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Safety Analysis of Rupsiabagar-Khasiabara Dam under Seismic Condition, Using CADAM

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Abstract- This paper presents Safety Analysis of Rupsiabagar Khasiyabara dam situated in Pithoragarh district of Uttarakhand in India, using CADAM. The purpose of this work is to see the impact of earthquakes on dam structure & if require modify it by seismic retrofitting to improve the resistance of dam to earthquake. The safety Analysis of concrete gravity dam owes continuous concern to dynamic seismic activities due to earthquake. These Earthquake results in change in seismic parameters due to tectonic movements. CADAM software has been primarily designed for structural stability evaluation of concrete gravity dam using pseudo static method & pseudo dynamic method.

Rupsiabagar-Khasiabara dam is located on river Goriganga, which is originates from the Milam glacial regions of Himalayas and has tremendous scope for development of hydro-power, which needs to be harnessed to meet the ever-growing demand for power.

With reference to the present value of Peak Ground Acceleration, seismic hazard analysis for Rupsiabagar-Khasiabara dam has been performed .The section of dam is checked for present value of Peak Ground Acceleration for stability for various loading conditions and was found safe with the present study.

Index Terms- CADAM, Seismic hazard Analysis (SHA), PGA (Peak Ground Acceleration).

I. INTRODUCTION

Earthquakes in many part of the world lead to the need of properly designed engineered structure to withstand the seismic hazard. Seismic hazard is the physical effect that that occurs as a result of earthquake, which is significant threat to human activities from the earthquake. Hence, it is required to design the structures having their careful consideration. The main objective behind the seismic hazard analysis is to design, construct & maintain structures to perform at earthquake exposure up to the expectations & in compliance with the codes. Determination of Seismic Hazard basically involves Model analysis to compute seismic response of dam, Assessment based on experimental observation & results evidences, Seismic response analysis. C. Allin Cornell in 1968 was first to formulate Computation for determining seismic hazard .In this area various studies has been performed depending upon their level. Earthquake resistant design of concrete gravity dams (Chopra, A .K., 1978).Seismic hazard analysis, getting an estimate of the strong motion Parameters at a site for the purpose of earthquake resistant design or seismic safety Assessment (Gupta, 2002). A deterministic seismic hazard analysis for the major cultural heritage Sites Of Tamil Nadu, India (Ganapathy.G.P, 2010).

II. STUDY AREA

Dams are large hydraulic structure, used to manage or prevent water flow into specific land regions. Dam failures and incidents involve unintended releases or surges of impounded water. They can destroy property and cause injury and death downstream. Rupsiabagar-Khasiabara Dam is concrete dam constructed across river Gorigang $30^{o}9'56"$ N, $80^{o}15'06"$E in Uttarakhand, India. . The dam has a height of 62m, a crest thickness of 9m and a maximum base width of 54.120m.

Salient features

Particulars	Details
Coordinates, Dam sites	30^{o} 9'56" N, 80^{o} 15'06"E
Coordinates, Power house	30^{o} 5'23.37"N, 80^{o} 16'14.55"E
Nearest railway station	Tanakpur\Kathgodam
Nearest airstrip	Lucknow
Nearest village	Paton
Nearest town	Munsiyari
Hills/valleys Project	area is located in the mountain ranges of western Himalayas
Monuments	Nil
Archaeologically important places	Nil
National Parks	Nil
List of Industries	Nil
Siesmicity	Seismic Zone-V

III. METHODOLOGY

CADAM performs Seismic analysis to determine Safety margins considered against sliding along the considered joint & all resultant of forces position acting on the joint. Analysis of present study involves: Static Analysis & Seismic Analysis through CADAM software using the pseudo-static method or the

pseudo-dynamic method. The gravity method for design requires several assumptions regarding the structural behaviour of the dam and the application of the loads that is the division of dam into lift joints of homogeneous properties along their length; mass concrete and lift joints are uniformly elastic, applied loads are transferred to the foundation by the action of cantilever of the dam without interactions with adjacent monoliths& there is no interaction between the joint,.

Joint are analyzed independently from the other, Normal stresses are linearly distributed along planes (horizontal), shear stresses follow a parabolic distribution along horizontal plane (uncracked condition).

SECTION GEOMETRY:

Dam's parameters has been re-generated or reproduce from the software are given in Fig.1, Table-A & B

Table-A Salient Features

Geometry		
L1=	54.120	m
L2=	3.870	m
L3=	9.000	m
L4=	9.000	m
Elev. A=	0.000	m
Elev. B=	0.000	m
Elev. C=	0.000	m
Elev. D=	0.000	m
Elev. E=	38.700	m
Elev. F=	55.000	m
Elev. G=	62.000	m
Elev. H=	13.000	m
Elev. I =	13.000	m

Figure 1 Dam Geometry

Table-B Reservoir Levels

Water Volumetric Mass		
r=	10	kg/m³
Ice cover		
Load=	0	kN
Thickness=	0	m
Elevation=	59	m
Silts		
Elevation=	13	m
g'=	7	kN/m³
f=	20	deg
Assumption=	at rest	

Reservoirs		
	Upstream side	
Normal operating level:	59	m
Flood level:	60.5	m
Crest overtopping pressure	100	%

Drainage system		
Gallery position from heel of dam=	3	m
Gallery elevation=	0	m
Drain Efficiency=	0.6667	
Highest drained elevation=	0	m
Modelisation:	USBR 1987	

IV. SEISMIC PARAMETERS

While evaluating Seismic parameters on large Dams International committee (ICOLD) recommendations are followed (ICOLD, 1989); thus Operating Basis Earthquake (OBE) and a Maximum Credible Earthquake (MCE) are taken in account.

Earthquake producing the greatest level of ground motion with a 50 percent probability of being exceeded in 100 years defines Operating Basis Earthquake (OBE) whereas largest possible earthquake that could occur along the recognized faults or within a particular seismic source motion is defined as Maximum Credible Earthquake (MCE). Maximum Credible Earthquake has a very low probability of occurrence. Ground motion associated with Krinitzsky (2005) explained through his studies that a Deterministic Seismic Hazard Analysis (DSHA) involves the study of geology and seismic history to identify & interrupt earthquake sources .As earthquake can happen today or tomorrow**.**

Seismic study of a dam site is done for following reasons:

(1)Defining whether structure seismic loading must be incorporated to design or not. (2)Usual basis for initial assessment is the map of seismic activity.

The seismic parameters are reproduce or regenerated from the CADAM software and given in Table C (1) & Table C (2).

Table-C (1) Seismic Coefficients

Pseudo-static (seismic coefficient)					
Horizontal Peak Ground Acceleration (HPGA)=	0.2000	g	Earthquake return period=	2500	years
Vertical Peak Ground Acceleration (VPGA)=	0.1000	g	Earthquake accelerogram period (te)=	1	sec
Horizontal Sustained Acceleration (HSA)=	0.1000	g	Depth where pressures remain constant=	Generalized	
Vertical Sustained Acceleration (VSA)=	0.5000	g	Westergaard correction for Inclined surface=	Corns et al.	

Table-C (2) Seismic Coefficients

Pseudo-dynamic (Chopra's method)					
			Dam only		
			Dam divisions for analysis=	201	divisions
Earthquake return period=2500	year		Dam damping on rigid foundation without reservoir=	0.05	of critical
Horizontal Peak Ground Acceleration (HPGA)=	0.2000	g	Concrete Young's modulus (dynamic)=	27400	MPa
Vertical Peak Ground Acceleration (VPGA)=	0.1000	g			
Horizontal Peak Spectral Acceleration (HPSA)=	0.0920	g	**Reservoir only**		
			Wave reflection coefficient=	0.5	
Horizontal Sustained Acceleration (HSA)=	0.1000	g	Velocity of pressure waves in water=	1440	m/sec
Vertical Sustained Acceleration (VSA)=	0.5000	g			
Vertical Sustained Spectral Acceleration (VSSA)=	0.0700	g	**Foundation only**		
			Foundation constant hysteretic damping=	$0.10	
Modal combination:	SRSS combination		Foundation Young's modulus (dynamic)=	27400	MPa
			Dam-reservoir-foundation system		
			Period of vibration=	0.178	sec
			Damping=	0.108	of critical

V. PSEUDO-STATIC ANALYSIS

Peak ground accelerations (horizontal & vertical) as well as the sustained accelerations specification.Hydrodynamic effects of the reservoir are represented byWestergaard added mass. Water compressibility effects, inclination of the upstream face, limiting the variation of hydrodynamic pressures are provided with options. Hydrodynamic pressures (silt) are approximated from Westergaard formulation for a liquid of higher mass density than water .Pseudo static analysis is timely conducted by concerned engineers related to field. It produces a scalar index of stability which shows the static stability analyses.

VI. PSEUDO-DYNAMIC ANALYSIS

This analytical procedure was developed as an alternative to more general procedures, which required the use of a computer in order to evaluate the structural seismic response. It consists of a simplified analysis of the spectral response, which determines the structure’s response in the fundamental vibration mode due to a horizontal ground motion .It is observed that the response of structures with short periods of vibration, such as concrete gravity dams, when subjected to seismic actions, was largely influenced by the fundamental vibration mode. It was also concluded that the vertical components of the ground acceleration exerted little influence on the structural response. Based on these conclusions this author suggested a simplified methodology for preliminary analysis of concrete gravity dams

LOAD COMBINATIONS

Load combinations support the following combination
Usual
Flood
Seismic 1
Seismic 2

Required Safety Factors

Each load combination has specified safety factors that ensure an adequate safety margin for structural stability. Though these values are not used in the computational algorithm of the program but are reported in the output results to compare safety factors with the corresponding allowable values.

Allowable Stress Factors

Each load combination is defined by applying multiplication factors to the tensile and compressive strengths allowable stresses. Safety guidelines mention various factors to ensure an adequate safety margin to maintain structural stability. Allowable concrete stresses compared with the corresponding allowable values which are reported in output result.

VII. CASE STUDY & THEIR RESULT

The outcome of stress & stability analysis for usual combination as obtained from CADAM has been presented through Table-1 & 2 respectively whereas Table-3 & 4 presents the result of stress & stability analysis for flood condition. Similarly for seismic-1 condition stress analysis has been shown through Table-5 & 6 & stability analysis has been presented in Table 8 & 9.Table-7 & 8 presents the results for seismic -1 for sustained acceleration. Table 9-12 presents the result of stress & stability analysis for seismic -2 conditions.

The result shows that in all the condition Safety factors for the overturning whether for peak or residual & sliding towards upstream or downstream are coming quite higher than the safe values as per codes, also stresses are coming within permissible limit.

VIII. CONCLUSION

The results demonstrate that the response of concrete gravity dam is significantly affected by various static & dynamic loading parameters. The design check dam is performed for the present PGA value of 0.2g to assess whether any other modification of a Rupsiabagar-Khasiabara Dam is necessary from seismic safety point of view. It can be concluded from the present study that the dam section is safe for all possible load combinations.

REFERENCES

[1] Khare, P., 2006, "Study of earthquake engineering & seismic hazard analysis for kodar & sondur dam sites in Chhattisgarh states,"Mtech thesis, *NIT, Raipur, India.*

[2] Cornell, A., 1938, "Engineering seismic risk analysis earthquake," B.Seismological Society of America, vol.58, Issue 5, pp 1583-1606.

[3] Chopra, A .K., 1978, "Earthquake resistant design of concrete gravity dams, "*ASCE Journal of Structural Division*, vol. 104, n. ST6, pp. 953-971, Jun. 1978.

[4] Ganapathy, G.P., 2010 "A deterministic seismic hazard analysis for the major cultural heritage Sites of Tamil Nadu, India," J.Geometics & Geosciences, vol.1. no.3, pp. 530-543.

[5] Gupta, 2002, "The state of the art in seismic analysis," J. Earthquake Technology, Vol.39, Issue 428, pp 311-346.

[6] ICOLD, 1989 'Selecting Parameters for Large dams-Guidelines and Recommendations' ICOLD Committee on Seismic Aspects of Large dams, Bulletin 72.

[7] Krinitzsky, E. L., 1995, "Deterministic versus probabilistic seismic hazard analysis for critical structures", Eng Geol 40, 1–7.

[8] Kramer, Steven L.1996, "Geotechnical Earthquake Engineering, Prentice Hall", pp.653.

[9] USBR,1976"*Design of Gravity Dams*", Denver: United States Department of the Interior – Bureau of Reclamation.

[10] Westergaard H. M., 1933, "Water pressure on dams during earthquakes" *Transactions ASCE*, v. 98, n. 1835, pp. 418-433.

[11] Koltuniuk, R.M., 1997,"Non-linear Dynamic Structural Analysis of Hoover Dam Including Modeling of Contraction Joint Opening and Concrete Cracking ", Bureau of Reclamation, HVD-8110-MDA-97-4.

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Table-1

USUAL COMBINATION (STRESS ANALYSIS)					
Joint		Stresses			
		Normal stresses		alowable stresses	
ID	Upstream elevation	Upstream	Downstream	tension	Compression
	(ft)	(ksf)	(ksf)	(ksf)	(ksf)
1	60.000	-48.000	-48.000	0.000	-9990.000
2	55.000	-168.000	-168.000	0.000	-9990.000
3	50.000	-368.138	-73.744	0.000	-9990.000
4	45.000	-516.099	-38.083	0.000	-9990.000
5	40.000	-648.000	-21.333	0.000	-9990.000
6	35.000	-741.215	-34.199	0.000	-9990.000
7	30.000	-828.421	-54.027	0.000	-9990.000
8	25.000	-920.178	-72.656	0.000	-9990.000
9	20.000	-1015.009	-90.413	0.000	-9990.000
10	15.000	-1112.010	-107.522	0.000	-9990.000
11	10.000	-1210.601	-124.140	0.000	-9990.000
12	5.000	-1310.390	-140.375	0.000	-9990.000
13	Base	-1411.104	-156.310	0.000	-9990.000

Table-2

USUAL COMBINATION (STABILITY ANALYSIS)												
Joint		Safety factors					Resultants				Uplift	Rock
		Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Final	Passive
ID	Upstream elevation	Peak	Residual	Toward U/S	Toward D/S						Force	wedge resistance
	(ft)						(kip)	(kip)	(kip·ft)	(% of joint)	(kip)	(kip)
1	60.000	> 100	> 100	> 100	> 100	> 100	-432.0	0.0	0.0	50.000		
2	55.000	> 100	> 100	> 100	> 100	> 100	-1512.0	0.0	0.0	50.000		
3	50.000	> 100	> 100	> 100	> 100	> 100	-2817.0	0.0	-3988.1	38.896		
4	45.000	> 100	> 100	> 100	> 100	> 100	-4572.0	0.0	-10845.0	35.624		
5	40.000	> 100	> 100	> 100	> 100	> 100	-6777.0	0.0	-21414.4	34.396		
6	35.000	> 100	> 100	> 100	> 100	> 100	-9448.4	0.0	-34991.2	34.803	609.3	0.000
7	30.000	> 100	> 100	> 100	> 100	> 100	-12627.8	0.0	-52859.1	35.374	1431.0	0.000
8	25.000	> 100	> 100	> 100	> 100	> 100	-16317.2	0.0	-76307.9	35.773	2465.3	0.000
9	20.000	> 100	> 100	> 100	> 100	> 100	-20516.6	0.0	-106166.3	36.060	3712.0	0.000
10	15.000	> 100	> 100	> 100	> 100	> 100	-25226.0	0.0	-143263.2	36.272	5171.3	0.000
11	10.000	> 100	> 100	> 100	> 100	> 100	-30445.4	0.0	-188427.2	36.434	6843.0	0.000
12	5.000	> 100	> 100	> 100	> 100	> 100	-36174.8	0.0	-242487.1	36.559	8727.3	0.000
13	Base	> 100	> 100	> 100	> 100	> 100	-42414.2	0.0	-306271.6	36.657	7793.3	0.000
	Required:	3.000	1.500	1.200	1.200	1.200						

Table-3

FLOOD COMBINATION (STRESS ANALYSIS)									
Joint		Stresses							
		Normal stresses		alowable stresses		Shear			
ID	Upstream elevation (ft)	Upstream (ksf)	Downstream (ksf)	tension (ksf)	Compression (ksf)	Upstream (ksf)	Maximum (ksf)	Maximum at l-axis (% of joint)	Downstream (ksf)
1	60.000	-48.000	-48.000	0.000	-15000.000				
2	55.000	-168.000	-168.000	0.000	-15000.000				
3	50.000	-368.138	-73.744	0.000	-15000.000				
4	45.000	-516.099	-38.083	0.000	-15000.000				
5	40.000	-632.918	-21.416	0.000	-15000.000	0.000	-4.620	32.095	16.062
6	35.000	-674.387	-37.440	0.000	-15000.000	67.439	-12.528	58.391	28.080
7	30.000	-703.389	46.594	0.000	-15000.000	70.339	70.339	0.000	-34.946
8	25.000	-729.306	-106.572	0.000	-15000.000	72.931	23.846	48.334	79.929
9	20.000	-751.677	-150.986	0.000	-15000.000	75.168	44.404	40.067	113.240
10	15.000	-770.793	-200.525	0.000	-15000.000	77.079	62.684	28.832	150.393
11	10.000	-787.106	-254.213	0.000	-15000.000	78.711	75.649	14.027	190.659
12	5.000	-801.058	-311.265	0.000	-15000.000	80.106	233.448	100.000	233.448
13	Base	-949.980	-371.062	0.000	-15000.000	94.998	278.297	100.000	278.297

Table-4

FLOOD COMBINATION (STABILITY ANALYSIS)												
Joint		Safety factors					Resultants				Uplift	Rock
		Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Final	Passive
ID	Upstream elevation (ft)	Peak	Residual	Toward U/S	Toward D/S		(kip)	(kip)	(kip·ft)	(% of joint)	Force (kip)	wedge resistance (kip)
1	60.000	> 100	> 100	> 100	> 100	> 100	-432.0	0.0	0.0	50.000		
2	55.000	> 100	> 100	> 100	> 100	> 100	-1512.0	0.0	0.0	50.000		
3	50.000	> 100	> 100	> 100	> 100	> 100	-2817.0	0.0	-3988.1	38.896		
4	45.000	> 100	> 100	> 100	> 100	> 100	-4572.0	0.0	-10845.0	35.624		
5	40.000	> 100	> 100	46.050	43.791	44.622	-6625.1	11.3	-20896.2	34.424	151.9	0.000
6	35.000	58.638	41.058	12.527	11.297	11.951	-8673.6	211.3	-31523.4	35.087	792.0	0.000
7	30.000	20.299	14.214	2.769	4.741	3.856	-9398.7	661.3	-51192.9	30.969	3291.3	0.000
8	25.000	14.413	10.092	6.712	5.212	6.066	-13737.7	1361.3	-56068.7	37.583	2711.8	0.000
9	20.000	10.352	7.249	5.901	4.295	5.198	-16753.4	2311.3	-68974.1	38.909	3990.4	0.000
10	15.000	8.172	5.722	5.422	3.727	4.665	-20091.7	3511.3	-81333.5	40.215	5481.5	0.000
11	10.000	6.837	4.788	5.113	3.344	4.306	-23752.5	4961.3	-92420.8	41.471	7185.2	0.000
12	5.000	5.946	4.164	4.900	3.067	4.047	-27735.8	6661.3	-101510.3	42.661	9101.3	0.000
13	Base	5.929	4.151	7.086	3.838	5.751	-35747.4	8611.3	-141302.8	42.696	7524.0	0.000
	Required:	2.000	1.300	1.100	1.100	1.100						

Table-5

SEISMIC #1 COMBINATION - PEAK ACCELERATIONS (STRESS ANALYSIS)									
Joint		Stresses							
		Normal stresses		alowable stresses		Shear			
ID	Upstream elevation (ft)	Upstream (ksf)	Downstream (ksf)	tension (ksf)	Compression (ksf)	Upstream (ksf)	Maximum (ksf)	Maximum at l-axis (% of joint)	Downstream (ksf)
1	60.000	-59.200	-46.400	0.000	-27270.000	0.000	-14.400	50.000	0.000
2	55.000	-263.200	-106.400	0.000	-27270.000	0.000	-50.400	50.000	0.000
3	50.000	-525.477	0.000	0.000	-27270.000	0.000	-71.656	46.250	0.000
4	45.000	-742.194	0.000	0.000	-27270.000	0.000	-101.208	41.067	0.000
5	40.000	-939.274	-0.001	0.000	-27270.000	0.000	-128.083	39.193	0.001
6	35.000	-1020.883	0.000	0.000	-27270.000	102.088	-171.014	43.988	0.000
7	30.000	-1044.704	169.115	0.000	-27270.000	104.470	-143.442	79.440	-126.836
8	25.000	-1148.618	0.000	0.000	-27270.000	114.862	-167.276	46.798	0.000
9	20.000	-1209.701	-0.001	0.000	-27270.000	120.970	-156.879	48.628	0.001
10	15.000	-1268.642	0.000	0.000	-27270.000	126.864	-143.663	50.668	0.000
11	10.000	-1324.087	-0.001	0.000	-27270.000	132.409	-124.219	53.138	0.001
12	5.000	-1375.347	-0.001	0.000	-27270.000	137.535	-101.777	56.146	0.001
13	Base	-1557.978	-0.001	0.000	-27270.000	155.798	-85.446	59.230	0.000

Table-6

SEISMIC #1 COMBINATION - PEAK ACCELERATIONS (STABILITY ANALYSIS)												
Joint		Safety factors					Resultants				Uplift	Rock
		Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Final	Passive
ID	Upstream elevation (ft)	Peak	Residual	Toward U/S	Toward D/S		(kip)	(kip)	(kip·ft)	(% of joint)	Force (kip)	wedge resistance (kip)
1	60.000	*7.855*	*5.500*	*24.750*	*> 100*	*> 100*	-475.2	-86.4	-86.4	47.980		
2	55.000	*7.855*	*5.500*	*7.071*	*> 100*	*> 100*	-1663.2	-302.4	-1058.4	42.929		
3	50.000	*7.855*	*5.500*	*4.824*	*> 100*	*> 100*	-3098.7	-563.4	-6090.9	30.834		
4	45.000	*7.855*	*5.500*	*4.320*	*> 100*	*> 100*	-5029.2	-914.4	-11359.5	27.378		
5	40.000	*7.855*	*5.500*	*4.161*	*> 100*	*> 100*	-7454.7	-1355.4	-19721.8	26.129		
6	35.000	*7.673*	*5.372*	*3.449*	*18.427*	*17.089*	-9802.0	-1824.5	-31371.2	26.266	609.3	0.000
7	30.000	*8.156*	*5.711*	*3.102*	*10.049*	*9.756*	-12529.7	-2193.9	-82853.7	26.895	1431.0	0.000
8	25.000	*9.125*	*6.389*	*2.896*	*7.238*	*7.343*	-15636.6	-2447.3	-70955.5	27.611	2465.3	0.000
9	20.000	*10.591*	*7.416*	*2.766*	*5.832*	*6.151*	-19122.0	-2578.6	-100755.4	28.389	3712.0	0.000
10	15.000	*12.703*	*8.895*	*2.681*	*4.992*	*5.445*	-22985.8	-2584.2	-138821.7	29.197	5171.3	0.000
11	10.000	*16.651*	*11.659*	*2.626*	*4.432*	*4.977*	-27214.7	-2334.2	-186452.8	30.036	6843.0	0.000
12	5.000	*24.490*	*17.148*	*2.596*	*4.031*	*4.645*	-31811.6	-1855.1	-245265.1	30.920	8727.3	0.000
13	Base	*45.581*	*31.916*	*2.909*	*4.906*	*6.111*	-39831.6	-1248.0	-339447.8	31.493	7793.3	0.000
	Required:	1.300	1.000	1.100	1.100	1.100						

Table-7

SEISMIC #1 COMBINATION - SUSTAINED ACCELERATIONS (STRESS ANALYSIS)									
Joint		Stresses							
		Normal stresses		alowable stresses		Shear			
ID	Upstream elevation (ft)	Upstream (ksf)	Downstream (ksf)	tension (ksf)	Compression (ksf)	Upstream (ksf)	Maximum (ksf)	Maximum at l-axis (% of joint)	Downstream (ksf)
1	60.000	-75.200	-68.800	0.000	-27270.000	0.000	-7.200	50.000	0.000
2	55.000	-291.200	-212.800	0.000	-27270.000	0.000	-25.200	50.000	0.000
3	50.000	-610.992	-51.831	0.000	-27270.000	0.000	-44.376	42.200	38.873
4	45.000	-849.958	-0.001	0.000	-27270.000	0.000	-42.498	48.901	0.001
5	40.000	-1067.021	-0.001	0.000	-27270.000	0.000	-53.351	47.047	0.000
6	35.000	-1169.524	0.000	0.000	-27270.000	116.952	-89.357	57.480	0.000
7	30.000	-1258.030	28.911	0.000	-27270.000	125.803	-79.717	65.300	-21.684
8	25.000	-1350.330	0.000	0.000	-27270.000	135.033	-69.579	63.147	0.000
9	20.000	-1441.605	-33.285	0.000	-27270.000	144.161	-56.126	61.114	24.964
10	15.000	-1531.186	-71.547	0.000	-27270.000	153.119	-40.687	58.903	53.660
11	10.000	-1618.547	-113.950	0.000	-27270.000	161.855	-23.017	56.625	85.463
12	5.000	-1703.477	-160.243	0.000	-27270.000	170.348	-4.228	54.225	120.182
13	Base	-1917.738	-191.230	0.000	-27270.000	191.774	13.377	53.943	143.423

Table-8

SEISMIC #1 COMBINATION - SUSTAINED ACCELERATIONS (STABILITY ANALYSIS)												
Joint		Safety factors					Resultants				Uplift	Rock
		Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Final	Passive
ID	Upstream elevation (ft)	Peak	Residual	Toward U/S	Toward D/S		(kip)	(kip)	(kip·ft)	(% of joint)	Force (kip)	wedge resistance (kip)
1	60.000	21.422	15.000	67.500	> 100	> 100	-648.0	-43.2	-43.2	49.259		
2	55.000	21.422	15.000	19.286	> 100	> 100	-2268.0	-151.2	-529.2	47.407		
3	50.000	21.422	15.000	13.157	> 100	> 100	-4225.5	-281.7	-7574.9	35.940		
4	45.000	21.422	15.000	11.783	> 100	> 100	-6858.0	-457.2	-18444.9	32.601		
5	40.000	21.422	15.000	11.347	> 100	> 100	-10165.5	-677.7	-32282.2	31.365		
6	35.000	23.159	16.216	7.891	23.346	23.293	-13582.2	-837.6	-52578.9	31.770	609.3	0.000
7	30.000	31.047	21.740	6.533	12.720	13.291	-17588.7	-809.1	-87844.9	32.549	1431.0	0.000
8	25.000	53.705	37.605	5.812	9.152	9.999	-22186.0	-590.0	-121505.6	33.323	2465.3	0.000
9	20.000	> 100	> 100	5.377	7.367	8.374	-27374.0	-178.7	-161709.7	34.086	3712.0	0.000
10	15.000	> 100	77.880	5.093	6.300	7.411	-33152.5	425.7	-208178.2	34.821	5171.3	0.000
11	10.000	44.885	31.429	4.899	5.592	6.775	-39518.3	1257.4	-260945.3	35.526	6843.0	0.000
12	5.000	28.738	20.123	4.763	5.089	6.325	-46471.9	2309.4	-319837.5	36.199	8727.3	0.000
13	Base	23.020	16.119	5.513	6.199	8.323	-57068.7	3540.5	-421408.2	36.356	7793.3	0.000
	Required:	1.300	1.000	1.100	1.100	1.100						

Table-9

SEISMIC #2 COMBINATION - PEAK ACCELERATIONS (STRESS ANALYSIS)									
Joint		Stresses							
		Normal stresses		alowable stresses		Shear			
ID	Upstream elevation (ft)	Upstream (ksf)	Downstream (ksf)	tension (ksf)	Compression (ksf)	Upstream (ksf)	Maximum (ksf)	Maximum at l-axis (% of joint)	Downstream (ksf)
1	60.000	-59.200	-46.400	0.000	-27270.000	0.000	-14.400	50.000	0.000
2	55.000	-263.200	-106.400	0.000	-27270.000	0.000	-50.400	50.000	0.000
3	50.000	-525.477	0.000	0.000	-27270.000	0.000	-71.656	46.250	0.000
4	45.000	-742.194	0.000	0.000	-27270.000	0.000	-101.208	41.067	0.000
5	40.000	-939.274	-0.001	0.000	-27270.000	0.000	-128.083	39.193	0.001
6	35.000	-1020.883	0.000	0.000	-27270.000	102.088	-171.014	43.988	0.000
7	30.000	-1044.704	169.115	0.000	-27270.000	104.470	-143.442	79.440	-126.836
8	25.000	-1148.618	0.000	0.000	-27270.000	114.862	-167.276	46.798	0.000
9	20.000	-1209.701	-0.001	0.000	-27270.000	120.970	-156.879	48.628	0.001
10	15.000	-1268.642	0.000	0.000	-27270.000	126.864	-143.663	50.668	0.000
11	10.000	-1324.087	-0.001	0.000	-27270.000	132.409	-124.219	53.138	0.001
12	5.000	-1375.347	-0.001	0.000	-27270.000	137.535	-101.777	56.146	0.001
13	Base	-1557.978	-0.001	0.000	-27270.000	155.798	-85.446	59.230	0.000

Tabel-10

SEISMIC #2 COMBINATION - PEAK ACCELERATIONS (STABILITY ANALYSIS)													
Joint		Safety factors					Resultants				Uplift	Rock	
		Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Final	Passive wedge	
ID	Upstream elevation (ft)	Peak	Residual	Toward U/S	Toward D/S		(kip)	(kip)	(kip·ft)	(% of joint)	Force (kip)	resistance (kip)	
1	60.000	*7.855*	*5.500*	*24.750*	*> 100*	*> 100*	-475.2	-86.4	-86.4	47.980			
2	55.000	*7.855*	*5.500*	*7.071*	*> 100*	*> 100*	-1663.2	-302.4	-1058.4	42.929			
3	50.000	*7.855*	*5.500*	*4.824*	*> 100*	*> 100*	-3098.7	-563.4	-6090.9	30.834			
4	45.000	*7.855*	*5.500*	*4.320*	*> 100*	*> 100*	-5029.2	-914.4	-11359.5	27.378			
5	40.000	*7.855*	*5.500*	*4.161*	*> 100*	*> 100*	-7454.7	-1355.4	-19721.8	26.129			
6	35.000	*7.673*	*5.372*	*3.449*	*18.427*	*17.089*	-9802.0	-1824.5	-31371.2	26.266	609.3	0.000	
7	30.000	*8.156*	*5.711*	*3.102*	*10.049*	*9.756*	-12529.7	-2193.9	-82853.7	26.895	1431.0	0.000	
8	25.000	*9.125*	*6.389*	*2.896*	*7.238*	*7.343*	-15636.6	-2447.3	-70955.5	27.611	2465.3	0.000	
9	20.000	*10.591*	*7.416*	*2.766*	*5.832*	*6.151*	-19122.0	-2578.6	-100755.4	28.389	3712.0	0.000	
10	15.000	*12.703*	*8.895*	*2.681*	*4.992*	*5.445*	-22985.8	-2584.2	-138821.7	29.197	5171.3	0.000	
11	10.000	*16.651*	*11.659*	*2.626*	*4.432*	*4.977*	-27214.7	-2334.2	-186452.8	30.036	6843.0	0.000	
12	5.000	*24.490*	*17.148*	*2.596*	*4.031*	*4.645*	-31811.6	-1855.1	-245265.1	30.920	8727.3	0.000	
13	Base	*45.581*	*31.916*	*2.909*	*4.906*	*6.111*	-39831.6	-1248.0	-339447.8	31.493	7793.3	0.000	
	Required:	1.300	1.000	1.100	1.100	1.100							

Table-11

SEISMIC #2 COMBINATION - SUSTAINED ACCELERATIONS (STRESS ANALYSIS)									
Joint		Stresses							
		Normal stresses		alowable stresses		Shear			
ID	Upstream elevation (ft)	Upstream (ksf)	Downstream (ksf)	tension (ksf)	Compression (ksf)	Upstream (ksf)	Maximum (ksf)	Maximum at l-axis (% of joint)	Downstream (ksf)
1	60.000	-75.200	-68.800	0.000	-27270.000	0.000	-7.200	50.000	0.000
2	55.000	-291.200	-212.800	0.000	-27270.000	0.000	-25.200	50.000	0.000
3	50.000	-610.992	-51.831	0.000	-27270.000	0.000	-44.376	42.200	38.873
4	45.000	-849.958	-0.001	0.000	-27270.000	0.000	-42.498	48.901	0.001
5	40.000	-1067.021	-0.001	0.000	-27270.000	0.000	-53.351	47.047	0.000
6	35.000	-1169.524	0.000	0.000	-27270.000	116.952	-89.357	57.480	0.000
7	30.000	-1258.030	28.911	0.000	-27270.000	125.803	-79.717	65.300	-21.684
8	25.000	-1350.330	0.000	0.000	-27270.000	135.033	-69.579	63.147	0.000
9	20.000	-1441.605	-33.285	0.000	-27270.000	144.161	-56.126	61.114	24.964
10	15.000	-1531.186	-71.547	0.000	-27270.000	153.119	-40.687	58.903	53.660
11	10.000	-1618.547	-113.950	0.000	-27270.000	161.855	-23.017	56.625	85.463
12	5.000	-1703.477	-160.243	0.000	-27270.000	170.348	-4.228	54.225	120.182
13	Base	-1917.738	-191.230	0.000	-27270.000	191.774	13.377	53.943	143.423

Table-12

SEISMIC #2 COMBINATION - SUSTAINED ACCELERATIONS (STABILITY ANALYSIS)												
Joint		Safety factors					Resultants				Uplift	Rock
		Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Final	Passive
ID	Upstream elevation (ft)	Peak	Residual	Toward U/S	Toward D/S		(kip)	(kip)	(kip·ft)	(% of joint)	Force (kip)	wedge resistance (kip)
1	60.000	21.422	15.000	67.500	> 100	> 100	-648.0	-43.2	-43.2	49.259		
2	55.000	21.422	15.000	19.286	> 100	> 100	-2268.0	-151.2	-529.2	47.407		
3	50.000	21.422	15.000	13.157	> 100	> 100	-4225.5	-281.7	-7574.9	35.940		
4	45.000	21.422	15.000	11.783	> 100	> 100	-6858.0	-457.2	-18444.9	32.601		
5	40.000	21.422	15.000	11.347	> 100	> 100	-10165.5	-677.7	-32282.2	31.365		
6	35.000	23.159	16.216	7.891	23.346	23.293	-13582.2	-837.6	-52578.9	31.770	609.3	0.000
7	30.000	31.047	21.740	6.533	12.720	13.291	-17588.7	-809.1	-87844.9	32.549	1431.0	0.000
8	25.000	53.705	37.605	5.812	9.152	9.999	-22186.0	-590.0	-121505.6	33.323	2465.3	0.000
9	20.000	> 100	> 100	5.377	7.367	8.374	-27374.0	-178.7	-161709.7	34.086	3712.0	0.000
10	15.000	> 100	77.880	5.093	6.300	7.411	-33152.5	425.7	-208178.2	34.821	5171.3	0.000
11	10.000	44.885	31.429	4.899	5.592	6.775	-39518.3	1257.4	-260945.3	35.526	6843.0	0.000
12	5.000	28.738	20.123	4.763	5.089	6.325	-46471.9	2309.4	-319837.5	36.199	8727.3	0.000
13	Base	23.020	16.119	5.513	6.199	8.323	-57068.7	3540.5	-421408.2	36.356	7793.3	0.000
	Required:	1.300	1.000	1.100	1.100	1.100						