GOVERNMENT OF REPUBLIC OF TURKEY

MINISTRY OF ENERGY AND NATURAL RESOURCES

GENERAL DIRECTORATE OF STATE HYDRAURIC WORKS

STRESS ANALYSIS OF

HEIGHTENED CUBUK I DAM

November 1970

OVERSEAS TECHNICAL COOPERATION AGENCY

GOVERNMENT OF JAPAN

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November 21, 1970

Mr. Hazim Tutuncuoglu
Director General
General Directorate of State
Hydraulic Works
Ministry of Energy and Natural Resources
Yucetepe, Mahallesi
Ankara, Turkey

Dear Sir:

In response to the request made by Mr. S. Maruyama, engineer, assigned to the State Hydraulic Works (DSI), by the Overseas Technical Cooperation Agency, I take pleasure to submit herewith the report on the heightening of the existing Cubuk I Dam. The engineering studies and analysis of the dam were carried out by the Electric Power Development Company, Ltd.

In submitting this report, I sincerely wish that the recommendations and conclusions contained will serve to be useful and valuable in the proposed heightening of the dam.

I take this opportunity to express my deepest appreciation to the officials and engineers of DSI for their kindness extended to our engineer.

Respectfully yours,

Keiichi Tatsuke
Director General
Overseas Technical
Cooperation Agency

CONTENTS

DRAWINGS

1. SCOPE OF REPORT

This Report summarizes the results of a series of stress analyses made to obtain the information necessary for judging the feasibility of heightening of Cubuk 1 Dam in the form of an arch-gravity dam. Examinations were made for both a 3-m and 5-m heightening with joint grouting at 84 m (low water level) and 103 m (present high water level) and cover the following:

(1) Stress analysis of heightened arch-gravity dam, and

(2) Examination of sound rock line of downstream shoulder

as the major items with in addition

(3) Study of the case of omission of joint grouting,

(4) Calculation of thermal stresses of arch-gravity dam, and

(5) Brief consideration of feasibility and method of heightening.

It is herein noted that the basic items related to this study were decided from the reports of the engineer dispatched to the site and upon consultations with the staff concerned at Electric Power Development Co., Ltd.

2. SUMMARY OF RESULTS AND RECOMMENDATIONS

The summary of the results of stress analysis is indicated as given below.

In the case the heightening is to be provided in the form of an arch-gravity dam, the height of the water level at joint grouting will have a great effect on stress distribution in the dam. At a high water level of joint grouting the load carried by the arch is reduced and in fact approaches the stress conditions when the heightening is made as a gravity dam. In the case of this dam, if the water level at joint grouting is taken at 84.0 m, within a range of 3.0 m to 5.0 m of heightening height ($\triangle H$), a maximum compressive stress of the degree of 12 to 14 kg/cm^2 occurs at the upstream face of the arch crest. The maximum tensile stress occurs in a diagonal direction near the lower abutment at the downstream face and its magnitude is -5 to -6 kg/cm^2.

In the case $\triangle H = 3.0$ m, even if joint grouting is not performed and the work is carried out with the dam remaining a gravity type, there will be hardly any tensile stress occurring at the upstream toe of the dam (not considering seismic forces).

When $\triangle H = 5.0$ m, if the joint grouting is carried out at a water level of about 90 m, no tensile stress occurs at the upstream toe similar to the above-mentioned.

The horizontal thrust produced by arching action is relatively little in any of the cases. Regarding the stability of the downstream shoulder, even by a simple examination, it is said to be adequate safety.

There is a possibility of rib shortening occurring to the extent arching action cannot be anticipated when the temperature of the dam body drops after heightening in the form of an arch-gravity dam. Therefore, it is desirable for thorough consideration to be given in selection of the timing of joint grouting.

As a result of the examination, a brief consideration of the heightening construction method of this dam suggests the following:

When the heightening height is 3.0 m, it is thought it will not be necessary to perform joint grouting, under the condition that the Turkish regulation permitts a little tensile stress of upstream toe.

In the case the heightening height is 5.0 m, it is thought desirable to lower the water level to about 90 m for joint grouting selecting the dam type to be arch-gravity. It is thought that further consideration should be given the timing of the grout operation.

Regarding the idea of prestressing the dam using steel, it may be considered that hardly any knowledge of the feasibility would be obtained while studying the matter without a clear picture of the foundation conditions.

Joint grouting not previously provided with grouting facilities is not thought to be of such difficulty considering the level of recent development of new materials and utilization of boring machines.

3. CONDITIONS GIVEN FOR STUDY

The shape and dimensions of the present dam are as shown in the drawing received with the outline as indicated below (See CUB-01).

Reservoir

High water level	103.0 (EL. 907.61)
Low water level	84.0
Estimated silt level	79.0

Dam

Type	curved gravity concrete dam
Height	58.0 m
Crest elevation	104.0 m
Crest width	4.0 m
Upstream face slope	vertical
Downstream face slope	1:0.72, 1:0.825, 1:0.828
Upstream face radius	222.0 m
Crest center angle	approx. 65°
Crest length	approx. 250 m
Overflow crest elevation	101.0 m
Overflow width	6.5 m x 3, 8.0 m x 2

Taking advantage of the fact that the present dam is a curved gravity dam, the heightening is considered to be provided carrying out joint grouting at a suitable water level to result in an arch-gravity dam and stress analyses are to be performed according to the cases given in Table 1. The overflow section is to be left in its present form to maintain its service function even during heightening work. Therefore, the crest elevation of the structure having arching action is to be 101.0 m.

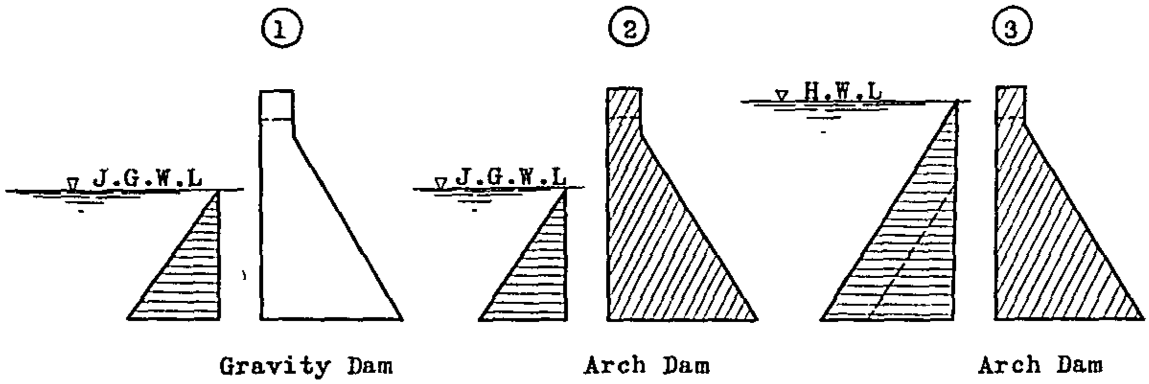
Table-1 Conditions Studied for Heightening

Case	A	B	C	D
High water level	105.0	105.0	107.0	107.0
Dam crest elevation	107.0	107.0	109.0	109.0
Joint grouting water level	84.0	103.0	84.0	103.0

4. METHODS AND ASSUMPTIONS OF STRESS ANALYSIS

4.1 Loading Conditions of Structures Subject to Calculations

The stress distribution of an arch-gravity dam which is established after completion of the heightening is estimated by superposing, as indicated in Eq. 1, the stress sought under the conditions given below. The horizontal thrust acting on the abutment is estimated similarly by Eq. 2.



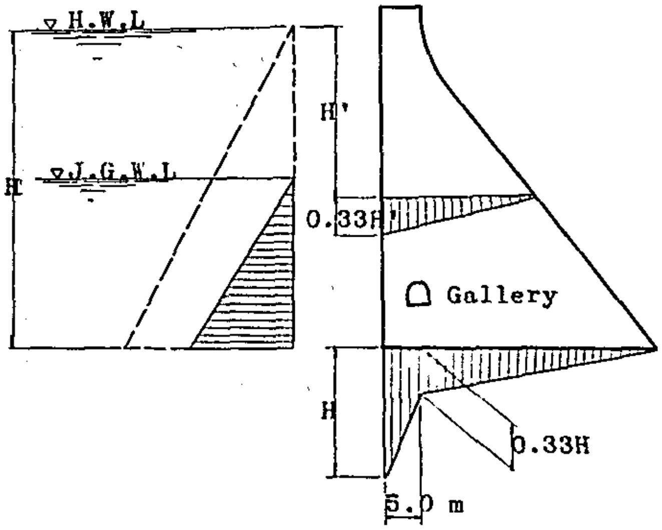
Stress of heightened arch dam at high water level = ① + ③ - ② .... (1)*

Horizontal thrust acting on abutment = ③ - ② .... (2)

The stress as an arch dam is calculated by electronic computer using a load division method adjusting the 3 components of displacements (radial, tangential and twisting).

* As a computer program to calculate stress of an arch dam for increased hydraulic pressure as ③ - ② is not developed, the stress due to the load was obtained as the difference of the values for the loads of ③ and ②.

The uplift pressure acting on the gravity dam is accounted for as indicated below.



The quantity of temperature variation to be considered in calculating thermal stresses of the three-dimensional structure is sought by the following equation:

$$t = \frac{60}{2.5 + T} \quad \cdots\cdots (3)$$

where

t: quantity of temperature variation of elevation considered (°C)

T: thickness of elevation considered (m)

Seismic forces are not considered.

4.2 Shape of Dam and Grid Element

The shape of the dam is idealized as shown in CUB-01 and the numbers of arch and cantilever elements for stress calculations by the load division method are taken to be 5 and 11 respectively, as indicated in the drawing. Therefore, considering the displacements in 3 directions for each of the 43 intersecting points a linear simultaneous equation having 129 unknowns is obtained.

4.3 Physical Constants and Other Values

The various values such as physical constants used for calculations are as follows:

Dam Concrete

Unit weight	2.35	t/m^3
Modulus of elasticity	2×10^6	t/m^2
Poisson's ratio	0.2	
Coefficient of thermal expansion	10×10^{-6}	/°C

Foundation Rock

Modulus of elasticity	4×10^5	t/m^2
Poisson's ratio	0.2	
Coefficient of friction	1.0	
Shearing strength	100	t/m^2

Silt

Unit weight (submerged)	1.0	t/m^3
Coefficient of silt pressure	0.4	

5. RESULTS OF STRESS ANALYSIS

5.1 Distributions of Horizontal and Vertical Stresses

The distributions of horizontal, vertical and shearing stresses after heightening for each case are as indicated in the upper halves of CUB-02 - CUB-05. The horizontal and vertical stresses occurring at the crown and both abutments, for study of the influence of height of joint grouting water level on the stress conditions of dam, are plotted as the graphs on the left side of CUB-06. From these graphs, it is seen that stress distribution differs considerably depending on the joint grouting water level, the vertical stress being small and horizontal stress being large when the water level is low. This is due to the difference of load carried by the arch according to the increased load acting after becoming an arch dam. This difference is shown well in the figure at the upper half of CUB-07 indicating the distribution of load division by height of joint grouting water level in the case of a 5-m heightening.

5.2 Magnitude of Principal Stress

The maximum compressive and tensile stresses for the upstream and downstream faces in each case are indicated in Table-2.

5.3 Distribution of Horizontal Thrust Acting on Dam Abutment

In the upper right part of CUB-06, the distribution of horizontal thrust acting on unit height of abutment and total thrust acting above a certain elevation are indicated. From this graph, it is seen that the horizontal thrust per unit height is generally below 300 t/m while total thrust, even in Case C with the severest conditions, is about 5,000 t.

Table-2 Maximum Compressive and Tensile Stresses

Unit: kg/cm^2

	A	B	C	D
Upstream Face				
Max. comp. stress	12.0 (C.100.H)*	2.1 (C.100.H)	13.9 (C.100.H)	4.0 (C.100.H)
Max. tens. stress	-3.3 (R.10.V)	-2.0 (LA.100.H)	-4.5 (R.90.V)	-3.3 (LA.100.H)
Downstream Face				
Max. comp. stress	11.3 (RA.90.H)	8.6 (C.60.V)	13.4 (RA.100.H)	9.5 (C.60.V)
Max. tens. stress	-5.4 (R.90.D)	-0.5 (R.70.H) (R.90.H)	-6.1 (R.90.D)	-1.1 (R.90.H)

* Notations in parentheses indicate location of stress occurrence as follows:

First row .... C: crown; L,R: left, right;
A: abutment

Second row .... elevation

Third row .... direction of stress

6. EXAMINATION OF ANALYSIS RESULTS

6.1 Influence of Joint Grouting Water Level on Stresses in Dam

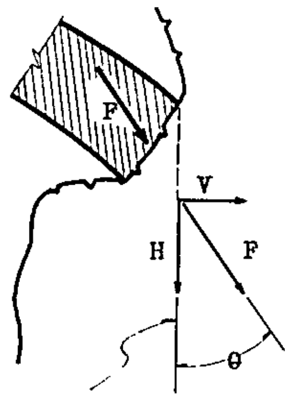
The graph at the lower right part of CUB-06 indicates the results of studies related to the influences of joint grouting water level on the horizontal stresses of the crest arch crown and the vertical stresses at the crown base. This graph also contains the results in the case joint grouting is not performed. According to this, when the heightening height ($\triangle$H) is 3 m, it is seen that hardly any tensile stresses are occurred at the crown base even if joints are not grouted; also in the case of $\triangle$H = 5 m, if the water level is at about 90 m when grouting is performed, similar results are obtained. Also, the compressive strength at the downstream aide of the crown base even with no joint grouting is of the degree of slightly less than 8 kg/sq.cm for $\triangle$H = 3 m and around 10 kg/cm^2 for $\triangle$H = 5 m. As for horizontal stress of the crest arch, it is seen that if the joints are grouted at a water level of 84 m, stresses of about 11 to 14 kg/cm^2 are occurred.

6.2 Study of the Required Sound Rock Lines of Downstream Shoulders of Abutments

CUB-08 gives the results of a very brief study made to estimate the depths of the sound rock lines required to support the horizontal thrust forces acting on the abutments at both banks when heightening is carried out in the form of an arch-gravity dam.

The study was made on a horizontal section with the sliding plane assumed to be linear starting from the upstream end of the dam. If it is assumed that a sliding plane is at an angle of θ to the direction of external force F, the vertical force V and the force along the plane H acting on the sliding plane are given as $V = F \cdot \sin\theta$ and $H = F \cdot \cos\theta$.

Therefore, if the shearing strength of foundation is τ and the internal coefficient of friction is f, the length ℓ of the sliding plane necessary to secure the required safety factor is given by Eq. 4.



Assumed sliding line

$$\ell = \frac{n \cdot H - f \cdot v}{\tau}$$

$$\ell = \frac{F}{\tau} (n \cdot \cos\theta - f \cdot \sin\theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where

$$n = \frac{\tau \cdot \ell + f \cdot v}{H} \quad \text{(factor of safety for shearing friction)}$$

The required sound rock line is indicated by the curve connecting the ends of the lines seeking various values of ℓ by varying the value of θ.

In CUB-08, the results of the required sound rock lines obtained by $f = 1.0$, $\tau = 100\ t/m^2$, $n = 4$ for representative elevations on both banks are indicated. The safety of the shoulder to be adequately secured, as the horizontal thrust is rather little and the required sound rock lines fall well within the present ground surface contour lines.

7. SUPPLEMENTAL STUDIES

7.1 Examination of Case of No Joint Grouting

The results of stress analysis of the case when heightening is provided with the dam in gravity-type without joint grouting are indicated in CUB-09. These results are contained in the graph at the lower right of CUB-06 described in 6.1. From the figure at the right side of CUB-09, in the case of H = 3 m, it is seen that the acting point of the resultant force is only very slightly off the middle third of the gravity dam.

7.2 Thermal Stresses

The results of calculations of stresses occurring in an arch-gravity dam (crest elevation of the structure having arching action = 101), when there are temperature changes such as indicated in 4.1 are given at the lower part of CUB-07. According to this, when there is temperature drop of this degree, a result that an absolute value of mean tensile stress greater than that of the mean compressive stress occurred by the heightening is obtained in the stress in the horizontal direction. Therefore, when there is such a temperature drop, the effect of rib shortening is magnified and the resisting action as an arch is lost as a matter of practicality and it is thought the water pressure will be resisted only as a gravity dam.* When heightening of the dam is planned according to this method, it is considered to give some thought to this problem.

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* It is assumed the displacement as a gravity dam is not so large that effect due to rib shortening is negated and the joint is closed.

7.3 Brief Consideration Regarding Heightening Construction Methods

Based on the results of stress analysis described in the above, a brief consideration of the heightening construction method of this dam would be as follows.

Case of $\Delta H = 3.0$ m

According to the analysis results, even if joint grouting is not carried out and the dam is heightened as a gravity-type, a result that there are hardly any tensile stress occurred at the upstream toe is obtained. Therefore, it would be thought there is no necessity to carry out joint grouting lowering the water level, if Turkish design regulation of dam allows a slight tensile stress occures at upstream toe of dam.

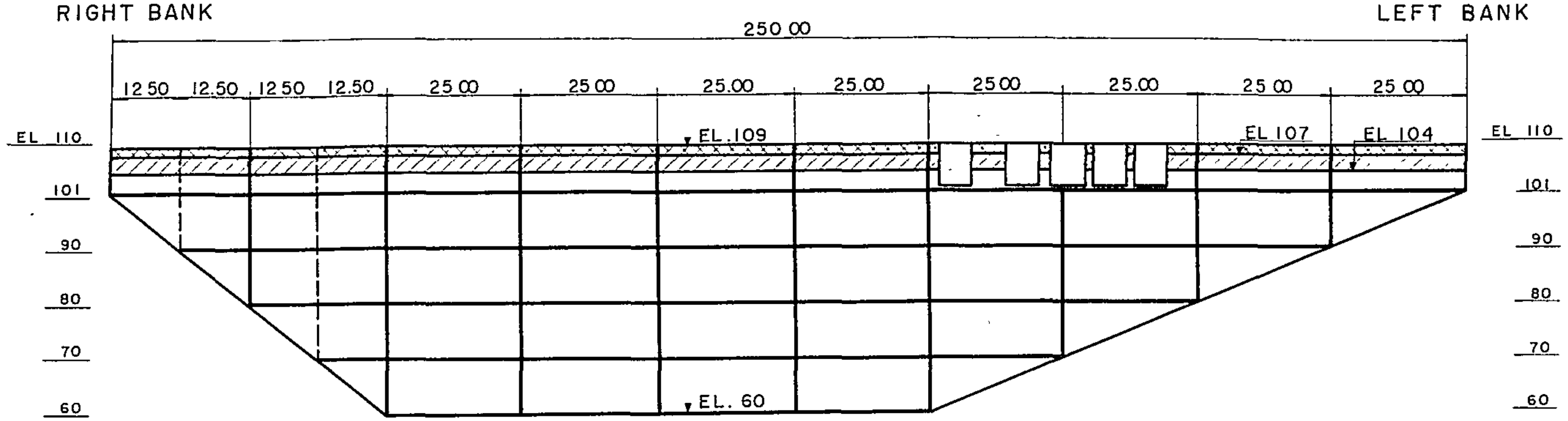
Case of $\Delta H = 5.0$ m

Since a tensile stress of 1.2 kg/cm^2 is produced at the upstream end when heightening is carried out as a gravity dam, it is thought desirable to provide some measures of reinforcement. If resistance by arching action is looked for by carrying out joint grouting, it is thought desirable to lower the water level to around 90 m.

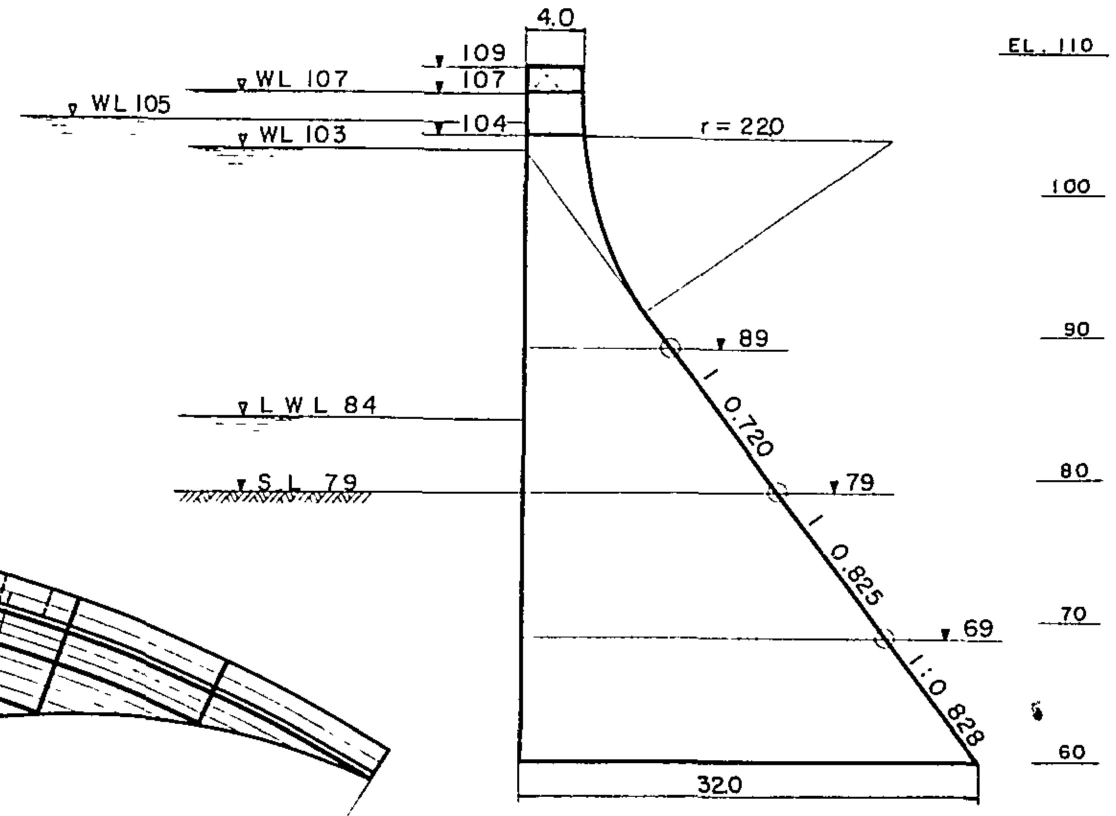
In the process of prestressing the dam using steel wires or rods, the basic function depends on the reliability of the anchors and the safety is greatly influenced by the geological conditions of foundation. As in the case of this site, when the geological conditions are not clear so that further surveys would be needed, it is thought for the moment advisable to eliminate this as an object of study.

For heightening to be provided in the form of an arch-gravity dam, a mandatory condition will be for reliable joint grouting to be carried out. Although it is certain that joint grouting is difficult at joints without grouting facilities, there have been cases of regrouting having been carried out at joints without regrouting facilities, and with the recent development and practical application of new materials for downstream face sealing and drilling along joints, the work should not be of such difficulty.

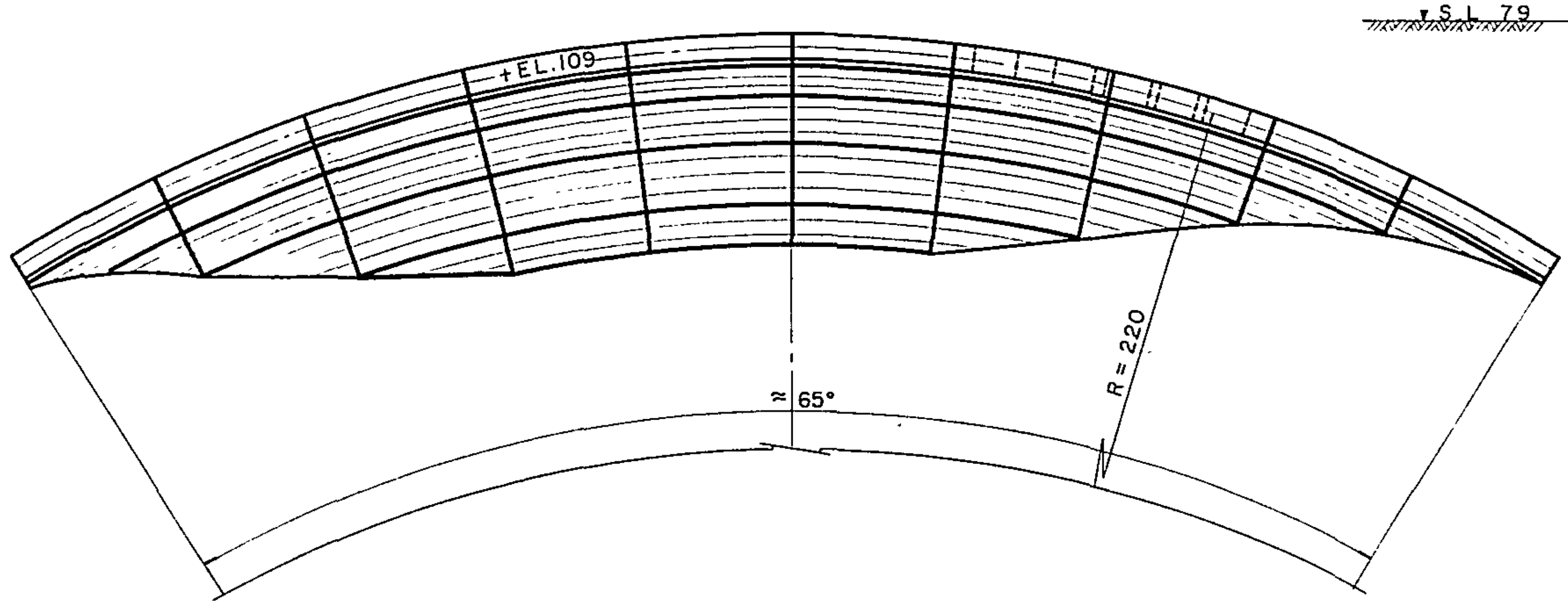
DEVELOPED ELEVATION OF UPSTEREAM FACE s=1/1,000



SECTION s=1/500



PLAN s=1/1,000



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MINISTRY OF ENERGY AND NATURAL RESOURCES	
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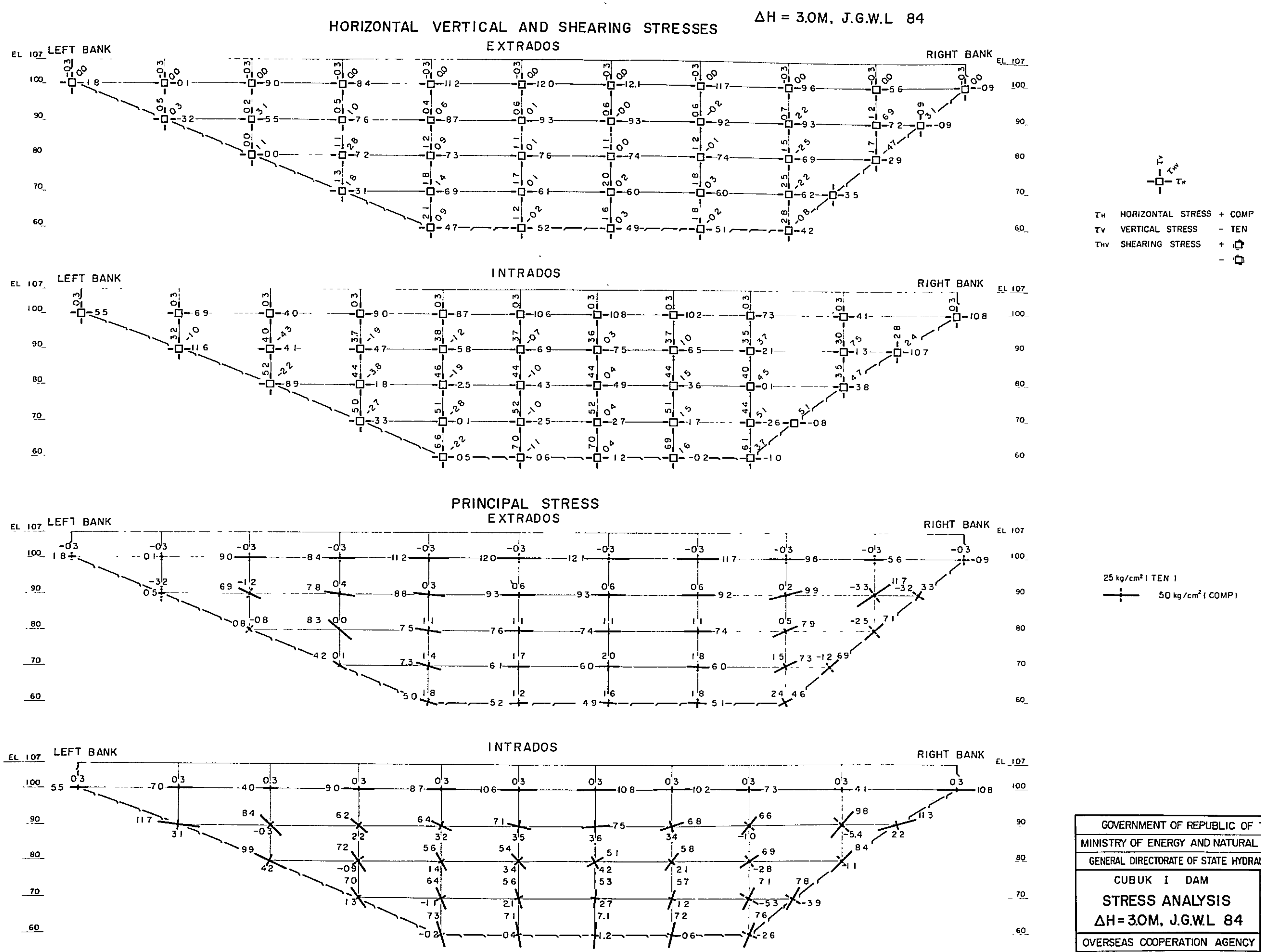
CUBUK I DAM SHAPE OF DAM & GRID ELEMENT	CUB 01
OVERSEAS COOPERATION AGENCY GOVERNMENT OF JAPAN	DATE Feb. 1970



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GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS

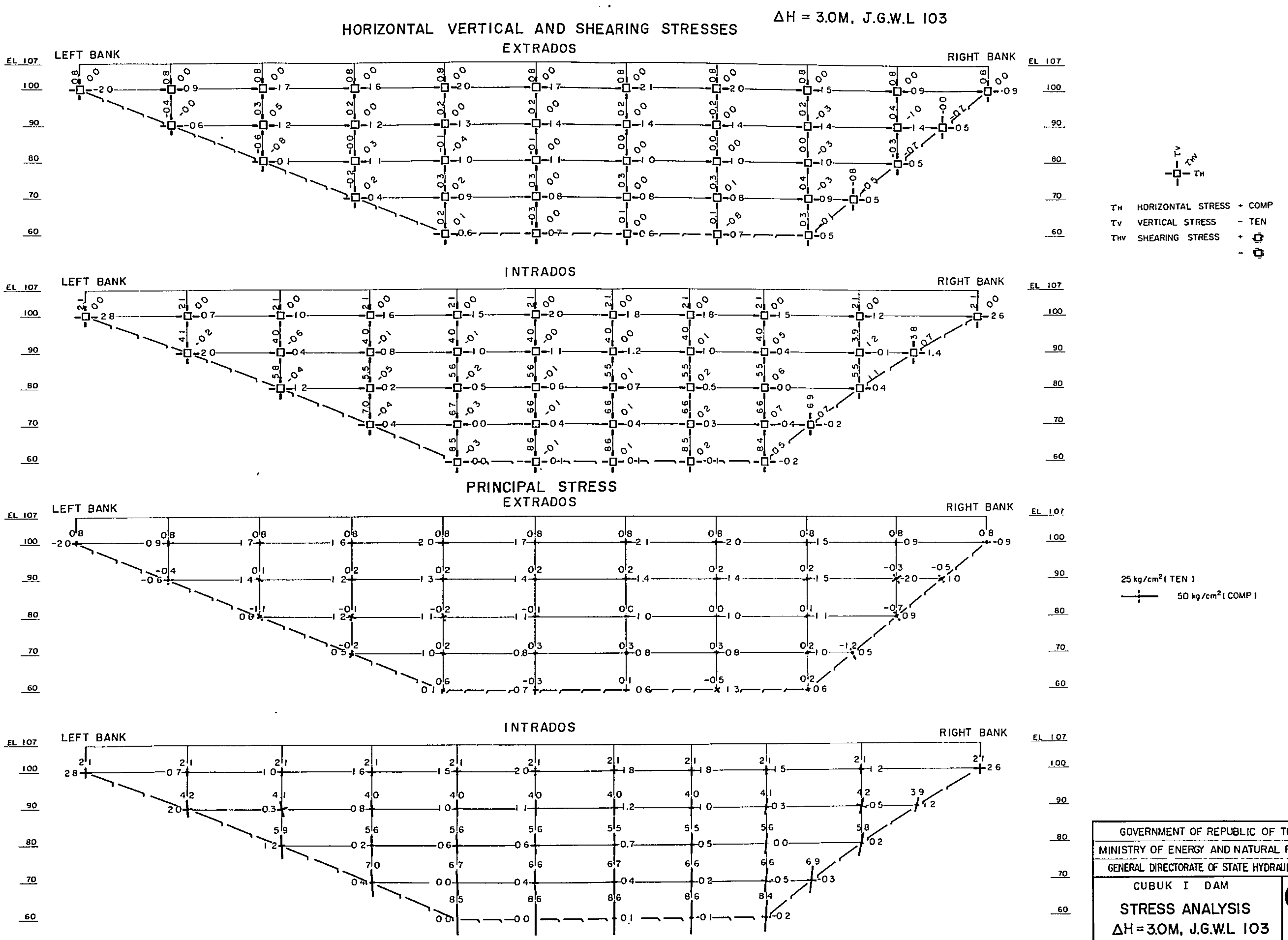
CUBUK I DAM
STRESS ANALYSIS
ΔH=3.0M, J.G.W.L 84

CUB 02

OVERSEAS COOPERATION AGENCY
GOVERNMENT OF JAPAN

DATE Feb 1970

SHEET NO OF



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MINISTRY OF ENERGY AND NATURAL RESOURCES

GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS

CUBUK I DAM

STRESS ANALYSIS

ΔH = 3.0M, J.G.W.L 103

CUB 03

OVERSEAS COOPERATION AGENCY

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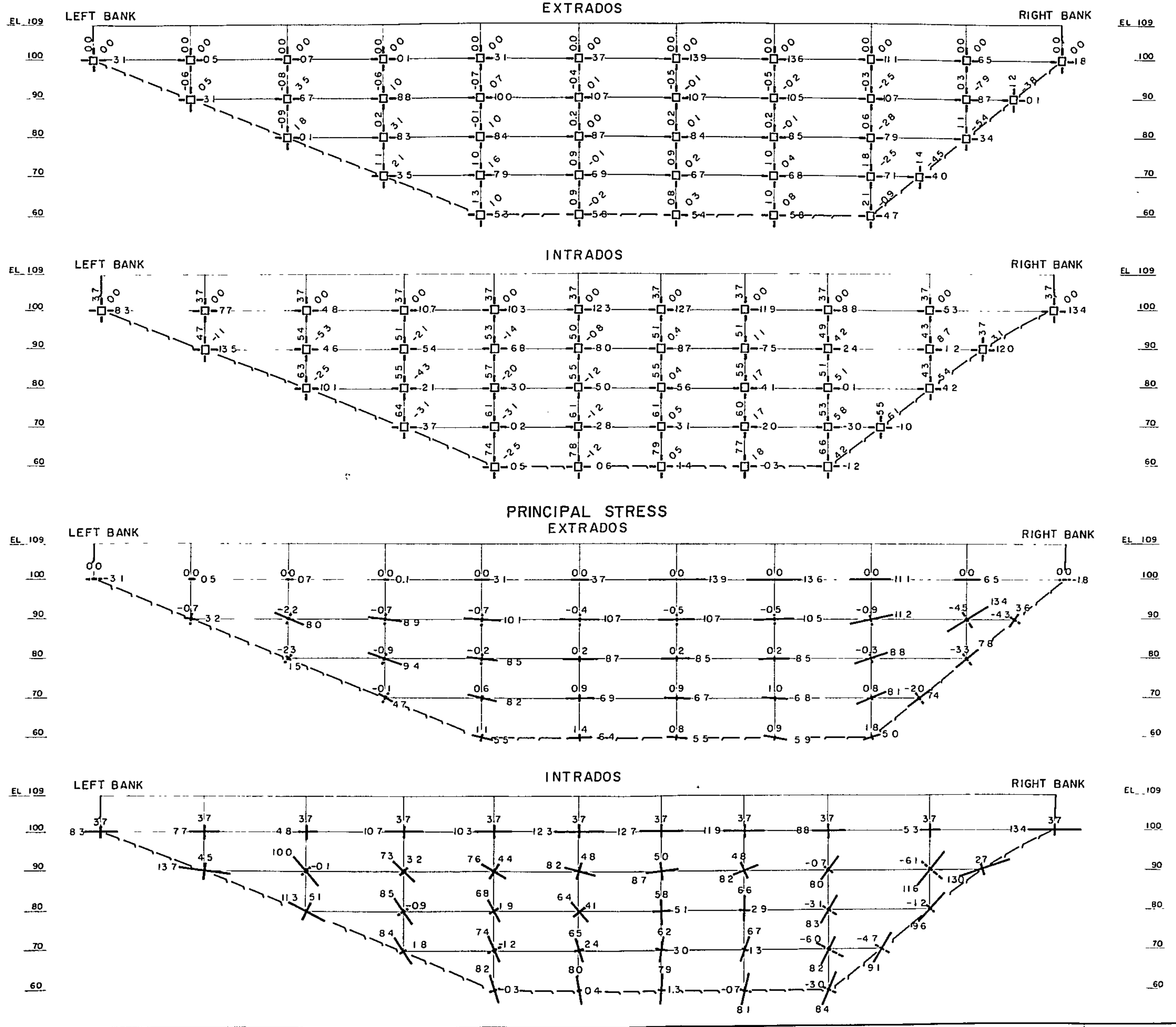
DATE Feb 1970

SHEET NO. OF

HORIZONTAL VERTICAL AND SHEARING STRESSES

ΔH = 5.0M, J.G.W.L 84



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MINISTRY OF ENERGY AND NATURAL RESOURCES
GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS

CUBUK I DAM

STRESS ANALYSIS
ΔH = 5.0M, J.G.W.L 84

CUB 04

OVERSEAS COOPERATION AGENCY
GOVERNMENT OF JAPAN

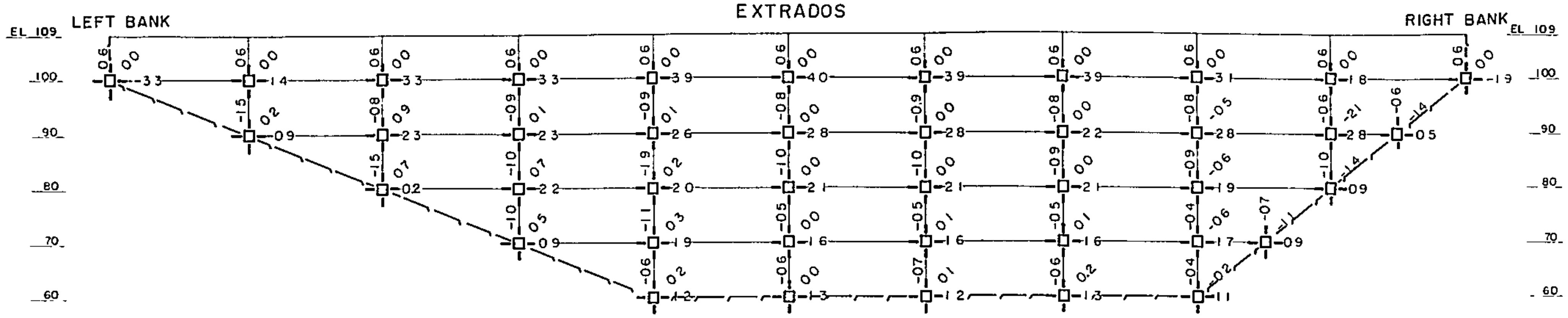
DATE Feb 1970

SHEET NO OF

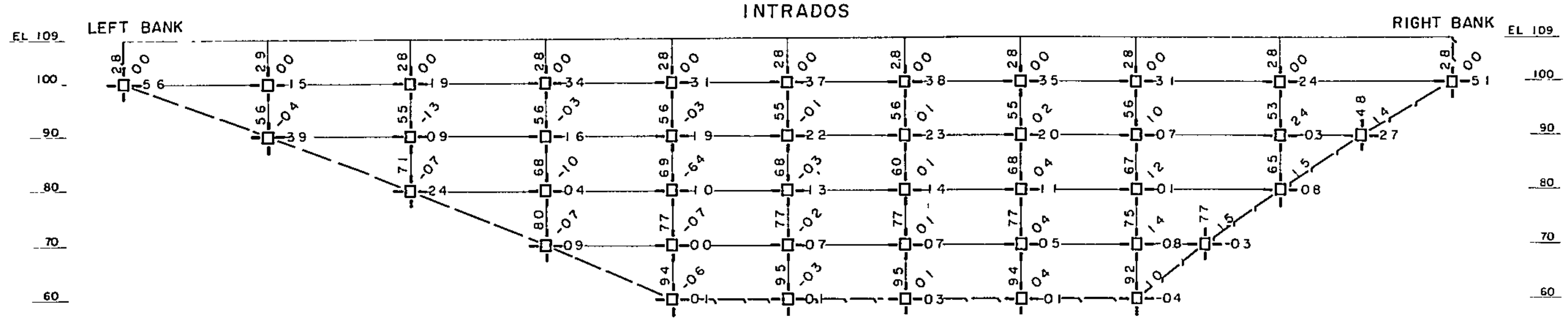
HORIZONTAL VERTICAL AND SHEARING STRESSES

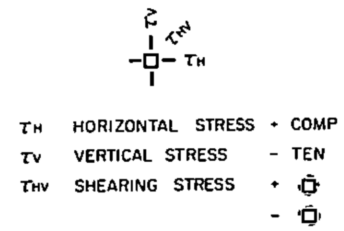
$\Delta H = 5.0M$; J.G.W.L 103

EXTRADOS



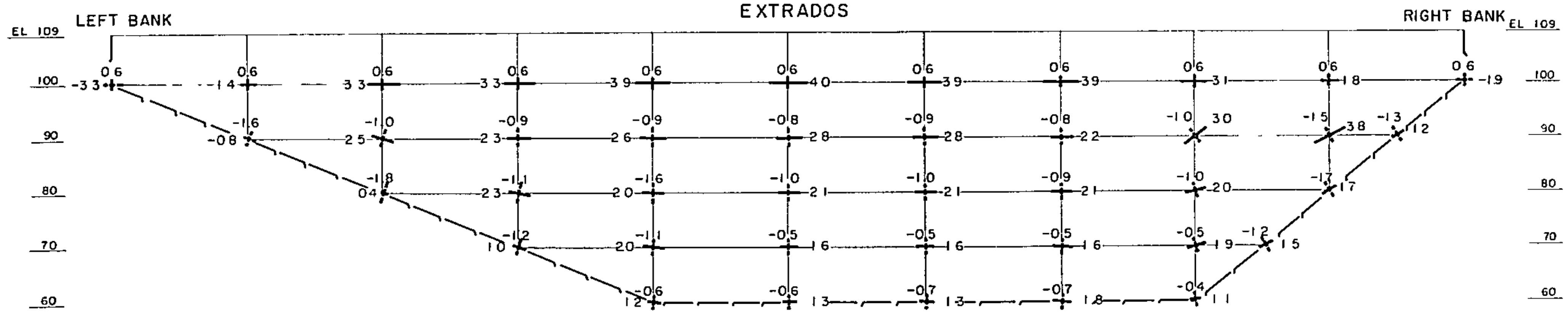
INTRADOS

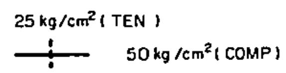




PRINCIPAL STRESS

EXTRADOS





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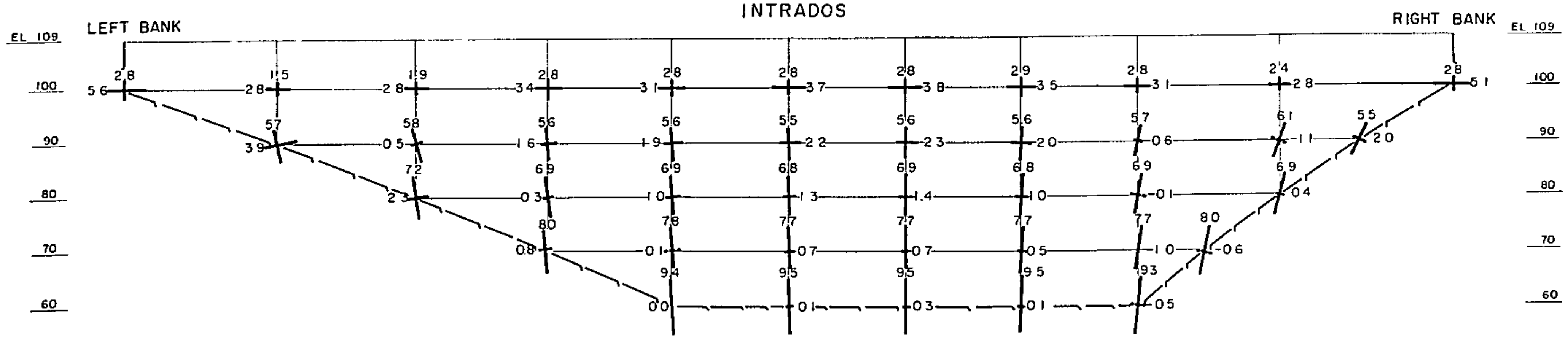

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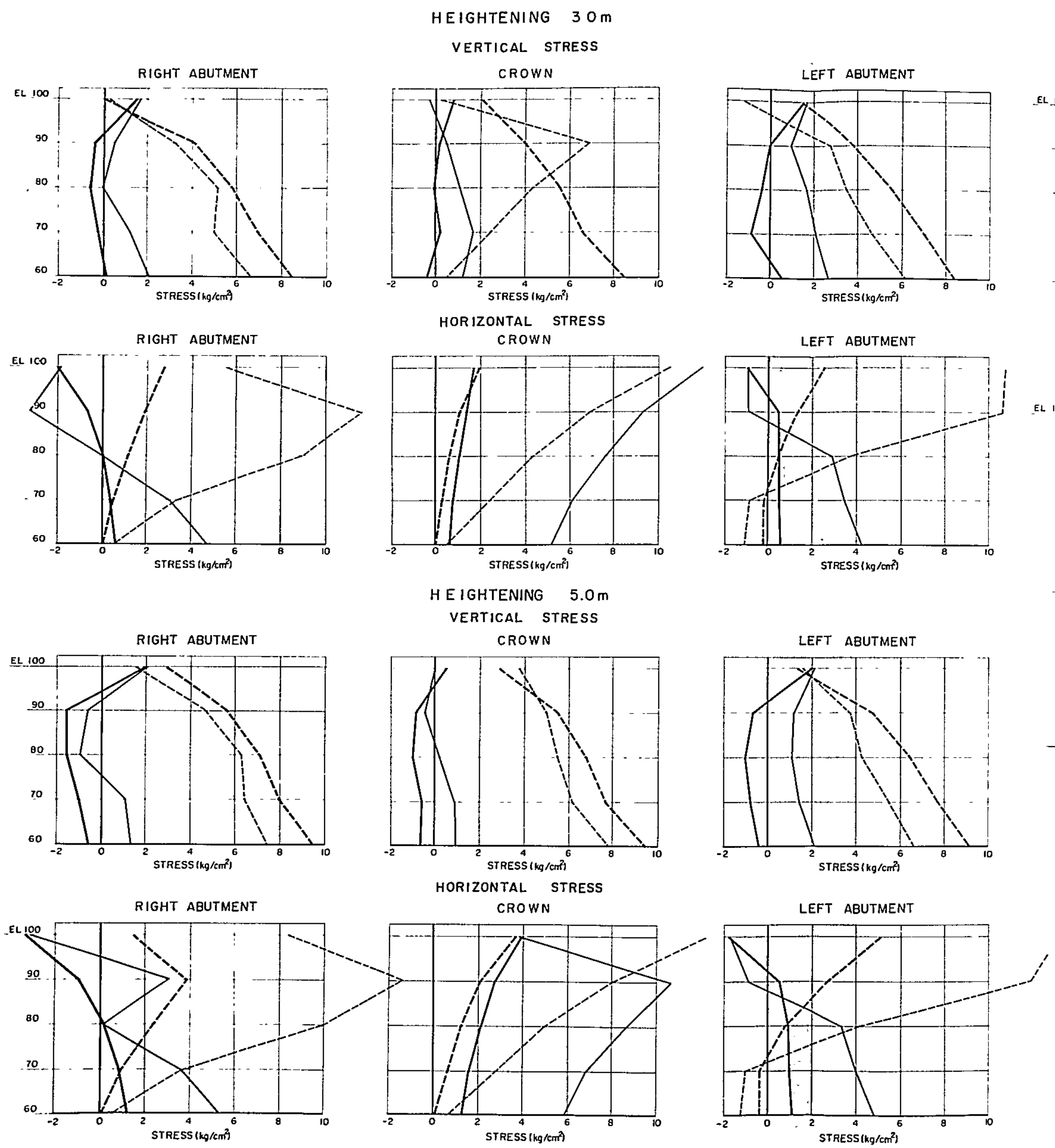
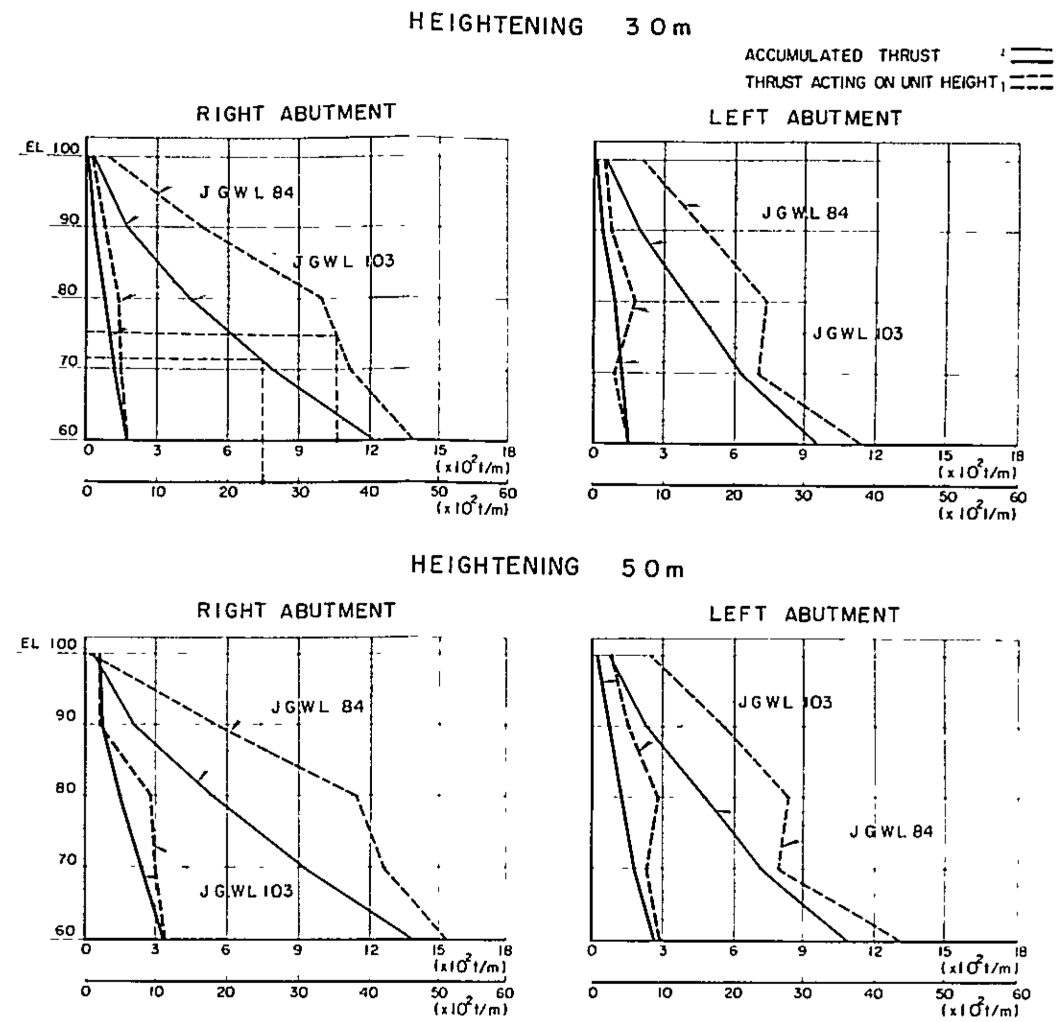
CUBUK I DAM STRESS ANALYSIS ΔH = 5.0M, J.G.W.L 103	CUB 05
OVERSEAS COOPERATION AGENCY GOVERNMENT OF JAPAN	DATE Feb 1970

SHEET NO OF

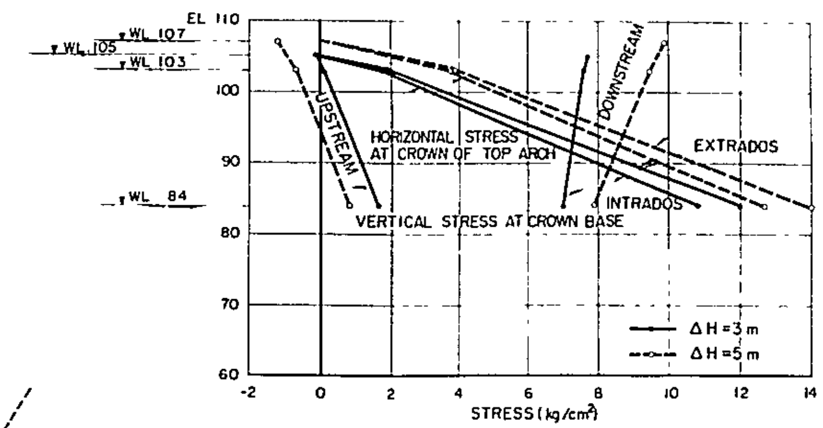
STRESS DISTRIBUSION FOR JOINT GROUTING WATER LEVELS 84 AND 103



HORIZONTAL THRUST AT ABUTMENT



COMPARISON OF CROWN STRESSES FOR VARIABLE J.G.W.L



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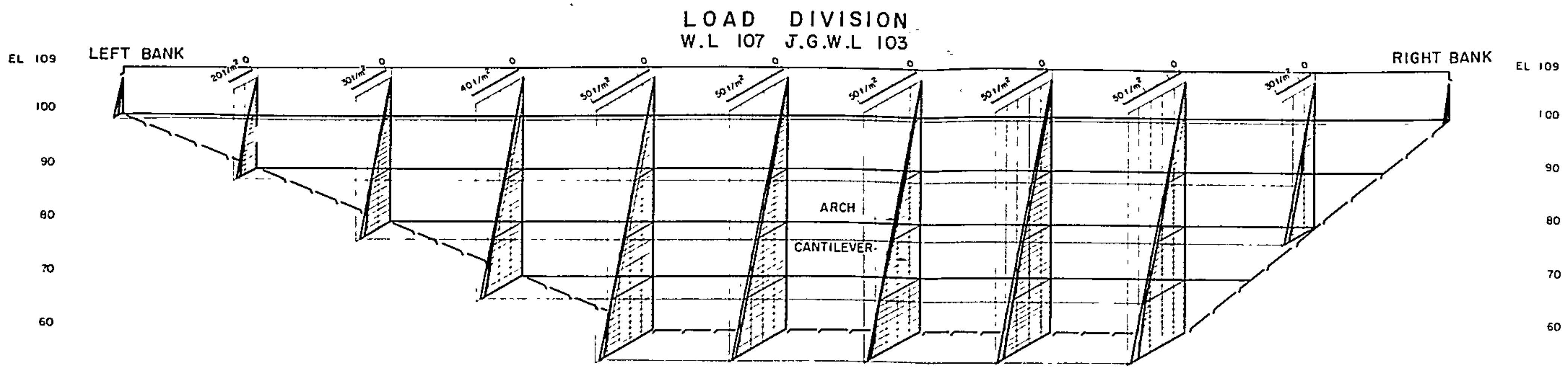
CUBUK I DAM STRESS DISTRIBUTION & HORIZONTAL THRUST	CUB 06
OVERSEAS COOPERATION AGENCY GOVERNMENT OF JAPAN	DATE Feb 1970

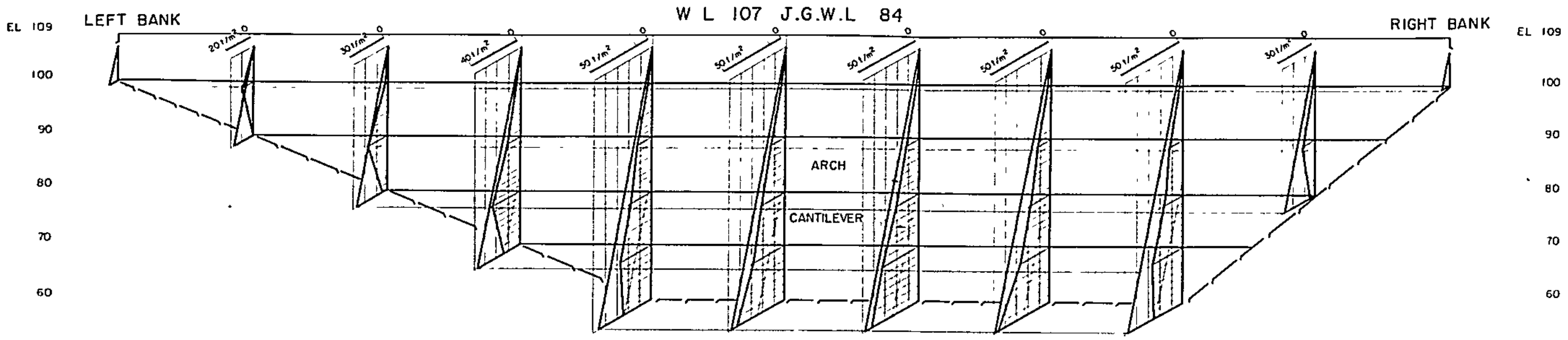
SHEET NO OF

LOAD DIVISION

W.L 107 J.G.W.L 103

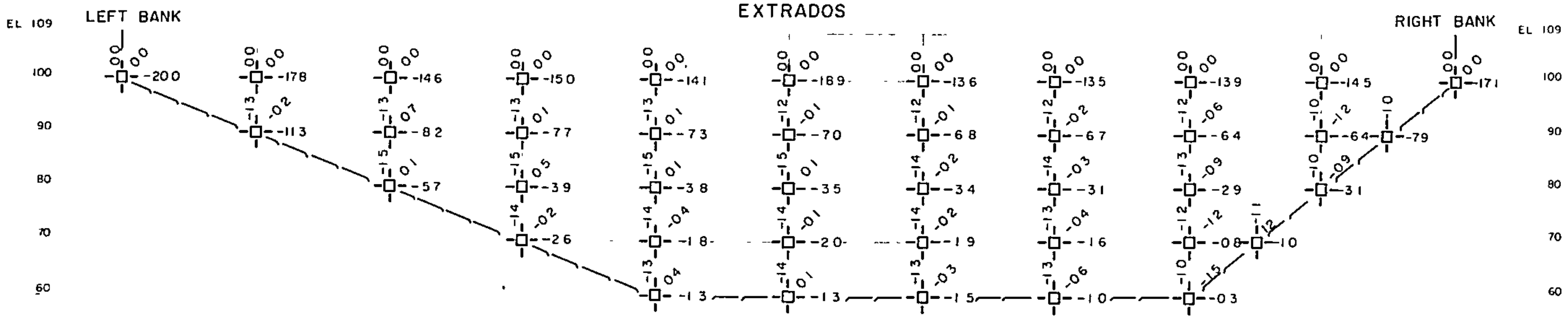


W L 107 J.G.W.L 84

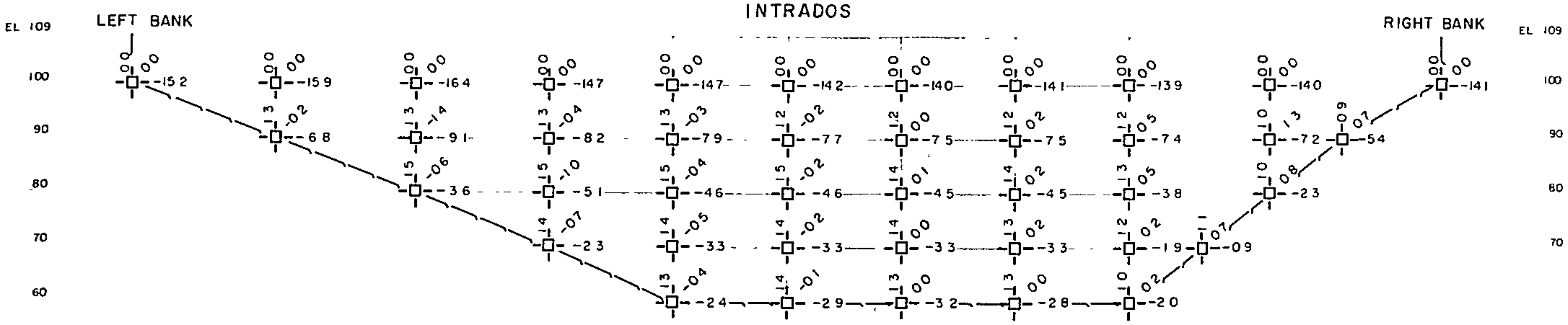


THERMAL STRESS

EXTRADOS



INTRADOS



τ_H HORIZONTAL STRESS + COMP
τ_V VERTICAL STRESS - TEN
τ_{HV} SHEARING STRESS

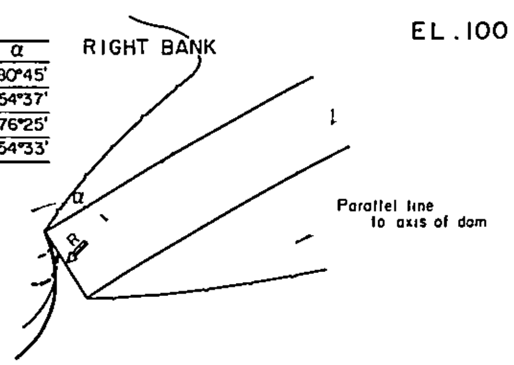
GOVERNMENT OF REPUBLIC OF TURKEY MINISTRY OF ENERGY AND NATURAL RESOURCES GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS	
CUBUK I DAM LOAD DIVISION & THERMAL STRESS	CUB 07
OVERSEAS COOPERATION AGENCY GOVERNMENT OF JAPAN	DATE Feb 1970

SHEET NO OF

EL. 100

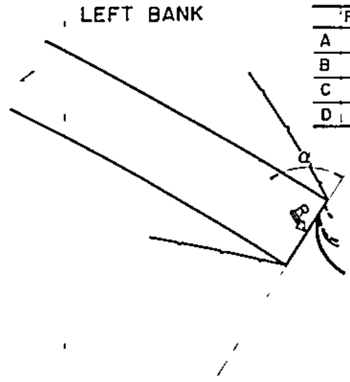
RIGHT BANK

	R (t/m)	α
A	211	80°45'
B	49	54°37'
C	256	76°25'
D	85	54°33'



LEFT BANK

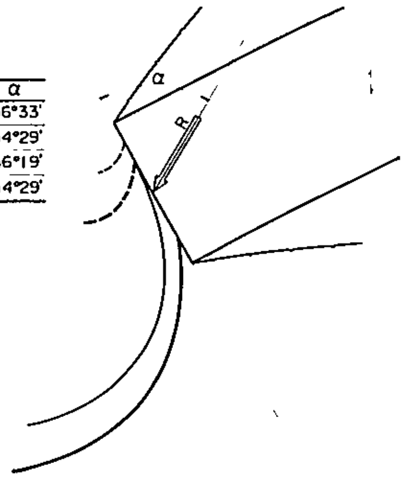
	R (t/m)	α
A	91	67°03'
B	25	37°55'
C	22	65°31'
D	61	52°22'



EL. 90

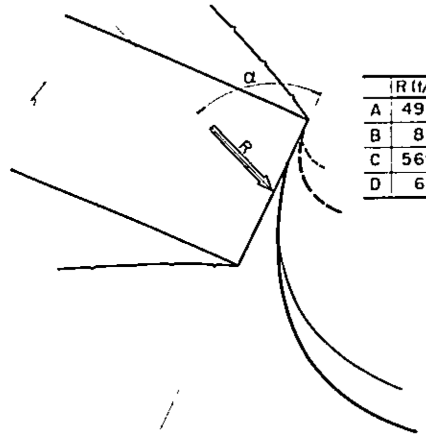
RIGHT BANK

	R (t/m)	α
A	473	56°33'
B	77	54°29'
C	550	56°19'
D	155	54°29'



LEFT BANK

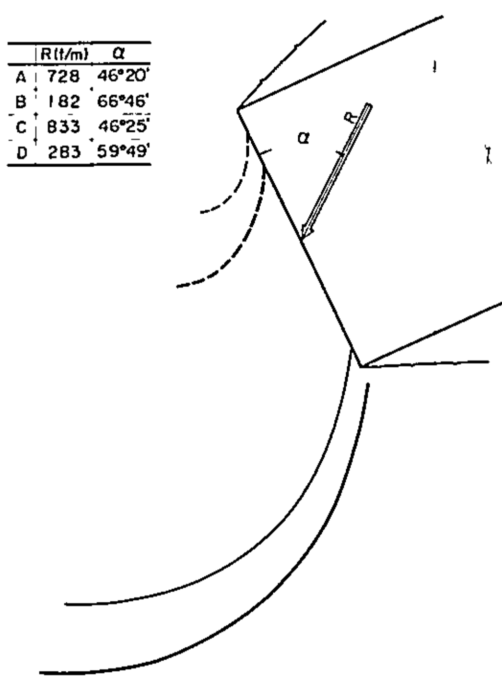
	R (t/m)	α
A	493	68°45'
B	87	69°08'
C	569	68°34'
D	63	68°16'



EL. 80

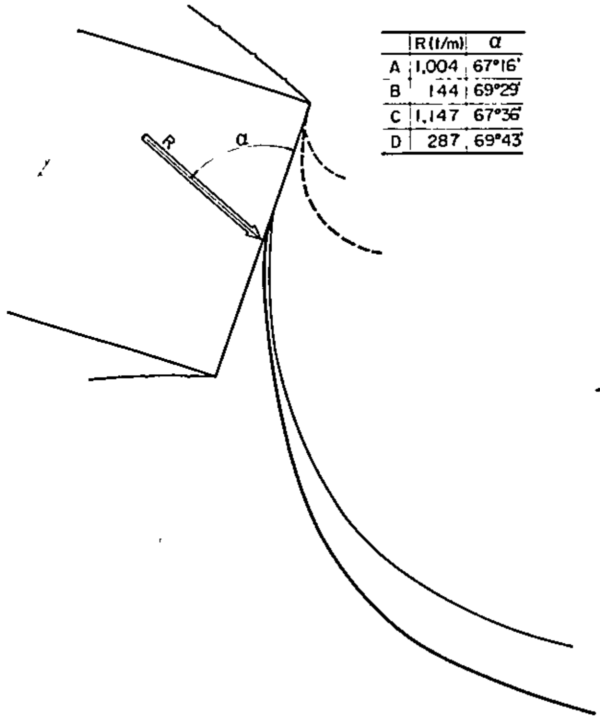
RIGHT BANK

	R (t/m)	α
A	728	46°20'
B	182	66°46'
C	833	46°25'
D	283	59°49'



LEFT BANK

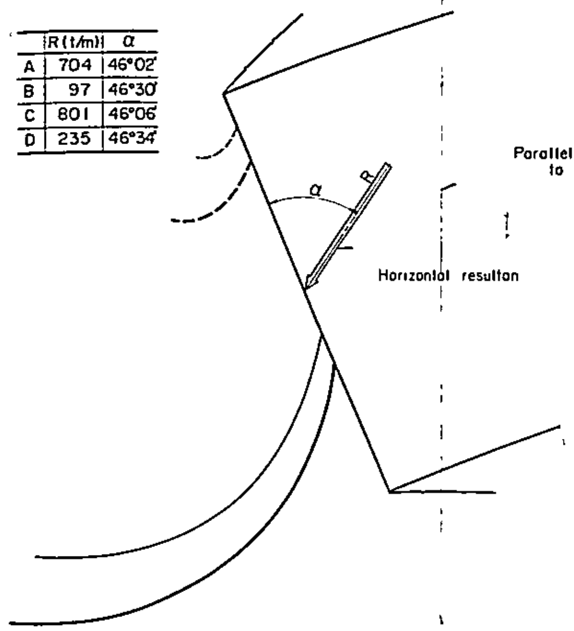
	R (t/m)	α
A	1,004	67°16'
B	144	69°29'
C	1,147	67°36'
D	287	69°43'



EL. 70

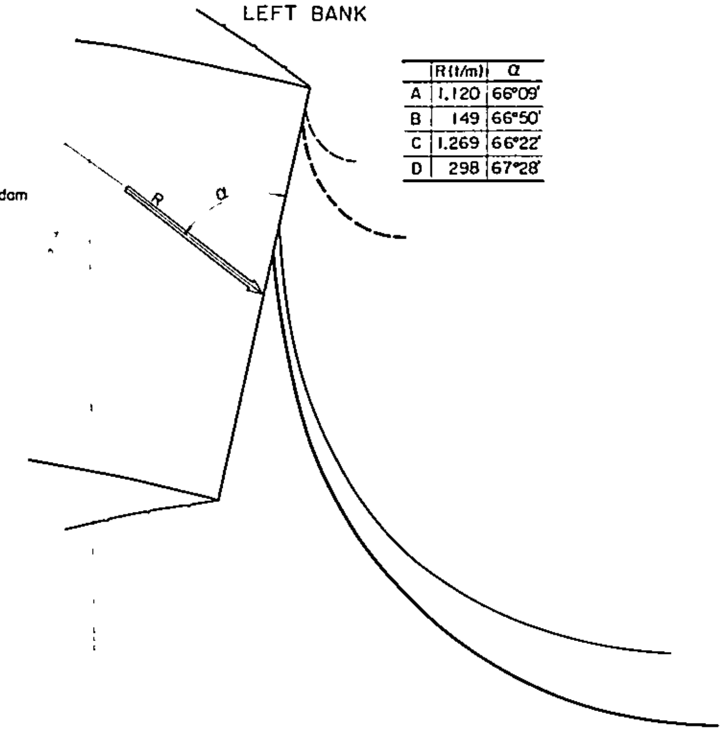
RIGHT BANK

	R (t/m)	α
A	704	46°02'
B	97	46°30'
C	801	46°06'
D	235	46°34'



LEFT BANK

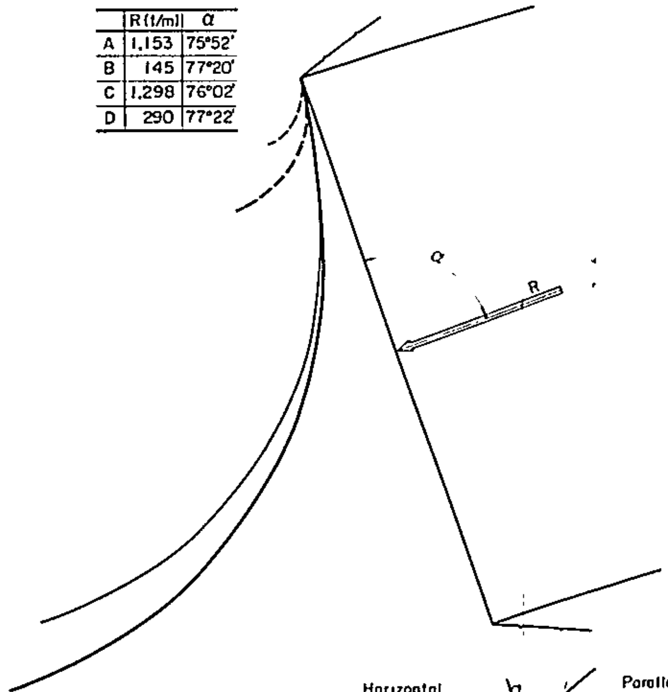
	R (t/m)	α
A	1,120	66°09'
B	149	66°50'
C	1,269	66°22'
D	298	67°28'



EL. 60

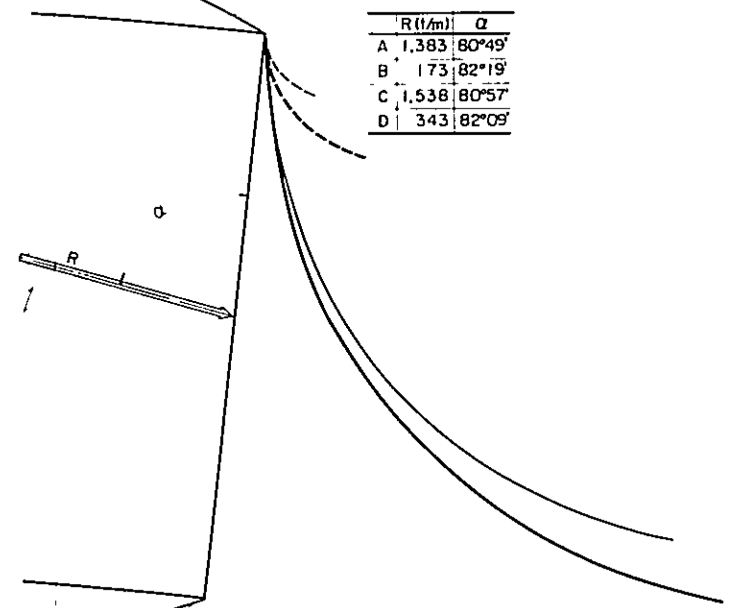
RIGHT BANK

	R (t/m)	α
A	1,153	75°52'
B	145	77°20'
C	1,298	76°02'
D	290	77°22'



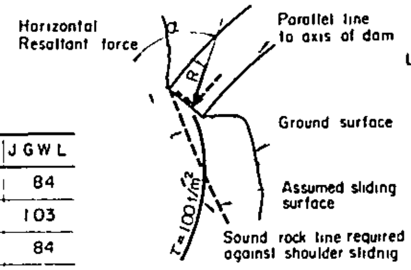
LEFT BANK

	R (t/m)	α
A	1,383	80°49'
B	173	82°19'
C	1,538	80°57'
D	343	82°09'



LEGEND

CASE	LINE	DAM HEIGHT	H W L	J G W L
A	———	107	105	84
B	----	107	105	103
C	———	109	107	84
D	----	109	107	103

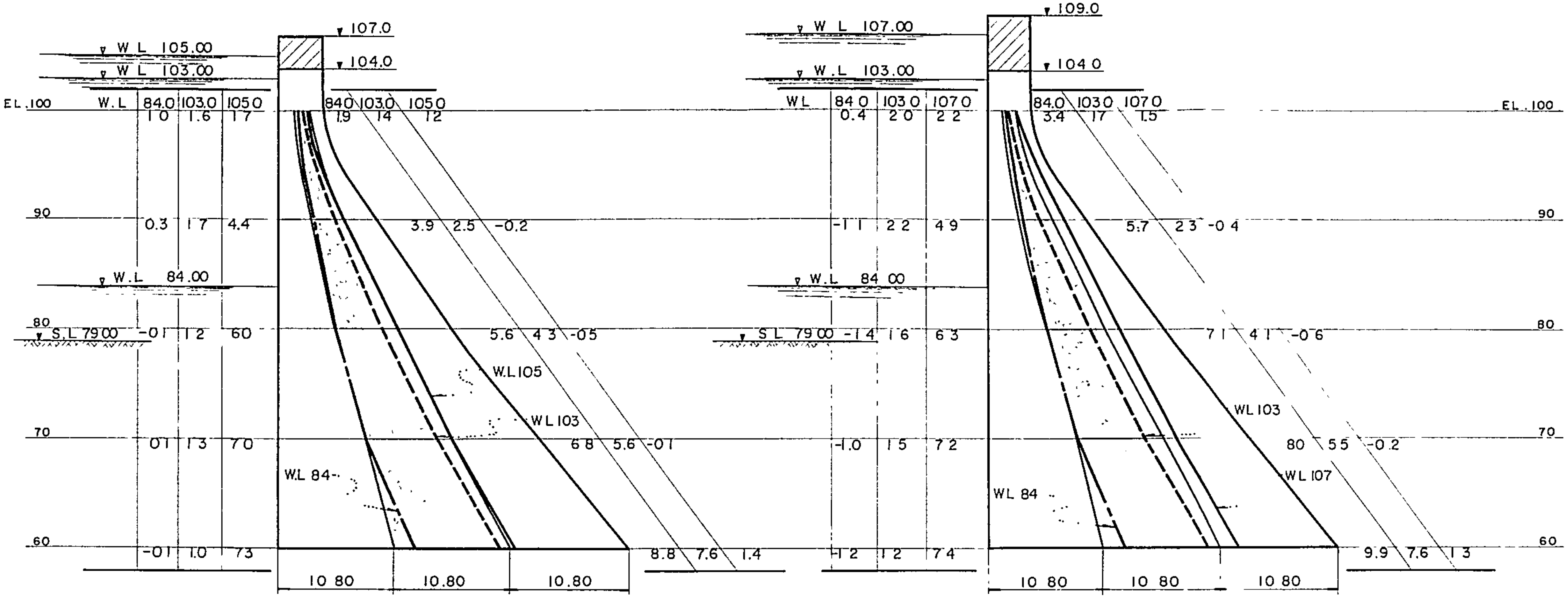


$$l = \frac{nH - fV}{\tau} = \frac{R}{\tau}(n\cos\theta - f\sin\theta)$$

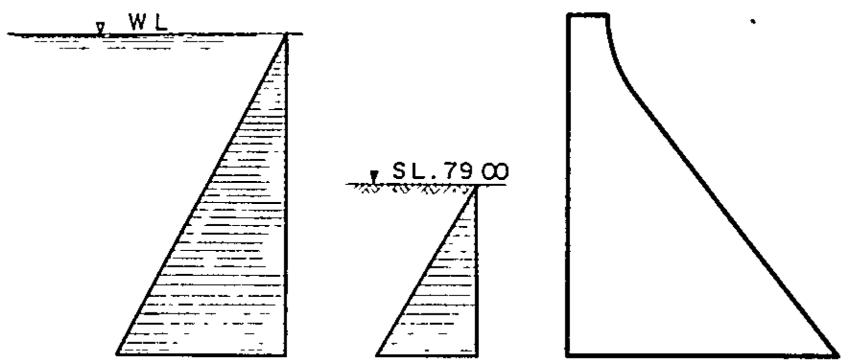
- l Required length of sound rock along sliding line
- τ Technical cohesion = 100 t/m²
- n Factor of safety = 4
- f Coefficient of friction = 1.0

GOVERNMENT OF REPUBLIC OF TURKEY	
MINISTRY OF ENERGY AND NATURAL RESOURCES	
GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS	
CUBUK I DAM	CUB 08
STABILITY OF ABUTMENT DOWNSTREAM SHOULDER	
OVERSEAS COOPERATION AGENCY	DATE
GOVERNMENT OF JAPAN	Feb 1970

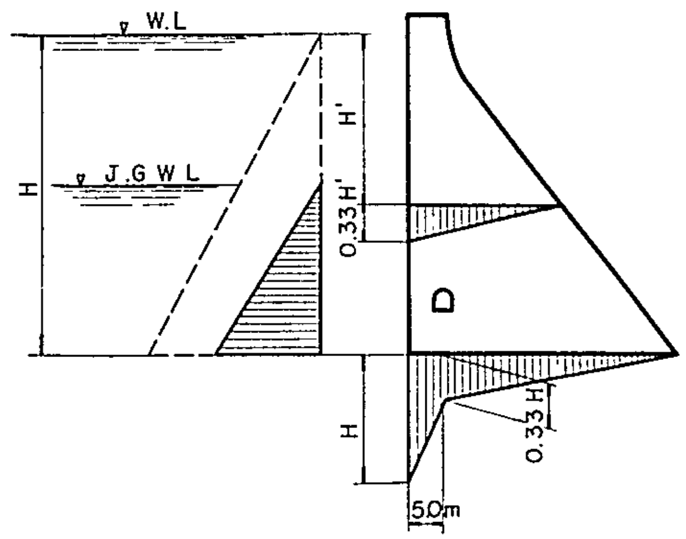
SHEET NO OF



LOADING CONDITION



UPLIFT



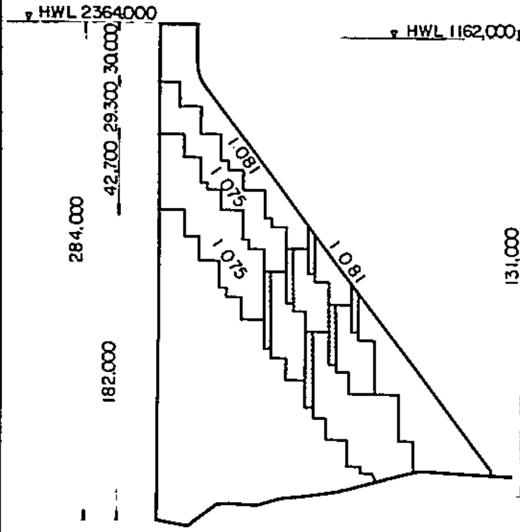
SILT UNIT WEIGHT (SUBMERGED) : 1.0 t/m³

COEFFICIENT OF SILT PRESSUR : 0.4

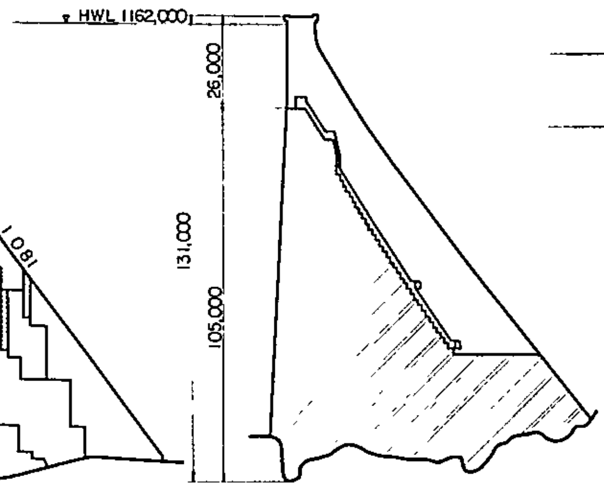
CONCRETE UNIT WEIGHT 2.35 t/m³

GOVERNMENT OF REPUBLIC OF TURKEY	
MINISTRY OF ENERGY AND NATURAL RESOURCES	
GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS	
CUBUK I DAM STRESS ANALYSIS ON GRAVITY DAM	CUB 09
CVERSEAS COOPERATION AGENCY GOVERNMENT OF JAPAN	DATE Feb 1970

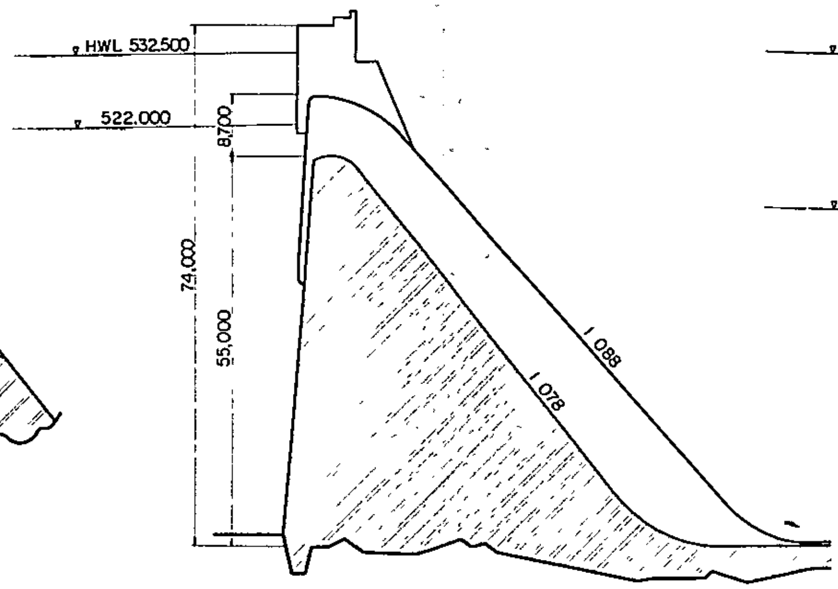
GRAND DIXENCE DAM



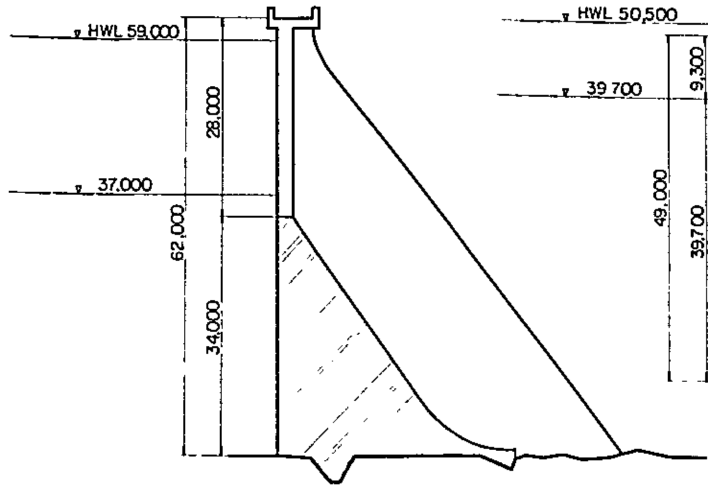
O'SHAUGHNESSY DAM



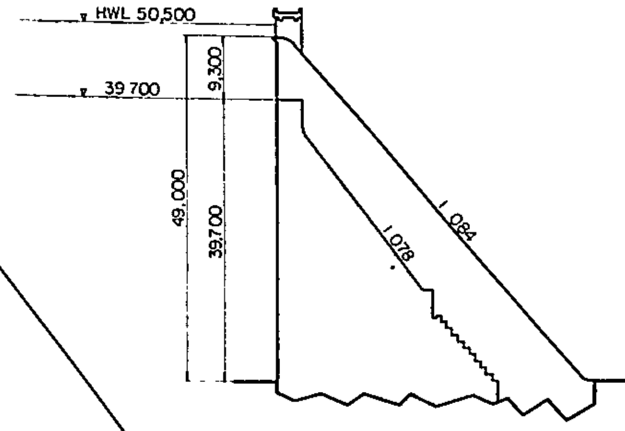
OHDOMARI DAM



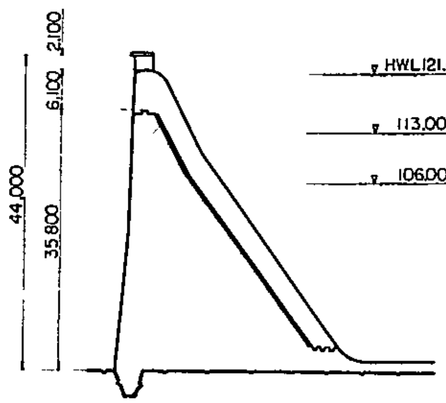
LAGES DAM



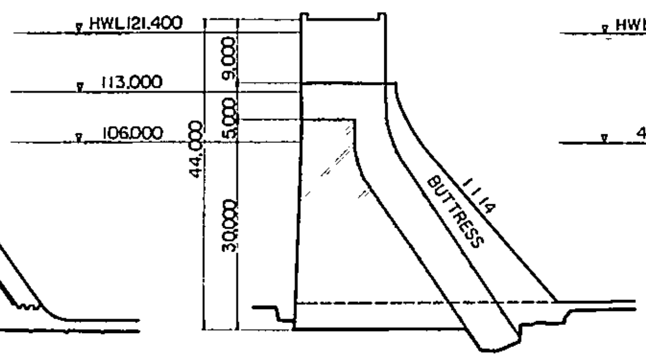
IRABIA DAM



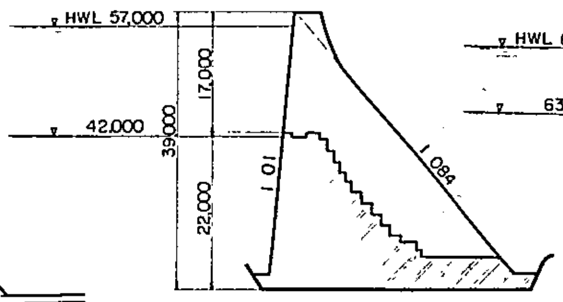
MULLARDOCH DAM



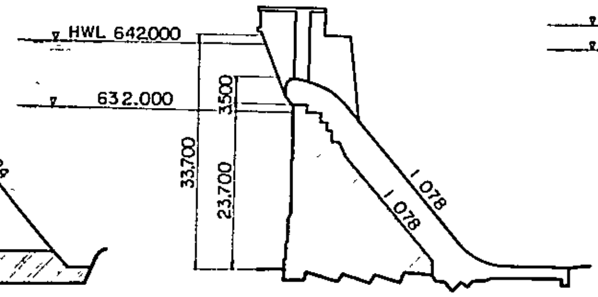
ASSWAN DAM



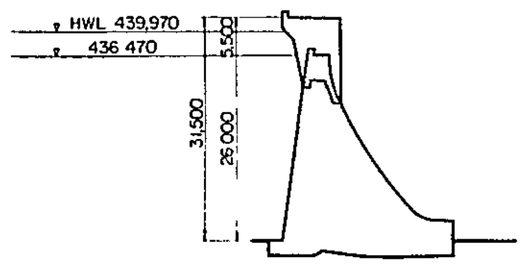
SAKURAYAMA DAM



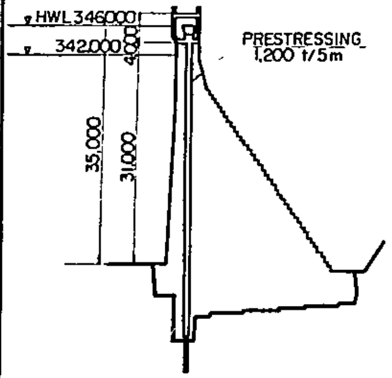
BOLARQUE DAM



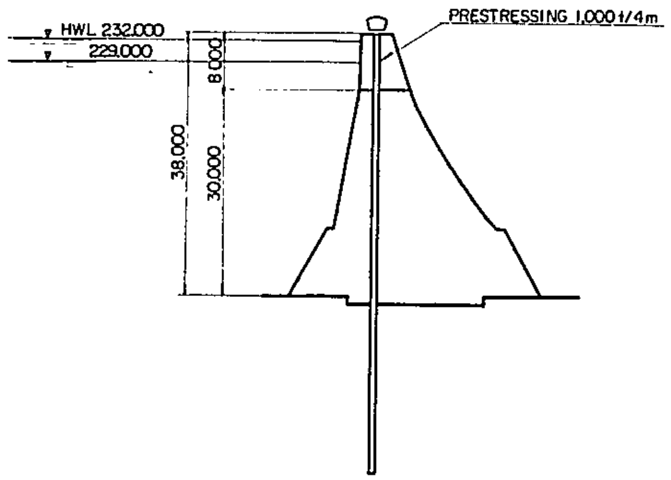
CAMPOFRIO DAM



AVON DAM



CHEURFAS DAM



DAM	TYPE		FINAL HEIGHT (m)	RAISING WATER LEVEL (m)	YEAR OF COMPLETION		REMARK
	BEFORE HEIGHTENING	AFTER HEIGHTENING			OLD	HEIGHTENED	
Grand Dixence	GRAVITY	GRAVITY	2840	(300)		1952	3 STEPS
O'Shaughnessy	•	•	1310	(260)*	1915	1938	
Ohdomari	•	•	740	105	1935	1959	
Lages	•	BUTTRESS	670	220	1908	1948	
Irabia	•	GRAVITY	520	108			4 STEPS
Mullardoch	•	•	440	(61)	1925	1952	
Asswan	•	BUTTRESS	440	62	1902	1933	
Sakurayama	•	GRAVITY	390	170	1945	1962	2 STEPS
Bolarque	•	•	337	95			
Camofrio	•	•	315	350		1956	
Cheurfas	•	PRESTRESS	380	30	1882	1930	1,000 t/4m
Avon	ARCH GRV	•	350	40			1,200 t/5m

( )

GOVERNMENT OF REPUBLIC OF TURKEY
MINISTRY OF ENERGY AND NATURAL RESOURCES
GENERAL DIRECTORATE OF STATE HYDRAULIC WORKS

CUBUK I DAM

EXAMPLE OF DAM HEIGHTENING

CUB 10

OVERSEAS COOPERATION AGENCY
GOVERNMENT OF JAPAN

DATE Feb 1970

SHEET NO OF