity are strong enough to withstand chemical decomposition against cement and weathering fluid.

Dry density varied from 2460 to 2680 kg/m$^3$ (Table 4). This range falls into the normal density category of aggregates (NF 1983). The density ranging between 2000 and 3000 kg/m$^3$ can also be considered medium weight aggregate, and the samples which have dry density exceeding 2600 kg/m$^3$ are more suitable for aggregate (Zafir amd Majid 2000).

## Aggregate impact value

Basically the aggregate impact value (AIV) is the percentage of fines produced from the aggregate sample after subjecting it to a standard amount of impact (Fig. 5). The standard amount of impact was produced by a known weight, i.e. a steel cylinder of 14 kg, falling a set height, a prescribed number of times (15 times), onto an amount of aggregate of standard size (10–14 mm) and weight retained in a mould. After impacting, the aggregate was removed from the cylinder and sieved through a 2.36 mm sieve. The AIV was then computed using the following expression (ASTM 1979):

$$AIV = (W_3/W_1)\ 100\% \qquad (3)$$

where, $W_3$ = weight of aggregate passing through 2.36 mm sieve and $W_1$ = initial weight of the sample.

Aggregate Impact Values (AIV) below 10% are regarded as strong, and AIV's above 35% would normally be regarded as too weak for using road surfaces. For the samples tested, AIV ranged from 14.1 to 16.1% (Table 4). These values lie in the range of BSI (1992) where strong aggregates possess AIV between 10 and 20%. According to NS (1994), AIV of aggregate which should be used for wearing surfaces should not exceed 30% and for other application, it should not exceed 45%. Therefore,

Table 3: Grading limits of coarse aggregate (NS 1994)

| Sieve size (mm) | Percentage passing for graded aggregate of nominal size | | | |
|---|---|---|---|---|
| | 40 mm | 20 mm | 16 mm | 12.5 mm |
| 80 | 100 | - | - | - |
| 40 | 95 to 100 | 100 | - | - |
| 20 | 35 to 70 | 95 to 100 | 100 | 100 |
| 16 | - | - | 90 to 100 | - |
| 12 | - | - | - | 90 to 100 |
| 10 | 10 to 35 | 25 to 55 | 30 to 70 | 40 to 85 |
| 4.75 | 0 to 5 | 0 to 10 | 0 to 10 | 0 to 10 |

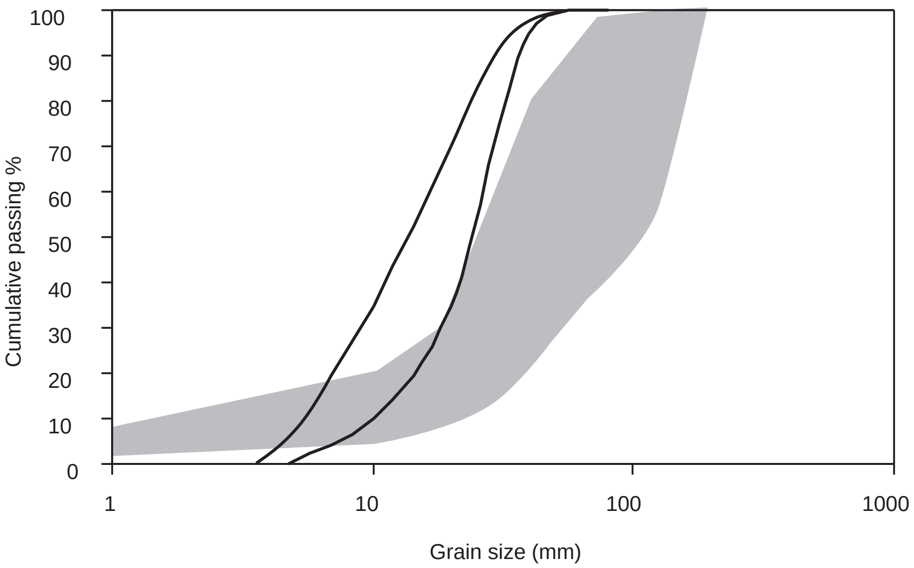

Fig. 4 Grain size distribution of the samples from the Rapti River represented by the shaded portion compared with gradation curves of 40 mm of NS (1994) as shown by dark curves

AIV of the studied samples lies within the standards of both NS (1994) and BSI (1992).

### Los Angeles abrasion value

Hardness (wearing property) and toughness (breaking property) of aggregates associated together are often carried out in Los Angeles test. The principle of the test is to obtain percent wear due to relative rubbing action between aggregates and steel balls used as an abrasive charge. Uniform factor and wear of gravel were determined by Los Angeles test (ASTM 1989). Los Angeles abrasion value was calculated as:

$$Wr_{100} = \{(W - W_{100})/W\}.100\% \qquad (4)$$

$$Wr_{500} = \{(W - W_{500})/W\}.100\% \qquad (5)$$

where, $Wr_{100}$ = %wear for 100 revolutions, $Wr_{500}$ = %wear for 500 revolutions, W = initial weight of sample, $W_{100}$ = weight of sample retained on 1.7 mm after 100 revolutions and $W_{500}$ = weight of sample retained on 1.7 mm after 500 revolutions. Uniformity factor (UF) was obtained as:

$$UF = (W - W_{100})/(W - W_{500}) \qquad (6)$$

UF should not exceed 0.2 for material of uniform hardness (ASTM 1989).

Mixture of samples R5, R6 and R7 was crushed to produce Grade A sample (Table 5) for Los Angeles test because there was no large variation in proportion of constituents and textures of clasts in these samples.

UF did not exceed 0.2 indicating that the hardness of sample was uniform (Table 4). The Los Angeles abrasion value of 500 revolutions ($Wr_{500}$) was 29.83%. This value falls within the specification of 30% of NS (1994) for coarse concrete aggregate.

### Sodium sulphate soundness value

Sodium sulphate test was carried out to test for chemical durability of samples. Sample of size 10–14 mm and weight 425±5 grams were immersed in the sodium sulphate solution of specific gravity 1.162 for 48 hours and were subsequently dried. The process was repeated five times and sodium sulphate soundness value (SSV) was obtained as below:

$$SSV = \{(W_1 - W_2)/W_1\} . 100\% \qquad (7)$$

where, $W_1$ = initial weight of the sample and $W_2$ = weight retained on 10 mm after the test.

Minimum allowance of SSV for coarse aggregate is 10% for concrete (ASTM 1978). The SSV of the tested samples varied from 4.46 to 7.29% (Table 4). The samples fall within specified range and are resistant against chemical weathering and frosting.

## EVALUATION OF GRAVEL

The Rapti River samples of gravel are dominantly quartzite group with few carbonate, schist and granite groups. Surface texture is smooth to rough. Clasts are mostly subrounded, oblate triaxial and sphered suggesting good workability. The samples are well graded but do not lie within the grading zone of standard.

Absorption values of the studied samples do not exceed the standard value of 3% as suggested by BSI

Fig. 5 Diagram showing aggregate impact test

Table 4: Results of water absorption, dry density, AIV, Los Angeles value and SSV

| Samples | $\rho_{dry}$ (kg/m$^3$) | Water absorption (%) | Samples | Los Angeles Value | | | SSV (%) |
|---|---|---|---|---|---|---|---|
| | | | | $Wr_{100}$ (%) | $Wr_{500}$ (%) | UF | |
| R2 | 2630 | 0.74 | | | | | |
| R3 | 2680 | 0.69 | 15.3 | | | | 5.39 |
| R4 | 2590 | 0.75 | | | | | |
| R5 | 2460 | 0.84 | | | | | |
| R6 | 2470 | 0.96 | 14.1 | | | | 6.44 |
| R7 | 2460 | 1.01 | 16.1 | | | | 6.43 |
| R8 | 2620 | 1.10 | | | | | 4.46 |
| R9 | 2500 | 1.12 | 15.3 | | | | 7.29 |
| R10 | 2620 | 0.96 | | | | | |
| R11 | 2610 | 1.10 | | | | | |
| R12 | 2560 | 1.11 | 14.2 | | | | 7.27 |
| R13 | 2630 | 0.95 | | | | | |
| Mixture of R6, R7, R8, R9 and R10 | | | | 5.35 | 29.83 | 0.19 | |

(1987). The samples also have medium density varying within 2000 and 3000 kg/m$^3$ and are considered good for medium weight concrete aggregates. Similarly, AIV varies between 10 and 20% of BSI (1992) and lies below 30% of NS (1994). Therefore, the gravel of the Rapti River can be used as aggregate for heavy duty concrete floor finishes, pavement wearing surfaces, sub-base, roadbase and for other concrete.

The Los Angeles abrasion value ($Wr_{500}$) of the test sample does not exceed 30%. The sample also abrades uniformly with time having UF around 0.2. Based on the specification of NS (1994), the Rapti River gravel is suitable for road and concrete aggregates.

Regarding chemical durability, the minimum allowance of SSV for coarse aggregate is 10% for concrete (ASTM 1978). As the SSV of the test samples is less than 10%, aggregate of the Rapti River gravel offer good resistance against chemical weathering.

## CONCLUSIONS

The gravel samples from the Rapti River are dominantly of quartzite group with few carbonate, schist and granite groups. They are mostly subrounded, oblate triaxial ellipsoid with high sphericity and rough to smooth surface texture. Workability of gravel is good considering the textural attributes. Grading is coarser compared with the Nepal standard.

AIV and Los Angeles values suggest that gravels are mechanically sound. They have normal density of medium weight aggregates. Water absorption value

Table 5: Grading of test samples of coarse aggregates for Los Angeles abrasion test (ASTM 1989)

| Sieve size (mm) | | Grade of sample (Wt. of fraction by sieving), gram | | | |
|---|---|---|---|---|---|
| Opening (mm) | Retaining (mm) | Grade A | Grade B | Grade C | Grade D |
| 40 | 28 | 1250± 25 | | | |
| 28 | 19 | 1250± 25 | | | |
| 19 | 12.5 | 1250± 25 | 2500± 10 | | |
| 12.5 | 9.5 | 1250± 25 | 2500± 10 | | |
| 9.5 | 6.3 | | | 2500± 10 | |
| 6.3 | 4.75 | | | 2500± 10 | |
| 4.75 | 2.36 | | | | 5000±10 |
| | Total weight | 5000±25 | 5000±10 | 5000±10 | 5000±10 |

is also low and is less than the standard, 3% (0.69 to 1.12%). SSV falls below 10% suggesting that gravel samples are competent against frosting and chemical decomposition. The results from different tests fall within the specified values of standards, suggesting that the Rapti River gravel materials are appropriate for concrete and road aggregates.

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