SUSITNA HYDROELECTRIC PROJECT

ACRES INTERNAL REVIEW BOARD
MEETING # 4

REPORT

SEPTEMBER 8, 1981

Prepared by:

ACRES

ALASKA POWER AUTHORITY

ALASKA POWER AUTHORITY

September 30, 1981
P5700.13

SUSITNA HYDROELECTRIC PROJECT
Internal Review Board Meeting No. 4

MINUTES OF MEETING
held at the offices of
Acres Consulting Services,
Niagara Falls, Canada on
September 8, 1981

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ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

INTERNAL REVIEW BOARD MEETING NO. 4,
NIAGARA FALLS, CANADA

SEPTEMBER 8, 1981

AGENDA

1 - 0830 - General Remarks - Dr. D. MacDonald

2 - 0845 - Status of Studies - J. D. Lawrence

3 - 0915 - Status of Seismic Studies - V. Singh

4 - 0945 - Status of Geotechnical Field Work - S. N. Thompson

- 1015 - Coffee and Discussion

5 - 1030 - Approach to Spillway Designs - Dr. J. W. Hayden

6 - 1115 - Devil Canyon Layout Studies - R. K. Ibbotson

1200 - Lunch and Discussion

7 - 1300 - Devil Canyon Arch Dam Analyses - R. K. Ibbotson

8 - 1330 - Approach to Watana Layout Studies - J. D. Lawrence

9 - 1345 - Watana Dam Design - D. W. Lamb

1500 - Coffee and Discussion

10 - 1515 - Watana Dam Layout Studies - R. K. Ibbotson

11 - 1630 - Watana Relict Channel Studies - V. Singh

ATTENDEES

Review Panel

Dr. D. H. MacDonald
Dr. I. McCaig
J. G. S. Thomson

L. Wolofsky
H. Eichenbaum

Presenters	J. D. Lawrence
	J. W. Hayden
	S. N. Thompson
	V. Singh
	R. Ibbotson
	D. W. Lamb
Observers	A. Burgess (afternoon only)
	G. Krishnan
	D. Meilhede
	R. Miller (afternoon only)
	L. Duncan
	R. Shery
	D. Shandalov (10:30 - 13:30)
	M. Dumont
	T. Gwozdek (afternoon only)
	D. Willett
	M. Vanderburgh

1. General Remarks (Dr. D.H. MacDonald)

In view of the restricted time available and the amount of material to be presented and discussed, Dr. MacDonald suggested that only pertinent remarks be raised at the meeting. Separate meetings should be arranged later for detailed discussion of points of interest.

2. Status of Studies (J.D. Lawrence)

General

J.D. Lawrence reiterated the tight schedule of the Agenda, and requested close adherence to it, without wishing to prevent useful discussion. He also requested that the Review Board members summarize and confirm in writing their major concerns and points raised during the meeting.

Minutes

M.F. Dumont would be recording the Minutes of the Meeting; J.D. Lawrence requested all presenters should provide him with copies of all pertinent documentation, slides and figures.

1981 Progress

(i) Hydrology:

- Field recording of flows and sedimentation studies
- Flood analysis continues
- Energy studies continue based on reservoir simulation program

(ii) Seismic:

- 13 features have been identified as significant for study. Geologic mapping continuing.

(iii) Geotechnical:

- Intensive program of seismic refraction studies and auger boring continues at both sites.

- Field studies continue on foundation conditions and material from the borrow areas.

- In addition, further study of the relict channel is anticipated.

(iv) Design:

- The development of design for the dam and power facilities at each site continues.

(v) Environment:

- Studies continue on temperature stratification and water quality in the reservoirs with particular emphasis for design, and on fish and game impacts.

- Access roads

- Transmission line route

(vi) Costs/Schedule:

- An upper limit cost estimate was prepared earlier this year.

- Preliminary cost estimates for the preferred developments will be prepared in October/November for vetting by an external consultant (to be elected by APA).

(vii) Licensing:

- On schedule

(viii) Finance/Risk:

- The State has passed legislation which should ensure the financial viability of the project. The implications are being looked into.

Deadlines

(i) Development Selection Report:

- The draft has now been reviewed by Client, Federal and State Agencies and is being revised for general issue.

(ii) W.C.C. Fieldwork:

- On schedule

(iii) R&M Fieldwork:

- On schedule

(iv) APA External Board:

- Meeting scheduled for October 6-8, in Buffalo, to consider recommended layouts at Watana and Devil Canyon. (Economics and environmental aspects are not scheduled for discussion.)

(v) Cost Estimates:

- Preliminary cost estimates will be provided as follows:

Devil Canyon: End of October 1981
Watana: End of November 1981

(vi) Geotechnical Report:

- 1980 Program - September 1981
- 1981 Program - February 1982

(vii) Feasibility Report:

- First draft due February 1982
- Final draft must be available by March 15, 1982 for general circulation. (Certain environmental aspects will, however, be studied further between March 1982 and June 1982; APA are aware of this).

(viii) FERC License:

- Submit to APA by May 1982, for both Watana and Devil Canyon, (as a result of a previous Review Board recommendation).

Previous Points of Discussion (for reference)

(i) Acres Internal Review Board Meeting No. 3 (February 1981):

- Watana Dam slopes of 2.5H:1V U/S, 2.0H:1V D/S reviewed
- Fingerbuster (downstream shear zone) to be included in WCC studies
- Nitrogen supersaturation problem highlighted (spillways)
- Low level outlet design concepts discussed
- Multi-level intake design requirements
- Earthfill dam at Devil Canyon considered
- Watana dam schedule tight for the volume involved
- License application should include Devil Canyon

(ii) Acres External Review Board Meeting (February):

- Seismic activity along Talkeetna Thrust, KD 37 (line along river), Susitna feature, Benioff Zone, and "floating" eq
- Nature of the andesite/diorite contact
- Relict channel
- Depth of alluvium at the upstream cofferdam
- Devil Canyon: Concern about shear zones
- Design of underground powerhouse, surface powerhouse, dam section, Watana arch alternative.

(iii) APA Review Board Meeting (June)

- Fieldwork in the relict channel
- Underground powerhouse exploration
- Downstream erosion
- Seismicity and nitrogen supersaturation problems highlighted
- The Oroville dam slope was considered acceptable for upper limit cost estimate for Watana (2.75 H:1V)
- Downstream water quality concerns emphasized

Current Layouts

These would be described in detail later by R.K. Ibbotson but major changes would be:

Devil Canyon: Orifice spillways changed to HB valves
Watana: Dam slope upstream amended to 2.4 major structures on the right bank

3. Status of Seismic Studies (V. Singh)

Previous Work

Thirteen features had been identified as requiring further study; 9 at Devil Canyon, 4 at Watana.

Three features were accepted as having a major effect on the sites:

- Denali Fault (8.5 M)
- Castle Mountain Fault (7.5 M)
- Benioff Zone (8.5 M)

W.C.C. Findings from 1981 Studies

- Watana:
  - Talkeetna Feature: Considered to be inactive.
  - Susitna Feature: No evidence of a fault.
  - KD37 (River Feature): No evidence of a fault.
  - Fins: A fault but size is insignificant.

- Devil Canyon
  - 3 faults identified, but inactive.
  - 6 others may be faults, but also considered inactive.

W.C.C. Conclusions

- Three major features identified are Denali, Benioff, and Castle Mountain.

- "Floating" earthquake, is related to the Benioff Zone, (5 to 5.5 M).

- Report may propose probabilistic approach to potential movements near structures.

Panel Comments

- On what basis was Talkeetna considered inactive? S. Thompson explained good evidence available to the South (50 million years), less good to the north (only 12,000 years).

- The panel were concerned with a probabilistic approach to prediction of likely earthquake motions near structures.

- It was noted that fault inactivity was presumed on a basis of lack of specific evidence of activity.

4. Status of Geotechnical Field Work (S. Thompson)

Summary of 1981 Work

(a) Watana:

- BH 12 (powerhouse left bank) drilled.
- BH 1 (powerhouse right bank) drilled.
- BH 3 (powerhouse right bank) drilled.
- Seismic refraction studies in the river upstream and downstream to assess the depth of alluvium.
- A summary of rock quality (RQD values) with depth was presented; the right bank powerhouse will be in good quality rock.

(b) Devil Canyon:

- Pond feature has been confirmed as a shear alignment (inactive)
- BH 5, BH 5A drilled in and near the river.
- A feature in the river at the Devil Canyon arch dam site has been identified from Acres drilling and confirmed by interpretation of Corps of Engineers cores as probably an inactive fault, thought to be small at this time. Not sufficient evidence to justify changing from arch dam design to rockfill at this time. Further investigations are in progress to obtain more data on this feature.

(c) Layouts:

- Watana: Avoid Fins structure with upstream diversion portal.

5. Approach to Spillway Designs (J. Hayden)

Current Design Concepts

- Philosophy:

  (i) Diversion flow - 1 in 50 years
  (ii) Nitrogen supersaturation - accepted 1 in 100 years
  (iii) Design flood - 1 in 10,000 years
  (iv) Probable Maximum Flood

- Devil Canyon:

  Values allow for routing through Watana, which is assumed constructed.

(a) Watana

Diversion:

- 2 tunnels 35 feet diameter
- Lower tunnel pressure, upper free flow which can be converted to low level outlet. Both concrete lined, design velocity 50 ft/sec.
- Upper tunnel would be clear of possible upstream sedimentation
- Emergency capacity of 10-30,000 cfs, capacity dependent on head, and energy dissipator for flood during construction.

Service Spillway (tunnel and values):

- 6 H.B. valves designed to mitigate nitrogen supersaturation for any flood up to the 1 in 100 year occurrence. Also provides mid level release for drawing down top 200 feet of reservoir.

Power Flow:

- Allowed in flood routing up to 1 in 100 year flood. Not for any higher flow.

Auxiliary Spillway (headgates, chute and flip bucket):

- Used for floods greater than the 1 in 100 year occurrence, when nitrogen supersaturation is considered acceptable, up to the 1 in 10,000 year flood, with some surchanging of the reservoir (up to 7 feet).

Emergency Spillway:

- Fuse plug dam fails, passing the PMF.

(b) Devil Canyon

- Diversion: One tunnel
- Service Spillway: 5 HB valves in the face of the dam
- Auxiliary Spillway: Chute and stilling basin on the right bank
- Emergency: Fuse plug dam as at Watana

Panel Comments

- Precedents should be established for diversion tunnel velocity of 50 ft/s, HB operation requirements and spillway design concepts.

- Dam break analysis of cofferdam required in view of volume of water retained; possible costs of damage downstream would affect optimization of tunnel diameter, and tend toward larger tunnel with lower cofferdam.

- All chutes will require aeration.

- Possible to design a cofferdam that can safely be overtopped.

- Fuse plug dam must be stable up to a fixed level and collapse thereafter; a gated structure would be more expensive, but more reliable.

- Stilling basin walls at Devil Canyon are subject to dynamic water loading.

- HB valves would cause icing problems in winter; although normal spillway operation would be in summer, it could also occur at unscheduled times. Loss of load owing to major industrial action was cited as a precedent for forced spilling.

6. Devil Canyon Layout Studies (R.K. Ibbotson)

Options Considered

(a) Powerhouse on right bank, 2 diversion tunnels on left bank, 4 orifices in the dam for auxiliary spillway discharging into a plunge pool at the dam toe, chute and flip service spillway on right bank.

(b) As (a) but service spillway replaced with chute and flip on left bank.

(c) As (a) but service spillway replaced by stilling basin on the right bank.

The preferred option was the stilling basin, to avoid extensive erosion downstream of the dam, and consequent high maintenance costs.

Nitrogen Supersaturation

Because of the nitrogen supersaturation problem, the orifice spillway has been changed to 5 H.B. valves as a service spillway; the stilling basin now will be used as the auxiliary spillway for floods in excess of the 1 in 100 year occurrence.

Extension to Portage Creek

Cost/benefit analysis for the tailrace extension to Portage Creek has been done, indicating CBR of about 1. Difficult tunnelling with little geotechnical data available.

Panel Comments

- Stilling basin walls are too thin if unsupported by rock.

- Need for precedent/experience report on HB valves particularly with regard to vibration and winter operation. Model studies will be required in design stage.

- Recommended at least 10D straight section before the valve to establish linear flow pattern, (particularly at Watana).

- To avoid supercooling the trashracks on the intake should not be exposed above W.L.

- Switchyard position is on opposite bank to powerhouse.

- Tailrace shown is freeflow; one extra set of gates?

7. Devil Canyon Arch Dam Analyses (R.K. Ibbotson)

Previous Work

- Static analysis was completed.

Current Studies

- Dynamic analysis has now been completed plus minor geometry changes to achieve a more symmetrical distribution of stress.

- Crest elevations are 10 feet lower than present thinking, (1445 EL).

- All work is done by Trial-load method.

Results

Static Cases:

(i) Self weight + normal hydrostatic
(ii) S.W. + drawdown (1295)
(iii) Full reservoir + temperature
(iv) Drawdown + temperature

Tensions stresses were as follows:

(i) -27 psi
(ii) -97 psi
(iii) -393 psi

Dynamic:

0.5g and 5% damping ratio: -2470 psi in arch

These results were discussed with Merlin Copen who stated 10% damping ratio was applicable. Design earthquake was also reduced to 0.4g and the analysis repeated.

Revised stresses (maximum tension): -1390 psi in arch

Allowing for redistribution of tensile stresses by cracking, the maximum tensile stress is -322 psi in the arch. If the water dynamic load is reduced 60% for valley shape and constricted approach, the maximum tensile stress is -251 psi.

Panel Comments

- Consider possible finite element analysis check on design by ISMES (Italy) D. Shandalov stated F.E. analysis does not allow for stress relief by cracking.

- Plastic non-recoverable deformation of abutments. This may be offset by grouting, which would tend to strengthen rock and give a more elastic response under load.

8. Approach to Watana Layout Studies (J. D. Lawrence)

It had been agreed that until the rockfill dam design had advanced sufficiently to warrant steeper dam slopes, conservative Oroville dam slopes would be adopted for layout studies on the other major structures, (2.75:1 upstream, 2:1 downstream). These slopes were also used to prepare the upper limit cost estimate. Field data are now being used to firm up the design with a view to steepening the side slopes to ease the site congestion.

9. Watana Dam Design (D.W. Lamb)

Borrow Areas

(a) Till from borrow area D has high permeability (10^{-5} cm/sec) but is otherwise suitable for the core. On the wet side of optimum moisture content by 2-5%. Control on compaction will be difficult. Estimates are to be adjusted to allow for haul distance, placing and compaction methods. Low P.I. on most samples. Some evidence of no clay at depth. Borrow area H is also available; longer haul distance.

(b) Filter material (Area E) must be processed for use, probably from a dragline operation, in 2 bands:

- Fine grained
- Coarse

Some of fine grained may be suitable for the core.

(c) Rockfill - This will be from quarry.

(d) Minimal data on river alluvium. Core and filter specs may need to be tightened up, which will affect costs.

(e) Quantities - An average of 2 to 5 times the volume requirements, which is on the low side. Fine filter material may be tight.

(f) Quarry is in the andesite (at least at the surface), which may not be suitable for concrete aggregates.

Design Factors

(a) Core thickness will be about 50% of the head of water acting. Core will be central and essentially symmetrical. Filters are a minimum of 15 feet thick. Crest width currently 50 feet for provision of a road.

(b) Present slopes follow Oroville dam which sustained 5.8M in 1975 without damage. Checks suggest it is safe up to 8.25M. Design work currently assessing stability of upstream slope of 2.25.

(c) Failure under earthquake loading was discussed, as described in Seed's Rankine Lecture, together with design details which would avoid possible failure mechanisms, e.g., use of rounded gravels as upstream fill.

(d) Grouting would be either from the surface or from a gallery under the dam. The gallery is believed to be useful for instrumentation, access for remedial works, and to avoid schedule delays. Disadvantage is drainage and pumping necessary.

(e) Core contact. This will be flared to 100 feet minimum at the abutments.

Analysis (A. Burgess)

(i) 2.25 slope dynamic analysis is being done at present by computer analysis, using assumed rockfill properties. Variation in material properties caused by current lack of realistic test data for fill materials will be subject of sensitivity analysis. Static analysis and slope stability studies will be done later.

(ii) Finite element methods are being used to assess the dynamic stability under earthquake loading. Material properties under cyclic loading are available only for sand, these have been uprated to estimated gravel values.

Static analysis results shown (performed initially to determine stress levels in dam) represent arching across the core, with some cantilever action of the upper core. Dynamic stress analysis shows highest stresses in the upstream face of the core and the upstream rockfill, using a simulated earthquake of record. This has to be repeated later with the WCC predicted earthquake record. The last phase of design will be amending these dynamic results to allow for pore water pressure distribution.

Panel Comments

- Any problems with frost damage in the core ? Should be allowed for in the unit costs

- Widths of filters and transitions are too small.

- Several Chinese rockfill dam failures under earthquake have been analyzed and failure modes reconstructed; the published work (ICOLD, 1980) should be studied.

- Assumed lift height currently 3 feet for rockfill. This is very critical to schedule.

10. Watana Dam Layout Studies (R.K. Ibbotson)

All layouts are governed by the requirement to set dam and structures between the major shear features (Fins and Fingerbuster).

(i) Cascade spillway on left bank. This layout has been kept in as a means of resolving the nitrogen supersaturation problem. Trade off in rockfill for use in the main dam was allowed for. Rockbolting and other strengthening measures allowed for in cost estimates.

(ii) Preferred (least cost) layout has chute and flip on right bank; nitrogen supersaturation up to 1 in 100 year flood eliminated by use of HB valves as service spillway.

The upstream dam slope is shown at 1 in 2.4. 1 in 2.25 is at present being analyzed, which would give more flexibility with arrangements of structures and position of dam centerline.

Panel Comments

- Downstream tunnel portals are too close together for construction.

- Precedent for use of HB valves as primary release devices? Need for a report on their use was reiterated.

- Significance of upstream dam slope? Change from 2.75 to 2.40 reduces cost by $10 million, with adjustment of dam center line.

11. Watana Relict Channel Studies (V. Singh)

- Since the channel may affect the feasibility of the project, a cost has been assigned to cover investigation and remedial work.

- Seismic lines were extended to trace the extent of the channel. Cross sections have been drawn, based on present information.

- 45 million dollars has been allowed for a continuous cut-off (slurry trench) to avoid piping failure. Saddle dam slopes are flat to allow for earthquake settlement and maintain stability.

- Further study will be undertaken in Phase 2 (auger drilling, Becker drilling). Rock surface contours will be drawn based on 6 boreholes and seismic refraction lines. Permeability measurements will be required in Phase 2; also adits may be driven to assess rock conditions at depth.

Reported by:

M.H. Dumont

MFD/ah

APPENDIX A

SUPPORTING DOCUMENTATION

SUSITNA HYDROELECTRIC PROJECT

STATUS OF STUDIES (J. Lawrence)

- SUSITNA STATUS -

- HYDRAULICS/HYDROLOGY
- SEISMIC STUDIES
- GEOTECHNICAL EXPLORATION
- WATANA/DEVIL CANYON DESIGN OPTIMIZATION
- ENVIRONMENTAL
- TRANSMISSION
- CONSTRUCTION COSTS & SCHEDULES
- LICENSING
- FINANCIAL & RISK STUDIES

– DEADLINES –

- FINAL DEVELOPMENT SELECTION REPORT – SEP. 81
- REVIEW OF WCC FIELD WORK – SEP. 81
- REVIEW OF ACRES/R&M FIELD WORK – SEP. 81
- APA EXTERNAL PANEL REVIEW – OCT. 81
- PRELIMINARY DEVIL CANYON ESTIMATE – OCT. 81
- PRELIMINARY WATANA ESTIMATE – NOV. 81
- FINAL GEOTECH. REPORT – FEB. 82
- FIRST DRAFT FEASIBILITY REPORT – FEB. 82
- FINAL DRAFT FEASIBILITY REPORT – MAR. 15 '82
- FERC LICENSE DOCUMENTS – MAY 82

SUSITNA
DEVELOPMENT SELECTION

WATANA:
- FILL DAM 880 FT.
- 2.75H:1V U/S SLOPE
- 63 MILLION CU.YD.
- 400 MW 1993
- 400 MW 1996

DEVIL CANYON:
- ARCH DAM 650 FT.
- 400 MW 2000

- ACRES INTERNAL PANEL -
FEB. 1981

- WATANA SLOPES 2.5H : 1V U/S
  2.1H : 1V D/S
- INCLUDE FINGERBUSTER IN SEISMIC STUDY
- NITROGEN SUPERSATURATION PROBLEM (SPILLWAYS)
- LOW LEVEL OUTLET DESIGN CONCEPTS
- MULTI-LEVEL INTAKE DESIGN CONCEPTS
- CONSIDER EARTHFILL DAM AT D.C.
- WATANA TIGHT SCHEDULE FOR DAM
- INCLUDE D.C. IN LICENSE APPLICATION

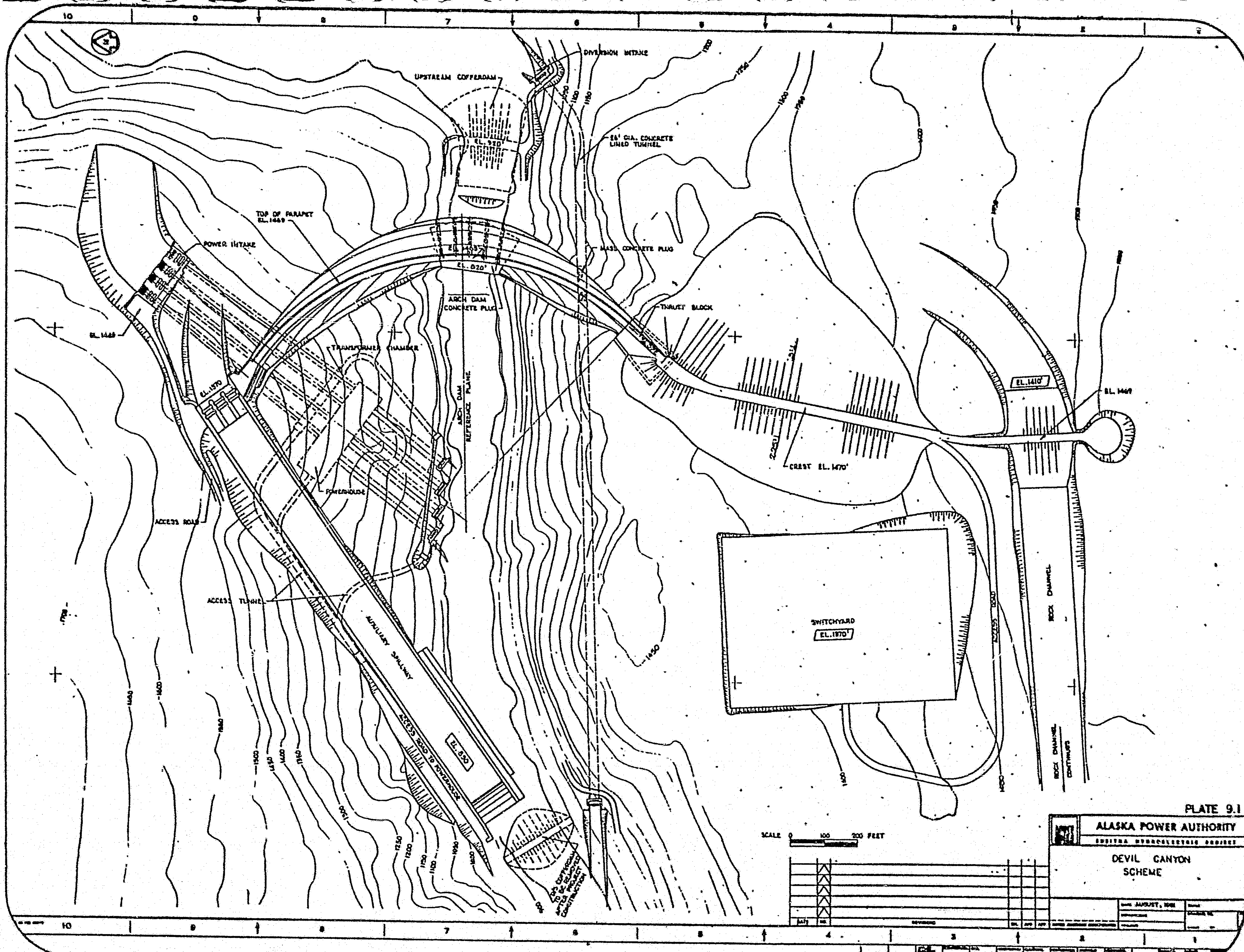
– ACRES EXTERNAL PANEL –
FEB. 1981

- SEISMIC:
  - TALKEETNA THRUST
  - KD3-7
  - SUSITNA FEATURE
  - FLOATING EARTHQUAKE
  - BENIOFF
- GEOTECH: WATANA
  - ANDESITE/DIORITE CONTACT (TUNNELS)
  - RELICT CHANNEL
  - ALLUVIUM DEPTH (COFFERDAMS)

  DEVIL CANYON
  - SHEAR ZONES
- DESIGN: WATANA
  - UNDERGROUND P/H
  - SURFACE P/H ALT.
  - OROVILLE SECTION
  - CONSIDER ARCH

- APA EXTERNAL PANEL -
JUNE 1981

- WATANA:
  - RELICT CHANNEL EXPLORATION
  - UNDERGROUND P/H EXPLORATION
  - TALKEETNA THRUST / SUSITNA FEATURE INVESTIGATIONS
  - BENIOFF ZONE EARTHQUAKES
  - OROVILLE DAM SECTION FOR WATANA (2.75H : 1V U/S SLOPE)
  - NITROGEN SUPERSATURATION (SPILLWAYS)
  - DOWNSTREAM EROSION (SPILLWAYS)
  - DOWNSTREAM WATER QUALITY (SEDIMENTATION, MORPHOLOGY, FISHERIES)


DIVERSION INTAKE
UPSTREAM COFFERDAM
EL. 920'
26' DIA. CONCRETE LINED TUNNEL
TOP OF PARAPET EL. 1469
POWER INTAKE
MASS CONCRETE PLUG
EL. 920'
ARCH DAM CONCRETE PLUG
THRUST BLOCK
EL. 1469
TRANSFORMER CHAMBER
ARCH DAM REFERENCE PLANE
EL. 1410'
EL. 1469
EL. 1370
CREST EL. 1470'
POWERHOUSE
ACCESS ROAD
ACCESS TUNNEL
SWITCHYARD
EL. 1370'
AUXILIARY SPILLWAY
ACCESS ROAD TO POWERHOUSE
EL. 850
ROCK CHANNEL
ACCESS
PLATE 9.1
ALASKA POWER AUTHORITY
DEVIL CANYON
SCHEME
SCALE 0 100 200 FEET

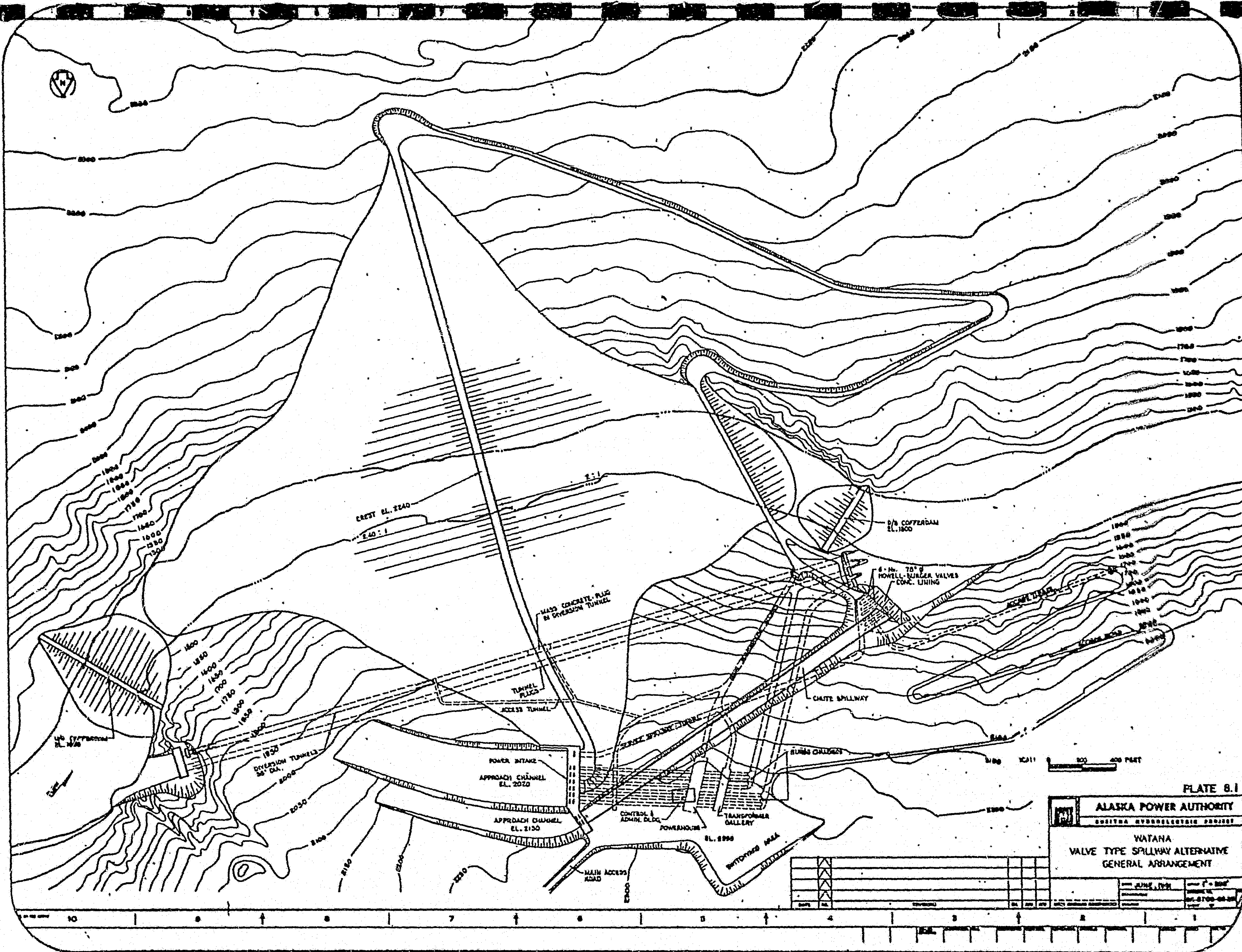
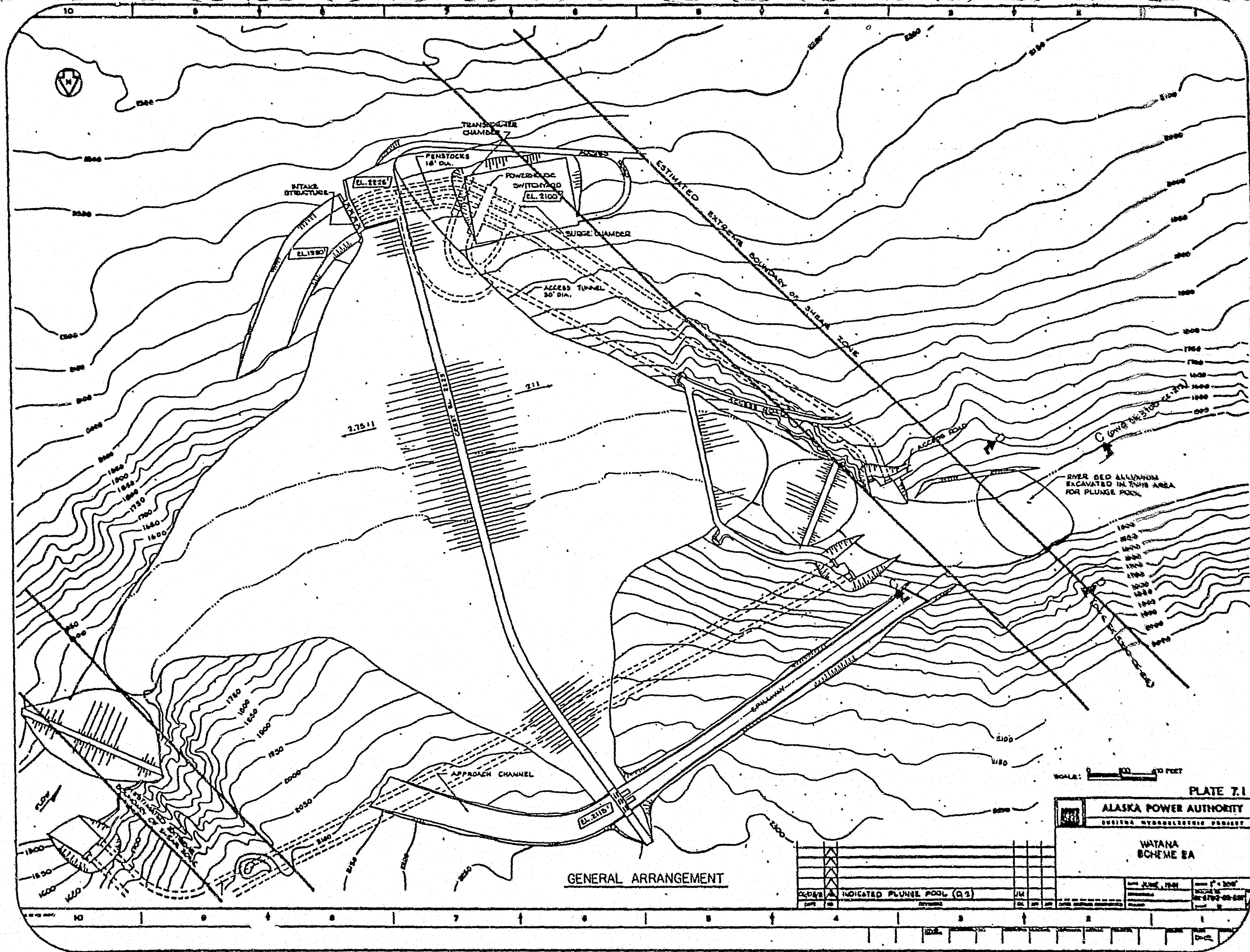
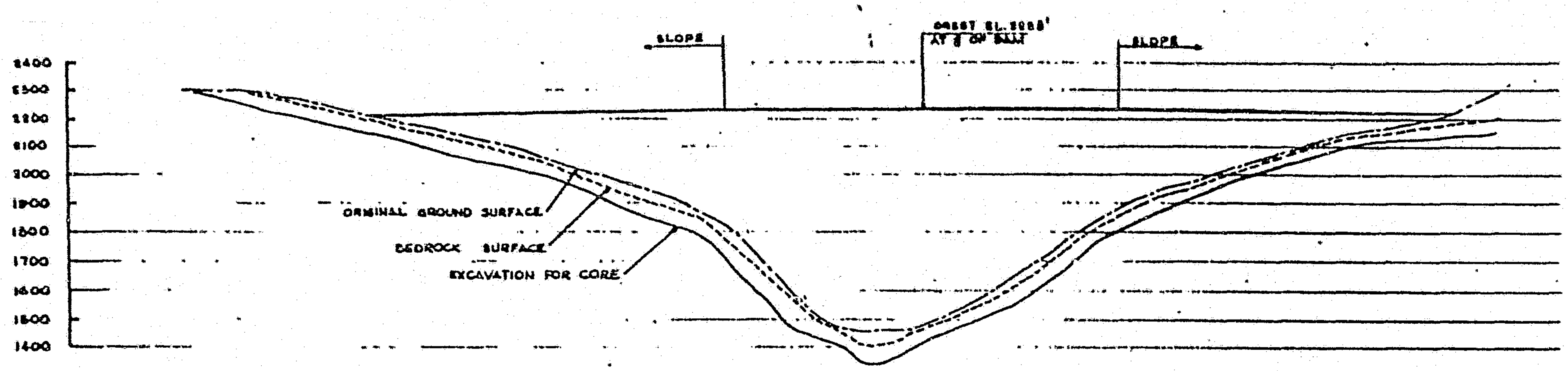

CREST EL. 2240
MASS CONCRETE PLUG IN DIVERSION TUNNEL
D/S COFFERDAM EL. 1800
HOWELL-BUNGER VALVES
CONC. LINING
CHUTE SPILLWAY
TUNNEL PLUGS
ACCESS TUNNEL
DIVERSION TUNNELS 38' DIA.
POWER INTAKE
APPROACH CHANNEL EL. 2020
APPROACH CHANNEL EL. 2130
CONTROL & ADMIN. BLDG.
POWERHOUSE
TRANSFORMER GALLERY
MAIN ACCESS ROAD
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
VALVE TYPE SPILLWAY ALTERNATIVE
GENERAL ARRANGEMENT
JUNE, 1981

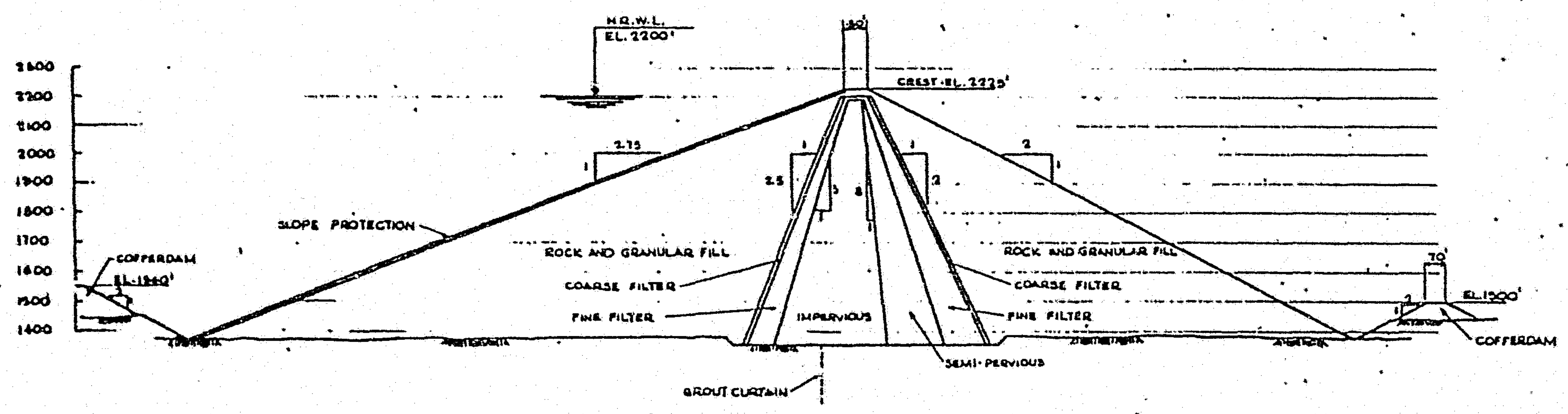
PLATE 8.1



TRANSFORMER CHAMBER
PENSTOCKS 18' DIA.
INTAKE STRUCTURE
EL. 2226'
POWERHOUSE
SWITCHYARD
EL. 2100'
SURGE CHAMBER
EL. 1930'
ACCESS TUNNEL 30' DIA.
ESTIMATED EXTREME BOUNDARY OF SHEAR ZONE
ACCESS ROAD
RIVER BED ALLUVIUM EXCAVATED IN THIS AREA FOR PLUNGE POOL
CREST EL. 2225
2:1
2.75:1
SPILLWAY
APPROACH CHANNEL
EL. 2115'
FLOW
GENERAL ARRANGEMENT
INDICATED PLUNGE POOL
PLATE 7.1
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
SCHEME 2A
JUNE, 1981



SECTION A-A



SECTION B-B

SCALE 0 200 400 FEET

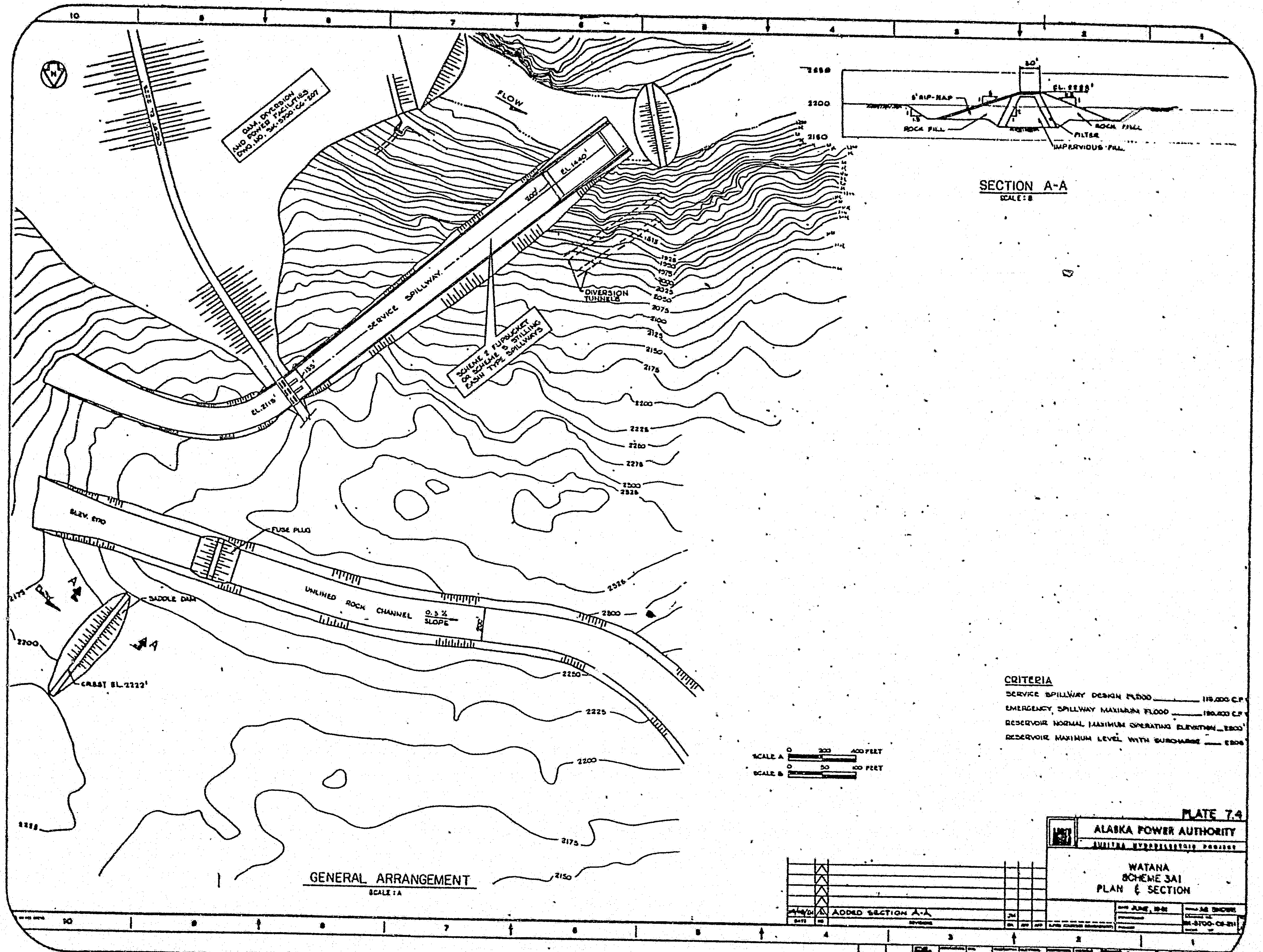
PLATE 7.2

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA

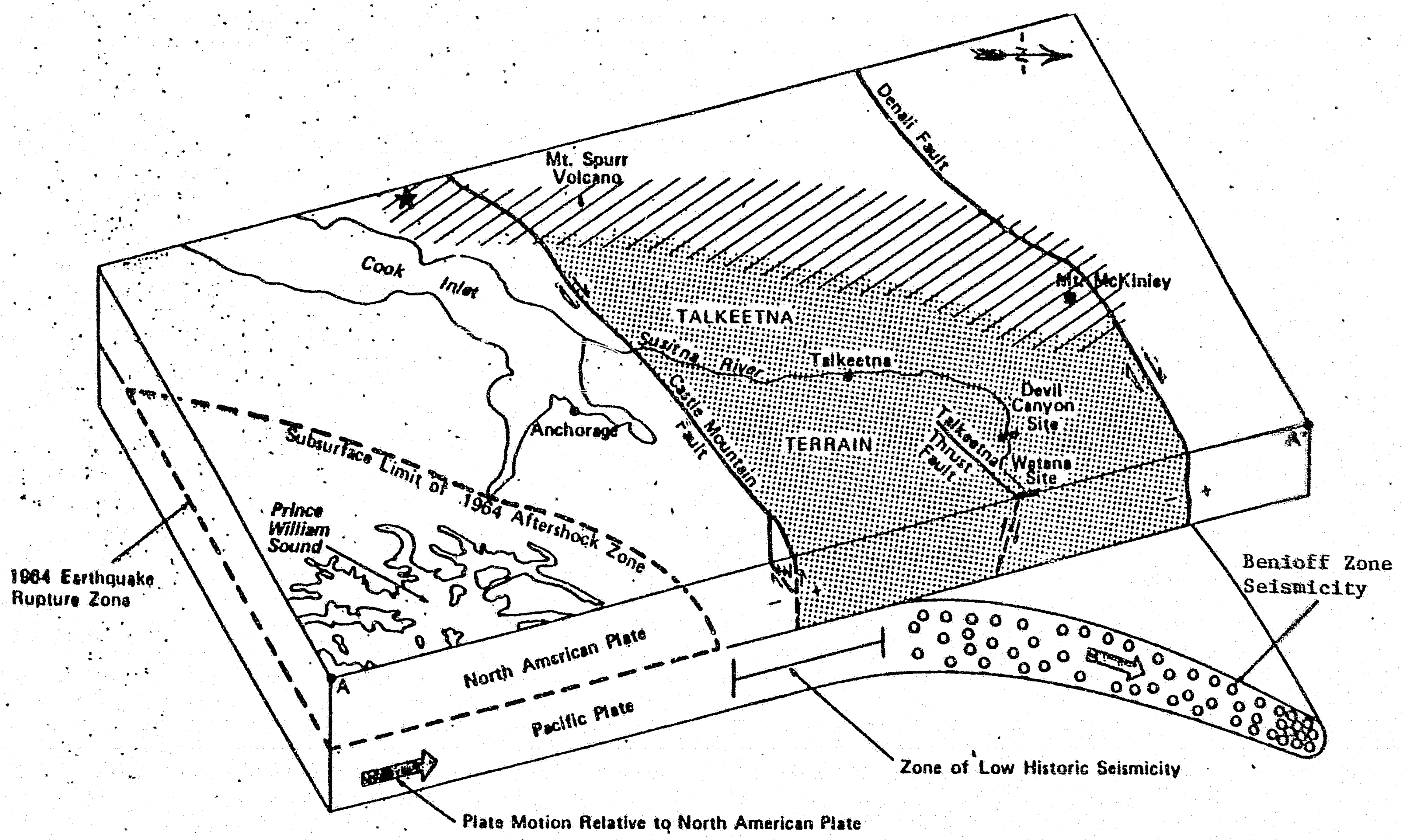
MAIN DAM (ALL SCHEMES)



DAM, DIVERSION AND POWER FACILITIES DWG. NO. SK-5700-C6-207
FLOW
SERVICE SPILLWAY
EL. 1440'
EL. 2118'
DIVERSION TUNNELS
SCHEME 2 FLIPBUCKET OR SCHEME 5 STILLING BASIN TYPE SPILLWAYS
ELEV. 2170
FUSE PLUG
UNLINED ROCK CHANNEL
0.5 % SLOPE
SADDLE DAM
CREST EL. 2222'
GENERAL ARRANGEMENT
SCALE: A
SECTION A-A
SCALE: B
RIP-RAP
ROCK FILL
FILTER
IMPERVIOUS FILL
CRITERIA
SERVICE SPILLWAY DESIGN FLOOD
EMERGENCY SPILLWAY MAXIMUM FLOOD
RESERVOIR NORMAL MAXIMUM OPERATING ELEVATION
RESERVOIR MAXIMUM LEVEL WITH SURCHARGE
SCALE A 0 200 400 FEET
SCALE B 0 50 100 FEET
PLATE 7.4
ALASKA POWER AUTHORITY
WATANA
SCHEME 3A1
PLAN & SECTION
ADDED SECTION A-A
JUNE, 1981

SEISMIC STUDIES (V. Singh)

WOODWARD-CLYDE CONSULTANTS 14668A December 1980



NOTES

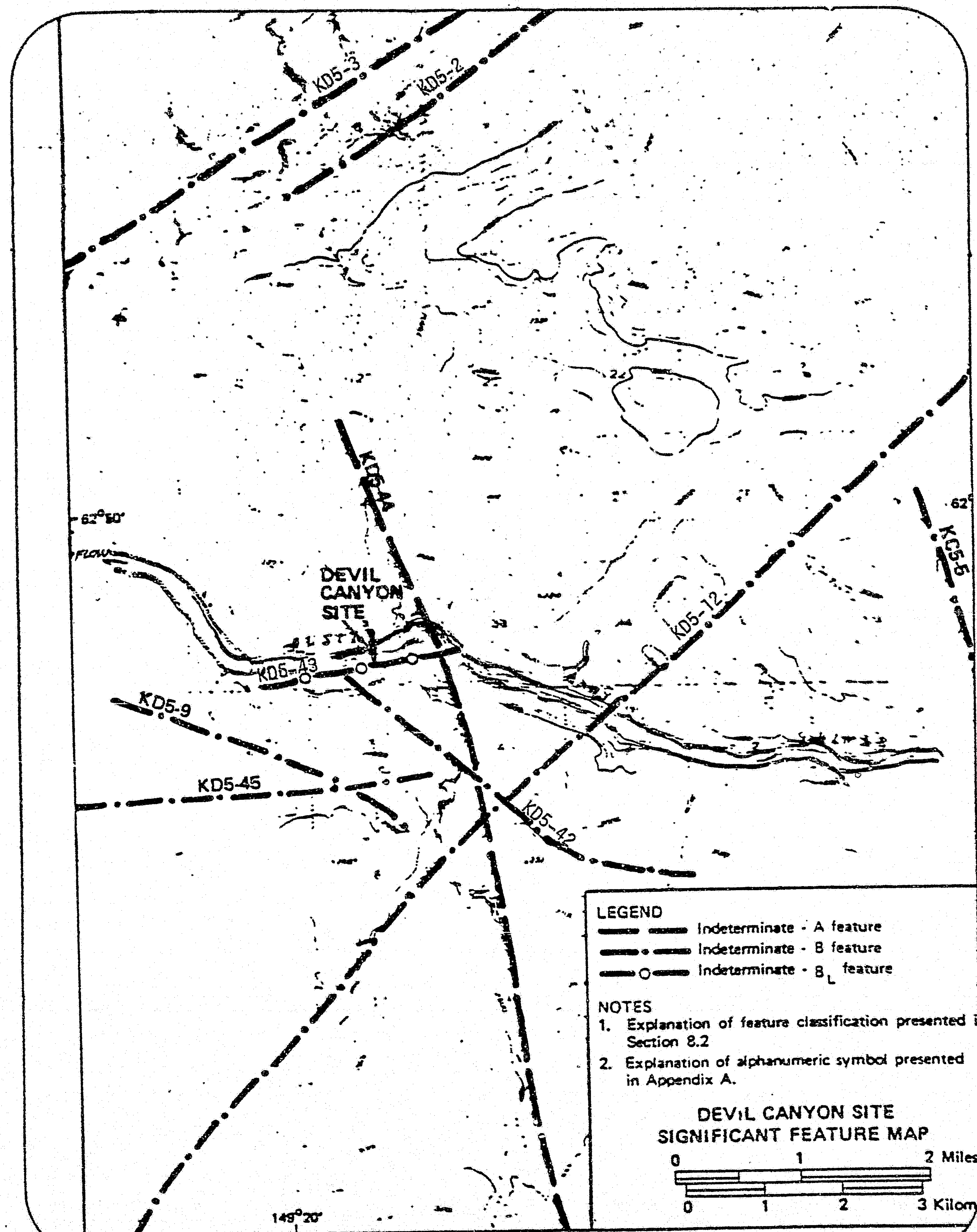
1. See Figure 5-1 for location of Section A–A'.
2. Geologic data sources included in those cited in Figures 4-1 and 5-1.

Prepared by: Woodward-Clyde Consultants, 1980

SCHEMATIC TALKEETNA TERRAIN SECTION

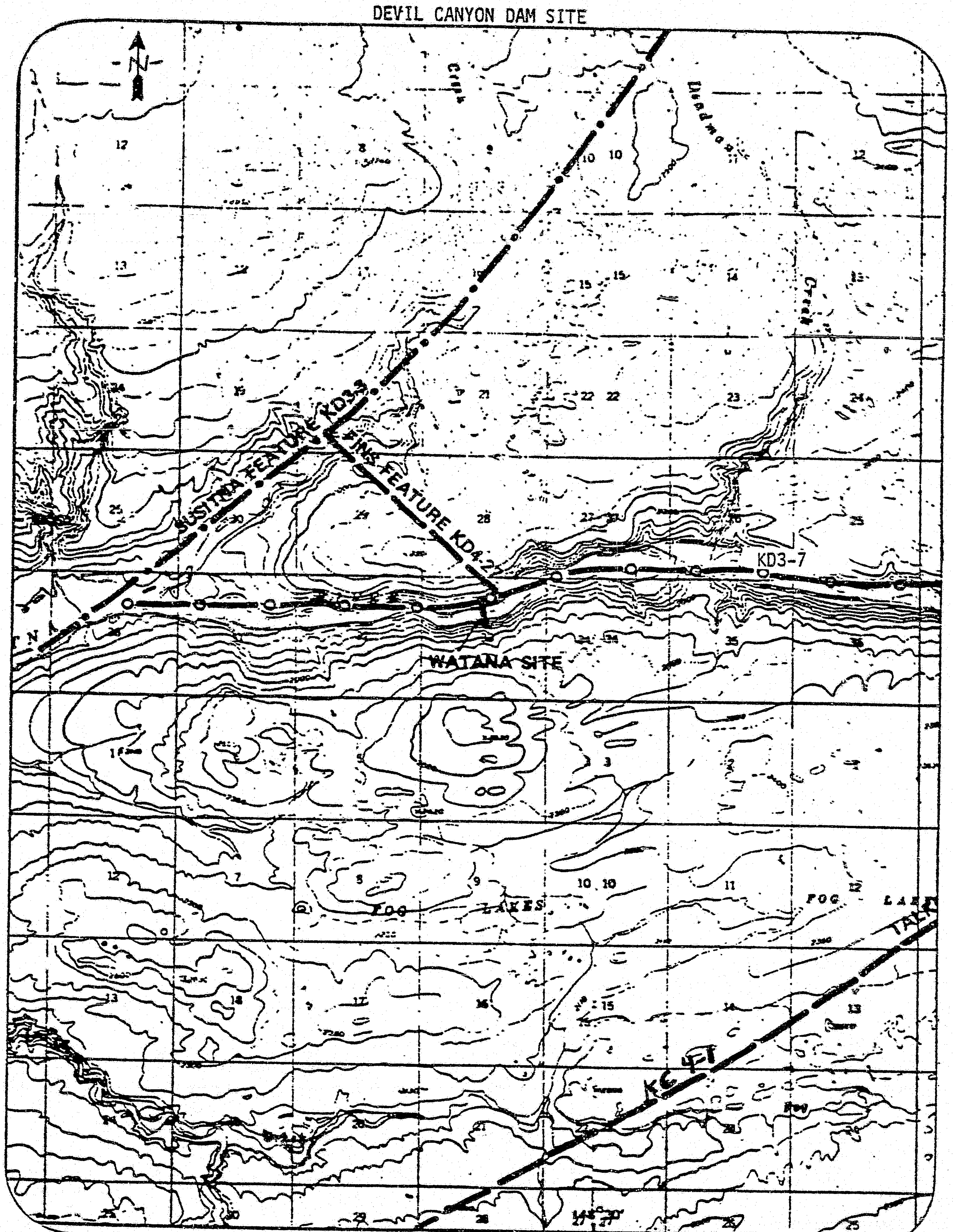
0 50 100 Miles

0 50 100 Kilometers



DEVIL CANYON SITE
SIGNIFICANT FEATURE MAP

DEVIL CANYON DAM SITE



GEOTECHNICAL FIELD EXPLORATION (S. Thompson)

1981 WATANA PROGRAM

ADDITIONAL WORK

1) GEOLOGY MAPPING & EMPHASIZE SPECIAL FEATURES

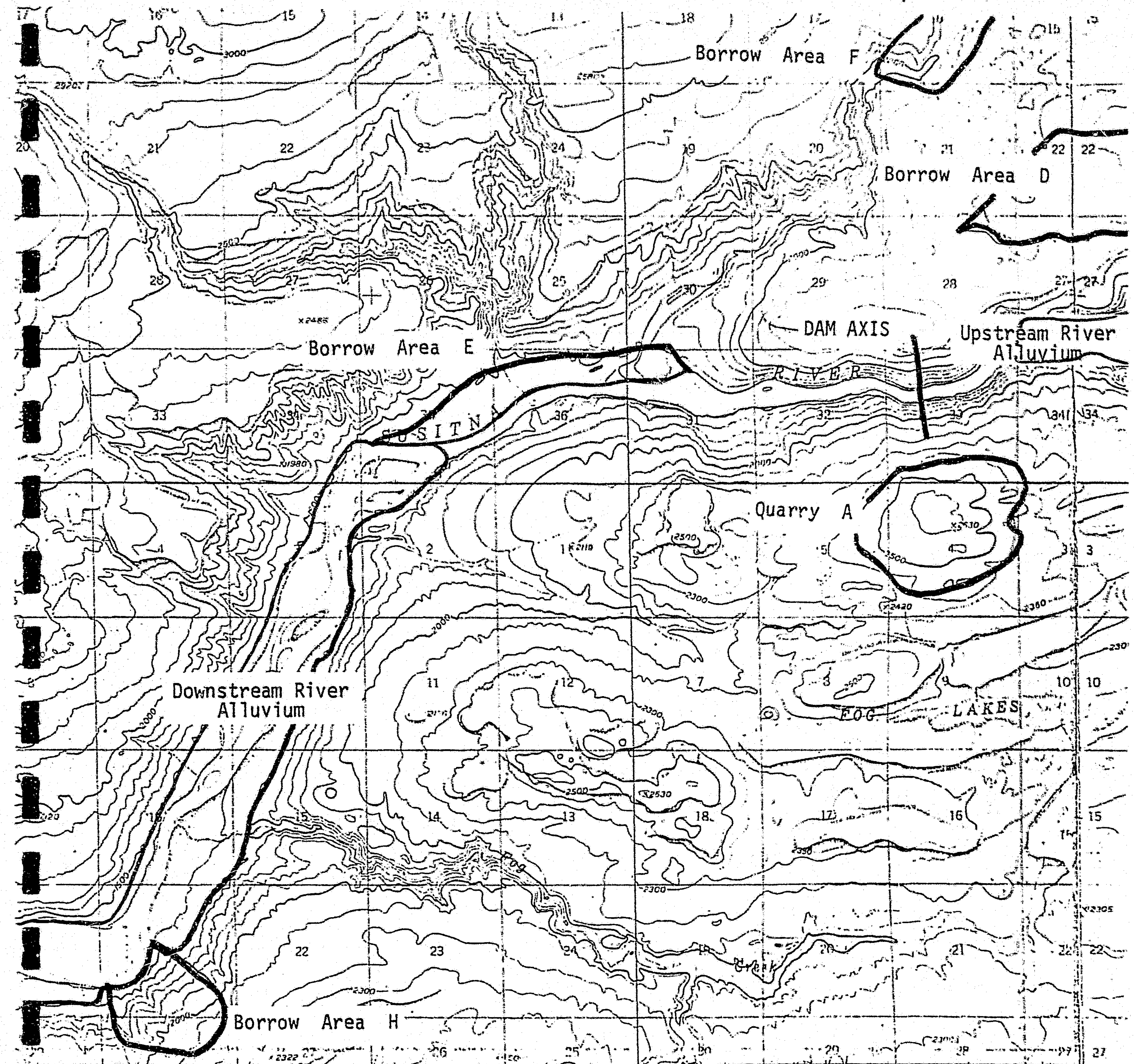
2) DRILL POWERHOUSE AREA *

3) RELICT CHANNEL MAPPING, SEISMIC LINES *

4) ROUNDED SHELL MATERIAL UPSTREAM OF THE DAM

5) RESERVOIR SLIDE POTENTIAL RECONNAISSANCE

NOTE: * RECOMMENDED BY APA EXTERNAL REVIEW BOARD
APA PANEL RECOMMENDED DRILLING TO DETERMINE MATERIAL PROPERTIES IN BURIED CHANNEL.



MOUNTAINS C-4)

40

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1975

423000m.E.

148°30'

1 0 1 2 3 4 MILES

0 3000 6000 9000 12000 15000 18000 21000 FEET

1 0 1 2 3 4 5 KILOMETRES

BORROW AREAS --- WATANA

ROAD CLASSIFICATION

No roads or trails in this area

Mapped
Control
Topogra
taken 1
Univers
10,000
1000 m
zone 6.
Land lir
protrete
Folios 5

INTERVAL 100 FEET
CURRENT 50 FOOT CONTOURS
VERTICAL DATUM OF 1929

ALASKA

QUADRANGLE LOCATION

TALKEETNA MOUNTAINS (D-4), ALASKA

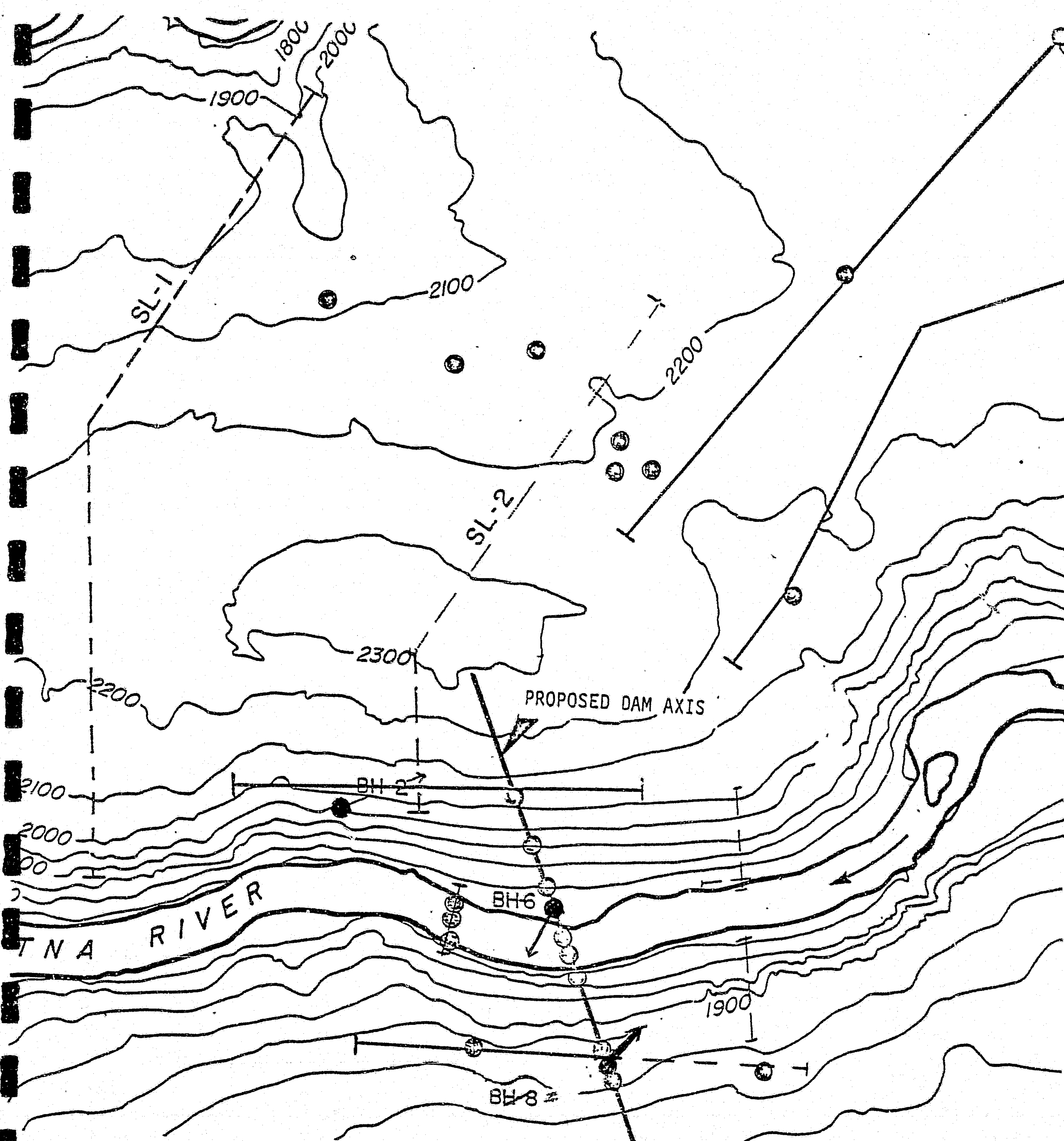
N6245—W14830/15X30

1951

MINOR REVISIONS 1965

U.S. GEOLOGICAL SURVEY
COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

Borrow Areas

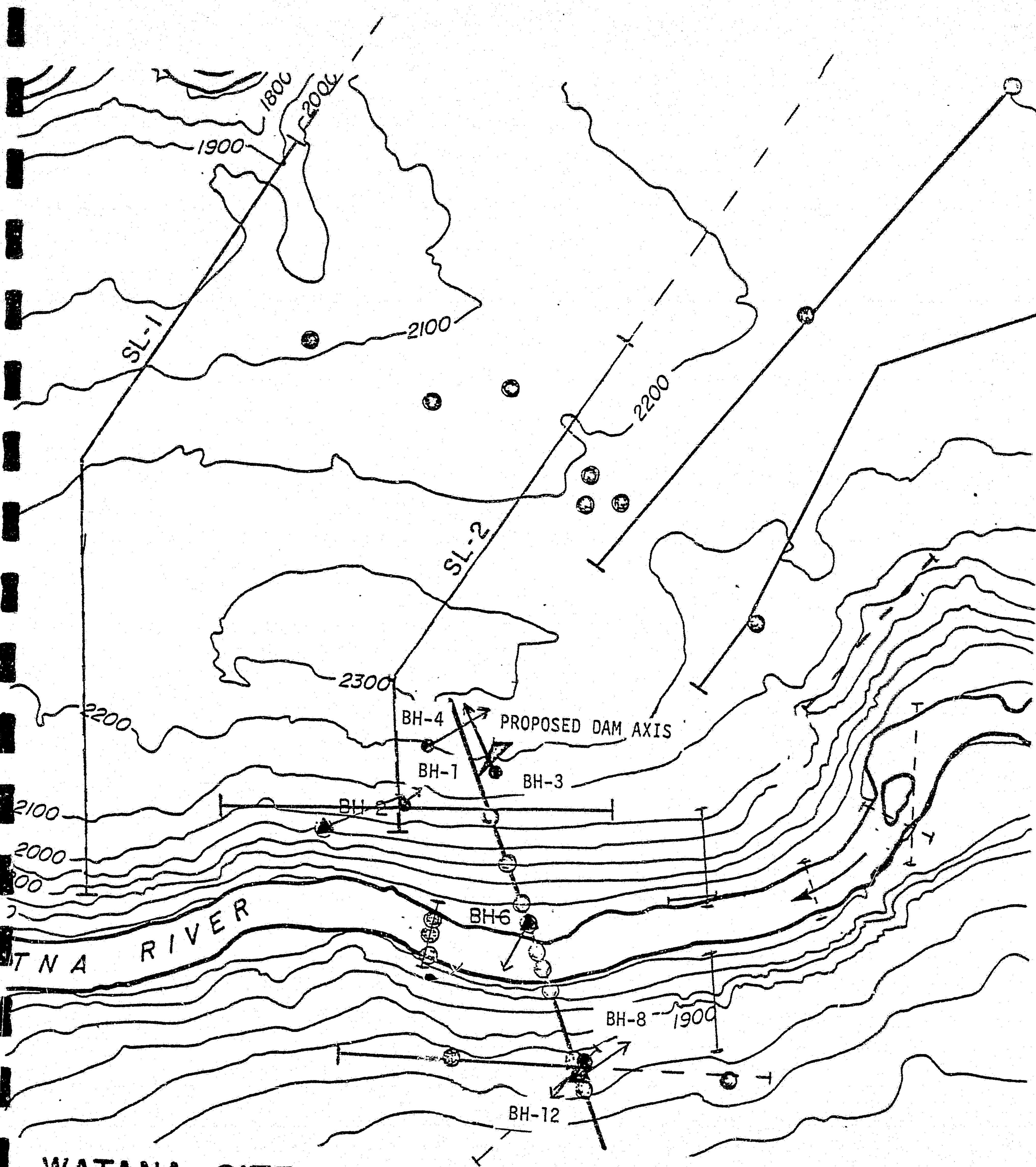


WATANA SITE
1980 GEOTECHNICAL INVESTIGATION

PREVIOUS WORK

1980 PROGRAM - DIAMOND CORE HOLES

- SEISMIC LINES



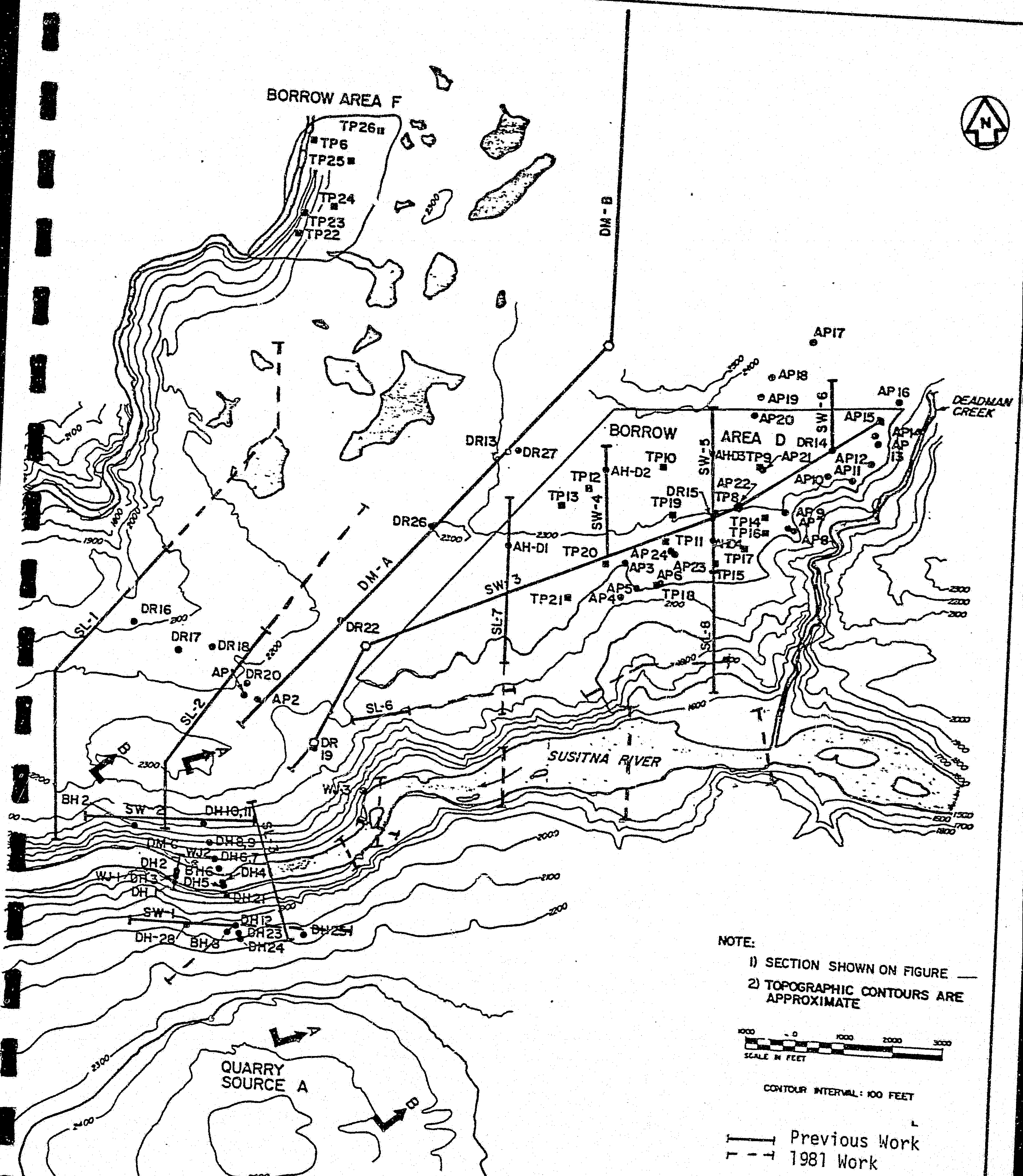
WATANA SITE

1981 GEOTECHNICAL INVESTIGATION

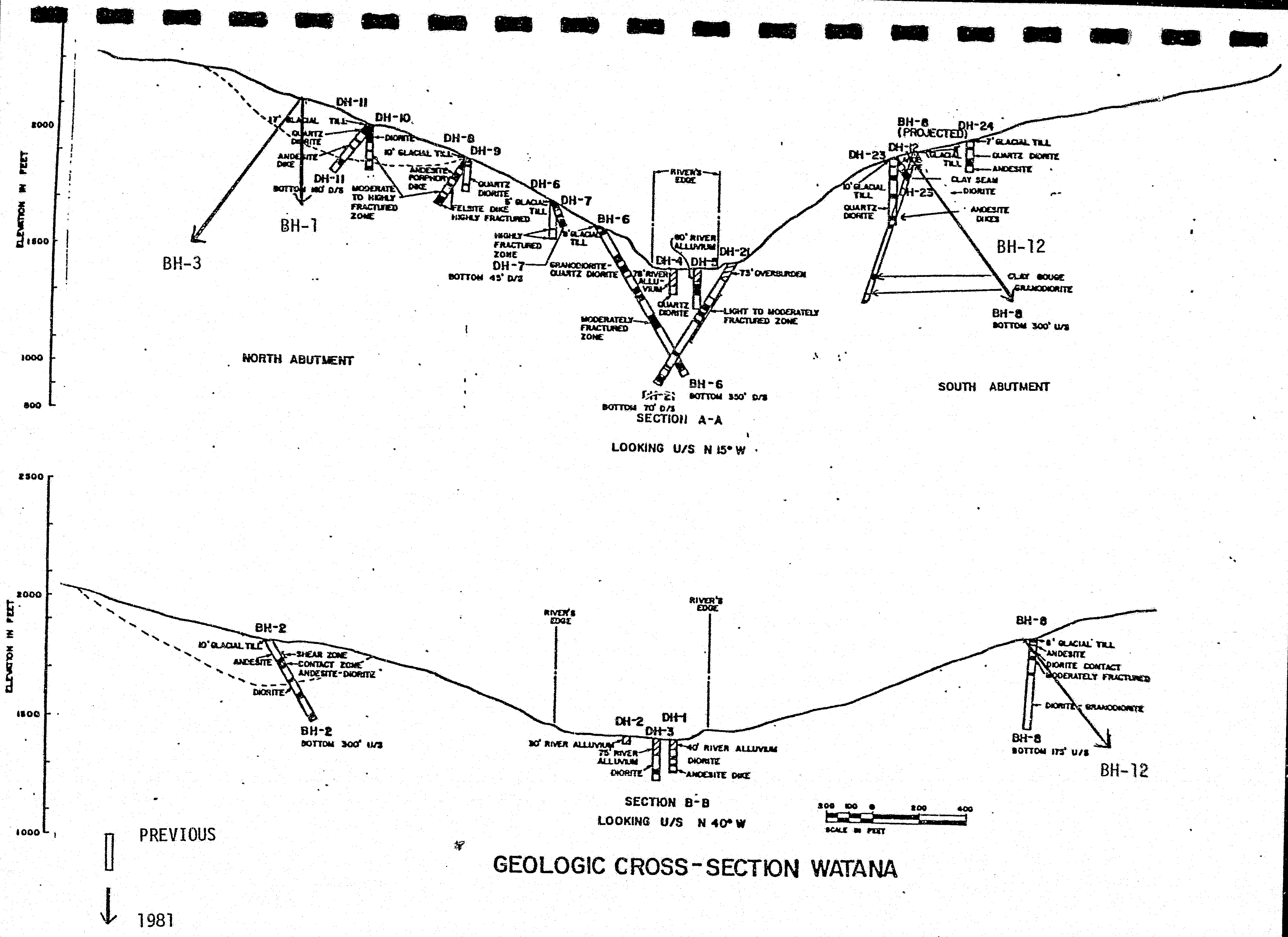
PREVIOUS WORK	BOREHOLES
1980 PROGRAM	- DIAMOND CORE HOLES
1981 PROGRAM	

SEISMIC LINES

- COE
- 1980
- 1981



1981 SEISMIC LINES SCHEMATIC
WATANA EXPLORATION



GEOLOGIC CROSS-SECTION WATANA

WATANA

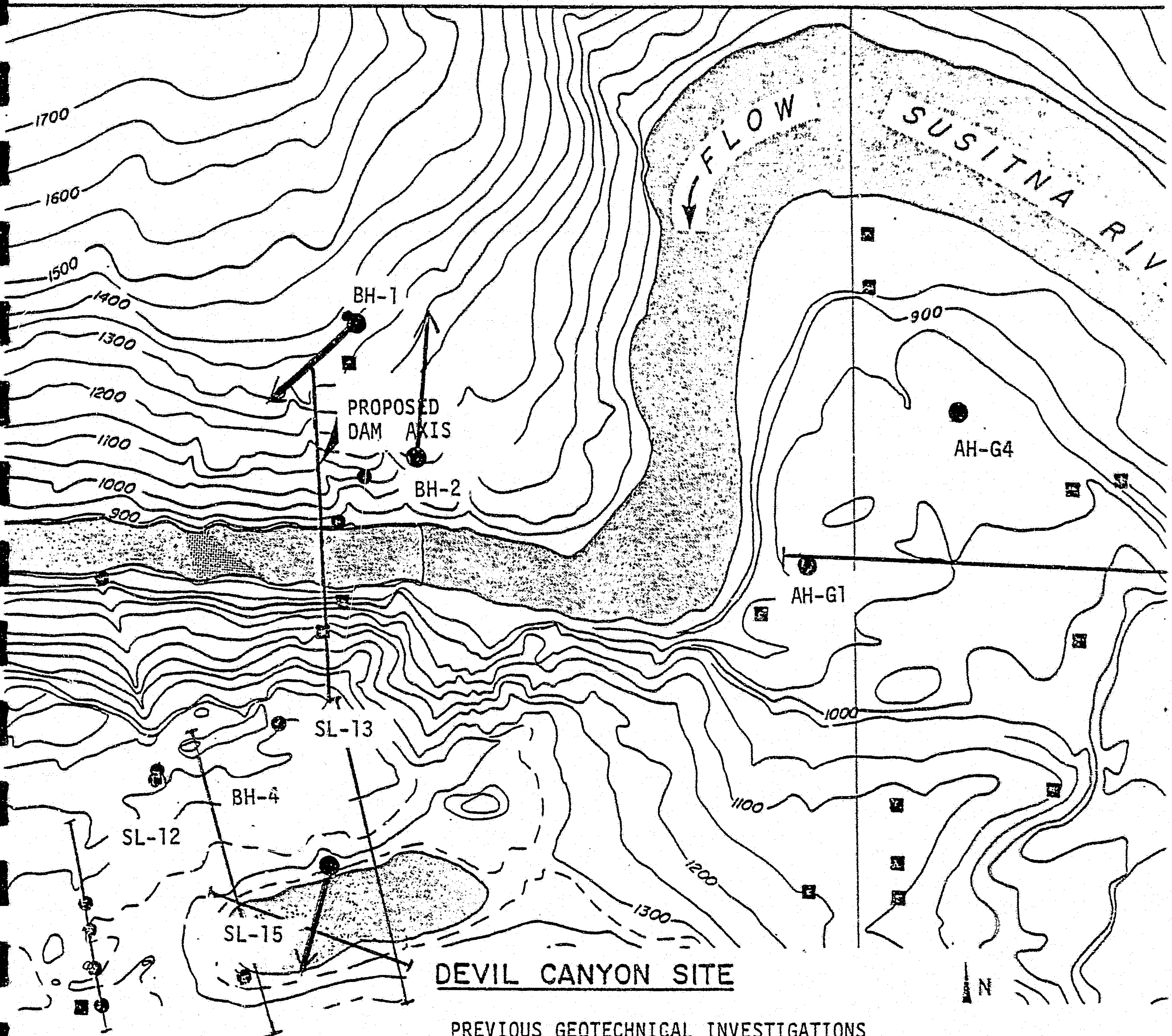
RQD SUMMARY

VERTICAL DEPTH BELOW ROCK SURFACE	FEET DRILLED	RQD %
0' - 50'	944.7	52%
50' - 150'	1472.0	61%
150' - 250'	753.4	74%
250' - 350'	467.7	80%
350' - 450'	338.2	83%
450' - 550'	233.0	76%
550' - 650'	196.8	83%
SITE AVERAGE	4405.8	67%

DATA BASE: DH-1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 21, 23, 24, 28.
BH-2, 6, 8.

RQD SUMMARY TABLE

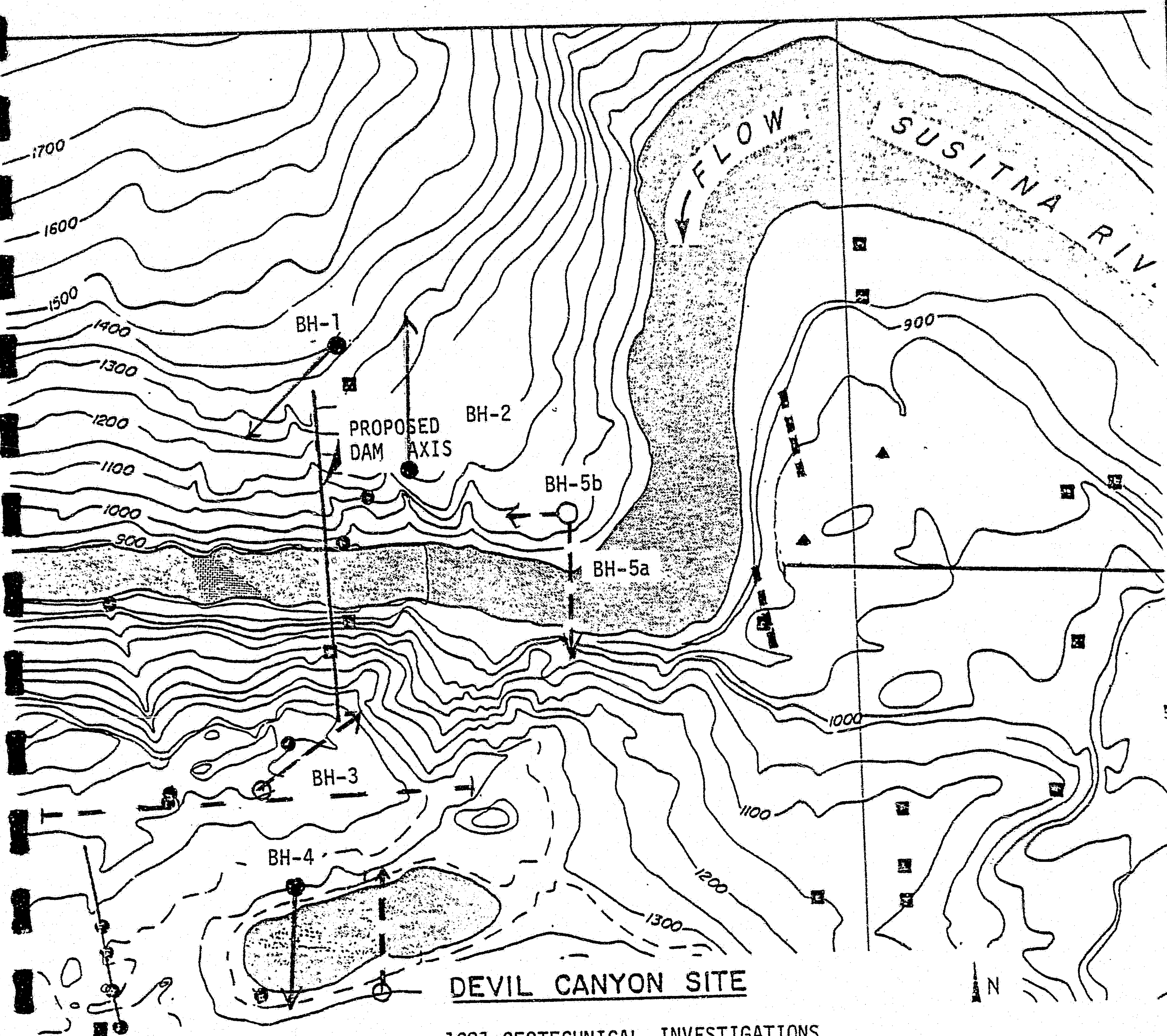
% WITHIN RANGE	0-25	25-50	50-75	75-90	90-95	95-100
	11%	12	25	25	10	17



DEVIL CANYON SITE

PREVIOUS GEOTECHNICAL INVESTIGATIONS

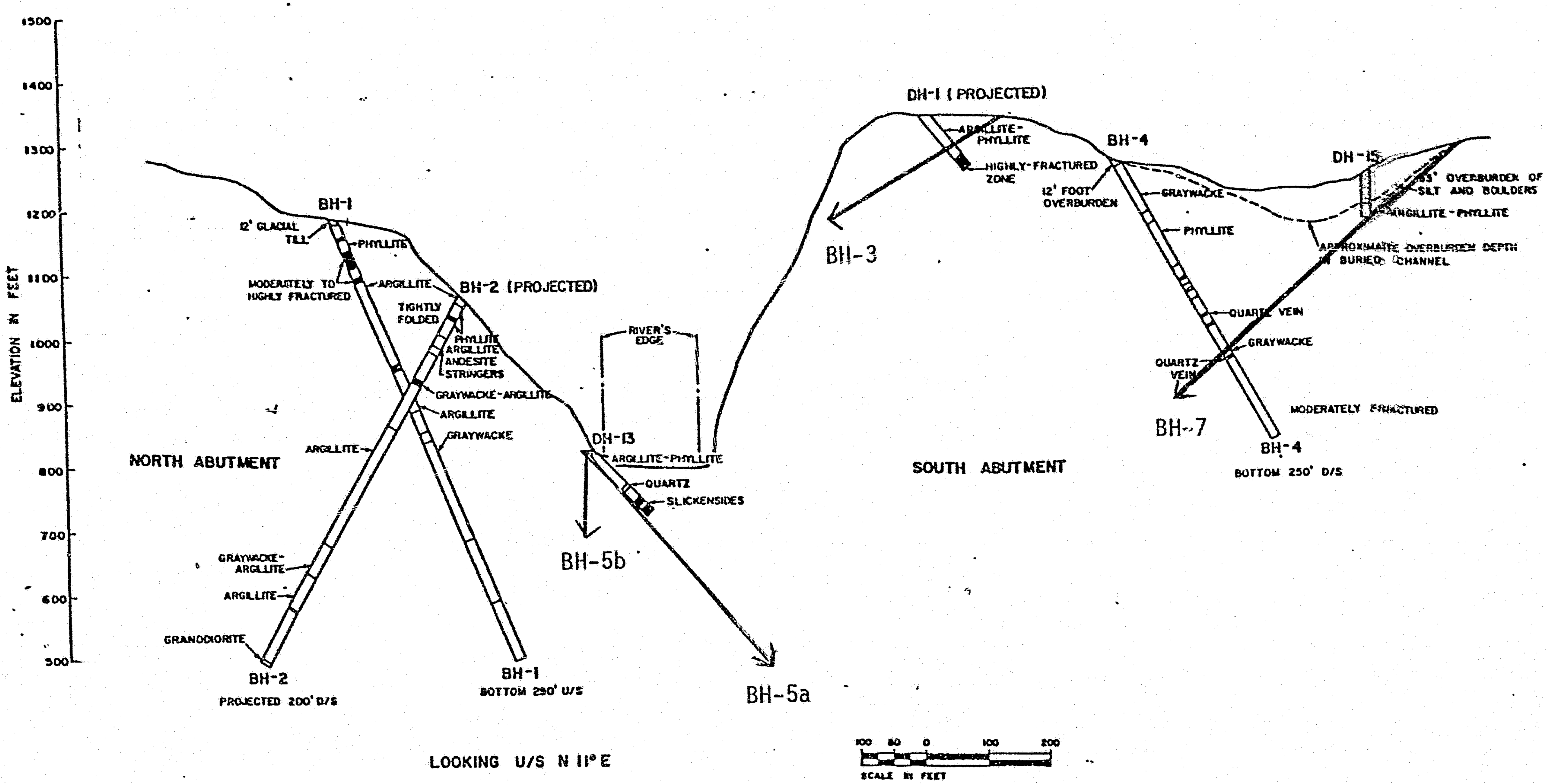
BOREHOLES BH
TEST PITS SL
AH



DEVIL CANYON SITE

1981 GEOTECHNICAL INVESTIGATIONS

	PREVIOUS	1981
BOREHOLES	●	○
TEST PITS	■	△
SEISMIC LINES	├─┤	├ – – ┤



PREVIOUS WORK

REFERENCES:
1. BUREAU OF RECLAMATION, 1960
2. CORPS OF ENGINEERS, 1978
3. SUMMER 1980 INVESTIGATION

1981

GEOLOGIC CROSS-SECTION DEVIL CANYON

DEVIL CANYON

RQD SUMMARY

VERTICAL DEPTH BELOW ROCK SURFACE	FEET DRILLED	RQD %
0' - 50'	477.60	72%
50' - 150'	924.90	76%
150' - 250'	727.70	81%
250' - 350'	626.1	87%
350' - 450'	412.8	91%
450' - 550'	223.9	90%
550' - 650'	128.8	85%
650' - 750'	34.5	85%
SITE AVERAGE	3556.3	81%

DATA BASE: BH-1, 2, 3, 4, 5A, 5B, 7.

RQD SUMMARY TABLE

% WITHIN RANGE	0-25	25-50	50-75	75-90	90-95	95-100
	06	05	14	22	15	38

APPROACH TO SPILLWAY DESIGNS (J. Hayden)

SUSITNA HYDROELECTRIC PROJECT

PROJECT FLOWS

TABLE 1 - RIVER FLOWS (FT ^{3}/S)

INFLOW RETURN PERIOD YRS.	WATANA ANNUAL PEAK	WATANA SUMMER PEAK	DEVIL CANYON* ANNUAL PEAK	DEVIL CANYON* SUMMER PEAK
MEAN ANNUAL	36,000	-	41,000 1/	-
1 IN 50	84,000	-	53,200	-
1 IN 100	92,000	70,000	54,000	-
1 IN 10,000 (DESIGN)	156,000	-	140,000	-
PMF	310,000	-	325,000	-

* WITH WATANA DEVELOPMENT UPSTREAM.

1/ NATURAL FLOW

TABLE 2 - ROUTED FLOWS FOR DISCHARGE FACILITIES (FT^3/S)

RETURN PERIOD YRS.	WATANA	DEVIL CANYON	
1:50	68,000 1)	53,200 1)	DIVERSION CAPACITY
1:100 ANNUAL	45,000	50,000	WATANA RESERVOIR STARTING LEVEL AT 2172' (HIGHEST SIMILATED TIME LEVEL) D.C. NORMAL MAX. OPERATING LEVEL
1:100 SUMMER	45,000	50,000	BOTH RESERVOIRS AT NORMAL MAX. OPERATING LEVEL
1:10,000	120,000	140,000	BOTH RESERVOIRS AT NORMAL MAX. OPERATING LEVEL
PMF	270,000	300,000	BOTH RESERVOIRS AT NORMAL MAX. OPERATING LEVEL

1) FIGURES TENTATIVE - OPTIMIZATION STUDIES UNDERWAY.

TABLE 3 - DISCHARGE CAPACITY OF OUTLET FACILITIES (FT ^{3}/S)

FACILITY	WATANA	D.C.	REMARKS
AVG. RIVER FLOW	7,860	8,960	
MAX. AVG. MONTHLY FLOW (JUNE)	23,100	26,200	
MIN. AVG. MONTHLY FLOW (MAR)	890	1,030	
SERVICE SPILLWAY	33,000	45,000	1:100 YR. RATED FLOW LESS 75% POWERHOUSE.
AUXILIARY SPILLWAY	87,000	97,000	1:10,000 YR. FLOW LESS 1:100 FLOW (NO POWERHOUSE AVAILABLE).
EMERGENCY SPILLWAY	150,000	160,000	PMF LESS 1:10,000 YR. FLOW (NO POWERHOUSE AVAILABLE).
LOWLEVEL OUTLET FOR COMPENSATION FLOW	10,000	10,000	AT 100' HEAD.
MAX. CAPACITY	24,000	45,000	AT 600' HEAD.
EMERGENCY DRAWDOWN	33,000	45,000	SERVICE SPILLWAY USED FOR EMERGENCY DRAWDOWN.

DEVIL CANYON LAYOUT STUDIES (R. Ibbotson)

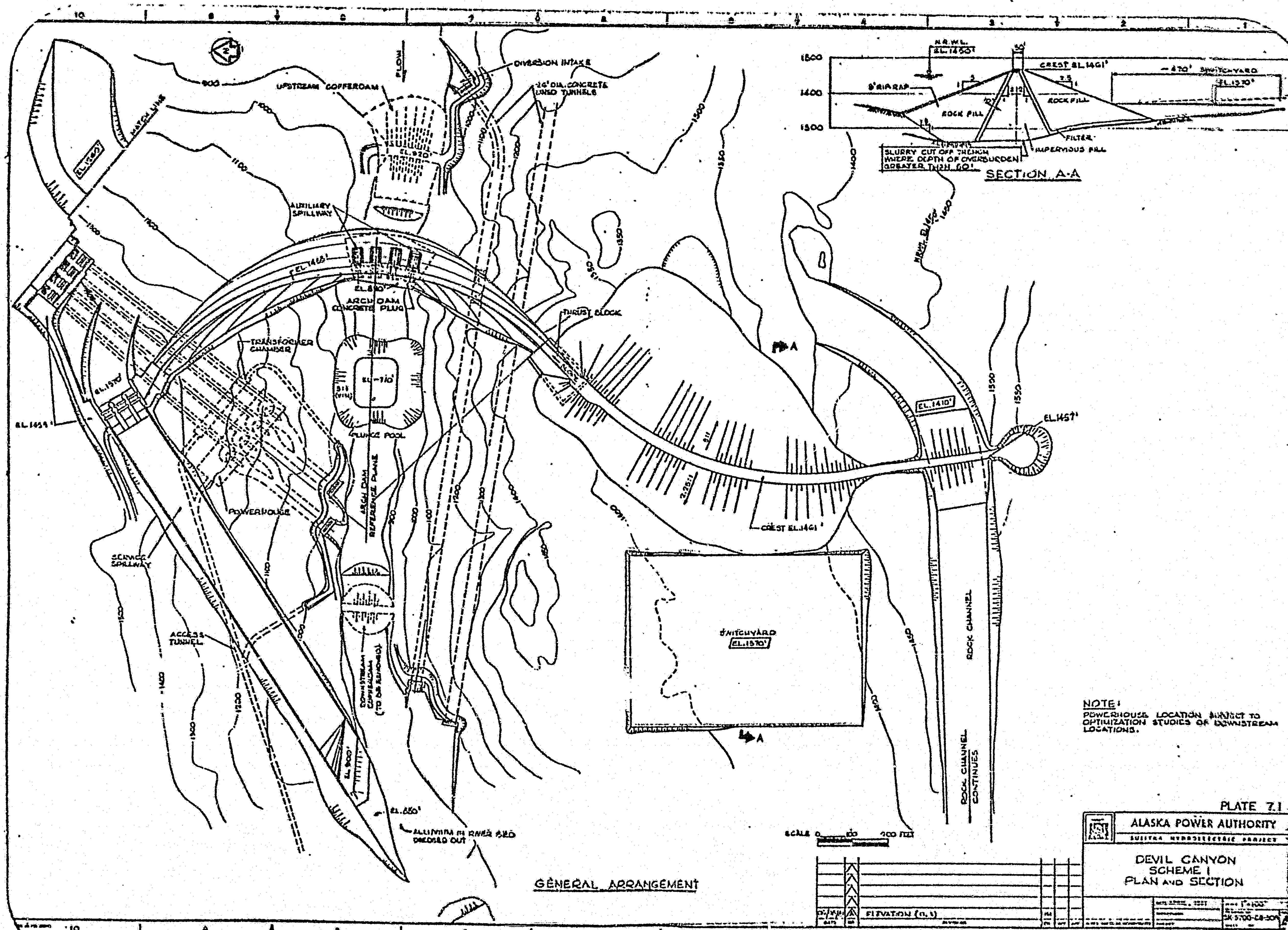
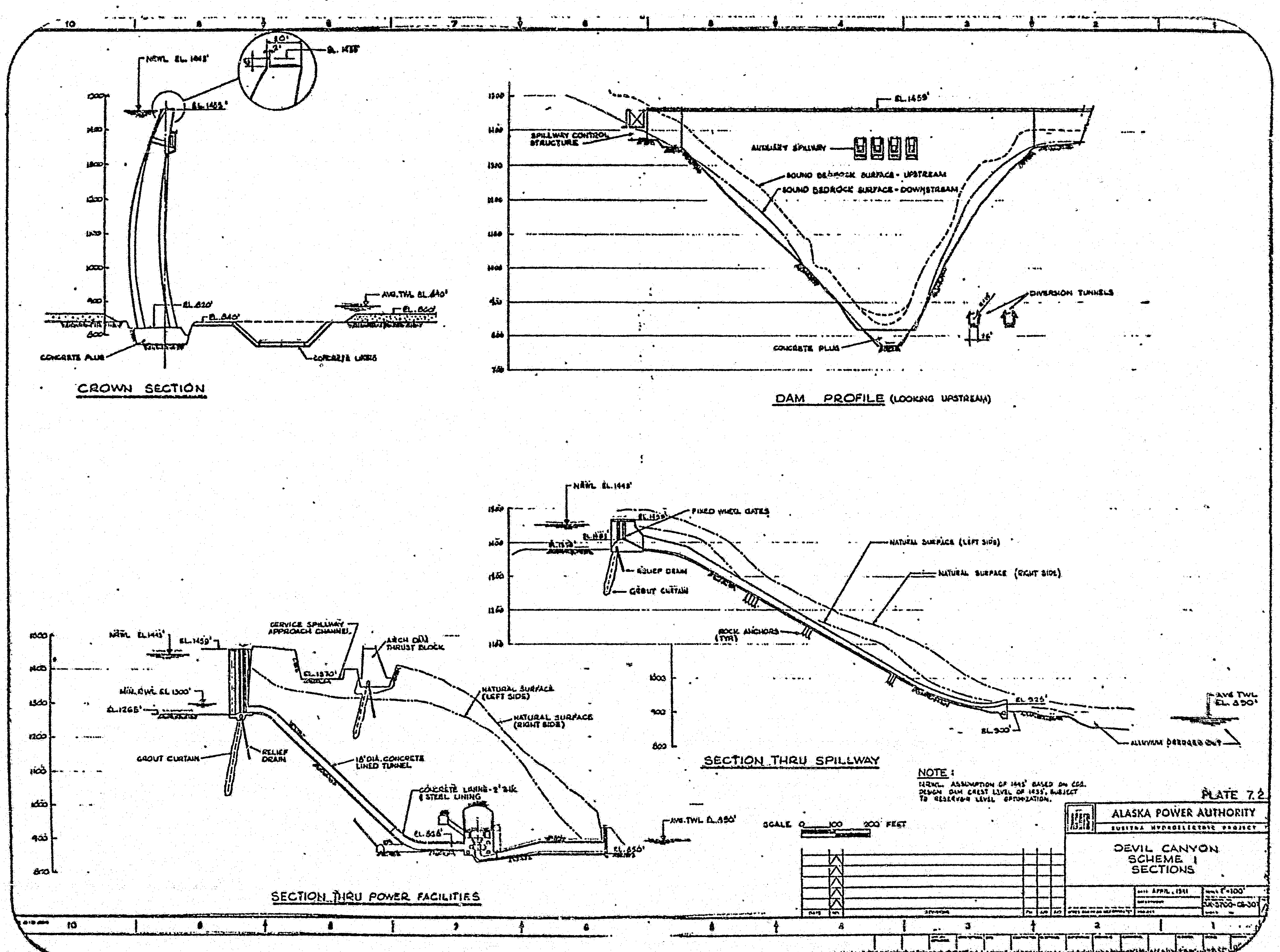


PLATE 7.1

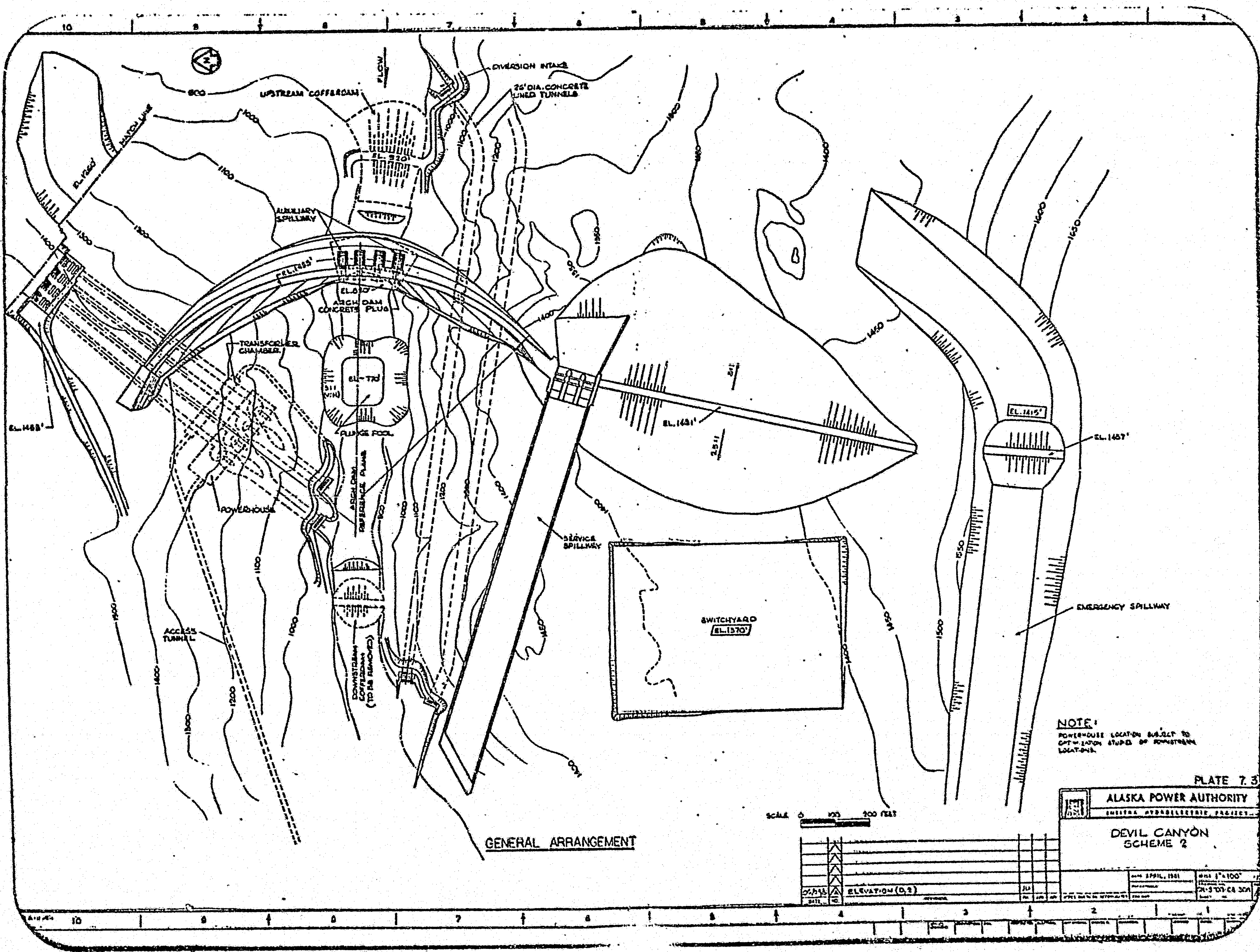
ALASKA POWER AUTHORITY

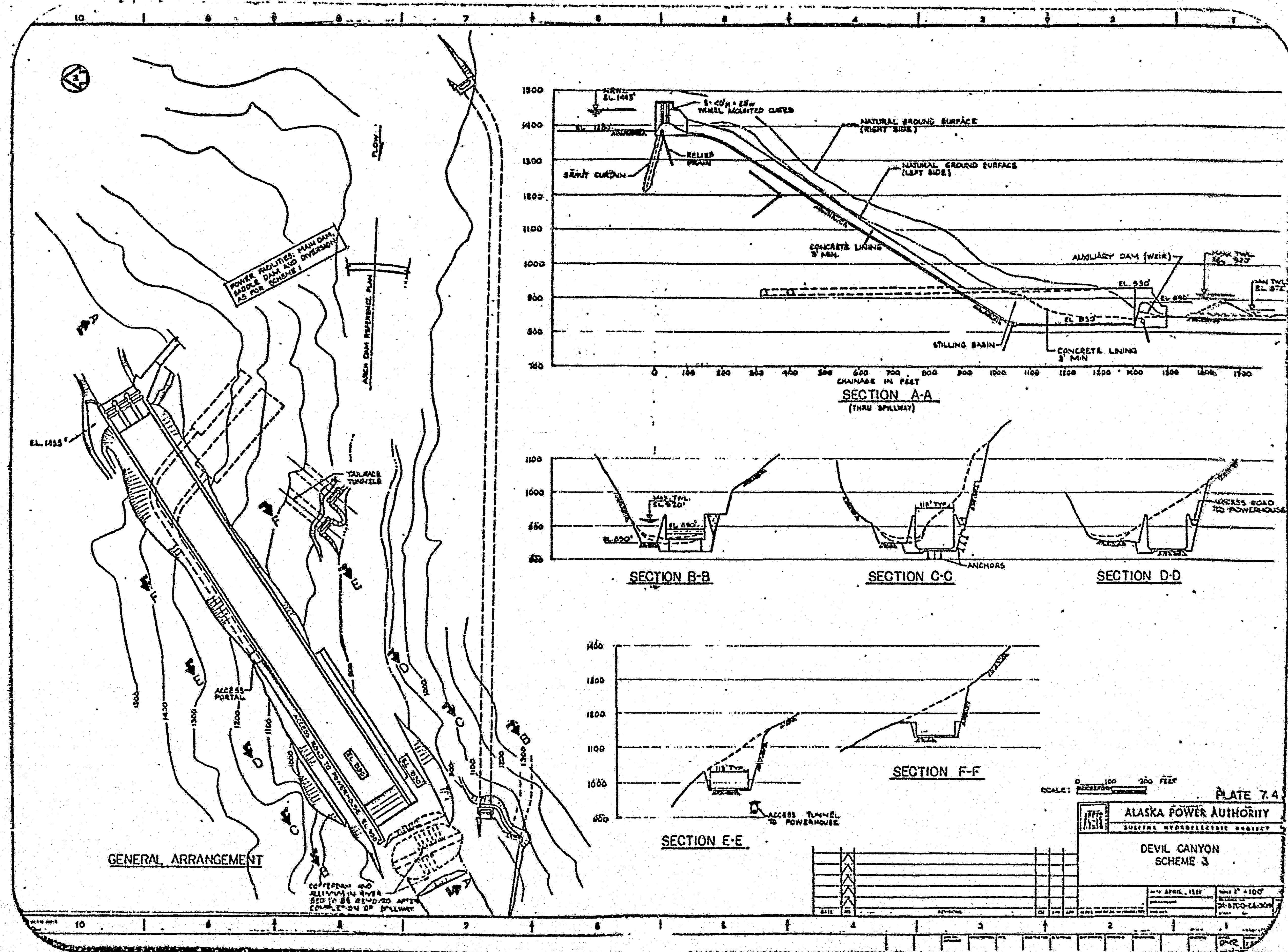
SUSITNA HYDROELECTRIC PROJECT

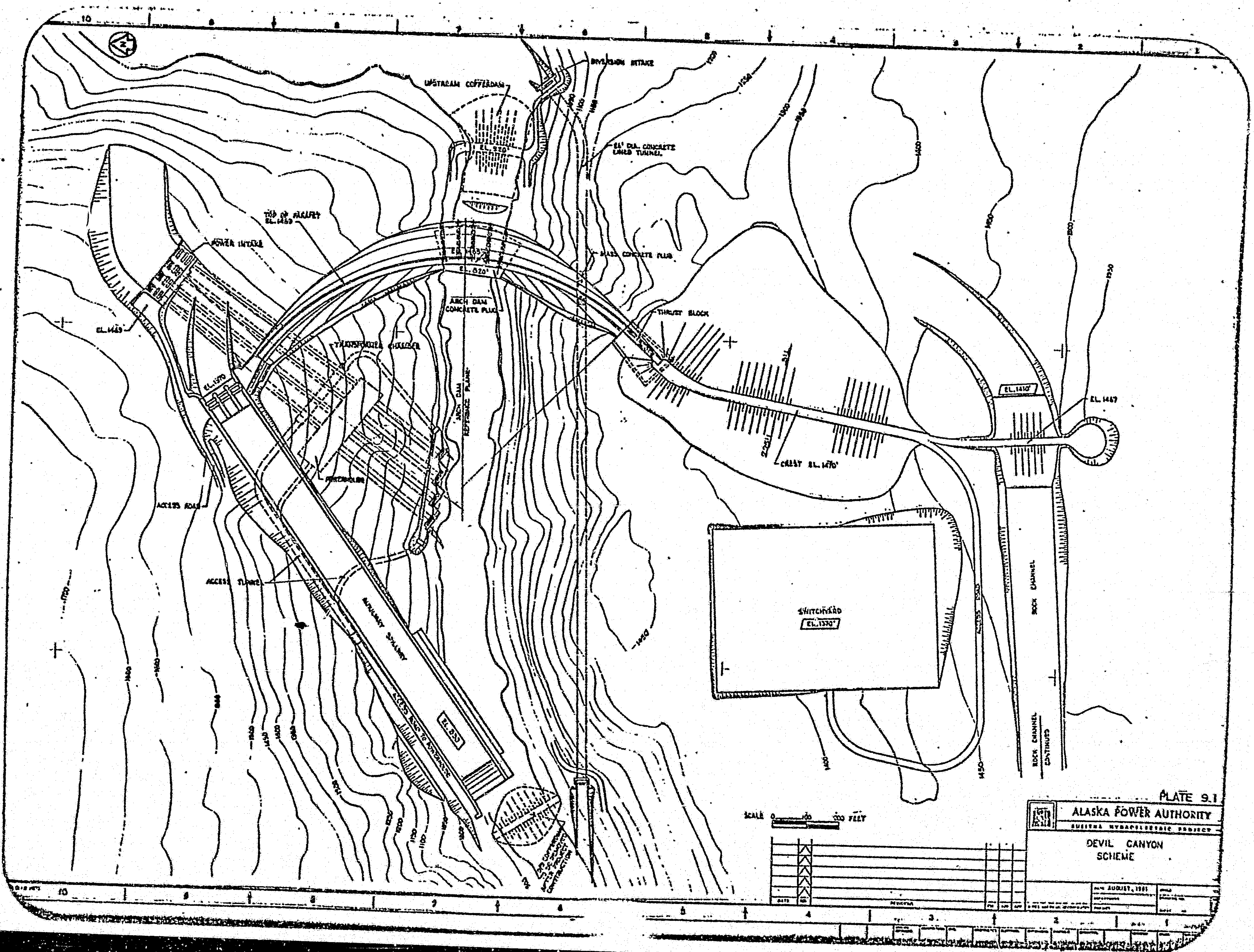
DEVIL CANYON
SCHEME I
PLAN AND SECTION



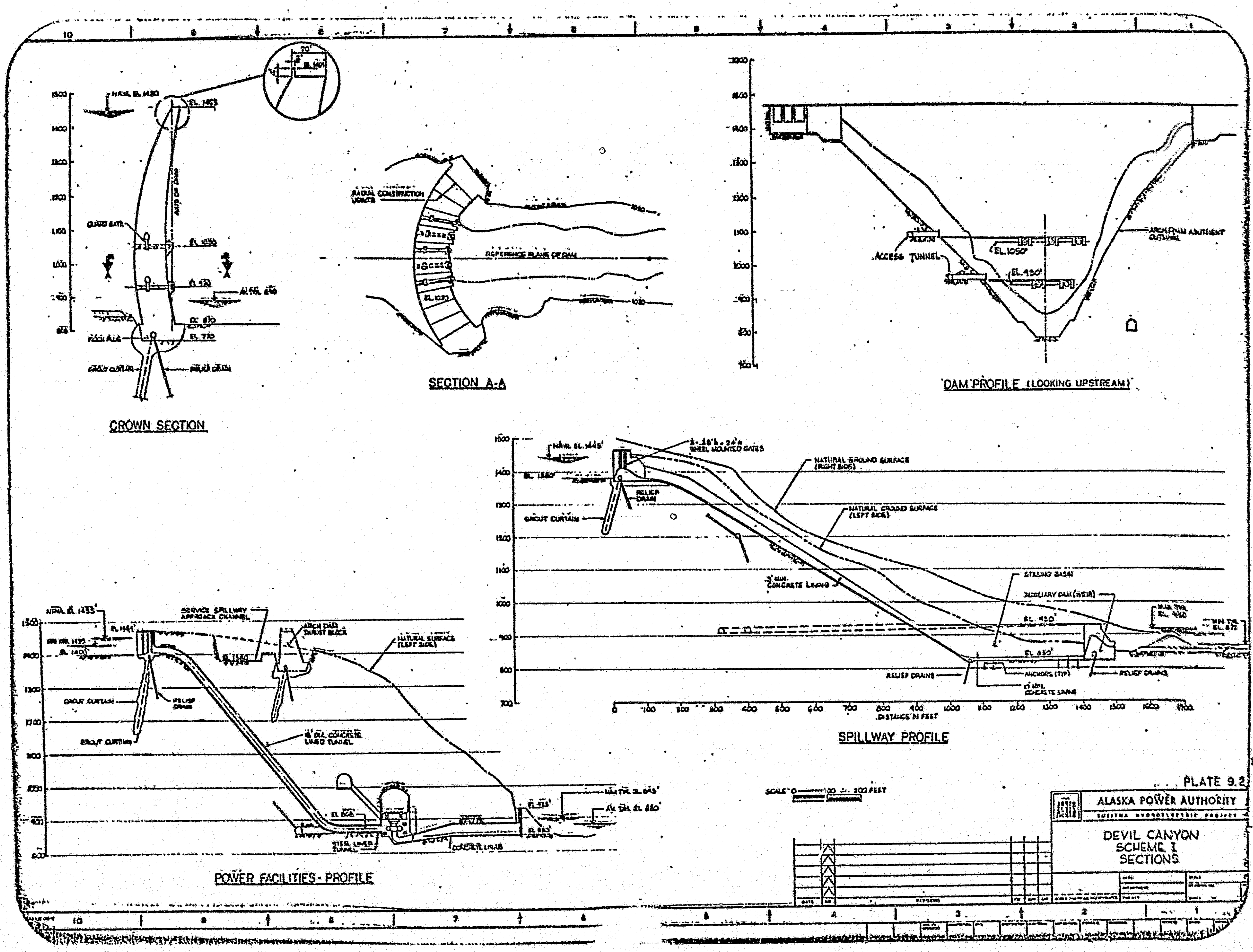
CROWN SECTION
NRWL EL. 1445'
EL. 1455'
EL. 1455'
EL. 820'
EL. 840'
AVG. TWL EL. 850'
EL. 860'
CONCRETE PLUG
CONCRETE LINED
DAM PROFILE (LOOKING UPSTREAM)
EL. 1459'
SPILLWAY CONTROL STRUCTURE
AUXILIARY SPILLWAY
SOUND BEDROCK SURFACE - UPSTREAM
SOUND BEDROCK SURFACE - DOWNSTREAM
DIVERSION TUNNELS
CONCRETE PLUG
SECTION THRU SPILLWAY
NRWL EL. 1445'
FIXED WHEEL GATES
NATURAL SURFACE (LEFT SIDE)
NATURAL SURFACE (RIGHT SIDE)
RELIEF DRAIN
GROUT CURTAIN
ROCK ANCHORS (TYP.)
EL. 925'
EL. 900'
AVG TWL EL. 850'
ALLUVIUM DREDGED OUT
SECTION THRU POWER FACILITIES
NRWL EL. 1445'
EL. 1459'
SERVICE SPILLWAY APPROACH CHANNEL
ARCH DAM THRUST BLOCK
EL. 1370'
MIN. OWL EL. 1300'
EL. 1265'
NATURAL SURFACE (LEFT SIDE)
NATURAL SURFACE (RIGHT SIDE)
GROUT CURTAIN
RELIEF DRAIN
18' DIA. CONCRETE LINED TUNNEL
CONCRETE LINING-2' 3/4 & STEEL LINING
AVG. TWL EL. 850'
NOTE:
NRWL ASSUMPTION OF 1445' BASED ON CSS. DESIGN DAM CREST LEVEL OF 1455', SUBJECT TO RESERVOIR LEVEL OPTIMIZATION.
SCALE 0 100 200 FEET
PLATE 7.2
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
DEVIL CANYON SCHEME 1 SECTIONS
APRIL, 1981
1"=100'

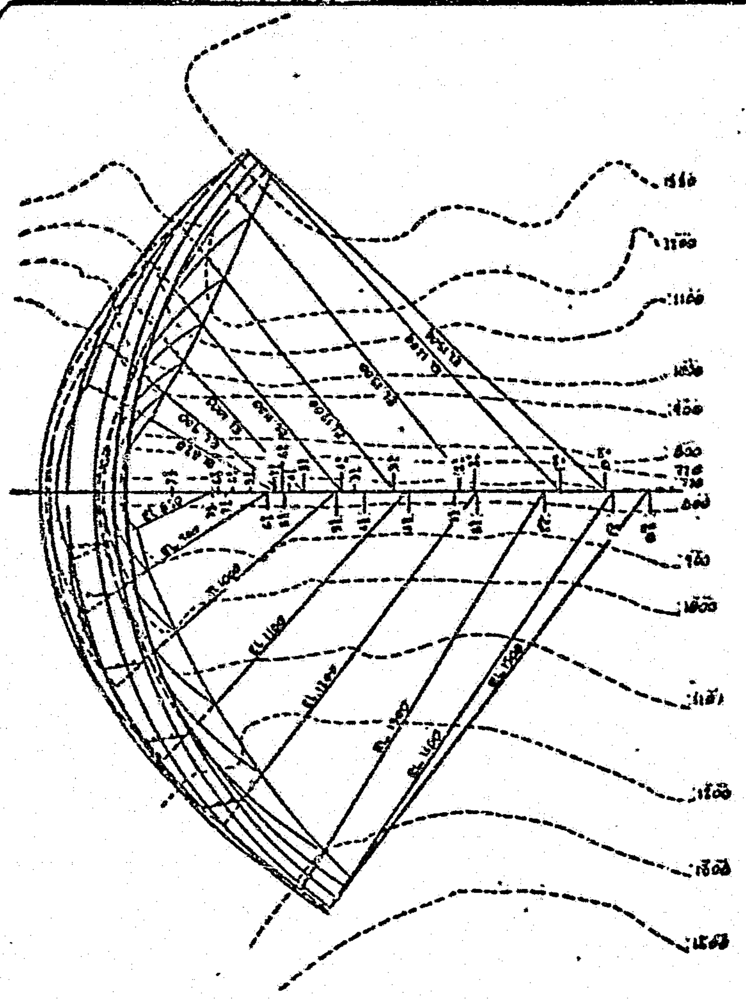

DIVERSION INTAKE
26' DIA. CONCRETE LINED TUNNELS
UPSTREAM COFFERDAM
FLOW
AUXILIARY SPILLWAY
EL. 1455'
ARCH DAM CONCRETE PLUG
TRANSFORMER CHAMBER
EL. 770'
PLUNGE POOL
ARCH DAM REFERENCE PLANE
POWERHOUSE
ACCESS TUNNEL
DOWNSTREAM COFFERDAM (TO BE REMOVED)
SERVICE SPILLWAY
EL. 1431'
SWITCHYARD
EL. 1370'
EL. 1415'
EL. 1457'
EMERGENCY SPILLWAY
EL. 1468'
NOTE:
POWERHOUSE LOCATION SUBJECT TO OPTIMIZATION STUDIES OF DOWNSTREAM LOCATIONS.
SCALE 0 100 200 FEET
GENERAL ARRANGEMENT
PLATE 7.3
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
DEVIL CANYON SCHEME 2
APRIL, 1981
ELEVATION (D,2)


GENERAL ARRANGEMENT
POWER FACILITIES; MAIN DAM, SADDLE DAM AND DIVERSION AS FOR SCHEME I
ARCH DAM REFERENCE PLAN
FLOW
EL. 1455'
TAILRACE TUNNELS
ACCESS PORTAL
ACCESS ROAD TO POWERHOUSE
COFFERDAM AND ALLUVIUM IN RIVER BED TO BE REMOVED AFTER COMPLETION OF SPILLWAY
SECTION A-A
(THRU SPILLWAY)
NATURAL GROUND SURFACE (RIGHT SIDE)
NATURAL GROUND SURFACE (LEFT SIDE)
GROUT CURTAIN
RELIEF DRAIN
CONCRETE LINING 3' MIN.
STILLING BASIN
AUXILIARY DAM (WEIR)
CHAINAGE IN FEET
SECTION B-B
SECTION C-C
ANCHORS
SECTION D-D
ACCESS ROAD TO POWERHOUSE
SECTION E-E
ACCESS TUNNEL TO POWERHOUSE
SECTION F-F
SCALE: 0 100 200 FEET
PLATE 7.4
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
DEVIL CANYON
SCHEME 3

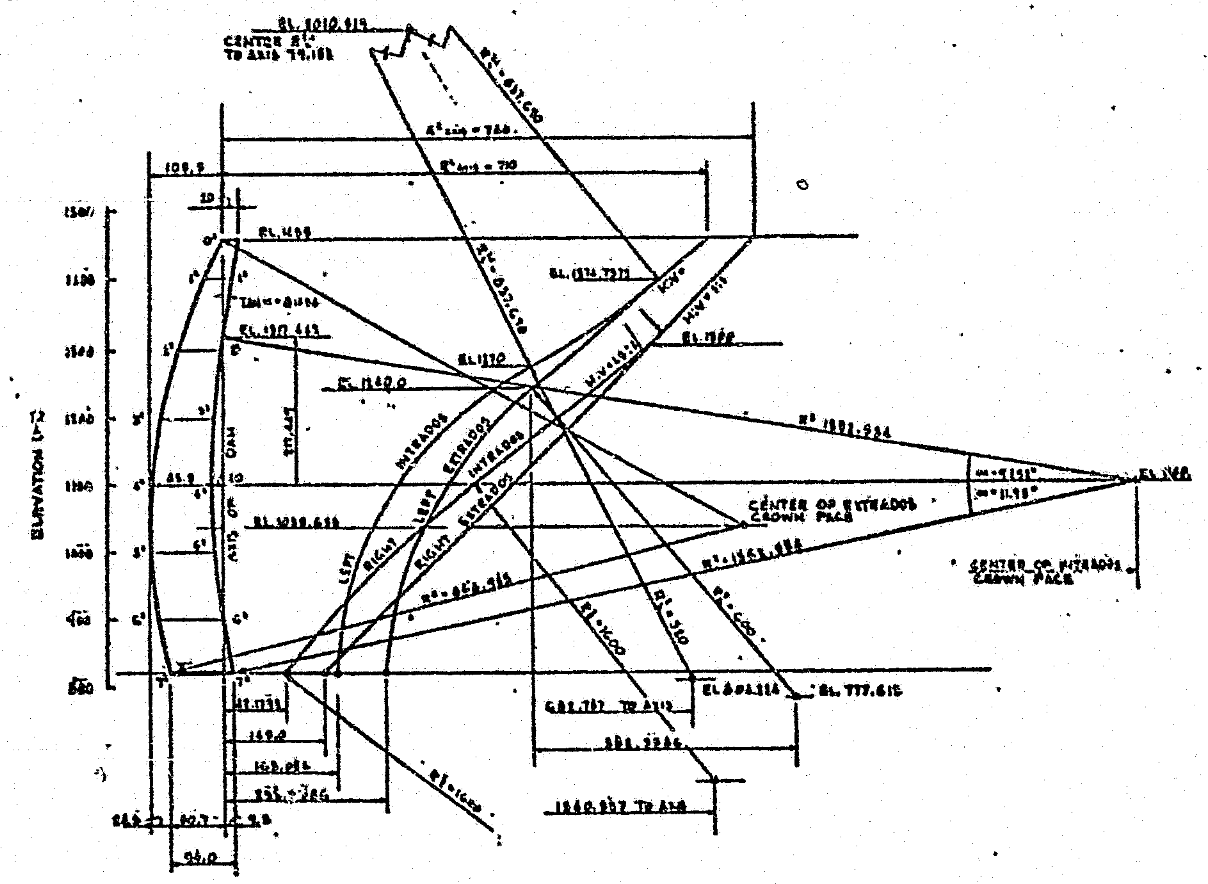


UPSTREAM COFFERDAM
DIVERSION INTAKE
POWER INTAKE
THRUST BLOCK
CREST EL. 1470'
SWITCHYARD
EL. 1370'
ROCK CHANNEL
ACCESS ROAD
PLATE 9.1
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
DEVIL CANYON
SCHEME
AUGUST, 1981


CROWN SECTION
SECTION A-A
DAM PROFILE (LOOKING UPSTREAM)
ACCESS TUNNEL
EL. 1050'
EL. 930'
SPILLWAY PROFILE
NATURAL GROUND SURFACE (RIGHT SIDE)
NATURAL GROUND SURFACE (LEFT SIDE)
GROUT CURTAIN
RELIEF DRAINS
DISTANCE IN FEET
POWER FACILITIES - PROFILE
SCALE 0 100 200 FEET
PLATE 9.2
ALASKA POWER AUTHORITY
DEVIL CANYON
SCHEME I
SECTIONS



PLAN OF ARCH



CROWN SECTION GEOMETRY

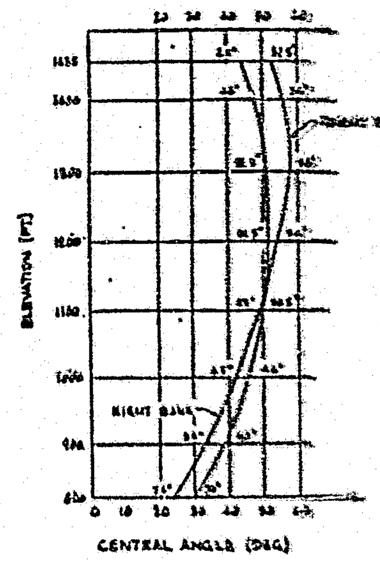


DIAGRAM OF CENTRAL ANGLES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

DEVIL CANYON
THIN ARCH DAM GEOMETRY

DEVIL CANYON ARCH DAM ANALYSIS (R. Ibbotson)

4 - DESIGN CRITERIA

4.1 - Material Properties

a) Concrete

Frost Resistance Concrete Strength (365 day)	5,000 psi
Unit Weight	150 lb/ft^3
Static Modulus of Elasticity (sustained)	3×10^6 psi
Dynamic Modulus of Elasticity (instantaneous)	5×10^6 psi
Poissons Ratio	0.2
Tensile Strength:	
Static (for estimating cracking only) 5% of strength	250 psi
Dynamic Flexural 15% of strength	750 psi
Thermal Properties:	
Conductivity	1.52 BTU/ft/hr/°F
Specific Heat	0.22 BTU/lb/°F
Coefficient of Thermal Expansion	5.6×10^{-6} ft/ft/°F
Diffusivity	0.046 ft^2/hr

b) Foundation Rock

Deformation Modulus (sustained)	2×10^6 psi
Poissons Ratio	0.2

4.2 - Temperatures (°F)

Air Temperature:

Mean Annual	28.9
High Mean Monthly	55.0
Low Mean Monthly	4.4
Highest Mean Monthly Maximum	63.8
Lowest Mean Monthly Minimum	-3.6

Highest Maximum	91.0
Lowest Minimum	-48.0
Lowest Difference Between Any Mean Monthly Maximum and the Corresponding Mean Monthly Minimum	-14.5

RESERVOIR WATER TEMPERATURE

Depth Below Surface (ft)	MONTH											
	4	5	6	7	8	9	10	11	12	1	2	3
0 - 50	32	32	46	57	53	45	39	32	32	32	32	32
70 to Reservoir Bottom	39	39	39	39	39	39	39	39	39	39	39	39

The effect of solar radiation has been at this stage neglected.

Grouting temperature of vertical construction joints: 39°F

4.3 - Earthquake

For maximum credible earthquake conditions two versions of the mean response spectra for the Penioff zone, developed by Woodward Clyde Consultants have been used.

Peak Ground Acceleration	Damping Factor
0.5 g	5%
0.4 g	10%

4.4 - Hydraulic Data

Reservoir Water Levels:

Normal Maximum	1,455 ft
*Normal Minimum	1,430 ft
1:10,000 Yr Flood Level	1,460 ft
Probable Maximum Flood	1,465 ft

Effect of tailwater, silt deposits, ice load, and uplift loads (internal pressure within the dam) have been neglected.

*This was assumed as 1,295 ft for stress calculations. However, minimum operating level has now been maintained at 1,430 ft from standpoint of firm energy considerations. Hence, this condition will be far less extreme.

4.5 - Loading Combinations:

a) Usual Loading Combination - Combination of basic loads that can simultaneously occur during time design life of the dam (self-weight, temperature and hydrostatic load condition.)

b) Unusual Loading Combination - Combination of loads that are possible, but which are unlikely to occur during the design life of the dam (probable maximum flood conditions.)

c) Extreme Loading Combination - Are related to earthquakes.

The loading combinations cases are given in Table 4.1.

4.6 - Factors of Safety:

a) Usual Loading Case UL-1, UL-2

- Compressive stresses - F.O.S. $\geq$ 4
- Tension stresses - not allowable.*

b) Usual Loading Case UL-3, UL-4, and Unusual Case

- Compressive stresses - F.O.S. $\geq$ 3
- Tension stresses not to exceed 250 psi.
- Tensile stresses above 250 psi are to be redistributed to other resistance mechanisms by local joint openings.

*These factors of safety correspond to the trial load method and are in line with the previous practice. They do not necessarily apply to other methods of analysis.

c) Extreme Loading Case EL-1, EL-2

- Compressive stresses - F.O.S. ≥ 1.
- Tension stresses exceeding the tensile strength of 750 psi are to be redistributed to other resistance mechanisms.

In case of horizontal tensile stresses across the arches the dam should be considered as a set of unrestrained cantilevers 50 percent of full height, because of opening vertical construction joints.

TABLE 4.1

Load Combination			Combination Class	USUAL				Unusual	Extreme	
			Combination Number	UL-1	UL-2	UL-3	UL-4	UNL-1	EL-1	EL-2
BASIC LOAD CASES	STATIC LOADS	DEAD LOAD		X	X	X	X	X	X	X
		Air and Reservoir Water Temperatures	February			X				
			April				X			
		Reservoir Water Levels	1,455	X		X			X	X
			1,465					X		
			1,295		X					
			1,430		X		X			
	DYNAMIC LOADS	Maximum Credible Earthquake	0.5 G 5% Damp.						X	
			0.4G 10 Damp.							X

5 - METHOD OF ANALYSIS

5.1 - General

The Arch Dam Stress Analysis System (ADSAS) program which is a computerized version of the trial load method, is used for static and earthquake dynamic analysis. In the analysis the arch dam is assumed to be a continuous structure. The dead load is applied in the cantilever direction (construction joints grouted at full height of sections).

The computer program SAP IV is used for the unrestrained crown cantilever analysis in cases where the dam is subjected to strong earthquake motions, causing opening of the upper part of vertical construction joints.

5.2 - Method of Definition of Loads

a) Temperature Load

The two-dimensional heat transfer program (heatflow) is used for determination of temperature distribution in the dam body.

The USBR Engineering Monography N34 is used for computation of the amplitude of the sinusoidal cycles,

(Annual, 15-Day and Daily). The temperature loads input into ADSAS are presented in Appendix A.

b) Hydrodynamic Load

The hydrodynamic pressure due to horizontal earthquake on the dam upstream face ("added mass") is defined by using Westergaards Formula

$$P_z = 7/8 \ a_n \gamma \sqrt{H_{1z}}$$

and is reduced to 60%, due to the effect of narrowness of the gorge, inclination of the dam face and water compressibility (see Appendix C.)

6 - ARCH DAM GEOMETRY

The arch dam abutments are founded on the sound bedrock of the canyon. The sound unweathered rock is determined as generally 40 feet below the bedrock surface and the foundation is trimmed so as not to cause an abrupt change in the dam profile and hence a concentration of stresses.

At the bottom of the valley, the dam sits on a massive concrete plug which can adjust to any disconformities of the bedrock at the valley floor without changing the geometry of the dam. Sound bedrock does not continue above approximately elevation 1350 feet on the left bank and a massive thrust block is constructed to take the thrust of the upper 100 feet of arches. A similar block is founded deep in the rock on the right side in order to preserve the symmetry of the dam profile.

The dam geometry is shown on Plate 6.2. It is a double curvature structure with the cupola shape of the crown cantilever defined by vertical curves of approximately 1352 feet and 869 foot radius. The horizontal arches are prescribed by varying radii moving along two pairs of center lines. The shorter radii of the intrados face cause a broadening of the arches at the abutment reducing the contact stresses. The dam reference plane is approximately central to the bottom of the valley and the two center configuration assign longer radii to the arches on the wider side of the valley thus providing comparable contact areas on both sides of the arches at the concrete/rock interface. The longer radii will also allow the thrust from the arches to be directed more into the abutment rather than parallel to the river. The net effect of this two center layout will be to improve the symmetry of the stresses right across the dam.

The crown cantilever is 635 feet high. It is 20 feet thick at the crest and 90 feet thick at the base. The bottom mass concrete plug is 50 feet high. The slenderness coefficient of the arch is equal to 90/635 = 0,142 and the radii of the dam axis at crest level are 710 feet and 780 feet for the left and right angles of the dam, respectively. The central angles vary between 51.5 DEG at El. 1300 and 25 DEG at the base for the left side of the arch dam and 58 DEG to 30 DEG for the right side. The ratio of crest length to height for the dam is 1260:635 = 1.98:1 (thrust blocks not included).

The left bank thrust block is 105 feet high and 170 feet long at the base. The right bank thrust block has a maximum height of 100 feet and a length of 155 feet and is adjacent to the spillway control structure, which will behave as a continuation of the thrust block, transferring the thrust directly into the rock.

7 - STATIC LOAD CONDITIONS

7.1 - Dead Load

In all analyses, the vertical construction joints within the dam are assumed to be ungrouted and hence the weight of the dam is considered as confined within the cantilevers, with no distribution through the arches, and directed vertically downwards into the foundation.

7.2 - Hydrostatic

Hydrostatic loadings induced by the reservoir at specified levels were considered in all load combinations. The effect of tailwater and uplift pressures will have little effect on the overall stresses and are not considered at this time.

7.3 - Temperature

(a) Solar Radiation

The dam orientation, running north-south, and the narrow valley will cause solar radiation to have only minor effects on concrete temperatures and hence stresses from radiation will be neglected at this time.

(b) Air Temperatures

Because of absence of temperature records, temperatures at the Devil Canyon site have been interpolated from records taken at two stations: Summit (El. 2405 feet) and Talkeetna (El. 345 feet). The stations are equidistant from Watana and their average altitude is similar to river level at Watana. The temperatures from the two stations were averaged to obtain the following temperatures at the dam site:

AMBIENT AIR TEMPERATURE (°F)

Mean Annual	28.9
High Mean Monthly	55.0
Low Mean Monthly	4.4
Highest Mean Monthly Maximum	63.8
Lowest Mean Monthly Minimum	-3.6
Highest Maximum	91.0
Lowest Minimum	-48.0
Lowest Difference between any Mean Monthly Maximum and the Corresponding Mean Monthly Minimum	14.5

Three sinusoidal temperature cycles - annual, 15-day and daily are developed based on USBR ENG MONOGRAPH No. 34.

The temperatures obtained are as follows:

	EXTREME CONDITIONS		USUAL CONDITIONS	
	Above Mean (DEGF)	Below Mean (DEGF)	Above Mean (DEGF)	Below Mean (DEGF)
Annual	26.1	24.5	26.1	24.5
15-day	28.8	42.15	15.15	22.95
Daily	7.25	7.25	7.25	7.25

(c) Reservoir Water Temperature

Average monthly reservoir temperatures are given below. Temperatures throughout the top 50 feet are as shown and below 50 feet they vary lineraly to 39°F at a depth of 70 feet.

Month	Top 50 ft (°F)	Below 70 ft From Surface (°F)
April	32	39
May	32	
June	46	
July	57	
August	53	
September	45	
October	39	
November	32	
December	32	
January	32	
February	32	
March	32	39

(d) Grouting Temperature

On account of the cold climate and the possibility of freezing, grouting temperature was selected at 39°F, as low as considered practicable, in order to reduce tension in the dam induced by shrinkage at lower temperatures.

(e) Temperature Distribution

The temperature distribution in the dam body was determined using the two dimensional heat transfer program "HEATFLOW" obtained from the U.S. Department of the Interior (formerly USBR) and was input as a uniform temperature combined with a linear distribution as described in Appendix A.

7.4 - Load Combinations

Static analyses were performed for the following normal loading combinations:

UL-1 - Hydrostatic and dead loads at normal reservoir level 1445 feet

UL-2 - Hydrostatic and dead loads at maximum drawdown reservoir level 1295 feet

UL-3 - The same as UL-1 plus temperature (February)

UL-4 - The same as UL-2 plus temperature (April)

UL-1 and UL-2 Conditions

The cantilever and arch stresses along the face of the dam are shown in Figures B7-1 to B7-4 in Appendix B. In both the arch and cantilever directions, the entire structure is in compression and below the allowable stress of 1250 psi, except for a few isolated areas where small tensile stresses occur. Maximum (compression) and minimum (tension) stress for conditions Ul-1 an UL-2 are shown in Table 7.1.

The arch and cantilever stresses for loading combinations UL-3 and UL-4 are shown in Figures 7.5 to 7.12.

The maximum and minimum stresses along the rock/concrete interface and in the dam above the foundation are given in Table 7.2.

7.5 - Conclusion

(1) Under hydrostatic loading, minor isolated tensile stresses occur up to a maximum of 97 psi.

(2) In both cases with temperature loadings UL-3 and UL-4, the compressive stresses are below the allowable limit.

(3) In UL-3 case, tensile stresses are acting in isolated areas. The tensile stresses is possible to eliminate by refining the shape of the arch.

(4) In UL-4 case, the crest of the dam is in the arch direction subjected to almost axial tension. Tensile stresses up to 200 psi are found at the whole height of the crown downstream face.

Prevention of these tensile stresses is possible only by application of special measures such as:

- Low closure temperatures at the upper part of the arch which may be obtained by using closure slots between adjacent blocks filled up with concrete in spring time when the blocks are at minimum temperature.

- Thermal insulation of the downstream face.

- Prestressing the upper part of the dam by means of flat jacks.

TABLE 7.1

EXTREME MAGNITUDES OF STRESSES AT ROCK/CONCRETE INTERFACE

Loading Combination (stresses in psi)

	UL-1	UL-2
Arch		
Max	792 (D. El 1100)	432 (U El 900)
Min	23 (U. El 1000)	3 (U El 1000)
Cantilever		
Max	722 (D. El 820)	760 (U El 900)
Min	-27 (D El 1370)	-97 (D El 1200)
Principal		
Max	1049 (D. 1000)	
Min	-140 (D. 900)	

- indicates tension
D indicates downstream face
U indicates upstream face

MAXIMUM STRESSES IN DAM ABOVE FOUNDATION

	UL-1	UL-2
Arch		
Max	958 (U El 1100)	548 (U El 1000)
Min	182 (D El 1000)	-36 (D El 1370)
Cantilever		
Max	575 (D El 1000)	542 (U El 1000)
Min	0 (D El 1370)	-44 (U El 1295)

TABLE 7.2

EXTREME MAGNITUDES OF STRESS

ALONG ROCK/CONCRETE INTERFACE

Loading Combination

	UL-3 (point)	UL-4 (point)
Arch		
Max	747 (U El 900)	381 (D 1100)
Min	-182 (U El 1455)	-157 (D 900)
Cantilever		
Max	689 (D El 820)	804 (U El 900)
Min	-393 (D El 1370)	-281 (D El 1455)

EXTREME MAGNITUDES OF STRESSES

IN DAM ABOVE FOUNDATION

Loading Combination

	UL-3 (point)	UL-4 (point)
Arch		
Max	1180 (U El 1200)	717 (U El 1100)
Min	-134 (D El 1000) (U El 1455)	-268 (U El 1455)
Cantilever		
Max	515 (U El 900)	608 (U El 1000)
Min	-75 (D El 1370)	-62 (U El 1295)

8 - DYNAMIC ANALYSES

Preliminary assumptions for purposes of analysis are as follows:

The assumed response spectra input to ADSAS is from Figure 3-4 of the Woodward Clyde Draft Report "Preliminary Earthquake Ground Motion Studies for the Proposed Susitna Hydroelectric Project". The mean response spectra for the Benioff zone is scaled up to 0.5g peak from 0.37g. The damping ratio is five percent. The response spectrum is shown in Figure 8.1. The response spectrum analysis was initially attempted for 1 to 20 modes. A larger displacement mode was encountered on mode 19. The high displacement induced unreasonable stresses in the dam and therefore made the results useless. The problem was re-analyzed using 14 modes of vibration.

The response spectrum analysis assumed an instantaneous concrete modulus of 5,000,000 psi.

The results of positive and negative earthquake are presented in the following tables. The load combinations are hydrostatic and grvity ± earthquake and hydrostatic + gravity + uniform and linear temperature ± earthquake:

Table 8.1 - Response Sectrum Analysis - Arch Stresses
Table 8.2 - Crown Cantilever Stresses

The resultant tensile stresses of 2580 psi and 729 psi in the arch and cantilevers, respectively, are greatly in access of the allowable tensile stress of 500 psi.

The results of a dynamic analysis of Devil Canyon Arch Dam based on a 0.4g peak ground acceleration, 10% damping, the Woodward Clyde Consultants response spectrum (see Figures 8.2) and using the ADSAS program are shown on Figures B.15 and B.16. For comparison, the results of dynamic analyses for a peak ground acceleration 0.5g and 5% damping are presented on Figures B.13 and B.14

The change of earthquake parameters to 0.4g and 10% damping has reduced the compressive, tensile and shear stresses at all points on the dam faces by a factor of 1.58 compared to the 0.5g acceleration and 5% damping case.

The case of upstream ground movement (hydrostatic, gravity and earthquake loads), the maximum cantilever tensile stress at the upstream face dropped from 729 psi to 427 psi (at elevation 1285 feet on the crown cantilever). The maximum compressive arch stresses at the upstream face (crown El. 1370) dropped from 3657 psi to 2551 psi. Stresses on the downstream face are much lower than on the upstream.

Downstream ground movement (hydrostatic and gravity minus earthquake load) shows extremely high tensile stresses across the arches (see Table 8.3). The stresses computed are not realistic. As discovered by field observations and model tests on other projects, earthquake induced ground movement in the downstream direction causes the radial construction joints at the upper part of an arch dam to open. The tension induced in the upper part of these arches is relaxed and the dam evolves into a set of independent, unrestrained cantilevers, deflecting freely in the upstream direction.

In order to accord more closely with the actual behavior of the Devil Canyon Arch Dam, when subjected to strong earthquake motions, dynamic analyses on the unrestrained crown cantilever were performed using the computer program SAPIV.

Model test on other arch dams with simulated radial construction joints, performed by "ISMES" have shown that opening of the joints take place over the top 1/3 to 1/2 (depending on the narrowness at the gorge) of the dam, while the lower part remained intack.

The analyses are based on:

(1) The Woodward Clyde Consultants response spectrum curves for the Benioff zone with peak ground accelerations of 0.5g and 0.4g and damping rates of 5% and 10%.

(2) The hydrodynamic stress distribution as proposed by Westerguard approach and reduced to 60% due to the effect of narrowness of the gorge, inclination of the dam upstream face and water compressibility (see Appendix C).

(3) Full reservoir water level 1445 feet computer program for dynamic analysis has been used.

The following combinations of earthquake parameters have been examined:

Peak Ground Acceleration "G"	Damping Ratio (Percent)	Added Mass (Percent)
0.5	5	100
		60
	10	100
		60
0.4	5	100
		60
	10	100
		60

The results of the cantilever dynamic analysis are as follows:

(1) The natural period of vibration "T" is 0.62 sec, 0.15 sec and 0.09 sec. (Various magnitudes of acceleration and added mass have little effect). For comparison, a full height cantilever, which is slender, has been computed. The periods were found 2.42 sec, 0.49 sec and 0.20 sec. The stresses in the upper part of the arch in this case were smaller than in the short cantilever.

(2) The stresses due to hydrostatic and gravity and dynamic loads are presented separately and in combinations. In Tables 8.4 and 8.5 and in Figure 4, maximum tensile stresses of 880 psi at the downstream face were obtained in the case of 0.5g, 5% damping and full Westergaard's added mass at 170 feet below crest level. Compressive stresses at the upstream face at that level are 1100 psi. The maximum tensile stresses in case of 0.5g, 10% damping and 60% of Westergaard's added mass are equal to 451 psi.

The change of damping from 5% to 10% decreases the maximum tensile stresses approximately 1.6 times. The application of 60% added mass instead of full Westergaard's provides a reduction of the maximum tensile stresses of about 25%.

In all combinations of dyanmic loads considered, the tensile stresses at the base of cantilever have changed to compressive (except of case 0.5g, 5% damping and full added mass, where tension is reduced to 55 psi) (Figure 8.4).

In the case of 0.4g, ground acceleration, the maximum tensile stresses at the downstream face of cantilever dropped to 509 psi 120 feet below the crest with 5% damping and full added mass, and to 272 psi with 10% damping and 60% added mass.

The effects of the change in damping and added mass are approximately the same as in the case of 0.5g acceleration.

TABLE 8.1

RESPONSE SPECTRUM ANALYSIS

i) Arch at Elv. 1455'

STATION	FACE	HYDRO + GRAVITY	HYDRO + GRAVITY + EQ	HYDRO + GRAVITY-EQ	HYDRO + GRV + TEMP + EQ	HYDRO + GRV + TEMP - EQ
1000	E	467	3404	-2470	3294	-2580
	I	313	1943	-1630	1784	-1476
1143	E	516	3229	-2197	3122	-2304
	I	307	2304	-1690	2146	-1848
1259	E	484	2948	-1980	2843	-2085
	I	366	2749	-2017	2611	-2155
1393	E	406	2498	-1686	2383	-1801
	I	438	3019	-2143	2896	-2266
1526	E	324	2033	-1385	1877	-1541
	I	417	2566	-1732	2376	-1922
1638	E	303	1591	- 985	1356	-1220
	I	342	2232	-1548	1962	-1818
1711	E	274	2513	-1965	2105	-2373
	I	576	2409	-1257	2465	-1201
1714	E	267	2574	-2040	2125	-2409
	I	607	2478	-1267	2596	-1146

TABLE 8.1

RESPONSE SPECTRUM ANALYSIS

ii) Arch at Elev. 1370'

STATION	FACE	HYDRO + GRAVITY	HYDRO + GRV + EQ	HYDRO + GRV - EQ	HYDRO + GRV + TEMP + EQ	HYDRO + GRV + TEMP - EQ
1000	E	642	3657	-2373	4119	-1911
	I	255	949	-439	697	-691
1143	E	707	3222	-1808	3677	-1353
	I	258	1597	-1081	1355	-1323
1259	E	593	2461	-1275	2884	-852
	I	396	2247	-1455	2021	-1681
1393	E	416	1634	-802	2006	-430
	I	518	2558	-1522	2323	-1757
1526	E	295	1188	-598	1511	-275
	I	498	2383	-1387	2111	-1659
1638	E	206	1071	-659	1297	-433
	I	413	1979	-1153	1733	-1399
1711	E	110	1220	-1000	1266	-954
	I	374	1449	-701	1345	-805

TABLE 8.2

RESPONSE SPECTRUM ANALYSIS

CROWN CANTILEVER

ELEV.	FACE	HYDRO + GRAVITY	HYDRO + GRAVITY + EQ	HYDRO + GRAVITY-EQ	HYDRO + GRV + TEMP + EQ	HYDRO + GRV + TEMP - EQ
1455	U	0	0	0	0	0
	D	0	0	0	0	0
1370	U	109	-581	799	-564	816
	D	56	653	-561	658	-576
1285	U	98	-729	925	-655	999
	D	222	1021	-577	950	-648
1200	U	71	-629	771	-508	892
	D	402	1111	-307	988	-430
1100	U	102	-435	639	-282	792
	D	544	1110	-22	948	-184
1000	U	223	-142	638	-31	799
	D	575	1026	124	851	-51
900	U	383	-19	785	113	917
	D	539	988	90	842	-56
820	U	305	-402	1012	-373	1041
	D	722	1541	-97	1508	-130

TABLE 8.3

EARTHQUAKE	ELEVATION OF ARCH (FT.)	FACE OF DAM	DISTANCE ALONG THE ARCH (FT) CROWN 0	143	394	638	ABUTMENT 714
0.5G	1455	U	-2470	-2197	-1686	-985	-2040
		D	-1630	-1690	-2143	-1548	-1267
5% Damp.	1370	U	-2373	-1808	-803	-659	-1000
		D	-439	-1081	-1522	-1153	-701
0.4G	1455	U	-1392	-1203	-919	-512	-1149
		D	-720	-957	-1196	-855	-757
10% Damp.	1370	U	-1267	-887	-355	-341	-592
		D	-185	-589	-774	-578	-306

Table 8.4

DEVIL CANYON ARCH DAM RESULTS OF SINGLE CANTILEVER DYNAMIC
ANALYSIS FOR 0.5 G PEAK GROUND ACCELERATION

		Stresses Due to Static Loads (Hydrostatic & Gravity) (psi)		Stresses Due to Earthquake Loads (Concrete Inertia & Added Mass of Water - Wester Gaard)				Resultant Stresses at Downstream Face (psi)				Resultant Stresses at Upstream Face (psi)			
				100% Added Mass		60% Added Mass		100% Added Mass		60% Added Mass		100% Added Mass		60% Added Mass	
Node	Elevation (ft)	Upstream Face	Downstream Face	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp
2	1428	-5	29	± 180	± 144	± 177	± 141	-151	-114	-148	-112	175	139	172	136
3	1375	-72	148	∓ 760	∓ 604	∓ 685	∓ 546	-612	-456	-537	-398	688	532	613	474
4	1322	-265	405	∓1210	∓ 960	∓1075	∓ 856	-805	-555*	-670	-451*	945	695°	810	591°
5	1269	-530	750	∓1630	∓1300	∓1450	∓1150	-880*	-550	-700*	-400	1100°	770	920°	620
6	1216	-930	1230	∓2060	∓1635	∓1823	∓1440	-830	-405	-593	-210	1135	705	893	510
7	1163	-1495	1885	∓2620	∓2081	∓2300	∓1825	-735	-196	-415	60	1125	536	805	330
8	1110	-2295	2785	∓2840	∓2255	∓2490	∓1570	-55	530	205	315	545	-70	195	-325

Notes: 1. Resultant stresses are computed for dynamic loads applied upstream

2. "*" indicates maximum tensile stresses; "°" indicates corresponding compressive stresses at the opposite side of the same level.

3. (-) indicates tension.

Table 8.5

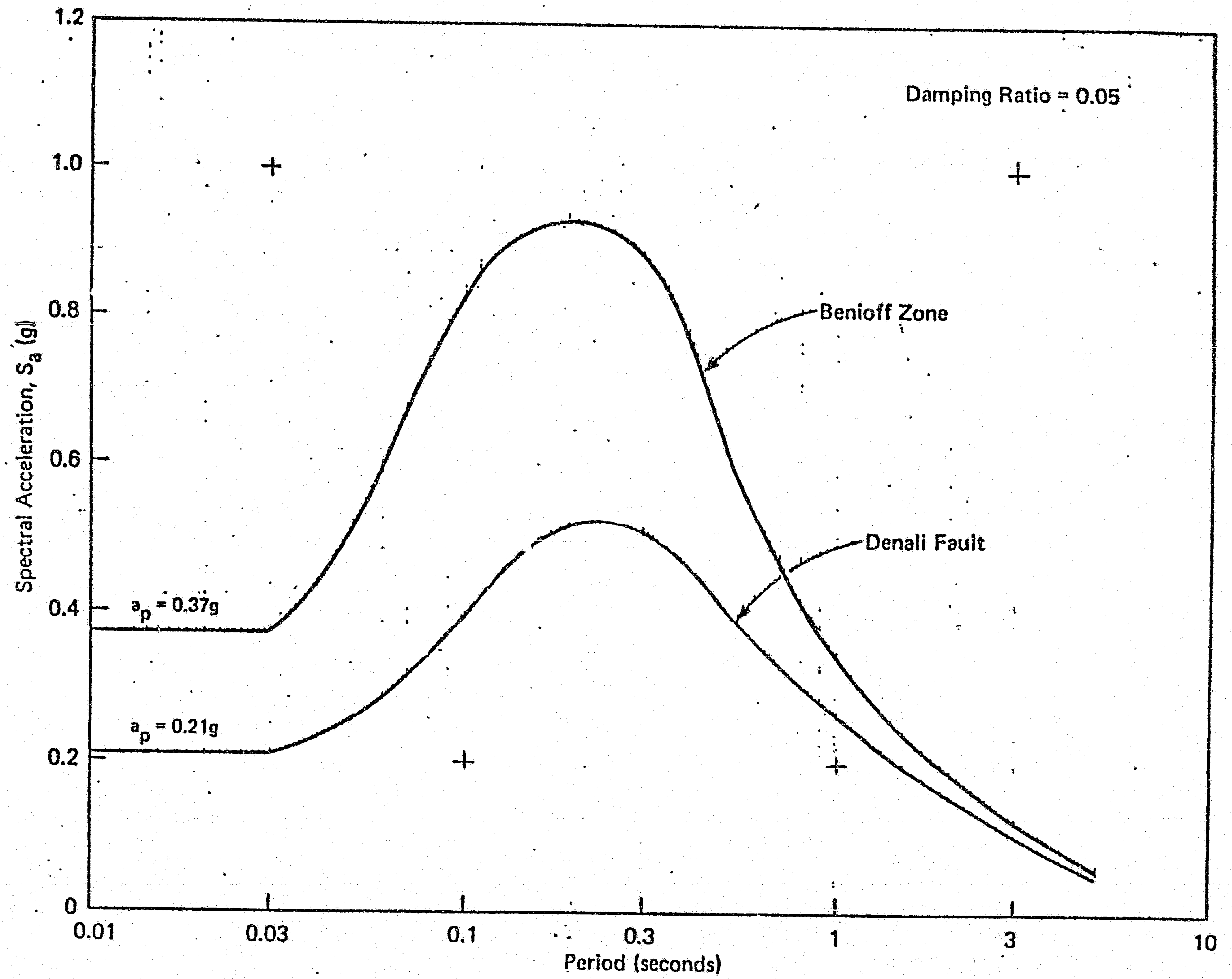
DEVIL CANYON ARCH DAM RESULTS OF SINGLE CANTILEVER DYNAMIC
ANALYSIS FOR 0.4 G PEAK GROUND ACCELERATION

		Stresses Due to Static Loads (Hydrostatic & Gravity) (psi)		Stresses Due to Earthquake Loads (Concrete Inertia & Added Mass of Water - Wester Gaard)				Resultant Stresses at Downstream Face (psi)				Resultant Stresses at Upstream Face (psi)			
				100% Added Mass		60% Added Mass		100% Added Mass		60% Added Mass		100% Added Mass		60% Added Mass	
Node	Elevation (ft)	Upstream Face	Downstream Face	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp	5% Damp	10% Damp
2	1425	-5	29	± 143	± 114	± 140	± 112	-114	-85	-111	-83	138	109	135	107
3	1375	-72	148	± 577	± 459	± 528	± 420	-429	-311	-380	-272*	505	382	456	348°
4	1322	-265	405	± 914	± 727	± 826	± 656	-509*	-322*	-421*	-251	649°	462°	561°	391
5	1269	-530	750	±1233	± 977	±1110	± 885	-483	-227	-360	-135	703	447	580	355
6	1216	-930	1230	±1547	±1230	±1394	±1105	-317	0	-164	125	617	300	464	175
7	1163	-1495	1885	±1971	±1560	±1750	±1390	-86	325	135	495	476	65	255	-105
8	1110	-2295	2795	±2130	±1692	±1897	±1504	655	1093	888	1381	-165	-603	-398	-791

Notes: 1. Resultant stresses are computed for dynamic loads applied upstream

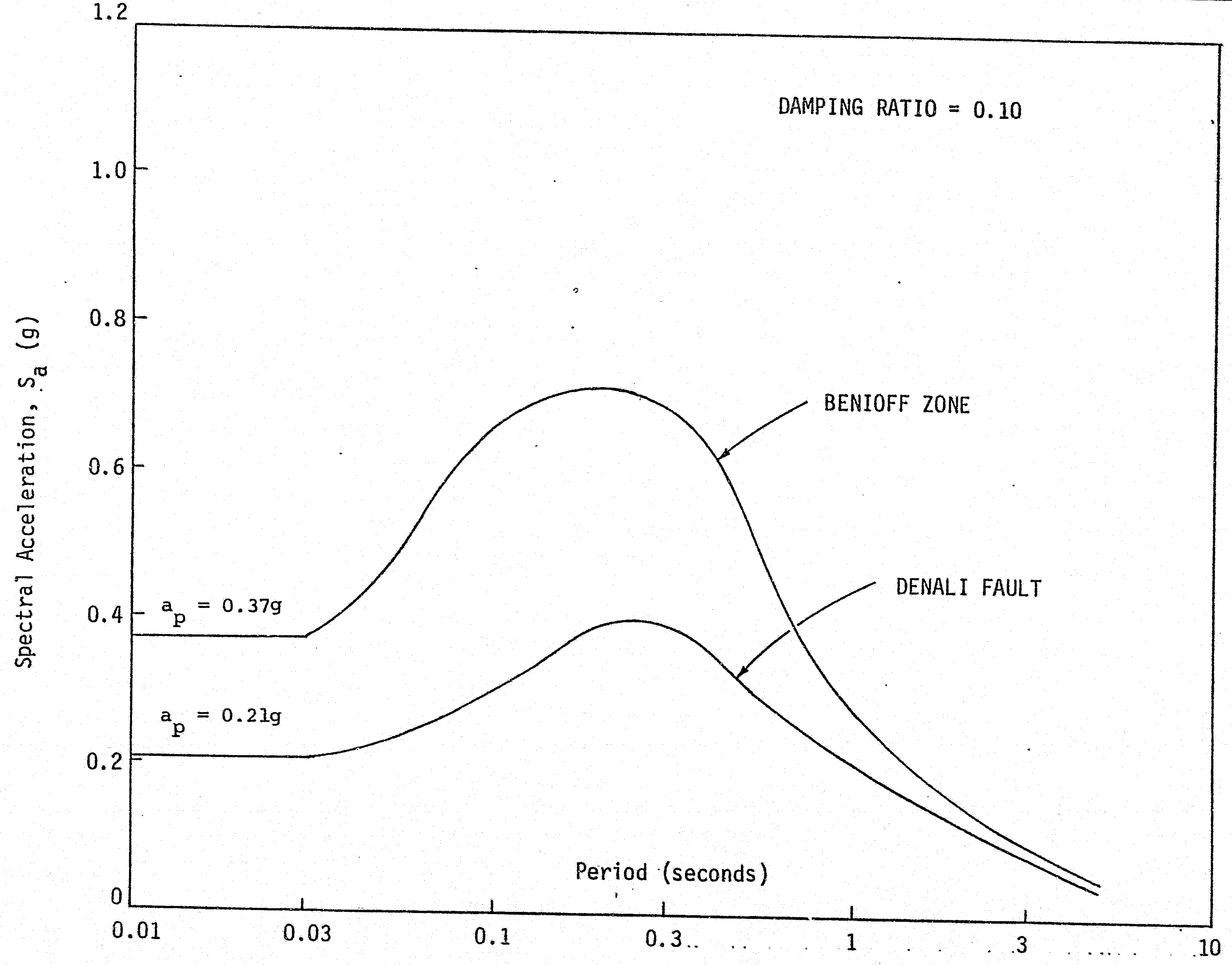
2. "*" indicates maximum tensile stresses; "°" indicates corresponding compressive stresses at the opposite side of the same level.

3. (-) indicates tension.



MEAN RESPONSE SPECTRA AT THE DEVIL'S CANYON SITE FOR MAXIMUM EARTHQUAKES ON KNOWN ACTIVE FAULTS

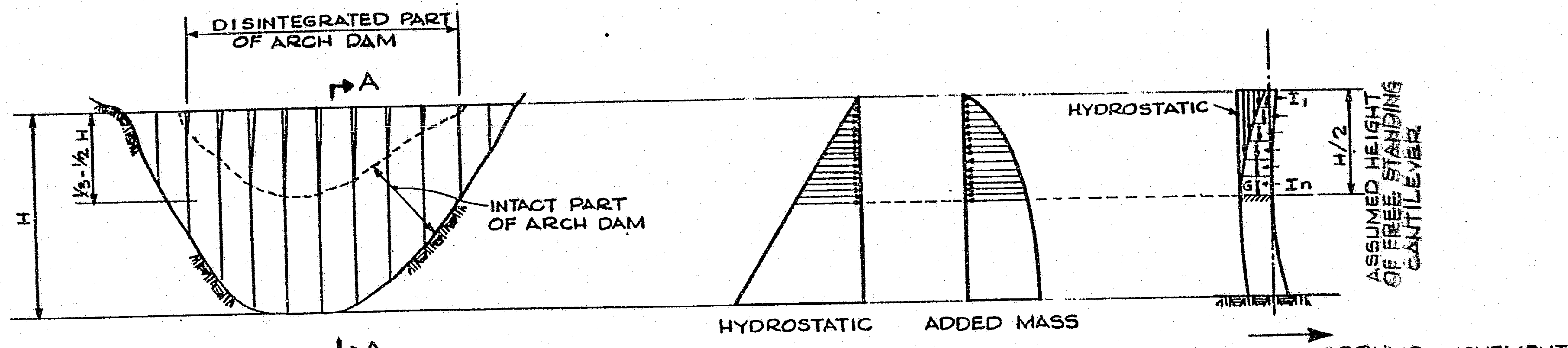
Figure 8.1



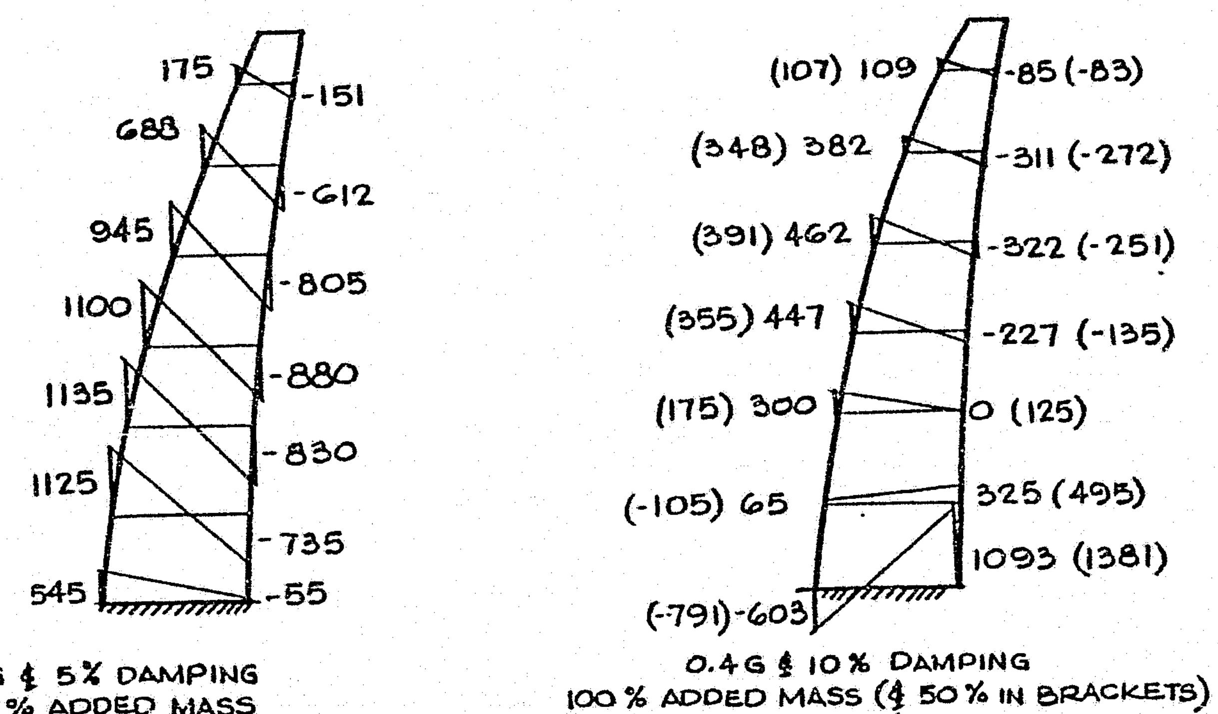
Prepared by Acres, 6/4/81 from data provided by M. Powers, WCC

MEAN RESPONSE SPECTRA AT THE DEVIL CANYON SITE FOR MAXIMUM EARTHQUAKES ON KNOWN ACTIVE FAULTS

Figure 8.2



ASSUMED SCHEME OF ANALYSIS



CANTILEVER STRESSES (PSI)

SECTION A-A

NOTE:

⊖ (MINUS) INDICATES TENSILE STRESS.

⊕ (PLUS) INDICATES COMPRESSIVE STRESS.

DEVIL CANYON ARCH DAM

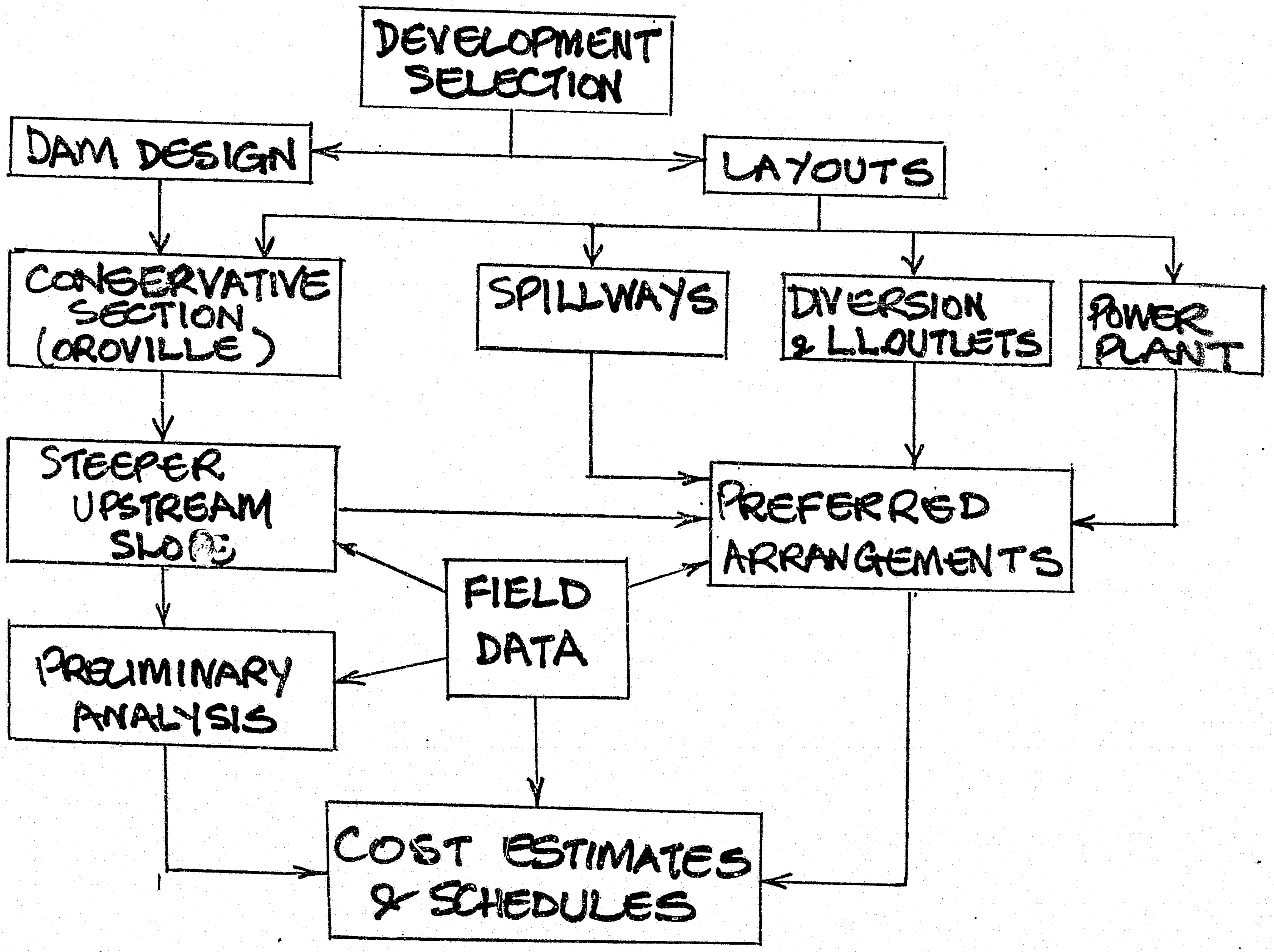
EARTHQUAKE DYNAMIC ANALYSIS

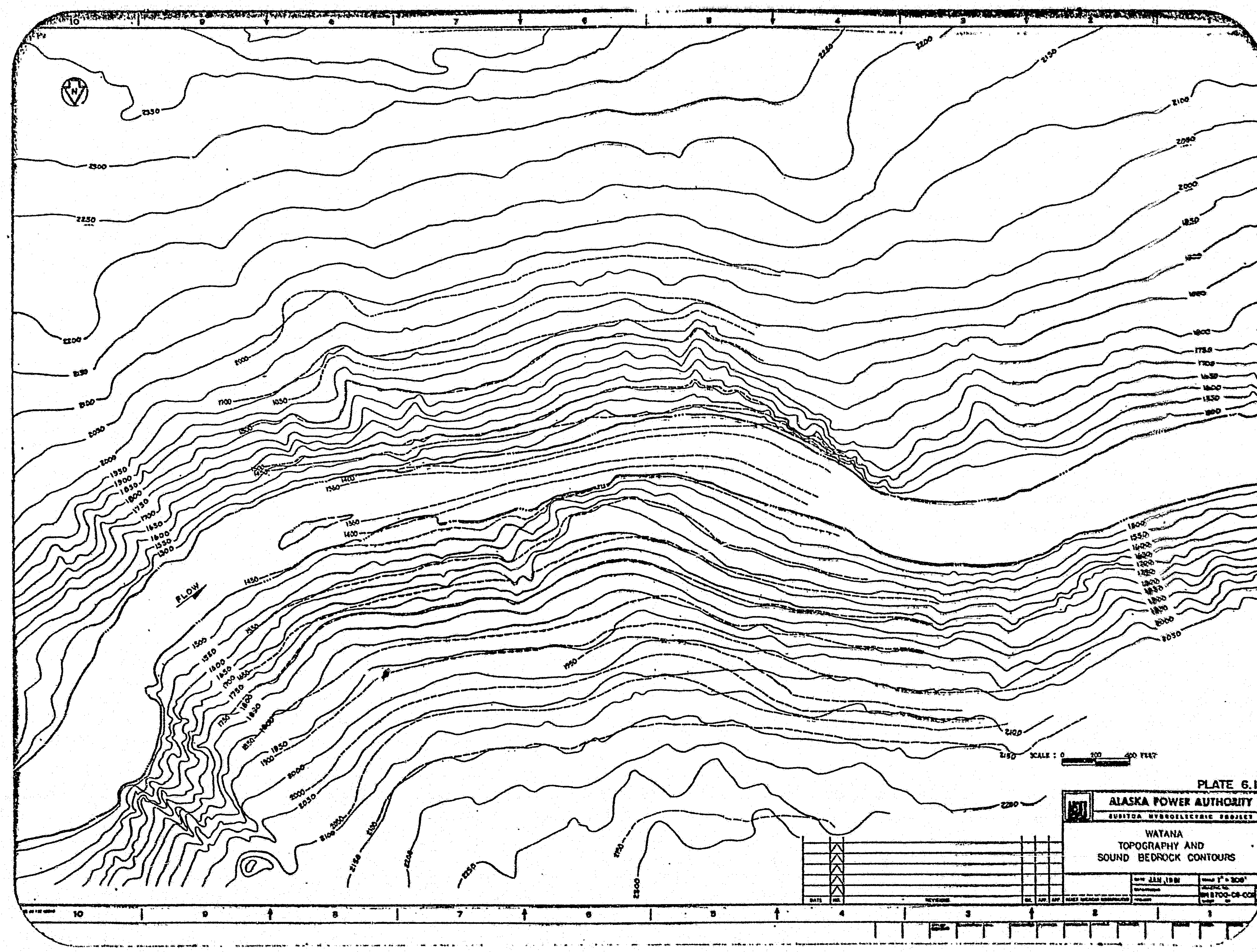
FIGURE 8.3

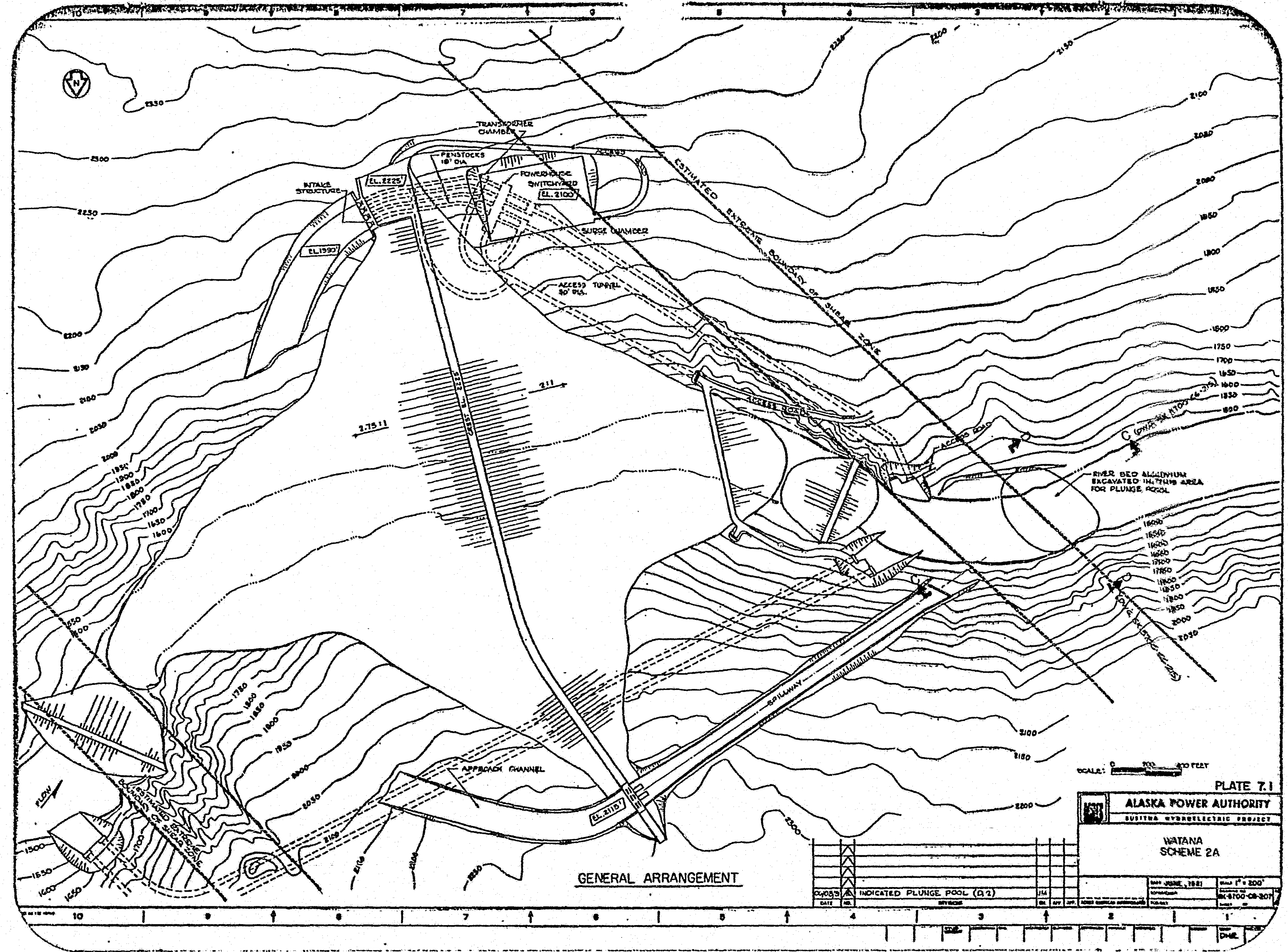
WATANA LAYOUT STUDIES

(J. Lawrence, R. Ibbotson)

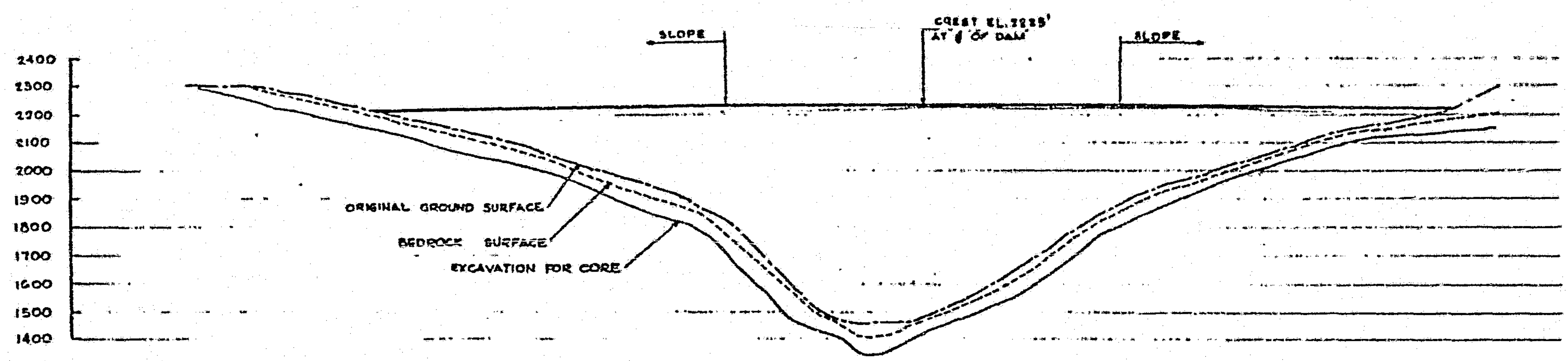
WATANA LAYOUTS



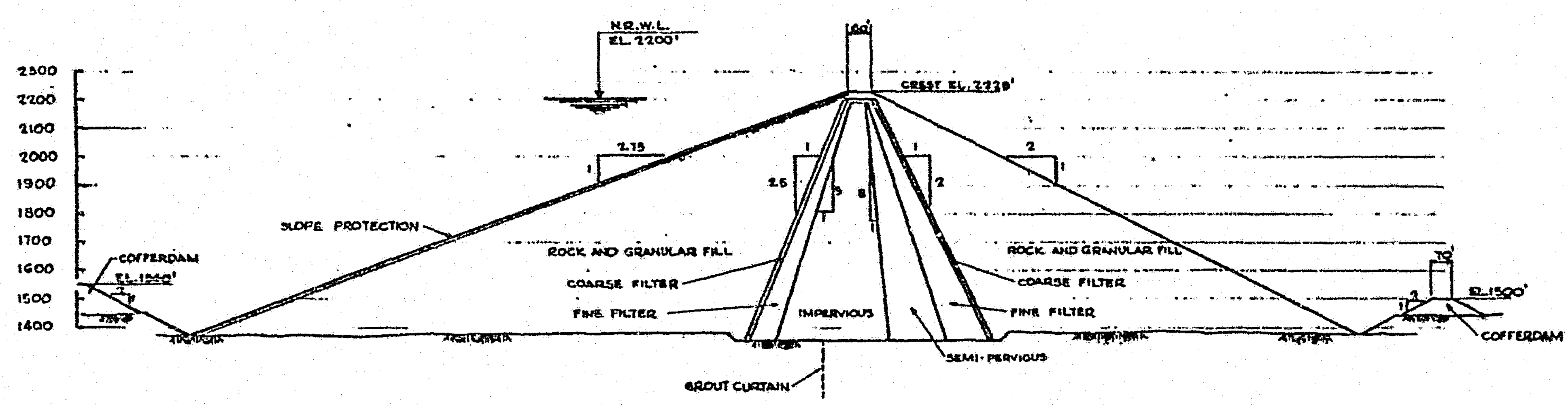

FLOW
SCALE : 0 200 400 FEET
PLATE 6.1
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
TOPOGRAPHY AND
SOUND BEDROCK CONTOURS
JAN, 1981
1" = 200'



TRANSFORMER CHAMBER
PENSTOCKS 18' DIA.
POWERHOUSE
SWITCHYARD
EL. 2100'
EL. 2225'
INTAKE STRUCTURE
EL. 1990'
SURGE CHAMBER
ACCESS TUNNEL 30' DIA.
ESTIMATED EXTREME BOUNDARY OF SHEAR ZONE
ACCESS ROAD
RIVER BED ALLUVIUM EXCAVATED IN THIS AREA FOR PLUNGE POOL
SPILLWAY
APPROACH CHANNEL
EL. 2115'
FLOW
ESTIMATED EXTREME BOUNDARY OF SHEAR ZONE
GENERAL ARRANGEMENT
PLATE 7.1
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
SCHEME 2A
INDICATED PLUNGE POOL (D.2)
JUNE, 1981



SECTION A-A



SECTION B-B

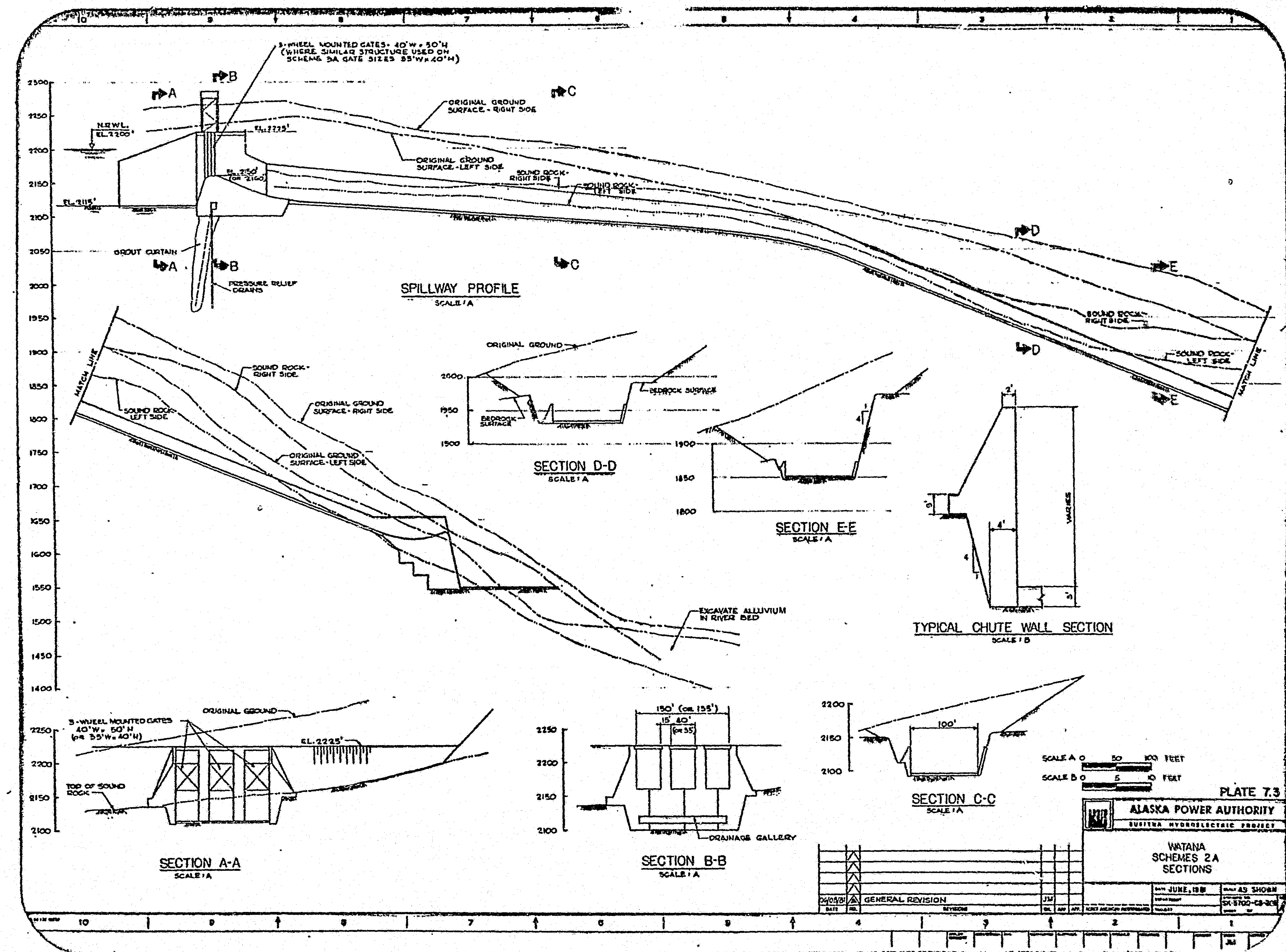
PLATE 7.2

SCALE 0 200 400 FEET

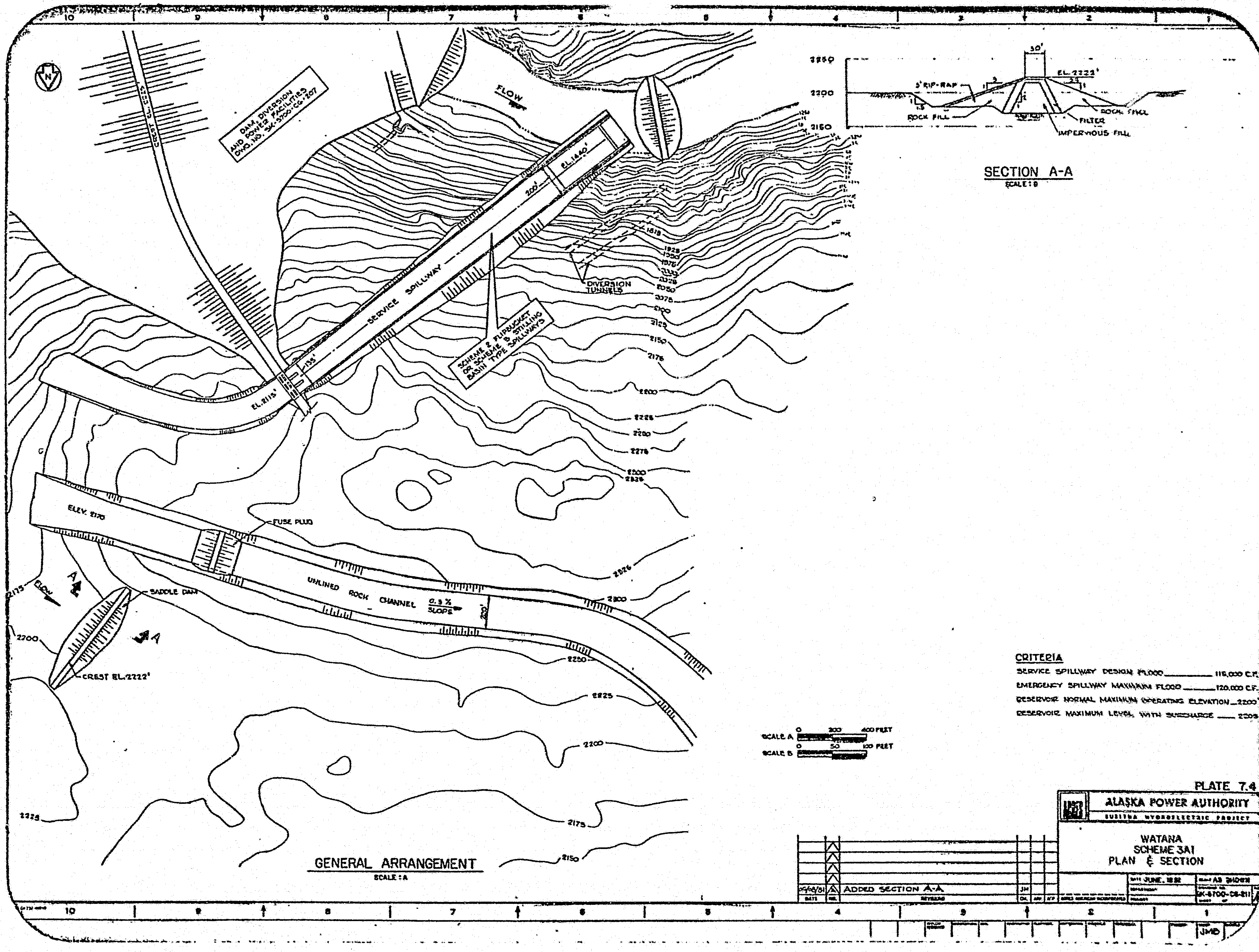
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT

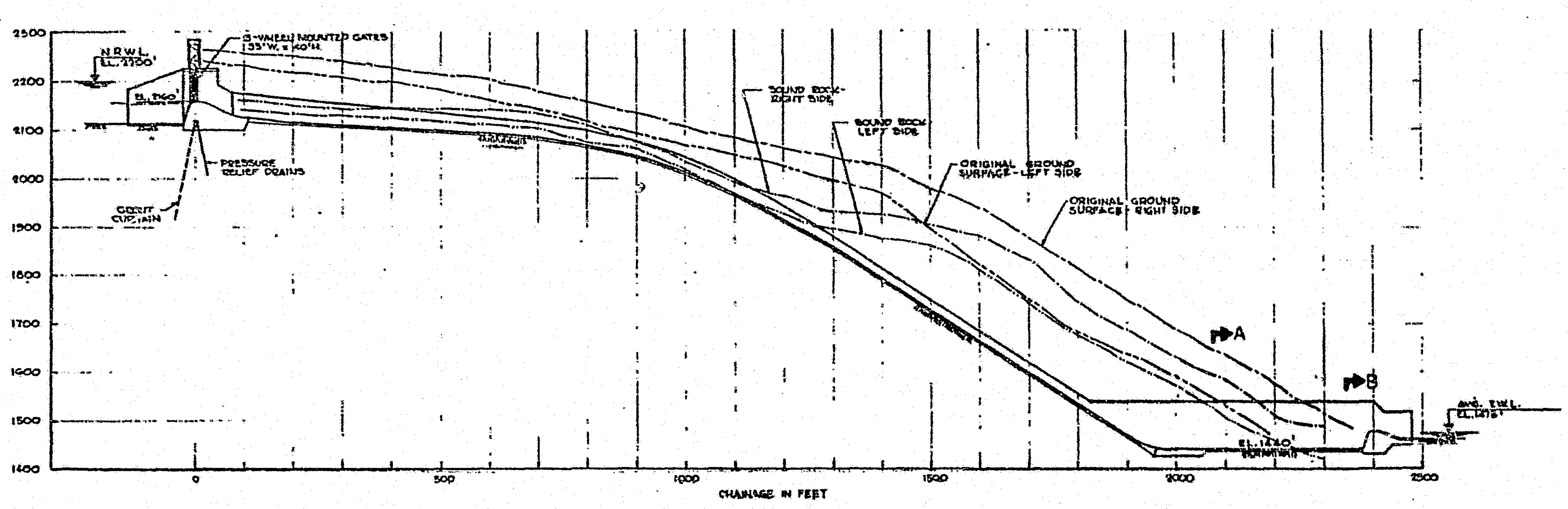
WATANA
MAIN DAM (ALL SCHEMES)

JUNE, 1981
1" = 200'

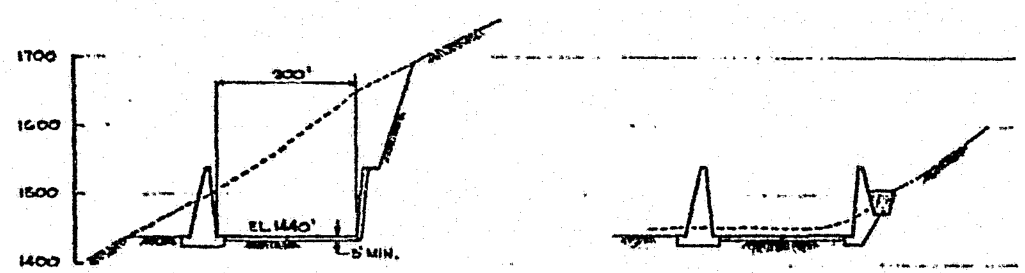


3-WHEEL MOUNTED GATES - 40'W x 50'H (WHERE SIMILAR STRUCTURE USED ON SCHEME 3A GATE SIZES 35'W x 40'H)
ORIGINAL GROUND SURFACE - RIGHT SIDE
ORIGINAL GROUND SURFACE - LEFT SIDE
SOUND ROCK - RIGHT SIDE
SOUND ROCK - LEFT SIDE
N.W.L. EL. 2200'
EL. 2225'
EL. 2150' (OR 2160')
EL. 2115'
GROUT CURTAIN
PRESSURE RELIEF DRAINS
SPILLWAY PROFILE
SCALE: A
MATCH LINE
EXCAVATE ALLUVIUM IN RIVER BED
ORIGINAL GROUND
BEDROCK SURFACE
SECTION D-D
SCALE: A
SECTION E-E
SCALE: A
TYPICAL CHUTE WALL SECTION
SCALE: B
VARIES
3-WHEEL MOUNTED GATES 40'W x 50'H (OR 35'W x 40'H)
TOP OF SOUND ROCK
SECTION A-A
SCALE: A
150' (OR 135')
DRAINAGE GALLERY
SECTION B-B
SCALE: A
SECTION C-C
SCALE: A
SCALE A 0 50 100 FEET
SCALE B 0 5 10 FEET
PLATE 7.3
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
SCHEMES 2A
SECTIONS
JUNE, 1981
AS SHOWN
GENERAL REVISION


DAM, DIVERSION AND POWER FACILITIES DWG. NO. SK-5700-CG-207
FLOW
SERVICE SPILLWAY
EL. 1640'
200'
135'
EL. 2115'
DIVERSION TUNNELS
SCHEME 2 FLIPBUCKET OR SCHEME 3 STILLING BASIN TYPE SPILLWAYS
ELEV. 2170
FUSE PLUG
UNLINED ROCK CHANNEL
0.5 % SLOPE
SADDLE DAM
CREST EL. 2222'
2200
2225
2250
2275
2300
2175
2150
SECTION A-A
SCALE: B
30'
EL. 2222'
5' RIP-RAP
ROCK FILL
FILTER
IMPERVIOUS FILL
GENERAL ARRANGEMENT
SCALE: A
SCALE A 0 200 400 FEET
SCALE B 0 50 100 FEET
CRITERIA
SERVICE SPILLWAY DESIGN FLOOD ______ 115,000 C.F.S.
EMERGENCY SPILLWAY MAXIMUM FLOOD ______ 120,000 C.F.S.
RESERVOIR NORMAL MAXIMUM OPERATING ELEVATION __ 2200'
RESERVOIR MAXIMUM LEVEL WITH SURCHARGE ____ 2203
ADDED SECTION A-A
PLATE 7.4
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
SCHEME 3A1
PLAN & SECTION
JUNE, 1982
AS SHOWN
SK-5700-CG-211
JMB



SPILLWAY PROFILE



SECTION A-A

SECTION B-B

SCALE: 0 100 200 FEET

PLATE 7.5

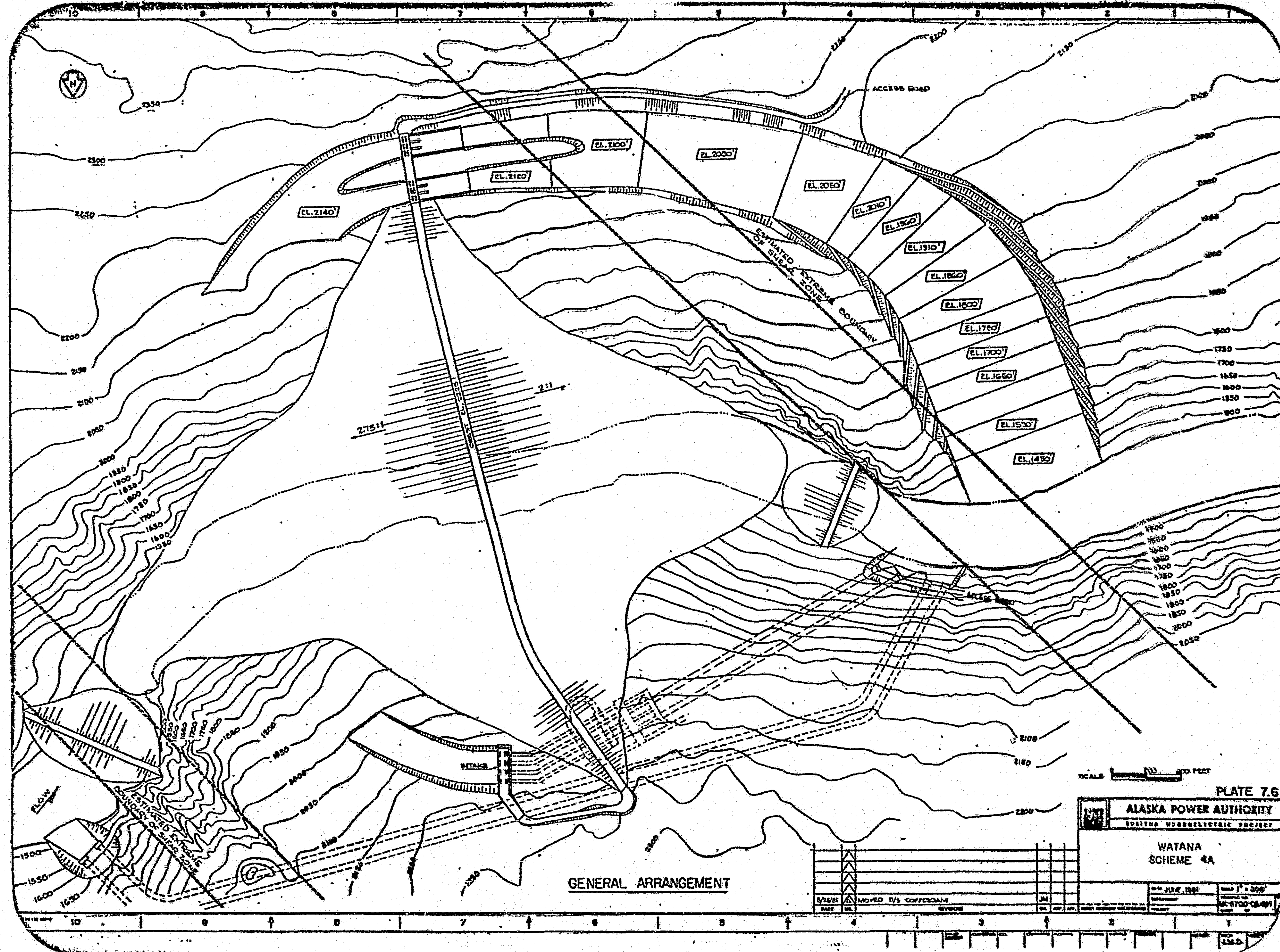
ALASKA POWER AUTHORITY

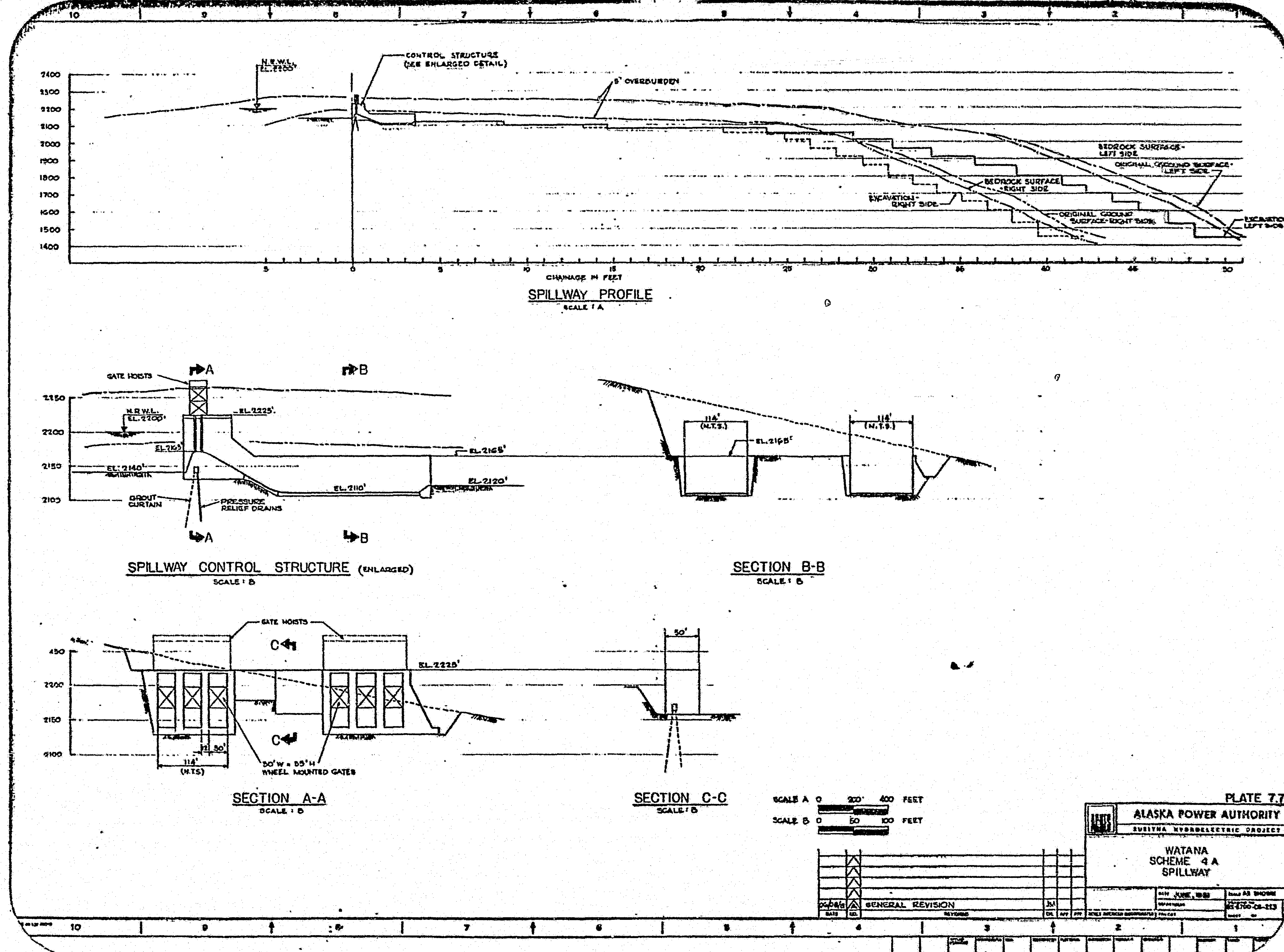
SUSITNA HYDROELECTRIC PROJECT

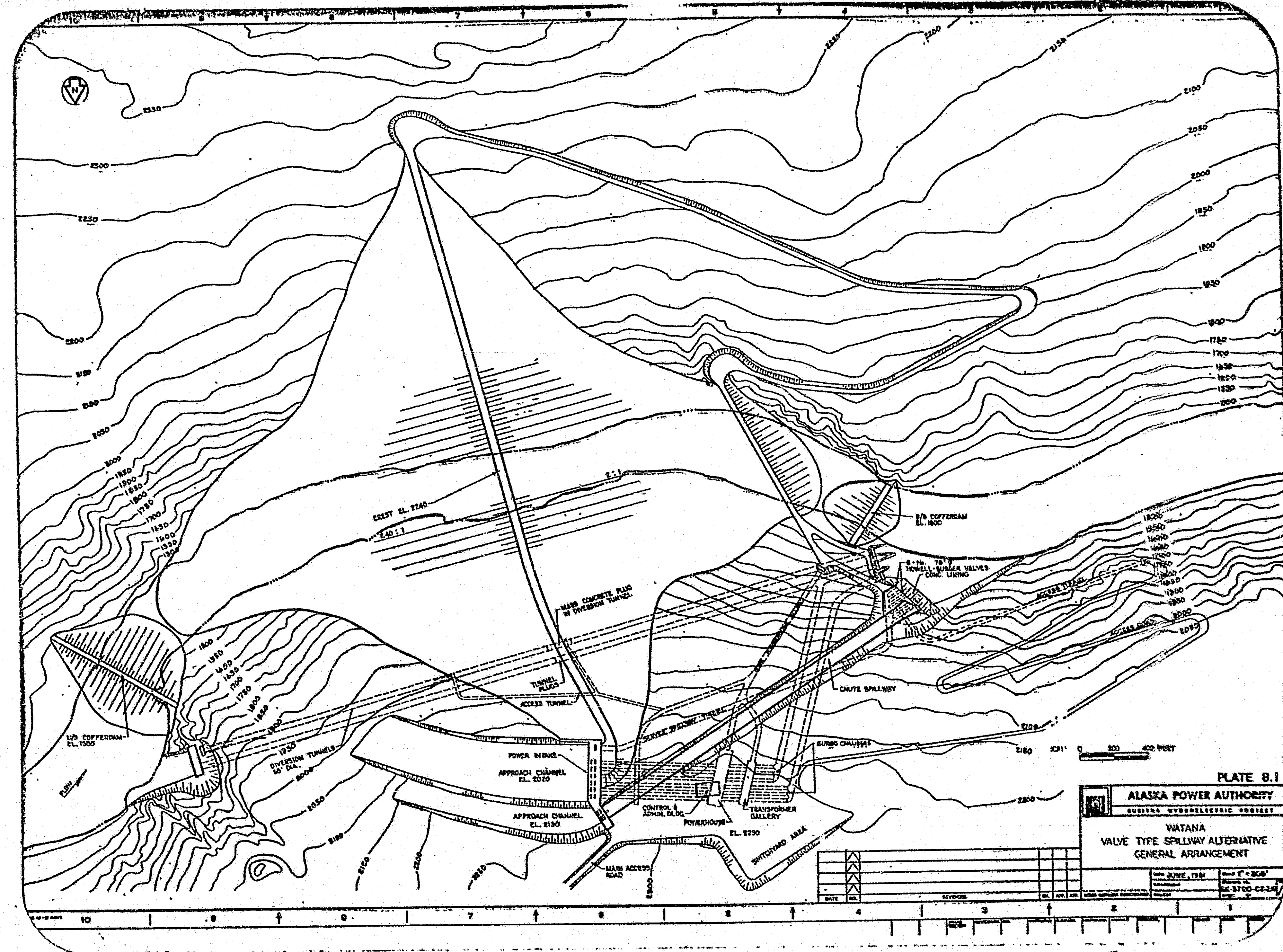
WATANA
SCHEME 3A1
SPILLWAY

JUNE, 1981

1" = 100'


ACCESS ROAD
EL. 2100'
EL. 2000'
EL. 2120'
EL. 2050'
EL. 2140'
EL. 2010'
EL. 1960'
EL. 1910'
EL. 1860'
EL. 1800'
EL. 1750'
EL. 1700'
EL. 1650'
EL. 1530'
EL. 1450'
ESTIMATED EXTREME BOUNDARY OF SHEAR ZONE
2:1
2751
INTAKE
FLOW
ESTIMATED EXTREME BOUNDARY OF SHEAR ZONE
GENERAL ARRANGEMENT
PLATE 7.6
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
SCHEME 4A
MOVED U/S COFFERDAM
JUNE 1981


CONTROL STRUCTURE (SEE ENLARGED DETAIL)
N.R.W.L. EL. 2200'
5' OVERBURDEN
BEDROCK SURFACE-LEFT SIDE
ORIGINAL GROUND SURFACE-LEFT SIDE
BEDROCK SURFACE-RIGHT SIDE
EXCAVATION-RIGHT SIDE
ORIGINAL GROUND SURFACE-RIGHT SIDE
EXCAVATION-LEFT SIDE
CHAINAGE IN FEET
SPILLWAY PROFILE
SCALE: A
GATE HOISTS
EL. 2225'
EL. 2165'
EL. 2140'
EL. 2110'
EL. 2120'
GROUT CURTAIN
PRESSURE RELIEF DRAINS
SPILLWAY CONTROL STRUCTURE (ENLARGED)
SCALE: B
114' (N.T.S.)
SECTION B-B
SCALE: B
50'W x 55'H WHEEL MOUNTED GATES
SECTION A-A
SCALE: B
50'
SECTION C-C
SCALE: B
SCALE A 0 200' 400 FEET
SCALE B 0 50 100 FEET
PLATE 7.7
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
SCHEME 4 A
SPILLWAY
JUNE, 1982
GENERAL REVISION


CREST EL. 2240
U/S COFFERDAM EL. 1555
D/S COFFERDAM EL. 1800
DIVERSION TUNNELS
MASS CONCRETE PLUG IN DIVERSION TUNNEL
TUNNEL PLUGS
ACCESS TUNNEL
POWER INTAKE
APPROACH CHANNEL EL. 2020
APPROACH CHANNEL EL. 2150
CONTROL & ADMIN. BLDG.
POWERHOUSE
TRANSFORMER GALLERY
EL. 2250
SWITCHYARD AREA
MAIN ACCESS ROAD
SURGE CHAMBERS
CHUTE SPILLWAY
HOWELL-BUNGER VALVES
CONC. LINING
ACCESS ROAD
0 200 400 FEET
PLATE 8.1
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
VALVE TYPE SPILLWAY ALTERNATIVE
GENERAL ARRANGEMENT
JUNE, 1981
1" = 200'

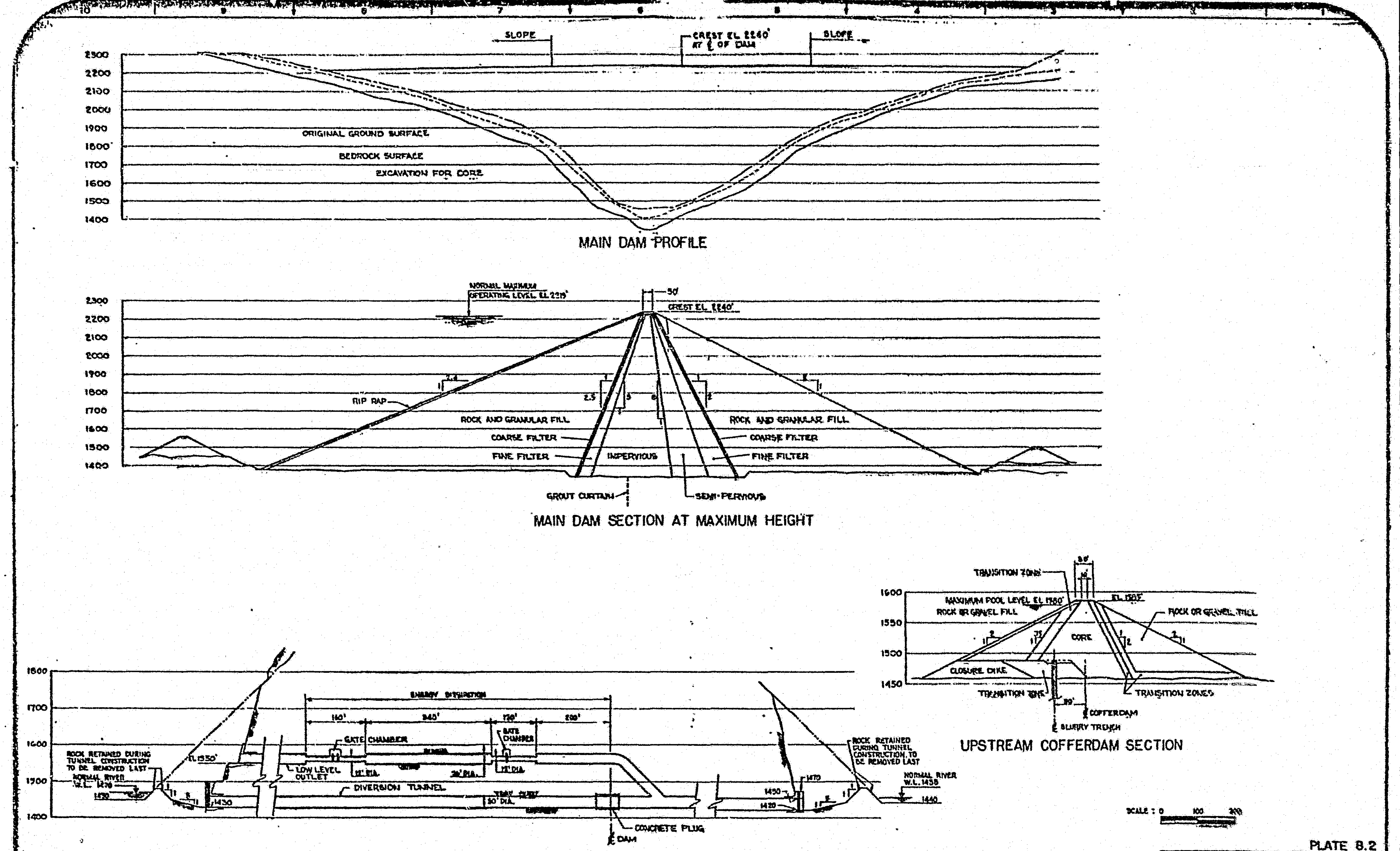
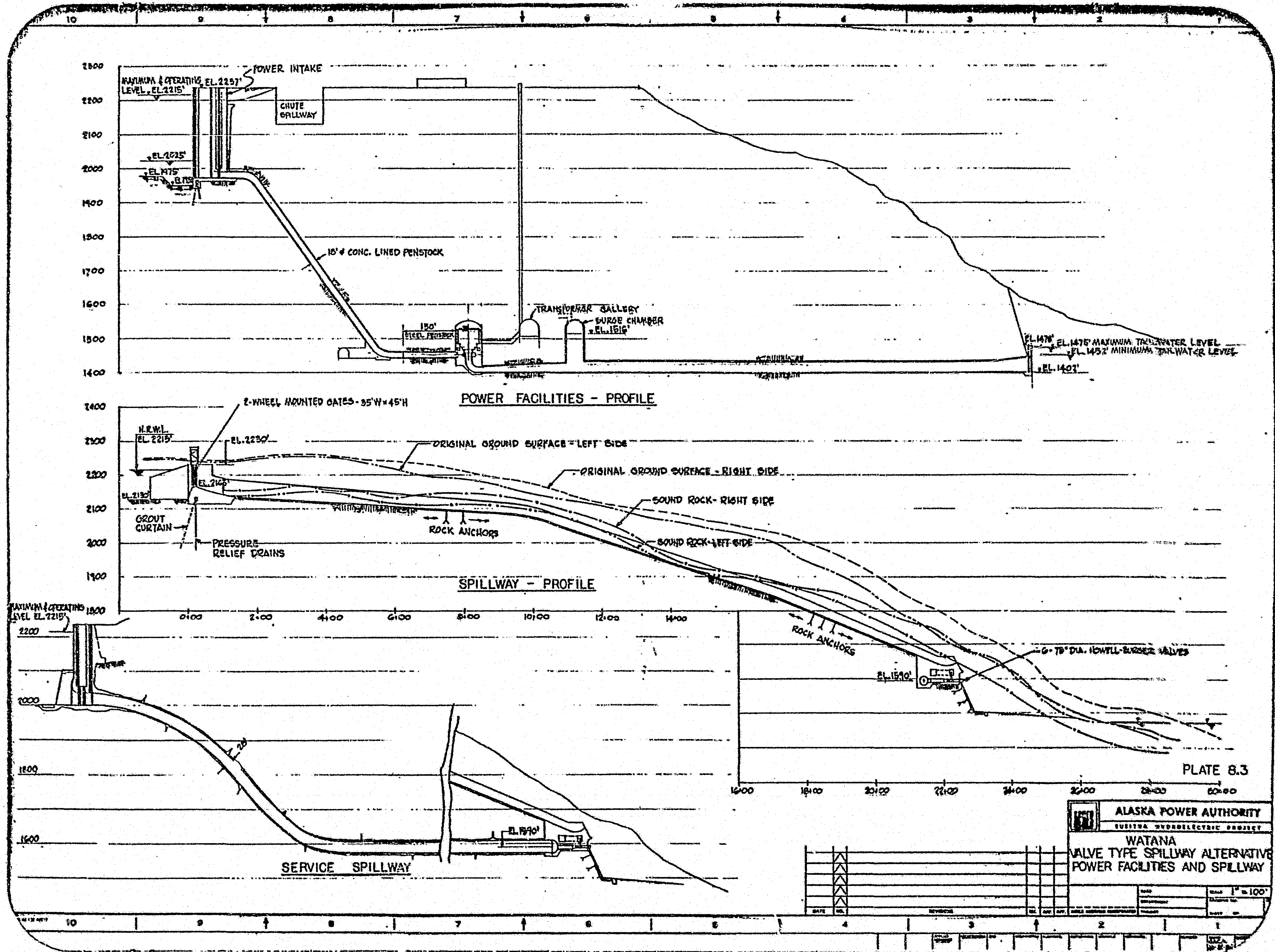


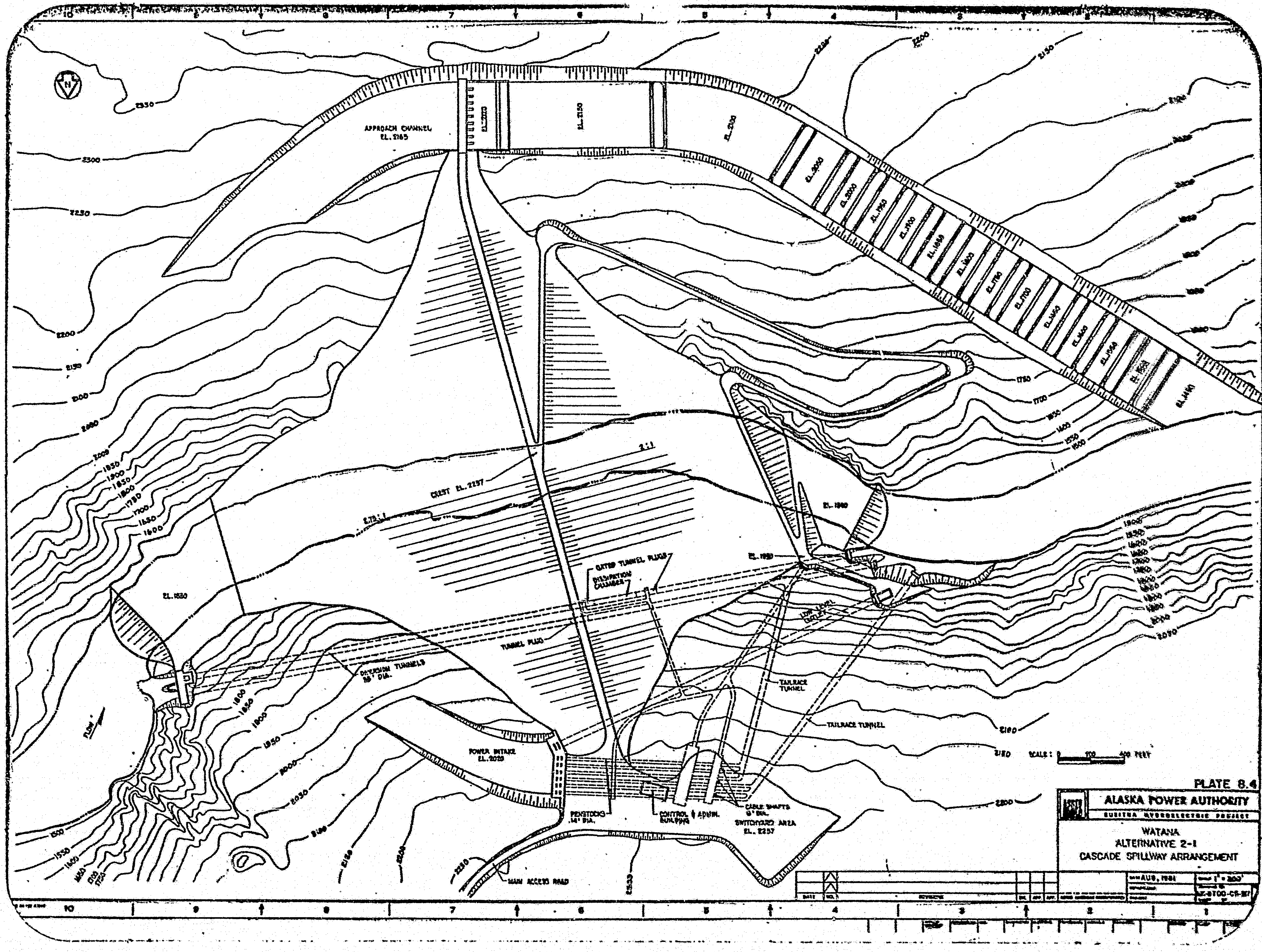
PLATE 8.2

ALASKA POWER AUTHORITY

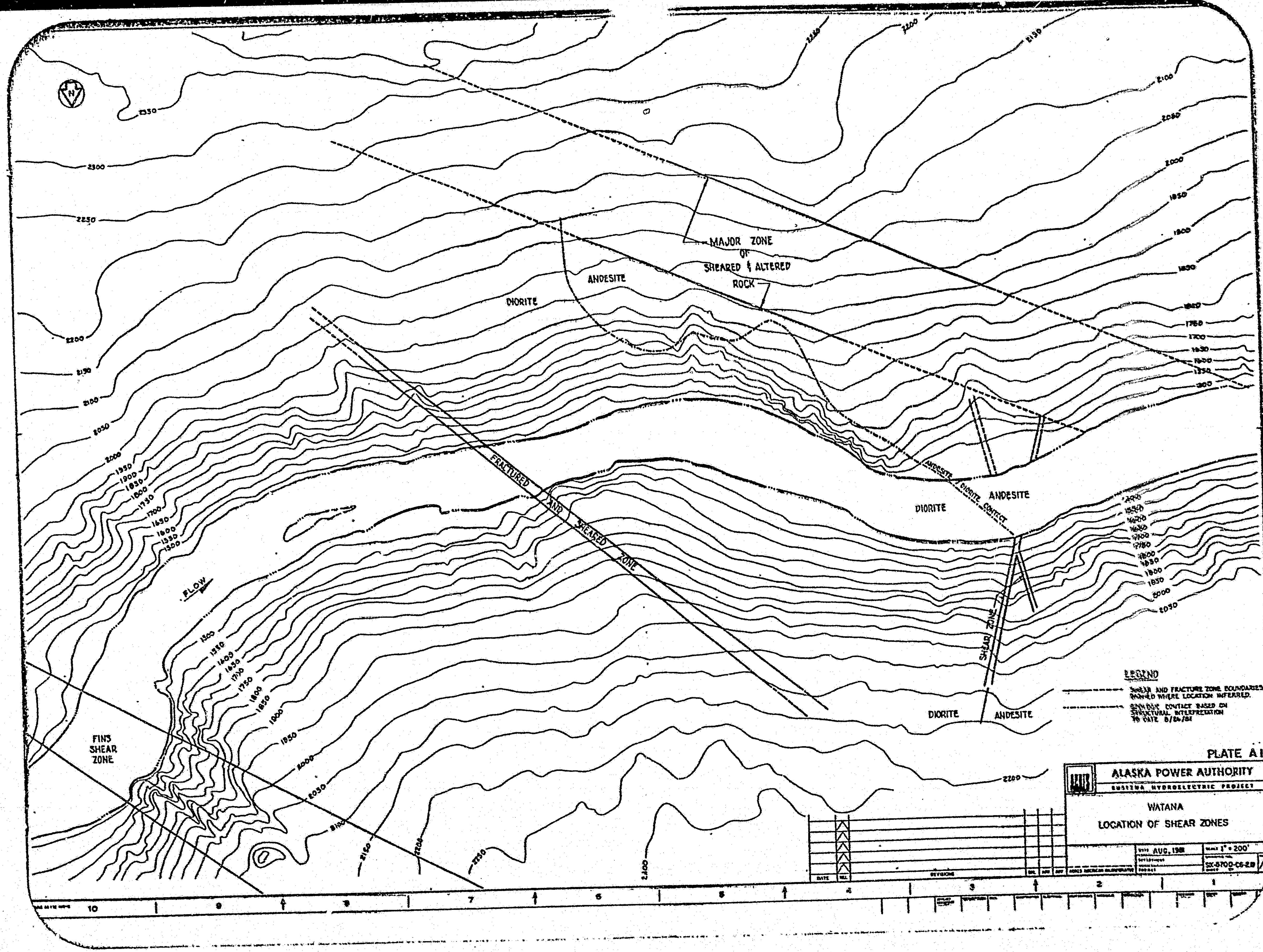
SUSITNA HYDROELECTRIC PROJECT

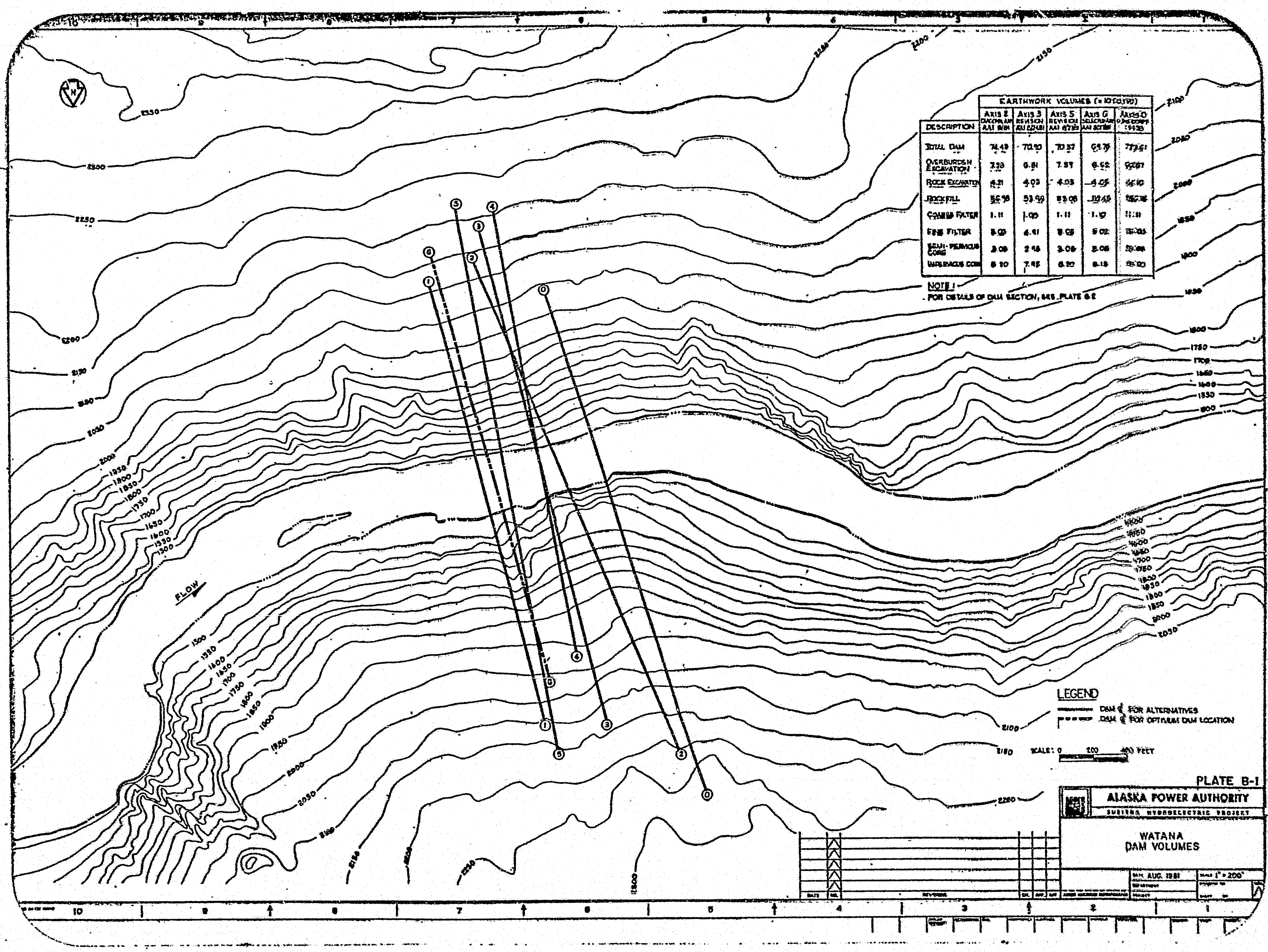
WATANA
VALVE TYPE SPILLWAY ALTERNATIVE
MAIN DAM AND DIVERSION


POWER INTAKE
MAXIMUM & OPERATING LEVEL, EL.2215'
EL.2257'
CHUTE SPILLWAY
EL.2025'
EL.1975'
10'Ø CONC. LINED PENSTOCK
150' STEEL PENSTOCK
TRANSFORMER GALLERY
SURGE CHAMBER
EL.1616'
EL.1475' MAXIMUM TAILWATER LEVEL
EL.1452' MINIMUM TAILWATER LEVEL
EL.1407'
POWER FACILITIES - PROFILE
2-WHEEL MOUNTED GATES - 35'W×45'H
N.R.W.L. EL.2215'
EL.2230'
EL.2130'
EL.2165'
ORIGINAL GROUND SURFACE - LEFT SIDE
ORIGINAL GROUND SURFACE - RIGHT SIDE
SOUND ROCK - RIGHT SIDE
SOUND ROCK - LEFT SIDE
GROUT CURTAIN
PRESSURE RELIEF DRAINS
ROCK ANCHORS
SPILLWAY - PROFILE
6 - 78" DIA. HOWELL-BUNGER VALVES
EL.1590'
MAXIMUM & OPERATING LEVEL EL.2215'
SERVICE SPILLWAY
PLATE 8.3
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
VALVE TYPE SPILLWAY ALTERNATIVE
POWER FACILITIES AND SPILLWAY
1" = 100'



APPROACH CHANNEL EL. 2165
EL. 2150
EL. 2100
EL. 2050
EL. 2000
CREST EL. 2257
2:1
EL. 1580
EL. 1580
GATED TUNNEL PLUGS
DISSIPATION CHAMBER
TUNNEL PLUG
DIVERSION TUNNELS 38' DIA.
LOW LEVEL OUTLET
TAILRACE TUNNEL
TAILRACE TUNNEL
POWER INTAKE EL. 2020
PENSTOCKS 14' DIA.
CONTROL & ADMIN. BUILDING
CABLE SHAFTS 8' DIA.
SWITCHYARD AREA EL. 2257
MAIN ACCESS ROAD
FLOW
SCALE: 0 200 400 FEET
PLATE 8.4
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
ALTERNATIVE 2-1
CASCADE SPILLWAY ARRANGEMENT
AUG. 1981


MAJOR ZONE OF SHEARED & ALTERED ROCK
ANDESITE
DIORITE
FRACTURED AND SHEARED ZONE
ANDESITE / DIORITE CONTACT
SHEAR ZONE
FLOW
FINS SHEAR ZONE
LEGEND
SHEAR AND FRACTURE ZONE BOUNDARIES DASHED WHERE LOCATION INFERRED.
GEOLOGIC CONTACT BASED ON STRUCTURAL INTERPRETATION TO DATE 8/24/81
PLATE A1
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
LOCATION OF SHEAR ZONES
AUG, 1981
1" = 200'
SX-8700-C6-28

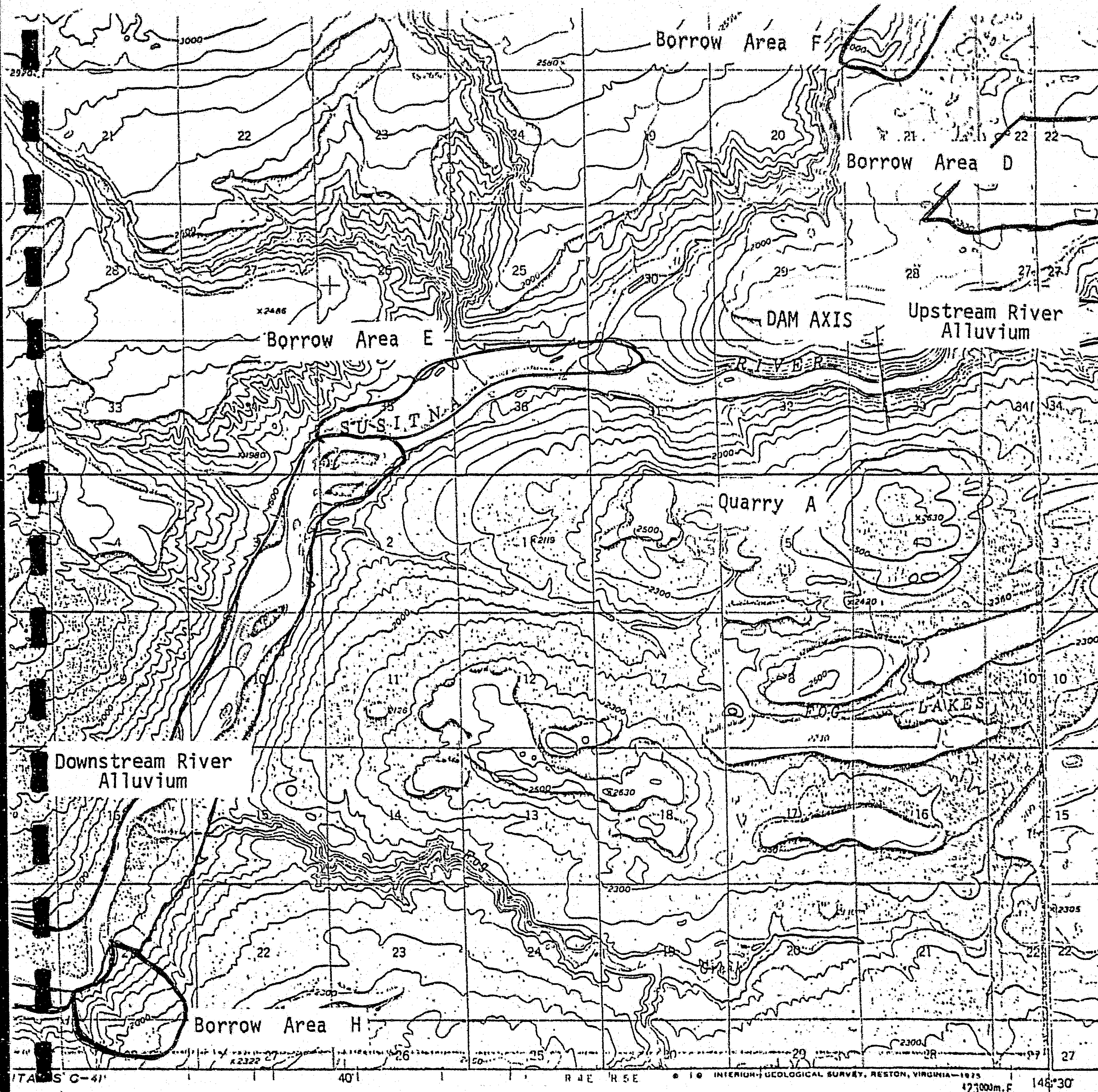


DESCRIPTION	EARTHWORK VOLUMES				
	AXIS 1	AXIS 3	AXIS 5	AXIS 6	AXIS 0
TOTAL DAM	74.49	70.90	70.57	69.79	[illegible]
OVERBURDEN EXCAVATION	7.28	6.81	7.31	6.62	[illegible]
ROCK EXCAVATION	4.21	4.03	4.03	4.05	[illegible]
ROCKFILL	56.98	53.99	53.08	52.45	[illegible]
COARSE FILTER	1.11	1.09	1.11	1.10	[illegible]
FINE FILTER	5.09	4.91	5.05	5.02	[illegible]
SEMI-PERVIOUS CORE	3.09	2.98	3.08	3.06	[illegible]
IMPERVIOUS CORE	6.10	7.95	6.20	6.18	[illegible]

NOTE:
FOR DETAILS OF DAM SECTION, SEE PLATE B2

WATANA DAM DESIGN

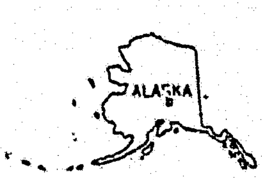
1. General Considerations (W. Lamb)



4 MILES
12000 15000 18000 21000 FEET
5 KILOMETRES

BORROW AREAS --- WATANA

ROAD CLASSIFICATION
No roads or trails in this area



QUADRANGLE LOCATION

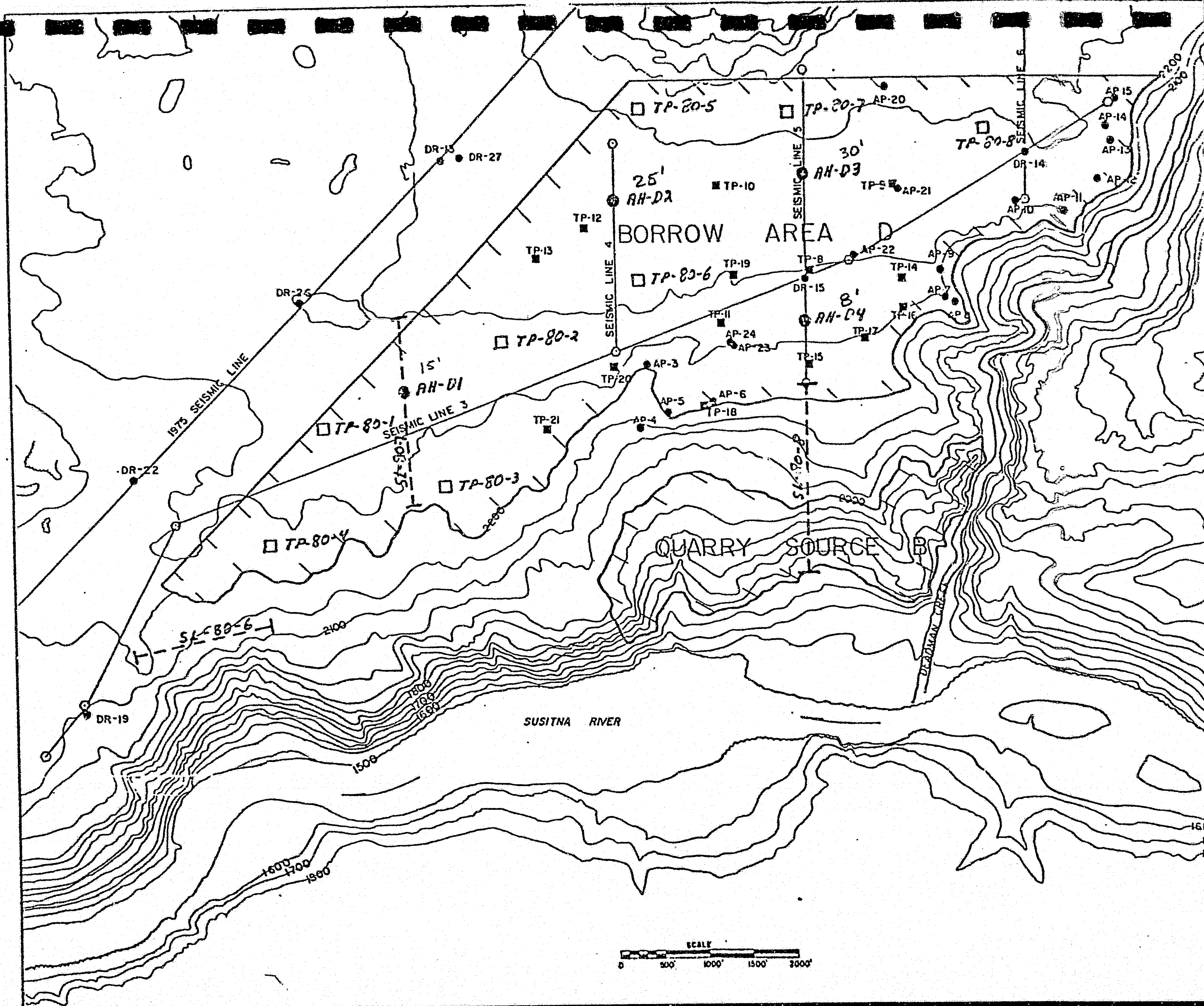
. 10 FEET
FOOT CONTOURS
L DATUM OF 1929

OGIC SURVEY
D 80225, OR RESTON, VIRGINIA 22092
SYMBOLS IS AVAILABLE ON REQUEST

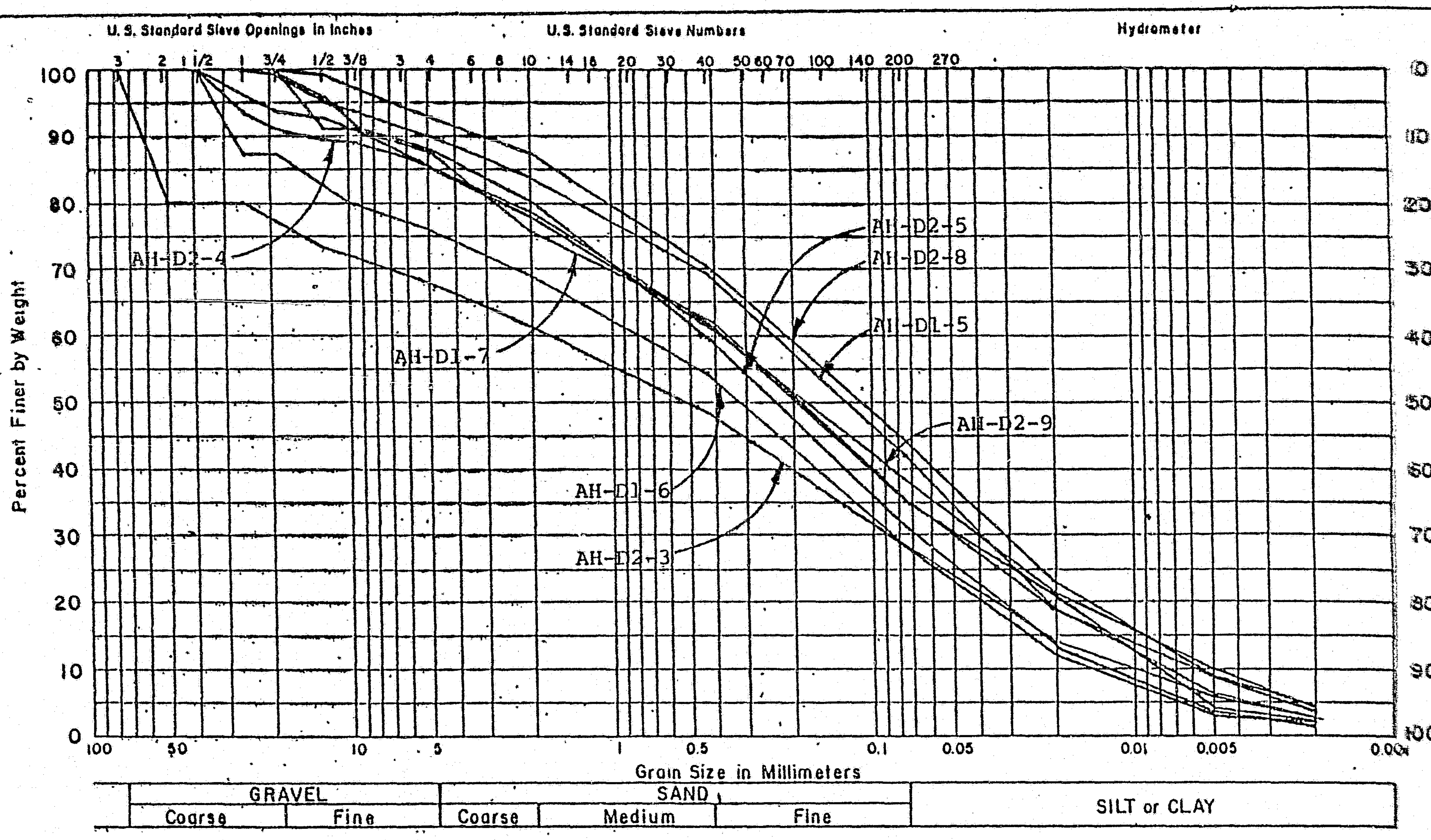
TALKEETNA MOUNTAINS (D-4), ALASKA
N6245—W14830/15X30

1951
MINOR REVISIONS 1965

Mapped,
Control by
Topograph
taken 194
Universal
10,000-fo
1000 metr
zone 6, sh
Land lines
predeterm
Folios S-1



WATANA DAM SITE
BORROW AREA D
15-1981 AUGER HOLES NOT SHOWN



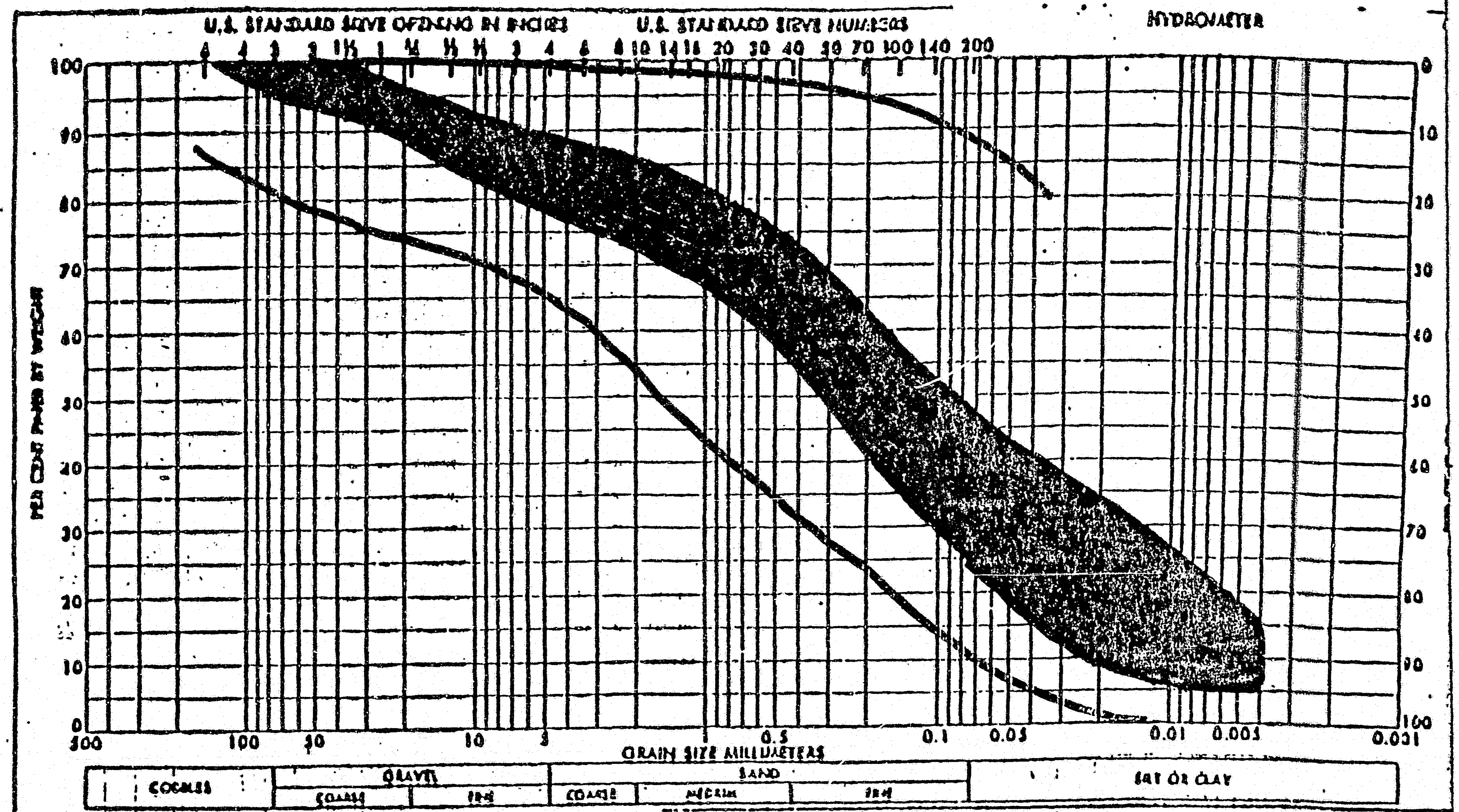
SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASSIFICATION & DESCRIPTION	
AH-D1-5					SM	Typical Gradation Curves
AH-D1-6					SM	
AH-D1-7					SM	
AH-D2-3					SM	
AH-D2-4					SM	
AH-D2-5					SM	
AH-D2-8					SM	
AH-D2-9					SM	

R & M CONSULTANTS, INC.

BORROW AREA D

SUMMARY OF GRAIN SIZE DISTRIBUTIONS

DRAWN BY DL
APPROVED BY
DATE DEC. 1980



Envelope of gradation curves derived from tests of samples from test pits 8 thru 19, Borrow area D.

(Outside lines represent extreme
range of preliminary 1981 results)

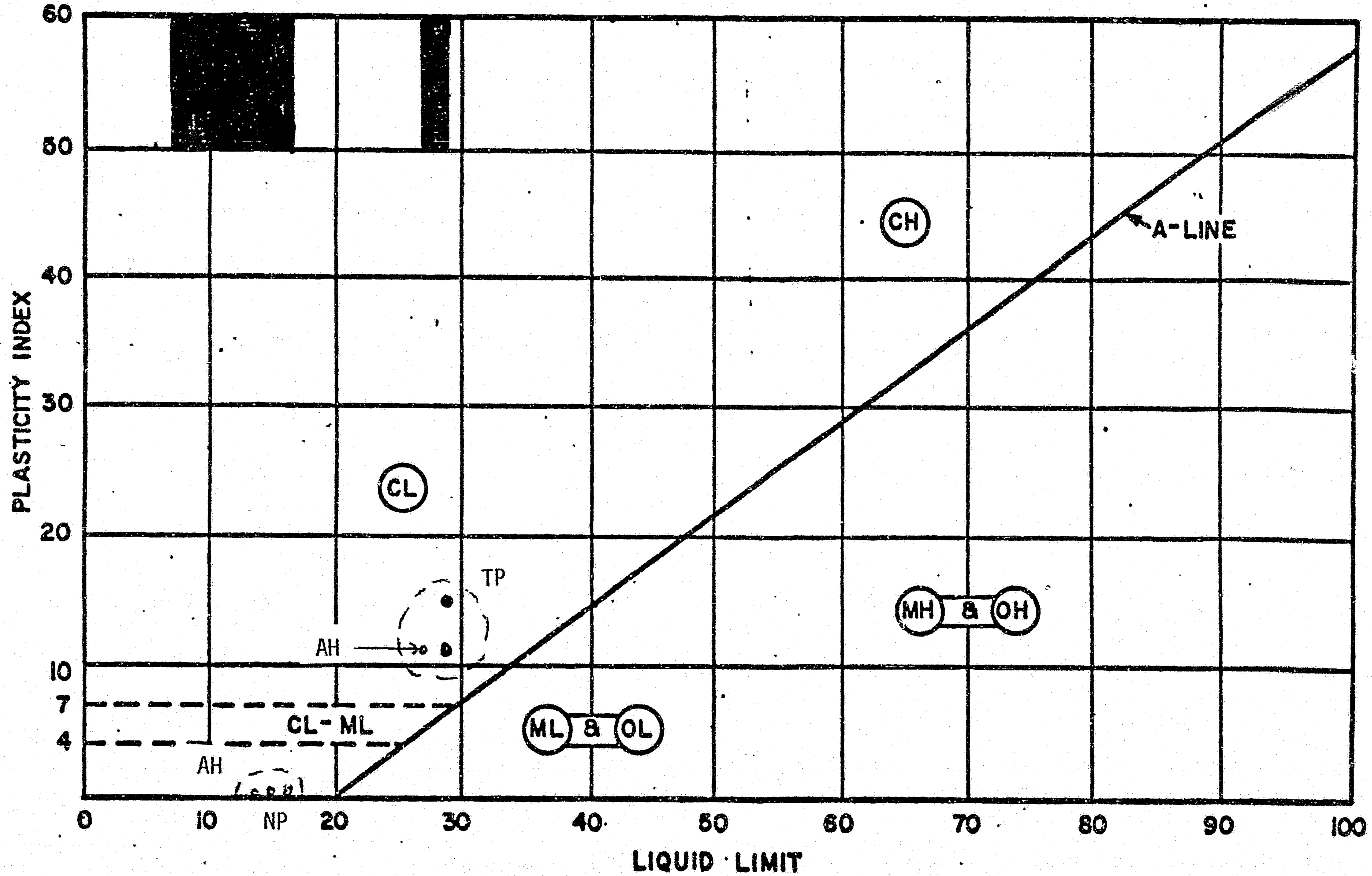
D-38

BORROW AREA D

ATTERBERG LIMITS FOR MATERIAL 0-10 FEET

Natural Water Contents

#200 SIEVE

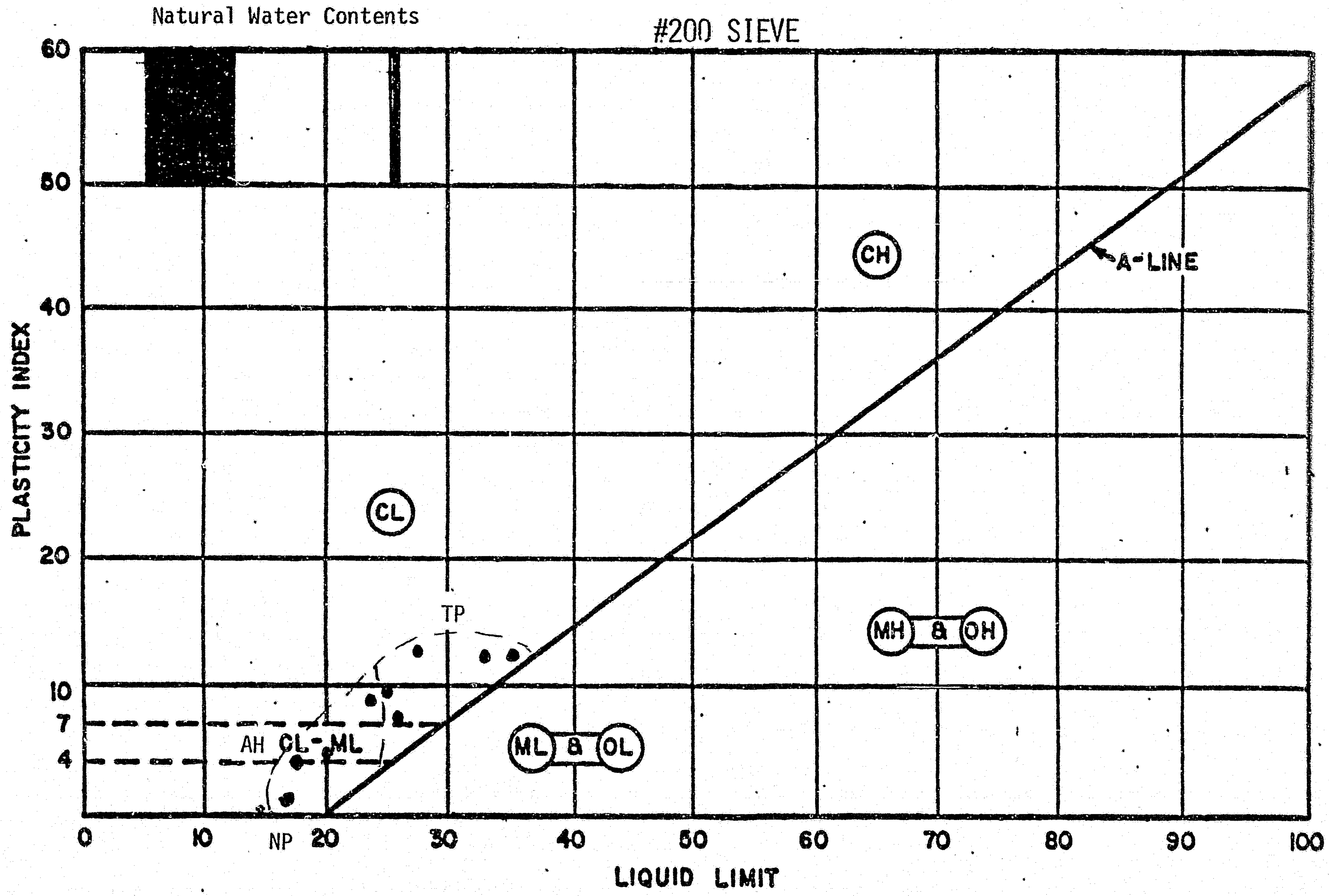


AH = Auger Hole Results
TP = Test Pits
NP = Non Plastic Samples

BORROW AREA D

ATTERBERG LIMITS FOR MATERIAL 10-20 FEET

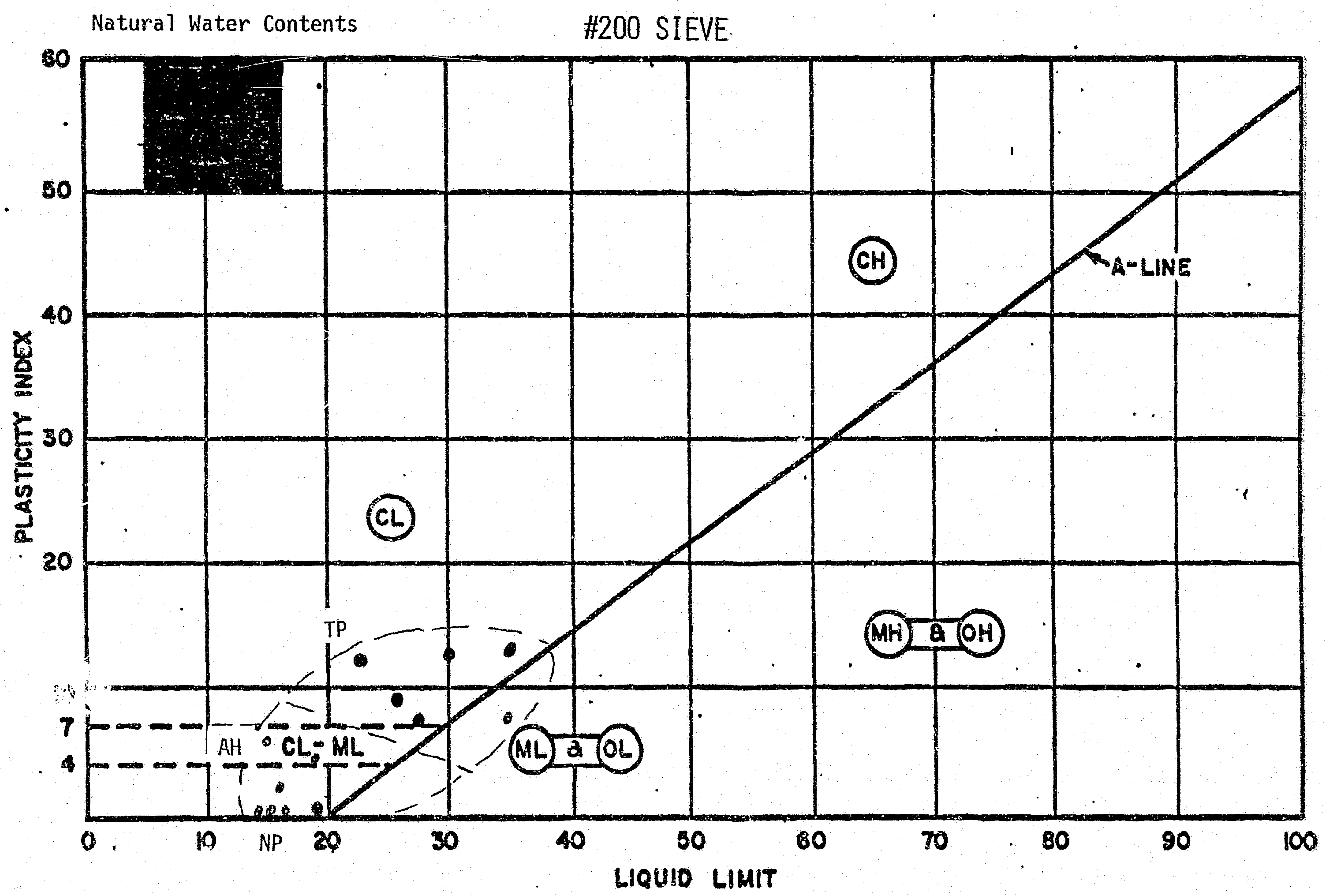
#200 SIEVE



BORROW AREA D

ATTERBERG LIMITS FOR MATERIAL >20 FEET

#200 SIEVE



Project No. ______
Date 11-20-

R&M Consultant Inc.

LABORATORY COMPACTION CONTROL REPORT

Job Name and Location: Susitna (Watana Dam Site)

Architect or Engineer: Acres American Inc.

Contractor: ______

A. Description of Soil: Well Graded 'Till'- GRAVELLY, SILTY SAND W/TRACE CLAY

Material Mark: B Unified Classification: SM AASHO Classification: ______

Source of Material: Deadman Creek Sample No. W-80-300 (Area D)

Natural Water Content: 6.6% % Natural Dry Density ______ PCF Specific Gravity ______

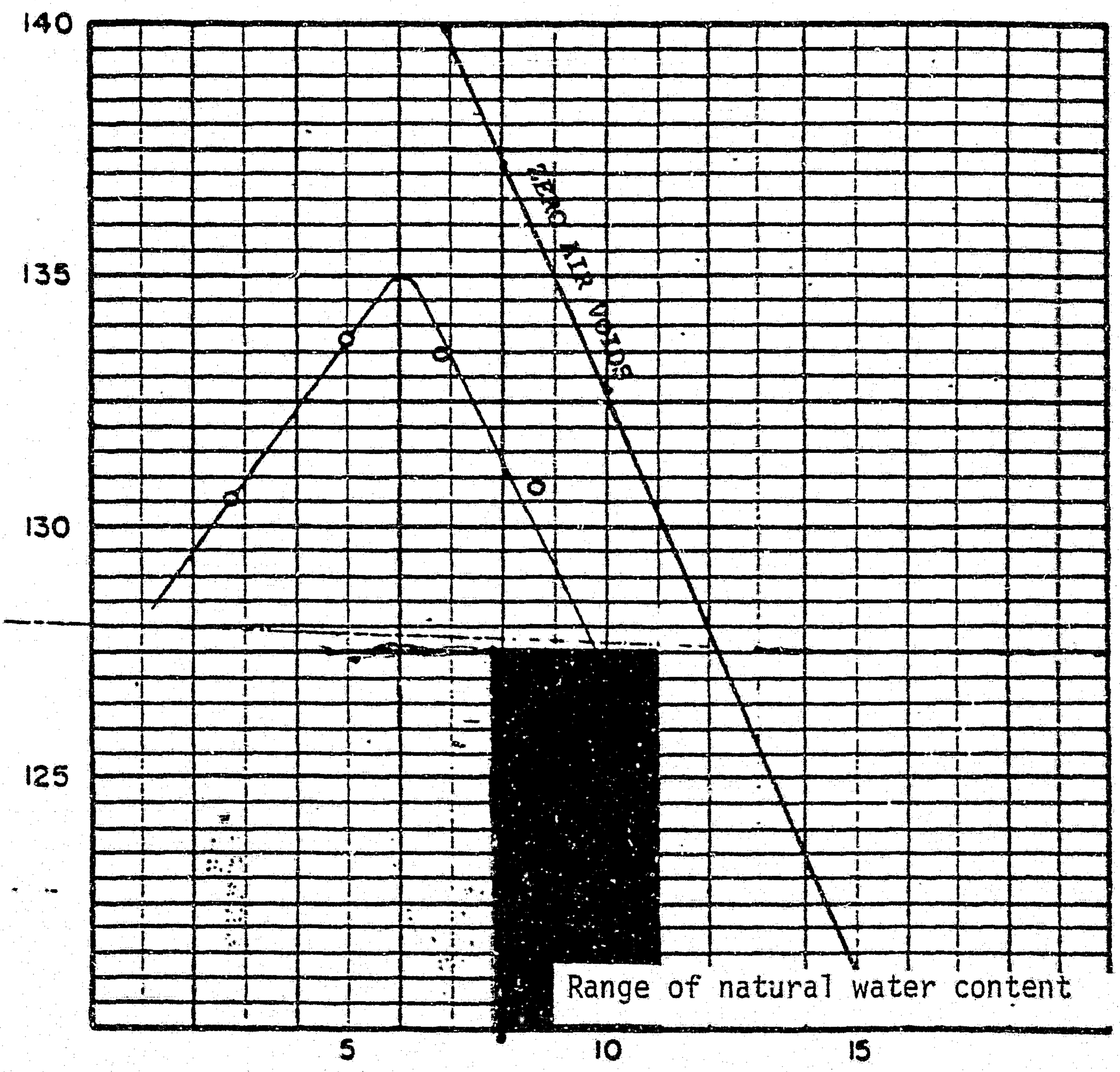
Liquid Limit: Non Viscous % Plastic Limit ______ % Plasticity Index: Non Plastic

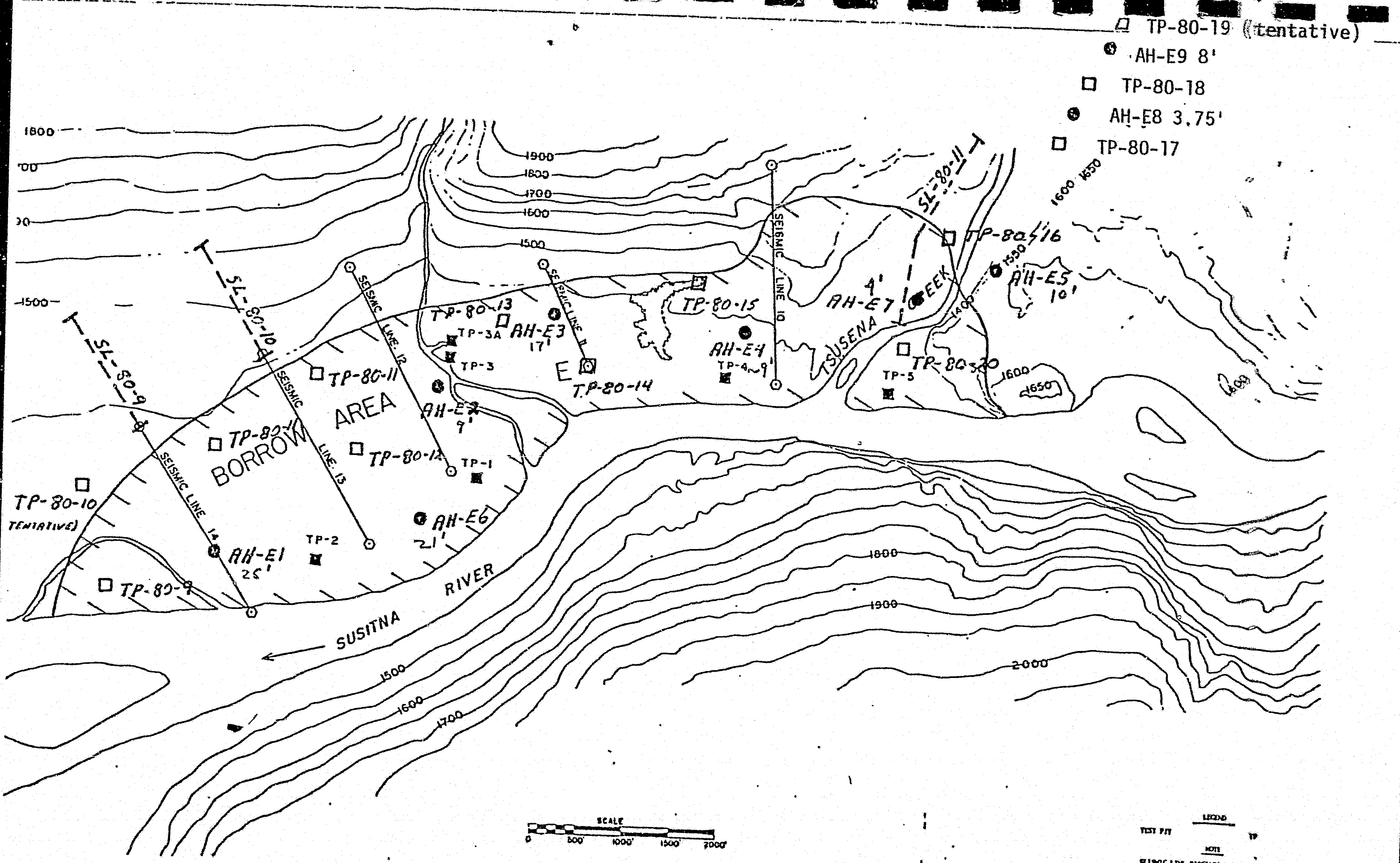
B. Test Procedure Used: T-180 "D" - AASHTO

C. Test Results: Maximum Dry Density 135.0 PCF Optimum Water Content 6.0

Sieve Analysis

Size	% Passing
2 "	100
1¼ "	95
1 "	93
3/4"	89
1/2"	87
3/8"	86
# 4	80
# 10	76
# 40	58
#200	26.9
.02mm	9.2
.005	3.0
.002	1.3





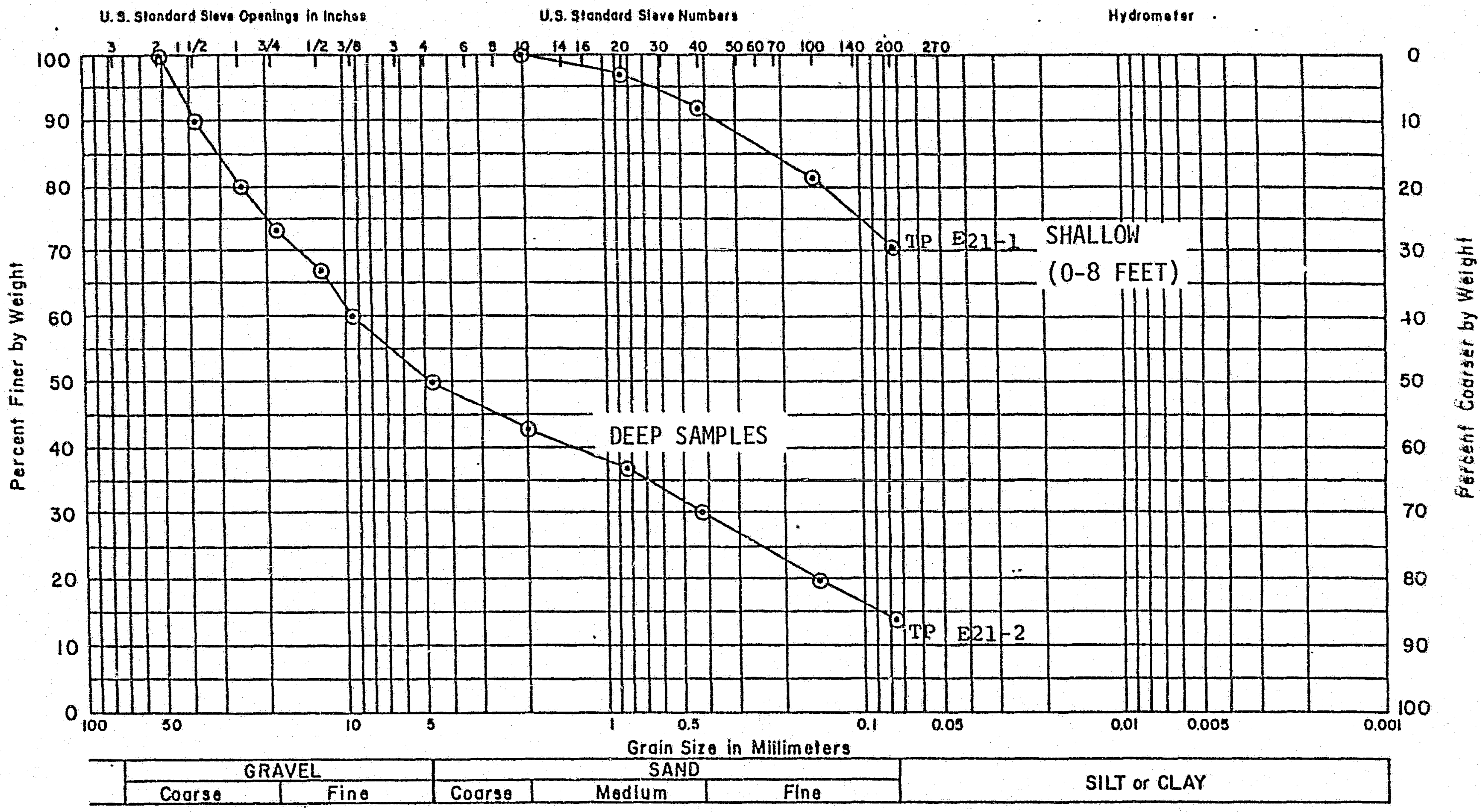
WATANA BORROW AREA E

PREVIOUS EXPLORATIONS
21 TEST PITS FROM 1981 NOT SHOWN

SL-10 Seismic Line

AH-7 Auger Hole

TP-9 Test Pit



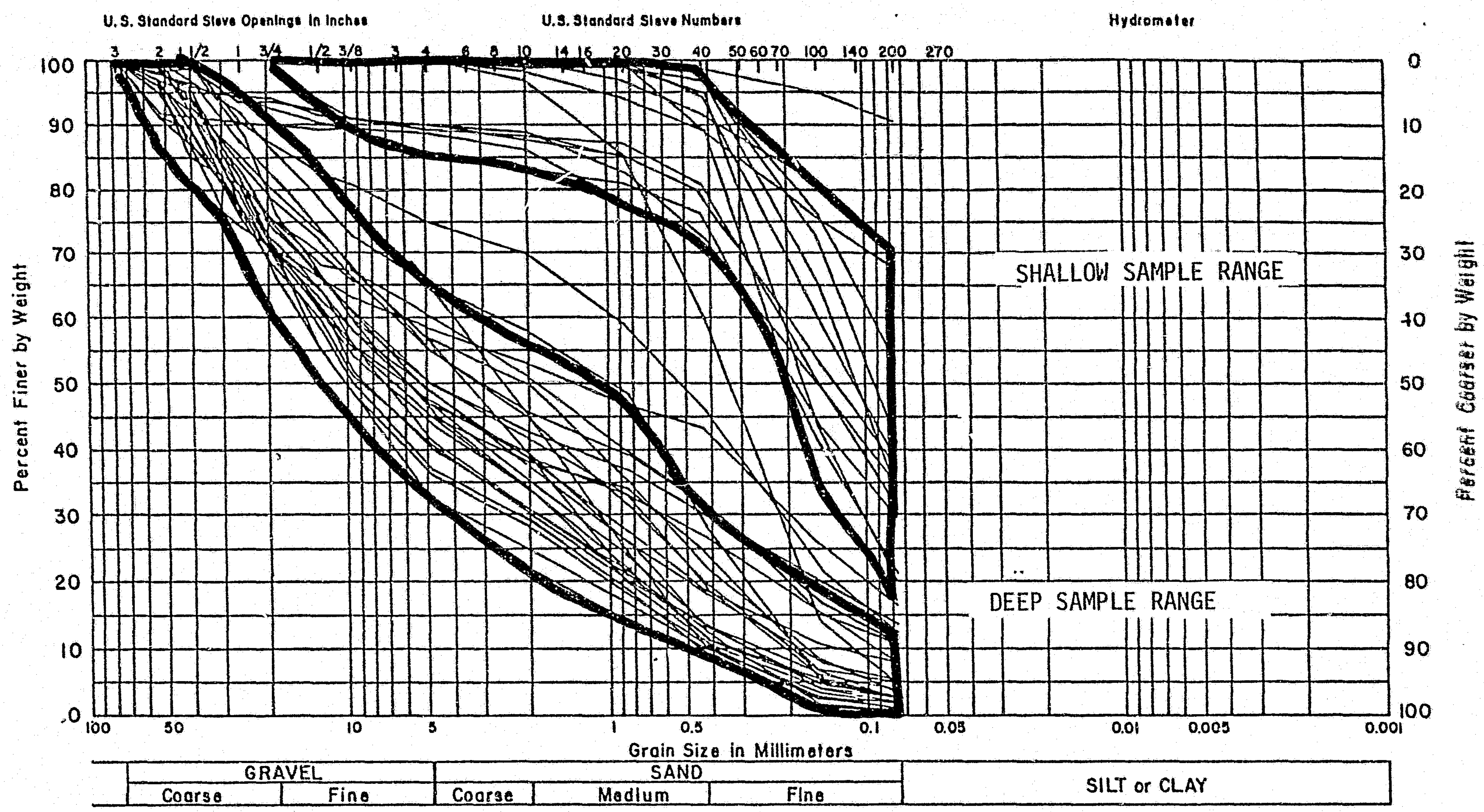
SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI		CLASSIFICATION & DESCRIPTION
TP E21-1						SANDY SILT WITH TRACE CLAY
TP E21-2					GM	SANDY GRAVEL WITH SOME SILT

R&M Engineering & Geological Consultants
ANCHORAGE FAIRBANKS ALASKA JUNEAU

GRADATION CURVES FOR BORROW AREA E
SUSITNA HYDROELECTRIC PROJECT

DRAWN BY REL
APPROVED BY MCH
DATE AUG. 1981
PROJECT NO. 052506

TYPICAL GRADATION

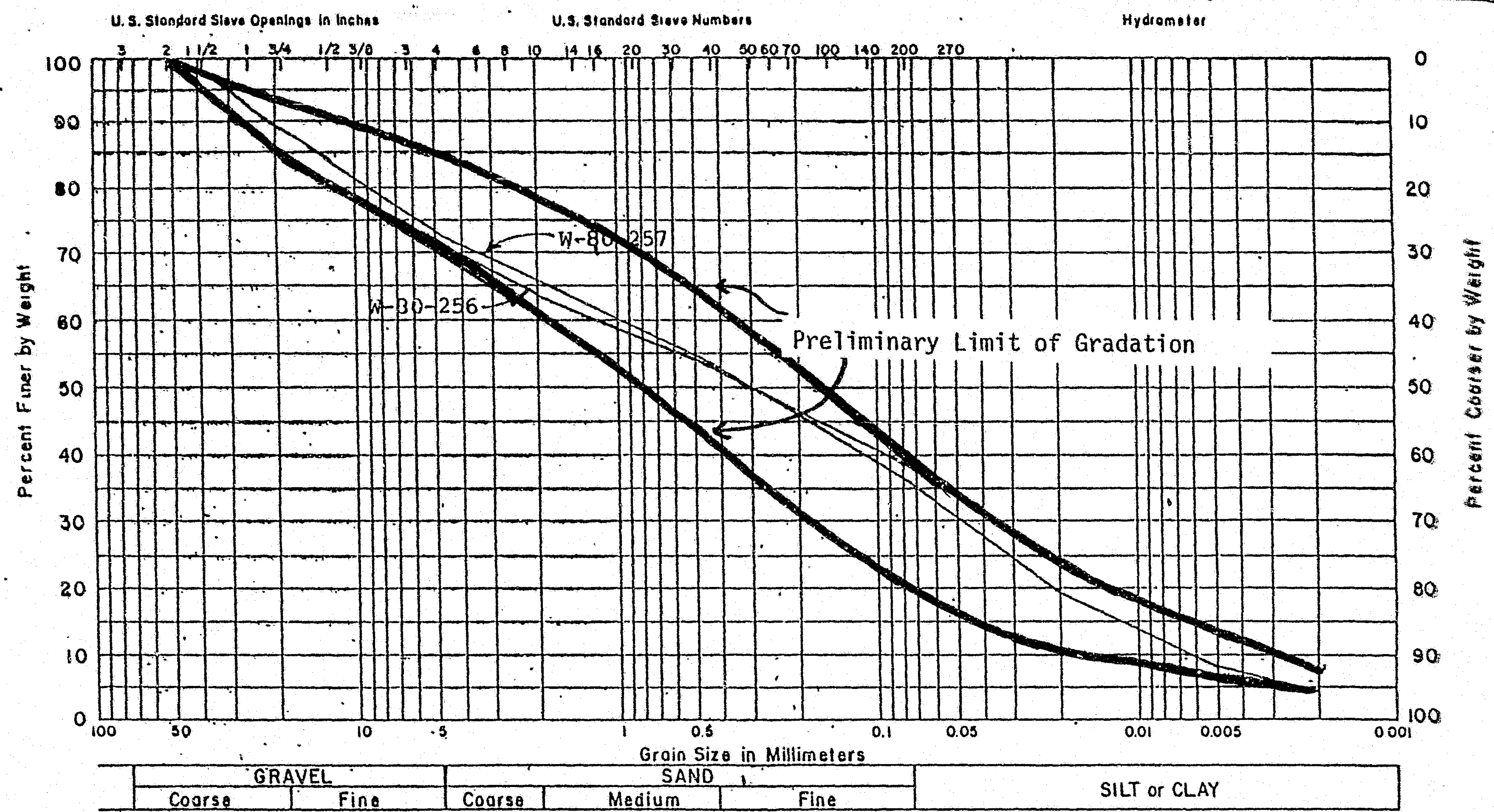


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASSIFICATION & DESCRIPTION

R&M Engineering & Geological Consultants
ANCHORAGE FAIRBANKS ALASKA JUNEAU

COMPOSITE GRADATION CURVES FOR BORROWN AREA E
SUSITNA HYDROELECTRIC PROJECT

DRAWN BY
APPROVED BY
DATE 8/21/81
PROJECT NO. 052506



SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASSIFICATION & DESCRIPTION
W-80-256	10.9		21.7	9.2	
W-80-257	12.3		17.1	2.5	

R & M CONSULTANTS, INC.

BORROW AREA H

SUMMARY OF GRAIN SIZE DISTRIBUTION

DRAWN BY DL

APPROVED BY

DATE DEC. 1980

H1

R&M Consultant Inc.

LABORATORY COMPACTION CONTROL REPORT

Job Name and Location: Susitna (Watana Dam Site)

Architect or Engineer: Acres American Inc.

Contractor:

A. Description of Soil: Poorly Graded 'Till', SILTY GRAVEL AND SAND W/TRACE CLAY

Material Mark: C Unified Classification: GC-SC AASHO Classification:

Source of Material: Borrow Area H Sample No. W-80-256

Natural Water Content: 10.9 % Natural Dry Density: ______ PCF Specific Gravity: ______

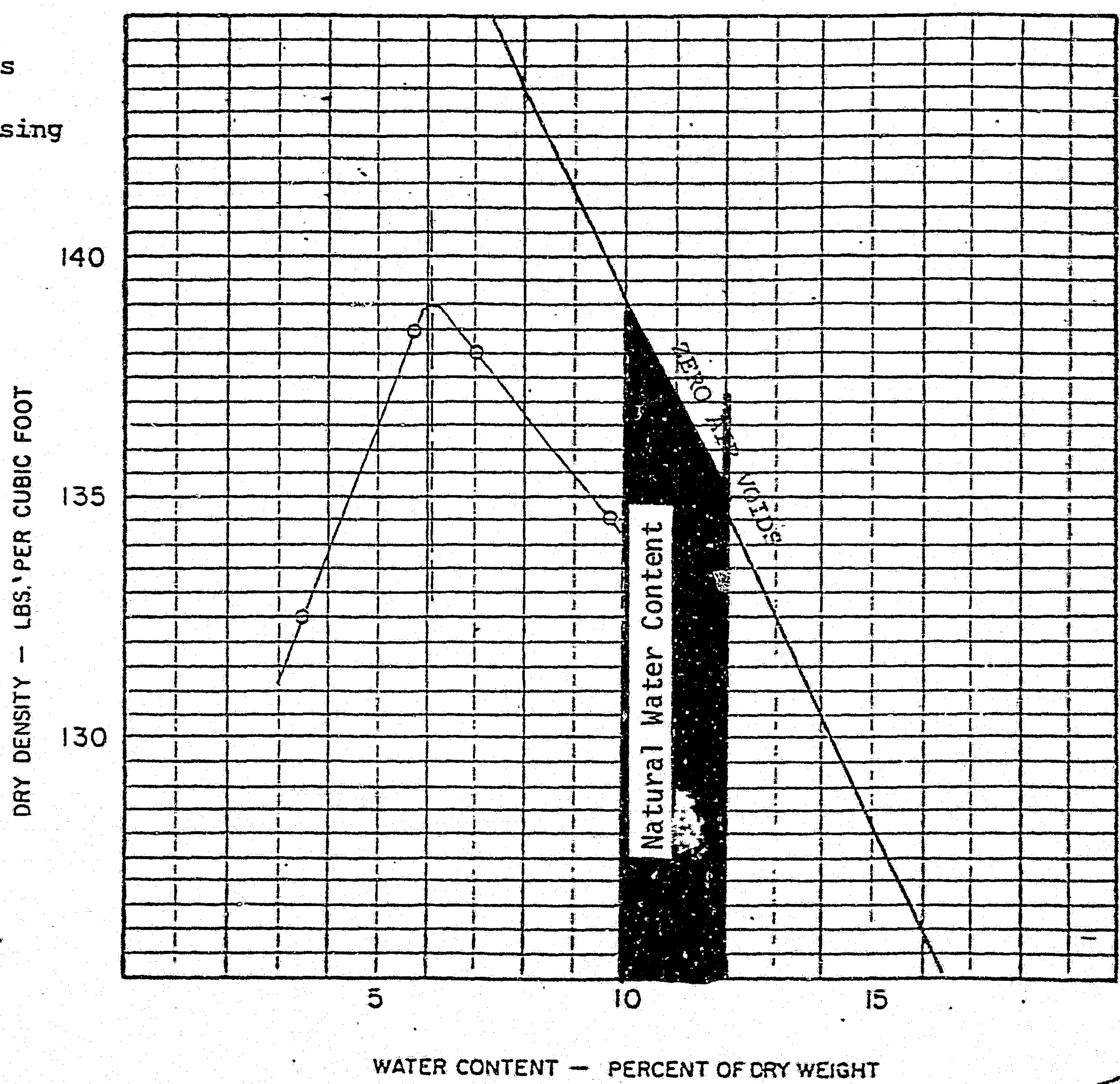
Liquid Limit: 21.7 % Plastic Limit: ______ % Plasticity Index: 9.2

B. Test Procedure Used: T-180 Method "D" - AASHTO

C. Test Results: Maximum Dry Density: 139.0 PCF Optimum Water Content: 6.2

Sieve Analysis

Size	% Passing
"	100
½"	95
"	88
/4"	84
/2"	81
/8"	78
4	71
10	64
40	53
200	38.2
.02mm	24.3
.005	13.6
.002	8.6



WATANA DAM SITE

RIVER ALLUVIUM AVAILABLE (x 10^6 CY)

LOCATION	DISTANCE TO AXIS FROM LONGEST HAUL						
	1	2	3	4	5	6	7
UPSTREAM	0	17	25+	25+	25+	25+	25+
DOWNSTREAM	0	0	0	31	47	79	95
TOTAL	0	17	25	86	72	104	120

HIGH CONFIDENCE ESTIMATE ON ABOVE QUANTITIES:

UPSTREAM	0	7	14	14+	14+	14+	14+
DOWNSTREAM	0	0	0	15	23	33	48
TOTAL	0	7	14	29	37+	47+	62+

WATANA DAM

EMBANKMENT QUANTITIES

(x10^6 CY)

(DEPENDENT ON FINAL LAYOUT REFINEMENTS)

TYPE OF MATERIAL	REQUIRED	EST AVAIL.	SOURCE
IMPERVIOUS	10-15	50-75	AREA D
		5-10+	AREA H
FINE FILTERS	5-6	12.5	AREA E
COARSE FILTERS	1-2	16	AREA E
ROCKFILL	55-60	100+	QUARRY A
GRAVEL FILL		47-104	WITHIN 6 MILES OF AXIS, IN RIVER.
CONCRETE AGG.		10+	AREA E
ROUGH TOTAL	71-83 MCY	2-5	TIMES REQUIREMENTS, BASED ON PRELIMINARY TAKEOFFS.

POSSIBLE WAYS IN WHICH AN EARTHQUAKE
MAY CAUSE FAILURE OF AN EARTH DAM

1 - Disruption of dam by major fault movement in foundation.

2 - Loss of freeboard due to differential tectonic ground movements.

3 - Slope failures induced by ground motions.

4 - Loss of freeboard due to slope failure or soil compaction.

5 - Sliding of dam on weak foundation materials.

6 - Piping failure through cracks induced by ground motions.

7 - Overtopping of dam due to seiches in reservoir.

8 - Overtopping of dam due to slides or rockfalls into reservoir.

9 - Failure of spillway or outlet works.

(Seed, 1979 - 19th Rankine Lecture)

DEFENSIVE MEASURES

1 - Allow ample freeboard to allow for settlement, slumping or fault movements.

2 - Use wide transition zones of material not vulnerable to cracking.

3 - Use chimney drains near the central portion of embankment.

4 - Provide ample drainage zones to allow for possible flow of water through cracks.

5 - Use wide core zones of plastic materials not vulnerable to cracking.

6 - Use a well-graded filter upstream of the core to serve as a crack stopper.

7 - Provide crest details which will prevent erosion in the event of overtopping.

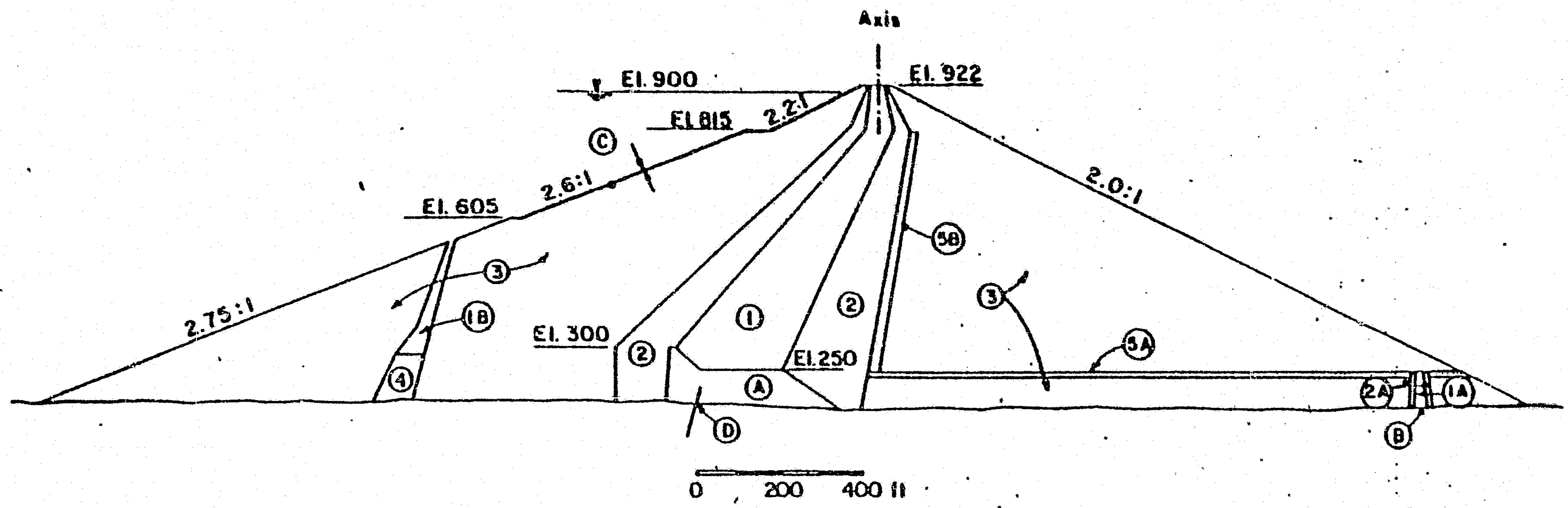
8 - Flare the embankment core at abutment contacts.

9 - Locate the core to minimize the degree of saturation of materials.

10 - Stabilize slopes around the reservoir to prevent slides.

11 - Provide special details if danger of fault movement in foundation.

(Seed, 1979 - 19th Rankine Lecture)



(1), (1A), and (1B) - Impervious core from main borrow area.

(2) and (2A) - Transition zone consisting of well graded mixture of silts, sands, gravels, cobbles and boulders to 15-inch maximum size.

(3) Shell zone of predominantly sands, gravels, cobbles and boulders to 24-inch maximum size.

(4) Imperious core from selected abutment stripping.

(5A) and (5B) - Drainage zones consisting of gravels, cobbles and boulders.

(A) Concrete core block

(B) Seepage measurement barrier

(C) Riprap

(D) Grout curtain

FIG. 42 MAXIMUM EMBANKMENT SECTION--OROVILLE DAM

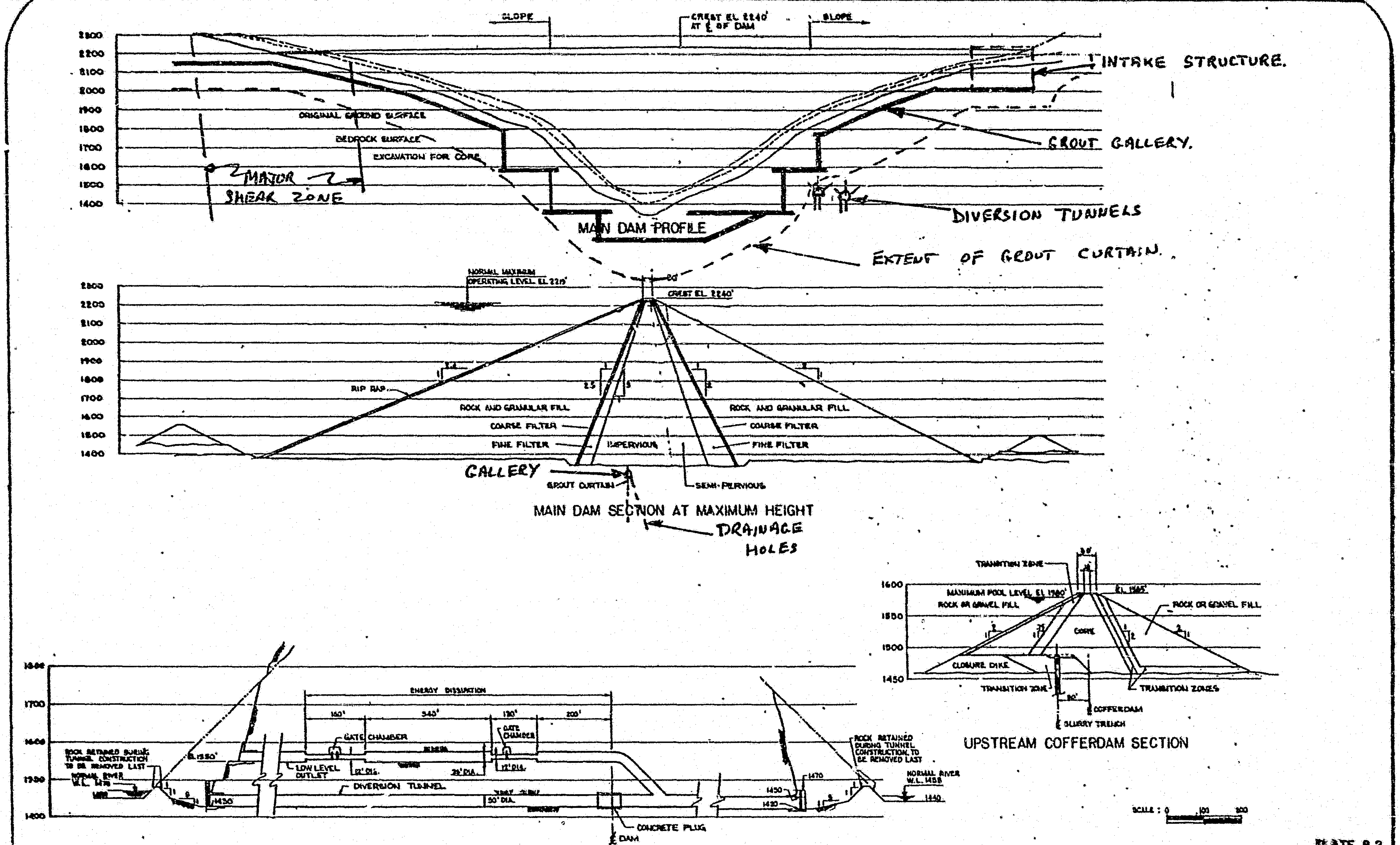
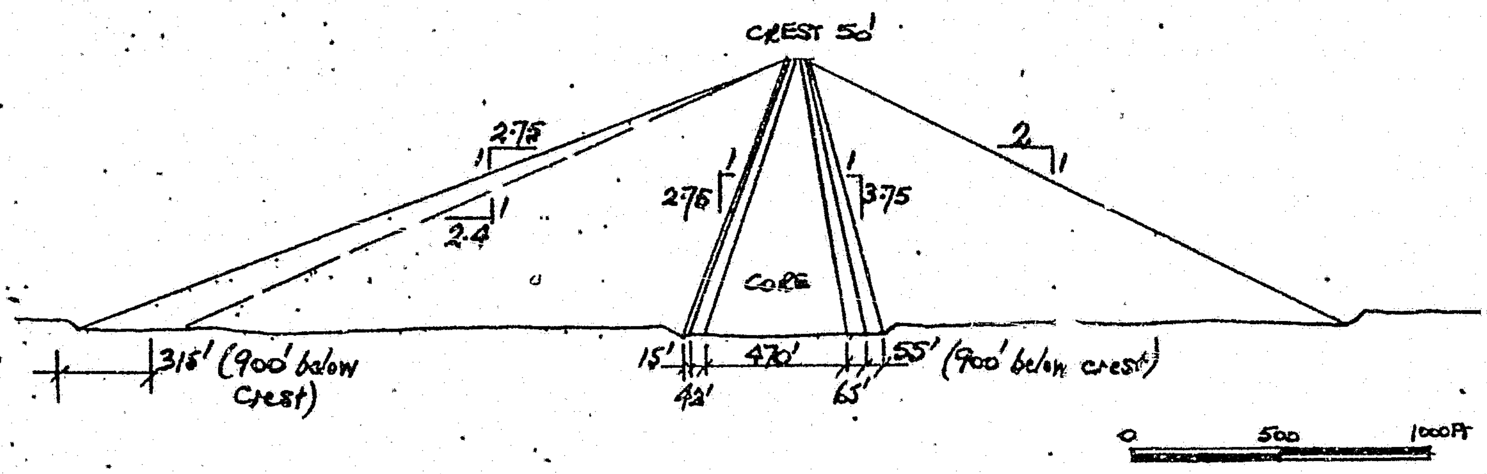


PLATE 8.2

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA
VALVE TYPE SPILLWAY ALTERNATIVE
MAIN DAM AND DIVERSION



CORE THICKNESS = 20' + 0.5 DEPTH BELOW CREST

WATANA DAM CROSS SECTION

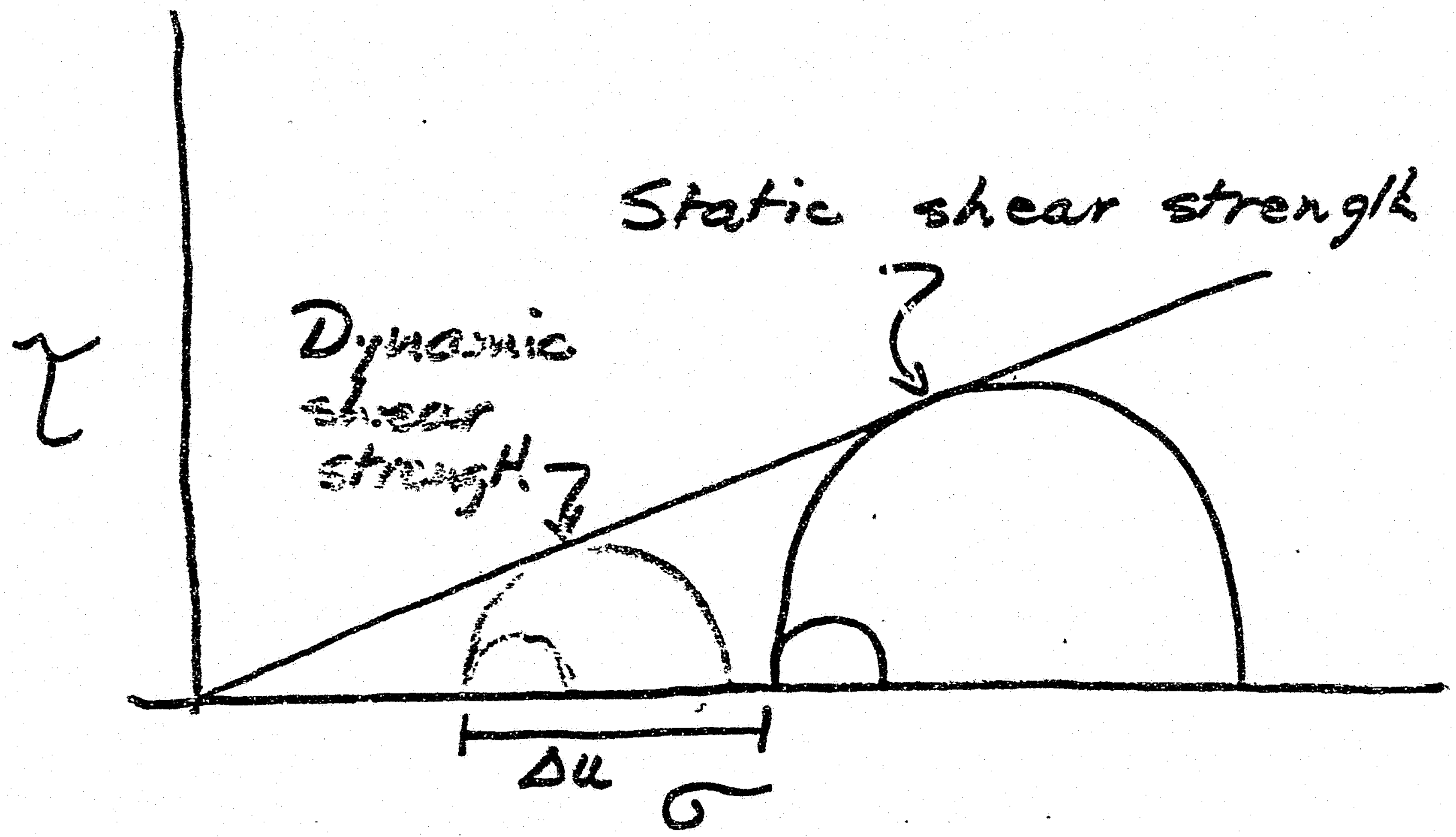
WATANA DAM DESIGN

2. Seismic Analysis (A. Burgess)

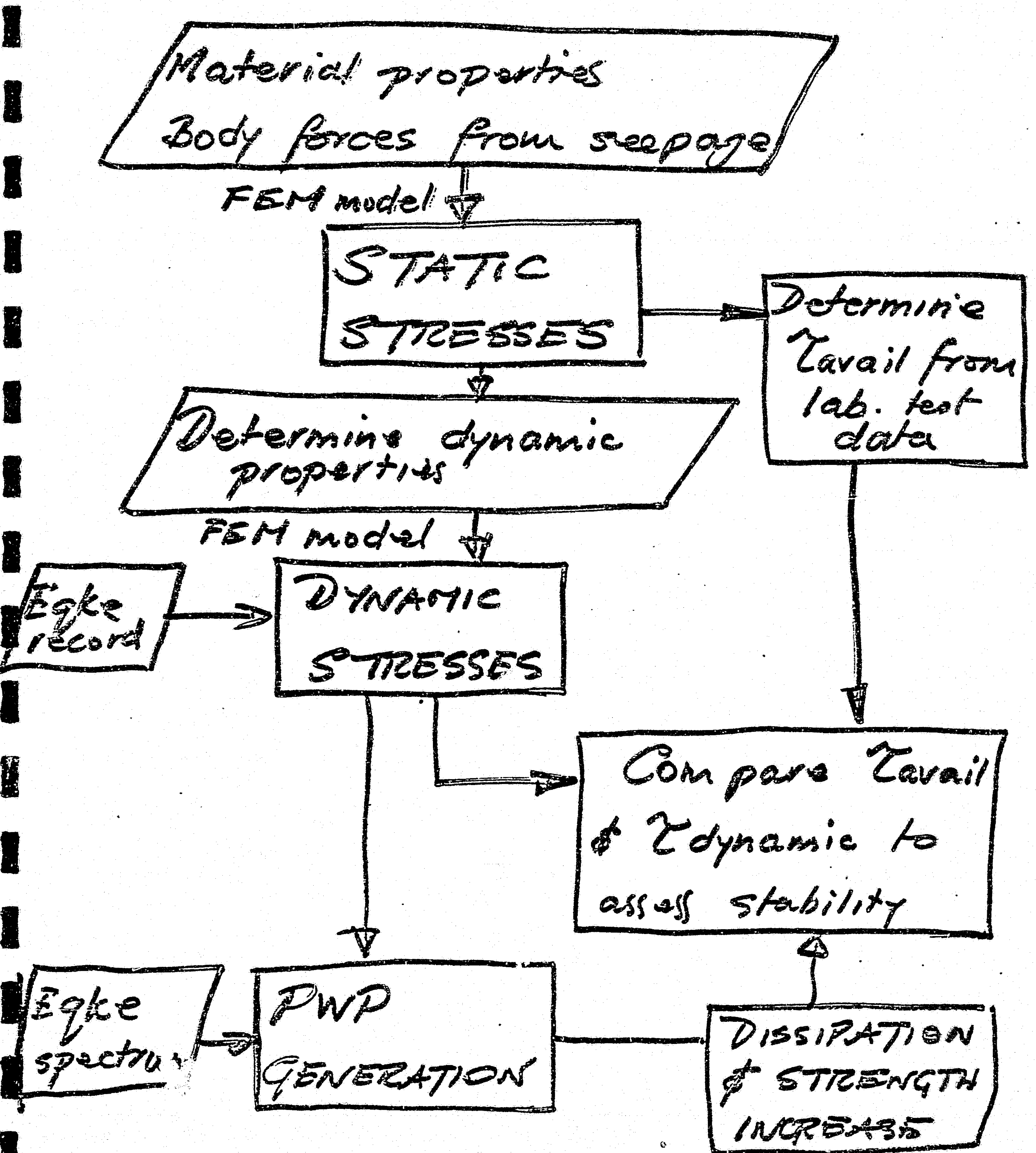
SEISMIC CONSIDERATIONS

1. MASS INSTABILITY FROM PWP GENERATION (I.E. LOSS OF STRENGTH)

2. DEFORMATION DURING SHAKING (DYNAMIC LOADING CAUSING STRENGTH EXCEEDENCE)



Effect of shaking


Material properties
Body forces from seepage
FEM model
STATIC STRESSES
Determine τavail from lab. test data
Determine dynamic properties
FEM model
Eqke record
DYNAMIC STRESSES
Compare τavail & τdynamic to assess stability
Eqke spectrum
PWP GENERATION
DISSIPATION & STRENGTH INCREASE

STATIC PROPERTIES

$$E = K\, p_a \left(\frac{\sigma_3}{p_a}\right)^n$$

K & n from literature

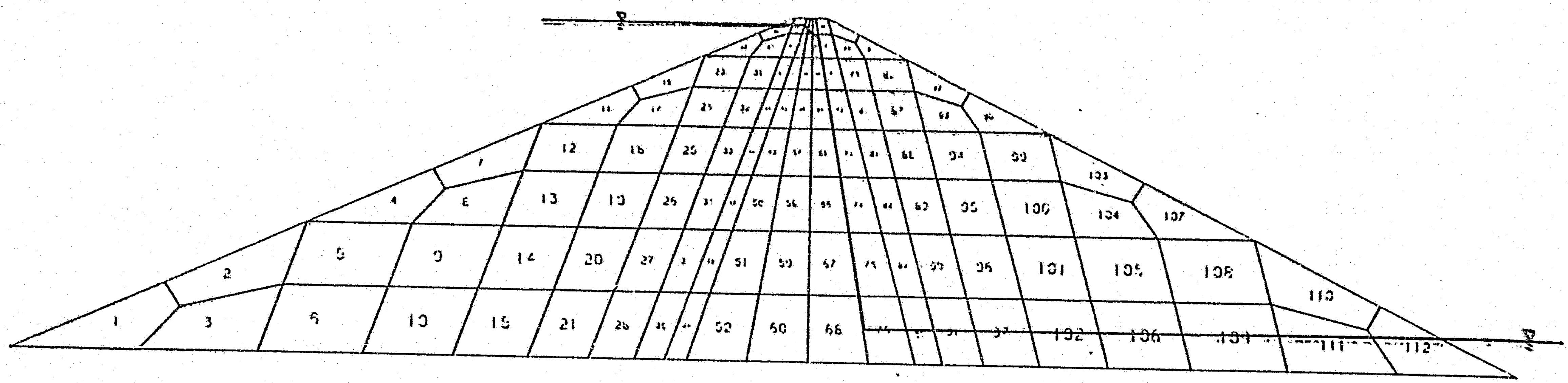
Poisson's Ratio ν for drained conditions (~ 0.25)

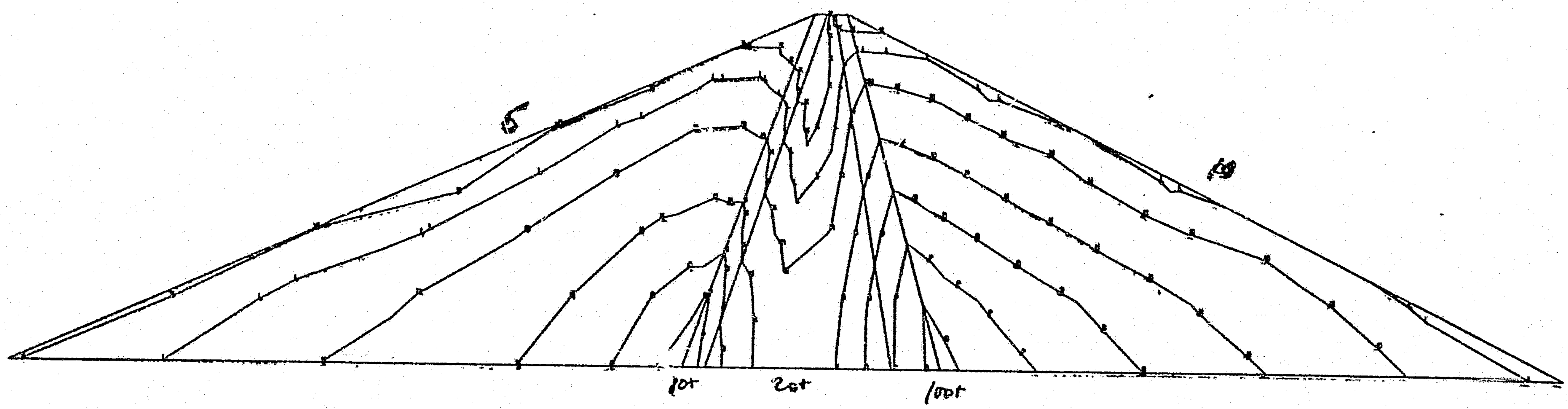
DYNAMIC PROPERTIES

$$G_o = K_2\, \sigma_{oct}'$$

K_2 from literature

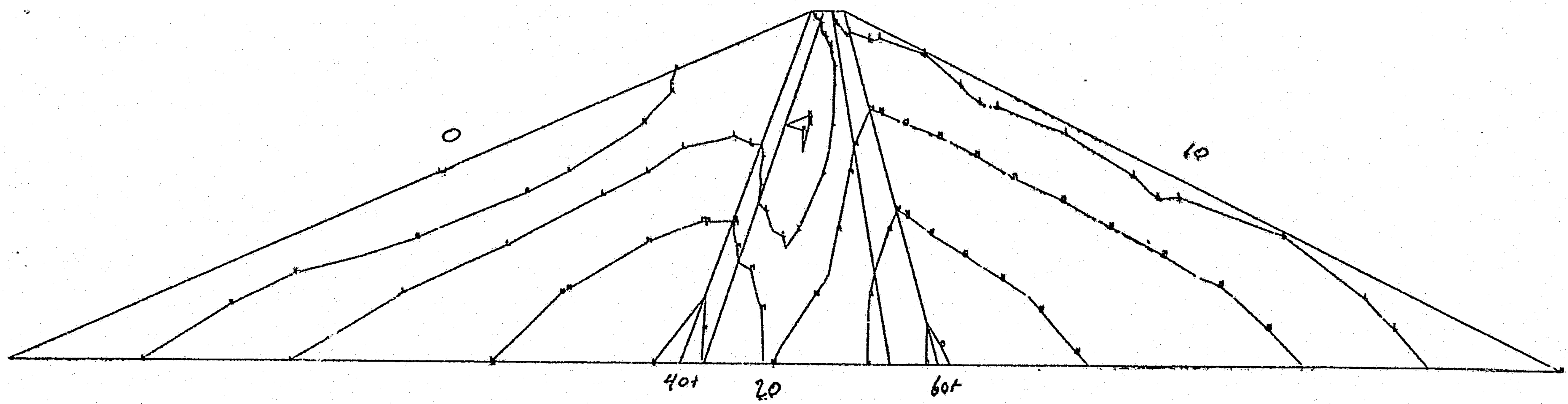
Reduction with shear strain from typical curves for sand & clay.





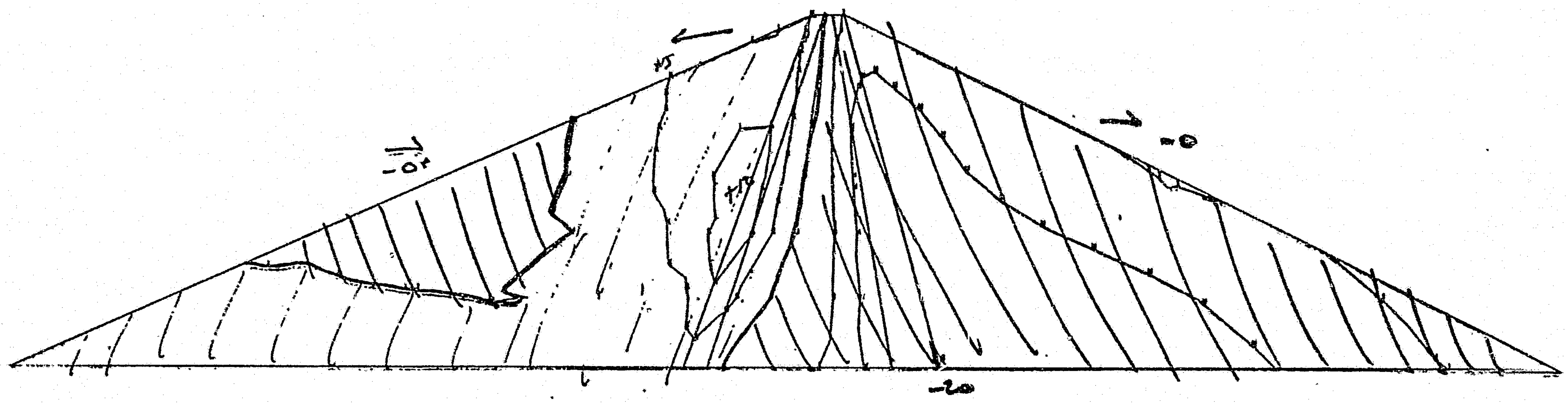
Symbol	A	B	C	D	E	F	G	H	I	J
Value	-140.	-120.	-100.	-80.	-60.	-40.	-20.	-10.	-5.	0.
Symbol	K	L	M	N	O	P	Q	R	S	
Value	5	10.	20.	40.	60.	80.	100.	120.	140.	

Static Run 2 - Vertical Effective Stress (SIGv') [klbf/ft**2]



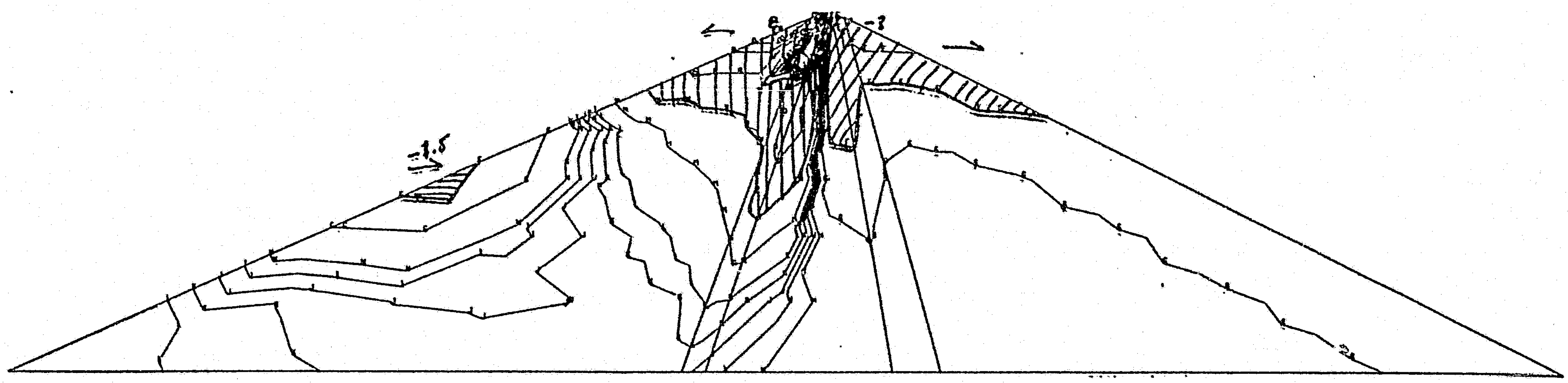
Symbol	A	B	C	D	E	F	G	H	I	J
Value	-140.	-120.	-100.	-80.	-60.	-40.	-20.	-10.	-5	0.
Symbol	K	L	M	N	O	P	Q	R	S	
Value	5	10.	20.	40.	60.	80.	100	120.	140.	

Static Run 2 - 3-D Effective Confining Stress (SIG3') [klbf/ft**2]



Symbol	A	B	C	D	E	F	G	H	I	J
Value	-140.	-120.	-100.	-80.	-60.	-40.	-20.	-10.	-5.	0.
Symbol	K	L	M	N	O	P	Q	R	S	
Value	5.	10.	20.	40.	60.	80.	100.	120.	140.	

Static Run 2 - Shear Stress (TAUxy) [klbf/ft**2]

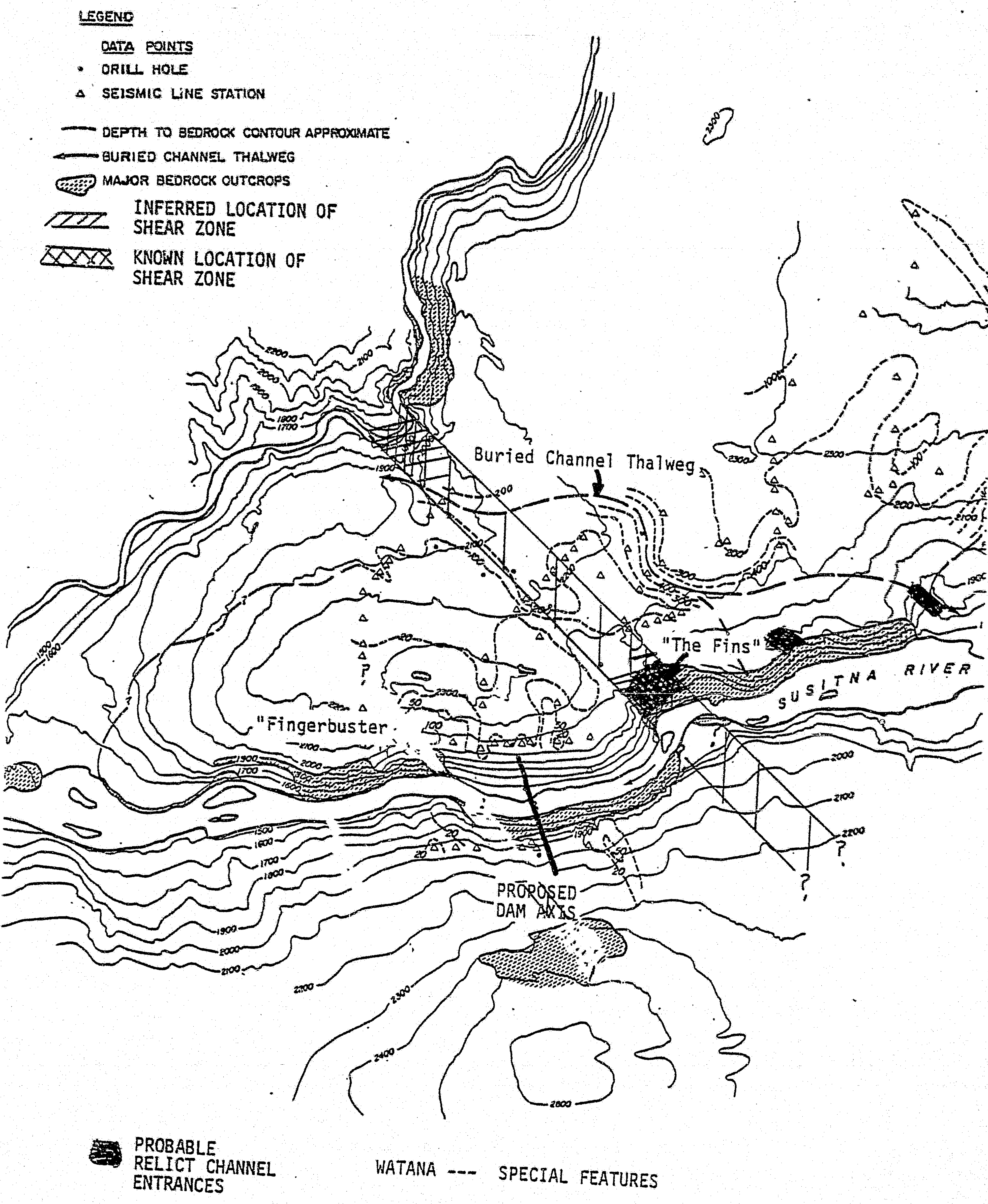


Symbol	A	B	C	D	E	F	G	H	I	J
Value	-10.0	-8.0	-6.0	-4.0	-2.0	-1.0	-0.5	-0.2	-0.1	0.0
Symbol	K	L	M	N	O	P	Q	R	S	
Value	0.1	0.2	0.5	1.0	2.0	4.0	6.0	8.0	10.0	

Static Run 2 - Local XY Shear Exceedance (TAUxy/Sh)

WATANA

Relict Channel (V. Singh)



WATANA --- SPECIAL FEATURES

APPENDIX B

REVIEW BOARD REPORT

SUSITNA HYDROELECTRIC PROJECT

BOARD MEMBERS'S SUGGESTIONS AS A RESULT OF A MEETING WITH PROJECT GROUP HELD IN NIAGARA FALLS ON SEPTEMBER 8, 1981

1 - GEOLOGY AND SEISMICITY

Board members believe that every effort should be made to expedite final logs of drill holes and drawings of geological plans and sections using old as well as new data. Early accomplishment of this will significantly aid the consideration of the fractured zone under the river at Devil Canyon.

The seismic ground motion for use in preliminary design should be defined in a manner which could be used in the license application.

2 - DAM DESIGN

Design of the Watana earth-fill dam is not yet a definitive stage but slopes have been selected which would facilitate construction of diversion and ancillary works. The adoption of these slopes in proposed arrangements should be reinforced by analysis or by a statement of precedents used in other dams of similar materials and in similar seismic terrain. Concern was expressed over the narrow width of filter zones at all elevations, and in particular near the base where a poor transition at rock contact could lead to piping.

The Board suggested that reference be made to the filter criteria in use in the James Bay structures. Board members suggested that grouting tunnels under the dam can be shown on the drawings, but the probability of main use is still an open question.

Although the arch dam appeared to limit stress levels to satisfactory value during earthquakes up to 0.4 g with a damping factor of 10 percent, some board members felt that a more comprehensive examination was required of other parameters such as in situ rock stresses in the abutment.

3 - RIVER DIVERSION, SPILLWAY AND OUTLET WORKS

Board members thought that precedents for each element of design in the river diversion, spillway and outlet works should be clearly stated.

The river diversion works at Watana appeared out of balance. The height of the upstream cofferdam was 140 feet and retained 125,000 acre feet of storage. The velocity of flow in the diversion tunnels was 50 ft/s, a high value. The economic optimum arrangement presented exceeded precedents and should be reviewed with the object of reducing risks in the event of the cofferdam overtopping. The merits of free flow tunnels should be considered more fully.

The avoidance of nitrogen supersaturation downstream from the dams during spillage or release of water from the reservoir has dominated the design and stretched a precedent in a number of areas. In view of the design implications of these criteria, the Board believes that every effort must be made to justify the need for these criteria.

The use of large Howell Bunger valves for spillway discharge requires trashracks upstream. The H.B. valves would cause an inordinate amount of spray in the summer and ice in the winter and could be subject to vibration. A precedent for Howell Bunger valves to be used for such duty had not been given. Neither had a precedent been given for a chute spillway with as large a drop and unit discharge.

The use of a fuse plug in the emergency spillway creates risks of accident al failure with catastrophic release of water or no failure when needed. The Board preferred a positive control of emergency releases by use of gates or similar structures.

Board members stated that more consideration should be given to other types of low and intermediate level outlet works. The Board suggested that "break head orifices" could be used in these works as was done at Mica.

The use of cascade spillways for service and auxiliary use should be considered in more detail at Watana.

The structural adequacy of the stilling basin at Devil Canyon was questioned. The fuse plug in the emergency spillway should, if possible, be replaced by a positive control.

Ian McCaig questioned the necessity of a diversion tunnel at Devil Canyon. No diversion tunnel was used at Kariba. In many cases, diversion is made initially through a channel and later through a port in the dam.

4 - INTAKE, POWERHOUSE AND TAILRACE TUNNELS

The Board considered that the intake trashracks projecting above the water surface increases the probability of trashrack blockage by frazil ice. Reference should be made to the Churchill Falls design. The need for drawoff at various reservoir levels at Watana requires better definition. Definition might allow simplification of the design.

The location chosen for the underground powerhouse should be justified by rock quality, proximity to access and power lines, etc.

Gates or stoplogs in the draft tube and tunnel outlet would, as shown, be subject to freezing; some modification is needed.

Successful operation of the facilities during construction, and in service after completion, requires that special attention be given to operating conditions and problems resulting from the vigorous winter climate in Alaska.

5 - CONSTRUCTION AND CONSTRUCTION MATERIALS

At Watana, the tunnel outlets for diversion, tailrace and spillway are located very close together. Cofferdam and penstock arrangements would be unduly complicated. The construction sequence should be considered in arriving at layout, particularly at Watana, since close location of structures can create problems for construction and for the operation of the facilities.

Borrow pits for earth dam construction have been established and the suitability of grading determined. Exploratory work is currently underway on concrete aggregates and the results will soon be available.

Some andesites are known to produce aggregates subject to alkali-aggregate reaction. The properties of all potential concrete aggregates that would be used in the Devil Canyon and Watana dams and powerhouses should be established soon.

cc: J. Lawrence
J. G. Warnock
All Board Members
J. MacPherson