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The importance of soil parameters on Newmark's deformations of rock-fill dam based on mobilized shear induced by earthquakes

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Abstract: Earthquake induced failure has never been seriously considered in Thailand. Important structures will be reevaluated to inspect the capacity of earthquake resistances and excessive deformation is one of index to evaluate dam failure. This study has emphasized on uncertainty of the material properties to seismic deformation. Parameters considered are maximum shear modulus, shear modulus reduction relations, unit weights, Poisson's ratios, cohesions, and friction angle. Seismic permanent deformation of dam under excitation will be considered using Newmark's deformation by induced mobilized shear stress. The analysis can be divided into three related parts; initial stress analysis, seismic response analysis, and seismic deformation analysis. The soil models used in the analysis are elastic model, equivalent-linear model and Mohr-Coulomb model. The onset of examination is the evaluation on possible range of those parameters. Maximum/minimum boundaries of each are evaluated and their difference influences are considered in forms of seismic deformation. San Fernando earthquake is used to examine seismic permanent deformation of a study large rockfill dam, located in the western part of Thailand. The analysis shows the soil parameters that has the critical effect to seismic permanent deformation in form of differential deformation. The differential deformation, is that deformations of maximum/minimum of the interested soil property parameter differ from those of mean same soil property parameter.

The critical parameters are maximum shear modulus (Gmax), shear modulus reduction curve (G/Gmax reduction curve), unit weights, and friction angles of rockfill zone.

Key words: Newmark's deformation, Rockfill dams, soil parameters, earthquakes.

1 Introduction

As our perceptions of earthquake hazard are never been ackhowaged, untill now, earthquake are more concerned, especially in old infrastructures. Many important dams are designed base on the concept of free earthquakes or having small earthquake that is concerned to engineers and related officials. Almost all infrastructures in Thailand are designed by excluding earthquake excitations and many importance structures were already done and still been in uses. Based on earthquake activities around neighbor countries, this importanct structure should be reevaluated in corresponding to get new valuable information and recommendation of Internation Commision of Large Dams(ICOLD)

The studied rockfill dam, located at the western part of Thailand own by Electricity Generating Authority of Thailand (EGAT), had been constructed since 1976 untill 1978 by compacting composited materials. This dam can generate electricity to feed to economic areas by hydro power generators.

Based on unsufficient knowledge on seismic soil properties and workmanship standard, no seismic parameters was been tested or mentioned in design. Parametric material property study is the first task to be performed. Newmark's deformations are analysed according to vary initial stresses and seismic responses of dam based on uncertainties of composited material. To evaluate the resistance capacity and maintenant of old dams, influenceing properties should be clarified.

2 Seismic permanent deformation

2.1 Newmark's displacement method

Newmark(1965) proposed method to evaluate seismic permanent deforamtion of slope based on sliding block on inclined plane. The method is limited to rigid materials having loosed strength of not less than 15%. Newmark's concept is based on Pseudo static method by considering movement of material when have average acceleration of failure mass exceeding yield acceleration. Yield acceleration is the accleration on the state of driving force equaling resisting force (Factor of safety = 1) which can be influenced by many factors; excitation chracteristic such as shape of acceleration time history, frequency of acceleration time history, effect of vertical acceleration, effect of two-way sliding , decreasing yield acceleration.

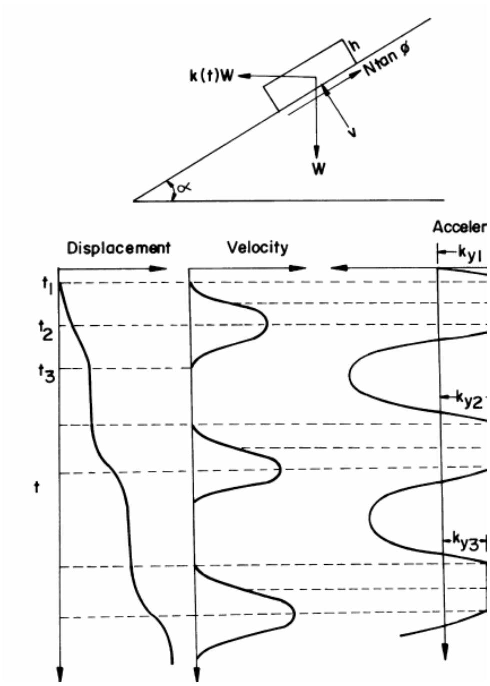

Figure 1 Seismic deformations of Newmark's deformation method
Ref. Seed (1979)

3 Dam configurations

Srinakharin dam, centered clay cored rockfill dam, is studied. The dam, having height of 140 meters, length of 610 meters and filled materials of 12 millioncubicmeters , is located in the western part of Thailand. This dam had been constructed since 1976 to 1978. The configuration of Srinakharin dam is shown on figure 2 and 3

The dam is designed to resistant earthquake of magnitude 7.5 within 200 kilometers by Pseudo-static method with maximum horizontal acceleration of 0.1g

Champa and Mahatharadol(1982) reports the fill materials of the centered clay cored rockfill dam;

Clay core is clayed sand having liquid limit of 25-50%, plastic index of 10-25%, maximum dry density of 1.7-1.9 t/m^2. Filter material is limestones of less than 15 centimeters in diameter and transition zone material is quartize of less than 25 centimeters in diameter. Rockfill material is limestones and can be separated into the inner with less than 70 centimeters of diameter and the outer with less than 150 centermeter of diamer

Bay and Chaiprakaikeow (2006) performed Spectrum Analysis of Surface Wave Method (SASW) on clay core and rockfill material of Srinakharin dam. Clay core can be classified into 2 layers; first layer, 0.05-43 meters, has shear wave velocity of less than 600 meters per seconds, second layer, > 43 meters in depth, has shear wave velocity of 900 meters per seconds. For rockfill material, first layer of rockfill material of 0-16 meters in depth has shear wave velocity of 350-600 meters per seconds and the second layer, depth of more than 16 meters, has shear wave velocity of more than 800 meters per seconds.

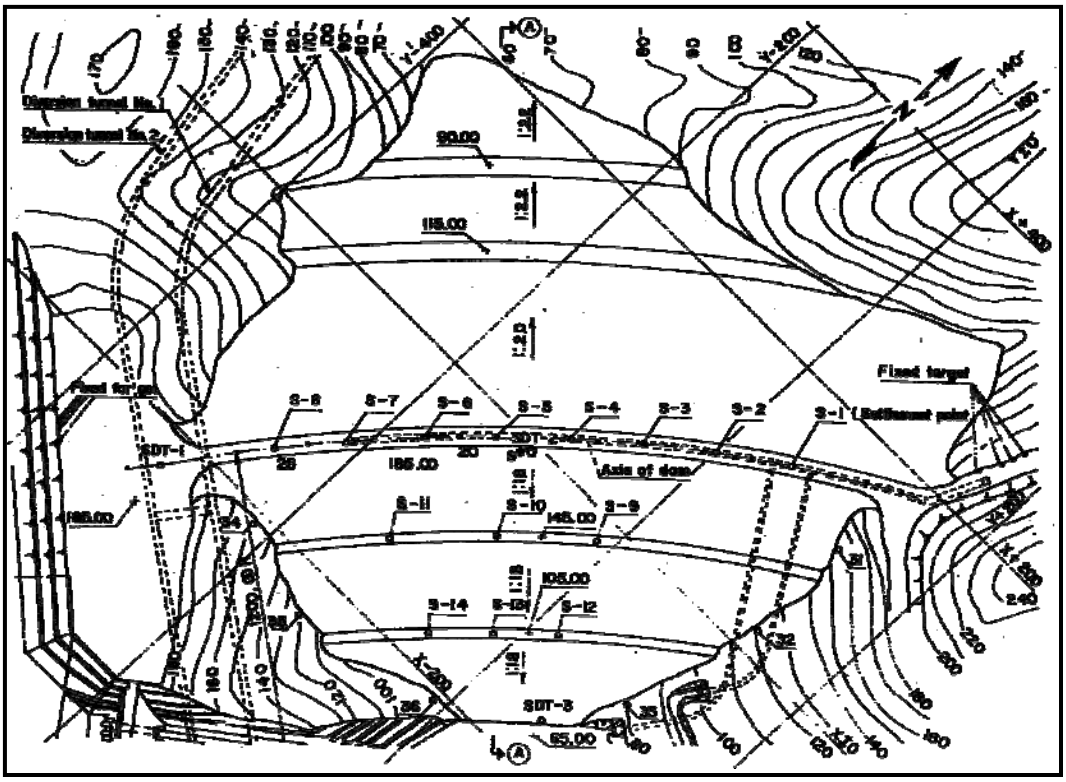

Figure 2 Long profile of Srinakharin dam
Ref. EGAT (1976)

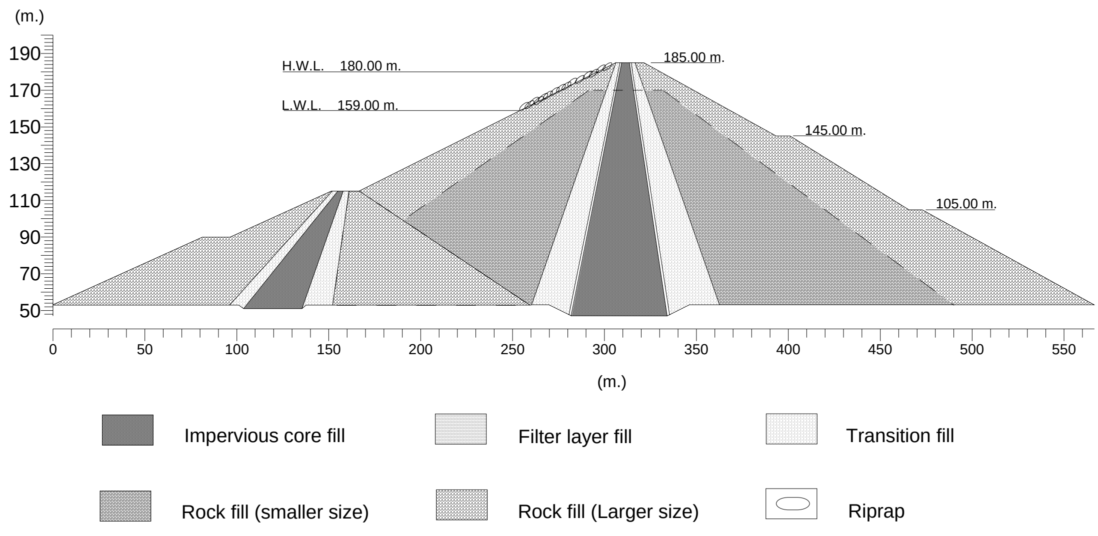

Figure 3. Cross section of Srinakharin dam
Ref. Kriengkrai (2008)

4. Methodology

Parametic study is composed of three consecutive model analysis; Initial stress analysis, Seismic response analysis, and Newmark's deformation analysis, shown in figure 4. Initial stress analysis is simulated the construction process of the dam to calculate stress states in static condition before excitations. Seismic response analysis is studied seismic behaviour in form of acceleration time history and seismic stress which will be used to find mobilized shear strength. Newmark's deformation analysis is the last analysis and will be presented in forms of deformations and yield acceleration.

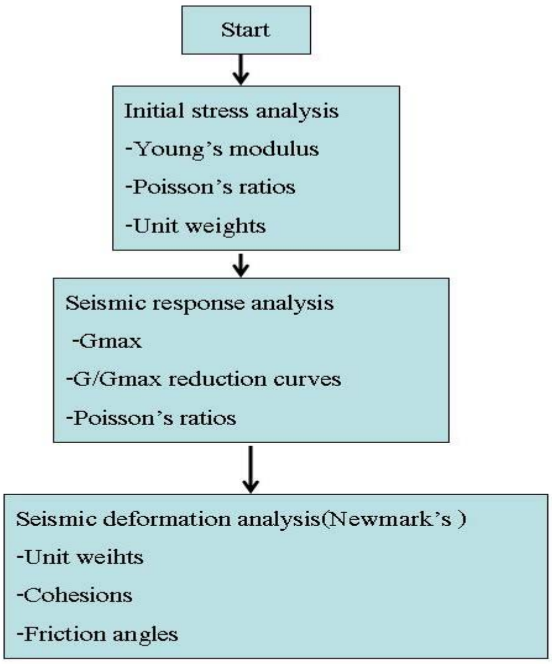

Figure 4 Methodology

Each runs of parameter investigations has to be done in all consecutively three models. Finally, magnitude of deformation and yield accelearation are used to justify which parameters have effected to the interested rockfill dam. For each loops of calculations, an interested variables is changed but other variables are in forms of mean values.

5. Acceleration time histories

San Fernando earthquake and cyclic sine wave are used in this parametric study. San Fernando earthquake is modified to has peak horizontal acceleration of 1 g, shown in figure 5. Equivalent sine wave of V,VI, and VII earthquakes are used to evaluated responses of dam for each parameters in models.

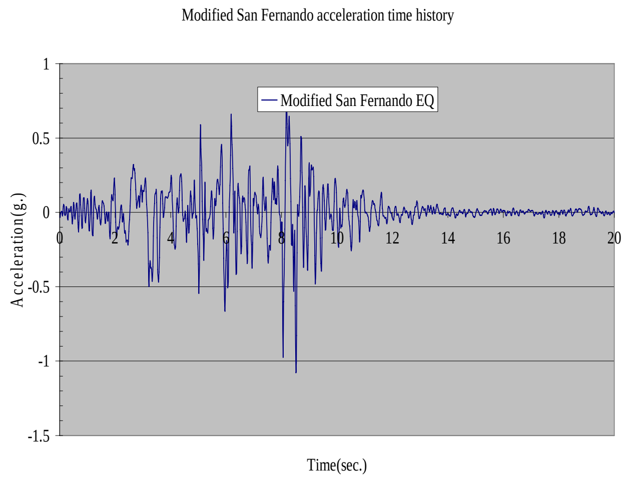

Figure 5 "Modified San Fernando earthquake" of peak ground horizontal acceleration of 1 g.

6. Failure surface

Failure surface can be selected by two different criterias; weak zone criteria and most damage criteria. For weak zone criteria, there are many factors,influencing weak zone failure surface. The weak zones are fructuated according time step of imposed loadings, magnitude of earthquakes, durations,and shape of acceleration time histories. Figure 6-8 are shown weak zone at the same time excited by same shape of different peak horizontal ground earthquake. Unfortunately, the expected future accelereation time histories can not be estimated thus the weak zone criteria will not used in this study.

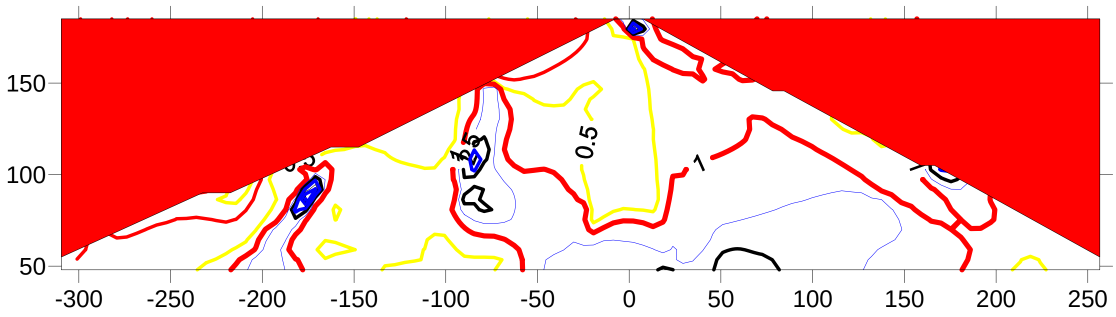

Figure 6 Contours of shear stress ratio (shear strength/shear stress) at 8.52 second (at peak horizontal ground acceleration) excited by San Fernando earthquake of 0.15 g.

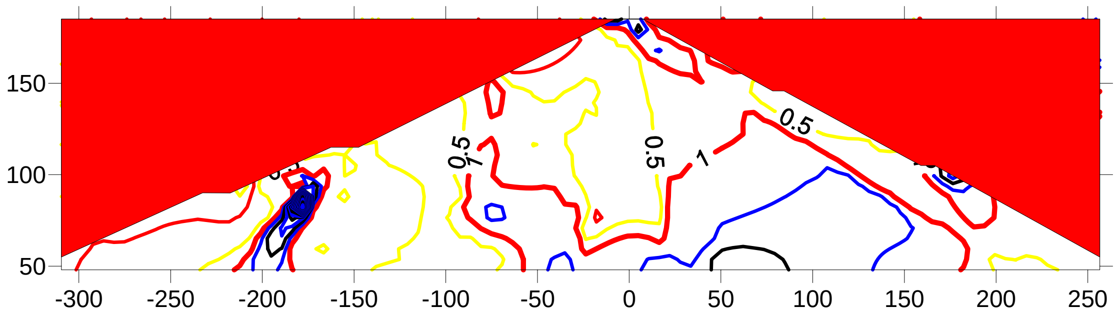

Figure 7 Contours of shear stress ratio (shear strength/shear stress) at 8.52 second (at peak horizontal ground acceleration) excited by San Fernando earthquake of 0.2 g

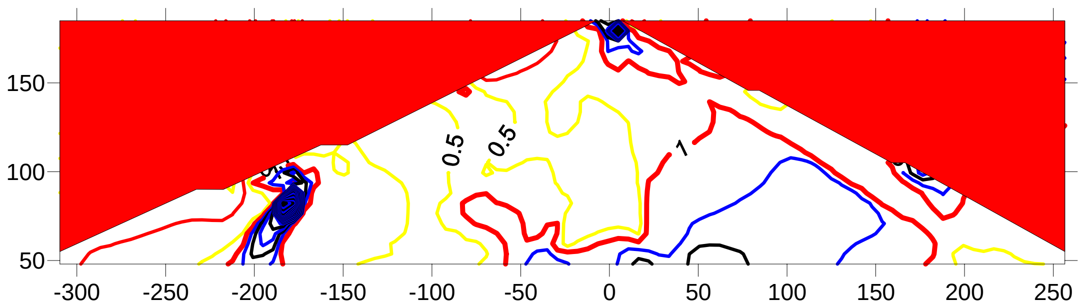

Figure 8 Contours of shear stress ratio (shear strength/shear stress) at 8.52 second (at peak horizontal ground acceleration) excited by San Fernando earthquake of 0.3 g

For the most devastated criteria, failure surface is assumed to be a circular one and operating water level is at maximum storage capacity. This surface may not yield the minimum factor of safety but, for the safety sake, the most devastated criteria is used in parametric study as shown in figure 9.

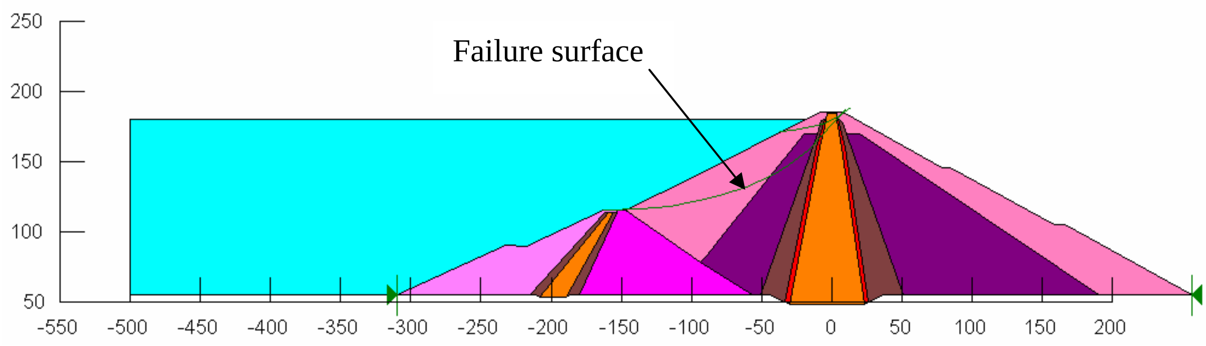

Figure 9 Failure surface of Newmark's deformation model

7. Mobilized shear and strength

Available resisting strength of each section within a failure mass can be calculated by the product of shear strenght at middle of each sections with length at base of each sections shown in equation 1

$$S_r = s\beta = \left(c' + (\sigma_n - u_a)\tan\phi'\right)\beta$$

Eq. (1)

Where

s = effective shear strength at middle of each sections

β = Base lenght

σ_n = Normal stress at middle of each sections

Mobilized shear force of each sections is the product of mobilzed shear stress, Tm, at middle and base length. Safety Factor in each section is estimated by equation 3

$$S_m = \tau_m \beta$$

Eq. (2)

$$Local - S.F. = \frac{S_r}{S_m} = \frac{s\beta}{\tau\beta}$$

Eq. (3)

8. Dynamic properties of soils

Intereseted soil properties are separated,according to type of analysis, initial stress model, seismic response model, and Newmark's deformation model, shown in Table 1

Without any recorded seismic material properties(Gmax, G/Gmax reduction curve, and Damping reduction curve), other document seismic properties are collected and analysed to find the upper/lower bounds. The limitation boundaries are formed in empirical relationship with mean effective stress, shown in Table 1. The rockfill dam are sectioned according to mean effective stresses resulted from initial stress analysis model.

Eventhough, field exploration was performed, location of SASW doesn't been covered along dam height/transition zone. Estimated maximum shear modulus of SASW are very much higher than those of document seismic properties.

Table 1 Soil properties in model and related value

Analysis model	Soil properties	Zone	Maximum value	Average	Minimum value
Initial stress	Young's modulus[a]	Rockfill	1.448e+006 KPa	8.4323e+005 KPa	2.3845e+005 KPa
		Transition	3.5356e+006 KPa	2.1253e+006 KPa	7.1498e+005 KPa
		Clay core	2.1241e+006 KPa	1.276e+006 KPa	4.2775e+005 KPa
	Unit weight[b]	Rockfill	26.4 KN/m^3	18.9 KN/m^3	11.47 KN/m^3
		Transition	22.07 KN/m^3	21.60 KN/m^3	17.85 KN/m^3
		Clay core	21.10 KN/m^3	20.89 KN/m^3	19.91 KN/m^3
Seismic response	Gmax[c]	Rockfill	$Y=28,181(X)^{0.5124}$	$Y=5,915.5(X)^{0.6126}$	$Y=2,237.3(X)^{0.55}$
		Transition	$Y=64,734(X)^{0.4417}$	$Y=23,088(X)^{0.525}$	$Y=10,033(X)^{0.5581}$
		Clay core	$Y=28,773(X)^{0.5}$	$Y=14,311(X)^{0.5111}$	$Y=5,467.5(X)^{0.5}$
	SASW[c]	Rockfill	$Y=8.9047(X)^2+3600(X)$		$Y=8.9047(X)^2+3600(X)$
		Transition	Not available		Not available
		Clay core	Y=3885.7(X)		Y=3022.2(X)
	Poisson's ratio[b]	Rockfill	0.23	0.2	0.16
		Transition	0.4	0.38	0.35
		Clay core	0.45	0.42	0.35
	G/Gmax[b]	Rockfill	Hara and Kiyota (1977)	Kokusho (1980)	Lowwer-De Alba et.al. (1975)
		Transition	Gravel-Yonezawa, Uemura and Ohmoto (1986)	Gravel-Ishihara (1996)	Gravel-Seed
		Clay core	AIT-Smapaco(1988)	Seed PI=20-40(1973)	Leon et.al. and Romo and Jaime (1974)
Newmark's deformation	Cohesion[b]	Rockfill	0	0	0
		Transition	0	0	0
		Clay core	30 KPa	40 KPa	100 KPa
	Friction[b] angles	Rockfill	35 °	39 °	60 °
		Transition	42 °	35 °	33 °
		Clay core	35 °	30 °	17 °

Note: X means mean effective stresses and Y means maximum shear modulus.,

[a] means that data are analysed by using mean values of poisson's ratio and maximum shear modulus.,

[b] means that data are analied by statistic data.,

[c] means that data are analied by regression.

9. Sampling assumption

Uncertainty of each parameters is summed of a data scatter and a systematric error because the collected data have not separated each type of uncertainty. Some parameters can not be collected to evaluate the material of dam such as seismic parameter of rockfill. To suit model, regression analysis is used. Each parameters are assumed to be equally likelyhood of occurrances such as shown in figure 10.

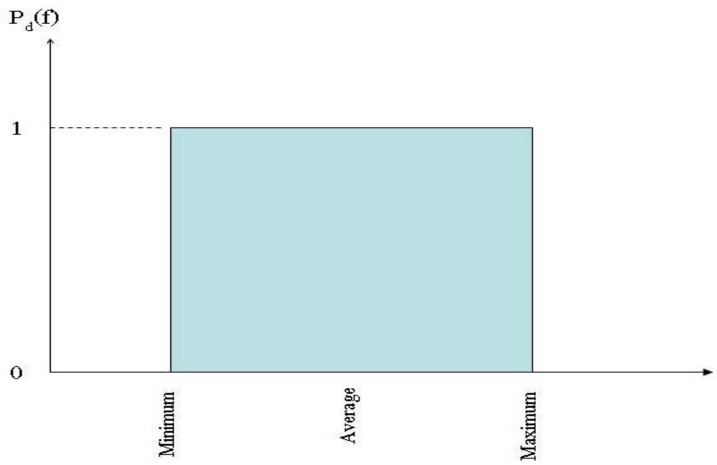

Figure 10 Uniform density functions

10. Parameter anatomy

Parameters have been investigated based on finite element theory in all three models. According to elastic behaviour, equivalent linear behaviour, and Newmark’s deformations, Seven parameters were investigated as state above. Numbers of usage,followed parameter names, are showed in figure 11 and dam responses are in the right side of figure. For Newmark’s deformation, unit weights have the most usaged number. They involves at the beginning of process, initial stress state, untill seisimic deformation process. Fortunately, unit weights properties can be easily examinated and have a narrow range of uncertainty. Cohesions and Friction angles properties is involved in seismic block slide on plane, but uncertainties of those two are documented widely. Maximum shear modulus, G/Gmax reduction curve have equal number of usage of cohesions and friction angles but these properties have never been tested at beginning and after construction. Nevertheless, uncertainties of rockfill are difficult and expensive process.

Poisson’s ratio is corelated to Young’s modulus and maximum shear modulus in form of $G = E \times 2(1+\nu)$, thus its uncertainties will effect those two uncertainties as well. Poisson’s uncertainty is modelled the uncertainty of maxmimum shear modulus and Young’s modulus.

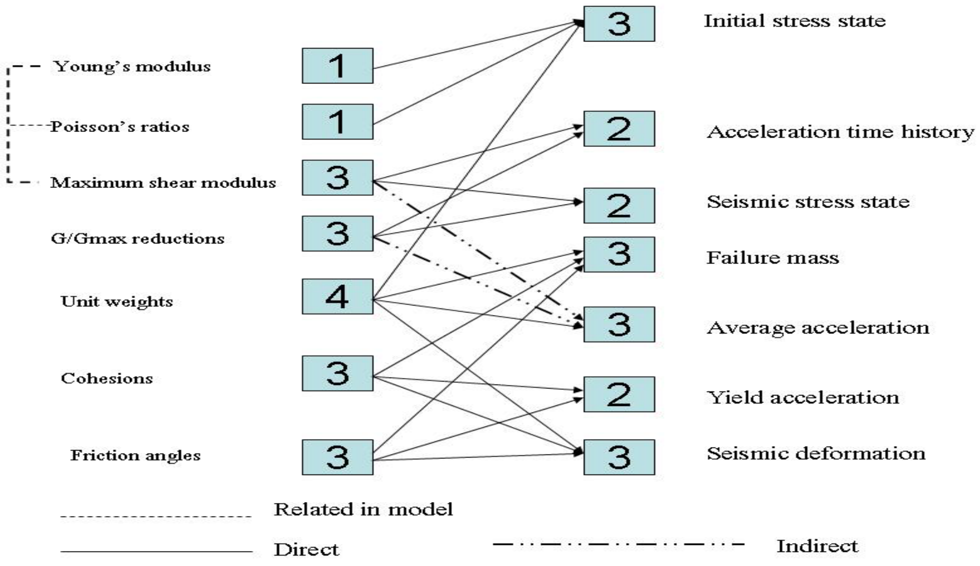

Figure 11 Parameter study chart

11. Results

11.1 Initial stress analysis

Initial stress analysis is modeled the initial stress of dam before seismic event. Soil behaviour are simulated as linear-elastic which is represented in forms of; Young's modulus, poisson's ratio, and unit weight. Excitation forces of cyclic sine wave, equivalent to earthquake of magnitude of VI and "Modified San Fernando Earthquake" , are investigated and founds that;

1. Cyclic sine wave of VI earthquake could not move expected sliding mass but "Modified San Fernando EQ" (1g PGA, not a real one) can move failure mass.

2. Uncertainty of rockfill unit weight is the most sensitive one in term of permanent deformation, shown in figure 12

3.Rockfill unit weights is a critical material properties and has more influencing than Young's modulus, and poisson's ratio in form of yield acceleration (Ky),shown in figure 13.

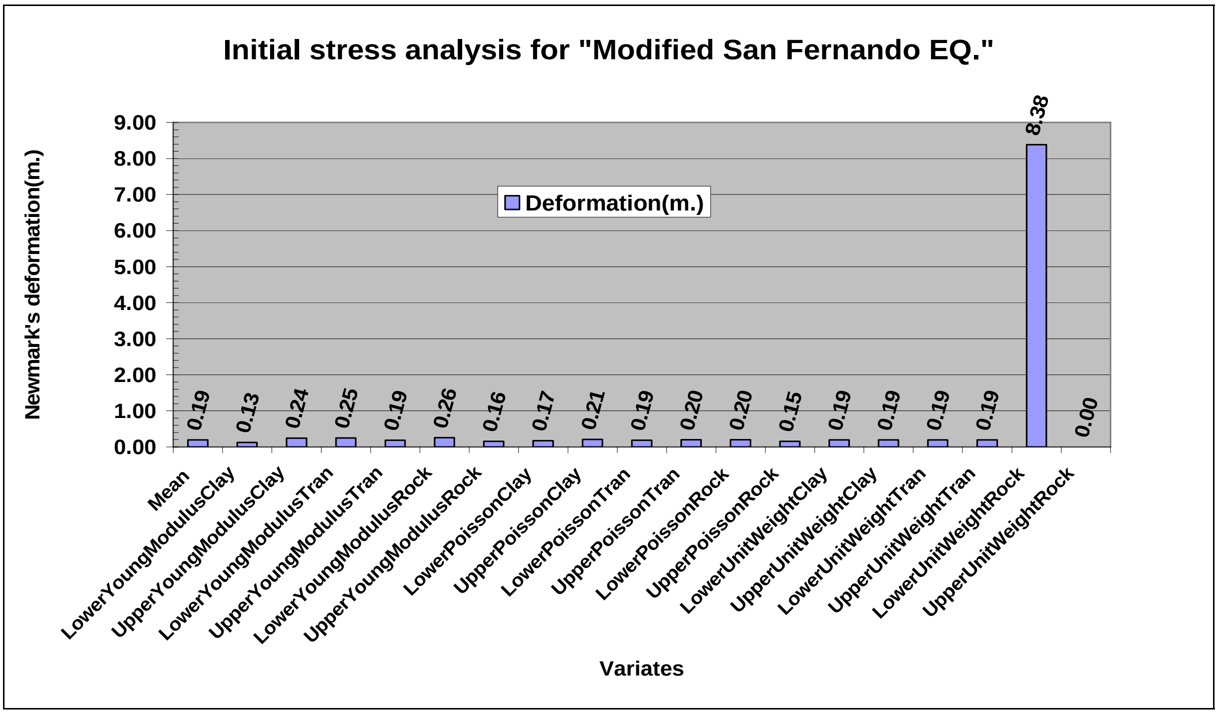

Figure 12 Seismic deformation in each variates of “Initial Stress Model”

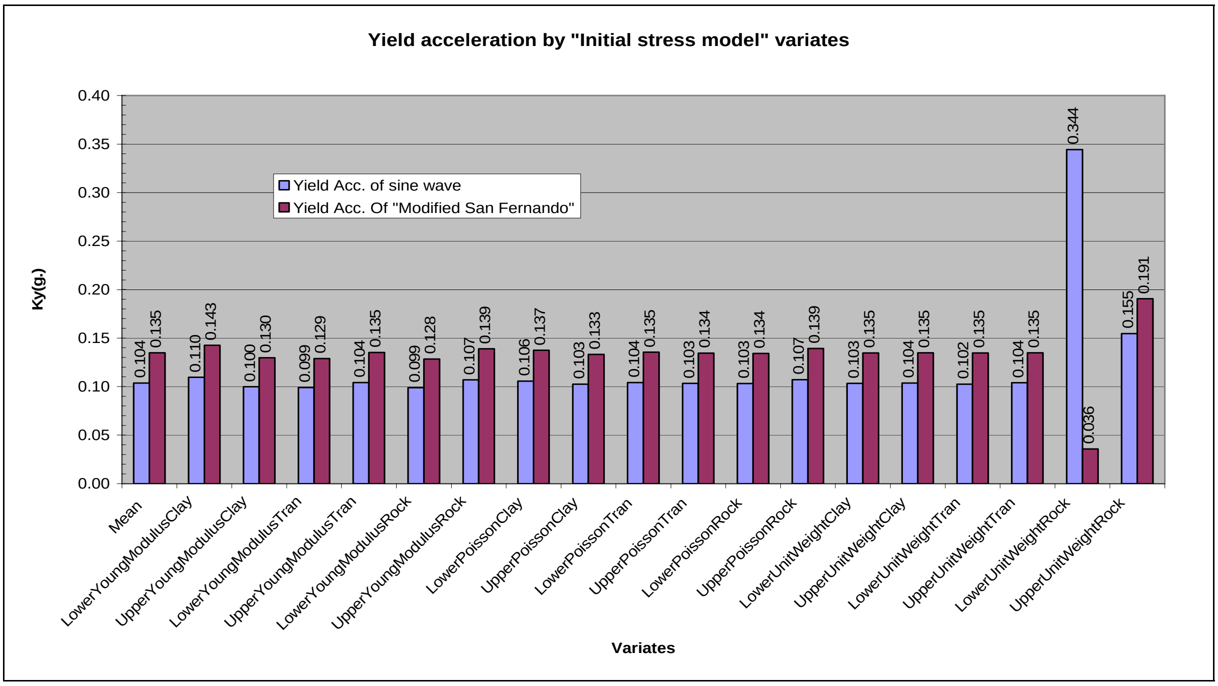

Figure 13 Yield acceleration in each variats of “Initial stress model”

11.2 Seismic response analysis model

As mention above, the investigated soil parameters in seismic response analysis are G/Gmax reduction curves, maximum shear modulus, poisson's ratio in each zones of dam. Seismic response analysis shows a same critical zone, rockfill zone. The critical seismic properties are maximum shear modulus and G/Gmax reduction curve of rockfill zone.

11.3 Deformation analysis model

Seismic deformation parametric study shows that unit weight of rock has more effect to deformation and yield acceleration. Fricition angle of rockfill is also influencing those indexes.

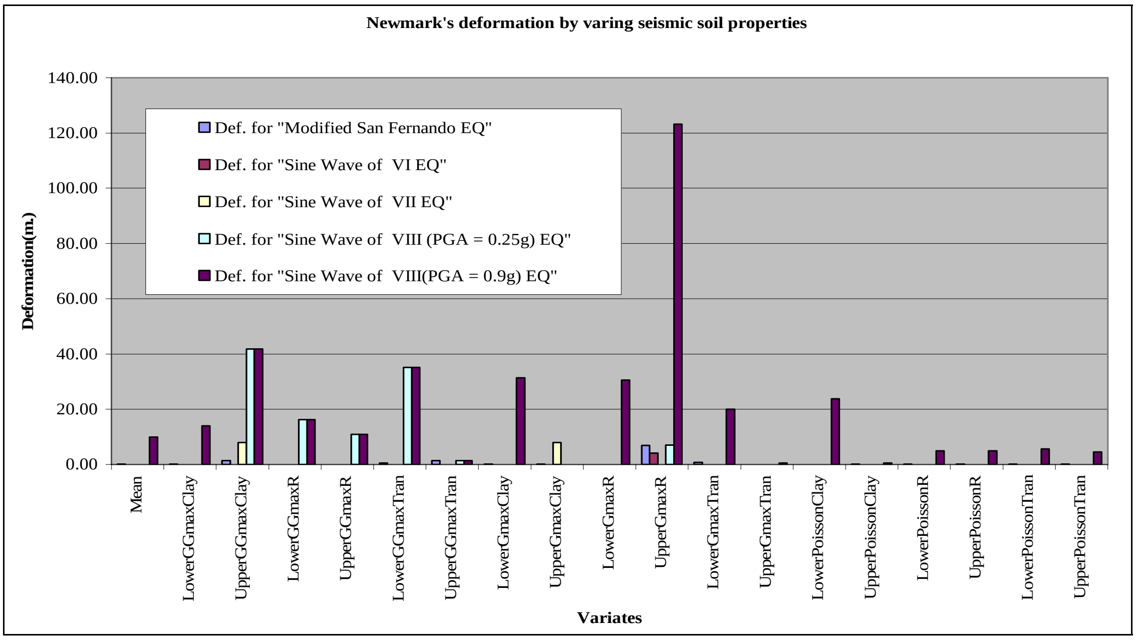

Figure 14 Deformation in each variates of "Seismic response analysis"

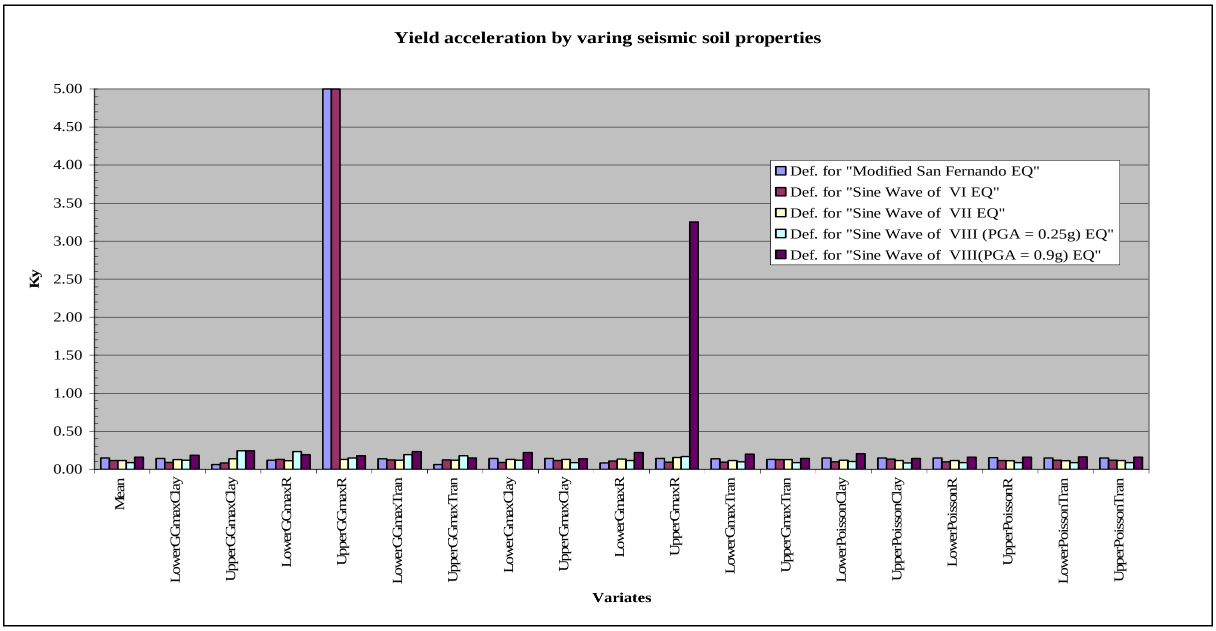

Figure 15 Yield acceleraton in each variates of “Seismic response analysis”

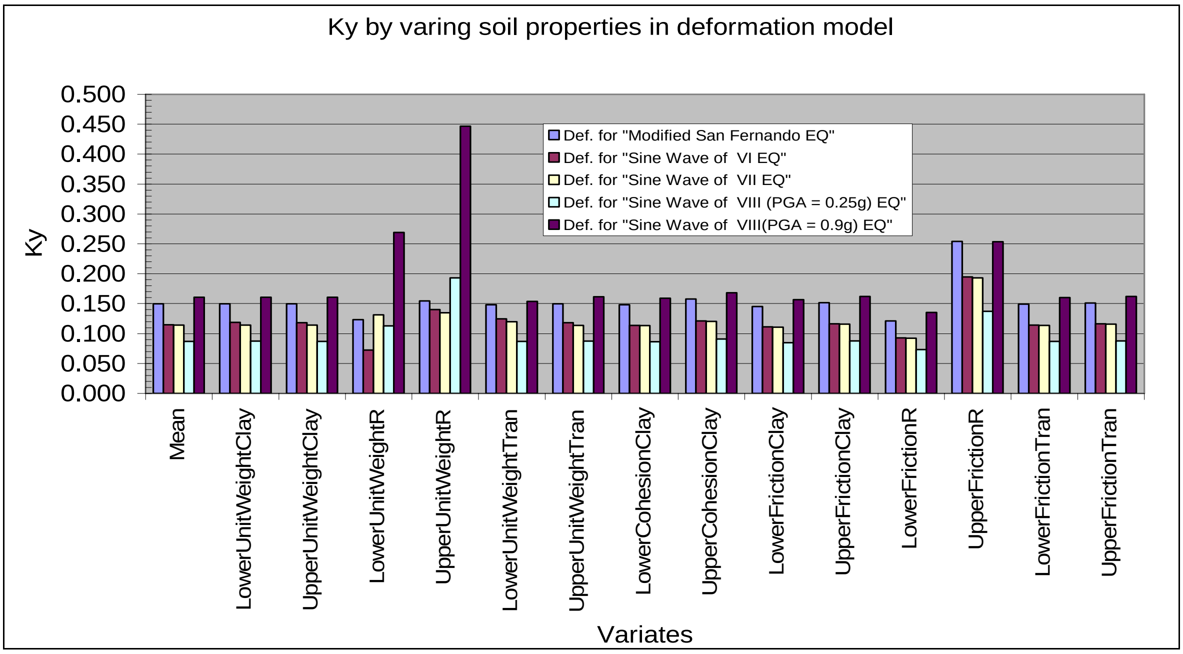

Figure 16 Yield acceleration in each variates of “Newmark’s deformation analysis”

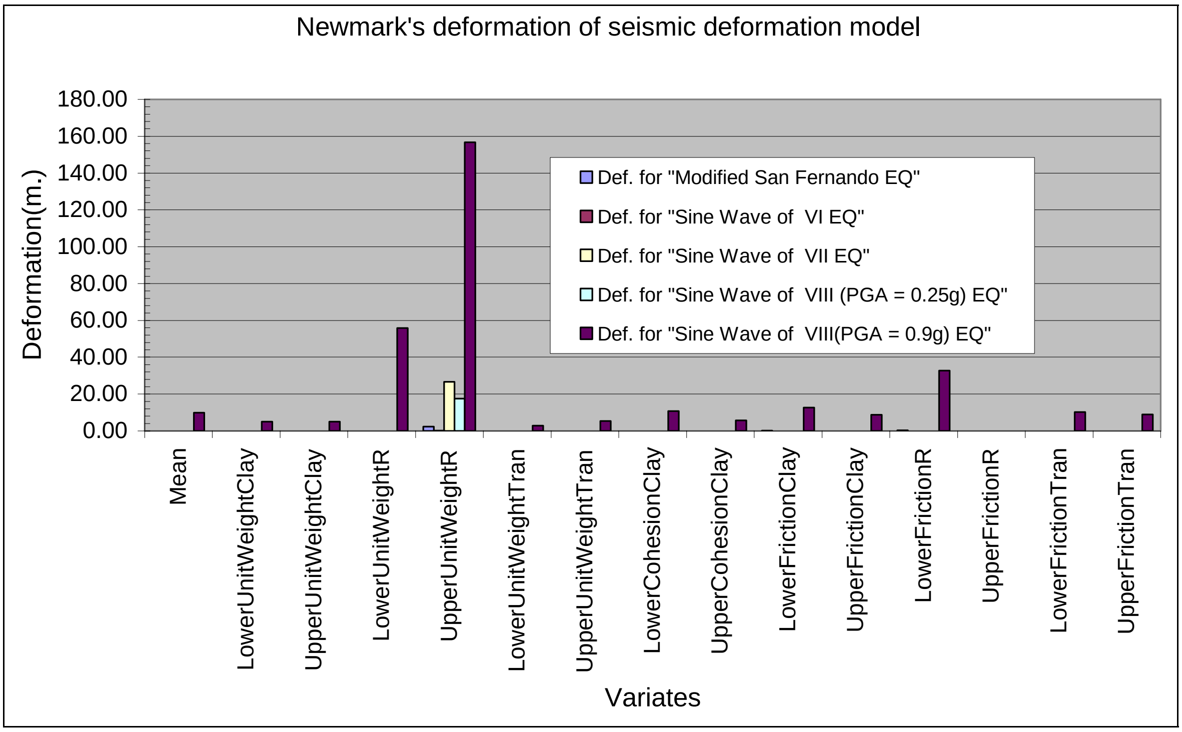

Figure 17 Newmark's deformation in each variates of "Newmark's deformation analysis"

12. Conclusions

Properties of rockfill zone are very critical to seismic deformations (Newmark's deformation). Those properties are Young's modulus, unit weights, maximum shear modulus, G/Gmax reduction characteristic, and friction angles. Properties, that can be neglected, are poisson's ratio of each zones.

Unit weights have shown to be influenced, but the range of this property is narrow or small,comparing to others.

Based on this result, rockfill properties should be monitored with extra care to evaluated for further study in maintenance program or new rockfill dam in Thailand.

13. Recommendations

The analysis is counted for how much possible range of uncertainty of each properties in each zones are deviated from average value model. Thus the average value model will effect a level of differential value, the selected critical properties may change along with selected average value. Results will depending on quality of used statistic data, that may not be written.

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