Double-stilling basin modelling, Pakistan – case study

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Abstract

The Mohmand Dam is a 213m tall concrete-faced rockfill dam (CFRD) under design by a consortium of consultants in Pakistan. The consortium comprises SMEC International (Australia), Nippon Khoe (Japan), National Engineering Services (Pakistan), Associated Consulting Engineers (Pakistan), Engineering General Consultants (Pakistan), and BAK Consulting Engineers (Pakistan). The dam is for construction on the Swat River in Pakistan.

A strategic component of the hydraulics studies has been large-scale physical model studies carried out by the Irrigation Research Institute, Pakistan. The paper will discuss in detail the use of, and the hydraulic behavior of a double hydraulic jump stilling basin facility incorporated in a 600m long concrete chute. The upper basin was designed to operate with a maximum head of about 100m, and the lower basin was designed to operate with a maximum head of approximately 120m with respect to tailwater level. The studies considered discharges up to approximately 25,500 m^3/s. Detailed pressure transducer measurements of transients as part of the design of the basins, and the chutes incorporated several aerators along the length of the chutes.

Keywords: Dams, spillways, hydraulic jump basins, energy dissipation, turbulence, pressure transients.

1. INTRODUCTION

The Mohmand Dam Hydropower Project (MDHP) is a large power project to be built on the Swat River approximately 200 km northwest of Islamabad. The location of the dam is illustrated in Figure 1. The project investigation and design passed through several studies with a detailed feasibility study preceding the lengthy study that derived the double-stilling basin spillway arrangement – the subject of the present paper. The work, comprising site and dam selection, detailed hydrology, reservoir sedimentation aspects, power station sizing, diversion detailing and hydraulics progressed the earlier feasibility studies and all has been carried out on behalf of the Water and Power Development Authority (WAPDA) by a consortium of consultant companies.

The diversion works comprise two 15m diameter tunnels. One is to be developed into a permanent, low level outlet facility for necessary releases to the downstream and for drawdown purposes. The power intake will direct flows into a separate tunnel leading to an 800MW power station on the right bank of the river a short distance downstream of the dam and near the spillway discharge location.

2. HYDROLOGY

In July 2010, the Swat River experienced extreme flooding with a discharge estimated as 9,909 m^3/s and considered to have an Annual Exceedance Probability (AEP) of 1 in 1,000. The return periods for the Project went through a number of studies, updating and finally an accepted series of magnitudes. It was confirmed by WAPDA in January 2016 that the Project design team should adopt a panel of expert's recommendation for the Probable Maximum Flood (PMF) of 27,427 m^3/s inflow discharge. The computed peak value for AEP 1 in 1,000 and 1 in 10,000 are 10,669 m^3/s and 18,640 m^3/s, respectively. Figure 2 presents the inflow flood hydrographs at Mohmand Dam site.

As will be described below, the energy dissipation arrangement selected a two-stilling basin arrangement. The flood routing yielded a PMF outflow discharge from the reservoir of 25,362 m^3/s. For the spillway energy dissipation design the design discharge was selected as 90% of the PMF for the upper stilling basin and the AEP 1 in 10,000 discharge for the lower basin.

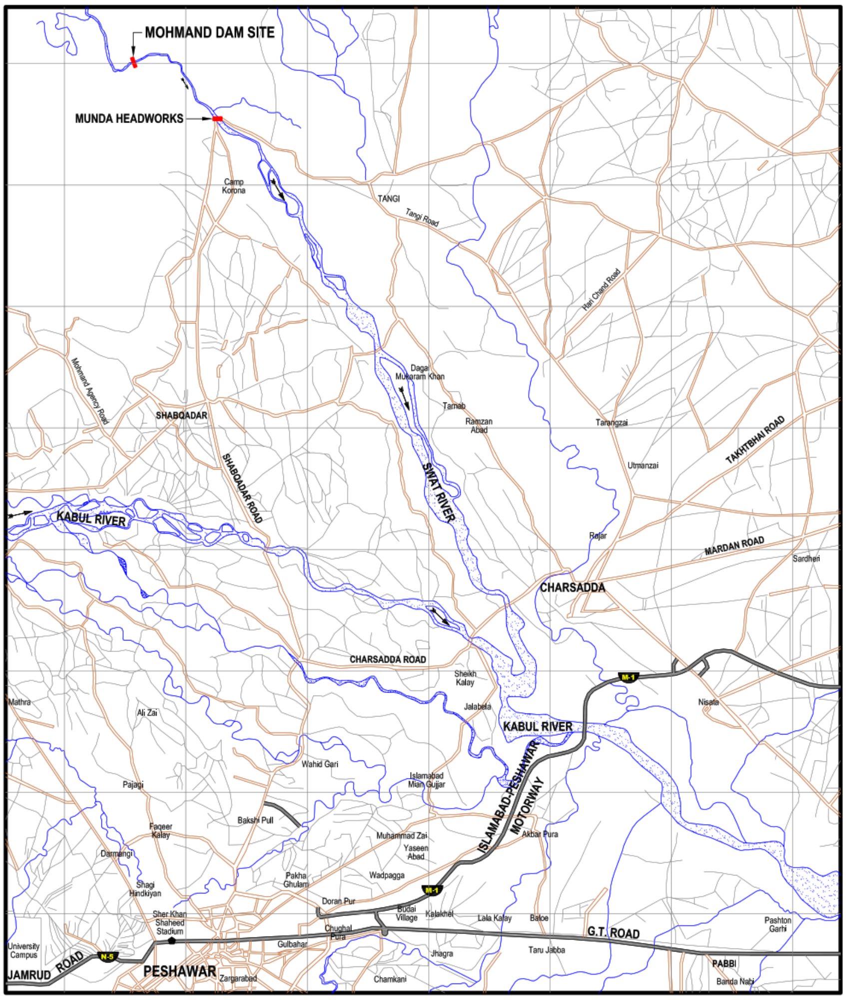

Figure 1. Location of Mohmand Dam Project, Pakistan

3. SPILLWAY TYPE AND KEY DIMENSIONS

The proposed spillway was to be located on the left abutment of the dam, following the dam-type selection of a concrete-faced rockfill dam (CFRD). The type of spillway received detailed consideration. Originally, the project commenced with the plan to use a flip bucket and plunge pool energy dissipation arrangement, for which the plunge pool pre-excavation would be a large-volume depression on the river's left and against a steep excavation of the hill on the spillway's left. Essential to the provision of an acceptable plunge pool dissipater was the consideration of rock scour and its longitudinal and lateral extent. Even the pre-excavation of the plunge pool would require a large slope excavation on the left side. The site investigations revealed rock largely classified as a foliated schist. Based on the Consultant's experience it was considered very erodible under the action of velocities around 45 m/s.

The main issue with the plunge pool erosion, apart from a likely depth to 60m below river bed level, was its lateral expansion and movement with the result that the entire left hill excavation would be undermined and be subject to collapse. Figure 3 is a portion-plan of an early plunge pool possibility; it shows the large excavation on the left side of the plunge pool. Such collapse in turn would produce a large volume of scoured and collapsed material to form a huge blockage in the river, affecting the power station, the permanent outlet works and the spillway itself.

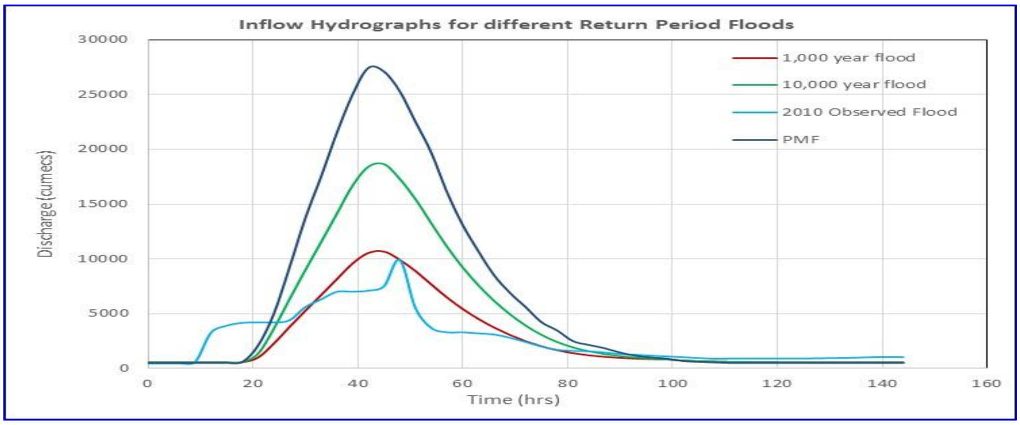

Figure 2. Inflow flood hydrographs

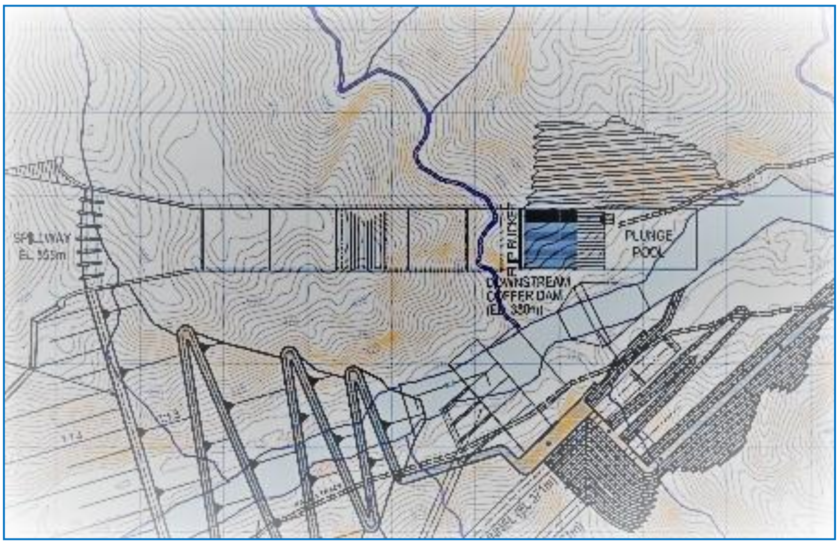

Figure 3. Early Plunge Pool arrangement

The flip bucket-plunge pool arrangement was abandoned and consideration moved to the application of a hydraulic jump stilling basin alternative as the means of dissipating the energy from the spillway. The dam with a crest level at EL 563, and a parapet wall level at EL 564.5, would provide for a reservoir with a full supply level of EL555m, and a spillway crest level of EL 539m.

Several chute and stilling basin arrangements were contemplated. The headworks also passed through several alternatives for the number of gates, and whether part of the spillway would remain ungated with the crest at FSL. The result was seven gates, each 15m wide, and piers 5.3m thick, all placed on a curved crest alignment on a 500m radius. The chute was converged from the total gross crest width of approximately 137m to a width of 100m. This led to a unit outflow discharge at PMF of approximately 255 m^2/s.

With a reservoir level in the region of EL 560 and the river bed in the dissipation area at EL360, clearly the 200m head placed stringent conditions on the spillway design. Early considerations of a single stilling basin indicated basin inflow velocities around 60m/s, and in due course it was decided to investigate the use of a double stilling basin configuration, somewhat similar to the arrangement used some decades earlier on the Mangla Dam spillway, also in Pakistan. The investigation of the double basin configuration is the thrust of this paper. Detailed physical model studies were carried out at the Irrigation Research Institute (IRI), Nandipur, Pakistan.

Figure 4 shows a plan view of the spillway and Figure 5 a profile, depicting the chute from the headworks into the upper basin with an end weir and discharge into the lower basin with an invert level at EL348.

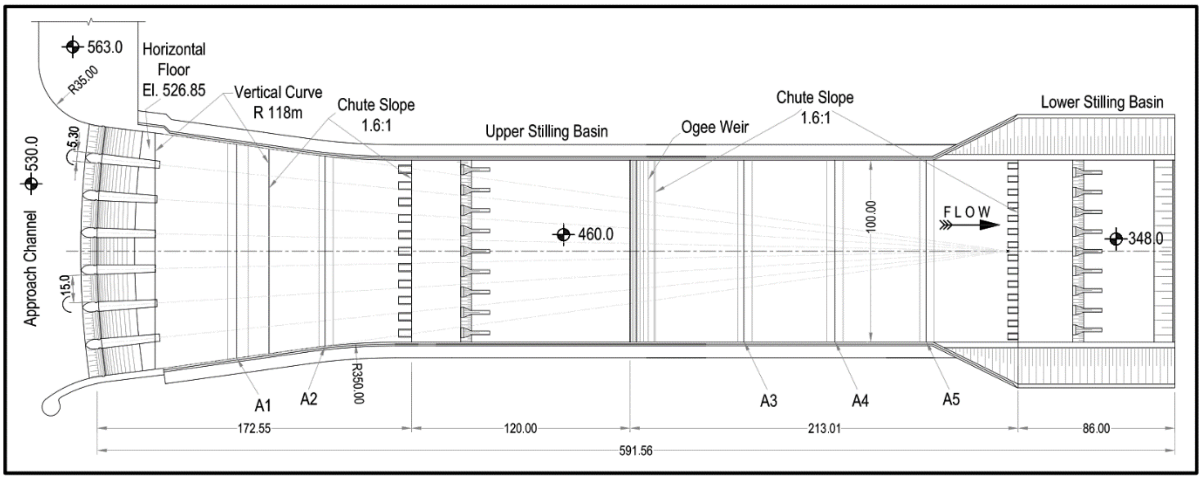

Figure 4. Plan of the double basin spillway

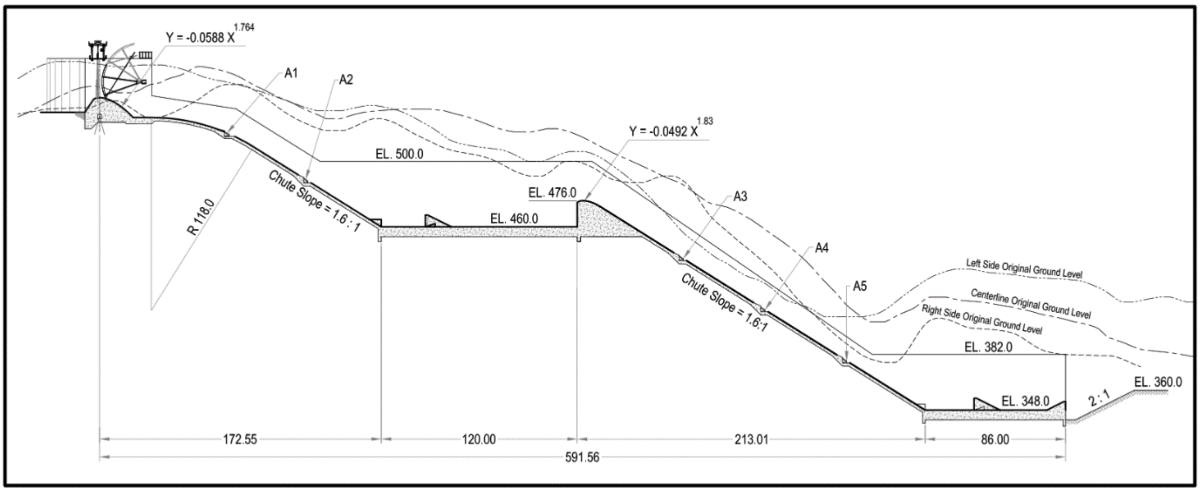

Figure 5. Profile of the spillway

The upper basin was designed to operate with a maximum head of about 100m, and the lower basin was designed to operate with a maximum head of approximately 120m. The studies considered discharges up to approximately 25,500 m^3/s. Detailed pressure transducer measurements of transients in the upper basin were made as part of the design of the basins, and the chutes incorporated several aerators along the length of the chutes, the geometry of which was studied and varied on the hydraulic model.

4. HYDRAULIC MODEL DESCRIPTION

The model was built and tested with a scale of 1:60. Figure 6 shows a general arrangement plan of the model boundary. Each stilling basin was designed initially with estimation of spillway losses, and basin length and depths based on the hydraulic jump characteristics, on the basis that a USBR Type III arrangement would be used. The basins were provided with conventional chute blocks, and baffle blocks were sized according to the jump characteristics and the USBR guidelines on sizes and spacing. The model was constructed in Perspex and instrumented with many piezometers and several locations for pressure transducers. Figure 7 is a view of the model in operation with a AEP 1 in 10,000 discharge, and Figure 8 shows the lower basin at AEP 1 in 1,000 discharge.

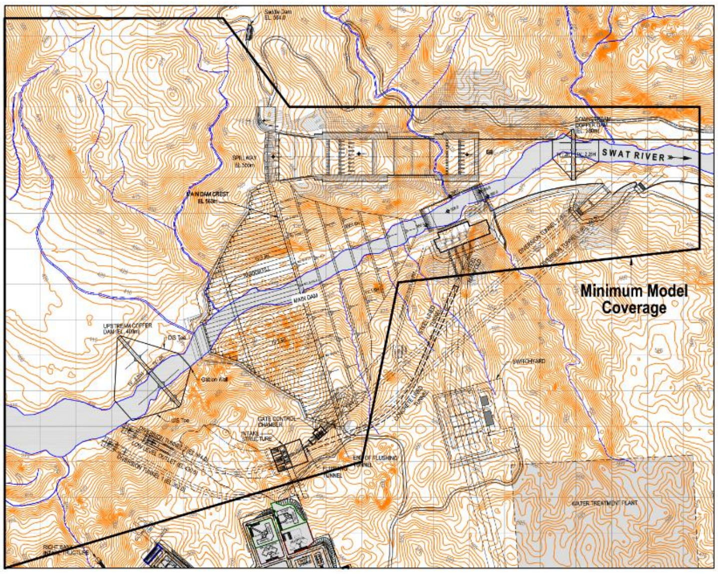

Figure 6. Coverage of the spillway model

5. THE MODEL STUDIES

Many of the key and major aspects of the hydraulics, leading to a final design arrangement, were studied. First, to obtain satisfactory retention of the hydraulic jumps, by making alterations to the basin lengths and floor levels, and numerous changes to the energy dissipation baffle blocks and aerators. A workable and safe design was achieved through the studies. The second major stage of the studies were the measurements of transient and static pressures in key locations. Several aspects of the model dimensions and details were subject to change:

- Upper basin length from 90m to 120m and end weir height from 14m to 16m
- Aerators reduced from six to five – two on the upper chute and three on the lower chute
- Aerator geometry
- Location, height and number of the baffle blocks in the upper basin, and
- Lower basin lowered from EL 355 to EL348 having regard to the tailwater rating based headworks 5 km downstream.

The baffle block utilized the shape developed by USBR studies of a "supercavitating" block during testing for the Folsom Dam auxiliary spillway (USBR, 2009). The purpose was to "push the limits" for which baffle blocks could be used in a cavitation environment, meanwhile ensuring generous aeration of the lower flow layers in the chute and into the stilling basins.

The aerators on the Mohmand model showed the nappe profiles well. The performance led to the lowering of ramp heights in some cases to reduce the length of the aerated zone as well as relocating the aerators to command the chute length sufficiently to provide assurance that the full chute flow would have adequate aeration. There is sufficient experience – model and prototype – to allow confidence in the designs, both in their location and in the air duct areas to meet the demands of the jets from the ramps. Figure 9 shows the dimensions of the five aerators. Figure 10 shows the flow profile at the two upstream aerators.

6. PRESSURE TRANSIENTS

A key consideration in stilling basin design is the amount of uplift forces due to the combination of under pressures, pressure transients and transmission of pressures through joints. The high-energy conditions in both stilling basins dictated close consideration of the pressure transients in the stilling basins for the slab and anchoring design. Pressure transducers were used on the floor of the basin both upstream and downstream of the baffle blocks, and on the sidewall of the stilling basin. Records of pressures were obtained at a sampling speed of 300Hz for generally up to 5 minutes (model).

Figure 7. View of the upper basin operation for AEP 1 in 10,000

Figure 8. Lower chute and lower basin entry Q1,000

By way of illustration, Figure 11 shows the deployment of 8 transducers on the floor of the model upper basin. Figure 12 shows a small part-sample of the 2,300s (prototype time) total capture of the transients at two of eight transducers in the upper basin. The information, together with cross correlation analysis of signals from pairs of transducers and spectra, provided information for the design of the basin floor thickness as well as anchors. A sample of the spectral density plots for two transducers for the PMF is shown in Figure 13. Clearly, the major fluctuations power is around 1 Hz or less, frequencies which are well within the "capability" of the structure floor slabs to respond and therefore relevant for any dynamic analysis of the slab/anchor system.

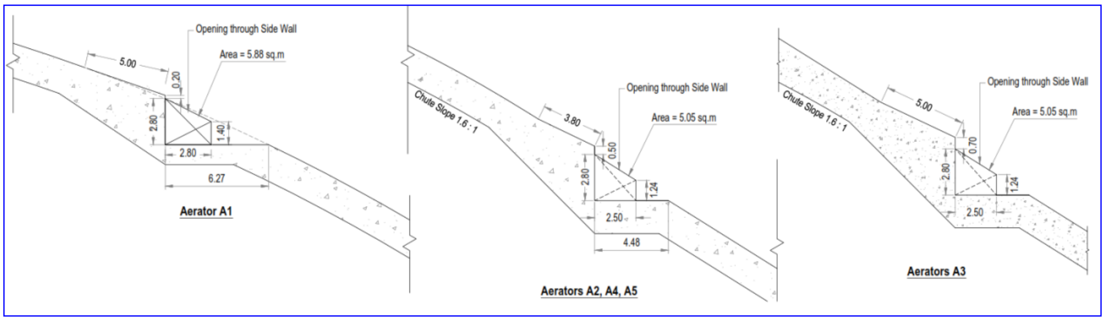

Figure 9. Final aerator geometry

Figure 10. Nappe profiles at aerators 1 & 2

7. CONCLUSIONS

The paper, describing detailed studies on a physical model, shows the value of the exercise in improving significantly on desk-type estimates. Many aspects of the hydraulic structures needed to be addressed by making modifications to the basins, the aerators, and the stilling basin appurtenances. The conditions are major by all comparisons, with high heads and large potential discharges. The double stilling basin presented a workable and desirable option to fit within a narrow corridor with a high mountain (and appreciable excavation) on one side and the dam on the other side. The model results allowed confidence in the detailed design exercise which followed.

8. ACKNOWLEDGMENTS

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9. REFERENCES

1. USBR, Denver, Colorado, 2009, Cavitation Potential of the Folsom Auxiliary Stepped Spillway, Hydraulic Laboratory Report HL 2009-07.

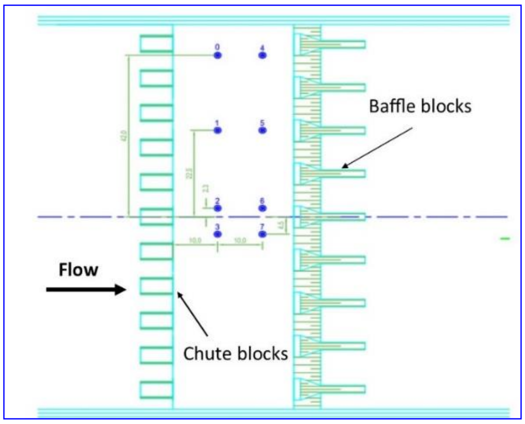

Figure 11. Transducer locations in the upper basin for one test configuration

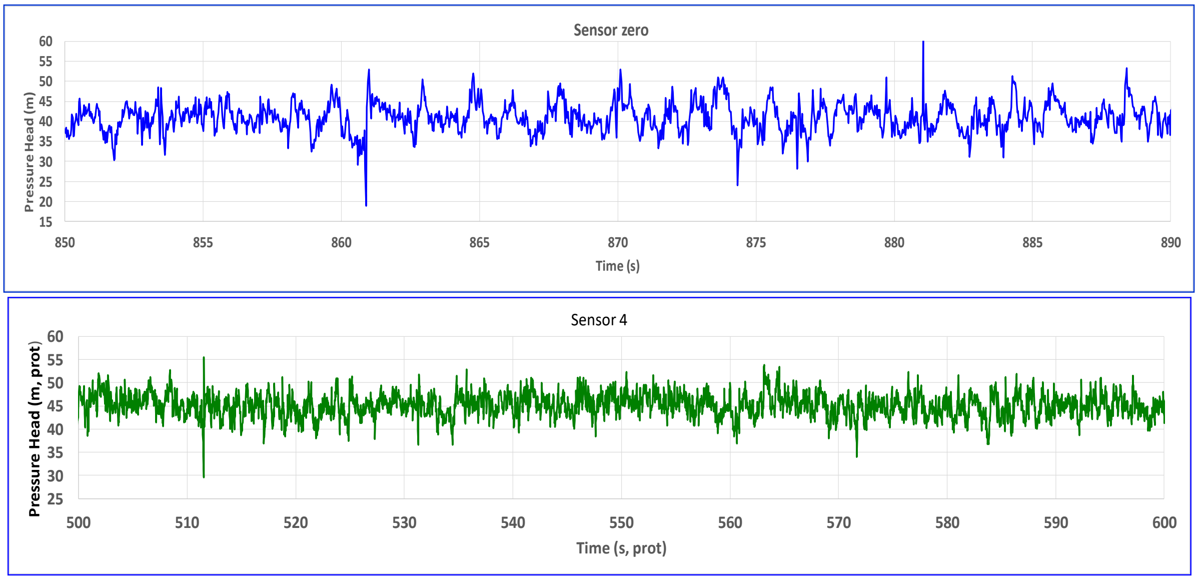

Figure 12. Sample transient pressures at two transducers, upper basin

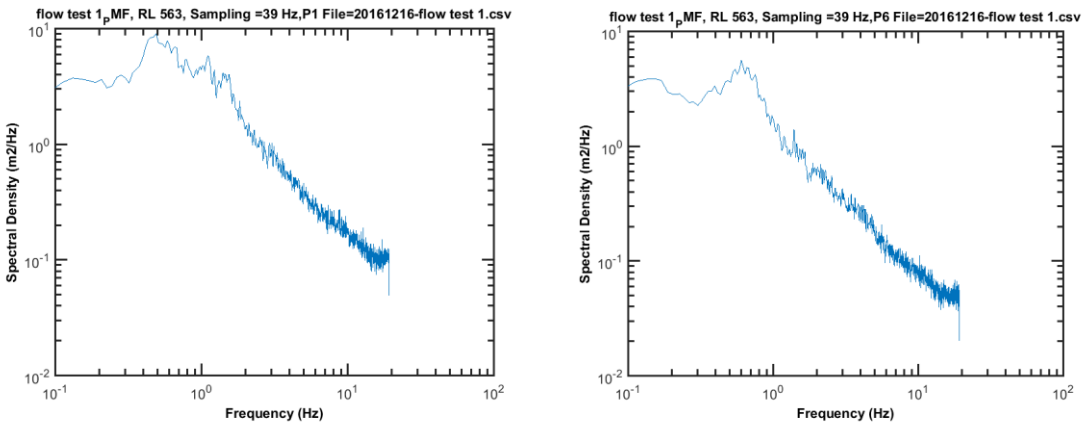

Figure 13. Sample spectral density plots for transducers 0 and 5 for the PMF