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Nonlinear Response of Low Rise Hospital RC Building in Malaysia Due to Far and Near Field Earthquake

Taksiah A. Majid[1], Mohd Irwan Adiyanto[2], Fadzli Mohamed Nazri[1,*]

[1]Disaster Research Nexus, School of Civil Engineering, Universiti Sains Malaysia, Penang, Malaysia
[2]Postgraduate Student, School of Civil Engineering, Penang, Malaysia

Abstract Geographically, Malaysia is situated in relatively far away from active seismic fault zones. Therefore, the earthquake hazard is not exist in Malaysian dictionary of life before the new century. Therefore, seismic consideration is not required in public buildings design. However, since a shock from a gigantic Mw 9.0 earthquake in Aceh, Indonesia on 26 December 2004, Malaysian authority and public citizen become aware of that hazard. The possibility to implement the seismic design start to be discussed at least for important structures such as bridge and dam. Hospital also cannot be ignored in discussion since the buildings is very important and must secure during disaster such as earthquake. This paper presents the study on the nonlinear response of three storey hospital reinforced concrete moment resisting frame designed for medium seismic region in Sabah, Malaysia. The typical frame had been designed according to Eurocode 8 for ductility class medium. The nonlinear response history analysis had been conducted on all five frames with far field and near field earthquake ground motion records as input. The result shows that the magnitude of interstorey drift ratio is strongly influenced by the value of behavior factor, q used in the design. The former is increases around 23% - 52% and 44% - 65% when subjected to the far field and near field earthquakes, respectively as the value of behavior factor, q is increases.

Keywords Hospital, Reinforced concrete, Eurocode 8, Behaviour factor, Interstorey drift ratio

1. Introduction

Since the gigantic Mw 9.0 earthquake in Aceh, Indonesia on 26 December 2004 which also triggered tsunami in the Indian Ocean, Malaysian authority and public citizen start to rethink about the earthquake hazard toward the nation. After 10 years, the number of tremors which can be felt in Malaysian soil due to Sumatra Andaman and Philippines earthquakes is rising. A lot of researches had been conducted related the that field including the possibility of considering seismic design. According to Mosti report [1], it is worth to consider seismic design for construction of new structures located in medium to high seismic region. Experience from the past earthquakes gave a very useful lesson that hospitals and health care facilities are considered as the most important facilities which must remain safe and operable after the disaster [2]. Damages on the non-structural elements and equipment also can make the building inoperable. As an example, in the 1999 ChiChi Taiwan earthquake, the whole Shiu-Tuwan hospital was closed due to damages of non-structural elements even the damages on structure was not severe. After a significant earthquake, the victims turn to hospitals where they expect to receive treatment for any injuries during the event. Therefore, in every community's post disaster plan, hospitals require special attention and should be the safest place because people's lives depend on its functionality [3, 4].

To implement the seismic design in a developing country like Malaysia, the increment of cost also has to be taken into account. Due to economical reason, it is not practical to design structures that can behave elastically during earthquake [5]. This mean that the use of lateral force which had been derived based on elastic response spectrum for design purpose will result in very high cost of construction. Therefore, the concept of behaviour factor, q is proposed to reduce the force obtained from a linear analysis, in order to take into account the nonlinear response of a structure [6]. In American code [7], the concept of behaviour factor, q also proposed namely as force or strength reduction factor, R. The behaviour factor, q strongly influencing the class of ductility, namely as low, medium and high. According to Borzi and Elnashai [8], both European and American codes are too conservative where the ductility demand which corresponds to the behaviour factor, q is higher than the ductility supply. The forward directivity ground motions require smaller value of strength reduction factor, R compared to the non-forward directivity ground motions [9]. Therefore, Jalali and Trifunac [10] suggested that the simple and effective modification is needed to replace the current

* Corresponding author:
takziah@usm.my (Fadzli Mohamed Nazri)
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value of behaviour factor, q.

This paper presents the nonlinear response of low rise hospital reinforced concrete (RC) building when subjected to the near and far field earthquakes. The typical three storey moment resisting frame (MRF) had been designed repeatedly based on different value of behaviour factor, q for ductility class medium (DCM). The seismic response is evaluated based on the value of interstorey drift ratio (IDR).

2. Material and Method

2.1. 2 Dimensional MRF Model

In this study, the nonlinear response history analysis had been conducted on the three storey RC MRF. A total of five typical model had been designed based on five different value of behaviour factor, q. According to Eurocode 8 [6], the value of behaviour factor, q for ductility class low (DCL) is equal to 1.5. for DCM structure, the value of behaviour factor, q lies in range of $1.5 < q < 5.85$ depend on the type of structure and material. The behaviour factor, $q \geq 5.85$ is used for the ductility class high (DCH). Therefore, the typical frame had been designed repeatedly based on five value of behaviour factor, q equal to 2.3, 3.1, 3.9, 4.7, and 5.5 for DCM. The typical frame is regular in plan and elevation where the floor to floor height is equal to 3.3 m for each stories. The frame is completed by three equal bays of 5.0 m. since this study focus on hospital building, the typical frame is classified into important class IV where the importance factor, γ_I used for design is equal to 1.4. All frames had been designed based on reference peak ground acceleration, a_{gR} equal to 0.12g to represent to the medium seismic region in Sabah, Malaysia [1, 11].

The size of beam located at top storey is equal to 250 mm x 550 mm while at the first and second storey is equal to 300 mm x 600 mm. The size for all columns is equal to 375 mm x 375 mm regardless its position either interior or exterior column. All five frames had been designed based on the aforementioned size of sections so that the dynamic characteristic of all frames is similar with fundamental period of vibration, T_1 equal to 0.5 sec. All frames had been designed with seismic provision based on Eurocode 8 [6] with concrete compressive strength, f_{cu} and steel yield strength, f_y is equal to 30 N/mm^2 and 500 N/mm^2, respectively. The detail of steel reinforcement for all frames can be found elsewhere [12].

Table 1. List of Selected Far Field Ground Motion Records

No	Event	Comp	Station	PGA [g]	PGV [cm/s]	Mw
1	Duzce	ATS 030	Ambarli	0.038	7.4	7.1
2	Duzce	ATS 030	Ambarli	0.025	7.1	7.1
3	Morgan Hill	A01040	58375 Apeel 1	0.046	3.4	6.2
4	Morgan Hill	A01310	58375 Apeel 1	0.068	3.9	6.2
5	Chi Chi	CHY069 N	CHY 069	0.039	10.3	7.6
6	Chi Chi	CHY069 W	CHY 069	0.047	10.9	7.6
7	Chi Chi	TAP026 N	TAP 026	0.073	14.3	7.6
8	Chi Chi	TAP026 E	TAP 026	0.077	11.7	7.6
9	Chi Chi	KAU074 N	KAU 074	0.028	10.0	7.6
10	Chi Chi	KAU074 W	KAU 074	0.032	6.7	7.6
11	Chi Chi	CHY054 N	CHY 054	0.097	19.3	7.6
12	Chi Chi	CHY054 W	CHY 054	0.094	17.9	7.6
13	Chi Chi	KAU010 N	KAU 010	0.034	16.6	7.6
14	Chi Chi	KAU010 W	KAU 010	0.034	11.3	7.6
15	Chi Chi	TAP006 N	TAP 006	0.071	14.1	7.6
16	Chi Chi	TAP008 N	TAP 008	0.061	14.2	7.6
17	Chi Chi	ILA042 W	ILA 042	0.085	21.6	7.6
18	Chi Chi	TAP014 N	TAP 014	0.073	19.4	7.6
19	Chi Chi	TAP095 W	TAP 095	0.098	18.8	7.6
20	Chi Chi	CHY090 W	CHY 090	0.079	14.5	7.6
21	Chi Chi	KAU063 W	KAU 063	0.039	12.5	7.6
22	Chi Chi	TAP013 E	TAP 013	0.094	19.7	7.6
23	Loma Prieta	MEN360	Foster City Menhaden Court	0.098	17.2	6.9
24	Loma Prieta	LKS360	Larkspur Ferry Terminal	0.12	18.6	6.9
25	Loma Prieta	TRI090	Treasure Island	0.13	20.1	6.9

2.2. Nonlinear Response History Analysis

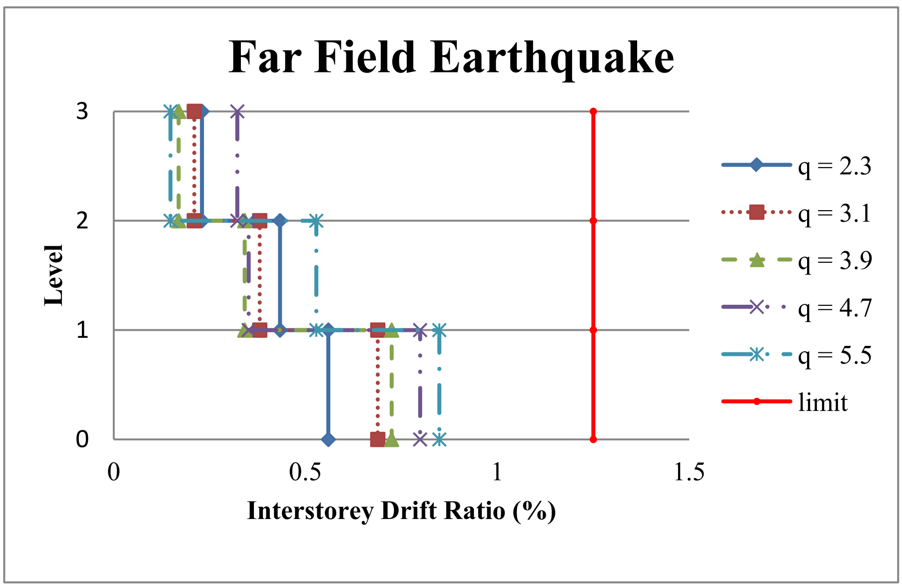
In order to study the nonlinear response of low rise hospital RC MRF in Malaysia, the nonlinear response time history analysis had been conducted on all frames using Ruaumoko program [13]. The nonlinear response history analysis simulates the response of the frames when subjected to the real earthquake represented by dynamic load which varies against time. For that purpose, the program requires input in form of ground acceleration against time known as ground motion records. A total of 25 ground motion records which had been downloaded from PEER database [14] is shown in Table 1. The list of near field ground motion records can be found elsewhere [15].

All ground motion records were recorded on soft soil with shear wave velocity, Vs < 180 m/s. Before being assembled as input in Ruaumoko program, all ground motion records had been scaled based on the spectral acceleration with damping ratio of 5% at the fundamental period of vibration, $Sa(T_1,5\%)$. The scaling process was referred to the Type 1 response spectrum of Eurocode 8 [6] for Soil Type D developed based on the reference peak ground acceleration, a_{gR} as mentioned in previous subsection.

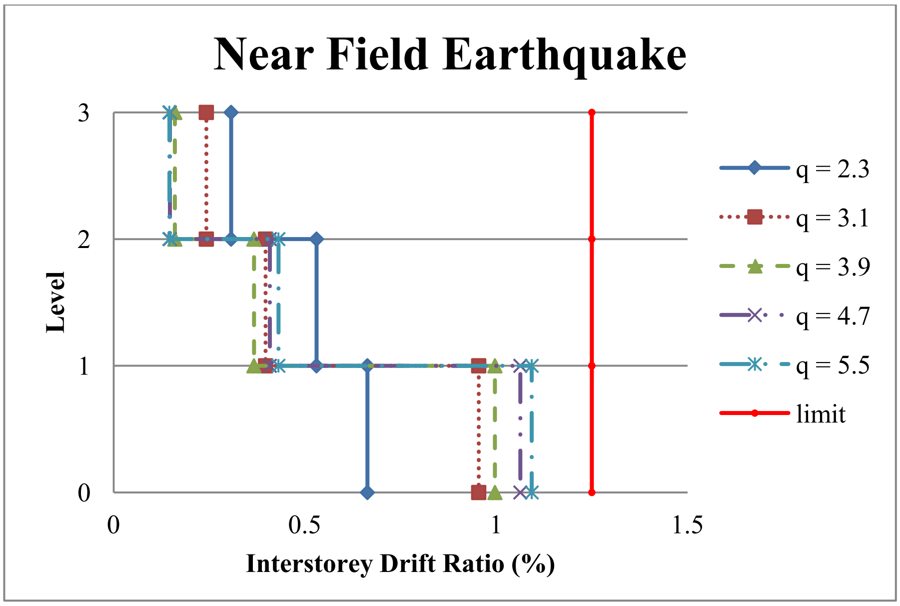
3. Result and Discussion

The action of earthquake induces lateral displacement on the structures. Large lateral displacement will cause damage to the non-structural and structural elements and then lead to collapse. Performance-Based Earthquake Engineering (PBEE) concept proposed four different performance level which might be experienced by structures due to action of earthquake load. The performance level is namely as Operational (OP), Immediate Occupancy (IO), Life Safety (LS), and Near Collapse (NC) [16]. All performance levels can be evaluated through the magnitude of IDR, which can be expressed as the relative lateral displacement between two adjacent stories normalized to its storey height. The magnitude of IDR equal to 0.5%, 1.0%, 2.0%, and 4.0% indicates the OP, IO, LS, and NC performance level, respectively. Hospitals and health care facilities are considered as the most important facilities which must remain safe and operable after the disaster [2]. Hence, such buildings should be categorized as IO performance level. According Eurocode 8 [6], the IDR for structures in important class IV, such as hospital in this study is limited to 1.25%.

Fig. 1(a) shows the distribution of IDR over the height of all three storey RC MRF used in this study when subjected to the far field earthquakes. Since a total of 25 ground motion records had been used in the nonlinear response history analysis, the magnitude of IDR presented here is the mean value. The frames designed based on lower behaviour factor, q experienced lower magnitude of IDR compared to the same frame designed with higher behaviour factor, q. For example, at the bottom storey, the IDR of frames designed with behaviour factor, q = 2.3 and q = 3.9 is equal to 0.56% and 0.72%, respectively. When designed based on behaviour factor, q = 5.5, the magnitude of IDR at same storey is rising to 0.85%. This trend is clear and indicates that frames designed with higher value of behaviour factor, q experienced larger lateral displacement compared to the frames designed with lower behaviour factor, q. This result is in good agreement with previous study which stated that the increase of force reduction factor, R always leads to an increase of the inelastic displacement ratio [17].



(a)



(b)

Figure 1. Interstorey drift ratio of 3 storey frame (a) Far Field Earthquake (b) Near Field Earthquake

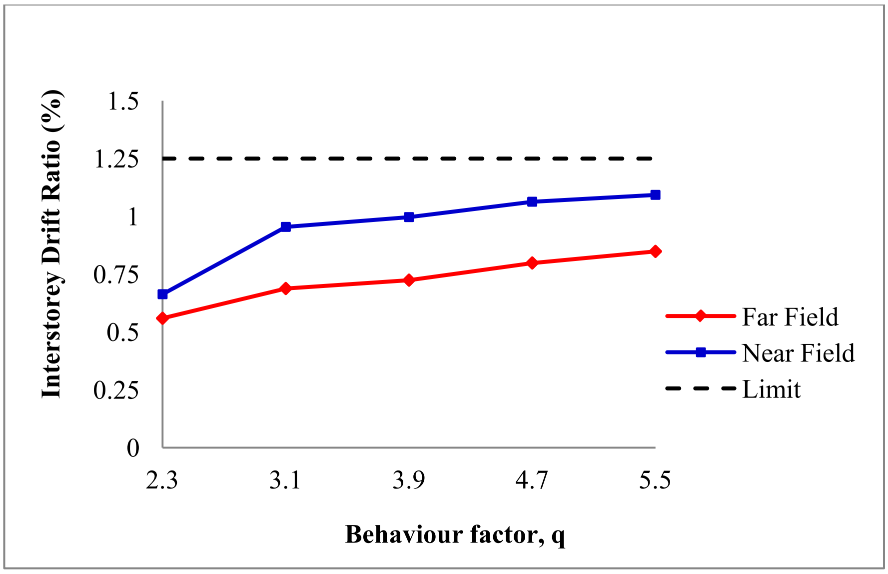


Figure 2. Maximum interstorey drift ratio of 3 storey frame

The distribution of IDR over the height for all five frames due to action of near field earthquakes in shown in Fig. 1(b). It is also observed that the magnitude of IDR is higher for frames designed with higher behaviour factor, q. This proves that the latter is weaker which result in larger lateral displacement. At the bottom storey, the magnitude of IDR for frames designed with behaviour factor, q equal to 2.3, 3.1, and 3.9 is equal to 0.66%, 0.95%, and 1.0%, respectively. When designed based on behaviour factor, q equal to 4.7, and 5.5, the magnitude of IDR is increasing around 61% and 65% higher from the IDR of frame with the lowest behaviour factor, q. From Fig. 1(a) and Fig. 1 (b), it can be clearly observed that the distribution of IDR over the height is in typical form regardless the value of behaviour factor, q used in design. The type of ground motion record, neither far field nor near field earthquake also did not influencing the form of IDR distribution over the height. For all frames, the maximum IDR is concentrated at the bottom storey.

Fig. 2 depicts the maximum IDR obtained from action of both far field and near field earthquakes on all five frames. As discussed in previous paragraph, the maximum IDR is concentrated at the bottom storey. It can be clearly observed that the action of near field earthquake induced higher magnitude of IDR for all frames. This result mean that even designed based on similar behaviour factor, q the IDR due to near field earthquake is higher compared to the one resulted from far field earthquake. As an example, for frame designed with behaviour factor, q equal to 3.9, the magnitude of IDR correspond to the far field and near field earthquakes is equal to 0.72% and 1.0%, respectively. However, in this study, it is found that the magnitude of IDR caused by both far field and near field earthquakes is lower than the limit of 1.25% regardless the value of behaviour factor, q used in design. Therefore, in term of seismic performance, the design of all frames are acceptable. However, the design also has to consider the total cost of material which is discussed elsewhere [12].

4. Conclusions

This paper presents the study on the nonlinear response of three storey hospital RC MRF designed for medium seismic region in Sabah, Malaysia. The typical frame had been designed according to Eurocode 8 [6] for DCM. Five different value of behaviour factor, q had been used for designed which is equal to 2.3, 3.1, 3.9, 4.7, and 5.5. Then, the nonlinear response history analysis had been conducted on all five frames with far field and near field ground motion records as input. The following conclusions can be drawn from this study:

- The value of behaviour factor, q used in design strongly influencing the magnitude of IDR where the latter is increases as the former is increases and concentrated at the bottom storey.
- Due to far field earthquake, the magnitude of IDR is increases in range of 23% to 52% as the value of behaviour factor, q used in design is increases.
- Due to near field earthquake, the magnitude of IDR is increases in range of 44% to 65% as the value of behaviour factor, q used in design is increases.
- For all frames, it is observed that the action of near field earthquake caused greater IDR compared to the far field earthquake.
- In this study, the magnitude IDR for all frames is below than the limit regardless the type of earthquake ground motion records, either far field or near field. Therefore, the design of all frames is acceptable in term of seismic performance. The cost evaluation is needed to find the most economic design.

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REFERENCES

[1] MOSTI. Seismic and tsunami hazards and risks study in Malaysia. Final Report, 2009.

[2] M. Hossain Nazer, and F. Nateghi Elahi. Seismic vulnerability of nonstructural components of hospitals. *Proc. of 13th World Conference on Earthquake Engineering*. Canada. 2004, paper no. 1250.

[3] J. Lewis, and M. Wang. Seismic risk mitigation of operational and functional components in hospitals – the British Columbia experience. *Proc. of 13th World Conference on Earthquake Engineering*. Canada. 2004, paper no. 1636.

[4] E.A. Tingatinga, and R.W. Arriesgado. Earthquake response analysis and simulation of sensitive hospital equipment in the Philippines. *Proc. of 15th World Conference on Earthquake Engineering*. Lisbon. 2012.

[5] FEMA NEHRP. Recommended provisions design examples, Topic 7: Concepts of Seismic-Resistant Design, FEMA 451B, *Building Seismic Safety Council for the Federal Emergency Management Agency*. 2006.

[6] CEN Eurocode 8. Design of structures for earthquake resistance, *Part 1: General rules, seismic actions and rules for buildings*, Brussels. 2003.

[7] ICC. International Building Code, United States of America. 2006.

[8] B. Borzi, and A. S. Elnashai. Refined force reduction factors for seismic design. *Engineering Structures*. 2000, 22: 1244 – 1260.

[9] J. L. Gillie, A. R. Marek, M. D. Cole. Strength reduction factors for near-fault forward-directivity ground motions. *Engineering Structures*. 2010, 32: 273 - 285

[10] R.S. Jalali, and M.D. Trifunac. A note on strength-reduction factors for design of structures near earthquake faults. *Soil Dynamics and Earthquake Engineering*. 2008, 28: 212-222.

[11] A. Adnan, Hendriyawan, A. Marto, P.N.N. Selvanayagam. Development of seismic hazard maps of east Malaysia. *Advances in Earthquake Engineering Applications*. 2008: 1-17.

[12] M.I. Adiyanto, T.A. Majid, F.M. Nazri. Cost optimization of seismic design of low rise hospital RC frame in Malaysia. *Submitted to the15th Asia Conference on Earthquake Engineering*. Taiwan. 2014.

[13] A.J. Carr. RUAUMOKO 2D-user manual for the 2-dimensional version. *Department of Civil Engineering, University of Canterbury,* Christchurch. 2007.

[14] Pacific Earthquake Engineering Research Center. *PEER strong motion database*, [accessed 08.12.13] *http://peer.berkeley.edu/smcat*.

[15] M.I. Adiyanto, and T.A. Majid. Seismic performance of three storey hospital RC frame subjected to multiple earthquake in moderate seismic region. *Proc. of International Congress on Natural Sciences and Engineering*. Kyoto. 2014.

[16] M.N. Fardis. *Seismic design, assessment, and retrofitting of concrete buildings*. Springer. New York. 2009.

[17] G.D. Hatzigeorgiou. and D.E. Beskos. Inelastic displacement ratios for SDOF structures subjected to repeated earthquakes. *Engineering Structures*. 2009, 31: 2744-2755.