GLJÚFURVER PROJECT

DEFINITE PROJECT REPORT

Prepared for

LAXÁRVIRKJUN

The Hydroelectric Development of Laxá

by

THORODDSEN AND PARTNERS

Consulting Engineers, Reykjavík, Iceland

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1. THE SUMMARY LETTER

GLJÚFURVER PROJECT

Definite Project Report

Laxárvirkjun
The Hydro-Electric Development of Laxá
Akureyri

Gentlemen,

INTRODUCTION

Herewith we are forwarding to you the Definite Project Report on the Gljúfurver Project, which is the result of studies which have been going on since 1957 when the State Electricity Authority charged our company with the task of preparing a plan for the development of the Laxá River basin and later in the year 1963 to prepare a masterplan for the development of the "Brúar" fall which is a part of the total fall of the river.

The studies connected with the "Brúar" fall have been complete and thorough both concerning field investigations and engineering analysis.

Our company has made an important contribution to the engineering of the Gljúfurver Project, both before and after the legislation of a new development on the Laxá River, which was made by an Act of the Althing at the beginning of the year 1965.

We have been engaged in the engineering of Iceland´s hydroelectric resources since 1937 and have made studies and reports on most potential hydro-electric projects in Iceland. Further, we have made a report on a general survey of the hydro-electric power potential of Iceland for the State Electricity Authority and on a masterplan for the development of the Thjórsá- and Hvítá-river basins, located in South-Iceland.
In addition we have designed and supervised several projects which have been carried out.

We have prepared 8 reports on the development of the Laxá. These are summarized in an appendix hereto.

We designed the 8 MW power plant, Laxá II, and had the responsibility of supervising the carrying out of this work which was completed in the year 1953.

In 1960 a diversion canal with regulating sluiceway and fish facilities at the outlet of the Laxá River from Lake Mývatn was completed, also under our supervision and in accordance with our design.

The Gljúfurver Project has now reached a definite project status and we are now preparing contract documents based on the intention of awarding contract for the general construction and for the purchasing of the first aggregate, turbine, governor, generator and other electric equipment in this year, 1968. Power production of the Gljúfurver plant could begin in the fall of 1970.

This report summarizes the engineering features of a definite project, Gljúfurver, on the Laxá River, intended to enlarge the existing system, primarily for supplying the power and energy needs of the Laxá Supply Area, but possibly also those of eastern Iceland and western North-Iceland, if studies now under way should indicate the desirability of connecting these regions with the Laxá System.

DESCRIPTION OF THE PROJECT

The Gljúfurver project will be located on the Laxá River about 75 km east of Akureyri and 30 km south of Húsavík in North-Iceland.

A dam about 57 m high above ground level will be erected in the Laxárgljúfur gorge. It will dam up a reservoir, some 15 km long, in the Laxárdalur valley, which will act as a regulating pond.

We should like to point out that we have consulted Norges Geotekniske Institutt in Oslo in connection with the design of the dam.

Water will be conducted from the regulating pond through a tunnel to an underground powerhouse located in the right bank of the rivergorge some 500 m downstream from the dam. A surge tower will be located above the tunnel upstream for the powerhouse. The powerhouse will contain two generating units, resp. 23, 9 and 30, 7 MW. From the powerhouse the water will be conducted through a short tailrace tunnel into the intake pond of the younger Laxá Power plant, Laxá II.

A gross head of 84 metres will be developed with a maximum drawdown of 7, 5 m, so the head will vary from 84 to 76, 5 metres.

A complete remote control, including remote starting, synchronizing, loading and stopping, will be from the control room of the older Laxá plant, Laxá I, which will be extended for this purpose. Besides equipment for performance of individual control functions locally will be provided in the machine hall.

Auxiliary features of the Gljúfurver Project will be roads on both sides of the reservoir up the Laxárdalur valley, as the existing roads will be set under water.

Neither operators village nor workshop will be needed as the existing commodities are sufficient.

DEVELOPMENT BY STAGES

In order to keep the cost of energy at an economical level as well as the production in conformity with future demand for power and energy, as estimated for the Laxá supply area and eventually also the Eastern-Iceland and Western-North-Iceland areas, a schedule for development by stages have been worked out as shown here :

Stage I

This stage will include waterways and powerhouse. Intake will be from the now existing intake pond for the Laxá I power plant. Installed power aggregate a 23, 9 MW unit for ultimate head 84 m will operate under 38 m head and yield 6, 5 MW.

Stage II

The dam will be built up to 135 m a.s.l. with normal waterlevel at 129 m. The aggregate will now operate under 59,5 m head and yield 14,7 MW.

Stage III

The dam will be heightened to its ultimate height with N.W. level at 153,5 m. The power aggregate will then operate under the ultimate head 84 m and produce 23,9 MW.

Stage IV

A second power aggregate 30,7 MW will be installed.

At the same time river Suðurá should be diverted to Laxá river, which will increase Laxá river´s mean flow by approximately 16,5 kl/s. This diversion is though outside the scope of this report, but elsewhere the feasibility of the diversion has been shown.

POWER AND ENERGY

The Laxá River has an unusually uniform streamflow, which will be further dealt with in a later chapter.

The existing two power plants, Laxá I and Laxá II, are run-of-river plants. With the erection of the diversion features and sluices at the Lake Mývatn some storage has been at hand, since autumn 1960.

In wintertime there have been some serious troubles from ice formations. The troubles have though diminished a good deal since 1960 after installation of the regulating features at Lake Mývatn, but as the distance therefrom to the plants is about 30 km and the river flow is nearly all the way of high velocity, ice troubles still happen with reduction in water supply due to ice conditions and clogging of the intakes (most serious at Laxá I).

With the new dam at Gljúfurver Project a regulating storage of around 60 Gl will be provided and this pondage will entirely prevent all ice troubles. In that way and in serving as reservoir it will secure the operation of the existing plants and increase their production.

Some regulating storage will be available in Lake Mývatn. A draw-down of 0.5 m will provide about 14 Gl of open water storage, but in addition there will be a substantial underground storage in the pervious lava fields around the lake.

Calculations of the energy production of the four stages, based on future power market studies, has been performed by the NEA (National Energy Authority) both for the Laxá supply area and this area connected with Eastern-Iceland and Western-North-Iceland areas.

The outcome of these calculations up to the year 1985 is shown on exhibit 9.02 (Estimated Loads and Resources).

Estimated energy production at the time of the end of each stage is as follows :

LAXÁ AREA	Stage I GWh/a	Stage II GWh/a	Stage III GWh/a	Stage IV GWh/a
Existing hydroplants	97	105	106	106
Gljúfurver	16	84	135	194
Thermal plants	2	3	3	
Total	115	192	244	300

LAXÁ AREA + EASTERN AND WESTERN NORTH-ICELAND AREAS	Stage I GWh/a	Stage II GWh/a	Stage III GWh/a	Stage IV GWh/a
Existing hydroplants	128	135	136	136
Gljúfurver	28	81	140	194
Thermal plants	4	3	4	
Total	160	219	280	330

The production of the existing two powerplants, Laxá I and Laxá II, is here shown as if the Gljúfurver Project had not been erected. Actually a part of this production will be obtained from the Gljúfurver plant, as Laxá I will only in the first stage (Stage I) be fully utilized.

As mentioned above the installed power capacity is based on the presumption that river Suðurá will be diverted to Laxá river, but this diversion is not included in the estimated energy production stated before.

PROJECT COSTS

The estimates of the construction costs are based on the assumption that the work will be let out to a contractor after a competitive bidding.

The cost estimate is considered in conformity with prices in January 1968 and includes the direct construction cost, contingencies, engineering and overhead costs, and costs of interest during construction.

Not included costs are : Water rights, compensation for damages of land and property, custom duties and taxes on imported equipment and materials and preliminary costs, some 4 million kronur.

The estimated construction cost for the Gljúfurver project including transmission features is as follows :

Stage I	168.300,000 kr.
Stage II	90.500.000 kr.
Stage III	85.300.000 kr.
Stage IV	85.900.000 kr.
Total cost	430.000.000 kr.

Estimate of the expenditure in connection with the performance of the construction of the first stage of the project by years is as follows :

Stage :				Domestic	Foreign
I-IV	Year	1967 and before		3,5 Mkr.	0,5 Mkr.
			Total	3,5 Mkr.	0,5 Mkr.
I	"	1968		10,6 Mkr.	22,8 Mkr.
I	"	1969		33,4 "	46,0 "
I	"	1970		21,7 "	33,8 "
			Total	65,7 Mkr.	102,6 Mkr.

CONCLUSIONS

There is no question about the technical feasibility of the Gljúfurver Project and it will not present difficult construction problems in spite of the somewhat unusual geological conditions of the damsite in the Laxárgljúfur gorge proper i.e. the two postglacial lavalayers in the bottom of the gorge. This condition will essentially require great skill in injection performance.

The Gljúfurver Project will, when carried out by stages, give power at an economical price in the future and meet the expected loads both of the Laxá supply area and if that will be the case, this area and the supply areas of the Eastern-Iceland and the western North-Iceland.

It may be expected that ice troubles will be met with during the time before the initial erection of the dam (up to el. 136 m a.s.l.), but those troubles will not be worse than what the older plants have met with until now (after year 1960).

After the erection of the dam all ice troubles should be eliminated and this will secure and increase the firm power from the then existing three power plants in considerable degree.

The Gljúfurver Project will serve as a requisite step in further developments of the Brúar-fall on the Laxá River, ultimately calculated to give approx. 400 GWh per year.

On basis of our knowledge of hydro-electric power resources development in Iceland and our studies regarding the development of Laxá River, our conclusion is that the Gljúfurver Project represents a very reasonable development of these resources to meet the expected loads of the areas here in question.

Sincerly yours,

THORODDSEN AND PARTNERS

Sigurður Thoroddsen
General Manager

2. MAIN SIGNIFICANT DATA

2.1 GLJÚFURVER: MAIN SIGNIFICANT DATA

Ultimate Development

Drainage area - square kilometers	1600
Discharge - cubic meters per second	
Maximum design flood	300
Maximum historical flood	164
Average	41,5
Minimum undisturbed flow	28
Regulated Storage Gl	
In the Gljúfurver Project pond, 7,5 m drawdown	60
Headwater elevation - m above sea level	
Maximum (at design flood)	155
Normal	153,5
Minimum (maximum drawdown)	146
Tail water elevation - m above sea level	
Maximum (design flood)	71,0
Normal	69,5
Minimum	69,5
Dam - Gravel and earthfill	
Crest elevation - meters	157,5
Total length - meters	410
Maximum height above ground level - meters	57
Volume of fill - cubic meters	710.000
Power tunnel and penstock	
Type : Arch crown, vertical sides	
From intake to gate, concrete lined :	
Length, meters	160
Cross section area, square meters	35,3
From gate to end of concrete lining :	
Length, meters	54
Cross section area, square meters	27

Unlined portion :

Length, meters	330
Cross section area, square meters	55, 5

Penstock upstream of bifurcation; concrete lined

Length, meters	75
Cross section area, square meters	27

From bifurcation to valve chamber, circular, steel lined

1st branch	Length, meters	15
	Diameter, meters	3
2nd branch	Length, meters	20
	Diameter, meters	3, 3

Power house

Type : subsurface

Length, meters	33
Width, meters	10, 5
Height, meters	28

Turbine valves	1st unit	2nd unit
Type : Butterfly		
Diameter, meters	2, 4	2, 7

Turbines

Type : Francis, vertical shaft

Rating at 81, 7 m net head metric horsepower	35.000	45.000
Discharge at rating kl/s	35	45
Speed, revolutions pr. minute	300	250

Generators

Type : vertical shaft, hydraulic turbine driven

Rating-kilovolt amperes	26.700	34.300
Power factor	0, 9	0, 9
Voltage-kilovolts	10, 5	10, 5
Phases	3	3
Cycles per second	50	50
Speed-revolutions per minute	300	250

Tailrace tunnel

Type : arch crown, vertical sides,
unlined, free water level

Length, meters	125
Cross section area, square meters	64

2.2 MAIN SIGNIFICANT DATA

Stage I and Stage II

Headwater elevation - m a. s. l.	Stage I	Stage II
Maximum (flood condition)	108, 5	134
Normal	107, 5	129
Minimum	107, 5	124
Turbine (1st unit)		
Normal net head	37, 8	59
Discharge, fullgate - kl/s	24	31
Output-metric horsepower	9.400	21.500
Speed-revolutions per minute	300	300
Generator (1st unit)		
Output-kilovolt amperes	7.200	16.300
Power factor	0, 9	0, 9
Speed, revolutions per minute	300	300

3. GENERAL DESCRIPTION OF THE PROJECT

3.1 Introduction

The Gljúfurver Project is located on the Laxá river about 75 km east of Akureyri and 30 km south of Húsavík. The location and the access thereto is shown on dwg. 9.01.

The project will develop 84 meters gross head in the uppermost reach of the Brúar-fall in the Laxárgljúfur gorge.

The main features of the project are : the dam with the spillway, the tunnel with a surge tower, a penstock to the underground powerstation in the right bank of the gorge, and a tailwatertunnel to the intake pond of the Laxá II powerstation, a short distance from the Laxá I power-station.

3.2 Dam, Spillway and Chute

The dam will be an earth- and gravelfill dam with an impervious core of compacted morainal materials. It is located just downstream of the Laxá I dam, which will serve as a cofferdam for the construction of the dam. The crest length of the dam will be about 410 meters, and the maximal height above original ground level 57 meters. The crest elevation will be 157,5 m a.s.l.

The dam will dam up a lake in the Laxárdalur Valley, some 15 km long, which will be a reservoir for the power plants, both the Gljúfurver and the existing plant Laxá II. The spillway will be a concrete structure, located on the right bank of the reservoir just upstream of the dam. The spillway is designed for 300 kl/s. The water will flow from the spillway along a concrete chute, and fall into the gorge some 150 m downstream of the dam.

3.3 The Power Features

The power features, including the power intake and tunnel, the surge tank, the penstock, the power station and the tailrace tunnel, will be located in the right bank of the Laxárgljúfur gorge.

The uppermost portion of the powertunnel, together with a diversion tunnel branching from it downstrem of the dam, will serve for diverting the river during construction of the dam. This portion of the power tunnel will be concrete lined throughout.

Just upstream of the bifurcation of the diverting branch from the power-tunnel a gateshaft with a main gate and a bypass will be located. This bypass will discharge water into the diversion tunnelbranch, behind a concrete plug. At the end of the diversion branch a new intake for the Laxá I power plant will be erected. The Laxá I plant will thus be able to operate after the erection of the dam.

Downstream of the bifurcation the powertunnel dips to a lower level for reason of geological condition of the rock. From hereon to the surge-tower the tunnel will be unlined except where condition should require it.

The surge tank, located about 150 m upstream from the powerhouse will be in rock excavation, concrete lined up to the ground surface (El. 145 m) and continue upwards as a welded steel plate construction to the required top level, at 160 m a.s.l. One main penstock will be provided in continuation of the power tunnel, serving the two turbines after bifurcating just upstream of the powerhouse. The penstock will be concrete lined throughout with steel lining additionally in the downstream end.

The powerhouse will be of the subsurface type, with a concrete sub-structure and a concrete lined machine hall.

The powerhouse will house the main generating equipment and will consist of an erection bay and two unit bays. The turbines will be of the vertical Francis type with steel spiral cases, and each will drive an alternating current generator. Each turbine will be protected by a butterfly valve positioned in a separate excavation behind the powerhouse excavation. The powerhouse will contain miscellaneous mechanical and accessory electrical equipment and service systems conventional for a powerhouse of this type.

The tailrace tunnel will be unlined, flowing with free water level, and discharging into the intake pond of the Laxá II powerstation.

3.4 Transmission Features

Laxá substation. It is proposed to enlarge and extend the Laxá substation in several stages, in accordance with increasing transmission requirements.

A step-up transformer capable of handling the ultimate output of the first unit (28 MVA) will be provided right from the start. The transformer's high voltage side will initially be at 66 kV, but with provisions for conversion to 132 kV at a later date.

The transformer will be located in its ultimate position near a future switchyard on the right bank of Laxá River, immediately upstream of the Laxá I powerhouse (see Dwg. 9.31). A concrete duct with bus-bars leads from the underground machine hall to the transformer. The high-voltage (66 kV) side will be connected by an underground cable, a circuit braker and disconnecting switches to an extension (in direction upstream) of the bus in the existing 66 kV Laxá substation.

This constitutes the first stage in the development of the Laxá substation. The power will initially be transmitted from the substation over existing power lines.

The subsequent stages are proposed as shown in the principal one line diagrams in Dwg. 9.62. The timing of individual stages is necessarily fairly uncertain since it depends on the load growth.

Akureyri substation. A new transformer, 7,5 MVA 60/11 kV will be installed in the Akureyri substation coincident with the first stage of the Laxá development, as described in this report.

Later additions to the Akureyri substation will not necessarily follow the Laxá development stages and are therefore not described here.

3.5 Construction by Stages

The Project as discussed above represents the ultimate development of the definite Project. However, construction is planned to proceed by stages in order to provide power and energy in conformity with the demand.

The water conductors and the power station will be completed in Stage I, except for the installation of one of the two generating units, guard valve, and associated electrical and mechanical equipment. The diversion tunnel and a new intake basin for Laxá I will also be constructed in Stage I.

The dam will be constructed up to El 135 in Stage II. The downstream portion of the spillway chute will be constructed in this stage, and a provisional flow diversion provided by a sloping tunnel between the chute and the power tunnel upstream of the gate.

The flow diversion tunnel will partly be constructed in Stage I. It will serve as a spillway after the main diversion tunnel has been plugged at the end of the construction of Stage I I, until the ultimate spillway is completed in Stage III.

The dam and the spillway with the chute will be completed in Stage III, and the provisional diversion tunnel plugged.

The second generating unit, with guard valve, associated electrical and mechanical equipment will be installed in Stage IV.

4. DETAILED DESCRIPTION OF THE PROJECT

4.1 Dam

The dam is an earth- and gravel fill dam. It is shown on Drawings 9.21, 9.22 and 9.23.

The crest length of the dam will be 410 metres and the maximal height above original ground level 57 metres.

A roadway will be along the dam crest, the dam will thus serve as a bridge over the gorge and relieve the very old and narrow bridges which now are the sole passage over the Laxá River in the Brúar-reach.

The geology of the damsite and the Brúar-reach is somewhat unusual. The Laxá river has in former times, when the sea level was lower, eroded a cleft or gorge about 50 m deep through a ridge which has at that time held up a lake in the Laxárdalur valley, a glacier-eroded valley. Later on at a higher sea level, the river built up a delta down-stream of the gorge, a gravel deposit named Presthvammsmelar.

3800 and 2000 years ago rsp. two lava flows originating in the Lake Mývatn region streamed down the Laxárdalur valley and the Laxárgljúfur gorge. These lava flows now make up the bottom of the gorge. Together they are maximal approximately 40 m in thickness.

The Laxárgljúfur gorge exposes the geology of the ridge mentioned above which has been built up of a series of basalt lava flows with intermediate layers of tuff and tillite. Further information has been obtained from exploratory drilling (Confer drawings 9.21 and 9.23).

A basalt lava flow or a series of such flows is a highly anisotropic rock formation as regards permeability, but generally the compression strength of these rocks presents no problems. Seepage occurs in two directions mainly, horizontal and vertical, the permeability in other directions is relatively unimportant.

Contacts between individual flows, and between a flow and its base, constitute the principal aquifers. The reason is that a layer of scoriaceous blocky lava is usually present on the top of a flow and another at its base. The surface layer of the lava is often rapidly tightened by deposits of windborne loessial soil and or river sediments. The lower contact, on the other hand, has no possibility of a relatively rapid tightening and therefore retains its permeability for a longer time.

The cooling process of a lava flow causes the flow to contract into vertical columns, separated by joints, which accounts for most of the vertical permeability of the basalt layers.

This permeability is however usually much smaller than the horizontal permeability along bedding contacts.

Exploratory drilling and permeability testing has shown that the rock formations of the banks of the gorge are relatively very tight, with the exception of one of the uppermost basalt layers on the left bank of the gorge. The base of the gorge beneath the postglacial lava flows also appears to be very tight.

The postglacial lava flows on the other hand, such as those which cover the bottom of the gorge and into which the Laxá River has cut its riverbed, are very permeable, the lower flow though less so than the upper one. This is the case of the flows themselves, of the contacts between them and between the lowest flow and its base also between both flows and the walls of the gorge.

A great deal of stripping and grouting is therefore to be expected. In our cost estimate we have made a considerable allowance on this account in conformity with our drawing 9.23. It is though difficult to say beforehand how much stripping and grouting will actually be required. This will in the end be decided upon under the execution of the work.

The foundation preparation will consist of clearing the rock on both banks for their earth-cover and stripping where needed. Stripping the lava flow in the riverbed ; grouting the foundation beneath the dam core, both with a blanket grouting and a central curtain grouting.

The foundation for the impervious core will then be covered with a concrete sludge.

The impervious core will be built up of compacted morainal material. The upstream slope of the core will have a grade 1 vertical to 2/3 horizontal, and the thickness of the core will be 4, 0 m at the top (el. 155, 5) and 19, 0 m at rock foundation (el. 97, 5). The morainal material will be borrowed from a morainal deposit located 1, 5 km from the damsite.

The crest of the dam will be at elevation 157, 5 m above sea level and the top of the core will be at el. 155, 5 m a. s. l. (Normal water elevation and crest of spillway will be at 153, 5 metres a. s. l. and the highest water elevation at max. design flood will be at 155, 0 m a. s. l. Thereto comes wave action which is reckoned to be max. 1, 5 metres).

On either side of the core a filter zone will be placed 3, 0 m thick, and above the core two filter zones 0, 25 m each. The material for the filters will be borrowed from the gravel deposit, Presthvammsmelar, located downstream from the Laxárgljúfur gorge at a distance of rd. 2, 0 km from the damsite.

Both upstream and downstream of the core and filters the supporting fill will consist of compacted gravel, borrowed from the same deposit, the Presthvammsmelar.

The upstream slope and the crest of the dam will be covered with a layer of rip-rap of quarried rock to meet the wave and ice actions, but the downstream slope will be covered with mould and sown with grass seed, except the toe, which will be of coarse stones.

The upstream slope will have a grade 1 vertical to 1, 6 horizontal, and the downstream slope will be graded 1 vertical to 1, 4 horizontal.

The crest of the dam will have a width of 7, 0 m and will as mentioned before, serve as a road over the Laxárgljúfur gorge. The surface layer will consist of compacted gravel. Wayposts of large stones will be placed on either side of the road.

The typical properties and quality of the fill materials are shown on drawing 9. 12.

The dam will dam up a lake in the Laxárdalur valley some 15 km long, which will be a reservoir for the Gljúfurver plant and the existing plant Laxá II.

The completed dam will consist of : 97.000 m^3 imp. core, 56.000 m^3 filter, 42.000 m^3 frontal protection and 515.000 m^3 coarse gravel fill. The total volume being 710.000 m^3.

The dam is, as mentioned before, to be built in two stages (Stages II and III). The crest elevation at Stage II will be 137,0 m a.s.l. A small strip, 5,0 m of width, nearest the water will be built up to this elevation, whereas the main body of the dam will have a crest el. 136,0 m a.s.l. Consequently, all work with the dam foundation i.e. stripping etc. up to el. 136,0 m will be necessary at the first stage of the dambuilding. At this stage the upstream side of the dam will be built in full width, i.e. the coarse gravel fill, the core and both filters. The downstream side will be reduced, from what it will be after the final erection of the dam to its ultimate height in Stage III. The total volume of a various fill material for Stage II will be 288.000 m^3. Normal water elevation will be 129 m and maximal flood at 134 m a.s.l.

About the geological conditions of the site conf. Appendix A.

4.2 Spillway and Chute

The spillway will be located on the right bank of the reservoir upstream of the right embankment of the dam. The crest of the spillway will be 75 m long and its elevation is 153,5 metres a.s.l.

Drawings 9.31 and 9.32 show the design. A concrete gravity retaining wall, at a right angle to the axis of the dam, will make the 75 m long crest of the spillway. Alongside this retaining wall a concrete trough will collect the water, which herefrom will stream along a concrete chute and fall into the gorge, some 150 m downstream from the dam.

A concrete bridge will serve as a crossing over the chute thus connecting the road on the crest of the dam to the road on the right bank of the river.

As stated elsewhere the calculated 100 and 1000 years floods are 195 and 260 kl/s respectively.

The spillway is though designed for 300 kl/s. The water level will then be 155 m a.s.l. An outlet sluice or bypass will be installed in the tunnel, in order to provide water for the existing plants (Laxá I and II) when the Gljúfurver Project is not producing electricity and this outlet will be able to convey 60 kl/s. It is therefore clear that the spillway, together with this sluice and the power discharges, will with safety pass all floods.

4.3 Intake and Power Tunnel

The power intake will be designed for low hydraulic losses. It will be a concrete structure provided with trashracks to retain debris and ice-blocks (Stage II). The intake sill is set at el. 99,0. A gateshaft is located in the tunnel about 160 m downstream from the intake. The main gate, a vertical lift wheeled gate, 5,5 by 5,5 m, will close the entire cross section except for a bypass installed in the top of the tunnel. The bypass gate, 2,0 by 2,0 m, will be parallel to the main gate in the same shaft. The bypass will be a steel pipe, 2,0 m in diameter, embedded in concrete. It will discharge into the diversion tunnel beyond a concrete plug, placed in Stage II.

The part of the tunnel between the intake and the gate is 160 m long. It will lie in three different rocklayers, a basalt layer (EB) and a tillite layer (MB) intervened by an approximately 3 m thick tuff layer, sloping towards the intake, where nearly the entire tunnel section will be in the EB basalt layer. This tunnel portion will be concrete lined throughout.

The lined tunnel section will be 7,0 m high by 5,5 m wide, with the top being a half-circle. The floor will be level across, and the side walls vertical. The cross section area will be 35,3 m^2.

Just downstream of the maingate the tunnel will dip down, at about 45^o grade, to a nearly horizontal portion which will be entirely situated in the preferable rock of the MB basalt layers. The concrete lining will

extend to just beyond the sloping leg, but on the horizontal portion a full concrete lining will only be provided where this may be required.
The length of the sloping leg is ab. 25 m and the difference in elevations 20 m. The cross section area of the sloping leg and eventual lined parts of the main tunnel will be 27,0 m^2, 5,5 m high by 5,5 m wide with the upper one-half being a half-circle. Unlined sections of the main tunnel will be 6,7 m wide by 9,0 m high, the top being a half circle. The cross section area will be 55,5 m^2.

The length of the unlined tunnel, inclusive of a bend at the downstream end, is 330 m.

4.4 Surge Tower

The surge tower is located about 150 m from the powerhouse. It will extend from El. 120 to El. 162. The part of the tower below top of rock will be circular, 12 m Dia. excavated in old pillow lava and tuff layers, and concrete lined. The upper portion of the tower viz. above ground level, which here is at El. 145 m will be a circular construction of welded steel plates, 13,0 m Dia.

A 4 meter diameter concrete-lined shaft will connect the surge tower to the tunnel through a restricted orfice. All excavation and the concrete lining of the shaft will be completed in Stage I, the concrete lining of the surge tower in Stage II, and the welded steel construction in Stage III.

4.5 Penstock

One main penstock will serve the two turbines bifurcating just upstream of the valve chambre. Its length will be 75 m between the bifurcation and the unlined power tunnel. The grade will be approximately 1 vertical to 10 horizontal. The penstock will be in the MB basalt layers, but intersected at a sharp angle in the upstream end by the MBc tuff layer. Full concrete lining will be provided throughout the penstock with steel lining additionally, beginning 10 m upstream of the bifurcation.

The main penstock will be horse-shoe shaped, 5,5 m by 5,5 m, converting into a circle, 5 meters in diameter, at the downstream end. Access to the penstock and the powertunnel during construction, will be provided through an extension of the penstock excavation to intersection with the access tunnel.

4.6 Power Station and Equipment

The underground powerstation will be located in the right bank of the Laxárgljúfur gorge some 100 meters from the Laxá I powerstation.

The excavation, 35 m long, 12 m wide and 28 m high will be in the MB basalt layers, under about 30 meters of rock cover. A tuff layer, approximately 3 meters thick, will intersect the upper one-half of the excavation, but this is not expected to cause any trouble.

The machine hall will consist of an erection bay and 2 unit bays, and will be concrete lined throughout. The crown voids behind the roof lining will be thoroughly grouted. Temporary supports during construction of the roof may probably be required over most of the length. The concrete walls will be constructed free of the rock. The powerhouse will have two floor levels ; the turbine floor at El. 68,15 m the generator floor and the erection bay floor at El. 72,35 m.

A longitudinal gallery for piping and access to the draft tubes will be downs-stream of the turbines at El. 62,60 m. Access stairs are provided between floors at convenient locations.

The two hydraulic turbines will be of the verticalshaft, single-runner Francis type, with platesteel spiralcases embedded in concrete and elbow draft tubes. Draft-tube gates are located in the main excavation just outside the machine hall. Only one gate is needed for each unit, since the draft tubes will not have a splitter pier. Unwatering pumps are planned to be built into the gates, pumping the water straight through the latter. With this arrangement the necessity for providing pipe lines to a permanent pumping installation is eliminated. A plate steel lining is employed for the vertical section of the draft tube, and the greater part of the elbow.

The first turbine, installed in Stage I, will have rated output of 35.000 metric horsepower, and the second, installed in Stage IV, 45.000 metric horsepower, both at a rated net head of 82,3 m. The fullgate turbine discharge at rated head is expected to be 38,5 and 49,5 cubic meters per second respectively, and the speed 300 rpm and 250 rpm.

Turbine inlet valves of the butterfly type will be located in a separate excavation 12 meters upstream of the spiral casing inlet. A dresser coupling will be provided downstream of each valve. The butterfly valves will be operated hydraulically.

The generators will be of the vertical shaft type, directly connected to the turbines. Each will be provided with a direct-connected main exciter, and either a direct connected or a motorgenerator pilot exciter. Steel cubicles near the generators will house motor-operated main exciter rheostat; a circuit breaker for the generator field and other auxiliaries for the excitation system; high voltage fuses and load breaking switch for the station supply and a grounding impedance.

The generators will be rated 26.700 kVA and 34.300 kVA at 60^{o} temperature rise and 0,9 power factor, 10,5 kV, three phase, 50 cycles, 300 and 250 rpm.

The station supply will be furnished from a 300 kVA 10,5/0,4 kV transformer, fed from the generator leads through a load-break switch and high voltage fuses, or altenatively from another transformer of the same rating, fed from the Laxá I 6 kV system through a cable.

The powerhouse crane will be a 70 metric tons electrically operated overhead travelling bridge crane. The crane runway, supported on concrete columns, will extend over the entire length of the powerhouse.

Access to the powerstation will be provided by a 50 meters long tunnel from a parking area, located between Laxá I powerstation and the cliff. The tunnel exacavation will be 6 m wide by 8,5 m high with sloping floor 1 vertical to 18 horizontal. It is planned to be unlined except for the floor, where cable and piping ducts will be located under a concrete slab. Access to the valve chambre will be through a tunnel, previously also used as an access to the penstock and the power tunnel.

4.7 Diversion Tunnel and Laxá I Intake Basin

The diversion tunnel will branch from the power tunnel just downstream of the gateshaft. It is planned to be unlined except for some 7 m next to the bifurcation, where the bypass pipe will be embedded into the roof lining. A concrete plug will be placed in this lined section at the end of the construction of Stage II.
The excavated cross-section of the diversion tunnel will be 5, 5 m by 5, 5 m, the upper one half being a half circle. The length will be about 135 meters.

A new intake basin for Laxá I powerstation will be constructed at the diversion tunnel portal. The basin will have an outlet into the Laxá river, provided with a segment gate 5, 0 m high by 10, 0 m wide, with the top at El. 107, 5 just as the spillway crest of the Laxá I dam.

The diversion features, with full gate opening, are designed for a discharge of 80 kl/s. The headwater elevation will then be 107, 4 m a. s. l.

4.8 Flow Diversion, Stage II

A provisional flow diversion tunnel will be used after completion of Stage II and during construction of Stage III. It will branch from the power tunnel a few meters upstream of the gateshaft. A 25 meters long portion at 45^{o} grade, excavated from the power tunnel will be constructed in Stage I. It will be concrete lined, 7, 0 m high by 5, 5 m wide, the roof being a half-circle.

In Stage II a 25 meters long horizontal portion will be constructed in continuation of the sloping one, with an outlet 5, 0 m high by 10, 0 m wide, discharging into a spillway chute. The outlet will be provided with a segment gate, previously used at the portal of the diversion tunnel intake basin of Laxá I.
The gate sill is set at El. 124, 0. The full-gate discharge at headwater El. 133, 0 will be about 250 kl/s.

4.9 Control Equipment, Metering and Relaying

The generator and step-up transformer will be provided with protection of the conventional type. A control room for the station will be built adjacent to the Laxá I powerhouse, where relays, metering, monitoring and control equipment conventional for stations of this type will be mounted in cubicles and on panels. Besides, equipment for performing individual control functions locally will be provided in the machine hall.

5. CONSTRUCTION

5.1 General

In order to provide a proper basis for the cost estimate the following has been taken for granted.

The project will be performed under a contract resulting from competition between qualified construction contractors. Purchasing of equipment and materials will also involve competition. The competition will be on international basis

Regarding Stage I, two construction contracts are intended.
The first will encompass the general construction of diversion and power tunnel, powerhouse, tailrace tunnel, plans and switch-yard. The second will comprehend the installing and erecting of the permanent equipment both mechanical and electrical, which the owner will buy and furnish.

5.2 Labour

Icelandic labour will be used to the greatest possible extent. If the contractor is a foreigner he will provide foreign administrating engineers and some special employees.

The supervising engineers, technicians, accountants etc. will be Icelanders, with the exception of one or two Norwegian consultants (Norges geotekniske Institutt) who will assist in supervising the building of the earthfill dam.

5.3 Material and Equipment

It is thought that almost all material and equipment will have to be imported.

Icelandic cement may eventually be had in adequate quality and quantity.

Modern heavy construction equipment and machinery will be used. Icelandic contractors may have some of the equipment but the cost estimate is based on importation of the equipment with a reasonable part of the cost written off on the project.

All of the projects permanent equipment is contemplated imported and shop fabricated as feasible.

Natural construction materials, such as concrete aggregates, impervious core material, rip-rap, filter, rock and road material, are available in abundant quantities and of suitable quality.

5.4 Course of Construction

On Drawing 9.13 is shown a graphic construction schedule made on the assumption that a contract for the first stage of the Gljúfurver Project will be awarded in the summer 1968; work will be commenced in the autumn 1968, and the Gljúfurver Powerstation will begin to deliver energy in the autumn 1970.

The installation of the powerhouse permanent equipment, which the owner, Laxárvirkjun, will purchase himself, will not be included in the main general construction contract. A separate contract will be made for this installation work, which mainly will be carried out in the winter 1969-1970. To meet this, the powerstation shall be nearly completed in the autumn 1969.

It is therefore essential and of critical importance to start the access tunnel and powerhouse excavation as early as possible in the autumn 1968, if the procedure of work, we here propose, will be adhered to.

The penstock and powertunnel excavation will also be started from the access tunnel, as soon as possible, by another team. Spoil from the powerstation and the tunnels will be used for levelling the switch-yard site, and parking areas. Excessive spoil can be stockpiled at given places, to be used later for the dam construction.

Concrete works in the powerstation are to be started as soon as possible. It is therefore assumed that the uppermost section of the powerhouse will be excavated first, and construction of the concrete roof arch then started.

Concrete and steel works in the tunnel and the penstock will mainly be carried out in the year 1970.

Excavation of the tailrace tunnel will be accomplished after the power-house excavation, and thereafter the excavation of the diversion tunnel and the upper section of the powertunnel. It is assumed, that all excavations will have been completed at the beginning of 1970.

The construction of the switch-yard, transmission features etc. does not present any critical time problem.

As pointed out above the Gljúfurver Project shall be able to deliver energy late in the year 1970.

Any work included in Stage I is to be completed in the autumn 1970.

A separate contract will be made for the construction of the dam up to El. 135,0 m, and the provisional flow diversion in Stage II.

The foundation preparation for the earth fill dam is expected to be considerable, and may be done by another separate contract.

Stage II will probably be completed in three summer seasons, two for the foundation preparation, and one for the construction of the dam and the flow diversion features.

The construction period of Stage II has not yet been fixed, but it will probably be started already in the summer 1971.

Works included in Stage III, viz. completion of the dam, the spillway and the chute, will be carried out in two summer seasons, and Stage IV, the installation of the second generatin unit, in about one and a half year. A separate contract will be made for each stage, but the periods of construction have not been fixed.

6. HYDROELECTRIC GENERATION

6.1 General

Laxá River originates in Lake Mývatn (El. 278 m above sea level), which has an area of about 38 square kilometers. From the outlet of Lake Mývatn the Laxá flows along the Laxárdalur valley to the sea near Húsavík. Its length from Lake Mývatn to the sea is about 58 kilometres. On the first 11 kilometres downstream from the Lake Mývatn there is a drop of about 100 metres in the river, and about 70 metres drop on the next 20 kilometres. Then the Laxárgljúfur cleft is reached, where a drop of about 70 metres is found on a distance of 1800 metres. Just downstream from the Mývatn outlet, a little tributary, Kráká, joins the Laxá.

The Gljúfurver Project will be the tird hydro-electric project on the Laxá River.

The two existing power plants Laxá I (4, 8 MW) and Laxá II (8,0 MW) were designed basically as run-off-river developments. For the reasons of local interest Lake Mývatn has not as yet to any degree been used as regulating storage. Up to the year 1960 ice troubles were a serious problem at the outlet of Lake Mývatn. Then a diversion canal with sluices came into use and since then the situation has altered. On the other hand there have been troubles in connection with ice formations in the river upstream from the plants. The distance from the lake to the plants is somewhat more than 30 milometres. It is chiefly bottom ice and sludge ice that causes the troubles, but step bursts happen too.

The Gljúfurver Project includes an earth-fill dam constructed in two stages. The first stage will provide a pondage of approximately 8 Gl, which is considered satisfactory to prevent ice troubles. The operation security of the existing plants will thus be increased.

6.2 Drainage Basin, Geology and Meteorology

The drainage basin of the Laxá upstream from the Gljúfurver Project has an area of about 1600 square kilometres. The drainage areas of Lake Mývatn and the Kráká River are about 1430 square kilometres hereof. The topography of the basin is relatively rough as a result of interaction of volcanic activity and weathering forces. The maximum elevation of the basin is about 1300 metres.

Geologically, all the rocks and surfacial materials are of volcanic origin. Much of the basin area consists of relatively pervious formations which act as substantial groundwater reservoirs. This, together with the natural open water storage of Lake Mývatn, provides a substantial degree of regulation of the Laxá streamflows, which actually has the most uniform flow of all significant rivers in the country.

The climate in the Laxá basin is rather dry with cool summers, and warmer winters than are normally experienced in a location less than 200 kilometres south of the Arctic Circle.

Some meteorological data from Staðarhóll, a weatherstation near to the Laxá area, are to be found on Dwg. 9.01.

6.3 Stream Flows and Storage

Stream flows in the Laxá at Brúar have been recorded since 1947.

The average annual stream flow for the 19 water years 1947-1966 was 41,5 cubic metres per second (kl/s): The maximum daily flow was 164 kl/s, and the minimum daily flow, since the diversion canal at Mývatn came into use, was 22 kl/s. 100-year and 1000-year floods have been estimated by Gumbel´s Method, 195 kl/s and 260 kl/s respectively.

On Dwg. 9.02 are shown graphically some hydrological characteristics of the Laxá River, the flow duration curve (A) and the flow utilization curve (B) for the period of record (19 water years 1947-1966).

Curve (A), the flow duration curve, shows the percentage of time in which a given discharge is equaled or exceeded.

Curve (B), the flow utilization curve, shows for a given discharge the amount of water, expressed as a percentage of the total run-off, utilized by a hydroplant without any storage, having the given discharge as rated discharge.

Construction of the Gljúfurver Project is, as above mentioned, planned to proceed by stages. The first stage will not provide any storage. In the second stage the dam will be constructed to such a height, that ice troubles will be prevented. Until that stage is completed, the Gljúfurver will operate as a run-off-river plant, at the risk of ice troubles in wintertime. However, such operation is very undesirable and will be limited to so short time as possible.

The volume of the ultimate reservoir will be about 150 Gl, thereof about 60 Gl in the uppermost 7, 5 metres.

6.4 Head

The tailwater elevation of the Gljúfurver will be nearly constant, about 69, 5 m above sea level; maximum elevation at flood condition being about 71 m a.s.l. Normal headwater elevation until Stage II is completed will be 107, 5 m a.s.l., rising at maximum flood to about 108, 5.

The gross head will then be nearly constant about 38 metres. After completion of Stage II the headwater elevation will be as follows : normal El. 129, 0, max. El. 134, 0, min. El. 124, 0. The minimum elevation will occur at flow regulation, because of ice troubles in the Laxá, upstream of the reservoir.

The gross head during this stage will thus vary from 54, 5 and 63 metres, being normally 59, 5 metres.

Ultimate normal headwater elevation will be 153, 5 metres above sea level corresponding to a gross head of 84, 0 metres. Maximal draw-down of the reservoir is expected to be about 7, 5 metres. Minimum gross head will thus be about 76, 5 metres.

The head losses have been calculated 0, 2 m, 0, 4 m and 1, 7 m for station flows of 25 kl/s, 35 kl/s and 80 kl/s respectively.

6.5 Power and Energy

As previously mentioned, a two-unit plant has been selected.

The first unit, installed in Stage I, will be rated to develop 23,9 MW at a rated net head of 82,3 metres, and a flow of 35 kl/s. The initial power capacity will be about 6,5 MW at a net head of 37,8 metres and 24 kl/s discharge.

At the intermediate Stage II (headwater El. 129 m) the capacity will be about 14,7 MW at a net head of 59,0 m and 31 kl/s discharge.

The ultimate peaking capability is expected to be about 26,5 MW at a full-gate turbine discharge of 38,5 kl/s.

The second unit, installed in Stage IV, will be rated to develop 30,7 MW at a rated net head of 82,3 metres and 45 kl/s discharge. The full-gate turbine discharge is expected to be about 49,5 kl/s, corresponding to a peaking capability of 33,7 MW.

Calculation of the energy production based on future power market studies has been performed by the National Energy Authority. The results of these calculations are shown on exhibit 9.02.

7. PROJECT COSTS

7.1 Capital Costs

Cost estimates for the Gljúfurver Project in this Definite Project Report were prepared for each of the four stages representing progressive construction to provide generation to meet expected power demands. Summary Cost Estimates here presented are based on the following Detailed Cost Estimates. All costs are expressed in Icelandic kronur. The rate of exchange is now 57 Icel.kr. to one U.S. Dollar.

The construction costs were prepared from detailed quantity surveys based on the Project drawings and on estimated unit prices for construction work. Lump sums were included for costs of items which could not be estimated conveniently by the unit cost procedure. The unit prices and lump sums were estimated on the basis of labour rates and the cost of material and equipment as of January 1968.

The unit prices basic to the detailed cost estimates include constractors' overhead, profit, applicable taxes and insurance. Customs duties and taxes on imported equipment and materials were not included.

The estimated costs for the main permanent electrical and mechanical equipment were based on recent quotation from well-known European manufacturers.

Contingency allowances were added to the sub-totals of the estimated direct construction costs as an indirect item. These allowances are intended to cover possible unforseen difficulties of construction and omissions from the estimate. The effects of change of rate of exchange are not included.

Engineering costs associated with design and the engineering supervision of construction plus the owner overhead costs during the construction period were estimated to be about eight percent of the sub-total of Direct Construction Costs plus the contingencies. Preliminary Costs now amounting about 4 Mkr. are not included. Interest during construction is estimated about ten percent of the Construction Cost.

Costs of water rights and compensations for damages of land and property including roads on both sides of the reservoir, are not included.

The estimated fund requirements are summarized by stages in Icelandic kronur as follows :

Stage	Domestic Currency Mkr	Foreign Currency Mkr	Total Mkr
I	65, 7	102, 6	168, 3
II	44, 1	46, 4	90, 5
III	42, 2	43, 1	85, 3
IV	27, 4	58, 5	85, 9
Total	179, 4	250, 6	430, 0

7.2 Detailed Cost Estimates

GLJÚFURVER
Project Costs Estimate
Stage I

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
Intake, Powertunnel Penstock and Gateshaft					
Care of water			L. S.	980.000	
Excavation, tunnel	m^3	34.500	480	16.560.000	
Excavation, gateshaft	m^3	1.400	700	980.000	
Steel tunnel supports	kg	60.000	25	1.500.000	
Rock bolting			L. S.	1.800.000	
Concrete	m^3	4.900	1500	7.350.000	
Guniting			L. S.	1.500.000	
Reinforcement steel	kg	30.000	14	420.000	
Forms, straight	m^2	270	420	113.400	
Forms, curved	m^2	1.600	800	1.280.000	
Forms, tunnel lining	m^2	3.680	650	2.392.000	
Steel lining, penst. a. bulkh.	kg	38.000	48	1.824.000	
Structural steel, slots and racks	kg	16.000	40	640.000	37.339.400
Diversion tunnel, Bypass and new Intake for Laxá I					
Excavation, overburden	m^3	2.200	55	121.000	
Excavation, rock open	m^3	2.400	230	552.000	
Excavation, tunnel	m^3	4.200	550	2.310.000	
Concrete	m^3	380	1500	570.000	
Reinforcement steel	kg	25.000	14	350.000	
Rockbolts			L. S.	500.000	
Steel lining	kg	5.000	48	240.000	
Forms, straight	m^2	450	420	189.000	
Forms, curved	m^2	160	800	128.000	
Guniting			L.S.	400.000	
Sluice gate and hoists			L.S.	1.300.000	
Hoists house			L.S.	100.000	
Miscellaneous			L.S.	100.000	6.860.000
Surge Tank					
Excavation, overburden	m^3	300	60	18.000	
Excavation, surge t.a. shaft	m^3	3.680	630	2.318.400	
Concrete	m^3	290	1500	435.000	
Forms, curved	m^2	450	800	360.000	
Bulkhead			L. S.	70.000	
Fencing etc.			L. S.	80.000	3.281.400
					47.480.800

GLJÚFURVER
Project Costs Estimate
Stage I, cont.

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
					47.480.800
Powerstation, Valve Chamber and Access Tunnel					
Excavation, overburden	m^3	2.000	55	110.000	
Excavation, open rock	m^3	2.800	230	644.000	
Excavation, tunnel	m^3	4.600	550	2.530.000	
Excavation, powerhouse	m^3	8.100	300	2.430.000	
Steel supports	kg	40.000	25	1.000.000	
Rockbolts and grouting			L.S.	300.000	
Concrete	m^3	2.450	1500	3.675.000	
Forms, straight	m^2	3.500	420	1.470.000	
Forms, curved	m^2	750	800	600.000	
Forms, drafttube	m^2	120	1100	132.000	
Reinforcement steel	kg	175.000	15	2.625.000	
Steel lining	kg	8.000	48	384.000	
Drafttube gate			L.S.	375.000	
Pumps and piping			L.S.	150.000	
Architectural			L.S.	2.300.000	
Mechanical equipment			L.S.	2.500.000	21.225.000
Tailrace and Bridge over Tailrace					
Excavation, overburden	m^3	400	55	22.000	
Excavation, open rock	m^3	3.000	230	690.000	
Excavation, tunnel	m^3	8.400	480	4.032.000	
Care of water			L.S.	500.000	
Concrete	m^3	250	1500	375.000	
Forms, straight	m^2	400	420	168.000	
Reinforcement steel	kg	25.000	15	375.000	
Architectural			L.S.	150.000	
Rockbolts			L.S.	400.000	6.712.000
Roads and parking area					
Fill	m^3	2.800	85	238.000	
Drains etc.			L.S.	80.000	318.000
					75.735.800

GLJÚFURVER
Project Costs Estimate
Stage I, cont.

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
					75.735.800
Bus- and Cableducts Switch-yard, etc.					
Excavation, open rock	m^3	850	300	255.000	
Backfill	m^3	360	100	36.000	
Concrete	m^3	280	1500	420.000	
Forms, straight	m^2	1.360	420	571.200	
Reinforcement steel	kg	18.000	15	270.000	
Miscellaneous			L.S.	520.000	2.072.200
Contractors Camp and Move In			L.S.	7.000.000	7.000.000
Powerhouse Equipment					
Turbine and governor			L.S.	13.650.000	
Generator			L.S.	15.500.000	
Butterfly valve			L.S.	3.250.000	
Station supply transformers			L.S.	1.500.000	
Power bus			L.S.	330.000	
Control cables			L.S.	330.000	
Installation of el. equipm.			L.S.	2.000.000	36.560.000
Transmission Features					
Transformer			L.S.	3.960.000	
One 66 kV field section			L.S.	600.000	
Step-voltage regulator (Laxá I)			L.S.	740.000	
66 kV cable			L.S.	65.000	
Installation of transm. feat.			L.S.	150.000	5.515.000
SUBTOTAL DIRECT COST					126.883.000
Contingencies, Civil Works, 15% ±					12.717.000
Contingencies, Electrical and Mechanical Works, 5% ±					2.100.000
TOTAL DIRECT COST					141.700.000
Engineering and Supervision, 8% ±					11.300.000
CONSTRUCTION COST					153.000.000
Interest During Construction, 10% ±					15.300.000
PROJECT INVESTMENT					168.300.000

GLJÚFURVER
Project Costs Estimate
Stage II

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
Dam					
Excavation, overburden	m^3	13.000	55	715.000	
Excavation, interbed	m^3	7.000	150	1.050.000	
Excavation, rock	m^3	800	300	240.000	
Foundation preparation	m^2	3.000	150	450.000	
Supporting fill, compact.	m^3	202.000	85	17.170.000	
Impervious fill	m^3	56.000	145	8.120.000	
Filters	m^3	18.000	180	3.240.000	
Rip rap	m^3	12.000	400	4.800.000	
Holes for grouting, checking etc.	m	3.500	1200	4.200.000	
Borehole tubes and fittings			L. S.	480.000	
Cement for grouting	ton	1.100	1600	1.760.000	
Sand for grouting	m^3	560	300	168.000	
Bentonite for grouting	ton	45	8000	360.000	
Calciumclorid for grouting	ton	30	8000	240.000	
Processing, mixing etc.			L. S.	1.950.000	44.943.000
Flow Diversion and Chute					
Excavation, overburden	m^3	4.500	55	247.500	
Excavation, open rock	m^3	6.000	230	1.380.000	
Excavation, tunnel	m^3	1.480	550	814.000	
Concrete	m^3	1.960	1500	2.940.000	
Forms, straight	m^2	1.700	420	714.000	
Forms, curved	m^2	500	800	400.000	
Reinforcement steel	kg	50.000	15	750.000	
Gate frames etc.			L. S.	130.000	
Backfill	m^3	1.800	50	90.000	
Fencing, grading, etc.			L. S.	60.000	7.525.500
Gates and Gateshaft					
Concrete	m^3	800	1500	1.200.000	
Forms, straight	m^2	1.250	420	525.000	
Main gate, slots and hoist			L. S.	4.600.000	
Bypass gate, slots and hoist			L. S.	850.000	
Gate house			L. S.	400.000	
Miscellaneous			L. S.	60.000	7.635.000
					60.103.500

GLJÚFURVER
Project Costs Estimate
Stage II, cont.

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
					60.103.500
Surge Tank					
Concrete	m^3	440	1500	660.000	
Forms, curved	m^2	830	600	498.000	
Reinforcement steel	kg	16.000	15	240.000	1.398.000
Contractors Camp and Move In			L. S.	4.000.000	4.000.000
Transmission Features					
One 66 kV field section			L. S.	600.000	
132 kV overhead connection			L. S.	60.000	
Installation			L. S.	150.000	810.000
SUBTOTAL DIRECT COST					66.311.500
Contingencies, Civil Works, 15% ±					9.798.500
Contingencies, Electrical Works, 5% ±					40.000
TOTAL DIRECT COST					76.150.000
Engineering and Supervision, 8% ±					6.150.000
CONSTRUCTION COST					82.300.000
Interest During Construction, 10% ±					8.200 000
PROJECT INVESTMENT					90.500.000

GLJÚFURVER
Project Costs Estimate
Stage III

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
Spillway and Chute					
Excavation, overburden	m^3	2.300	55	126.500	
Excavation, open rock	m^3	7.900	230	1.817.000	
Concrete	m^3	2.650	1500	3.975.000	
Forms, straight	m^2	2.870	420	1.205.400	
Forms, curved	m^2	200	800	160.000	
Reinforcement steel	kg	55.000	15	825.000	
Backfill	m^3	2.000	50	100.000	
Anchor bars, placed			L.S.	440.000	
Fencing and sowing, clean up, etc.			L.S.	210.000	8.858.900
Dam					
Excavation, overburden	m^3	10.500	55	577.500	
Foundation preparation	m^2	2.200	150	330.000	
Supporting fill, compact.	m^3	313.000	85	26.605.000	
Impervious fill	m^3	41.000	145	5.945.000	
Filters	m^3	38.000	180	6.840.000	
Rip rap	m^3	30.000	400	1.200.000	
Drilling holes for grouting, testing, etc.	m	1.500	1200	1.800.000	
Cement for grouting	ton	225	1600	360.000	
Sand for grouting	m^3	70	300	21.000	
Bentonite for grouting	ton	8	8000	64.000	
Processing, mixing and injecting			L.S.	450.000	
Wayposts, sowing, etc.			L.S.	670.000	44.862.500
Gateshaft and Gatehouse					
Concrete	m^3	200	1500	300.000	
Forms, straight	m^2	450	420	189.000	
Forms, curved	m^2	380	800	304.000	
Reinforcement steel	kg	12.000	15	180.000	
Structural steel	kg	4.000	40	160.000	
Gatehouse demont. and remont., clean up, etc.			L.S.	170.000	1.303.000
					55.024.400

GLJÚFURVER
Project Costs Estimate
Stage III, cont.

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
					55.024.400
<u>Surge Tower</u>					
Plate steel	kg	45.000	48	2.160.000	
Miscellaneous			L.S.	520.000	2.680.000
<u>Move In</u>			L.S.	2.000.000	2.000.000
<u>Transmission</u>					
Line end, installation			L.S.	50.000	
Three winding trafo. 132/66/6,5 kV			L.S.	2.800.000	
Installation			L.S.	50.000	2.900.000
SUBTOTAL DIRECT COST					62.604.400
Contingencie, Civil Works, 15% ±					8.995.600
Contingencies, Electrical Works, 5% ±					150.000
TOTAL DIRECT COST					71.750.000
Engineering and Supervision, 8% ±					5.750.000
CONSTRUCTION COST					77.500.000
Interest During Construction, 10% ±					7.800.000
PROJECT INVESTMENT					85.300.000

GLJÚFURVER
Project Costs Estimate
Stage IV

I t e m	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
Powerhouse					
Concrete	m^3	780	1500	1. 170. 000	
Forms, straight	m^2	300	420	126. 000	
Forms, curved	m^2	120	800	96. 000	
Forms, draft tube	m^2	120	1100	132. 000	
Reinforcement steel	kg	35. 000	15	525. 000	
Steel lining	kg	10. 000	48	480. 000	
Draft tube gate and hoist			L. S.	425. 000	
Architectural			L. S.	420. 000	3. 374. 000
Switch-yard, Cableducts, etc.					
Excavation, open rock	m^3	1. 600	300	480. 000	
Backfill	m^3	2. 500	100	250. 000	
Concrete	m^3	500	1500	750. 000	
Forms, straight	m^2	1. 450	420	609. 000	
Reinforcement steel	kg	20. 000	15	300. 000	
Structural steel	kg	45. 000	48	2. 160. 000	
Miscellaneous			L. S.	720. 000	5. 269. 000
Extension of Control Room at Laxá I			L. S.	1. 500. 000	1. 500. 000
Powerhouse Equipment					
Turbine and governor			L. S.	16. 100. 000	
Generator			L. S.	18. 000. 000	
Butterfly valve			L. S.	3. 900. 000	
Power bus			L. S.	380. 000	
Control cables			L. S.	330. 000	
Installation of el. equipment			L. S.	2. 000. 000	40. 710. 000
Transmission Features					
Transformer			L. S.	5. 050. 000	
Six 132 kV field sections			L. S.	5. 955. 000	
Ten 132 kV p. t. transformers			L. S.	165. 000	
Insulators, bus conduct., etc.			L. S.	1. 500. 000	
Piping, cables, etc.			L. S.	1. 000. 000	
Control cubicels 6 fields			L. S.	900. 000	
Miscellaneous			L. S.	950. 000	
Erection, installation, etc.			L. S.	1. 500. 000	17. 020. 000
					67. 873. 000

GLJÚFURVER
Project Costs Estimate
Stage IV, cont.

Item	Unit	Quantity	Unit price kr.	Icel. kr.	Icel. kr.
					67.873.000
SUBTOTAL DIRECT COST					67.873.000
Contingencies, Civil Works, 15% ±					1.527.000
Contingencies, Mechanical and Electrical, 5% ±					2.900.000
TOTAL DIRECT COST					72.300.000
Engineering and Supervision, 8% ±					5.800.000
CONSTRUCTION COST					78.100.000
Interest During Construction, 10% ±					7.800.000
PROJECT INVESTMENT					85.900.000

8. SUMMARY OF ENGINEERING REPORTS

8.1 Álitsgerð um fullvirkjun Laxár í S.-Þingeyjarsýslu
(Report on the hydro-electric power resources and development of the Laxá River - South-Thingeyjarsýsla N.-Iceland. May 1958)

The report proves the feasibility not prior envisaged of diverting the flow of Svartá River to Kráká River, a tributary to Laxá River and thus increasing the potential power resources of the Laxá River by some 40%.

The report presents appraisals of seven alternative ways of development of Laxá River. The report shows that conclusions as to which method is preferable cannot be drawn directly by comparison of the cost estimates in the report, as the difference in cost between the different projects is not so marked as to serve this purpose. It is pointed out that other conditions for instance and particularly power demand will be a more decisive factor in this connection.

Furthermore, it is necessary to provide more sufficient data as to topography, geology, hydrology etc.

The report served to initiate field and engineering investigations in the years 1963-1964 in the Brúar-region.

8.2 Laxá í Suður-Þingeyjarsýslu
Áætlanir um heildarvirkjun Laxár við Brúar
(Report on a masterplan of the development of the Brúarfall in Laxá River. May 1964)

The scope of the report was to find out how the fall could be developed in the most convenient way to meet the power demand for the Laxá area and eventually the power demand for the North-Iceland and East-Iceland areas.

This report presented appraisals of four different alternatives of development of the total fall in the Laxárgljúfur gorge at the Brúar farm, where the two now existing power plants, Laxá I and Laxá II, are located.
In all it presented ten different appraisal with cost estimates of plants from 11 to 50 MV. The total power resources of this stretch of the river amount from 386 to 404 GWh per year.

Besides the report presented, an appraisal of a 6 MW power plant alongside Laxá I, a run-off-river plant. It was though pointed out that a run-off-river plant would not be free of troubles from ice. The existing plants have often had serious such troubles, especially the upper one, Laxá I. This project was therefore not thought feasible.

In all four alternatives a 36 m high dam located in the upstream end of the fall was thought most appropriate, giving extra head, large regulating pondage as well as excluding all ice troubles both for future and the existing plants and increasing in their production.

The report included a separate volume on the hydrology of the Laxá River, on geological data and on construction material deposits based on extensive field investigations performed by the State Electric Authority in intimate cooperation with Thoroddsen and Partners.

8.3 A letter to Laxárvirkjun dated 26. okt. 1964

In the letter was presented an appraisal of an 11 MW power plant with a dam located in the same place as in the Efstafall Project and utilizing the head down to the intake pond of the Laxá II powerplant, a gross head of 69,5 m.

8.4 Laxá at Brúar - December 1964 and January 1965

These reports presented an appraisal of an 11 MW powerplant, the Efstafall Project. The reports showed the 11 MW plant to have a reasonable low unit power and energy costs.

These reports initiated the decision of the Board of the Laxárvirkjun to beg our firm to work out a definite report on the Efstafall Project and contract documents in order to let the work out on competitive bidding.
Letters on this matter are dated 6. and 25. of May 1965.

8.5 Efstafall Project. Definite Project Report. March 1966

A dam about 37 m high was planned in the uppermost part of the Laxárgljúfur gorge some 150 m upstream of the existing dam for Laxá I. A tunnel was to be located in the right bank of the river leading to a powerhouse of the surface indoor type located just downstream from the toe of the dam. The Efstafall Project would operate under a gross head varying from 20 to 31 m, depending on the drawdown of the reservoir and with a nearly constant tailwater elevation, about 107, 5 m a. s. l. Installed capacity was to be 12 MW in one generating unit.

The Efstafall Project was not considered to present any difficult or unusual construction problems. With its high dam and pondage (31 Gl) it would increase the firm power from the existing power plants, Laxá I and Laxá II, considerably. The selection of installed capacity was based on estimation of the future demand of power and energy in the Laxá area. Further development was not considered necessary until the year 1975.

8. 6 Skýrsla um Gljúfurver, 10, 5 MW virkjun í Laxá við Brúar. Júlí 1966 (Report on a 10,5 MW power plant at Gljúfurver. July 1966)

This power plant was to be operated parallel to Laxá I under the same gross head 38, 0 m (107, 5 to 69, 5 m a. s. l.). Together these two plants would have the same station flow capacity as the above mentioned Efstafall Power-plant (50 kl/s).

The scope of this report was to show how energy and power for the Laxá area could be provided until the year 1985.

8. 7 Athuganir á ýmsum virkjunarleiðum í Laxá, S. Þing. Sept. 1966 (Studies on Some Alternative Developments of Laxá River. Sept. 1966)

In this report some alternative possibilities of providing energy for the Laxá area until the year 1985 are discussed.

8. 8 Skýrsla um Gljúfurver 50,6 MW virkjun í Laxá við Brúar. Marz 1967 (Report on a 50,6 MW power plant at Gljúfurver. March 1967)

This is a preliminary study on utilizing the whole head, which in previous studies had been divided in two, Efstafall and Gljúfurver developments.

The present report is a further development of this alternative.

9. THE EXHIBITS

9.0 General

9.01 Map and Climatological Data.
9.02 Hydrological Data. Loads and Recourses.
9.03 Daily Discharge Hydrograph. Laxá at Gljúfurver.
9.04 Gljúfurver and the Laxá Powerplants. General Plan.
9.05 Axis of Dam and Drill Holes. Location.
9.06 Laxá at Brúar. Geological Map and Graphic Core Logs.
9.07 Graphic Core Logs.
9.08 Topography.

9.1 Construction

9.11 Construction Materials. Location and Test Results.
9.12 Construction Materials. Test Results.
9.13 Construction Schedule.

9.2 Dam

9.21 Geology and Drill Holes.
9.22 Section and Specifications.
9.23 Geological Section. Foundation Grouting, Preliminary Plan.

9.3 Waterways and Powerstation

9.31 Plan.
9.32 Water Conductors.
9.33 Powerstation. Logitudinal Section.
9.34 Powerstation. Transverse Section.
9.35 Powerstation. Transverse Section.

9.4 Waterways and Powerstation. Stage I.

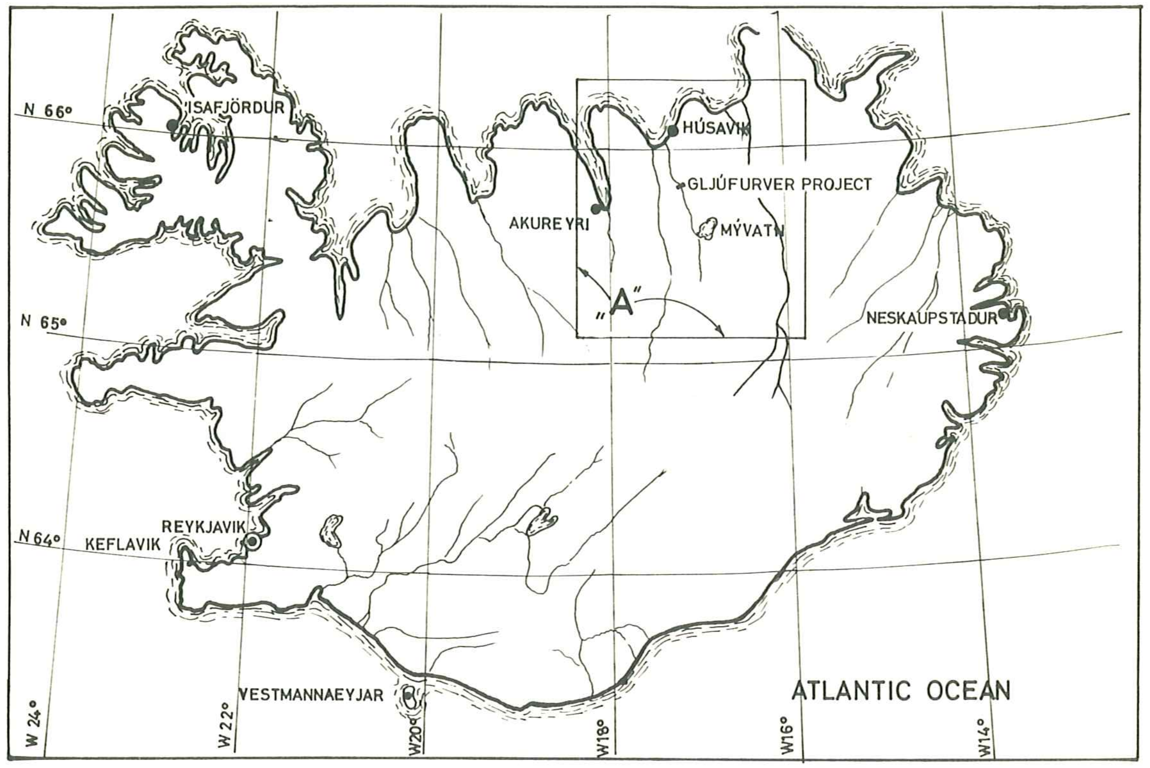
9.41 Plan.
9.42 Water Conductors.

9.5 Waterways and Powerstation. Stage II.

9.51 Plan.
9.52 Water Conductors.

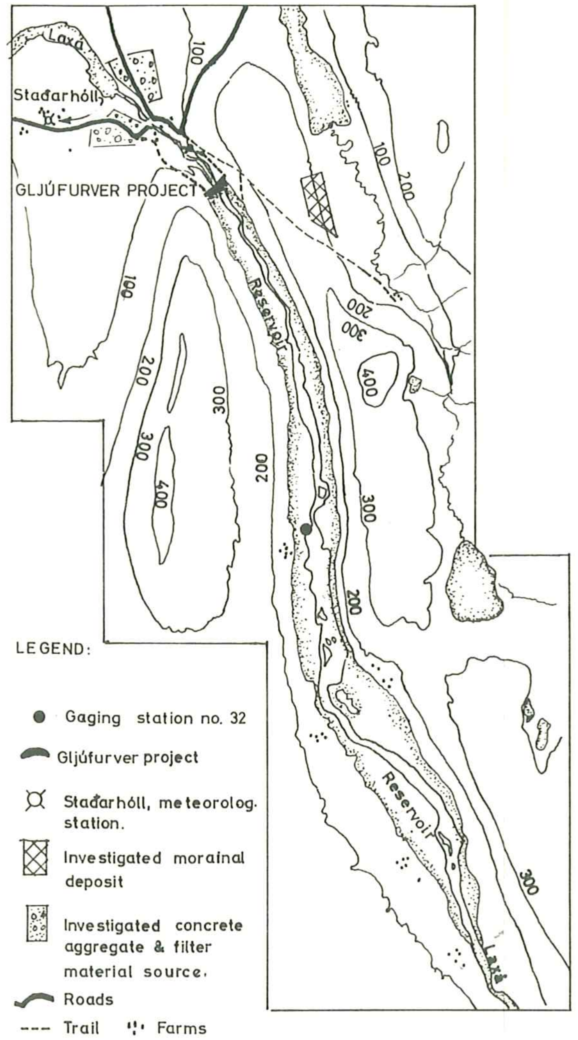
9.6 Transmission

9.61 One Line Diagram.
9.62 Principal One Line Diagram of Laxá Substation.



Map of Iceland

Scale
km 0 50 100



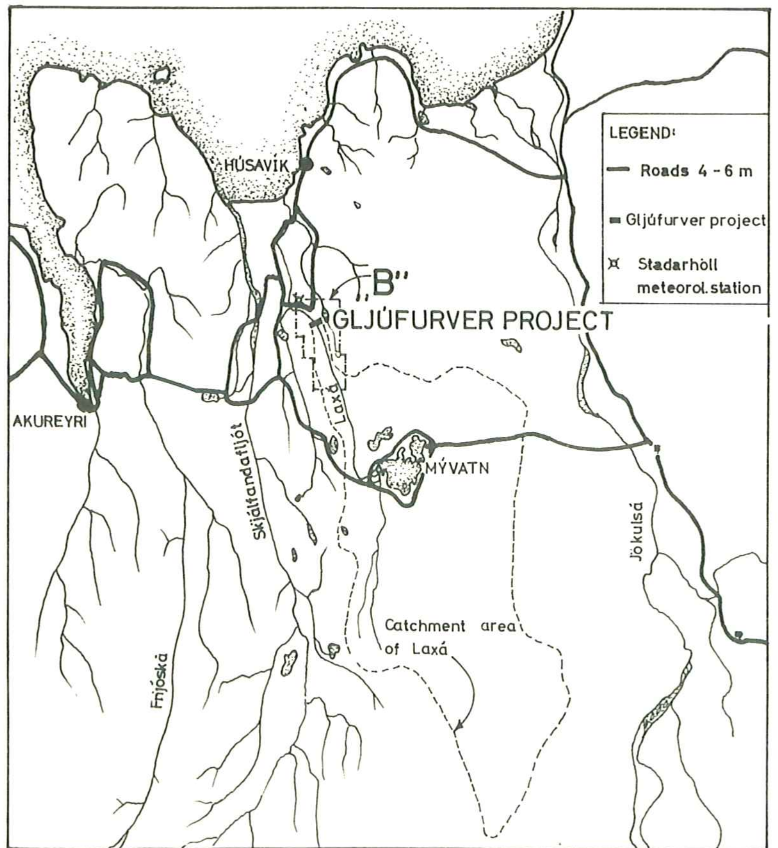
Regional map „B"

Scale
m 1000 0 1 2 km

YEAR:	'61	'62	'63	'64	'65	'66	'61	'62	'63	'64	'65	'66
JANUARY		21	9	12	19	16		24	27	24	27	25
FEBRUARY		15	13	7	6	13		24	26	16	15	28
MARCH		20	17	8	18	26		29	18	23	28	30
APRIL		13	21	16	17	13		20	18	20	23	20
MAY		12	22	16	10	24		12	16	7	16	10
JUNE		16	16	13	12	16		3	1	7	3	0
JULY		11	20	18	15	21		1	1	2	2	0
AUGUST		20	15	22	18	20		2	7	1	1	6
SEPTEMBER		15	20	19	27	18		9	8	11	9	8
OCTOBER		19	14	18	20	17		16	17	19	11	23
NOVEMBER	17	20	23	21	22	19	21	23	29	24	27	25
DECEMBER	17	18	15	21	12	24	29	29	27	29	31	31

NUMBER OF DAYS WITH PRECIPITATION — NUMBER OF DAYS WITH TEMPERATUR BELOW 0° C

AT STAÐARHÓLL.



Regional map „A"

Scale
km 10 0 50 km

YEAR	1961	1962	1963	1964	1965	1966	1961	1962	1963	1964	1965	1966	1961	1962	1963	1964	1965	1966
JANUARY		-1.1	-5.1	0.3	-3.4	-4.9		-4.6	-9.4	-3.0	-6.7	-8.4		54.7	7.0	18.2	127.5	52.4
FEBRUARY		-2.5	-3.4	0.1	1.0	-7.8		-6.7	-7.7	-3,5	-1.9	-11.1		36.1	34.7	10.3	33.2	40.4
MARCH		-6.3	1.2	3.5	-5.9	-4.9		-10.0	-1.4	-0.1	-9.9	-8.6		52.2	19.9	21.9	18.5	113.7
APRIL		1.9	0.5	1.9	0.4	0.0		-2.1	-2.5	-2.3	-3.6	-3.7		31.1	83.2	31.1	32.5	32.2
MAY		5.1	3.3	5.8	3.9	3.4		1.0	0.2	1.9	-0.2	0.4		18.6	44.2	43.3	18.0	28.1
JUNE		8.1	10.1	8.4	8.0	10.0		4.3	5.4	3.7	3.1	5.7		39.7	49.2	21.2	24.2	21.5
JULY		10.0	8.1	9.0	9.4	9.3		5.1	4.7	5.9	4.7	7.1		26.8	47.9	47.3	24.3	68.9
AUGUST		7.8	7.0	7.0	8.7	7.8		5.3	2.7	3.6	5.1	3.9		38.0	10.5	107.0	28.1	40.4
SEPTEMBER		5.6	3.7	3.7	3.9	5.6		1.7	0.7	0.7	1.1	2.0		57.9	105.3	81.5	63.9	21.7
OCTOBER		3.1	2.3	2.7	5.6	0.2		0.0	-1.0	-0.9	1.5	-2.7		50.9	24.3	70.9	60.8	43.1
NOVEMBER	0.3	-1.6	-3.7	-0.6	-2.8	-1.8	-4.0	-5.7	-7.7	-4.6	-6.1	-6.8	127.0	29.8	85.5	66.4	61.6	123.7
DECEMBER	-4.4	-2.7	-1.5	-3.2	-5.8	-4.2	-8.0	-6.6	-5.4	-7.2	-10.9	-8.1	95.4	55.1	26.3	67.5	58.5	132.7

MEAN TEMPERATURE DEGREES C. — MEAN LOWEST TEMP. °C — PRECIPITATION IN mm

AT STAÐARHÓLL.

Meteorological data.

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT — GENERAL

MAPS & CLIMATOLOGICAL DATA

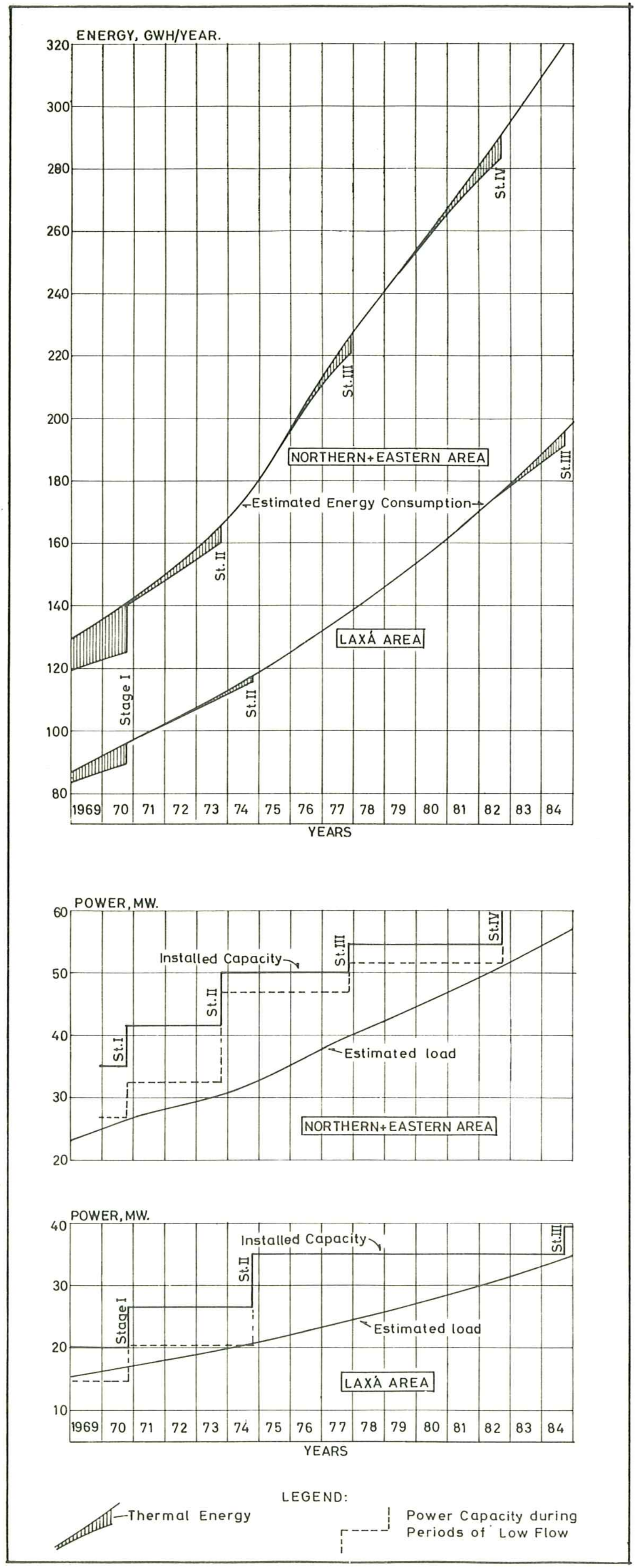
THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

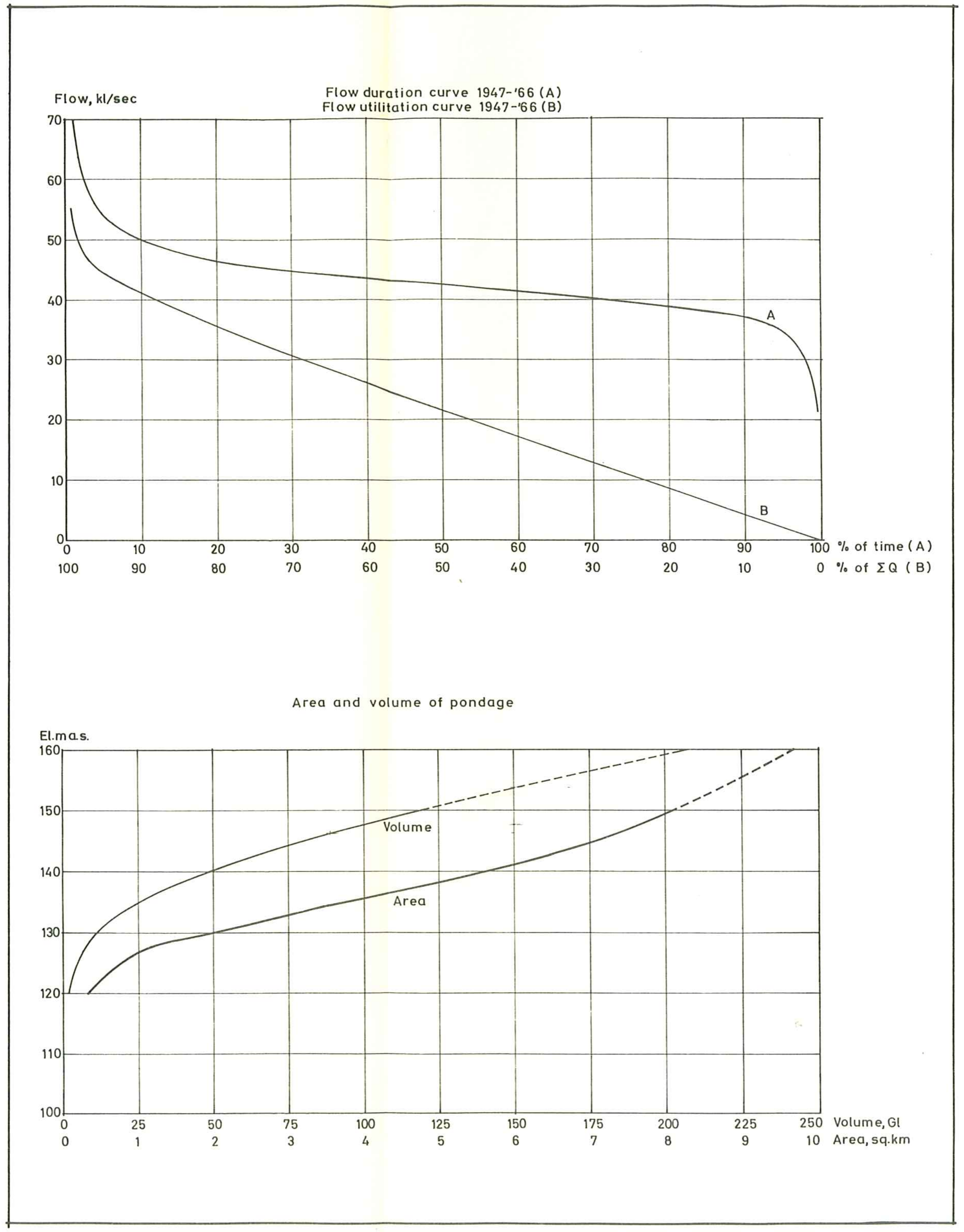
DES:	CHECKED:	DATE:	APPROVED:	DRWG. NO.
S.T.	Joh. G.	January 1968		07.03.0.01

Breytt:

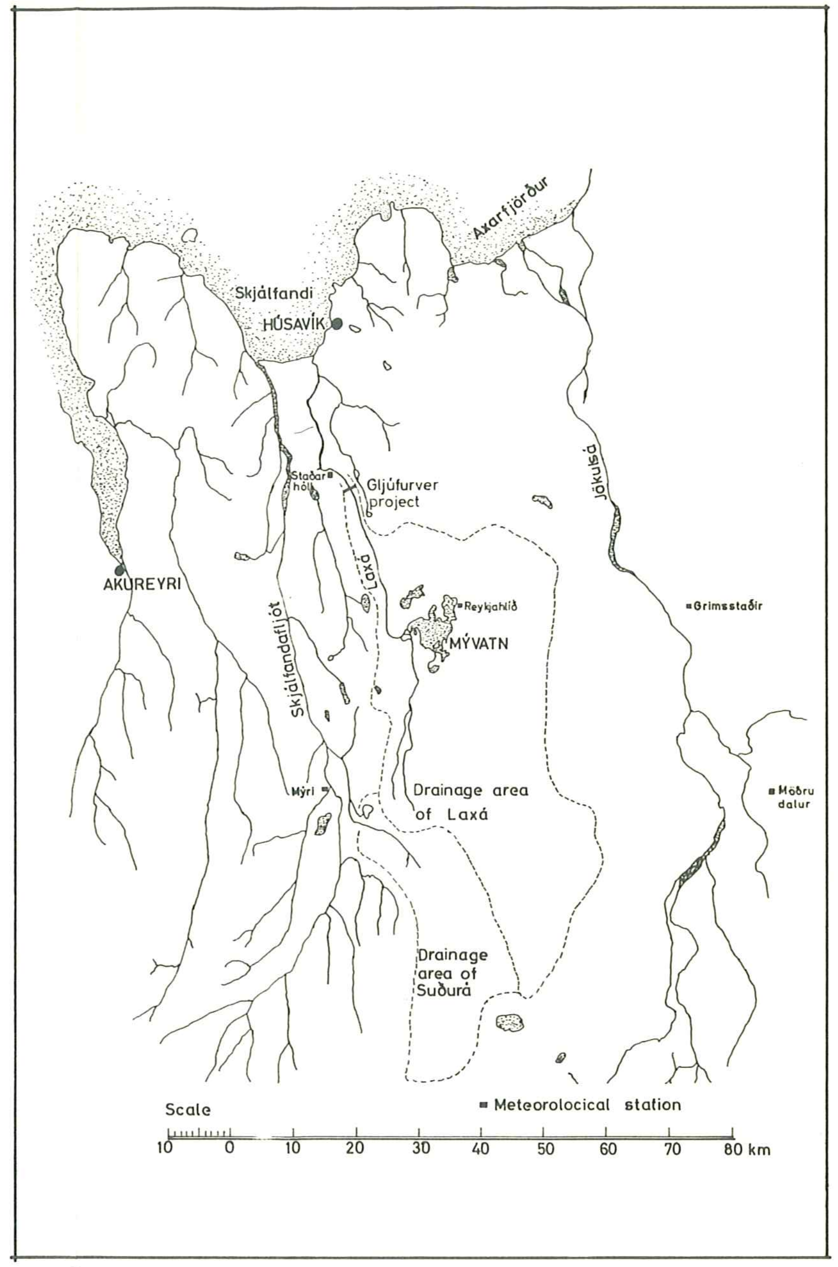
ESTIMATED LOADS AND RESOURCES



STREAM FLOWS AND STORAGE



DRAINAGE AREA



LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJUFURVER PROJECT	GENERAL

HYDROLOGICAL DATA
LOADS AND RESOURCES

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

DES:	CHECKED:	DATE:	APPROVED:	DRWG. NO.
S.H.	L.A.	JAN 1968	[signature]	07.03.0.02

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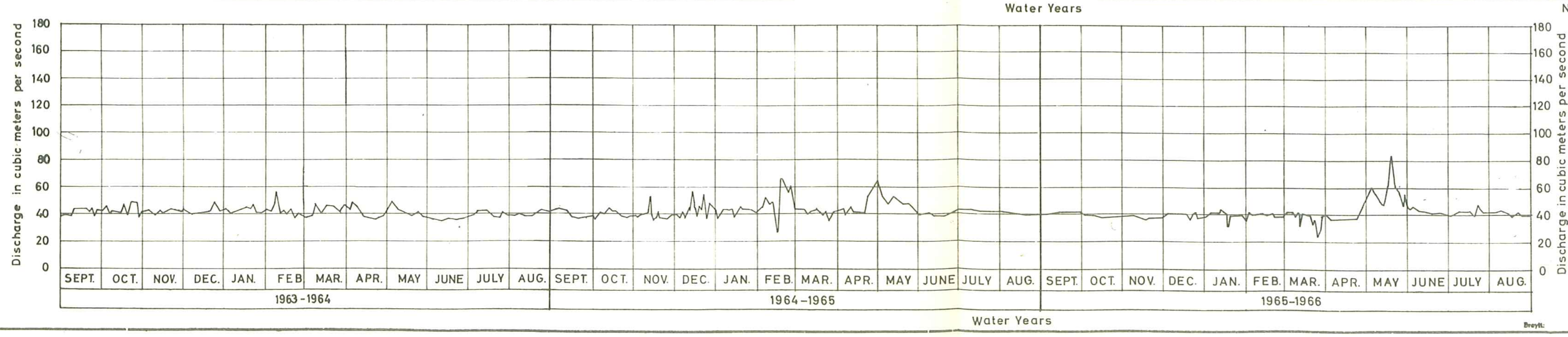
Note: Daily discharge at Gljúfurver based on discharge records for Laxá at Birningsstadasog (gaging station nr 32)



LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

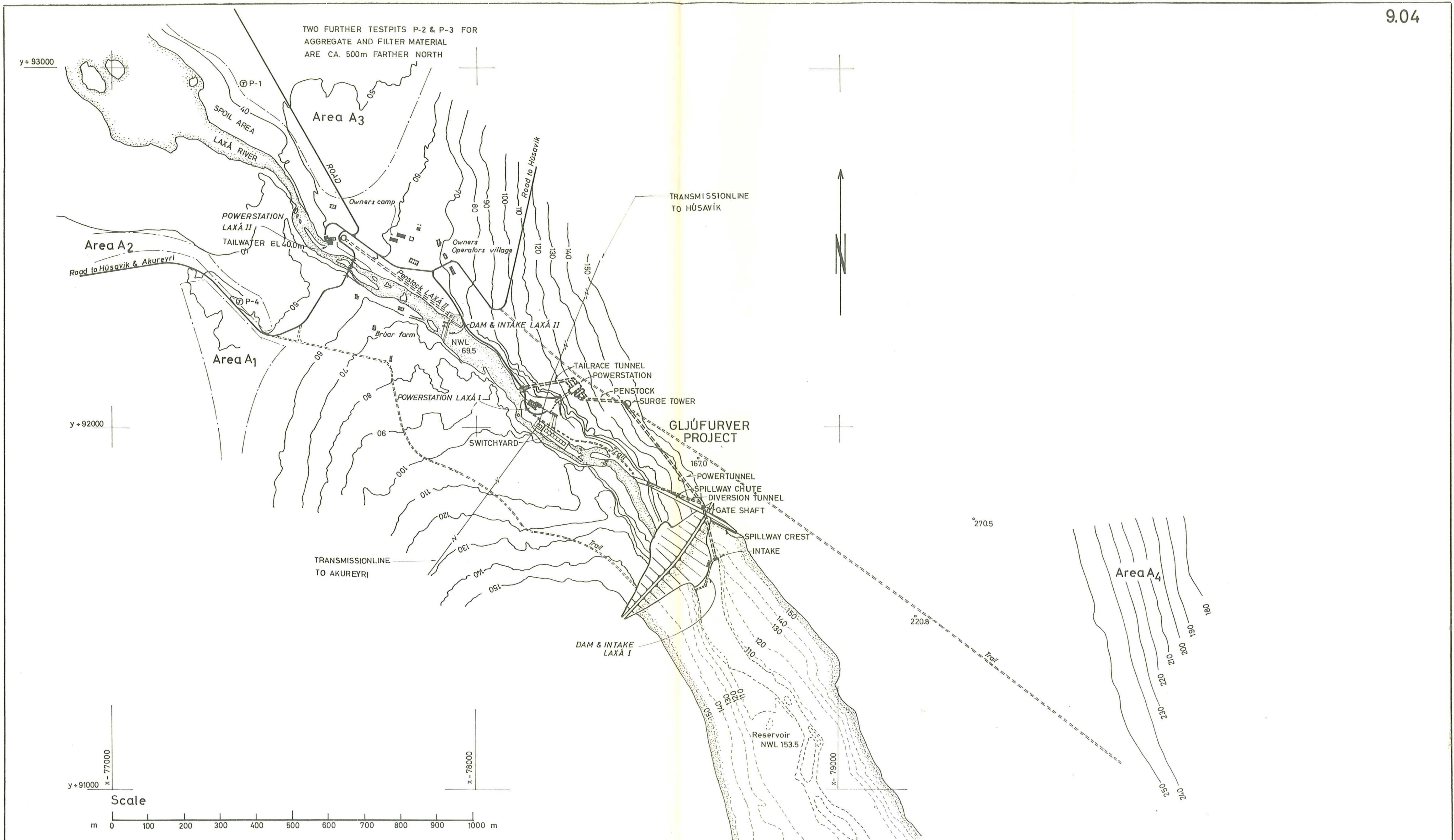
GLJÚFURVER PROJECT | GENERAL

DAILY DISCHARGE HYDROGRAPH LAXÁ AT GLJÚFURVER

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

DES: S.Þ. S.H. | CHECKED: | DATE: Nov. 1968 | APPROVED: | DRWG. NO. 07030.03



Notes:

1. *Topography based on aerial surveying performed by The State Electricity Authority Reykjavik and on topographic mapping performed by Thoroddsen and Partners. Contour interval 10 m.*
2. *Sources for concrete aggregate, filtermaterial and rolled fill will be in areas A_1, A_2 and A_3.*
3. *Sources for impervious core fill will be in area A_4*
4. *Test pits for concrete aggregate filtermaterial and rolled fill are marked thus:* Ⓣ

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	GENERAL

Gljúfurver and the Laxá powerplants
General plan

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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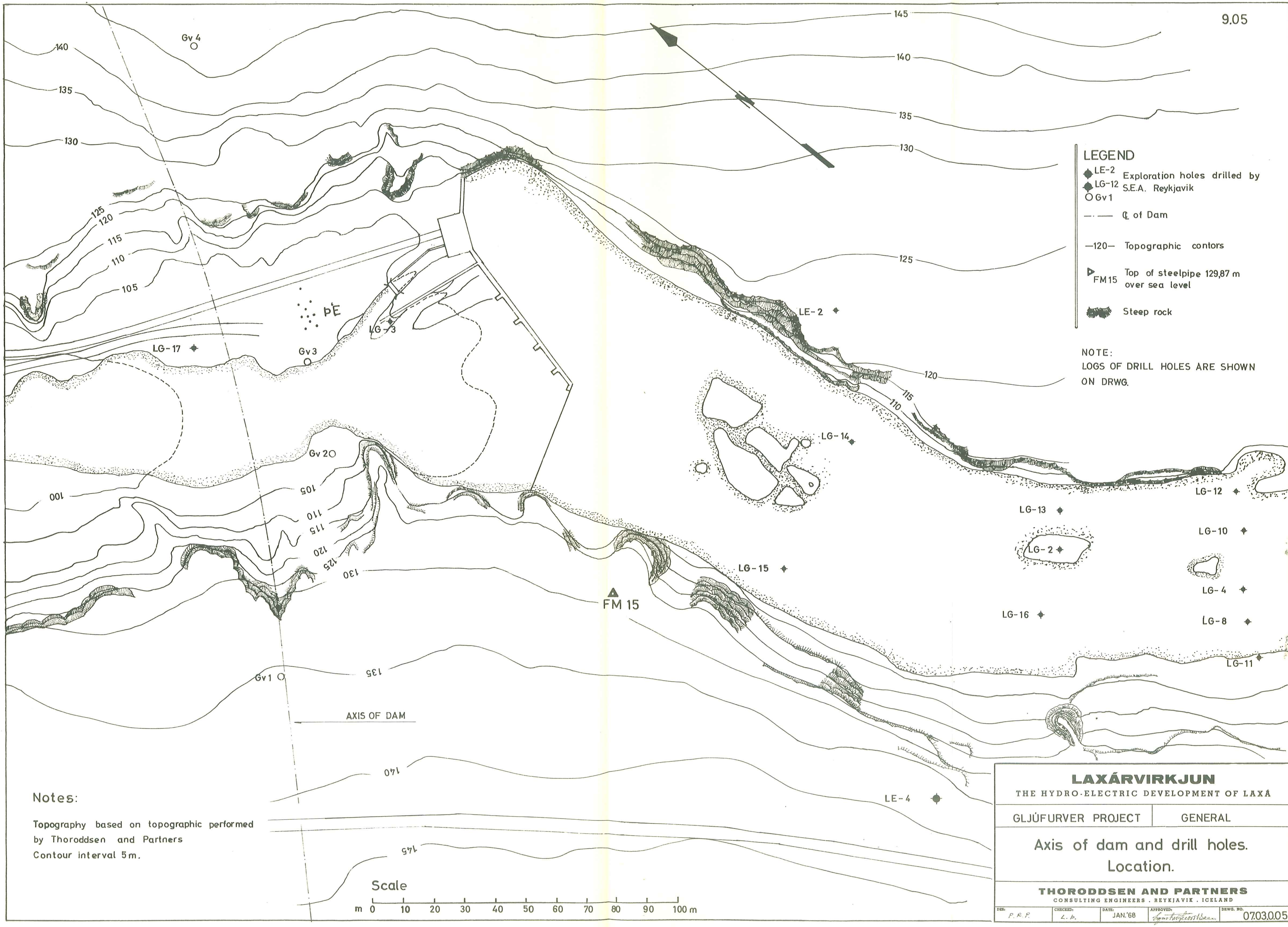
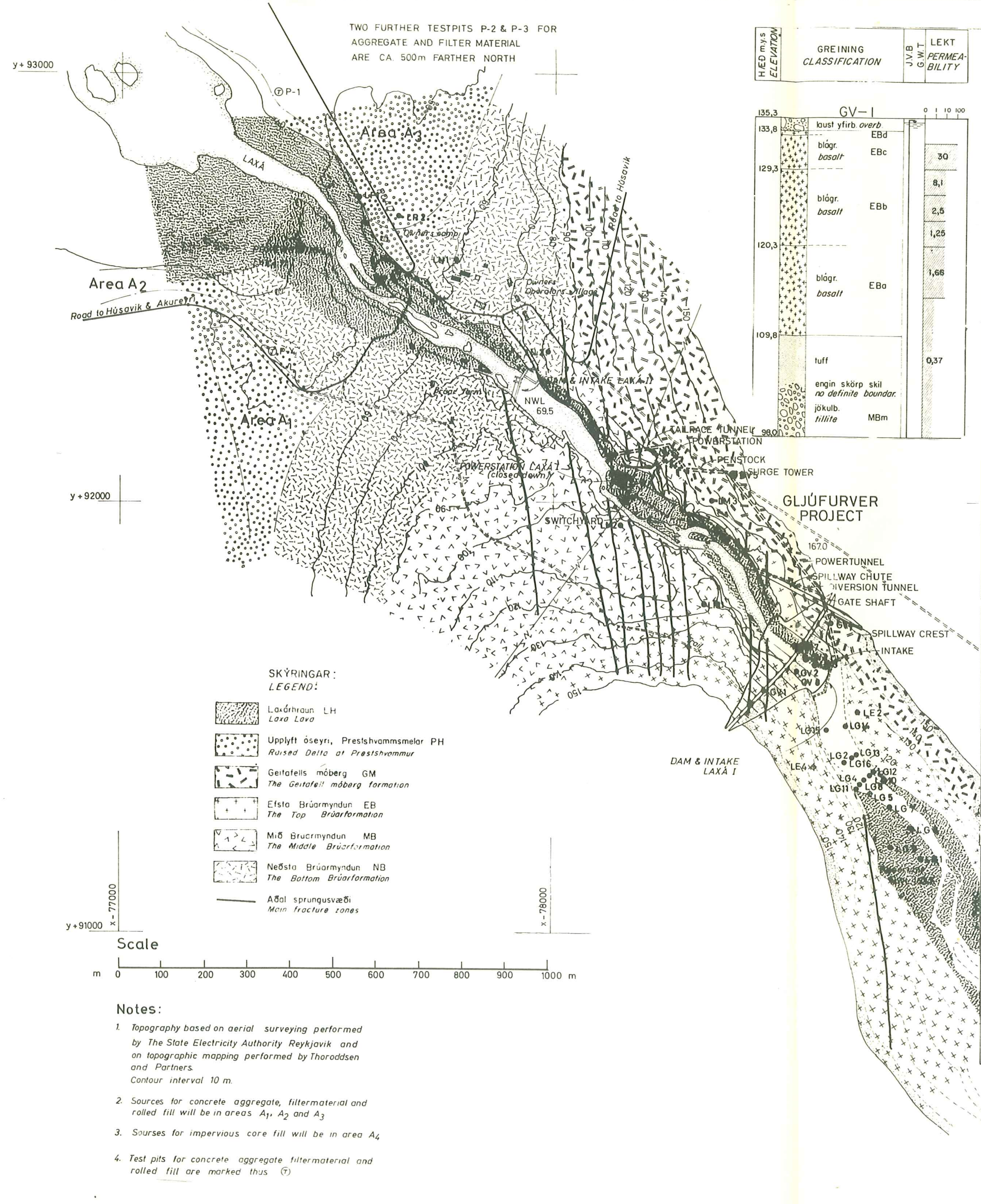
	Hþ. 31	L.Þ.	JAN 1968	[signature]	07.03.0.04

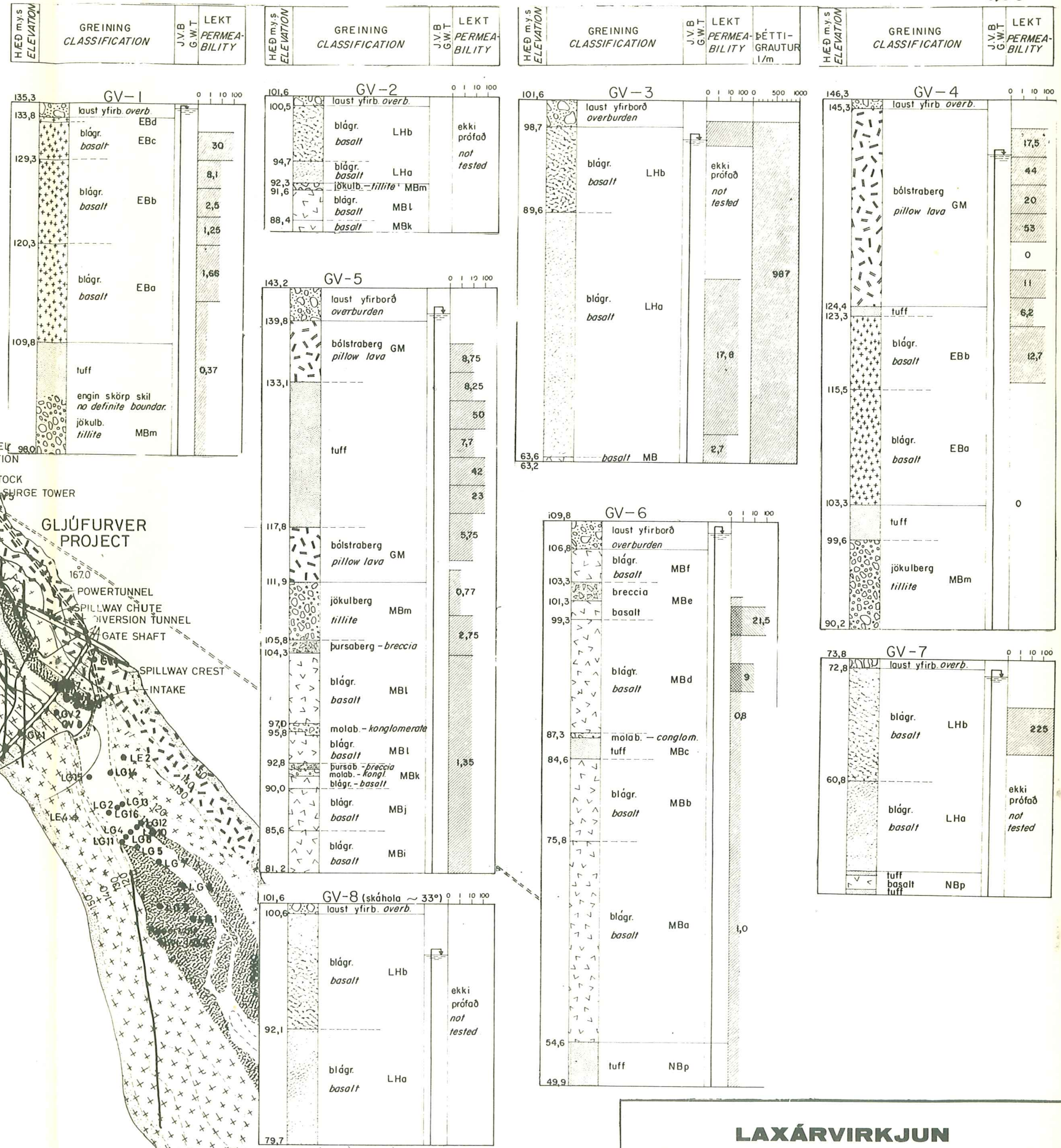


LEGEND
LE-2
LG-12
Gv 1
Exploration holes drilled by S.E.A. Reykjavik
℄ of Dam
—120— Topographic contors
FM15 Top of steelpipe 129,87 m over sea level
Steep rock
NOTE:
LOGS OF DRILL HOLES ARE SHOWN ON DRWG.
145
140
135
130
125
120
115
110
105
100
Gv 4
Gv 3
Gv 2
Gv 1
LG-17
LG-3
LE-2
LG-14
LG-12
LG-13
LG-10
LG-2
LG-15
LG-4
LG-16
LG-8
LG-11
LE-4
FM 15
AXIS OF DAM
Notes:
Topography based on topographic performed by Thoroddsen and Partners
Contour interval 5 m.
Scale
m 0 10 20 30 40 50 60 70 80 90 100 m
LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ
GLJÚFURVER PROJECT
GENERAL
Axis of dam and drill holes.
Location.
THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND
DES: P.R.P.
CHECKED: L.B.
DATE: JAN.'68
APPROVED:
DRWG. NO. 07.03.0.05



Notes:

1. Topography based on aerial surveying performed by The State Electricity Authority Reykjavik and on topographic mapping performed by Thoroddsen and Partners. Contour interval 10 m.
2. Sources for concrete aggregate, filtermaterial and rolled fill will be in areas A_1, A_2 and A_3
3. Sourses for impervious core fill will be in area A_4
4. Test pits for concrete aggregate filtermaterial and rolled fill are marked thus (T)



NOTES ON GRAPHIC CORE LOGS SEE DRWG. 9.07

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJUFURVER PROJECT	GENERAL

LAXÁ AT BRÚAR. GEOLOGICAL MAP AND GRAPIC CORE LOGS

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

DES:	CHECKED:	DATE:	APPROVED:	DRWG. NO.
	Z. B.	JAN 1968	[signature]	07.03.0.06

NOTES

1. The drilling, testing and classification was performed by The State Electricity Authority (S.E.A)
2. Rock classifications shown here are generalized. Mineral content, structure and other details are not shown.
3. Cores from the drillholes will be available for examination in the office of S.E.A. Reykjavik.
4. The permeability unit Lugeon (LU) is equivalent to 1 liter of leakeage per meter of hole (D= 76mm) per minute at a 10 kg/cm² pressure.
5. Groundwater levels are shown by the arrows.

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	GENERAL

GRAPHIC CORE LOGS

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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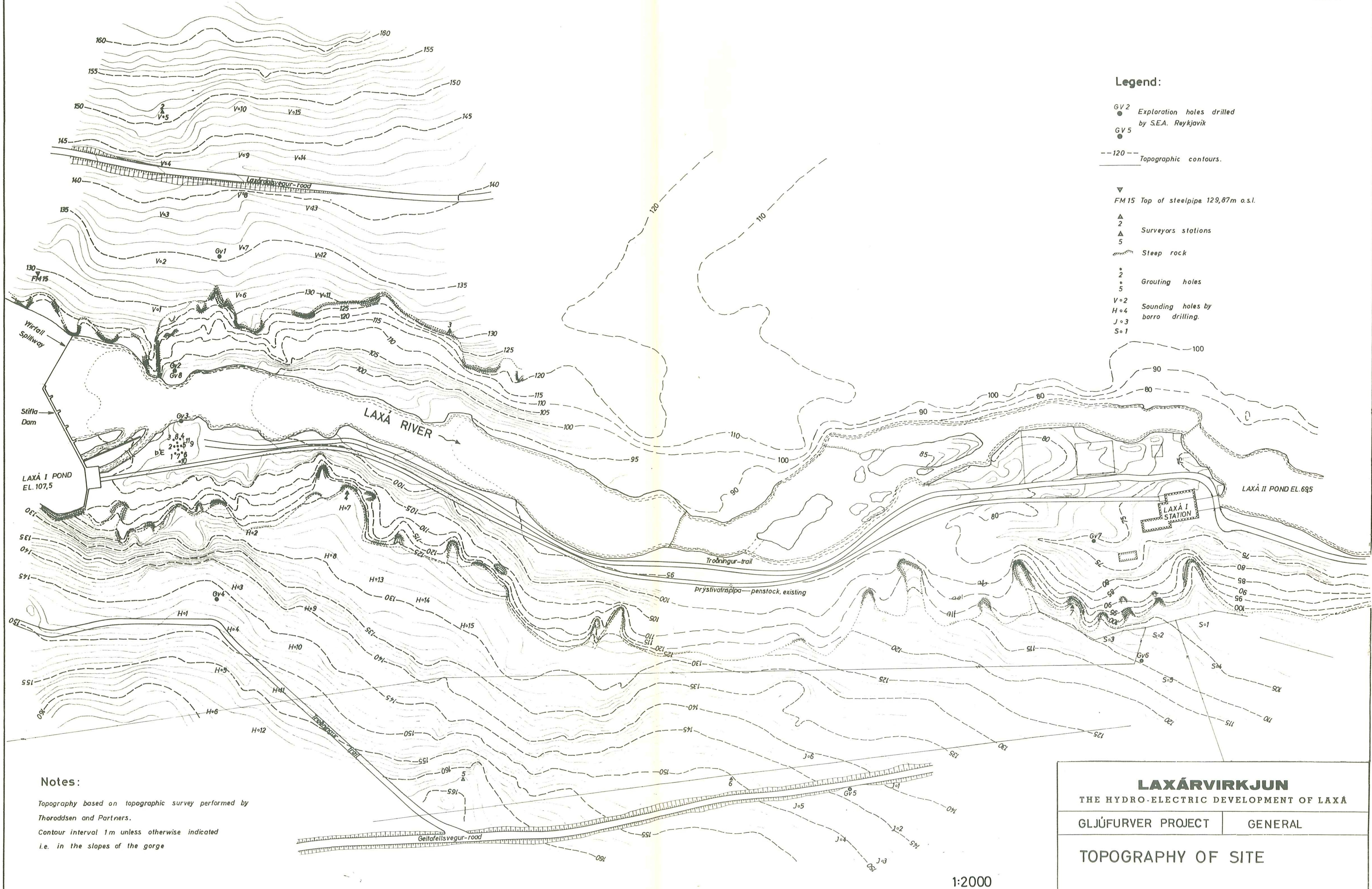
		JAN 1968		0703007



Legend:

- GV 2, GV 5 — Exploration holes drilled by S.E.A. Reykjavik
- – – 120 – – — Topographic contours.
- FM 15 — Top of steelpipe 129,87m o.s.l.
- 2, 5 — Surveyors stations
- Steep rock
- 2, 5 — Grouting holes
- V∘2, H∘4, J∘3, S∘1 — Sounding holes by borro drilling.

Notes:

Topography based on topographic survey performed by Thoroddsen and Partners.
Contour interval 1m unless otherwise indicated i.e. in the slopes of the gorge

1:2000

LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	GENERAL

TOPOGRAPHY OF SITE

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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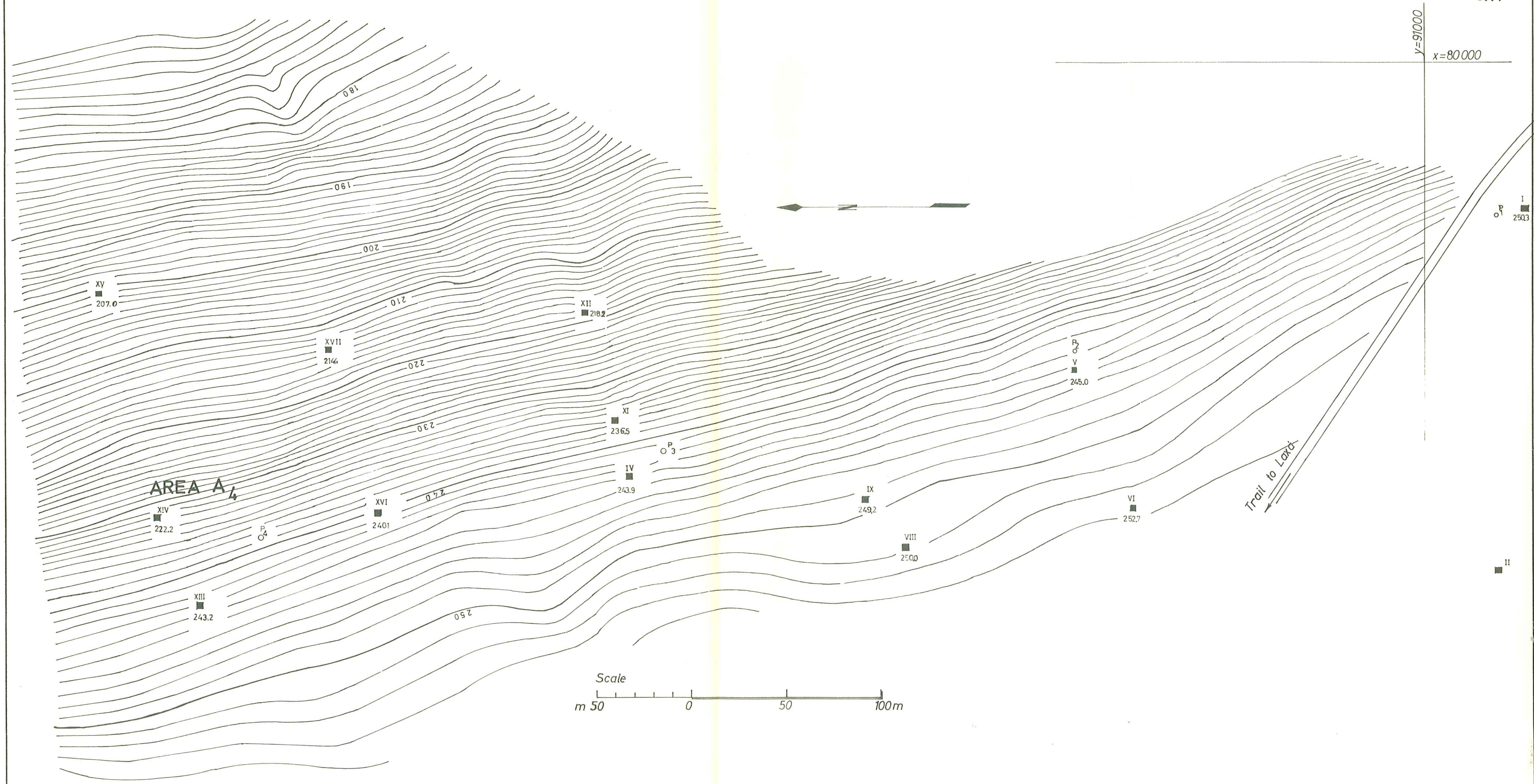
P. R. P.	L. b.	JAN 1968	[illegible]	07.03.0.08



Notes:

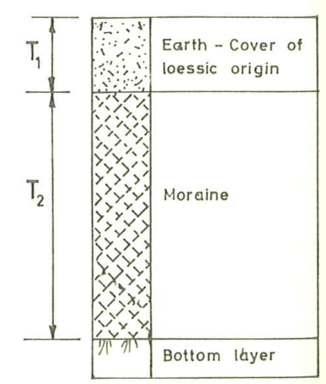
1. Topography based on topographic mapping performed by Thoroddsen and Partners.
   Contour interval 1 m.

2. Area A_4 will be the source of impervious core material. As to location of area see GENERAL PLAN. Drwg. No. 07.03.0.04

LEGEND

■ VI 252.7 — Test pit. Elevation 252.7m above sea level.

THICKNESS OF MORAINAL DEPOSIT AND EARTH - COVER



Test pit No.	T_1 m	T_2 m	Bottom-layer
IV	0.4	3.2	Rock
XI	0.8	4.3	Rock
XII	0.7	2.5	Rock
XIII	0.4	5.3	Moraine
XIV	1.2	4.4	Rock
XV	0.8	2.5	Rock
XVI	2.0	3.0	Moraine
XVII	1.4	2.0	Rock

Notes:

Samples for grain-size analyses of the morainal deposit have been taken every metre in the test pits.
Grain-size distribution see drwg. No. 07.03.1.02

LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	CONSTRUCTION

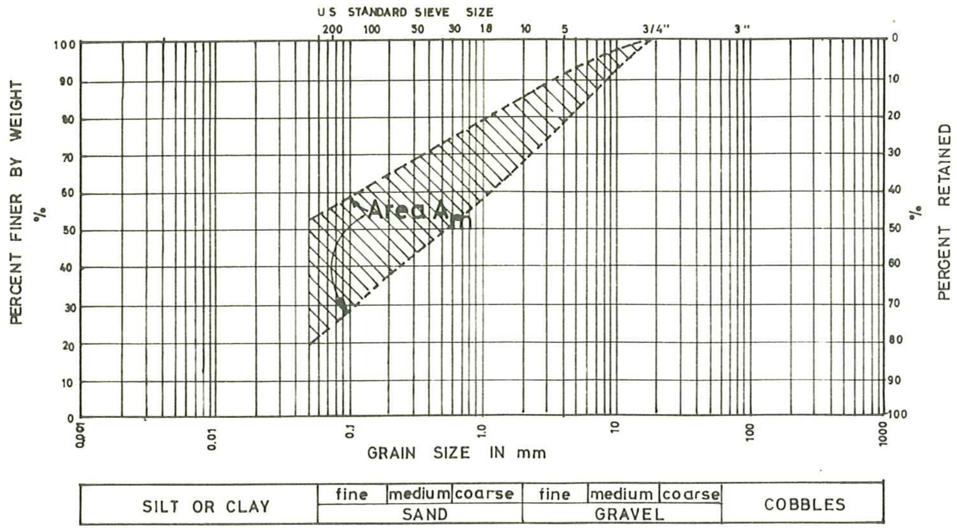
Construction materials
Location and test results.

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

Breytt:	DES:	CHECKED: Joh. G.	DATE: DEC. 1968	APPROVED:	DRWG. NO 07.03.1.01

MORAINAL MATERIAL

GRAIN SIZE DISTRIBUTION



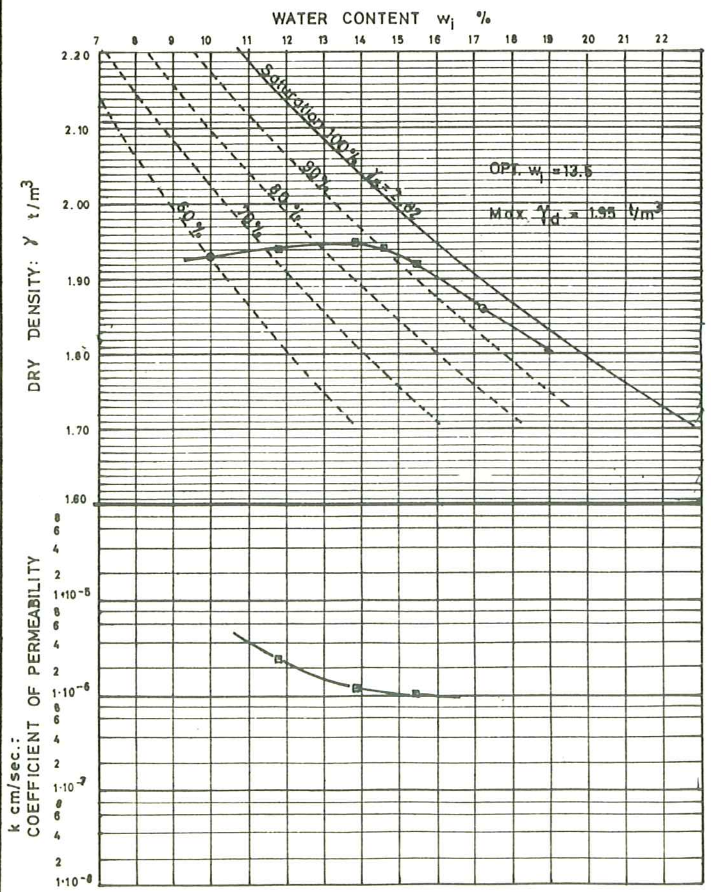
NOTES

GRAIN-SIZE CURVES FOR SAMPLES FROM TESTPITS NO. IV AND XI TO XVII LIES WITHIN THE AREA A_m ON THE DIAGRAM.

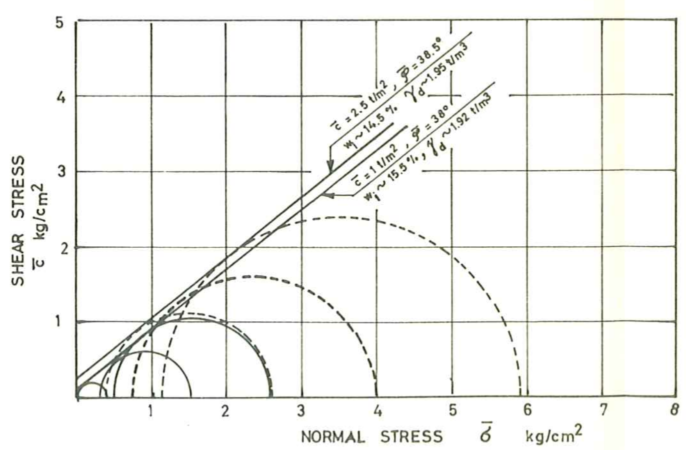
GRAINS COARSER THAN 16mm IN THE SAMPLES WERE 2 TO 10 % OF THE TOTAL WEIGHT. STONES LARGER THAN 100 mm HAVE NOT BEEN FOUND IN THE MORAINAL DEPOSIT.

SAMPLES FOR GRAIN-SIZE ANALYSES WERE TAKEN EVERY METRE OF THE TEST PITS.

PROCTOR STANDARD COMPACTION AND PERMEABILITY TESTS.



TRIAXIAL COMPRESSION TESTS.



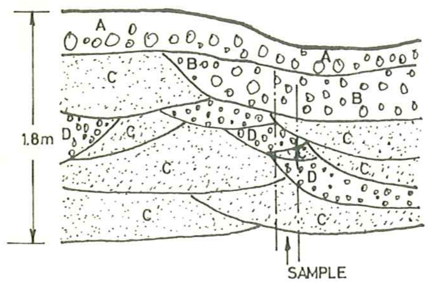
NOTES AND ABBREVIATIONS

NATURAL WATER CONTENT IN THE MORAINAL DEPOSIT HAS BEEN TESTED FOR ONE SAMPLE AND WAS FOUND TO BE 13.9 %

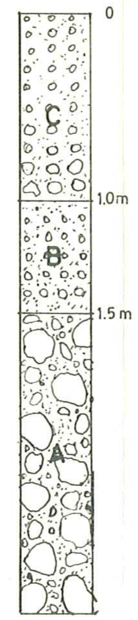
γ_s:	SPECIFIC GRAVITY
Max γ_d:	MAXIMUM DRY DENSITY
OPT. w_l:	OPTIMUM WATER CONTENT

ALLUVIAL SAND- AND GRAVEL MATERIAL

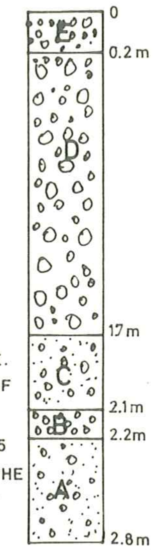
P-3



P-4



P-2



NOTES ON P-3

A TRENCH WAS DUG WITH A BULLDOZER. THE SECTION SHOWED A TYPICAL CROSS-BEDDING AS INDICATED ON THE FIGURE.
LAYER „A" IS LOESSY SOIL WITH SOME BOULDERS AT THE BOTTOM.
LAYER „B" IS STRATIFIED GRAVEL.
" „C" IS MOSTLY SAND.
" „D" " " GRAVEL.

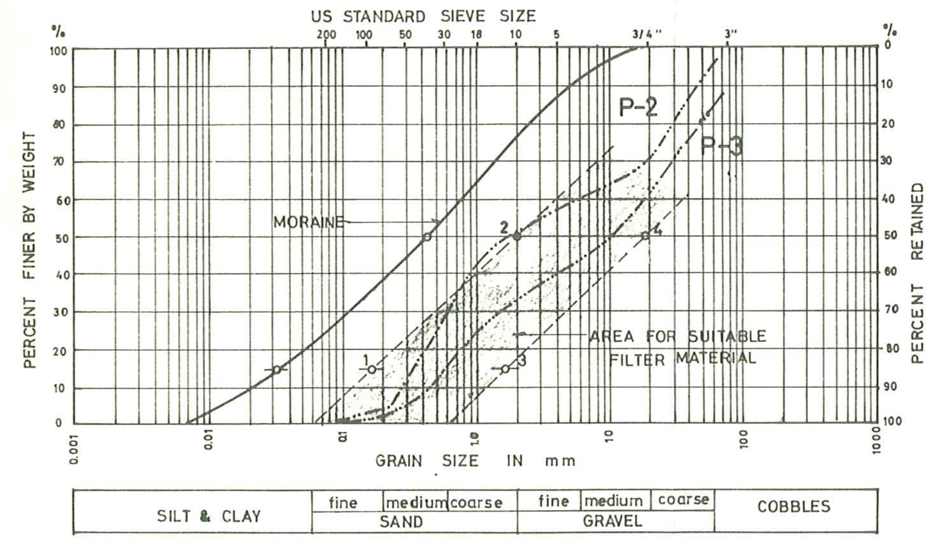
NOTES ON P-4

SECTION IN AN OLD GRAVELMINE.
LAYER „A": A MIXED STRATUM OF SAND, GRAVEL AND BOULDERS (DIA. 40-65 cm COMMON SIZE). THE BOULDERS ca. 60 % OF THE LAYER.
LAYER „B": SAND, GRAVEL AND UP TO 9 cm DIA. BOULDERS.
LAYER „C": BOULDERS 5 cm DIA. AT THE TOP AND UP TO 30 cm AT BOTTOM.

NOTES ON P-2

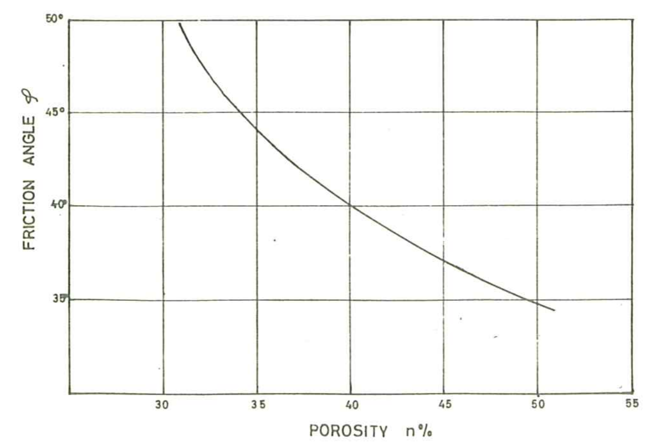
LAYERS „A" & „C": MOSTLY SAND.
" B & E : SAND AND GRAVEL WITH BOULDERS UP TO 8 cm.
LAYER D : SAND, GRAVEL AND BOULDERS UP TO 40 cm DIA. THOSE ca. 40 % OF THE LAYER.

GRAIN SIZE DISTRIBUTION



LOCATION OF P-2 P-3 AND P-4: SEE DRWG.

EFFECT OF POROSITY ON FRICTION ANGLE φ



FILTER MATERIAL

SPECIFICATION OF GRAIN SIZE DISTRIBUTION

o1 D_{15} FILTER MATERIAL $\geq 5D_{15}$ MORAIN
o2 D_{50} —"— —"— $\geq 5D_{50}$ —"—
o3 D_{15} —"— —"— $\geq 45D_{15}$ —"—
o4 D_{50} —"— —"— $\geq 45D_{50}$ —"—

GRAIN SIZE CURVE FOR MORAINE IS MADE FOR GRAINS FINER THAN 16 mm.

LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT | CONSTRUCTION

CONSTRUCTION MATERIALS TEST RESULTS

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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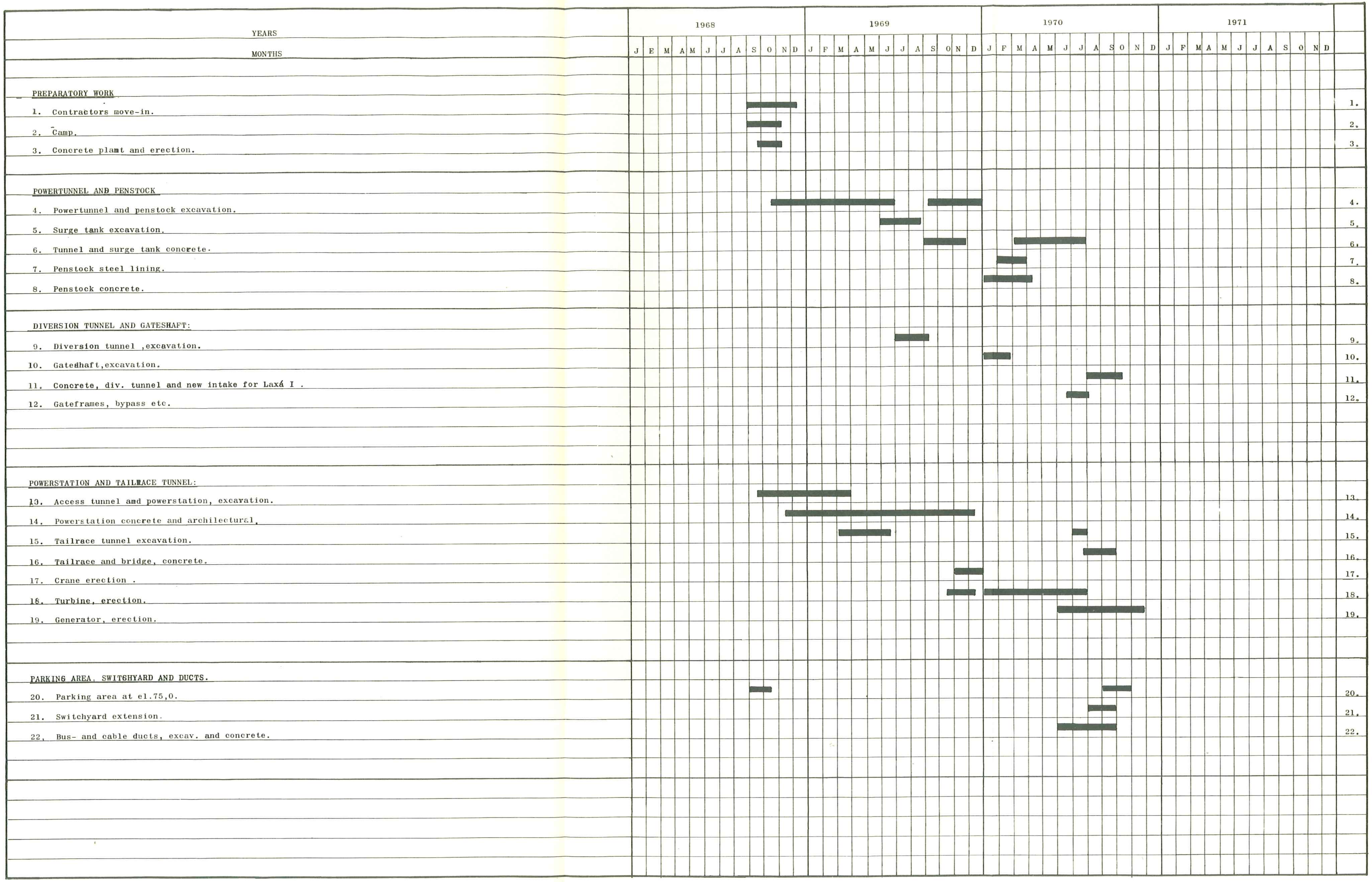
	Joh. G.	JAN 1968	[signature]	07031.02



LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT | CONSTRUCTIONE

CONSTRUCTION SCHEDULE

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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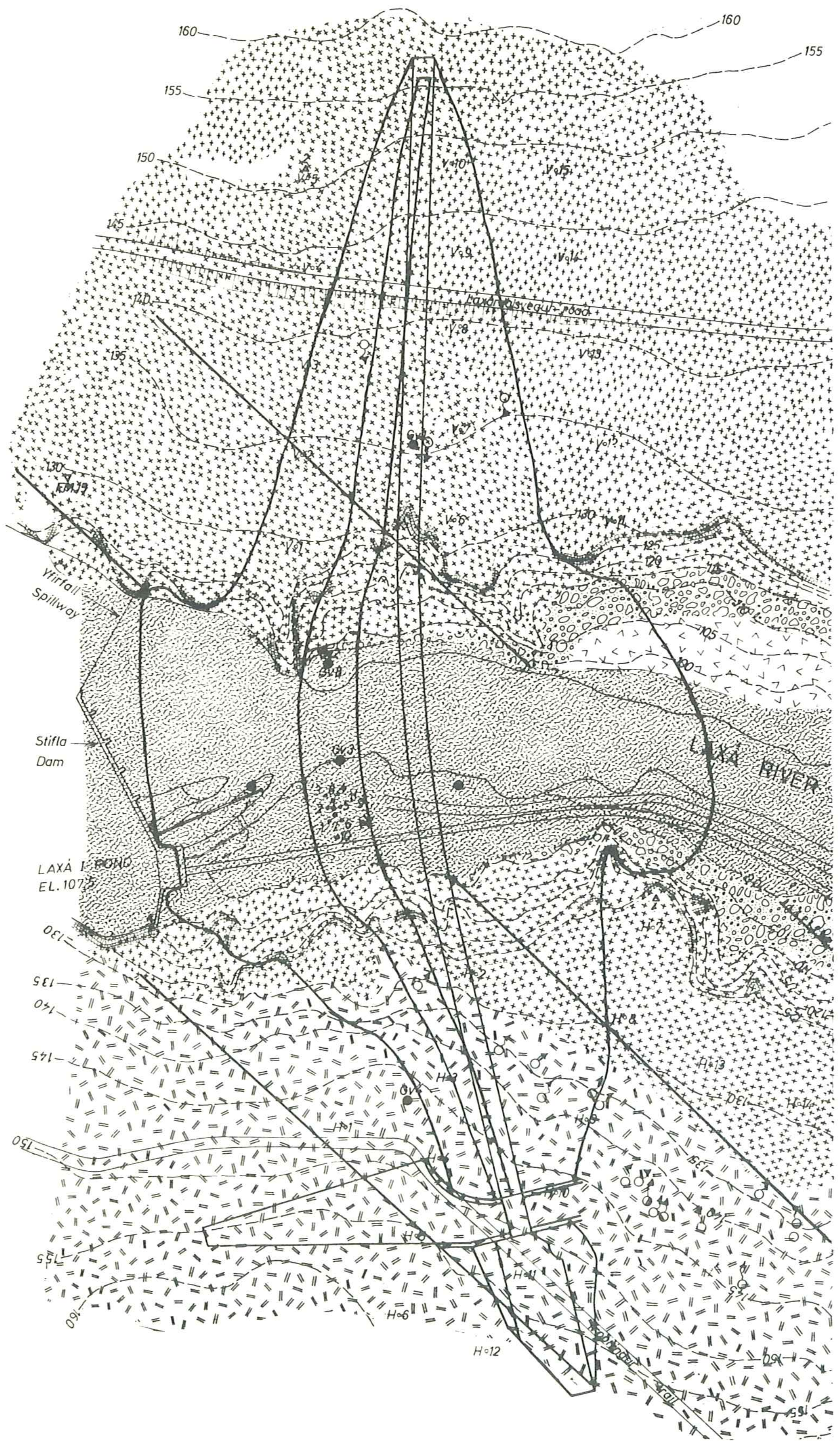
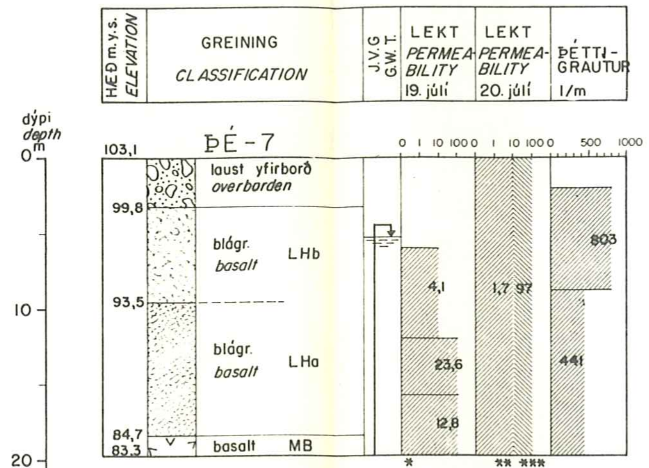
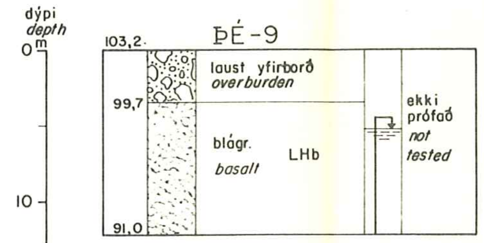
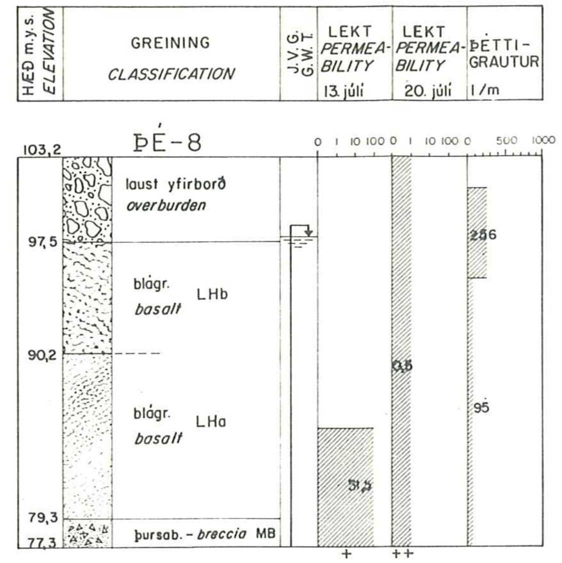
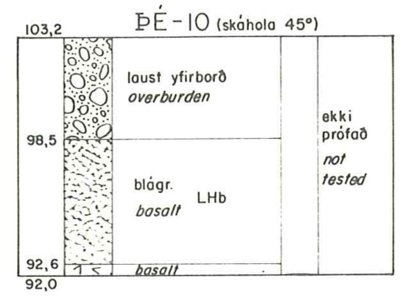


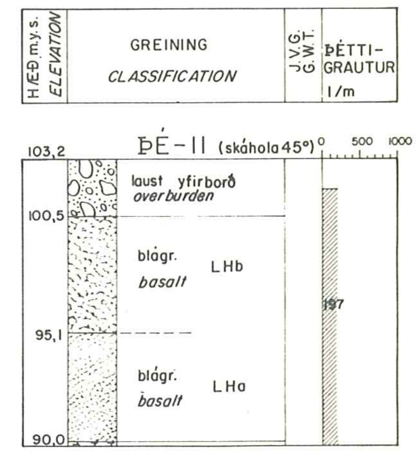


* Lekt 19. júlí. – Áður grautuð nokkrum sinnum. – þó oftar í efri hlutanum. Síðan var öll holan grautuð.
** Lekt 20. júlí við 1.0 kg/cm² þrýsting.
*** þrýstingur hækkaður og sprengt út úr.









\+ Neðsti hluti ógrautaður 13. júlí
\+\+ Öll holan grautuð 20. júlí

Ath: Laust yfirborð merkir í öllum ÞÉ-holum og í GV-2, 3, 7 og 8 frauðkennt, laust hraunyfirborð fyllt með jarðvegi. Í öðrum holum að mestu fok-jarðvegur eða mór.

Note: *Overburden is in all the ÞÉ-holes and in GV-2,3,7,and 8 serious fragmental surface of a lavaflow filled with soil. In all the other holes it is loessy soil or peat.*

Sjá skýringar á bl. 9.07
See legend on sheet 9.07

SKÝRINGAR: *LEGEND*:

- Blágrýti, mið Brúarmyndun MB
  Basalt, the middle Brúarformation MB
- Jökulberg MBm
  Tillite MBm
- Blágrýti, efsta Brúarmyndun EB
  Basalt, the top Brúarformation EB
- Bólstraberg og móberg, Geitafellsmóberg GM
  Pillow lava and breccia, the Geitafell móberg GM
- Laxárhraun LHb
  Laxá lava flow LHb
- Sprungur með eða án misgengis
  Faults, with or without dislocation
- Lindir
  Springs
- Ransóknarborhola
  Exploration drillhole
- Þéttitilraunaborhola
  Grout test drillhole
- Mót laganna EBa og EBb
  The contact between EBa and EBb

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	DAM

GEOLOGY AND DRILL HOLES

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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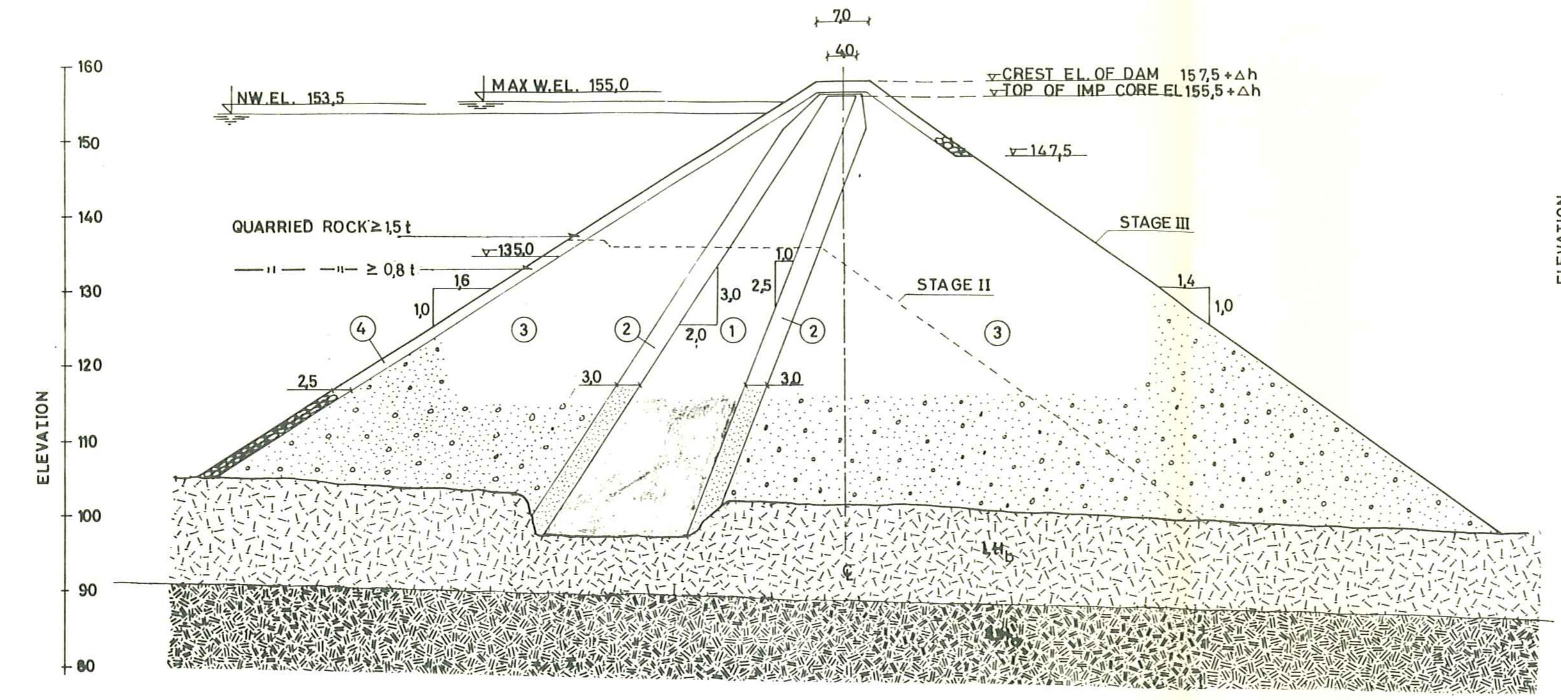
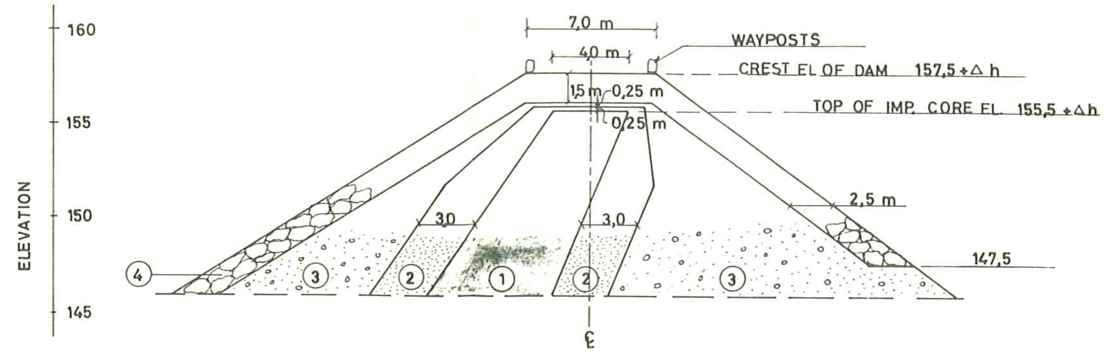
	P. R. P.	L. Þ.	JAN 1968	[signature]	07.032.01

CROSS SECTION OF DAM IN RIVERBED



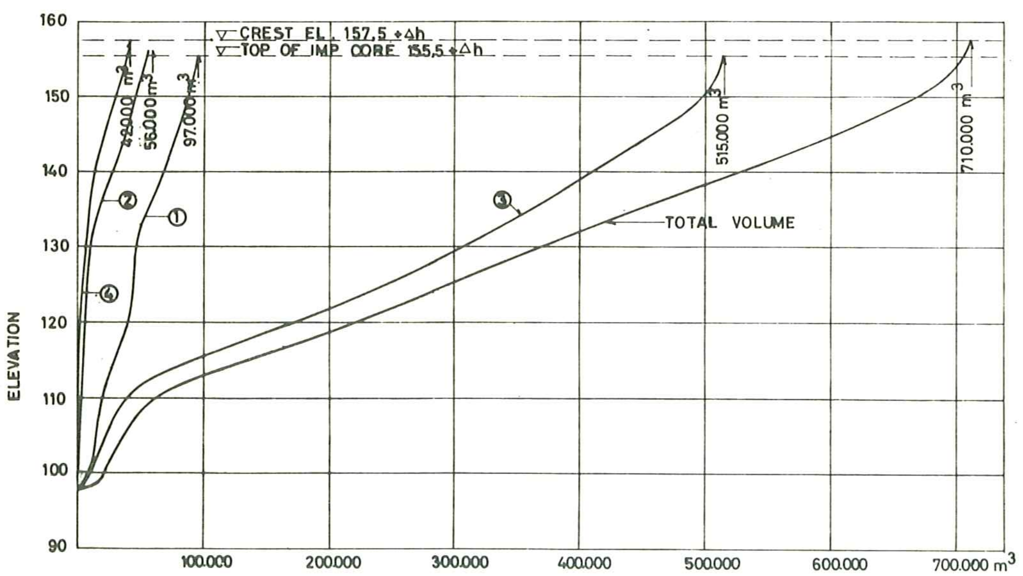
CROSS SECTION TOP OF DAM



Δ h = 1/2 % OF HEIGHT FROM ROCK FOUNDATION AT ANY CROSS SECTION

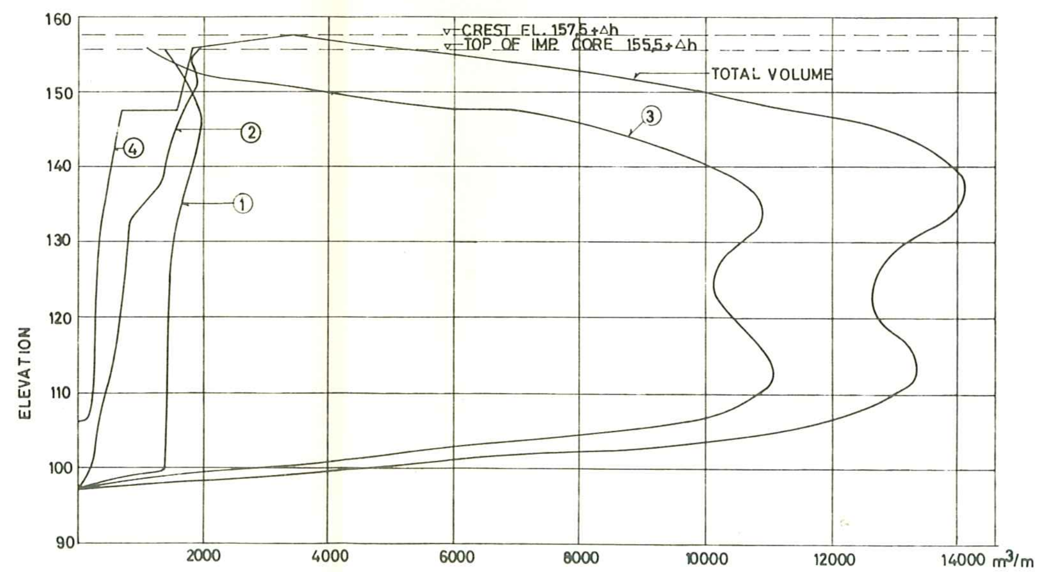
VOLUME OF FILL AS FUNCTION OF CONSTRUCTION ELEVATION

(FINAL STAGE)



APPROX. VOLUME PR. METRE FILL AS FUNCTION OF CONSTRUCTION ELEVATION

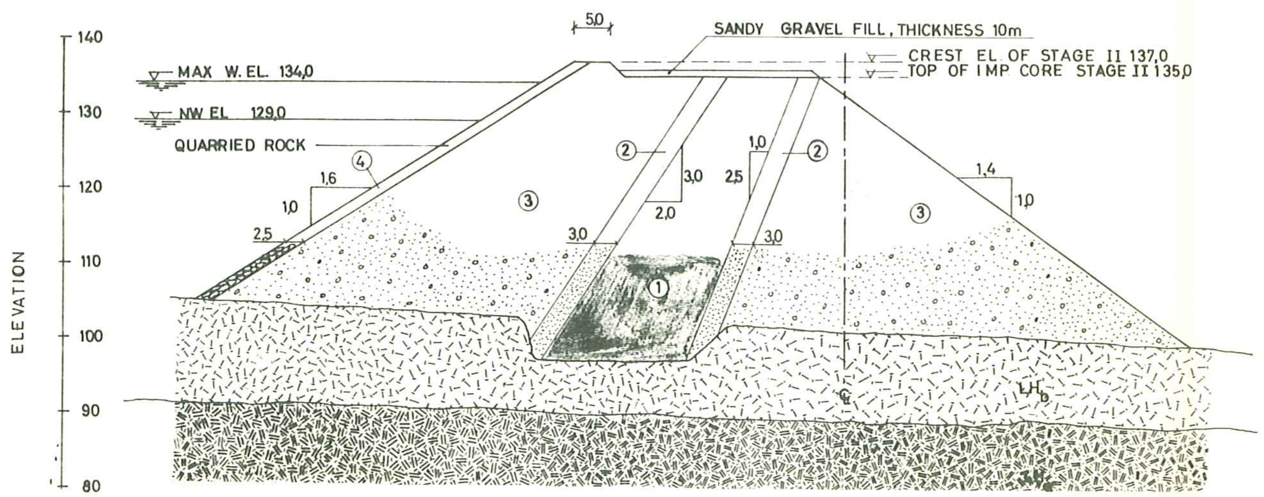
(FINAL STAGE)



ZONE		MATERIALE	LEGEND
1	IMPERVIOUS CORE	MORAINE	BASALT LH_b YOUNGER LAXÁ LAVA FLOW
2	FILTER	SANDY GRAVEL	
3	SUPPORTING FILL	SANDY GRAVEL	BASALT LH_a OLDER LAXÁ LAVA FLOW
4	PROTECTION	QUARRIED ROCK	

ELEVATIONS AND UNNAMED MEASURES ARE METRES.

CROSS SECTION OF DAM IN RIVERBED (STAGE II)



LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT | DAM

SECTION AND SPECIFICATIONS.

VOLUME OF FILLS AND CONSTR. CAPACITY.

THORODDSEN AND PARTNERS

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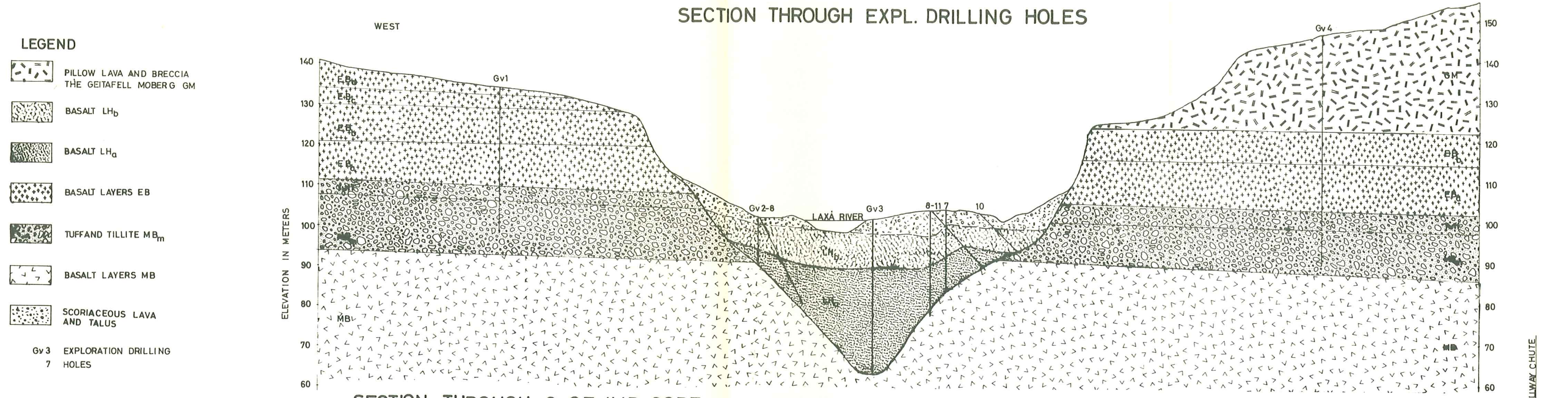
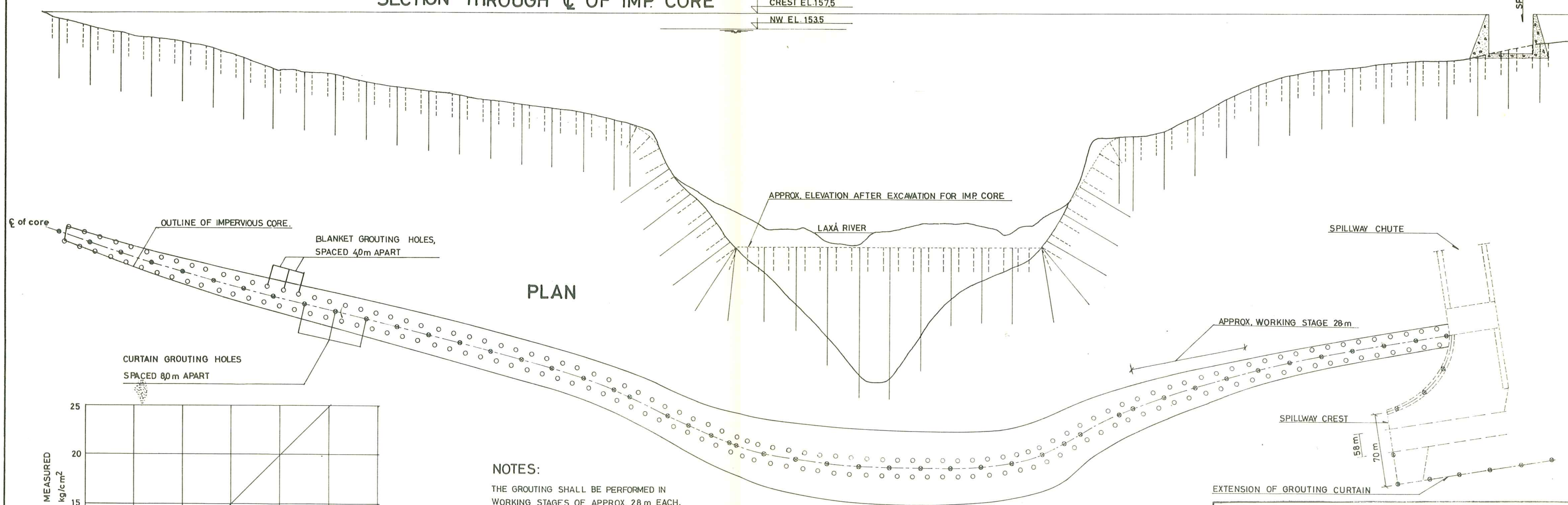
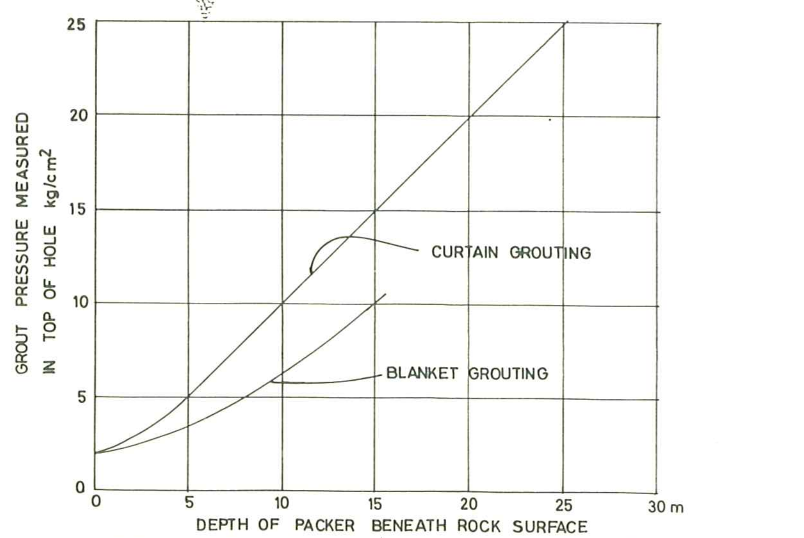
SECTION THROUGH EXPL. DRILLING HOLES



SECTION THROUGH ℄ OF IMP. CORE





PRELIMNARY DETERMINATION OF GROUT PRESSURE

NOTES:

THE GROUTING SHALL BE PERFORMED IN WORKING STAGES OF APPROX. 28 m EACH.
BLANKET GROUTING (o) SHALL BE PERFORMED FIRST AND ALLOWED TO SET FOR TWO DAYS BEFORE DRILLING FOR CURTAIN GROUTING STARTS.
CURTAIN GROUTING SHALL BE CARRIED OUT IN STEPS. PRIMARY HOLES (⊗) SPACED 8 m SHALL FIRST BE DRILLED AND GROUTED. IF NECESSARY HOLES WILL BE DRILLED AND GROUTED IN BETWEEN THE PRIMARY ONES.

L 6.0 m — HOLES FOR BLANKET GROUTING 2.0 m FROM ℄ OF CORE ON EITHER SIDE

L MIN 15 m — HOLES FOR CURTAIN GROUTING LOCATED IN THE ℄ OF CORE AND EXTENDED IN LINE BECAUSE OF SPILLWAY

SCALE 10 0 10 20 30 40 50 m

LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	DAM

GEOLOGICAL SECTION
Foundation grouting
Preliminary plan

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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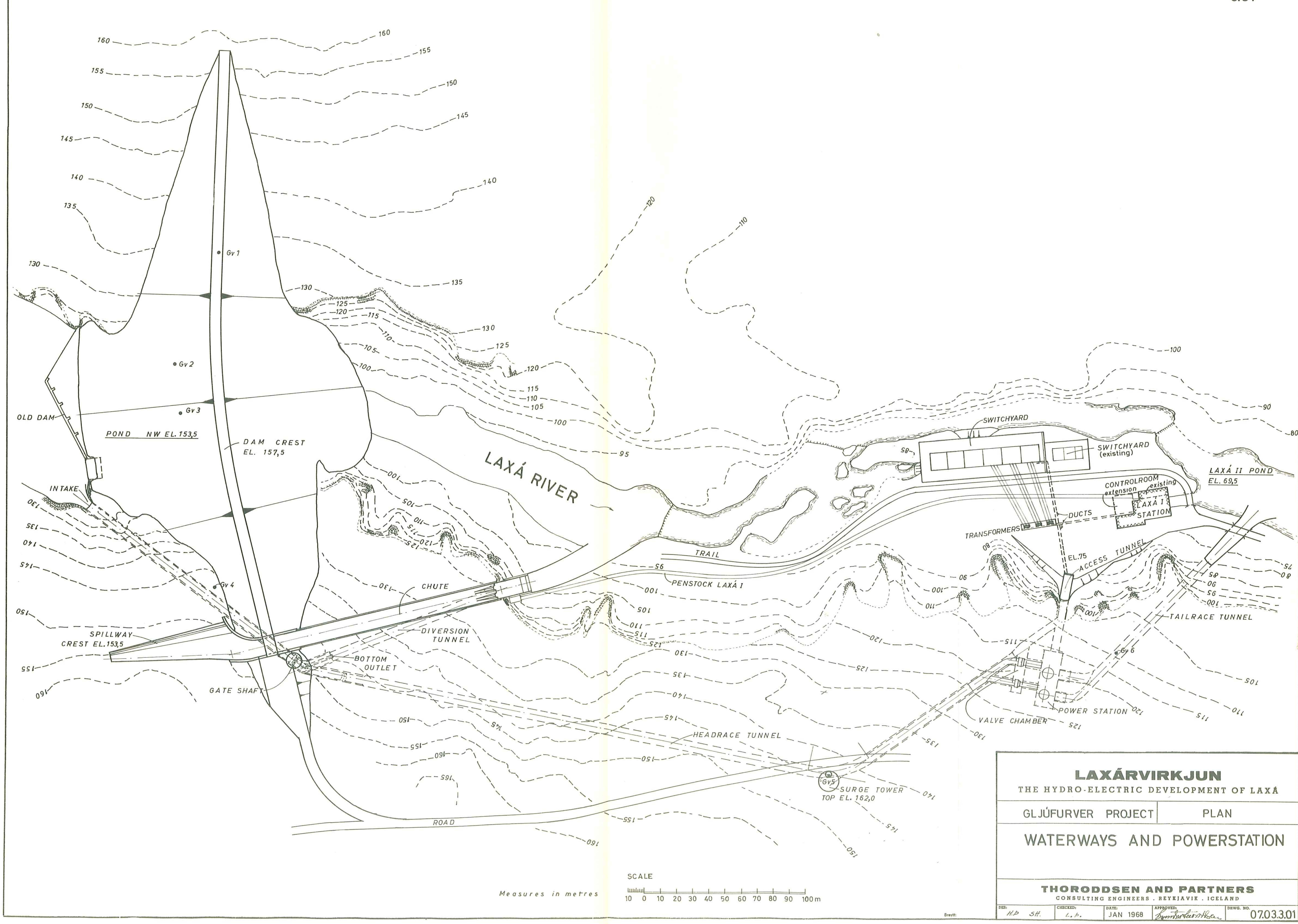
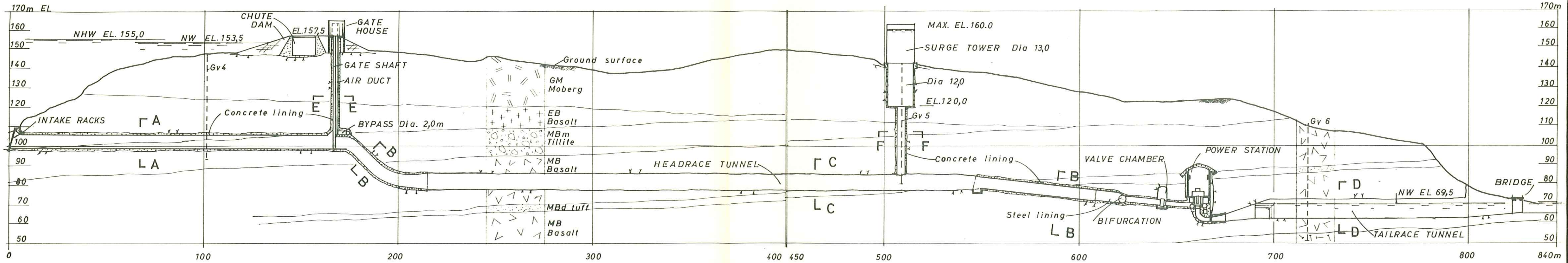
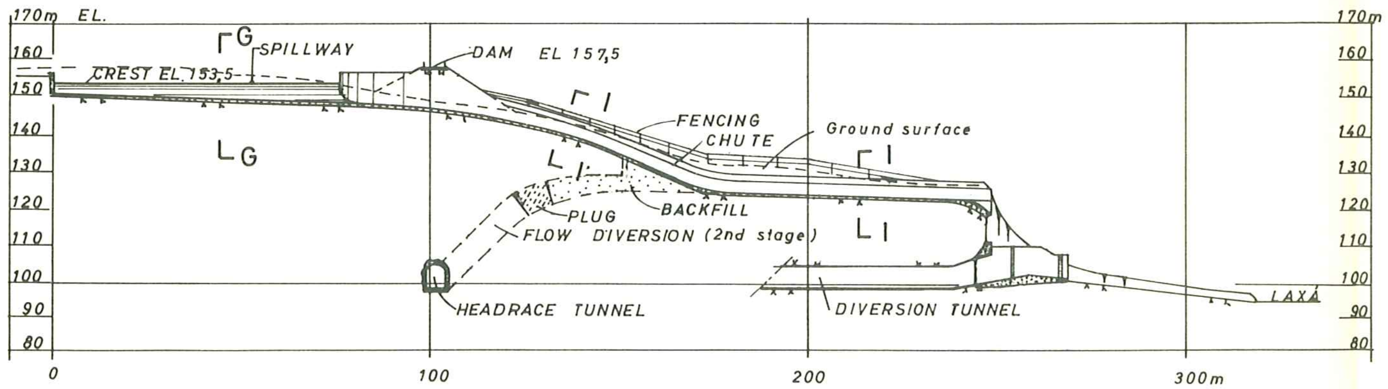
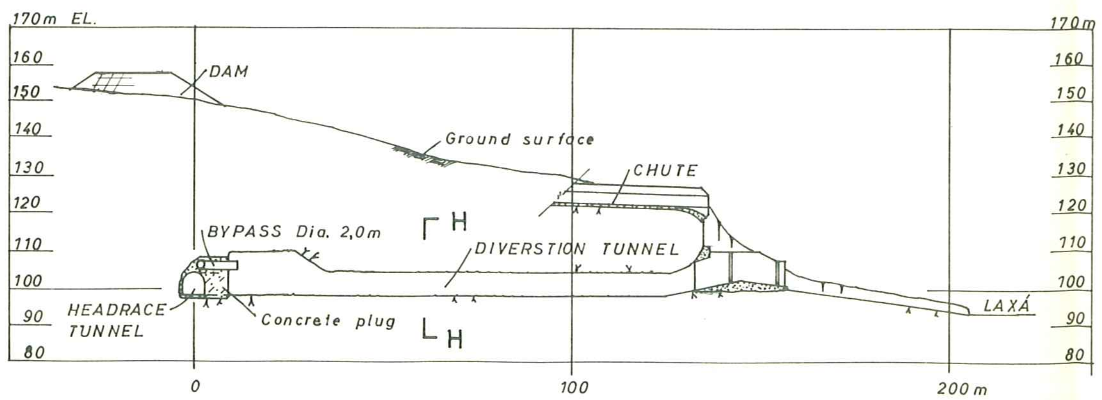

OLD DAM
POND NW EL. 153,5
DAM CREST
EL. 157,5
LAXÁ RIVER
INTAKE
SPILLWAY
CREST EL. 153,5
CHUTE
DIVERSION
TUNNEL
BOTTOM
OUTLET
GATE SHAFT
HEADRACE TUNNEL
SURGE TOWER
TOP EL. 162,0
ROAD
TRAIL
PENSTOCK LAXÁ I
SWITCHYARD
SWITCHYARD
(existing)
CONTROLROOM
extension
existing
LAXÁ I
STATION
LAXÁ II POND
EL. 69,5
DUCTS
TRANSFORMERS
EL. 75
ACCESS TUNNEL
TAILRACE TUNNEL
VALVE CHAMBER
POWER STATION
Gv 1
Gv 2
Gv 3
Gv 4
Gv 5
Gv 6
Measures in metres
SCALE
LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ
GLJÚFURVER PROJECT
PLAN
WATERWAYS AND POWERSTATION
THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND
JAN 1968
07.03.3.01



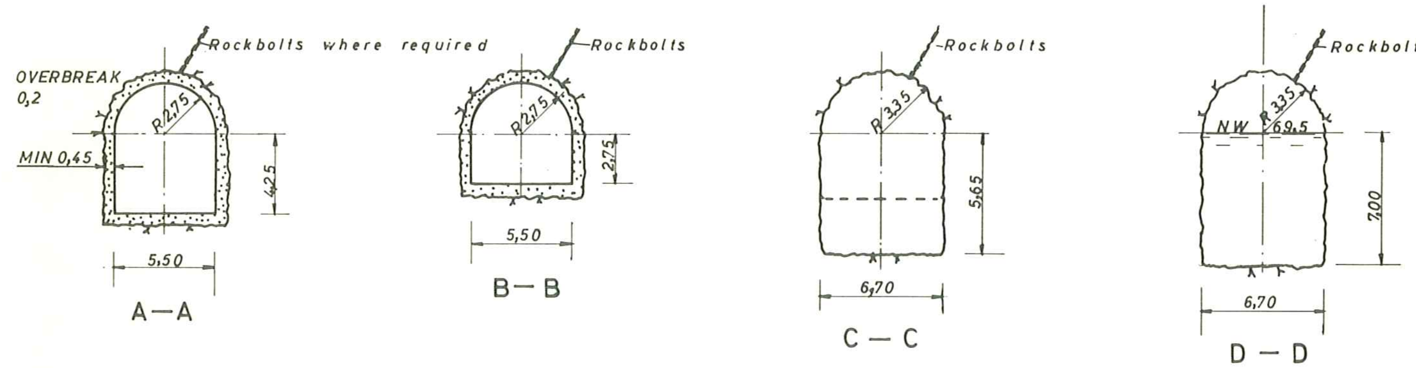
POWER TUNNEL, PROFILE

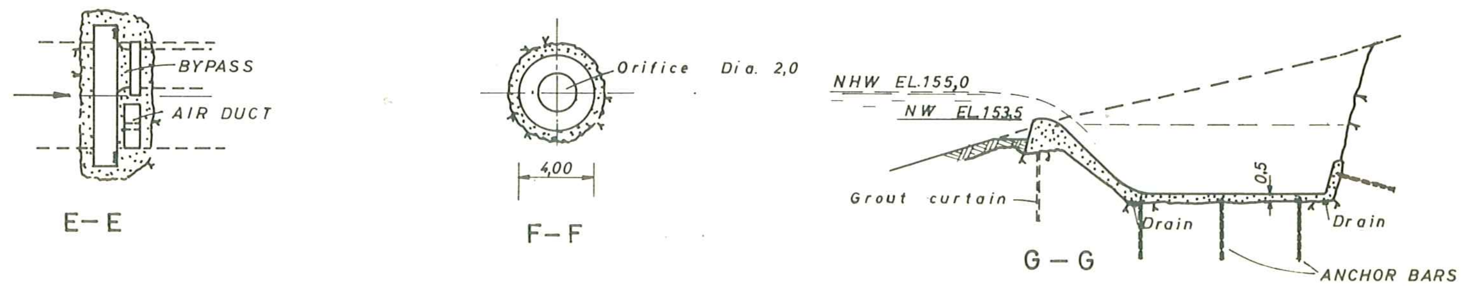


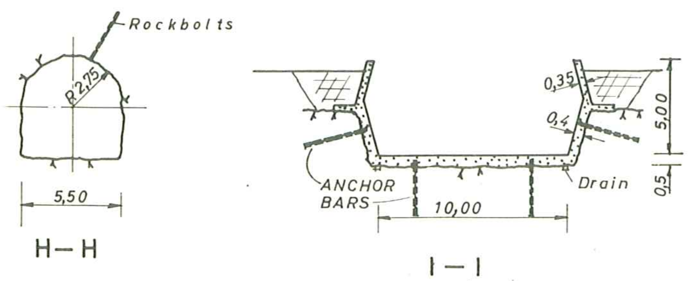
CHUTE, PROFILE



DIVERSION TUNNEL & BYPASS, PROFILE







Measures in metres

SCALE

5 0 5 10 15 20m

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	WATER CONDUCTORS

WATERWAYS AND POWERSTATION

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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H.Þ. S.H.	L.Þ.	JAN 1968	[signature]	07.03.3.02

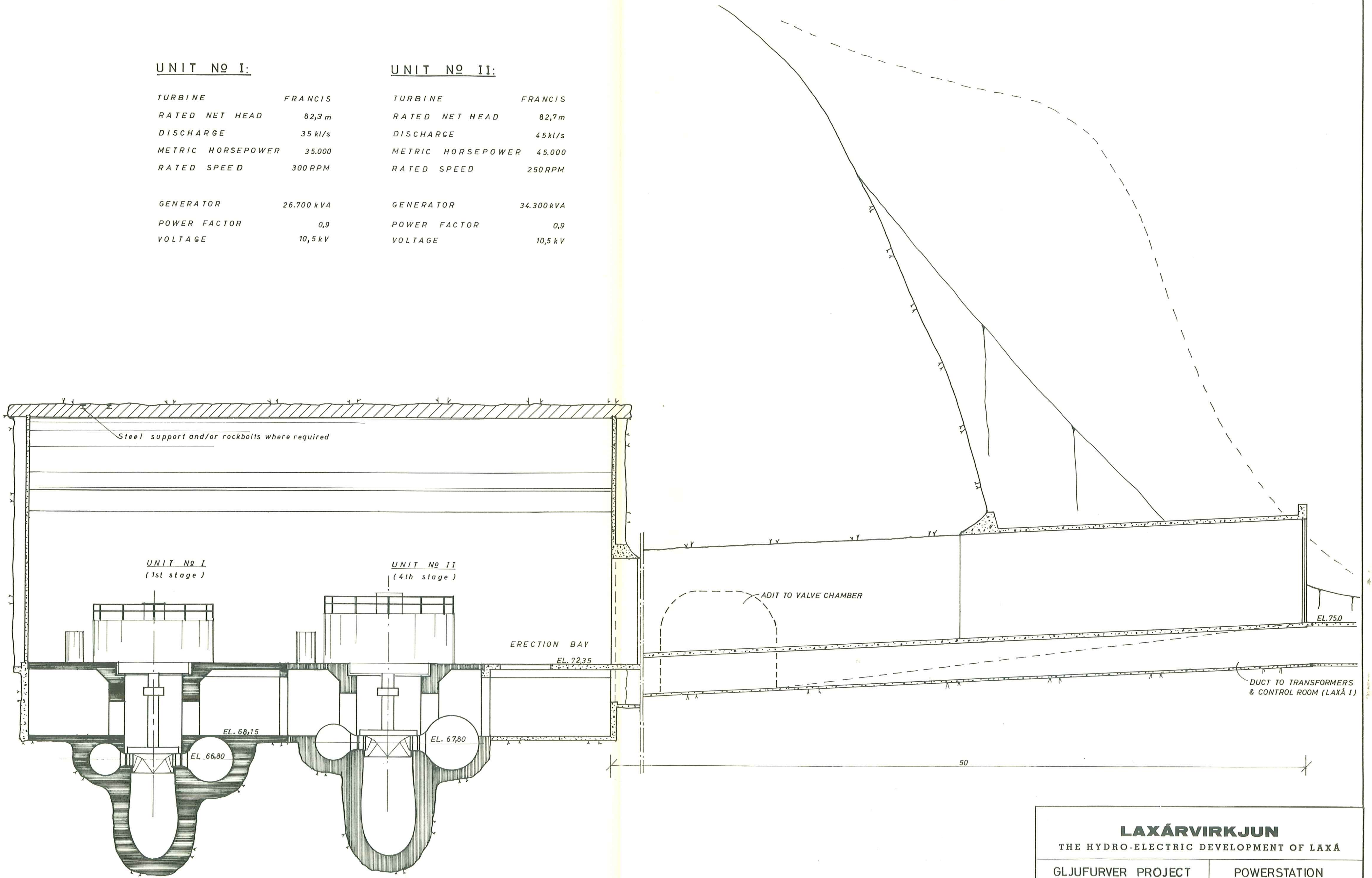
Breytt:

UNIT Nº I:

TURBINE	FRANCIS
RATED NET HEAD	82,3 m
DISCHARGE	35 kl/s
METRIC HORSEPOWER	35.000
RATED SPEED	300 RPM
GENERATOR	26.700 kVA
POWER FACTOR	0,9
VOLTAGE	10,5 kV

UNIT Nº II:

TURBINE	FRANCIS
RATED NET HEAD	82,7 m
DISCHARGE	45 kl/s
METRIC HORSEPOWER	45.000
RATED SPEED	250 RPM
GENERATOR	34.300 kVA
POWER FACTOR	0,9
VOLTAGE	10,5 kV



LONGITUDINAL SECTION

SCALE 1 0 1 2 3 4 5 6 7 8 9 10 m

Measures in metres

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJUFURVER PROJECT	POWERSTATION

LONGITUDINAL SECTION

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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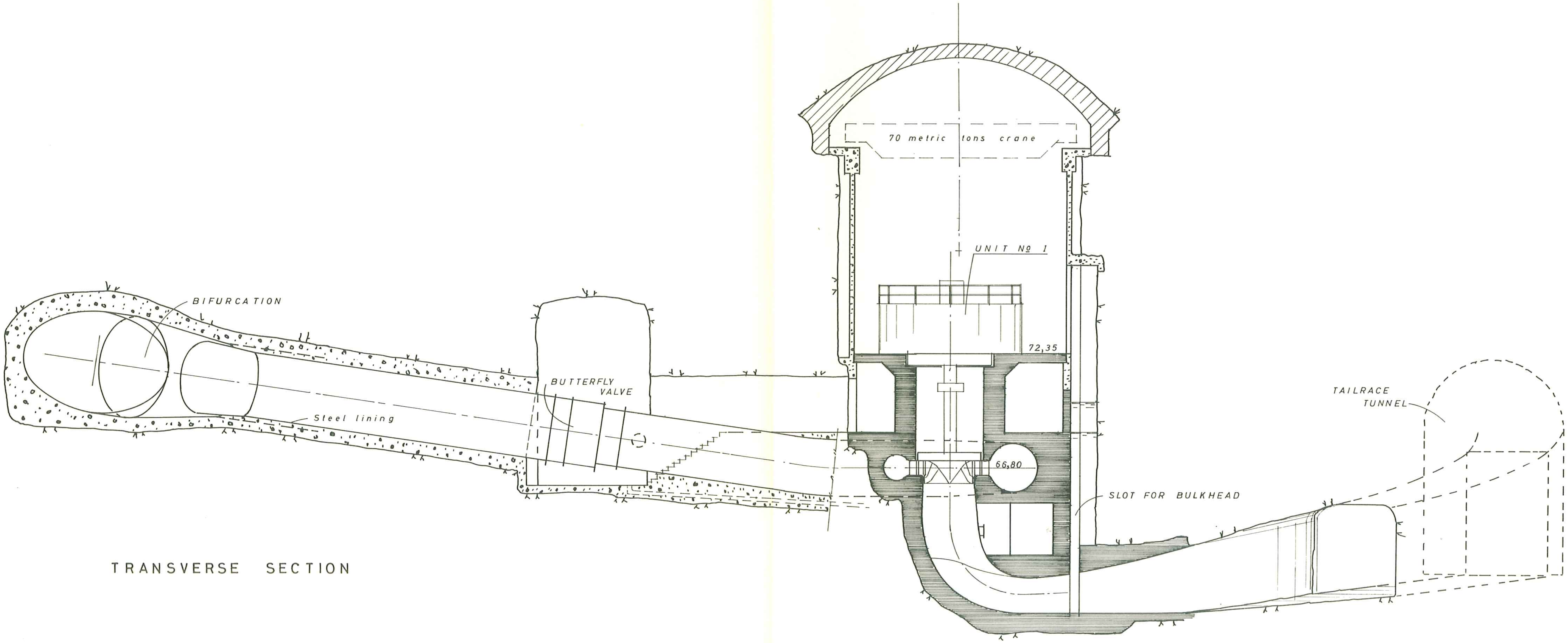

TRANSVERSE SECTION

SCALE

Measures in metres

1 0 1 2 3 4 5 6 7 8 9 10m

LAXÁRVIRKJUN THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ	
GLJÚFURVER PROJECT	POWERSTATION
TRANSVERSE SECTION	
THORODDSEN AND PARTNERS CONSULTING ENGINEERS . REYKJAVIK . ICELAND	

DES:	CHECKED:	DATE:	APPROVED:	DRWG. NO.
H. Þ.	L. Þ.	JAN 1968	[signature]	07.03.3.04

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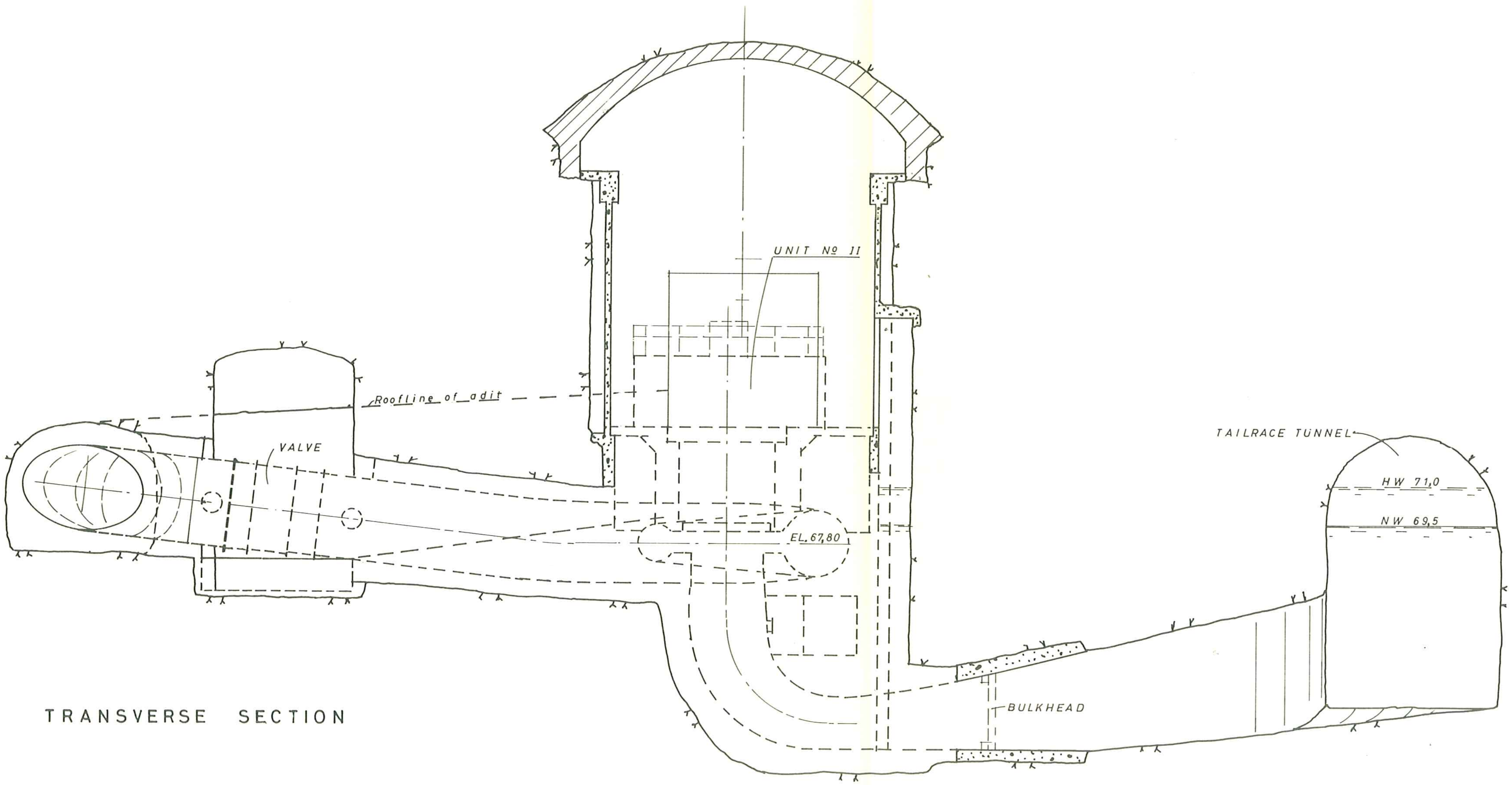

TRANSVERSE SECTION

SCALE

1 0 1 2 3 4 5 6 7 8 9 10m

Measures in metres

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	POWERSTATION

TRANSVERSE SECTION

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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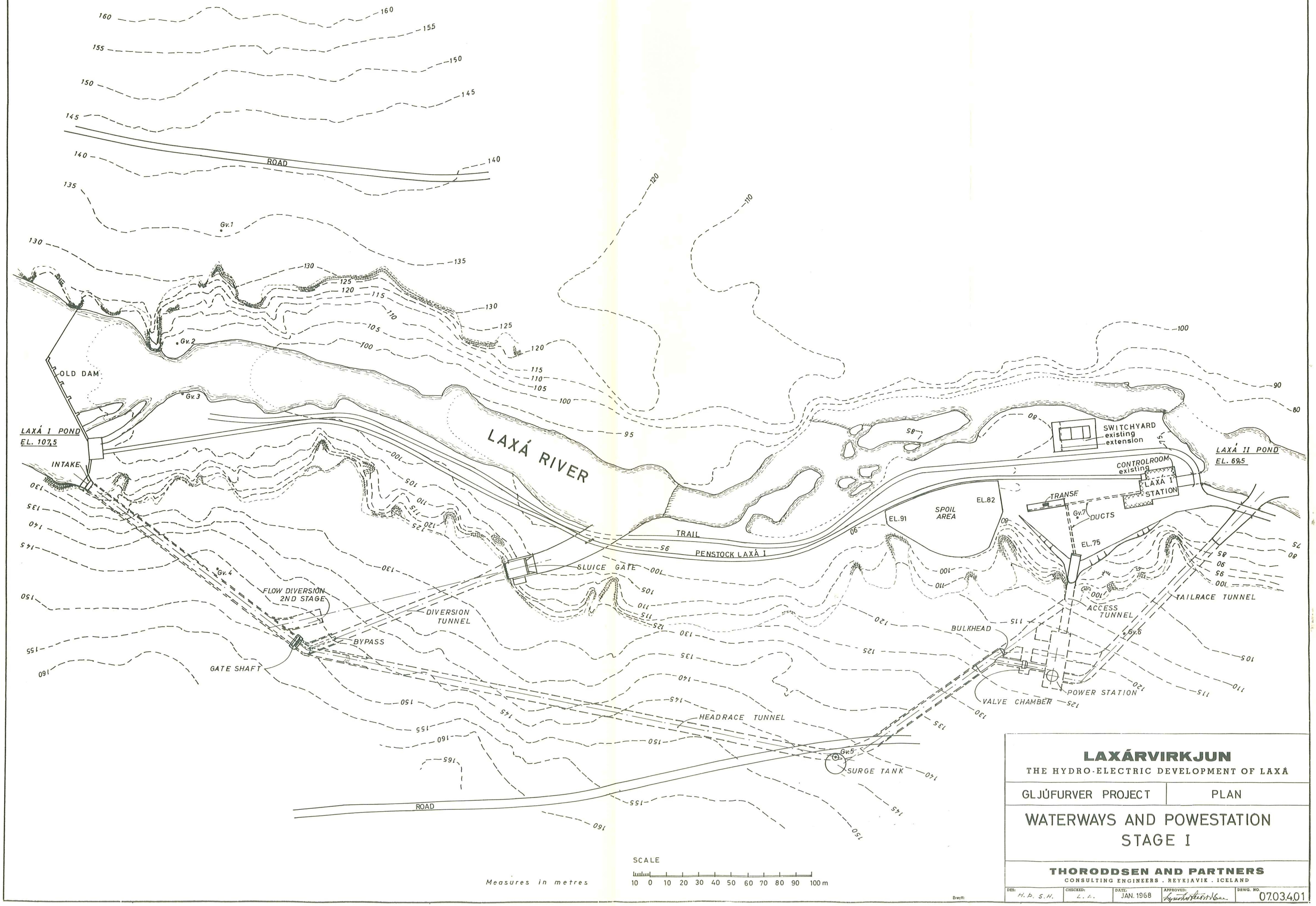

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	PLAN

WATERWAYS AND POWESTATION
STAGE I

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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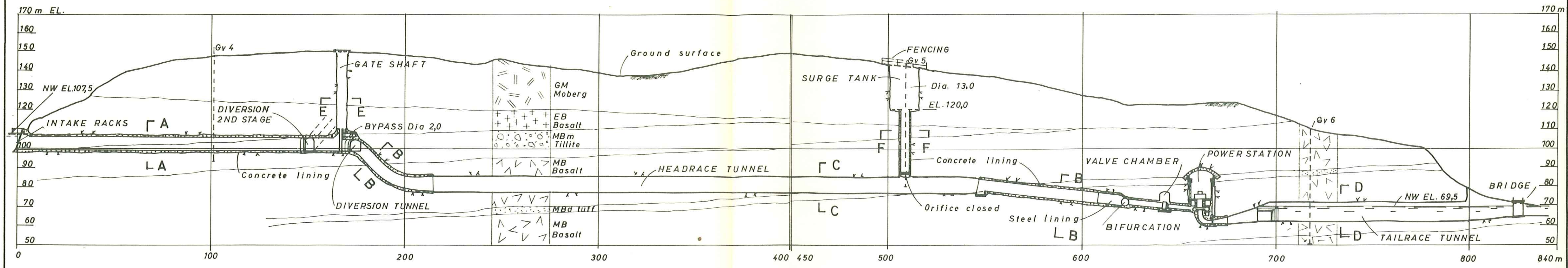
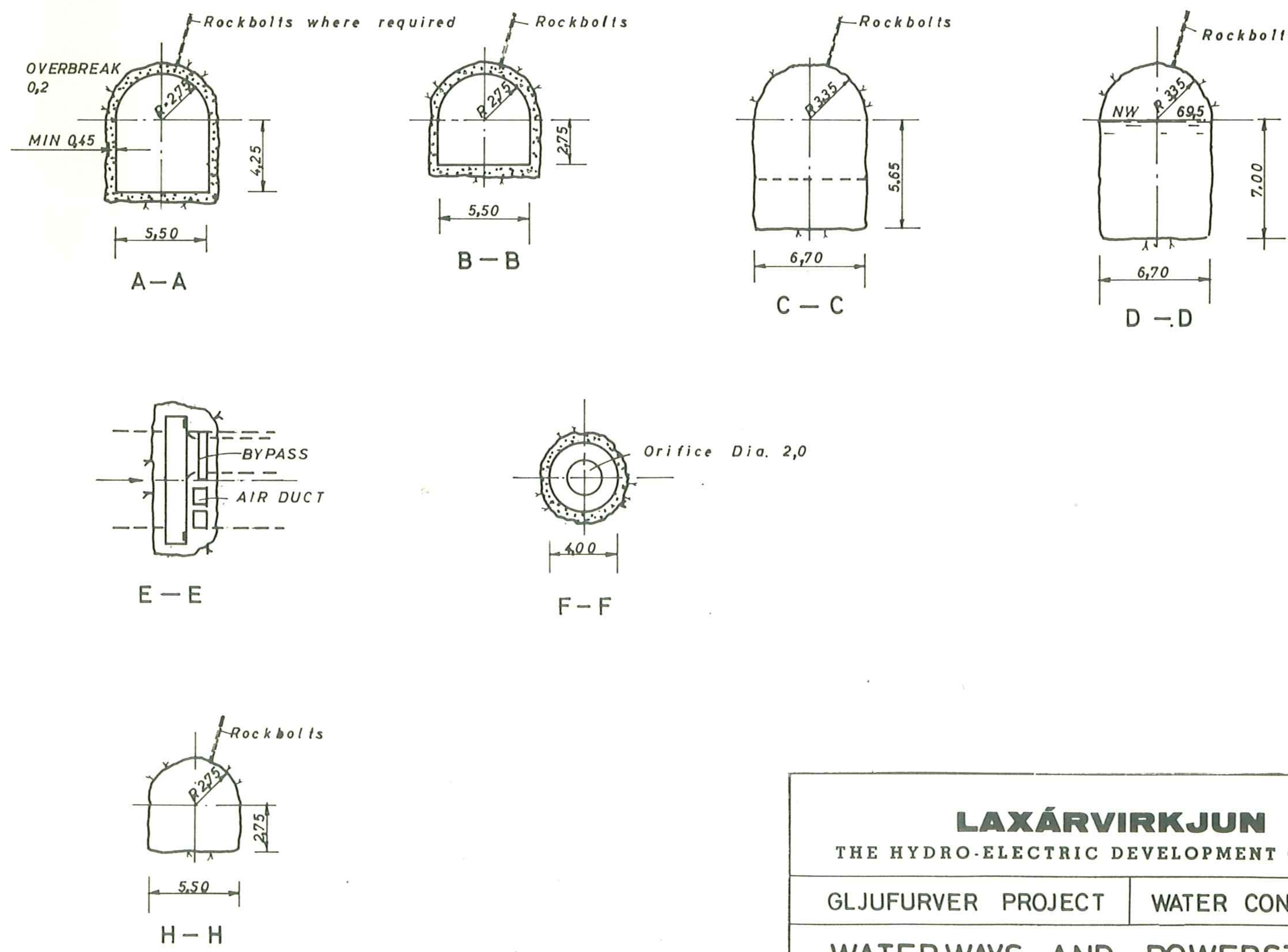
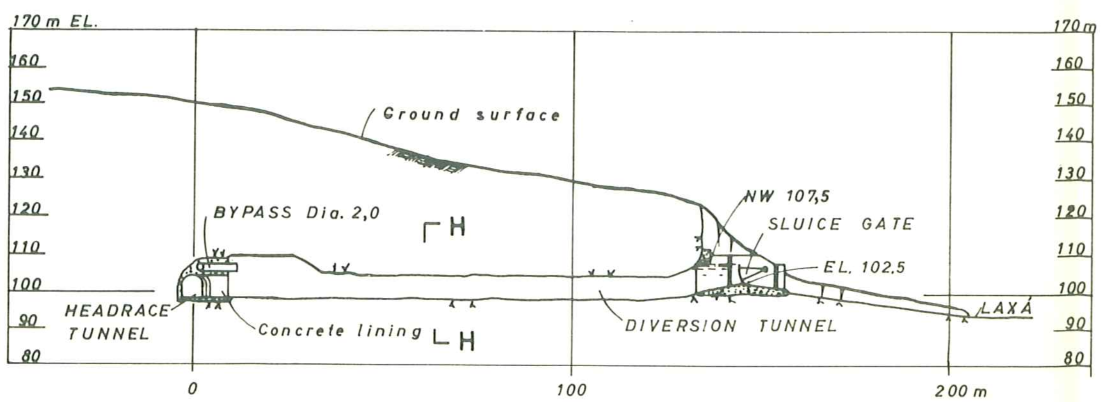
H. P. S. H.	L. I.	JAN. 1968	[illegible]	07.03.4.01



POWER TUNNEL, PROFILE





DIVERSION TUNNEL & BYPASS, PROFILE

SCALE

5 0 5 10 15 20 m

Measures in metres

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJUFURVER PROJECT	WATER CONDUCTORS

WATERWAYS AND POWERSTATION.

STAGE I

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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H.Þ. S.H.	L.Þ.	JAN 1968		07.034.02

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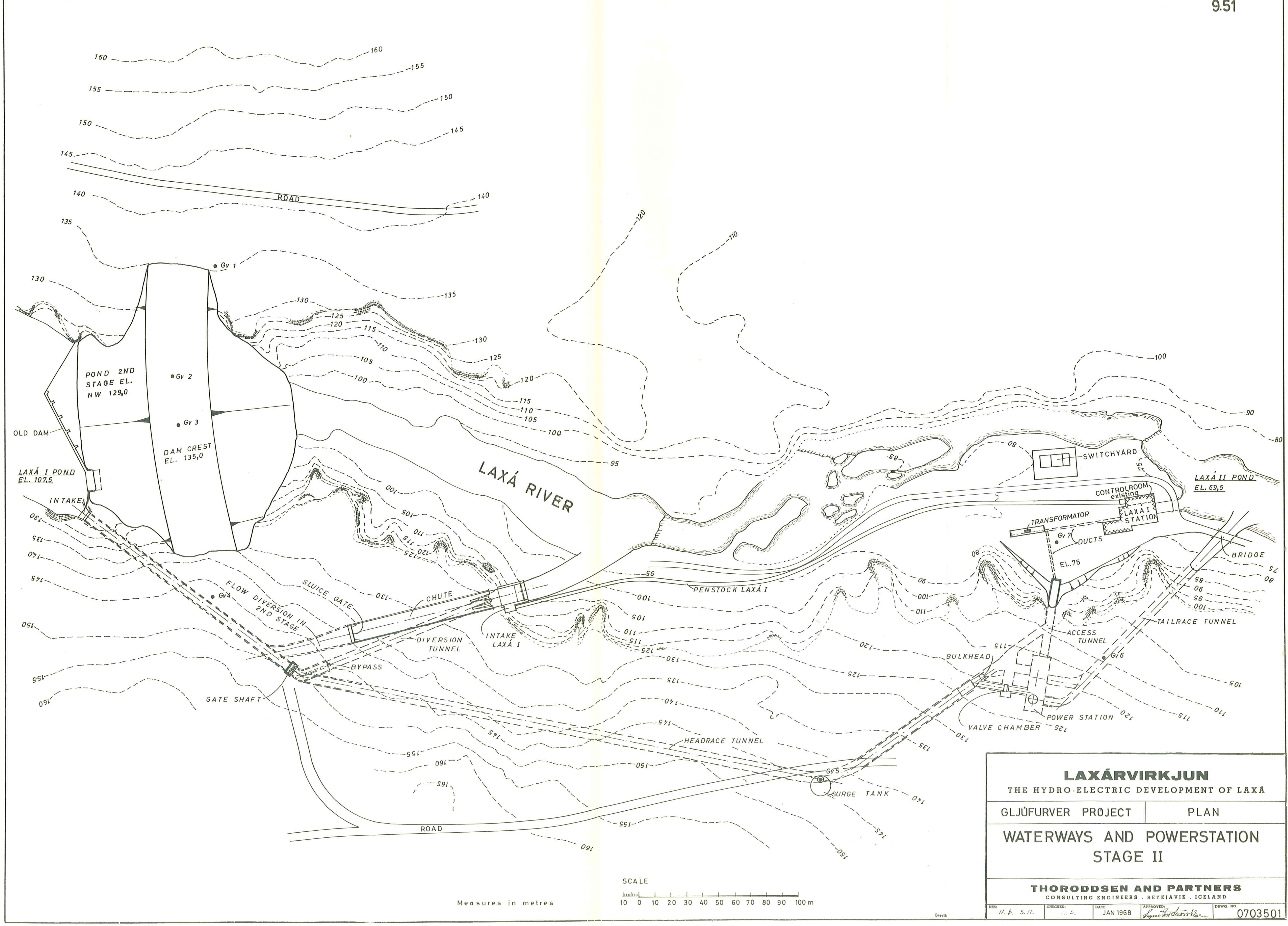


LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

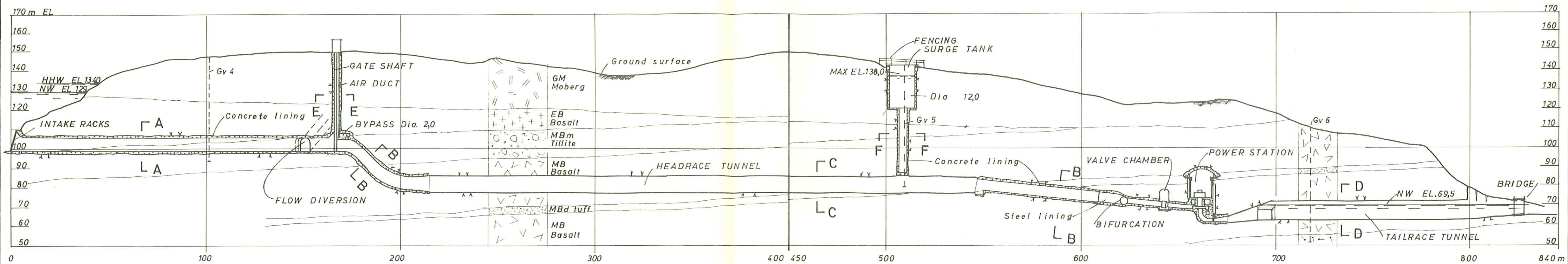
GLJÚFURVER PROJECT | PLAN

WATERWAYS AND POWERSTATION STAGE II

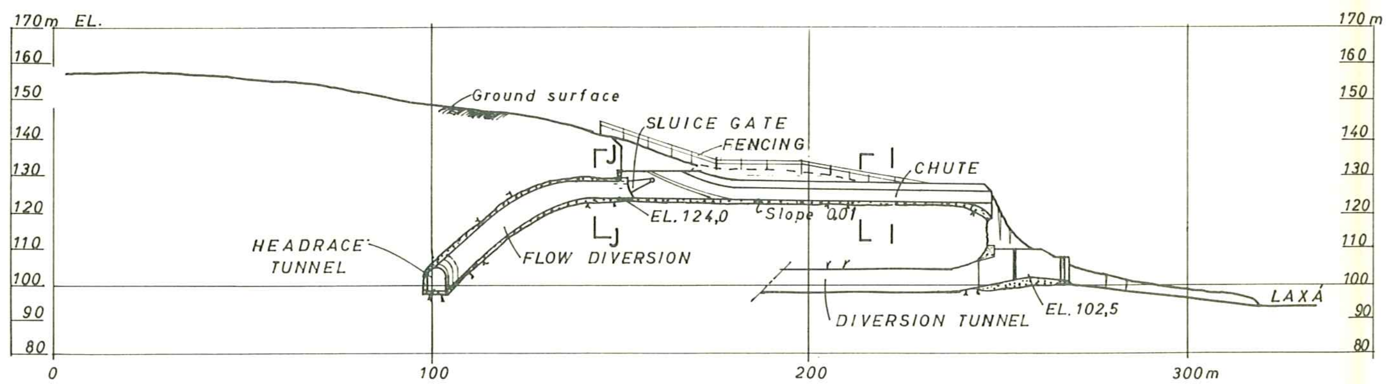
THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

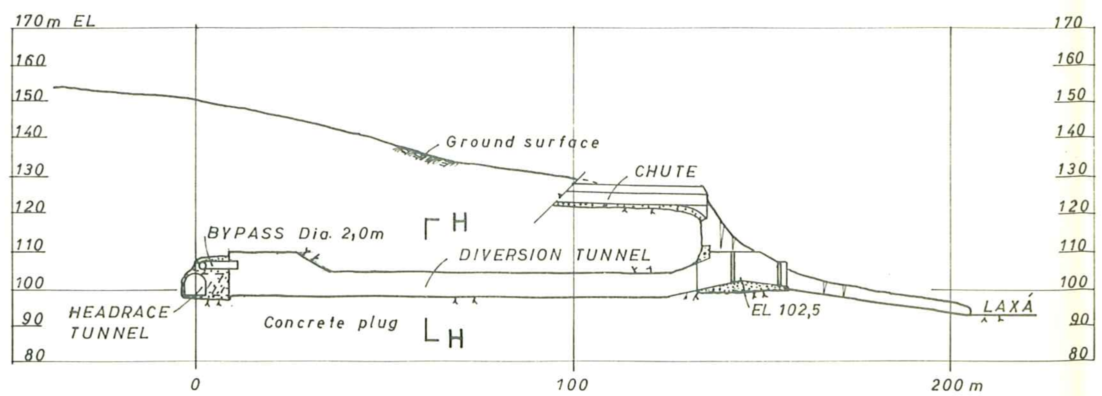
DES: H. Þ. S.H. | CHECKED: | DATE: JAN 1968 | APPROVED: | DRWG NO 0703501



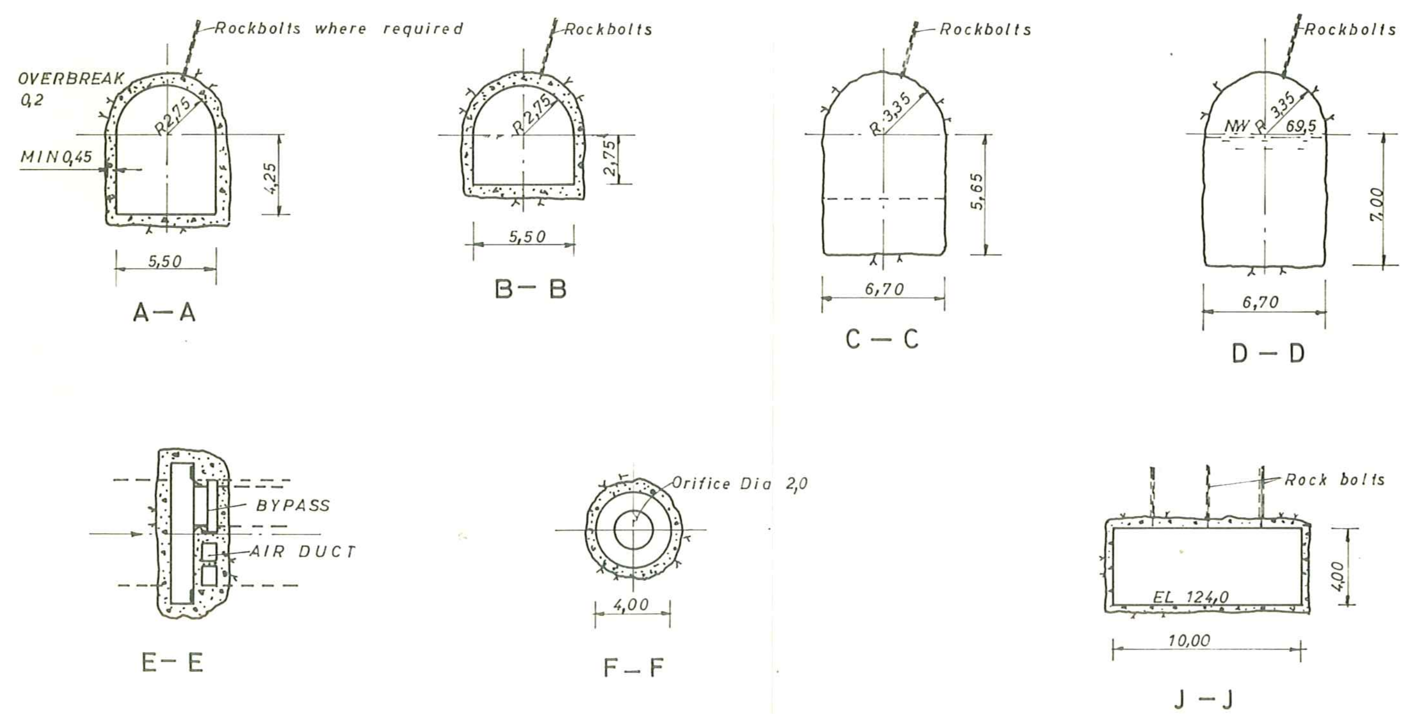
POWER TUNNEL, PROFILE

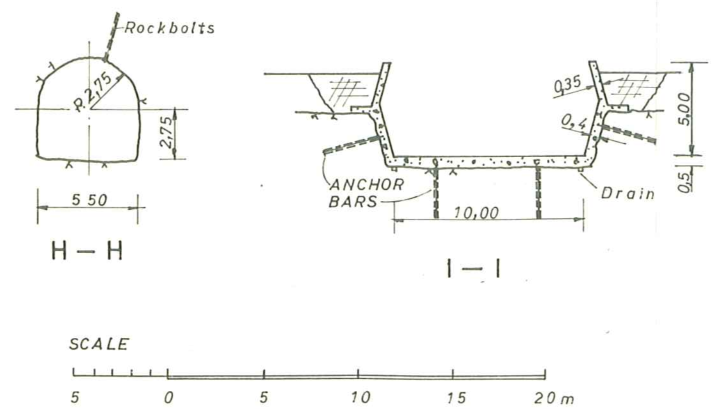


FLOW DIVERSION, PROFILE



DIVERSION TUNNEL & BYPASS, PROFILE





Measures in metres

LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	WATER CONDUCTORS

WATERWAYS AND POWERSTATION
STAGE II

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

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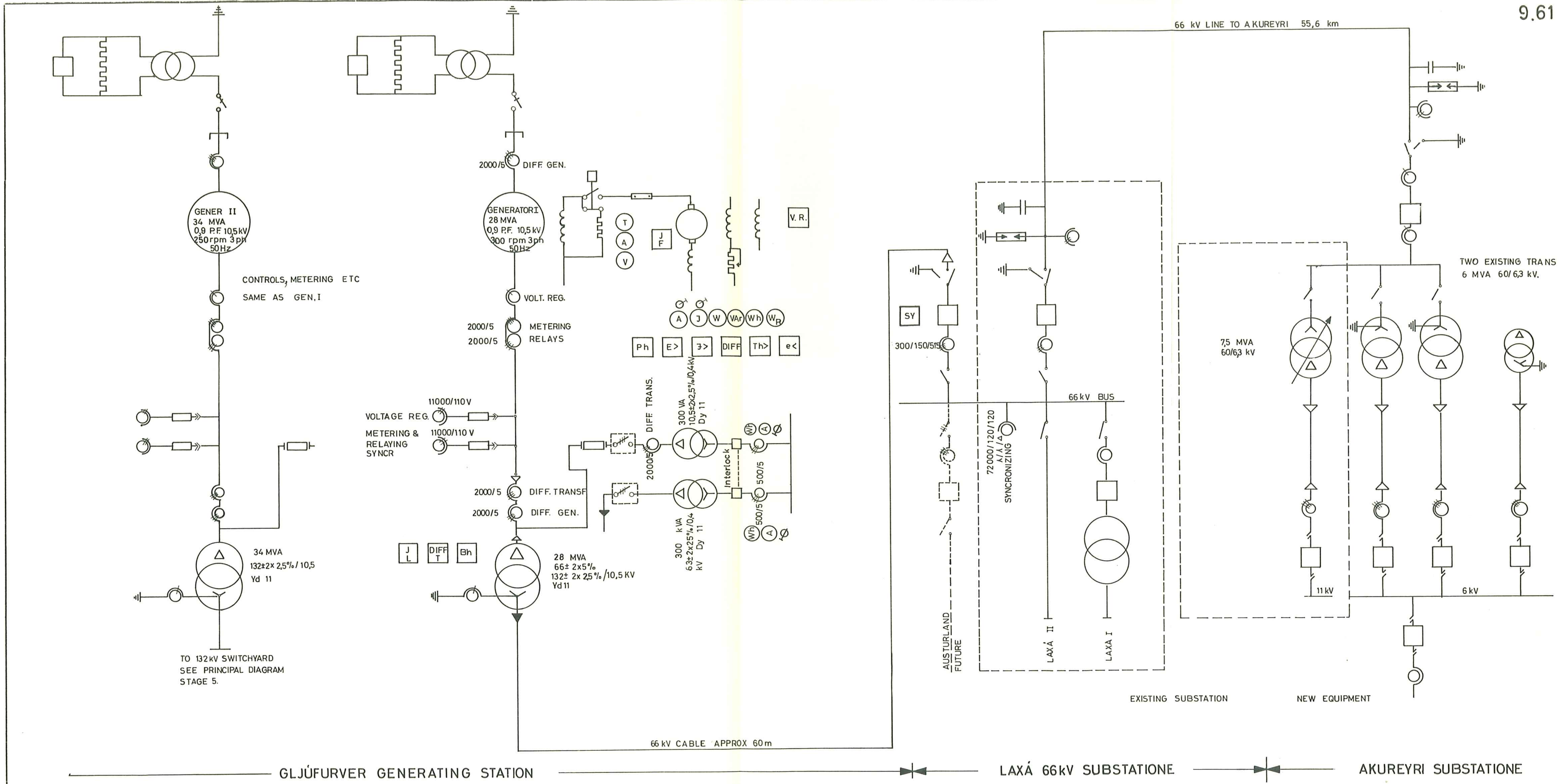
		JAN. 1968		07.03.5.02



LEGEND

- TRANSFORMER
- TRANSFORMER WITH ON-LOAD VOLTAGE REGULATION
- POWER CIRCUIT BREAKER
- POWER CIRCUIT BREAKER (Indoor, draw-out type)
- LOAD BREAKING SWITCH
- DISCONNECTING SWITCH
- CURRENT TRANSFORMER
- POTENTIAL TRANSFORMER
- WINDING
- RESISTOR
- LIGTNING ARRESTER
- COUPLING CAPACITOR
- SHUNT CAPACITOR BANK
- MEASURING INSTRUMENTS
- UNDERGROUND CABLE
- GROUNDING
- RELAY OR SWITCH

VR	VOLTAGE REGULATOR
Ph	GEN. PHASE BALANCE RELAY
E>	OVERVOLTAGE RELAY
I>	OVERCURRENT RELAY, WITH VOLTAGE RESTRAINT
Bh	BUCHOLZ RELAY (TRANSFORMER)
Th>	THERMAL RELAY
DIFF	DIFFERENTIAL RELAY ; G GENERATOR; T TRANSFORMER
e<	LOSS OF FIELD RELAY FOR GENERATOR
J	GROUND FAULT DETECTOR; G GENERATOR; F GENERATOR FIELD; L LINE
Sy	SYNCHRONIZING SWITCH

LAXÁRVIRKJUN
THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT | TRANSMISSION

ONE LINE DIAGRAM.

THORODDSEN AND PARTNERS
CONSULTING ENGINEERS . REYKJAVIK . ICELAND

DES:	CHECKED:	DATE:	APPROVED:	DRWG. NO.
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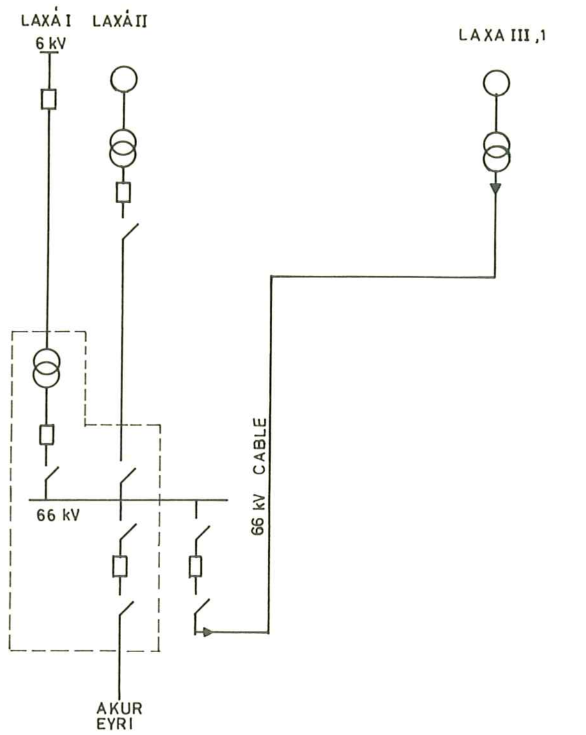
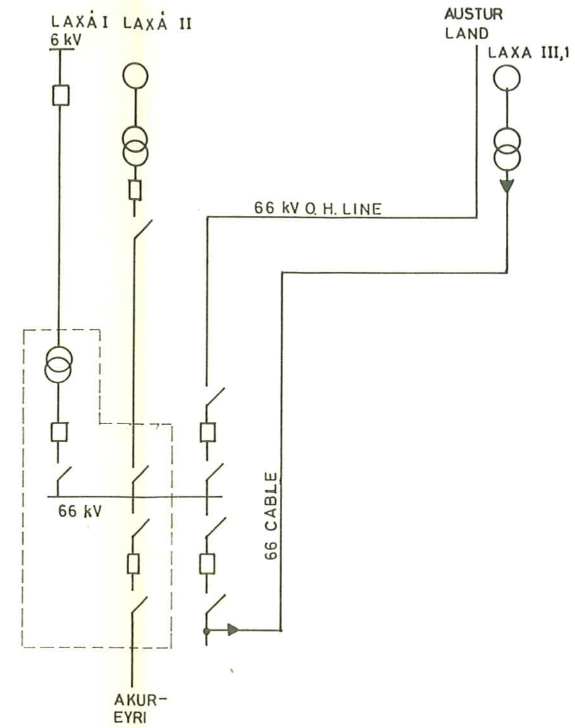


1. STIG



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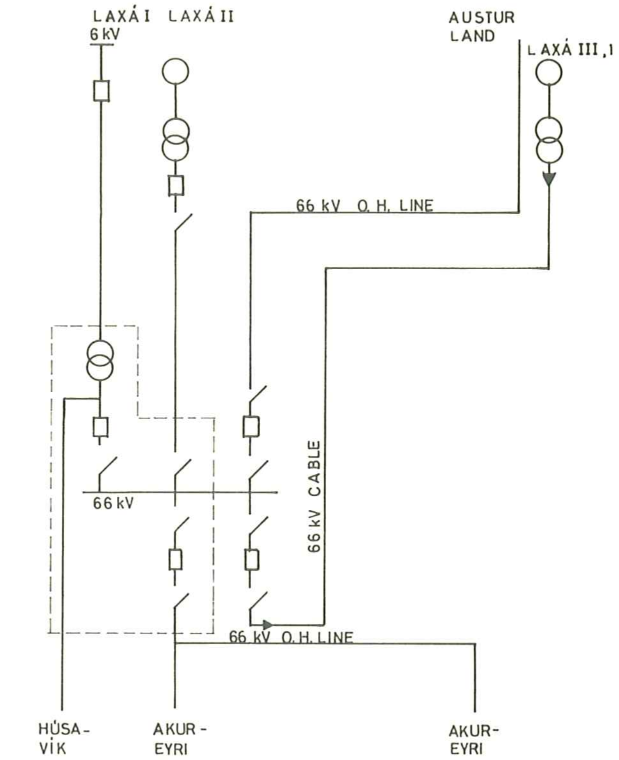
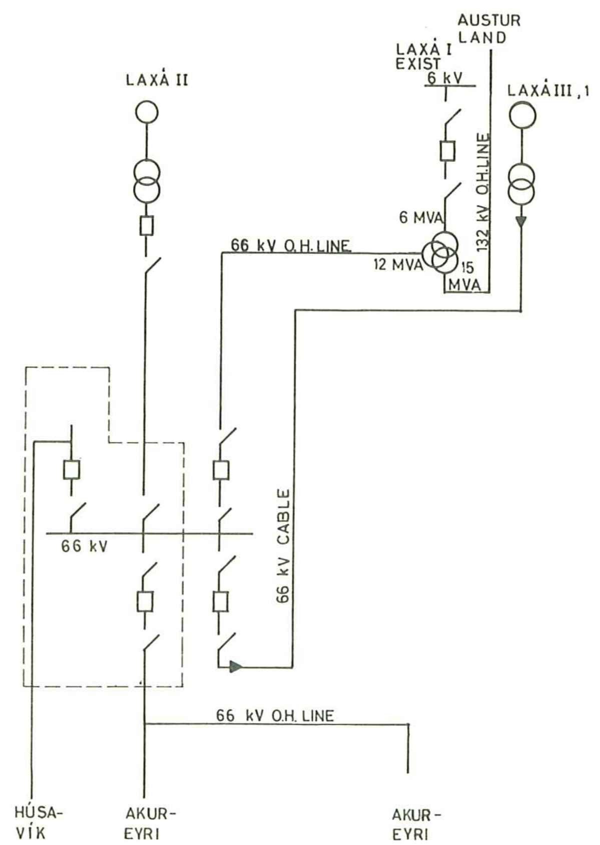
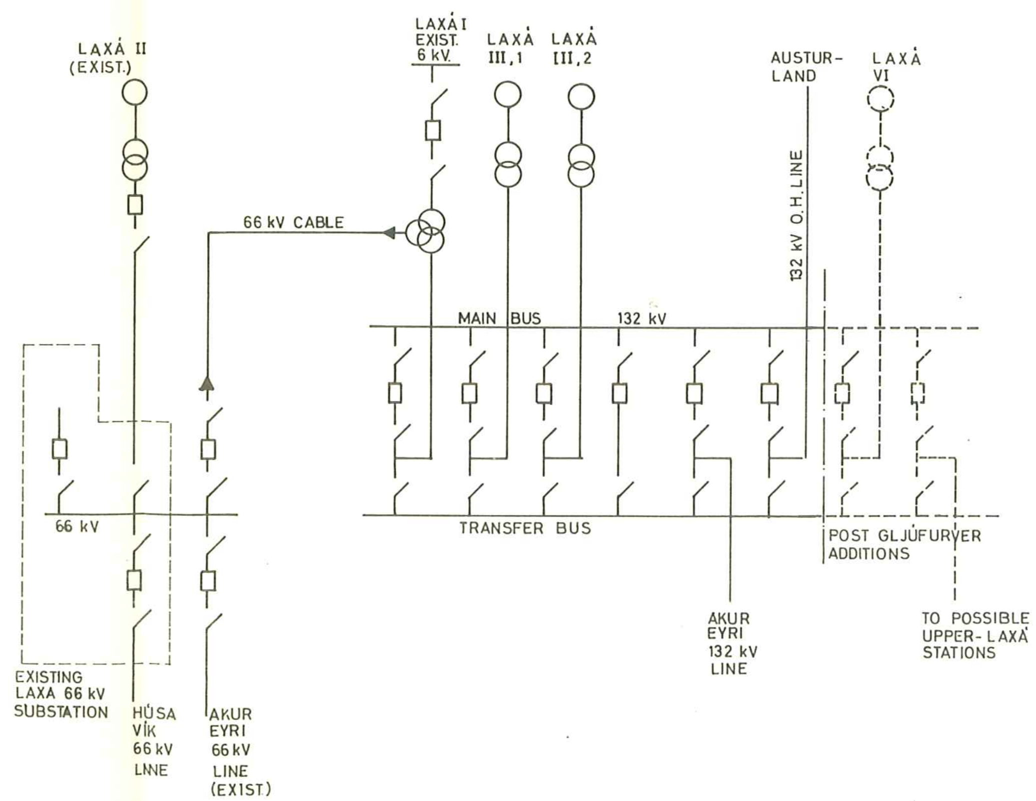


3. STIG



4. STIG



LAXÁ 66 kV SUBSTATION

LAXÁ 132 kV SUBSTATION

5. STIG

LAXÁRVIRKJUN

THE HYDRO-ELECTRIC DEVELOPMENT OF LAXÁ

GLJÚFURVER PROJECT	TRANSMISSION

PRINCIPAL ONE LINE DIAGRAM OF LAXÁ SUBSTATION

THORODDSEN AND PARTNERS

CONSULTING ENGINEERS . REYKJAVIK . ICELAND

DES:	CHECKED:	DATE:	APPROVED:	DRWG. NO.
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APPENDIXES

A REPORT ON THE GEOLOGY OF THE LAXÁ AREA

by Haukur Tómasson geologist,
the National Energy Authority

Introduction

In the years 1962 and 1963 geologic investigation in connection with plans for further hydropower developments on Laxá River, Northern Iceland, was conducted by the State Electricity Authority. This investigation was mainly directed at a master plan on the harnessing of the river at Brúar and also at the possibilities of supplying additional discharge from Suðurá and Svartá rivers and the construction of power plants further inland on the drainage area. In these years altogether 34 holes for a total length of 873 metres were drilled and some Borro sounding and seismic measurements were also accompliced.

In the summer 1967 the investigation was carried on and now directed at a particular power plant on Laxá at Brúar, the Gljúfurver power plant. The investigation was now as before done in cooperation with S. Thoroddsen and partners, consulting engineers. Drilling was carried out in the damsite, along the tunnel route and in and on the power station site. The drilling was mostly done with rotation drill rigs, but some Borro soundings were also made in the damsite having the purpose to determine the thickness of the overburden. The rotation drill rigs were also used in a grouting test of the lava in the damsite.

The core from the investigation boring was photographed on the location, then samples were collected and sent to Reykjavík for preservation at Keldnaholt. The samples make up about 10% of the core obtained in the boring. The rest of the core is kept at the Laxá power plant in a store house.

Geology

As to the general geology of the Laxá area reference is made to the report on the investigations of 1963. Yet the classification of strata in this area into formations will be described briefly. The oldest rock unit is the Brúar group (formations), subdivided into the uppermost, middle and lowest Brúar formations. These consist of a great number of basalt layers most of which are very thin, i.e. only 1-3 m thick. The layers have an easterly dip of 3-4^{o}. This group includes three sedimentary layers the uppermost of which is tillite and is the thickest single layer of the formations being about 15 m in thickness in many places. The other two layers are composed of tuff each of which is about 2-4 m thick. The three sedimentary layers are key horizonts for the formations as they are easily recognizeable and known throughout the project area. The tillite layer is a demarcation between the uppermost and middle Brúar formations, the lower tuff layer the demarcation between the middle and the lowest Brúar formations.

Discordant on top of the Brúar formations lies the Geitafell móberg east of the canyon and valley. The Geitafell móberg varies in composition from pillow lava to tuff. It occupies a previously existing valley east of the present Laxárdalur valley and Laxárgljúfur canyon.

In postglacial time the canyon has twice been overrun by lavaflows, in the former case about 3800 years ago but in the latter about 2000 years ago. These lava flows are termed the younger Laxá lava flow and the older Laxá lava flow, the former coming from the shield volcanoe Ketildyngja and the latter from Lúdentsborgir crater row at Lake Mývatn.

Damsite

On the map fig. 2 the stratigraphy of the damsite is shown. The bottom of the canyon is covered with postglacial lava flows, but in both canyon walls the tillite layer MB_m is found. Below it are thin basalt layers but above it appear two rather thick basalt layers, the EB_a and EB_b. Above these in the west side thin basalt layers belonging to the EB formation follow, but in the east side the Geitafell móberg. Its contact with the EB dips away from the canyon as shown on fig. 5.

On the map fig. 4 depth to bedrock and outcrops of bedrock on the damsite is shown. This map is based on borro drilling results from the area above the cliffs. On the whole overburden is very thin or just about one meter or so. In the canyon at the base of the cliffs some talus is common. Depth to bedrock is here estimated by extrapolation of the slope of the bedrock where exposed and information is also obtained from drillholes showing the position of the bedrock underneath the postglacial lava flows.

In the area overlain by postglacial lava flows the map shows the depth to the old bedrock. One of the holes, GV-3 revealed a depth to the old bedrock of 38 m, which is by far the greatest depth encountered with in drillholes in the canyon so far.

The most probable explanation of this is to suppose a waterfall to have existed on this spot and a deep and narrow trench been cut along a fracture zone. The contour lines as they are drawn on fig. 4 are in accordance with that hypothesis.

On fig. 4 the elevation of the contact between the two Laxá lava flows is mapped, being at approximately 90-94 m a.s.l. The younger lava is much thinner and very scoriaceous quite through. The older lava is much denser especially that part of it lying in the trench. Both the lava flows have large phenocrysts of feldspar but it had been noticed that at its base the older lava flow contains a layer with little or no phenocrysts. Their usual thickness is only a few teens of cm.
In the trench the older lava is on the whole almost free of phenocrysts, yet they occur incidentally forming porhyritic lentiles. In the damsite thin MB basalt layers form the foundation underlying the lava flows, but laterally the tillite layer MB_m adjoins them.

The younger Laxá lava is widely covered with considerably but very unevenly thick layer of loessy soil intermingled with lava fragments. As a whole the topmost 3-4 m of this layer should be workable by bulldozers. In places the younger Laxá lava is even scoriaceous quite through. A similar layer overlies the older lava but is there supposedly as a whole thinner.

The rock in the canyon walls is on the whole dense out to the surface but frost weathering penetrates it somewhat, though hardly more than 1 m. The frost weathering is most active in projecting outcrops and in the top edge of the canyon. Below the talus accumulation some frost weathering is probable but below soil cover and in the móberg it is inactive.

The damsite is traversed by three faults with an approximate north-south direction. At the westernmost fault some displacement has taken place, but at the others no displacement is discernible. The faults are most clearly visible in cliff walls and they are the reason for the frequently occurring outcrops with depressions in between along the canyon walls. These outcrops occur everywhere, where the direction of the canyon is not north-south; in the other case the canyon walls are straight. The fractures are somewhat weaker than the surrounding rock, therefore they have been susceptible to erosion. Probably they all consist of a large number of fault planes. The faults are invisible on the surface both in Geitafell móberg and on the lavas which indicates their having ceased to be active a long time ago.

Most likely the faults are somewhat more leaky than the surrounding rock, yet they seem on the whole to be quite impermeable due to alteration. Permeability in boreholes in Brúar formations is generally not more than 0-10 LU, the usual being 1-2 LU, except near the surface where the permeability can amount to teens of LU. On the geologic map springs issued from the Brúar group are shown in five places. Lower, lying in the east wall there are two springs, one a tiny spring of cold water is coming from a contact, but the other is much greater, seemingly coming from a fault. Above the canyon on the west bank three springs are met with of which the uppermost has hot water of nearly 20°C. Probably the hot water emerges from a fracture which lies close by. The other two springs may to some degree be fed by the same water source, the water having run a little farther in the surficial loose material.

The Geitafell móberg is greatly more leaky than the Brúar group, usual permeability some teens of LU up to 50 LU. At the base of the Geitafell móberg a spring horizon is found. This horizon is shown on the geologic map. Most of the springs are small, but all together the outpouring water amounts to at least some teens of liters per second.

The lava flows are by far the most leaky stratas in the damsite of which the upper lava flow and the contacts, usually both the contact between the two lava flows and between lava flow and the old bedrock, are the most leaky. Usual permeability is 100-200 LU, but this difference in permeability between the lavas on the one hand and Brúar group and Geitafell móberg on the other does in fact not give an accurate picture of difference in permeability, because in the permeability testing head loss in pipes was not taken into account, but this begins to have measurable effect at about 50 LU and at 200 LU a greater part of the pressure usually goes to head loss due to the friction in the pipes. The permeability of the postglacial lava flows is so great that a discharge of between 1 and 2 m^3/sec can be estimated to flow through the lava aquifer at the damsite. The lower part of the older Laxá lava is comparatively tight and its contact with the old bedrock in hole GV-3 is exceptionally tight, the permeability reached only 2.7 LU. The reason for the tightness of this contact is apparently that here the lava flow has remelted the bedrock to form a uniform and compact contact. This has probably only taken place in the deepest part of the trench and it is rather uncommon for the heat of a lava flow to be sufficient to remelt a contact.

Because of the great permeability of the postglacial lava flows they have to be tightened below the high dam proposed to be built. By the tightening the water now flowing through the lava aquifer will be made available for the power plant. A grout test of the lava flows in the damsite was performed. This testing will not be discussed here to any degree, since this has been done in an other report.

Tunnels

The tunnels will be situated in the east side of the valley. Figure 5 shows contours for some of the contacts in the area traversed by the tunnels. The contact between GM and EB dips away from the edge of the canyon to north-east. This is an old valley side, the valley having been east of Laxárdalur valley and Laxárgljúfur canyon and later filled with eruptive material of Geitafell móberg. The present valley and canyon were eroded along the western margin of the Geitafell móberg. In it the surge tank will be situated for the most part. Supposedly it will therefore have to be lined.

The next contact shown on the map is the upper contact of the tillite layer MB_m. Evidently the surface has there been irregular with hillocks and depressions and the layer is of considerably different thickness from one place to another. The third contour shows the lower contact of the tillite layer. It probably represents with the greatest accuracy the general dip and strike in the area. On the map fig. 5 the continuation of the lower contact of the layer MB_m to north is shown and also the upper contact of the tuff layer MB_c.

The basalt layers on top of the tillite layer MB_m are thick and consistent. Yet the lower layer is very variable in thickness because of hillocky topography of the top of MB_c. Conditions for tunnelling in these layers are good. The tillite layer MB_m is apparently very compact and well consolidated, and there is no reason but to consider its arch action as being good during tunneling. On the other hand its resistance to water erosion is more doubtful. Below the tillite, between it and the tuff layer MB_c, nine basalt layers are to be found. Since the total thickness of them is only 10-15 m individual layers must be very thin. They are formed by a shield volcanoe and there are neither any sedimentary interbeds nor any appreciable flow breccias. All these layers seem to be well cohered and compact. In this rock the tunnels will be located for the most part. The resistance can be considered as rather good.

The direction of tunnels with reference to direction of fractures and consequently horizontal stress in the rock is a very important factor no less than the strata in which they lie. It is most desireable to go as perpendicular to the direction of fractures as possible, going parallell to them can invite many difficulties. A major part of the tunnels will cross the fractures at a 45^o angle, which is a favourable direction. Yet a small section of the tunnel will be almost parallell to a fault and special precaution is needed not to let this part lie in a fractured zone. This is the uppermost part of the power tunnel going straight out from the reservoir in a northerly direction.
This section may be expected to cause difficulty while under construction and will require the greatest lining.

Power Station and Tailrace Tunnel

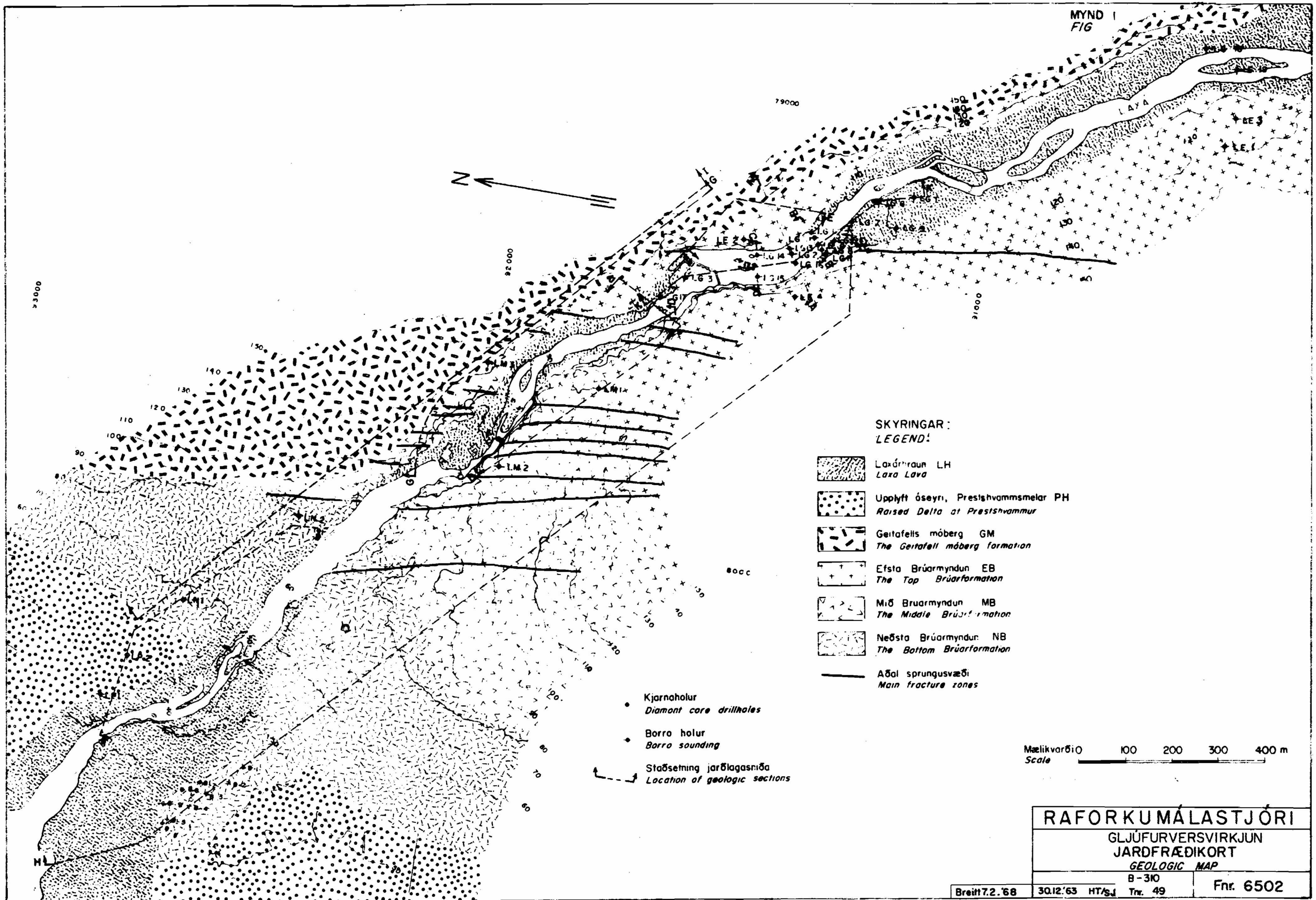
On fig. 3 is a geologic map of the power station site. It reveals that the bedrock is middle Brúar formation for the most part overlain by Geitafell móberg. The middle Brúar formation contains the tuff layer MB_c underlain by two rather thick basalt layers MB_a and MB_b.
The power station will for the most part be located in these layers, yet reaching over the tuff layer MB_c and even down into the tuff layer intercalated between the middle and lowest Brúar formations.
The tailrace tunnel will be in the lowest basalt layers of the middle Brúar formation.

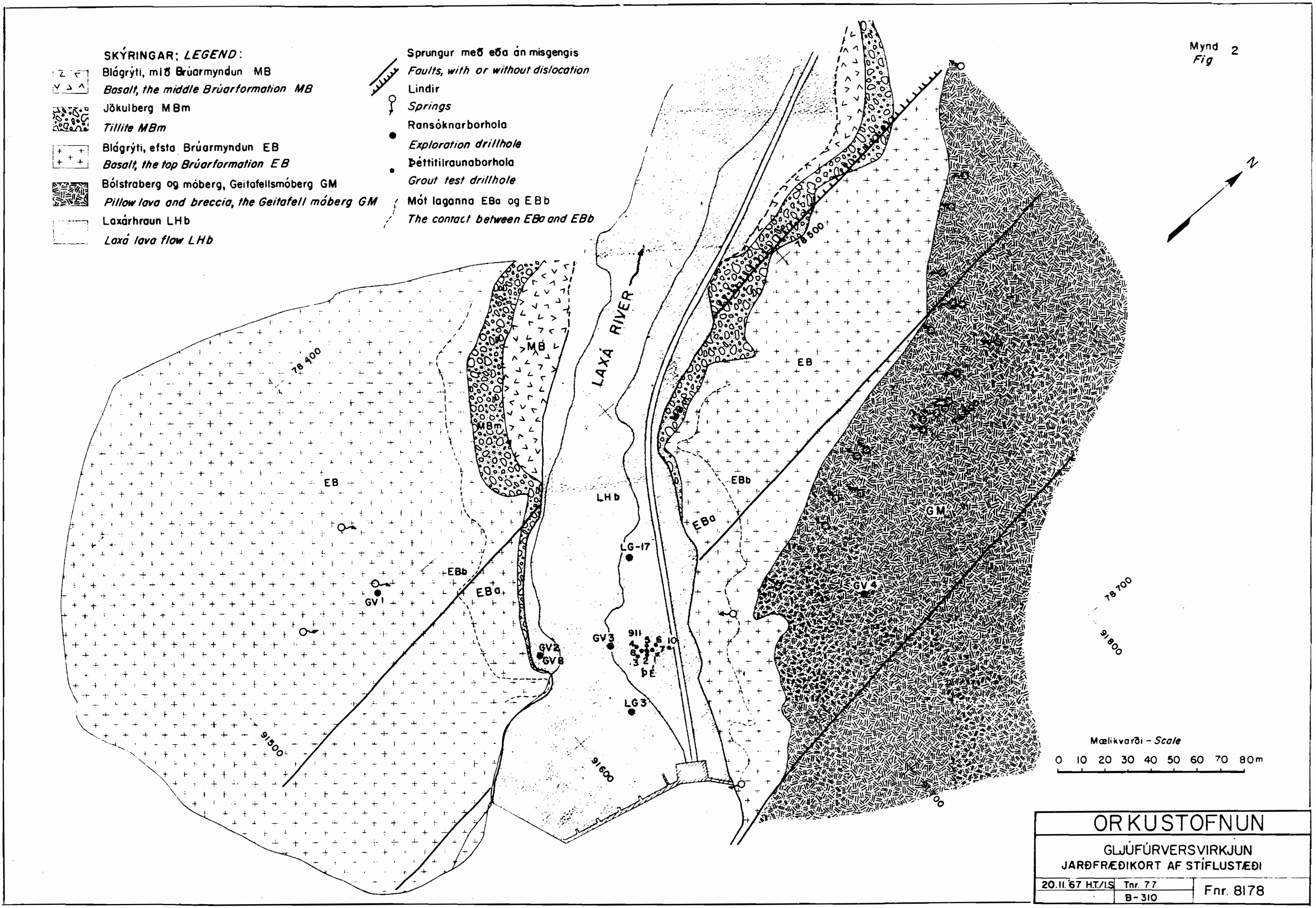
The tuff layer MB_c is no doubt the weakest layer here and probably needs some supporting, especially if it is much altered, which is probably is in this area, since it is densly fractured with a dike just west of the power station site.

As can be seen on the geologic map fig. 3 the area in which the power station is located is very densely fractured. It is therefore probable that the rock is on the whole considerably weakened by these fractures. It is possible that a greater part of the roof needs supporting even though the direction of the power station is at a nearly 45^{o} angle to the direction of fractures.

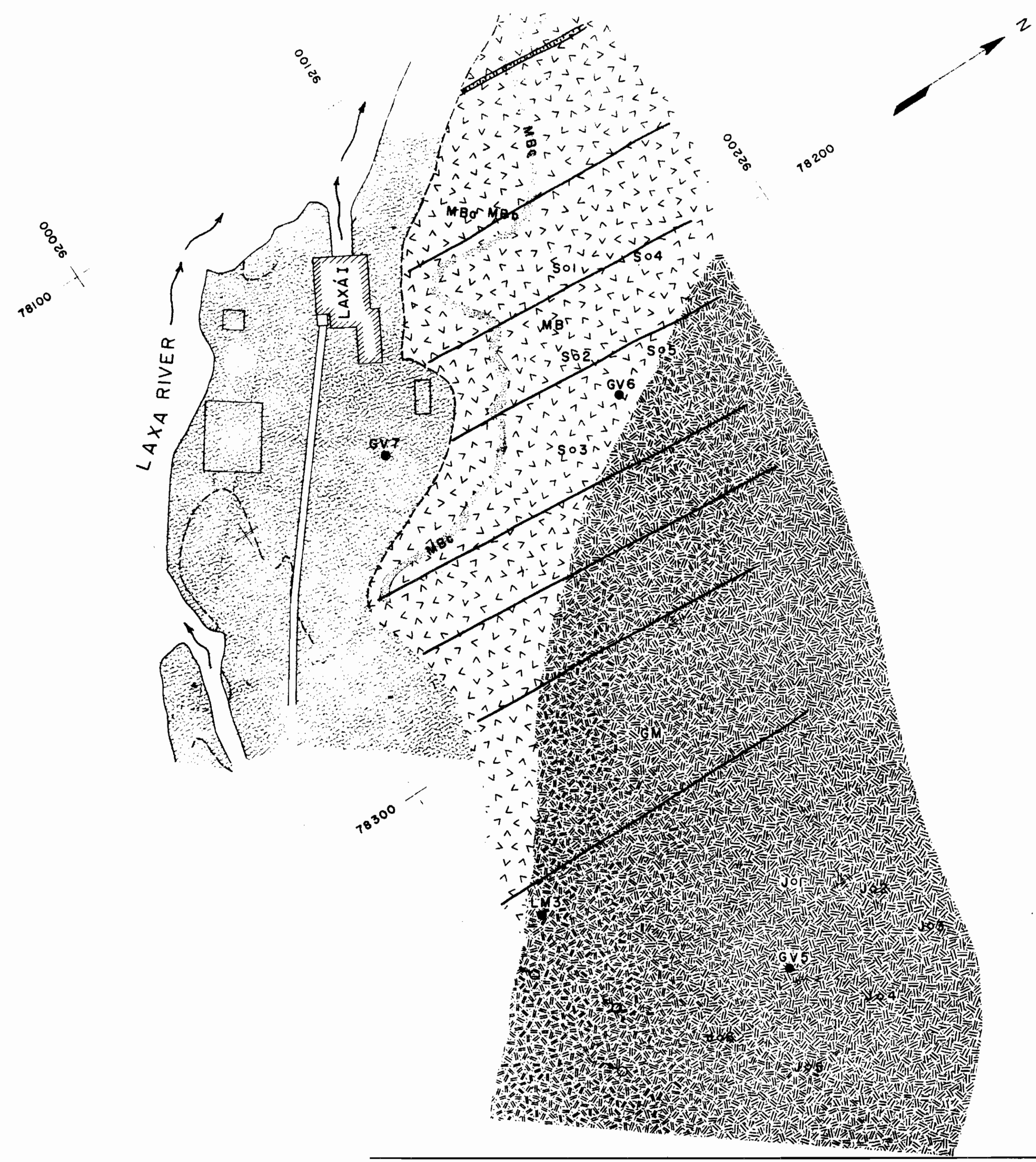
The tailrace tunnel lies almost perpendicular to the direction of fractures, which is very favourable and therefore should not require much supporting even though it is located in a greatly fractured rock, all of which is basalt.

The tunnel leading from the surge tower has the same direction as the tailrace tunnel but passes through less fractured rock. It passes the tuff layer MB_c and will there need a lining.


MYND 1
FIG
LAXA
SKYRINGAR:
LEGEND:
Laxárhraun LH
Laxa Lava
Upplyft óseyri, Prestshvammsmelar PH
Raised Delta at Prestshvammur
Geitafells móberg GM
The Geitafell móberg formation
Efsta Brúarmyndun EB
The Top Brúarformation
Mið Brúarmyndun MB
The Middle Brúarformation
Neðsta Brúarmyndun NB
The Bottom Brúarformation
Aðal sprungusvæði
Main fracture zones
Kjarnaholur
Diamont core drillholes
Borro holur
Borro sounding
Staðsetning jarðlagasniða
Location of geologic sections
Mælikvarði 0 100 200 300 400 m
Scale
RAFORKUMÁLASTJÓRI
GLJÚFURVERSVIRKJUN
JARÐFRÆÐIKORT
GEOLOGIC MAP
Breitt 7.2.'68
30.12.'63 HT/SJ
B-310
Tnr. 49
Fnr. 6502


Mynd 2
Fig
SKÝRINGAR: LEGEND:
Blágrýti, mið Brúarmyndun MB
Basalt, the middle Brúarformation MB
Jökulberg MBm
Tillite MBm
Blágrýti, efsta Brúarmyndun EB
Basalt, the top Brúarformation EB
Bólstraberg og móberg, Geitafellsmóberg GM
Pillow lava and breccia, the Geitafell móberg GM
Laxárhraun LHb
Laxá lava flow LHb
Sprungur með eða án misgengis
Faults, with or without dislocation
Lindir
Springs
Ransóknarborhola
Exploration drillhole
Þéttitilraunaborhola
Grout test drillhole
Mót laganna EBa og EBb
The contact between EBa and EBb
N
LAXÁ RIVER
MB
MBm
EB
EBa
EBb
LHb
GM
GV1
GV2
GV8
GV3
GV4
LG-17
LG3
ÞE
78 400
78 500
78 700
91500
91600
91800
Mælikvarði - Scale
0 10 20 30 40 50 60 70 80m
ORKUSTOFNUN
GLJÚFÚRVERSVIRKJUN
JARÐFRÆÐIKORT AF STÍFLUSTÆÐI
20.11.67 H.T./I.S.
Tnr. 77
B-310
Fnr. 8178

Mynd 3
Fig



SKÝRINGAR: *LEGEND:*

Blágrýti, mið Brúarmyndun MB
Basalt, middle Brúarformation MB

Tuffsandsteinn MBc
Tuffsandstone MBc

Móberg og bólstraberg, Geitafellsmóberg GM
Tuff, breccia and pillow lava, Geitafellmóberg GM

Yngra Laxárhraun LHb
Younger Laxa lava flow LHb

Sprungur
Faults

Gangur
Dike

Lindir
Springs

Rannsóknarborholur
Exploration drill holes

Borro borun
Borro sounding

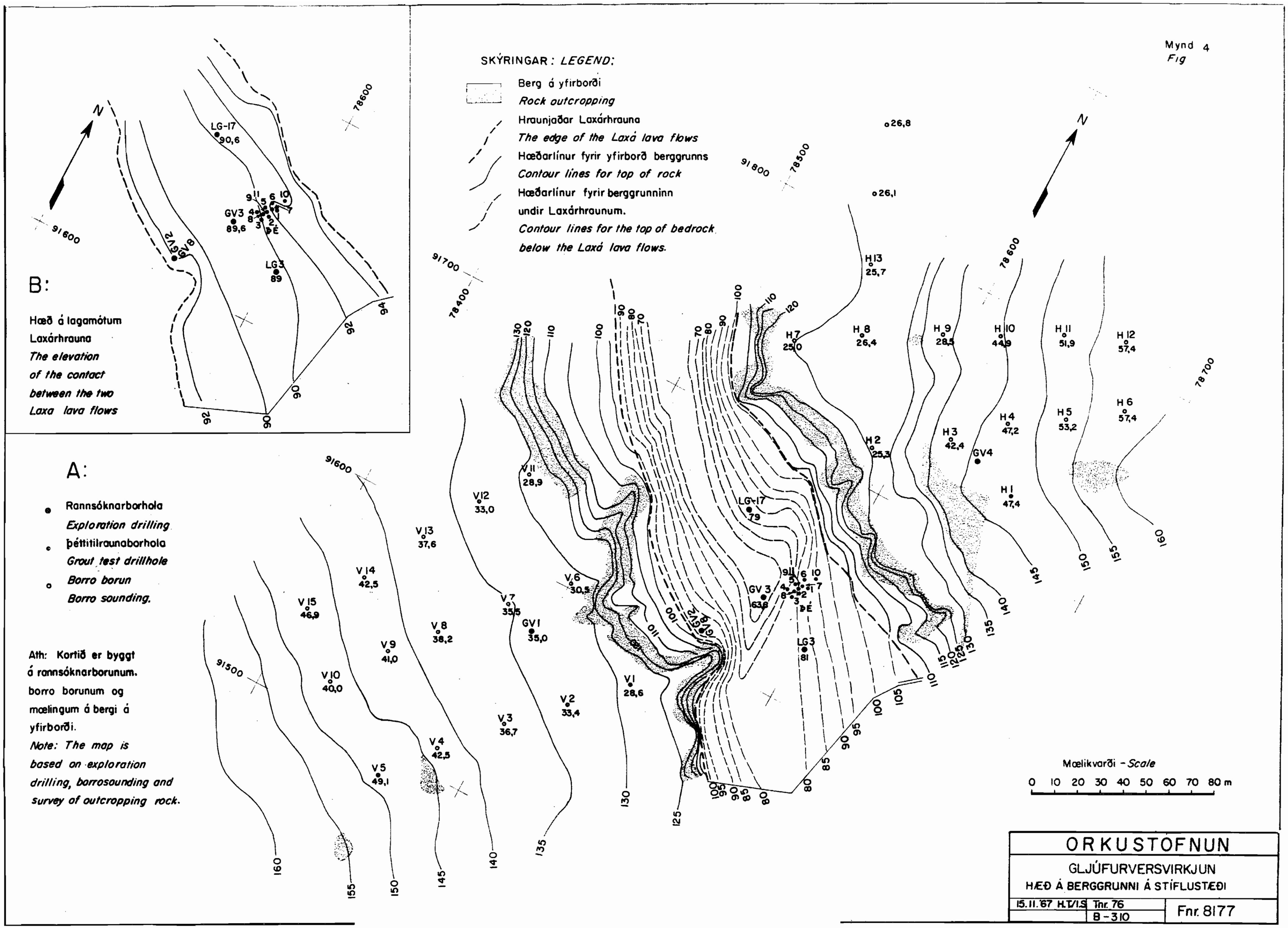
Mælikvarði – *Scale*

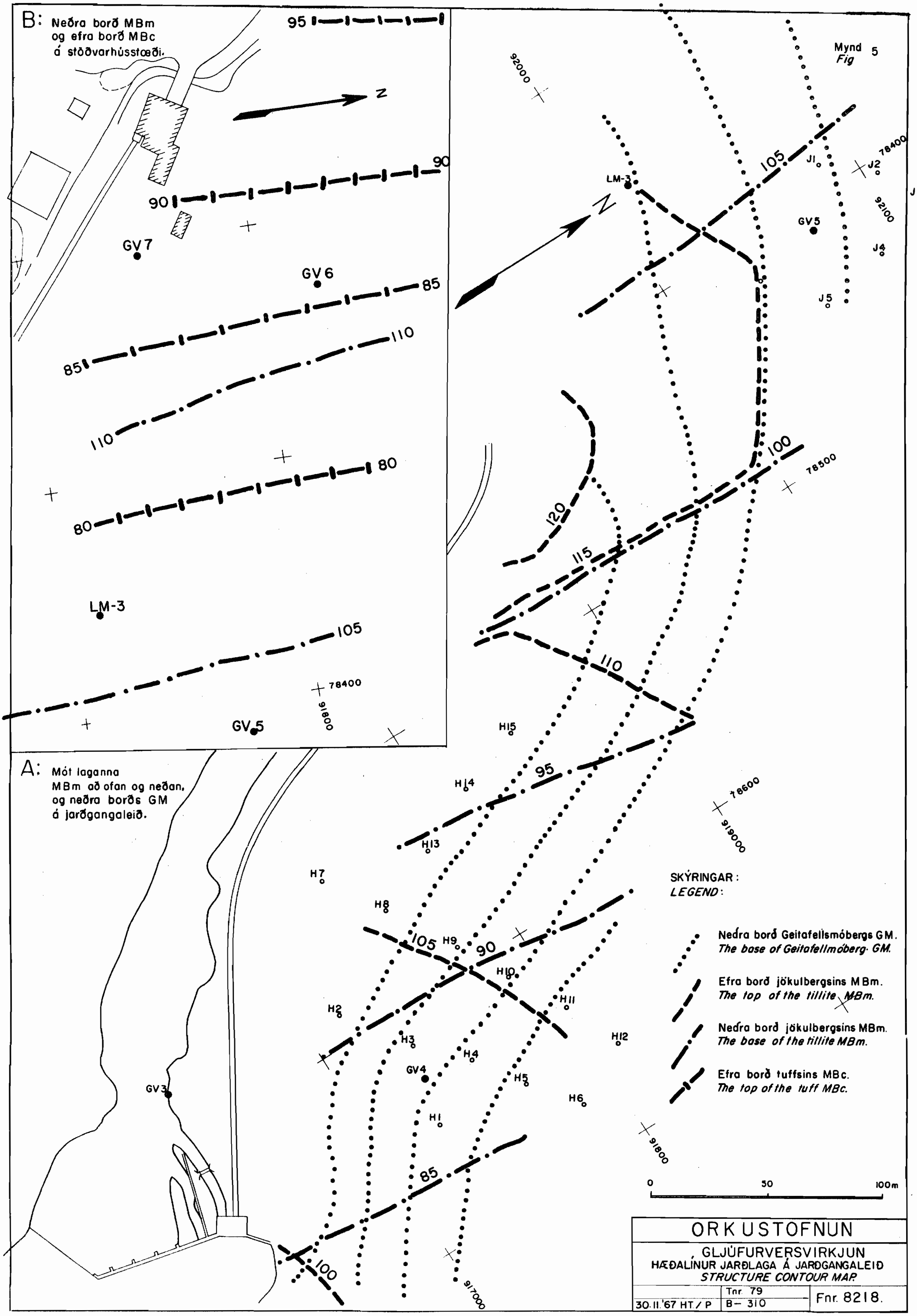
0 10 20 30 40 50 60 70 80 m

ORKUSTOFNUN

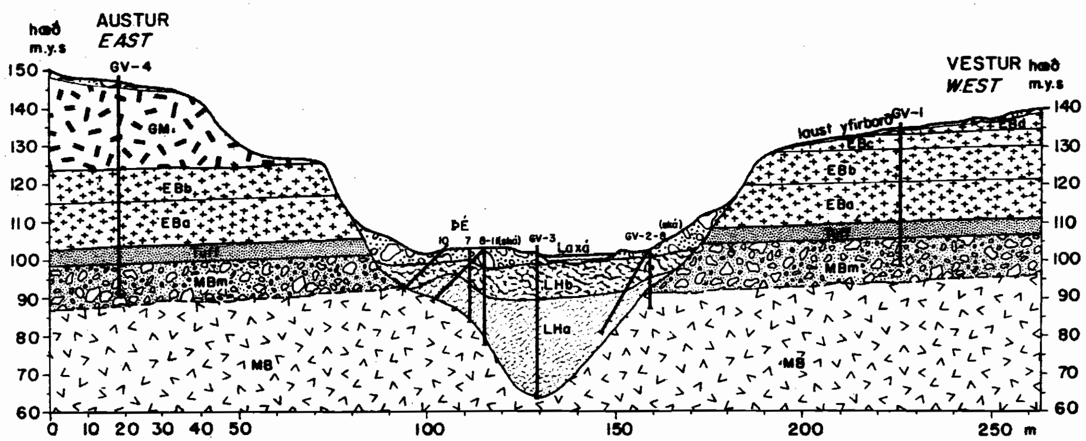
GLJÚFURVERSVIRKJUN
STÖÐVARHÚSSTÆÐI, JARÐFRÆÐIKORT

29.11.67 H.T./I.S.	Tnr. 78 B-310	Fnr. 8179


Mynd 4
Fig
SKÝRINGAR: LEGEND:
Berg á yfirborði
Rock outcropping
Hraunjaðar Laxárhrauna
The edge of the Laxá lava flows
Hæðarlínur fyrir yfirborð berggrunns
Contour lines for top of rock
Hæðarlínur fyrir berggrunninn
undir Laxárhraunum.
Contour lines for the top of bedrock
below the Laxá lava flows.
B:
Hæð á lagamótum
Laxárhrauna
The elevation
of the contact
between the two
Laxa lava flows
A:
Rannsóknarborhola
Exploration drilling
Þéttitilraunaborhola
Grout test drillhole
Borro borun
Borro sounding.
Ath: Kortið er byggt
á rannsóknarborunum,
borro borunum og
mælingum á bergi á
yfirborði.
Note: The map is
based on exploration
drilling, borrosounding and
survey of outcropping rock.
Mælikvarði - Scale
0 10 20 30 40 50 60 70 80 m
ORKUSTOFNUN
GLJÚFURVERSVIRKJUN
HÆÐ Á BERGGRUNNI Á STÍFLUSTÆÐI
15.11.'67 H.T./I.S.
Tnr. 76
B-310
Fnr. 8177


Mynd 5
Fig
B: Neðra borð MBm
og efra borð MBc
á stöðvarhússtæði.
N
GV 7
GV 6
LM-3
GV 5
78400
91800
95
90
85
110
80
105
A: Mót laganna
MBm að ofan og neðan,
og neðra borðs GM
á jarðgangaleið.
GV3
GV4
H1
H2
H3
H4
H5
H6
H7
H8
H9
H10
H11
H12
H13
H14
H15
J1
J2
J4
J5
92000
92100
78500
78600
91900
91800
91700
120
115
100
SKÝRINGAR:
LEGEND:
Neðra borð Geitafellsmóbergs GM.
The base of Geitafellmóberg GM.
Efra borð jökulbergsins MBm.
The top of the tillite MBm.
Neðra borð jökulbergsins MBm.
The base of the tillite MBm.
Efra borð tuffsins MBc.
The top of the tuff MBc.
0
50
100m
ORKUSTOFNUN
GLJÚFURVERSVIRKJUN
HÆÐALÍNUR JARÐLAGA Á JARÐGANGALEIÐ
STRUCTURE CONTOUR MAP
30.11.'67 HT / P
Tnr. 79
B– 310
Fnr. 8218.

Mynd 6
Fig



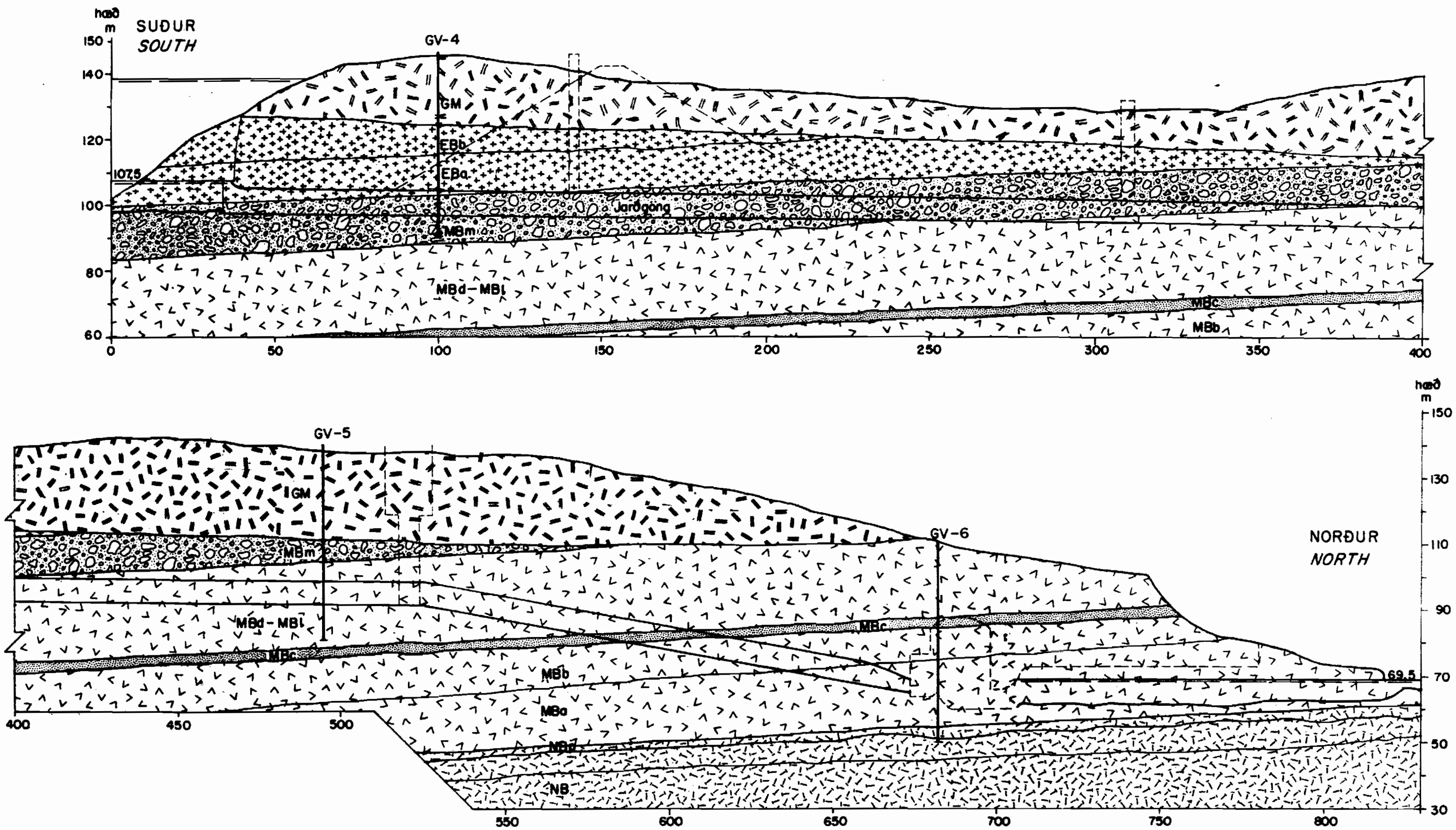
SKÝRINGAR:
LEGEND:

- laust yfirborð eða frauðkennt hraun — ***overburden or scorious top of a lavaflow***
- LHb blágrýti – Laxárhraun yngra — ***basalt – younger Laxa lavaflow***
- LHa blágrýti – Laxárhraun eldra — ***basalt – older Laxa lavaflow***
- GM bólstraberg, breksia og tuff – Geitafellsmóberg — ***pillowlava, breccia and tuff – Geitafell móberg formation.***
- EB blágrýti – efsta Brúarmyndun — ***basalt – top Bruarformation***
- Tuff Brúarmyndun — ***Tuff Bruarformation***
- MBm jökulberg – Mið Brúarmyndun — ***tillite – Middle Bruarformation***
- MB blágrýti – Mið Brúarmyndun — ***basalt – Middle Bruarformation***
- NB blágrýti – neðri Brúarmyndun — ***basalt – bottom Bruarformation***

Snið í stíflustæði – horft upp eftir á.
Section in damsite – looking upstream.

ORKUSTOFNUN		
GLJÚFURVERSVIRKJUN JARÐLAGASNIÐ *Geologic section*		
11.10.'67 BJ/AI	Tnr. 74	Fnr. 8103
Blað 1. af 2	B-310	

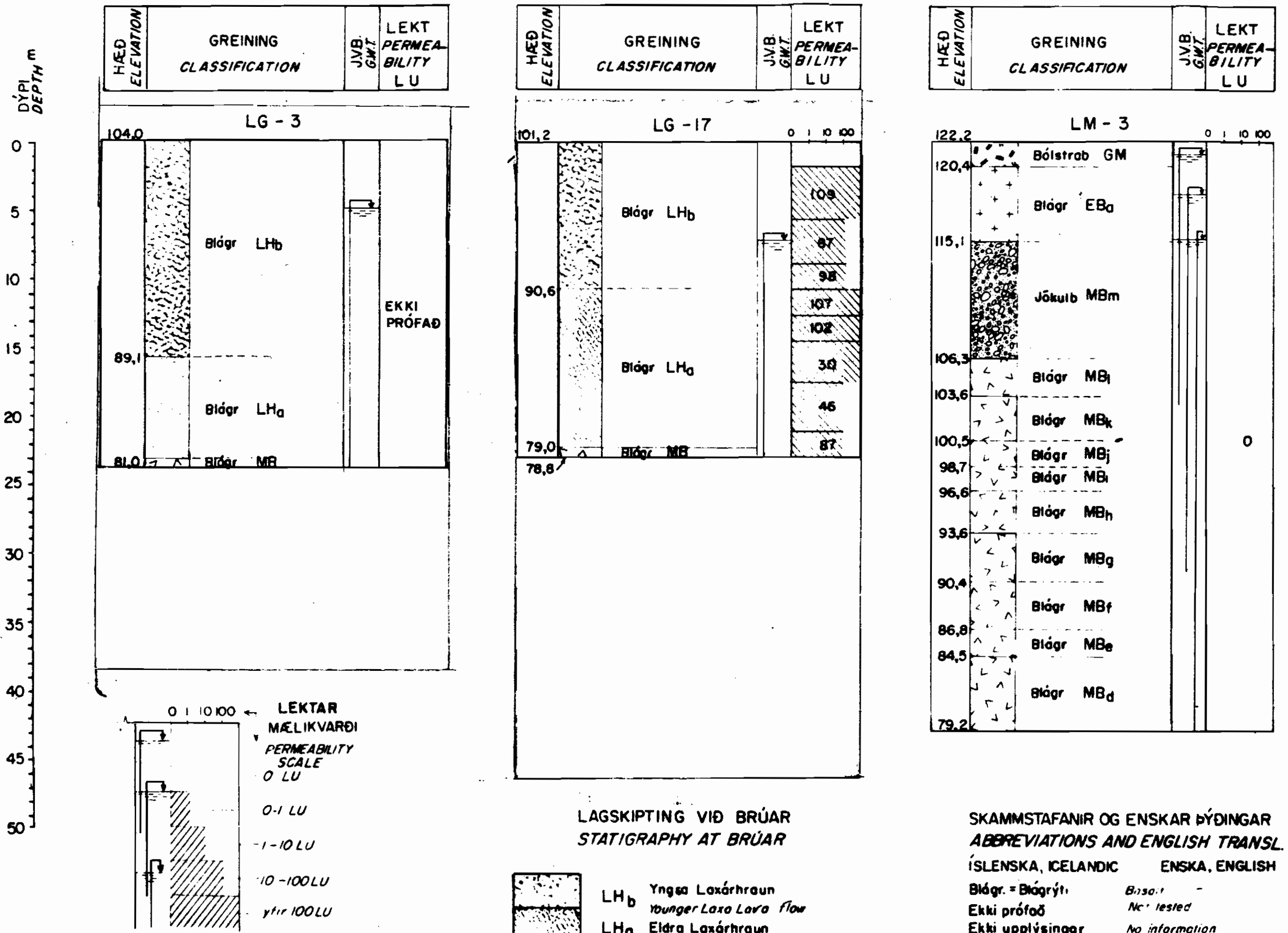
Mynd 7
Fig



Sjá skýringar á bl. 1 af 2
See legend on sheet 1 of 2

ORKUSTOFNUN		
GLUFURVERSVIRKJUN JARÐLAGASNIÐ *Geologic section*		
14.10.'67 BJ/Al	Tnr. 75	Fnr. 8104
blað 2 af 2	B – 310	

MYND 8
FIG.



LEKTAR OG JARÐVATNS ÚTSKÝRING

Jarðvatnsborð er sýnt með örvum. Neðri endi örvarinnar sýnir holudýpið, þegar jarðvatnsborð breyttist. Jarðvatnsörvunum er raðað frá vinstri til hægri í sömu röð og jarðvatn breytist. Ef jarðvatn breytist ekkert í borun, nær örin í botn.

Ground water levels are shown by arrows. Base of the arrows indicate the hole depth when water level changed. Successive levels are shown from left to right in the same sequence as observed during drilling. If no change in level was observed the arrow reaches the hole bottom.

1LU = Lugeon Unit = 1 l/min/m/NX holu1 við þrýsting 10kg/cm²

1 LU = Lugeon Unit = 1 l/min/m/NX hole at pressure 10 kg/cm²

LAGSKIPTING VIÐ BRÚAR
STATIGRAPHY AT BRÚAR

- LH_b Yngsa Laxárhraun — *Younger Laxa Lava flow*
- LH_a Eldra Laxárhraun — *Older Laxa Lava flow*
- PH Prestshvammsmelar — *The Prestshvammur gravel*
- GM Geitafells móberg — *The Geitafell Móberg (Palagonite)*
- EB Efsta Brúar myndun — *The Top Brúarformation*
- MB Mið Brúar myndun — *The Middle Brúarformation*
- NB Neðsta Brúar myndun — *The Bottom Brúarformation*
- Mislægi — *Unconformity*

SKAMMSTAFANIR OG ENSKAR ÞÝÐINGAR
ABBREVIATIONS AND ENGLISH TRANSL.

ÍSLENSKA, ICELANDIC	ENSKA, ENGLISH
Blágr. = Blágrýti	*Basalt*
Ekki prófað	*Not tested*
Ekki upplýsingar	*No information*
Grágr = Grágrýti	*Dolerite*
J.V.B. = Jarðvatnsborð	*GWT Ground water table*
Jökulb. = Jökulberg	*Tillite*
Molab = Molaberg	*Clastic rock*
Molar	*Unconsolidated*
Mórena	*Moraine*
Möl	*Gravel*
Vatn	*Water*

Ath: Staðsetning borhola er á mynd 3, 9, 10 og 11
Note: Location of drillholes see figures 3, 9, 10 and 11

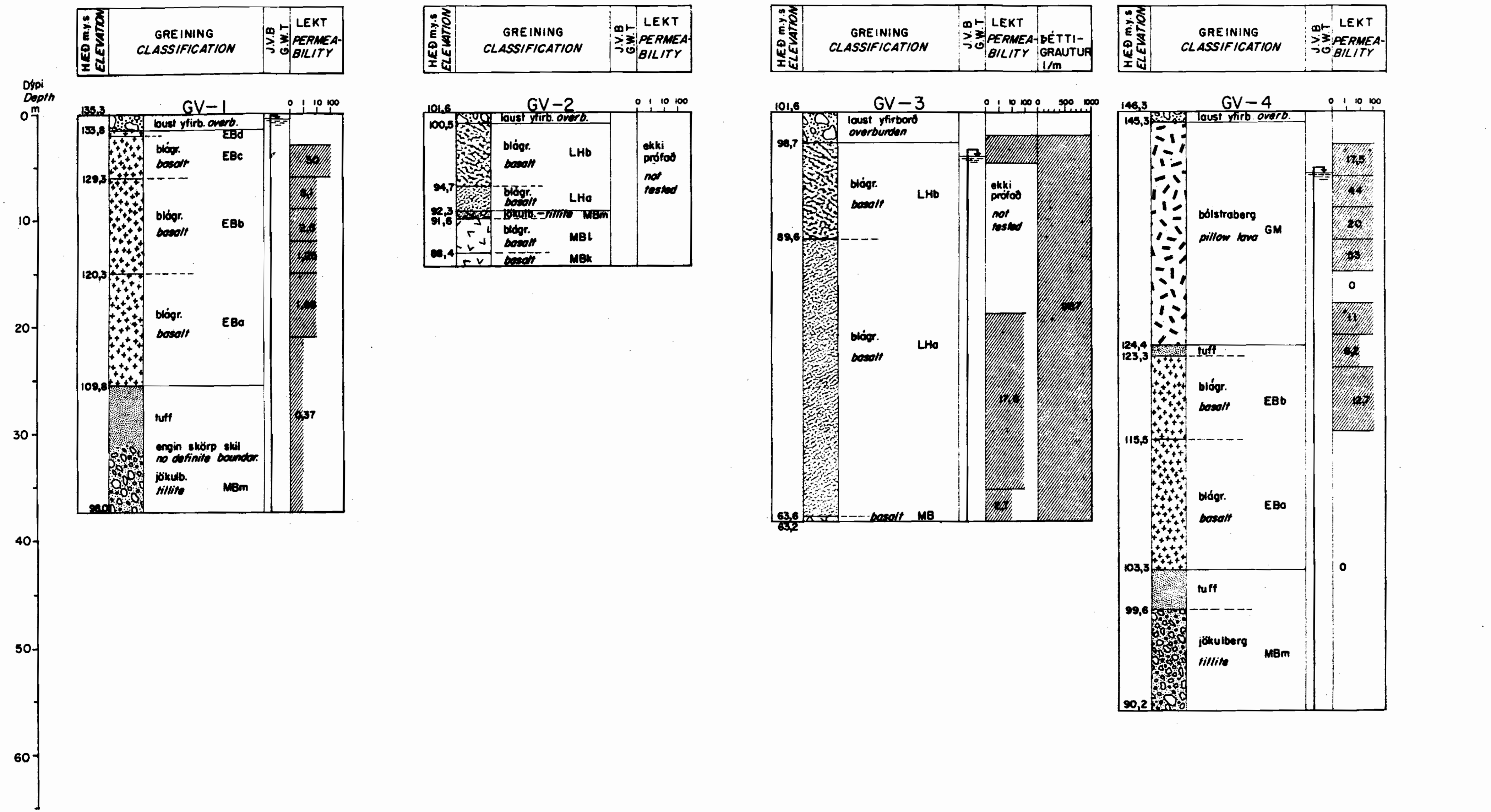
SKÝRINGAR:
LEGEND:

- Molar, óhörðnuð yfirborðslög eða millilög í og undir hrauninu. *Unconsolidated overburden or interbeds in postglacial lava flows*
- Blágrýti, yngra Laxárhraun LH_b — *Younger Laxa lava flow.*
- Blágrýti, eldra Laxárhraun. LH_a — *Basalt, older Laxa lava flow*
- Möl úr fornum óseyrum Laxár PH — *Gravel from raised delta at Laxa.*
- Bólstraberg, Geitafells móbergsmyndun GM — *Pillowlava Geitafell móbergformation*
- Blágrýti Efsta Brúarmyndun EB — *Basalt Top Brúarformation*
- Blágrýti, mið Brúarmyndun MB — *Basalt, Middle Brúarformation*
- Blágrýti, neðsta Brúarmyndun NB — *Basalt, Bottom Brúarformation*
- Tuff, Brúarmyndun — *Tuff, Brúarformation*
- Molaberg, Brúarmyndun — *Sedimentary breccia, or conglomerate, Bruarformation*

GLJÚFURVERSVIRKJUN

RAFORKUMÁLASTJÓRI		
LAXÁ VIÐ BRÚAR SNIÐ AF BORHOLUM *GRAPHIC CORE LOGS*		
Breitt 28.12.'67 blað I.af 4	blað 1 af 5 5.12.'63 H.T./P.J.	B - 310 Tnr. 36	Fnr. 6481

Mynd 9
Fig



ORKUSTOFNUN

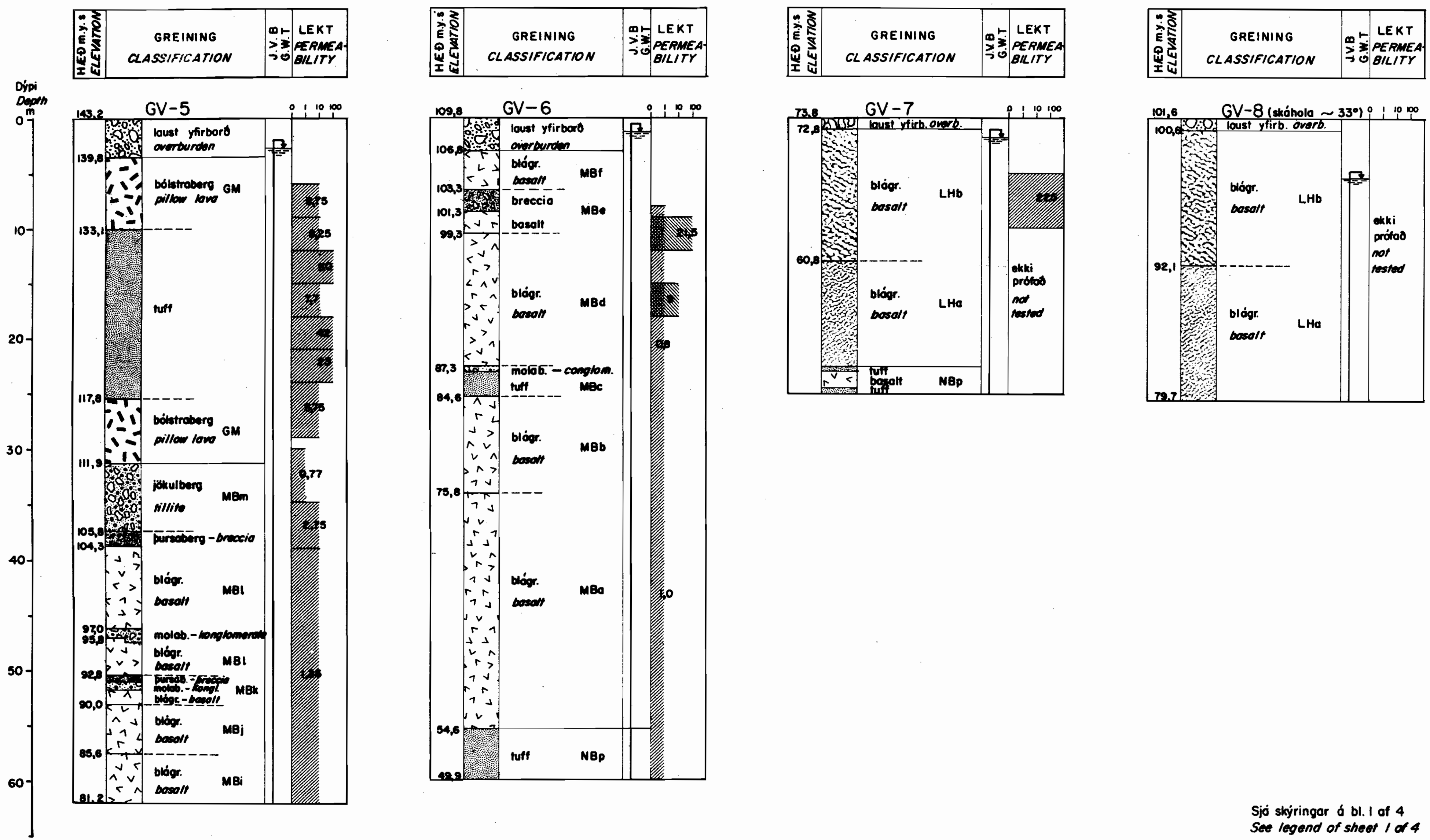
GLÚFURVERSVIRKJUN

SNIÐ AF BORHOLUM

Graphic Core Logs.

10.10.'67 BJ/AI	Tnr. 72	Fnr. 8101
blað 2 af 4	B – 310	

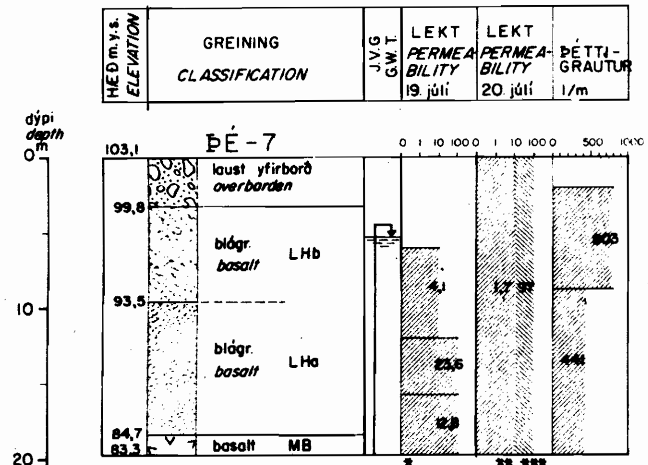
Mynd 10
Fig



Sjá skýringar á bl. 1 af 4
See legend of sheet 1 of 4

ORKUSTOFNUN
GLJÚFURVERSVIRKJUN
SNIÐ AF BORHOLUM
Graphic Core Logs
9.10.'67 BJ/Anna Tnr. 73
blað 3 af ... B-310
Fnr. 8102

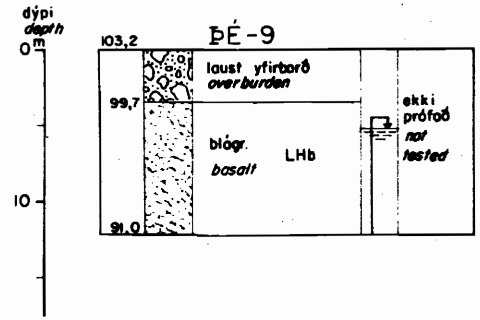
Mynd 11
Fig

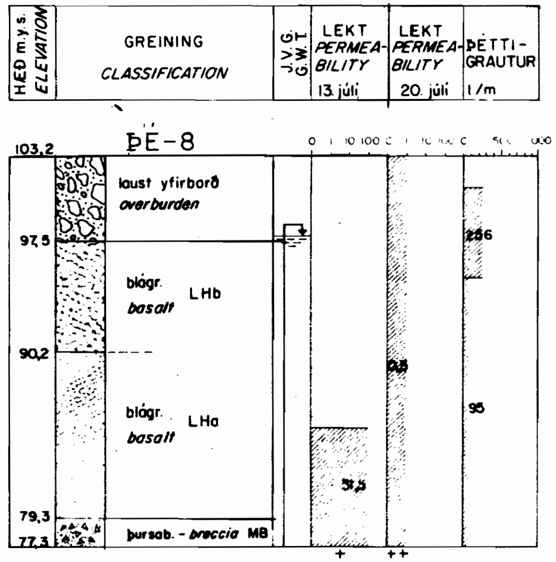


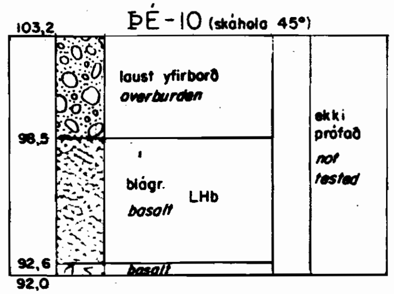
* Lekt 19. júlí. – Áður grautuð nokkrum sinnum. – þó oftar í efri hlutanum. Síðan var öll holan grautuð.

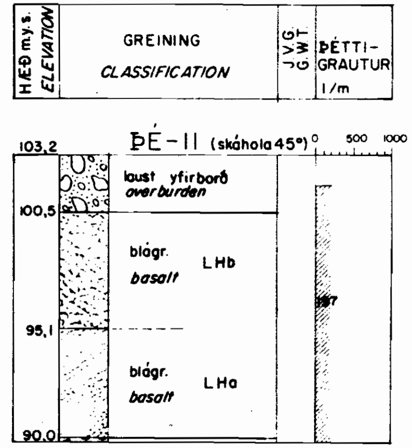
** Lekt 20. júlí við 1.0 kg/cm² þrýsting.

*** þrýstingur hækkaður og sprengt út úr.









\+ Neðsti hluti ógrautaður 13. júlí

\++ Öll holan grautuð 20. júlí

Ath: Laust yfirborð merkir í öllum ÞÉ-holum og í GV-2, 3, 7 og 8 frauðkennt, laust hraunyfirborð fyllt með jarðvegi. Í öðrum holum að mestu fokjarðvegur eða mór.

Note: *Overburden is in all the ÞÉ-holes and in GV-2,3,7,and 8 serious fragmental surface of a lavaflow filled with soil. In all the other holes it is loessy soil or peat.*

Sjá skýringar á bl. 1 af 4

See legend on sheet 1 of 4

ORKUSTOFNUN	
GLJÚFURVERSVIRKJUN SNIÐ AF BORHOLUM *Graphic Core Logs*	
9.10.'67 BJ/AI	Thr. 71
blað 4 of 4	B-310
Fnr. 8100	

RESUME OF A REPORT ON TEST GROUTING PERFORMANCE IN POST-GLACIAL LAVALAYERS IN THE LAXÁRGLJÚFUR GORGE

In the summer 1967 a test grouting performance was carried out in the postglacial lava layers in the Laxárgljúfur gorge.

The test was performed in order to try to find out an economical way to tighten the layers viz. to find out a logical pattern for the injection boreholes, their depth, what materials were preferable and how they should be mixed, how much grout the holes would take etc. so that the test might be a guide or give information for the benefit of the later performance.

As stated elsewhere there are two layers of the lava.
The younger or uppermost one is far more scoriaceous and permeable than the older underlying one, so much so that it is proposed to strip the uppermost 4 to 5 m. It is considered that this may be done by ripping and bulldozing. In the two holes where those uppermost metres of the lava were injected with grout this part took much more grouting than the part beneath, conf. the table I, which follows.

The two lavalayers are very permeable and this aquifier carries a good deal of underground water, which by rough estimate may be somewhat between one and two kl/s over the whole section.

This moment will undoubtly involve some difficulties in the grouting work, which should only be given to a firm with great skill and experience in work of this kind.

Another moment which also will involve hindrance in good performance is the existence of diatomaceous deposits which are to be found in high degree in the voids in the lavalayers. These deposits will up to a certain degree diminuate the permeability of the layers.
On the other hand the deposits are not able to meet the high pressure, which here must be reckoned with. It is believed, in conformity with tests elsewhere from, though concerning another matter viz. glacial

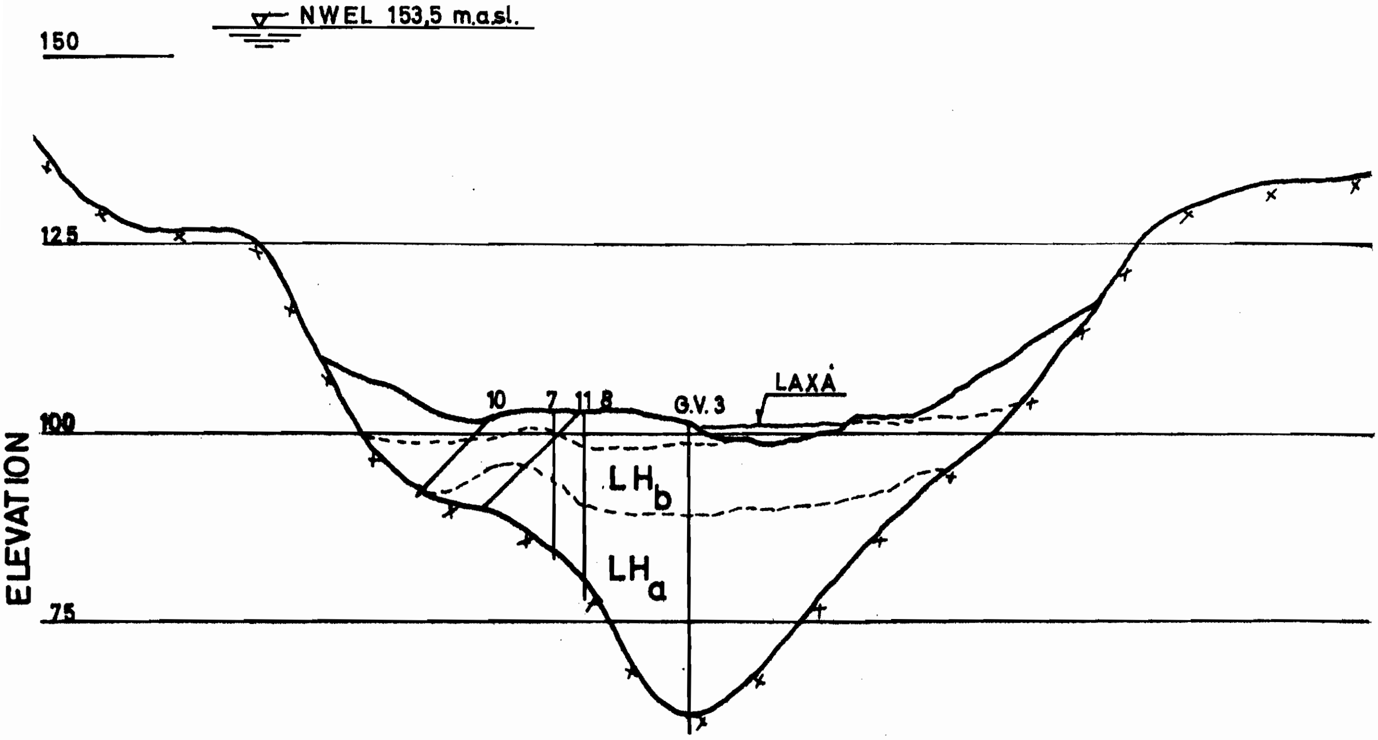
clay in lava voids, that the deposit will not be able to stand higher pressure than 1,5 to 2 kg/cm^2. These deposits must therefore be broken up and washed away.

The materials used in the tests were : cement, bentonite, sand, saw dust, $CaCl_2$ and water.

In the table some of the results of the tests are given and on Fig. 1 the boreholes are shown.

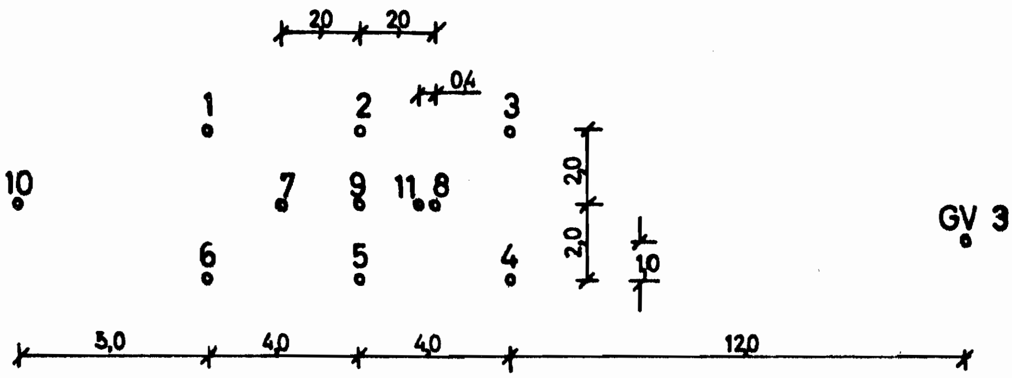
The cement/water ratio used during the tests, as a whole and for each test, varied from 1/1,46 to 1/0,64. Likewise varied the cement/sand-ratio from 1/2 to 1/1, the bentonite/cement-ratio from 0,03 to 0,09, the sawdust/cement-ratio from 0,03 to 0,06 and the $CaCl_2$ cement-ratio from 0,03 to 0,06.

1	2	3	4	5	6	7	8	9	10	11
Bore-hole Nr.	Depth m	Grouted Depth m	Quantity of grout m^3	Quantity of Cement kg	5/4 kg/m^3	4/3 m^3/m	Core recovery %	Depth in scoriaceous lava m	%	4/10 $m^3/\%$
1	9.2	7.2	11.700	5.900	504	1.625		5	55	0.213
2	8.4	6.4	6.655	4.000	602	1.040		3.5	42	0.158
3	11.8	9.8	11.250	6.900	613	1.150		5.8	49	0.230
4	8.9	6.9	15.450	8.650	560	2.240		1.5	17	0.910
5	9.2	7.2	6.650	3.360	504	925		1.5	16	0.415
6	8.0	6.0	9.500	4.950	550	1.590		5.5	6.9	0.138
7	19.75	17.75	10.250	5.950	581	577	82	3.8	21	0.489
7 Upper part	8.7	6.7	5.382	2.550		803	78	1.3	19	0.282
7 Lower "	11.05	11.05	4.868	3.400		441	89	2.5	23	0.212
8	23.85	23.85	3.150	1.950	618	132	95	5	21	0.150
8 Upper "	8.0	6.0	1.532	1.000		256	75	3.7	62	0.015
8 Lower "	17.85	17.85	1.618	950		95	98	1.3	7	0.231
9	12.2									
10										
11	18.75	16.75	3.300	2.850	864	197	66	5	33	0.100
GV 3	38.0	16.75	18.500	10.600	573	987	45	13.5	72	0.257



SECTION THROUGH ℄ OF DAM.

M. 1:1000



BOREHOLE PATTERN. M. 1:200

FIG.1