THE STATE ELECTRICITY AUTHORITY
GOVERNMENT OF ICELAND

BURFELL PROJECT

GENERAL APPRAISAL

SWISS ALUMINIUM LTD.
ELECTRO-WATT
ZURICH

NOVEMBER 1963

THE STATE ELECTRICITY AUTHORITY

GOVERNMENT OF ICELAND

B U R F E L L   P R O J E C T

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INTRODUCTION

Investigations have been performed by Harza Engineering Company International since 1959 on the feasibility of the Burfell Project for the State Electricity Authority, Government of Iceland.

In the course of their investigations they have studied various alternate schemes developing the bend of the Thjorsà River near Burfell or the head existing between the Thjorsà River and its affluent the Fossà River in the same area. These various schemes are illustrated on drawing no. 50397. The Scheme C (see dwg. 50397) was recommended by Harza Engineering Company International as the most favourable of the alternate solutions suggested.

Swiss Aluminium Ltd., which plans to develop together with partners an aluminium reduction plant using power generated by the Burfell Project, has asked Electro-Watt to review the scheme proposed by Harza in an attempt to find an alternate solution which could be readily developed in stages and would result in the lowest possible initial power cost and investment. An installed capacity of 105'000 kW has been suggested for the first stage of development.

It has been suggested further to investigate possibilities of providing mostly surface structures since this would permit more readily the development in stages. Finally, while Harza recommends a tail-race scheme, it has seemed interesting to study a more conventional, head-race project, inasmuch as the tail-race type of development results necessarily in major underground structures.

The following reports prepared by Harza Engineering Company International were put at Electro-Watt's disposal by Swiss Aluminium Ltd. for this study :

- Summary Report on Burfell Project, Thjorsà River, Iceland, November 4th, 1961
- Appraisal Report on Burfell Project, Thjorsà River, Iceland, March 1962
- Project Planning Report, Burfell Project, Volume I, January 1963
- Project Planning Report, Burfell Project, Volume II, February 1963
- Second Supplementary Report, Burfell Project, October 1963

The present study was prepared in cooperation with Swiss Aluminium Ltd. and is necessarily of a general nature. In view of the extensive investigations performed by Harza, the results of this study, as well as the comments on the scheme selected by Harza, are merely presented as suggestions and should be scrutinized by those engineers having a thorough knowledge of the site from the viewpoints of the geology, climatology and topography.

REVIEW OF THE SCHEME RECOMMENDED BY HARZA

The project suggested by Harza is based on extensive investigations from all viewpoints. It has been recommended after various alternatives were studied and compared. Demand growth and economics of the project were first analysed thoroughly before arriving at the recommended solution. Work performed by Harza is very commendable and the reports summarizing the studies give a complete picture of the conditions to be encountered and of the reasons for selecting the alternative suggested.

Geological conditions appear to be very complex and to vary considerably over the area. Layers of volcanic rock of limited thickness and extent, suitable for large underground structures, alternate with rather poor formations. Difficulty in finding a favourable location for the underground powerstation and surge tank seems to have been the determining factor in the selection by Harza of a tail-race type of scheme.

Favourable geological conditions would permit to leave unlined the long tail-race required by such a scheme and to provide underground large surge tanks at reasonable cost, while a head-tunnel under pressure would require concrete lining irrespective of geological conditions, and surge tanks would tend to be expensive when built on the surface. However, the advantages accruing from the tail-race type of scheme appear to be impaired in this particular case by unfavourable geological conditions.

Drill holes have been made in the area selected for the powerstation. However, owing to the volcanic character of rock formations (flows and intercalated sediments), it appears questionable whether the site suggested for the powerstation would actually lie in the basalts of the Samsstadamuli group which have been recognized as the only rock formation in the immediate vicinity suitable for large caverns. The selected site lies very near the limits of this zone which cannot be ascertained with a sufficient degree of accuracy on the basis of the existing investigations. Even if this basalt layer extends actually as surmised from explorations, the cavern roof will be excavated very near the layer top. Since basalt is surrounded in this area by talus-fanglomerates, difficulties are to be expected during excavation. The pervious character of the talus-fanglomerates layer which the penstocks will encounter is indicated in Harza's study.

The location of the powerstation dictates the route selected for the tail-race. It will encounter mostly tufaceous sandstones which will not be very favourable for excavation, a fact that is indicated in the lining suggested by Harza for this portion of the tail-tunnel.

While the feasibility of such a scheme as suggested by Harza is by no means questioned, attention is drawn to the risk involved which is undoubtedly inherent to underground works, but would appear greater than normal in this particular case. Poor rock conditions and water seepage are to be expected during excavation. These increased difficulties can seldom be estimated in terms of construction expenses with a sufficient degree of accuracy.

Under these circumstances it is feared that construction budget might be exceeded if geological conditions are slightly different from expected. The advantage of underground structures with respect to working conditions and operation in winter is recognized, but should be balanced against the contingencies of underground works under uncertain geological conditions.

ALTERNATIVE SCHEME SUGGESTED BY ELECTRO-WATT

General

The considerations mentioned in the previous part of this report led to study, as an alternate, a head-race scheme with surface structures. The additional requirement of providing low initial cost of power dictated the search for a shorter route of the waterways, even at the expense of reduced head.

It appears that a headrace development with a powerhouse located near the bottom end of the Samsstadaklif would reduce the waterways considerably (900 m long headrace against 1700 m long tail-race) while the head developed would be only 15 percent less. The scheme suggested along these lines is shown on drawings no. 50393 and no. 50394. Diversion dams, intake and sluiceway would be located as in the Harza's Scheme C.

In order to develop the same power, flow would be increased in proportion. Energy production would be similar for the first stages of development since the design flow, although higher, would still be available close to 100 percent of the time. A reduction of energy production would occur, however, at the later stages of development which could be compensated by increased storage volume.

Basis of the study

In order to enable a comparison with the tail-race type of development, the study was based on the project alternative presented in the Harza Report entitled "Second Supplementary Report, Burfell Project, October 1963".

A first stage with 3 units of 35 MW each (total 105 MW) was considered and a final development with 6 units (total 210 MW) was analysed.

Structures which could be assumed to be the same as in the Harza Scheme were not studied again. All others were designed on a preliminary basis.

Construction costs were based on the Harza study mentioned above which includes the recent labor cost increase in Iceland.

The pattern of the cost estimates used by Harza was followed closely to facilitate the comparison.

Description of the project

As indicated above, diversion dams, weirs and spillways, in general all works located above the intake, are not altered in this project.

The intake structures and the sluiceway are identical with respect to their general concept, but have been moved about 80 m downstream along the line of the approach canal. A transition section leads to the pressure tunnel.

The pressure tunnel is 900 m long and has a diameter of 8.00 m. It is concrete lined over its whole length and can pass a maximum flow of 250 m3/s. The pressure tunnel will encounter basalts of the Samsstadaklif group. Excavation in this rock is not expected to present great difficulties. The minimum rock cover will be 15 m over the tunnel roof.

The intake will be built in two stages while the pressure tunnel will be constructed during the first stage of development for the maximum flow.

Two surge tanks will be provided at the lower end of the pressure tunnel. One only will be constructed during the first stage of development. Two penstocks of 5.65 m diameter and 250 m length each are suggested, one only being provided in the first stage.

The powerstation can readily be built in stages since it is a surface structure. However the tail-race will be built at once for the final stage of development.

Capital cost estimate

Design for those parts of the project which are different from the Harza's Scheme was made in sufficient details to allow the preparation of preliminary cost estimates. Unit prices used in the estimates are those indicated in Harza's Project Planning Report, Burfell Project, Volume I, January 1963. An allowance has been made, however, to take into consideration the recent labour cost increase in Iceland.

For those structures which are not modified cost estimates were taken from Harza's Second Supplementary Report, Burfell Project, October 1963. They include the above mentioned labour cost increase.

Allowances for general expenses, engineering cost, overhead, initial expenditures have been made on the same basis as for the Harza's Scheme.

A comparison of capital cost estimates is given below for initial and final stages :

		Harza	Electro-Watt
Initial stage			
Installed capacity	kW	105'000	105'000
Capital cost	$ US	26'100'000*	22'400'000
Capital cost per kW	$ US/kW	250*	213

Final stage

Installed capacity	kW	210'000	210'000
Capital cost	$ US	38'750'000*	34'800'000
Capital cost per kW	$ US/kW	185*	165

More detailed capital cost estimates for the Scheme suggested by Electro-Watt are presented in Appendix to this Report.

A contingency allowance of 15 percent has been made on all civil works while a 5 percent is included on all electrical and mechanical equipment. These percentages are the same as those used by Harza, although it can be said that costs of surface structure would be less uncertain than those of underground works, particularly under unfavourable geological conditions.

Interest during construction is based on the same interest rate and construction period as used in the Harza's study and, thus, is proportionated to the construction cost.

The allowance made by Harza for engineering, supervision and overhead was not changed, although these costs can be assumed to vary owing to modification of design concept and construction cost.

* Note: There is a slight addition mistake in the figures presented in Exhibit VII of Harza's Second Supplementary Report, Burfell Project, October 1963, on page 2. The figures (capital costs and unit costs of power) related to the Harza's Scheme which are mentioned further in this report have been corrected accordingly.

A decrease of this allowance did not seem to be warranted at this stage since basis of Harza's computation for this item is not clearly explained in the Second Supplementary Report, Burfell Project, October 1963. It can, however, be assumed to include an additional contingency allowance.

Unit cost of energy

Power production has been estimated on the basis of Harza's study. For the first stage of development there would not be any significant decrease in power production since the used flow (125 m3/sec.) would be available close to 100 percent of the time. For the final stage power production would be reduced. Estimates of power were prepared by comparison of usable annual flows obtained from duration curve for both alternatives.

Annual cost estimates include the same allowance for operation and maintenance as in Harza's report. Debt service of 5, 7 and 9 percents have been considered. Finally 7.8 percent has been analysed as the most likely figure according to Harza's study.

A comparison of unit cost of delivered primary energy is given below for the assumption of a debt service of 7,8 percent :

		Harza	Electro-Watt
Initial stage			
Annual energy production	MkWh	820	820
Unit cost of energy	US Mills/kWh	3.10	2.74

		Harza	Electro-Watt
Final stage			
Annual energy production (cumulative)	MkWh	1575	1500
Unit cost of energy (cumulative)	US Mills/kWh	2.50	2.42

A more detailed estimate is presented in Appendix to this Report and includes unit cost of energy for other debt service rates.

CONCLUSIONS

The table below summarizes the comparison of the underground scheme suggested by Harza and the surface development proposed by Electro-Watt :

	Harza (underground scheme)	Electro-Watt (surface scheme)
Volume of underground works		
access tunnel	37'600 m3	-
tailrace tunnel	120'000 m3	-
headrace tunnel		60'000 m3
powerstation	64'000 m3	-
surge tank	28'200 m3	-
penstocks	9'000 m3	-
Length of waterways (from intakes till tailrace canal)	1'850 m	1'300 m
Gross head (normal)	118 m	102 m
Flow		
initial stage	~ 108 m3/s	125 m3/s
final stage	~ 215 m3/s	250 m3/s
Installed capacity		
initial stage	105'000 kW	105'000 kW
final stage	210'000 kW	210'000 kW
Annual energy production		
initial stage	820 MkWh	820 MkWh
final stage	1575 MkWh	1500 MkWh

	Harza (underground scheme)	Electro-Watt (surface scheme)
Investment cost		
initial stage	26'100'000 $ US	22'400'000 $ US
final stage	38'750'000 $ US	34'800'000 $ US
Unit cost of energy (7,8 percent debt service)		
initial stage	3.10 US Mills/kWh	2.74 US Mills/kWh
final stage	2.50 US Mills/kWh	2.42 US Mills/kWh

The review of the project recommended by Harza which includes major underground structures indicates that geological conditions are complex and uncertain over the area, and that difficulties in excavation might arise if conditions differ slightly from those expected. In particular, pumping during excavation of the tailrace, access tunnel and powerstation might become very costly if seepage is greater than assumed. This might result in the following :

- increase of construction cost
- delay in completion time.

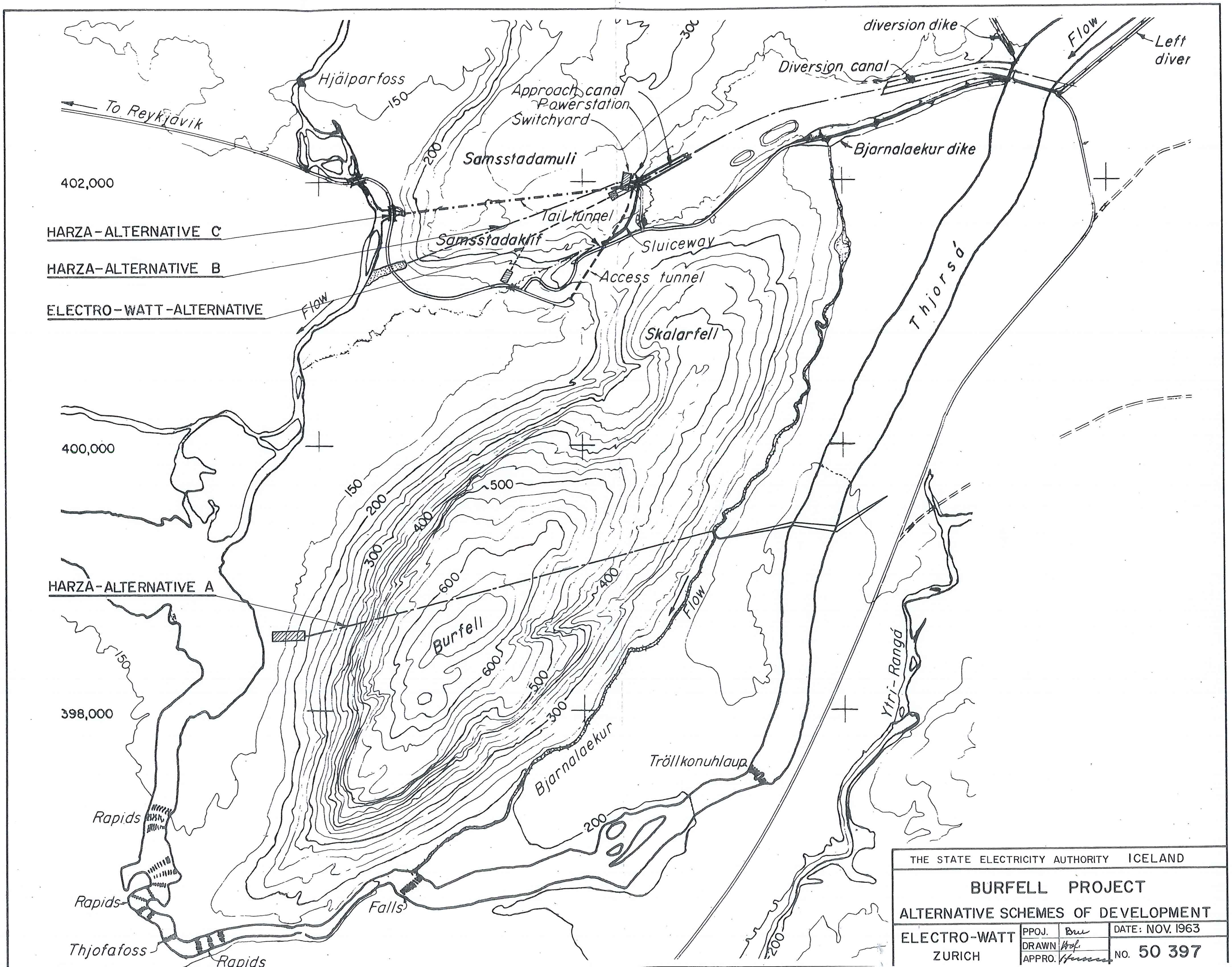
While it is difficult to accurately assess quality of rock formations without having performed on-site-inspections, it is felt on the basis of the reports submitted to Electro-Watt that large underground works in this area would present more risks than usually associated with this type of work and, thus, should be avoided as much as possible.

It is felt further that a development with as many surface structures as possible will be more readily developed in stages, hence, would tend to reduce initial investment to a minimum. The project concept suggested by Electro-Watt along these lines would result in lower initial investment without impairing the future development of the site potential.

Investment costs for initial development would be about 15 percent lower than for the corresponding underground scheme suggested by Harza, for the same installed capacity, while final investment costs would be 10 percent lower. Contingency allowances are included in both estimates on the same basis. However, it should be noted that estimates for a scheme with most structures on the surface would be less subject to unexpected cost increase and that, therefore, differences in investment costs are very likely to be higher than indicated above.

Unit cost of energy for initial development would be about 10 percent lower than for the corresponding scheme suggested by Harza, for the same energy production, while cumulative unit cost of energy for final development would be slightly lower for a somewhat reduced annual energy production. It is felt that these differences represent minimum values.

The construction period assumed for the underground scheme (3 years) appears to be rather short, particularly because the excavation of the powerhouse which is determining for overall completion time cannot be started before the 900 m long access tunnel is completed. The construction of the surface scheme which can be started simultaneously at various locations (intake, pressure tunnel, penstock, powerhouse) could be completed more easily within the three year deadline.



diversion dike
Flow
Left diver
Diversion canal
Hjälparfoss
150
To Reykjavik
Approach canal
Powerstation
Switchyard
300
Samsstadamuli
200
Bjarnalaekur dike
402,000
Tail tunnel
HARZA-ALTERNATIVE C
Samsstadaklif
Sluiceway
HARZA-ALTERNATIVE B
Access tunnel
ELECTRO-WATT-ALTERNATIVE
Flow
Thjorsá
Skalarfell
400,000
500
150
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300
600
HARZA-ALTERNATIVE A
400
Flow
Burfell
600
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Ytri-Rangá
Bjarnalaekur
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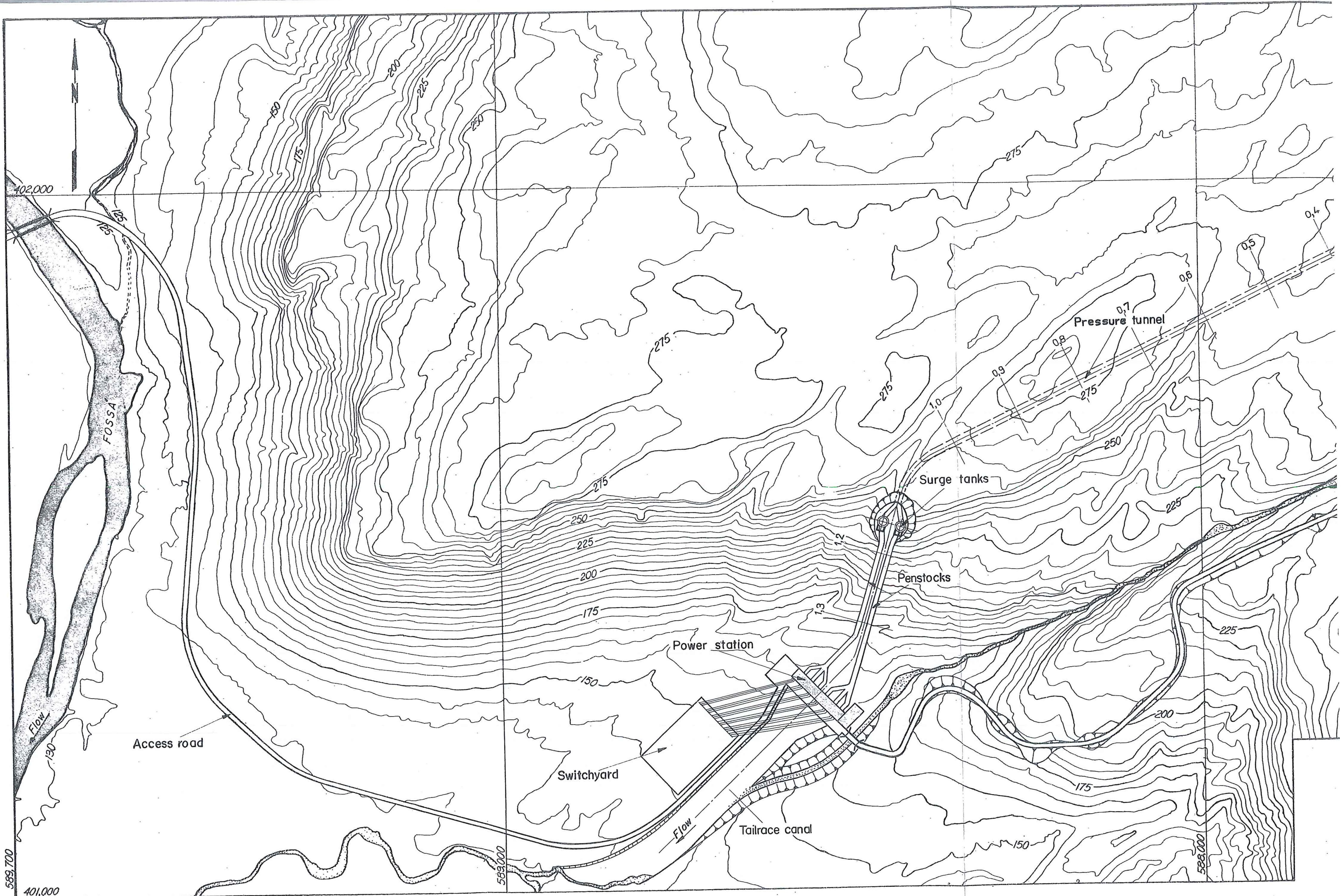

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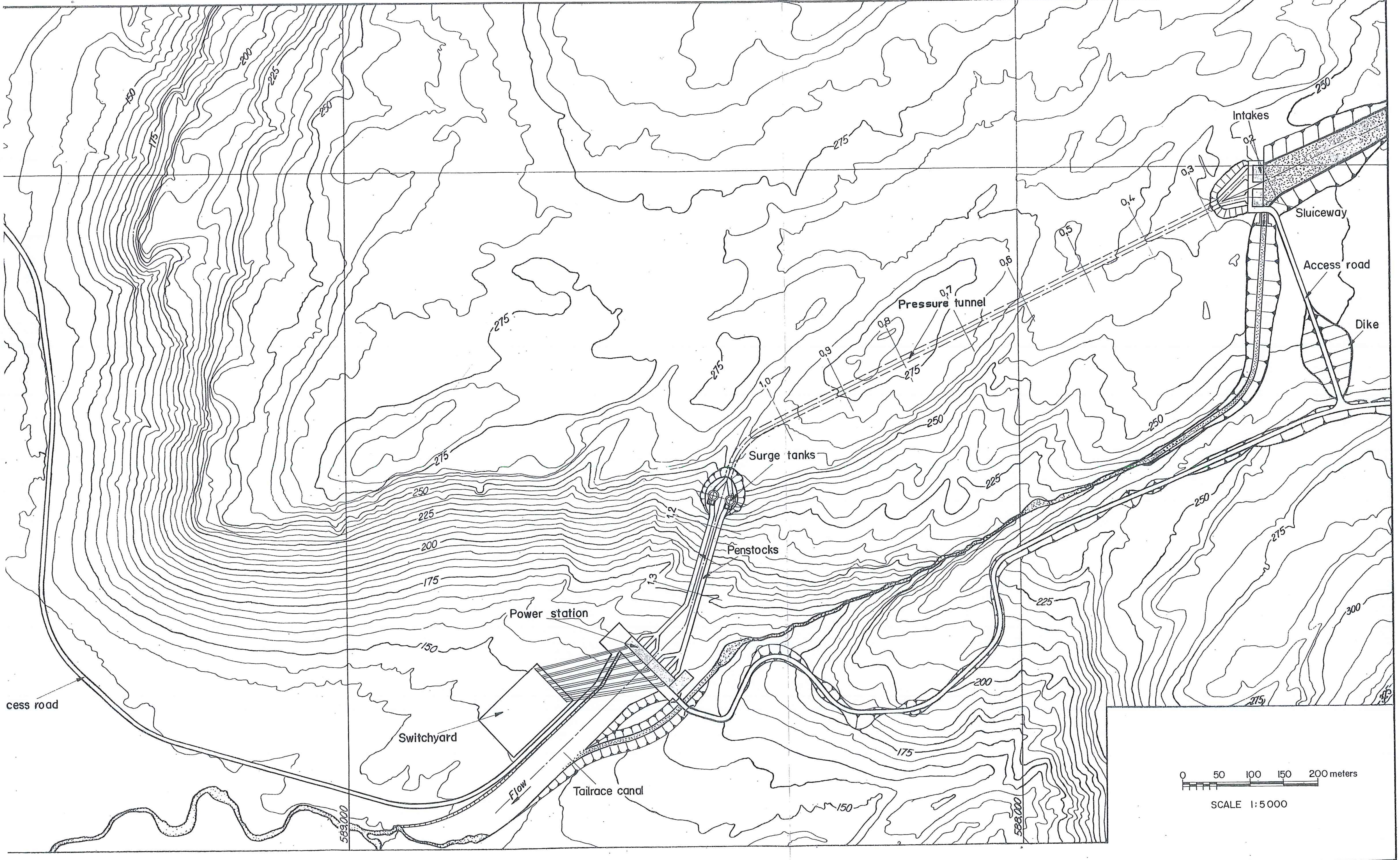

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BURFELL PROJECT ALTERNATIVE SCHEME – GENERAL LAYOUT.		
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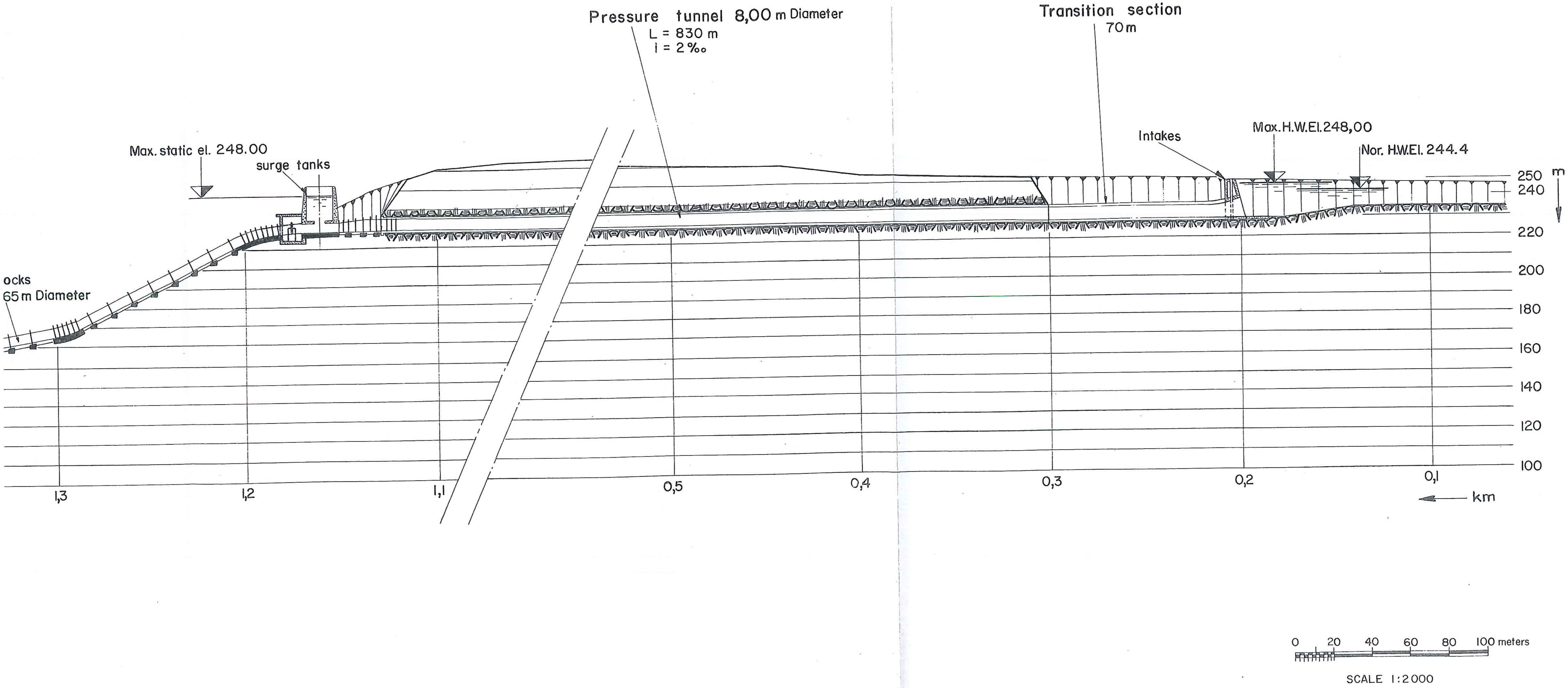

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ALTERNATIVE SCHEME - LONGITUDINAL-SECTION

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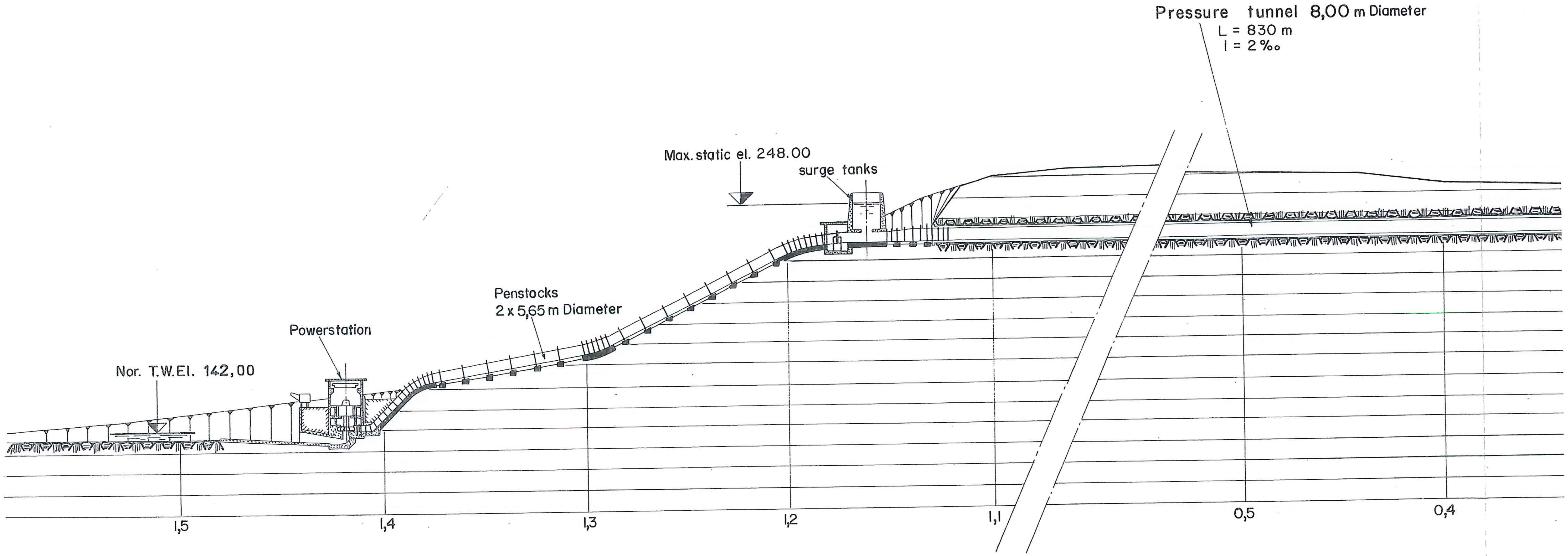
Pressure tunnel 8,00 m Diameter
L = 830 m
i = 2 ‰
Max. static el. 248.00
surge tanks
Penstocks
2 x 5,65 m Diameter
Powerstation
Nor. T.W.El. 142,00
1,5
1,4
1,3
1,2
1,1
0,5
0,4

APPENDIX

ESTIMATES OF CAPITAL COST AND UNIT COST OF ENERGY

CAPITAL COST ESTIMATES

Item	Initial Stage 105 MW $ US	Final Stage 210 MW $ US
POWER PLANT STRUCTURES		
Power Station	1.400.000	2.000.000
Access Tunnel	-	-
Subtotal	1.400.000	2.000.000
RESERVOIRS, DAMS AND WATERWAYS		
Burfell Reservoir	75.000	75.000
Bjarnalaekur Dike	1.039.000	1.206.000
Right Bank Dike		133.000
Left Bank Dike		553.000
Diversion Canal	536.000	917.000
Bjarnalaekur Canal	453.000	453.000
Diversion Weir and Inlet	1.454.000	2.114.700
Approach Canal	200.000	200.000
Sluiceway	248.800	248.800
Dike of Sluiceway	94.480	94.480
Intake and Transition Section	620.000	1.040.000
Pressure Tunnel	1.600.000	1.600.000
Surge Tanks and Valve Chambers	530.000	760.000
Penstocks	900.000	1.600.000
Tailrace Canal	250.000	250.000
Subtotal	8.000.280	11.244.980
TURBINES AND GENERATORS	2.145.000	4.290.000
ACCESSORY ELECTRICAL EQUIPMENT	470.000	948.000

Item	Initial Stage 105 MW $ US	Final Stage 210 MW $ US
MISCELL. POWER PLANT EQUIPMENT	504.000	750.000
ACCESS ROADS	450.000	450.000
OPERATORS VILLAGE AND GEN. PLANT	235.000	324.000
SUBTOTAL PRODUCTION PLANT	13.204.280	20.006.980
TRANSMISSION PLANT	2.812.000	3.488.000
SUBTOTAL DIRECT COSTS	16.016.280	23.494.980
Contingencies	2.063.720	3.025.020
TOTAL DIRECT COSTS	18.080.000	26.520.000
Eng., Superv. O.H.	1.800.000	2.440.000
Total Construction Cost	19.880.000	28.960.000
Interest	2.020.000	2.690.000
Thorisvatn Initial Storage	-	2.000.000
Preliminary Costs	500.000	500.000
Extra Cost for Increm. Costs	-	650.000
TOTAL INVESTMENT COST	22.400.000	34.800.000

ESTIMATED UNIT COST OF ENERGY

Percent of Debt Service

		5	7	9	7.8
Stage Initial					
O & M, Reserves, etc.	$ 1.000	505	505	505	505
Debt service	$ 1.000	1.120	1.570	2.015	1.750
Total	$ 1.000	1.625	2.075	2.520	2.255
Annual energy	MkWh	820	820	820	820
Cost of energy	US Mills/kWh	1.98	2.53	3.07	2.74
Final Stage					
O & M, Reserves, etc.	$ 1.000	920	920	920	920
Debt service	$ 1.000	1.740	2.440	3.130	2.710
	$ 1.000	2.660	3.360	4.070	3.630
Annual energy	MkWh	1.500	1.500	1.500	1.500
Cost of energy	US Mills/kWh	1.77	2.24	2.71	2.42