DUKE POWER COMPANY

KEOWEE-TOXAWAY PROJECT
JOCASSEE DEVELOPMENT

SUMMARY OF MATERIALS TESTING AND STABILITY DESIGN

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DUKE POWER COMPANY
KEOWEE-TOXAWAY PROJECT
JOCASSEE DEVELOPMENT

SUMMARY OF MATERIALS TESTING AND STABILITY DESIGN

OUTLINE

I Testing

A materials testing and subsurface exploration program was carried out by Duke personnel and by Law Engineering and Testing Company prior to detailed design. In the summer of 1965, a pilot quarry was opened and test embankments were constructed using materials available for main dam. The design values used for stability analysis were based upon the results of shear and density tests conducted on the test fills and on supplementary laboratory tests. A compilation of these design values is attached.

II Tabulation Soil Properties From Testing

(See Page 2)

III Bases of Stability Analysis

Materials available dictated that the dam be built as a combination earth and rock-fill section with a central impervious core. The materials range from hard rock to random rock having a large proporation of fines, to silty sands and clayey silts. The stability analysis used applicable methods for both earth fill and rock-fill embankments. Sliding block, sliding wedge, and circular (or cylindrical) modes of failure were examined.

The primary tool of the stability investigation was a computer program based on the "Method of Slices Swedish Slip Circle" analysis procedure as outlined in EM 1110-2-1902 of the Corps of Engineers. The computer made it practical to analyze a very large number of possible slip circles and locate the potential failure surfaces. Once the critical circles were determined, the "Friction Circle" method as given in Taylor's "Fundamentals of Soil Mechanics" was applied to the same circles by hand computation. It is believed that application of the slip circle method through zones having large proportions of granular cohesionless materials yields somewhat lower safety factors than would actually exist. It is further felt that the friction circle results reflect more closely actual performance of in-place materials. In every instance where slip circle and friction circle safety factors were compared, for the same center and radius, the friction method gave higher values. It was determined that the safety factor design criteria were satisfactorily met if the friction circle values equaled or exceeded the design values.

Considering the embankment as a rock-fill, the sliding wedge method was used to choose trial shear planes; however, the calculated factors of safety were so high that this method was not considered to determine a critical condition. A modified sliding wedge analysis, which has recently been used by the Corps of Engineers for rock-fill dams, was later adopted as the design analysis for that failure mode. This procedure considers the extreme condition where the downstream mass of the dam is acted upon by a driving force due to the "at rest" condition in an assumed horizontal embankment to the top of the dam. Using this analysis and neglecting any effective initial strength or "cohesion" along the foundation contact, higher safety factors were determined than those from either of the two methods for circular arc failure described.

IV Criteria for Allowable Safety Factors

The Factor of Safety criteria used for Jocassee Dam are as follows:

		d' - R ess re)	Consolidated Undrained - S (corrected for pore pressure)	
Material	Co F	ϕ_2 degrees	C ksf	ϕ degrees
Red Clayey Silt	D	26	0	28
Micaceous Silty Sand	I	12	0	35
Random A	D	22.5	0	35
Random B	[illegible]	13.5*	0	38.5
Rockfill	I	-	0	37
Foundation	D	35	0	38

Note: *1 Probably too
porosity, so
will be high

bjs

IV Criteria for Allowable Safety Factors - contd

Case No	Condition of Dam	Required Safety Factor
I	Reservoir Full (Steady Seepage)	1.5
II	Sudden Drawdown	1.25
III	Construction Period With Reservoir Empty	1.25

Material strength values which were used for analysis are as follows:

1) "Q" - Construction Period and zones never subjected to saturation.

2) "R" - All zones below line of saturation and steady seepage.

V Design

As was described in Section III, the majority of the stability calculations were done by use of a computer program. In general, for each circle center in a large specified grid, the minimum safety factor value was determined by testing numerous radii, starting at a depth of 40 feet into the assumed firm foundation, and indexing upwards in 50 foot increments. The circles having the lowest safety factors were chosen from the grid as the potential critical failure circles. These circles were then examined by friction circle method of analysis.

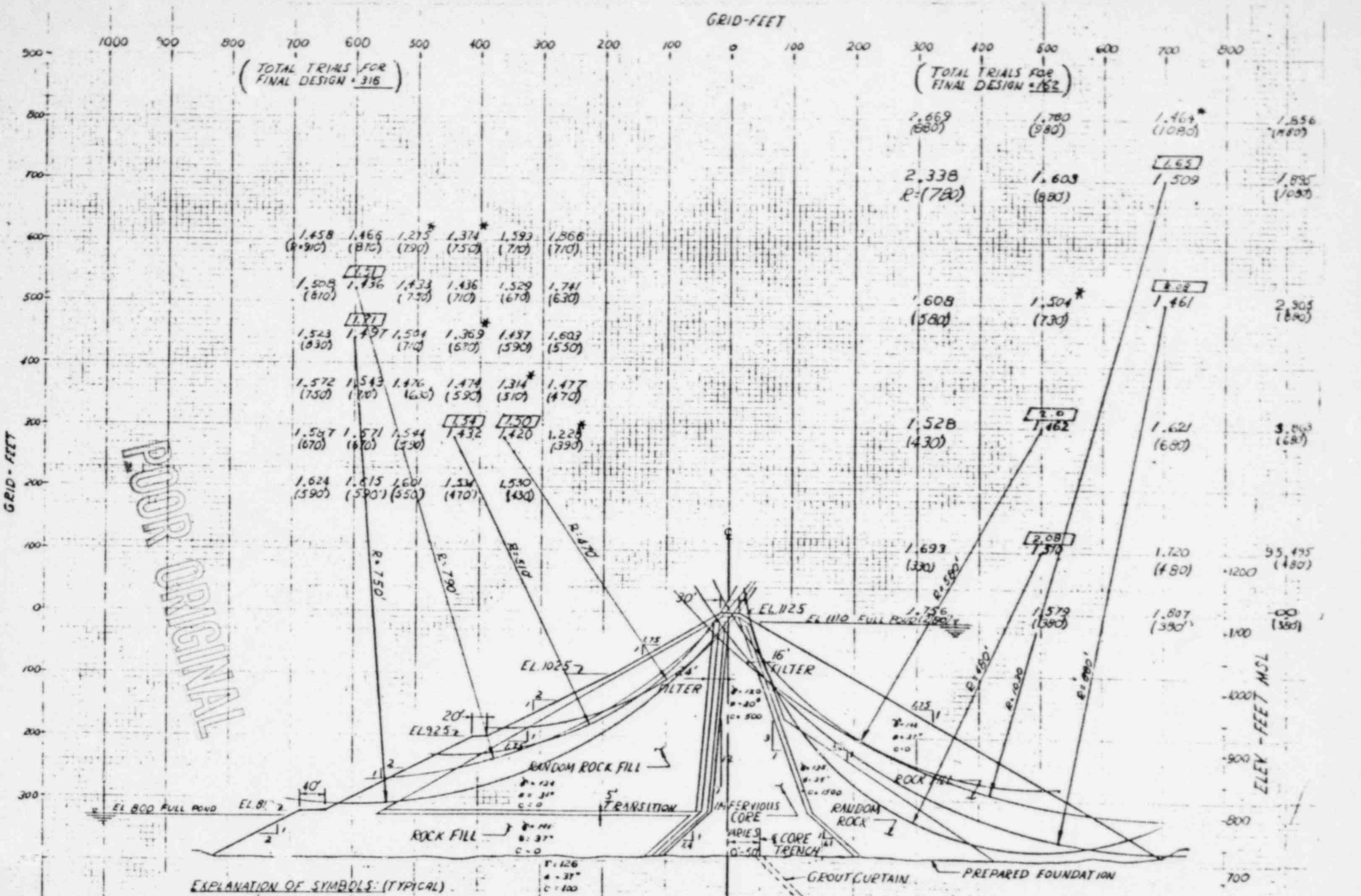
Prior to the fixing of the final design cross section and slopes, numerous preliminary trials were run on the computer with the total number of circles examined running into the thousands.

VI Results of Stability Analysis

Attached, Section VI, is a summary chart for each of the final design conditions showing the matrix of calculated minimum safety factor values with their respective radii. The critical circle or circles are shown as they would pass through the completed embankment. Also noted for each critical circle is the corresponding safety factor computed by the friction circle method.

The safety factors identified with an asterisk (*) are those which have relatively low values, but are considered to represent a sheet sliding mode of failure not critical to the stability of the embankment. For this type of failure, the shear planes are very shallow and the condition is an indication of the ratio of the slope to the angle of internal friction of the material. This surficial sheet sliding on circular planes more or less parallel to the surface is actually equivalent to a shallow wedge failure parallel to the surface.

The limiting minimum safety factor for sheet failure is $SF = \frac{\tan B}{\tan \phi}$ where B is the angle of the slope with the horizontal. When the safety factor is 1.0, $B = \phi$ and the slope would be at its angle of repose which is equal to the angle of internal friction in the slope surface. The safety factor criteria in Section IV do not apply in this case, since the majority of dumped or rolled rock-fill dams have been constructed with the downstream "sheet failure" safety factor equal to 1.0 and the slope at the angle of repose.



EXPLANATION OF SYMBOLS: (TYPICAL)

1.60 - Minimum S.F. for Centers Shown; Slip Circle Method (Decimal in S.F. Locates Center of Circle)

(790') - Radius of Critical Circle for Center Shown

[1.65] - S.F. by Friction Circle

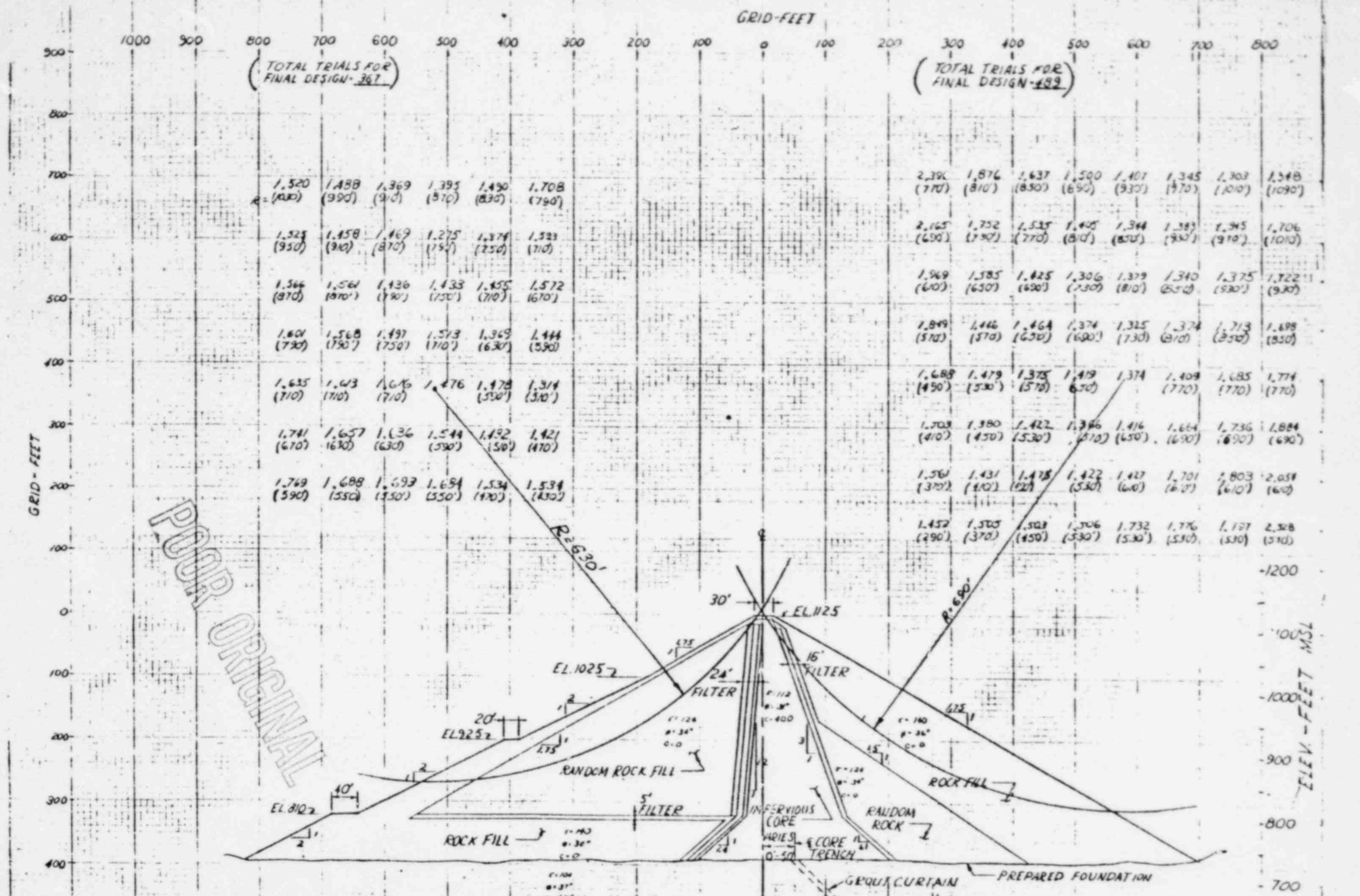
1.40* - S.F. for Sheet Type Shear Failure, Slip Circle Method

JOCASSEE DAM
CASE I
STEADY SEEPAGE
(Q & R VALUES)

Summary 2-20-68

(Half Size)

Scale: 1" = 100'



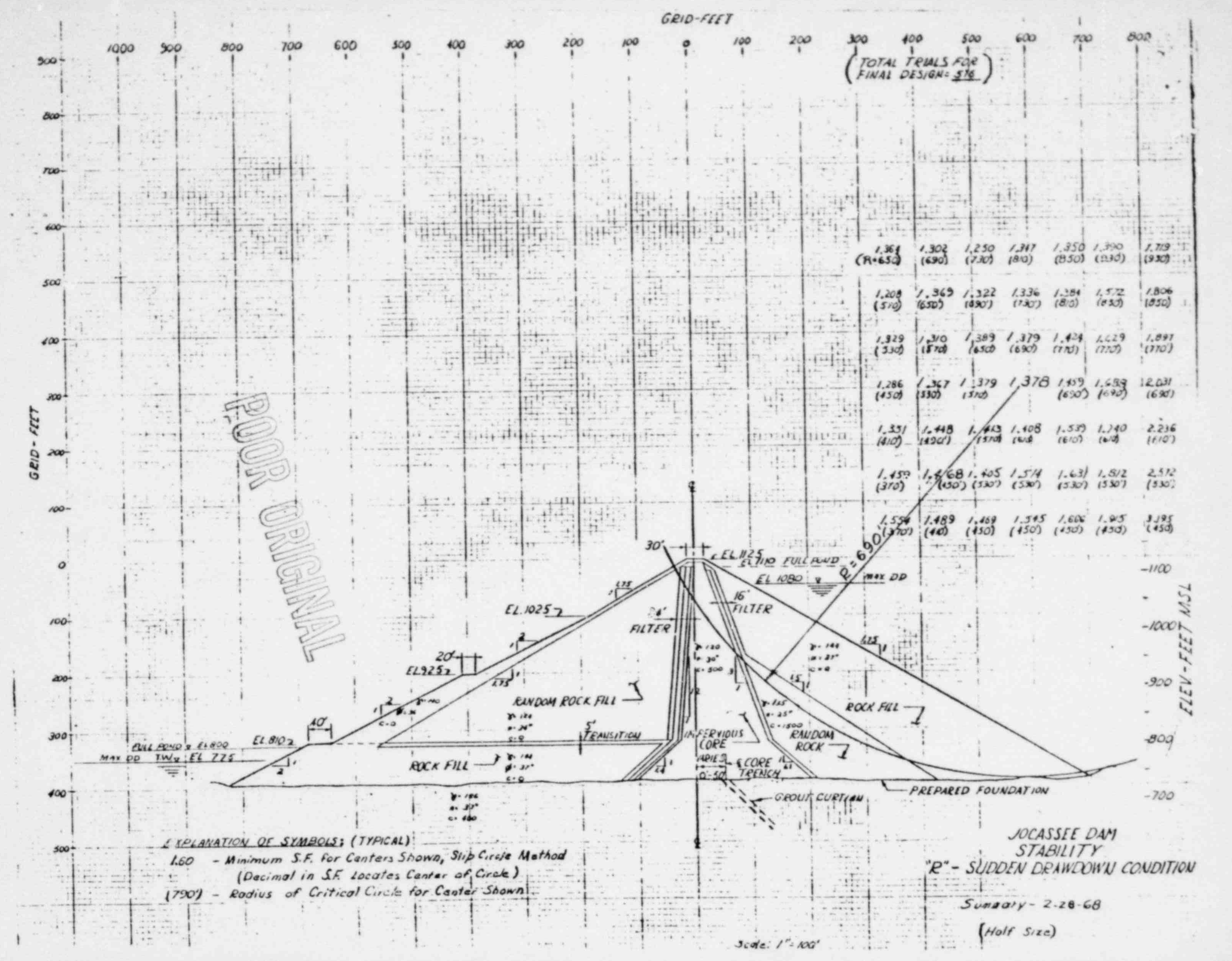
EXPLANATION OF SYMBOLS: (TYPICAL)

1.60 - Minimum S.F. for Centers Shown, Slip Circle Method (Decimal in S.F. Locates Center of Circle)

(790') - Radius of Critical Circle for Center Shown

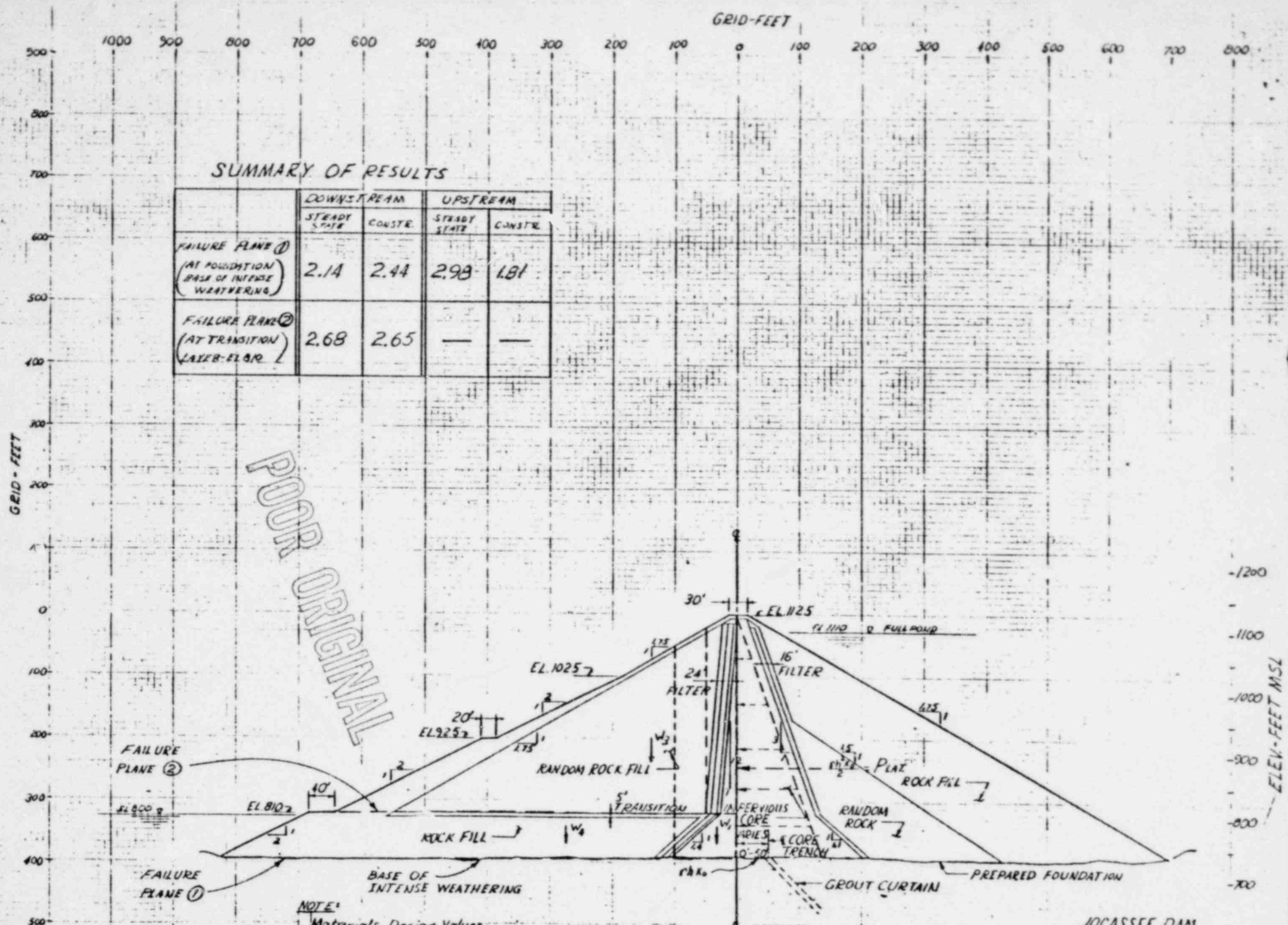
JOCASSEE DAM
STABILITY
"Q"-CONSTRUCTION CONDITION

Summary 2-26-68


GRID-FEET
(TOTAL TRIALS FOR FINAL DESIGN=576)
1.361 (R=650) 1.302 (690) 1.250 (730) 1.317 (810) 1.350 (850) 1.390 (930) 1.719 (930)
1.208 (570) 1.369 (650) 1.322 (690) 1.336 (730) 1.384 (810) 1.572 (850) 1.806 (850)
1.329 (530) 1.310 (570) 1.389 (650) 1.379 (690) 1.424 (770) 1.629 (770) 1.891 (770)
1.286 (450) 1.367 (530) 1.379 (570) 1.378 1.459 (690) 1.688 (690) 2.031 (690)
1.331 (410) 1.448 (490) 1.413 (570) 1.408 (610) 1.535 (610) 1.740 (610) 2.236 (610)
1.459 (370) 1.468 (450) 1.405 (530) 1.514 (530) 1.631 (530) 1.812 (530) 2.512 (530)
1.559 (370) 1.489 (410) 1.469 (450) 1.545 (450) 1.606 (450) 1.915 (450) 3.195 (450)
R=690'
POOR ORIGINAL
30'
EL 1125
EL 1110 FULL POND
EL 1080 MAX DD
16' FILTER
24' FILTER
EL 1025
20'
EL 925
RANDOM ROCK FILL
5' TRANSITION
IMPERVIOUS CORE
APIES
℄ CORE TRENCH
RANDOM ROCK
ROCK FILL
ROCK FILL
40'
EL 810
FULL POND & EL 800
MAX DD TW EL 725
PREPARED FOUNDATION
GROUT CURTAIN
GRID-FEET
ELEV-FEET MSL
EXPLANATION OF SYMBOLS; (TYPICAL)
1.60 - Minimum S.F. for Centers Shown, Slip Circle Method
(Decimal in S.F. Locates Center of Circle)
(790') - Radius of Critical Circle for Center Shown
JOCASSEE DAM
STABILITY
"R" - SUDDEN DRAWDOWN CONDITION
Summary - 2-28-68
(Half Size)
Scale: 1" = 100'

SUMMARY OF RESULTS

	DOWNSTREAM		UPSTREAM	
	STEADY STATE	CONSTR.	STEADY STATE	CONSTR.
FAILURE PLANE ① (AT FOUNDATION BASE OF INTENSE WEATHERING)	2.14	2.44	2.98	1.81
FAILURE PLANE ② (AT TRANSITION LAYER-EL 810)	2.68	2.65	—	—



NOTE:
Materials Design Values Are Same As Used In Slip Circle Analysis

Scale: 1" = 100'

JOCASSEE DAM
STABILITY ANALYSIS
SLIDING BLOCK
ALONG FOUNDATION

Summary - 2-26-68
(Half Size)

Jocassee

SEISMIC DESIGN FOR JOCASSEE DAM

Analysis for seismic loading of Jocassee dam has been made using the same criteria that were used at Keowee dam and outlined in answer to Question 8.6, Supplement No 1. A complete static stability analysis was first performed using as a principal tool a computer program based on the "Method of Slices Swedish Slip Circle" found in EM 1110-2-1902 of the U S Army Corps of Engineers. The computer made it practical to analyze a very large number of possible slip circles and locate the potential critical failure surfaces. In addition, the critical circles thus determined were analyzed by hand computation using the "Friction Circle Method" as illustrated in Taylor's "Fundamentals of Soil Mechanics."

It is the opinion of our Consultant, Professor George F Sowers of Law Engineering Testing Company, that application of the slip circle method through a zoned dam having large proportions of granular, cohesionless materials yields somewhat lower safety factors than would actually exist. It is further felt that the friction circle analysis more closely reflects the actual performance of the in-place materials. It was, thus, determined that the safety factor criteria were satisfactorily met if the friction circle analysis yielded values equal to or exceeding the critical safety factor for the same circle as determined with the slip circle method.

For seismic design the computer program, with modification to account for .10g acceleratic was again used as the basic tool in locating the critical failure circles. It was found, as expected, that the critical failure circles under seismic loading were not the same as for those found in the static loading case. The critical centers and corresponding safety factors were then used in performing the dynamic analysis based on Dr Newmark's method, as was previously done for Little River and Keowee dam seismic design.

Listed below are the design criteria for Jocassee dam:

Analysis	Design Condition	Required Safety Factor
Static	Reservoir Full (Steady Seepage)	1.5
	Sudden Drawdown	1.25
	Construction Period (Reservoir Empty)	1.25
Seismic	Earthquake ($a = .10g$)	1.0
	Newmark's Factors FS	1.0
	Newmark's Factors N	.10

Attached is a tabulation of safety factors for both the static and the seismic design loadings. Also attached are prints of sketches showing the matrix of lowest safety factor values for each point and the failure surface circles which have been taken as critical.

The safety factors identified with an asterisk (*) are those which may have lower values but are considered to represent a sheet-sliding mode of failure, not critical to the stability of the embankment. The safety factor criteria listed above do not apply in this case, since the large majority of dumped or rolled rockfill dams have been constructed with the "sheet failure" safety factor equal 1.0 and the slope at or near the angle of repose.

CQR-i 6-12-70

Copy of data taken to AEC by P H Barton on June 17, 1970.

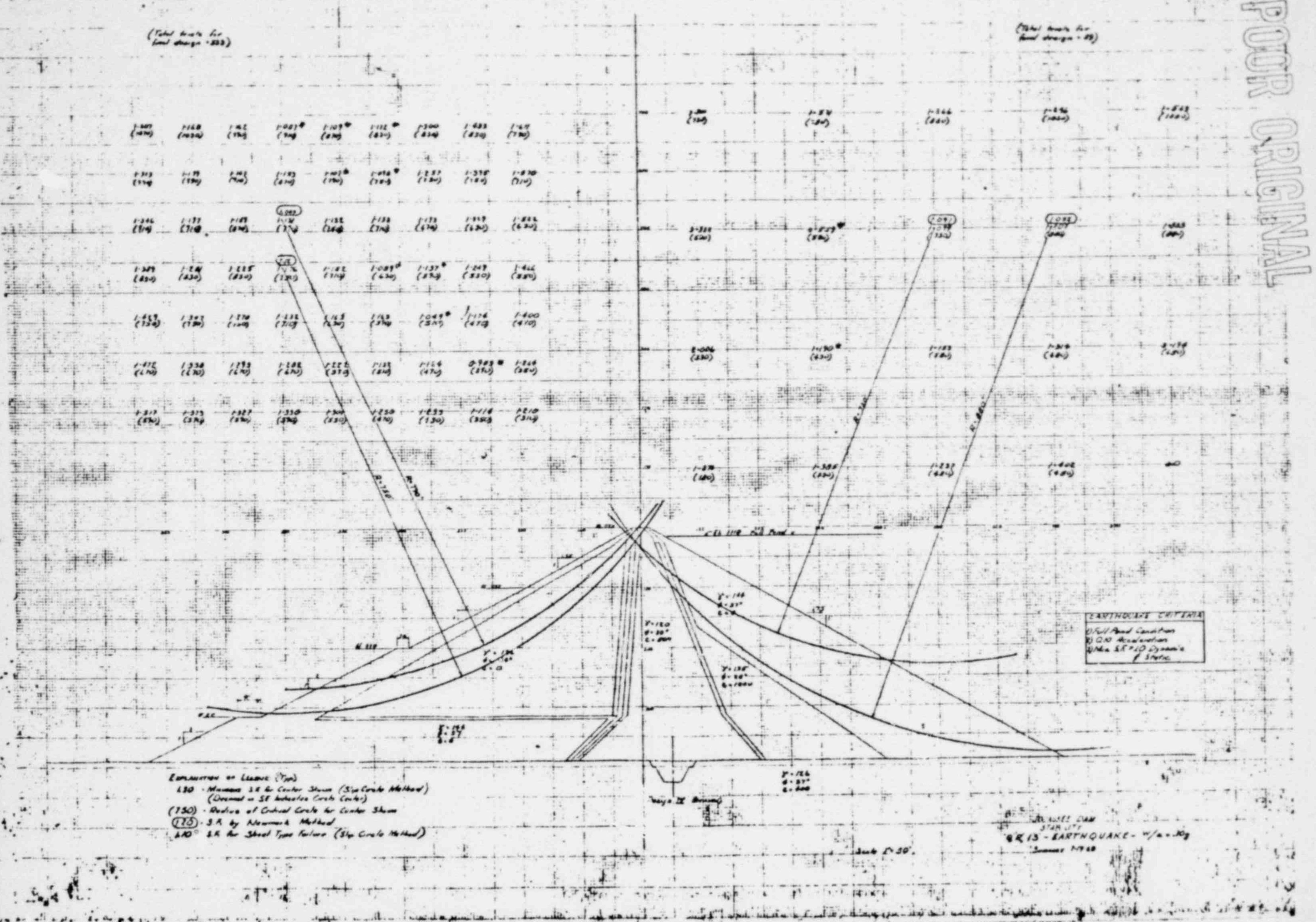
POOR ORIGINAL

Development OCONEE STATION See Dwg. File No.
Subject AEC-DRL QUESTIONS Sheet No. of
MEMO FOR RECORD, 6-1-70 By CGR Date 6-11-7

D. SEISMIC DESIGN FOR JOCASSEE DAM:
(COMPLETE STABILITY ANALYSIS)

SUMMARY OF SAFETY FACTORS

DESIGN CONDITIONS				STATIC		EARTHQUAKE W/.10		
				SLIP CIRCLE by COMPUTER	FRICTION CIRCLE	SLIP CIRCLE by COMPUTER	NEWMARK ANALYSIS	
SLOPE	CONDITION						FS	N
DOWNSTREAM	STEADY STATE	SHORT RADIUS	SHALLOW X=-440 Y=720	1.432	1.54	1.132	–	–
			DEEP X=-360 Y=280	1.420	1.50	1.124	–	–
		LONG RADIUS	SHALLOW X=-600 Y=520 r=790	1.436	1.51	1.131	1.089	.113
			DEEP X=-600 Y=440 r=750	1.497	1.71	1.176	1.12	.117
	CONSTRUCTION X=-520 Y=+260			1.476	–	–	–	–
UPSTREAM	STEADY STATE	SHORT RADIUS	SHALLOW X=500 Y=300	1.462	2.0	1.153	–	–
			DEEP X=500 Y=100	1.510	2.08	1.237	–	–
		LONG RADIUS	SHALLOW X=500 Y=500 r=730	1.509	1.65	1.099	1.091	.151
			DEEP X=700 Y=500 r=880	1.461	2.08	1.207	1.052	.131
	CONSTRUCTION X=580 Y=480			1.374	–	–	–	–


(Total trials for final design = 333)
(Total trials for final design = 89)
EARTHQUAKE CRITERIA
1) Full Pond Condition
2) 0.10 Acceleration
3) Min S.F. = 1.0 Dynamic & Static
Explanation of Legend (Typ)
1.30 - Minimum S.F. for Center Shown (Slip Circle Method)
(Decimal = S.F. below Circle Center)
(750) - Radius of Critical Circle for Center Shown
(1.25) - S.F. by Newmark Method
1.10 - S.F. for Sheet Type Failure (Slip Circle Method)
Scale 1" = 50'
STAR CITY
DAM
S.R. 13 - EARTHQUAKE - w/a = .10g