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The Effect of Site Classification on Incremental Dynamic Analysis for RC Buildings without Seismic Provision in Penang

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Abstract Malaysia has been long term subjected to far field from neighboring country and local earthquake although it is not located in the active fault region. Local soil condition or site classification may play a major role in the soil dynamic characteristic correspond to the tremors. This study is to evaluate the effect of site classification on seismic response to the non-seismic design existing RC buildings in Penang. Five types of moment resistance RC building with 3, 8, 12, 16 and 20 storey are evaluated by using Incremental Dynamic Analysis (IDA). IDA result show that the non-seismic designed RC frames behaved low ductility and collapse at relatively lower IDR_{max} which between the performance level of Immediate Occupancy, IO (1%) and Life Safety, LS (2%). 20 storey buildings give the highest IDR_{max} followed by 8 storey buildings for every type of site classification. This phenomenon is more obvious in harder soil (Class B) and the effect reduces in softer soil condition by observing the slope reduction of the IDR_{max} vs T_1 curves.

Keywords Site classification, Incremental dynamic analysis, Maximum interstorey drift ratio

1. Introduction

Dynamic soil properties provide important information on the dynamic response of the soil structure needed for the dynamic structural analysis of superstructures. Local site classification always plays a major role in the seismic soil amplification of a site, a critical factor affecting the level of ground shaking [1]. Although Malaysia is not located close to the seismic prone area with active fault, buildings erected on soft soils often exposed to the far-field earthquakes generated from along Sumatran fault and subduction zones, particularly in areas on the west coast of Peninsular Malaysia, such as in Penang, Johor Bharu, and Kuala Lumpur [2, 3].

In the past 30 years, over 40 earthquakes originating from the Sumatra fault and subduction zone have been recorded in Penang, two of which are among the greatest earthquakes in the world [4]. Table 1 summarises the most recent significant earthquake events (MMI ≥ IV) that have been felt in Penang and have caused panic to the local citizens. Malaysian Meteorological Department has recorded that a series of local earthquakes (intra-plate fault) in Peninsular Malaysia and Sabah in the past 5 years as shown in Table 2.

Malaysia has been long term subjected to far field and local earthquake, this have been raised questions on the structural stability and the integrity of the existing building which is not designed seismically in Malaysia in tackling of the far field earthquakes effect from Sumatra and local earthquakes. The vulnerability of these non-seismic BS designed buildings either a distance earthquake originated from at Sumatra or local source may also increase due the low performance of its joint ductility. This study is to evaluate the effect of site classification on seismic response to the existing reinforced concrete (RC) buildings in Penang.

2. Consideration of Site Classification in Structural Analysis

2.1. Models

Five types of RC building with storey height of 3, 8, 12, 16 and 20-storey were selected for the analysis in this study. The selections of these buildings are intended to consider the low, medium and the high-rise buildings in order to cover the wider range of building's fundamental period from 0.2 s to 1.4 s in the analysis. The selected frame which has 2 bays framing and 3.0 m storey height was structurally designed by using EsteemPlus software. British Standard 8110 [5] was adopted as the design code since the aim of the study is to evaluate the seismic resistance for the non-seismic designed RC buildings in Malaysia. The design parameters for the RC building are tabulated in Table 3.

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Table 1. Recent earthquakes (MMI ≥ IV) from the Sumatran fault and subduction zone experienced by Penang (Malaysian Meteorological Department)

No.	Earthquake location	Date	Epicenter Coordinate (^{0})	Focal depth (km)	Magnitude	Distance to Penang (km)
1	Northern Sumatera	17 July 2013	5.4, 98.0	40	5.5 (M_w)	250
2	Southern Sumatera	30 Sept 2009	-0.9, 99.7	91	7.6 (M_s)	680
3	Mentawai Trough	12 Sept 2007	-4.4, 101.1	50	6.9 (m_b)	1075
4	Mentawai Strait	14 May 2005	0.8, 98.2	63	6.7 (m_b)	550
5	Nias	28 Mar 2005	2.0, 97.3	47	8.7 (M_w)	490
6	Aceh	26 Dec 2004	3.2, 95.9	30	9.3 (M_w)	540

Table 2. Recent local earthquakes in Malaysia (Mb ≥ 3.8) (Malaysian Meteorological Department)

No.	Location	Date	Epicenter Coordinate (°)	Magnitude (M_b)
1	Baling	20 Aug 2013	5.6, 100.9	3.8
2	Tasik Temenggor	20 Aug 2013	5.4, 101.4	4.1
3	Kudat	23 July 2013	6.8, 117.8	4.2
4	Kunak	29 May 2012	4.6, 118.3	4.4
5	Lahat Datu	21 Aug 2010	5.4, 118.4	4.2
6	Bukit Tinggi	07 Oct 2009	3.4, 101.8	4.2

Table 3. Design parameter of RC frames

Design Parameter	Description
Code of Practice for RC	BS8110
Concrete grade for slab, beam and column	30 N/mm^2
Concrete grade for foundation	35 N/mm^2
Characteristic strength for main reinforcement	460 N/mm^2
Characteristic strength for stirrup and link	250 N/mm^2
Statutory live load	2.0 kN/m^2
Superimposed dead load as floor finishes	1.0 kN/m

Table 4. Expression for spring stiffness and their corresponding embedment factor for pile cap [6]

Mode	Stiffness Coefficient	Embedment factor
Horizontal	$K_x = \frac{GB}{2-v}[1.2+3.4\left(\frac{L}{B}\right)^{0.65}]$	$\beta_x = \left(1+0.21\sqrt{\frac{D}{B}}\right).[1+0.16(\frac{hd(B+L)}{BL^2})^{0.4}]$
Vertical	$K_z = \frac{GB}{1-v}[0.8+1.55\left(\frac{L}{B}\right)^{0.75}]$	$\beta_z = \left(1+\frac{D}{21B}\left(2+2.6\frac{B}{L}\right)\right).[1+0.32(\frac{d(B+L)}{BL})^{0.67}]$
Rotational	$K_\theta = \frac{GB^3}{1-v}[0.+0.47\left(\frac{L}{B}\right)^{2.4}]$	$\beta_\theta = 1+1.4(\frac{d}{L})^{0.6}\ [1.5+3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}]$

Note: G is the effective shear modulus; v is poisson's ratio; L is the length of the pile cap; B is the width of the pile cap; d is thickness of the pile cap; D is the embedment depth of the pile cap.

2.2. Soil-Structure Presentation

Pile foundations are considered since the buildings in this study consist of low, medium and high-rise buildings. According to Fema356 [6], the footing uncouple spring model shall be represented by a various spring stiffness in difference axes. The pile cap spring stiffness was expressed in the horizontal, vertical and rotational springs since the two dimensional frame were considered. The embedment of the pile caps are represented by the spring stiffness which is multiplied by the embedment factor according as shown in Table 4. The vertical axial spring stiffness, k_{sv} and rotational spring stiffness, k_{sr} of the pile group are shown in Table 5.

Table 5. Expression for spring stiffness of pile group [6]

Mode	Stiffness Coefficient
Axial spring stiffness	$K_{sv} = \sum_{n=1}^{N} \frac{AE}{L}$
Rocking spring stiffness	$K_{sr} = \sum_{n=1}^{N} k_{vn} S_n^{\ 2}$

Note: A is cross-section area of a pile; E is modulus of elasticity of piles; L is length of piles; N is number of pile in group; k_{vn} is axial stiffness of *n*th pile; S_n is distance between *n*th pile and axis of rotation.

3. Incremental Dynamic Analysis

Incremental dynamic analysis (IDA) involves implementing a series of nonlinear time history analyses to a structure for multiple ground motion records by scaling every record to several levels of intensity to discover the full range of the structure's behaviour from elastic to yielding, nonlinear inelastic and eventually leading to global instability [7]. To comply with the minimum requirement of the codes, seven ground motions were used for the nonlinear time history analysis as tabulated in Table 6. Tan el al. [4] had concluded that the site classification of Penang consists of Soil Type B (V_s = 360 - 800 m/s), C (V_s = 180 - 360 m/s) and D (V_s < 180 m/s) as defined in Eurocode 8 [8], hence only ground motion records with these three soil types were selected. Moreover, far field ground motion records were selected due to the studied area only subjected to far field earthquakes. IDA carried out have covered (i) five types of fundamental period of moment resistance frame (MRF); (ii) four types of foundations (three flexible and one fixed); (iii) seven ground motions; (iv) fourteen types peak ground accelerations by using SAP2000. Total numbers of 1960 nonlinear time history analyses have been carried out in the IDA.

3.1. The Effect of the Site Classification on IDA

Figure 1 shows the IDA curves for 3, 8, 12, 16 and 20 storey buildings. Noted that the parameter of peak ground acceleration (PGA) was used as the intensity of seismic action in the IDA instead of the first mode spectral acceleration, Sa(T_1) because of PGA is more familiar and applicable to the academic and industry sectors in Malaysia. The results indicated that the increase of the building storey height and lower soil hardness had reduced the stiffness of the IDA curves. IDA curves show that buildings in Class D site have comparable much higher maximum interstorey drift ratios, IDR_{max} for the same PGA than other sites.

The typical performance levels and the associated damages state according to FEMA indicated that the concrete frame is expected to collapse at 3% to 4 % of the drift. However, all IDA curves found the non-seismic designed RC frames behaved low ductility and collapse at relatively lower IDR_{max} which between the performance level of Immediate Occupancy, IO (1%) and Life Safety, LS (2%). The discrepancy of this result can be explained by the finding of the Ghobarah [9]. He concluded that the drift limits in current available codes are found not suitable for the structures which designed without seismic detailing as in this study. The MRF of this structure behave in a non-ductile manner and often suffer in brittle failure modes due to poor confinement of lap splices, lack of shear reinforcement in the beam-column joint and inadequate embedment. More importantly, he had established the drift ratio limits associated with damage levels for various types of structures as shown in Table 7. His result concluded that the collapse of non-ductile MRF structures would happen at more than 1.0% IDR which fully support the finding of the current study.

3.2. IDR_{max} with Respective to Storey Height RC Buildings

IDR_{max} versus building fundamental period (T_1) with respect to various site classification and PGA are plotted as shown in Figure 2. The T_1 for 3, 8, 12, 16 and 20 storeys are 0.236 s, 0.567 s, 0.824 s, 1.071 s and 1.333 s, respectively. It noted that the maximum PGA plotted in these graphs are up to 0.7 g, 0.4 g and 0.125 g for Class B, Class C and Class D, respectively. The results show that the 20 storey buildings give the highest IDR_{max} followed by 8 storey buildings for every type of site classification. This phenomenon is more clearly observed in harder soil (Class B) and the effect reduces as the soil become soft by observing the slope reduction of the curves.

Table 6. Selected far-field ground motion records for nonlinear time history analysis (PEER)

No.	Earthquake	Year	Magnitude (M_w)	PGA (g)	Depth (km)	V_{s30} (m/s)	Time step size (s)	No. of time step
1	Morgan Hill	1984	6.2	0.067	8.5	158.80	0.005	5665
2	Hector Mine	1999	7.1	0.194	5.0	271.40	0.02	3000
3	Whittier Narrows	1987	6.0	0.038	14.6	332.80	0.02	1834
4	Landers	1992	7.3	0.119	7.0	370.80	0.02	2000
5	Northridge	1994	6.7	0.153	17.5	405.20	0.01	2999
6	Northridge Aftershock	1994	5.5	0.044	6.0	508.10	0.02	1000
7	N. Palm Springs	1986	6.1	0.099	11.0	684.90	0.005	4077

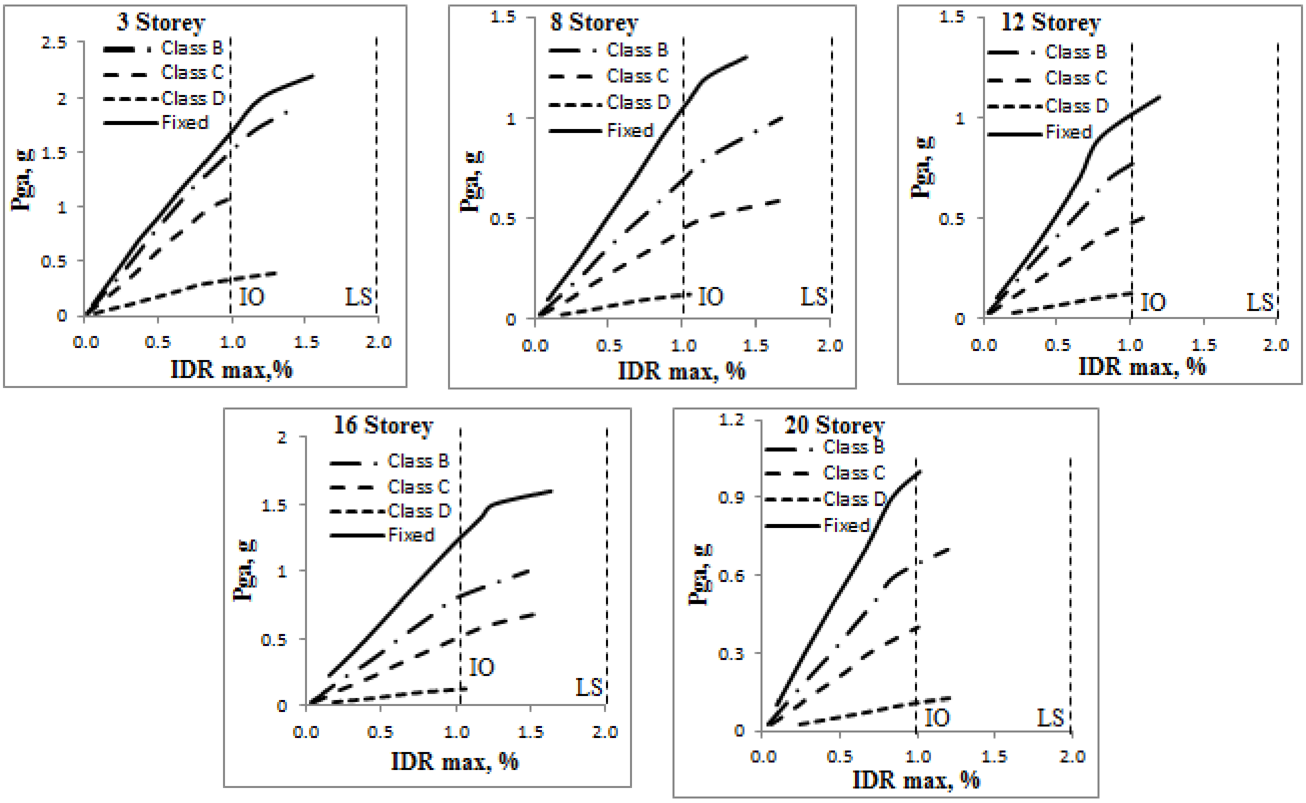

Figure 1. IDA curves for 3, 8, 12, 16 and 20 storey buildings

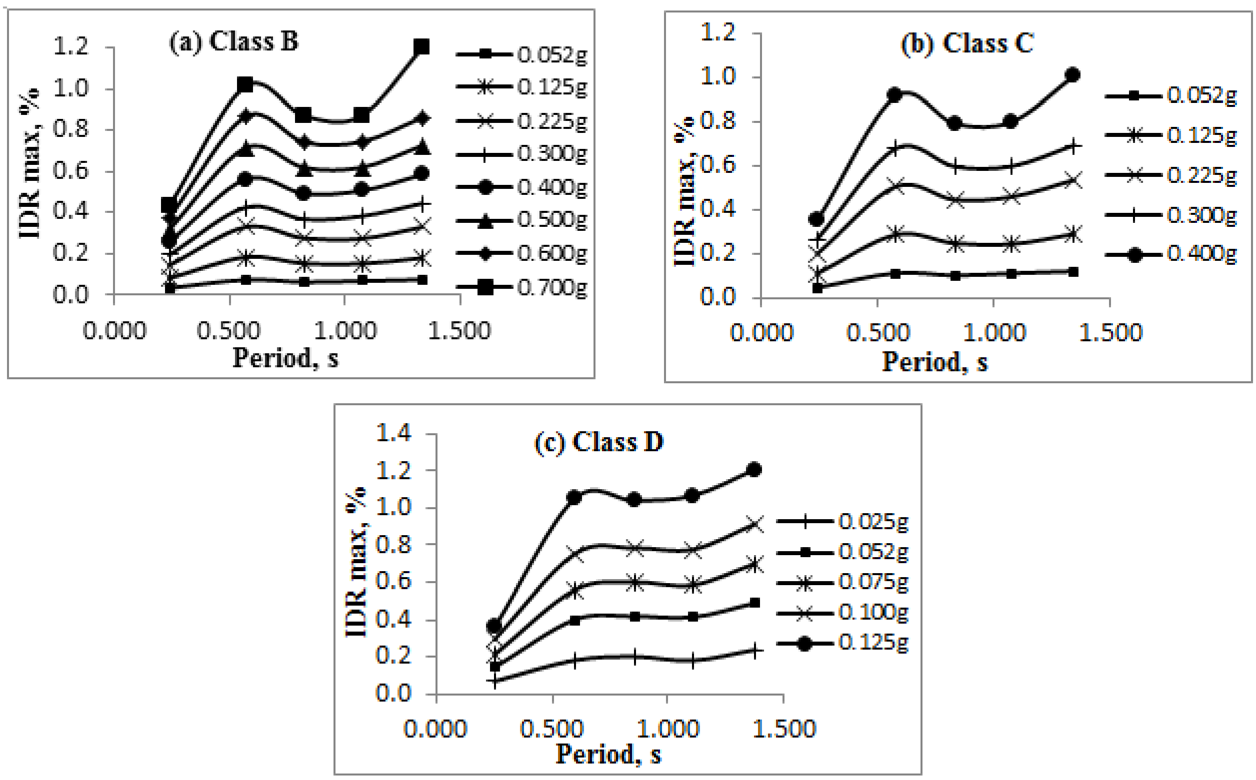

Figure 2. The IDR_{max} plot with respect to T_1 of the buildings for (a) Class B, (b) Class C and (c) Class D

Table 7. IDR_{max} associated with various damage level [%] [9]

State of Damage	Ductile MRF	**Non-ductile MRF**	MRF with Infills	Ductile Walls	Squat Walls
No Damage	< 0.2	**< 0.1**	< 0.1	< 0.2	< 0.1
Repairable Damage	< 1.0	**< 0.5**	< 0.4	< 0.8	< 0.4
Irreparable Damage	> 1.0	**> 0.5**	> 0.4	> 0.8	> 0.4
Severe Damage	1.8	**0.8**	0.7	1.5	0.7
Collapse	> 3. 0	**> 1.0**	> 0.8	> 2.5	> 0.8

4. Conclusions

Total numbers of 1960 nonlinear time history analyses have been carried out to produce the IDA curves for 3, 8, 12, 16 and 20 storey non-seismic designed RC buildings. IDA curves found the non-seismic designed RC frames behaved low ductility and collapse at relatively lower IDR_{max} which between the performance level of Immediate Occupancy (1%) and Life Safety, LS (2%). This may due to the non-seismic resistance RC structure behave in a non-ductile manner and often suffer in brittle failure modes due to poor confinement of lap splices, lack of shear reinforcement in the beam-column joint and inadequate embedment. IDA results shows that the 20 storey buildings (T_1 = 1.33 s) give the highest IDR_{max} followed by 8 storey buildings (T_1 = 0.57 s) for every type of site classification.

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