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EVALUATING THE HYDRAULIC CAPACITY OF EXISTING HYDROPOWER PLANTS

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ABSTRACT

Expanding the generating capacity of existing hydropower plants requires an increase in the hydraulic capacity of the conveyance system. Hydraulic analysis must be undertaken not only to establish the hydraulic capacity of the existing system but also to serve as aid in the formulation of schemes to increase the hydraulic capacity. Guidelines for the conduct of hydraulic analysis for small hydropower plants are discussed. Major factors which have to be considered are also outlined.

INTRODUCTION

In the past two years, the National Hydraulic Research Center (NHRC) has been involved in the hydrologic and hydraulic analysis and design of Small Hydropower Plants, plants which have generating capacities of at most 5 MW. It is presently involved with the hydraulic analysis of an existing small hydropower plant in the province of Benguet. The main objectives of this project is to increase power generation and to determine the operating characteristics of the turbines installed in the power plant. This article sets downs the guidelines and major considerations in the conduct of hydraulic analysis towards increasing the hydraulic capacity.

CHARACTERISTICS OF SMALL HYDROPOWER PLANTS

Existing small hydropower plants in the country are mostly run-of-the-river, high-head plants which exploit the relatively lower flows but higher heads available at the headwaters of the watershed. They are, therefore, typically located at the relatively more rugged and inaccessible portions of the watershed. Conveyance lines are from a few hundred meters to a few kilometers long and are usually laid along steep stream banks. Because of high stream gradients, the vertical distance of the conveyance line from the stream bed rapidly increases from the point of diversion to the point of transmission above the turbines presenting the possible recovery of potential energy with operating heads ranging from 150 - 200 m. This means that about 1 m^3/s of flow will be able to generate more than 1 MW.

This physiographic characteristic adversely influences the accessibility and availability of labor and materials. Slope stability also poses significant danger to the conveyance line. Because of these factors, a low pressure conduit is usually adopted to convey water from the intake to the surge tank. The whole conveyance system typically includes a diversion weir, an intake combined with a desilting basin, a low pressure conduit, a surge tank, a penstock, a powerhouse and a tailrace canal. Common turbines utilized are Pelton and Francis turbines.

EXPANDING THE POWER GENERATION CAPACITY

If enough water is available as shown by hydrologic analysis, it is possible to increase the power generation of the hydropower plant by increasing the water intake. This could easily be accomplished if the conveyance system including the generating units have been designed in anticipation of such a future course of action or if the design had been so conservative that generous factors of safety have been adopted for the various hydraulic structures comprising it. This means that no structural modification is needed but changes to the operating procedure might have to be adopted. Whether this is true or not, it is imperative to establish the hydraulic capacity of the existing conveyance system to determine if it is indeed adequate and if not, formulate possible schemes to increase its capacity.

In most cases, however, the system will likely require some modifications. Improvement may take the form of increasing the height of the diversion weir crest to increase the available head. This change may, of course, result to corresponding modifications of other civil works components. For example, energy dissipating devices will have to be checked if they have adequate strength to contend with the resulting higher heads, and training works and abutment protection structures might have to be extended to account for higher water levels, among other considerations.

Another possible solution will be to operate the low pressure conduit as an open channel. This could be done if the conduit is originally laid on a suitable gradient. In this case, the surge tank will have to be replaced by a forebay because it becomes incompatible with the conveyance system which will be operating in an open channel mode. In addition to changes in operating procedures, air inlet pipes may have to be introduced at suitable sections along the conveyance line to provide insurance from transitional flows brought about by surges emanating from the forebay or the intake.

GUIDELINES FOR HYDRAULIC ANALYSIS

Whatever the final form of solution to be adopted, a hydraulic analysis has to be performed. The main objectives of the hydraulic analysis are the determination of the existing hydraulic conveyance capacity and the verification of the proposed improvements. In both cases the major steps in the analysis are quite similar. These steps include the establishment of controls, determination of flow characteristics at various discharges, and analysis of the effect of transient conditions among other considerations.

Establishment of Controls

In most of the existing small hydropower plants, the conveyance system operates with fully open gates except at the powerhouse where the operation of the turbine gates or valves determines the discharge and the upstream water levels.

The controls to be established as limits to operation are usually water levels which must fulfill specific minimum and maximum levels at various locations of the conveyance system. These are ordinarily specified at major hydraulic structures such as the intake, the surge tank, and the tailrace. At the intake, for example, the minimum may be fixed by the submergence required for the prevention of vortex formation while the maximum is determined by the crest level of its weirs while at the surge tank, the minimum and maximum levels are fixed by the relationship of the water surface oscillations during transient conditions and the structure. In addition to this, the relationship of the hydraulic grade line with respect to the conveyance line must be considered in fixing the water levels to ensure that suction pressures will not occur in the pipeline.

The location of the control is not fixed but may change in position with changes in discharge. In general, at lower discharges, the control is usually at the intake while at higher discharges, the control is at the surge tank.

Determination of Hydraulic Capacity

After the establishment of controls, flow characteristics at various discharges are determined with the controls as boundary conditions. The largest flow which could be accommodated with suitable flow characteristics must be verified against transient flow conditions. This step includes a check on the strength of the penstock against the expected positive and negative water hammer pressures, and a check on the effectivity of the surge tank to contain and damp the oscillations. If the hydraulic transients could be contained then the largest flow is the hydraulic capacity, otherwise, it has to be lowered until a discharge is found which fulfills transient flow conditions.

Visualization of flow conditions is facilitated by the determination of the hydraulic grade line. This step also allows the formulation of schemes to increase the hydraulic capacity to what is required.

An insight into the cause of operational problems which may have been previously experienced by the hydropower plant can be gained during these analysis. For example, collapse of sections of the low pressure conduit may be traced to inadequate submergence giving rise to air entraining vortices which may have caused transient conditions or cavitation of the turbines may be traced to improper turbine setting or to the entry of air through the surge tank because of inadequate water surface level.

Verification of Proposed Improvement

In case improvements are incorporated to increase the hydraulic capacity, the modified conveyance system must be checked to determine if it could transmit the required discharge. This is done by analyzing the flow characteristic at the required discharge given the specified controls followed by a check against transient flow conditions.

If the proposed improvement has been found to be feasible, operating procedures have to be established. Again, this is gleaned from an analysis of flow characteristics at various discharges. This results to an array of water levels from which operating procedures could be specified including the turbine operating heads.

CONSIDERATIONS IN HYDRAULIC ANALYSIS

In the course of hydraulic analysis, a number of factors have to be considered as they exert considerable influence on the behavior of the conveyance system and the choice of improvements which could be introduced. Some of these major considerations are now considered.

Head Losses

The energy loss as water flows through the conveyance system consists of losses due to friction and pipe fittings. Mainly due to topographic considerations, the conveyance pipe will be quite long with a considerable number of bends. Losses will thus be greatly influenced by friction and bend losses which are directly proportional to the velocity head. Increasing the discharge will, therefore, significantly increase the head loss.

Care must be taken in evaluating the coefficients to be used in calculating the head losses. In particular, the friction factor f must be estimated closely as friction loss will most likely be the major loss. Judicious formulation of a field measurement program of discharge and water levels will produce reasonable estimates of the roughness of the pipe from which friction factors could be estimated. This estimate will reflect the deterioration of the inner surface of the conveyance pipe. In addition, sensitivity analysis on the head loss as against the estimated roughness coefficient can be done to determine the effect of variations in the roughness on the conveyance capacity of the system.

Vortex Formation

The presence of vortices especially at intakes is undesirable as it may cause structural damage and loss of turbine efficiency. Although there is no definitive design procedure to avoid intake vortices, experiments show that if the Froude Number based on the intake is less than 0.50, the flow will be free of vortices. Increasing the discharge will, therefore, increase the possibility of vortex formation. This could be remedied by increasing the submergence either by lowering the intake or by increasing the depth of flow. Structural devices could also be introduced to decrease the possibility of vortex formation.

Sediment Exclusion

Mountain streams contain significant amounts of sediment. Because of very high heads for typical small hydropower plants, only small diameter sediments could be allowed to pass through the conveyance system to avoid damage to the turbines. This is accomplished by the proper selection of the location of the intake and the adoption of an appropriate design supplemented by the inclusion of a sediment exclusion device if necessary. The simplest structure usually employed is the desilting basin which is usually located at the intake or intermediate between the intake and the surge tank where topography and geology allows it.

The dimension of the desilting basin is directly proportional to the discharge and inversely proportional to the diameter of sediment to be allowed to pass. Increasing the discharge will make the existing basin ineffective in dealing with the specified sediment limit. This means that larger diameter sediments may be able to pass through the desilting basin, enter the penstock and damage the turbines.

Hydraulic Transients

Pressure surges caused by operation of valves have to evaluated as increasing the discharge will result in more severe cases of water hammer than have been previously anticipated. The strength of the penstock will have to be checked to see if it is adequate to resist the higher stresses. The minimum hydraulic grade line must also be checked to see if it can drop below the penstock. If so, operating water levels must be increased upstream.

The surge tank, which serves to limit to the penstock the portion of the conveyance line under attack by significant surge pressures, must also be checked for adequacy, i.e., the damping ffect of the surge tank is not impaired and that the water level oscillation during downsurge and upsurge could be contained.

Turbine Operation

Cavitation is the most significant problem as far as turbine operation is concerned as it will not only result in structural damage but will also cause a decrease in efficiency. For Francis turbines, it is influenced by the setting of the turbine with respect to the tailwater. If new generating units are introduced to maintain the same flow through each turbine, no problem may occur unless the net head is increased significantly, a possibility which can be discounted if only minor structural changes are envisioned. If the discharge for each turbine is to be increased, however, the cavitation parameter may have to be reevaluated to determine if a new setting is needed.

Cavitation and loss in efficiency might also result if the flow entrains significant amount of air due to vortices. The swirl produced by the vortices will result not only in non-uniformity in the approach velocity distribution but could also result in surges due to the formation and dissipation of vortices. This could be minimized by adequate submergence not only at the intake but also at the surge tank at the head of the penstock.

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