Glendoe Hydroelectric Scheme, Optimisation and Dam Selection

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SYNOPSIS. The Glendoe Hydroelectric Scheme will be the first major conventional hydro scheme to be built in the UK for over 40 years. The scheme will include a 1km long, 35m high rockfill dam, over 18km of hard rock tunnelling, and an underground powerhouse with an installed capacity of 100MW and an operating head of over 600m.

The project was tendered on a design-build basis in order to proceed to contract award in parallel with the planning process. This led to a phased development of the design through a two stage tender process leading onto the detailed design.

The dam is located in the Monadliath mountains at an elevation of 600m. The natural materials available are the bedrock and glacial fill, which is overlain by peat. A range of dam types were considered through the design process, with the final design developed by the successful construction tenderer. As with any dam a number of alternatives are viable and the final design reflects a judgement on the most efficient construction in the particular site, with due regard to the particular skills of the contractor.

This paper gives a brief overview of the background to the project, the approach to procurement, the scheme optimisation and the choice of dam type.

INTRODUCTION

As part of their commitment to generating electricity from renewable sources Scottish and Southern Energy (SSE) are constructing a new hydroelectric project in the Scottish Highlands. With an installed capacity of 100MW and an operating head of over 600m Glendoe will be the first major conventional hydro scheme to be built in the UK since the completion of the North of Scotland Hydro Electricity Board schemes in the early 1960's.

The Glendoe hydro scheme is located in the Monadliath mountains to the south east of Fort Augustus, overlooking Loch Ness. The reservoir is at an elevation of 630m, with a direct catchment of 15km^2 supplemented by transfer aqueducts in pipeline and tunnel to give a total of 75km^2. The indirect catchments are all on tributaries which naturally discharge to Loch Ness in the vicinity of the scheme. From the reservoir the pressure tunnel leads to a power house and tailrace. The total tunnel length between the reservoir and Loch Ness is 8km.

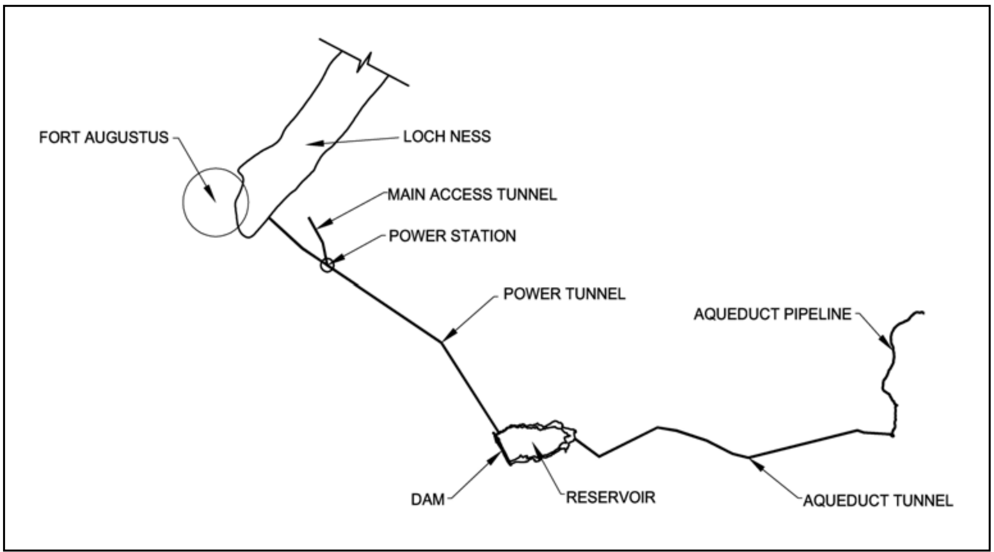

Figure 1. Glendoe Scheme Layout

SCHEME OBJECTIVES

As part of the Scottish Climate Change Programme, the Scottish Executive is committed to raising the overall proportion of electricity generated from renewable sources in Scotland to 18% by 2010. In 2001 the Renewables Obligation confirmed that new Hydro Electric schemes of any magnitude would qualify under this incentive, whereas this had previously only been expected to be applicable for new hydro schemes of less than 10MW. Under the Renewables Obligation, all licensed suppliers are required to source an increasing amount of their electricity from renewable sources or alternatively make a payment into the “buy-out” fund. Hence the size of the “buy out” fund is directly related to the level of suppliers compliance with the Renewables Oblgation (bearing in mind that the target levels of renewable generation increase year on year). A Renewable Obligation Certificate (ROC) is evidence that a supplier has sourced a megawatt hour (MWh) of its electricity from renewable sources. Once ROCs and buy-out fund payments have been produced Ofgen then re-distributes the buy-out fund collected to the holders of each ROC. In 2003/04 this gave a net benefit of around £54 per ROC , which is considerably greater than the energy value of the electricity.

SSE revisited the large schemes that had previously been identified, but not constructed, during the North of Scotland Hydro Electricity Board days. A review of these schemes was carried out taking into account current environmental, planning and construction practice. Of the areas previously identified for large hydro development, all bar Glendoe were shelved due to the potential environmental impact in areas highly valued for recreational and habitat uses.

Options considered for Glendoe, ranged from a sub -10MW run of river scheme to a large pumped storage scheme. The output from the smaller schemes could not justify the substantial capital costs of transporting the water from the plateau down to Loch Ness. The pumped storage option was discarded for two reasons:

- Because the electricity generated would not qualify for Renewable Obligation Certificates (ROCs) as pumping may use non-renewable sources of energy.
- The horizontal distance between the upper and lower reservoirs was excessive which would lead to hydrualic and construction issues which would be uneconomic to overcome.

The selected scheme at Glendoe involves a 100MW power station which will produce 180 Gigawatt hours (GWh) in a year of average rainfall. The net head of water at Glendoe will be greater than 600m – the highest head of any hydro scheme in the UK. In terms of water to power, the Glendoe hydro scheme will be the most efficient in the UK.

PLANNING PROCESS

In October 2001 the Glendoe area was identified as the preferred location for the development of a large scale hydro scheme and initial contact meetings were arranged with the statutory consultees and other interested parties. The preparation of the environmental statement and the refinement of the outline design for Glendoe were carried out from Spring 2002 until May 2003 when an application was made for planning consent under Section 36 of the Electricity Act 1989. An addendum to the Environmental Statement was issued in January 2004. The Highland Council recommended acceptance of the application (with conditions) on the 20th April 2004. A second addendum was submitted in January 2005. Final consents were granted in June 2005.

IMPROVEMENTS IN RESERVOIRS

PROJECT STRATEGY

It has generally been expected that the level of compliance with the Renewables Obligation will improve with time, hence the buy-out fund is expected to reduce towards zero over a period of several years. In addition, there is uncertainty in future UK electricity prices. In order to minimise income risk there was a need for SSE to minimise the overall project programme. The greatest programme uncertainty for Glendoe was the time taken to obtain all necessary planning consents. At Glendoe even though there were very few letters of objection to the scheme, and the local community have generally been supportive, the Section 36 application still took over 2 years to be granted approval.

The strategy taken was to initially concentrate on submission of the planning application and finalising landowner deals. While the planning application was being considered the design and construct tendering process was to be taking place.

One reason why the design and construct route was selected for Glendoe was that until deals with the landowners had been finalised SSE were not permitted to carry out intrusive site investigation works on the land. Deals with the landowners were not concluded until early 2004. To minimise the overall project programme SSE could not afford to wait until then to start the design process.

This strategy meant that the planning application was based on SSE's preliminary design work. As there were no site investigation results available at this time, it was essential to keep adequate flexibility within the planning application to enable a detailed value engineering exercise to take place during the procurement phase. As a result, the initial planning application covered a relatively wide scenario of development including options for the power station to be underground or on the surface, the output from the station ranging between 50MW and 100MW and the likely dam construction technique being either roller compacted concrete or rockfill.

PROJECT DEVELOPMENT PROCESS

By electing to proceed with the design and procurement of the project in advance of planning approval, SSE were under a number of constraints relating to site access, budget availability and timing of the various activities. The project development therefore consisted of a series of increasing levels of expenditure and commitment as confidence in gaining approval increased.

The process adopted involved:

Activity	Resources	Programme
SSE concept development and planning submission.	SSE, planning & environmental consultants.	September 2001 - May 2003
Environmental surveys.	environmental consultants	2002/2003
Concept optimisation, scheme definition through workshops.	SSE and Jacobs	September 2003
Prequalification of Civil and Plant Contractors.	SSE	December 2003
Phase 1 Reference Design and Tender documents.	SSE and Jacobs	October 2003 – January 2004
Phase 1 Tender period to select 2 contractors for subsequent bid.		January – May 2004
Aerial geophysics survey.	Fugro	February 2004
Intrusive Site Investigation.	Fugro	May - July 2004
Phase 2 Tender Design and bid.	Skanska-Morgan Est jv. Hochtief	July – November 2004
Tender Assessment.	SSE and Jacobs	December 2004 - July 2005
Planning Approval and decision to proceed with project.	Scottish Executive / SSE	Final decision July 2005
Notification of preferred Contractor.	SSE	August 2005
Finalisation of Contract.	SSE / Jacobs / Hochtief	August – December 2005
Contract Award	SSE	December 2005
Detailed Design and Construction.	Hochtief	January 2006 onwards

The objective of the phased tender process was partly to respond to the increasing availability of information and client confidence in the project, but also to balance the SSE requirement for competitive tenders with the desire to minimise the tenderer's costs as far as practicable.

SSE adopted the NEC as their standard form of construction contract, and aim for a fixed price basis as far as practicable. Option A of the NEC (Priced contract with activity schedule) was therefore used. A variable payment mechanism which allows predetermined compensation for the ground conditions actually encountered in the tunnels is incorporated through 'Z clauses' {Seaton & Hobson 2005}.

IMPROVEMENTS IN RESERVOIRS

CONCEPT OPTIMISATION

The planning application was made in such a manner to enable the optimisation of the scheme to be delayed so that SSE could get a better assessment of the likely capital costs of the scheme against the potential income that the scheme would generate on the renewable energy market.

For the Reference Design to be used for the first tender phase, the key issues were:

- Aqueduct System: intake type, aqueduct alignment, tunnel construction;
- Dam: dam type, spillway and outlet works layout;
- Power Tunnel System: alignment (vertical and horizontal), tunnel construction, surge system;
- Power Station and Generation Plant: location, turbine type and size, transformer location, operating regime

Jacobs were appointed in September 2003, and tasked with working with SSE to prepare the Phase 1 Tender by the end of the year. To achieve this, the basic scheme parameters had to be fixed within 4 weeks, which precluded detailed feasibility and optimisation studies. The approach taken was to run a series of workshops, interspersed with technical studies, in order to make best use of the diverse experience and skills available within the combined SSE/Jacobs team. The workshops were attended by representatives of all the engineering disciplines in the Jacobs team, with SSE staff representing planning, construction, operation, maintenance and energy trading disciplines. Achieving a balance between the physical constraints of the site and the objectives of the end users was particularly critical for the optimisation of the power system and the multidisciplinary workshop approach worked well in this area.

<u>SSE ‘end user’ objectives</u>

SSE gain significant value from the scheme by the ability to provide peaking power when required by the grid. The most important factors are:

- reliability – the certainty of being able to supply power at the time promised
- rapid response (how quickly the scheme can come on or go off load)
- efficiency – obtaining the maximum power for the water available
- flexibility – the ability to generate efficiently over a wide output range
- ease of operation and maintenance, minimum downtime

One of the benefits of hydro generation over other forms of power production is its ability to store power in a reservoir, ready to be used when required. This flexibility has significant benefits to the environment, transmission system and developer. ‘Peaking power’ attracts a significant premium value compared with base energy prices. Although the proposed volume of the reservoir is small in comparison to SSE’s existing stock, due to the altitude above the turbine and the relatively small amounts of water required to generate large amounts of electricity, Glendoe does have the ability to contribute substantially. The reservoir has the capacity to store water to generate over 10 GWh of electricity ready for dispatch when the demand requires, thus complementing other forms of “must take” renewable energy.

Physical Constraints

The reservoir is located on a plateau approximately 8km from Loch Ness. After crossing a ridge adjacent to the River Tarff the ground profile above the pressure tunnel falls relatively regularly towards the loch. Hence there is no suitable site for a surge shaft, except close to the reservoir where it has limited hydraulic benefit. The rock cover is also relatively low over the downstream section of the tunnel. Where the reservoir head gives a water pressure greater than the confining rock pressure, rock joints will be opened by the water and leakage will result. Over time the water will penetrate throughout the rock leading to increased leakage and in areas of low cover could create slope instability. It thus becomes necessary to provide a steel lining wherever the water pressure could be greater than the confining rock pressure. This situation is exacerbated by transient pressures arising due to the operation of the system.

Turbine Characteristics

With 600m head the two most viable types of turbine are either Francis (where the runner is enclosed within a fully pressurized hydraulic system) or Pelton (where the runner is in air and turned by the impact of water jets). To achieve a station which could come on or off load within a matter of seconds would require a Francis turbine. However it is impossible to avoid the potential to trip the guide vanes on the turbine, giving substantial transient effects. This would require substantial engineering to ameliorate the transient pressure in the absence of a surge shaft (pressure release valves, air pressure chamber or steel linings to the tunnels were considered). A Francis turbine requires submergence and a long tailrace would also lead to the need for a downstream surge shaft.

A multiple jet Pelton turbine has a good efficiency over a broad range, but cannot be brought on load quite as quickly as a Francis. The Pelton turbine jets have deflectors which can isolate the runner, without instantaneously stopping the water flow, thus reducing the transient effects. SSE determined that the additional commercial benefit of a very fast response time did not justify the increased complexities required in adopting a Francis turbine.

The main civil works for the scheme are substantially the same for either a 100MW or a 50MW scheme, as the tunnels are close to the minimum diameter for efficient construction. There was therefore relatively little cost increase in adopting the 100MW scheme. There are significant operational benefits in the increased capacity (water management is greatly improved as SSE will have far more control the upper reservoir water level, thus being able to hit more periods of peak energy prices) , although the total annual energy production is constrained by the water available to around 180 GWhr/year.

Selected Power System

For the Glendoe site the physical constraints and operational priorities lead to the following system:

- an underground power house, located to minimise the length of steel lining
- a headrace tunnel inclined at the maximum gradient for constructability, to maximise rock cover
- a tailrace at near-horizontal gradient, to maximise head on the power station
- a 6-jet pelton turbine, which can minimise transient pressures and which has a broad efficiency range, while providing secondary response
- a 100MW capacity, with a load factor of 20%

Although the optimum power house location was considered to be at the point minimizing the steel lining, for the Phase 1 tender it was moved downstream in order to obtain additional cost information. Both Phase 2 bidders moved the power station back upstream in their later tenders.

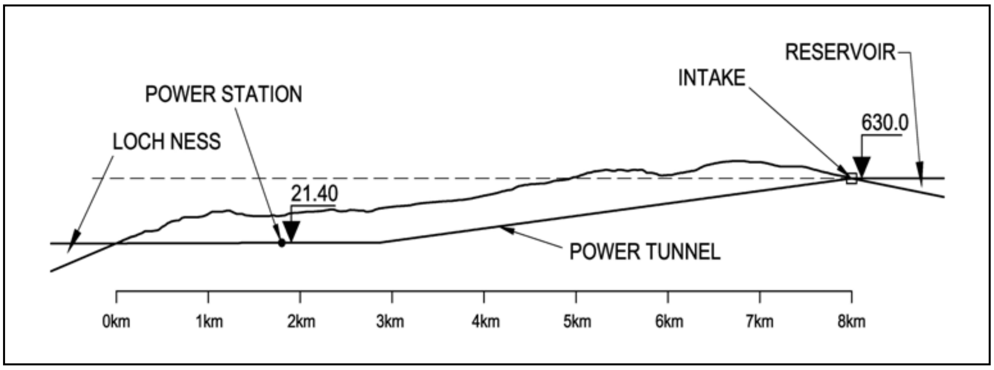

Figure 2. Section on Power Tunnel.

DAM SITE GEOLOGY AND MORPHOLOGY

The reservoir is on the river Tarff, which eventually passes through Fort Augustus to discharge into Loch Ness. The reservoir has a full supply level of 630m, a total storage volume of 11.5M,m^3 and a live storage volume of 5.8M.m^3. The area at full supply is around 1.5km^2. The reservoir water level is restricted to a 6m operating range on environmental grounds.

The river is in a steep sided channel, leading to a rocky gorge. The surrounding area is a broad plateau of peat-hag, with further hills rising beyond the reservoir margin. Thus the dam is around 35m high for the 100m wide river channel section, and typically 10m to 15m high over most of the remaining 900m length.

The bedrock is schist with granite intrusions, overlain with glacial till and peat. The till is a variable granular material, largely sand and gravel with some boulders and little clay.

A number of major faults have been identified, including the Stronlairg fault which passes through the left abutment of the dam.

The construction materials which will be readily available at the site are:

- tunnel spoil : variable rock
- quarried rock
- glacial till : variable granular material

No reliable source of clay has been identified, and only limited quantities of natural river sand have been located. Aggregates and fill are therefore likely to be produced from processed rock, including tunnel spoil where practicable.

DAM AND SPILLWAY OPTIONS

The principle constraints on the dam selection are:

- profile : long, relatively low flank sections, with higher river section
- materials : no clay for core, tunnel spoil and rockfill readily available
- access : high transport costs for off-site materials
- climate : severe winter environment, restricted access for operations staff
- hazard rating : Fort Augustus lies on the river downstream of the dam
- limited site investigation : need for adaptable design
- environmental : maximum re-use of site produced material

For the Reference Design it was also appropriate to use generally available technology and avoid specialist operations which would limit competition between contractors.

Prior to developing the Reference Design an `Options Study' was carried out for all the major elements of the scheme. The dam types which were evaluated included:

- Concrete: roller compacted concrete (rcc), gravity
- Rockfill Embankment:
- Upstream membrane: concrete faced rockfill (cfrd), asphaltic face, geomembrane,
- Central cutoff: asphaltic core, geomembrane, diaphragm wall

In addition a range of spillway layouts were considered:

- gravity section ogee weir in river channel
- rcc weir in river channel
- weir at right abutment, with channel to river
- drop shaft spillway at river channel
- side-channel weir at right abutment.

The PMF flood inflow is relatively modest at around 200 m^3/s, which is routed to around $160m^3/s$ depending on spillway design. The climate is extreme and access can be difficult in winter so no gated designs were considered. One tenderer offered a vented siphon spillway option, which had not been seriously considered by Jacobs.

DAM AND SPILLWAY ADOPTED DESIGNS

For the Reference Design, Jacobs considered issues of buildability, use of local materials, uncertainties in foundation conditions, conformity with the planning application, integration of the outlet structures and suitability for competitive tender. The rockfill embankment was the clear favourite for the long sections on the flanks. Asphaltic options would have restricted competition, so the CFRD was adopted. This was detailed to the typical details of ICOLD Bulletin 70 (1989). The low embankments are not ideal for slipforming the concrete face efficiently, but this is a well proven design, with good precedent within the SSE portfolio of dams. For the Stage 2 Design-Build tender, one contractor adopted the CFRD, with minor modifications, and the other proposed an asphaltic core rockfill embankment. This is a standard solution in Scandinavia under similar conditions, and the contractor had good access to this expertise.

The spillway adopted for the Reference Design was a gravity concrete ogee weir in the river valley. In order to set the wing-walls out of the river channel to reduce cost, the weir was 100m long. This had the added benefit of minimising the flood rise and hence freeboard requirements, albeit the weir concrete volume was substantial. This central spillway facilitated the integration of diversion and low level outlet works. The tenderers identified the spillway as an area for cost saving and almost all the layouts considered in the options study were proposed by various contractors. The two preferred solutions on the Stage 2 tender were either the drop-shaft spillway in the river channel, or a side channel weir at the right abutment. The significant potential cost of the channel from the abutment to the river has been mitigated by excavating the channel into rock and leaving it largely unlined. This is the solution adopted by the winning tenderer.

PHASE 2 TENDER AND CONTRACT AWARD

While the Phase 1 Tender assessment was in process an intrusive site investigation was carried out. This followed consultation with the contractors to ensure that any particular information they required was targeted. Access to the upper plateau was only available on foot and by helicopter, which severely constrained the amount of drilling work which could be carried out. Reasonable access was available on the power tunnel alignment, permitting a number of 400m deep boreholes, with hydrofracture water pressure testing of the insitu rock stresses at full depth. This indicated that the horizontal confining stress is at least as great as the vertical rock stresses, reducing possible requirements for steel lining to the tunnels. The intrusive investigation was supplemented by geophysical techniques on the dam alignment and a helicopter mounted resistivity survey of the entire project area. The aerial geophysics gives a broad indication of the depth of cover to sound rock and of major geological features across the entire site. The combination of techniques permitted increased confidence in the Phase 2 design, though detailed investigations will still be required at key structure locations during the construction period.

Figure 3. Dam Site Investigation

IMPROVEMENTS IN RESERVOIRS

Two consortia were invited to submit detailed tenders during the second phase of the tender process. The tenderers were encouraged to optimise their design by being given tender assessment criteria identifying the monetary value (identified in terms of NPV over the project life) that SSE would place on their tender designs in respect of the following:

- water yield from catchment, achieved by:
  - additional intakes (limited by the planning application)
  - moving intakes downstream by reducing aqueduct gradients
- net head on turbine, improved by:
  - reduced headloss through larger diameter power tunnel or revised tunnel construction method
  - raising reservoir storage level by up to 6m by a limited relocation or construction of a larger dam
  - lowering the turbine closer to the Loch Ness flood level.
- efficiency of plant
  - Tenderers encouraged to offer high quality plant to increase reliability
- useful volume of reservoir storage (scheme flexibility), increased by:
  - raising dam height
  - relocating dam.

This is a balance between the various elements as changes to any part of the hydraulic system affect the others. Hence for example raising the reservoir storage level could improve head on the turbine and increase storage volume, but may reduce the available catchment. Taking the above criteria into account together with the tender price and programme enabled the project team to accurately establish the optimum design for the site for the assumed electricity market conditions.

The successful tenderer, Hochtief, has optimised the scheme, with modest adjustments to the Reference Design tunnel and dam alignments and various detailed design changes, in particular moving the power station upstream to minimise the length of steel lining, and relocating the aqueduct intake structures to give the maximum practical yield.

A letter of intent was placed with Hochtief in November 2005 and design work started immediately. The construction contract was awarded in December 2005. Tree felling commenced in December as soon as site possession was available. Mobilisation and enabling works started in January 2006 with a start to work on site roads, assessment and upgrading of the River Tarff Road Bridge to accommodate all predicted construction traffic, placing a contract with Herrenknecht for provision of a 5.0m diameter refurbished TBM and submitting a planning application for the work camp. Construction started in the Spring allowing the full labour force to be mobilised by early summer. Contract completion is currently planned for 28 February 2009.

REFERENCES

Seaton, M, Hobson DA (2005). *Glendoe Hydroelectric Scheme – Planning and Procurement.* Underground Construction 2005, UK