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ENERGY EFFICIENCY STUDY REGARDING THE CONSTRUCTION OF A MICROHYDROPOWER PLANT ON THE GALBENA RIVER IN THE CONTEXT OF CONCERNS REGARDING ENSURING ENERGY INDEPENDENCE FOR ISOLATED FARMING COMMUNITIES

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Abstract*: Micro-hydropower plants are renewable energy sources that have a significant impact on rural communities and isolated areas. These are small installations, producing up to a few hundred kilowatts, that harness the energy of flowing water to generate electricity without the need for large dams or extensive environmental interventions. Thus, micro-hydropower plants provide an eco-friendly solution, with minimal effects on natural habitats and biodiversity.Another advantage of micro-hydropower plants is that they can supply electricity to isolated communities not connected to the national grid, contributing to their development. With simpler infrastructure and lower operating costs, these plants are affordable and easy to maintain. They can provide energy for household use, agriculture, and local businesses, thereby improving quality of life.Therefore, these installations offer a viable solution for communities, reducing reliance on the national grid. The micro-hydropower plant to be constructed will be located on the Galbena River, which runs through Haţeg. This plant will be built next to a privately owned guesthouse and will supply electricity to the guesthouse, with the project funded by the owner. These plants also encourage sustainable tourism and local business growth by providing reliable and green energy sources for remote accommodations and services. By utilizing local water resources, micro-hydropower projects support energy independence and promote eco-friendly practices within communities that prioritize sustainability.*

Keywords*: Micro-hydropower, isolated communities, energy, natural prezervation, lower costs.*

INTRODUCTION

Hunedoara County is located in the southwestern part of Transylvania, covering parts of the hydrographic basins of the Mureș and Jiu rivers. The county is intersected by the 46° N parallel and the 23° E meridian.

The extreme points of Hunedoara County, without specifying absolute coordinates, are:

- la North – the northwestern area of the village of Rusești
- la South – the sources of the Lăpușnic River
- la East – the branches of some tributaries of the Jieț stream
- la West – the western boundary of the village of Pojoga (Zam commune)

The micro-hydropower plant to be constructed will be located on the Galbena River, which traverses Hațeg. This plant will be built near a private guesthouse, supplying it with electricity. The project is funded by the guesthouse owner.

MATERIAL AND METHODS

Core Technology

In a micro-hydropower plant (MHP), the available potential energy, or gross head, is converted into electrical energy through the main components of the hydropower system.

The key components of an MHP include:

- The reservoir;
- Transfer system;
- Hydraulic turbine;
- Generator rotor;
- Grid connection line.

Run-of-River Installations

Run-of-river installations refer to a mode of operation in which the power plant uses only the water available from the natural river flow. These installations imply that there is no water reservoir or flooding, and the power output fluctuates with the river flow. Diversion is often required to maximize the advantage of a greater head.

Climate

Hunedoara County has a varied climate, with mountainous areas experiencing a mountain climate and hilly regions a moderate continental climate. Winters are wet, and summers are sunny with balanced rainfall. Westerly winds bring mild and wet winters, while northwesterly and northerly winds bring cold winters and unstable summers.

Average annual temperatures vary significantly, from +10 °C in the Mureș valley to -20 °C in the Retezat and Parâng Mountains. June averages range between 6 °C and -20 °C, while January averages range from -10 °C to -1 °C. The first frosts typically appear around September 20, and snow falls for about 80 days per year in mountainous areas. The predominant winter wind direction is from west-northwest, while in summer, it is from east-southeast. Annual precipitation is moderate, highest in July and lowest in February, with a generally thin snow cover that lasts briefly on the ground.

Main Components of Micro-hydropower Plants

A micro-hydropower plant can be described in two main categories:

a.Civil Works

The main civil works of a micro-hydropower plant include the dam or weir, water conduits, and the powerhouse. To reduce costs, the design is simplified by using a small dam or weir made from local materials, as a large dam is not justified for these projects.

b. Mechanical and Electrical Equipment

The main components of a micro-hydropower plant are turbines and generators. The turbine converts the water’s energy into mechanical energy and is selected based on the water’s head and flow rate. Turbines can be high, medium, or low head and are classified into action turbines, which use the water’s kinetic energy, and reaction turbines, which convert both kinetic and pressure energy.

Geotechnical Data

The intake structure will be founded on bedrock composed of an alternation of quartzitic schists and quartz-chlorite-sericite schists, with the following geotechnical coefficients as indicated in the table below.

Nr. crt.	Geotechnical parameters	Simbol	Fissured, poorly altered rocks	Highly fractured rocks, with frequent alteration zones
1	Modulus of elasticity	E_e	35.000-40.000 [daN/cm^2]	25.000-30.000 [daN/cm^2]
2	Conventional pressure	P_{cov}	15-20 [daN/cm^2]	10-15 [daN/cm^2]
3	Rock-rock friction	tgφ r/r	0,55	0,50
4	Rubbing concrete rock	tgφ b/r	0,50	0,45
5	Volumetric weight	γ_w	25,0 [KN/cm^3]	23,0-24,0 [KN/cm^3]
6	Inner cohesion	C	2-3 [daN/cm^2]	1,5-2,0 [daN/cm^2]
7	Internal friction	φ	30-35^0	27^0-30^0
8	Poisson's ratio	μ	0,30-0,32	0,35
9	Infiltration coefficient	K	0,3-1,24 m/zi	0,3-1,24 m/zi

Datele zonării seismice

The studied perimeter falls within the macroseismic zone I = 6 (with a 50-year return period) and is located in Zone E, which corresponds to a seismic coefficient K_C = 0.12g and a corner period T_c= 0.7 seconds.

RESULTS AND DISCUSSION

Hydraulic Calculations

Excess water flow that surpasses the captured flow is discharged through an "overflow field" functioning as a spillway, with a flow coefficient m = 0.38 . The intake is classified as a permanent structure of Class IV and Category 4. For an overflow field length of 8.5 meters, the maximum water level for discharge is calculated using the overflow discharge formula with a coefficient of m = 0.23. Hydraulically, with the water depth ensuring the maintenance of service flow being significantly less than the canal bottom length, the transport capacity is calculated using the channel flow formula:

$$Q = \omega C \sqrt{Ri}$$

$$\omega = 0,40 \cdot 0,06 = 0,024 m^2$$

$$R = \frac{\omega}{P} = \frac{0{,}024}{0{,}52} = 0{,}046$$

$$C = \frac{1}{\eta} R^{y} = \frac{1}{0{,}014} \cdot 0{,}046^{\frac{1}{6}} = 42{,}75$$

$$Q = 0{,}024 \cdot 42{,}75\sqrt{0{,}046 \cdot 0{,}01} = 0{,}021 m^3 / s \geq 0{,}081 m^3 / s$$

The calculation of forces acting on the structure

The calculation of forces acting on the structure will be performed for both vertical and horizontal forces as follows:

a) Vertical Forces

Cross-sectional analysis S=24,80 m^2

$$G = 24{,}80 \cdot 1{,}00 \cdot 2{,}4 = 59{,}5 tf \Rightarrow 595 kN$$

Upstream Water Pressure

$$P_{v1} = \left(1{,}30 \cdot 1{,}50 \cdot 1{,}00\right) = 1{,}95 tf \Rightarrow 19{,}5 kN$$

$$P_{v2} = 0{,}5(1{,}30 \cdot 3{,}80)1{,}00 = 2{,}47 tf \Rightarrow 24{,}7 kN$$

$$\sum F_v (gravit) = 63{,}92 tf \Rightarrow 639{,}2 kN$$

The subpressure on the foundation base is calculated using a coefficient m=0,6 → in accordance with the foundation rock characteristics.

$$m\gamma H = 0{,}6 \cdot 1 \cdot 5{,}30 = 3{,}18$$

$$P_{v3} = 0{,}5(3{,}18 \cdot 7{,}50) = 11{,}92 tf \Rightarrow 119{,}2 kN$$

b) Horizontal Forces

- Hydrostatic Pressure (for regular operational conditions)

$$P_h = 1/2\gamma H^2 = \frac{1}{2} \cdot 1 \cdot 5{,}30^2 = 14{,}05 tf \Rightarrow 140{,}5 kN$$

- Hydrodynamic Pressure (for the case of spillway flow during peak discharge events)

$$Q_{\max}^{1\%} = 45 m^3 / s \Rightarrow h_{lama} = 2{,}00 m$$

$$h_v = \frac{v^2}{2g} = \frac{2{,}80^2}{2 \cdot 9{,}81} = 0{,}40 m$$

$$P_h^{1\%} = \frac{1}{2}\gamma\left[\left(H^{1\%} - hv\right)^2 - h_{lama}^2\right] = \frac{1}{2} \cdot 1\left[\left(7{,}30 - 0{,}40\right)^2 - 2^2\right] = 21{,}8 tf \Rightarrow 218 kN$$

Thus, we consider that $P_h^{1\%} = 218 kN \quad \rangle\rangle \quad P_h = 140{,}5 kN$

Sliding Stability

F represents the concrete-to-rock sliding coefficient, equal to 0.5.

$$\sum F_{vert} = 63{,}92 - 11{,}92 = 52{,}00tf = 250kN$$

a) $\sum F_{oriz}$ *- Normal operation -14,05tf=140,5kN*

b) $\sum F_{oriz}$ *- Current operation after sedimentation - (14,05+2,44)=16,49tf=164kN*

a) $\sum F_{oriz}$ *- During peak discharge verification - 21,8tf= 218kN*

C.S.- safety coefficient for sliding:

$$a)\, C.S = \frac{\sum Fv\cdot f + c * Ac}{\sum Fh} = \frac{(52\cdot 0{,}5)+(15\cdot 7{,}5}{14{,}05} = 9{,}8\, \textit{for normal operation}$$

$$b)\, C.S = \frac{\sum Fv\cdot f + c * Ac}{\sum Fh} = \frac{(52\cdot 0{,}5)+(15\cdot 7{,}5)}{116{,}49} = 8{,}4$$

$$c)\quad C.S^{1\%} = \frac{\sum Fv\cdot f + c * Ac}{\sum Fh} = \frac{(52\cdot 0{,}5)+(15\cdot 7{,}5)}{21{,}80} = 6{,}3\, \textit{during peak discharge}$$

verification (p=1%)

d) $C.S^{1\%+clogging} = \frac{\sum Fv\cdot f + c * Ac}{\sum Fh} = \frac{(52\cdot 0{,}5)+(15\cdot 7{,}5)}{22{,}04} = 6{,}2$ *and for peak discharge verification + sediment load pressure*

Overturning Stability

Stabilizing Moments:

$$G \times 3{,}92 = 59{,}50 \times 3{,}92 = 233{,}196\ tf.m$$

$$P_{v1} \times 6{,}65 = 1{,}95 \times 6{,}65 = 12{,}967$$

$$P_{v2} \times 6{,}90 = 2{,}47 \times 6{,}90 = 17{,}0433\ tf.m$$

$$\sum M_{st} = 263{,}206tfm = 2632{,}06KNm$$

Overturning Moments

a) Normal operation

$$P_{v3} \times 5{,}0 = 11{,}9 \times 5{,}00 = 59{,}50\ tfm$$

$$P_h \times 1{,}77 = 14{,}5 \times 1{,}77 = 25{,}67\ tfm$$

$$\sum M_r = 85{,}17tfm = 851{,}70KNm$$

b) During peak discharge verification (p=1%)

$$P_{v3} \times 5{,}0 = 11{,}9 \times 5{,}00 = 59{,}50\ tfm$$

$$P_h \times 2{,}15 = 21{,}8 \times 2{,}15 = 46{,}87\ tfm$$

$$\sum M_r = 106{,}37tfm = 1063{,}7KNm$$

c) **For the 1% Verification Flood + Sediment Load Pressure after Siltation in Front of the Threshold**

$$P_{v3} \times 5{,}0 = 11{,}9 \times 5{,}00 = 59{,}50\ tfm$$

$$P_h \; x\; 2{,}15 = 21{,}8 \; x \; 2{,}15 = 46{,}87 \; tfm$$

$$E_{a\,x\,2{,}83}=2{,}44 \; x \; 2{,}83 = 6{,}91 \; tfm$$

$$\sum M_r = 113{,}28 tfm = 1132{,}8 KNm$$

Overturning Safety Coefficient

a) Normal operation

$$C.S._{rast} = \frac{\sum M_{stab}}{\sum M_r} = \frac{263{,}206}{85{,}17} = 3{,}09 \rangle\rangle 1{,}35$$

b) Verification flood scenario (p=1%)

$$C.S._{rast} = \frac{\sum M_{stab}}{\sum M_r} = \frac{263{,}206}{106{,}37} = 2{,}47 \rangle\rangle 1{,}20$$

Calculation of Foundation Ground Stresses

Eccentricity of the Vertical Resultant Relative to Point P

$$E_x = \frac{M_{st} - M_{rast}}{\sum F_{vert}} = \frac{263{,}206 - 113{,}28}{63{,}92 - 11{,}92} = 2{,}88 m$$

Eccentricity (e) with respect to the midpoint of the foundation base

$$e = \frac{B}{2} - \frac{M}{F_v} = \frac{7{,}50}{2} - 2{,}88 = 0{,}87$$

The maximum stress on the foundation base will be calculated for the case of hydrostatic pressure during the 1% verification flood as follows.

$$\sigma_1 = \frac{N}{B}\left[1 + \frac{6e}{B}\right] = \frac{63{,}92}{7{,}50}\left[1 + \frac{6x0{,}87}{7{,}50}\right] = 14{,}45 tf/m^2 \Rightarrow 1{,}45 kg/cm^2$$

$$\sigma_2 = 2{,}59 tf/m^2 \Rightarrow 0{,}26 kg/cm^2$$

CONCLUSIONS

Micro-hydropower plants represent a viable, eco-friendly solution for generating electricity in isolated communities, reducing reliance on conventional energy sources and supporting sustainable development in these areas. Due to their small size and the technology used, these plants have a low impact on natural habitats and biodiversity compared to large hydropower plants, which require substantial dams and extensive environmental interventions.

An additional benefit is that micro-hydropower plants can support local economic growth by supplying energy for domestic use, agriculture, and small businesses. This improves residents' quality of life and stimulates economic activity in rural areas. The project on the Galbena River, situated near a guesthouse, highlights the practical applicability of this technology in meeting the energy needs of property owners and supporting local tourism.

With simplified design and low operating and maintenance costs, micro-hydropower plants are accessible for rural communities, which can manage these installations effectively. Moreover, this project can serve as a model for implementing other micro-hydropower plants in Hunedoara County and beyond, with the potential to expand the renewable energy network across mountainous and rural regions of Romania.

Finally, the geotechnical data and seismic analysis emphasize the importance of proper foundational support and adherence to safety standards to ensure the micro-hydropower plant's durability and resilience against natural risks. Building this micro-hydropower plant will not only improve energy access for the local community but also contribute to promoting renewable energy use, creating a positive impact on both the environment and local economy.

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