LETTER REPORT ON
ADVANCED PLANNING
OF
THJORSA DIVERSION FEATURES

# BURFELL PROJECT

BY THE

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED FOR

THE STATE ELECTRICITY AUTHORITY
GOVERNMENT OF ICELAND

MAY 1963

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HARZA ENGINEERING COMPANY INTERNATIONAL
CONSULTING ENGINEERS
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TELEX NUMBER CG 1-4385

May 7, 1963

# BURFELL HYDROELECTRIC PROJECT
# THJORSÁ DIVERSION FEATURES
# ADVANCED PLANNING

The State Electricity Authority
P.O. Box 40
Reykjavík, Iceland

Subject: Burfell Project
Thjórsa Diversion
Features

Gentlemen:

## Introduction

We discussed, in Chapter V of our Project Planning Report of January 1963 for the Burfell Hydroelectric Project, the need for further design studies with respect to ice and silt problems which might occur during operation of the Project. Your ice research studies conducted this past winter produced some worthwhile data, but were handicapped by prevailing high temperatures and the resulting general absence of ice.

We have continued to advance the engineering planning studies for the Thjorsá Diversion Features. The results of our studies accomplished since the issuance of the Planning Report are now presented in this Letter Report. The designs included are to be considered as replacing those of the Planning Report. Replacement Exhibits carry the same Exhibit Number, but with the prefix "R". In some cases, two or more Exhibits replace one Exhibit of the Planning Report. In these cases consecutive suffix letters are added.

A cost estimate is included which replaces appropriate portions of the Estimate in the Planning Report. The Summary Estimate compares the corresponding features. The cost of the new designs for the Thjorsa Diversion Features is so near that presented in the Planning Report that there appears no need at this time to consider any modifications to overall Project Costs.

## General

The Thjorsá Diversion Works were modified greatly from the provisions shown in the Planning Report. The major changes included:

1. Moving the Diversion Weir and Inlet about 300 meters upstream, and redesign of same
2. Addition of the Bjarnalækur Canal at low level from the right end of the Bjarnalækur Diversion Weir to the Bjarnalækur
3. Elimination of the Silt Excluder, and
4. Relocation and redesign of the Left Bank Dike.

In addition, there were a number of more minor design changes required to fit in with these major changes. In general, the Thjorsa Diversion Features can be considered as virtually redesigned. The relocated and redesigned Thjorsa Diversion Features are shown in plan on Exhibit R-14A. Each of the changes is discussed in detail below. In part, these new designs were based on additional field investigations accompanied by required further evaluation of the previous field information. These field investigations were accomplished in March, 1963.

## Additional Field Investigations

The additional field investigations included diamond core drilling, topographic profiling, auger borings, and geologic reconnaissance. The information obtained supplemented that gained previously and was useful in the redesign of the structures.

Four of the core borings accomplished in 1962 were deepened, and three new holes were drilled. All are located in the general area of the Diversion Structures. Holes PC-6, 7, 12. and 13 were deepened to pass through the interbed below the uppermost Thjorsa lava flow (THg). The latter three holes are located in the general area of the Diversion Inlet. They were deepened to establish the general bottom level of the THg flow as a guide to setting the foundations for the concrete structures in that vicinity. The thinness of the interbed in these holes and other drilling to the west indicated that the front of the second Thjorsa lava flow (THf) passes a short distance to the west of the face of the relocated Diversion Inlet.

The three new drill holes were drilled in important locations to determine stratigraphic relationships down to the top of the older basalts. Hole BD-12 was located towards the west end of the Bjarnalækur Canal. Hole PC-14 was located along the Diversion Canal in the vicinity where sealing of the underlying interbed, first encountered by the grade of the Canal, will be required. Hole PC-15 was located midway along the Bjarnalækur Dike to obtain additional information with respect to a cut-off through the same interbed. Information obtained from these core borings, together with that of the earlier foundation explorations, was used to establish the approximate geologic profiles along the routes of the several structures. These profiles have been included on Exhibit R-14 B.

The logs of these seven core borings are shown on revised Exhibits B-14 and B-15 of Appendix II of the Planning Report. The log of Drillholes PC-8 and BD-4 were also corrected with respect to elevations only. The location of the three new borings are shown on Exhibit R-12, Sheet 2 of 2, which represents a revision of Exhibits 12 and B-4, Sheet 2 of 2, of the Planning Report.

Additional geologic reconnaissance was carried out on the Thjorsa lava plain east of the Thjorsa to determine the general extent to which the river might have overflowed that plain in the recent geologic past. This reconnaissance revealed evidence that the Thjorsa had overflowed much of that plain within the past 1000 years or so. It was evident that some of that flow reached the Ytri-Ranga even though there is no known historic record of such an occurrence. The evidence pointed to river rather than wind erosion being the principal agent in removing most of the vegetal, loess and lapilli cover from that lava plain upstream for many kilometers from slightly downstream of the proposed Diversion Works. Since historic accounts indicate that the now barren area once was covered largely with brush, it may be inferred that the erosion was accomplished since the settlement of Iceland.

The physical evidence indicated that the Thjorsa overflowed at four points probably as a result of ice jams at those points. These points included the lower and upper ends of the island, Klofaey, opposite a braided area about five kilometers upstream of Klofaey, and at another braided area on the Tungnaa about three kilometers upstream of its junction with the Thjorsa. At the latter point the Tungnaa has now eroded fairly deeply and, thus, the most recent overflow at that point may have been centuries ago. From these points the overflow waters spread out thinly over the generally flat plain and flowed southward following the general slope of the top of the lava and paralleling the river channel. Much of this water returned to the Thjorsa in the general vicinity of the proposed Diversion Works, but some cut through to the Ytri-Ranga. The overflow waters left a thin layer of river sand covering much of the surface of the lava plain. Generally, this sand overlies a layer of lapilli, averaging about one meter deep, which rests on the Thjorsa lava.

Inasmuch as the potential still exists for ice jams to form at these points with diversion of waters to the Ytri-Ranga, it was decided to relocate the Left Dank Dike to extend eastward from the Diversion Weir to the front of a Hekla lava flow as shown on Exhibit R-14 A. This Dike will force overflow waters to return to the Thjorsa upstream of the Diversion Weir. The location of the Dike was established by map and field reconnaissance. This was followed by topographic profiling of the proposed alignment. Thereafter a power auger was used to determine the thickness of the sand and lapilli overlying the top of the Thjorsa lava.

<u>Bjarnalækur Sluice Structure and Canal</u>

The general engineering experience in ice control at river intakes or inlets has indicated the great desirability of placing the entrance ports as far below the normal winter water surface as is feasible. The earlier studies indicated that a level of the Diversion Inlet ports below that shown in the Planning Report was not feasible by utilizing a sluiceway canal extending downstream along the right side of the Thjorsa. The recent studies have indicated that a sluceway canal, extending from the right end of the Thjorsa Diversion Weir southwesterly to the Bjarnalækur, is feasible. The length will be about two kilometers to attain a level in the Bjarnalækur of about 223 meters with the diverted flow. This level is about 19 meters below the natural level in the Thjorsa at the upper end of the proposed Canal. This differential permits adequate height both for a canal grade providing relatively high velocities and for lowering the Inlet ports to eight meters or more below the Thjorsa surface.

The Canal grade was set at elevation 234 at the Thjorsa end. This permits an adequate thickness (three to four meters) of the base of the uppermost Thjorsa lava flow as the foundation for the concrete structures in that vicinity. The Canal was set at a grade of 0.0045 with a base width of six meters in order to maintain the moderately high velocities over the required flow range to transport silt and ice. The resulting velocities will range between about 2.4 and 3.5 meters per second over a flow range of 25 to 100 cubic meters per second, respectively.

The grade of the Bjarnalækur Canal will cut through the uppermost Thjorsa lava flow and into the underlying interbed as shown by the profile on Exhibit R-14B. This geologic profile was inferred from the several diamond corc drill holes along and close to the proposed alignment. A thickness of about five meters of Thjorsa lava below the Canal grade will remain for only about 500 meters from the Sluice Structure. For the next kilometer, the remaining lava will be relatively thin. It is possible that the grade as constructed may penetrate through the lava where a hump of dolerite is inferred to occur about 600 to 700 meters from the Sluice Structure. This will be checked by further drilling.

The high velocities will erode quickly the unconsolidated materials in the Bjarnalækur downstream from its junction with the Canal and in the Canal bottom itself. The thin basalt layer remaining over the interbed after construction will also be eroded. This will be followed by further erosion in the underlying interbed. Retrogression of the channel is expected to develop within a short operation time and extend upstream to where the basalt is relatively thick. A falls or rapids will develop at this point which might in time require maintenance control to stabilize. Corrective work, if required, should be relatively inexpensive. Retrogression of the Bjarnalækur and of a major downstream segment of the Canal, together with some lateral erosion, is not now expected to result in any operational difficulties, though some maintenance will be required.

The entire Bjarnalækur Canal will be constructed initially. Suitable rock from the excavation will be used in the nearby Bjarnalækur Dike. Early construction should ease water control problems during construction of the concrete structures at the Thjorsa. Accordingly, some of the excavation might be used in the fill cofferdam for those structures.

The discharge to the Canal will be controlled by a Sluice Structure representing the right bay of the Thjorsa Diversion Weir. This concrete structure, shown in plan and section on Exhibit R-15, will contain two sluices set at the elevation 231. 5 grade, with control provided by two 2. 5 meter square wheeled gates. Each gate will be controlled by hydraulic cylinders positioned in a gallery within the concrete mass above. These undersluices will permit desilting from in front of the Diversion Inlet Structure, and also provide water, if required, for aiding in ice and silt transport within the Canal.

The overflow section of the control structure was established with a crest width of twelve meters and a modified ogee downstream face. A two-meter high fishbelly flapgate will provide crest control. Stoplog slots will be provided on the face of the structure for maintenance closure of each undersluice.

The section of each of the undersluices will be expanded laterally and graded upward downstream from the gate. The upward grading will extend through a concrete-paved stilling basin and terminate in a 0. 5 meter high sill located 25 meters downstream from the undersluice outlet. The crest elevation of 234 for the top of this sill represents the beginning of the Canal grade. The walls of the stilling basin will be concrete lined below the top of rock. The lining will continue on the right side of the Canal for 40 meters downstream from the end of the stilling basin. At this point the twelve-meter wide canal will begin to transition smoothly over a distance of 33 meters to attain its normal base width of six meters.

The right pier of the sluice structure will extend to elevation 250 and also serve to retain, in part, the fill of the Bjarnalækur Dike. A sloping concrete wall resting, in part, on the stilling basin and Canal lining will extend far enough downstream as required to retain the Dike fill. The right pier will contain a gage well, with stage recorder and transmitter.

A slightly V-shaped hollow pier will be provided at the left end of the Sluiceway structure. The right leg will provide a training wall in the downstream direction. The left leg will serve as a training wall for the first gated bay of the main spillway, then extend as a separator wall to elevation 244 downstream to exclude all but extreme floods of the main Thjorsa from entering the Bjarnalækur Canal. This separator wall will extend for 80 meters downstream from the pier. Its toe will rest on the right concrete lining of the stilling basin and Canal, which will extend to the same terminus. This lining beneath the separator wall will be posttensioned with steel anchors into the rock to assure the stability of the foundations of these two features, as shown on Exhibit R-15.

The hollow center of the right pier of the Sluiceway will provide access to the sluicegate operating galley and to the gallery leading to the Diversion Weir piers upon which the spillway gate operating cylinders will be positioned. A bridge deck will connect the left and right Sluiceway piers.

## Diversion Inlet

The plan and sections of the Diversion Inlet Structure are shown on Exhibit R-15. The basic design of the structure was not changed from that of the Planning Report. The sill of the ports was lowered to elevation 232.5 at the left end and graded upward as before towards the right end. The height of the ports was increased to two meters in order to lower the entrance velocities. The width of the ports normal to the piers was maintained at ten meters each. The bellmouth entrance was shortened to 1.5 meters in order to lessen possibilities for ice clogging. The face parallels the alignment of the Bjarnalækur Canal. The piers, however, are skewed 37°-30′ from right angles to this alignment in order to parallel the alignment of the Diversion Canal and assure smooth flow conditions entering that Canal. Pier rounding will be asymetrical.

The increase in over-all height of the structure resulting from the lowered grade requires increasing the base width to about 15 meters. Also, the great height of the piers probably means that they will need to be connected by struts. The width of the deck was increased to five meters in order to permit operation of a crane, if required, for silt removal of deposits which might accumulate immediately upstream or downstream of the structure. The deck will be level at elevation 250 instead of sloping slightly upward as in the Planning Report.

Retaining walls will extend downstream from the left and the right end piers to retain the Bjarnalækur and Right Bank Dikes, respectively. A curved guide wall will extend upstream from the right pier to form a connection with the Right Bank Dike and also to retain the fill turning area.

The Bjarnalækur Canal will, in effect, be extended upstream with a base width of twelve meters in front of the entire Diversion Inlet Structure. The riverward side slopes will be flattened in order to provide gradual velocity reductions in the diverted power flow. All Construction associated with the Diversion Inlet, Bjarnalækur Canal Sluiceway and the gated portion of the Diversion Weir will be accomplished behind a single fill-type first-stage cofferdam, tied to the river bank upstream of the Diversion Inlet and downstream of the end of the Bjarnalækur Canal separator wall.

Diversion Canal.

The moving of the river structures upstream from the location shown in the Planning Report required shifting of the Diversion Canal to the location shown on Exhibit R-14A. The location was selected in order to provide the minimum amount of rock excavation and also to permit placing as much of the Bjarnalækur Dike as feasible on the older basalts which are far less permeable than the Thjorsa lavas. The rock excavation was held to a minimum because of the plentiful availability of rock from other required excavations to assure adequate total amounts for the rockfill of the Bjarnalækur Dike.

The section shown on Exhibit R-14B was established to provide a maximum average velocity of about 0. 5 meters per second in order to encourage the formation of an ice cover early in each winter season. The Diversion Canal requires a grade at about elevation 238 near the Inlet Structure and a slope of about 0. 001. This grade is 5, 5 meters above that of the Inlet. Accordingly, it will be necessary that these grades be connected by ramping on about five horizontal to one vertical.

The base width of the Canal at grade will be about 88 meters immediately downstream of the Inlet Structure. The base width will be gradually narrowed to become 60 meters as a point about 450 meters downstream from the Inlet. No rock excavation is required in front of the right two bays of the Inlet, except for possibly a minor amount to smooth flow conditions. However, the overburden will be removed from downstream of these two bays as shown by the plan of Exhibit R-14A.

The suitable rock excavation from the Canal as well as from the Diversion Inlet, and Bjarnalækur Canal and Canal extension will be placed in the Bjarnalækur and Right Bank Dike shells. All overburden and rock excavation unsuitable or not required for dike shells will be wasted outside the area of the Bjarnalækur Pond.

The profile of the centerline of the Diversion Canal is shown on Exhibit R-14B. The geology shown thereon has been inferred from several diamond drill holes, Borro soundings and the geologic mapping. This geologic profile, together with the geologic information included in Volume II of the Planning Report, shows a possible leakage path from the Canal into the permeable lapilli interbed underlying the uppermost lava flow. This interbed will be exposed by excavation entirely across the Canal and beyond on either side at a section about 500 meters downstream from the Diversion Inlet. This interbed will then be covered completely with a concrete seal extending at least as high as the normal water level in the Canal. It will also extend southward, if necessary, to a tie with the core of the Bjarnalækur Dike.

Bjarnalækur Dike and Outlet

The Bjarnalækur Dike was shifted slightly from the location shown in the Planning Report, principally because of the change in location of the Diversion Weir. The analysis of required excavation available showed adequate amounts to construct all Dikes without the need for transporting rock from the excavation for the Power Features.

The Dike section was changed to provide a sloping upstream core instead of the central core of the Planning Report section. The revised section is shown on Exhibit R-14B. The selection of this section reduces the requirements for the relatively expensive impervious core. It also permits the use of single filter zones on either side of the core rather than the two zones on either side required for a central core.

The profile of Exhibit R-14B shows the geologic stratigraphy as inferred from several diamond drill holes, Borro soundings, and the geologic mapping. This information, together with general geology included in Volume II of the Planning Report, shows the danger of shortpath leakage from the Bjarnalækur Pond to the Bjarnalækur via the interbed under the uppermost Thjorsa lava flow (THg) for about 500 meters of the westerly one-half of the Dike. In this reach a tongue of Thjorsa lava extends northerly over the unconsolidated materials lying in a valley formed by two ridges of the generally impermeable older basalts.

It is considered necessary to provide a cut-off between the top of the older basalts and the base of the impervious core of the Dike. Several alternative methods were investigated. A slurry trench was selected as the least costly, and more positive than grouting. Recent experience at other projects has verified the relative economy and effectiveness of the relatively new slurry trench procedure.

The construction procedure of this proposed slurry trench will involve excavating a three and one-half meter wide trench through the lava below the impervious core. This trench will be extended downward through the interbed to bottom on the old basalts using a bentonite slurry to seal and retain the sidewalls below the groundwater table. The trench will be backfilled with one meter of concrete followed by a mixture of silt, sand, and gravel dumped into the slurry to just above the groundwater table. From this level to the base of the impervious core of the Dike a rolled impervious fill will be placed. A section through this proposed cutoff is shown on Exhibit R-14B. Grouting of the foundations will be required elsewhere under the impervious core of the Bjarnalækur Dike as shown on the profile.

Proposed elimination of the silt sluice at the Power Intake makes it necessary to provide other means for evacuation of the Bjarnalækur Pond, if ever required. A controlled outlet structure was added to pass under the Bjarnalækur Dike on the west side of the Bjarnalækur. The outlet, shown in plan on exhibit R-14A, will consist of a two-meter square concrete conduit placed in an excavated trench. Control will be provided by a wheeled gate located in a control structure at the upstream end. Access to the tower will be by boat.

The outlet structure will provide a means for diverting the Bjarnalækur during construction of that portion of the Bjarnalækur Dike. It may also serve for silt sluicing during the operation period.

## Diversion Weir

In order to be more advantageous with respect to the passing of floating sludge ice, the design of the Diversion Weir was changed from that of the Planning Report. The most important change from this standpoint was the lengthening of the gated section, using flap gates only.

The relocated and redesigned Diversion Weir is shown in plan and sections on Exhibit R-15. To the left of the Bjarnalækur Sluice Structure it will consist of two segments. The right segment, 122.4 meters long, will be a gated section; the left segment, 240 meters long, will be an overflow section surmounted by flashboards. The left pier of the overflow section will extend downstream as a training wall and also serve to retain the Left Bank Dike. Beyond the pier a concrete gravity wall will extend for 30 meters to provide a tie to the Left Bank Dike core.

The crest of the gated section was set at elevation 242.5, or only slightly above the existing riverbed. Crest control will be by four thirty-meter wide by two-meter high fishbelly flapgates. These overflow type gates will permit passing ice with a minimum of water loss. Operation of each gate will be by a single hydraulic hoist at one end. Thus only three piers must be wide enough to accommodate the hoists. One of these will be the left pier of the Bjarnalækur Sluiceway Structure. Two relatively narrow intermediate piers will be required for the installation of sideseals and heating elements.

Alternatively, the gates may be controlled at their centers by cylinders located within the gallery. This arrangement would permit a continuous crest unobstructed by intermediate piers.

Access to the two left pier hoist operating platforms will be by a gallery within the concrete sill, thence vertically by a shaft within each of the two piers. This gallery will also house the oil lines to the cylinders and electrical service to the heating elements and for lighting. The operating center for all gates will be provided in the left pier of the Bjarnalækur Canal Sluiceway Structure. Operation will be by remote control from the Powerstation.

The total gated section of the Diversion Weir, including the Sluiceway, has thus been increased from 48 meters for the structures shown in the Planning Report to 132 meters. Further, one-half of the length in the Planning Report structures was controlled by underflow type Tainter gates, whereas the gates proposed herein are all of the overflow type. Thus, the ability of the Diversion Weir to pass floating ice has been improved greatly.

The crest of the left overflow section beyond the gated section will be at elevation 243.75. Three-fourths of a meter of timber flashboards will be required to bring the controlled level to 244.5. The gated section together with the Sluiceway and power discharges will pass all floods with a frequency of less than about four years. Only larger floods would overtop the flashboards. Any rare loss of boards can be replaced easily and cheaply. The overflow section will be constructed within the second-stage fill cofferdam, with the river diverted through the completed gated section.

The grade of the spillway bucket was set at elevation 239.5 for both the gated and ungated sections. This level with respect to that of the crest is somewhat higher than the section provided in the Planning Report and therefore less costly. It is also considered superior from the hydraulic standpoint. However, the design will need to be checked prior to final design by hydraulic model studies.

The changes in the Diversion Weir from the Planning Report design will cause changes in the Diversion Weir Rating Curve and the backwater profiles shown on Exhibit 6 of that Report. These changes are rather minor and the graphs have not been revised. However, the backwater profiles on the revised basis show that it will be unnecessary to provide crest levels of the structures higher than elevation 250, except for the slope provided in the Left Bank Dike.

## Left Bank Dike

The reasons for the relocation of the Left Bank Dike have been discussed above. The ground surface and rock profiles determined by the March 1963 field investigations are shown on Exhibit R-14B. The selected grade of the top of the Dike is also shown on that profile. The location is shown in plan on the General Project Plan of Exhibit R-14B.

Two dike sections are proposed. The first kilometer of the Dike eastward from the tie to the Diversion Weir will be identical to that of the Bjarnalækur Dike, except for the variable grade. The typical section is shown on Exhibit R-14B. This design will retain the Thjorsa waters to the normal level of elevation 244.5. The remainder of the Dike will be constructed according to the section also shown on Exhibit R-14B. Through this reach water retention, in itself, is not important. It is only necessary to assure that the rare natural diversion overflow waters which may leak through that portion of the Dike do not produce piping velocities. The rockfill under the sand core will be selectively placed for filter effect with fine materials, such as quarry spalls, to the upstream and coarser materials to the downstream.

Rockfill will be quarried from the Hekla lava front at the east terminus of the Dike. A small portion may be available from the river cofferdam, and from the Weir excavation. It will be necessary to manufacture the filter material. The clay core will be obtained from the loess deposit, IMP-II, located about five kilometers upstream. The sand core can be obtained from the thin river deposits covering the general area adjacent to the Dike.

## Right Bank Dike

The Right Bank Dike was relocated and shortened from the location proposed in the Planning Report to the location shown on Exhibit R-14A. The profile and section are shown on Exhibit R-14B. The crest will be level at elevation 250. The Dike is required only to prevent Thjorsa flood waters from carrying sediment into the Bjarnalækur Pond, and to dewater the Pond. Accordingly, the core is only carried to elevation 246 which assures that unwatering can be accomplished during all except very extreme flood periods. The core will tie to the curved concrete wall extending 40 meters upstream from the Diversion Inlet. Rockfill will be placed on the downstream side of that wall in order to form a turn-around for vehicles crossing the deck of the Inlet.

The Right Bank Dike shell will be constructed of rock from the Diversion Canal excavation. Filter and core materials will be obtained from the deposits located upstream along the right bank of the Thjorsa, as discussed in Volume II of the Planning Report.

## Burfell Reservoir

The snow fences along the banks of the Thjorsa upstream from the Diversion Weir, shown in the Planning Report, were considered to be installed initially. The same is true for the stage recorder and transmitter.

## Cost Estimates

Detailed quantity and cost estimates were prepared for the revised designs discussed above and shown on the Exhibits for the Thjorsa Diversion Features. The detailed and summary estimates are included as Exhibit R-8.

The Summary Estimate shows a comparison with the similar items presented in the Planning Report. The difference in favor of the new designs is shown to be $ 170,000 at the Total Investment level. This is only about two and one-half percent of the total for these Features and about one-half of one percent of the Total Project Investment as estimated in the Planning Report. This small difference is well within the range of estimating accuracy.

All costs are presented in United States Dollars, and on early 1963 price levels. Thus, there is no specific allowance for the effect which any inflation or differential currency valuations may have between the present time and the time when contracts may be awarded.

## Summary And Conclusions

The design modifications presented herein for the Thjorsa Diversion Features appear to have advanced considerably the solution to the ice problems discussed in the Planning Report. More studies with regard to these problems are, of course, required. Further, the designs will need to be verified by hydraulic model tests. These is little precedent for model studies involving sludge ice transport on relatively shallow, moderately high gradient rivers. However, it is believed that studies of such ice transport can be incorporated in hydraulic model studies with significant and worthwhile results.

The Diversion Weir will create a partial barrier across the river with much or all of the low flow, common with floating sludge ice conditions, diverted for power. Accordingly, it may be necessary to provide a source of sluicing water. The inclusion of the Thorisvatn Initial Storage substantially as proposed in Volume II of the Planning Report may be required and should probably be considered with the financing. This relatively small storage will also provide some water for the generation of firming energy during some part or nearly all of the low flow periods; depending somewhat on the volume and rate required for ice sluicing.

The cost estimates for the redesigned features of the Thjorsa Diversion Works are, in total, so near the costs presented in the Planning Report for the similar features that there does not now appear to be any reason for changing Project Cost estimates from the amounts shown in the Planning Report.

We very much appreciate this opportunity to present to you our advanced designs for the Thjorsa Diversion Features of the proposed Burfell Hydroelectric Project.

Very truly yours,

HARZA ENGINEERING COMPANY INTERNATIONAL

C. K. Willey

C. K. Willey
Vice President

Exhibit R-8
Sheet 1 of 5

## BURFELL PROJECT

## THJORSA DIVERSION FEATURES

## COST ESTIMATES- SUMMARY
(in United States Dollars)

| | REVISED ESTIMATE | PLANNING REPORT ESTIMATE |
|---|---|---|
| Burfell Reservoir | 75,000 | 75,000 |
| Bjarnalækur Dike and Outlet | 1,160,000 | 1,146,000 |
| Right Bank Dike | 130,000 | 133,550 |
| Left Bank Dike | 530,000 | 1.415,000 |
| Diversion Canal | 697,500 | 435,000 |
| Bjarnalækur Canal | 438,000 | - |
| Diversion Weir & Inlet | 1,865,900 | 1,816,610 |
| SUBTOTAL DIRECT COSTS | 4,896,400 | 5,021,160 |
| Contingencies | 734,600 | 752,840 |
| TOTAL DIRECT COSTS | 5,631,000 | 5,774,000 |
| Engineering And Supervision | 449,000 | 466,000 |
| CONSTRUCTION COST | 6,080,000 | 6,240,000 |
| Interest During Construction | 610,000 | 620,000 |
| TOTAL INVESTMENT | 6,690,000 | 6,860,000 |
| Decrease | 170,000 | |

Exhibit R-8
Sheet 2 of 5

# BURFELL PROJECT

## THJORSA DIVERSION FEATURES

| | Quantity | Unit Price $ U.S. | Amount $ U.S. |
|---|---|---|---|
| **BURFELL RESERVOIR** | | | |
| Snow fences | | L.S. | 70,000 |
| Water level recorder stations | | | 5,000 |
| SUBTOTAL BURFELL RESERVOIR | | | 75,000 |
| **BJARNALÆKUR DIKE & OUTLET** | | | |
| Diversion and care of water | | L.S. | 13,000 |
| Excavation, common | 282,000 $m^3$ | 0.50 | 141,000 |
| Excavation, rock | 11,000 $m^3$ | 5.00 | 55,000 |
| Foundation preparation and treatment | | L.S. | 31,000 |
| Curtain grouting along dike | | L.S. | 70,000 |
| Slurry trench - Sta. 4+80 to 10+30 | | L.S. | 290,000 |
| Impervious core | 80,000 $m^3$ | 1.80 | 144,000 |
| Filters | 115,000 $m^3$ | 2.40 | 276,000 |
| Rockfill (from required excavation) | 360,000 $m^3$ | 0.25 | 90,000 |
| Outlet Structure | | L.S. | 50,000 |
| SUBTOTAL BJARNALÆKUR DIKE & OUTLET | | | 1,160,000 |

Exhibit R-8
Sheet 3 of 5

## BURFELL PROJECT

## THJORSA DIVERSION FEATURES

## COST ESTIMATES

| | Quantity | Unit Price $ U.S. | Amount $ U.S. |
|---|---|---|---|
| **THJORSA DIVERSION DIKE, RIGHT BANK** | | | |
| Excavation, common | 120,000 $m^3$ | 0.50 | 60,000 |
| Excavation, rock | 2,600 $m^3$ | 5.00 | 13,000 |
| Foundation preparation and treatment | | L.S. | 5,000 |
| Impervious Core | 10,000 $m^3$ | 2.10 | 21,000 |
| Filters | 5,600 $m^3$ | 2.50 | 14,000 |
| Rockfill (from required excavation) | 68,000 $m^3$ | 0.25 | 17,000 |
| SUBTOTAL THJORSA DIVERSION DIKE, RIGHT BANK | | | 130,000 |
| **THJORSA DIVERSION DIKE, LEFT BANK** | | | |
| Excavation, common | 70,000 $m^3$ | 0.50 | 35,000 |
| Excavation, rock | 9,000 $m^3$ | 5.00 | 45,000 |
| Foundation preparation and treatment | | L.S. | 9,000 |
| Impervious core | 30,000 $m^3$ | 2.10 | 63,000 |
| Filters | 20,000 $m^3$ | 3.50 | 98,000 |
| Rockfill | 120,000 $m^3$ | 2.00 | 240,000 |
| Sand backfill | 20,000 $m^3$ | 2.00 | 40,000 |
| SUBTOTAL THJORSA DIVERSION DIKE, LEFT BANK | | | 530,000 |

Exhibit R-8
Sheet 4 of 5

## BURFELL PROJECT

## THJORSA DIVERSION FEATURES

## COST ESTIMATES

| | Quantity | Unit Price $ U.S. | Amount $ U.S. |
|---|---|---|---|
| **DIVERSION CANAL** | | | |
| Excavation, common | 345,000 $m^3$ | 0.50 | 172,500 |
| Excavation, rock | 210,000 $m^3$ | 2.50 | 525,000 |
| SUBTOTAL DIVERSION CANAL | | | 697,500 |
| **BJARNALÆKUR CANAL** | | | |
| Excavation, common | 146,000 $m^3$ | 0.50 | 73,000 |
| Excavation, rock | 146,000 $m^3$ | 2.50 | 365,000 |
| SUBTOTAL BJARNALÆKUR CANAL | | | 438,000 |
| **DIVERSION WEIR AND INLET*** | | | |
| Diversion and care of water | | L.S. | 235,000 |
| Excavation, rock | 68,000 $m^3$ | 3.00 | 204,000 |
| Foundation preparation and treatment | | L.S. | 25,000 |
| Concrete, ungated spillway, mass | 8,800 $m^3$ | 25.00 | 220,000 |
| Concrete, gated spillway, mass | 2,400 $m^3$ | 25.00 | 60,000 |
| Concrete, gated spillway, structural | 250 $m^3$ | 35.00 | 8,750 |
| Concrete, sluice structure, mass | 3,500 $m^3$ | 27.00 | 94,500 |
| Concrete, sluice structure, structural | 500 $m^3$ | 35.00 | 17,500 |
| Concrete, inlet structure, mass | 7,000 $m^3$ | 27.00 | 189,000 |
| Concrete, inlet structure, structural | 4,250 $m^3$ | 35.00 | 148,750 |

Exhibit R-8
Sheet 5 of 5

BURFELL PROJECT

THJORSA DIVERSION FEATURES

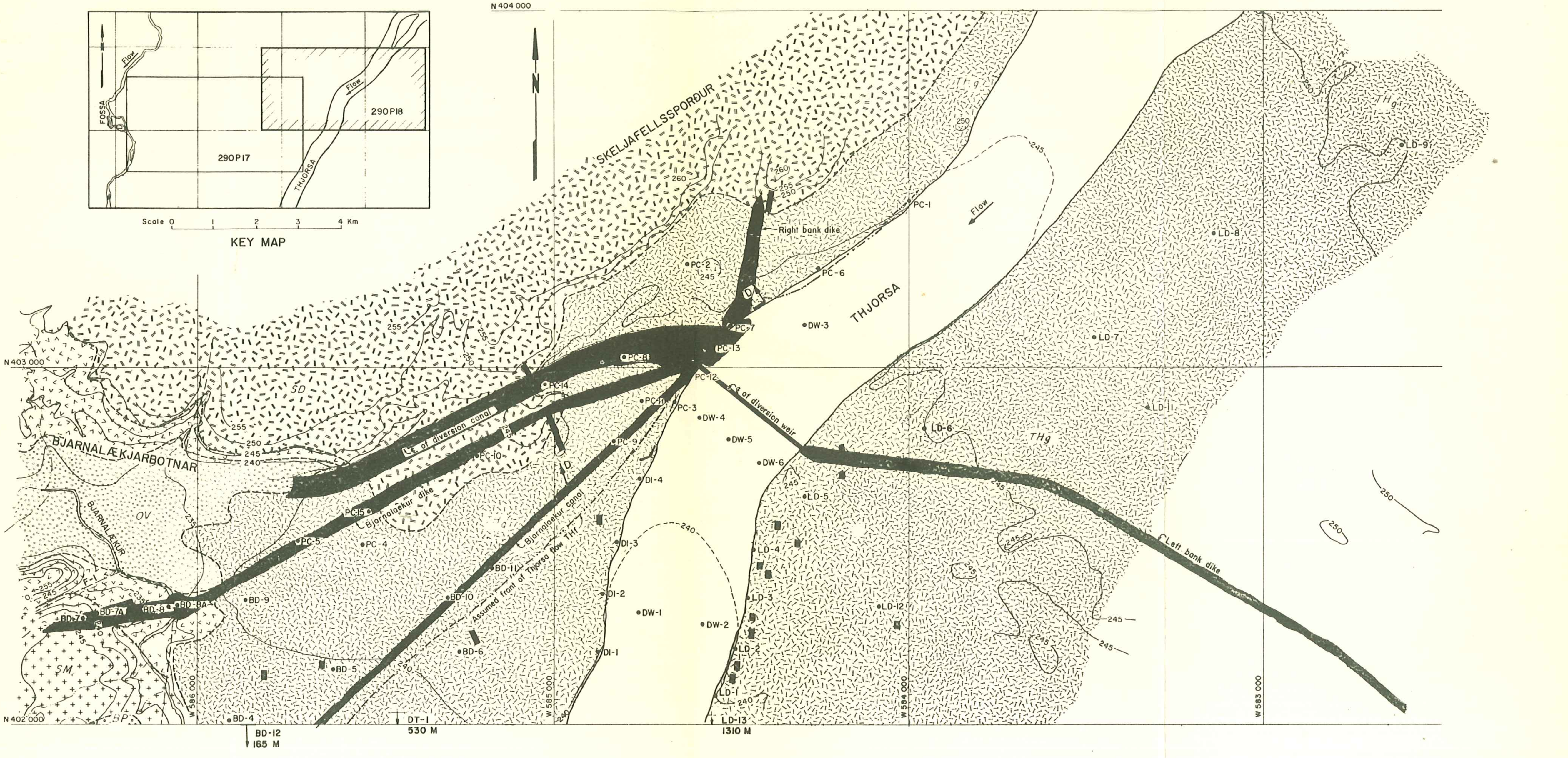
COST ESTIMATES

| | Quantity | Unit Price $ U.S. | Amount $ U.S. |
|---|---|---|---|
| Formwork, straight | 21,500 $m^2$ | 10.00 | 215,000 |
| Formwork, curved | 550 $m^2$ | 20.00 | 11,000 |
| Reinforcing steel | 530 t | 280.00 | 148,400 |
| Wheel gates, guides, and frames (2.5 x 2.5 m) | 2 | 10,000 | 20,000 |
| Gate hoists | 2 | 2,500 | 5,000 |
| Stoplogs, guides, and frames | | L.S. | 15,000 |
| Flap gate, guides, and hoist (12 x 2 m) | 1 | 20,000 | 20,000 |
| Flap gates, guides, and hoists (30 x 2 m) | 4 | 50,000 | 200,000 |
| Gate heating | | L.S. | 23,000 |
| Flash boards | | L.S. | 4,000 |
| Miscellaneous steel | | L.S. | 2,000 |
| SUBTOTAL DIVERSION WEIR AND INLET | | | 1,865,900 |

* Includes also terminal walls for the Bjarnalækur Dike, Right Bank Dike, and Left Bank Dike.

| | |
|---|---|
| SUBTOTAL DIRECT COSTS-THJORSA DIVERSION FEATURES | 4,896,400 |

EXHIBIT R-12A




## LEGEND

- Overburden (OV) — Ash and lapilli
- Thjorsa flow (THg) — Upper flow of Thjorsa group, consisting of porphyritic basalt flows with soil and ash interbeds
- Skeljafell dolerite (SD) — Dolerite and basalt
- Samsstaðaklif basalt (SB) — Basalt and volcanic breccia
- Samsstaðamuli group (SM) — Basalt flows
- Approximate geologic contact between groups
- Fault
- Exploration hole drilled under the supervision of Harza Engineering Co. International 1961 – 1962 and 1963
- Trench
- Outline of structure

## NOTES

Topography based on topographic mapping performed under the direction of Harza Engineering Co International and on aerial surveying performed by Wideroe Aerial Survey Co, Norway.

Geologic sections shown on dwg. 290 P 20

Scale 0 100 200 300 Meters

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| DWN. | W.H. | | | |
| DEPT. | GROUP LEADER | SECT. HEAD | DEPT. HEAD | |
| CIVIL | | RJF | | |
| MECH. | | | | |
| ELECT. | | | | |
| PLAN. | | | | |
| STAFF | | CH.ENGR. | | |

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|---|---|---|---|---|---|
| 1 | 4-18-63 | General revisions | R.H. | | |

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ICELAND

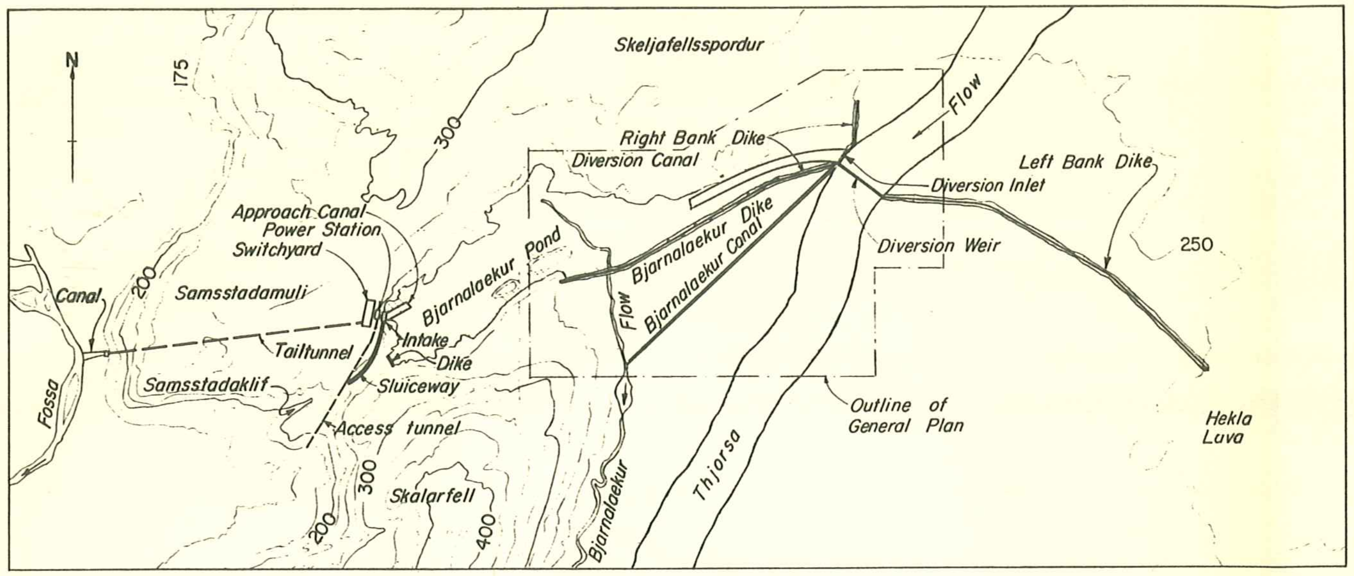
BURFELL PROJECT

**GEOLOGIC MAP-PROJECT AREA**
**SHEET 2 OF 2**

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED

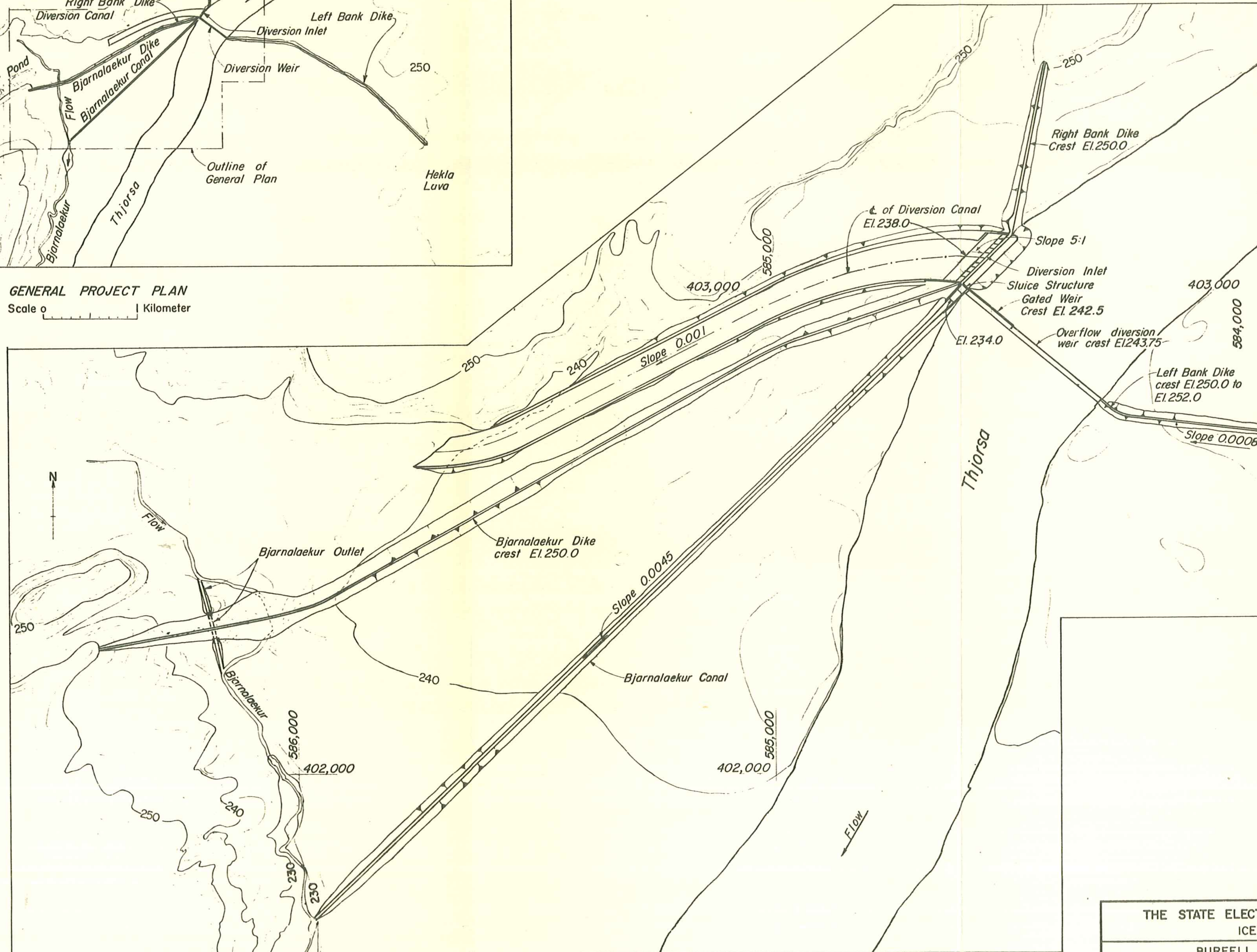
CHICAGO, ILLINOIS | DATE Jan., 1963 | DWG. No. 290 P18 R1

EXHIBIT R-14A




GENERAL PROJECT PLAN

Scale 0 — 1 Kilometer




GENERAL PLAN OF DIVERSION STRUCTURES

Scale 0 100 200 300 400 Meters

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|---|---|---|---|---|
| DSGN. | | | | |
| DWN. | SSF | Apr. 1963 | VT | Apr. 1963 |
| DEPT. | GROUP LEADER | SECT. HEAD | DEPT. HEAD | |
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| MECH. | | | | |
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BURFELL PROJECT

DIVERSION STRUCTURES
GENERAL PLAN

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
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|---|---|---|

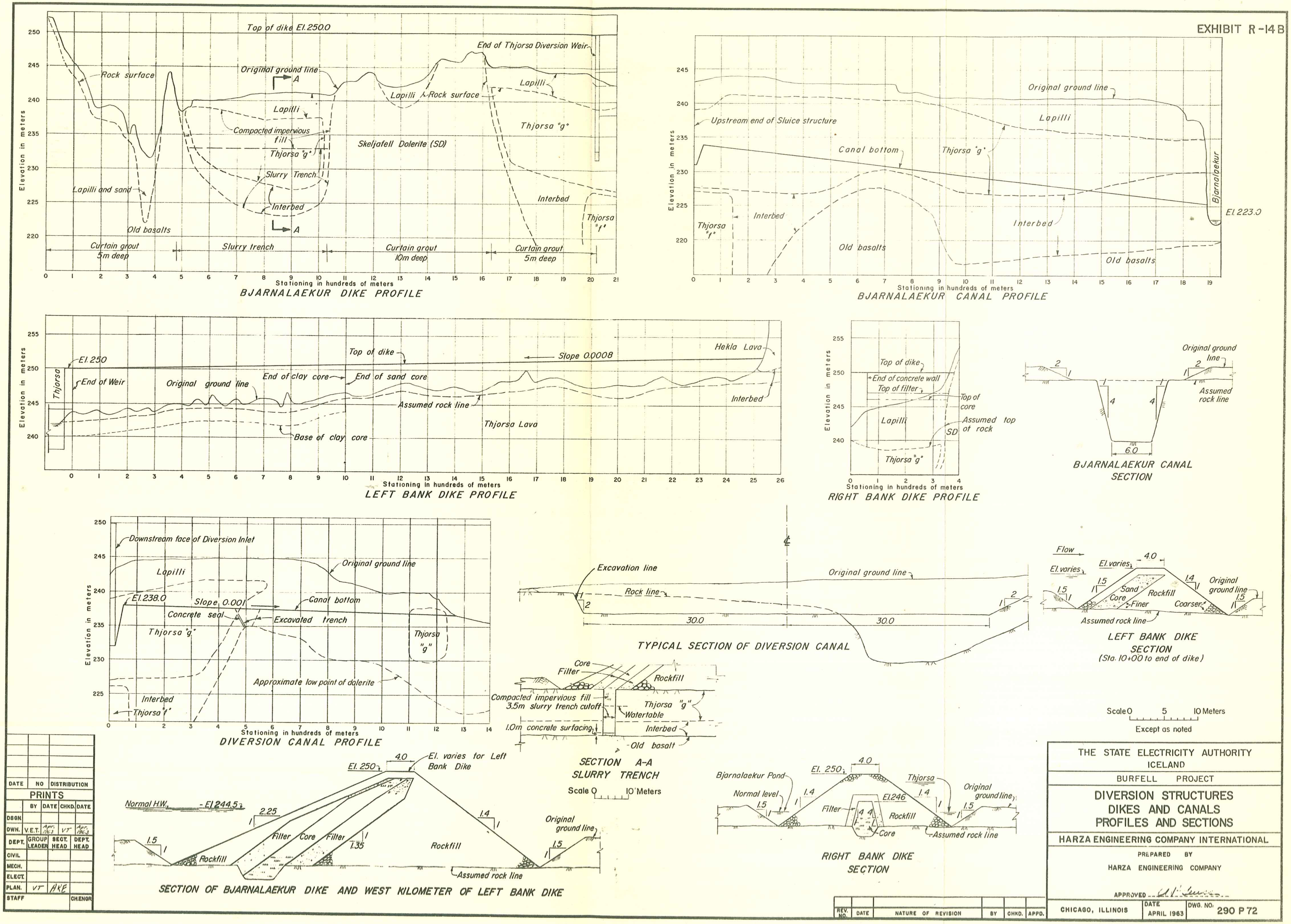
EXHIBIT R-14B
Top of dike El.250.0
End of Thjorsa Diversion Weir
Rock surface
Original ground line
Lapilli
Rock surface
Compacted impervious fill
Thjorsa "g"
Skeljafell Dolerite (SD)
Slurry Trench
Interbed
Lapilli and sand
Old basalts
Thjorsa "f"
Curtain grout 5m deep
Slurry trench
Curtain grout 10m deep
Curtain grout 5m deep
Elevation in meters
Stationing in hundreds of meters
BJARNALAEKUR DIKE PROFILE
Upstream end of Sluice structure
Canal bottom
Bjarnalaekur
El. 223.0
Old basalts
BJARNALAEKUR CANAL PROFILE
El. 250
End of Weir
Thjorsa
Top of dike
Slope 0.0008
Hekla Lava
End of clay core
End of sand core
Assumed rock line
Thjorsa Lava
Base of clay core
LEFT BANK DIKE PROFILE
Top of dike
End of concrete wall
Top of filter
Top of core
Assumed top of rock
SD
RIGHT BANK DIKE PROFILE
Original ground line
Assumed rock line
BJARNALAEKUR CANAL SECTION
Downstream face of Diversion Inlet
El. 238.0
Slope 0.001
Canal bottom
Concrete seal
Excavated trench
Approximate low point of dolerite
DIVERSION CANAL PROFILE
Excavation line
Rock line
30.0
TYPICAL SECTION OF DIVERSION CANAL
Flow
El. varies
4.0
Sand
Core
Rockfill
Finer
Coarser
LEFT BANK DIKE SECTION
(Sta. 10+00 to end of dike)
Core
Filter
Rockfill
Compacted impervious fill
3.5m slurry trench cutoff
Watertable
1.0m concrete surfacing
Old basalt
SECTION A-A
SLURRY TRENCH
Scale 0 10 Meters
Scale 0 5 10 Meters
Except as noted
Bjarnalaekur Pond
Normal level
El. 246
RIGHT BANK DIKE SECTION
El. 250
El. varies for Left Bank Dike
Normal H.W. - El. 244.5
Filter
Core
Filter
SECTION OF BJARNALAEKUR DIKE AND WEST KILOMETER OF LEFT BANK DIKE
THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT
DIVERSION STRUCTURES
DIKES AND CANALS
PROFILES AND SECTIONS
HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED
CHICAGO, ILLINOIS
DATE APRIL 1963
DWG. NO. 290 P 72
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DATE NO DISTRIBUTION
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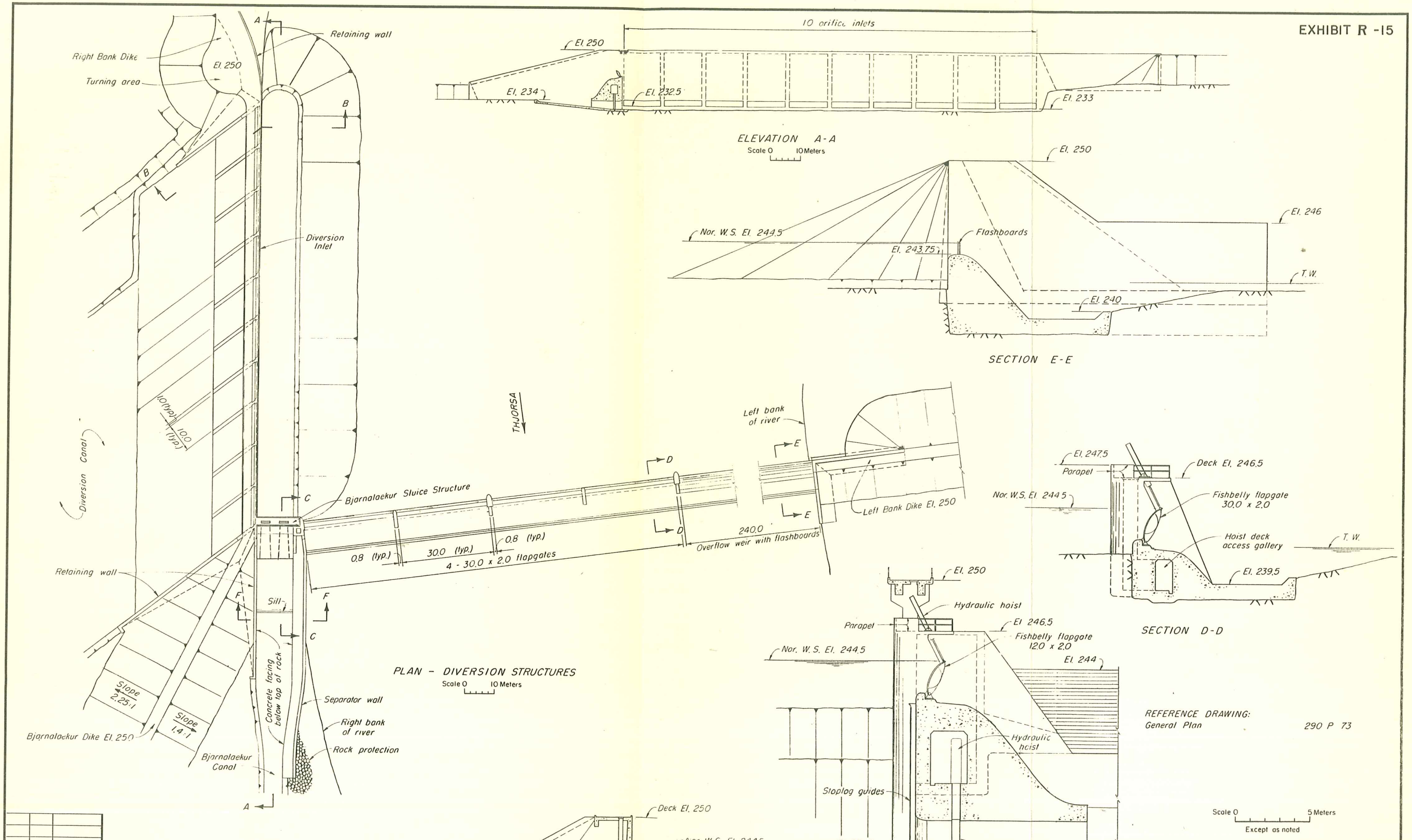
DWN. V.E.T. VT
DEPT. GROUP LEADER SECT. HEAD DEPT. HEAD
CIVIL
MECH.
ELECT.
PLAN. VT AKF
STAFF CH.ENGR.

EXHIBIT R -15

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| ELECT. | | | | |
| PLAN. | VT | ARE | | |
| STAFF | | | CH.ENGR. | |

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ICELAND

BURFELL PROJECT

**DIVERSION STRUCTURES**
**WEIR AND INLET**

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED ____ [signature]

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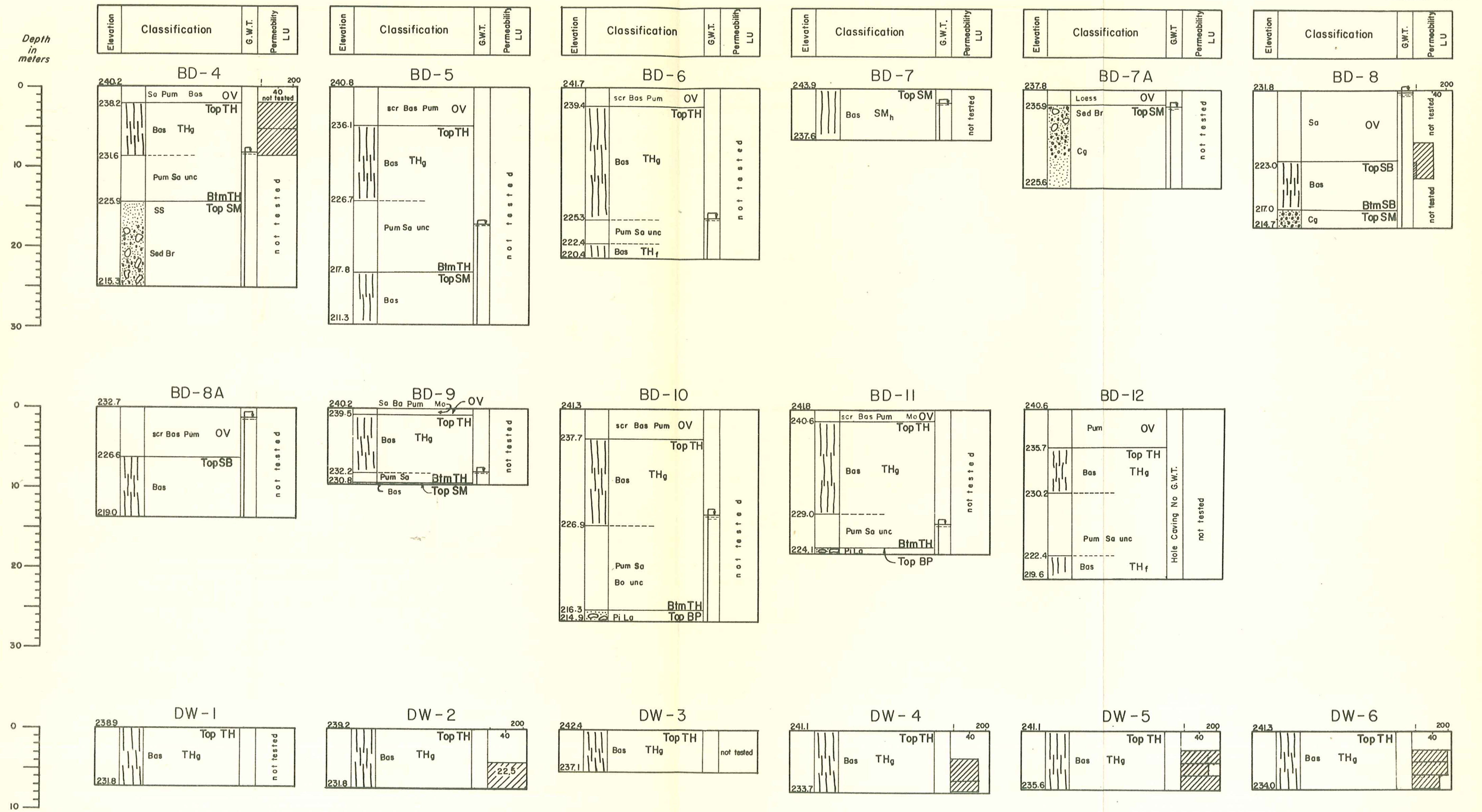
EXHIBIT B-14

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| CIVIL | | | |
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| ELECT. | | | |
| PLAN. | | | |
| STAFF | | | CH.ENGR. |

*NOTE:*
*For general notes, legend and abbreviations see Dwg. No. 290P34.*

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| 1 | 4-17-63 | Added BD-12. Corr. BD-4 | RH. | GZD | RSL |

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BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 8 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL
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APPROVED C. K. Willey

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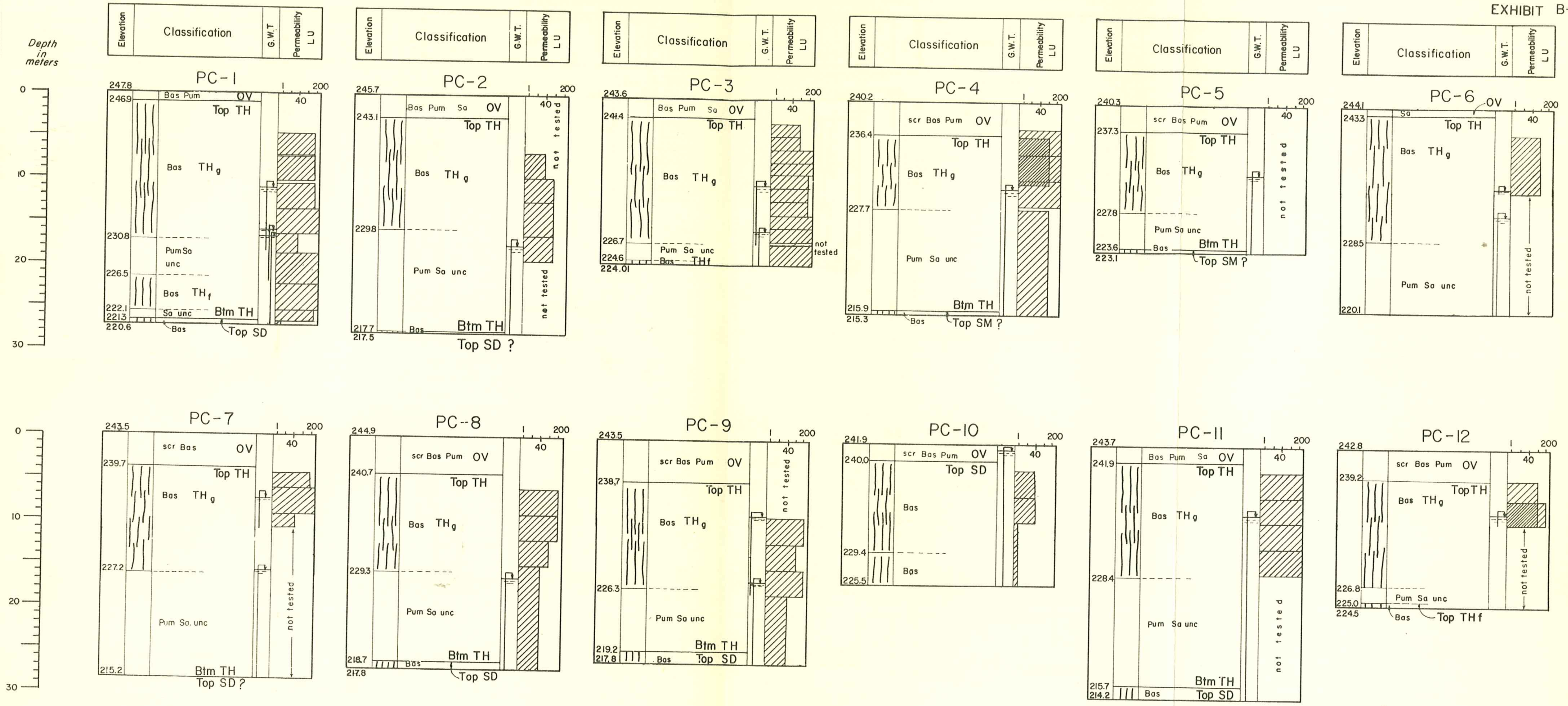
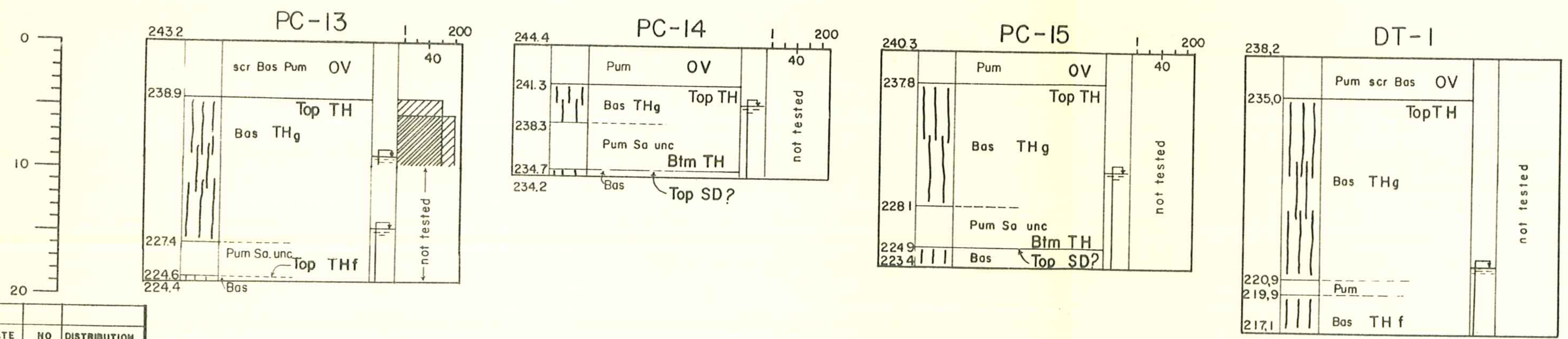
EXHIBIT B-15




*NOTE*

*For general notes, legend and abbreviations see Dwg. No. 290P34.*

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| DEPT. | GROUP LEADER | SECT. HEAD | DEPT. HEAD |
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| CIVIL | | RJF | WHD |
| MECH. | | | |
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| PLAN. | | | |
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| 1 | 4-17-63 | Corrected PC-2, PC-8. Extended depth PC-6, 7, 12, 13. Added PC-14, PC-15 | WLS | GZD | RSL |

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GRAPHIC CORE LOGS
SHEET 9 of 10

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