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ANALYSIS OF AIR VENTS ON PENSTOCK EMERGENCY GATES
(Subject C.a.)

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SYNOPSIS

Powerplants are usually protected by an emergency gate located near the penstock entrance. If the gate closes while the turbine is running low, pressures can develop in the penstock. The low pressures are prevented by allowing air to enter the penstock through an air vent. The air vent dimensions are determined by solving two equations of motion which include inertial terms. The air flow through the vent is assumed to be incompressible. A good correlation between the analytical prediction and field measurements was obtained. The field results indicate that design standards for maximum velocities in air vents may be relaxed for the term event of an emergency gate closure.

RÉSUMÉ

Les usines hydroelectrique sont normalement protéges par une vanne de sécuretée situeé près de l'entrance du conduit forcé. Si la vanne ferme pendant que la turbine est en marche, les pressions peuvent abaisser dans le conduit forcé. Les pressions abaissées sont évitées par l'air qui entre par un conduit d'air. Les dimensions du conduit d'air sont determineés par la solution de deux équations de movement qui comportent l'inertie. Le movement d'air par le conduit est assumé de n'être pas compressible. On a trouvé un bon correspondence entre les resultats des calculs et les mesures de la nature. Les mesures de la nature indiquent que les normes de dessin pour la vitesse maximum dans un conduit d'air peuvent être relâcher dans un évenément de courte duration comme la fermeture d'une vanne de sécureté.

1. INTRODUCTION

Usually a powerplant is protected against catastrophic failures by an emergency gate located in the penstock. The emergency gate is designed to close automatically whenever an abnormal condition is sensed in the powerplant. The types of emergency conditions that cause gate closures are: abnormally high water levels in the powerplant sumps, high water levels in the turbine pit, overspeed of the turbine, low oil levels in the turbine governor, and creep of the turbine shaft when the brakes are applied.

For most of the emergency conditions, the turbine wicket gates would close automatically. However, with the overspeed condition, it is conceivable that the emergency gates would close while the wicket gates on the turbine remained open. In this case, the water would drain from the penstock. If no air was admitted as the penstock drained, dangerously low pressures could develop in the penstock. For this reason, air vents are provided either in the gate chamber or immediately downstream of the chamber.

Several factors need to be considered in the design of the air vents. These include: the minimum pressure the penstock and gate chamber can withstand without collapsing, surging in the penstock, flow induced vibrations of the emergency gate, water column separation, and cavitation damage due to reduced pressures in the flow passage. To investigate some of these adverse conditions, various analytic techniques have been developed.

McCaig and Jonker [1] considered the case of a surge tank located on the penstock. They were primarily concerned with surging between the surge tank and an air vent located immediately downstream of the gate chamber. The equation of motion neglected friction but included the inertia of the water between the surge tank and the gate chamber. Grigg, Johnson, and Kellerhals [2] investigated the case of a relatively long penstock section located upstream of the gate chamber. The gate chamber was considered to act as a surge tank. Guidelines were given to prevent water column separation at the gate chamber. The equation of motion included the inertia of the water only in the gate chamber and not in the penstock during an emergency gate closure. Neither of these studies investigated the air flow relations because the air vents were very large.

The present study is applicable to installations without surge tanks in which the emergency gate is located at the reservoir, figure 1. Air to relieve the low pressures in the penstock enters the gate chamber through a relatively small air vent located in the gate chamber. The analysis considers the air flow characteristics, inertia of the water in the penstock and the gate chamber, and friction in the conduits. The results of the computations were confirmed by field tests.

2. DESCRIPTION OF THE ANALYSIS

Typically, emergency gates close in 30 seconds to 3 minutes. This seems to be a very rapid closure. However, compared with the water hammer wave travel time

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[1] McCaig, I. W. and Jonker, F. H., Surges in Air Vents Adjacent to Emergency Gates, Transactions of the American Society of Mechanical Engineers, Journal of Basic Engineering, Vol 84, Series D, No. 4, 1961, pp. 679-684.
[2] Grigg, W. L., Johnson, R. E., Kellerhals, R., Some Design Aspects of a Divided Gate Tower, Proceedings of the American Society of Civil Engineers, Journal of the Power Division, Vol 93, No. PO2, 1967, pp. 1-14.

in the penstock, the closure rate can be considered to be slow. Therefore, on the equation of motion only inertial effects need to be included. The effects of compressibility can be ignored.

The water flow in the system is described by two second order differential equations of motion. They were written for flow in the gate chamber and in the penstock respectively. These were linked through an energy equation at the junction of the two flows. The two equations were integrated numerically using the finite difference scheme of Runge-Kutta. Details of these equations and their solution are described elsewhere [3].

The air flow in the vent was calculated using adiabatic compressible flow equations. To more closely simulate the actual vent geometries, the equations were separated into an inlet and a duct flow regime. Within the gate chamber an adiabatic expansion of the air was assumed.

The turbine characteristics were approximated by assuming the turbine to behave as a fixed orifice. The orifice loss characteristics were determined as a function of the wicket gate opening. For reaction turbines with heads exceeding 100 meters, this assumption appears to be reasonable. If the generator is disconnected from the electrical distribution system, all of the water drains from the penstock. However, if the generator remains connected, power will be taken from the electrical system to keep the turbine at speed as the water level drops in the penstock. This results in the generation of a head in the penstock when the discharge goes to zero. To simulate this condition, an additional head equal to the generated head was added to the tailwater elevation.

The computations were performed with a digital computer. The program output consists of all the air and water flow properties at all significant points within the system. Thus, problems arising from water column separation, surging, and minimum pressures could be readily evaluated. If one or more of these conditions was not satisfactory, another air vent size was chosen and the process repeated.

3. FIELD CONFIRMATION

To verify the analysis, field measurements were conducted at Morrow Point Powerplant. The quantities measured were: water surface elevation in the gate chamber, gate position, head across the turbine, inlet air velocities in the vent, sound pressure levels at the vent intake, and the pressure drop across the air vent. To prevent a runaway situation from damaging the turbine, the generator was kept on line during the tests. However, the wicket gates were blocked in the full open position.

The comparison of the analytic predictions with the field measurements was very good for all of the measured quantities, figure 2. To obtain this comparison it was necessary to input the correct gate closing rate and speed-no load head into the program. Prior estimates of these two quantities were inaccurate. For instance, the designed gate closing time was 60 seconds, whereas, it took about 100 seconds to actually close the gate.

The analytic predictions were performed several years prior to the field tests. During the debugging process it was noticed that the pressure drop across the vent fluctuated in an unpredictable manner. Considerable effort was expended in various smoothing techniques to eliminate these fluctuations. However, nothing seemed to be successful. It was very interesting to find these same fluctuations in the field data.

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[3] Falvey, H. T., Air Vent Computations, Morrow Point Dam, Colorado River Storage Project, Bureau of Reclamation Report HYD 584, 1968.

4. AIR VENT DESIGN CONSIDERATIONS

4.1 Maximum Air Velocity in Vent

The maximum allowable air velocity in the vent is determined primarily from physiological considerations. In Bureau practice the maximum allowable air velocity in a vent is usually considered to be 30 m/s. During the field test, the maximum measured air velocity between the grillwork at the air vent inlet was slightly in excess of 80 m/s. The maximum sound level intensity 5 m from the vent was 105 db. United States safety standards require ear protection if sound levels exceed 105 db for longer than 8 minutes.

The field test gives some guidelines for future air vent designs. If it is assumed that the sound level intensities vary as either the sixth or eighth power of velocity, then a 200 m/s velocity would have produced sound level intensities between 128 and 136 db. These levels will damage the ears for any exposure time. At the other extreme, a velocity of 30 m/s produces sound level intensities between 70 and 79 db which will not damage hearing for any exposure time. Thus, a 30 m/s limitation should be placed on vents operating for extended periods; whereas, during short term events the air vent velocities could rise to 80 or 90 m/s.

4.2 Estimates of Air Flow Rate

An air vent can be designed with respect to the maximum allowable velocities if the flow rate through the vent is known. The Morrow Point tests indicated that the maximum air flow rate was approximately equal to the water flow rate before the gate closure began. Analytic studies of other similar installations have shown this crude rule of thumb is a good first approximation.

4.3 Collapse Pressure

For most installation, penstocks are designed to withstand the negative pressure of one atmosphere. However, the deck plates covering the gate chamber may not withstand large pressure differentials across them. Therefore, all elements in the gate chamber and the penstock must be examined when considering the maximum pressure differential allowed across the air vent.

4.4 Surging in the Penstock

The analysis discussed in this study was not formulated to investigate surging during wicket gate closures. With the emergency gate closure no tendancy for significant surging was observed either in the computations or during the field tests.

4.5 Flow-induced Gate Vibrations

The problem of flow-induced gate vibrations is too broad to be discussed in detail here. However, during the closing interval, flow passes both over and under gates having upstream seals. In addition, a large quantity of flow passes behind the gate while the water exits from the gate chamber. The pressure differential across the air vent and the apparent unsteady flow in the vent can produce pressure fluctuations on the gate. All of these factors need to be critically examined.

4.6 Water Column Separation

If the air flow restriction through the vents is excessive, the pressure in the penstock can drop to the vapor pressure of the water. When vapor pressure is reached, then water column separation can become a problem. To avoid the damaging effects of water column separation, the vents must be large enough to prevent the formation of vapor pressure in the penstock.

4.7 Cavitation Damage

Cavitation induced by lowered pressures downstream of the emergency gate can eventually lead to damage of the penstock. This is especially true for gates that remain partially open for extended periods. During emergency closures the reduced pressures are present for extremely short periods of time. Therefore, cavitation damage is of no great concern during emergency closures.

5. SUMMARY

This study has shown that an accurate description of the air and water flow quantities can be obtained by analytic methods. The effect of air vent size on surging, pressures, water column separation, and sound levels at the vent can be easily evaluated.

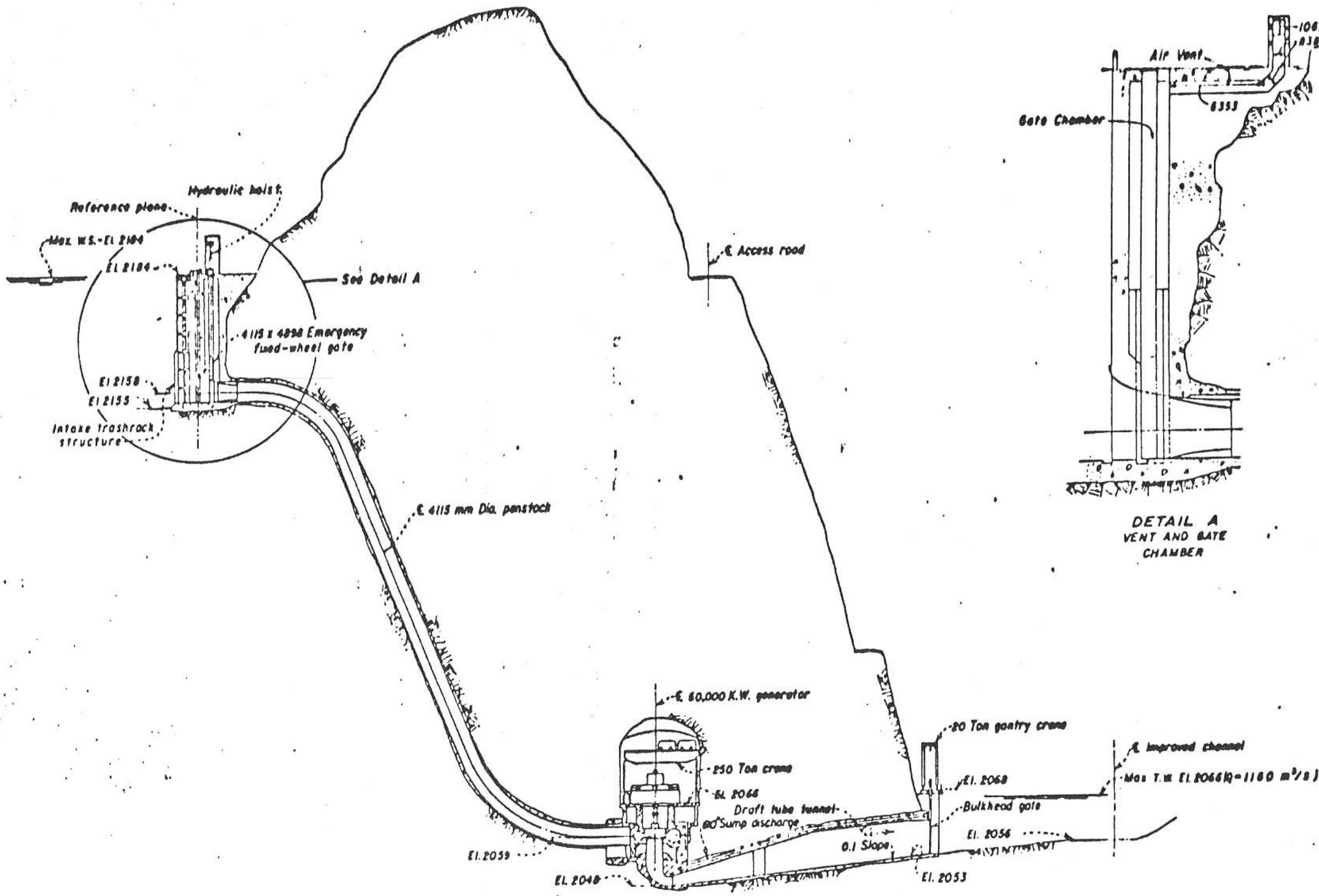

FIGURE I. SECTION THRU PENSTOCK AND POWER PLANT
Coupe sur un conduite forcée et l'usine

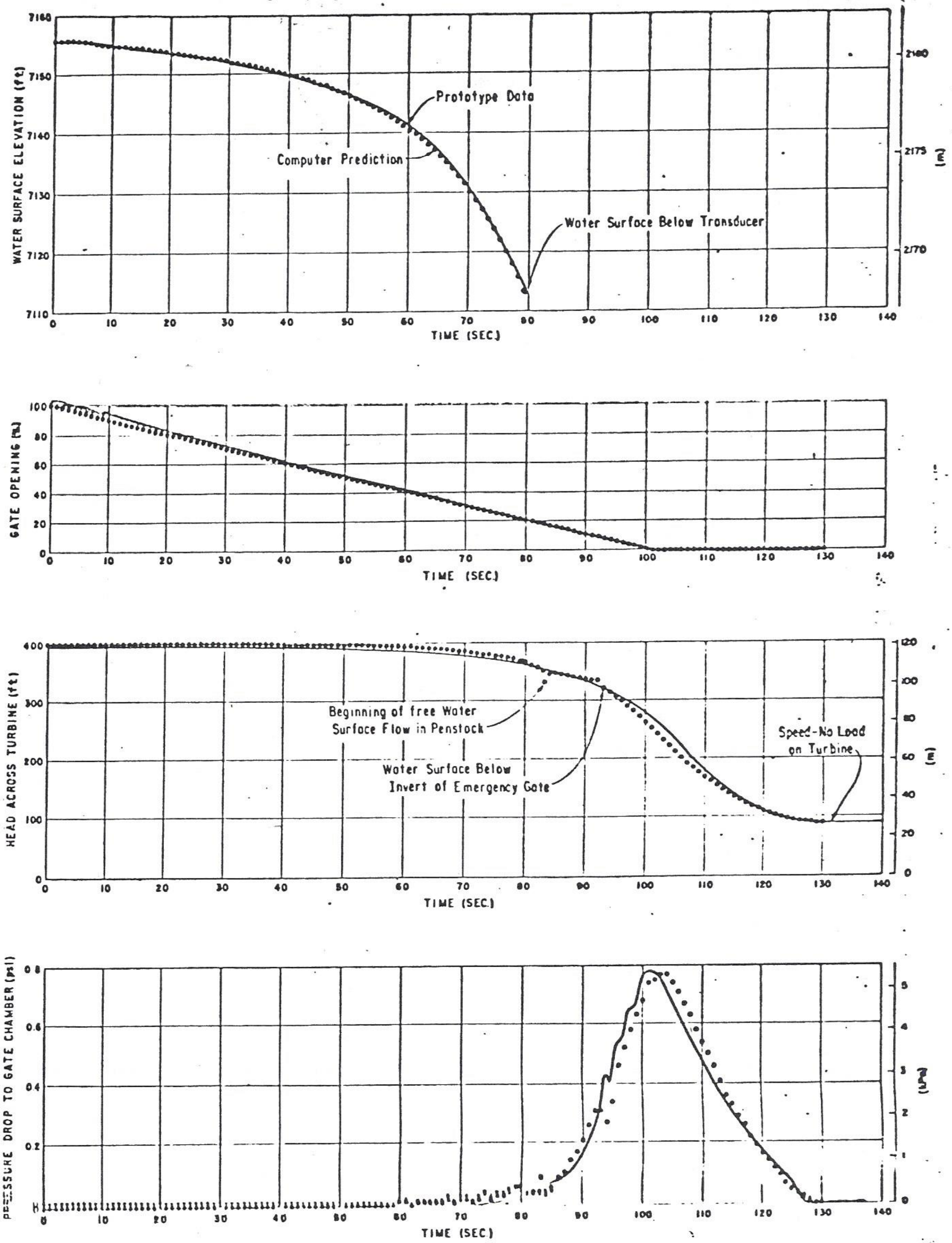

FIGURE 2. COMPARISON OF FIELD DATA WITH COMPUTER PREDICTION

Correspondance entre les resultats des calculs
et les mesures de la nature