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CANADIAN CONSULTING ENGINEERING AWARDS

ALLAIN DUHANGAN HYDROELECTRIC PROJECT IN INDIA

NATURAL RESOURCES, MINING, INDUSTRY & ENERGY

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Innovation:
Were it not for its many innovations, this project would never have seen the light of day. From upstream to downstream, our team provided highly creative solutions facing tremendous constraints, such as two very different intake sources converging towards the underground penstock into a combined flow of 26 m3/sec, under a gross head of 876 m – one of the longest in the world. A specially designed surge shaft was needed to reduce the impact of the "water hammer" effect created by the transformation from free flow to pressure flow in the Duhangan tunnel. To reach the 308,500-m3 flow required to operate the plant during its 4-hour daily peak, an intermediate storage reservoir, with a capacity of 221,400 m3, was built. The natural reservoir upstream added a total volume of 61,400 m3, which was insufficient, so our team calculated the volume available in the headrace tunnels and desanders and turned them into residual tanks with a capacity of 25,700 m3. The intermediate reservoir was the subject of several innovations in order to reduce its ecological footprint to a minimum: cantilever walls were used to increase storage volume with a minimal amount of concrete; high performance drainage discharges excess water into the river and recovers excess water during flash floods. The need for an upstream intermediate reservoir impelled our engineers to innovate in order to deal with free flow and pressure flow entering the Duhangan tunnel. We developed a mathematical model to study this phenomenon and then validated the results with a hydraulic model in a laboratory. Due to the size of the hydraulic system, the tunnels of the physical model took the form of a labyrinth and pressure losses needed to be compensated for using Froude's law of similarity, supplemented by a new technique. In a hydraulic structure of this magnitude, any solid particles above 0.2 mm can cause extensive damage, so we conceived an ultra-efficient water filtration system. In a context where soils are particularly heterogeneous and friable, it was necessary to develop two types of non-standard gravel traps and desanding basins. Due to the height limitations of Alimak raise climbing equipment, we also designed the geometry of the pressure conduit with three sections inclined at 52°, linked by horizontal sections. The inclined midsection (567 m) is one of the longest ever built with Alimak equipment.

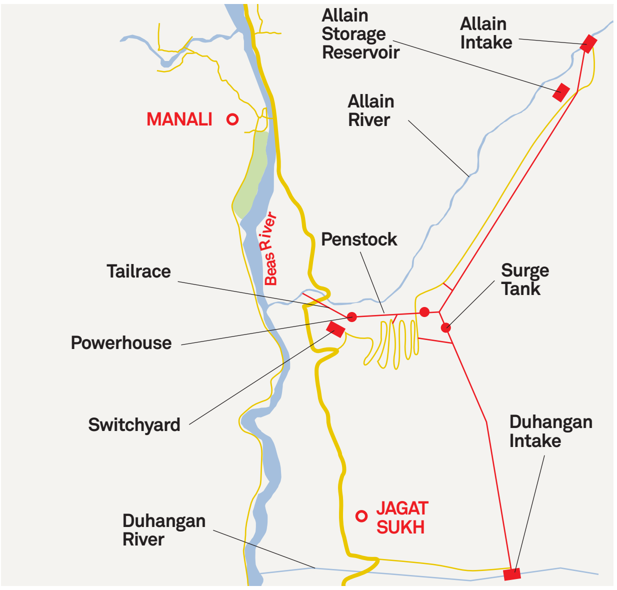
Complexity:
This project opens the way for a new era of energy development in poorly accessible regions with inclement weather. The project's complexity doesn't lie in only one or two major aspects, but affects all of its aspects: design, construction and even how it was perceived by the local population. Design: • Space didn't allow traditional storage solutions or filtration; • Distance between the two intake sources made it impossible to create an identical model on a 1:20 scale; • Difficulty in maintaining an environmental flow in conditions varying from scarcity to flash floods. Construction: • Severe weather conditions and particularly heterogeneous geology called upon our team to come up with practical solutions in dealing with a general contractor who didn't always have all the required experience; • Having to build 23 km of mountain access roads using non-mechanical methods; • High-strength steel imported from Japan and folded onsite through a TMCP process; • A penstock with a length exceeding Alimak raise climbing equipment capacity; • Having to excavate two caverns with suspended ceiling protecting from debris and water infiltration; and, • Sometimes unreasonable administrative constraints requiring solutions such as creating a 400 m steel bypass pipe to protect a few trees without delaying work. Local perception: • Having to find ways to get locals to progressively embrace the project without coming into conflict with local customs and culture, since the energy produced must also represent an asset in terms of social, if not spiritual, energy.

Social & Economic Benefits:
From 2004 to 2012, the design and construction stages brought many benefits to the people of the Himachal Pradesh region. Obviously, this project offered them a tremendous opportunity for enrichment they could not pass up. Beyond the understandable opportunistic actions of some locals, who opposed the project so as to raise the stakes, the plant had a truly positive impact on several aspects of daily life in the region. Our team was respectful of traditional methods of road construction, not only making possible the construction of a 23-km network of access roads, but also sending a strong signal of openness to the Himachalis. This team integrated 2,000 people on-site, 50% of which were women. Construction of gabion walls to prevent landslides and manual excavation of the surge shaft also positively influenced perception of the project by the locals. We reassessed the placement of a structure in order to protect a sacred Hindu place, and helped promote recreational and touristic development by creating easier access to the mountain, thereby aligning tradition with modernity. Besides benefits directly related to the electrification of surrounding villages, other local benefits included social services such as a doctor's office, pharmacy, schools, playgrounds, temples, police station, roads, bridges, drains, irrigation and drinking water facilities, street lights, electricity bills and many more. At national level, benefits include: rising employment, $7.5 M worth in free power to state government every year, boost to economy by helping meet shortage of peaking power, sustainable development/generation of clean energy.

Environmental:
The main power generation sources in the area are still the rather inefficient coal fired power plants with enormous GHG emissions. This project allowed the production of clean, renewable energy using the existing hydroelectric potential. This hydroelectric power plant became feasible due to the status of hydroelectric power as a clean and renewable energy source, since it would have been impossible to launch and finance such an ambitious project in such difficult conditions, without benefitting from the Clean Development Mechanism. The total estimated reduction in CO2 emissions over 10 years is of more than 5 million tons! The safety of the local villagers was increased, beyond all doubt, by the high-performance steel lining the underground pressure shaft, as well as by placing the intermediate reservoir on a high plateau. In fact, the particular design of the reservoir's enclosure prevented creating a flooded area that would certainly have had a much greater impact on flora (through erosion) and wildlife. Seismic studies, prepared by the Department of Earthquake Engineering, Indian Institute of Technology, Roorkee University, based on a recurrence of 1:200, established that the structures would resist up to a level 8 on the Richter scale, ensuring their stability and durability. Benefits to the environment and safety: - Comprehensive plantation, restoration of muck dumping sites, scientific disposal system for garbage; - 29,500 planted trees; - Respect of environmental standards; - Maximum amount of muck-dumping sites restored; - World class EHS standards implemented, resulting in minimum numbers of "Lost Time Incidents"

Client Needs:
During the summer monsoon, the plant can operate with 15% continuous overload. From October to May, the plant operates at its rated peaking capacity of 192 MW for four hours per day. The energy produced by the plant is transmitted to a substation that serves as a distribution center, located 175 kilometres to the south, from where it is sold to the northern India grid. Despite a sensible increase in the budget, the partners were more than satisfied with the overall development of the project, as our team demonstrated a high commitment level and the solutions provided over the 16-year long project limited the cost inflation. The customer acknowledges that our specialized expertise in energy, combined with our extensive experience in construction in extreme weather conditions, enabled them to save at least $150 million. As this project was a first on a technical point of view, this achievement is a real investment that opens the path for future development of other high-altitude sites in the Himalayas. The project's success opened new work opportunities for AECOM, as ADHPL decided to intrust us with the design of new hydroelectric plants. After the resounding success of the Allain Duhangan project, AECOM will use the same approach, with the same customer, to develop the hydrological potential of Nepal through the design and construction of the three new hydroelectric complexes: the 800 MW on Nyamyanchu River, the 120 MW Likhu hydroelectric complex and the 60 KW Balephy hydroelectric complex.

Allain headworks site with four desander basins



Maps locating the Allain Duhangan hydroelectric project

SUMMARY

AECOM was mandated by ADHPL to perform the detailed design and construction supervision of a 192 MW underground run-of-river hydroelectric project located high in the Northern Himalayas of India, harnessing the flow of two different rivers.

AECOM's professionals had to deal with huge natural and human constraints to deliver this strategic, low environmental impact project that establishes a new area of development for sites with high gross heads. The plant will supply electricity to populations struggling with frequent shortages and will reduce CO_2 emissions by more than 5 million tons over 10 years.

Intermediate reservoir

INNOVATION

Were it not for its many innovations, this project would never have seen the light of day. From upstream to downstream, our team provided highly creative solutions to the tremendous constraints they faced, such as two very different intake sources (ground morphology, altitude, flow, storage potential) that converge towards the underground penstock into a combined flow of 26 m^3/sec, under a gross head of 876 m – one of the longest in the world. A specially designed surge shaft was needed to reduce the impact of the "water hammer" effect created by the transformation from free flow to pressure flow in the Duhangan tunnel. Since the plant was to be used during peak hours only, and its valves therefore closed daily, it was crucial to design a special vent pipe to prevent air from the Duhangan tunnel to enter the pressure shaft.

The difference between the two types of flow was made even greater because the intermediate storage reservoir, with a capacity of 221,400 m^3, was built upstream on the Allain section of the design, rather than near the surge shaft (which would have automatically regulated the flow of the two rivers), because if an incident were to occur at that point, there was a potential for serious human and environmental implications. The two intake sources allowed for a partial storage reservoir built upstream on the Allain section. The 7-meter increase in water level generated by the natural reservoir upstream generated a total volume of 61,400 m^3, which was insufficient to reach the 308,500 m^3 required to operate the plant during its 4-hour peak. Therefore, we calculated the volume available in the headrace tunnels and turned them into residual tanks with a capacity of 10,200 m^3. The desanders were also set up to store 15,500 m^3 for peak hours.

Desanding basins (on the left) and sluiceway (on the right), upstream of the Allain intake

INNOVATION

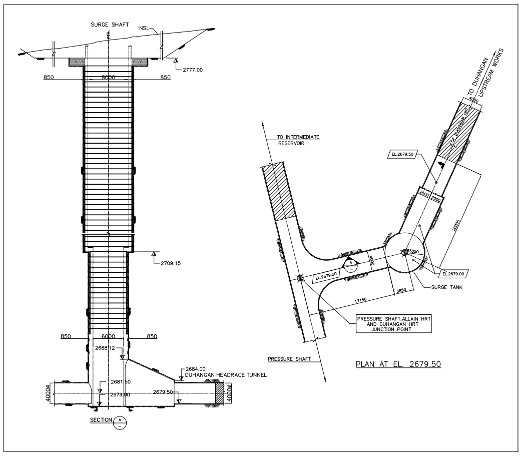
The intermediate reservoir itself was the subject of several innovations in order to reduce its ecological footprint to a minimum and create a veritable ''prison of water''. This was achieved by designing cantilever walls rather than gravity walls to increase storage volume using a minimal amount of concrete, as well as high performance drainage to discharge excess water back into the river and recover the excess water as needed during flash floods, thus preventing the creation of a flood zone. However, having to use an upstream intermediate reservoir made us innovate once again in order to deal with the combination of two types of flows – free flow (Allain) and pressure flow (Duhangan) – entering the Duhangan tunnel, which no existing tool could evaluate! We therefore developed a unique mathematical model to study this complex phenomenon by digitally integrating differential equations of momentum and continuity. The results were validated with a hydraulic model in a laboratory in LaSalle, Montreal. Due to the size of the hydraulic system and the limited space in the laboratory, the tunnels of the physical model, made with ABS pipes, took the form of a labyrinth. This meant that the pressure losses in the model were higher than in real life. To compensate, the scaling of the physical model was made using Froude's law of similarity, supplemented by a new technique, called the method of equivalent dimensions.

In a hydraulic structure of this magnitude, with a gross head of 876 m, any solid particles above 0.2 mm can cause extensive damage, thus we conceived an ultra-efficient water filtration system. In a context where soils are particularly heterogeneous and friable, it was necessary to develop two types of non-standard gravel traps and desanding basins. With four independent desanding basins 110 m long and 8 m wide, the headworks at the Allain site slows flow rate to 17 cm/s. Each basin is equipped with a valve to drain it without affecting the use of the other three. The trench weir at the Duhangan site (one of the largest capacity in the world for this type of work) is covered with a trash rack that feeds an underground 120 m long by 10 m wide desander (a device never used in America) leading to the headrace tunnel, as well as a drain pipe guaranteeing environmental flow back to the river bed during dry periods. The desander has two discharge devices; the first removes the gravel, the second removes sand. A bypass tunnel allows for necessary repairs to the intake works. In order not to stop energy production when the Duhangan flow was added, a horizontal valve was installed and opened when balance between the upstream and downstream water pressure was achieved.

Due to the height limitations of Alimak raise climbing equipment, we had to innovate once again. We designed the geometry of the pressure conduit with three sections inclined at 52°, linked by horizontal sections. It should be noted that the inclined midsection of 567 m, is one of the longest ever built with Alimak equipment.

Desanding basins for the Allain intake

Interior of intermediate reservoir



Plan for the headrace tunnel (left) and surge shaft (right)

Access tunnels

COMPLEXITY

This project can be considered a flagship project, as it opens the way for a new era of energy development in poorly accessible regions with inclement weather (temperatures ranging from -10º C to +40º C, heavy rains during monsoon period and heavy snowfall in winter, which meant importing snow blowers from Quebec). The project's complexity doesn't lie in only one or two major aspects, but affects all of its aspects: **design**, **construction**, and even **how it was perceived** by the local population.

Design

It was complex in terms of design because of:

- Space limitations that did not allow traditional storage solutions or filtration (both crucial to the feasibility of the project);
- The distance between the two intake sources, making it impossible to create an identical model on a 1:20 scale (a more than 300 m long lab would have been necessary);
- The difficulty in maintaining an environmental flow when dealing with conditions that can vary from scarcity to flash floods.

Duhangan intake

COMPLEXITY

Construction

It was complex in terms of construction because of:

- Severe weather conditions;
- Particularly heterogeneous geology that even extensive studies could not fully apprehend (presence of overburden and soil porosity at unusual depths caused by a hidden lake upstream), which called upon our team to come up with practical solutions and have great flexibility in dealing with a general contractor who did not always have all the required experience (excavation methods requiring additional steel belts, grouting, multiplication of boreholes to accelerate work);
- Having to build 23 km of mountain access roads using non-mechanical methods, and onsite folding of high-strength steel imported from Japan through a TMCP process;
- A penstock with a length exceeding the capacity of Alimak raise climbing equipment, thereby influencing the decision to design it in three inclined sections;
- Having to excavate two caverns, with suspended ceilings protecting from debris and water infiltration, on the main bank of the Allain river (the machine hall – 68 m long x 18.4m wide x 31.4 m high – houses the two Pelton units, auxiliary equipment, services, control room, etc. and transformer cavern – 72 m long x 11 m high x 12 m wide – houses seven transformers);
- Sometimes unreasonable administrative constraints requiring solutions such as creating a 400 m steel bypass pipe to protect a few trees without unduly delaying work.

Local Perception

Finally, it was complex in terms of finding ways to get the local population to progressively embrace the project without coming into conflict with local customs and culture:

- Through a productive integration of ancestral methods of construction (gabion walls);
- By contributing to the modernization of local infrastructure and institutions while respecting religious rites that led to ‘‘acceptance of the project by the gods”, an intangible, yet important part of the acceptance and successful completion of the project, since the energy produced must also represent an asset in terms of social, if not spiritual, energy.

Switchyard and transmission lines

Superior reservoir

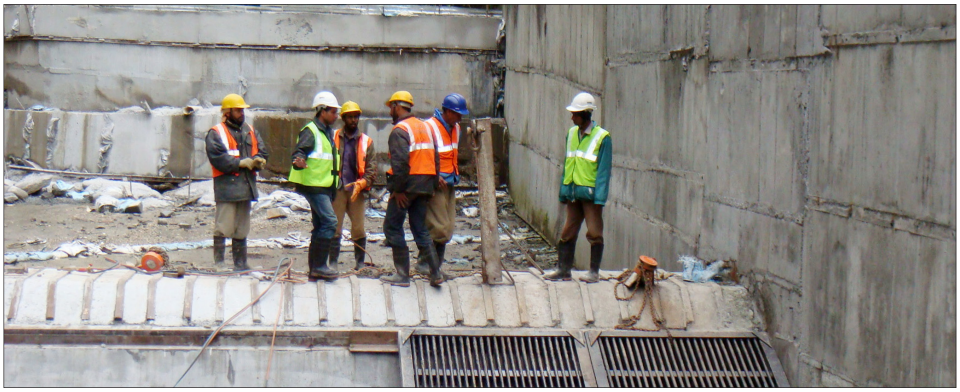
Intermediate reservoir

SOCIAL AND ECONOMIC BENEFITS

The art of channelling power for change

Spread over more than 16 years, this major project underwent several stages. From 1995 to 2003, prefeasibility studies, recognition of land, and bankable feasibility studies were carried out, then; from 2004 to 2012, the design and construction stage brought many benefits to the people of the Himachal Pradesh region ("The land of snowy mountains") and the local population. Obviously, this project offered them a tremendous opportunity for enrichment that they could not pass up. Beyond the understandable opportunistic actions of some locals, who opposed the project so as to raise the stakes, the plant had a truly positive impact on several aspects of daily life in the region.

This impact was maximized through the open-mindedness of our team who was able to integrate the local workforce with great discernment and respect. Also, use of traditional methods of road construction not only made possible the construction of a 23-km network of access roads that boosted specialized tourism (trekking, outdoors), but also sent a strong signal of openness to the Himachalis: knowledge is not the exclusive property of the promoter and specialists! Our team employed 2,000 people on-site, 50% of which were women. Besides the access roads, construction of gabion walls to prevent landslides and manual excavation of the surge shaft (a hole 100-meters deep, with a diameter of 8.5 meters) were two elements that also positively influenced perception of the project by the locals. Our proactive approach to workplace safety ensured that, in five years, no serious accidents occurred on the different work sites. For such a large project to be as in synch with its environment as possible, it was not only important to avoid physical injuries, but also to pay close attention to any "cultural" wounds. With this in mind, we strove to rethink the placement of a structure in order to protect a sacred location, wetlands that were a place of pilgrimage for Hindus, while also helping to promote recreational and touristic development by creating easier access to the mountain, thereby aligning tradition with modernity.



Local construction workers working on the trench weir site at Duhangan intake

Official and traditional inauguration of Allain site

In addition to providing electricity for the benefit of people in northern India, the Allain Duhangan hydroelectric project contributed locally to the implementation of different important services for the population, such as a pharmacy, a doctor, a school, a police station and a temple. The modern nature of this type of work will generate a second form of sustainable development for the surrounding communities.

SOCIAL AND ECONOMIC BENEFITS

Social Services

Besides the benefits directly related to the electrification of surrounding villages, many other social services were set up:

- Construction of a doctor's office and pharmacy
- Construction of school buildings and playgrounds
- Construction of temples and religious structures
- Construction of a police station
- Construction of foot paths, roads, and bridges
- Construction of drains/kuhls
- Irrigation and drinking water facilities
- Donations for fairs and other religious meets
- Financial help for persons in need of medical treatment, education, house repairs
- Donation to organize sports competitions
- Construction to prevent land erosion
- Community sanitation facilities
- Construction of community hall and other infrastructures
- Street lights and electricity bills
- Cleaning in project-affected ''Panchayats'' (local self-governments in small villages)
- Income generation and awareness programme

Benefits at national level:

- Employees were more than 75% Himachalis
- The company will be giving royalty to the State Government in the form of free power equivalent to Rs 40 Crores ($7.5 M CAD) every year
- Promotion of sports like boxing and volleyball at state level by cultivating young talents at ground level
- The project will help meet shortage of peaking power in a country where the power is a major driver to boost the economy
- Generation of employment in the project area
- Infrastructure development in remote and border areas
- Sustainable development/generation of clean energy

Corporate Social Responsibility

As part of our CSR initiatives and commitment, we are proud that half of the workers on-site were women and 75% were local Himachalis. Our respect for their local customs and traditions allowed us to integrate them easily into our workforce. The client even sponsored the Winter Carnival Celebration at Manali.

Local construction workers on site

Construction of access roads using traditional methods.

ENVIRONMENTAL IMPACT

A mountain that slowly reveals all its secrets while safeguarding its soul

The main power generation sources in the area are still the rather inefficient coal fired power plants with enormous GHG emissions. This project allowed the production of clean, renewable energy using the existing hydroelectric potential. This hydroelectric power plant became feasible due to the status of hydroelectric power as a clean and renewable energy source, since it would have been impossible to launch and finance, such an ambitious project in such difficult conditions, without benefitting from the Clean Development Mechanism. The reduction in CO_2 emissions over 10 years is estimated at more than 5 million tons!

The safety of the local villagers was increased, beyond all doubt, by the high-performance steel lining the underground pressure shaft (610 MPa, with a thickness gradually increasing from 16 mm upstream to 65 mm at the surge shaft), as well as by placing the intermediate reservoir on a high plateau. In fact, the particular design of the reservoir's enclosure prevented creating a flooded area that would certainly have had a much greater impact on flora (through erosion) and wildlife.

Powerhouse and switchyard

Benefits to the environment and safety

- ADHPL took initiatives for comprehensive restoration of muck dumping sites and garbage collection from the project areas, deploying scientific methodology for its disposal.
- ADHPL planted about 22,000 trees in the project areas under the income generation schemes by deploying local self-help groups. Besides this, the project also planted about 7,500 trees around the project area at various occasions like World Environment day, Earth day and Van Mahostav.
- During construction, all environmental standards were observed by deploying qualified staff, headed by senior management officers. Regular monitoring and compliance as per standards of the "Pollution Control Board" is done since construction.
- ADHPL was allotted nine muck-dumping sites for storage of muck generate, out of which a maximum number of sites have been restored under the guidance of State forest department and pollution control board.
- These efforts of ADHPL have been recognized by the Sh Abhay Shukla committee appointed by the Honourable High court of Himachal Pradesh in compliance with environment safeguards. The committee has even recommended the project roads as a model for other agencies.
- ADHPL implemented world-class EHS standards, resulting in the successful completion of the project with minimum numbers of "Lost Time Incidents".

SEISMIC STUDIES

Seismic studies, prepared by the Department of Earthquake Engineering, Indian Institute of Technology, Roorkee University, based on a recurrence of 1:200, established that the structures would resist up to a level 8 on the Richter scale, ensuring their stability and durability.

Pelton turbines, inside the main cave.

MEETING CLIENT'S NEEDS

An extraordinary structure with an impact on everyday life

During the summer monsoon, the plant can operate with 15% continuous overload. From October to May, outside the monsoon season, the plant operates at its rated peaking capacity of 192 MW for four hours per day. The energy produced by the plant is transmitted to a substation that serves as a distribution center, located 175 kilometres to the south, from where it is sold to the northern India grid.

A key budget that opens many doors

Despite a sensible increase in the budget, the partners were more than satisfied with the overall development of the project, as our team demonstrated a high commitment level, and the solutions provided over the 16-year long project limited the cost inflation. The customer acknowledges that our specialized expertise in energy, combined with our extensive experience in construction in extreme weather conditions, enabled them to save at least $150 million. As the project was, on many levels, a first on a technical point of view, this achievement is a real investment that opens the path for future development of other high-altitude sites in the Himalayas.

Showcasing Canadian engineering by harnessing a mountain's power

The project's success opened new work opportunities for AECOM, as ADHPL decided to entrust us with the design of new hydroelectric plants. After the resounding success of the Allain Duhangan project, AECOM will use the same approach, with the same customer, to develop the hydrological potential of Nepal through the design and construction of three new hydroelectric complexes: the 800 MW on Nyamyanchu River (more than 4 times that of Allain Duhangan), the 120 MW Likhu hydroelectric complex and the 60 KW Balephy hydroelectric complex.

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