Performance of Low and Medium-Rise Concrete Frames under Various Intensities Earthquake in Malaysia

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Abstract- This paper presents the vulnerability of public buildings in Malaysia subjected to earthquakes from Sumatra and Philippines. Tremors in Peninsular Malaysia and East Malaysia due to Sumatra and Philippine earthquakes have been reported several times. Engineers are concerned of the seismic vulnerability of public buildings due to lack of earthquake consideration in Malaysia's building design procedure. 21 reinforced concrete buildings which are mostly categorized as moment resisting frames has been selected for vulnerability study. A case study has been conducted on low rise with 6 (six) buildings and 15 numbers of medium rise building. The buildings are analyzed using Finite Element Modeling (FEM) under different types of analyses including Free Vibration Analysis (FVA), and Time History Analysis (THA) considering low to medium earthquake intensities. Different intensities of earthquake load, 0.01g up to 0.5g are applied to the structures to know the maximum allowable earthquake load intensities for the buildings. In the non-linear analysis of modal frames, it indicates that most of the buildings were categorised in the moderate damage level where there is no structural damage but some non-structural damage are expected. Most of the buildings were collapse with the intensity of 0.5g. The performances of the structure are shown by the yield point at beam-column connections where the internal forces at beam elements exceed the design capacity of the beams. The study indicates that the plastic hinge initially formed on the beam at the lower storey level for medium-rise of building frame. However for low rise building, it shows that the plastic hinge formed begun at low and higher storey level at beam.

Keywords: Building vulnerability, seismic demand, dynamic analysis, non-linear analysis

INTRODUCTION

In recent years, Malaysia is more aware of the seismic effect on their structures because of the tremors were repeatedly felt over the centuries from the earthquake events around Malaysia. Most bridges in Malaysia do not take earthquake loadings into structural design consideration. A case study conducted by Tan [11] on the behavior of high-rise building under seismic effect for Petronas Twin Tower (KLCC) used Finite Element Analysis. The studies on performance of high rise buildings in Malaysia with various intensity of earthquake using Finite Element Modeling have been conducted by Noor Aishah, [7] and Yew [12]. Therefore the assessment due to seismic is very important in order to recognize the performance of the buildings. A seismic risk analysis addressed to earthquake emergency management and protection strategies planning, requires vulnerability and damage evaluation performed at territorial scale [2]. IDARC-2D dynamic non-linear analysis software is used to analyse the structures with different intensities load to know the maximum allowable earthquake load intensity for the buildings.

Suradi [9] also adopted the performance base seismic engineering in her study. The intent of earthquake resistance design therefore has become one of attempting to limit the damage experience by a building to levels, which are considered acceptable by structural engineers. Historically, damage that would not result in loss of life was deemed acceptable for most structures [3]. Performance-based seismic engineering (PBSE) is defined as the procedure of design and construction of structures that will resist earthquakes in a predictable manner [3]. It is to make owners and designers capable of selecting alternative performance goals or objective for the design of different structures. Severe earthquakes are relatively frequent events, which may or may not ever occur within the life of a building.

IDARC2D involves the non linear analysis by using IDARC-2D. Barron[4] chose the IDARC 2D two-dimensional inelastic finite element analysis program for RC structure [5] to perform the nonlinear dynamic analysis and found that a flexible diaphragm model produces more frame displacement and interstorey drift than the rigid diaphragm model.

Suradi [9] study the comparison on the effect of earthquake and wind loads on the performance of reinforced concrete buildings by using IDARC2D to analyze the seven buildings due to dynamic non-linear analysis. Various earthquake ground accelerations (0.01g, 0.03g, 0.10g, 0.20g, and 0.50g) were used in earthquake Static Equivalent, Response Spectrum and Time History Analysis. The ground motions were scaled to 5% damped spectral acceleration at the fundamental frequency of the structure. Under the earthquake linear static analysis, the performances of the medium and high-rise reinforced concrete buildings were generally deemed satisfactory under 0.20g intensity earthquake level.

The performance level is a qualitative statement of damage. For it to be quantitatively defined, the performance level must be converted to the limiting values in the structural response parameter, which reflect the expected damage state. The ATC-13 damage level [10] was adopted by Alel [6] in defining of the damage state level by referring to Table 1

DYNAMIC NON-LINEAR ANALYSIS

The scopes of the study are to study the performance of buildings with less than 20 stories by using Finite Element Modeling for dynamic non-linear analysis (IDARC 2D) and to use a variation of low earthquake intensities (0.01g up to 0.50g) in the analysis with the ground motion scale of 5% damped spectral acceleration. The El-Centro time history data is shown in Figure 1. A single main frame was chosen from each building for the modeling in the finite element analysis.

Modeling Concept

Figure 2 shows the moment resisting frame of the Airport Labuan. The structural framing system is highly visible and the building is readily classified as concrete moment resisting frame can be seen in Figure 2. The building height is equal to 20.00 m which is categorised as a low-rise building (3 stories). The materials of properties are 2500N/mm^2 (Ec), 460N/mm^2 (fy), 27.6N/mm^2 (fc) and 25mm for cover (c). Loadings applied in the analysis was determined according to British Standard [1].

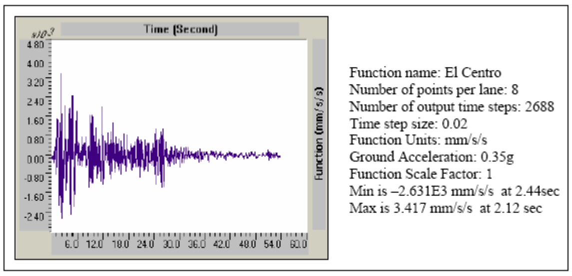

Figure 1: Time History Record of Imperial Valley Earthquake (May 18,1940 – El Centro)

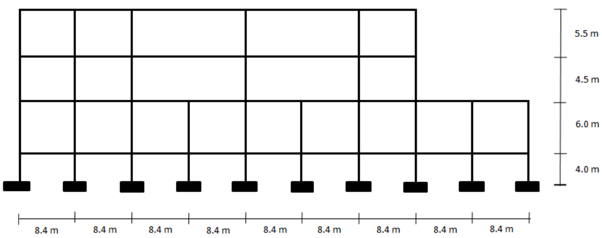

Figure 2: Moment Resistance Frame of Airport Labuan (AL)

SEAOC EQ Level	SEAOC Damage	ATC-13			
		None		=	0
Minor	Without any Damage	Slight		<	0.01
Moderate	No Structural damage, some non-structural damage	Light		≤	0.1
		Moderate		≤	0.3
Major	No collapse, some structural damage, non-structural damage considerable	Heavy		≤	0.6
		Major		<	1
Collapse	Collapse	Collapse		=	1

Table 1: SEAOC Damage Level

RESULT AND DISCUSSION

Damage Pattern due to Plastic Hinge

For moment resisting frame type of buildings, the plastic hinges due to structural local failures normally occur either at beam or column connection. Table 2 and Table 3 shows the summary of the first development of plastic hinges on the local structural element for each low and medium rise building. From the results, most of the buildings that developed plastic hinge due to the lowest earthquake intensity of 0.03g. The plastic hinge initially formed on the beam at lower storey level of most of buildings. Sekolah Kebangsaan Bombalai Tawau building frames were the earliest to experience first yielding on beam element at 2.505sec with the intensity of 0.5g.

Figure 3 show the damage state location and plastic hinge formation of Airport Labuan. From the resultant of dynamic nonlinear analysis under earthquake loads, the modal frame experienced cracking and yielding at the beam and column elements. The 'x' symbol denotes the crack formation for concrete and the 'o' symbol denotes the severe yield of plastic hinge formed.

Table 2: Summeraisation of first yielding point for low-rise buildings.

No.	Building name	Storey	Plastic hinge location	Floor level	Intensities (g)	Time, sec. (first yield)
1	Airport Labuan (AL)	3	COLUMN	0	0.03	4.175
2	Blok Makmal Kuala Terengganu (BMKT)	2	BEAM	2	0.5	3.445
3	Flat Kelas G Bintulu (FGB)	3	BEAM	1	0.5	2.985
4	Hospital Kuala Terengganu (HKT)	3	BEAM	1	0.5	3.390
5	Pejabat Jabatan Laut Bintulu (PJLB)	2	BEAM	1	0.5	3.515
6	Perpustakaan Negeri Kuching (PK)	2	BEAM	1	0.5	3.435

Table 3: Summeraisation of first yielding point for medium-rise buildings.

Damage Analysis

In this study, the damage analysis of buildings has been carried out by using the original version of the program developed by Park [8] to provide a measure of the accumulated damage sustained by the components of the structure, by each story level, and the entire building. This damage index included the ratio of the maximum to ultimate deformations. Table 4 show in detail the summary of overall damage index of each building Sabah under various intensities; 0.01g up to 0.50g, The overall damage index for the building can be referred to the SEAOC Damage Level in Table 1.

The result shown in Table 5, only seven (7) modal frames buildings in Sabah were being able to resist up to 0.10 g of earthquake intensity. Sekolah Kebangsaaan Bombalai building in Tawau is affected by earthquake and collapse when 0.20g intensity is applied to the building. Same goes to Hospital Kuala Terengganu (HKT). Bangunan Canseleri (USMPP) and Kuarters Polis Pulau Pinang (KPPP) have no structural damage and only have some non-structural damage. All buildings have no damage at 0.01g. While others buildings were start experienced damage at 0.03g and 0.10g with moderate level. It can be seen that most of the buildings were categorised in the moderate damage level where there is no structural damage but only obtained some non-structural damage up to 0.03g intensity.

No.	Building name	Storey	Plastic hinge location	Floor level	Intensities (g)	Time, sec. (first yield)
1	Bangunan C07 (UTM)	4	BEAM	2	0.03	8.265
2	Bangunan Censeleri USM Pulau Pinang (USMPP)	6	BEAM	5	0.5	3.275
3	Hospital Bersalin KL (HKL)	6	BEAM	2	0.5	3.515
4	Hospital Duchess Sandakan (HDS)	4	BEAM	1	0.5	3.445
5	Kuarters Polis Pulau Pinang (KPPP)	5	BEAM	1	0.5	2.630
6	Majlis Daerah Johor Bahru (MDJB)	5	BEAM	2	0.5	2.840
7	Maktab Perguruan Pulau Pinang (MPPP)	4	BEAM	2	0.5	2.790
8	Markas Simpanan Persekutuan Ipoh (MSPI)	5	BEAM	2	0.5	2.860
9	Pejabat Balai Bomba Miri (PBBM)	4	BEAM	2	0.5	3.195
10	Pejabat Daerah Kuala Terengganu (PDKT)	5	BEAM	1	0.5	2.750
11	Pejabat RISDA Negeri Sembilan (RISDANS)	4	BEAM	2	0.5	2.810
12	Perumahan Kastam Kudat (PKK)	5	BEAM	1	0.5	2.87
13	Quarters Balai Bomba Miri (QBBM)	5	BEAM	1	0.5	3.845
14	Quarters Type F limbang (QFL)	4	BEAM	1	0.5	3.200
15	Sekolah Kebangsaan Bombalai Tawau (SKBT)	4	BEAM	2	0.5	2.505

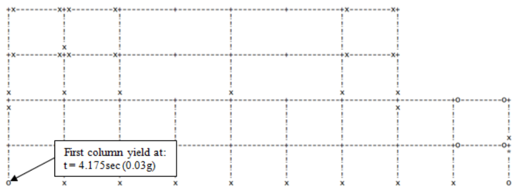

Figure 3 : Damage state frame of first yielding point for Airport Labuan building.

Table 4: Summary of overall damage index for all buildings

No.	Building Name	Overall Structure Damage Index				
		0.01g	0.03g	0.10g	0.20g	0.50g
1	Bangunan C07 (UTM)	0.000	0.023	0.087	0.141	0.233
2	Bangunan Censeleri USM Pulau Pinang (USMPP)	0.000	0.000	0.024	0.057	0.099
3	Hospital Bersalin KL (HKL)	0.000	0.000	0.032	1.000	1.000
4	Hospital Duchess Sandakan (HDS)	0.000	0.000	0.027	1.000	1.000
5	Kuarters Polis Pulau Pinang (KPPP)	0.000	0.000	0.033	0.048	0.089
6	Majlis Daerah Johor Bahru (MDJB)	0.000	0.013	0.034	0.054	1.000
7	Maktab Perguruan Pulau Pinang (MPPP)	0.000	0.018	0.039	0.085	1.000
8	Markas Simpanan Persekutuan Ipoh (MSPI)	0.000	0.015	0.035	0.125	0.335
9	Pejabat Balai Bomba Miri (PBBM)	0.000	0.000	0.021	0.038	1.000
10	Pejabat Daerah Kuala Terenggganu (PDKT)	0.000	0.019	0.038	1.000	1.000
11	Pejabat RISDA Negeri Sembilan (RISDANS)	0.000	0.017	0.038	0.080	0.127
12	Perumahan Kastam Kudat (PKK)	0.000	0.000	0.028	0.111	1.000
13	Quarters Balai Bomba Miri (QBBM)	0.000	0.000	0.048	0.074	1.000
14	Quarters Type F limbang (QFL)	0.000	0.000	0.020	0.048	0.299
15	Sekolah Kebangsaan Bombalai Tawau (SKBT)	0.000	0.020	0.072	1.000	1.000
16	Airport Labuan (AL)	0.000	0.046	1.000	1.000	1.000
17	Blok Makmal Kuala Terengganu (BMKT)	0.000	0.014	0.023	0.055	1.000
18	Flat Kelas G Bintulu (FGB)	0.000	0.000	0.033	0.087	1.000
19	Hospital Kuala Terengganu (HKT)	0.000	0.000	0.026	1.000	1.000
20	Pejabat Jabatan Laut Bintulu (PJLB)	0.000	0.000	0.043	1.000	1.000
21	Perpustakaan Negeri Kuching (PK)	0.000	0.000	0.000	0.018	1.000

CONCLUSION

It can be concluded that all buildings have different performance in terms of damage level when various intensities are applied to the buildings.

Most of the buildings analysed subjected to the El-Centro earthquake ground motion, developed plastic hinge due to the lowest earthquake intensity of 0.03g and have damage indexes in range of 0.0 to 0.445 before some of them were collapse. The result indicates that Airport Labuan only can resist up to 0.03g. It can be seen that most of the buildings were categorised in the moderate damage level where there is no structural damage but only obtained some non-structural damage when intensity 0.01g and 0.03g applied.

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