Evaluation of Swedish Hydro Power Centre 2013-2016

Evaluation of the Hydraulic Engineering (Vattenbyggnad) part of the program

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Summary

The vision of the Swedish Hydropower Center (SVC) is to become one of the top international centers for education, research and development in the area of hydropower and dams. The activities of the Center are focused on technological issues that are unique to hydropower and to tailings dams for the mining industry.

This report contains an evaluation of SVC at the end of 2015, a review of the planned activities for 2016, and some recommendations for future activities and Center operation. The evaluation presented is primarily based on a review of documents related to the competence area Hydraulic Engineering (Vattenbyggnad), but some conversations with researchers in the SVC program have also taken place.

The SVC is successful and has the potential of being even more successful in the future. The set-up of the organisational structure and financing is unique in an international perspective and offers a number of very attractive features. The regular annual review and updating of activities is important and makes it possible to incorporate new ideas and make planned changes in priorities. The participation and interaction with the users and the support of reference groups is essential, and, in the future, reference group meetings should be even better planned and prepared to take advantage of the members' input and advice. The close co-operation between academia and industry with short communication lines should be maintained and strengthened as one of the great advantages in the SVC.

With the support of SVC, The Royal Institute of Technology in Stockholm (KTH) and Luleå University of Technology in Luleå (LTU) have together built a strong undergraduate and graduate teaching program in Hydraulic Engineering in Sweden. The program is also attractive to foreign students as not many programs of such content and quality exist. The international reputation of SVC may be enhanced by writing more papers for publishing in recognized international journals and by arranging special lecture series and/or conferences.

In the SVC Program Plan for the period 2013-2016 more emphasis than earlier was placed on experimental activities and also on the establishment of a research program in structural engineering for dams and ancillary structures. Furthermore, SVC's scope was expanded to highlight three strategic system-oriented areas: "Balancing power", "Environmental technology" and "Active management". An important goal is to obtain a clearer focus on hydropower interaction with the power grid.

There has been some emphasis on "Environmental technology", for instance related to fish migration and the fauna in the river downstream of powerplants, but very little so far has been achieved or planned in the new areas of "Balancing power" and "Active management". This should be corrected in the next program period. Specifically, there is too little emphasis on the importance of maintenance, repair and strengthening of existing embankment dams, both for the hydropower and mining industry. To meet the demand for engineers to the industry it is important to fill the present gap between Hydrology/Hydraulics and Structural engineering with personnel dedicated to hydraulic engineering and design of hydropower structures.

The last section of this report contains some specific suggestions and recommendations for further R&D and for improving the future operation and activities of the SVC.

Approach

The reviewers for the area of Hydraulic Engineering (Vattenbyggnad) were provided with the following documents:

1. SVC Program Plan for the period 2013-2016, document issued 2012-11-30;
2. Planned Activities for the period 2013–2016, updated and adjusted each consecutive year (2012-11-01; 2013-10-04; 2014-10-14; 2015-07-03 and 2016-03-08);
3. Reports by Senior Research investigators for the years 2013, 2014, and 2015.

The two reviewers were asked to evaluate different parts of the R&D-program and the accompanying documentation, but to present the results of their evaluations in a common report.

- Leif Lia: "Hydrology and Hydraulics" and "Structural Engineering", activities at KTH
- Kaare Höeg: "Geotechnology", activities at KTH and LTU and "Hydraulics", activities at LTU

The reviewers have not visited any of the universities in the review period or made formal interviews of any of the researchers during the evaluation process. For the topics Hydrology and Hydraulics and Structural engineering at KTH there has been a telephone meeting during the review period. The evaluation presented in this document is therefore primarily based on a review of the documents provided by the SVC Central Office. Some of the specific papers and reports were known to the reviewers from other sources.

Detailed assessment

Project focus

In the SVC Program Plan for 2013-2016 there are specific guidelines for R&D projects to be focused on in the reporting period. The plan states that more emphasis should be placed on experimental studies than in previous program periods, and gradually more emphasis should be placed on the three system-oriented areas: Balancing power, Environmental technology, and Active management. That requires more co-operation and interaction than before among the organizations within the SVC including the competence area of "Hydro Turbines and Generators". Specifically, the SVC Program Plan emphasizes the following topics for R&D projects in Hydraulic Engineering (Vattenbyggnad) during the period 2013-2016:

Hydrology

- Development of computer models for optimization of water resources;
- Improvement of existing flood estimate models;
- Combination of run-off models with dam safety aspects and active management;
- Combination of water resources management and electro-mechanical engineering.

Geotechnology (Soil and Rock Mechanics)

- Internal erosion in embankment dams;

- Slope stability analyses for hydropower and tailings dams;
- Embankment dam deformation analyses to evaluate performance and safety;
- Methods of repair and strengthening for existing embankment dams;
- Concrete and embankment dams founded on jointed rock foundations;
- Tunnelling and construction of channels in rock;
- Grouting and sealing of rock;
- Evaluation of concrete dam stability based on performance monitoring.

Hydraulic engineering

- Analysis and design of bottom outlets;
- Analysis of water flow in tunnels and channels with rough rock surfaces;
- Hydraulic loads, erosion of rock surfaces and effects of aeration;
- Environmental concerns related to fish migration and river fauna;
- Interaction with other areas of expertise in SVC, for instance related to "Balancing power" (Reglerkraft).

Structural engineering

This is a new topic in SVC starting during the program period 2013 – 2016. Typical concrete hydropower structures, frequent load changes and effects of large loads are being considered. Areas of special focus are:

- Dynamic loads on concrete structures;
- Development of concrete with less cracks and joints;
- Anchoring of concrete structures to the rock foundation.

The new area of Structural engineering has very ambitious goals, but presently only a limited group of researchers.

In general, the projects performed by the university research staff and the licentiat and doctoral candidates follow the guidelines in the continuously updated SVC Program Plans.

The “Hydrology” topics listed above are studied at the Division of “Vattendragsteknik” at KTH. In Sweden the research institute SMHI has played a key role in the development of methods, tools and knowledge, and SMHI is partly involved in the research at KTH.

Under "Geotechnology" the first four topics listed above are studied by LTU, and the remaining four by KTH. As LTU, KTH is also active in studies of internal erosion in embankment dams. Furthermore, KTH is applying probabilistic and reliability methods in the area of "Geotechnology".

Under "Hydraulics", LTU has a strong background in basic fluid mechanics, experimentally as well as in numerical analyses (e.g. CFD and SPH), but this capability has not been applied in the areas of main interest to SVC until very recently. This may be seen from the nature of the previous research projects and the direction of more applied research during the period 2013-2016. The users and Reference Groups should be actively engaged to define the practical problems and challenges encountered in hydraulics related to new hydropower development and to rehabilitation of existing facilities.

LTU is also doing research related to environmental issues, for instance making it possible for fish to more easily migrate passed power plants and of changes in fauna downstream of power stations.

Structural engineering is a common topic for all technical universities in Sweden, but the listed topics in the SVC program are investigated mainly at KTH. No other universities are presently engaged in this topic, and more interaction and co-operationbut with other organizations should be considered.

Overall goal achievements

In addition to strengthening the teaching programs in Hydraulic Engineering in Sweden, SVC should develop tools and methods for design, construction, upgrading, operation and maintenance of hydropower plants and tailings storage facilities to assure dam safety, hydropower production and its flexibility in the power system. All the research reported in the SVC documents available to the reviewers are within this wide scope.

Very little effort has so far been devoted to methods of repair and strengthening of existing embankment dams, both for the hydropower and mining industries. This should be corrected as it is considered to be one of the most important aspects to focus on in Sweden and also internationally.

Very good and internationally recognized research work at KTH and LTU has been and is being done in investigating the phenomena related to internal erosion. However, little effort seems yet to be spent on developing ways and methods to avoid internal erosion in existing dams that, based on the research findings, are likely to develop internal erosion and cause safety hazards with time. This should be corrected, and the R&D required belongs under the general topic of methods of repair and strengthening.

KTH applies probabilistic methods in the analysis, design and safety evaluation in the area of "Geotechnology". The same methodology may be used in other SVC-areas as well. This is a very useful approach and should be continued as it provides valuable insight and is applied more and more internationally. At an earlier stage of SVC Program Planning, focus was placed on writing a "user's manual" on the subject, mainly for use in Sweden, but this subject is no longer emphasized in the recent plans. Although many books have been written on the subject in recent years, this task should be given higher priority in SVC to serve the Swedish hydropower and mining industry.

Project fulfilments of goals

The goals for Hydraulic Engineering listed in the program document include most of the relevant issues for hydropower. This is appropriate for the educational part of the SVC activities, but it is impossible to carry out top level research in many fields with a limited staff. In the end, only some selected topics can be brought to top level. Top level research is carried out in already existing research fields at KTH and LTU, but not necessarily in the areas of most relevance to SVC. In general, the progress in the Licentiat and Doctoral projects is good and in accordance with the plans for SVC. Below, some specific areas will be mentioned for each main topic.

Hydrology and Hydraulics

The educational and research work at “Vattendragsteknik” at KTH is a result of long term, high level research in Hydrology at KTH and experimental and more applied hydraulic research in the Älvkarleby hydraulic laboratory. The main focus

in Hydrology is the increase of general knowledge, simulations of different hydrological and hydraulic aspects, and development of new software tools. This is certainly within the scope presented in the framework for SVC.

However, SVC should consider in the future planning that these topics are just small pieces in the large area of hydraulics for hydropower. Most of the reported activity is from simulations and software tool development, and a gap is detected between this field and the actual design of hydropower strutures. As long as the hydraulic group at KTH is the main group for hydraulic design within the SVC, it seems like the selected topics will be chosen from a narrow field of more basic research. However, LTU may gradually develop its capability to do more applied research in co-operation with the hydropower industry.

The specific projects reported as Licentiat and Doctoral projects are defined from the framework program for SVC. It seems that the Reference Groups may have had significant influence on the framework program, but only little influence on the individual projects, which have been defined by the academic personnel. However, there has been and is a very positive interaction with SMHI, which for decades has influenced all hydrology research and applications related to hydropower in the Nordic countries.

Structural engineering

Structural engineering has been introduced as a separate topic in SVC in this review period (2013-2016). From a start with very little ongoing activity, in three years time a large and relevant portfolio of projects has been developed. The Senior Researcher has industrial background and a user-oriented approach. This may be seen from the three consecutive senior reports, as the activity is showing significant progress and growth. A comparison of the reports from 2013 and 2015 highlights this development.

The projects carried out are well within the scope of SVC, and correspond with the focus areas in the hydropower industry in Sweden (and other Nordic countries). However, the chosen projects seem to have too little interaction with the groups for hydraulic design. Most of the projects listed are related to simulation and development of numerical tools and few are related to the development of new concepts and design of structures. With a much stronger interaction with research groups in hydraulics, the required change in focus should be possible.

It is positive that some of the listed projects are co-operation projects with other groups in SVC, like the Rotor Dynamics and Ice Load projects. This brings knowledge into the Structural engineering group. Interaction among the research groups influences the work in the projects and may increase the relevancy and value of the results.

Geotechnology

There is a positive trend over the years that the research projects performed by the Licentiat and Doctoral students are better defined and focused (less general). This is especially noticeable when comparing the Activity plan written 2016-03-08 compared with that dated 2015-07-03. As many as five new projects are approved at LTU in the areas of "Geotechnology" and "Hydraulics". They are better defined and more application oriented than earlier projects. Experience shows that the better defined the topic is, the higher is the probability that the research candidate (Licentiat or Doctoral) will be successful.

In general, the SVC projects that were started in earlier years have been completed with satisfactory results, but in a few cases the student has terminated his/her efforts before completion. (This is not unusual in research also independent of SVC). In some cases, it therefore has been found advantageous to narrow down the scope of work to make it more specific. At LTU very good and systematic research work completed by a recent PhD-candidate (who got his Licentiat degree at KTH) has led to very promising follow-up projects.

In summary, the reviewers find that the quality of the research work being done with SVC financing has been improving over the years. This has happened at the same time as the structure of the research teams at KTH and LTU with Senior Researchers heading the teams and specifically appointed Adjunct Professors assisting, has found its form, and the research staff has gained experience in running the SVC projects following the SVC Program Plan.

The Senior Researcher plays a key role in the SVC teaching and R&D programs, and it is important that he/she has the inclination and the time to lead and take initiatives. The Senior Researcher reports give very useful summaries of the activities, including activities that are not financed by SVC, but are relevant for hydropower and tailings storage facilities. However, the reporting model/layout should be improved to better identify the SVC-financed activities and the progress made on the topics defined by SVC. Current reporting practice makes it hard to evaluate what publications come out of the SVC-financing and fit into the SVC research plans, and which ones do not. For instance, to simply mention SVC in the acknowledgement of a paper does not qualify the paper to be classified as a SVC-contribution. It is also difficult to sort out from the annual reports what are continuous activities and what are activities just in the specific year.

Results and potential utilization for industry, society and academia

In the way SVC is structured, each of the program areas "Hydrology", "Geotechnology", "Hydraulics" and "Structural engineering" relates to a Reference Group (user group/stake holder group). This should ensure that industry, authorities and society get a say in deciding/adjusting R&D directions and emphasis. It should ensure that the research will be more applied than otherwise would have been the case if only the academic personnel were to decide. In addition, the main area of Hydraulic Engineering (Vattenbyggnad) has an overall user-oriented Steering Group that reports to the SVC Board.

The Reference Groups have the opportunity to both influence the framework program for the SVC and to influence and bring relevance to individual projects during the period. It seems from the available information that the Reference Groups so far have made their influence mainly on the framework program, but little influence on the individual R&D projects.

The reviewers recommend that in the future more emphasis should be placed on regular meetings with the different Reference Groups. Up until now, it seems a bit random when a meeting of the group is called, and what issues are discussed. The Senior Researcher should be responsible for calling and preparing such meetings.

The results and products from SVC are both research (reports, theses, papers etc.) and candidates qualified for the industry and for academia. In spite of some limitations, all new research results are available in open access journals, university home pages, electronic conference proceedings etc. The capabilities of graduates

with relevant and updated knowledge and skills have been increasing. From that perspective, SVC has been very successful in increasing the number of strong candidates entering the Swedish hydropower industry.

Industrial relevance

Through the Steering Group and the Reference Groups, the hydropower and mining industries have the possibility and duty to guide the work done in the SVC.

Improved and more reliable methods to evaluate the safety of hydropower and mining dams have very significant impact on the respective industries as well as on society. It is not only a matter of fiscal losses and environmental damage, but potential loss of life, if a dam breach occurs. The safety record for mining dams is poor, and catastrophic failures occur too often, very recently in Canada and Brazil. The state of the art has to be improved, and SVC can contribute together with international partners. Mitigation and repair methods have to be introduced when the safety of an existing structure is judged to be inadequate.

For hydropower dams, the research work done with SVC financing for improved design, upgrading and repair of bottom outlets and spillways is essential. Experience and risk analyses show that these ancillary structures, and their less than optimal functioning and operation, in many cases significantly increase the failure probability and risk associated with the power station.

The work on internal erosion in existing dams and the development of methods of repair and strengthening is essential for the hydropower as well as mining industry.

For engineers in the hydropower industry and in consulting companies hydraulic design and detailed design is the main work load and the most sought-after skills. For educational purposes it is very important to establish an educational program that prepares the students for this profession. The education in the universities is research based, and then the research must also have some elements of design of structures and development of new concepts. The industry, and the Reference Groups in particular, have the possibility to influence the specific topics that are selected for further research in SVC. For instance, by submitting potential topics for graduate theses, the industry can create close co-operation with research groups and academia.

Research in the area of environmental technology is required to respond to society's concern, for instance, about loss of fish migration and river fauna, topics studied with financing from SVC. Internationally, and especially in the USA, quite a few existing dams have been decommissioned partly due to loss of fish migration along the river.

Balancing power and hydropower interaction with the power grid represents great opportunities and promise for the industry and society. Active management and maintenance are essential, and the search for optimum operation of a system of dams in a river system (e.g. cascade development) clearly requires further studies.

Quality of the scientific work

The laboratories and experimental facilities available to the SVC researchers are exceptionally good, and the university staff capabilities within the area of numerical

analyses are at the level of the state of the art. The research students have also access to several existing dams and hydropower systems that offer case studies. Many of the publications from the research performed are peer reviewed and accepted for publication in highly recognized, peer-reviewed journals. That is usually a stamp of quality. The doctoral theses are reviewed and approved by international committees, and that in itself is a verification of scientific quality.

For a research group in applied science it is recommended to publish a mix of reports, conference papers and journal papers. However, to enhance the international reputation of the SVC, more effort should be spent writing papers for publishing in the most recognized journals. Conference and seminar papers are valuable to get in touch with other researcher and industry candidates, but high quality journal papers get more recognition and reach a wider audience.

Co-operation within and outside of SVC

Based on a review of the documents provided, the co-operation within the SVC seems to be good and sound, and the communication and interaction with the hydropower and mining industry and regulatory authorities positive. The co-operation between the universities and Vattenfall's laboratory in Älvkarleby is very valuable, likewise the field visits to existing dams and power stations. Despite the good co-operation, there are some gaps to be filled which can improve the situation and the relevancy of the research and education. An example is the area of design of hydropower structures which fits in-between the areas of hydraulics and structural engineering. There seems, at present, to be both a lack of focus and lack of personnel to fill this gap.

There are examples of fruitful international interaction and exchange of know-how and information. However, there is potential for more well-planned international co-operation as the topics studied by SVC are very relevant to the international community, and the structure of the SVC and the mode of operation and financing is flexible. The international co-operation should be based more on stragetic planning to benefit the SVC program and less on "random" selection of collaborators. This should be formulated in the SVC documents. For instance, for Swedish hydropower technology the most strategic and accessible research groups are located in Austria, Canada, Norway and Switzerland. Some promising co-operation with the Technical University in Graz, Austria is mentioned, but very little is reported. Relevant and partly parallel research is going on in other organizations, and more effort should be put into the planning of strategic international co-operation.

As an example, SVC may become better known internationally and attract even better students/researchers to SVC, by arranging a special series of lectures presented by recognized experts in the design of new mining dams and the strengthening of existing ones. The idea presented by LTU is a good one, and should be pursued. The bi-annual lecture series may be combined with a conference or workshop where papers and discussions may be presented.

Recommendations

General recommendations

- Continue the successful mode of operation of SVC in the way it started and has gradually improved over the years, especially during the program period 2013-2016. The engagement of senior personnel with industrial background and experience is a very fruitful way to bring both industrial relevance and capacity into the Universities and the SVC research groups.
- The SVC should be given the opportunity to continue its successful work to strengthen the education, R&D and vitalization of the Swedish hydropower industry. The significant external financing of the SVC program is essential for further success, and the Reviewers' evaluation is that the sponsors in return receive results of value more than commensurate with the industry's investments.
- More emphasis should be placed on the use of the Reference Groups by scheduling, structuring, and preparing the meetings in a more systematic way. The Senior Researcher should take an active role in achieving this.
- There should be more strategically planned international co-operation with groups in Austria, Canada, Norway and Switzerland that work with many similar challenges to those encountered in Sweden.
- There is a potential for strengthening the co-operation among the different research groups in SVC. This is one way to ensure the relevancy of the research in each specialty area.
- The thesis (Licentiat and Doctoral) topics and goals should be well-defined to increase the likelihood of a successful outcome. In some cases the scope of work should be less general and more specific and problem-oriented. Involving the Reference Groups more may improve upon this.
- The content/layout of the annual Senior Research report should be modified so it more clearly shows the results of projects that belong in the SVC Program Plans.

Specific technical recommendations

- Research work on methods of maintenance, repair and strengthening of embankment dams should be given higher priority.
- The research work on internal erosion in embankment dams has been very successful. Emphasis should now be placed on how to prevent internal erosion and methods to improve the situation in existing dams that are likely to develop internal erosion in the future.
- More focus should be placed on areas related to hydraulic design, development of concepts and development of upgrading methods for existing hydropower. The "gap" in the SVC program between hydraulic and structural engineering should be filled by senior personnel with main focus on hydraulic design.
- Work related to the application of probability and reliability methods should be given higher priority in SVC.
- In the area of Geotechnology, more emphasis should be placed on publishing papers in well-recognized journals with peer review. That does not prevent papers on the same topic/project to be presented at Conferences.

- Although SVC's goal is to cover both the hydropower and mining industry, relatively little R&D is currently going on related to tailings storage facilities. Therefore, the reviewers support the LTU proposal of arranging an annual or bi-annual special lecture series (combined with a conference/workshop) on the design, construction and safety evaluation of tailings dams. This will encourage and facilitate international co-operation, make SVC much better known internationally, and will present topics of critical importance to an industry that has experienced catastrophic dam failures in recent years.
- More emphasis should be placed on the system-oriented areas: Balancing power, Environmental technology, and Active management as defined in the SVC Program Plan for 2013-2016. There should be a clearer focus on hydropower interaction with the power grid.