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An Initial Discussion of the Persistence and Movement of Water within Fractured Massifs, Case of Drainage Galleries in the Landslide

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Abstract **-** In the last 30 to 50 years, the planet has been accumulating and experiencing changes in the regional water cycle. This variation makes us all, especially in the Andes Mountain range, ask ourselves what is the current state of the persistence and movement of water from a regional to a local approach. We all know that nature is highly complex, even more so when we want to understand the elements that constitute one or more geological masses that make up, for example, a landslide. The physical stability of these is very important for civil works operations, so it is important to understand today more than before not only their properties but also the interaction with the flow of water over time.

We invest high costs in indirect investigations and even more so in direct ones, with the desire to know that vertical column of the materials or natural aggregates present in these geological masses, not only understanding it is necessary, but also monitoring over time is essential with the support of hydraulic instrumentation.

Given these climatic changes, the central zone of Peru is not immune to an increase in the average rainfall rates that converge in the investigated area, but now we must not only create predictive scenarios, but also expand the expectations that we used to have in the initial monitoring, adding models with high performance in modeling the flow in domains of fractured rocks.

The initial results suggest an RMSE below 5%, which is an acceptable value for this initial discussion, which has allowed us to validate the filtration flows that were obtained with a range of 7 m^3/hr to 18m^3/hr, comparing them with the flows measured during the construction of these galleries in fractured rocks.

Keywords**:** Hydrogeology, Filtrations, Modeling FEFLOW, Landslide.

1. Introduction

The technique for solving the equations governing groundwater flow in porous and fractured media can be approximated through numerical schemes (finite differences, finite elements, finite volumes, fractals, or others enabled by contemporary technology). The finite element numerical technique has allowed and will continue to contribute to increasingly precise approximations for filtration flow in complex geometries (discretized through an approximation in a numerical model). This highly emerging technique is feasible provided that direct research data is available, allowing for the inference of stratigraphic and/or lithostratigraphic profiles (the conceptual model), as well as prior knowledge of historical data regarding the behavior of the local hydrological model, which affects recharge areas, flow circulating through channels and/or primary and secondary voids present in the geological masses in situ. Bear (1997).

2. Information analysis

2.1. Hydrogeological conceptual and numerical model

The formulation of the conceptual model is derived from the analysis and discretization of data resulting from direct research (diamond drilling surveys), geophysical investigation, monitoring of water surface and groundwater levels, complemented with piezometer data. The results allowed establishing the surfaces of the strata and translating them into a three-dimensional digital reproduction as shown in Figure 1. Note the contrast between a theoretical conceptual approach (Figure 1) and Figure 2, which is inferred based on direct research information (reality).

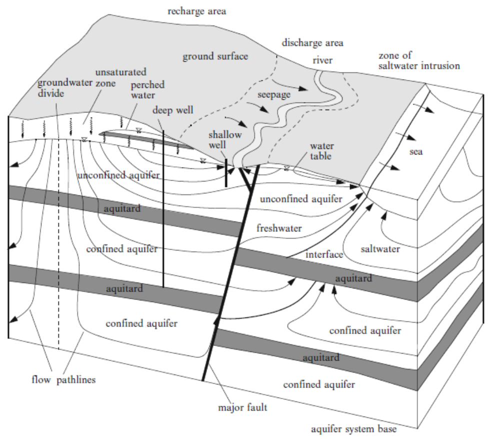
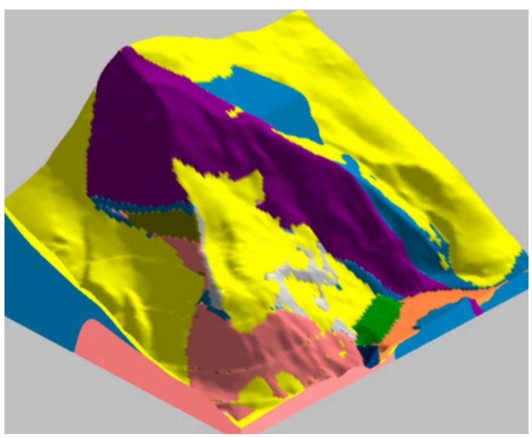


Fig. 1: Theoretical and conceptual illustration of complex nature and types of aquifers.



No	Color	Nombre	Simbolo
1		Relleno contrafuerte	Con
2		Sedimentos	Sed
3		Presa	Pr
4		Aluvial	Al
5		Coluvión	Qc
6		Paleoderrumbe	Q-pd
7		**Coluvión de pizarra**	Q-p
9		Grupo Ambo	Ci-a
10		Grupo Excelsior (Pizarras)	D-ep
11		Grupo Excelsior (Cuarcitas)	D-ec
12		Grupo Excelsior (Esquistos)	D-ee

Fig. 2: Conceptual illustration inferred from geological formations and types of aquifers.

2.2. Numerical model

Please refer to satellite image Figure 3, which shows the area of surface recharge and the topographic characteristics of the relief of the area of interest. Similarly, visually compare it with Figure 4, which shows the discretization into finite elements using the FEFLOW (Finite Element Flow) code for the nearly 75 hectares of the research area. In Figures 4 and 5, observe the color scale zoning of the hydraulic conductivity obtained in the field through the Le Franc and Lugeon tests, respectively, in the diamond drilling tests.

Fig. 3: View of the natural domain of the Landslide 5.

The following figure shows the construction of the mesh in finite elements and view profile see figure 5.

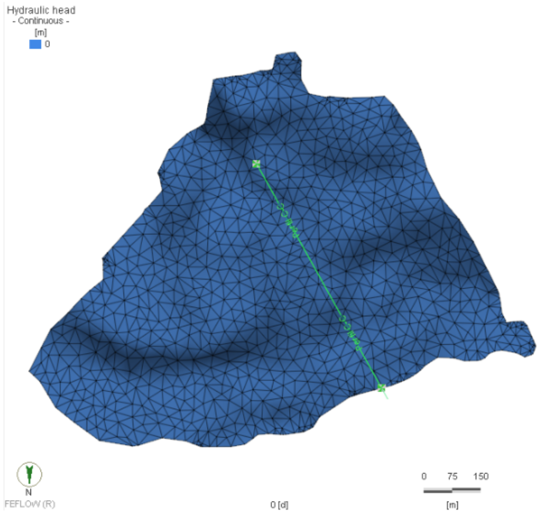


Fig. 4: 3D discretization of the natural domain into finite elements - Landslide 5.

2.3. Hydraulic conductivities and piezometers

From the existing direct research and piezometer measurements (see Table 1), a water surface has been inferred, as shown in Figure 5 and 6. This demonstrates the existence of water within the geological masses, hydraulic conductivities, filtration flow that is directly related to the hydrogeological behavior and the typology of the aquifers present in a complex geometry.

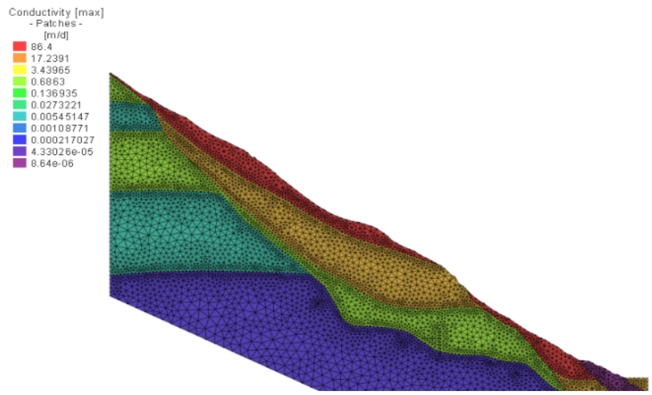


Fig. 5: Hydraulic conductivities in geological mass - Landslide 5.

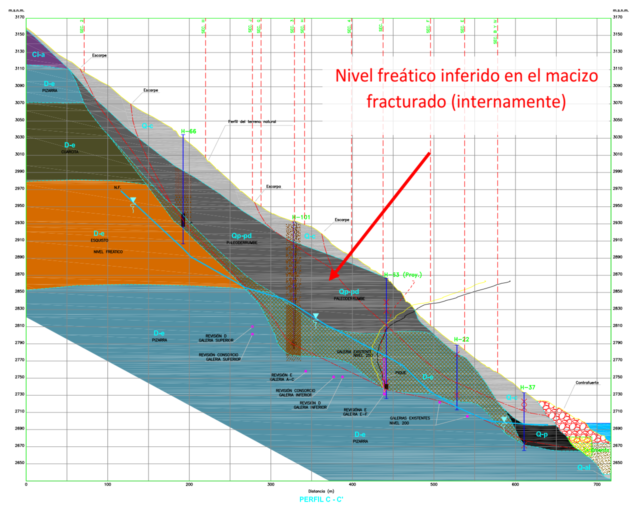


Fig. 6: Stratigraphic Profile, note the inferred water table.

The following table shows the summary of the readings of all piezometers:

Table 1: Piezometer instrumentation.

Piezometer	Liner Elevation (m.s.n.m.)	Reading (H)	Water Elevation (m.s.n.m.)
H - 21R	2 776,20	74,83	2 701,37
H - 22	2 788,52	72,46	2 716,06
H - 24R	2 953,53	79,80	2 873,73
H - 30A	2 890,94	5,29	2 885,65
H - 30R	2 890,77	119,05	2 771,72

H - 32R	2 953,68	116,95	2 836,73
H - 33R	2 866,39	90,90	2 775,49
H - 35	2 739,51	41,93	2 697,58
H - 37	2 733,05	36,53	2 696,52
H - 51	2 702,99	5,29	2 697,70
H - 52	2 702,00	5,79	2 696,21
H - 53	2 702,95	5,45	2 697,50
H - 62	2 840,74	92,57	2 748,17
H - 63	2 866,64	90,48	2 776,16
H - 64R	2 950,10	91,22	2 858,88
H - 66	3 034,15	125,38	2 908,77
H - 67A	3 105,67	5,82	3 099,85
H - 69	2 707,12	9,69	2 697,43
H - 71	2 797,38	79,55	2 717,83
H - 72	2 901,47	93,55	2 807,92
H - 73	2 736,50	33,68	2 702,82
H - 101	2 933,42	97,15	2 836,27
H - 102	2 945,97	110,11	2 835,86
H - 103	2 990,02	132,15	2 857,87
H - 104	2 845,36	69,84	2 775,52

3. An initial estimation of water movement in fractured geologic masses

The importance in constructing the model lies in considering the infiltration process as a function originating from soil hydrology and percolation through the porous medium (first strata overlying the bedrock). Through the interstices of the porous medium, materials manage to penetrate and migrate towards the fractured rock (breach), reaching deep drainage galleries with structural control (cracks, joints, faults).

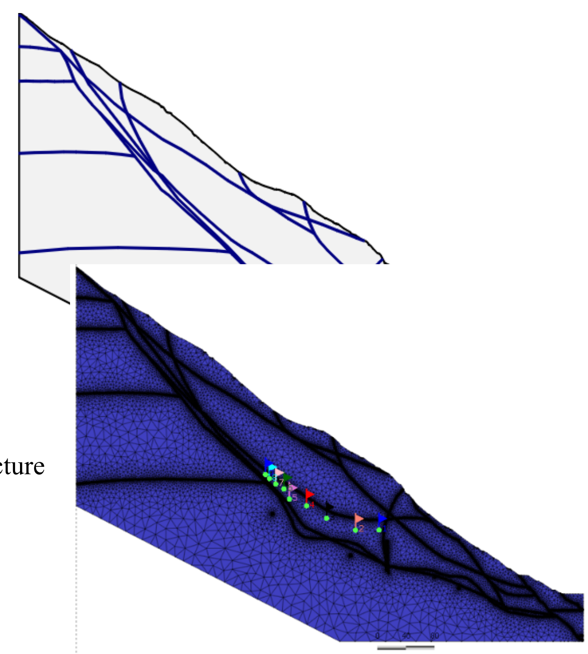


Fig. 7: Incorporation of fault and fracture maps into the model domain in the Landslide 5.

Fig. 8: Calibration using observation points -piezometers-.

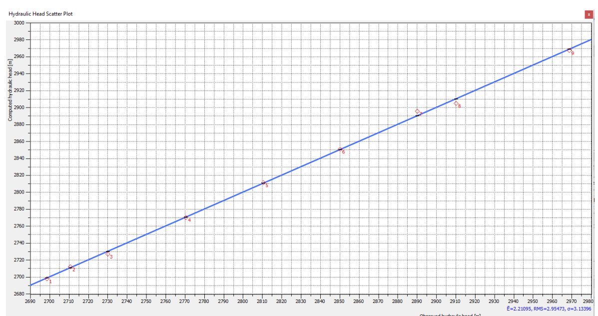


Fig. 9: Model calibration RMSE below 5%,

For the calibration or inverse modeling process, the series of water level readings within the existing piezometers have been used, which have been compared with the numerical curve versus the curve of the monitored and recorded water table level in the field.

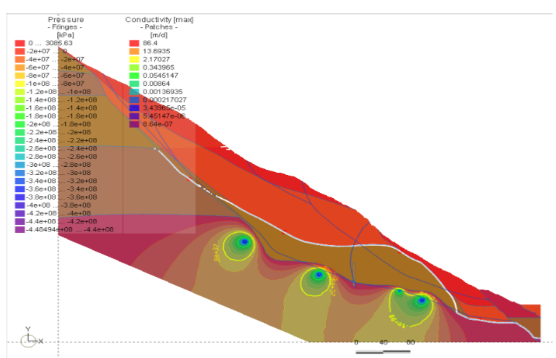


Fig. 10: Simulation with the presence of drainage galleries, note the pressure contours exerted by the Flow.

4. Conclusion

For a conceptual and numerical scenario without considering drainage galleries, we can indicate that desirable results have been obtained. For a calibration period of 3.0 days, an RMSD value in the range of 2.954% was obtained, as shown in Figure 9 and 10. This initial comparison allows us to address our alternate hypothesis: "Will the numerical model be able to represent the complexity of nature?" With the RMSD value, we can indicate that we have a good approximation. However, we must note that increased discretization of faults and fractures in the modeled domain (fractured mass) would lead to increased computational time, as the number of finite elements would increase. For this research work, a mesh with 149,086 finite elements and 74,986 nodes was constructed. Finite element models have a superior advantage over finite differences due to their flexible mesh and rapid adaptation to complex geometries.

With the calibrated model and after obtaining an acceptable response from the calibration, the filtration flow converging to the galleries was estimated using FEFLOW. With these numerical results (see Figures 8, 9, and 10), we can address a central hypothesis proposed as follows: "Will the conceptual and numerical model allow for the estimation of filtration flow through the bedrock to the drainage galleries?" The values of the filtration flow are in the range of 1.5 to 5.0 l/s, where 11.1 $m^3/d/m$ is approximately 5.32 l/s. For the gallery with a length from the right abutment of 1.4 m plus a height to the vault of 1.1 m, the total length is 2.5 m with a flow rate of 0.321 l/s.

Acknowledgements

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