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Evaluation of Optimum Performance of Lateral Intakes

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***Abstract*—**In designing river intakes and diversion structures, it is paramount that the sediments entering the intake are minimized or, if possible, completely separated. Due to high water velocity, sediments can significantly damage hydraulic structures especially when mechanical equipment like pumps and turbines are used. This subsequently results in wasting water, electricity and further costs. Therefore, it is prudent to investigate and analyze the performance of lateral intakes affected by sediment control structures. Laboratory experiments, despite their vast potential and benefits, can face certain limitations and challenges. Some of these include: limitations in equipment and facilities, space constraints, equipment errors including lack of adequate precision or mal-operation, and finally, human error. Research has shown that in order to achieve the ultimate goal of intake structure design – which is to design long-lasting and proficient structures – the best combination of sediment control structures (such as sill and submerged vanes) along with parameters that increase their performance (such as diversion angle and location) should be determined. Cost, difficulty of execution and environmental impacts should also be included in evaluating the optimal design. This solution can then be applied to similar problems in the future. Subsequently, the model used to arrive at the optimal design requires high level of accuracy and precision in order to avoid improper design and execution of projects. Process of creating and executing the design should be as comprehensive and applicable as possible. Therefore, it is important that influential parameters and vital criteria is fully understood and applied at all stages of choosing the optimal design. In this article, influential parameters on optimal performance of the intake, advantages and disadvantages, and efficiency of a given design are studied. Then, a multi-criterion decision matrix is utilized to choose the optimal model that can be used to determine the proper parameters in constructing the intake.

***Keywords*—**Diversion Structures Lateral Intake, Multi criteria Decision Making, Optimal Design, Sediment Control

I. INTRODUCTION

GIVEN the importance of water resources, it is evident that water supply networks used for industrial, sanitation, agricultural or residential purposes need to be adequate and reliable. Any disruption in water supply, however short in duration, or any decline in water quality will have negative impacts on the end users and their activities. A water supply network should meet existing standards in terms of quality and quantity. With growth in population and water demand, it seems logical that in addition to building new intakes and sediment control structures, engineers should study the problems and operation of existing structures in order to apply that knowledge to future projects. Identification and evaluation of aforementioned structures can be a significant aide in reducing water waste since optimal performance of these structures improves the efficiency of other networks.

Some of the most substantial factors that should be taken into consideration in designing lateral intakes are to facilitate water conveyance into the intake channel as well as exclusion of sediment inflow and its deposition at intake entrance. This can remarkably increase the efficiency of the intake [1].

Some experimental Researches carried out on a lateral intake at 90° with a straight channel. They concluded that the formation of diversion flow is due to the presence of transverse hydraulic gradient at intake entrance. They also found out that the pressure variation at intake entrance is such that to decrease at the inner intake entrance and increase in outer intake entrance. It is also proportional to the water level variation at intake entrance. The diversion flow rate is dependent on the surface of the dividing stream-flow. The equilibrium between longitudinal pressure gradient as well as shear and centrifugal forces causes a secondary clockwise flow in the outer entrance of the diversion channel. The flow pattern in lateral intakes is so that there is a possibility of particle accumulation and sedimentation near the inner entrance of the diversion channel [2].

Investigations carried out along bend cross-sections of the curved channels revealed that the flow velocity decreases as the depth increases. The transverse slope also decreases from the outer bend towards the inner bend direction. This occurs due to pressure gradient in the bend. Therefore, the boundary layer is affected by a dynamic pressure gradient which leads to the formation of a spiral flow in the bend. The existing conditions forces the sediments to migrate from outer bend towards the inner bend [3]. Those who have studied on the bend channels suggest using a U-shape (180°) channel when experimenting on the secondary flow, as the secondary flow can be fully developed in such conditions [3, 4 and 5].

Considering the flow pattern in the bends, many researchers suggest the preferable location for the intake to be the outer

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bend [1, 6, 7 and 8]. Razvan (1981) has obtained that the best intake location is in 3/4 of central angle in the second half of the bend channel [7]. In addition, diversion angle of the intake has been the subject of some studies. Boillat, J. L. and G. De Cesare (1994) concluded that optimum diversion angle varies with diversion rate (Qr=QD/Qm) and intake location in channel bend [9]. Reference [7] defined the best diversion angle as where separation zone in the intake is a minimum value. Optimum diversion angle was also determined experimentally by some investigators and proved to vary a wide range of 30-65° [7].

The water-intake sediment problem is illustrated a lateral intake adjoining the Ohio River. The sandbar formed in the intake for bay is an indication that the intake is withdrawing a significant amount of sediment and that the performance of the plant is diminished because of the resulting non-uniform approach flow. One strategy to mitigate such a problem is to separate mechanically the sediment from the water and eject it from the intake. Such an approach is rather expensive and may impact adversely the river environment by disturbing the local sediment regime [2 and 10].

To cut along story short, improper project designs that are not discovered during the early stages can become very costly during the execution stage and are irreversible in some instances. Potential for these problems magnify the importance of collection and evaluation of different parameters in optimizing a project design.

II. DEFINITION OF ASSESSMENT MODELING

Fig (1) shows the Creating of the modeling and evaluating the performance of the lateral intake and diversion system.

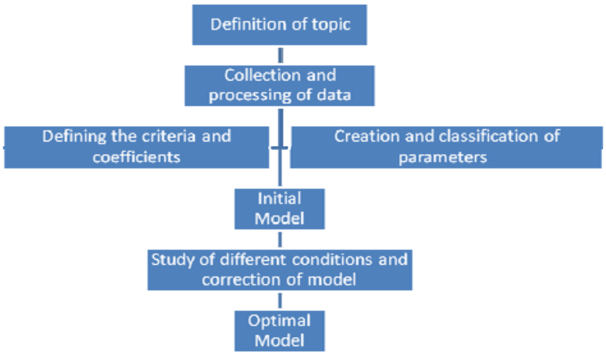


Fig. 1 The process of modeling

To study the affect of different parameters on the amount of sediments entering the intake and the corresponding effectiveness, the following parameters were analyzed in a variety of states:

A. Intake location in the outer bend of the river

Typically, the outer bend of the river or a location in the near proximity is chosen as a suitable location for the intake. This reduces the sediments entering the intake and directs them towards the inner bend of the river. The optimal location should be chosen by examining the model and studying the type and amount of load in the river bed, speed of flow, and shape of the river. Survey of current literature proposes the location of the intake to be in the second half of the outer bend. A wide portion of this area (second half of the outer bend) has been suggested in the literature. Given the high recommendation of placing the inlet in the third quarter of the outer bend, the following intake positions were chosen: 90, 102.5, 115, 135 and 150 degrees.

B. Diversion Angle

Existing literature proposes diversion angles in the 30-45 degrees range in some cases and 60-75 degrees range in others. Therefore, in this work, the following three diversion angles were studied: 45, 60 and 75 degrees.

C. Effect of inlet sill

Structures such as inlet sill can be used to control the flow of sediments into the intake. Height of the sill is determined by the topography of the river bed or the thickness of the moving layer of load on the river bed. These parameters are themselves influenced by the hydraulic conditions of the river and the intake. By utilizing the existing research on sills, three relative heights (ratio of sill height to water depth) in the range of 0.2 to 0.5 is used. In addition, the affect of absence of sill on lateral intake is also studied. In summary, the following scenarios were considered: sill with relative height of 0.25, 0.34, 0.45 and no sill.

D. Effect of submerged vanes

Use of submerged vanes is one method of creating and strengthening secondary flows. These flows prevent the entrance of sediment into the intakes and guide them in the lateral direction. Due to lack of significant practical information about the arrangement of submerged vanes in lateral intakes, laboratory-based suggestions are used in this work. Therefore, two rows of five parallel submerged vanes are used in this study. The following two scenarios were considered: Use of submerged vanes and Lack of submerged vanes.All possible permutations of the aforementioned scenarios create 120 different for modeling.After all the models were analyzed and the results were collected, a multi-dimensional decision making process is used to choose the optimal intake model. This process is performed by utilizing Expert Choice 11 software.

The following criteria were used in the decision making process.

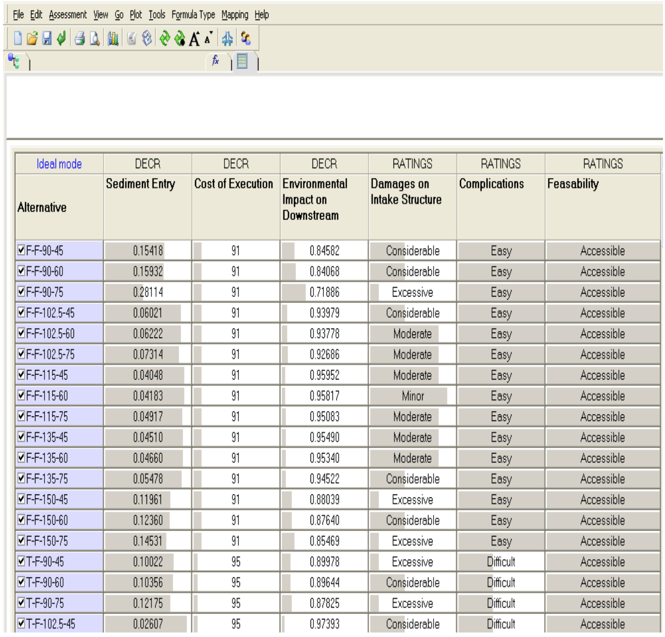
1. Sediment entry
2. Cost of execution
3. Environmental Impact on downstream
4. Damages on intake structure
5. Complications
6. Feasibility

The dynamic sensitivity analysis capabilities of the software permits increasing or decreasing the priority associated with each criterion.

Once the required data is collected, they are entered into the

Expert Choice software. The preliminary model is executed in the software to rectify any potential bugs. Any problems with input files can be immediately identified and resolved.

120 files are created by considering all possible combinations of parameters that influence the intake efficiency. These parameters include intake location, diversion angle, sill, and submerged vanes. Each model is entered into the software and is named according to the following convention: Starting from left to right, the presence of submerged vanes, use of sill, intake location, and diversion angle is indicated in the model name. For example, the first model, F-F-90-45 implies a model without submerged planes (False), no sill (False), intake location at φ=90°, and diversion angle of θ=45°. The last model T-T(0.45)-150-75 implies a model with submerged planes (True), existence of sill structure (True) with relative height of 0.45, intake location at φ=150°, and diversion angle of θ=75° (Fig 2).



Ideal mode	DECR	DECR	DECR	RATINGS	RATINGS	RATINGS
Alternative	Sediment Entry	Cost of Execution	Environmental Impact on Downstream	Damages on Intake Structure	Complications	Feasability
☑F-F-90-45	0.15418	91	0.84582	Considerable	Easy	Accessible
☑F-F-90-60	0.15932	91	0.84068	Considerable	Easy	Accessible
☑F-F-90-75	0.28114	91	0.71886	Excessive	Easy	Accessible
☑F-F-102.5-45	0.06021	91	0.93979	Considerable	Easy	Accessible
☑F-F-102.5-60	0.06222	91	0.93778	Moderate	Easy	Accessible
☑F-F-102.5-75	0.07314	91	0.92686	Moderate	Easy	Accessible
☑F-F-115-45	0.04048	91	0.95952	Moderate	Easy	Accessible
☑F-F-115-60	0.04183	91	0.95817	Minor	Easy	Accessible
☑F-F-115-75	0.04917	91	0.95083	Moderate	Easy	Accessible
☑F-F-135-45	0.04510	91	0.95490	Moderate	Easy	Accessible
☑F-F-135-60	0.04660	91	0.95340	Moderate	Easy	Accessible
☑F-F-135-75	0.05478	91	0.94522	Considerable	Easy	Accessible
☑F-F-150-45	0.11961	91	0.88039	Excessive	Easy	Accessible
☑F-F-150-60	0.12360	91	0.87640	Considerable	Easy	Accessible
☑F-F-150-75	0.14531	91	0.85469	Excessive	Easy	Accessible
☑T-F-90-45	0.10022	95	0.89978	Excessive	Difficult	Accessible
☑T-F-90-60	0.10356	95	0.89644	Considerable	Difficult	Accessible
☑T-F-90-75	0.12175	95	0.87825	Excessive	Difficult	Accessible
☑T-F-102.5-45	0.02607	95	0.97393	Considerable	Difficult	Accessible

Fig. 2 Sample of all possible combinations of parameters in lateral intake efficiency

To decide the option that provides the optimal performance of the intake, 3 different conditions are considered to compare the aforementioned parameters. The comparison matrix for these 3 conditions along with the evaluation methodology from Expert Choice is presented in tables 1-4 to 3-4. To define the value associated with each criterion, experts and professors are consulted along with laboratory results.

In the first scenario, based on the majority of laboratory experiments in this field, quality of water entering the intake has been given a higher priority relative to other parameters such as cost of execution and environmental impacts (Table 1).

TABLE I

THE FIRST SCENARIO

	Sediment Entry	Cost of Execution	Environmental impacts	Damage on intake structure	Complication	Feasibility
Sediment Entry		1/2	3	2	5	4
Cost of Execution			1/5	1/2	1/3	2
Environmental impacts				1/6	1/3	1/4
Damage on intake structure					1/3	2
Complication						1/4
Feasibility						

In the second scenario, project execution related parameters are given a higher priority. During the intake construction process, costs and complications are more prevalent than other parameters such as quality of water (Table 2).

TABLE II

THE SECOND SCENARIO

	Sediment Entry	Cost of Execution	Environmental impacts	Damage on intake structure	Complication	Feasibility
Sediment Entry		1/6	1/4	1/2	1/3	1/5
Cost of Execution			1/2	2	4	3
Environmental impacts				1/4	1/2	2
Damage on intake structure					1/5	1/3
Complication						1/3
Feasibility						

Given the ultimate goal of this research, that is to determine the optimal conditions for the intake, a middle ground between laboratory perspective and project execution perspective is chosen. In the third scenario, the decision matrix is constructed to strike a balance between ideal laboratory conditions and real world conditions (Table 3).

TABLE III

THE THIRD SCENARIO

	Sediment Entry	Cost of Execution	Environmental impacts	Damage on intake structure	Complication	Feasibility
Sediment Entry		1/2	5	3	4	2
Cost of Execution			1/3	4	2	3
Environmental impacts				1/5	2	1/2
Damage on intake structure					1/4	3
Complication						1/6
Feasibility						

III. ANALYSIS OF RESULTS

This research was performed by using the available laboratory results, collection of data, and survey of active experts in execution of similar projects in the country.

Based on the results reported in the previous section, alternatives F-F-102.5-60, F-F-102.5-75, F-F-115-45, F-F-115-60, F-F-115-75, F-F-135-45, and F-F-135-60 with priority 0.1 are among the proposed desirable conditions for achieving optimum intake performance. It can be seen that 5 of the 7 desirable conditions contain intake angles between 115 and 135 degrees. Under these conditions, minimum amount of sediments enter the intake which was also verified by previous research results by other experts.

Based on the results of previous experiments, which indicate that creation of erosion scour in angles higher than 150 or lower than 90 will cause undesirable damage on structures, an intake angle between 115 and 135 degrees can be recommended to minimize the sediment entry. Furthermore, the amount of diverted sediment is lower for diversion angles of 45 degrees in comparison to 60 and 75 degrees. The only exception to this occurs when maximum flow is going through the intake. In that case, a diversion angle of 60 degrees is more effective.

The decision matrix in Expert Choice is designed in such a way, that after considering the effects of all parameters, a balance between the optimal conditions from the laboratory and real world will be achieved. This is why intake location of 102.5 degrees and diversion angles of 60 and 75 were included in the optimal solutions in addition to alternatives that minimize sediment entry such as locations of 115 and 135 degrees and diversion angle of 45. It can be concluded that the proposed conditions also optimize other parameters such as environmental impacts and transfer of sediments. It can also be observed that alternatives that use submerged vanes and inlet sills are given a lower ranking. This is significant since laboratory results, which predominantly focus on reduction of sediments, would have placed a higher ranking on these alternatives. In real world conditions, with consideration of environmental impacts and the negative consequences of high sediment transfer to downstream, these structures which significantly minimize the sediment entry to the intake are not very desirable. Also, as discussed previously, these structures increase the cost and difficulty of project execution. Subsequently, they were not included in the optimal intake parameters discovered by this research.

IV. CONCLUSION

Our aim in this article was to introduce the optimum performance of a lateral intake, by gathering and analyzing all the scattered data regarding the location of intake in the outer bend of the river, diversion angle, effect of inlet sill and submerged vanes from various researches. Thus far, an assessment of all the above mentioned parameters has not been executed.

The results of the first scenario, with the aim of minimizing the amount of sediment entry to the intake, it can be concluded that alternatives such as T-T(0.34)-150-75 which utilizes both submerged vanes and sill to increase the quality of diverted water have a lower priority compared to alternatives possessing better locations and/or diversion angles such as F-F-115-45.

The significance of the cost of a project in second scenario provides similar preference for alternatives such as F-F-115-45 and F-F-135-45, which were amongst favorable options in first scenario, and F-F-90-75 or F-F-150-60 which comprised of least acceptable conditions. This would result in the renunciation of laboratory researches concerning allowable location and diversion angle of the intake.

In final scenario, by incorporating the real conditions of a project and laboratory results, we made an attempt to attain the ideal conditions of the intake. The introduced alternatives are shown in Fig 3.

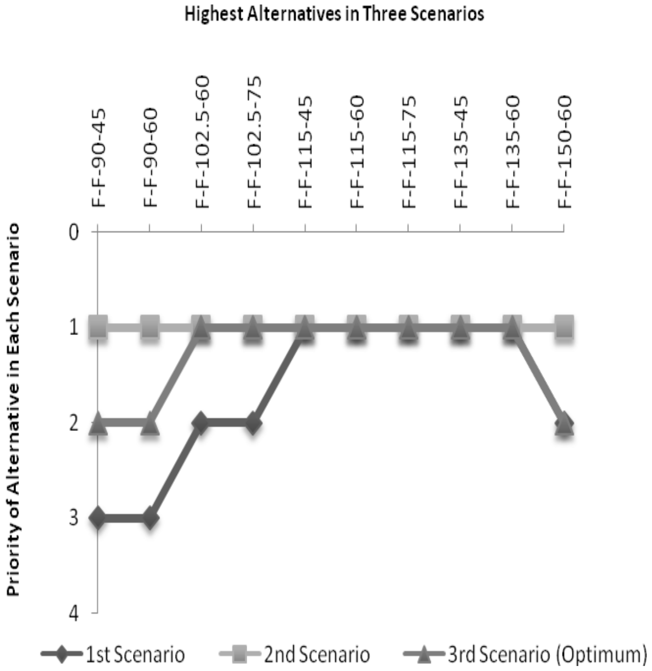


Fig. 3 Comparison of highest ranking alternatives in three scenarios

The difference between the rankings of the appointed alternatives of each scenario to their position in other scenarios clearly demonstrates the importance of precise and factual evaluation (Fig. 3). Thus, designing a project based solely on two extreme scenarios (scenario 1 and 2), will generate complications in long term operation of the structure, higher expenses and lower quality of the diverted water. The proposed alternatives in last scenario, which covers a convenient range of options, improved the accuracy and practicality of selecting the desired conditions of a lateral intake according to the scope of a project.

REFERENCES

[1] A. J. Raudkivi, “Sedimentation, Exclusion and Removal of Sediment from Diverted Water,” IAHR, Balkema, The Netherlands, 1993, pp. 63-87.

[2] V. Neary, F. Sotiropoulos, and A. J. Odgaard, “Three-Dimensional Numerical Model of Lateral-Intake Inflows,” Journal of Hydraulic Engineering, Vol. 125, No. 2, 1999, pp. 126-140.

[3] M. A. Bergs, “Flow Processes in a Curved Alluvial Channel,” Unpublished, Ph. D Thesis, University of Iowa, 365 pp, 1990.

[4] R. Booij, “Modeling of the Secondary Flow Structure in River Bends,” River Flow, Bousmar & Zech (eds), ISBN 90 5809 509 6, 2002, pp. 127-133.
[5] K. Blanckaert, “Analysis of Coherent Flow Structures in a Bend Based on Instantaneous-Velocity Profiling,” Third International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering EPFL, Lausanne, Switzerland, 2002, pp. 51-58.
[6] J. C. A. Russel, “The Optimum Location for a Canal Sediment Extractor,” Report OD/TN 55, HR Wallingford, Oxford shire, UK, 1991.
[7] E. Razvan, “River Intakes and Diversion Dams,” Amsterdam, 1989.
[8] P. Novak, A. Morfett, and C. Nalluri, “Hydraulic Structures,” Pitman, London, 546 pp, 1990.
[9] J. L. Boillat, and G. De Cesare, “Dichtestrmungen im Bereich des Grundablasses des Stausees Luzzone-Modellversuche,” Tagungsband (proceeding) des Symposiums "Betrieb, Erhaltung und Erneuerung von Talsperren und Hochdruckanlagen", Graz, Austria, 1994, pp. 183-192.
[10] P. J. Kerssen, and A. Urk, “Experimental studies on sedimentation due to water withdrawal,” J. Hydr. Engrg., ASCE, 112(7), 1986, pp. 641-656.