Mineral Analysis and Erosion Potential of Sediment Samples from Nepalese Hydro Power Plant

A Case Study of Lower Marsyangdi Hydropower Plant

Anil Kumar Bastola[*1], Hari Prasad Neopane[2]

Department of Mechanical Engineering, School of Engineering, Kathmandu University, Dhulikhel, Nepal

[*1]anilbastola2002@gmail.com, [2]hari@ku.edu.np

***Abstract*-In Nepalese hydropower plant, sediment erosion is a major technical problem as large amount of sediment flows through the Himalayan Rivers. Most of the hydropower plants are affected by the sediment erosion problem. This erosion mainly depends on sediment characteristics like size, concentration, mineral composition and shape of the sediments. This paper focuses on variation of particle size distribution, mineral composition and erosion potential of sediment samples from lower Marsyangdi hydropower plant of Nepal. Sediment samples were collected and analyzed from three different locations: headwork, intake and tailrace. Mineral analyses were carried out by physical method called particle count method in Stereo Zoom Microscope and revealed that quartz is the most abundant mineral and common particle size distribution of sediment varies at different locations of plant. Furthermore, erosion tests were also carried out in rotating disc apparatus (RDA) and found that erosion rate is directly proportional to the sediment size and quartz content.**

Keywords- Sediment; Particle Size Distribution; Mineral; Particle Count Method; Stereo Zoom Microscope; Erosion Rate

I. INTRODUCTION

The topographical condition and runoff have made Nepal rich in hydropower with a total potential of 83000 MW. Despite of Nepal's enormous hydropower potential, only about 42000 MW is economically and technically feasible, but only about 700 MW has been harnessed [1]. An important challenge in developing hydropower projects is the difficulty in operation and maintenance of the plants, due to large quantities of sediment with hard abrasive mineral/rock fragments in Himalayan Rivers [2]. Excessive amounts of sediment in these rivers are due to presence of weak rocks and extreme relief, and hence sediment management has become the primary importance for the safety, reliability and life of infrastructures [1, 2]. Even with sediment trapping systems, complete removal of fine sediment from water is impossible and uneconomical [2]; hence most of the turbine components in Himalayan Rivers are exposed to sand-laden water and subject to erosion, causing reduction in efficiency and life of the turbine.

Run of river (RoR) hydropower plants are the main sources of electricity in the Nepal. Among the different sources of energy, hydropower is considered economical, non-polluting and environmental friendly renewable source of energy. There is a huge potential for hydropower development in Himalayan region in general. However, there are also technical challenges for hydropower development due to erosion and sedimentation problem. The climatic and physical conditions are highly responsible for the erosion and sedimentation problem in the region. The tropical climate, immature geology, and intense seasonal rainfall, are the main reasons for this problem. As a result, the rivers in this region transport substantial amount of sediments during the monsoon season [1].

The management of the hydropower projects for achieving higher efficiency of hydraulic turbines is an important factor. Hence, this problem has become a primary concern for the safety, reliability and longer life of the RoR hydropower projects in Nepal. Therefore, dealing with sediment has been a great challenge while developing hydropower projects in sediment-loaded rivers.

Small hydro energy is developing as one of the rich renewable energy source all around the world. This renewable energy source has many challenges, and one of them is sediment erosion. To address the problem, samples from Marsyangdi Hydropower Plant (HPP) were analyzed, and this paper focuses on following objectives:

a) Investigate the sediment particle size distribution at different stations of the plant: to see how sediment particle are distributed, and the range of particle size that reaches to the turbine

b) Perform mineral analysis of the collected samples so that we can visualize the composition of the sediments and variation of minerals in different locations of the plant.

c) Evaluate erosion potential in rotating disc apparatus (RDA): to see how erosion rate varies with respect to mineral size, mineral content and the site of the samples

RDA is designed and Fabricated at Kathmandu University, Nepal. It consists of rotating disc and test specimens are mounted on it. It is driven by 7.5 kW asynchronous motor at 2280 rpm. This can be used for the pure cavitation test, pure sediment erosion test and combined effect of both [3].

Hydro energy could be the one of the major source of renewable energy supply in Nepal. But this energy source has many challenges, and erosion problem is very common in Nepalese Hydropower plants. So the scientific contributions of this paper could be:

a) To identify the particle size distribution of sediment at different locations of the plant, and find out the range of particle size responsible for the erosion to the turbine. So that we can choose the best location to install the new plant.

b) To identify the composition of the sediment responsible for the erosion, so that turbine design can be improved to minimize the erosion.

c) To identify whether the sediment composition varies with the location and erosion potential of the sediment, and decide whether to do some preventive maintenance to reduce the sediment erosion. Preventive maintenance could be, that during the flooding when larger sediment particle flows to the power plant; shut off plant and could also be deciding where to put the sediment trapping system.

II. METHODS

A. Sample Collection and Processing

Representative samples were collected by grab sampling method. Samples were collected from river bank by using shovel and hand. This sampling technique was used as it has the advantage to collect a large number of representative samples. Our sampling site includes the following:

TABLE 1 DETAIL OF SAMPLE COLLECTION STATION

Hydropower Plant (HPP)	Location	River (Source)	Capacity	Turbine	Sampling station
Lower Marsyangdi	AanbooKhaireni, Tanahun, Nepal	Marsyangdi	69 MW	Francis	Headwork, Intake and Tailrace

After the sample collection, it is also important to process samples carefully for further processing of samples and following operations are carried out:

a) Drying of samples

b) Separating debris from samples

c) Proper labeling of samples

d) Safe storing of samples

B. Sieve Analysis

Sieve Analysis is a procedure for assessing the particular size distribution of granular materials like sands, crushed rocks, clay, feldspars, coals, grains and seeds [4]. It is performed on the materials where the size distribution is often of critical importance. The particle size distribution of granular materials is determined by the mechanical analysis, which is usually made by shaking the materials through series of sieves. Sieve sizes used for the analysis are: 75, 125, 200, 300, 600 and 1000 µm. So, as it is a simple and easy technique of particular sizing, it is probably the most common method for PSD [4, 5]. This method is implemented for the PSD of the sediment collected from the prescribed sites. The data obtained from particular size distribution curve is used to predict the concentrations of what size of sediments will hit the turbine materials. The mass of the aggregates retained in each sieve is used to get the percentage finer, which is plotted against sieve size or particle size in semi log graph as Fig. 2. This graph is known as particle size distribution curve.

C. Mineral Analysis

Most of the recent research papers on sediment analysis are focused on a specific site to determine its mineral content and composition, using Fourier Transform Infrared, X-ray diffraction (XRD) and X-ray fluorescence spectroscopy method [6]. XRD is the most widely used method for mineral analysis as it is easy and results are obtained in computerized form. The main objective of this study is to identify mineral composition and its variation along different sampling sites within a hydropower plant. Among various methods to identify mineral and perform mineral analysis, particle count method was used as this method is cost efficient and easier to use although it is time consuming. In this method, a magnifying microscope was used to observe the sample, identify and count them. Stereo zoom microscope with the following specifications was used for this purpose [6].

Name:	Trinocular Stereo zoom Microscope
Manufacturer:	Radical Instruments
Model:	RSM-9
M. No.:	B-1260

Eye piece:	WF 10x
Binocular Head:	0.7x to 4.5x
Magnification:	7x to 45x
Camera:	IS 300 of 3 Megapixel (USB)

Based on requirements and available instruments, standard procedure developed by the Surendra Sujakhu [6] was followed to perform mineral analysis by particle count method illustrated below:

a) Four samples on the grid line watch glass were prepared for each sediment sample.

b) The sample was then observed under microscope and USB camera to identify mineral types based on their physical properties.

c) For each sample prepared, each type of minerals was counted and observation table was developed.

d) Percentage of each mineral was calculated separately for all four samples.

e) Average percentage of each mineral was calculated from above calculated percentages.

Quartz is the most common mineral in river sediments with Mohr's hardness of 7 which can easily cause erosion of turbine. Other minerals harder than turbine materials includes feldspar, garnet, tourmaline, etc. whereas mica is softer than turbine material found in river sediments of Nepal [7, 8].

D. Erosion Test

Erosive wear involves several wear mechanisms, which are largely controlled by the particle material, the angle of impingement, the impact velocity and the particle size. If the particle is hard and solid, then it is possible that a process similar to abrasive wear will occur [3, 8].

Rotating Disc Apparatus (RDA) is a rotating type test rig to study erosion with specific purpose. RDA available in Turbine Testing Lab (TTL) and consists of four important parts, rotating disc with blade and blade attachments, housing and supporting structure, cover and shaft connected to motor as shown in Fig. 1 [9].

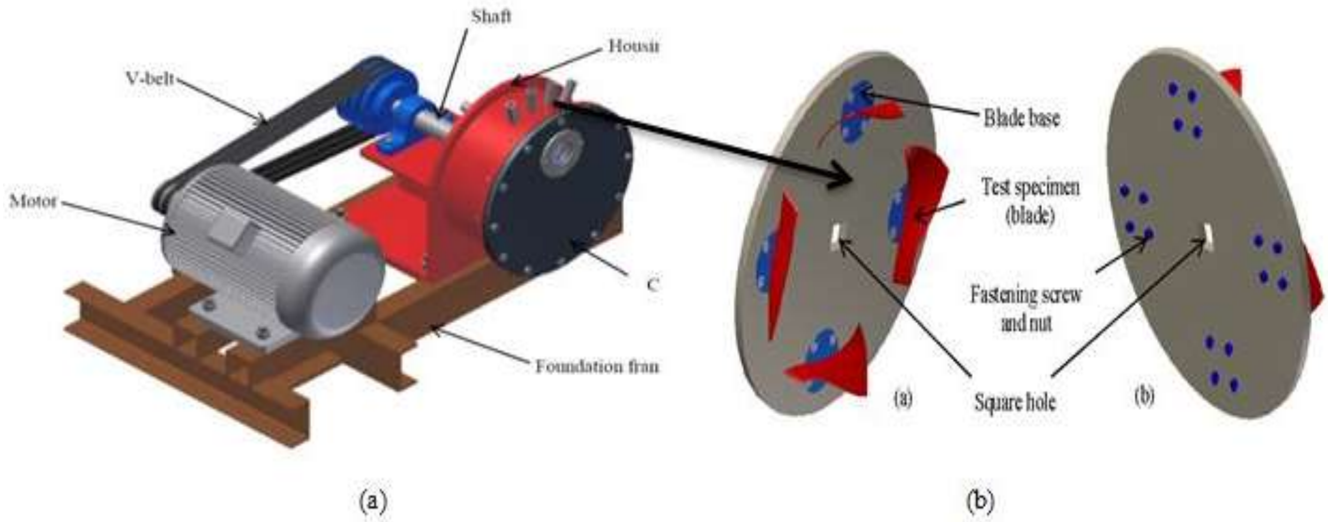

Fig. 1 (a) Rotating disc apparatus for erosion test (b) Position of test specimen [9]

a) Clean set of test specimen (Francis runner blade) is mounted on the disc as shown in Figure above, and with the help of mounting nut and bolts, specimen is securely tightened.

b) The disc is mounted on the shaft, and the lock nut is tightened. Weights of the specimens are recorded before they are mounted on the disc.

c) The cover is closed, and the nut and bolts are tightened to ensure no leakage of water. The cashing is then completely filled with water and the sand sample of required size and concentration after that inlet to water and sand are air tightly closed and motor is started.

d) After being run for one hour, the motor is stopped and water is drained out of the casing. The cover is opened and the disc is removed from the shaft.

e) The test specimens are removed from the disc and are cleaned carefully. The test specimens are dried and weighed.

f) Steps (a) to (e) are repeated for another observation. A total of ten observations are taken.

g) Finally, the dependence of erosion (depicted by wear and material loss in the blade) with size and site of the HPP is determined at constant sediment concentration.

III. RESULTS AND DISCUSSION

All results are presented pictorially in the paper. And the analyses were done on the basis of results obtained.

A. Sieve Analysis Result

The Particle size distribution (PSD) curve of Marsyangdi HPP can be seen in Fig. 2 with comparative analysis of 3 different representative location of the plant.

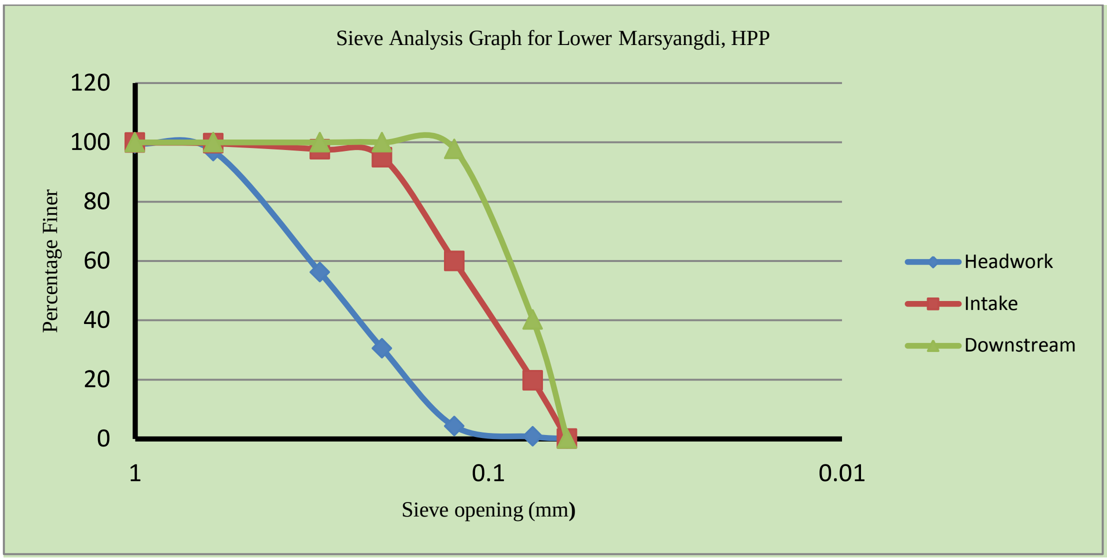

Fig. 2 Sieve analysis graph for Marsyangdi HPP

The significance of this curve is the slope of the graph which shows the most of the particles are in that size range. There are different PSD curve for each location of the plant. Sediment size gradually changes as sediments flow from headwork to downstream, and change in individual percentage finer curve. At headwork, percentage finer curve has steep gradient in the sieve opening of 0.125 mm to 0.6 mm indicating most of the sediments in that size range. Some portions of larger sediments are blocked by headwork structure and remaining samples pass to intake where most of the sediments larger than 0.2 mm get settled as velocity decreases in desanding basin. Thus the gradient of PSD curve is steeper at sieve opening of 0.075 mm to 0.2 mm at intake. For downstream, most of the sediments are in the size range of below 0 .075 mm to 0.125 mm as indicated by steep gradient in PSD curve. PSD analysis result for Lower Marsyangdi HPP also indicates that the most critical sediment size that reach hydraulic turbine and cause erosion on various components of runner ranges mostly from below 0.2 mm.

B. Mineral Analysis Result

A pie chart is plotted to compare the minerals contents of different location of a plant (headwork, intake and tailrace). There are different major minerals like quartz, feldspar, muscovite, biotite, tourmaline and garnet as shown in Fig. 3.

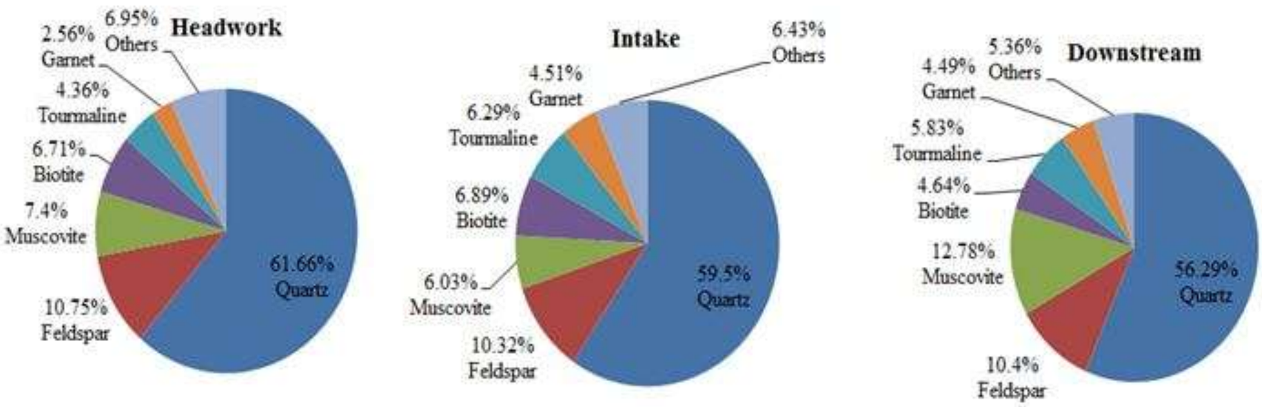

Fig. 3 Pie chart representing the mineral analysis of the Marsyangdi HPP

The pie chart of the Lower Marsyangdi HPP shows that quartz is the most abundant mineral in the sediments. Quartz content slightly decreases on going from head-works to intake and then to the tail race. Feldspar is almost constant in all three locations and Muscovite, and other soft minerals have increased from headwork to tailrace. There is no clear reason to this variation, but it might be due to the fact that heavy minerals settle down and breakages of the minerals like muscovite (having perfect cleavage). Other probable reasons might be mixing of small streams to the main source and action with water, sediment passages, weathering by internal temperature variation and etc. As experiment was incorporated with 2D microscope for the study of minerals, so the breaking process which might increase the mica contents cannot be differentiated.

C. Erosion Analysis Result

Erosion rate is the amount of material eroded from specimen per unit time. Erosion rate can be calculated by using the following equation.

Erosion Rate, $e = \left(W_{\_i} - W_{\_j}\right)/\left(W_{\_i} \times \Delta t\right) \times 1000$ (mg/g per hour)

Where, $W_{\_i}$= weight of specimen before testing in grams

$W_{\_j}$ = weight of specimen after testing in grams

Δt = operation time in hour

For erosion rate analysis, tests were carried out by two methods: firstly, test by making the site constant and varying the size obtained from sieve analysis and lastly, keeping size constant and varying the site locations. Graphical representation of the two tests is given in Fig. 4.

Site constant: For Marsyangdi HPP, head works samples were taken and sieve size was varied as 125– 200 µm, 200 – 300 µm and 300 – 600 µm. After the test observation, the weighted were noted and erosion rate were calculated. From analysis, it is observed that erosion rate varies with size of the sediments. The erosion rate increases with increase in the size of the sediments keeping all other parameters constant. The higher the particle size, the higher the sediment erosion.

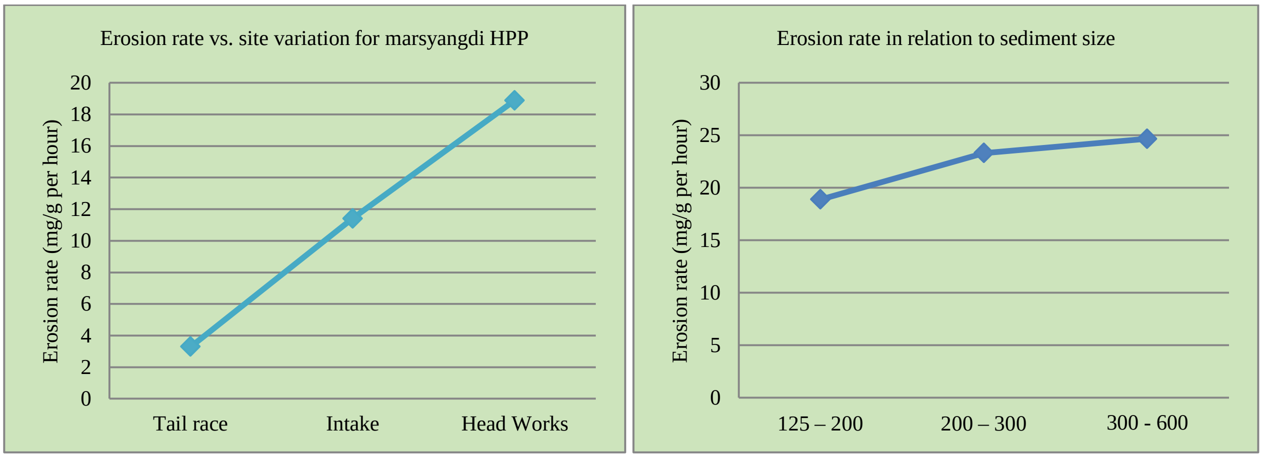

Fig. 4 Erosion analysis graphs

Size constant: Erosion test was performed keeping the size constant as 125-200 µm for all three samples. From analysis of Marsyangdi HPP, it is found that erosion rate decreases in going from head works to tailrace keeping size 125-200 µm microns. The erosion rate is also affected by the quartz content in the sample. Since the density of quartz is high in head works, quartz settles down while going from head works to tail race as shown in the mineral analysis chart.

IV. CONCLUSION

In this research, investigation of sediments sample for the particle size distribution, mineral analysis and erosion were done experimentally. Three experiments were done in sequence: particle size distribution, mineral analysis and erosion test, respectively.

Based upon the experimental analysis, the size of sediment particles is not equally distributed in different locations of the lower Marsyangdi hydro power plant. Bigger particle size was found in head works and observed that particle size decreases while the sediment particle travels from head works to tailrace. It is also found that, quartz is the most abundant mineral and its percentage goes on decreasing from head works to tailrace. Furthermore, it is found that sediment erosion is directly proportional to the size of the particle and percentage of quartz. The critical range of sediment size that reaches to the turbine is in the range of 0.2 mm. This could be useful information while designing new hydropower turbines and controlling the sediment for existing hydropower plants in order to avoid sediment erosion.

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