UDC – 631.895:57.084.2

DESIGN AND OPERATIONAL FEATURES OF TRASH RACKS FOR SMALL HYDROPOWER PLANTS ON MOUNTAIN RIVERS

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https://doi.org/10.56243/18294898-2025.3-78

Abstract

The article examines the specific aspects of designing trash racks for small hydropower plants (SHPs) operating on mountain rivers characterized by high turbidity and strong seasonal flow variability. Dependencies to automate the selection of the optimal bar spacing of trash racks are presented depending on the type of installed turbines, based on the recommendations of SHP equipment manufacturers. Empirical relationships and guidelines for the hydraulic parameters of racks are proposed, taking into account operational conditions in mountainous areas. A critical review of existing design recommendations for racks used on high-altitude rivers is also provided.

Keywords: Small hydroelectric power station, high-altitude conditions, trash rack, Pelton turbine, Crossflow turbine.

Introduction

Operating conditions for small hydropower plants (SHPs) on mountain rivers are characterized by high heads, uneven discharges, elevated concentrations of suspended and bed material, and an increased probability that solid particles and floating debris will enter intake structures. Under such conditions, an improper choice of the trash rack design and its geometric parameters inevitably leads either to frequent clogging of turbine components—causing unjustified downtime—or to damage to guide vanes and runner blades and, as a consequence, a loss of unit output.

Summer Operating Conditions of Trash Racks

Regulatory sources [1–3] provide practical rules for selecting bar spacing, setting angle, and permissible head losses, but predominantly as limiting and tabulated recommendations. The literature cites three principal criteria for assigning the spacing between bars of trash racks.

Equipment protection.

This is the primary criterion for setting bar spacing: the turbine and its components must not be fouled by debris and floating objects. It should be noted that, according to statistics over the past 20 years, high-mountain SHPs tend to favor Crossflow turbines (for heads up to ~200 m) and Pelton turbines (for heads of ~180 m and above), both maintaining comparatively stable efficiency over a wide range of flow variation.

For Pelton turbines, source [2] recommends that the bar spacing of the rack be less than the minimum dimension of any opening in the turbine's inlet assembly. In practice, the suggested range for bar spacing is 15–25 mm.

Source [7] proposes determining the bar spacing b from a relationship that relates the spacing to the jet diameter at maximum needle opening.

$$b \leq \frac{1}{5} D_{jet.max} \quad (1)$$

where: $D_{jet.max}$ — jet diameter at maximum needle opening.

Our appraisal of this relationship across different ranges was based on consolidated data from European Pelton turbine manufacturers. The results of the analysis are shown in Fig. 1.

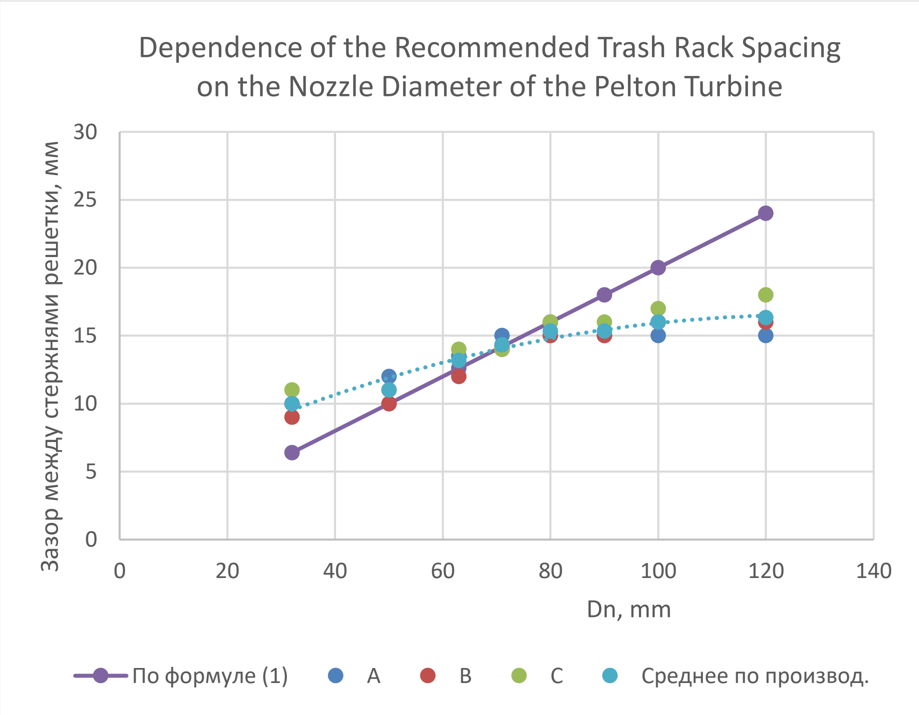

Fig. 1. Recommended grate rod clearance versus Pelton turbine nozzle diameter

The analysis shows acceptable agreement between the proposed relationship and manufacturers' recommendations only within a narrow nozzle-diameter band of approximately 60–80 mm. The averaged manufacturer data are well approximated by a second-order polynomial ($R^2 \approx 0.962$).

$$b = -0.0008D_n^2 + 0.1949D_n + 4.079 \quad (2)$$

where: D_n — nozzle diameter in mm.

For Crossflow turbines, published information is fragmentary: the recommended bar spacing ranges from 15 to 35 mm, yet without reference to turbine size or characteristic dimensions. The most complete information on the principle for choosing rack spacing in relation to Crossflow turbine dimensions was kindly provided by “Ossberger GmbH + Co. KG” (Germany), a leading developer of the modern Crossflow turbine. According to these data, the rack spacing correlates with the turbine runner diameter, which indirectly reflects the inter-blade gap. To automate design calculations for SHP settling basins, these data were approximated with a second-order polynomial, which demonstrated very good agreement ($R^2 \approx 0.987$).

$$b = -7 \times 10^{-7} D_{rd}^2 + 0.0349 D_{rd} + 2.4496 \quad (3)$$

where: D_{rd} — turbine runner diameter in mm.

Therefore, for Crossflow turbines, the spacing determined by this dependency varies from about 9 mm (runner diameter 200 mm) to about 40 mm (runner diameter 1800 mm).

Conflict Setting

Many recommendations are founded on calculating head losses across clean racks, which is relevant for low-head plants. However, for high-head SHPs on mountain rivers this approach has little practical importance in terms of total head. Moreover, project calculations for a number of SHPs showed that, when the first criterion is observed and settling-basin velocities are within limits, head loss on a clean rack is minimal and does not exceed 2–3 cm.
When assessing rack capacity, actual clogging by debris and floating objects during operation must be taken into account. Where the upstream catchment includes many settlements and economic activities, and where vegetation is abundant, intense clogging can occur. According to [1], calculations should be performed assuming 30–35% of the rack area is clogged. (Fig.2).

Fig. 2. Clogging of the settling tank screens. A) Fallen tree leaves in the autumn at the Chirukhi SHPP (Georgia), b) Clogging of the small screen at the Shaki SHPP (Armenia) with aquatic vegetation and debris

According to [1], calculations should be performed assuming 30–35% of the rack area is clogged. Source [3] suggests using a clogging factor of 1.25. Some references recommend estimating the expected amount and maximum size of debris, which in practice can only be done qualitatively, depending on the level of development in the basin and on vegetation subject to shedding and washout into the river.

Research Results

The most effective solution when high clogging is anticipated is to equip racks with automatic raking machines (Fig.3). These devices typically operate by monitoring the maximum permissible differential head across the rack. In practice, the threshold differential is set at about 5–7 cm, which prevents air entrainment into the pressure conduit due to a drop in water level within the intake forebay.

Fig. 3. Automatic cleaning machine at SHPP

Ecological aspects of selecting rack spacing.

The intake rack is not only a mechanical shield for the turbine; it is also a biotechnical barrier that determines the feasibility of fish migration, the risk of entrainment and mortality, and the degree to which the rack disturbs the hydrodynamics of the channel and benthic fauna. Large bar spacing entails a risk that juveniles and small fish will enter the pressure conduit and die when passing through the turbine. In addition to spacing, the approach velocity at the rack is prescribed.

To determine environmentally acceptable spacing, recommendations from various sources [13–18] were reviewed. For example:

- DFO (Canada) suggests ≤ 2.54 mm openings for protecting 25 mm fish;
- NMFS/NOAA (USA, SW Region) commonly requires 6.35 mm maximum openings for wire/perforated screens for juvenile anadromous salmonids; USFWS/NMFS recommends around 3.2 mm for salmonid juveniles < 60 mm;

- California DFG uses 3.2 mm for fry/fingerlings (~L ≈ 60 mm);
- New Zealand DOC (Canterbury) cites 2–3.2 mm for small salmonid juveniles;
- the UK Environment Agency provides screen sizes tied to juvenile length classes (8–26 mm), numerically giving about 0.05–0.10·L.

Generalizing these sources, the recommended spacing for downstream migration through intakes can be expressed as a proportionality to the body length of the smallest protected species.

$$b \leq 0.1DL_{min} \quad (4)$$

where: Lmin — body length of the smallest protected species (fry aged 0.2 years).

In practice on small mountain rivers, where protected fish are present, this criterion is limiting and nearly impossible to meet. As an illustration, the fish assemblage in rivers flowing into Lake Issyk-Kul—an area experiencing intensive energy development—features species whose juvenile sizes would dictate extremely fine screens.

Table 1

Migratory and Semi-Migratory Fish Species of the Issyk-Kul Basin

Fish	Migration Elevation, m	Migration		Body length, cm			Recommended bar spacing [13-18]
		Start	End	Mature	Juvenile h=1 yar	Fry t=0.2 yar	
Trout	2100	March	April	55	18	5.5	0.55
Naked Osman	2500	April	June	30	10	3	0.3
Matinka	1800	June	July	40	13	4	0.4
Chebak	2200	May	June	28	9	2.8	0.28
Small Chebak	1900	May	June	20	7	2	0.2
Lip fish	2200	June	June	16	5	1.6	0.16
Cyprinus carpio	1700	May	June	60	20	6	0.6
Maximum		March	July	60	20	6	0.6
Minimum				16	5	1.6	0.16

Analyzing the species and their size ranges shows that under the harsh climatic and morphological conditions of mountain rivers used for high-head SHPs, it is practically impossible to comply with ecologically driven spacing recommendations for conventional trash racks. A potentially acceptable option is the use of Coanda screens at the intake, feasible only on very small rivers with modest design flows.

Based on design and operational experience in high-mountain regions, it is necessary to develop alternative fish-protection methods tailored to local conditions; a strict requirement to limit bar spacing for ecological reasons is often inappropriate in these settings. As alternatives, one can consider fish deterrent systems, aerators, and bypasses for downstream migrants—always adapted to local conditions. The lack of realistic guidance for downstream fish protection is a key reason why, at the vast majority of SHPs built or under construction in many developing countries, fish-protection measures are limited at best to a fishway—sometimes of questionable design that does not ensure passage.

To prevent the entrainment of small fish, approach velocity limits at the rack are used. According to [12], the maximum permissible velocity at the rack face is 0.3–0.5 m/s. This condition is almost always satisfied when a single-chamber settling basin is provided without narrowing the width at the entrance to the forebay, because design velocities for high-mountain basins are typically held to about 0.4 m/s.

Winter Operating Conditions of Trash Racks

Numerous studies address winter operation of racks [3–5], focusing on the negative effects of frazil ice, anchor ice, slush, and hummocked ice. Adverse impacts are considered primarily as:

- clogging of racks due to icing;
- blockage of nozzles and turbine blades due to ice fragments entering the pressure conduit.

Conclusions

However, experience from the last two decades of SHP construction in high-mountain areas shows that most plants are of the derivation type, with relatively long pressure conduits (2–12 km) buried in trenches below native ground. Under such conditions, even if ice and slush enter the conduit, they are unlikely to reach the units. Therefore, for these stations in winter, the principal concern is preventing rack icing.

A critical analysis of various measures recommended in the literature, based on operational experience in Armenia, Kyrgyzstan, and Georgia, is as follows.

1. **Increasing bar spacing by 10–30 mm relative to the calculated value**

Effective mainly at low-head plants and only for modest subzero temperatures. For high-mountain SHPs with temperatures below –20 °C, even with 40 mm spacing, a solid ice crust formed within 1–2 hours (e.g., Tegirmenti SHP, Issyk-Kul Region, Kyrgyzstan).

2. **Heating the bars (electric or thermal fluid)**

This method is of limited effectiveness and is rarely used at SHPs for several reasons: it requires a reliable power supply at the intake node with high cost; and in crisis situations (heavy snowfall, blizzards) it is ineffective on its own and demands additional anti-icing measures.

3. **Enclosing the settling basin (closed-type basin)**

Ineffective in terms of raising temperature in the basin and forebay. There were cases where icing even intensified—for example, at the Dzhradzor SHP (Armenia) icing increased above the settling basin and on the fine rack due to higher humidity in the enclosed space and airflow between the basin entrance and the rack zone. A practical mitigation is to use flexible curtains at the basin inlet and outlet. Nevertheless, a closed-type basin can be very effective—and sometimes the only solution—if heavy snow drifts and wind-driven snow are expected.

4. **Increasing the embedment depth of the rack at the design stage**

In winter, river discharges in mountains are typically minimal. This allows ensuring adequate open (ice-free) rack area at the bottom by deeper placement to maintain acceptable face velocities. The drawback is that deeper embedment lengthens the forebay/settling chamber.

5. Installing an automatic raking machine on the rack

One of the most effective measures. The machine activates regardless of the cause of the differential—debris in summer or icing in winter. In winter, it is often necessary to reduce the activation threshold by 30–40%. The exact setting is determined empirically so as to prevent the formation of a solid ice layer beyond the rake's cutting capacity.

In practice, depending on local conditions, combined anti-icing strategies are usually the most effective. For very high-elevation intakes (~2000 m and above), closed-type settling basins are typically combined with automatic rakes.

References

1. Lučin D. et al. Assessment of Head Loss Coefficients for Water Turbine Intake Trash Racks. J. Adv. Res., 2020.
2. Intake Structures and Trash racks //M: Design Standards No. 6., 2015.
3. Methodological recommendations for the design of water intake structures for small hydroelectric power plants // VNIIG im. B.E. Vedeneyev, 1986.
4. Michel B., Frazil Ice Formation and Blockage in Intakes //Canadian NRC, 1984.
5. Frazil Ice Blockage of Intake Trash Racks //J. Hydraulic Research, 2005.
6. Recommendations for accounting for ice loads // VNIIG im. B. E. Vedeneyev, 1986.
7. IS 11388:2012. Recommendations for Design of Trash Racks for Intakes. BIS, New Delhi.
8. Latif M. et al. Estimating Energy Efficient Design Parameters for Trash Racks at Low //Head Hydropower Stations. Water, 2022.
9. Methodological recommendations for the design of water intake structures for small hydroelectric power plants // VNIIG im. B.E. Vedeneyev. 1986.
10. CEN/TR 16939:2016 — Fish protection requirements for hydro power plants.
11. USFWS Fish Protection Guidelines, 2019.
12. Baigún C., Oldani N. Fish-friendly design for small hydropower in mountainous streams 2016.
13. Fisheries and Oceans Canada (DFO). Freshwater Intake End-of-Pipe Fish Screen Guideline. — Ottawa: Government of Canada, 1995 (rev. 2004). — 29 p.
14. National Marine Fisheries Service (NMFS, NOAA). Fish Screening Criteria for Anadromous Salmonids (Southwest Region). — Portland, OR: U.S. Department of Commerce, NOAA Fisheries, 1997. 27 p.
15. U.S. Fish and Wildlife Service (USFWS). Fish Protection Screen Guidelines and Water Intake Recommendations. — Washington, D.C.: USFWS, 1993, 35 p.
16. California Department of Fish and Game (DFG). California Salmonid Stream Habitat Restoration Manual. — Sacramento, CA: DFG, 2002, 212 p.
17. Department of Conservation (DOC). Criteria for Fish Screen Design in Canterbury for Sports Fish. — Christchurch: New Zealand DOC, 2006. 18 p.

18. Environment Agency (EA). Screening for Intake and Outfalls: a Best Practice Guide. — Bristol, UK: Environment Agency, 2005. 98 p.

References

1. Lučin D. et al. Assessment of Head Loss Coefficients for Water Turbine Intake Trash Racks. J. Adv. Res., 2020.
2. Водоприемные и мусоросабирающие конструкции //М: Нормы проектирования в СССР № 6, 2015.
3. Методические рекомендации по проектированию водоприёмных сооружений малых ГЭС //ВНИИГ им. Б.Е. Веденеева,1986.
4. Michel B., Frazil Ice Formation and Blockage in Intakes //Canadian NRC, 1984.
5. Frazil Ice Blockage of Intake Trash Racks, J. Hydraulic Research, 2005.
6. Рекомендации по учёту ледовых нагрузок //ВНИИГ им. Б. Е. Веденеева, 1986.
7. IS 11388:2012. Recommendations for Design of Trash Racks for Intakes. BIS, New Delhi.
8. Latif M. et al. Estimating Energy Efficient Design Parameters for Trash Racks at Low Head Hydropower Stations. Water, 2022.
9. Методические рекомендации по проектированию водоприёмных сооружений малых ГЭС //ВНИИГ им. Б.Е. Веденеева. 1986.
10. CEN/TR 16939:2016 — Fish protection requirements for hydro power plants.
11. USFWS Fish Protection Guidelines, 2019.
12. Baigún, C., Oldani, N. Fish-friendly design for small hydropower in mountainous streams 2016.
13. Fisheries and Oceans Canada (DFO). Freshwater Intake End-of-Pipe Fish Screen Guideline. — Ottawa: Government of Canada, 1995 (rev. 2004). — 29 p.
14. National Marine Fisheries Service (NMFS, NOAA). Fish Screening Criteria for Anadromous Salmonids (Southwest Region). — Portland, OR: U.S. Department of Commerce, NOAA Fisheries, 1997. 27 p.
15. U.S. Fish and Wildlife Service (USFWS). Fish Protection Screen Guidelines and Water Intake Recommendations. — Washington, D.C.: USFWS, 1993, 35 p.
16. 4. California Department of Fish and Game (DFG). California Salmonid Stream Habitat Restoration Manual. — Sacramento, CA: DFG, 2002, 212 p.
17. Department of Conservation (DOC). Criteria for Fish Screen Design in Canterbury for Sports Fish. — Christchurch: New Zealand DOC, 2006. 18 p.
18. Environment Agency (EA). Screening for Intake and Outfalls: a Best Practice Guide. — Bristol, UK: Environment Agency, 2005. 98 p.

ԼԵՌՆԱՅԻՆ ԳԵՏԵՐԻ ՎՐԱ ԳՈՐԾՈՂ ՓՈՔՐ ՀԷԿԵՐԻ ԱՂԲ ՈՐՍԱՑՈՂ ՉԱՂԱՎԱՆԴԱԿՆԵՐԻ ՆԱԽԱԳԾՄԱՆ ԵՎ ՇԱՀԱԳՈՐԾՄԱՆ ԱՌԱՆՁՆԱՀԱՏԿՈՒԹՅՈՒՆՆԵՐԸ

Ս.Գ. Գաբայան
Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Հոդվածում դիտարկվում են լեռնային գետերի վրա գործող փոքր հիդրոէլեկտրակայանների (ՓՀԷԿ) աղբորսիչ վանդակների նախագծման առանձնահատկությունները, որոնք բնութագրվում են ջրի բարձր տիղմայնությամբ և հոսքի սեզոնային փոփոխականությամբ: Ներկայացվում են կախվածություններ, որոնք թույլ են տալիս ավտոմատացնել վանդակների ձողերի օպտիմալ բացի ընտրությունը՝ կախված տեղադրվող տուրբինների տեսակից՝ հիմք ընդունելով ՓՀԷԿ սարքավորումների արտադրողների առաջարկությունները: Առաջարկվում են էմպիրիկ հարաբերություններ և ուղեցույցներ՝ հաշվի առնելով լեռնային պայմաններում շահագործման հիդրավլիկ պարամետրերը: Կատարվել է գործող նախագծային առաջարկությունների քննադատական վերլուծություն՝ բարձրալեռնային գետերի համար նախատեսված վանդակների նախագծման առումով:

Բանալի բառեր. փոքր հիդրոէլեկտրակայան, բարձրալեռնային պայմաններ, աղբ որսացող ցանց, Պելտոնի տուրբին, լայնակի հոսքի տուրբին:

ОСОБЕННОСТИ ПРОЕКТИРОВАНИЯ И ЭКСПЛУАТАЦИИ СОРОУДЕРЖИВАЮЩИХ РЕШЁТОК МАЛЫХ ГЭС НА ГОРНЫХ РЕКАХ

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Рассмотрены особенности проектирования сороудерживающих решёток малых гидроэлектростанций (МГЭС), работающих на горных водотоках с повышенной мутностью и сезонной изменчивостью стока. Приведены зависимости для автоматизации выбора оптимального зазора между прутьями решёток в зависимости от типа устанавливаемых турбин, основанный на рекомендациях производителей оборудования для МГЭС. Предложены эмпирические соотношения и рекомендации по гидравлическим параметрам решёток с учётом условий эксплуатации в горных районах. Проведен критический анализ существующих рекомендаций по проектированию решеток в условиях высокогорных рек.

***Ключевые слова*:** малая гидроэлектростанция, условия высокогорья, сороудерживающая решетка, турбина Пелтона, турбина с поперечным потоком.

Submitted on 30.06.2025
Sent for review on 04.07.2025
Guaranteed for printing on 30.10.2025