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**Research Paper**

# 2-Dimensional Finite Element Analysis of Reinforced Concrete Buildings Subjected to Seismic Load

Ismail. R[1], Shamsudin. N[1], Arshad. M.F[1], Ibrahim. A[1], Rusop. M[2], Adnan. A[3]
*[1]School of Civil Engineering, College of Engineering,*
*Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.*
*[2]NANO-SciTech Centre, Institute of Science,*
*Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.*
*[3]School of Civil Engineering, Faculty of Engineering,*
*Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.*
*Corresponding Author: rozaina4076@uitm.edu.my*

**ABSTRACT:** There are several methods to predict buildings' damage index using traditional non-destructive evaluation method, such as visual inspection and instrument evaluation method. However, these types of method are complex for large structures since it is difficult to assess some parts of them. The evaluation of damage index in Malaysia is limited especially when the building subjected to earthquake loading. Due to increased number of earthquake incidents in Malaysia, the development of damage detection method therefore become much more challenging. This paper presents the prediction of damage index of building using RUAUMOKO 2D program. The RUAUMOKO 2D program presents Park and Ang damage model to predict damage index of buildings. The study of the damage state of building on the reinforced concrete (RC) frame which subjected to four ground motions was conducted. The time history analysis method was applied using Acheh earthquake recorded at Ipoh, Malaysia which occurred on December 26, 2004 at Indian Ocean with magnitude 9.3 on Richter scale and the analyses were carried out using four intensities of seismic load; 0.05g, 0.10g, 0.15g, and 0.20g, respectively. The performance of the structure is shown by the damage index recorded from RUAUMOKO 2D analysis. Seismic performance of the RC frame structures indicates that high-rise buildings are much affected than low-rise when exposed to the ground acceleration up to 0.15g.

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## I. INTRODUCTION

Most people perceive that Malaysia is free from life-threatening seismic crisis. In reality, seismic hazards in Malaysia are irrefutable, with seismic hazard originating from seismically active neighboring countries such as Indonesia and Philippines. Even though the occurrence of earthquake in Malaysia is not disastrous, hence, incorporating to the shaking of ground which will cause severe damage on the structures [1]. Now, Malaysia exposed to near-field earthquake and long-distance earthquake from Sumatera [2]. The epicenter of the earthquake is focused on east Cost of Sabah with shallow depth less than 70 km. A faultiness in Sabah such as Lahad Datu faults, Mensabah faults, and Crocker faults could cause local earthquake events in Sabah and attribute to movements along these fault zones. Thus, these earthquakes could cause damage to buildings which were previously designed to cater for gravity load only under BS8110 which only considered the vertical loading and not the lateral load that comes from the earthquake loading. Having been affected by both local and distant ground motions, Malaysia has come to realize that seismic hazard in the country is real and may threaten the public safety and cause damage to the properties. On top of that, the concern of less than one percent of the buildings in Malaysia are seismic resistant which can easily cause them damage when earthquake occurs [3].

Impact of earthquakes is one of the major concerns of scientists and engineers for a long time. Many studies have been made to mitigate the seismic responses of structures due to seismic loads [4-21].

Due to the increased number of incidents involved earthquakes, it has become increasingly important to develop efficient methods of seismic structural evaluation. This research is significant as its outcomes contribute towards the safe and efficient performance of buildings and result in reducing loss of lives and property when subjected to long term deterioration of earthquake loads [24]. Earthquake loadings differ from other loads because of high deformations and stresses conducted under earthquake effect [25]. Therefore, structural design should achieve high probability of survival under earthquake loads. The seismic hazard mitigation was necessary for existing buildings that were designed only according to gravity loads. Moreover, the use of earlier codes in conducting the design analysis for existing buildings need to be analyze further to avoid mishap in the future [26].

In Malaysia, the evaluation of building damage index is very limited especially related to seismic loading due to the complexity of evaluation method such as visual inspection and instrument evaluation method. The instrument evaluation methods contained experimental approaches such as stress waves, ultrasonic waves, and X-ray which only practical when the parts of the structure are accessible [26]. Therefore, these types of methods are complex to be used at large structures as they are incapable to produce quantitative damage indexes, hence, the Park-Ang model from RUAUMOKO 2D program implemented to generate the quantitative damage indexes without a thorough structural analysis.

Driven by the demands for an optimal prediction of existed buildings due to seismic effect, this research has a direct impact to predict earthquake risk of the existed framed buildings where the potential structural deficiencies are determined by analyzing the damage index. Damage detection and prediction of civil structures is important to ensure the safety and for the maintenance of these structures [27]. To analyze the seismic performance of the buildings, a seismic damage prediction study was carried out by choosing a single main frame from each building for the modeling in the finite element analysis. The buildings chosen are located in Peninsular Malaysia where three of them from central region; Selangor and one of them from southern region; Negeri Sembilan. The objective of the paper is to determine and evaluate the degree of damage of buildings when subjected to predicted seismic loading using RUAUMOKO 2D program.

## II. CURRENT PRACTICE IN MALAYSIA

Most structural damage assessment is carried out through visual inspection. This provides a global picture of the structure, with the limitation that no information is available between inspections. In conventional method, structure condition will be evaluated visually using a standard inspection form. Damage ratings will be assigned by the inspector according to their engineering judgement, experience, and state of emotion. As a result, there is significant variability in the condition state assignment and in some cases, the ratings are not applied correctly to the element. Inspection reports on site are made in a form-basis then back to the office, data will be installed in a database manually. This is not only involved double work that will reduce the

productivity, but also lead to the possibilities of misplacing the document before information is properly stored. It has been reported that few inspection details, repairs, and replacement conducted on various parts of some structures are unrecorded. This may result in an erroneous prediction for future structure condition.

The adopted seismic inspection currently used in Malaysia is Rapid Screening Procedure (RSP) survey. There are two different sets of protocols or procedures for inspectors to rapidly evaluate the seismic risk of a particular building. The first method known as ATC 21 survey [28] which serve as a preliminary tool to assess the building's capability under seismic threats, judging barely on external appearance. After evaluation of ATC 21, the building that deemed unsatisfactory will then have to be undergo ATC 22 evaluation [29]. The evaluation is a checklist of structural integrity of the building. The non-structural implications will also be considered; hence, the assessment still produce qualitative evaluation based on score sheet.

## III. DAMAGE ANALYSIS

The time history responses of the reinforced concrete (RC) frames are evaluated by means of structural analysis software RUAUMOKO. RUAUMOKO 2D Program incorporates Park and Ang damage model [28]. Quantitative assessment of damage has been proved effective in controlling the earthquake-induced damage of structure and is feasible using damage models [30]. Park and Ang damage model is the most widely used in research communities. Accordingly, the performance levels of RC structural members are quantified by setting the individual limit value of damage index.

It is now generally accepted that the energy dissipated by structures during earthquakes influences the level of the structural damage. Experiments on structural members and structures indicate that the excessive deformation and hysteretic energy are both the most important factors contributing to seismic damage [30]. Hence, the damage models are defined as a combination of maximum displacement (ductility) and plastic energy of dissipations [31,32]. One of the best known and most widely used cumulative damage models is the Park and Ang model [27,31-34] as follows:

$$D_{PA} = \frac{\delta_m}{\delta_u} + \beta_{PA}\frac{\int dE}{F_y \delta_u}$$

where;
$\delta_m$ = maximum deformation,
$\delta_u$ = ultimate deformation under monotonic loading,
$F_y$ = yield strength,
$d_E$ = incremental absorbed hysteretic energy,
$\beta_{PA}$ = non-negative combination coefficient.

This model has been well accepted due to its simplicity and it has been calibrated against a significant amount of observed seismic damage. Table 1 shows the Park and Ang indices with various damage states of building model [27,31-34].

**Table 1 The relation between degree of damage, damage index and damage state [14,17-20].**

| Degree of damage | Physical appearance | Damage index | State of building |
|---|---|---|---|
| Slight | Sporadic occurrence of cracking | < 0.10 | No damage |
| Minor | Minor cracks | 0.10 – 0.25 | Minor damage |
| Moderate | Extensive large cracks | 0.25 – 0.40 | Repairable |
| Severe | Extensive crushing of concrete | 0.20 – 1.00 | Beyond repair |
| Collapse | Partial or total collapse | > 1.00 | Loss of building |

## IV. DESCRIPTION OF STRUCTURE AND MODELING

Two of the structures are considered to represent low-rise and high-rise reinforced concrete buildings for study. They consist of two typical beam-column RC frame buildings without shear walls, located in Peninsular Malaysia considering seismic loads where the input ground motion recorded was scaled to four different intensities and continually applied to the building RC frame to inflict increasing level of damage. All the structures are designed using BS8110 which did not consider lateral load that comes from earthquake ground motion. Table 2 shows the configuration of Building A and B that serve as an input to the RUAUMOKO 2D analysis.

**Table 2 Description of Structure**

| Category @ Storey | Frame Dimension | | Material properties | Element Dimension | |
|---|---|---|---|---|---|
| | Bay | Floor level | | | |
| High-Rise @ 10 | 3.2 m, 6.3 m | Ground floor: 3.5 m<br>$1^{st} – 9^{th}$ floor: 3.0 m<br>$10^{th}$ floor: 2.5 m | $E_c$ = 25000 N/mm$^2$<br>$E_s$ = 10400 N/mm$^2$<br>$f_y$ = 460 N/mm$^2$<br>$f_c$ = 30 N/mm$^2$<br>$f_{ys}$ = 300 N/mm$^2$<br>c = 25 mm | Beam (mm)<br>Ground and $9^{th}$: 230 x 600<br>$1^{st} – 8^{th}$ floor: 150 x 600<br>$10^{th}$ floor: 150 x 450 | Column (mm)<br>Ground floor: 300 x 750<br>$1^{st} – 6^{th}$ floor: 300 x 600<br>$7^{th} – 8^{th}$ floor: 300 x 450<br>$9^{th} –10^{th}$ floor: 230 x 230 |
| Low-Story @ 4 | 3@ 4.8 m | Ground floor: 3.2 m<br>$1^{st} – 3^{rd}$ floor: 3.0 m | | Beam (mm)<br>Ground floor: 200 x 400<br>Above $1^{st}$ floor: 150 x 450 | Column (mm)<br>Ground floor: 230 x 400<br>Above $1^{st}$ floor: 230 x 350 |

A two-dimensional model for structure is created in RUAUMOKO [4] to carry out nonlinear time-history analysis. The height of the buildings will play an important part in prediction of damage index as we know that high rise buildings will be likely affected to ground motion when earthquake incidents occurred. Beam and column elements are modelled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both ends of the beams and columns. On the beams, axial forces were assumed to be zero since all floors are assumed to be rigid in plan to account for diaphragm action of concrete slabs so that the nodes within each floor level deformed the same amount laterally. The contribution of floor slab to strength and stiffness are neglected and the columns were assumed to be fixed at the basement level. The value of damping coefficient for RC frame structure of 5% is used. The predicted structures may not be the same as the actual on-site observed performance after earthquake incidents since the model used in this study neglect foundation flexibility and other elements that contribute to the strength of structures such as shear wall.

## V. NON-LINEAR RESPONSE HISTORY ANALYSIS

In performing the non-linear response history analyses using RUAUMOKO 2D Program, the Acheh ground motion data was scaled to four levels of peak ground acceleration (PGA) value of 0.05g, 0.10g, 0.15g, and 0.20g, respectively. The Sumatra–Andaman (Acheh Earthquake) time history record is shown in Fig. 1 with 5000 number of outputs within 0.02-time steps with the maximum acceleration of 0.012g. The Acheh earthquake occurred in December 26, at Indian Ocean near to Acheh with magnitude 9.3 on the Richter scale. Table 3 shows the summarisation of seismic input data from Acheh earthquake. Table 4 shows the damage index and degree of damage for high-rise RC frame structures.

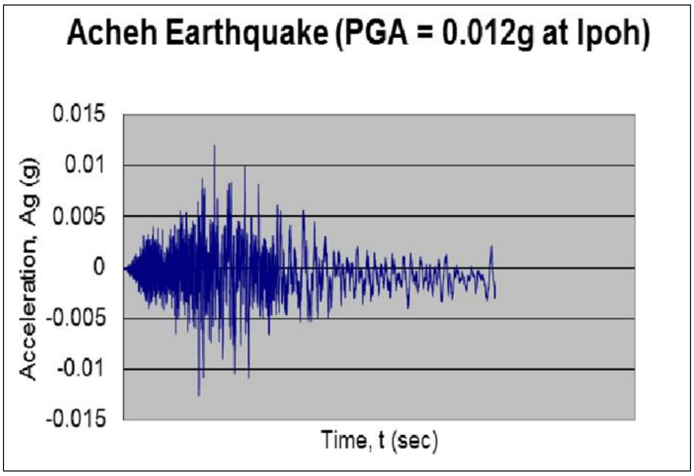


**Figura 1 Time History of Acheh Earthquake recorded at Ipoh, Malaysia**

**Table 2 Summarisation of seismic input data**

| **Seismic Sequence** | **Sumatra-Andaman (Acheh)** |
|---|---|
| Station | Ipoh, Malaysia |
| Date | 26th December 2014 |
| Magnitude (Richter Scale) | 9.3 |
| Recorded PGA (g) | 0.012 |
| Normalized PGA (g) | 0.05, 0.10, 0.15, 0.20 |

## VI. RESULT

The behavior of the examined RC frame structures which are subjected to four intensities, is investigated in this section. This study focuses on the damage index according to Park and Ang approach [27]. The tables show the cumulative damage on both RC frame structures. It is evident that, in any case seismic sequences lead to increased damage of the structures. The comparison of damage indices obtained from the analysis can be seen as the high-rise structure was more affected towards the seismic load.

The high-rise building was affected by earthquake load when the damage index shows that it will collapse under peak ground acceleration (PGA) of 0.15g and 0.20g. The first yielding point location happened at first floor beam for all cases of four intensities.

**Table 3 Damage index and degree of damage for high-rise RC frame structures**

| Intensity (g) | Plastic hinge location | Time (sec) | Overall Damage Index | Degree of damage |
|---|---|---|---|---|
| 0.05 | Beam | 6.71 | 0.043 | Slight |
| 0.10 | Beam | 6.02 | 0.127 | Minor |
| 0.15 | Beam | 4.22 | 1.000 | Collapse |
| 0.20 | Beam | 3.16 | 1.000 | Collapse |

**Table 4 Damage index and degree of damage for low-rise RC frame structures**

| Intensity (g) | Plastic hinge location | Time (sec) | Overall Damage Index | Degree of damage |
|---|---|---|---|---|
| 0.05 | Beam | 20.08 | 0.022 | Slight |
| 0.10 | Beam | 20.05 | 0.027 | Slight |
| 0.15 | Beam | 18.67 | 0.035 | Slight |
| 0.20 | Beam | 11.55 | 0.043 | Slight |

The low-rise building has a range of 0.022 to 0.043 damage indexes which are considered as slight damage occurred on the building. In general, there are no significant damage occurred to the low-rise RC frame structure.

## VII. CONCLUSION

This paper examines the damage state of building with the analysis of RC frames under time history ground motions which simulated into four variation of earthquake intensities; 0.05g, 0.10g, 0.15g, and 0.20g. Seismic performance of the RC frame structures indicates that the high-rise building is likely affected by earthquake ground motion while the low-rise building still can survive the effect of ground motion. Sequential ground motion possibly affected the high-rise building rather than low-rise building. The current practice of Malaysia which are essentially based on visual inspection in seismic evaluation should be reconsidered since multiple earthquakes phenomenon cannot be ignored.

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