The impact of insufficient hydropower plant safety: A case study

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This article highlights the example of a hydropower plant where insufficient due diligence during the implementation of a construction project led to serious damage, both to the hydropower plant itself and to the land affected by it. In particular, the paper emphasizes the discrepancies between the permit application design and the actual hydropower plant and pressure pipe that were constructed.

A small hydropower plant in Upper Styria in Austria was built in 2009/2010 and has since then been operated as a diversion powerplant. The powerhouse, which accommodates two twin-jet Pelton turbines, is located approximately 3.5 km south of the water intake and is supplied with water by a DN 800/900/1000 GRP (glass reinforced plastic) pressure pipe. The powerplant has a net head of approximately 200 m and a design flow of 1.2 m^3/s. According to data provided by the operating company, the maximum capacity of the plant is a turbine output of roughly 1.8 MW, and the plant produces an average of 7.1 GWh/year (2011–2015).

Since the commissioning of the powerplant, 10 incidents of pipe damage have occurred, with local failures of the GRP pipe. Every incident of pipe failure has resulted in repair costs and necessitated powerplant closures to repair or replace the respective pipe section. During these periods, no energy can be produced and consequently no revenue from selling energy can be generated by the operating company.

The pressure pipe runs along a route that passes through tracts of land owned by several landowners, who have agreed, by way of easement contract, to the pressure pipe crossing their property. The basis for the contracts concluded at the time was the permit application design for the project.

As the current situation with regard to safety for the landowners is no longer considered acceptable, and as the operating company of the powerplant no longer fulfils the agreed obligations, several of the landowners have unilaterally terminated these easement contracts. This has sparked a legal dispute between the operating company and the landowners which has not only resulted in proceedings with the responsible authority, but has also led to eight lawsuits so far at the regional court between the affected landowners and the operating company.

Table 1: Overview of pipe damage incidents

Pipe damage event no.	Date	Station [km]*
1	18/10/2010	km 0+900
2	21/10/2010	km 0+600
3	13/02/2012	km 2+600
4	09/07/2012	km 2+600
5	10/10/2014	km 0+900
6	08/10/2015	km 3+250 at the powerhouse
7	03/12/2015	km 0+900
8	07/2016	km 3+250 at the powerhouse
9	08/2017	km 2+600
10	08/2019	km 2+590

* Start at km 0+000 at the water intake

Table 2: Technical data on pressure pipe as indicated in the longitudinal section drawing, which forms part of the permit application design

Pipe	DN/PN	Length (m)	Cumulative length (m)*
GRP	1000/06	1050 m	1050
GRP	1000/10	360 m	1410
GRP	1000/16	102 m	1512
GRP	1000/20	128 m	1640
Steel	800/40	1614 m	3254

Data inlet to power house

*Start at the water intake

1. Pipe damage incidents and boundary conditions

Since the first year of its operation, pipe damage incidents have occurred regularly at this hydropower plant. The history and location of damage incidents are summarized in Table 1.

According to the permit application design submitted for the project, for which the respective permitting authority granted approval for construction of the plant, the pressure pipe was to be constructed with various pressure classes.

It was planned, as is standard practice for hydropower plants, to design the different sections of the pressure pipe and the respective pressure classes according to the boundary conditions, determined by the topography of the terrain and the prevailing pressure conditions.

As is obvious from the operating company's documents submitted to the authorities, pipe materials, which differ from those specified in the permit application design, were used over long distances and pipes of lower pressure classes were installed. The documents mentioned (documentation of most recent leak tests in February 2016 and May 2018) from the operating company (simultaneously the former construction company) have become known on account of the great number of administrative and legal proceedings.

Table 3: Technical data on installed pressure pipe (source: documentation relating to leak tests) provided by the construction company			
Pipe	DN/PN	Length (m)	Cumulative length (m)*
GRP	1000/06	895 m	895
GRP	1000/10	270 m	1165
GRP	900/10	248 m	1413
GRP	900/16	1183 m	2596
GRP	900/20	458	3054
GRP	900/22	200	3254
Data inlet to power house			3254
*Start at the water intake			

It is particularly noticeable that in the lower area, in the last approximately 1850 m-long section (divided into 200 m + 458 m + 1183 m) upstream of the power house, GRP pipes with pressure classes of PN 22, PN 20 and PN 16 respectively were installed. However, inthe permit application design (see Table 2), steel pipes with a pressure class of PN 40 were foreseen for the last 1600 m of the pressure pipe route.

Another drawing by the operating company shows other discrepancies related to the pressure classes of the installed pressure pipes (see the last line of Fig. 1 where the pipe classes PN 20/PN 16/PN 20 and PN 22 are indicated).

It can be inferred from this that in the area of damage no. 10 at chainage km 2590 (660 m upstream of the powerhouse, on a length of about 100 m), PN 16 pipes have been laid from km 2550 to km 2650. A check of the pressure conditions in this area showed the static pressure to be about 154 m water column (water level at intake at about el. 1280 m and pressure pipe approximately el. 1126 m) where damage occurred in August 2019.

The fact that pipes of pressure class PN 16 were installed in the mentioned area as confirmed by checking the pipe class during the repair works in this section, see also Photo (i), is not reasonable from a technical point of view, as a PN 16 pressure class is only nearly sufficient in terms of safety for the static pressure load of 154 m water column. But furthermore, no additional dynamic pressure fluctuations were taken into account in the permit application design. For example, there are no transient analyses for the system or any other sufficiently reasonable pressure surge estimates for the pressure pipe system.

The facts show that technically sufficient safety was provided in the permit application design, but different pipe classes were installed and the laying of the pressure pipe was not performed as specified in the permit application design.

In the permit under the Water Act, issued by the respective permitting authority, it is stated that anything more than minor modifications made prior to construction require an update of the design and dimensioning of all structural components, plant components and auxiliary installations, as well as an update of the authority's water rights permit.

These updates have not been done by the project owner, despite the use of PN 16/20 and 22 pipes instead of the planned PN 40 pipes clearly being considered more than a minor modification.

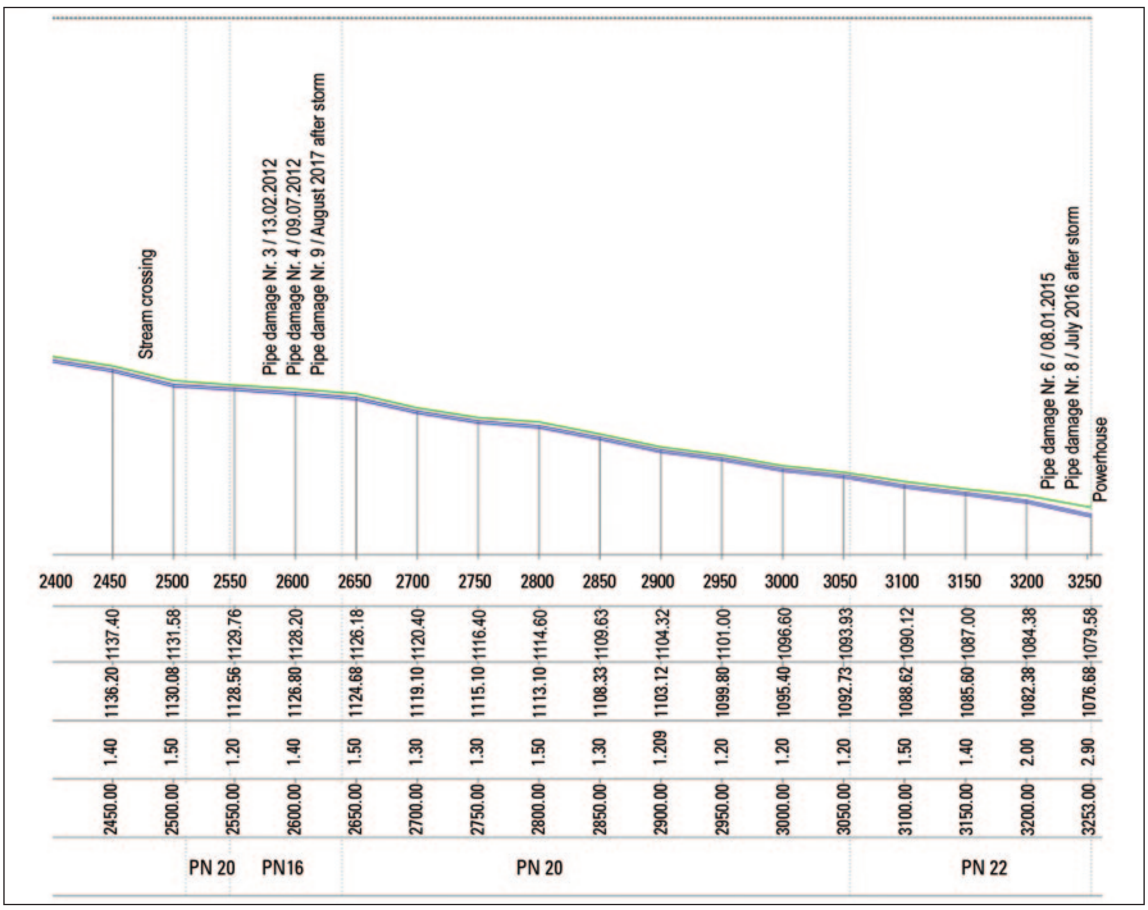


Fig. 1. Detail from drawing depicting pipe damage incidents (prepared by the operating company).

(a) Excavation works for uncovering the pressure pipe in the summer of 2019.

(b) Excavation material of the pipe trench with rocks of up to 1 m in diameter, in the summer of 2019.

2. Pipe pressure tests

Another aspect that is essential for the safety of the powerplant, especially in the present case with the pipe damage incidents, is the performance of a pressure test for the pressure pipe.

According to the administrative decision, this pressure test is to be conducted at 1.5 times the operating pressure.

There is a written confirmation (dated 2 October 2010) that the pressure test was conducted at 1.5 times the operating pressure. Further confirmation has been given that the leak test was carried out at exactly the operating pressure. These confirmations were however issued by one of the co-owners of the operating company who also holds a licence as technical expert for hydropower plant construction. In addition, according to the available documents (test reports from February 2016 and May 2018), there are contradictory statements that conducting the pressure test at 1.5 times the operating pressure would not have been possible for the pipe (potential destruction incident = failure of the pipe) and that therefore this test was not conducted at 1.5 times the operating pressure. This alone proves that the confirmation given by the co-owner of the operating company can be called into question.

(c) Excavation/ backfilling material of the pipe trench with rocks of up to 1 m in diameter, summer of 2019.

3. Laying of pressure pipe

As regards the laying of the pressure pipe, it was indicated in the course of the permit application design that the respective guidelines and recommendations of the pipe manufacturer had to be observed. Among others, a more stringent requirement of a minimum cover of 2 m was indicated in the permit application documents.

Some landowners were present during the laying of the pressure pipe and the partial rehabilitation of the damaged pipes. Based on their observations, statements were also made that the pressure pipe was not laid in accordance with the manufacturer's laying guidelines.

Furthermore, accusations that the GRP pipe had not been laid according to general codes of practice were raised against the respective authorities by affected landowners. These assertions have also been recorded in documents from experts who have been involved in the administrative and legal proceedings (valuation report and experts' statements).

4. Uncovering of the pressure pipe in the summer of 2019

In the course of the legal dispute, the operating company of the powerplant agreed to uncover the pipe in individual sections to check the pipe laying and the pipe bedding.

The works to uncover the pipe were carried out by a licenced earthworks company during a period when the powerplant was shut down. This was done with the consent of the operating company and in the presence of the affected landowners. The pressure pipe was uncovered at five locations between km 0+600 and km 1+600 (at five randomly selected places) on the landowners' properties.

The landowners affected by the excavation works defined five locations at which the pipe was subsequently uncovered in the summer of 2019 (chainage starts at the water intake):

- Location 1: approx. km 1 + 600.
- Location 2: approx. km 1 + 300.
- Location 3: approx. km 0 + 950.
- Location 4: approx. km 0 + 725.
- Location 5: approx. km 0 + 600.

According to the permit application design, the placement by the construction company should have been carried out as per the manufacturer's guidelines. This would also have met the minimum requirements of the standards applicable at the time and the accepted codes of practice. In particular, this would have required placing the following horizontal layers into the backfilled trench (starting from the bottom):

- bedding on which the pipe is placed;
- lateral filling to support the pipe and avoid deformations;
- cover above the pipe crown; and,
- main backfilling.

(d) Accumulation of groundwater on the embankment side after approx. 24 h in dry weather conditions (no drainage), in the summer of 2019.

According to the manufacturer's laying guidelines, the respective layers of the backfilling material have to meet the following requirements, among others, for:

- maximum grain size;
- compactability and sufficient compaction;
- load-bearing capacity; and,
- non-cohesiveness.

Furthermore, regulations, standards and recommendations also specify the installation of drainage systems or, if required, soil replacement or soil improvement works, and certainly a general proper compaction of the horizontal layers.

When uncovering the pressure pipe in the summer of 2019, there was no evidence of the above-mentioned uniform layers in the backfilled pipe trench containing the GRP pipe. In fact, it became evident that in the course of laying the GRP pipe, the trench had been backfilled with the initial excavation material, which had not been properly prepared. There were no indications of any limitation to maximum grain size, pipe bedding and drainage works, as specified in the manufacturer's laying guidelines and in the permit application design documents, in any of the uncovered places.

In particular, the following requirements have not been met by the construction company during the pipe laying works (as far as could be detected by uncovering the pressure pipe):

- The requirement of a minimum cover of 2 m as indicated in the permit application design was not fulfilled.
- The pipe trench and the subsequent backfilling have not been carried out in accordance with the general codes of practice and the manufacturer's laying guidelines: the material for the lateral backfilling was not chosen according to general codes of practice; instead of using gravel size 16/32, cohesive or partly cohesive material was used as lateral backfilling material; drainage installations were obviously not installed (especially noticeable at location 3 of the uncovered pipe), see also Photos (d) and (e); and, soil replacement as specified in the requirements stipulated in the permit was not carried out.

(f) Pipe damage incident no. 10 (no bedding material and unsuitable backfilling material), August 2019.

It can be inferred therefore that at least on the 1000 m between the mentioned locations of the uncovered pipe, the pipe was not laid in accordance with general codes of practice and the manufacturer's laying guidelines (which stipulate that drainage installation or soil replacement should be provided, if required). This length of about 1000 m is about one third of the total length of the pressure pipe (total length 3250 m).

From the 10 pipe damage incidents that have occurred since 2010, it is obvious that the pressure pipe was not laid according to general codes of practice.

According to the available documents it is also noticeable that:

- In the permit application design documents, no surge analyses and/or transient analyses were carried out. These analyses should have included: changes of pressure conditions in case of operational changes; and, worst case scenarios or even turbine failures (especially nozzle break and waterhammer effects).
- In the permit application design documents, neither a stress and strain analysis of the pipe (in particular for anchor blocks) nor, at least, a verification that no anchor blocks were required, was done.

(e) Accumulation of groundwater and stormwater in the pipe trench about 48 h after rainfall event (no drainage). Same location as in Photo (d), summer of 2019.

(g) Pipe damage (excavation works), August 2019.

(h) Pipe damage (broken pipe), August 2019.

• In the permit application design documents, no representative standard cross section for the area of the uncovered pressure pipe sections is available, and thus no serious comparison between the actual pipe installation and the authority-approved pipe design is possible.

• In the permit application design documents, no filter layers (such as a gravel-packed filter) were provided for any sections despite it being clearly shown that there are waterbearing embankment sections, see photo (d). But such measures are indicated in the manufacturer's laying guidelines.

• As per the administrative decision, a crossing of the pipe route should have been made possible for trucks with a total weight of up to 40 t. However, the available documents do not include any proof (such as pipe stress analysis) or other indication that the pipe laying was carried out in line with these requirements.

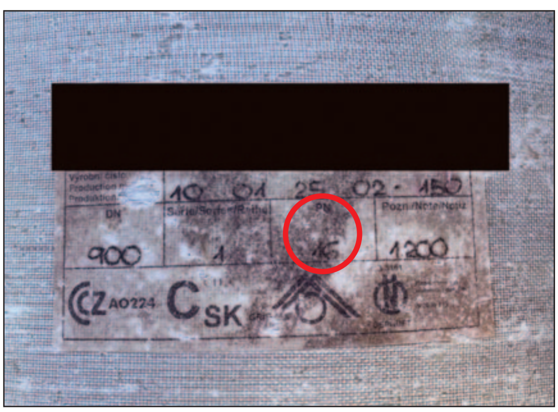
5. Conclusion

During review of the available project documents it was identified that a satisfactory permit application design was prepared for the permit application process. In the further course of the project, especially during construction, major modifications were made, which were not taken into account with due care by all parties involved in the project. The project owner was also the construction company and later the operating company for the hydropower plant. In this case it seems that the common best practice approach, involving tender design, detailed design and design documentation, has not been adopted.

One major issue identified is that the pressure classes and the materials for the pressure pipe specified in the permit application design were not installed, nor was the construction of the powerplant supervised and approved by a qualified and technically competent and responsible site supervision manager, who should have been appointed by the project owner.

The fact that several damage incidents have occurred since the plant began operating in 2009/2010 makes it difficult to understand why the respective authority tolerates these circumstances especially in view of the associated risks to safety. It would be assumed that the operating company would act in its own interest, operating the hydropower plant without shutdowns, generating revenue by selling energy, and ensuring safe plant operation.

For a technically complex structure such as a hydropower plant, this case highlights the need for due care to be taken to follow design specifications precisely, and personnel with appropriate experience and knowledge to be employed for the design and project work, as well as for construction, site supervision and operation. ◊



(i) Broken pipe, see photo (h) with specification sticker on pipe (pipe class PN 16 at a static pressure of 154 m water column), August 2019.

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Michael Schwarzkopf graduated from the University of Karlsruhe, Germany, with a Master's degree (Dipl.- Ing.) in civil engineering, specializing in river engineering, hydrology and hydropower. In 2008, after completing his Master's thesis on design variations of a small hydropower plant in a karst cave in Indonesia, with a focus on dimensioning a wooden pressure pipe while analysing waterhammer scenarios, he joined ILF Consulting Engineers. Since then he has been involved in various hydropower and river engineering projects of different types and sizes in numerous locations worldwide (Austria, Azerbaijan, Bosnia, Canada, Georgia, Germany, Indonesia, Kazakhstan and Central Asia, Lao PDR and Southeast Asia and Romania).

He has extensive national and international experience in all stages of hydropower projects, from preparing potential studies, feasibility studies, and studies of alternatives, to commissioning new or rehabilitated plants. He is also familiar with tender preparation, procurement and site supervision services. In 2018 he worked abroad on a site in Georgia where he held a site supervision job for a cascade of hydropower plants. During this assignment, he was involved in supervising concrete construction works (intake, power house, reservoirs, and so on) and pipe laying works. The works included a total of 10 km of pipe laying (steel and GRP, DN 1600–2400), which contributed to broadening his experience and to gaining the knowhow to assess the quality of pipe-laying works.

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