1. INTRODUCTION

The original natural alpine lake, which was created by the cutting action of the glacier, was during the construction of the Fragrant power plant unit converted to a reservoir when a raised dam was erected. The height of this reservoir thus far has twice been increased and recently had to be adapted to conform to the current status of technology. This so-called reinforcement of the dam in addition to an airside improvement of the embankment stability also included the erection of a modern drainage system as well as a new flood discharge system, but particularly a comprehensive campaign to improve the subsoil seal.

* Consolidation du barrage Feldsee avec observation des points forts du colmatage amélioré du sous-sol.
2. HISTORICAL DEVELOPMENT

From 1963 to 1985 the KELAG-Kärntner Elektrizitäts-Aktiengesellschaft (KELAG) constructed the Fragrant power plant group, which is a very complex network comprised of numerous alpine reservoirs as well as an immense number of tributaries and several power plants, at different elevations [1]. This power plant group, which is comprised of 9 high as well as a series of smaller river dams, has a significant power output of 404 MW as well as an average annual output of 707 GWh. A new pumped storage phase was recently installed within this group while integrating the Feldsee reservoir. (Fig. 1)

![Diagram of the Fragrant power plant group](image)

**Fig. 1**
Longitudinal section of the Fragrant power plant group
*Coupe transversale du groupe de centrales de Fragant*

1 Reservoir 1 Retenue
2 Power house 2 Centrale électrique
3 Overall production 3 Production totale
4 Overall capacity 4 Puissance totale

2.1. CONSTRUCTION AND ORIGINAL CONCEPT OF THE FELDSEE DAM

In 1969 and 1970 the Feldsee dam was poured as a 12-meter high raised dam. The surrounding moraine material was used as fill while the seal consisted of a dual layer bitumen surface seal on top of a bitumen binder layer and a cut-off wall with corresponding subsoil injections in the area of the alluviums. The original concept for this small reservoir was based on its use as a remote reservoir for
the Wurtenalm reservoir located 500 meters below while the reservoir water was only discharged once annually when necessary by opening the bottom drain.

2.2. PHASED EXPANSIONS FROM A STRUCTURAL AND OPERATIONAL ASPECT

In 1980, after gathering detailed water management data and according to the requirements of the energy industry the reservoir was for the first time increased by 4 m and the usable reservoir volume was thus expanded by 470,000 m³ to 1,650,000 m³. In 1986 the construction of a parallel pump line resulted in the reservoir being connected to a reservoir system that was located at a higher elevation, which in turn allowed the energetic use of a 500-meter fall height potential [2].

2.3. CHANGED CONCEPT: FROM ANNUAL RESERVOIR TO WEEKLY-/DAILY RESERVOIR

The construction of the Feldsee pumped storage phase and its new functionality gave the small reservoir of Feldsee a special energy-industrial upgrade. After it is put into operation in early 2009, its high daily flow rate will increase the annual volume of the useable reservoir water volume from originally 2 million cubic meters to 120 million cubic meters.

3. GOVERNMENTAL REQUIREMENTS FOR DAM REINFORCEMENT

The in Austria legally required inspections for high river dams to be performed by the Austrian Commission on Dams are normally conducted every 5 years. Based on the last inspection conducted in 2005 specific measures were instituted to bring the dam into compliance with the latest status of technology [3]:

3.1. SEEPAGE WATER REDUCTION

Long term interior erosion could not be ruled out due to the high amount of seepage water and the intent was to reduce that amount of seepage water since the dam is based on a layer of loose gravel that is up to 33 m thick and the underlying rock in addition is weathered where exposed to the surface.

Already during the early years of operation, but particularly after the river dam had been raised in 1980, an amount of seepage water began to appear that
was incredibly high for such a relatively low dam, reaching amounts of 100 l/s and making a prolonged total damming hard to support (Fig. 2).

Fig. 2
Amounts of seepage water prior to the injection campaign 1985/1987
Volumes de l’infiltration avant la campagne d’injection 1985-87

<table>
<thead>
<tr>
<th></th>
<th>Storage Goal</th>
<th></th>
<th>Objectif de stockage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Storage goal</td>
<td>1</td>
<td>Stockage en cours</td>
</tr>
<tr>
<td>2</td>
<td>Storage goal partial development</td>
<td>2</td>
<td>Niveau de la retenue</td>
</tr>
<tr>
<td>3</td>
<td>Storage level</td>
<td>3</td>
<td></td>
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In 1985 and 1987 an extensive injection campaign was conducted beginning from the cut-off wall into the permeable subsoil to act as a structural counter measure, at the same time performing improvements to the cut-off wall by widening it and installing a new bitumen connection. The injections have also resulted in a significant reduction in seepage water amounts (Fig. 3). This did not provide any final satisfactory results, however, since the injections were performed while the reservoir was only partially filled, thus being performed while affected by current, and the entire cross-section was not captured in the alluvial area.
A requirement for the future should include that the reduction of seepage water to 20 l/s, which was the result of the injections from 1985 and 1987, is furthermore significantly reduced to lastingly prevent a risk for interior erosion. This goal could only be reached applying a new, extensive and multi-phase injection campaign.

3.2. IMPROVING THE STABILITY OF THE DAM

The status of safety technology has changed since the river dam has been in existence and requires proof of the dam embankments’ stability that also includes the newest information regarding seismic safety. A reanalysis for the Feldsee Dam requires the leveling of the a Pierre embankment.

The a Pierre embankment was originally built having a slope of 1:1.5 to 1:1.6, the waterside embankment having a slope of 1:1.7. These slopes were also continued when the river dam was elevated for the first time.
An inspection regarding the stability of the dam embankments revealed that airside a leveling was necessary to obtain slope of at least 1:1.8 while at the waterside a leveling was not necessary. Associated with the in-filling that was necessary for the airside leveling it was also prudent to improve the drainage system with sectioned drainage lines and capturing it in a new measuring chamber. The additional embankment made it also necessary to extend the bottom drainage structure and elevate the access structure for the bottom drainage. The decision was finally made to not only level the airside embankment but to also raise the river dam by 4 m and thus increase the reservoir volume by 500,000 m³ (Fig. 4).

![Fig. 4 Dam main cross-section](image)

**Fig. 4**  
*Dam main cross-section  
*Coupe principale du barrage*

1. additional embankment due raising the dam  
2. necessary embankment due to leveling the dam

3.3. **FLOOD WATER RELIEF**

A recently published governmental requirement provides the new “Guideline for designing flood water relief systems for river dams” by the Austrian Commission on Dams. The design floodwaters must therefore be newly established and the conveying capacity for floodwater discharge of existing systems must be adjusted accordingly and verified.

The floodwater discharge system for the Feldsee Dam originally existed in form of a trapezoidal discharge flume over the top of the dam with continuation into a lateral parallel valley to the former Feldsee drainage. The original design floodwater was established applying the former status of technology for a small contributory of only 2 square kilometers to be just 6 m³/s and the relief system was calculated accordingly.
According to the new guideline, the established design floodwater has shown a multiple volume of that which was originally applied, requiring a complete new concept including the construction of a new system.

3.4. REQUIREMENTS DUE TO THE PUMPED STORAGE OPERATION

The changing water levels resulting from the pumping operation not only affect the storage space itself but also the embankments of the natural storage area.

As illustrated in the following diagram, the change from the original annual storage operation to the weekly storage operation that changes daily results in significant variations of the daily levels (Fig. 5).

![Fig. 5](image_url)

Storage level variations for the Feldsee reservoir

Variations du niveau de la retenue de Feldsee

| 1 | Actual | 1 | Effectif |
| 2 | Target | 2 | Objectif |
| 3 | Lake level | 3 | Hauteur du lac |
| 4 | Annual hours | 4 | Heures année |

It is generally known that rapid water level decreases can be problematic for the stability of embankment materials in steep slopes. Slides may occur in relation to the material parameters. Thanks to the bitumen surface the river dam
with respect to the Feldsee reservoir is not affected although the embankments in the surrounding storage areas had to be evaluated with regards to their fitness to withstand rapidly changing water levels.

A stability calculation of the embankments of the storage areas had to performed by means of capturing the soil specifications through drilling and additional tests. The evidence of the stability must be geodetically established in reality.

4. STRUCTURAL BUILDING REQUIREMENTS

4.1. GENERAL MATTERS AND 4 M DAM RAISING

To comply with the governmental requirements for improving the dam stability would generally only have required a leveling of the airside embankment. The significant secondary costs necessary for the additional embankment at the airside (clearing the contact area, improved drainage system, expansion of the bottom drainage, new access road to the top of the dam, new floodwater discharge system, ecological compensating measures, etc.) helped in reaching the decision to just go ahead and instead of planning a leveling to also plan raising by it 4 meters. (Fig. 6)
4.2. COMPREHENSIVE SUBSOIL INJECTIONS

4.2.1. Assessing the actual condition

Although the documentation of the injection campaigns during the eighties roughly separated the injected cross-section in the area of the loose gravel the underlying rock surface had not been exactly captured. This first required the
evaluation of the subsoil along the waterside cut-off wall, that means along the intended injection shield in form of a row of drilled holes included a total of 7 test holes over a length of 26 m to 40 m. In addition to the section of the thus far injected area and the exact rock line, the result also gave an indication regarding the quality of the loose gravel and the underlying rock and was the basis for the detailed planning and invitation to tender for the new intensive injection campaign. (Fig. 7)

Fig. 7
Injection measures - longitudinal section
Mesures d'injection – Coupe transversale

1 minimum program
2 alluvial injection (dual screen)
3 rock injection
4 alluvial injection (rock injection) drilled holes for third row
5 injection campaign 1985 -1987
6 dam

4.2.2. Contact injections

This first step, which can be called a pre-injection, served to prepare the alluvial injections and was necessary to seal the topsoil layer in the area of the injection plate that will counter balance the injection. The following planning criteria was implemented for this step (Fig. 8, Fig. 9):

- 120 drilled holes, caliber 139.7 mm, drilled hole depth of 1.50 m
- System simple packer, drilled hole spacing of 3 m
- Drilling hole raster single row, between the two alluvial injection rows
- Injection pressure of 2 bar, volume criteria 300 l, W/B-value 1.2
Fig. 8
Contact injection (Pre-injection)
Injection de contact (pré-injection)

1. contact injection
2. sealing layer
3. cut-off wall
4. rockline
5. injection plate control with precision leveling

Fig. 9
Arrangement of contact injections - Layout
Disposition des injections de contact
9.2 tons of injection material was used as pre-injection material for 190 running meters of drilled holes.

4.2.3. Alluvial shield

This second step was identified as the main injection for the loose gravel section between cut-off wall and upper rock level and was performed in the following manner: (Fig. 10 and 11)
Fig. 11
Arrangement of alluvial injections – Layout
Disposition des injections alluviales

- 210 drilled holes, caliber 139.7 mm, drilled hole depth of 3.0 m integrated into the rock
- System double packer, synthetic sleeves, 33 cm section spacing
- Drilling hole raster double row, drilling hole spacing 3 m
- Injection using start-stop method, every second row trailing
- Pressure criteria:  
  - from 0 to 5 m: 5 bar
  - from 5 to 10 m: 10 bar
  - from 10 to 20 m: 15 bar
  - from 20 m: 25 bar
- Volume criteria: 700 l/section water- and airside
- W/B-value 1.2

During the first phase of the alluvial shield seal 367.2 tons of injection material was injected for a total of 4600 running meters of drilled holed.

4.2.4. Rock injection and additional alluvial injection

In order to also seal the zones of the rock that were near the surface this third phase was performed in the following manner: (Fig. 12 and 13)

- 93 drilled holes, caliber 139.7 mm, drilled hole depth app. 20 m in rock
- System simple packer, 5 m section spacing, drilled hole spacing of 6 m
- Drill raster single row, between the two alluvial injection rows
- Pressure criteria:  
  - from 0 to 10 m: 15 bar
  - from 10 m: 20 bar
- Volume criteria: 1.0 l/running meter
- W/B-value 1.2
Fig. 12
Rock injection
Injection dans la roche

1. injection plate control with precision leveling
2. contact injection
3. sealing layer
4. cut-off wall
5. alluvial injection
6. rock injections drilling depth
   app. 20 m in rock
7. rockline

1. Contrôle d'injection avec nivellement de précision
2. Injection de contact
3. Tapis d'étanchéité
4. Mur parafouille
5. Injection alluviale
6. Injections dans la roche
   Profondeur du forage d'environ
   20 m dans la roche
7. Ligne de roche
The injection material absorbed by the rock section consisted of the amount of 128.8 to for drilled hole lengths totaling 2020 running meters.

After the rock injection was complete the loose gravel section penetrated by drilling was performed as a third alluvial injection in accordance with the pressure- and volume criteria set forth in item 4.2.3 (Fig. 14).
During the first phase of the alluvial shield seal, 43.4 additional tons of injection material was injected.
4.2.5. **Controlling the permeability**

After completing the aforementioned steps as well as additional local injection measures by means of tightening the injection raster in the areas of injection material absorption through 700 l/section test holes were drilled to document the success of the injections. The fill tests performed in the loose gravel and the pressure tests performed in solid rock intended to prove that the water loss was no more than 1 Lugeon (1 l/min . m).

4.2.6. **Supplementary injection measures**

The first three phases were generally performed using injection material that consisted of 70 % cement, 27.5 % supplement comprised of rock powder and 2.5 % bentonite stabilizer. The coating mix also received additional amounts of bentonite and stabilizers.

In the areas of the first and second alluvial seal where the injection material was heavily absorbed the same mixture was used to again apply an additional seal resulting in the application of an additional 23.4 tons of injection material.

Since the specified pressure- and volume criteria still did not provide the desired success it was decided to apply an additional injection step to the area where the injection material was increasingly absorbed by using a special mix consisting of micro-cement. In 2009, depending on the success of this measure another attempt will possibly be made using chemical injection materials.

4.3. **OTHER STRUCTURAL MEASURES**

4.3.1. **Drainage**

The drainage system for the adapted river dam was improved twofold. A filter and sectional drainage lines were installed on the entire airside contact area that holds the additional fill to observe the remaining seepage water in sections. These drainage lines and those of the existing dam were consolidated at the foot of the adapted river dam into a new measuring chamber. In the future the seepage water can be captured there separately and the data can be remotely transmitted.

After opening the waterside control slot in the cut-off wall connection of the bitumen seal it was determined that the previously installed drainage system had become practically ineffective, partially due to an incorrect construction that was not in compliance with the current status of technology and partially due to the misdirected absorption of the injection material applied in previous campaigns. This knowledge required immediate action and a new concept for the waterside
drainage system. Required was a complete opening of the cut-off wall connection of the asphalt concrete seal with deep excavation and installation of new drainage pipes including the erection of a new filter zone together with an exact resealing of the asphalt concrete. Additionally, a 77 m long pipe had to be force-cut through the old dam body which would receive the discharge of the new cut-off wall drainage separated by section “left” and section “right”.

4.3.2. Dam embankment airside including raising the dam by 4 m

The main embankment body of the airside pre-embankment was constructed from moraine- and colluvium material of the reservoir area, which was processed, sorted, mixed and poured in 70 cm-high layers with a maximum grain-size no larger than 500 mm. Heavy shaker cylinders were used in no less than six applications to achieve the minimum criteria that had been established in a previously performed large-scale pouring test.

Producing this fill, which was comprised of app. 120,000 cubic meters of fill material, included some noteworthy features when connecting the river dam with the adjoining terrain by means of generously planned rounding radii and in considering ecological requirements by means of strict provisions during the installation of indigenous plants and greening for the airside dam surface. One particular challenge existed in securing the existing structures that because of the embankment had to be filled-in to a height of 10 m and also had to be measured for the overburden weight.

4.3.3. Floodwater discharge

Based on the newly established design floodwater the completely redesigned floodwater discharge system has relatively large dimensions where, following a 10 m wide overflow ledge, the initially trough-shaped discharge diameter subsequently converts to a trapezoidal flume. The hydraulic evidence for the conveyance capacity of the design floodwater required allowances for so-called shock waves, which subsequently required an additional enlargement of the discharge flume.

REFERENCES

SUMMARY

The Feldsee dam is within the Fragant power plant group one of the smaller of a total of 14 high river dams of the KELAG-Kärntner Elektrizitäts-Aktiengesellschaft located in the south of Austria. Nevertheless, during its near 40-year existence this river dam has acquired an interesting history. The dam despite its low height as well as a series of previous restoration measures still had relatively high amounts of seepage water. Additionally, the original expansion criteria were no longer in compliance with the status of technology in respect of dam stability and floodwater discharge. In 2008, the river dam was reinforced and at the same time raised and the safety could subsequently be brought into compliance with the current status of technology. The main focus was particularly on reducing the amount of seepage water by means of a multi-phase injection campaign. This shall ensure that within the powerful subsoil, which is comprised of alluviums, internal erosions or suffosion events are lastingly and continuously prevented. The expanded and modernized monitoring system shall particularly support this protection.

RÉSUMÉ

Le barrage de Feldsee fait partie du groupement de centrales de Fragant. C’est l’un des plus petits barrages de cet ensemble qui comprend 14 barrages de vallée appartenant à KELAG-Kärntner Elektrizitäts-Aktiengesellschaft dans le Sud de l’Autriche. Pourtant, depuis sa construction il y a presque 40 ans, ce barrage s’est créé un historique intéressant. Malgré sa faible hauteur et une série de mesures de rénovation dans le passé, le barrage présente encore un niveau d’infiltration conséquent. De plus, les critères de finition d’origine concernant la stabilité du barrage et l’évacuation des crues ne correspondaient plus à l’état actuel de la technique. Une consolidation du barrage avec, en même temps, une surélévation de celui-ci ont été réalisées en 2008. La sécurité a ainsi pu être mise au niveau actuel de la technique. L’attention a été principalement portée sur la réduction extrême des quantités d’eau d’infiltration au moyen d’une campagne d’injection à plusieurs niveaux. De ce fait, il est possible de garantir durablement que, dans l’épais sous-sol se composant d’alluvions, il ne puisse se produire au-
cune érosion interne ou fuite. Le système de surveillance étendu et modernisé devra tout particulièrement renforcer cette sécurité.