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Performance of Concrete Gravity Dams with Height 50m and 75m based on Incremental Dynamic Analysis

Performance of Concrete Gravity Dams with Height 50m and 75m based on Incremental Dynamic Analysis

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***Abstract*.** This paper discusses the performance of concrete gravity dam with a height of 50m and 75m is studied by using the incremental dynamic analysis (IDA). The IDA curves were develop based on seven ground motions which fulfil the criteria of i) the distance of near field is less than 15km, (ii) the earthquake magnitude is greater than 5.5 and (iii) the PGA is equal to or greater than 0.15g. Seven of ground motions were converted to response spectrum and scaled according to the characteristic of the soil type for development of elastic response spectrum. Referring to Eurocode 8, elastic response spectrum was developed based on soil type B. By using IDA method, the limit states of the dam which are yielding and ultimate state are identified based on the cracking schemes. The displacement of yielding state for 50m height of dam is 14.60mm and 23.18mm for 75m height of dam. Meanwhile, the ultimate state is 23.18mm and 52.05mm for 50m and 75m height of dam respectively. The results show a greater damage occurred on higher dam and allow us to study the performance of dam with various height under seismic loadings.

Keywords: Concrete gravity dam, Incremental Dynamic Analysis, Crest Displacement, Yielding State, Ultimate State

1. Introduction

Concrete dams are one of the heaviest structure in the world designed with a high safety factor to resist natural forces such as flooding and earthquakes. However, failure of the structure compost of a substantial threat to the public including human lives and economic consequences. The design and evaluation of these systems for seismic hazards is increasingly conducted using time history analyses given the need for the accurate prediction of the performance level of the existing dam inventory as well as the new systems[1]. The earthquake was the strongest disaster to affect Malaysia since 1976. After more than 30 years, a deadly earthquake struck Ranau, Sabah, Malaysia with a moment magnitude of 6.0 on 5 June 2015[2] with its epicenter approximately 15 km that lasted for 30 seconds. A total of 104 aftershocks have been recorded, with almost all of them felt in Ranau district. The devastating earthquake, which struck at 7.15am on that fateful Friday and surpassed the 5.8 tremblor recorded in Lahad Datu in 1976[3].

For evaluation and design, the ground motion selection is a vital part of the process. In IDA, a series of earthquake records with increasing intensity is applied to the structure, leading the structure to its severer limit-states[4]. With the aid of a computer, it is possible to perform time-consuming analysis method such as Incremental dynamic analysis (IDA) by applying a series of earthquake records to a structure at successively increasing intensity levels, which causes the structure to shift from the elastic state into the inelastic state and finally into collapse. In this way, the limit-states and capacity of a structure can be determined.

2. Methodology

The development of damage on 50m height and 75m height of dam will be studied by performing an incremental dynamic analysis (IDA). This study utilises the 2D Planar in ABAQUS software to model two different height of dams with the height of 50m and 75m. The material properties of concrete gravity dam are assumed to be representative of the concrete material in the Koyna Dam adopted from Abaqus Example Problems Manual[5]. The dam is subjected to gravity loading due to its self-weight, hydrostatic pressure on the upstream wall and earthquake loadings at the base.

Total seven number of ground motions were selected and summarised in Table 1. The motions were obtained from Pacific Earthquake Engineering Research (PEER) strong motion database[6] which were recorded on rock or stiff soil (type B of USGS). The motion data must fulfil the criteria such as the near field distance, R is less than 15 km from earthquake source with the magnitude greater than 5.5 and Peak Ground Acceleration (PGA) is equal to or greater than 0.15g. This is to allow the effect of different characteristics of ground motions could be investigated at different scaled levels.

Table 1: Summary parameters of selected ground motion

Earthquake Event	R(km)	Magnitude (M)	PGA-H (g)	PGA-V(g)
1. Kobe Japan, 1/16/1995	11.34	6.9	0.276	0.342
2. Friuli Italy-01, 5/6/1976	14.97	6.5	0.357	0.277
3. Loma Prieta, 10/18/1989	7.58	6.93	0.514	0.396
4. Imperial Valley-06, 10/15/1979	8.54	6.53	0.163	0.153
5. Parkfield-02 CA, 9/28/2004	10.33	6.0	0.341	0.170
6. Bam Iran, 12/26/2003	0.05	6.6	0.808	0.970
7. Niigata Japan, 10/23/2004	10.21	6.63	0.862	0.573

In order to develop an IDA curve, scaling of ground motions intensity measure (IM) and damage measure (DM) are required. Based on the ground motions, increasing of scale factor with peak ground acceleration, PGA(g) as Intensity Measure(IM) is used for this study. The maximum crest displacement(mm) as Damage Measure(DM) is considered and the limit states of the dam can be identified. The method of scaling utilized the spectrum acceleration at fundamental period of the structure. Firstly, the natural frequency of the dam is obtained via the analysis in ABAQUS and then the fundamental period, T_1 can be calculated by $\frac{1}{f}$. The fundamental period is used to for the scaling of response spectrum referred to Eurocode 8[7] and Draft Malaysia Standard[8] (Vertical component for Sabah region) along with the ground motions. By using SeismoSignal software, time history of the seven ground motions were converted to acceleration response spectrum. The acceleration ranging from 0.10g to 1.10g with increments of 0.20g per interval is considered. The acceleration response spectrum of each ground motion is scaled to the same pseudo-spectrum acceleration at the fundamental period of the structure, T_1 as shown in Figure 1. The dam is subjected to a set of ground motion which are scaled to multiple levels of intensity until the structure failed[9]. The crack patterns can be identified with the tensile damage measured using the variable DAMAGET available in ABAQUS.

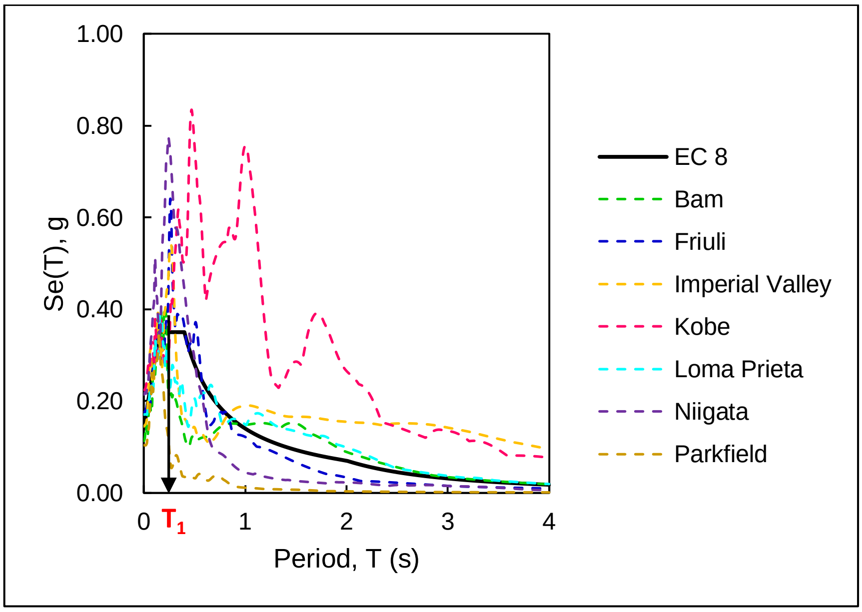


Figure 1: Scaling of ground motions to the same spectrum acceleration at T_1

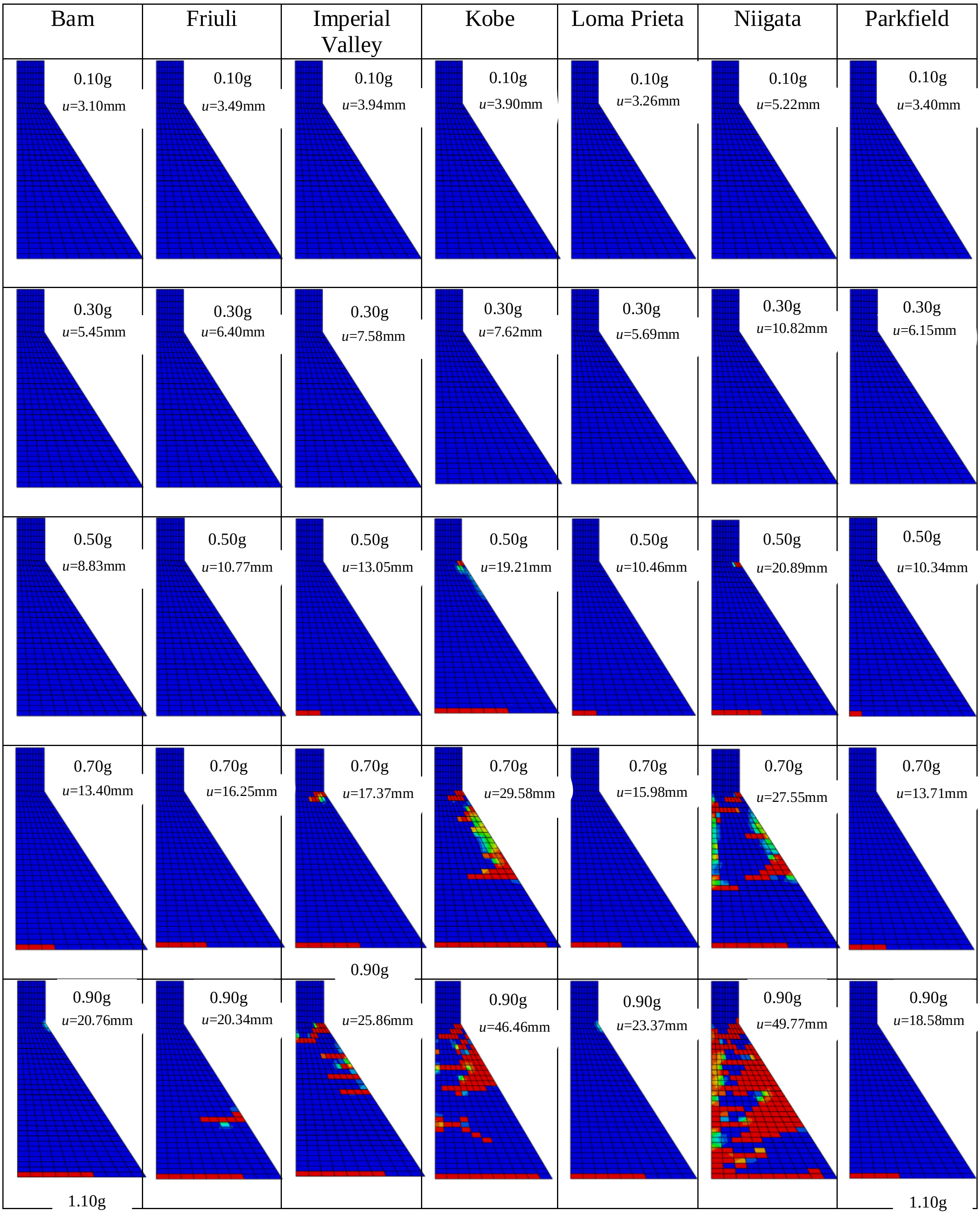
3. Result and Discussion

A total number of 84 number of analyses were conducted and cracking schemes for both 50m and 75m height of dams were recorded. The IDA curve was developed based on the analysis data with PGA(g) as Intensity Measure (IM) and maximum crest displacement as Damage Measure(DM). Figure 2 and Figure 3 presented the damaged cracking schemes of both 50m and 75m height of dam based on the seven ground motions together with the maximum crest displacement.

Based on the cracking schemes, the point where the dam starts to crack is the yielding state and the ultimate state is the point where the crack lines reach half of the width dam. The average maximum displacement for yielding and ultimate with respect to the seven ground motions are recorded and summarised in Table 2. The points of yielding and ultimate for 50m and 75m height of dam are plotted in IDA curve shown in Figure 4 and Figure 5.

Table 2: Average displacement for yielding and ultimate state of both dams

Ground Motions	50m Height of Dam		75m Height of Dam	
	Yielding	Ultimate	Yielding	Ultimate
	Displacement(mm)		Displacement(mm)	
Bam	13.40	20.76	21.63	57.01
Friuli	16.25	20.34	29.70	51.67
Imperial Valley	13.05	17.37	29.19	39.08
Kobe	19.21	29.58	31.73	75.62
Loma Prieta	10.46	23.37	28.03	42.11
Niigata	20.89	27.55	23.89	39.76
Parkfield	10.34	23.32	39.98	59.08
Average	14.80	23.18	29.16	52.05


Bam
Friuli
Imperial Valley
Kobe
Loma Prieta
Niigata
Parkfield
0.10g
u=3.10mm
0.10g
u=3.49mm
0.10g
u=3.94mm
0.10g
u=3.90mm
0.10g
u=3.26mm
0.10g
u=5.22mm
0.10g
u=3.40mm
0.30g
u=5.45mm
0.30g
u=6.40mm
0.30g
u=7.58mm
0.30g
u=7.62mm
0.30g
u=5.69mm
0.30g
u=10.82mm
0.30g
u=6.15mm
0.50g
u=8.83mm
0.50g
u=10.77mm
0.50g
u=13.05mm
0.50g
u=19.21mm
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u=20.34mm
0.90g
u=25.86mm
0.90g
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u=49.77mm
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1.10g
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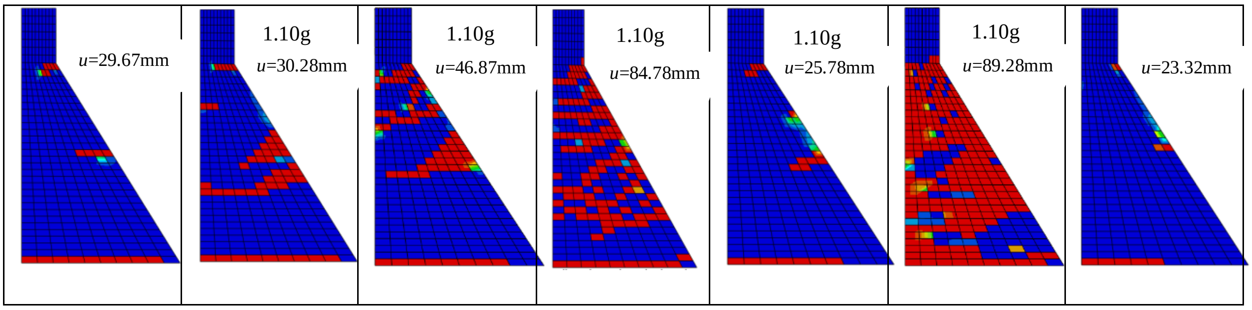
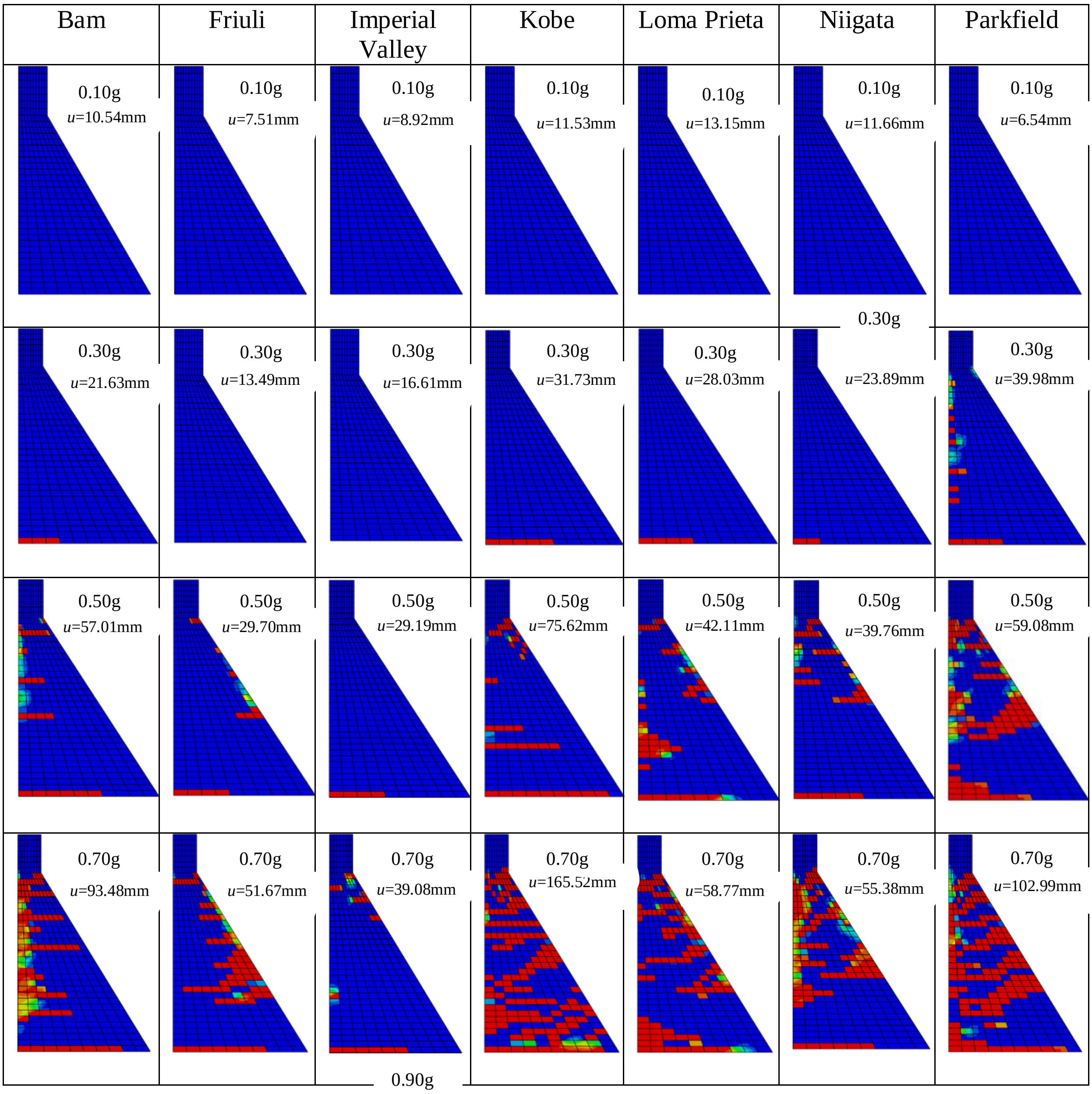


Figure 2: Cracking Patterns and Maximum Crest Displacement from IDA for 50m Height of Dam



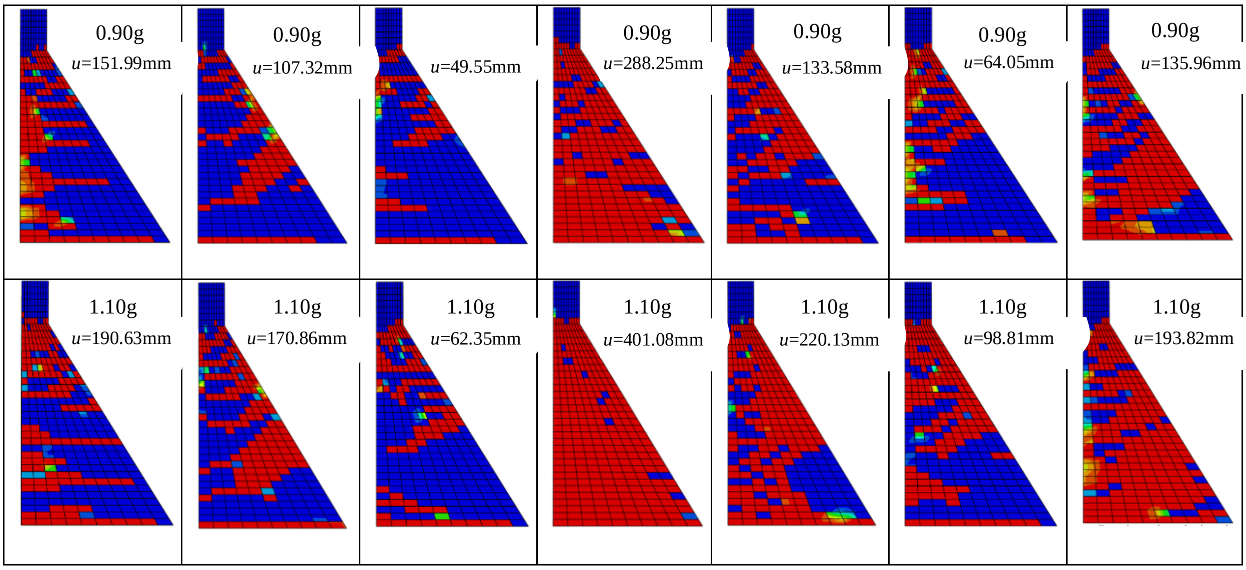


Figure 3: Cracking Patterns and Maximum Crest Displacement from IDA for 75m Height of Dam

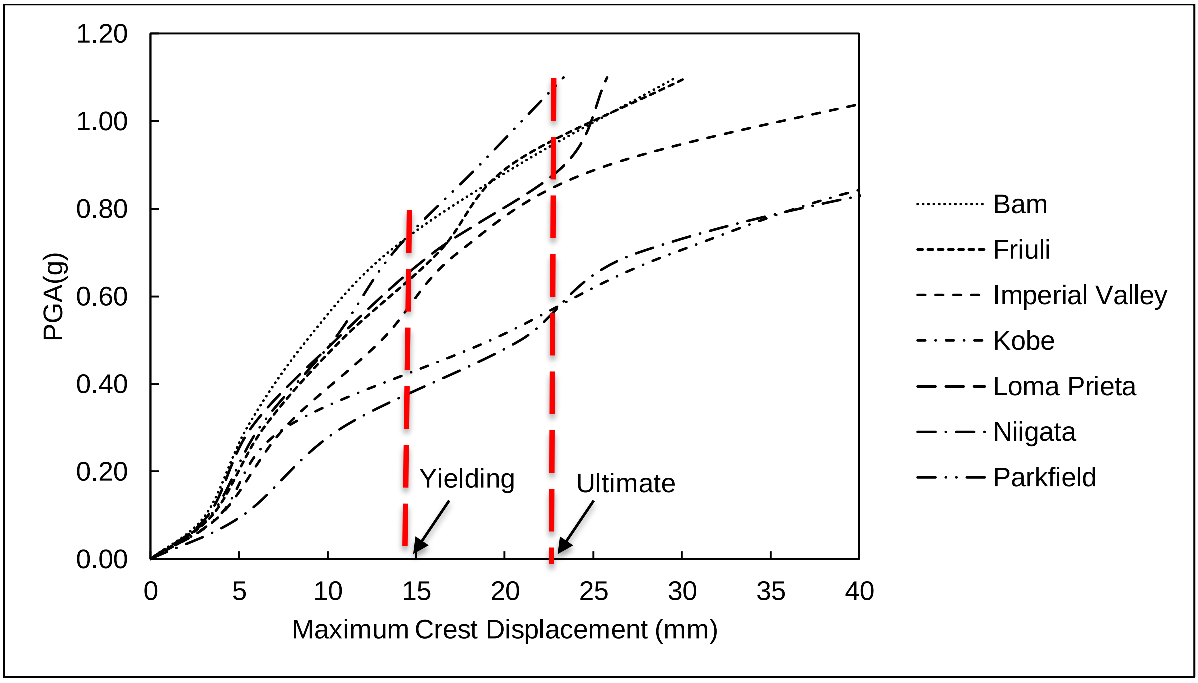


Figure 4: IDA Curves for 50m Height of Dam

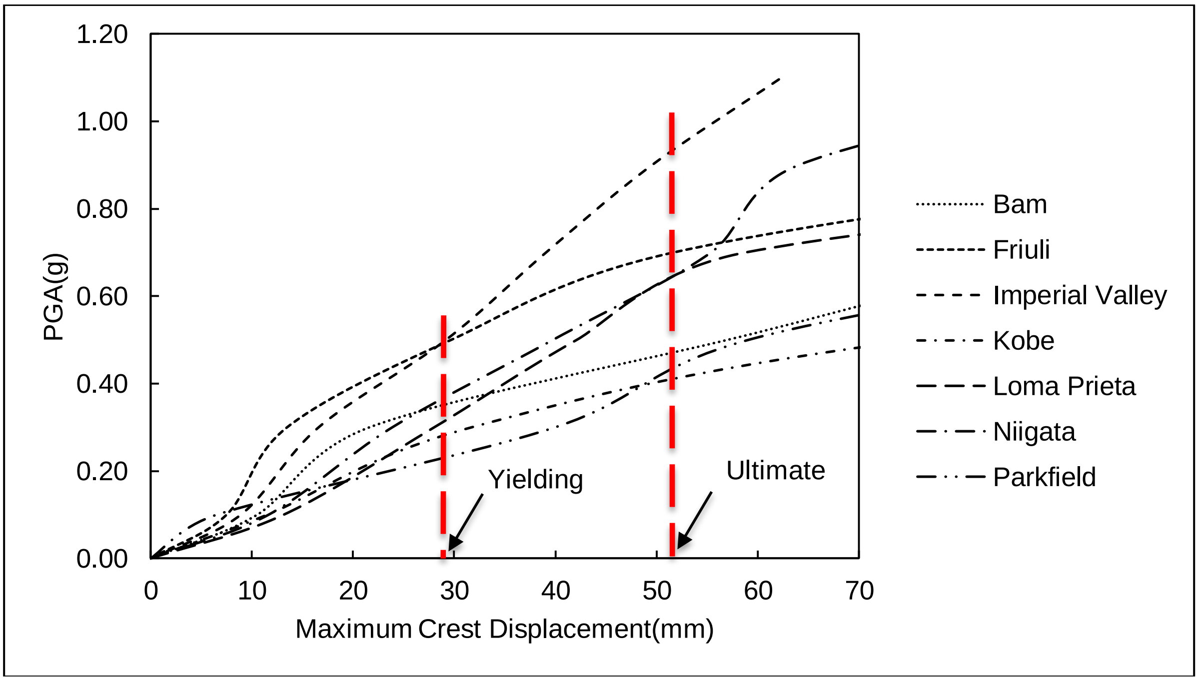


Figure 5: IDA Curves for 75m Height of Dam

4. Conclusion

In incremental dynamic analysis (IDA), the structure is subjected to a set of ground motions which are scaled to multiple levels of intensity so that the relationship between the damage and intensity measures is obtained. Based on IDA, the displacement of yielding state for 50m and 75m height of dams is 14.60mm and 29.16mm respectively. The displacement of ultimate state for 50m height of dam is 23.18mm and 52.05mm for 75m height of dam. The displacement and damage occurred are bigger on dam with greater height. For 50m dam, the crack started at the heel of the dam whereas for 75m dam, the crack is more significant at the neck of the dam. For IDA method, the ultimate state is more difficult to be identified as the maximum crest displacement in IDA curve follows the equal displacement rule. Further study needs to be carried out based on Static Pushover Analysis (SPO) to identify the accurate limit state of a concrete gravity dam.

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