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PROJECT ADMINISTRATION DATA

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Security class (U,C,S,TS): U  ONR resident rep. is ACO (Y/N): N
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AMENDMENT 1 AUTHORIZES A NO-COST EXTENSION, AS REQUESTED.
GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 10/07/93

Project No. E-20-X38__
Center No. 10/24-6-R7721-0A0_

Project Director MARTIN C S_________ School/Lab CIVIL ENGR____

Sponsor PATTERSON PUMP COMPANY/TOCCOA, GA__________________________

Contract/Grant No. AGREEMENT SIGNED 12/22/92____ Contract Entity GTRC

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Title INTAKE MODEL TESTS, LOW & HIGH HEAD WATER SYSTEMS, CITY OF MONTREAL____

Effective Completion Date 930815 (Performance) 930815 (Reports)

Closeout Actions Required: Y/N Date Submitted

Final Invoice or Copy of Final Invoice Y __________
Final Report of Inventions and/or Subcontracts N ______
Government Property Inventory & Related Certificate N ______
Classified Material Certificate N ______
Release and Assignment N ______
Other ____________________________ N ______

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GTRI Accounting/Grants and Contracts Y
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Research Security Services N
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Project File Y
Other CARL BAXTER-FMD__________________________ Y
FRED CAIN-00D__________________________ Y
FINAL REPORT

HYDRAULIC MODEL STUDY OF
HIGH PRESSURE
AND
LOW PRESSURE
PUMP INTAKE STRUCTURES
CITY OF MONTREAL

by

C. Samuel Martin

Prepared for
PATTERSON PUMP COMPANY
Toccoa, Georgia

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Toccoa, Georgia

June 1993

School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
FOREWORD

Hydraulic model investigations of the High Pressure and Low Pressure Pump Intake Structures of the City of Montreal were conducted in the Hydraulics Laboratory of the School of Civil Engineering of the Georgia Institute of Technology. The investigations were performed under the supervision of Professor C. S. Martin.

The models were constructed in the Shop of the School of Civil Engineering under the supervision of Mr. Scott Williams and Mr. Mingt Thein. The model data were collected by Mr. Salik Javaid.

The assistance and advice given by Mr. Jack Claxton of Patterson Pump Company in the course of the investigation is gratefully acknowledged.
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ABSTRACT

Hydraulic model studies of the Pump Intake Structures of the High Pressure and the Low Pressure installations of the City of Montreal were conducted at the Hydraulics Laboratory of the School of Civil Engineering of the Georgia Institute of Technology. The models were constructed at an undistorted scale of 1:8 and operated on the basis of the Froude Law of hydraulic modeling. Tests were conducted to determine the flow pattern approaching the Pump Intake Suction Channels and the variation of the hydraulic grade lines from the wet wells to the suction manifolds of the respective model pumps.

Observations of the flow pattern and the shape of the free water surface were made for both models utilizing dye injection at both design flow and at 150% of design flow. Except for a dimpled vortex in the intake sump of the High Pressure Pump, both models performed very well hydraulically, with indications of nearly symmetrical flow entering the bells of the model pumps. There was no significant vortex activity on the free surface nor within the flow passages of the Low Pressure Pump Model.

The measurement of the hydraulic grade lines from the suction wet wells to the suction manifold of the pumps resulted in the determination of the total head loss within the suction flow passages. The total head loss coefficient $K_L$, based upon the velocity head at the suction manifold, was approximately 0.10 for both models, indicating that the energy losses were minimal.
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INTRODUCTION

Hydraulic models of the Pump Intake Structures of both the High Pressure and Low Pressure Pump Installations of the City of Montreal were built and tested in the Hydraulics Laboratory of the School of Civil Engineering of the Georgia Institute of Technology. The models were constructed at an undistorted scale of 1:8 and operated on the basis of the Froude Law of hydraulic modeling. Both models were built using plywood, wood, fiberglass, and Plexiglass materials. The models was built to scale using drawings furnished by Patterson Pump Company and the City of Montreal.

The same supply pump and intake basin was employed for both the High Pressure and Low Pressure Models, as shown by the overall view depicted on the photograph in Figure 1. Siphons were utilized to simulate the flow within the suction channel and suction piping to the respective pump. The piping on the left is the siphon representing the High Pressure Pump. The siphon simulating the Low Pressure Pump Model is on the right side of the picture.

![Figure 1. View of High Pressure and Low Pressure Pump Intake Models](image)

The operation of the models was accomplished as follows. By submerging the discharge end of the siphon the piping was primed by means of a vacuum pump. After a few minutes the siphon could be completely primed, allowing the required flow to be set using control valves on each siphon. The flow could be set to 100% or 150% of pump capacity by adjusting a valve until the proper flow was attained.
Tests were conducted to determine the flow pattern approaching the pump intake bays and within the suction channels and suction piping of each model. Observations of flow patterns were performed for the pumps operating at both high and low water intake levels. In this report the consideration of model selection, model limitations, and the final choice of model scale will be initially discussed, followed by a presentation and interpretation of the results.

HYDRAULIC MODELING LAW

For pump intake investigations the Froude Law is by far the most important in the prototype as the effects of viscosity and surface tension are considered negligible. The hydraulic model should be designed such that the effects of viscosity and surface tension do not affect its results. This is accomplished by choosing a model scale as small as possible. The Froude Law, which relates gravitational and inertial forces, yields the following expressions for length ratios and flow rate ratios between prototype and model:

\[ LR = \frac{L_p}{L_M} \]

\[ H_p = H_M L_R \]

\[ Q_p = Q_M L_R^{2.5} \]

For this 1:8 scale model, \( L_R = 8 \), and \( Q_R = 8^{2.5} = 181 \). This flow ratio was used for the setting of model flow rates, except that the maximum flow for the simulated model pumps was in accordance with accepted practice, 150% of that dictated by the Froude Law. Therefore, the flows for the simulated pumps were either 0.00552 of the prototype value (100%) or 0.00829 (150%).

MEASURING EQUIPMENT

The models consisted of a sump, pumps, distributing pipes with flow-control valves and flow meters. The flow measuring devices used for the model were of the differential-pressure type -- elbow meters. These flow meters have been calibrated in situ utilizing orifices in the Hydraulics Laboratory. The flow through each pump was determined by the use of differential air-water manometers connected to
each elbow meter. Each pump effluent was measured by the elbow meters on the discharge of the model pumps in the siphon. For each pump model the water level was set and monitored with scales attached to the walls of the Basin and the Pump Intake Bays.

The variation of the hydraulic grade lines (HGL) along the suction channels and suction pipes was determined via pressure taps connected to 20-tube manometer board, which could be subjected to a vacuum for ease of reading. The manometer board was graduated in tenths of an inch, readable to 0.02 to 0.05 inch, corresponding to a prototype resolution ranging from 4-10 mm.

For the suction piping, suction manifolds of four tubes were installed at the specified horizontal planes -- one for the High Pressure Pump Model and four for the Low Pressure Pump Model. The four pressure sources around the circumference of the suction pipe were led into one final tube by employing three pair of tees, the first two pair for the four taps, and the last one to connect the output from the first tees. For the High Pressure Pump Suction Manifold initial readings were taken from the four taps directly.

**HIGH PRESSURE PUMP MODEL**

Figure 2 is a plan view of the existing intake basin for supplying water to High Pressure Pumps 1, 2, 3, and 4. Pumps 3 and 4 are existing units with rated flows of 4.2 m³/sec. There is no Unit 1 at present nor is one planned for the near future. The model pump tested is Unit 2. As shown on Figure 2 Unit 1 is modeled up to the point where it is blocked off. For Units 3 and 4 the entire suction channels, which are identical to that for Unit 2, are not simulated. Instead, the piping is furnished as shown only to convey the flow.

Portions of the pump intake structure, the suction channel, the pump suction pipe, and the vertical part of the pump discharge pipe was constructed out of cast acrylic, as shown on the oblique view of Pump 2 in Figure 3. Figure 4 is another view of the suction channel and piping of Pump 2. The suction bell curvature supplied by the Patterson Pump was molded from cast acrylic. A vortimeter constructed of four radial vanes was mounted on a shaft with bearings in order to have a relative measure of vorticity and/or asymmetric flow through the model pump. Figures 5 and 6 show the location of the pressure taps along the suction channel, and suction pipe, respectively.
UNIT 1
(Blocked)

UNIT 2

UNIT 3

UNIT 4

Figure 2. Plan View of High Pressure Pump Intake Model

Figure 3. Oblique View of Unit 2 of High Pressure Pump Intake Model
Figure 4. View of Suction Channel and Suction Piping of High Pressure Pump Intake

Figure 5. Profile Section of Suction Channel and Piping of High Pressure Pump Intake Model
Figure 6. Profile Section of Suction Pipe and Manifold of High Pressure Pump Intake Model

Hydraulic Grade Line and Head Losses

Utilizing the 20-tube manometer board the variation of the hydraulic grade line (HGL) was measured for the two extreme intake levels of 22.0 m (maximum) and 17.4 m (minimum) for both 100% flow (4.2 m³/sec) and 150% flow (6.3 m³/sec). A pressure tap connected to the wall of the intake basin was used as the reference value for the specified wet well level. Initially, up to 23 manometer readings were taken inasmuch as there were pressure taps on each side of the suction channel shown in Figure 5, and four individual taps connected to the manometer board from the suction pipe, Figure 6. Eventually, since the apparent symmetric flow did not yield differences along the suction channel nor around the suction manifold taps, only the readings for five pressure taps shown on Figure 5, plus the reservoir tap and the suction manifold tap were reported. The results from these seven taps are plotted on Figures 7 and 8 for the high intake level (22.0 m) and the low intake level (17.4 m), respectively. The abscissa of the four graphs corresponds to the developed length from the intake shown on Figure 5.
Figure 7. Variation of HGL Along Intake for High Pressure Pump Model at Low Intake Level
Figure 8. Variation of HGL Along Intake for High Pressure Pump Model at High Intake Level
Assuming one-dimensional flow at the suction manifold of the High Pressure Pump the total head line (EGL) can be determined, from which an estimate of the head loss from reservoir to pump suction can be assessed. Table 1 is a summary of the head losses for the four tests of the High Pressure Pump. Defining the total head in terms of the velocity head at the suction manifold the head-loss coefficient

\[ H_L = K_L \frac{V_s^2}{2g} \]

The head-loss coefficient \( K_L \) for the four tests has an average value of 0.08.

<table>
<thead>
<tr>
<th>Intake Level ((m))</th>
<th>Flow Rate ((m^3/sec))</th>
<th>Head Drop from Intake to Suction Manifold ((m))</th>
<th>Velocity Head at Suction Manifold ((m))</th>
<th>Head Loss from Intake to Suction Manifold ((m))</th>
<th>Head Loss Coefficient Based on Suction Manifold Velocity Head, (K_L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.0</td>
<td>4.2</td>
<td>0.46</td>
<td>0.44</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>22.0</td>
<td>6.3</td>
<td>1.07</td>
<td>1.00</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>17.4</td>
<td>4.2</td>
<td>0.49</td>
<td>0.44</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>17.4</td>
<td>6.3</td>
<td>1.10</td>
<td>1.00</td>
<td>0.10</td>
<td>0.11</td>
</tr>
</tbody>
</table>

**Observations**

Observational testing was conducted, principally at the low water elevation of 17.4 m, for the purpose of visualizing rotation of the vortimeter, and dye patterns indicating flow distribution. For these tests the flow for Pump 2 was set at the design flow rates of 4.2 \(m^3/sec\) (100%) or 6.3 \(m^3/sec\) (150%).
For some of the tests, Pumps 3 and 4 were also operating. In fact, the following combinations of pumps were tested: Pump 2 alone, Pumps 2 and 3, Pumps 2 and 4, and Pumps 2, 3, and 4. Neither the variation of the HGL in Pump 2 nor the observed flow patterns were seen to be affected by the inclusion of Pumps 3 and/or 4 during the running of Pump 2.

Figure 9 is a photograph of the suction manifold and the vortimeter of Pump 2. For all flow conditions tested there was never a complete revolution of the vortimeter. Indeed, the vanes only occasionally exhibited some flutter. This inaction indicates that the flow down the suction channel and into the suction pipe had no asymmetry nor vorticity.

Dye was injected into the long channel leading up to Pump Bays 1, 2, 3, and 4. Figure 10 shows the dye pattern for Pump 2 running alone at 6.3 m$^3$/sec and the intake level at 17.4 m elevation. The flow in this channel is generally uniform until the water nears the approach to Pump 2 intake. Figure 11 shows the dye distribution directly into the suction channel of Pump 2. Although there is a definite turning of the flow the streamline configuration is relatively smooth. It was also observed that the flow on down the suction channel appeared symmetric.

For the low intake level of 17.4 m, a dimpled vortex was observed in the basin very close to the intake of Pump 2. This vortex, while the strongest at 6.3 m$^3$/sec flow, still existed at the design flow of 4.2 m$^3$/sec. The vortex was intermittent, usually forming on the right side of the intake looking downstream into the suction channel of Pump 2. On occasion, however, the vortex would disappear and reform on the left side of the intake. Although the vortex appeared up to 75% of the time under the severe conditions of flow and water level (6.3 m$^3$/sec and 17.4 m elevation), it was broken up by the flow itself upon entering the suction channels. Indeed, the dye quickly dispersed as soon as the flow became horizontal. The dye pattern within the suction channel and the suction pipe of the pump always had a general appearance of symmetry, as exhibited by no rotation of the vortimeter.

Exploratory tests were conducted for the purpose of breaking up the vortex by the insertion of a horizontal plate below the water level. This plate had prototype dimensions of about 3 m by 3 m and was placed at approximately elevation 16.0 m. The plate was quite effective as a vortex suppressor although there was some weak vorticity under it, as observed by dye motion.
Figure 9. View of Suction Manifold and Vortimeter of High Pressure Pump Model
Figure 10. Photograph of Dye in Approach Channel of Basin of High Pressure Pumps

Figure 11. Photograph of Dye in Approach to High Pressure Pump Model
LOW PRESSURE PUMP MODEL

Figure 12 is a plan section of the existing intake basin for four of the Low Pressure Pumps. The pump to be tested is also shown on Figure 12. The other three units were not modelled, but instead blocked off back at the intake wall. The model pump had a design flow of 4.2 m³/sec. Figures 13 and 14 show the profile sections of the suction channel and piping, and the plan view of the suction channel, respectively. Figure 15 gives the precise location of the four levels of suction pressure manifolds. At each elevation the three tee arrangement was utilized for pressure averaging, as shown by the photograph in

Figure 12. Plan Section of Low Pressure Basin and Location of Model

Figure 13. Profile Section of Suction Channel of Low Pressure Pump Model
Figure 14. Plan Section of Suction Channel of Low Pressure Pump Model

Figure 15. Location of Pressure Taps on Suction Piping of Low Pressure Pump Model
Hydraulic Grade Line and Head Losses

Utilizing the same 20-tube manometer board as described earlier for the High Pressure Pump Model the variation of the hydraulic grade line (HGL) was measured for the two extreme intake levels of 18.3 m (maximum) and 16.46 m (minimum) for both 100% flow (4.2 m$^3$/sec) and 150% flow (6.3 m$^3$/sec). A pressure tap connected to the wall of the intake basin was used as the reference value for the specified wet well level. Including the reservoir, there were a total of 10 pressure taps, five on the top of the suction channel (Figure 14), and at the four in the suction pipe (Figure 15). For all four tests reported -- two flow rates at the maximum and minimum intake levels -- the first pair of pressure taps in the suction channel and the three at the next location indicated no change across the channel at these two locations depicted in Figure 14. Therefore, the results for the four tests shown in Figures 18 and 19 have only seven readings -- the reservoir, at the two cross sections of Figure 14, and finally, at the four suction manifolds shown in Figure 15. Using the same definition of the head loss coefficient $K_L$ as employed for the High Pressure Pump the results for the Low Pressure Pump are tabulated in Table 2. Similarly, the value of $K_L$ is quite low, in this instance approximately 0.14.

TABLE 2. Summary of Head Loss Data for Low Pressure Pump

<table>
<thead>
<tr>
<th>Intake Level (m)</th>
<th>Flow Rate (m$^3$/sec)</th>
<th>Head Drop from Intake to Suction Manifold (m)</th>
<th>Velocity Head at Suction Manifold (m)</th>
<th>Head Loss from Intake to Suction Manifold (m)</th>
<th>Head Loss Coefficient Based on Suction Manifold Velocity Head, $K_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.3</td>
<td>4.2</td>
<td>0.76</td>
<td>0.66</td>
<td>0.10</td>
<td>0.15</td>
</tr>
<tr>
<td>18.3</td>
<td>6.3</td>
<td>1.71</td>
<td>1.48</td>
<td>0.23</td>
<td>0.16</td>
</tr>
<tr>
<td>16.46</td>
<td>4.2</td>
<td>0.74</td>
<td>0.66</td>
<td>0.08</td>
<td>0.12</td>
</tr>
<tr>
<td>16.46</td>
<td>6.3</td>
<td>1.65</td>
<td>1.48</td>
<td>0.17</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Figure 16. View of Suction Channel and Suction Piping of Low Pressure Pump Model

Figure 17. View of Suction Manifold and Vortimeter of Low Pressure Pump Model
Figure 18. Variation of HGL Along Intake for Low Pressure Pump Model at Low Intake Level
Figure 19. Variation of HGL Along Intake for Low Pressure Pump Model at High Intake Level
The hydraulic grade line variation along the suction channel and up the suction pipe shown in Figures 18 and 19 indicate that there is no loss between the four suction manifolds nor any bad flow condition tending to skew the pressure distribution. The suction manifold can be located at elevation 14.74 m just below the pump suction flange shown on Figure 15.

Observations

The injection of dye into the basin and into the suction channel of the Low Pressure Pump Model did not show any bad flow condition into the model. Moreover, no free surface vortex nor submerged vortex was observed for this model. Furthermore, the vortimeter shown in Figure 17 never made one half of a revolution. In conclusion, the flow into the Low Pressure Pump did not have any adverse effects.

CONCLUSIONS AND RECOMMENDATIONS

The hydraulic model studies of the High Pressure and Low Pressure Pump Intake Structures showed that the flow into the pump bays was apparently symmetric under all modes of operation. For both models there was no significant vortex activity under the range of operating conditions as severe at 150% of design flow and at the lowest intake water level for the respective model.

Although there was a weak vortex in the intake basin of the High Pressure Model at the minimum intake water level, there is no recommendation of modification to the Intake Basin nor the suction channel.

There are no recommendations for modification to the Intake Structure of the Low Pressure Pump.

The average total head loss coefficient was 0.08 and 0.14 for the High Pressure and the Low Pressure Model, respectively.

The suction manifold for the Low Pressure Pump can be located just below the pump suction flange -- elevation 14.74 m.