Cost Implementation on Earthquake Resistance Design for Building in Malaysia

Safiah Zaleha Awaludin, Azlan Adnan

Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia

azlanadnan@utm.my

Keywords: earthquake resistance; design; cost.

Abstract. Earthquake is one of the most costly natural disasters. It can cause severe damage to the structure. Due to this hazard effect, the structures need to be designed to resist the dynamic forces from the earthquakes. When the structure is designed to resist earthquake, the damage of the structure will not be too severe compared to the conventional structures. The objectives of this study are to analyze the structure under static and dynamic loads, to design the reinforced concrete building frames based on Eurocode 2 (conventional design) and Eurocode 8 (seismic design). Besides, this study also estimates the cost of the earthquake building and compare with the normal buildings. The structure is analyzed using the STAAD.Pro V8i software. The seismic designed structures were designed based on the ductility class because the ductility will result in different earthquake forces. When the ductility is increased, the steel bars required in the structures are also increased. The final results of analysis show the weight of the steel bars and volume of concrete that are used in the construction of the frame structures. These results were used in calculating the cost of the buildings. The findings conclude that the cost of the seismic designed structure was higher compared with the conventional structures due to its requirement to resist dynamic loads.

Introduction

An Earthquake had been long feared as the one of the most hazard natural phenomena. In the simplest way, an earthquake can be defined as the sudden movement of the earth's surface that cause from the release of energy in the earth crust [1]. These phenomena are one of the most hazard natural disasters because it brings sudden fatality, great economy loss and shock to the community. Throughout historic time, earthquake had caused the destruction in the countless country and cities. Therefore, a lot of researches have been carried out to find the solution to prevent this problem.

Due to this hazard effect of earthquake to the building, there a lot of researchers come out with the design of the structure that considered the seismic force during earthquake strike. One of the design that usually been used during an earthquake structure design is the Capacity design. In the capacity design, structural engineers increase the structural strength by additional reinforced bars and substitution of a larger cross-section area. Besides, the ductility of structure also designed by using the capacity design approach.

An earthquake structure design will be different with the normal structure. It must have higher strength and stiffer in order to resist horizontal seismic force. The structure must have sufficient strength to resist the bending moment and shear forces that cause by the seismic force. Besides, the stiffer the structure, the less it deflect under seismic force. In order to increase the strength and stiffness of the structure, more reinforced bars need to be added at the place that easy to failure. Therefore, earthquake structure is more costly compare with the normal structure.

Objectives of Study

This study is conducted to analyze the structure under static and dynamic loading and to design the reinforced concrete building frame under Eurocode 2 as a conventional design and Eurocode 8 as the seismic design. Besides, this study also conducted to estimate the cost of the earthquake building and compared with the normal building. From the design, the additional of material in earthquake structure can be known and the cost of the earthquake structure can be estimate.

Significance of Study

The structure will be design in two types of buildings, which are low rise building (3-storey) and medium rise building (8-storey). Design and analysis of the structure will be done by using STAAD.Pro V8i software. Besides, in this study the wind load will not be considered in the design. The reinforcement steels in beam and column of structure will be calculated in order to determine the cost of the structure. Finally the cost of the conventional design structure and seismic design structure will be compare in order to estimate the increment in cost of structure under difference ductility class.

This study is conducted because the engineers in Malaysia usually did not concern about earthquake resistant during designing the structure. In their perception, Malaysia is not the critical seismic zone. But in reality, Malaysia is actually surrounding with a very active seismic bay on the west and on the east. Therefore, Malaysia has a high risk potential to face earthquake disaster. In recent case, a 5.9-magnitude quake hit Sabah on June 5 and killing 18 climbers on Mount Kinabalu. The damage occur during this earthquake includes rock fall, mudslides, landslide and crack to the building.

West coast Malaysia, Sabah and Sarawak were exposed to local moderate earthquake. From the Maximum Zonal Acceleration in Malaysia shown that the Sabah were in Zone 2B that have the highest maximum acceleration which is between 0.10g to 0.16g. From the argument, Malaysia is still not free from the earthquake tremor and need more attention in seismic resistant design. The damage that occurs to the building during the earthquake was connected with the excessive displacement on the building. Therefore the design of earthquake structure is important to reduce the failure of the structure during earthquake. The study need to carry out in order to design and estimate the cost for earthquake structure.

Previous Study

An earthquake occurs when of the energy release and the excess strain spread in various directions. The point where the earthquake initiate is called focus or the hypocenter and the point directly on the surface vertically above the hypocenter called the epicenter. The released energy at the hypocenter then transmitted in form of seismic waves to structures. Since the rapture can spread over a considerable distant, a structure may receive signals from all along the rapture line. Hence, the distance of structure from the epicenter may be far less significant than the distance from the nearest point on the rapture surface.

An Earthquake can cause a huge damage to the building structure because the structure will resist the horizontal seismic force that produce during the earthquake. The main source of the structural damage during the earthquake is the dynamic response of the structure to the ground motion. There is several typical damage of RC building such as the concrete failing in shear in column and beams, buckling of longitudinal bars in beams or column, shear cracking in beam-to-column connections, concrete brittle failure in structural walls, short column effect and overturning and uplift. Besides, an earthquake also can cause the foundation displacement associated with fault break and liquefaction of soil causing foundation failure.

Malaysian tremor occasion in history is not all that significant and the closest separation of tremor epicenter from Malaysia is around 350 km. At further distance, amplitudes of incoming seismic shear waves are generally small. The Peninsular Malaysia is located in the stable Sunda Shelf with low to medium seismic activity level. However, the report of tremor due to Sumatra earthquake still be reported several time. In 2002, there were two large earthquakes near Sumatra which occurred at the end of 2002 (Mw = 7.4) and early 2003 (Mw = 5.8). Although no report about the damage and casualties were reported due to those earthquakes, the tremors caused panic to several cities in Peninsula Malaysia which included Penang and Kuala Lumpur [2].

Due to earthquake on 2nd November 2002, the cracks on buildings in Penang have also been reported. The previous study shown that the peak acceleration at bedrock increases about 2 to 5 times at the surface due to the effect of local soil condition during those two earthquake. The effects of the building cause by those earthquakes depend on the natural frequency of the building. According to the data analysis, the maximum effect of the motion will occur on 1 to 10-storey buildings in Penang and Kuala Lumpur [2].

The standard code applied in the EC8 is the response spectrum design based on the Peak Ground Acceleration (PGA). The shape of the response spectrum is a function of the soil category. Besides, the EC8 also account for the effect of earthquake magnitude by introducing two types of response spectra, which are type 1 and type 2. Type 1 is used if the earthquake that contribute most to the seismic hazard defined for the site for the purpose of probabilistic seismic hazard assessment have a surface-wave magnitude, Ms, bigger than 5.5. Type 2 is for Ms less than 5.5.

The building standards in Eurocode 8 allow for the design to be conducted according to ductility classes low (DCL) or medium (DCM) when the design ground acceleration exceeds 0.10 g (EN-1998-1:2004). The ductility classes define the allowed remaining deformation in structural elements, which ultimately is connected to the energy dissipation capacity that reduces the structural response due to earthquake excitation.

The concept of Ductility Class is adopted and corresponds to the recognition that, although earthquake resisting structure must have simultaneously resistance and ductility, a certain trade-off between these two characteristic is possible. In fact, the resistance and ductility to be assigned to the structure are related to the extent to which its non-linear response is to be exploited and therefore the code allow the designer to choose among different Ductility Classes, enabling an adjusted solution to each design case. For reinforced concrete building, three Ductility Classes are established:

1. Ductility Class L (DCL) corresponding to the structures designed and dimensioned according to Eurocode 2 (Code for concrete structures) and only lightly supplemented by a few additional detailing rules for the enhancement of ductility.
2. Ductility Class M (DCM) corresponding to structures designed, dimensioned and detailed in order to enable the structure to enter within the inelastic range without brittle failure
3. Ductility Class H (DCH) corresponding to structure for which the design, dimensioning and detailing provisions ensure the development of chosen stable mechanisms associated with large hysteretic energy dissipation.

The values of the behavior factor q decrease as the Ductility Class decreases. For reinforced concrete building, the q factor varies proportionally to 1.00, 0.75 and 0.50 respectively for DCH, DCM and DCL. For all higher ductility classes therein foreseen, EC8 resorts to Capacity Design procedure which aim at forcing a certain behavior into the structure considered to be more suitable for the dissipation of energy under the seismic excitation [3].

Table 1: Classification of Ductility class based on the Seismic Zone

SEISMIC ZONES	PGA	DESIGN CATEGORY
Very Low (0)	< 0.04g	No need
Low (1, 2A)	0.04g – 0.08g	DCL
Medium (2B)	0.08g – 0.3g	DCM
High (3, 4)	>0.3g	DCH

There are two different approaches to seismic design which are direct design and capacity design. Capacity design is based on both strength and ductility of component. Capacity design employs a mixture of member with high load capacity and member with high inelastic deformation capacity to optimize the response of the structural system. This is achieved by identifying a failure mechanism, the member and regions responsible for its development, and providing these member and regions with adequate ductility. In parallel, the rest of the structure is protected by providing it with adequate strength to ensure nearly elastic behavior [1].

Previous study shows the designs of civil engineering structures are mainly to resist static loads. Generally the effects of dynamic loads acting on the structure are not considered. This feature of neglecting the dynamic forces sometimes becomes the cause of disaster, particularly in case of earthquake. The basis designs of Conventional Civil Engineering structures are based on strength and stiffness criteria. The strength is related to ultimate limit state, which assures that the forces developed in the structure remain in elastic range. The stiffness is related to serviceability limit state which assures that the structural displacements remains within the permissible limits [4].

In case of earthquake forces the demand is for ductility. Ductility is an essential attribute of a structure that must respond to strong ground motions. Ductility is the ability of the structure to undergo distortion or deformation without damage or failure which results in dissipation of energy. Larger is the capacity of the structure to deform plastically without collapse, more is the resulting ductility and the energy dissipation. This causes reduction in effective earthquake forces [4].

Methodology

Earthquake load acting on a structure depends on epicenter distance and depth of hypocenter below earth surface and the energy released during an earthquake. For easier understanding, it can be said that the line of action joining hypocenter to the center of mass of structure indicates direction of load vector. The most determinant effect on a structure is generally caused by lateral component of earth quake load. As compared to gravity load effect, earthquake load effects on buildings are quite variable and increase rapidly as the height of building increases. For gravity loads, structure is designed considering area supported by a column and spans of beam, whereas for earthquake loads, design is a function of total mass, height. It is likely that low and medium rise structures, having good structural form can carry most of earthquake loads. The strength requirement is a dominant factor in the design of structure. As height increases the rigidity and stability of structure get effected [5].

The seismic force resisting systems that are used is RC Moment Resisting Frame. The two type of building involve in this designs, which are low building (3-storey), medium building (8-storey). Refer Figure 1 and Figure 2 for the design flow chart.

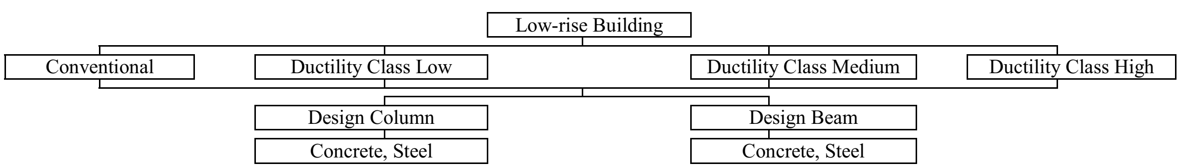


Figure 1: Design Flow Chart for Low-rise Building

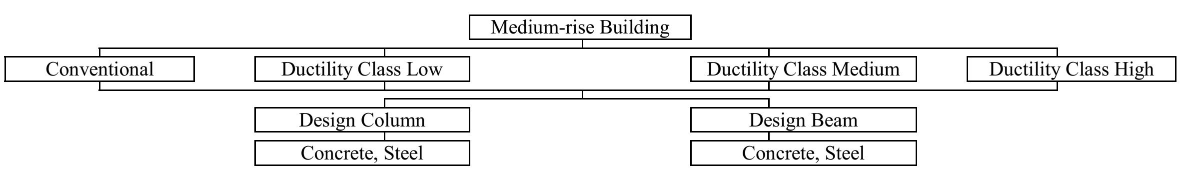


Figure 2: Design Flow Chart for medium-rise Building

In order to calculate the impact of earthquakes on building structures, the ground accelerations are used as an important factor in Eurocode 8. Supplemental factors for the soil's acceleration amplification, including importance factors, also affect the final design value for the acceleration used in an analysis model. Ductility class for design is chosen depending on the dimensioning value of ground acceleration at the location of the specific building (Table 2). This means that the seismic forces and acceleration can be reduced if higher ductility class in selected members, which also means a more inelastic and energy dissipative behavior.

The figures below show the response spectrum graph is generated from the specifying ground acceleration and type of soil. This response spectrum will be use during applying the seismic force to the structure.

Table 2: The Selected Ground Acceleration (Ag) for Different Ductility Class

Ductility Class	A_g Used In Design (G)	Location In Malaysia	Structural Vulnerabilities
DCL	0.06	Kelantan, Terengganu, Penang, Kedah, Johor	Crack Initiated
DCM	0.2	Kuala Lumpur, Putrajaya, Selangor, Perak, Negeri Sembilan, Sarawak, Sabah	Slight To Local Damage
DCH	0.4	None	Damage

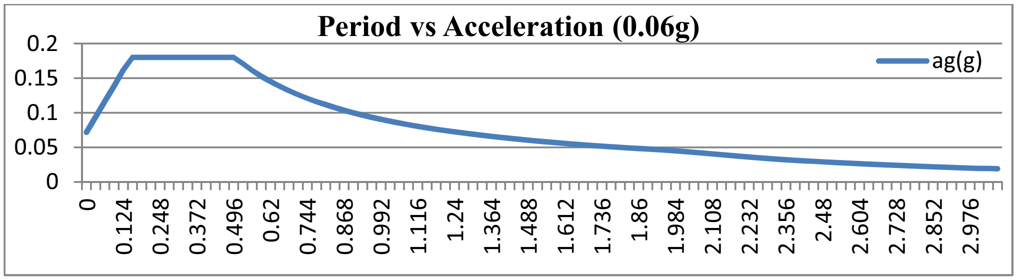


Figure 3: Response Spectrum for ground acceleration 0.06g

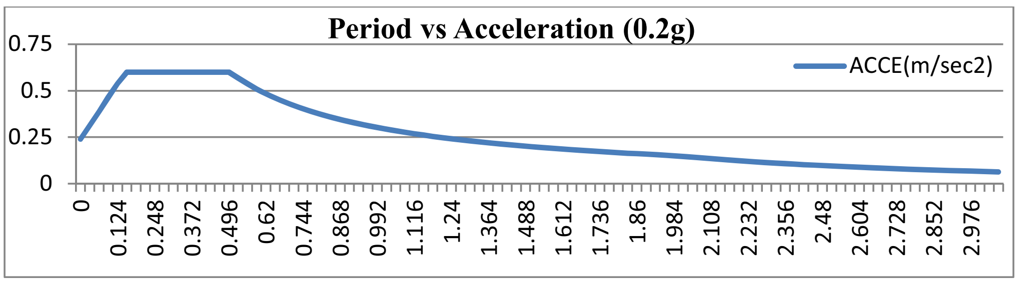


Figure 4: Response Spectrum for ground acceleration 0.2g

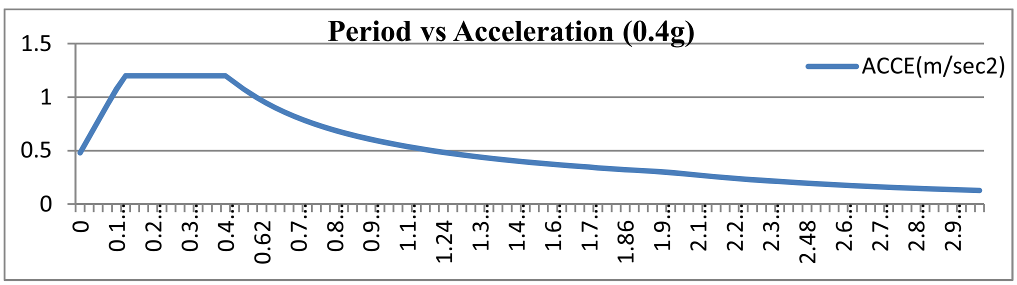
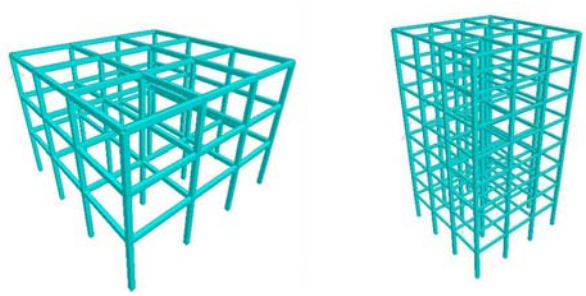


Figure 5: Response Spectrum for ground acceleration 0.4g

In this study, the conventional design structure and seismic design structure will be analyzed by using STAAD.Pro V8i software. STAAD.Pro is stands for Structure Analysis and Design. The method to analyze the structure in STAAD.Pro is by using the method called Stiffness Matrix Method. The stiffness analysis implemented in STAAD is based on the matrix displacement method. In the matrix analysis of structure by the displacement method, the structure is first idealized into an assembly of discrete structural components (frame member or finite element). Each component has an assumed form of displacement in a manner which satisfies the force equilibrium and displacement compatibility at the joints.

First step to perform the analysis of structure is to design the model. The model will be design manually by connecting the node to form the beam and column. The building is the simple moment resistance frame model of 3-storey and 8-storey with 3 bays which is 5 meter length for each bay in both directions. The height of first floor is 4.5 meter and the others level is 3.5 meter. The 3 dimensional views of model are shown in Figure 6.



(a) (b)

Figure 6: (a) 3-storey structure, (b) 8-storey structure

After the modeling, the first thing to specify to the structure is the support. In this study the foundation of the structure is the fixed support. Then specify the shape and size of beam and column for the structure. In this simple model the load distribution from slab are distribute using shown floor dead load value below. After considered the shear coefficient of the floor, the final uniform distribution load shown in Figure 7 for both middle and edge beams.

DEAD LOAD:	10mm Ceramic Tile + 30mm mortar	= 1.015 kN/m^2
	120mm Thick Concrete Slab	= 3 kN/ m^2
	TOTAL gk	= 4.015 kN/ m^2

LIVE LOAD:	According to Eurocode 1 (EN 1991-1-1:2002)	
	Imposed Load, q_k	= 2.0 kN/m^2 (Category A)
	TOTAL qk	= 2.0 kN/ m^2

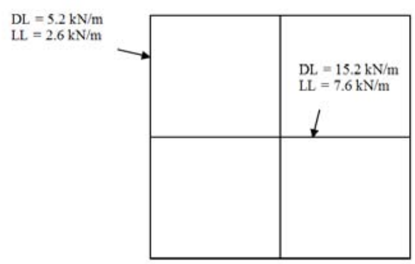


Figure 7: Distribution loads for both middle and edge beams

Table 3: Distribution of base shear force for 3-storey (Ductility Class Low)

Frame	LEVEL	z_i (m)	m_i (kg)	$z_i m_i$ (kgm)	$z_i m_i / \sum z_i m_i$	F_i (kN)	V_i (kN)	M_i (kNm)
1 and 4	3	11.5	17,584	202,217	0.4792	**25.29**	25.29	88.52
	2	8	17,584	140,673	0.3333	**17.60**	42.89	150.11
	1	4.5	17,584	79,128	0.1875	**9.90**	52.79	237.53
	S		52,752	422,018	1.0000	**52.79**		
2 and 3	3	11.5	35,168	404,434	0.4792	**50.59**	50.59	177.05
	2	8	35,168	281,346	0.3333	**35.19**	85.78	300.21
	1	4.5	35,168	158,257	0.1875	**19.79**	105.57	475.07
	S		105,504.59	844,037	1.0000	**105.57**		

In this study, the base shear force for difference type of building is calculating manually. The distribution of base shear force then inserted in the STAAD.Pro as the response spectrum force. The example of distributions of base shear force for 3-storey building is show in Table 3.

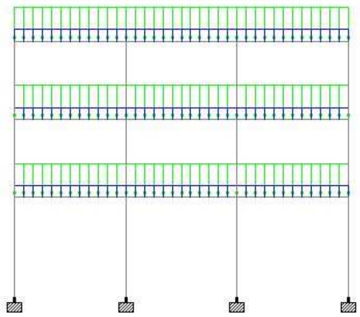


Figure 8: Distribution load

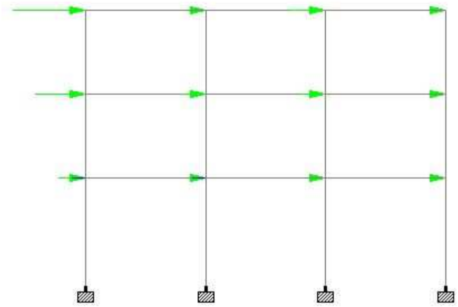


Figure 9: Distribution of base shear force along the height

From the Modeling > Design > Concrete. The analysis can be done after specifying the parameter needed in design such as size of main bar, shear link, and cover. After the analysis based on EC 2, the result of the reinforcement bar needed in the beam and column will be shown.

To perform the geometry check per Eurocode 8, STAAD.Pro must first calculate the center of mass of each defined floor. The EC8 response spectrum load must be specified in the model in order to perform any further check, design, or detailing per Eurocode 8. The “Earthquake” mode has been provided to allow the user to check if the structure conforms to the basic geometric recommendations made in EC8. This mode is in addition to the normal post processing mode which gives the various analysis results. These checks are intended to give the user a 'feel' for the structure and are not mandatory to proceed to the design phase. This mode will be activated only if the analysis has been successful.

A preliminary design per Eurocode 2 must be made for all concrete members prior to detailing and design per Eurocode 8. Once this is completed, click on the Earthquake tab in the RC Designer module. The Collapse Check Setup dialog will launch.

In order for EC8 checks to be performed, a member must have passed all EC2 checks in the initial design step. To also help identify issues in design or detailing, if one step of checks fails for a member, further checks will not be performed on that member. The program will first check that all materials in the design brief are satisfactory. Then, moment capacity of beams and columns are evaluated and compared. EC8 stipulates that columns must have a moment capacity of 1.30 times the sum of the moment capacity of beams framing at that joint. This ensures beams are the initial failure mode.

The price of building material is based on the current price from Quantity Surveyor Online. The price for mild steel bar R10mm, R12mm diameter is RM 2,500.00 per tonne and for R16mm, R20mm diameter is RM 2,300.00 per tonne. The price for ready mixed concrete, grade 30 is RM 210.00 per cubic meter.

Result and Discussion

During design phase, reinforcement bar percentages sometimes exceed the limit of element size because of the requirement of internal forces and ductility class reinforcement requirements. Table 4 shows the different between size of beam and column for different ductility class. Table 5 shows the result of the weight of the steel bar and volume of concrete require for frame structure with the cost of the materials.

The result of analysis show that when the design base on the ductility class, the size of beam and column increase due to the requirement of internal force and ductility class. Therefore, the volume of the concrete also increase when the size of beam and column increase.

Table 4: Beam and Column Size for different ductility class 3-storey and 8-storey model

Type of model	Element	CONVENTIONAL	DCL	DCM	DCH
3-Storey	Beam size (mm)	300 x 200	300 x 200	300 x 200	400 x 300
	Column size (mm)	300 x 300	300 x 300	300 x 300	400 x 400

8-storey	Beam size (mm)	300 x 200	400 x 300	400 x 300	500 x 350
	Column size (mm)	400 x 400	400 x 400	400 x 400	500 x 500

Table 5: Taking off for 3-storey and 8-storey frame structure

Types of frame	Ductility class	Total weight of steel bar (kg)	Total cost of steel bar (RM)	Volume of concrete (m^3)	Total cost of concrete Grade 30 (RM)
3-storey	Conventional	3,647	8,675.72	38.16	8,013.60
	DCL	3,898	9,283.55	38.16	8,013.60
	DCM	4,603	10,900.67	38.16	8,013.60
	DCH	5,334	12,806.89	72.64	15,254.40
8-storey	Conventional	9,725	23,135.82	136.11	28,583.10
	DCL	11,839	28,020.80	193.71	40,679.10
	DCM	12,727	30,078.79	193.71	40,679.10
	DCH	15,005	35,679.43	290.67	61,040.70

Table 6: Total cost for frame structure

Ductility class	Types of frame	
	3-storey	8-strorey
Conventional	RM 16,689.32	RM 51,718.92
DCL	RM 17,297.15	RM 68,699.90
DCM	RM 18,914.27	RM 70,757.89
DCH	RM 28,061.29	RM 96,720.13

When the ductility class increases, the weight of steel bars also increase. The 3-storey frame structure show that the costs of the DCL structure increase to 4% of the cost for the conventional structure. The cost between conventional structure and DCL structure did not show the huge different because the size of beam and column were similar and the DCL structure was design without energy dissipation and ductility to EC2 and EC7. DCL structure does not required delayed ductility and the resistance achieved through the capacity of structure. The cost for DCM and DCH structure increase 13% and 68% respectively. The cost for DCH structure shows the huge different because the design was used the higher ductility levels. The higher ductility class needed more additional steel bar in structure.

The 8-storey frame structure also shows the increment in the cost of the material needed. The cost for DCL structure increase to 33% compare with the cost of conventional building. The cost between conventional structure and DCL structure increase by 33% because there was increment in beam and columns size. The cost for DCM and DCH structure increase 36% and 87% respectively. The graph below show the increment in cost of the structure with difference ductility class

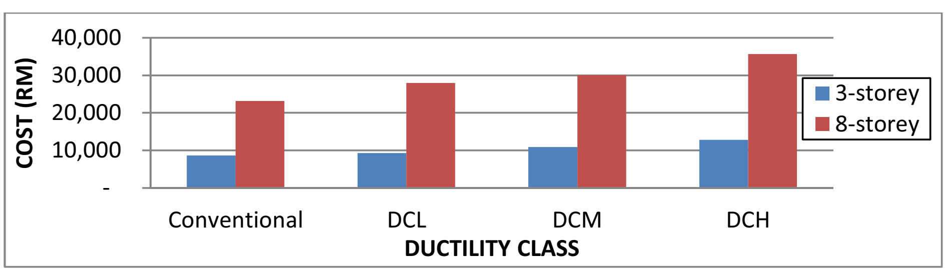


Figure 8: Cost of steel bar versus Ductility class

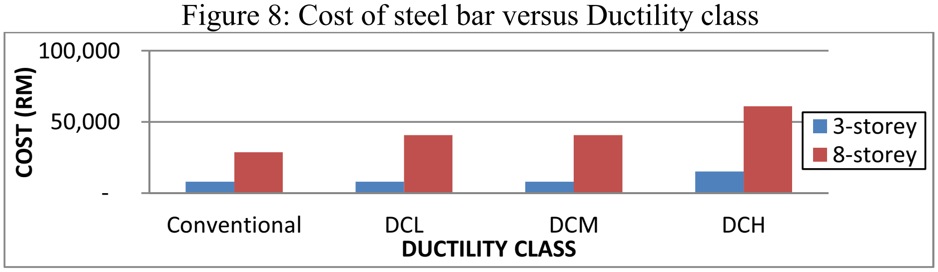


Figure 9: Cost of concrete versus Ductility class

Conclusion

This study presents the analysis of conventional building design that based on Eurocode 2 and seismic building design that based on Eurocode 8. The conventional structure only analyzes based on the static loading and the seismic structure analyze based on static and dynamic loading. The structure analyze by using the STAAD.Pro software.

In general, the findings conclude that the cost of the seismic structure design is higher compare with the conventional structure design. It is because the seismic structure needs to be design to resist dynamic load. The seismic structure was design based on the ductility class because the higher ductility will result in smaller earthquake force. When the ductility class increase, the steel bar required in structures also increase. Increasing of steel bar causes the cost of the structure increase.

References

[1] Amr S.Elnashai and Luigi Di Sarno. (2008). Fundamental of Earthquake Engineering. The Atrium, Southerrn Gate, Chichester, West Sussex, United Kingdom, John Wiley & Sons Ltd. 48-88.

[2] Adnan, A., Marto, A., & Irsyam, M. (2007). Seismic Hazard Assessment For Peninsular Malaysia using Gumbel Distribution Method, Vol. *42*, pp.57–73.

[3] Carvalho, E., Coelho, E. & Fardis, M.N., 1996. Assessment of EC8 provisions for reinforced concrete frames. 11th European Conference on Earthquake Engineering, Paris, p.Paper No. 2049.

[4] Vasavi, M., 2007. Analysis And Capacity Based Earthquake Resistant Design Of Analysis And Capacity Based Earthquake Resistant Design Of Multi. National Institute of Technology, Rourkela.

[5] Prof. K S Sable, Er. V A Ghodechor, P.S.B.K., 2012. Comparative Study of Seismic Behavior of Multistory Reinforced Concrete Framed Structures. Comparative study of seismic behaviour of multistory flat slab and conventional reinforced concrete framed structures, 2(2), pp.17–26.